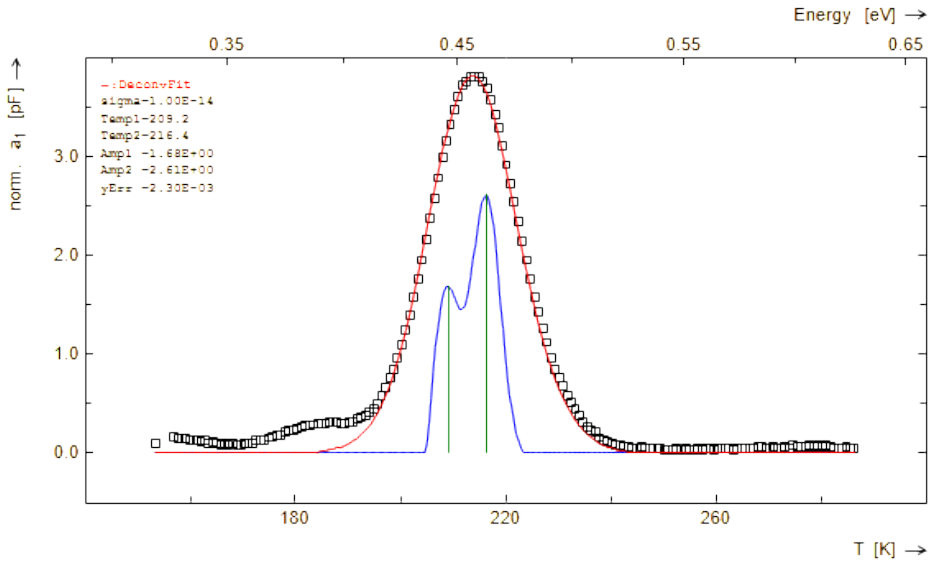
FT-1230
HERA - DLTS

Software Manual

Version 7.3, 2025-12-10



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Contents

Introduction

This manual is the 3. part of the main DLTS documentation set:

1) **Hardware manual H**
2) **Installation manual I**
3) **Software manual S** (this manual)
4) **Basics manual B**
5) **Theory manual T**

The Software (program) manual provides information on how to use the DLTS system and how to work with the DLTS program. It describes our newest DLTS electronic **FT-1230** with the new PhysTech **CGI-Meters** FT-1235, 1241, 1243, 1244 and 1245. The CGI-Meter measures the capacitance **C**, the conductance **G** and the current **I**. The CGI-Meter includes a 1MHz capacitance bridge, a current amplifier, a capacitance compensation and a fast pulse interface. Therefor you find sometimes the name 'bridge' in this manual. Some features depend on your hardware and licence version.

In the following only **user class 4** will be described, except at some marked parts. Features needing a higher user class are not visible or not enabled (grey text) in input dialogs and menus. Sometimes inputs are not visible or not enabled because these depend on the data or evaluation mode. The most general examples are coming from the Tempscan program module.

In the most menus and input windows you get **help** information by the F1-key. Then the electronic manual will be opened at the corresponding page. For this you need a PDF viewer, either the Adobe Reader, the Foxit Reader or the SumatraPDF, or a plug-in for your Web browser.
At some input windows there is a help button. It have the same function as the F1-key. You get help information by the F1-key also if there is no help button!
In some input windows you get by the F1-key different help information depending on the selected input group. For example if there is an input group for interpolation then you get the help text of chapter 2.7.1 if activating this input group and pressing the F1-key.
At many buttons and inputs you get a hint by moving the mouse to this position.

Reference to another chapter of this manual will be denoted only by this chapter, for example 1.1.3. If there is a reference to another manual the type of this manual will be additionally given, for example I3.1 for chapter 3.1 of the software installation manual. The equations, most abbreviated by 'equ.', refers to the Theory Manual. The chapter reference inside this manual is in many cases a hyperlink, that means if you click onto the blue chapter number, the document jumps to this chapter.

All inputs in this manual will be shown in the Windows classic style. The inputs may have another look on your computer, it depends on your Windows Themes, see chapter 2.3.1.

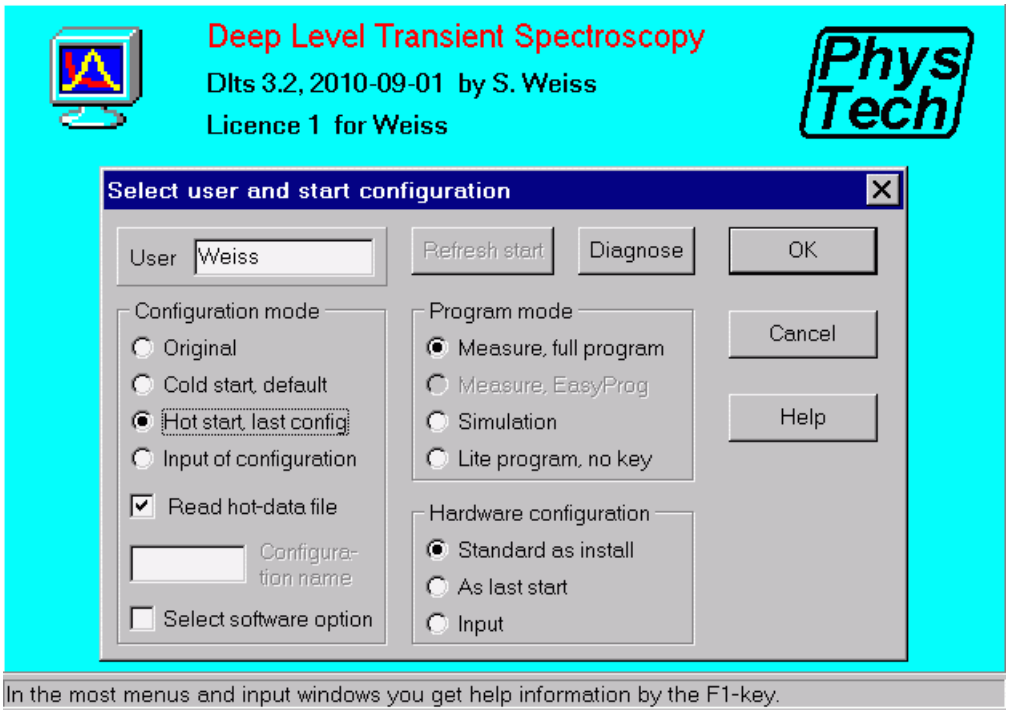
FT 1230 HERA-DLTS is an abbreviation for **F**ourier **T**ransform, **H**igh **E**nergy **R**esolution **A**nalysis and **D**eep Level **T**ransient **S**pectroscopy. The software contains the conventional tempscan maximum analysis, the period scans, the direct transient evaluation by DLTFS (**D**eep **L**evel **T**ransient **F**ourier **S**pectroscopy) and the HERA transient evaluation (DISCRETE, Laplace transform) and the HERA coefficient deconvolution.

1. Program start, structure and Basics

1.1 Program start

1.1.1 Main start window

After activating the DLTS icon on your desktop the software is coming up with the start window and included there an input window. On the top you see the program name, the program version and date, and the licence number and name.



The **input window** defines which initialization (init) files should be loaded (configuration mode), which hardware options should be used, and whether the software should work as a measurement or without the hardware as a simulation and evaluation software. It also defines the data path.

First type in your **user name.** You can type in up to 16 characters. These, without blanks, will also be used for your personal data directory. In the measurement data file and in the database will be only maximal the last 8 characters saved. If you type in no name then as name 'Guest' will be set.

The **Configuration mode** define which user initialization will be loaded**.** This sets the program, sample and measurement parameters (except reverse bias voltage):

Original A predefined configuration file set, that can not modified in any case, only init files from the system directory Sys\Init will be read. Here only the original calibration CGI-Meter without cryostat offsets will be used. It should only be used, if the 'Cold start' configuration set is not working properly.

Cold start The cold start files will be used. This mode is the default mode after installation and for a new user. Cold start files can not be automatically created after program start but only manually, see 1.2.1. In most cases the cold start uses the 'Original' files, see 1.1.2.

Hot start This is the standard mode, it is a configuration file set, that can be saved during the closing procedure, to make sure, that a user can work the next day or week with the same configuration as the software has been left.

Input configuration A configuration file set, saved under a particular name, allows you to start a previous saved configuration The name has to be defined in the input box below this flag. It can be saved before during the closing procedure.

Read hot data file loads also the last or predefined user changes of parameters which normally should be fixed because they hardware dependent, for example the recovery time of the capacitance bridge.

Select software option gives you an optional second start window, see 1.1.6. Normally this is not necessary. For a new user it will be automatically opened.

At **Program mode** you select the kind of using the program. **Measure** starts the full measurement program with the hardware. All hardware has to be attached and powered.
Simulation don't use the hardware, only simulations and evaluations are possible.
Lite program works similar as the 'Simulation' but need no protection key, see in the Installation Manual.

By **Hardware configuration** you can select how your hardware will be started. Normally use the 'Standard'. Here the software expects all in the setup program installed hardware options (as fast pulse interface and cryo system) attached to the system, see chapter I3.3 of the Installation Manual. But in some cases there is no need for some options or it is not attached. In that case this input box enables a hardware configuration only for the actual use of the software without modifying the system setup. But only options that has been installed can be switched off, new options can not be activated here. This has to be done using the set up program.

Standard Starts the software with all hardware options as it has been installed.
Last start Starts the software using the hardware configuration of the last start.
Input Opens an additional input window (after 'OK') for a definition of the hardware that shall be used, for example working without cryostat, see chapter 1.1.6. The default input values will be taken from the last start.

The **Refresh** button refresh the main start window if you change the user name.
With Diagnose you get an input window for diagnose parameters. It is only necessary if you have start problems, see chapter 1.1.3. At this input window you can also define remote working.

Note: You can start only one **instance** of the measurement program. For the lite program you can start some instances on one computer. You can also start the measurement program for making long time measurements and parallel (multitasking) an instance of the lite program for evaluation of your data files. But the lite program must have already created the lite licence. This will be done at the first start of the lite program, see in chapter I1.3 and I7.1 of the Installation Manual.

Tip: If start problems occur, select the cold or original start. The original start loads only the original calibration files of PhysTech, no files for the capacitance offsets of the cryo system done by the customer. So the original start is only for testing not for working.

1.1.2 Search strategy for user init files

The following give an example of the search strategy for the user init file 'Globals.Cfg' in the standard mode 'Hot start'. We assume that UserX is the personal data directory and the software version is 3.2:

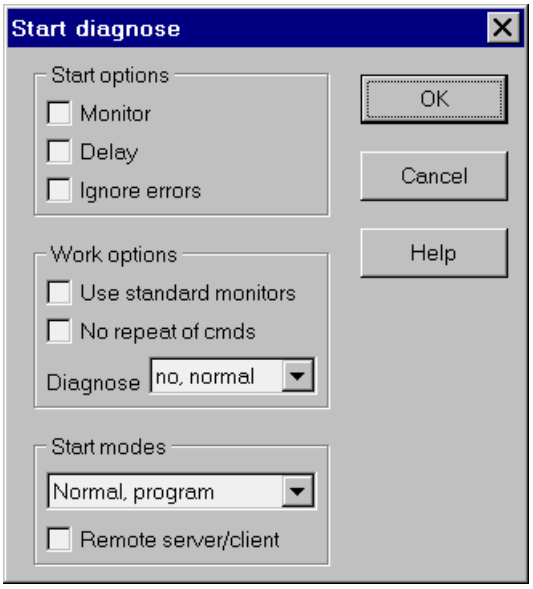
1) UserX\Init\32\Globals.Hot.Cfg
2) UserX\Init\32\Globals.Cold.Cfg
3) Conf\Init\Globals.Cfg
4) Sys\Init\Globals.Cfg

If the file was found in 1 (1 is the highest priority), this file will be load and the search will be canceled. In the other case the file will be searched in 2 and so on. With the mode 'Cold start' the search starts in 2.

At the personal init directory there is also the program version number as sub directory. So you can work with different program versions. After installing a new program number version the old init files will be copied to the new sub directory at first program start if possible.

1.1.3 Diagnose and start problems

This input is only necessary if you have start problems or if you want to look which files will be loaded or which commands will be send to the hardware. The diagnose is for checking problems at the hardware communication. All inputs here are only temporary, a new start will deactivate all. You find a log file of the start in the directory Diag\Start. For the measurement program it is 'Start_A.LOG'.



Start options are only valid for the program start. With 'Monitor' you get a monitor window on your screen with information about loaded system and user initialization files and commands send to the hardware. 'Delay' gives a 1 s delay after every action, by 'Ignore errors' the start goes on although errors occur.

Work options are valid for the whole program and not only at start. With 'Use standard monitors' you get at working a monitor window on your screen, 'No repeat of cmds' do not repeat a command if an error occur.

Diagnose is a special work mode to check problems with the hardware communication. Different diagnose work modes D1 to D7 and, sometimes for special customers, S1 to S3 exist. Use these diagnose modes only after authorization from PhysTech. The program saves then automatically or manually some or all communication commands into a report file. After leaving the program you get an information window about the report file name, usually Diag\Report\Diagnose.Zip. Send this report file to PhysTech.
The most used diagnose mode is D1. It reports the commands for the first and last measurement. So, if PhysTech request you for diagnose mode 1, start the program, make one measurement (usually a single transient), save the measurement, leave the program and send the report file to PhysTech.
Diagnose mode D5 reports only commands of the cryo system (temperature controller).
Diagnose mode D7 reports only errors and semi-errors. It can be activated permanently in Set_Conf, see chapter I3.2 and I6.5 of the Installation Manual.

Start modes defines how the hardware should be used. 'Normal, program' starts the program with the full hardware. 'Commands, all inits' starts not the standard program but a special monitor program in which you can send commands to the hardware. Here are also the full hardware will be used and initialized. 'Commands, no inits' starts also the monitor program but which no initialization of hardware. 'Commands, cryo init' starts the monitor program and initialized only the cryo system.

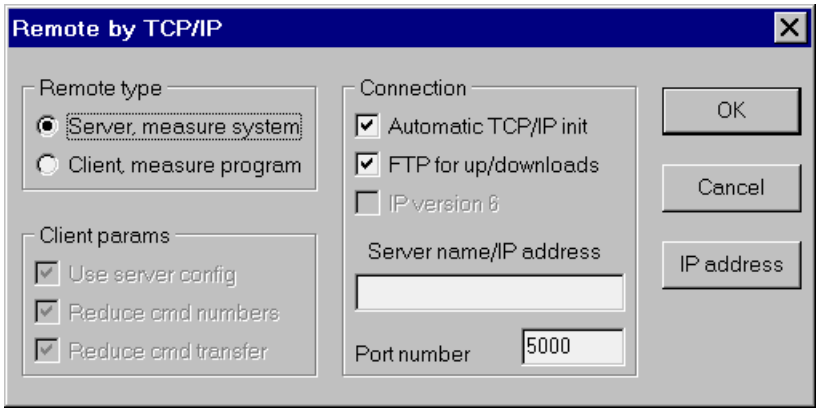
If you get start or hardware problems, the program breaks with an error message and asks you for making the report file 'Diag\Report\Rep_Err.Zip'. Please save this file and send it to PhysTech if you have questions to PhysTech. A short description of possible **start errors** will be given in chapter I6 of the Installation Manual, additional expert information in Sys\Doc\Diagnose.Txt.

Remote server/client gives you the possibility to use remote working as server or client.

1.1.4 Remote working

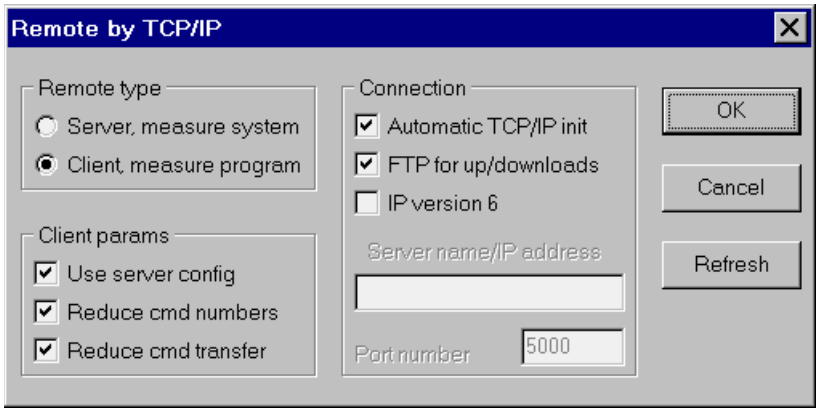
Here you can define remote working. One use can be to check hardware problems by PhysTech. In this case you start your program as a server and PhysTech will control it as a client. The other use can be making measurements from home via internet. In this case you start the measurement program in your laboratory as a server. At home you start the simulation program as a client, for this you need the simulation hardlock key.

You get the following input window if you start your system as a **server**:



With 'Automatic TCP/IP init' your IP address and port number will be send to a hidden directory of PhysTech server. In this case it is not necessary to inform the client about these parameters. In the other case you must phone or send a mail to the client with these 2 values. With 'FTP for up/downloads' you use FTP instead HTTP. Make sure that FTP is allowed.
For the remote connection you have to input the Server name or your IP address and the port number. If you don't know your IP address click onto the 'IP address' button. Make sure that the port is opened, ask your administrator.

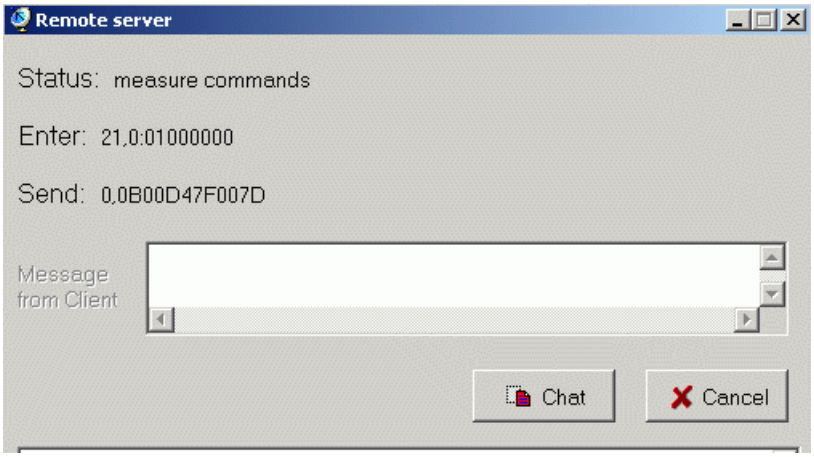
For the **client** you get following input window:



Without 'Automatic TCP/IP init' you must input the Server name or IP address and the Port number. In the other case it will be automatically read from PhysTech server, see at remote server. IP version 6 will not be supported by all providers/servers.

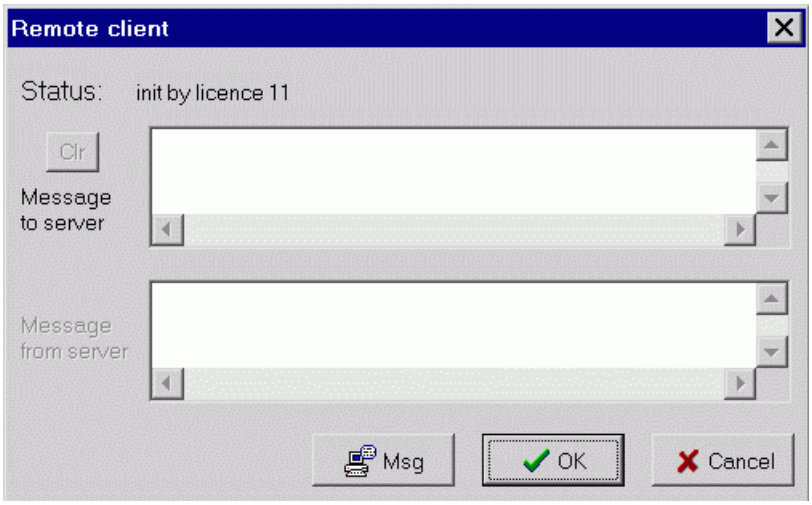
'Use server config' means that the configuration from the server will be copied to the client. By 'Reduce cmd numbers' and 'Reduce cmd transfer' the transfer is faster but for checking problems it can be useful to switch off these options.

The remote **server** will stay in a special window as shown below.



After the server and client were started, you see the actions and the transfer of commands initiated by the client. 'Enter' is the current command from the client, 'Send' the last answer from the server to the client. The send and enter strings will be listed in the memo text field below the buttons. The text field will be cleared after 500 entries. You can initiate a chat by the 'Chat' button.
At Windows 2000 and XP you should deactivate a screen saver.

If the server was started, you can start the remote **client** by the 'Start' button. If the connection and the initialization were successful, you get following window for the client:



You start the measurement program by the 'OK' button. After the initialization of the hardware the program goes into a measurement menu as usually.
By the 'Msg' button you can send a message to the server (chat mode). This message has to be input in the top text field. A message received from the server will be shown in the bottom text field.

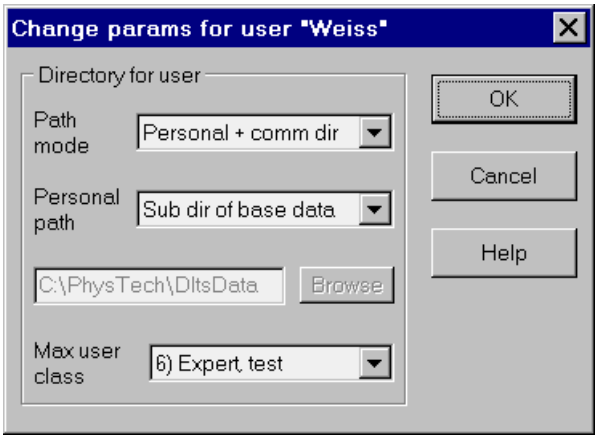
From the client you can call a chat window similar as above in 'Base tools → Utils → Remote program'. There are following **buttons**:

Break: Disconnects the remote connection.
Tools: There you can switch on or off peripheral hardware components, if available. You can also shut down the remote server by the client.
Msg: Sends a message to the server.
Close: Leaves this input window and goes back to the measurement program.

The server must be started before the client. You can start the client some times without new starting of the server.

1.1.5 New user

If you start the main program with a new/unknown user name or if you start with start option 'Original', you see the following input:



By **Path mode** you define your data path:

Guest directory:	Your measurement data will be saved to Guest data directory 'DltsData\Guest' and the Guest database will be used.
Common data directory:	The common data directory 'DltsData\Data' will be used for measurement data and database.
Personal directory:	Your personal data directory, for example 'DltsData\UserX' will be used for data and database.
Common + Personal directory:	You may switch between these both data paths, the default one is the common.
Personal + Common directory:	You may switch between these both data paths, the default one is the personal.
Personal, Common, Input:	As before, additionally an input of the path is possible.

With **Personal path** you define your personal data directory:

Sub dir of base data:	Defines your personal data path as a sub directory of the base data path, for example 'DltsData\UserX', see chapter I7.3.
Windows Personal:	Selects the Windows Personal directory.
Input of dir:	Here you can define the path by an input.

The directory for loading **initialization files** will also be defined by the path mode. This directory is a sub directory of the data path. At the first mode above it is 'Guest/Init', at the second 'Data/Init' and at all others a sub directory of your personal data path, for example 'UserX/Init' if UserX is the user name.

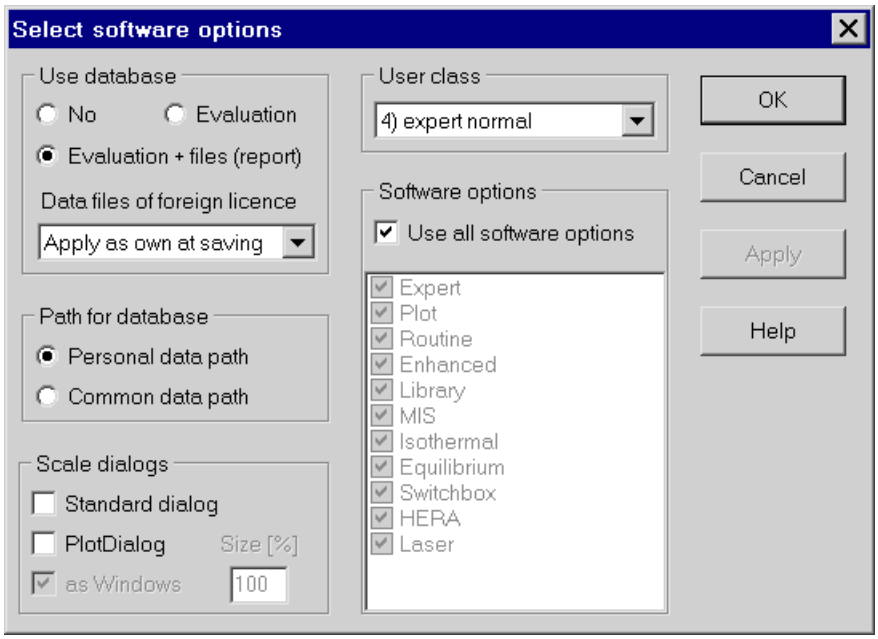
Note: The Windows guide lines prefer the Windows Personal directory. We prefer that the data path is a sub directory of the base data path. In this case users can read data from other users.

Max user class defines the maximal user class which you can use. This is the maximum value for the user. For the most users it is not necessary to change it. The real maximum value can be restricted later in the software.

You can modify these user inputs also in the Help menu in 'Configuration info' by clicking onto the 'User file' button. The user file is in Dlts\Work\Users.

1.1.6 Optional start windows

If a new user starts the program or if you select in the main start window 'Select software option' you get following input:



At **Use database** you can define if you want to work with the database. 'Evaluation database' means that only evaluation values will be saved into the evaluation database. Before saving you get a question or you have to call the save dialog.
At 'Evaluation + files (report)' additionally the measurement action, but not the measurement data, will be saved into the file database as a report. If measurement data will be saved, then automatically this report will be done.

With **Data files of foreign licence** you define what happens if you read foreign measure data files and want to save the modified file. This input is only important if you get measure data from foreign customers. 'Keep licence, no database' means that the foreign licence will be kept and no entries will be done in your database. At 'Use database' your database will be used for the foreign licence. 'Apply as own at saving' means that at saving this data file the licence number will be set to your licence number.

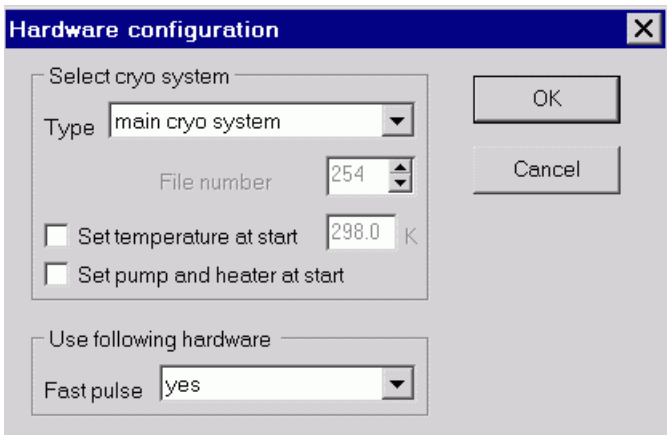
With **Path for database** you define whether you want to use your Personal or the Common data path for saving your data. **User class** defines your input level see chapter 2.4.1. With deactivating of 'Use all software options' you can select your **software options** for the start.

By **Scale dialogs** you can scale the standard and the plot dialogs. Either you can define a percentage size or the option as 'Windows'. In the last case the dialogs will be scaled by the Windows display text size (DPI). Especially at high resolutions screens it may be important to increase the scale with an individual percentage value bigger than 100 to avoid too small dialogs. Plot dialogs are dialogs which contain additionally a plot or grid. Look in chapter 2.3.1 for more information, especially for high resolution screens.
After changes in the 'Scale dialogs' input group, the Apply button will be enabled. A click onto this button shows immediately the optional start window in the new size.

If you start the program with the option **Input of hardware configuration**, you get an additional input window.

If **Fast Pulse** is installed, it can be defined whether the software shall work with the fast pulse generator or not. If it should work with it, the pulse generator has to be switched on. If it is connected by IEEE and another device (temperature controller) uses also the IEEE bus, then the fast pulse generator has always to be switched on.

When using a **variable laser**, you can here define its use, see chapter I3.3.



The input of **Select cryo system** defines the cryo system the software should work with:

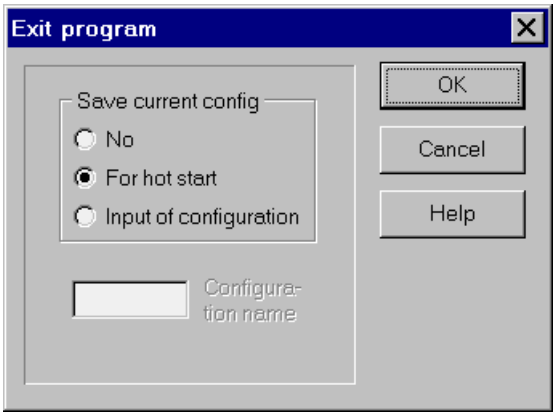
main cryo system:	As installed by the set up program.
alternate cryo system:	If a second (alternative) cryo system has been installed, it can be selected here.
input of cryo file no.:	Not for common use.
no cryo, simulation:	The software is working without a cryo system. The cryostat is simulated.
no cryo, input temp:	As above, but the cryo system is not simulated. The temperature can be set as a parameter. All measurements except temperature dependent ones are possible.

It is also possible to define a new **temperature** at program **start**. At every program start then the set point of the temperature controller will be set to this value.
You can also switch on **pump and heater** at program start if these options are available.

1.1.7 First start after installation

After starting the measure program first time after installation you get an information that you should do a calibration of the capacitance bridge because no customer specified calibration file exist. This calibration procedures and other is in the 'Calib' menu of the program module Base Tools. Normally this calibration will be done by PhysTech service, see chapter H1.5 of the Hardware Manual. The transient background noise should also be checked.

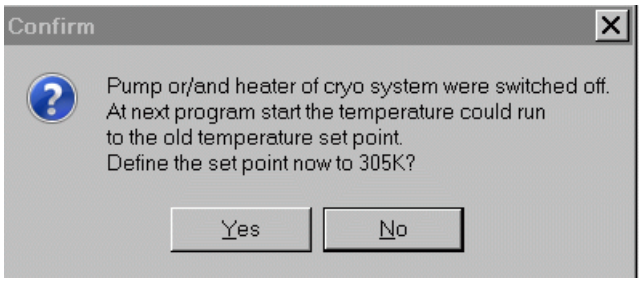
1.1.8 Program exit



Before leaving the program you will be asked for saving your current configuration. Here you define how the configuration files including all modifications done throughout the last working with the software should be saved into init files. By **Hot start** you can start your current configuration next time by selecting the start mode 'Hot start'. It is available as long as it is overwritten. You can also input a name of configuration.

Tip: We recommend to save once a 'well' running configuration with your preferred style, face and inputs. Call it for example 'Good'. Then you can start this configuration when the hot start contains too much unfavorable changes.

If you have changed the **material parameters**, not the sample parameters, it is possible that you get a checkbox for confirmation that you want also to save the new material parameters, see in 2.4.2. Here you can save these parameters only for the selected configuration, not for a cold start.



In some cases you get at program exit an additional question for the **cryo system**. This means that the pump or heater was switched off by the program, the set point has still the old value. It could be that this value is very low or very high. If you start the program again some temperature controllers run to the old set point. Some controllers save its set point although you have switched it off. Defining the set point to room temperature the cyro system will not cool or heat at new program start. You can input the value for the 'room temperature' in the general cryo options, see chapter 2.4.6.2.4. By default it is 305K.

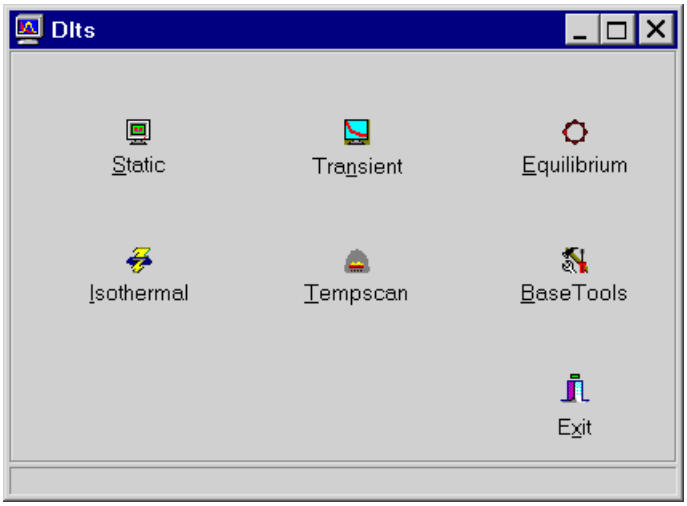
1.2 Program structure

1.2.1 Main program modules

By starting with 'Original' or 'Cold start' you see the main menu of program modules. These program modules will also called in this manual programs but all these are included in the DLTS program, these are not separate programs.

Base Tools:

Here you find some tools, for example calibration of the CGI-Meter (chapter H1.5 of the Hardware Manual) and a hardware test procedure. You can switch between measure and simulation program. A direct access is possible to other program tools as presentation plot program, database and trap library. Manually making and saving of single user initialization files are possible (user class 5). In the Utils sub menu you can refresh your lite licence for the portable program.



The following 5 program modules are called **measurement modules** or main programs:

Static: This module enables you to make static measurements, C/V and I/V curves, at a fix temperature. A temperature variation is also possible.

Transient: Here you can measure the time depending change (transient) of the capacitance or the current after a pulse. These measurements will be done at a fix temperature.

Isothermal: Isothermal transients can be measured at systematic variation of one measurement parameter.

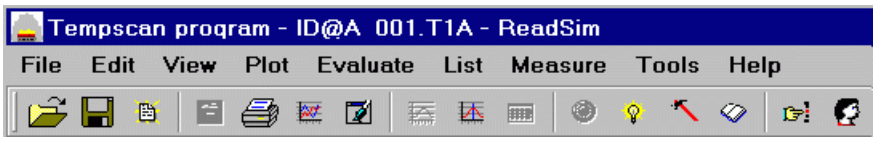
Tempscan: This module enables you to measure transients as a function of temperature. This is the main DLTS program module.

Equilibrium: Measures the equilibrium capacitance and current at a variation of temperature. TSC/TSCAP evaluations are possible.

The 5 measurement modules are meant to work independent from each other, although results from the static program can be transferred into the global (relevant for all modules) parameter set, especially the sample parameters. All these measurement modules contain also sample characterizing and test measurements (I/V, C/V, C(t), I(t)) to avoid unnecessary moving from one measurement module to another one. For example, in the tempscan module a C/V can be done and evaluated to get the shallow doping Ns necessary for the tempscan evaluation. Also all global parameters for data evaluation, viewing the data or configuration of the software are available in all these modules. This give a software structure, that is similar for all the measurement modules, and differs only in data relevant tasks.

1.2.2 Menu structure

All measurement program modules have a similar menu structure. The following picture shows as an example the tempscan:



The **top line** gives the program name, the data file name and the mode. 'Read' means that the data was read from a file and not currently measured, 'Sim' denotes that the data are simulated. Under this caption line there is the menu bar. Below the toolbar there is the **main canvas**. The data during the measurement will be shown on this canvas, after measurement or if you open a data file the standard plot resp. evaluation will be placed on this main canvas as shown in 1.3.4.

In the **status line** additional information or hints will be given, see picture in 1.3.4.

Menus exist for File, Edit, View, Plot, Evaluate, List, Measure, Tools and Help. The menus Edit, Plot, Evaluate, List and Measure are very program specific, the other are very similar. So you find for the common functions in File, View, Tools and Help a common explanation, chapter 2. There are also the common measurement menu points explained.

The **toolbar** contains symbols for the main important actions:


Open a data file.


Save a data file.


Read/View is a special procedure for reading/exploring data, see 2.2.1.


Data tasks for saving and printing data, save evaluation to database.


Print the standard plot on a printer.


Plot program will be called for the standard plot.


Refresh the standard plot**.**


Last plot calls again the last menu point in the menu Plot.


Last evaluation calls again the last menu point in the menu Evaluation.


Last list calls again the last menu point in the menu List.


Last measurement calls again the last menu point in the menu Measure.


New sample starts the test measurements for a new sample, see chapter 2.1.1.1.


Check measurement calls the check measurement tool, see chapter 2.1.1.


Sample parameters enables the input of sample parameters, see 2.4.4.


Temperature calls the temperature tools, see chapter 2.4.6.


Last menu point shows the sub menus of the last menu.


User button is a user definable button, see chapter 2.3.4.

Following **shortcuts** exist for these menus:

F1:	Help information, opens this manual at the corresponding chapter.
F2:	Repeats the last menu action.
F5:	Refresh the plot.
F11:	Personal hot key 1, see chapter 2.3.4.
F12:	Personal hot key 2, see chapter 2.3.4.
Ctrl+O:	Open a data file.
Ctrl+P:	Print the standard plot or evaluation.
Ctrl+S:	Save the current data.
Alt+F4:	Close the program.

You can also use the **keyboard** instead the mouse for calling the menu points. For this you have to press Alt+'key' as usual for Windows. If you press the Alt-key, you see which key/character is necessary. The character will be underlined in the menu name. So if you type Alt+F, the file menu opens.

1.2.3 Program tools and sub programs

Depending on the kind of work which you do in the main program modules you can call further common program modules (tools), so different plot programs, list programs, the database and the library. An explanation for these tools will be given in chapter 5.
At some program modules there are sub programs with his own data files, for example the Arrhenius plot by the tempscan maximum analysis. These sub programs will be described in chapter 4.
Program tools and sub programs have his own sub window with menu bar and toolbar. The plot or list will not shown on the main canvas but on the canvas of the sub window. A marker, movement by mouse or cursor keys, exist at many sub programs or program tools. In the last part of chapter 5.1.6.5 this marker will be explained.

1.2.4 Windows and Personalization

The size of all windows except pure text dialogs can be changed by the mouse. Normally you see this option by the additional minimize and maximize button at the top right of the window. Mixed windows with inputs and plots have also this possibility although there these both buttons are missing.

Inside of some mixed windows there is a so called splitter, moving this splitter changes the size ratio, for example between a data grid and a plot as shown in chapter 2.2.1.1.

At some software parts there are additional separate windows which are not fixed to the main window. You can change the size and position of these windows. If you click on the symbol of such window you get a short menu with additional features. Often there is the entry 'Stay on top'. Activating this flag means that this window has the highest priority for the visibility. This window hides this screen part of all other program windows.

The size of main and plot windows will be automatically scaled, usually this is sufficient. Chapter 2.3.1 and 2.3.5 describe how to change the style and size of these windows.

The dialog (input) windows have by default a fix size, but these can be scaled, see '**Scale dialogs**' in chapters 1.1.6 and 2.3.1. This can be important at high resolutions screens because the dialog windows may be too small by default for such screens. If this scale option is not activated, the Windows display text size (100%, 125%, ...) has only an influence on the menu size but not on the size of dialog text or dialog buttons of the DLTS program.
If the size of the toolbar buttons is too small, you can enlarge the buttons. Look in chapter 2.3.1 for more tips for high resolution screens.

You can define personal shortcuts at the most menus, see chapter 2.3.4.

Usually the current **configuration** will be saved for the next hot start, see chapter 1.1.7. But sometimes it can be helpful to make a cold start with the default configuration. Then you would lose your personal styles, sizes and shortcuts. Therefor it is possible to save only these parameters for a cold start. This will be described in chapter 2.3.4.
You should save once your complete 'well' running configuration, see chapter 1.1.7.

1.2.5 Parameter guide

The DLTS program allows the input of a lot of user defined parameters. These are parameters for the measurement, evaluation, plot, sample, view and so on.

Some parameters are only valid for the selected action or for a group of actions. We call these **local parameters**. Usually you get after calling a menu action an input window. It contains the main parameters for the selected action. Most of them are local parameters. So before a measurement you can input the corresponding measurement parameters, before a plot you can define it view.

Other parameters are **global**, these are valid for the whole program, for example the material parameters. Most of the global parameters are in the menus 'View' and 'Tools'. The following lists the main menu entries for the global parameters (in brackets the menu and chapter of manual):

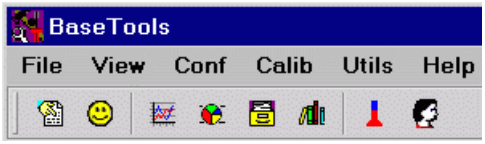
- **Measure params** (Measure, 2.1.2): Inputs of the main global parameters for measurements, for example the DLTS mode and special options for the hardware.
- **Form and panel styles** (View, 2.3.1): Defines the main face of the program.
- **Default plot parameters** (View, 2.3.2): Will be used for the initialization of a plot.
- **Global plot parameters** (View, 2.3.3): These will be used for all plots.
- **New size** (View, 2.3.5): Defines the window size of the program.
- **Program params** (Tools, 2.4.2): Defines the global physical, evaluation, simulation and material (2.4.3) parameters.
- **Sample parameters** (Tools, 2.4.4): These are *global* for the physical used sample in all measurement program modules or *local* for the current module after reading data. Here you can call the database parameters (2.4.5).

Some global parameters have to be input at a selected action, for example the global value for the reverse bias UR before a transient measurement.
In some cases a global and a local value for a parameter exist. For example, you can activate in the tempscan a flag for varying the reverse bias for each tempscan file. Then there is a local input for UR of each file. This local input has higher priority than the global value and will be used for the measurement.

1.2.6 Base Tools

Here you find some general tools. Most of them are also available in the measurement program modules and will be explained there. The most important menu here is the 'Calib' menu with the offset calibration of the CGI-Meter because the cryosystem

The **toolbar** contains buttons for following actions: User class, Simulation mode, Edit plot program, Presentation plot program, Database, Library, Temperature, User button.



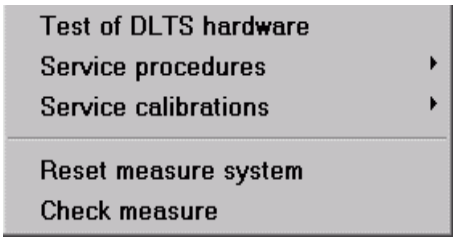
The **File** menu enables the movement between the main program modules.

In the **View** menu you can set the kind of style, the window size, and personal short cuts as explained in chapter 2.3.

In the **Conf** menu you can define the user class and switch between measure and simulation program. At user class 5 there is the feature for manual making and saving single user initialization files.

The **Utils** menu enables a direct access to other program tools as Edit data program, Edit plot program, Presentation plot program, database and trap library. Setting of the temperature, calling the monitor and refreshing the licence for the lite or portable program are here available. When using the remote client, a chat window can be opened.

The **Calib** menu contains follwing:



The '**Calibrate cable/cryostat offsets**' for the offset calibration of the cryostat and of the cables is important and has to be done after first program start. Look in chapter H1.5 of the Hardware Manual.

Use '**Test of DLTS hardware**' if hardware probems occur. More details are in chapter H.4.2.2 of the Hardware Manual.

At user class 6 you find some **service calibrations** which usually are not necessary because these were already done by PhysTech. The original calibration files of PhysTech are in the directory PhysTech\Dlts\Conf\Calib. If you make a calibration again, the new file will be saved in the directory PhysTech\Dlts\Work. The original file will not be deleted or overwritten. The DLTS program tries at program start first to find a calibration file in 'Work', then in 'Calib' and at last in PhysTech\Dlts\Sys\Meas.

Service procedures contains some special tests and measurements, especially the 'Test of pulse timings'.

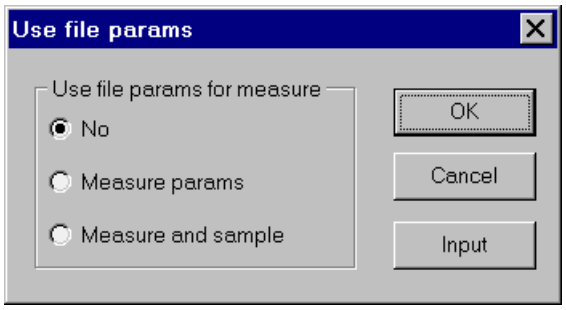
A Reset of measure systems make a new initialization, helpful at communication problems.

'Check measure' is the standard menu 'Check measurements'.

1.3 Program Basics

1.3.1 Measurements and data files

The DLTS program contains procedures for the measurement and for the evaluation. You can save the measurement data and read the data files. For the evaluation it is not a difference whether the data come directly from the measurement or from a read data file. The sample and measurement parameters will be saved into the header of the data file. So if you read a data file, it could be that the program works with other sample parameters as your physical sample in the cryo system. Before reading file data the parameters of the current physical sample will be stored internally. If you then want to make a new measurement the program ask you for using the parameters of the read file:



No: The parameters of the read file will not be used, the parameters of the physical sample will be restored. This is the normal mode.
Measure params: Only the parameters of the measurement will be taken over, these are reverse bias, pulse voltage, period width and so on. Use this option if you want to make a measurement under the same condition as the read file.
Measure and sample: Additionally the sample parameters as sample type, area and so on will be taken over, see 2.4.4 for sample parameters. This mode gives the possibility to shorten the input time for a measurement of the same or similar sample.

With the **Input** button you can input the sample parameters before starting the measurement. If you don't use the sample parameters of the read file the parameters of the current physical sample will be first restored and then you can make the input.

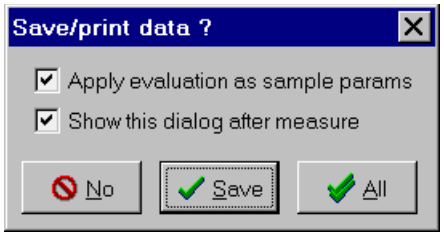
If you have loaded file data and leave the measurement module and goes to another one then the parameters for the physical sample will be restored without question.

If you have changed sample parameters or other data of a loaded file then these changes were made only in the memory but not in the file itself. For permanent changes you have to save the file again.

Note: At a hot start all measurement parameters of the last start will be loaded, except the reverse bias voltage. This is always zero after start of the measurement (not simulation or lite) program. The reason is the protection of your sample.

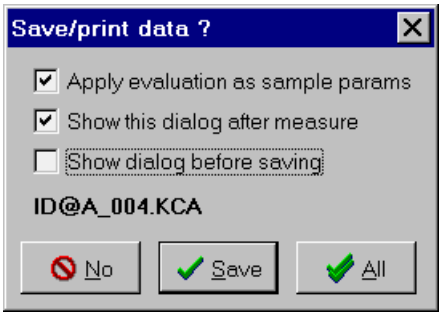
1.3.2 Data savings

In the tempscan measurement module the measure data will be always saved into the file(s) at every temperature at which a measurement will be done. In the Static, Transient and Isothermal measurement module the measure data will be normally not automatically saved in a file. After the measurement you get the following question for saving data:



No: The data will not be saved into a file.
Save: You get the standard Windows dialog for saving data.
All: Opens the data task dialog for saving and printing data and saving evaluation into the database, see chapter 2.2.3.

You see the question for 'Apply evaluation as sample params' only in some cases, for example after measurements of C/V curves.
You can deactivate the question for saving data by 'Show this dialog after measure'. In the data tasks menu of the File menu you can it activate again.
The program shows the dialog in the face above only at the first saving after program start.



If you have already saved a file you get a similar window. Now you have the additional question for **'Show dialog before saving'**. If you deactivate this option and confirm with 'OK', the program does not open the standard Windows dialog for saving data but save the data directly into the file. You see the automatic generated file name in the line below this option.

1.3.3 Data file extensions

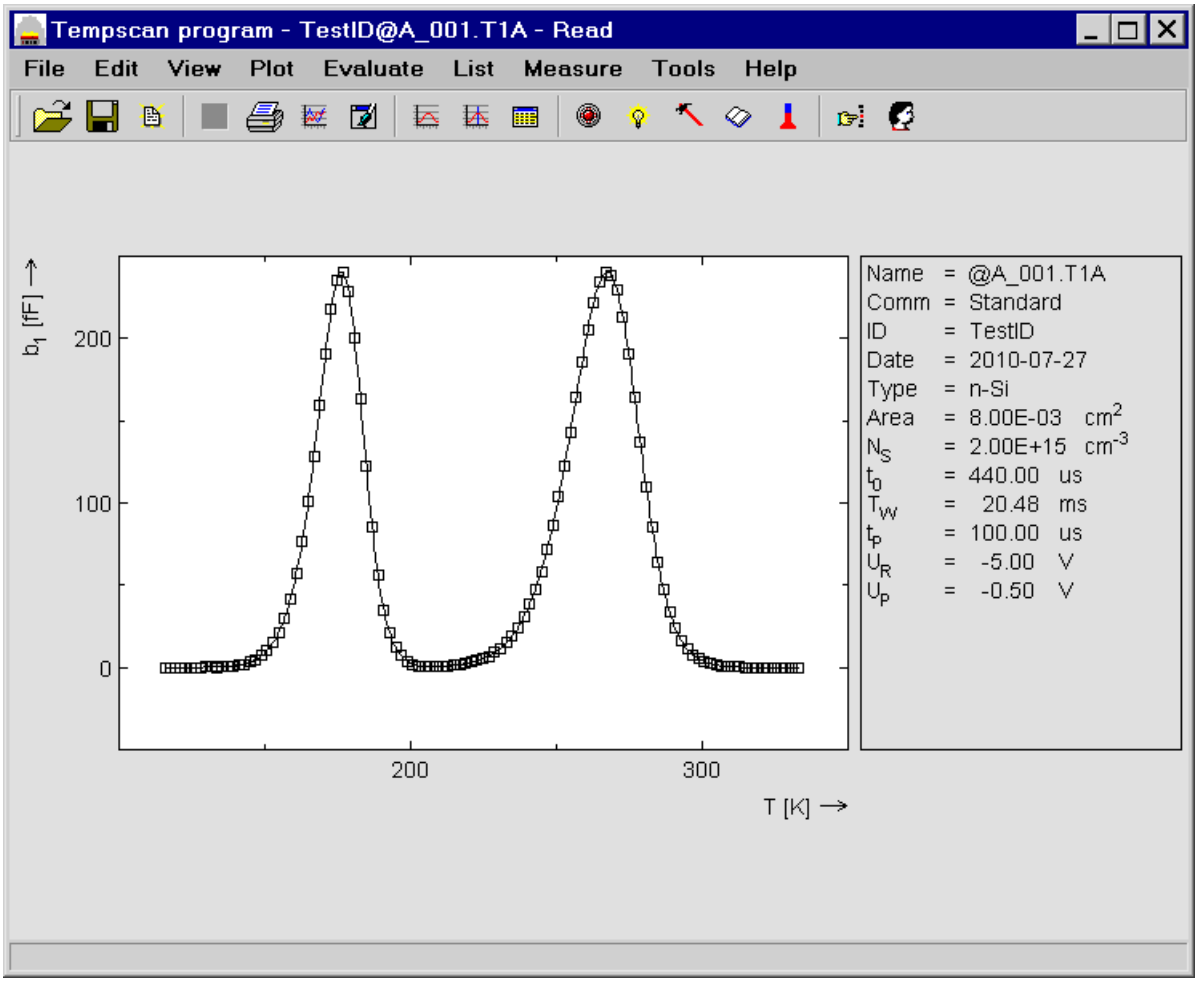
The DLTS measurement data are binary data. The extension for the Windows file system is DLT. Additionally to this Windows extension the files have a second extension, we call it data extension. In the sample below, 'TestID@A_001.T1A.DLT', it is T1A.

The first character of this extension denotes the **data type.** Different data type files were used in the different program modules and have different data formats:

A : Arrhenius data file, used in all main program modules
F : Data file of presentation plot program
K : Static data file, C/V or I/V curve
P : Isothermal data file
Q : Equilibrium data file, TSC/TSCAP
T : Tempscan data file, fix period width
V : Tempscan data file, variable period width
Y : Transient data file

The second character of this data extension denotes the kind of measurement. The meaning depends on the first character.
The third character is normally user definable, by default it is an 'A'. If you use the sample switch box then it is automatically a '1' to '6' and define the number of measured sample.

1.3.4 Text header in plots, abbreviations



The file name is TestID@A_001.T1A.DLT in the example above. At the right side of the plot you see the plot text header. The following data values are in all plots:

Name : Base file name without ID and data extension DLT.
Comm : Comment
ID : Sample identification, see in 2.4.4
rcID : Record ID in the file data base
Date : Date of measurement
Type : Material name and type of doping (n- or p-type).
Area : Area of sample contact.

There are further values depending of the kind of plot and measurement. The following give a list of these **abbreviations**:

an : n-th cosine coefficient
bn : n-th sine coefficient
Correl : Correlation of linear regression
CR : Capacitance at reverse bias voltage
CP : Capacitance at pulse voltage
Cox : Oxide capacitance
Energy, dE : Energy of trap level, EC-ET for n-type, ET-EV for p-type
IR : Leakage current at reverse bias voltage
IS : Saturation current
n-fac : n-factor of Schottky diode
NS : Shallow doping concentration
Nss : Density of surface states
NT : Trap concentration
NTs : Trap concentration, calculated with the space charge region
phiB : Barrier height
sigma : Capture cross section from Arrhenius-plot
sigmaC : Capture cross section from capture measurement
tau : Time constant
Temp, T : Temperature, if 2 sensors then sensor 2 (sample)
TempC, TC : Temperature of control sensor 1
TempD, TD : Temperature difference after - before measurement
TempV, TV : Temperature difference sensor 2 (sample) – 1 (control)
TempX, TX : Maximum temp. difference between all transients, only isothermal module
tP : Pulse width
t0 : Time between end of pulse and first transient data point
Tw : Period width = Time of one transient, start at t0
UR : Reverse bias voltage
UP : Pulse voltage
UP* : Pulse voltage, measurement at pulse, see also chapter 3.2.1.1.2.
UD : Diffusion voltage

Abbreviations for the **DLTFS** evaluation, more in chapter 3.2.3.1:

a1L : a1 with Tw'=Tw/4
a1M : a1 with Tw'=Tw/2, t0'=t0+Tw/16
N : Numbers of sampling (transient) points
td : Sampling interval, time between 2 transient points, Tw=N*td
ts : Time when the transient has decreased to the ADC resolution
tau(an,bn) : tau calculated from an and bn
ExpClass : a1/a2 * b2/b1, is 1 for a single exponential transient
TauClass : Classification of the tau calculation, where
- **1 – 6** : Error during measurement
- **7 – 9** : Transient is not taken into account
- **10** : No evaluation was done
- **11-29** : No signal suitable for evaluation
- **30-39** : Coefficient ratios do not correspond to the assumed transient type or shape
- **40-49** : There is an evaluable signal but the shape is not assignable
- **50-59** : Probably the transient is of the assumed type
- **60-75** : The transient is of the assumed type

Further abbreviations in **equations**:

ε	: Dielectric constant of semiconductor
E_F	: Fermi level
F	: Area of contact
k	: Boltzmann constant
n_i	: Intrinsic concentration
N_C,N_V	: Effective density of states of electrons resp. holes
q	: Elementary charge
v_{th}	: Thermal velocity
W	: With of space charge region

1.3.5 Data dimensions

The data saved in the binary and ASCII files and in the program memory have always the same base dimension, for example V for the voltage. The axis numbers on the plot or the values at the text header can be shown as technical dimensions if this base dimension, for example nV, uV, mV, kV and so on. Complex dimensions are composed by the base dimensions.

Following **base dimensions** will be used:

Area	: cm^2
Capacitance	: pF
Charge	: C
Concentration	: cm^-3
Current	: A
Energy	: eV
Frequency	: Hz
Length	: cm
Resistance	: Ohm
Temperature	: K
Time	: s
Voltage	: V

1.3.6 Temperature measurement

Depending on your cryosystem 1 or 2 temperature sensors will be used:

- **1 sensor:** The same sensor will be used for the temperature control and for the measuring of the sample temperature.
- **2 sensors:** Usually sensor 1 is for the temperature control (setting of temperature), sensor 2 is for the measuring of the sample temperature. It is possible that sensor 1 and 2 will be denoted as sensor A and B on your cryosystem. Sensor 2 will only be used for the measurement plot and evaluation, the temperature of sensor 1 will be used at waiting for (constant) temperature and so on. That means sensor 1 defines when the measurement starts, sensor 2 gives the sample temperature at this measurement.

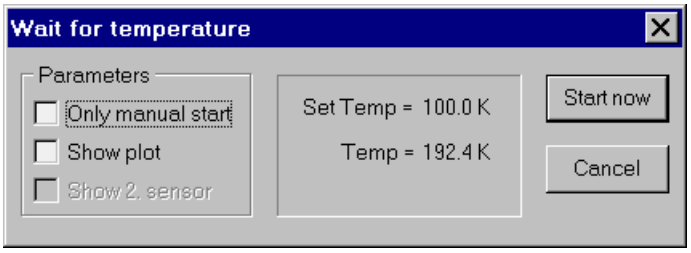
The temperature will be measured before and after a measurement (C/V, transient …). The shown temperature (plot) is the **average** of both, called Temp. This average and the value 'before' will be saved into the data file. Then the difference 'after – before', called TempD or TD, can be calculated.

If using **2 sensors** then the temperatures 'average', 'before' and 'after' come from the sample sensor 2. The average temperature will further be called 'Temp'. Additionally the temperature of the control sensor 1 will be measured before and after a measurement. The average of these both values will be called TempC and will also be saved. The difference 'sensor 2 - sensor 1' will be called TempV or TV. Sensor 1 or 2 means the average temperatures of sensor 1 or 2.

Before the start of a measurement with setting temperature you see the window of **Wait for temperature**. The current temperature will be permanently shown until achieving the set point 'SetTemp'. Depending on the 'cryo times' (chapter 2.4.6.2) parameters and the waiting time the measurement may start earlier.

At using two temperature sensors both temperatures will be shown. 'Temp' is here the temperature of the control sensor 1, 'TempS' is the temperature of the sample sensor 2. Both temperatures are here not averaged. The control sensor 1 will be used to check the achieving of the temperature set point.

By clicking on the button '**Start now**' the measurement starts without waiting for the start temperature.



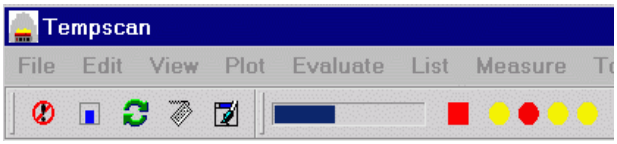
At the **Parameters** you can activate some flags:
If activating **Only manual start** then the program don't start when achieving the temperature set point. Only a manual start by the 'Start now' button is possible.
When activating **Show plot** or **Show 2. sensor**, if enabled, the window increases and shows at the bottom a plot with the up to 100 last temperatures measurements versus time, made here at waiting for the temperature. 'Show 2. sensor' means here sample sensor 2. If you activate these both flags then the curves of the control sensor 1 (black) and of the sample sensor 2 (red) will be shown.

Note: 'Temp' denotes always the standard temperature, independently if it comes from sensor 1 or 2.

If the temperature measurement and its repetition was not successful, the temperature will be set between 1.1K and 1.4K. The reason for this problem can be a communication error or no connection of the sensor.

1.3.7 During the measurement

During the measurement the menus are not enabled and a new toolbar is visible. At the right side of this toolbar there are in most cases a progress bar, shapes for transient state and range, and further information, for example at a tempscan the current temperature.



The color of the square behind the progress denotes the **state** of transient measurement:

- Green: Compensation, CC-regulation and equilibrium measurements.
- Aqua: Settings before transient measurement and DC background measurement.
- Red: Transient measurement, first loop.
- Maroon: Repetition of transient measurement after changing range or amplification.
- Blue: Reading of data and settings after transient.

The circles show, depending on the DLTS mode, the possible capacitance or current ranges. The red circle marks the **actual range**, in the picture above it is range 2.

Tip: The status monitor gives more details about the measurement, see chapter 2.4.7.2.

Not all options of the **toolbar** exist for all measurement modules:

Break the measurement after confirmation by the user.

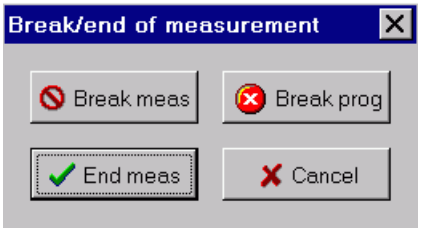
Hides the standard window and show only the **progress window**.

Makes a **measurement** if the program is in the temperature waiting loop.

Input (change) of parameters.

Refresh the plot.

If you click onto the break button you get the following question and buttons for the **break** of measurement, but not all buttons are enabled at all measurement modules.



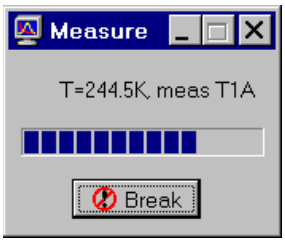
Break meas: Break the measurement immediately, it can be that the last measure point is not valid and will not be overtaken in the data array.

End meas: Break the measurement after the current measurement block/record is finished, so that this gives a correct end of the measurement.

Break prog: This function will interrupt the program. Use it only if the normal break doesn't work and after program problems like access violation. After this interrupt the program doesn't work accurately. Close the program and start it again after this function.

Cancel: Close the break window and go back to the measurement.

The **Progress window** hides the standard window and shows a small window with a progress bar and the current temperature. Use this option if you need your screen for other programs. Then you can watch the progress of the measurement, but you need only a small place on the screen.
If you close this window by the Windows close button (right top) you go back to the measurement with the full standard window. If you minimize the progress window then you see it only in the task bar.
You can break the measurement by the Break button.



1.3.8 Miscellaneous

At many input fields you have to put in **numbers**. Only a range within of a minimum and maximum value is possible. If the input is smaller/bigger than the minimum/maximum, the minimum/maximum value will be applied. Sometimes you get a warning at the closing of the input window when an input is out of the valid range. Then you get a separate input window with the chance of a new input. This is especially important to avoid too high voltages or currents on the sample or to avoid too long measurement times. This warning can be disabled by a special flag.

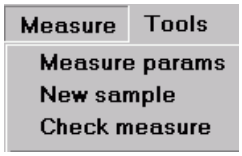
The DLTS program forbids Windows to go into the **sleep mode** after some time of inactivity of user interaction. This avoids that Windows suspends the DLTS program during long measurements which would yield to communication errors after wake-up. The display standby mode will not be changed.

2. Common functions

All measurement program modules have a similar menu structure. So you find in all the same or very similar menus for File, View, Tools and Help. In the following these common functions and the common measurement menu points will be explained.
Chapter 2.6 explains common functions from the other menus Edit, List, Plot and Evaluate.
Chapter 2.7 don't describe menu functions but only parts of input windows which will be used in some input windows.

2.1 Measurement menu

The measurement menu of all measurement program modules contains specific and 3 common measurement routines. In the following the common routines will be explained while the specific measurements will be described in the chapters 3.1.1 to 3.5.1 of the measurement program modules.



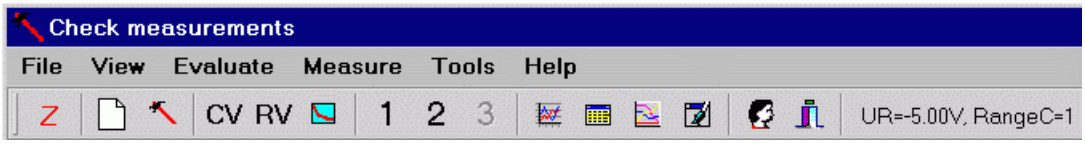
'**Measure params**' contains the main global parameters for measurements, for example the DLTS mode and the minimum ranges. Usually you will not change often these parameters.
'**Check measure**' contains sample characterizing and test measurements, it will be introduced in the next chapter.

New sample should be used if you change the sample in the cryostat. After the first input window the current voltage will be set to zero. In many cases it is enough to use this routine as preparation for tempscan measurements. Here you can check the contact and calculate the shallow concentration Ns. This procedure can be called from each main measurement program module and from the sub program 'Check measurements'. It will be explained there in chapter 2.1.1.1.

Caution: Before making contact to the sample, always set the reverse bias to zero!

Tip: Use for contacting a new sample the 'Check measurements' sub program. There you can set the reverse bias to zero by the 'Z'-button, see next chapter.

2.1.1 Check measurements



This sub program contains sample characterizing and test measurements (I/V, C/V, C(t)) and evaluation of the shallow doping Ns, necessary for the DLTS evaluations. In most cases it is not necessary to go to the Static or Transient program because you can do here the most important static and transient measurements and save its data. So you avoid unnecessary moving from one measurement module to another one.

A small information text will be shown on the right of the toolbar. It contains the applied voltage and, depending on the DLTS mode, the actual capacitance or current range. A square denotes the transient state during a transient measurement, see chapter 1.3.7.

The DLTS program uses a global value for the **reverse bias** UR. Usually it will be applied before a transient measurement, except at using a local value. It will be always set to the sample after a complete measurement, for example after a C/V curve in the Static module. The sample stays then at this voltage until a new measurement.
The 'Check measurements' sub program allows to set the applied sample voltage locally to zero without clearing the input value of UR. This can be done by the 'Z'-button and the 'New sample' and 'Test of contact' procedure. This local value will be kept until a new static or transient measurement. Tools with an input of UR sets also this voltage. When calling the 'New sample' procedure, the applied voltage will be locally set to zero.

The toolbar of 'check measurements' contains a so called **'Z'-button**. With this you can set the sample voltage to zero and clear the global input value (variable) for UR. The color of 'Z' in this button denotes the state:

- **Green:** The applied voltage and the global input variable are zero. A click onto this button clears again the voltage.
- **Blue:** The applied voltage is zero but the global input variable for UR is not zero. A click onto this button sets the global value to zero.
- **Yellow:** The applied voltage is zero but a high voltage range is used. A click onto this button selects locally voltage range 1 resp. switches off the high voltage relay.
- **Red:** The applied voltage and the global input variable aren't zero. A click onto this button applies zero voltage to the sample without clearing the global variable. If using a high voltage range, this range will be kept.

Tip: You see the applied sample voltage behind the toolbar and in the status line. The status monitor shows this voltage and additional information in all measurement modules, see chapter 2.4.7.2. The status monitor allows also to plot the measured temperatures of the last 20 seconds.

The **toolbar** contains symbols for the main important actions:

Break the current measurement, visible at a static or transient measurement.

New sample starts the test measurements for a new sample.

Test of contact checks whether the sample is well contacted.

C/V measurement for evaluation of Ns.

Measurements of **C/V and I/V** curves at **reverse** voltages.

Transient measurements.

Show **alternative plot 1**, the hint gives more information.

Show **alternative plot 2**.

Show **alternative plot 3**.

Plot program will be called for the selected plot.

List data.

Evaluation of data will be shown.

Refresh the last plot.

User button is a user definable button, see chapter 2.3.4.

Close the check measurement tool, go back to the measurement program module.

The main important procedures here are:

1. New sample
2. Test of contact
3. Polarity and bias search
4. Ranges and compensation
5. C/V curve with Ns calculation

2.1.1.1 New sample

This procedure is for the preparation (first test measurement) of a new sample, that means for changing the sample in the cryostat. Following actions will be done:

1. Question whether the polarity/bias test should be done, necessary if the polarity is unknown, and whether the C/V curve should be measured to calculate the shallow concentration Ns. For the last question different variables will be used if calling from measurement module or from Check measurements.
2. Test of contact, if polarity/bias search at 0 V. In the other case at reverse bias, but reverse bias will be applied on the sample after starting the test of contact. At the input window the current voltage is always 0 V if you have selected the menu 'New sample'.
3. Polarity/bias search if selected in 1.
4. Setting of minimum ranges and capacitance compensation.
5. Input of sample parameters and measurement of C/V curves if selected. The calculated Ns value will be applied here. It is recommendable to save the C/V curve.

The points 2 to 4 will be explained below, the sample parameters in chapter 2.4.4, the C/V curve in 3.1.1.

Note: If using a new sample you must be sure that the sample will not be destroyed by the voltage. So the best is to call the menu new sample, define there using of the polarity/bias search (known or unknown sample doping) and click then on the 'OK' button. After this the current voltage will be set to zero, the program jumps to the test of contact. Then take out the old sample, if one was already used. Then load the new sample into the cryostat and contact the sample. Start the test of contact.

2.1.1.2 Test of contact

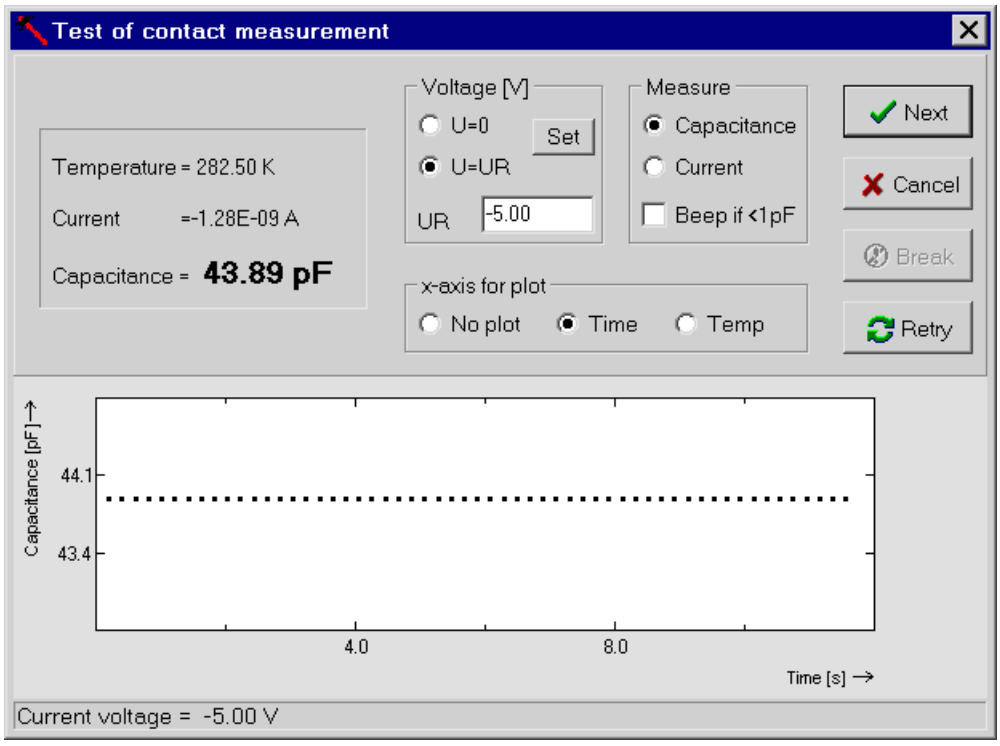
This procedure is for testing whether the sample is well contacted by the probes. This test measures permanently the sample capacitance or leakage current and shows the values on the screen. You start this test by the '**Start'** button which set also the voltage.
When calling this procedure from the 'New sample' procedure, the **voltage** applied to the sample is 0 V. If you start it separately or if you have not selected 'Polarity/bias search' you can here define the voltage, either 0 V or the reverse bias voltage UR:

- **U=0:** The button will be labeled by 'Clr' and sets the applied voltage to zero, similar as the red 'Z'-button described at the previous page. If activating '**VoltRange=0**' then additionally a high voltage range will be set to 0, as yellow 'Z'-button.
- **U=UR:** The button will be labeld by 'Set' and sets immediately the applied voltage to UR. If a high voltage range was selected, it will be switched on.

The current voltage will be shown in the status line. If selecting 'U=0' (local voltage) the global bias UR (and a high voltage range) will be applied later after a new input window of a full measurement (static, transient …) without a message. At other measurement procedures you get an information window.
You can select the measurement value, either the capacitance, the current or the conductance. The computer gives a beep at no contact if 'Beep if <1pF' is activated.

Caution: Use for the 100V option or for an external voltage only the Voltage mode U=0 because high voltage may be at the probes if you try to contact the sample!

Observe the capacitance whilst making the contact with your sample. A stable reading at a reasonable sample capacitance is a sign of a **good contact**. The capacitance value of your sample will depend upon the size of contact and the doping concentration. Bear this in mind when considering what a reasonable capacitance should be.



The following **buttons** here are possible but not all are visible at all times:

Start	**Start** the test of contact.
Next	**Next:** Stop test measurement if running and go on to the next action (ranges).
Retry	**Retry** the test of contact.
Ignore	**Ignore** (skip) test measurement and go on to the next action
Temp	**Temp** and current (if capacitance selected) or capacitance measure one times.
Break	**Break** the contact test measurement.
Cancel	**Cancel:** Break and leave the contact test, go back to the menu.

Note: Here and in the following input windows the default button for doing is always on the top. So if you don't want to break or to retry, you have only to click on this button, these are 'OK', 'Start' or 'Next'.

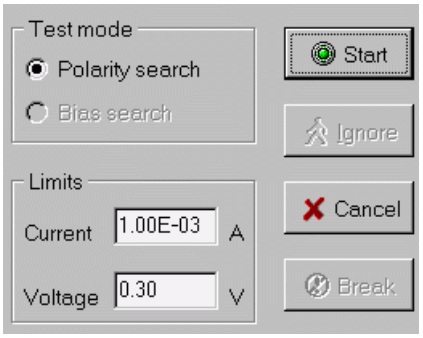
If you want to make only the test of contact without the next action, the setting of ranges and compensation, leave the test of contact by the 'Cancel' button.
The plot symbol (Measure) can be changed in 'View → Default plot params', see chapter 2.3.2.1.

If you have stopped the measurement, you can copy the shown curve as ASCII data into the clipboard by Ctrl-C.

2.1.1.3 Polarity and bias search

This procedure consists of two parts (called Test mode), the first is the **Polarity search**. The software will measure both I/V and C/V curves using a small voltage range and will give an indication of the polarity of the device and the direction in which the bias should be applied to the sample. Normally it is not necessary to input here any values, the defaults are suitable.

At the first input window there are the absolute maximum limits for the current and the voltage. Maximum this voltage will be applied to the sample. So for 0.3 V test I/V and C/V curves will be done from 0 to -0.3 V and from 0 to 0.3 V. The maximum current is only a stop condition. The current will not be set but measured. So if the absolute measured current is higher than this value, the measurement stops. By the button '**Start**' the polarity test begins.



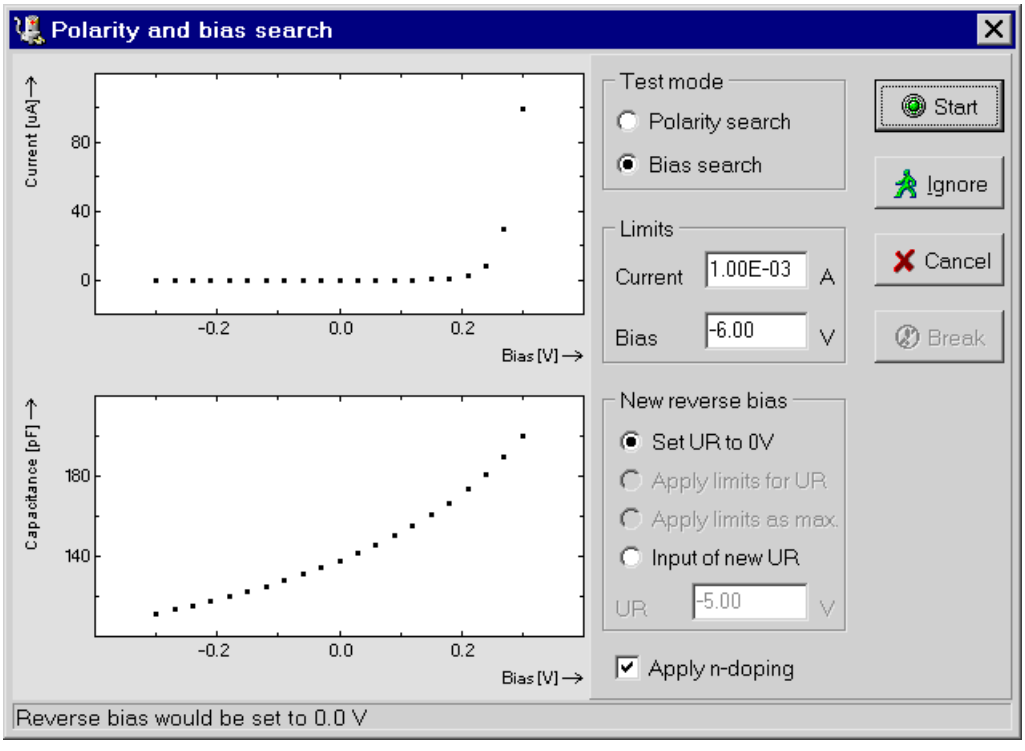
After the polarity search is finished, you see the I/V and C/V curves. The program decides by these curves the polarity. You can apply this proposal by 'Apply n-doping' resp. 'Apply p-doping'. If this flag is not activated, the software keeps the old doping type.
The doping type means for the reverse bias:

n-type: The reverse bias direction will be in the negative voltage direction.
p-type: The reverse bias direction will be in the positive voltage direction.

The program changes the test mode to **Bias search**. At the limits now there is a maximum value for the bias. So for -6 V the I/V and C/V curves goes from 0 to -6 V. You can here set the bias value to 0 V or to an input value. This is only important if you skip the bias search by the 'Ignore' button. UR is always zero before and between polarity and bias search. With the button '**Start**' you start the bias search, by the button 'Ignore' you skip the bias search and go to the next action. 'Cancel' closes the total procedure, sets UR to 0V and goes back to the menu.

The picture on the right shows the I/V and C/V curves after the polarity search and the inputs for (before) the bias search.

If leaving here by 'Cancel', the inputs will not be applied. But 'Ignore' applies the inputs.



The automatic bias search is usually not for MIS samples because you should set here the bias by special measurement conditions.

After the **Bias search** the I/V and C/V curves will be shown and the selection for setting a **New reverse bias** is now enabled:

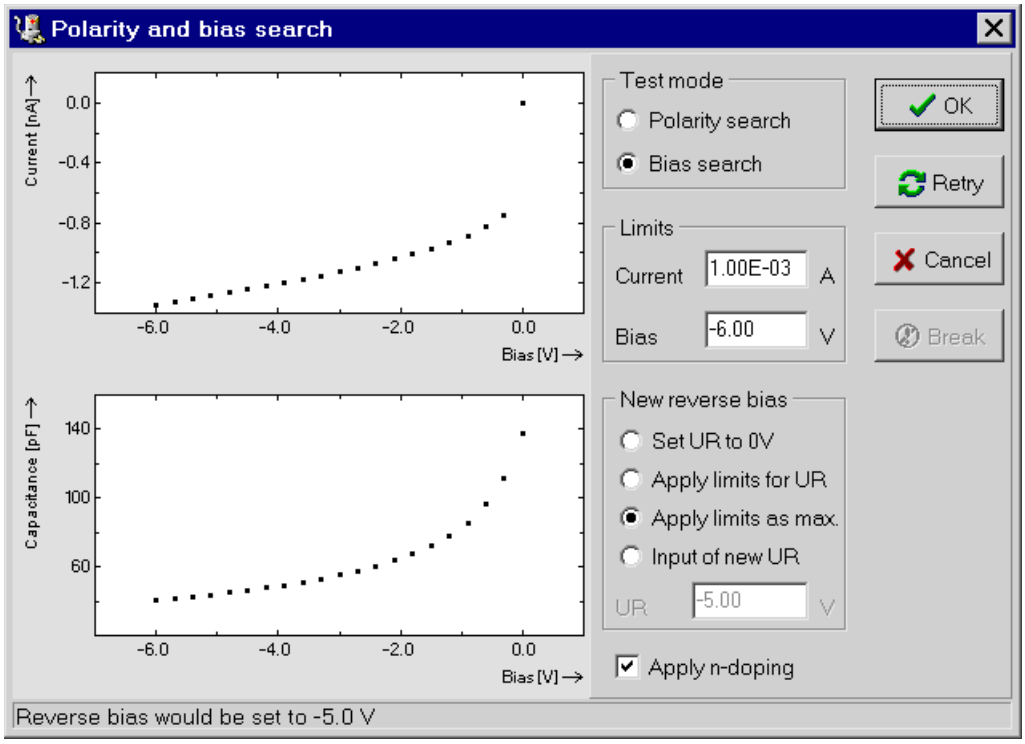
- '*Set UR to 0V*' sets UR to zero V
- '*Apply limits for UR*' applies the reverse bias from the limits of the I/V and C/V curves, in this example -6 V. It takes the current limit into account.
- '*Apply limits as max.*' takes the smaller value from the predefined UR and the new one from the I/V and C/V curves, in this example -5 V.
- '*Input of new UR*' applies the value of the input box below.

The software shows the reverse bias proposal in the status line. The new reverse bias will not be applied before leaving this procedure. After leaving the bias search the actual bias will be shown in the status line.

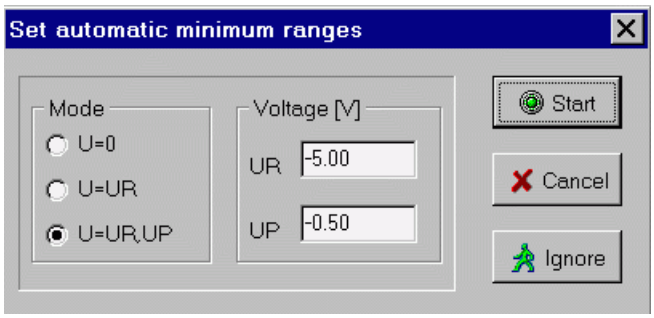
Note: DLTS measurements can be done normally without problems up to a leakage current of about 1 uA.

The test mode stays at the bias search, so you can retry this search by the button 'Retry'. The program applies the new reverse bias to the sample and goes to the next action by the '**Next**' button. By 'Cancel' zero voltage will be applied to the sample and the program goes back to the menu.

The picture on the right shows the I/V and C/V curves after the bias search. The inputs are valid for repeating the bias search and for applying the reverse bias and the doping sign.



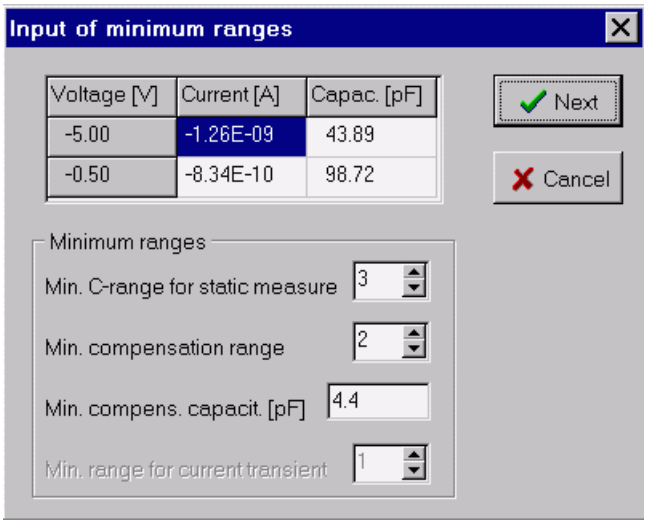
2.1.1.4 Ranges and compensation



Before the software sets automatically the **minimum ranges** for the current and capacitance measurements you have the possibility to define the voltages at which the measurements should be done. Mode **U=RR,UP** means that for the automatic ranges the reverse bias voltage UR and the pulse voltage UP will be used.

The minimum compensation range will be set by the reverse bias current and capacitance and by the difference pulse – bias capacitance, the limits are described in chapter 2.1.2.3. The capacitance difference will be used only here while the other limits will be used at each searching of a new compensation range (but not at each compensation).

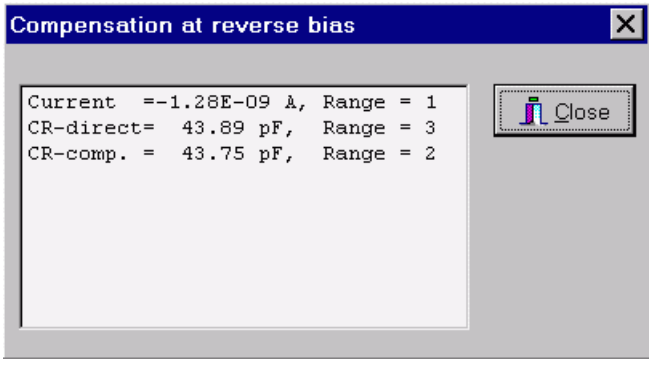
After the software has done the test measurements for the determination of the minimum ranges, you get a list with the current and capacitance values and with the proposal of minimum ranges. You can change these values by the input.



Min C-range for static measure is the minimum range for C/V curves.
Min. compensation range is the minimum range for capacitance compensation and for capacitance transient measurements.
Min. compensation capacitance is a minimum value for the compensation.
At I-DLTS you can define the **min. range for current transients**.

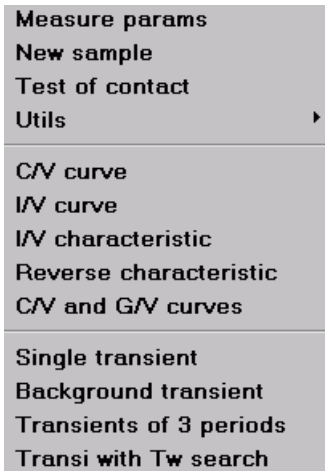
Note: All these ranges are only minimum ranges. The used range will be automatic set by the software before resp. during measurement. It can be higher.

The CGI-Meter FT-1235 has 4 ranges with a maximum capacitance of 4, 40, 400 and 4000pF (standard limits). The I/V converter has 6 ranges with a max. current of 100nA, 1uA, 10uA, 100uA, 1mA and 10mA.
Before compensation you get the question for the reverse bias, that means for the voltage at which the **compensation** will be done.



After compensation you see a list with the measurement values and the used ranges at UR. **CR-direct** means a capacitance measurement without compensation, so directly measured by the bridge.
CR-comp. gives the capacitance measured with the compensation capacitors.
A small difference is normal, because an absolute calibration of the capacitors is only possible by an error of 1 percentage.

2.1.1.5 Menus



In the **Measure menu** there are menu points for Measure params, New sample, Test of contact, Utils, Static and Transient measurements. More static and transient measurements and an explanation of all curves you get in chapter 3.1.1 and 3.1.2.

In the **Utils** sub menu you can set the reverse bias, measure the equilibrium at UR/UP, compensate the capacitance, define the minimum ranges and list the actual ranges.
The 'Polarity/Bias search' (2.1.1.3) can here be called without test of contact, the 'polarity check' is only the first part of this. UR will not be automatically set to zero.

When working with FET's here the UGS and UDS curves can be measured. In the other case following measurements of static curves are possible:

1. **C/V curve** with Ns calculation.
2. **I/V curve**.
3. **I/V characteristic**, that means I/V in reverse and forward voltage.
4. **Reverse characteristic**, that means I/V and C/V in reverse voltage.
5. **C/V and G/V curve** as described in chapter 3.1.1.4.

Following measurements of transients are possible in 'Check measurements':

1. **Single** (emission) transient, that is standard one.
2. **Background** transient, that means measurement without pulse for checking noise.
3. Transients of **3 period widths** (10ms, 300ms, 10s) for an overview.
4. Transient with **Tw search** for searching the best period width.

In the **File menu** you can save the data and call the data tasks (if possible), or jump to the Plot or List program tool. If you have measured a C/V curve and want to save the data and to apply the Ns calculation then use the 'data task' item instead the 'save data' item.

In the **View menu** you can select the kind of plot. Some alternative plots can exist additionally to the standard plots. In most cases the meaning will be used for the item caption. The corresponding tool buttons are labeled by 1 to 3. The hint denotes its meaning. If an alternative plot is selected, the corresponding tool button is down. If you click again on the selected tool button, it goes up and the standard plot will be shown. The kind of alternative plots depends on the measurement. The following gives a short overview:

- C/V: 1) C/V curve, 2) Plot and evaluation, 3) Evaluation
- I/V charact.: 1) Reverse curve, 2) Forward, 3) Evaluation
- Rev. charact. 1) I/V curve, 2) C/V curve, 3) C/V evaluation
- C/V and G/V: 1) C/V curve, 2) Plot and evaluation, 3) 3 plots (Cp,Cs; Rs; Q)
- Transient: 1) Transient without evaluation, 2) Spectrum
- 3 Tw's: 1) Transient with logarithmic time axis

In some cases you can list and apply the evaluation in the **Eval menu**, for example the shallow concentration NS after a C/V curve.
The procedures Sample params, Temperature and Monitor of the **Tools menu** will be explained in chapter 2.4.
A **CC-DLTS menu** will here be visible at U-DLTS mode, see chapter 6.2.1.2.

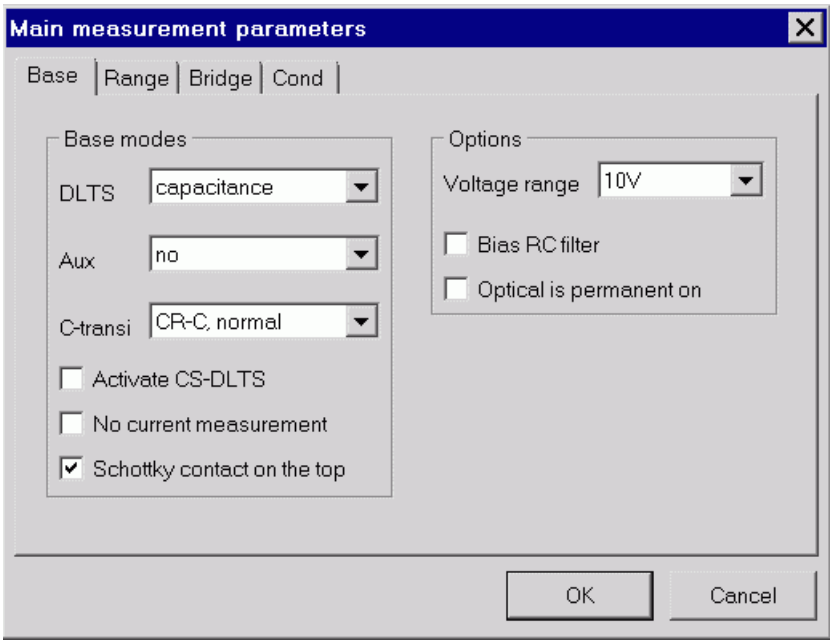
2.1.2 Main measurement parameters

Here are the inputs of the main global parameters for measurements, for example the DLTS mode (capacitance or current) and special options for the hardware. Normally there are no changes necessary, except perhaps the DLTS mode. The default values are suitable. Changes could be useful for very sensitive measurements or very low or very high capacitance.

Blue text denotes that these values are hardware data and not user parameters. Normally these values should be fix, they are saved not in user but in hardware initialization files. Nevertheless these values resp. their changes will be saved in a special init file. If you activate at program start 'Read Hot-data file' then these values will be loaded instead of the original hardware data, see chapter 1.1.1.
At user class 5 here is a button for the access to extended measurement parameters.

2.1.2.1 Base Input sheet

Here are the base inputs. Which inputs are visible depends on your hardware option. If you have the 100 V option, you can switch it on/off here. If you have the sample switch box you can select here its mode and use.



The **DLTS mode** define which kind of transient will be measured and which evaluations are possible. It will automatically uncover and hide any other relevant menus:

Capacitance: C-DLTS, capacitance transients will be measured, it is the standard mode.
Voltage: U-DLTS, voltage transients will be measured. This mode will also be called CC-DLTS because the **C**apacitance will be kept **C**onstant during the measurement of transient.
Current: I-DLTS, current transients will be measured.
Charge: Q-DLTS, current transients will be measured and from these the charge transients calculated by numerical integration.
Conductance: G-DLTS, conductance transients will be measured, not always available.

A more detailed explanation of U-, I- and Q-DLTS and FET's will be given in chapter 6.2.

C-transi defines how the transient data will be formed from the measurement values, for more information have a look in the Theory Manual. CR in the following equations will also be used for normalization, so that the transient data represent a capacitance and not the square from this. The transient will be formed in such way that they are not absolute values but only differences from the equilibrium value CR. Normally we define that the transients decrease at majorities. At the Extended parameters you can change it.

CR-C, normal: This is the standard.
CR^2/C-CR: MIS inversion.
CR^3/C^2-CR: MIS inversion.
(CR-C^2/CR)/2: It is also called C^2-DLTS.

Aux defines the use of the second voltage for an additional third sample contact:

No: No use of the second voltage.

Auxiliary voltage: Use the second voltage, no special options.

FET-DS (standard): Use the aux voltage for FET's as a **D**rain-**S**ource voltage, the aux inputs will be renamed to DS voltage. The standard bias is then the **G**ate-**S**ource voltage. This is the sandard mode for FET's.

FET-GS voltage: Use the aux voltage for FET's as a **G**ate-**S**ource voltage, the aux inputs will be renamed to GS voltage. The standard bias is then the **D**rain-**S**ource voltage. Compared to the standard FET mode UDS and UGS are swapped. So you have also to swap the bias and aux cable at your sample, see chapter H1.4 of the Hardware Manual.

The difference between the aux modes is that the last two are only available at current DLTS and the voltages will be called UGS and UDS resp. UDS and UGS instead of UR and UAux. The voltage UDS (mode 2) resp. UGS (mode 3) resp. UAux is at all modes permanently on the sample, not only during a measurement. If selecting these aux modes then this voltage will be applied before the next measurement. If switching the aux mode off ('No') then its voltage will be set immediately to 0 after leaving this input window.

The flag '**Activate CS-DLTS**' is a special option and will be explained in chapter 6.2.2.

Activating of **Disconnect bridge** forbids static capacitance measurements. At I-DLTS the bridge will be automatically disconnected. But by default (without this flag) the reverse bias capacitance will be measured before each transient, so the bridge has to be connected and disconnected.

Schottky contact on the top denotes where the Schottky contact is, normally it is on the top. By this option the bias sign is fix, that means that negative voltages are bias direction for n-samples.

Up to four **voltage ranges** may be possible for the bias source:

10V: The fastest bias.
20V (40V): Depending on your hardware +-20V or +-40V are possible.
40V limit: Uses the high voltage option '100V' with a limit of 40V.
100V: Uses the high voltage option with the full range. Be carefull with this option!

You may use a **Bias RC filter** to reduce the speed and overshoot at pulsing and changing the bias. See also chapter 3.2.1.1.3 for the pulse form.

'Optical is permanent on' switches the fix laser always on, not only at a pulse during the transient measurement. Be careful with this option!

2.1.2.2 Range input sheet

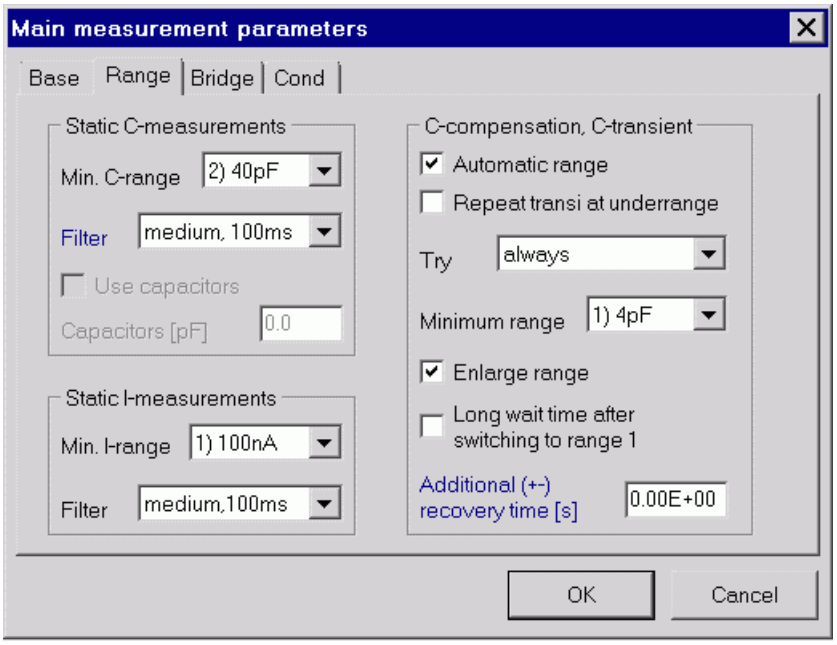
Here are the range and some other inputs for the static and transient measurements. The minimum ranges will be set automatically if you use the option 'New Sample' or 'Set minimum range', see chapter 2.1.1.4.

Static measurements:

Minimum C-range: Input of the lowest range the capacitance meter is switched to during C/V measurements. The used range can be higher. Sometimes there are jumps in the C/V plot due to this range switching. Use a bigger range or a long wait time or recalibrate to avoid the problem. Standard range limits are 4, 40, 400, 4000pF, see also chapter 2.1.2.5

Filter defines the averaging time and so the density for one C/V or I/V point. The exact measurement time takes into account the powerline frequency by using full periods of the powerline frequency.

Use capacitors: The C/V curve will be measured normally directly by the bridge without the compensation capacitors. By activating this option you can measure C/V curves with a fix capacitor. This option needs user class 5.



Minimum I-range: Input of the lowest range the current meter is switched to during I/V measurements. This range will be also used for leakage current measurements at UR.
Up to 6 ranges are available at the FT1235: 100nA, 1uA, 10uA, 100uA, 1mA, 10mA.
The values denote the max. current in its range. 'HiPreAmp' uses additional amplifiers for range 1 and 2.

C-compensation,transient:

Automatic range: By activating this option the range of the capacitance meter will be set automatically for the transient measurement and the capacitance compensation. The software takes into account the capacitance at reverse bias and pulse voltage and the amplitude of the transient signal.

Auto range after C-transi: Here you can select whether the transient measurements should be also repeated if there was an under range. At an over range the transient will be always repeated if auto range is on. If not activating this flag then an under range check will be done one times at the next transient measurement after following actions: Leaving the sample, voltage or measure params inputs by 'OK' (chapter 2.4.4, 3.2.1.1.2, 2.1.2) or setting the minimum ranges (2.1.1.4). Activate this flag if you expect big changes in the amplitude during your measurements.
Try defines when the software should test whether a smaller range is possible. The soft-

ware will try to set the capacitance meter to the lowest defined range first. If an error is recorded (overload), each range will be tried in succession until the highest range is reached.
'Always' means that this check will be done at each transient measurement. Every 10 resp. 50 Kelvin means that the given temperature range must be between the tests. The last possibility is that a new test will be done if you have changed the sample by 'New sample' procedure or you have applied a new reverse bias voltage.
The reason for the different possibilities is that switching ranges may take some seconds. So if the amplitude is very high but the capacitance is small, it could be that compensation in range 1 is possible but for the transient range 2 is necessary.

The **minimum range** is the lowest range that the software use for transients and compensation. The used range can be higher. This input is only enabled at auto range. In the other case you can here define manually a fix range for transients and compensation.
Most sensitive measurements have to be done in range 1 if possible (CR<100pF resp. CR<200pF at large limits), range 2 is the default.

Enlarge range means that the maximum transient amplitude may be up to 50% higher than defined by the range limits. For example, you measure a transient with an amplitude higher than 4pF in range 1. Then without this flag the transient measurement will be repeated by switching to range 2. By acivating this option an amplitude up to 6 pF would be possible in range 1. This option respects also the maximum ADC voltage, so that usually only a 25% higher range is possible, means in this example 5pF for range 1. The advantage of this option may be a higher sensitivity, the disadvantage perhaps a small non-linearity.

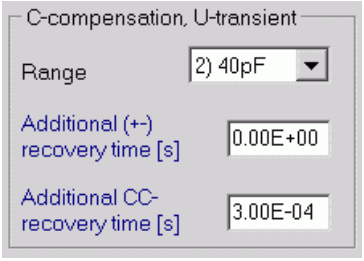
Long wait time after switching to range 1 waits a longer time when switching to range 1. This may avoid slow drifts but increases the measurement time.

Additional (+-) recovery time: The recovery time of the C-meter depends on the range of the bridge. This will be taken into account by the software. But the recovery time of the C-meter is not independent from the sample. And this sample influence depends also on the pulse width. Because of the single transient measurement mode used in this system, this is not a big problem. The recovery time is not limiting the period width directly as it is in standard DLTS systems where the recovery time is directly limiting the repetition rate and the rate windows (equal to period width). This value here will limit the time after pulse, when a transient measurement can start. This time is named **t0** and saved in the header data of every transient or tempscan signal. t0 cannot become smaller than this particular value, even if there is a very short period width used. In practice, this value can be used to avoid wrong signals coming from a too long recovery time of the C-meter.
Here you can input a recovery time additionally to the pre-defined one. If necessary, set a positive value which increases the total recovery time. A negative value decreases the total recovery time.
The pre-defined recovery times are specific for each range. At each range these are the same or smaller than in a lower range. The recovery times decreases with a rising range, especially at I-DLTS. Therefor the recovery time will at 'automatic range' not be selected by the actual range but by the **minimum** range (see above). So the used recovery time is during all measurements the same independently of the range. That is especially important for tempscan measurements with fix period widths because t0 must not be changed there.

Look in chapter H1.3 of the Hardware Manual for the recovery time and phase delay of the

capacitance bridge. The default settings are for standard applications, for example 500us for range 1. If you see a **recovery** at the first transient points, define a positive value of some hundreds us to increase t0 for the transient. If you don't see a recovery, you may try a negative value, for example -100us, to get a shorter recovery time (here 400us). This yield to a shorter t0 which has the advantage that you can observe better the first time range of the transient. The selection of the additional recovery time depends also on the amplitude of the transient. At big signals a small effective recovery it is not a problem.

At **U-DLTS transients** you have to define a fix range. You may also define an addtitional CC-recovery time which will be used only in the U-DLTS mode.

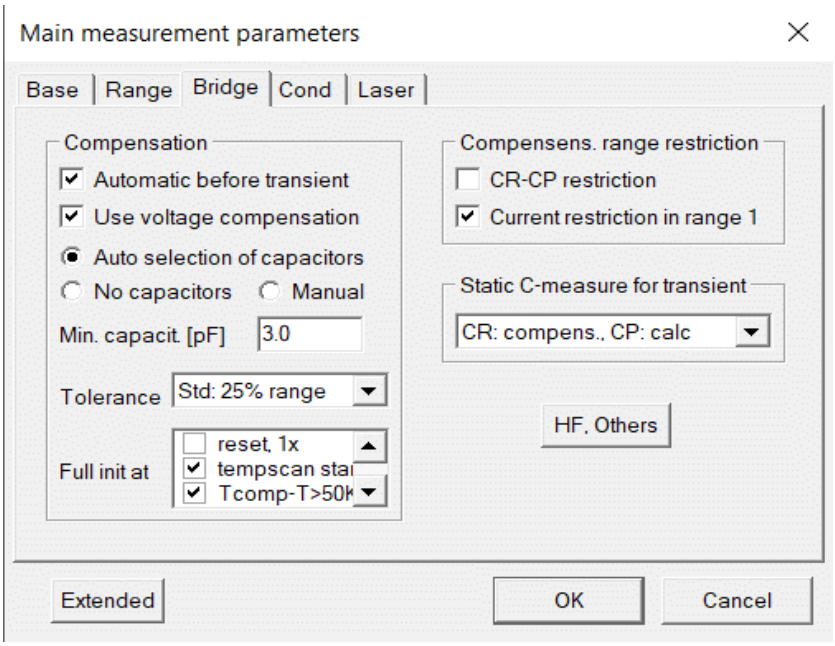


Note: If the parameters for all transient mode above are not adequate for the particular sample, this can be seen by **warnings** appearing on screen during transient measurements. Typical warnings are 'ADC overflow' and 'Compensation error'. In most instances these warnings relate to sample preparation and not to problems with the hardware. Conditions which may lead to these warnings include:

1. Uncalibrated system: Make a new calibration, see chapter 6.
2. Very high transient amplitude: Usually this happens only in range 1, change the transient minimum range to 2.
3. High leakage current: Often when scanning up in temperature the leakage current increases. This may be overcome by manual changing to a higher range.
4. A tempscan that is too fast compared to the bias capacitance change; slow down the temperature rate and/or change the minimum range.
5. Fast recovery signal at transient start: The reason can be a high leakage current. Use range 2 or higher, transients with bigger period widths and/or increase the bridge recovery time.

2.1.2.3 Bridge input sheet

Here are very special parameters of the capacitance bridge.



Compensation:

Automatic before transient:
Before a transient will be measured the reverse bias capacitance will be compensated. Manual compensation is still possible (Utils in chapter 2.1.1.5).

Use voltage compensation:
Additional to the compensation by capacitors the signal will be compensated by a DAC voltage in the measurement system.

You may define how the compensation capacitors will be selected:

Auto selection: The software selects automatically the capacitors for the compensation, this is the standard mode. Min. Compensation capacitance may be set.

No capacitors: The compensation will be switched off.

Manual: The compensation is switched on and you have to define a fix compensation capacitance.

Min. compensation capacitance is the lowest capacitance that shall be compensated. It will be set automatically at ' Set minimum range' procedure. There it will be set to 10% of the reverse bias capacitance. This input is necessary to get a correct overload signal.

Tolerance defines how the compensation works and when a new compensation capacitor should be set. In the standard mode a new capacitor will be set when the measured compensated capacitance is bigger than 25% of the capacitance range. For example, the sample has a capacitance of 30pF and range 1 is used with 4pF limit. If the compensation capacitor is between 29pF and 31pF, then the measured compensated capacitance is smaller than 1pF. That is smaller than 25% of the range limit. So the compensation capacitor will be kept, the voltage compensation compensates the not compensated value by a voltage for the ADC. If the compensation capacitor is 28pF, the measured compensated capacitance is 2pF. The compensation selects then another capacitor so that the resulting compensated capacitance is about zero.

Full init defines when a full initialization of the compensation should be done. At this initialization the software measure the reverse bias capacitance directly and starts a new compensation. In the other case the software keeps the old compensation and try to make it better, because temperature change and so on. In many cases it is here enough to change only the voltage compensation.

A full initialization will be done after selecting 'New sample' and is possible at:

reset,1 x:	The values at which temperature and voltage the compensation was done, will be reset. Only one times valid, flag will not be saved.
tempscan, start:	Reset as described above at start of tempscan cycle.
Tcomp-T>50K:	Difference between current temperature and the last temperature where compensation was done is bigger than 50 K.
new UR:	Change of the reverse bias voltage.
pulse params:	Reset as described above when leaving the pulse parameter input window (other params in chapter 3.2.1.1) by 'OK'.

Compensation range restriction:

The **CR-CP restriction** restricts the automatic range selection by checking the difference between the capacitance at reverse bias and pulse voltage. It avoids that the capacitance meter will be in overload. This will take a few milliseconds until seconds to stabilize.

Current restriction in range 1 forbidds range 1 as compensation range if the leakage current is too high. By default this value is 30uA. The C-meter is very sensitive to leakage current density. So it is not direct possible to give limits of leakage currents at that capacitance measurements are possible. Range 1 is the most sensitive range for leakage current and the most problems caused by leakage current will be in the compensation routine if compensating the reverse bias capacitance down to range 1. On the other hand the leakage current normally decreases exponentially with temperature. So for a tempscan it could be useful to measure at high temperatures (> 220 K) only in range 2 and then in range 1 due to the leakage current. This value will give the current limit at that a measurement in range 1 will be tried. In practice a realistic (due to the sample) current limit will save time and keeps the system in the most sensitive operation mode.

The CR-CP restriction will be used only at setting the minimum range, see chapter 2.1.1.4. The both other restrictions will be taken into account at each search of a new **compensation** range, but a new range will not be searched at every compensation!

Note: Range 1 is from the electronic more complicate as the other ranges, so it have bigger recovery times and other offsets. The offset will normally be corrected by the bridge calibration. Another problem of all ranges is the **overload** signal of the bridge. It means that if you measure a capacitance bigger than the range limit of range 1 (4pF) without compensation, you should get an overload signal. But the capacitance bridge may cut the output level and there is no overload signal, so you see a 'valid' capacitance smaller than 4pF. To avoid this problem it is necessary first to start with a high range and then to decrement the range. This guarantees that you measure the correct capacitance directly by the bridge. By the knowledge of this value you can introduce a minimum compensation capacitance which is the lowest capacitance that shall be compensated. This avoids the use of the 'wrong' too low bridge range.

Static C-measure for transient:

CR, the capacitance at reverse bias UR, and CP, the capacitance at pulse voltage UP, will be measured resp. calculated before measuring a transient measurement. These data will be saved in the data header and are necessary for some evaluations. For measuring CR and CP there are some modes:

CR: compens., CP: calc: CR will be measured with compensation switched on. In fact this will give you the compensation capacitance. Due to the compensation mode this value can differ from the correct value, but it is good enough to have a look on the temperature dependence of CR and to check the contacting of the sample all-over the temperature range. It is also good enough for calculating of the (approximated) trap concentration NT.
CP will be calculated from a theoretical C/V curve by CR, UR, UP and the shallow concentration Ns, see equ. 1.7 and 1.8 of the Theory Manual. The correct doping sign is important for it. The calculation is limited to UP+UD>0 in equ. 1.7 where the voltages will be inverted for n-type samples. A shifting of the C/V curve on the bias axis during a tempscan (MIS sample) makes no error in the CP calculation, but a non ideal curve yields to bad results. When Ns changes strongly with the temperature, the CP calculation will be wrong.
If you change Ns after a transient measurement, you have to re-calculate CP by 'Edit → New CR, CP, Ns', see chapters 3.4.2.2 and 2.2.1.3 (sample apply).

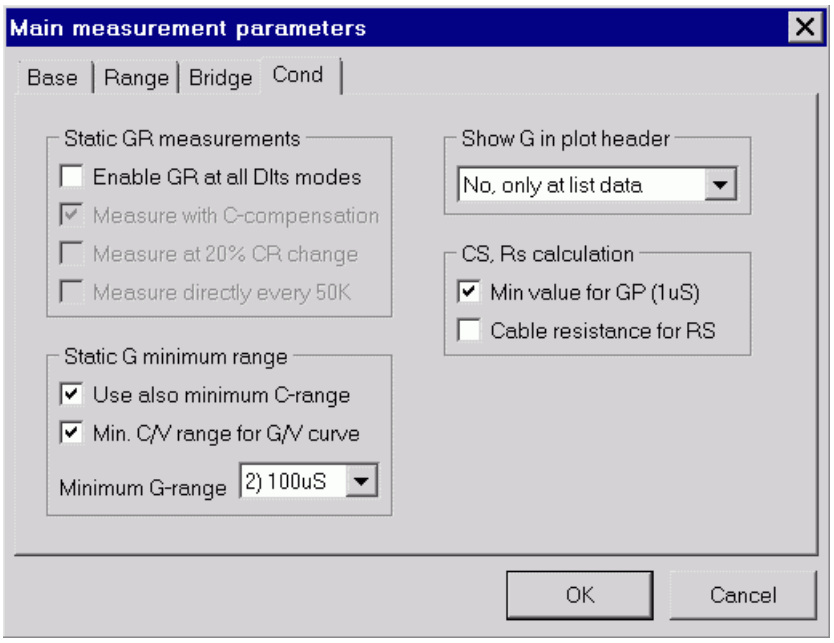
CR: bridge, CP: calc: CR will be measured with compensation switched off, directly by the bridge. It gives the correct value of CR, but this will cost a lot of time, because the capacitance range must be changed. This leads to a long recovery time. Either you have to wait a long time or you see in the transient an additional recovery signal. CP will be calculated as above.

CR,CP: bridge: CR and CP will be measured directly by the bridge without any compensation. So filling pulse voltage will be set to the sample, and the capacitance will be measured at that voltage. This method gives the correct values for CR and CP and the correct space charge region. With this you can calculate the trap concentration NTs which respects the space charge. You are then not any more limited to the standard DLTS approximation for concentration analysis. This mode costs a lot of time and is only useful for very slow tempscans or single transient measurements with special respect to a very correct trap concentration analysis.

Note: If you use above the second or third mode, then the compensation will be switched off before measuring a transient. This will be done by some relays. Additionally the range has to be switched. A longer waiting time is necessary to avoid drift problems after changing the range. Depending on your sample the pre-defined waiting time may be too short. So the standard mode should be the first one.

2.1.2.4 Conductance input sheet

The CGI meter FT1235 allows to measure also the conductance G. The base values will be explained in chapter 3.1.1.4. The following input sheet is here visible.



G/V-curves are always allowed when possible. The input group '**Static GR measurements**' defines weather and when the conductance before a transient will be measured. At G-DLTS this is always enabled. '**Enable GR at all Dlts modes**' allows it also for the other DLTS modes. It will be measured one times at a new sample, at tempscan start and at special conditions to avoid switching the range of bridge. It can be measured every 50K or when CR changes more than 20% at the last GR measurement. In the other cases it can be measured with the capacitance compensation without switching the range. When CR will be measured without compensation, see previous chapter, then also GR will be measured before each transient.

The input group **Static G minimum range** defines parameters for the minimum range of static conductance measurements. Here you can input the minimum G-range. By activating 'Use also minimum C-range' the maximum of the minimum C- or G-range will be used. By 'Min. C/V range for G/V' the G-range at a G/V curve will not be smaller than the maximum C-range at the last C/V curve.

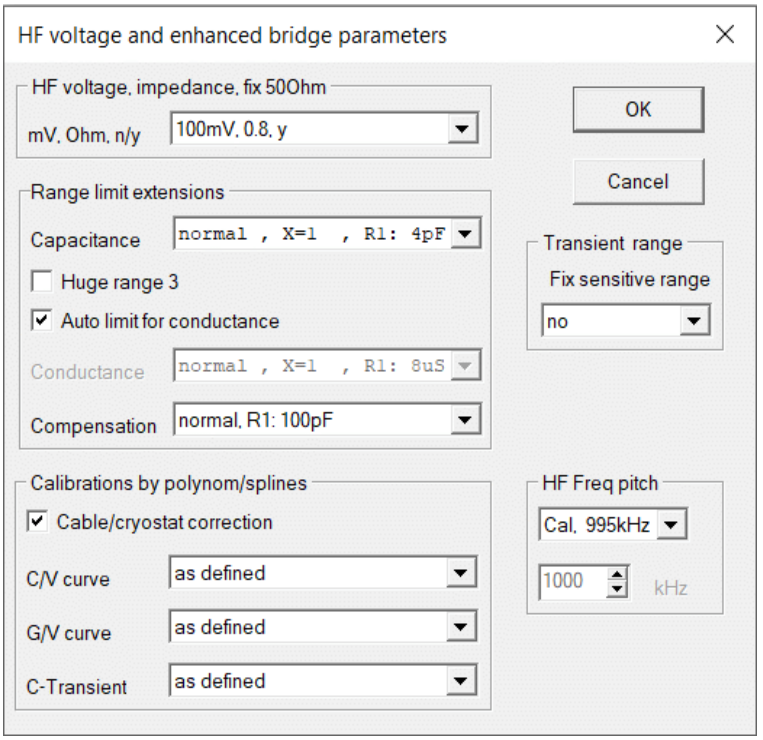
Show G in plot header lists the reverse bias conductance, resistance or quality in the plot header at a transient, isothermal or tempscan measurement:

- **No:** Doesn't show G in the plot header.
- **No, only at list data:** Shows G only at listing data.
- **GR at quality < 1:** Shows the parallel conductance GR, means Gp at UR, only when Q<1. The serial resistance has a big influence on the measured parallel capacitance Cp at Q<1.
- **Rs at quality < 1:** Similar as above but shows the serial resistance Rs=1/Gs.
- **GR always:** Shows always the parallel conductance at UR independently of Q.
- **RS always:** Shows always the serial resistance independently of Q.
- **Impedance always:** Shows always the impedance in the plot header.
- **Quality always:** Shows always the quality Q in the plot header.

Activating **Min. value for GP** means that all conductance measurements below 1uS will not be used for the evaluation. You may also take into account the **cable resistance** for the calculation of the serial resistance.

2.1.2.5 HF voltage and enhanced bridge parameters

After clicking onto the 'HF/Others' button of the bridge input sheet a new dialog opens for enhanced bridge parameters of the FT-1235, 1241, 1243, 1244 and 1245.



Up to 7 **HF voltages** of 1MHz (or of other frequencies) with different impedance exist. The FT-1245 has one HF-voltage block for the DDS and one for the fix oscillator, see chapter.
In the following the effective voltage and the impedance [Ohm] will be listed. A 'y' denotes whether a fix 50 Ohm resistor is parallel to the HF source output (n=no), 'OP' means a direct output of the operation amplifier LM6172 without a transformer, see also chapter *6.4.6.1.2*.

	FT-1235/41	FT-1243/44/45	FT-1245-Fix
1)	20mV, 0.03Ohm, y	20mV, 0.03Ohm, y	20mV, 0.03Ohm, y
2)	40mV, 0.06Ohm, n	40mV, 0.03Ohm, n	40mV, 0.03Ohm, n
3)	100mV, 0.8Ohm, y	100mV, 0.8Ohm, y	100mV, 0.8Ohm, y
4)	200mV, 1.6Ohm, n	100mV, OP, n	100mV, 0.06Ohm, n
5)	210mV, 1.6Ohm, y	200mV, 1.6Ohm, n	200mV, 1.6Ohm, n
6)	400mV, 6.3Ohm, n	400mV, 6.3Ohm, n	500mV, 1.6Ohm, n
7)	-	1000mV, OP, n	1000mV, 6.3Ohm, n

Range limit extensions define the limits of the capacitance or conductance ranges. This has influence to all range definitions of the previous pages. 'Large' sets the maximum capacitance or conductance twice so big as the standard one, 'Huge' is 5-times so big. For example, the maximum capacitance in range 1 is 4pF for 'standard', 8pF for 'large' and 20pF for 'huge'. Following limits exist for the capacitance with the maximum capacitance for each range, where range 5 is available only for 250kHz:

Range	1	2	3	4	5 (FT-1243/44/45)
• **normal-S, X=0.5**	2pF	20pF	200pF	2nF	20nF
• **normal, X=1**	4pF	40pF	400pF	4nF	40nF
• **large-S, X=1.25**	5pF	50pF	500pF	5nF	50nF
• **large, X=2**	8pF	80pF	800pF	8nF	80nF
• **huge-S, X=4**	16pF	160pF	1600pF	-	-
• **huge, X=5**	20pF	200pF	2000pF	-	-

The limit extensions without suffix in the table above are the main limits. These uses differential amplifiers for the HF signal and for the DC signal. A sub-limit with a suffix uses the same amplifications as the main limit mode, only the limit will be decreased or increased.

Following limits exist for the conductance:

Range	1	2	3	4	5 (FT-1243/44/45)
• **normal-S, X=0.5**	4uS	40uS	400uS	4mS	20mS
• **normal, X=1**	8uS	80uS	800uS	8mS	20mS
• **normal-L, X=2**	16uS	160uS	1600uS	16mS	-
• **large, X=2**	16uS	160uS	1600uS	16mS	-
• **large-L, X=4**	32uS	320uS	3200uS	-	-
• **huge, X=5**	40uS	400uS	4000uS	-	-

'**Huge range 3**' means that the limit mode 'huge' will be used for range 3 and 4 but for smaller ranges different limit modes (1MHz). So it is possible to use 4pF resp. 40pF for range 1 and 2, and 2000pF for range 3. The advantage is that you perhaps avoid switching into range 4 or that you have a bigger maximum capacitance.

'**Auto limit for conductance**' sets the conductance limit by the selection of the capacitance limit. You see the used values in the grayed input field.

The maximum **compensation** capacitance in range 1 can also be set by the compensation limit mode. For 1MHz at 100mV HF level the values are:

normal: 100pF; large: 200pF; huge: 500pF

The 200pF mode gives the possibility to make transient measurements in range 1 also at samples with higher capacitance. But having high leakage current the 200pF value can cause problems for the compensation. And the absolute accuracy of the compensated value and of the transient decreases with the reverse bias capacitance CR in a fix range. And respect that CR may changes with the temperature. The tempscan will try again the lowest range, if CR will become lower than this value. In practice it saves a lot of time to set reasonable values at room temperature because the compensation routine then only will test the measurement possibility in range 1 if there is really a chance to do it. The compensation routine itself will switch automatically to a higher range if a measurement is not possible, but this will cost at least two complete transient measurements at any measurement temperature.

Additionally to the linear **calibration** with factor and offset a calibration by **polynomials** or **splines** is possible. PhysTech saves complete calibration cures with many points for your CGI-Meter. Separate corrections of C/V- and G/V-curves exist:

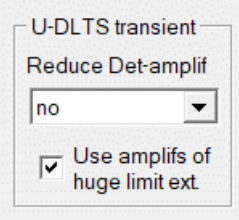
- **As defined:** The correction will be done as defined by PhysTech.
- **No:** No correction will be done.
- **Polynom:** A correction with a polynomial of 3rd order will be used.
- **Polynom, auto:** As above, but the polynomial range may be restricted.
- **Splines:** Splines of 3rd order will be used for the correction.
- **Splines, auto:** As above, but the splines range may be restricted.

Correction of transient amplitude corrects the transient capacitance depending on the compensation capacitance. Especially at large and huge compensation limit extensions this may be important:

- **As defined:** The correction will be done as defined by PhysTech.
- **No:** No correction will be done.
- **No, save at large+huge:** No correction will be done, but the correction factor will be saved at large and huge compensation limit mode.
- **No, save at all:** No correction will be done, but the correction factor will be saved.
- **Huge:** Correction will be done only for the huge compensation limit mode.
- **Large+huge:** Correction will be done for large and huge compensation limit.
- **At all:** Correction will be done for all compensation limit modes.

As you see in list above, it is possible only to save the correction factor without doing the correction. Then you may try the correction after the measurements. You may also calculate the results after the measurement without correction.

Note: Different amplifications, calibration curves and some other parameters exist for different limit extensions and for all different HF voltages. A smaller maximum capacitance has a better accuracy, a higher value may yield to a higher density. So use a higher range limit only if necessary and not in all cases. If the standard limit extension is sufficient, then it is the best one. If the capacitance or the amplitude is too high for range 1 of the standard mode, the large limit extension may give the possibility to use range 1.
Depending on the frequency, the bridge connection mode, and the HF voltage the limits in the tables above may be restricted.

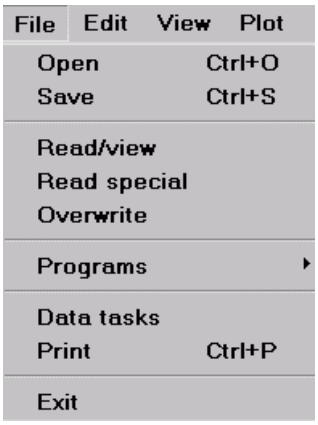


If the U-DLTS mode is activated, then the input window shown on the right appears. All FT 124X have high amplifications for the HF and DC voltage. This increases the sensitivity. But this amplification may be too high for U-DLTS (CC-DLTS) measurements in range 1 or 2. So you can reduce the amplification of the **detector amplification** (DC output voltage of the C-meter) in up to 3 steps. Not all of these different amplification combinations are full calibrated. So this may lead to an error of 1%.
An additional possibility is to use the amplifications of the **huge limit extension** but to keep the limits of the selected limit extension. This possibility is full calibrated. But you loose sensitivity.

Additional inputs exist for he FT-1241, 1243/44/45. These will be explained in chapter 6.4.6.1.2.

2.2 File menu

The file menu covers all the data handling and enables the movement between the main program modules.

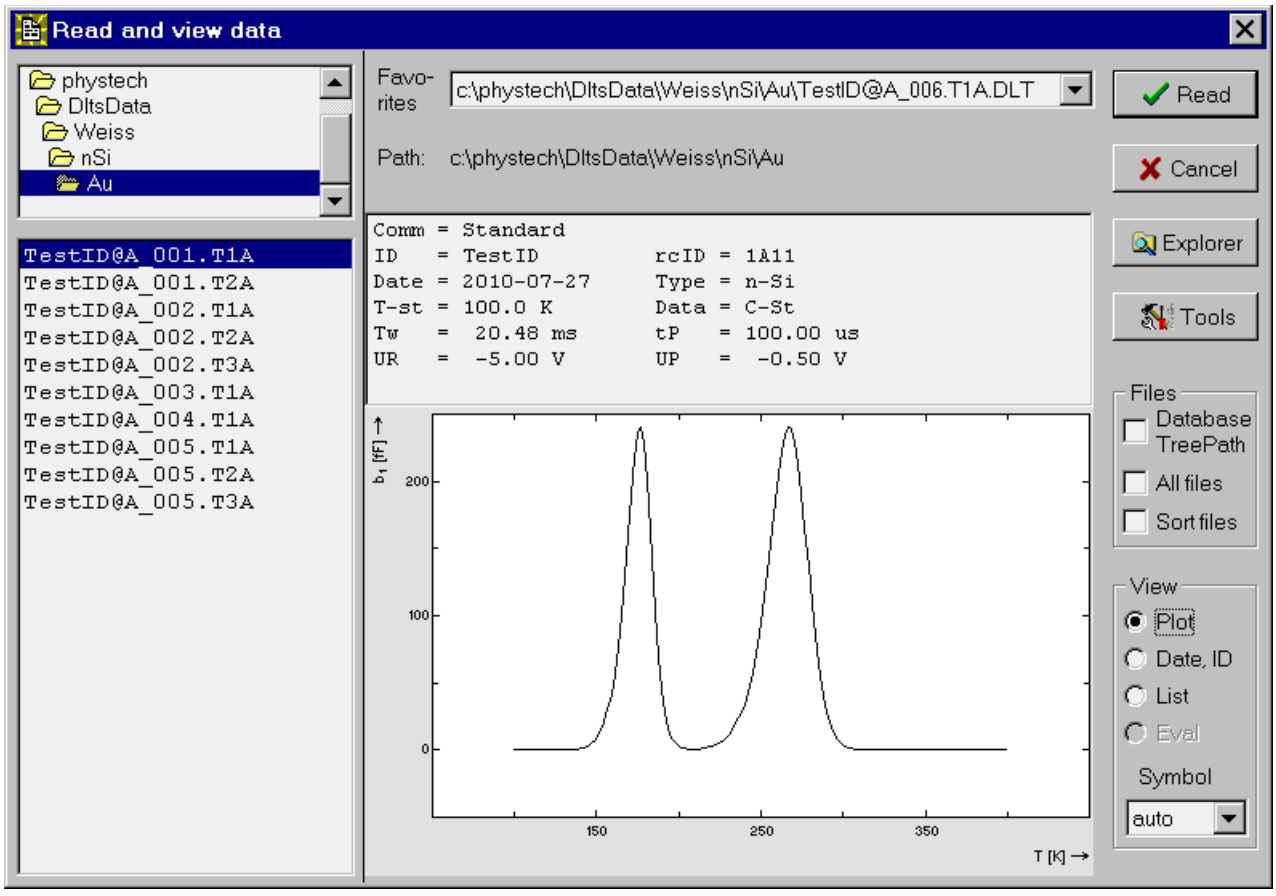


Open and **Save** open the windows standard procedures for reading and saving data. In 'View → Form and panel styles' you can select the new Vista dialogues, see chapter 2.3.1.
The open and save routines know the data that can be handled by the actual module, so e.g. tempscan data will not be read in using the static module.
Overwrite saves the current data by keeping file name and date.
Programs enables the movement from the actual main program module to another one (Base tools, Static, Transient, Isothermal, Tempscan, Equilibrium).
Exit opens the program closing procedure.

2.2.1 Read/View

This special procedure gives much more features before or during the reading of the data, for example a list of favorites, a preview, a data grid with measurement parameters, an explorer and a file or database search. It gives you also a help to find a special or 'lost' file or measurement easier and to find out the differences of various measurements.

2.2.1.1 Main window



The main window opens a file read program with a special explorer. Using this explorer the measurement data can be displayed in several ways before it's read in. It enables an easier searching for a particular measurement.
On the top a list of previous read in file including paths (**Favorites**) can be shown to find data used in former sessions.
On the left side, the **data path** (top) and a **list of files** of that folder are displayed. The button **Read** or a double click on the marked file opens the marked file.
The main window size shows a plot of one file or a data list of all files. On the right there are buttons and parameter inputs.

In the **Files** input box there are some options:

Activating **Database TreePath** shows only those directories which are used in the file database. The view is as an explorer, see picture below with selection of 'date and ID'. In the other case all directories will be shown in the folder view as in the picture with selection of 'plot'.
By the flag **All files** all data files without the restriction to the valid ones for the particular measurement/evaluation main program (like tempscan or static) will be shown. Notice that the standard files at the tempscan are only files with constand period width but not with variable or logarithmic.
Sort files by name is also an option.

The graph of marked file can be shown using the **Plot** option of the **View** box on the right, see picture above. This box defines the kind of data that is shown. The plot shows the main curve of the marked data file. Above the plot there is a text field with some important sample and measurement parameters.
The files can be marked using the mouse or the cursor keys for an easy data scrolling.
Several plot symbols can be defined in the **Symbol** input.

If activating 'Plot' and not 'All files' then a **multi selection** of files is possible. This means you can mark up to 6 files in the file list box. The marked files will be shown together in one plot if possible, because all curves must have the same x- and y-axis. Above the plot there is a small list with important parameters of each shown file, there is on the right a color explanation for each curve. The multi selection must be done with the Shift or Ctrl key, as defined by Windows. The Shift key (in conjunction with the left mouse button or arrow keys) is used to select a contiguous sequence of list items. The Ctrl key is used to select non-contiguous list items. Reselecting a selected list item will deselect it.

A preview of some or all tempscan files which were measured together is possible by the tool item '**family data**', see chapter 2.2.1.3 and 3.4.4.5.

Above the plot or in the grid view (see below) there is a text field called **Data type**. It gives a short information about the data files. Following information are given:

Structure: first (1 spelling), minus sign (-), second (2 spellings)

First gives the measured variable (as defined in DLTS mode):

`C:` for capacitance
`I:` for current
`U:` for voltage (Constant Capacitance measurements only)
`Q:` for charge

The second values gives an information about the kind of measurement or evaluation saved in that file. It depends on the type of data (static, transient, …). The following list contains only the important entries:

Static:
`U-:` Standard I/V curve
`HF:` Standard C/V curve (high frequency curve)
`P-:` Pulsed C/V curve (MIS diode only)
`CG:` C/V and G/V curves, the C/V is the main
`DS:` I/V curve of a FET diode (Drain source)
`GS:` I/V curve of a FET diode (Gate source)

Transient:
`E-:` Emission transient
`U-:` Background transient
`C-:` Capture transient
`P-:` Logarithmic capture transient
`L-:` Transient with logarithmic time axis

Isothermal:
`Tw:` Measurement with variation of period width, no use of oversampling
`TW:` Measurement with variation of period width, use of oversampling
`UR:` Measurement with variation of reverse bias voltage
`UP:` Measurement with variation of pulse voltage
`UH:` Measurement with variation of reverse bias and pulse voltage
`DS:` Measurement with variation of drain source voltage
`tP:` Measurement with variation of pulse width, linear steps
`tL:` Measurement with variation of pulse width, logarithmic steps
`OF:` Measurement with variation of optical frequency resp. wave length

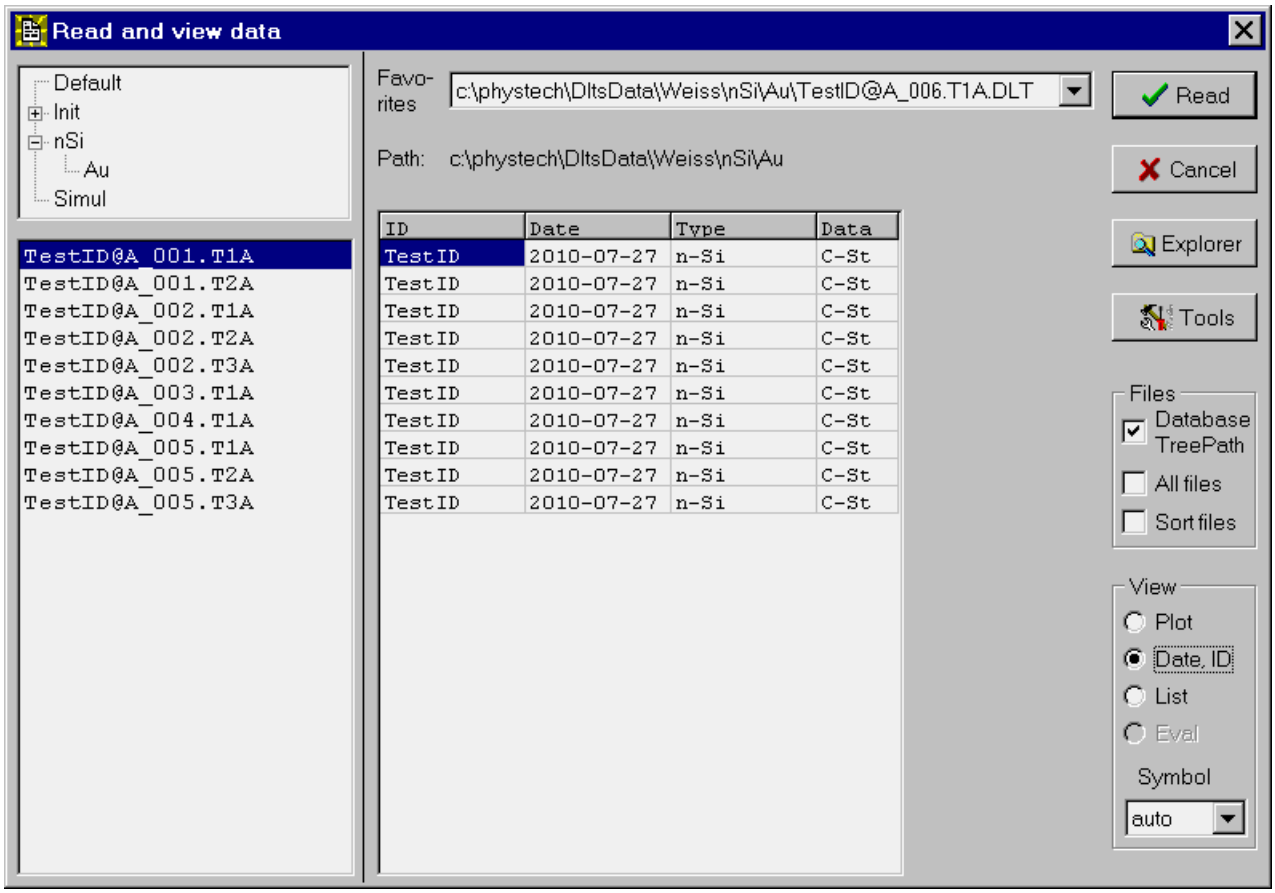
Tempscan:
`St:` Tempscan with constant period width
`He:` Tempscan with constant period width, optimized for HERA transient evaluation
`Tw:` Tempscan with variable period width
`Lg:` Tempscan with logarithmic period width

Arrhenius:
`T-:` Arrhenius evaluation of a tempscan measurement
`W-:` Arrhenius evaluation of isothermal measurements

Equilibrium:
`R-:` CR and IR measured as a function of the temperature
`F-:` CR and IR measured, set pulse voltage before start
`P-:` CP and IP measured as a function of the temperature
`C-:` CR and CP measured as a function of the temperature
`I-:` IR and IP measured as a function of the temperature

Optional additional 1 or 2 characters for transient, isothermal, tempscan:
`*:` Start of measurement at pulse, see chapter 3.2.1.1.2.
-N,*N: Number of pulse mode if N <>1 (normal), see chapter 3.2.1.1.2.

Selecting **Date and ID** in the view box, a sample data list directly correlated to the files list is shown. The grid contains sample ID, measurement date, doping type, material name and data type:



Selecting **List** in the view box gives a list of some measurement parameters used for the measurement files on the left. The List view is not in all program modules possible. 'All files' must not be activated.

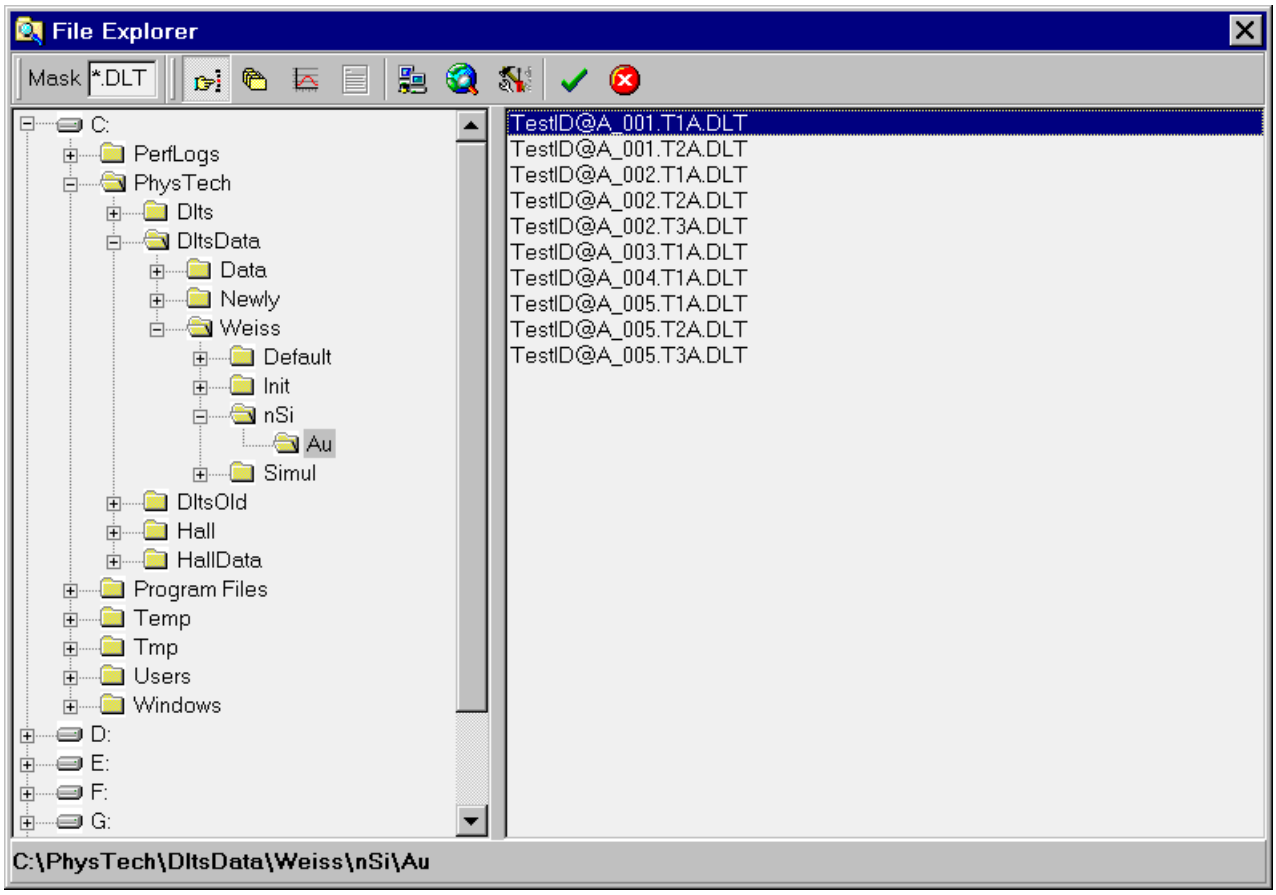
Tw [s]	tP [s]	UR [V]	UP [V]
2.05E-02	1.00E-04	-5.00	-0.50
2.05E+00	1.00E-04	-5.00	-0.50
1.92E-02	1.00E-04	-5.00	-0.50
1.92E-01	1.00E-04	-5.00	-0.50
1.92E+00	1.00E-04	-5.00	-0.50
2.05E-02	1.00E-04	-5.00	-0.50
2.05E-02	1.00E-04	-5.00	-0.50
2.05E-01	1.00E+00	-5.00	-0.50
2.05E-01	1.00E-06	-5.00	-0.50
2.05E-01	1.00E-04	-5.00	-2.00

Selecting **Eval** in the view box lists some evaluation values but is only in some program modules available.

Tip: You can change the total size of the Read/View window by the mouse, you can also change the ratio of the left (file list) and right (plot or grid) size. For the last one go with the mouse cursor to the splitter between these two parts.

2.2.1.2 Data Explorer

The Explorer button opens an additional data explorer similar to the Windows explorer and similar to use. Files can be listed, plotted or deleted, folders created or removed, database records deleted. The current data path will be shown in the status line. The list shows all files which matches the **Mask**, independently if they can be read in the current program module. After you have changed the mask you must press the 'enter' key to refresh the list.




Search files gives on the right side a file list of the marked directory.


Extended file search restrict the search by sample and measurement parameters.


Include in the list also the files of all **sub directories** of marked directory.


Show at the right bottom a **plot** of the marked file, see picture below.


Show at the left bottom a **memo** of measurement parameters for the plotted file.


Opens the Windows **network** dialog.

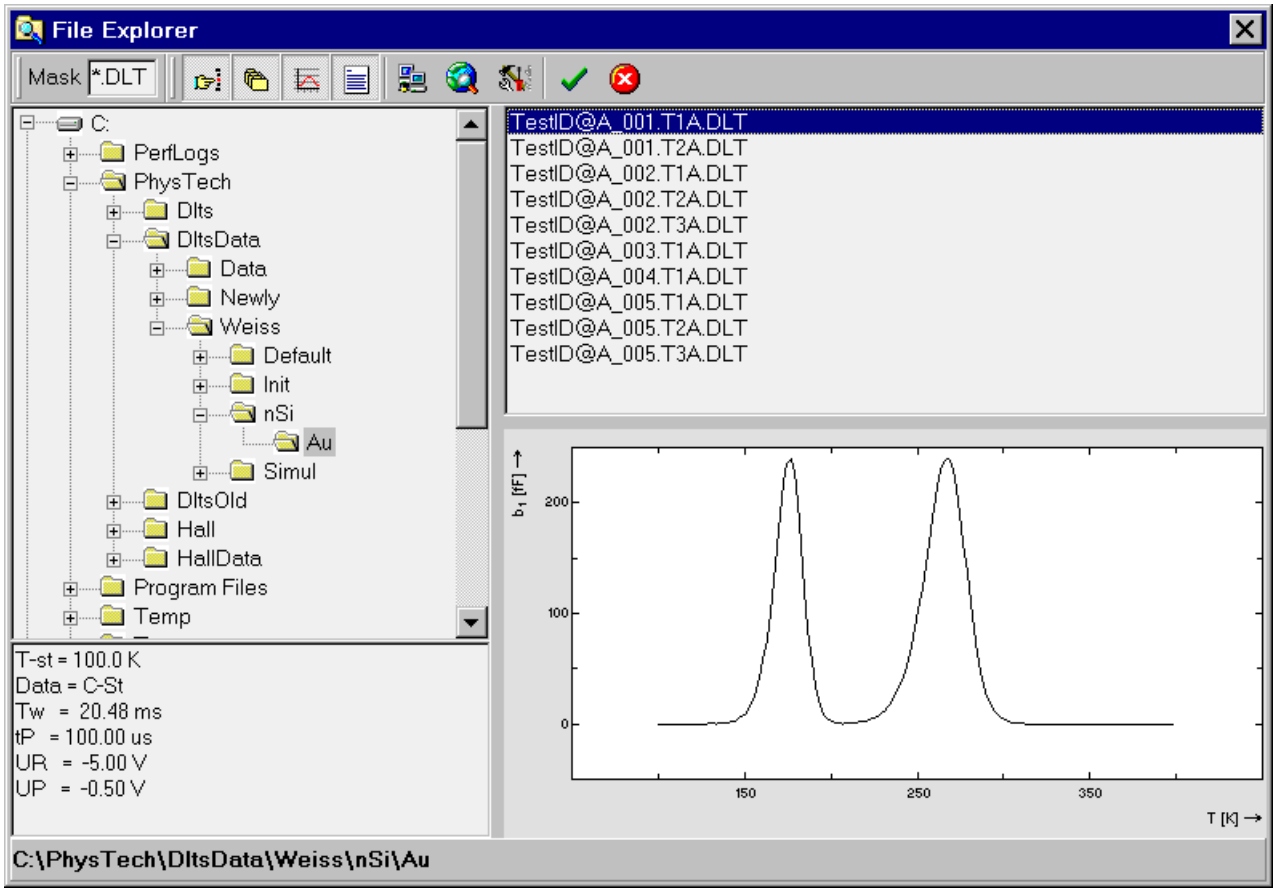

Find a path either by a path or a file mask.


File tools for create/remove directory, delete files and delete records in database.


Okay apply the file if possible, in the other case the path.

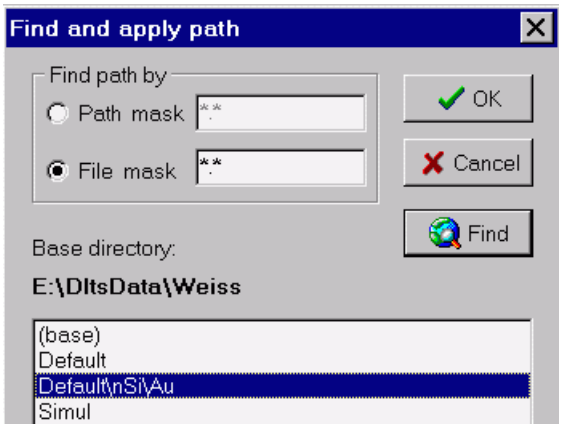

Cancel, goes back to the ReadView window without apply.

The next picture shows the data explorer with activated plot and memo field. Plot and memo are only visible if one file was marked. The file search will be restricted by the 'Mask'. The file names must match this mask, Windows wildcards '?' and '*' are valid for it.



In **File tools** you can create or remove an empty directory. You can delete the selected file (file list on the right side) or all files of the current directory (explorer view on the left) or all files of the current directory and of all its sub directories. In all cases you must confirm the action. If deleting files you can activate the option to delete additionally the corresponding records in the file and/or evaluation database.

Find and apply path is a tool to find a path either by a path or a file mask. It lists all sub directories of the selected directory (called here base directory) which matches the path resp. file mask. The selected directory will be applied as new current (base) directory by clicking onto the 'OK' button.
This tool can also be used to find the location of a special file. To search a special file by the ID use the database search of the next chapter.



The data explorer allows also an **extended file search** by special sample or measurement criterion. All files of the marked directory, and if the button is activated, and its sub directories will be checked. The 'Mask' is further valid. If all search criteria are fulfilled, the file will be listed.

For this option click onto the 'Extended file search' button. Then the following input window opens. If leaving by 'OK' then the extended file search is activated and remains until you deactivate it. For the deactivation click again onto this button and leave the input window by 'Cancel'.

Each criterion can be activated or deactivated by a flag. If activated then an input defines which condition the file must fulfill.

Selections for following **criteria** exist:

- Sample type
- Material name
- Doping type
- Evaluation mode
- DLTS mode
- DataStr
- Special mode

Following Special modes are available: Nothing, Search by MeasStr, Search by HeadStr, Tempscan tP variation, Tempscan HERA files, by pulse mode.

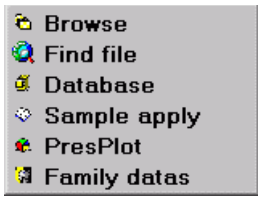
If selecting the last special mode then only tempscan files will be listed which are optimized for the HERA transient evaluation. That means minimum 3 different period widths and 128 internal saved transients points are necessary.
'Tempscan tP variation' means that only tempscan files will be searched which were be measured together by 2 or more different pulse widths.

DataStr and Search by MeasStr or HeadStr is only for special cases. These strings of a data file will be listed in 'List → File header' at user class 6, an explanation of these strings will be given in Dlts\Sys\Doc\Data.Txt. The input strings must match these strings. Wildcard characters are '?' and '*' as in the Windows file search.

Tip: The extended file search shall help to find files of special sample or/and measurement parameters. So it can be important to compare new results with old ones. For searching in all directories mark the data directory. This search needs not the database. Use the database search of the next chapter for searching a special file by its ID.

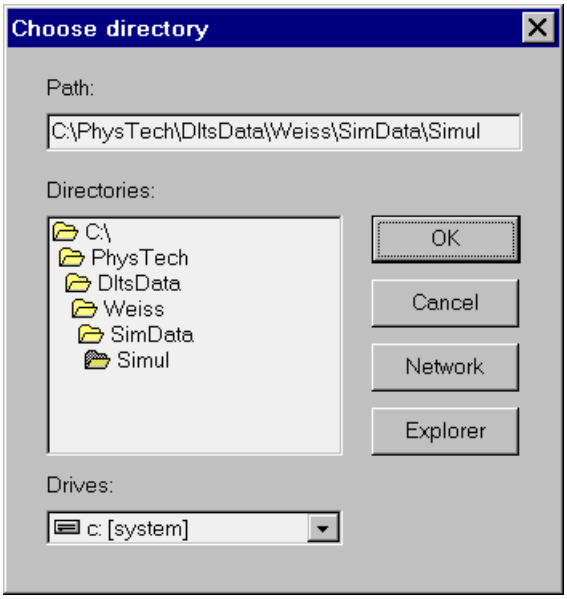
2.2.1.3 Tools

By the Tools button in the main Read/View window you get additional tools for the data handling.



Browse is for the defining of the current data path.
Find file search for data files in the file database.
Database calls the database program module.
Sample apply is for changing sample parameters of many files.
PresPlot applies the current plot into the presentation plot program.
The **Family data** option is only visible if you stay in the tempscan measurement module, see chapter 3.4.4.5.

Browse opens the following input window for defining the actual data path.
The path can directly be defined by keyboard input. Drive and higher folders can be selected by browsing through the file structure as known from windows. Drive and folders are automatically shown in the input line at the top. With the button 'Network' you get the Windows network dialog, 'Explorer' opens the Windows explorer.

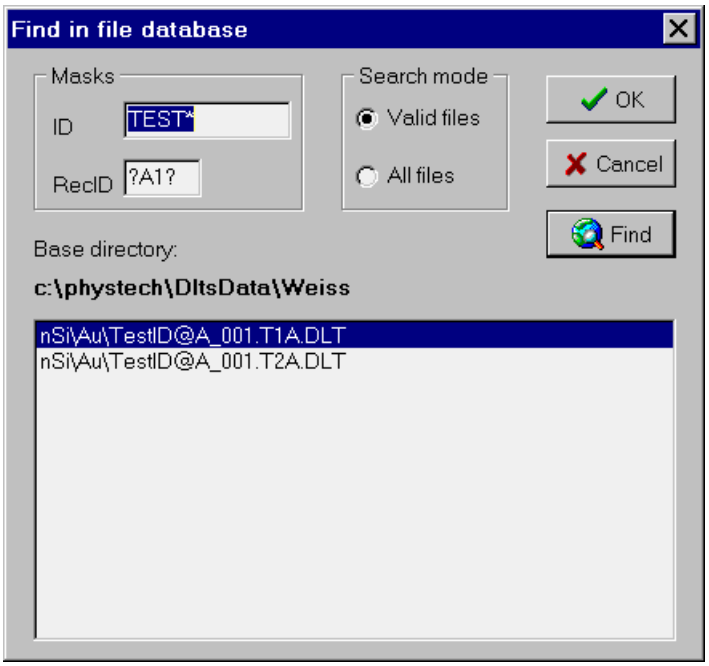


Find file (at the Tools button) search for data files in the file database using search masks for the sample ID and RecID. Base directory is the directory of the used database.

Only files which match the **Sample ID** mask and the **RecID** mask will be listed. The RecID is a file specific record ID in the database. Sample ID and RecID are definite for a record in the file database.
Wildcard characters are '**?**' and '*****' as in the Windows file search.

By **Valid files** as search mode only files usable in the actual program module are shown, by **All files** as search mode all files independent of actual program module are shown.

Find looks for all files fitting to the masks.
Okay apply/read the selected file.



The entry '**Sample apply**' by clicking onto the 'Tools' button is for changing sample parameters for many files. It can be helpful if you have for example typed in the wrong area. The header of all files which names match a given or computed mask will be restored, the file dates will be kept. Only selected sample parameters will be restored, an evaluation will here not be automatically done. For example, if you change the area for many C/V curves, the calculation of Ns will not be repeated at restoring the header. This function needs user class 5 and is only enabled after reading data from a file but not after a measurement.

The current file name will be shown in the status line. For the examples above we take ID@A_001.T1A. Three **file search modes** exist:

Mask input: You have to input a directory and a file mask for the search. Wildcard characters are '?' and '*'. The software appends always the data extension 'DLT'.

Same ID: Only files with the same sample ID and contact in the file name will be applied. The software sets the mask, for example 'ID@A_*.???.DLT'.

Same no: Only files with the same sample ID, contact and number in the file name will be applied, for example 'ID@A_001.???.DLT'. If the file name comes from a 'set of temp variation', see chapter 2.4.5, then this will be taken into account. So ID@A_00T001.PWA yields to the mask 'ID@A_00T???.???.DLT'.

If activating '**With sub directories**' then files in all sub directories will be searched by the same given mask. This flag is only visible at mode 1.
The flag '**With sub data directory**' is visible at mode 2 and 3, all files in the sub data directories will here also be restored. For example, the data directories are 'ID@A_*' for mode 2 and ID@A_001 for mode 3.
'**Same 3. extension character**' means that only files will be searched which 3. data extension character is the same as in the current file name, for example 'A'.

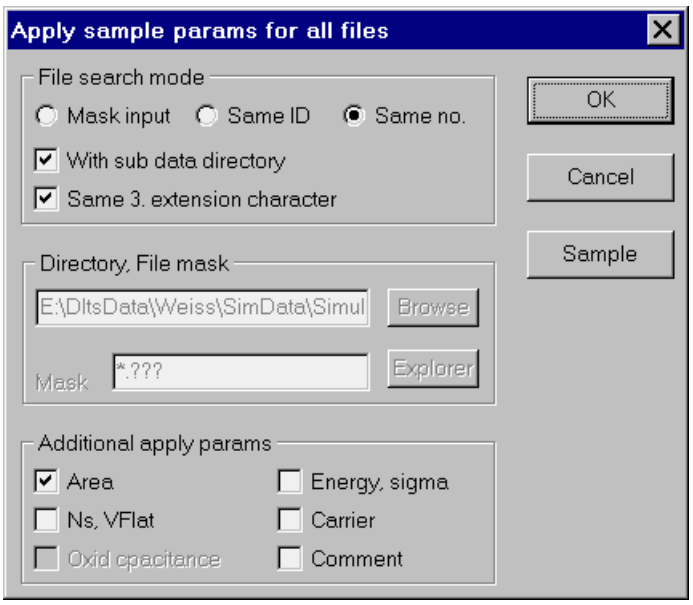
Independently of the mask only files with the same **sample ID** and contact in the file header will be searched! All file names found by the search will be listed before changing the file headers. There you can cancel this operation.

By the '**Sample**' button you can check and change the current sample parameters. The selected sample parameters will be applied and stored in the sample header of each file.

The **base sample parameters** 'Type, material, doping type, evaluation mode and process (for library) will be applied always.

Additional apply parameters are:

- Area
- Ns, VFlat
- Oxide capacitance (at MIS)
- Energy, sigma
- Carrier and pulse mode
- Comment

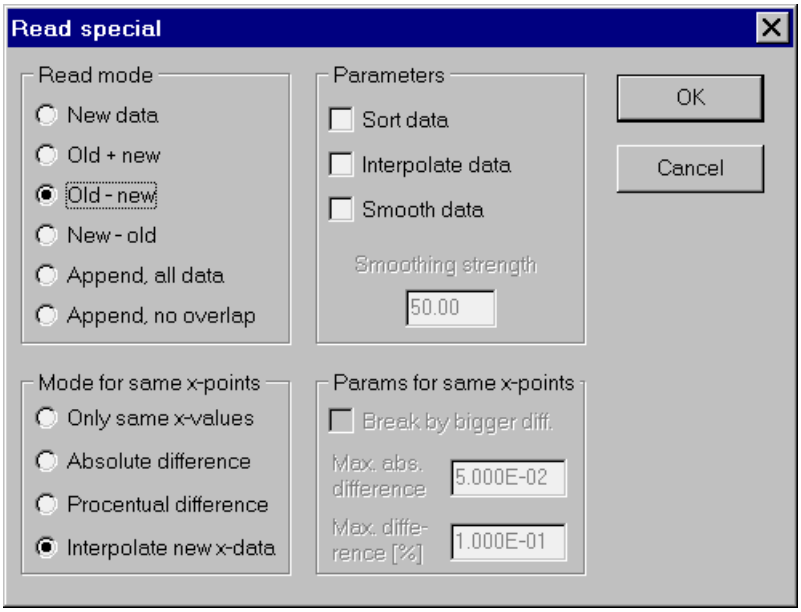


Note: Usually CP will usually be calculated for transients by CR, Ns and the doping type. The change of one of this value yields to another CP. This will here not automatically be done. You have to do this for each file in 'Edit → New CR, CP, Ns', see chapter 3.4.2.2.

2.2.2 Read special

The Read special procedure enables some features for the reading of data, a main application is the combination of current (already loaded) data with new ones.
Not all possibilities shown in the input below exist in every measurement module.

The **Read mode** define how the new data should combined with the old current data. Old data refers to data in the memory (already loaded), new refers to data that will be read in by the new input of file name.
New data use only the new one and makes no combination with the old one.
Old + new, Old – new, New – old add or subtract the data, this will done data point for data point.
Append the new data to the old ones, either all new data or only those data which x-values don't exist at the old one (no overlap).



Tip: If appending data and one overlap range has bad data points then read first the file with the good data and then the file with the bad overlap range. If you select 'Append, no overlap' then the bad data over the overlap range of the second file will not be included in the new data arrays.

At the **Mode for same x-points** you define which data regarding to the x-axis will be used at addition or subtracting data. That means that the program search which data point of the new data belongs to a corresponding point at the old data.

Only same x-values: Only data points which x-data are the same at old and new data will be used.
Absolute difference: Data points of old and new data can combined which absolute difference is smaller than a given maximum.
Percentage difference: Data points of old and new data can combined which percentage difference is smaller than a given maximum.
Interpolate new x-data: The new data will be interpolated to the old (reference) x-axis data. This is the favored mode for tempscan data.

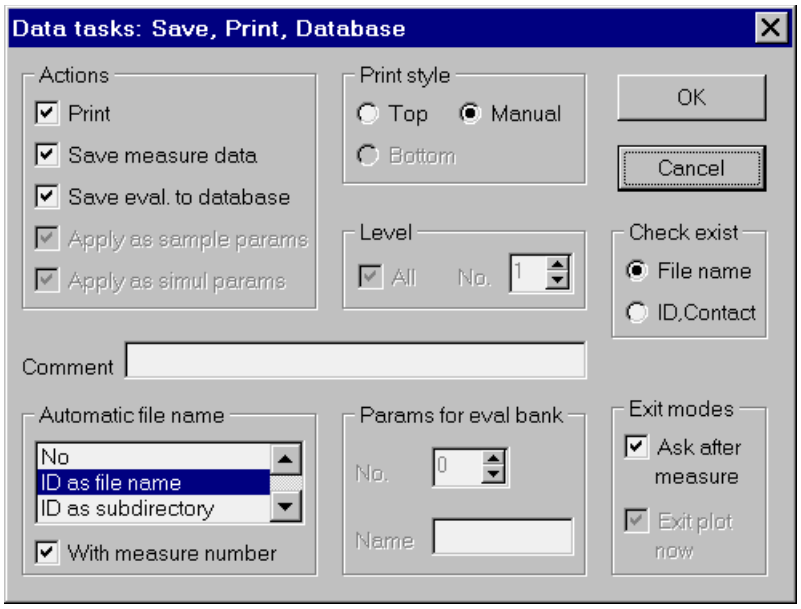
Note: It is not a problem to measure 2 transients with the same time-axis, normally it is also no problem to measure 2 C/V curves with same voltage points. But it is not possible to measure 2 tempscan files with the same temperature axis. If you measure file 1 and then file 2 the temperature will drift a little bit. With the mode 'Interpolate new x-data' you make from file 2 data with the x-axis from file 1. For example, if the first data point of file 1 is 100.0 K and the first point from file 2 100.1 K, then the program interpolate all y-data of the first point of file 2 to 100.0 K.

At **Parameters** you can **sort**, **interpolate** and **smooth** (approximate) the data.

2.2.3 Data tasks (All)

Several tasks, so saving and printing the data and saving evaluation values into the database, can here done. Not all inputs are possible for all measurement modules. At the question for saving data after the measurement you can call this window by the button **All**.

The **Actions** inputs define what happens after clicking 'OK'. The data can be **printed** and **saved.** If evaluation exist, it can be saved into the **evaluation** database. If the evaluation gives a sample parameter likes Ns, it can be applied as sample parameter and for the simulation.
If the file was already saved, then you get the checkbox 'Override measure data' instead 'Save measure data'.
If the evaluation was already saved in the database, you get the question, whether you want to delete the existing record.



If saving Arrhenius data in the evaluation database a selection of **level** is possible.
At some evaluations and deactivating 'All levels' you can define a **number** and **name** of evaluation. The name is only for searching in the database (eval bank). The number is only for an easier comparison of results in the database. So you can at the database restrict your search of results by selection of an evaluation number.

'**Apply as sample params**' applies the results into the sample parameter set.
'**Apply as simul params**' applies the results as simulation parameters. When 'all levels' is activated, the number of levels will also be defined.

Input of **comment** for the data header is here also possible.
Automatic file name will be explained in chapter 2.4.5.
Print style defines the position of the plot on the paper (top, bottom, manual).

Check exist search if the new **file name** or the **ID and contact** already exist in the database.

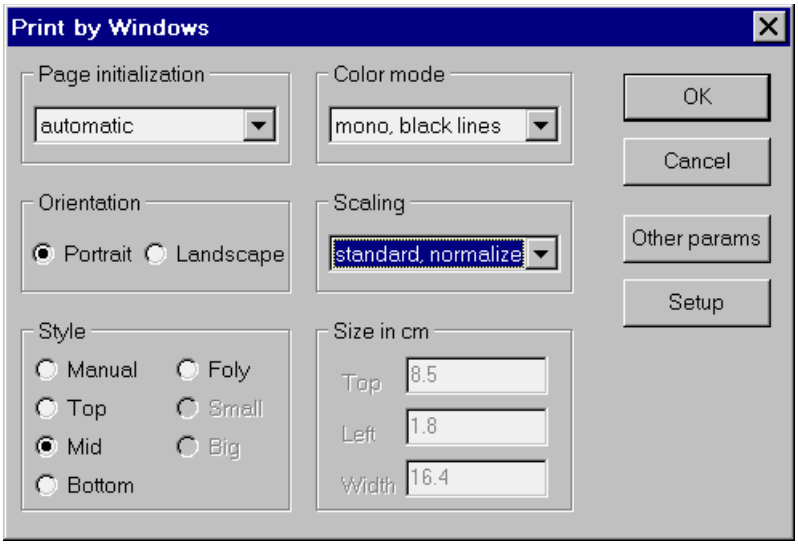
By **Ask after measure** (Exit modes) you activate the automatic question for saving data after measurement at static, transient and isothermal module, see chapter 1.3.2.

Tips: Applying into the evaluation database and as sample or simulation parameter is often also possible at an evaluation plot, see chapter 5.1.5.3.
Apply the results of an Arrhenius plot as simulation parameters before using the 'TempFit', see chapter 3.4.4.3. The level number corresponds to the simulation level.

2.2.4 Print

This menu opens a special print dialog. The 'Other parameters' button opens a second window with further (not so important) inputs, the 'Setup' button the Window printer setup.

The **page initialization** for the printer is normally 'automatic'. This means depending on the style the initialization will be set. So if Top as style is set then the start initialization, at Bottom style the end initialization and at other styles both initializations will be done. At selecting Top or Bottom the style will be set to Bottom resp. Top after printing. The other possibilities are initialization only at start or end, always start and end (full page) or nothing. The paper will be 'really' printed only after the end initialization.



With **Style** you define the size and the position of the plot on the paper page. At Manual the inputs of the Size group will be applied.

As **color mode** there are monochrome with black (lines, symbols, text), 256 grey scales, color without background and color with background color as used on the screen.

Scaling defines the scaling of the plot on the paper in comparison to the screen:

as screen:	Same scaling as screen, normally not used.
aspect as screen:	The paper print has the same aspect (y/x) ratio as on the screen.
Search correct font:	As above, but the font will be adapted.
Standard, normalized:	The standard aspect ratio will be used for the paper print, independent from the used aspect ratio on the screen. This is the standard scaling.

If data were be interpolated then there is an additional input group called **Print data**:

Original:	Only the original data (not interpolated) will be printed.
Interpolation:	Only the interpolated data will be printed with the selected symbol.
As screen:	The data will be printed as shown on the screen, normally the original data with symbols, the interpolated data by lines.

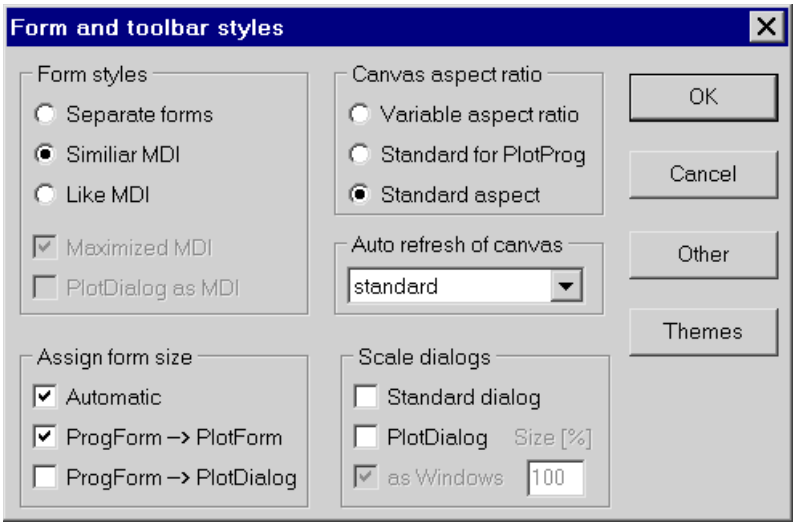
Note: Before printing new data the data should be saved to disk. In the other case you don't get the file name at the paper page.

2.3 View menu

In the view menu you can set the kind of style, the window size, default and global plot parameters and personal short cuts.

Refresh plots the standard plot again on the main window.
Params for standard plot doesn't exist in all measurement modules.

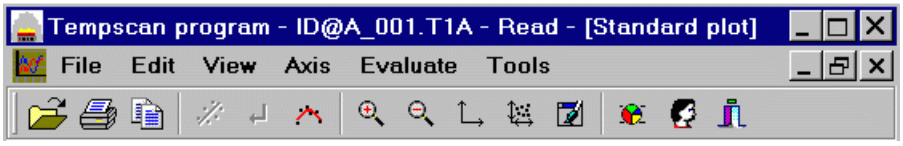
2.3.1 Form and panel styles



Form styles defines the main form style. The standard plot will be shown on the canvas of the measurement program, see picture in 1.3.4. If you select a plot or evaluation, the program opens one of the plot programs by a new form. This form (window) has as the main form a caption line, a menu, toolbar, canvas and status line. The form style define how the old (main) form is visible.
There are 3 possibilities:

Separate forms: Only the current (new) form is visible. If you close this form you don't leave the program but show the old form.

Similar MDI: From the old form is only the caption visible, the old form is de-activated but not hidden. The current (new) form will be placed under the old caption line.



Like MDI: The current (new) form is a child of the main window of the measurement program.
The software use for this the **M**ultiple **D**ocument **I**nterface of Windows, but only one child window is possible. By **Maximized MDI** will the child always maximized. If activating **PlotDialog as MDI** dialogs with plots inside will also be shown as a child window.

Note: The Windows guide lines would prefer the third mode. Our preferential mode is the second one (Similar MDI). It is much faster.

At **Assign form size** you can define how a change of the form size will be overtaken from other program modules:

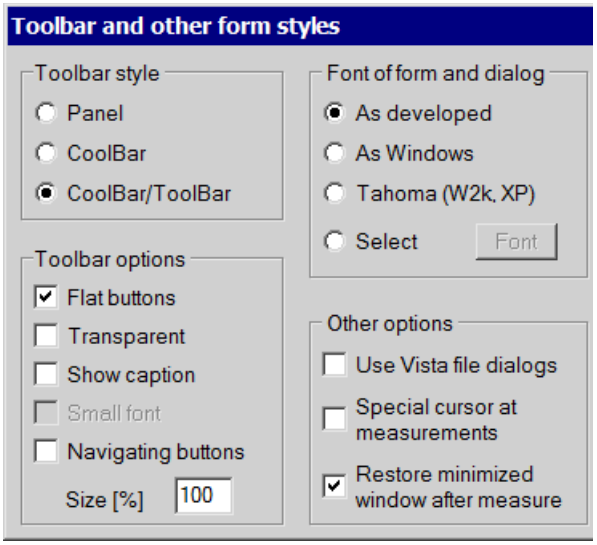
- **Automatic:** If you change the size of the main program this change will be applied for other programs, except the plot programs. There are an additional option.
- **ProgForm → PlotForm:** If you change the size of one of the main programs, then this size will overtaken for the plot programs.
- **ProgForm → PlotDialog:** If you change the size of the main programs, this size will be overtaken for dialogs with plots, for example the ReadView window in 2.2.1.

Canvas aspect ratio defines the ratio of the used y/x canvas points for plots on the screen, see chapter 2.3.5.

Auto refresh of canvas defines when the canvas should be refreshed after an action.

By **Scale dialogs** you can scale the standard and the plot dialogs. Either you can define a percentage size or the option as 'Windows'. In the last case the dialogs will be scaled by the Windows display text size. Especially at high resolutions screens it may be important to increase the scale with an individual percentage value bigger than 100 to avoid too small dialogs. Plot dialogs are dialogs which contain additionally a plot or grid.
If this scale option is not activated, the Windows display text size (100%, 125%, ...) has only an influence on the menu size but not on the size of dialog text or dialog buttons. Sometimes the enlarging yields to a too 'long' text, a text string may be cut by a text box, a wordwrap may be wrong. Try then different scales for the best result.

The **Other** button opens a new input window. Changes here will only directly applied when leaving also the main input window (previous page) by 'OK'.



You can define the style and options of the **toolbar**. If the size of the toolbar buttons is too small, you can enlarge the buttons by a percentage input of the size. The activation of 'Show captions' enlarges also the button size.

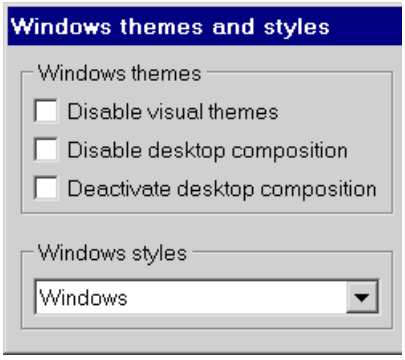
You can select the **font** of the form and dialogs. 'As developed' uses the new Microsoft Sans Serif, 'as Windows' uses Tahoma for Windows 2000 and XP, Sergoe UI for Windows Vista and Seven.

By **Use Vista file dialogs** the new Windows standard file dialogs will be used under Windows Vista, Seven and 8.X.

Special cursor at meas means that during the measurement a special form of the cursor, the hour glass, will be shown.

If you have minimized your form (window) during the measurement and the option **Restore minimized window after measure** is activated, then the software restores the old form size automatically after the measurement is finished.

Clicking onto the **Themes** button opens an input for the Windows themes. These are customizations of the graphical user interface and include visual styles. You can choose the theme in the Windows control board. All themed applications have a similar appearance.



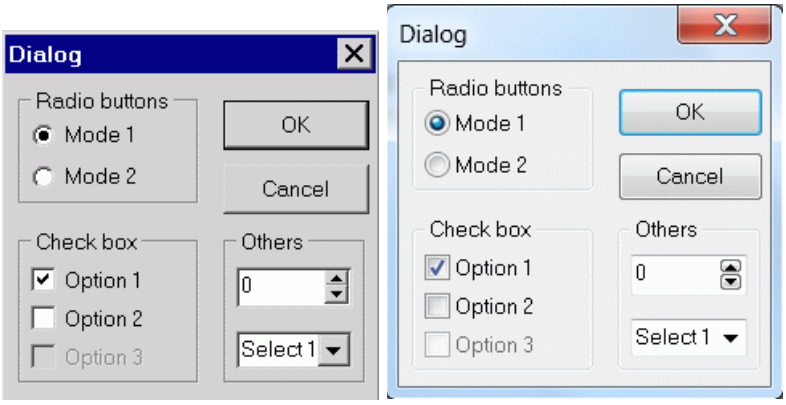
If activating '**Disable visual styles**', the DLTS program doesn't use themes. The look and feel is then as Windows Classic, independently from the selected Windows themes except the caption line, menu and boarder.
By '**Disable desktop composition**' the windows will not be animated when minimizing and maximizing, the Aero design will be switched off for the DLTS program.
Both flags have no meaning at Windows 8.X. There you can switch off these only in the Windows system properties.

A change of these flags will be visible after a program restart because it changes the registry. These are not available for the Portable Program. You find these flags also by a right mouse click onto the DLTS program and selecting there 'Properties → Compatibility'. Further possibilities are in 'Visual effects' of the Windows system properties.

'**Deactivate desktop composition**' has the same effect as the flag above but it will immediately be done without the registry. It is not valid at a cold start or for other DLTS users.

Windows styles defines the colors and styles of the buttons and other control elements. The default is 'Windows', colors and styles will here be used as selected in the Windows themes. The change of the Windows style will be active after leaving the 'Form and toolbar styles' input window. The new rendering of some control elements may be not perfect. So a wordwrap of the checkbox label will not be shown.

All inputs in this manual will be shown in the Windows classic style. An example gives the left picture. The default themes depends on the operating system. It is 'Aero' for Windows 7, as shown in the right example.



Tips for screens with a **high resolution** (big DPI value):

- Select in the Windows **Display** (from control panel) a text size of 125%, 150% or higher. It enlarges the menu and caption size.
- Activate the **scaling** of the standard and plot dialogs, see previous page. The scaling size can be defined by an input or by the Windows display property.
- Enlarge the **toolbar** buttons by an individual input if necessary, see previous page.
- The **plot** size will usually automatically be scaled. If the aspect ratio is not optimal, change the line and column numbers, see chapter 2.3.5.
- By default the maximum **canvas** size is limited to 1840x1196 pixels (see chapter 2.3.3.7), which is enough for a 2560x1600 screen.

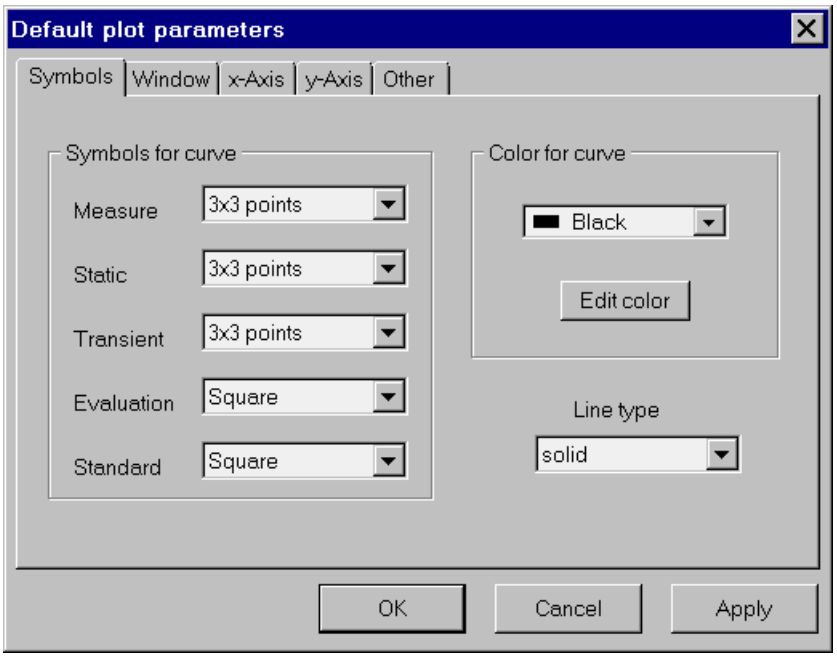
Tip: You can save your settings for a cold start in 'Personal shortcuts', see chapter 2.3.4.

2.3.2 Default plot parameters

The default plot parameters will be used for the initialization of a plot. In the plot program you can change these parameters, but these changes are only local, after leaving the plot program and start a new plot the default parameters will be used. The global plot parameters are an exception, see chapter 2.3.3.

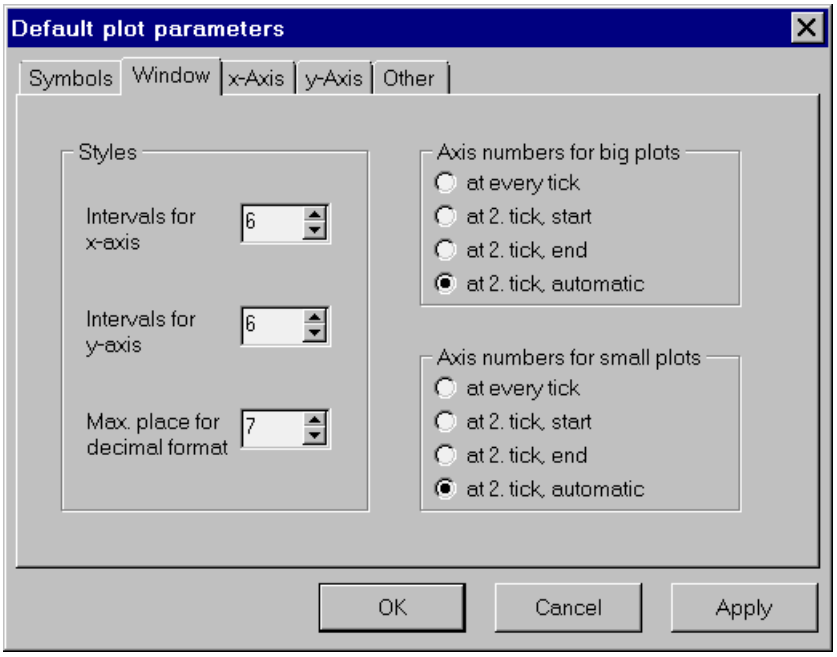
2.3.2.1 Symbols input sheet

There are default symbols for different kind of plots. These default symbols will be used only at standard plots with one curve. 'Measure' symbol will be used for example at the test of contact, 'Static' at C/V and I/V curves, 'Transient' for transient plots, 'Evaluation' for all plots which show evaluation values, for example the Arrhenius plot. 'Standard' is the default symbol for other curves not listed above, for example for the tempscan.

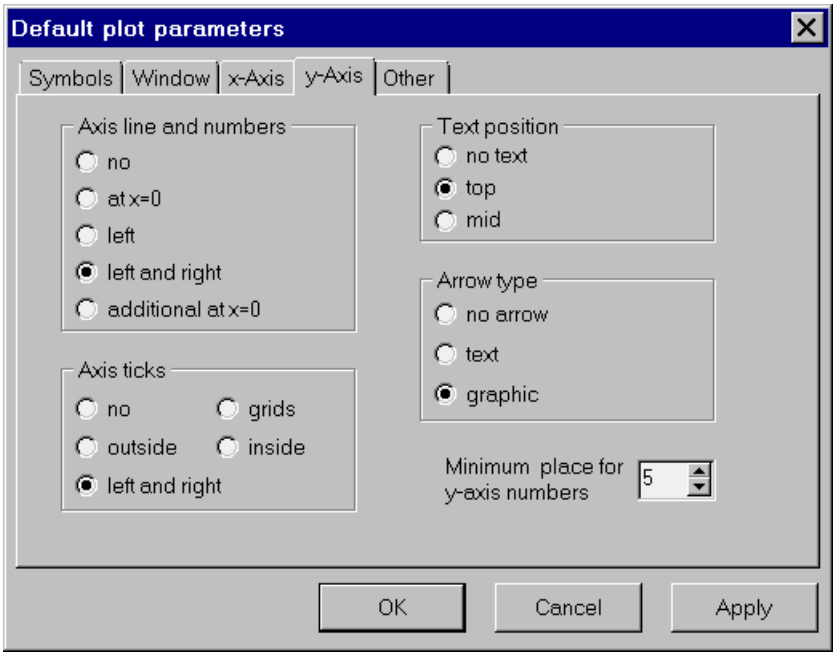


2.3.2.2 Window input sheet

At **Styles** you can define the number of intervals for the x- and y-axis. Maximum place for decimal format determine when the software change form the decimal to the exponential format.
Axis numbers for plots defines when at the axis the number will be printed. It can be done at every tick or every 2. tick. At start/end means that there is at the first/last tick a number. At 2. tick automatic means that the start will be set by the software.
The mode exist separately for big plots which use the full canvas and for small plots which use only a part of the canvas, for an example two plots one below the other.



2.3.2.3 x/y-Axis input sheet

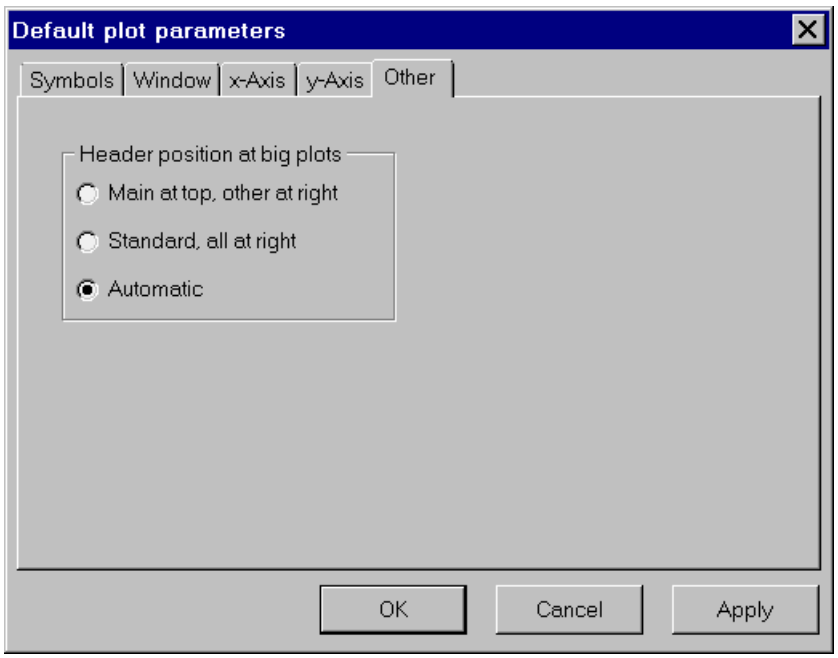


The window around the plot will be defined by **Axis line and numbers.** If selecting bottom and top for x-axis and left and right for y-axis then there is a full window around the plot and on the bottom and left axis line there is the numbers and axis text.
You can also select the kind of **axis ticks**. Left and right means that the ticks are inside of the left and right axis line.

Text position defines the position of the axis text.
Top means that the y-axis ends at the top line.
The **arrow type** behind the axis text is only a text string or a graphic arrow.

For the y-axis there is also the input of the **Maximum place for y-axis numbers**. This means that software reserves the place for the selected numbers. This shift the left axis line and change the size of the plot. This can be important if you compare different plots on a paper.

2.3.2.4 Other input sheet

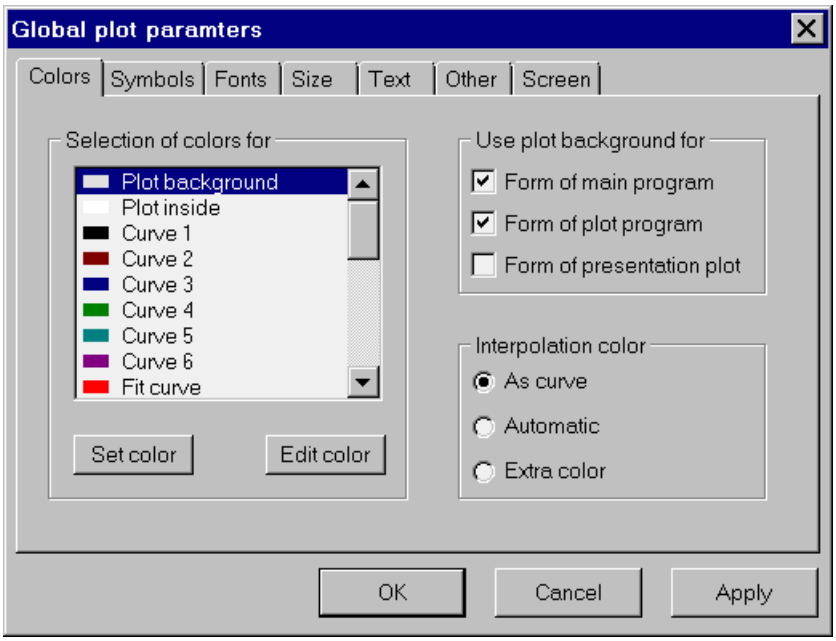


Here you define the header position at big (full) plots.
The first mode prints the file name and comment of the text header above the plot window, others will be printed at the right outside of the plot window.
Automatic means that if there is enough place on the right mode 2 will be used, in the other case mode 1.

2.3.3 Global plot parameters

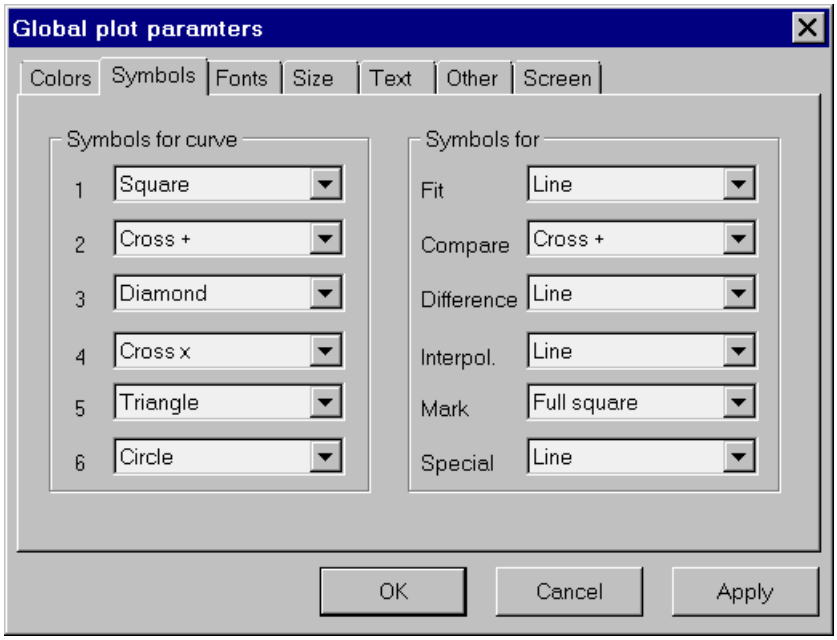
The global plot parameters are valid for the whole program and can only changed here.

2.3.3.1 Colors input sheet



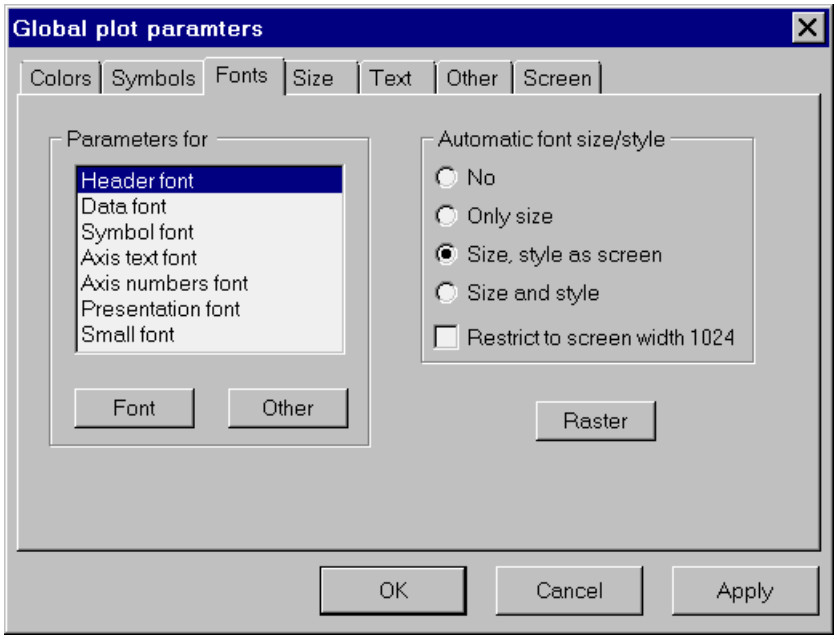
Colors for special kind of curves and for plots with many curves can here be defined. Plot inside is the background color of the plot inside the window. Plot background is the color of the canvas.
This plot **background** can be separately used for the form (not used size by the canvas) of the main, the standard plot and the presentation program. In the other case it will be defined by Windows.
3 modes are possible for the color of an **interpolation** curve. 'As curve' means that original data and interpolation have the same color. The software selects the color at 'Automatic'. Extra color takes the user defined color for interpolation.

2.3.3.2 Symbols input sheet



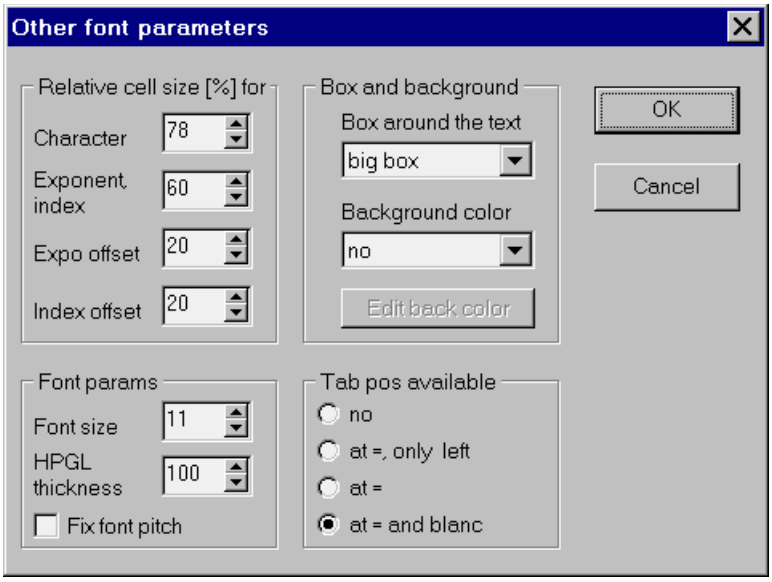
Here you can define the symbols for curve 1 to 6 at plot with many curves and the symbols for special curves.
Fit means if you fit a given curve by a simulation or calculation. **Compare** will be used for the curve which will be compared with another one. The **Difference** of 2 curves have his own symbol. You can also define the symbol for the **Interpolation** curve. **Mark** means if you mark a special point, **Special** is for special applications.

2.3.3.3 Fonts input sheet



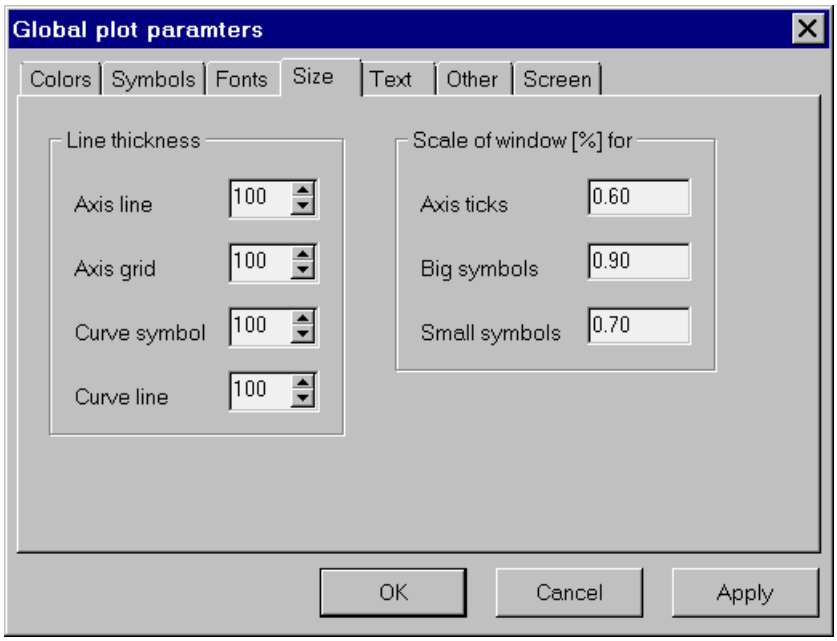
Here you can select the font of the plots. **Header font** is the font for the text header at plots, normally at the right side. Data font will be used for data inside the plot, for example Arrhenius evaluation list. Symbol font will be used for symbol explanation. Axis font exists for the axis text and numbers. Presentation font will be used in the presentation plot program. In some cases a special small font will be used.
The 'Font' button opens the Windows font dialog. The inputs by the 'Raster' button will be explained in 2.3.5.

Automatic font size/style defines whether the size and style of the selected font will be changed at other screen resolutions as the default 120 dpi. Change of style means that at too small sizes the small font will be used.
The **used font size** is not the defined size. It will be corrected by the used x-pixels of the current window in respect to the virtual x-pixels of a virtual raster window size. The virtual x-pixels size will be defined in the inputs of the Raster button, see chapter 2.3.5. So the default virtual raster font has the size 11 and 10 x-pixels per character. With 92 columns you get a virtual x-pixels size of 920.
You can **restrict** the automatic font size on the screen to screen width 1024. This means if you have more than 1024 x-pixels on the screen the used font size will not be bigger as for 1024 x-pixels.



By the **Other** button you get the other inputs for the font.
You can define the **relative cell size** for the normal character, for characters which used at an exponent or index text, and the offset for exponent or index character.
You can select a box around the text and the background color of a character.
Tab pos available means after which character the software can set a tabulator and starts a new position. This is useful at proportional fonts for list of data with text and values.

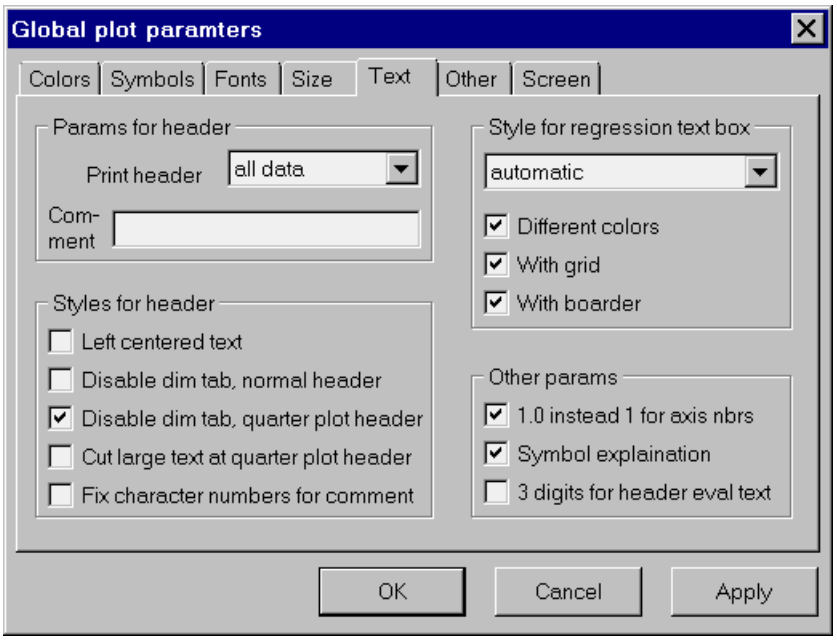
2.3.3.4 Size input sheet



Here you can define the **line thickness**. The standard value is 100.

You can define the **size** of the axis ticks and the plot symbols. The size will be given as percentage scale of the plot window. The symbol size exist separately for big plots which use the full canvas and for small plots which use only a part of the canvas, for an example two plots one below the other.

2.3.3.5 Text input sheet



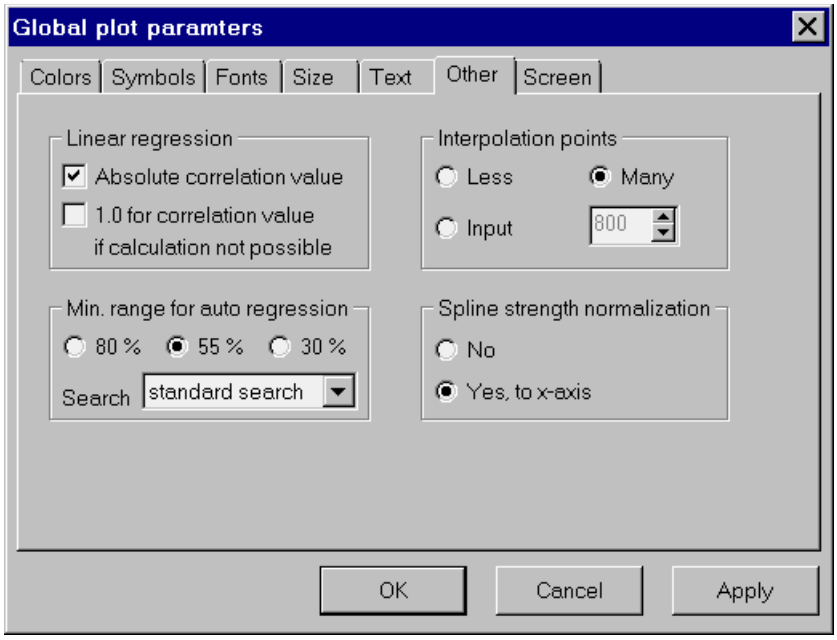
Print header defines which data will be shown in the plot header, possibilities are **no** use of header, **comment** only, **main data**, **all data** and an **anonymous** mode (no name, ID, date).

Styles for header enable an optimization of the header look, especially for pictures with 3 plots and a quarter header at the right top.

As **style for the regression text box** there a horizontal list with and without the evaluation dimension and a vertical list. 'Automatic' sets one of these types, normally the horizontal with dimension. Different colors for the different lines (horizontal), a data grid and a boarder around the box are options.

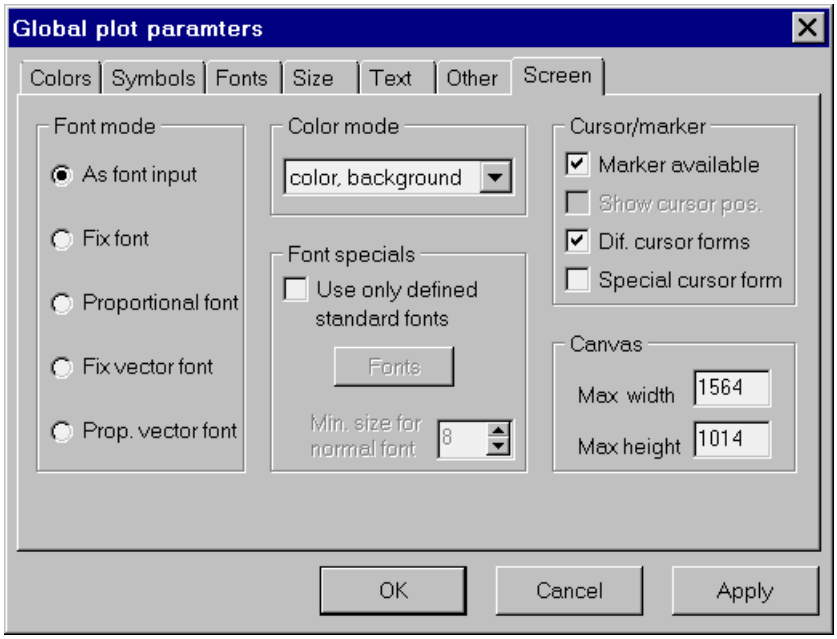
At other params you can activate the **symbol explanation**. So if you have a plot with some curves you get in the plot an explanation of these curves.
Normally the evaluation data in the header text will be shown with 2 digits, for example 1.12E15. By activating **3 digits for header eval text** 3 digits will be shown, for example 1.123E15.

2.3.3.6 Other input sheet



For the **linear regression** there are some options.
For the automatic search of linear regression can the used minimum range and the search method be selected. Preference to a big range width or to a very good correlation value are possible. The standard search is a compromise of both.
The points of a plot **interpolation** curve can be selected. Less use two times, many four times more points as the original. The minimum interpolation points in both cases is 501.
The **spline strength** can be normalized in respect to the x-axis data.

2.3.3.7 Screen input sheet



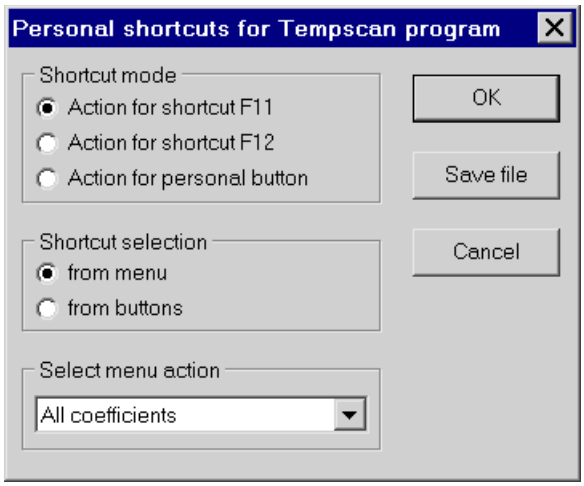
The following inputs are only valid for the plots on the screen, not at printing on a paper.

The **font mode** determines whether the defined fonts will be used or special ones.
The **color mode** defines whether the curves are in color or only in black and whether the plots on the screen have a background color.

There are some options for the **cursor** resp. **marker**:
'Marker available' means that you can the regression start and end position not only set by the mouse cursor but also by an additional marker (vertical line).
'Different cursor forms' means that, for example at the regression, not only the standard mouse cursor will be used but different cursors which are specific for the current action.

You can restrict the width and the height of the **canvas**. Memory must be reserved for the maximum size. If the maximum values are too small then the full screen size is not possible for the plot canvas.

2.3.4 Personal shortcuts



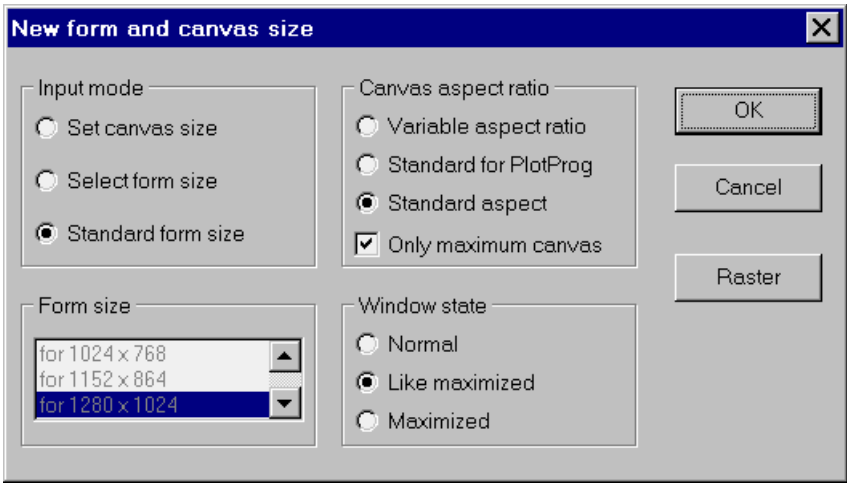
Here you can define your two personal shortcut keys F11 and F12 and your personal button. These definitions are specific for every program module. If you press F11 in the program module, the defined action will be done. You can select all the actions which are possible from the menu or from the toolbar.

By the '**Save file**' button you can save your personalization of program style, face and size and your shortcuts for a cold start. These are all parameters described in chapter 2.3.1, 2.3.4 and 2.3.5.

Usually the current configuration will be saved for the next hot start, see chapter 1.1.7. But sometimes it can be helpful to make a cold start with the default configuration. Then you would lose your personal styles, sizes and shortcuts. If you have saved here these parameters, these will be kept also at a cold start. Look in chapter 1.1.2 for the search strategy of initialization files.

2.3.5 New size

Here you can define a new form (window) size of the program on the screen after leaving these inputs. Form size means here the total size of the program window, including caption, menu bar, toolbar, canvas for plot, not used size and status line. Canvas size means only the size of the canvas on which the plots will be shown, see picture in 1.3.4.



3 input modes are possible:

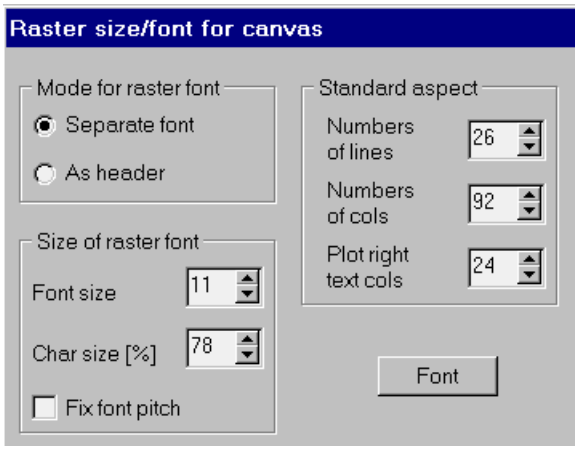
- **Set canvas size:** The canvas size will be set by the current form size.
- **Select form size:** You can define manually the form size (pixels) by the next input. There means 'for 1280x1024' that 1280 horizontal and 1024 vertical pixels are necessary. This mode can be helpful to use not the total screen size but keep the standard aspect ratio.
- **Standard form size:** The software defines automatically the form size from the screen size/resolution.

At mode 1 and 3 you can define the **Canvas aspect ratio** (y/x points) on the screen:

- **Variable aspect ratio:** The canvas uses the total free size of the form. This has the advantage that there is no unused size in the form, but depending on the form aspect the plots may look not nice because unfavorable height to width ratio.
- **Standard for PlotProg:** A standard definition of the aspect ratio, see below, will be used only for the plot programs, in the other case the aspect ratio is variable.
- **Standard aspect:** A standard definition will be always used, see input window of 'Raster'. The advantage of this mode is that you have always the same aspect and nice plots, but it is possible that you lose space on the screen.

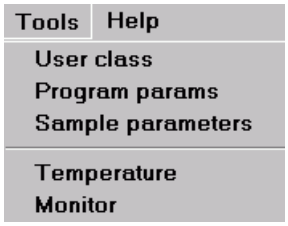
At the standard aspect is the use of the maximum canvas size possible.
The **window state** defines if the window size is as normal defined or maximized. In the first case the biggest used size by the standard aspect will be set. 'Like maximized' means that is not really maximized by Windows but use also the total screen size.

By the button **Raster** the inputs for a virtual text raster of the canvas is possible. This raster will be used for tabulators if text will be printed onto the canvas. You can select the font for this raster and the font size. 'As header' means that the font for the right text header will be used. The number of lines and columns of this virtual font define the standard aspect ratio for the canvas resp. plot. 'Plot right text cols' means the columns of the right text header at a single standard plot.



2.4 Tools menu

The Tools menu enables a selection of different input menus for setting up the software (not the installation).



User class is a value that enables or disables software parts, evaluations or measurements, due to a selected level. The working with the software might become easier if only the needed options are shown.
At user class 5 you find in Tools a calculator, especially for semi-conductor equations.

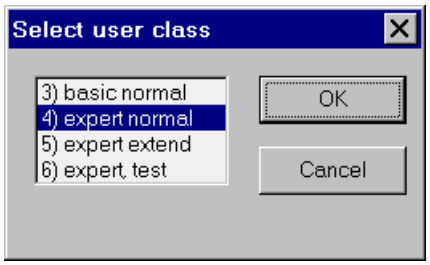
Program Parameters changes physical models for corrections and simulation parameters. Inputs depend on the user class. There is also the button for access of **Material parameters**.

Sample parameters opens the input window of all necessary values to describe and define the sample. Here you define also the **use of the database**.

Temperature enables the direct working with the temperature controller. Temperature reading, changing of the temperature, setting of the PID parameters and sending of commands to the controller are supported (depending from the kind of the controller).

Monitor allows to monitor the measurement and to define a WebView.

2.4.1 User class

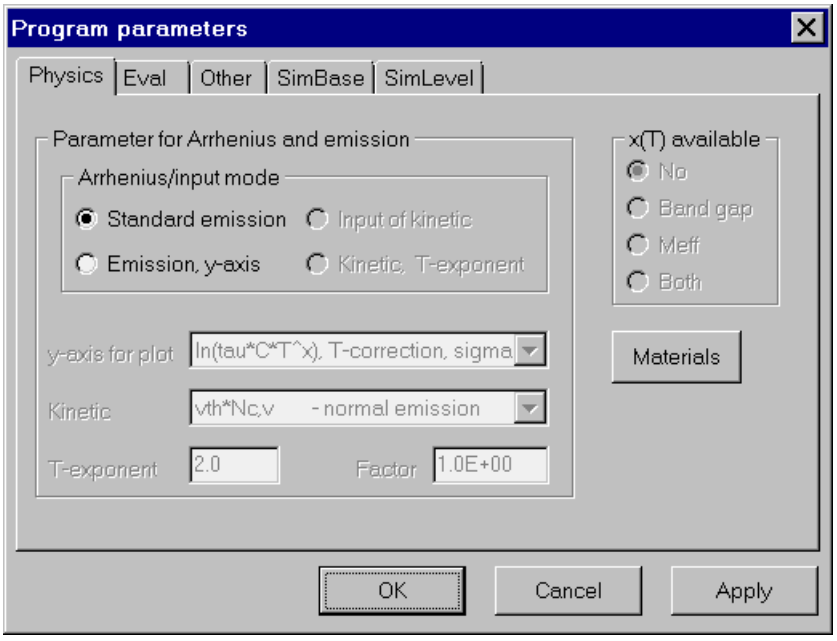


User class does not mean a classification of the user. It is a value defining how to work with the DLTS software and so far with the complete DLTS system. For standard and routine measurements, not needing a user with a particular physical background, or not wanting to think about different physical models for the actual sample the user class 3 (**basic**) is introduced. All inputs concerning measurements, evaluations, plots, etc. based on standard DLTS approximation and standard emission processes are possible.
Higher user classes enable more features, at lower classes these features are not visible or the input is not possible (grey text). The DLTS software provides a great many options to provide the most detailed analysis available in systems of its type. To avoid excessive complexity you are advised initially to use class 3.
For enhanced measurements, evaluations, plots etc, the **expert** classes are introduced. It enables also evaluations with a change of the standard emission / DLTS model or special measurements / evaluations needing a physical background for using it (direct capture cross section measurements / evaluations etc.). Level 4 is the last ´checked´ level, meaning that all inputs and evaluations are checked for data mismatch or conflicts. Fatal errors should not appear. User class 5 (**extend**) give you additional features, especially for evaluations and simulations, user class 6 is only for testing and hardware diagnose. Above level 4 it´s due to the user to check the data with the selected evaluation. A conflict might cause an error with a rebooting of the software.
In this manual only **user class 4** will be described, except at some marked parts.
The input of the user class will be restricted by the maximum user class, see chapter 1.1.5.

2.4.2 Program parameters

2.4.2.1 Physics input sheet

This input of Program Parameters defines the physical model used calculating the Arrhenius plot y-axis. Specially the temperature correction of the time constants is defined here. Materials opens an input sheet for changing and adding the material parameters for the used semiconductors.
The inputs depend on the used input mode and the user class. The below shown input mode selections is valid up to user class 4. User class 5 and higher enables you more features, at user class 4 these features are not visible or the input is not possible.



The **Arrhenius/input mode** defines the evaluation and the y-axis of the Arrhenius-plot. Starting from Standard emission process (DLTS Theory Manual) with emission time constant tau, effective density of states Nc resp. Nv and the thermal velocity vth we get the Arrhenius plot by ln(tau(T)*Nc(T)*vth(T)) versus 1000/T. To get the correct energy from the slope and the correct capture cross section from the intercept of this curve, we have to eliminate the temperature dependence in the argument of the logarithm. This is meant with the so called temperature correction of the Arrhenius plot. For the standard emission process (**S**chockley **R**ead **H**all) we get with vth ~ $T^{-0,5}$ and Nc,v ~ $T^{-3/2}$ as y-axis:

$$y(tau) = \ln(tau*C*(T/300)^2), \text{ with } C=vth(300K)*Nc,v(300K)$$

This is known as T^2 correction. In general it will be called **T-correction**, we get an exponent as a temperature correction (2 for the SRH mechanism above) and a constant consisting of the values of the corrected parameters at 300K (vth(300) and Nc(300) in the SRH model). Only for this standard model a correct energy and capture cross section can be evaluated.
In some cases this model is not valid. Therefore is the possibility to change these correction values. This should only be done if the user knows exactly what kind of emission model is valid.

The **Standard emission** uses the so standard SRH T^2 correction and have as y-axis for the Arrhenius plot ln(tau*vth*Nc). The capture cross section sigma is calculated from the T-corrected intercept.

Emission, y-axis enables some small selections for the y-axis and for evaluation:

- **ln(tau*C*T^x), T-correction,sigma:** Similar to the standard emission, the y-axis is ln(tau*vth*Nc), the y-axis text is ln(tau*C*T^2).
- **ln(tau*(T/300)^x), T-correction,sigma:** The y-axis is ln(tau*(T/300)^2). No effective mass is used for the y-axis, for the calculation of sigma ln(tau*vth*Nc) will be used.
- **ln(tau*(T/300)^x), T-correction, y0=intercept [s]:** Same as above, but the intercept is shown as y0 and not as a capture cross section sigma.
- **ln(tau), y0=intercept [s]:** No temperature correction is used. The slope is given as an energy, the intercept as y0 including all parameters, means without any correction.
- **ln(tau), T^0 for kinetic, y0=intercept [s]:** As above no temperature correction is used, but the intercept is calculated with respect to the values at T=300K.

The input mode **Input of kinetic** enables the selection of different emission process models (kinetics) and from that the use of different exponents x for the T-correction of the slope and factors for the correction of the intercept. This button is only available with user class 5 and a change from normal emission (SRH mechanism) to the other models should only be done if exactly known, that the selected model is valid for the sample.
Several emission models for use in the temperature correction of the Arrhenius plot can be selected now using the input window **Kinetic**.
The input mode **Kinetic, T-exponent** enables additionally the direct input of the temperature correction exponent x.

The small selection window **x(T) available** on the right side of the Physics input window enables an additional correction for the temperature dependent values of the time constant axis in the Arrhenius plot. At DLTS normally this correction will not be used:

No: No additional corrections are available (standard).

Band gap: The temperature dependence of the band gap is available.

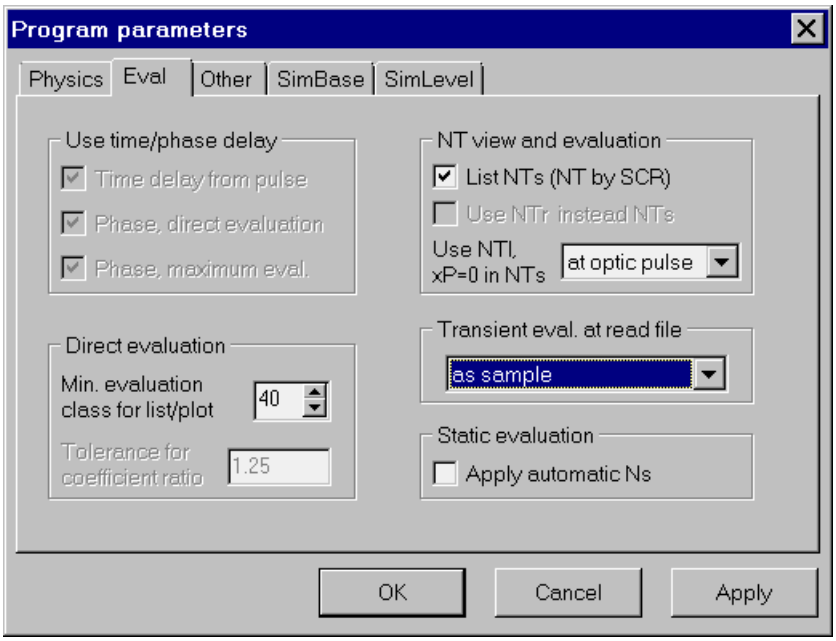
meff: The temperature dependence of the effective electron resp. hole mass is available. This effective mass will be used in the effective density of states Nc resp. Nv and in the thermal velocity vth for electrons resp. holes.

Both: Enable band gap and meff correction.

The input above enables only this option, a use of it is not always given. This input comes from the material file and will not be automatically saved at leaving the program, for more details look in chapter 2.4.3. For this use the temperature dependence must be defined additionally in the initialization file MatTemp.Cfg. From the installation there are only curves for silicon and 4H-SiC. You can plot the temperature depending values in the semiconductor calculator.

2.4.2.2 Evaluation input sheet

This input sheet enables the change of some parameters used in transient or maximum evaluation that normally have not to be changed or that are used as a predefinition for the evaluation.



Use time / phase delay (user class 5):

It defines whether the **time delay from pulse** due to the recovery time of the capacitance meter (see measurement parameters) is used for the evaluation or calculation of time constants or not. Similar to it the **phase** shift of the capacitance meter can be taken into account for the **direct** evaluation or the **maximum** evaluation of the time constants or not. To get correct values all of these corrections have to be used. Only for not normal transients a change of these values might give a hint whats happening.
Handle very carefully.

Direct evaluation:

The **Minimum evaluation class for list / plot** defines the evaluation class value for showing or listing data of a direct analysis of a tempscan, ITS or other transient measurement. Only data points of the measured and for a particular model (e.g. exponential transient) direct evaluated data are shown that gives an evaluation class (for that particular model) better than this value, see Basics Manual.

NT view and evaluation:

If activating **List NTs**, this kind of trap concentration calculation will additionally be listed at the data header, see chapter 3.2.3.1. While the standard DLTS approximation NT uses the total space charge region, NTs considers the correct filling area in the space charge region, look in chapter T1.2.2 of the Theory Manual. At some special listings or evaluations you see this value always or you will be asked for it.
NTs is calculated by the emission amplitude from the transient and the crossing point of the Fermi level with the trap level in reverse bias voltage condition xR and in pulse voltage condition xP. xR and xP reduce the volume for the trap filling and emission in the semiconductor compared to the standard DLTS approximation with xP=0 and xR=WR (space charge width at reverse bias condition). So NTs includes the lambda correction.

Use NTI, xP=0 in NTs:

In some cases a pulse condition cannot be clearly defined. This is always due for optical pulses where a xP value can not be calculated from the measurement conditions. Therefore here it can be defined when xP=0 should be used in the NTs calculation. This is still a better calculation as the DLTS approximation.
The use of xP=0 can be defined only at optical pulses, or never (also not at optical pulses) or always (should not be used as a standard due to higher systematical errors in the calculation).

If the checkbox '**Use NTr instead NTs**' is activated, a special calculation of NT will be shown at I-DLTS: $N_{Tr} = N_S \Delta I/I_R$, where ΔI is the amplitude of the current transient and I_R the leakage current. This calculation can be helpful especially at optical DLTS. NTr will be shown in a list instead of NTs. This flag is only enabled at user class 6 or activating the optional software, see next chapter.

If the current evaluation mode is 'Exp. surface states and traps', the input group '**Energy calib. for Nss/NsT**' is visible instead of the 'NT view' input group. Here you can define whether the defined evaluation is for surface states traps (NsT) or for surface states with a small energy interval (Nss), see chapter 6.3.3.

The **Transient evaluation at read file** defines the mode of evaluation that should be used as a standard when measurement files are read in:

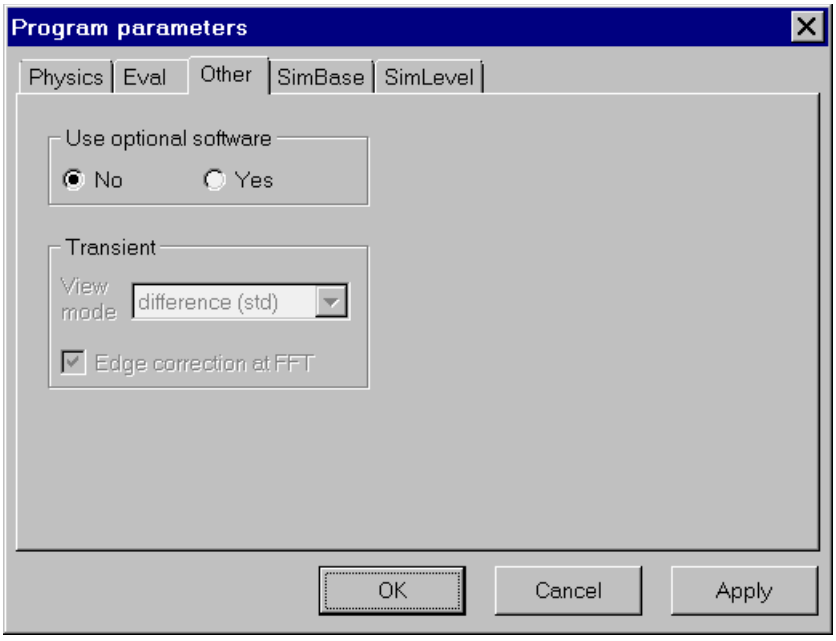
- **As sample** uses the evaluation model saved in the measurement file. This selection should be the standard.
- **Exponential discrete levels** uses always independently of the defined model in the saved file the model of an exponential emission from a discrete trap level.
- **Linear, inversion** uses a linear emission model normally due to inversion process in MIS structures (minority carrier generation).
- **Log., surface/oxide states** uses a logarithmic emission model normally due to surface or oxide states emission in MIS structures.
- **Exp., surface states/traps** uses the model of an exponential emission from surface states or traps in MIS structures.

The standard mode here is 'As sample'. Then the saved evaluation mode of a read measurement file will be used. A change should only be done, if known that during the measurements the kind of evaluation model was not correct or these measurements should be evaluated under different view means different emission models. To change it here makes only sense if several data files in a row should be analyzed. For single files it may be changed in the sample parameters (see below). If selecting a here a fix evaluation then this will be used as sample parameter independently of the defined model in the saved file. If you save the file again then the new evaluation mode will be saved.

Static evaluation:

Apply automatic Ns defines whether the calculated shallow doping calculated from a C/V measurement is automatically saved into the sample parameters set or not.

2.4.2.3 Other input sheet



Use optional software enables the use of software part in the DLTS program that is normally not available and also not completely explained in a manual. These optional software consist mainly some particular evaluations especially written for some customers.

The **Transient** input window, available at user class 5, defines how the transient is shown in the standard plot during or after a measurement. The measured and saved transient data is not effected by this input. All the selections of the view mode can also be selected in the particular plots of the transients is several 'plot' menus:

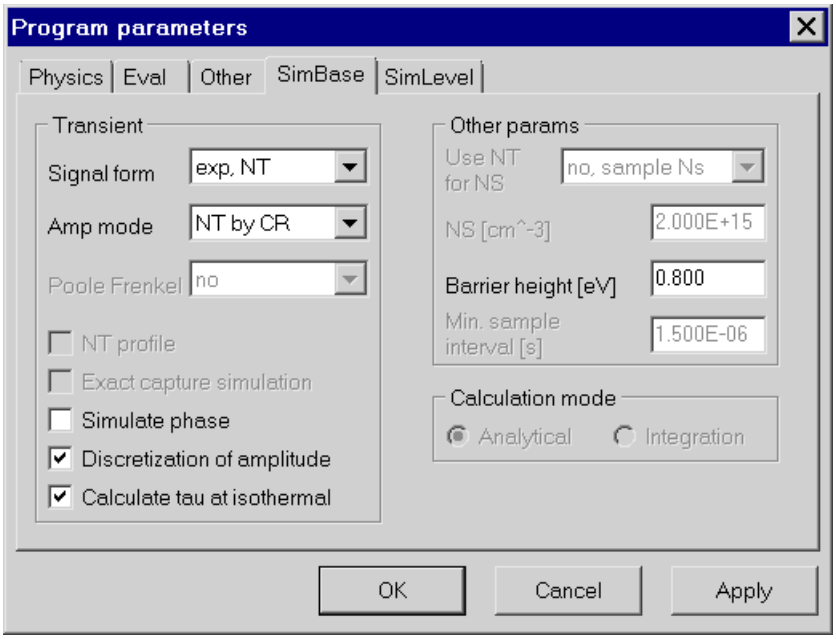
Difference (std): Shows the transient data as it is measured from the output of the capacitance meter in the compensated mode (see hardware manual). This is the standard selection.
Absolute: Shows the transient with the compensation capacitance added to the measured signal (the difference transient). It shows the complete capacitance of the sample versus time. Normally the transient, means the time dependent change of the capacitance, is too small in value compared to the reverse bias capacitance (the compensation capacitance) so that this kind of view makes not much sense. Only if the capacitance transient is of same order of magnitude compared to the reverse bias capacitance, this mode should be used.
Difference (Text): Same as the difference mode above, but using a different text for the y-axis as above.
Without DC: Shows the transient in the difference mode, but subtracts the offset capacitance (DC, measured directly before every transient measurement) from the measured capacitance values.
Without y-Last: Shows the transient in the difference mode, but subtracts the last measured transient value from all data.

The minimum class for valid data (no error) can be input at user class 6, for more details look in chapter 3.4.6.4.

2.4.2.4 SimBase input sheet

The two input sheets SimBase and SimLevel define the parameters and values of the DLTS program uses for **simulations** of the emission processes (transient). Nearly all measurements that are possible with this DLTS system can be simulated and the data can be used for all evaluations in the same way as the measured data.

Different emission models or processes (**signal forms**) can be simulated as well as different modes for the trap concentration (**amp mode**) simulation. In dependance of the selected signal forms and amplitude modes additional physical effects can be used for the emission transient simulations as there are the Pool Frenkel effect, trap concentration profiles, capture cross sections for capturing simulations. Also some hardware parameters can be changed for the simulations as the **phase** shift of the capacitance meter and the anti aliasing filter, the **discretization** of the signal by the transient recorder. **Calculate tau at isothermal** means that at isothermal simulations the time constant will be calculated from temperature, activation energy and capture cross section. In the other case you get at SimLevel an additional input for the time constant tau.



The **Signal form** defines the physical for the calculation of transient. Usually only the exponential transient will be simulated. The other signal forms are only available at user class 6 and not all combinations of inputs work here well. These signal forms should only be used if the physical model behind it is accurate known:

Exp NT: Uses the Shockley Read Hall mechanism for single trap levels in the band gap, simulates a sum of exponential transients at some levels.

Linear: Simulates a linear capacitance transient due to the minority carrier generation in MIS samples, the inversion process.

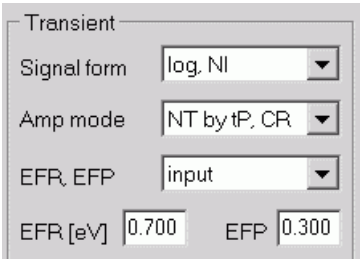
Log, Nss: Simulates logarithmic transients coming from surface states Nss with an energy depending capture cross section (normal case).

Log, sigma(E): Simulates logarithmic transients coming from surface states with an energy depending capture cross section or with other special kinetics (only for special experts).

Log, NI: Simulates transients coming from oxide states of all kinetic ranges.

Log, NIT: Simulates transients coming from oxide traps.

The last 4 signal forms need **EFR** and **EFP**, these are the Fermi levels at reverse bias and pulse voltage. An input with following possibilities exist here:



input: EFR and EFP can be input.

EF(T)-EF(150): As above but adds the Fermi level from the current temperature and subtracts the Fermi level from 150K.

abs(U/10): Defines it from voltages by EFR=abs(UR/10) and EFP=abs(UP/10).

Nicollian calcul.: Calculation from C and U by Nicollian, see chapter 6.3.3.

read calib table: Reads the Fermi levels from a table.

The tunnel constant, necessary for NI and NIT, can be entered or calculated by the tunnel barrier height. The 'Calc' button opens its input. The oxide thickness dox will be calculated by the oxide capacitance, the contact area and the dielectric constant of the oxide. The kinetic mode and gamma resp. Esigma are necessary for sigma(E), see chapter 6.3.4.5 for the description.

The transients of the last 4 signal forms can be calculated analytically by a simplification or numerically by an integration over an energy. The analytical mode is only a simplification but is faster than the integration mode. The integration enables a definition of an energy and oxide distribution by clicking onto the 'Para' button. The energy distribution 'fix' means a constant (homogeneous) distribution and is the default at each program start.

The **Amp mode** defines the mode for calculating the amplitude of transient. The values for the defined parameters are given in the SimLevel input window. The first 2 input modes are the standard ones. The others (user class 5) should only be used when the capturing process is known:

Amplitude: The capacitance amplitude in pF, V ... will be defined.

NT by CR: In the SimLevel input window the **trap concentration NT** is defined. During the simulation the DLTS approximation for the filling area is valid; all traps from surface to the end of the depletion width are filled. The time constant of the transient is calculated from the energy and the capture cross section (sigma Arrhenius).

NT by tP,CR: In addition to the input mode above a capture cross section for capture processes (sigma capture) can be defined in the SimLevel input window. Also an energy for simulating an activated capture process can be defined. All traps in the depletion area are used for the filling simulation (DLTS approximation), but the capture process is calculated with respect to the capture cross section and the pulse width. Therefore using this mode, capture transients and the evaluation of capture cross section measurements can be simulated.

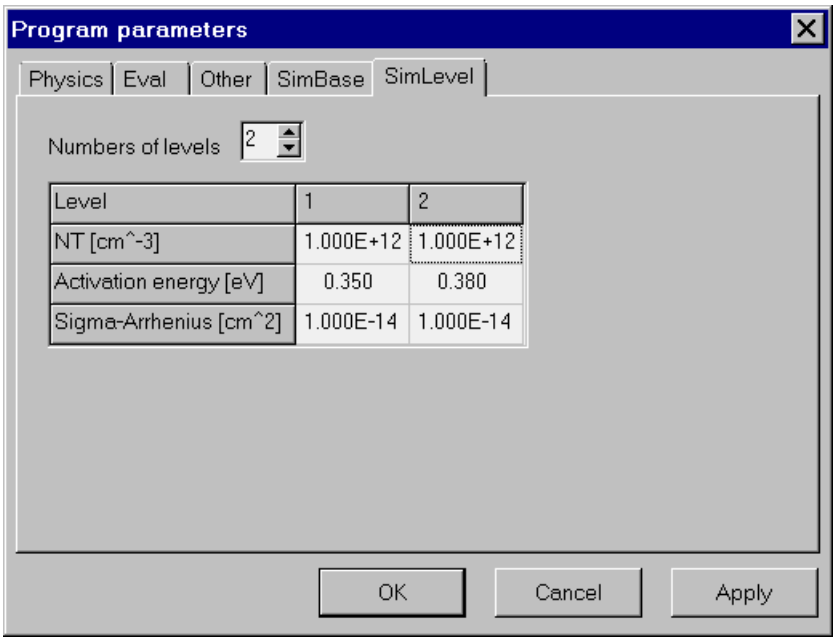
NT by tP, SCR: In addition to the mode above here also the correct filling- and emission area, the crossings of the Fermi Level with the trap levels at bias (xR) and pulse voltage (xP) conditions are used for the simulation of the transient's amplitude.

At other signal forms than 'Exp' NT means the concentration, for example Nss. The 4. 'Amp mode' has here the same meaning as the 3.

The **barrier height (Other Parameters)** of the simulated Schottky diode should be changed due to the material that shall be simulated.

2.4.2.5 SimLevel input sheet

Opens an input window defining the trap levels that shall be used in the emission transients simulations. Up to 9 different levels can be defined for the simulation in **number of levels.**
For each level values for the **amplitude [pF]** or trap concentration **NT** [cm^{-3}] (depending on the amplitude mode), the **activation energy** [eV] and the capture cross section **Sigma-Arrhenius** [cm^2] can be input.



The activation energies are energy differences from the majorities band, at n-type sample this is EC-ET, at p-type ET-EV.

Sigma-Arrhenius include the entropic factor XT. We distinguish between the capture cross section evaluated from Arrhenius plot (sigma Arrhenius) and that one evaluated from direct capture measurements **Sigma-Capture**. These two are related by the Entropic factor XT as:

Sigma_Arrhenius = XT*Sigma_Capture

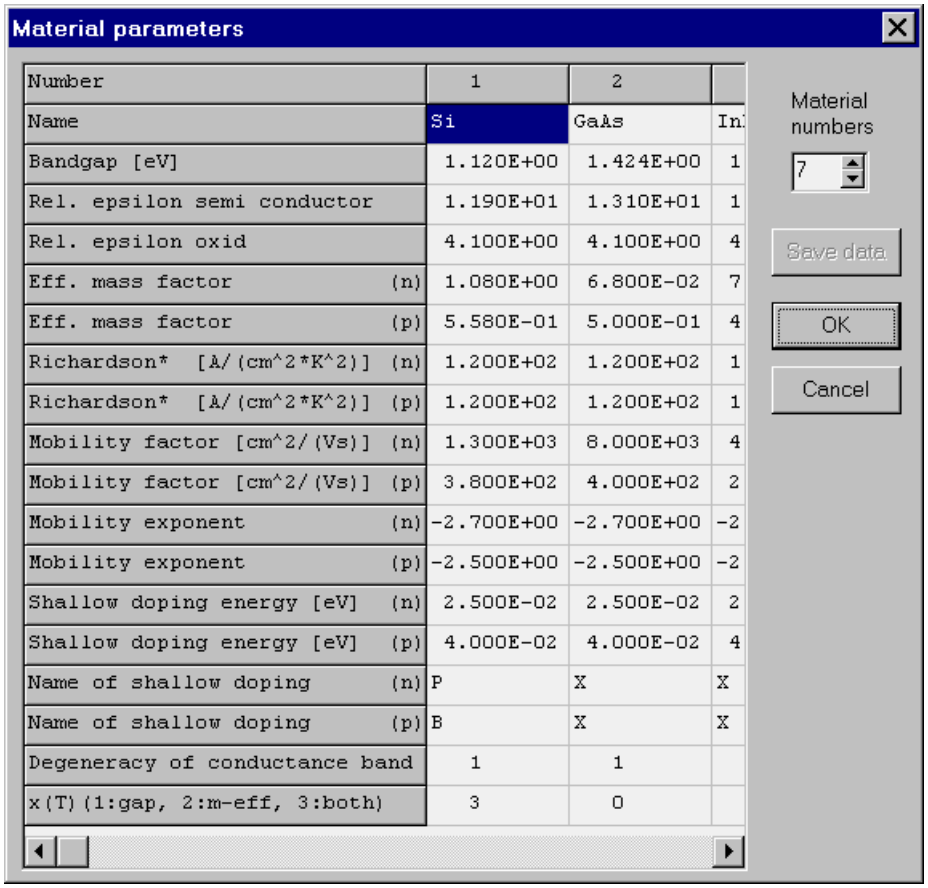
Sigma-Capture is used for all capture simulations. It is enabled for all amp modes including **tP**, the pulse width. The trap level occupation (trap filling) is within this mode correctly simulated concerning the capture cross section, the shallow doping Ns and pulse width, so emissions from partly filled trap levels can be simulated.

Also an energy activated capture cross section can be simulated (amp modes with tp, user class 5). For this an energy **Energy-Capture** can be defined that modifies Sigma-Capture as:

Sigma_Capture(T) = Sigma_Capture * exp(-Energy_Capture/(K*T))

2.4.3 Material parameters

One button of the Physics input sheet leads to the inputs of the material parameters partly used in the DLTS software. Several semiconductor materials are still predefined, but of course there are not all defined. Therefore the user has to define it here, by changing the values of still defined materials or by introducing a new parameter set and name of a semiconductor material. Not all parameters are used in the DLTS software, some are not used at all, some are used only for the library as a description and not for any calculation. The most important parameters are epsilon and the effective mass.



Number		1	2	
Name		Si	GaAs	In
Bandgap [eV]		1.120E+00	1.424E+00	1
Rel. epsilon semi conductor		1.190E+01	1.310E+01	1
Rel. epsilon oxid		4.100E+00	4.100E+00	4
Eff. mass factor	(n)	1.080E+00	6.800E-02	7
Eff. mass factor	(p)	5.580E-01	5.000E-01	4
Richardson* [A/(cm^2*K^2)]	(n)	1.200E+02	1.200E+02	1
Richardson* [A/(cm^2*K^2)]	(p)	1.200E+02	1.200E+02	1
Mobility factor [cm^2/(Vs)]	(n)	1.300E+03	8.000E+03	4
Mobility factor [cm^2/(Vs)]	(p)	3.800E+02	4.000E+02	2
Mobility exponent	(n)	-2.700E+00	-2.700E+00	-2
Mobility exponent	(p)	-2.500E+00	-2.500E+00	-2
Shallow doping energy [eV]	(n)	2.500E-02	2.500E-02	2
Shallow doping energy [eV]	(p)	4.000E-02	4.000E-02	4
Name of shallow doping	(n)	P	X	X
Name of shallow doping	(p)	B	X	X
Degeneracy of conductance band		1	1	
x(T) (1:gap, 2:m-eff, 3:both)		3	0	

In the following the material parameters itself and it's use in the software are explained.

Number is the number of the data row. The last number is given and can be changed at the right scroll bar input window. The increase of the material numbers add a column for adding a new material parameters set. The name of this column is empty, the other data is predefined by the first (1) data set, normally Silicon.

Name defines the name of the material like Si, GaAs, etc. The name is not only an information, it is used by the DLTS software in the library and as the searching value for this material list. The name is a part of the sample parameter set and saved in any data. After loading the data the material parameters are searched by this name. If a saved material name is not found in a material's parameter set a '*' is added to the name (e.g. Si* or GaAs*) to show that no materials parameters are available and that of the first entry (normally Silicon) is used. If using different material parameter sets (see save data) it is important to use always the same name for the same material (e.g. for SiC either always SiC or H3SiC or H6SiC for the different materials).

Band gap defines the band gap of the semiconductor material.

Rel. epsilon semiconductor defines the relative dielectric constant of the semiconductor. This value is always used for any calculation a capacitance is involved, especially for Ns.

Rel. epsilon oxide defines the relative dielectric constant of the main oxide used for the particular semiconductor material. This value is always used in calculations where a capacitance of MIS structures involved.

Eff. mass factor (n/p) gives the relation between effective electron (resp. hole) mass and electron mass m_0, used for effective density of states and thermal velocity. Therefore these values have influence to the capture cross section calculated by the intercept of the Arrhenius plot.

Richardson* (n/p) defines the Richardson constant for diodes in n/p-type material, used for simulations.

Mobility factor (n/p) defines the mobility of electron (resp. hole) at 300K, not used in the DLTS Software.

Mobility exponent (n/p) defines the temperature dependance of the mobility of electrons resp. holes. My(T) = my(T=300)*(T/300)^{exponent,}, not used in the DLTS Software.

Shallow doping energy (n/p) give the energy level of the main dopand material for donors (electrons) resp. acceptors (holes), used for simulations.

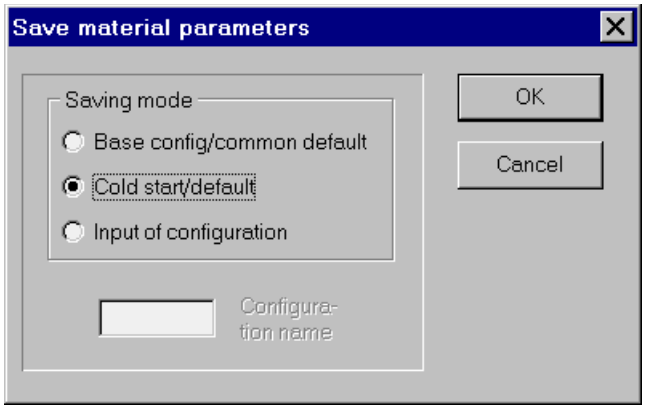
Degeneracy of the conductance band is by default 1 for all predefined materials except of 4H-SiC. For silicon 6 could bet nearer at the physics but our default value is here also 1 because compatibility. If you change this value then you get another value for the capture cross section!

x(T) enables the **temperature depending** use of band gap (1), effective mass (2) or both (3) of this material, (0) disables it. But it will only be used when additionally selected 'x(T) available' at the Physics input sheet, see chapter 2.4.2.1. When using temperature depending parameters then a table must exist for this material in the file MatTemp.Cfg.

Summary: For a materials list for correct calculations and evaluations of any DLTS measurements and evaluations the **name, the correct dielectric constant** (epsilon) of the semiconductor and of the oxide (if MIS samples are used), the **effective mass** and the **degeneracy** are a must.
The default material file contains for the predefined materials correct values only for epsilon of the semiconductor and for the effective masses. The other parameters could be dummy values, but are not so important. The dielectric constant of the oxide depends on the kind of oxide. If you don't use the oxide thickness but area and oxide capacitance then this value is not necessary. For silicon all default parameters should be okay except the degeneracy.
The name of dopand can be a search criterion in the trap library. The other parameters are more or less only used for simulations or information.

By leaving this input sheet by '**OK**' all modifications are saved in the internal program memory, so that these changes are valid until you leave the program. At the program exit (chapter 1.1.8) you get then an additional question for saving the material parameters into an initialization file. There you can save these parameters only for the selected configuration, not for a cold start.

Leaving the material input sheet by the **Save data** button leads to the input shown on the right.



Three different **Saving modes** can be selected. This is necessary for defining for which users or which samples the new material file should be valid. This is sometimes not an easy decision, because several groups working with the DLTS system may have different parameters for the same sample material or work with completely different materials and do not want to have other ones in their material list. On the other hand is the working with different material parameters lists quite dangerous, because the same measurement may give different results if analyzed with different material parameters. Therefore the saving of the materials parameters list has to be thought about very accurate. For search strategy and priorities of init files at the program start see chapter 1.1.2.

Base config/common default saves the parameters in Dlts\Conf\Init\Materials.Cfg, for loading this has the priority 3. It will be loaded at any cold start or if the material parameter file doesn't exist at higher priorities. A hot start file does not exist normally, except you have made changes and have confirmed the saving at the program exit. The changed and saved materials parameters file does not exchange our original one, this is saved in the Dlts\Sys\Init directory which have the lowest priority 4. This input mode is the best if some users are working with the DLTS system and all users want to use the same material parameters. For this mode user class 5 is necessary.
Depending on your Windows access rights it could be that you need administrator rights for changing files in Dlts\Conf, see chapter I4.

Cold start /default saves the materials parameters file to the personal user init path in DltsData\UserX\Init\32\Material.Cold.Cfg, which has the priority 2. In this example the user name is UserX and the program version is 3.2. For only one user working with the system, we recommend this saving mode.

Input of configuration enables to input of a configuration name. If this name is 'Test' then the material parameters will be saved in DltsData\UserX\Init\32\Material.Test.Cfg, which have the highest priority 1. But this file will only be loaded if you start at program start your configuration 'Test'. This mode is for our opinion the best way to work with several materials parameters files.

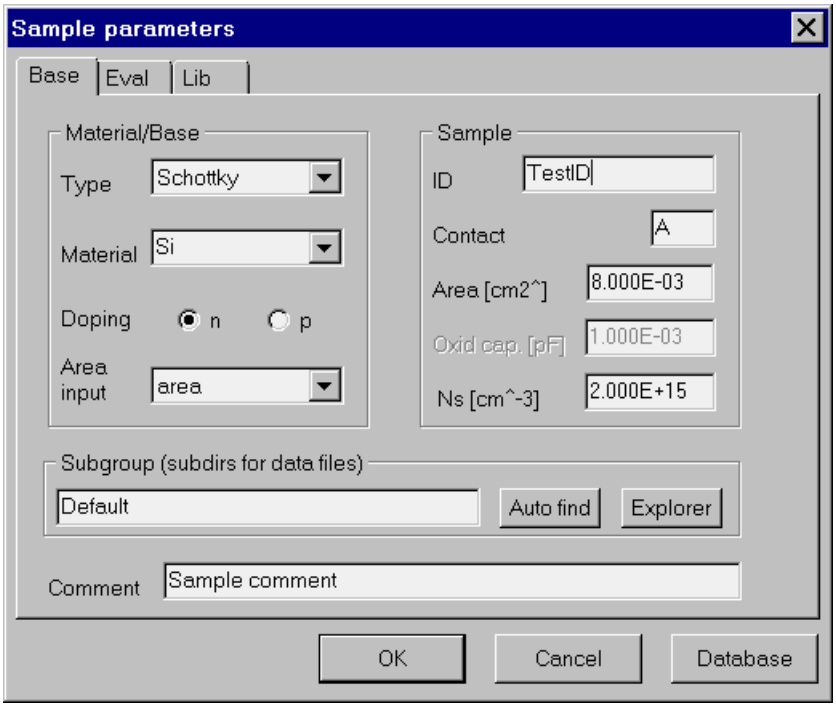
2.4.4 Sample parameters

The **sample parameters** are one of the more important parameter sets and have to be defined for every sample before a measurement is done or saved. This parameter set is saved with any measurement data in the file header, base parameters are also uses in the trap level library as keywords.

The sample parameters are **global** for the physical used sample in all measurement program modules or **local** for the current module if you have data load from a file. If you see the caption 'Sample parameters' at the input window then they are valid for the sample. If there is the caption 'Sample parameters for the read file' they are only valid for the data of the current file, but the file itself will not be changed. Changes then will not automatically be applied for the physical sample, before a new measurement the software ask for applying, see chapter 1.3.1.
If you change the sample parameters after the measurement and the data was already saved then you have to save the data again to apply the changes also in the file.

It defines (**Base**) for the actual sample the kind of diode and its area, the semiconductor material, the doping in type and value as well as the sample identification.
Also the kind of evaluation (**Eval**) that should be used (as a predefinition) with some additional parameters, the use of the trap library (**Lib**) and some library keywords valid for this sample and the use of the **database** can be defined. Library and database inputs are only available if these are part of the software.

2.4.4.1 Base input sheet



Type gives the diode type of the sample. A Schottky diode, p+n or n+p diode or a MIS capacitor. The MIS, or called MOS, type enables all measurements and evaluations for metal insulator structures as there are pulsed C/V measurements Zerbst evaluations etc.

Material gives a list of the material names defined in the material parameters list, see chapter 2.4.3. The selected name defines the parameters for the material which the software is using in calculations and evaluations. If a name of a read in measurement is not known the name is given with a '*' at the end. This might happen, if measurement data from a foreign user is read in.

Doping defines the doping type n or p type.

Area input defines the input mode for the diode area. The area itself or the diameter of a circled contact can be selected to be given in the sample parameters input field. Special modes exist for MIS, see chapter 6.3.2.4.

Sample ID stands for a 10 characters long text that is meant to be used as an identification for the sample. The sample ID is a significant description of your sample. This ID will be used for automatic file names and for the data base option for comparison of results and so on. By this ID you can also search all stored files for this sample.
Forbidden characters for the ID are: '*', '?', '"', '<', '>', '|', '/', ':', '\', '. ', '@',' '. Depending on the parameters for the automatic file name (chapter 2.4.5) only uppercase characters are allowed. Upper and lower case characters of this ID will not be distinguished in the database and in the Window file system.

Contact stands for a 2 characters long text that defines the diode dot on a sample material containing several ones. You can also use the two characters for the x- and y-position. Sample ID and contact are also used for the automatic file name creation, see 2.4.5.

Area (Diameter) defines the value of the diode area in cm² or diameter in cm. The value is always used for any calculation of concentrations. As exactly this value is known, as exactly concentrations (absolute ones) can be calculated.

Oxide capacitance is enabled for MIS diodes. The value for the oxide capacitance in pF can be defined here or this value can be calculated from measurements (C/V pulsed C/V) and transferred to this value of the sample parameters.

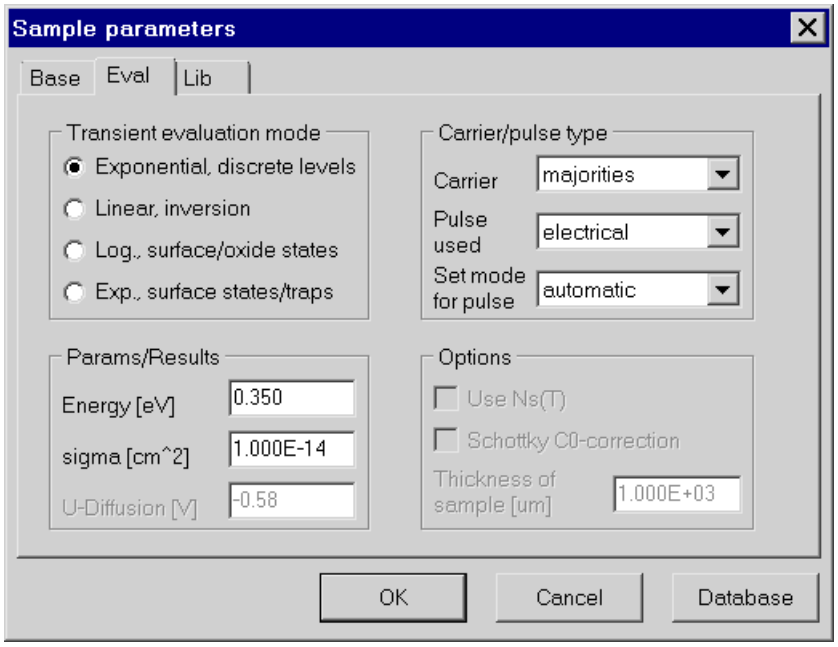
Ns defines the value for the shallow doping in cm^{-3}. Similar to the value for the oxide capacitance this value can be defined by an input from the user (if well known), or (the normal way) a C/V measurement with a $1/C^2$ evaluation defines it by a transfer from the evaluation to this value. Ns is necessary for the calculation of the trap concentration. See also the distinction between Ns and N_{SP} explained in chapter 3.1.1.1

Comment enables you to input a comment to the sample or measurement, the maximum length are 60 characters. The comment will be saved into the data file and into the database.

Subgroup means sub directories for the data files. An explanation of this and the both buttons are given in chapter 2.4.5. This input is only visible if you confirm it at the database input. The input is only enabled if you have changed the sample ID. Put in the subgroup before the measurement, the sub group directory will not be created automatically after the measurement.

2.4.4.2 Eval input sheet

The evaluation input sheet in the sample parameters defines values and variables used in direct evaluations of measurements of this sample, or for first approximate energy or capture cross section evaluation.



Transient evaluation mode defines the mode for the direct transient evaluation (DLTFS):

- **Exponential, discrete levels:** Uses the Shockley Read Hall mechanism for single trap levels in the band gap (exponential emission) and the measured Fourier coefficients for the calculation of the time constant of the measured emission transient.
- **Linear, inversion:** Uses a linear transient model due to the minor carrier generation in MIS samples, the inversion process for calculation of minor carrier lifetime etc.
- **Log., surface/oxide states:** Analyzes logarithmic transients coming from surface states (Nss), oxide states (NI) or oxide traps (NIT). Uses the Fourier coefficients for calculating the surface states density Nss and the predefined capture cross section sigma (Parameters/Results) for calculation of the energy distribution of surface states density, Nss(E). Special evaluations exist for oxide states.
- **Exp., surface states/traps:** Calculates from exponential transients the surface states Nss using the model of small signal measurements and evaluations (nearly no energetic and local distribution of the surface states in the measurement information depth). It can also be used for traps at the surface. You can select the type in Tools → Program params → Eval → Energy calibration.

The first mode is usually for Schottky diodes, the last 3 are only for MIS samples. The standard mode for MIS samples is the third (log. transient). You get more information about evaluations of MIS samples in the MIS chapter 6.3.
The evaluation mode is a sample parameter which will be saved into each measurement file and be set when loading a measurement. To avoid this you can define a global evaluation mode in Tools → Program params → Eval, see chapter 2.4.2.2.
The evaluation mode defines also the possibilities in the evaluation menus but some special evaluations are independent from the selected mode. So the Zerbst analysis is always available at a MIS sample.

Parameters/Results:

Energy and **sigma** (capture cross section) values defined here are used for calculating an energy or capture cross section from the evaluated time constant of a measured transient. For a calculation of an estimated trap energy the value for **sigma** is used, for an estimated capture cross section the value for the **energy**.

U-Diffusion (the diffusion voltage) is a value transferred from a $1/C^2$ evaluation of measured C/V curve of a Schottky diode into the sample parameters. For MIS samples the flat-band voltage (**U-Flatband**) is shown here. Because this value is saved with the other sample parameters in the file header of every measurement this value is meant to be used as a short sample diode characterization.
The input is only enabled for user class 6 (expert test) and should only be changed if the user is completely sure that the measured value is incorrect. If working without capacitance bridge, for example at current DLTS, then U-Diffusion will be used for the capacitance calculation. In this case user class 4 is enough.

Carrier/Pulse type:

Some more information about the measurements and the sample itself can be defined in this input window. The defined values are used in the trap library as keywords for searching algorithms. At this time it will not be used for evaluations.

Carrier defines the kind(s) of carrier types that is analysed in Arrhenius plots etc.. The standard (and the only one for the Schottky diode without light) selection is **majorities** (electrons in n-type, holes in p-type semiconductor). In p/n junctions or using optical excitations also minorities (holes in n-type and electrons in p-type material) can be observed.

The **Pulse used** defines the pulse type which is currently used for plots and the evaluation of the sample. Available are 'electrical', 'optical' and 'electrical and optical'.

The **Set mode for pulse** define the setting of pulse type after next transient measurement. In the standard mode **automatic** the pulse mode (this is a measurement parameter) of next measured transient defines the value for 'Pulse used'. **Auto, light on** is a special mode for transient measurements at permanent light.
Electrical, optical and elec. & optic as set mode defines the selected pulse type as the used pulse after a transient has been measured independently of the really used pulse mode for this transient.

Note: The values above do not set the real pulse mode at transient measurements. This mode you have to set in the 'Bias/pulse params'.

Options:

A special **Schottky contact correction** can be selected at user class 6, the so called C0 correction. Using this correction, the contact diameter is corrected (enlarged) by the space charge region, as d_corrected = d_defined + W(UR). This correction will also be used for the Ns calculation from the C/V curve.

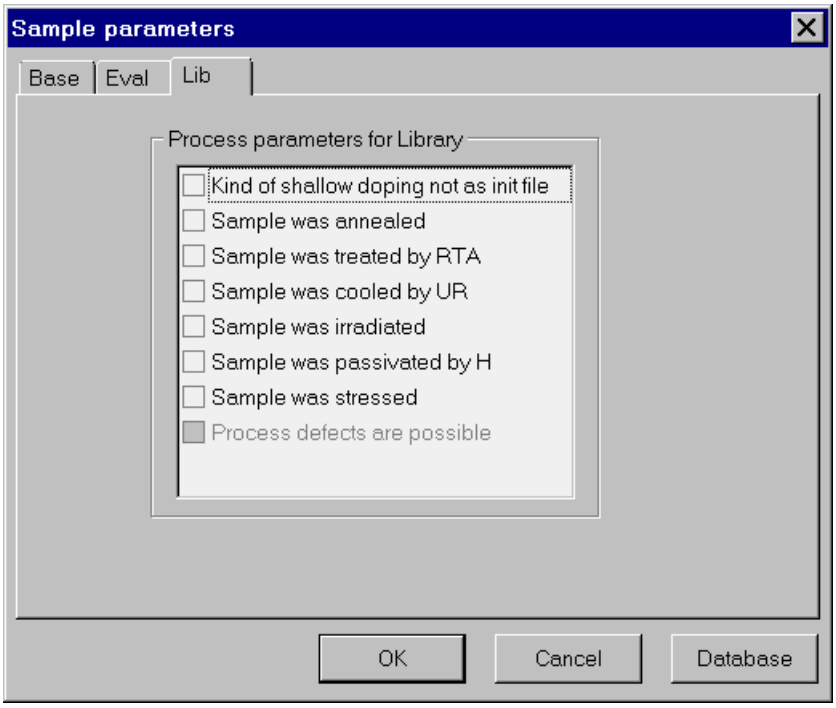
The **thickness of sample** is only necessary for some evaluations from the conductance, therefore it only enabled in the static module or at user class 5.

Ns(T) means that temperature depending values for the shallow concentration Ns instead of the fix value of the input at 'Sample' will be used. This input is only possible at the temp-scan program and if you have measured Ns at different temperatures. This flag has for example an influence of the calculation of the trap concentration curve NT(T). If activating this flag then the fix Ns value of the sample parameter set will be denoted as Ns0 in the plot header.

At I-DLTS the flag '**Full depleted thin film MIS**' is visible for surface and oxide states evaluation. If activating then the factor (Cox-CR)/Cox will be set to 1 for the evaluation.

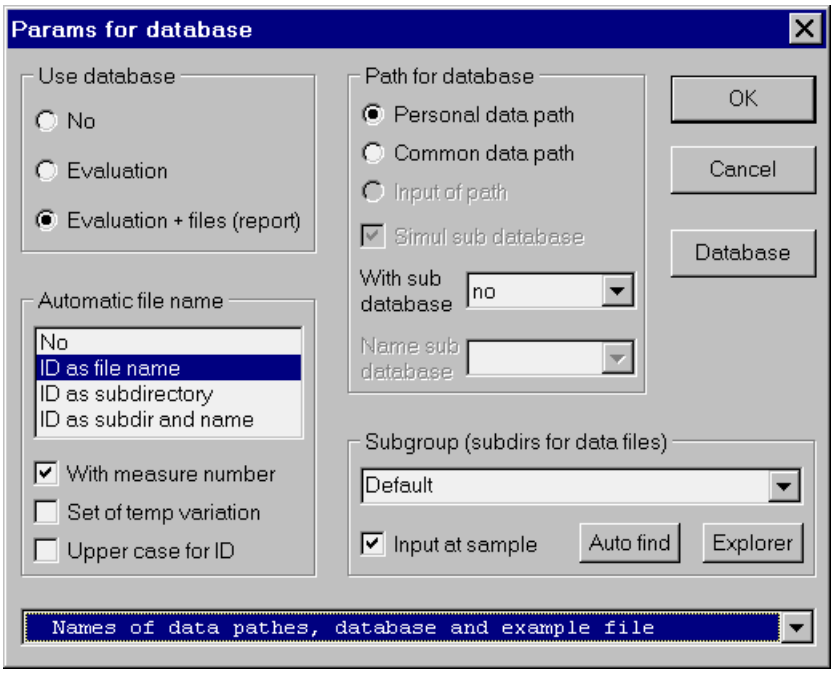
2.4.4.3 Lib input sheet

Defines sample parameters concerning the semiconductor material. Some keywords can be selected explaining how the semiconductor material has been treated during the processing or specially done for tests to find some new process induced traps. These keywords are used in our trap library to find energy levels known from literature fitting to a measured unknown trap. All these keywords are also saved with the sample data header. Library and database inputs are only available if these are part of the software.



2.4.5 Use of Database

The right button **Database** at the 'Sample parameters' opens an input window that defines the use of the database, the database itself will be explained in chapter 5.4.



Use of database defines how you want to work with the database:

No: No database will be used, automatic file names are not possible.
Evaluation: Only evaluation values will be saved into the **evaluation database**. Before saving you get a question or you have to call the save dialog.
Evaluation + files: Additionally the measurement action, but not the measurement data, will be saved into the **file database** as a report. If measurement data will be saved, then automatically this report will be done.

Automatic file name defines how the file name should be generated. It is only a proposal. You can change it before saving data. In the following examples is 'ID' the sample ID and 'A' the contact, the 2. example is 'With measure number':

No: The file name is not generated by the software, the user has to define it before the saving procedure.
ID as file name: The file name is automatically generated using the sample ID, a '@' and the contact, see 2.4.4.1. This is standard mode. Example for the file name is ID@A.T1A.DLT resp. ID@A_001.T1A.DLT.
ID as sub directory: Measurement data is saved in a new created sub directory with the ID as folder name. The file name is generated from the contact and, if selected, the number of the measurement. Example is ID\A.T1A.DLT resp. ID\A_001.T1A.DLT.
ID as subdir and name: Combination of the two option above. The measurement data are saved in a separate sub directory with the sample ID as directory name and the sample ID is also used for creating the file name, ID\ID@A.T1A.DLT resp. ID\ID@A_001.T1A.DLT.

The checkbox **With measure number** activates the automatic counting of measurements for the given ID and contact. So in the 2. examples above the number 001 is automatically added. Therefore it can not happen with this option that several measurements are saved under the same name and former data will be overwritten.

Set of temp variations defines that in the following same measurements will be manually done for different temperatures. In this case the proposal file name is for example ID@A_00M001.T1A.DLT. For the next measurement at a different temperature set it to ID@A_01M001.T1A.DLT. This option enables the automatic plotting of all measurements (all in one …) of one temperature set. It is not necessary at an automatic temperature variation (tempscan). This option will be switched off by a change of the program module.

Upper case for ID allow only upper case characters for the input of sample ID.

Path for database defines the location of the database that should be used. If a database is not found at that selected location, a new one is generated by the software after request. You can select your **Personal data path**, the **Common data path** and an **Input of path** (directory), which are available depend on your configuration, see chapter 1.1.5.

Simul sub database is an option that is only available if the measurement program (measurement hardlock key) works in the simulation mode. By activation of this option the simulation data will not be saved into the measurement data path and database but in a special one.

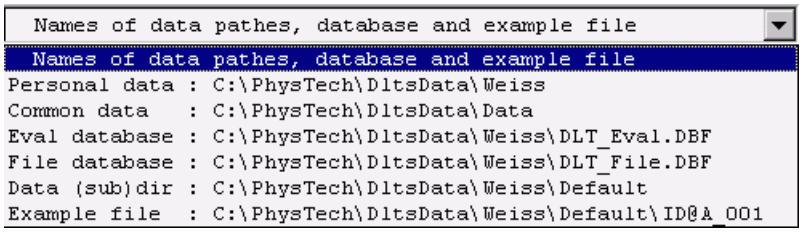
With sub database means that a new database will be created in a sub directory of data path. In this case you have more than one database. This option you should only use if you have a lot of different samples. If there are a strictly divided directories for users or materials it makes also sense to use different databases. Normally you should only work with one database. Data saved in one database can also easily selected to different materials or users. For only data sub directories define a new subgroup (see below).

For the using of sub database there are some possibilities:

No:	No sub database, only one database will be used.
Year:	A sub database in a sub directory with the current year will be created, for example for the common data path 'Data\2010'.
Year,check:	As above, but it will be checked if data of the current ID already exist in a directory of a year before. In this case the old year will be used.
Material:	The material name will be used as sub database resp. sub directory.
SimData:	Use of the predefined sub directory 'SimData', used for simulations.
Input:	Input of the sub database name, up to 8 characters.

Subgroup means sub directories of data files. Don't save data directly to the main data path. You should use sub directories and make a structure for material, samples and measurements. Here you can define a sub directory with sub sub directories and so on. The maximum subgroup size is 48 characters. You can input a new directory, select an existing one or call the 'Explorer' by a button. The button 'Auto find' search for an existing subgroup of the current sample ID.
By activating 'Input at sample' you can input the subgroup also at the sample parameters. In the database you can search or select by Subgroup.

When activating the down arrow of **Names of data paths, database and example file** you get the following list:

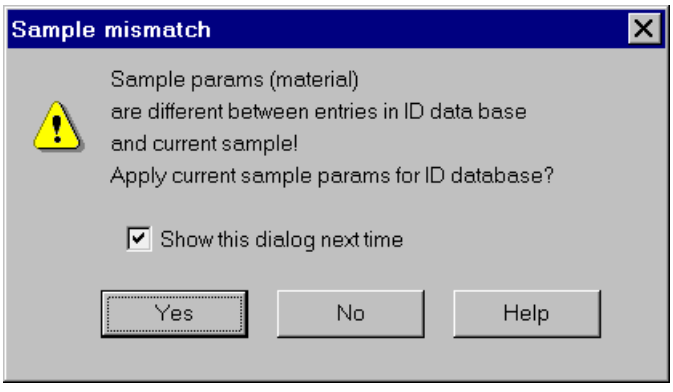


In some cases additional files will be created and saved. These files will then saved into a sub directory of your selected subgroup. The name of this sub directory will be taken from the main file name. For example, transient files in a tempscan, if the main file name is ID@A_001.T1A.DLT then the sub directory is ID@A_001. The transient names are T001.Y1A.DLT, T002.Y1A.DLT and so on.

Notes and tips:

- Upper and lower case characters of the sample ID will not be distinguished in the database and in the Window file system! So 'TestID' and 'TESTID' denote the same sample ID.
- Blanks in directory or file names are not forbidden if manually created resp. defined, but should not be used! Blanks in the subgroup or in the sample ID are not allowed. Therefore are no blanks in the proposal of the automatic generated file name.
- The automatic counting (with measure number) starts at the current number. So if the current name is ID@A_005, the proposal for saving would be ID@A_006. If you manually set here ID@A_011, the next proposal would be ID@A_012. You can use this to divide measurements in different blocks (applications).
- One sample ID, that means also one sample, should belong to only one subgroup.

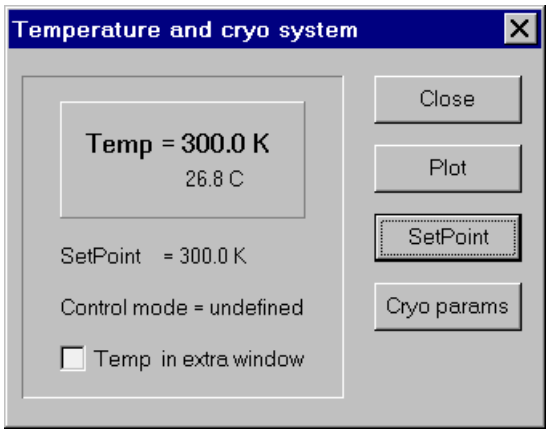
It is possible that you get before saving data a **sample mismatch** warning:



This warning occurs if the sample parameters already saved for the given sample ID in the ID data base are not identical with the current sample parameters. So it should not be possible that at one measurement the material name for the same sample is 'Si', at the next measurement 'GaAs'. One sample ID should belong always to one sample. In the brackets you see the sample parameter which was changed.
If you click onto the 'Yes' button then parameters in the ID data base will be changed to the new parameters. Clicking onto the 'No' button let the ID data base unchanged.
If deactivating the flag 'Show this dialog next time' then this dialog will not be shown and the ID database will not be changed at the next sample mismatch for the current ID. The deactivating is only valid for the current sample ID.

2.4.6 Temperature

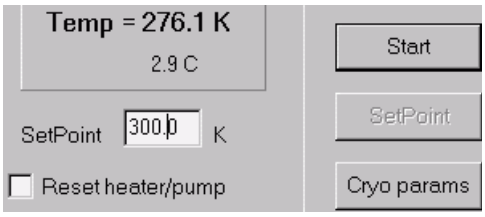
This software tool is meant to control the sample temperature and to setup the temperature controller. The supported options depend on the possibilities of the used controller. Not all options are possible with every temperature controller. The minimum and maximum temperature can be changed only by the Set_Conf program (I3.4).



After selecting this function, the actual sample temperature is measured and shown in Kelvin and Celsius. If the controller supports a vacuum measurement also the pressure in the sample chamber of the cryostat is shown in the temperature display window. Below that window the actual temperature set point and the actual control mode for the temperature controller is shown.

By the button 'Close' you go back to the previous menu.

Plot starts a permanent temperature measurement and a permanent actualized plot of the temperature versus time. There you get information about the buttons by its hints. A special flag for testing deactivates only here the repeat of temperature commands if an error occurs. If using 2 sensors both temperatures will be listed. The first value (TC or TempC) comes from the control sensor 1, the second (TS or TempS) from the sample sensor 2. Look in chapter 1.3.6 for information about the different temperatures. You can select showing sensor 1, 2 or both by the button 'Alternative plot'.



The **SetPoint** button opens an input field where the temperature set point can be changed.

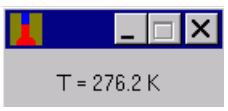
If activating '**Reset heater/pump**' then heater and pump will be newly initialized if setting the temperature by the 'Start' button. Normally this is not necessary. But some controllers like the Lakeshore switch off the heater after the sensor (cables) was disconnected. And they don't switch the heater automatically on after the sensor was connected. By this flag our software knows that it have to switch on the heater and, if available, to set the maximum heating rate. This input will not be saved.

After clicking onto the SetPoint button the Plot button changes to the Start button.

The **Start** button transfers the set point to the temperature controller and starts the temperature regulation. The temperature will be measured and viewed during its change to the set point temperature. Hereafter changes the Start button to Plot button again.

The **cryo parameters** button opens a new input window, see next chapter.

The flag **Temp in extra window** opens after closing the temperature control window a small permanent available window that gives every 5 s the current temperature of the sample.

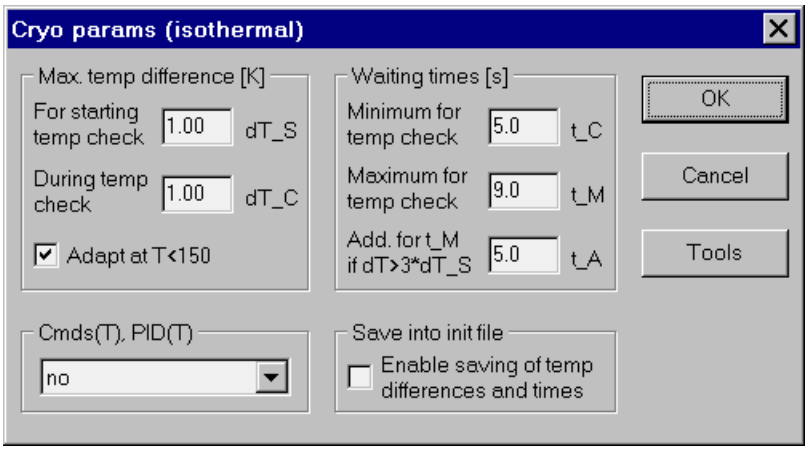


Note: If working with 2 sensors the temperature in this chapter comes from the control sensor 1. It will also be used for the regulation (ramp) as described in the next chapters.

2.4.6.1 Cryo parameters

At the isothermal program modules (Static, Transient, Isothermal) a new temperature will be set normally in one step, similar to a rectangular ramp. The following inputs define when the new measurement starts after a new temperature, that means how the program defines that a temperature is stable enough for the next measurement. These values are only for the isothermal measurements, for the temperature depending measurements there are separate ones and more possibilities.

Because the temperature setting at isothermal program modules use the same procedure as a boxcar (rectangular) temperature ramp, you find a description of the both top groups of parameters in chapter 2.4.6.2.1.
The both bottom parameters will be explained in 2.4.6.2.4.



By the **Tools** button you get a menu with some tools. For these you need user class 5 or higher, the possibilities depend also from the temperature controller:

PID parameters: The proportional, the Integral and the differential part of the regulation slope of the temperature controller can be defined.
Temp depend cmds: Definition of temperature depending commands transferred from the software to the temperature controller, only available if Cmds(T), PID(T) are used, see chapter 2.4.6.3.
Other parameters: Define LN2 and room temperature, give options if working with 2 cryo systems.
Send commands: Opens a command module to send commands or receive data from the temperature controller.
Load/init cryo file: Load the cryo file and initializes the controller.
List cryo status: Gives a list of the actual used parameters of the controller.
Temperature test: Test routines for testing temperature ramps or regulations.
Make/edit Tcal file: Create or edit a cryo/temperature calibration file Tcal_???.cfg.

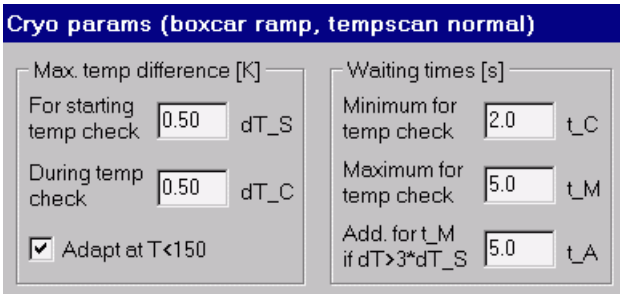
2.4.6.2 Cryo times and parameters for a ramp

This input module defines how the software and the cryostat with the temperature controller work together concerning the times for setting and regulating a new temperature.
At the following input windows the both top groups of parameters will be called here **Cryo parameters**. These parameters depend on the kind of temperature **ramp** (boxcar, linear controller, linear computer). Different sets of Cryo parameters exist for isothermal and tempscan (normal, slow, fast, very fast, ITS, init file) measurements.
The other general 4 inputs at the following input windows will be explained in 2.4.6.2.4.

2.4.6.2.1 Boxcar (rectangular) ramp

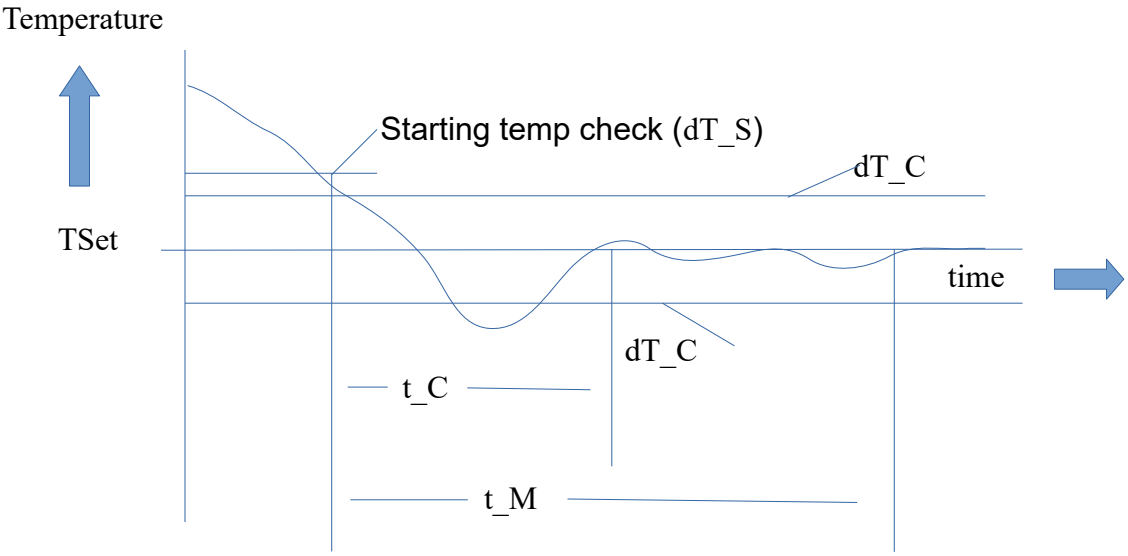
The inputs define when the new measurement starts after a new temperature, that means how the program defines that a temperature is stable enough for the next measurement.

Two temperature differences and three waiting times can be defined to check a correct temperature regulation and start a measurement at a stable temperature T close to the temperature set point TSet. Its meant as a synchronizing of the software with the cryostat for measurements at a fix stable temperature.



The **start cycle** for an isothermal measurement under respect of these parameters is:

1. After the definition of the kind of measurement, the measurement parameters and the measurement temperature T_S by the user and starting the measurement, the measurement cycle is started and the new temperature **set point TSet** is transferred to the temperature controller.
2. The temperature controller heats or cools the cryostat (and the sample) due to the set point temperature. During the cooling or heating the software measures continuously the actual temperature **T**.
3. When the **temperature difference dT** between the measured temperature T and the temperature set point TSet becomes smaller than the value **for starting temp check dT_S** the software starts the **temp**erature stability **check**.
4. During the temp check the software checks whether the temperature difference dT stays smaller than the value **during the temp check dT_C**. The check is at least done for a **time** given in **minimum for temp check t_C**. If dT < dT_C is always valid during t_C, the measurement is started.
5. If dT < dT_C is not fulfilled during the time t_C, the check procedure is continued till the time **maximum for temp check** t_M has been reached. After this waiting time the measurement is started even if dT is larger than dT_C.
6. If during the temp check it happens that dT > 3*dT_S, then the maximum time for check will be increased by **the additional waiting** time t_A.

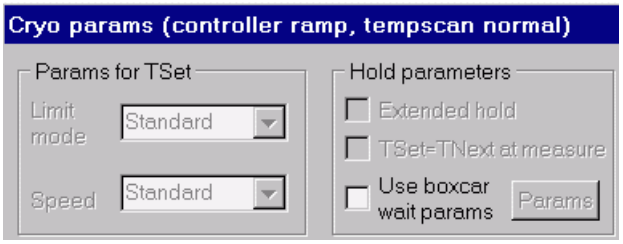


The flag **Adapt at T<150** reduces the given values for dT_S and dT_C with 1/T for temperatures below 150 K by the equation: dT' = dT * (0.3+0.7*T/150).

The times and temperature differences given in the input window above are for normal tempscan measurements. The times can go up to minutes if the cryostat is oscillating or very slowly. When the temperature don't reach its set point, optimize the PID parameter, increase dT_S or deactivate the flag above.

2.4.6.2.2 Linear ramp of controller

At the tempscan inputs you can define that the linear ramp will be stopped and the temperature will be hold before a measurement. In this case you can define how the software waits before a measurement starts. This waiting is the same as for the computer ramp, see next chapter.



2.4.6.2.3 Linear ramp of computer

The software emulates a linear controller ramp if using the computer ramp. It increases or decreases the temperature set point TSet of the controller in a loop to reach the temperature TNext where the next measurement should be done. Only very small temperature differences, normally 0.1 K, will be used in a given time, defined by the ramp rate. During the measurements no new set point will be set, so the temperature will be 'hold'.

While setting TSet in a loop 2 points will be considered:

- **TSet<TNext+TOfs** means that the set point of controller is always smaller as the next measurement temperature plus a temperature offset. If this can not be fulfilled the computer waits (called pause time) with setting new set point until next measurement was done.
  This point can be helpful if temperature runs too fast so that you have only less temperatures at which measurements will be done. But the controller must reach TNext+TOfs. Depending on your cryostat and controller this can be a problem if TOfs is too small. So some cryostats don't reach that temperature which was defined by the set point. Therefore we have introduced TOfs.
- **TSet<TGet+TOfs** means that the set point of controller is always smaller as the current temperature plus an offset temperature. If this can not be fulfilled the computer waits (called pause time) with setting a new set point. So the difference between TSet and the current temperature TGet is only small.
  This point can be helpful if there is a big difference between TSet and TGet. This can yield to regulation problems, so that the temperature oscillates. This point avoids this behavior but it can expand the time of the temperature ramp because the waiting.

TOfs in the equations above is the offset temperature, it will be calculated by the software. The 'smaller sign' is valid for increasing of temperatures, at decreasing it is a 'bigger sign' and TOfs will be used as a negative value.

The loop can be explained by following **simplification**:

For example it should be TGet=299.5K, TSet=299.5K, TNext=300K and TR=0.1K/s. Then first TSet will be set to 299.6K. The software waits then 1s before setting 299.7K. This will be repeated until 300K was reached.

In the practice the loop is more complex. So the 2 points above will be considered. TOfs will be calculated by the ramp rate TR. Additionally the 'pause time' will be limited by a time limit t_L calculated by TR:

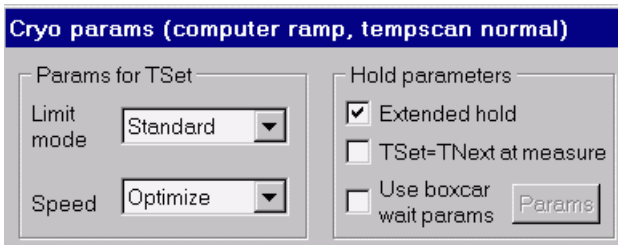
TOfs = 0.2+sqrt(TR), t_L = 1/TR, for example TOfs=0.5K and t_L=10s for TR=0.1K/s

This is also a simplification. All calculated parameters depend on the Cryo times, the ramp rate, the limit and speed mode and the limit level. The initial **limit level** will be defined by the limit mode. If the time limit will be exceeded too often then the limit level TL will be exceeded. A bigger limit level can yield to a bigger TOfs and t_L. This means that the control by the 2 points above is not so strong. The limit level TL goes from 0 to 16.

We can divide the working for one temperature point in 4 **phases**:

1. The set point TSet is not closed to TNext, for example the difference is bigger than 1K. Depending on the difference TNext-TSet, the set point TSet will be set in bigger steps, for example 0.2K, or in smaller times. This yields to a bigger effective ramp rate as defined. This will be done in a loop until TSet comes near to TNext.
2. TSet is closed to TNext. TSet will now be incremented resp. decremented in 0.1K steps. The time will be defined by the ramp rate or, if the flag 'Extended hold' is activated, in smaller rates. This phase will be finished when TGet reaches TNext. If a special flag is activated then TSet=TNext will be set at leaving this phase.
3. The software waits a fix time or as explained for the boxcar ramp.
4. The measurement will be done.

The left input group contains parameters for setting TSet.



The **Limit mode** defines the initial limit level which is important for controlling the temperature stability:

Standard: The software starts with the old saved limit level.

Adapt: The initial limit level is the minimum of old limit level and 5. The limit level can also be decremented at the measurement. Usually it should be the best one but it can cost time if the limit level oscillates in rare cases.

Fix start: The software starts with a fix limit level of 5. The advantage can be a reproducible behavior, disadvantages occur if a much higher limit level is necessary or a much smaller level is possible.

Tolerance: The start limit level is the maximum of old limit level and 11. The time limit t_L will be cut in half. This yields to more tolerance in the temperature stability.

The software can increment the limit level at all modes. After the complete measurement the current limit level - 1 will normally be saved as old limit level. So the software starts in the standard limit mode one level lower as the final level at the last measurement. The limit level will only be saved at leaving the software if the flag 'Save into init file' is activated, see chapter 2.4.6.2.4.

The **speed mode** defines the temperature steps and pause time in phase 1 and 2 and so the effective ramp rate:

Standard: The standard mode uses in phase 1 a higher speed. In phase 2 the temperature steps are 0.1K, the time will be defined directly by the ramp rate.

Optimize: The speed will be optimized, that means in phase 1 it is much higher as in phase 2. This should give the 'optimal' speed and a faster ramp but can reduce the temperature stability.

Fix: The fix ramp rate defines always the speed but a pause time is also possible. The temperature steps are always 0.1K.

High: Similar to 'optimize' but designed for a high speed ramp. The temperature stability may be here not so good.

The input group '**Hold parameters**' contains options how the temperature should be hold:

Extended hold reduces the speed at phase 2. That means if TGet is closed to TNext then the effective ramp rate is smaller than the defined ramp rate. Activate this option except you want a high speed.

TSet=TNext at measure means that if TNext was reached then the set point TSet will be set to TNext. This improves normally the temperature stability during the measurement because it is possible that TSet is 'faster' than TNext, especially at a big TOfs. But some cryostats have a problem with this feature because they don't reach that temperature which was defined by the set point.

If the temperature TNext was reached then the software exits the TSet loop and sets no new temperature set point, it 'holds' the current one. The software **waits** a time before the measurement can start. 2 kinds of waiting exist. The standard one is a simple wait procedure where the waiting time t_W depends on the ramp rate TR:

$t\_W = 0.2/TR$, for example, t_W=2s for TR=0.1K/s

If activating **Use boxcar wait params** then the software waits until the temperature is stable enough, similar to the check temperature procedure introduced in chapter 2.4.6.2.1. But now the software starts directly the temperature stability check (cycle point 4) and dT_C has only a meaning for t_A. The 'Params' button opens the input for these parameters which are the same as for the boxcar ramp.
If the measurements need a high temperature stability, for example for very sensitive or long measurements at one temperature, then you should activate this option. Define then strong criteria and long waiting times.

Summary: We prefer the computer ramp for the most applications. The default modes depend on the selected cryo times. The standard modes for the limit and speed mode are good compromises. The 'Optimize' mode should be the best speed mode, so it is the default one except for 'slow ' cryo times. There is 'Adapt' the default limit mode to get the highest temperature stability. Except for fast overview measurements the flag 'Extended hold' should be activated.
The temperature stability increases normally by activation of 'TSet=TNext at measure'. But some temperature controllers could have a problem with this option. So it is off by default, check this option with your cryostat. It is important!
'Use boxcar wait params' can be necessary for sensitive or very long measurements at one temperature. Here you should adapt manually these parameters.

The ramp rate input is not the effective rate but only a hint because the temperature will be hold during the measurement and, depending on the cryo times parameters, the software waits or uses temporary faster rates. In most cases the effective rate is smaller than the defined one.
A problem of the controller ramp can be a too small heating rate. Then the set point runs away while the current temperature hangs or is much smaller than the controller set point temperature. Finally the measurement will be finished before the measured temperature has reached his end point. The controller ramp don't wait except you have activated the hold option. The computer ramp avoids this problem because it holds always the temperature at the measurement.

Note: The quality of the temperature stability depends, also at the other ramp modes, from the cryostat, the controller, the selected PID parameters and from the ramp parameters as discussed. The predefined ramp parameters can not be optimize for all cryo systems. So you should adapt these parameters. The temperature test, see chapter 2.4.6.4, is here an important help. In chapter H3 of the Hardware Manual are tips for the PID parameters.

2.4.6.2.4 General cryo options

The cryo input window contains for all ramp modes and for all cryo times the same additional input groups.

Cmds(T), PID(T) enable temperature depending commands and/or PID parameters. This is only available if such commands exist. At some temperature controllers various maximum heating power can be set for different temperature ranges:

no: No such cmds will be used.

last block: Only the last temperature block of these cmds will be used for all others.

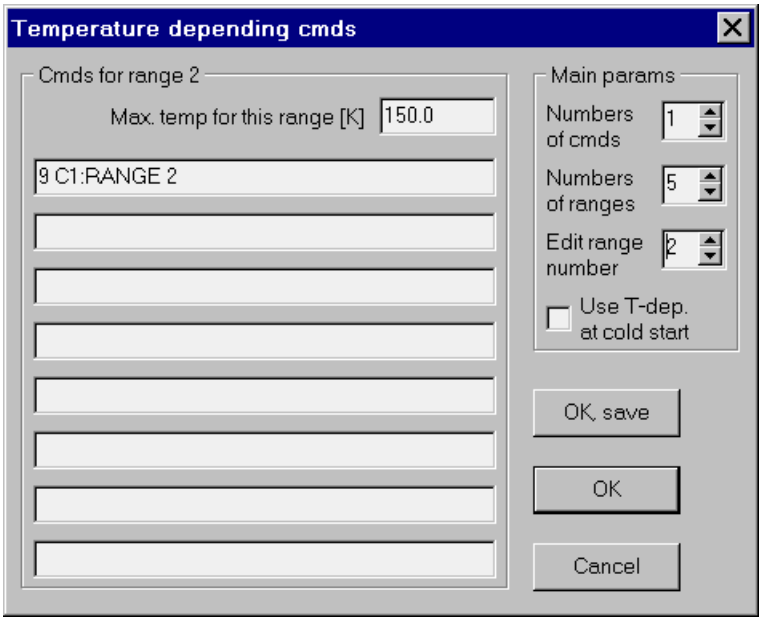
yes: For different temperatures ranges different cmds and/or different PID parameters will be used.

Save into init file means that all changes of the cryo parameters will be saved at program end into the init file of your selected configuration, normally hot start. In the other case are the changes only temporary, at program new start the old values will be loaded.

2.4.6.3 Temperature depending commands

At user class 5 here the definitions of temperature depending commands are possible. During a heating or cooling cycle the software now transfers all defined commands to the controller after the temperature has reached the temperature limit of the particular range. This can yield to a better (more stable) temperature regulation.

5 different temperature ranges can be defined. For each range the **maximum temperature** up to this range is valid and up to 8 different commands for the temperature controller can be defined, e.g. PID parameters, heating ranges etc.. An explanation of the syntax is in the file Cryo.Txt.
'Edit range number' defines the temperature range which is visible for editing.
By activating a flag these commands will be used also at a program cold start. A hot start will be defined by the 'Cmds(T),PID(T)' value.



OK stores the commands only in the memory. After a new program start the old commands are valid.
OK, save stores additionally the commands into the particular cryo init file.

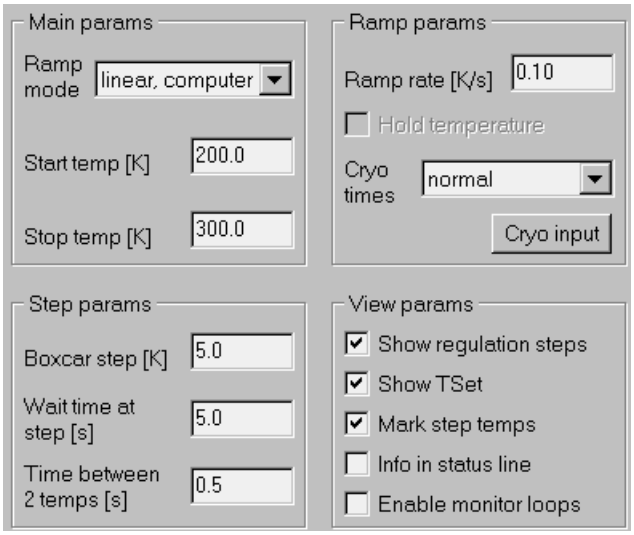
2.4.6.4 Temperature test

The quality of the temperature stability depends on the selected PID and ramp parameters. The default values can not be optimize for all cryo systems. So you should adapt these parameters. The following temperature test, available at user class 5, is here an important help. At a result you get a plot temperature versus time.

The inputs depend on the selected **ramp mode**:

Set stop temp, Set no temp, boxcar, linear controller, linear computer.

'Set stop temp' means the program sets the stop temperature and measures, for example, every 0.5s the temperature so that you can observe how the controller reach the stop temperature and how good the temperature stability is. 'Set no temp' means that the temperature will only be measured without setting a new set point. The other ramp modes are explained above. In all cases the measurement don't stop automatically after reaching the stop temperature, you have to do it manually. So you can check how stable the temperature is at the stop value.



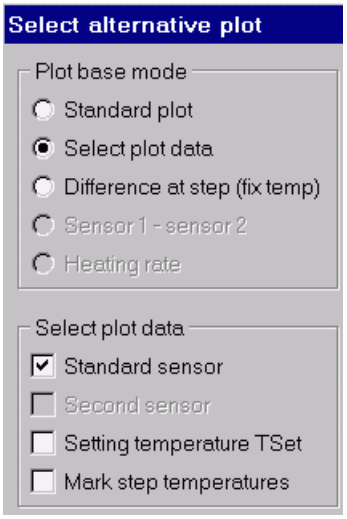
The right picture is for the computer ramp mode.
The software sets at the begin the temperature to the **start temperature**. You get an information window with the set point, the current temperature and the time after setting the temperature. Start the test measurement manually if the current temperature is stable enough and has reached the start temperature.
The reaching of the **stop temperature** stops the setting of a new set point.

The **boxcar step** corresponds to the delta temperature at a tempscan, there it is the temperature difference between 2 tempscan data points. You have to observe the temperature stability at these boxcar steps. The **wait time at step** defines how long the software stays on this temperature without setting a new set point. **Time between 2 temps** means the time interval of the temperature measurements.

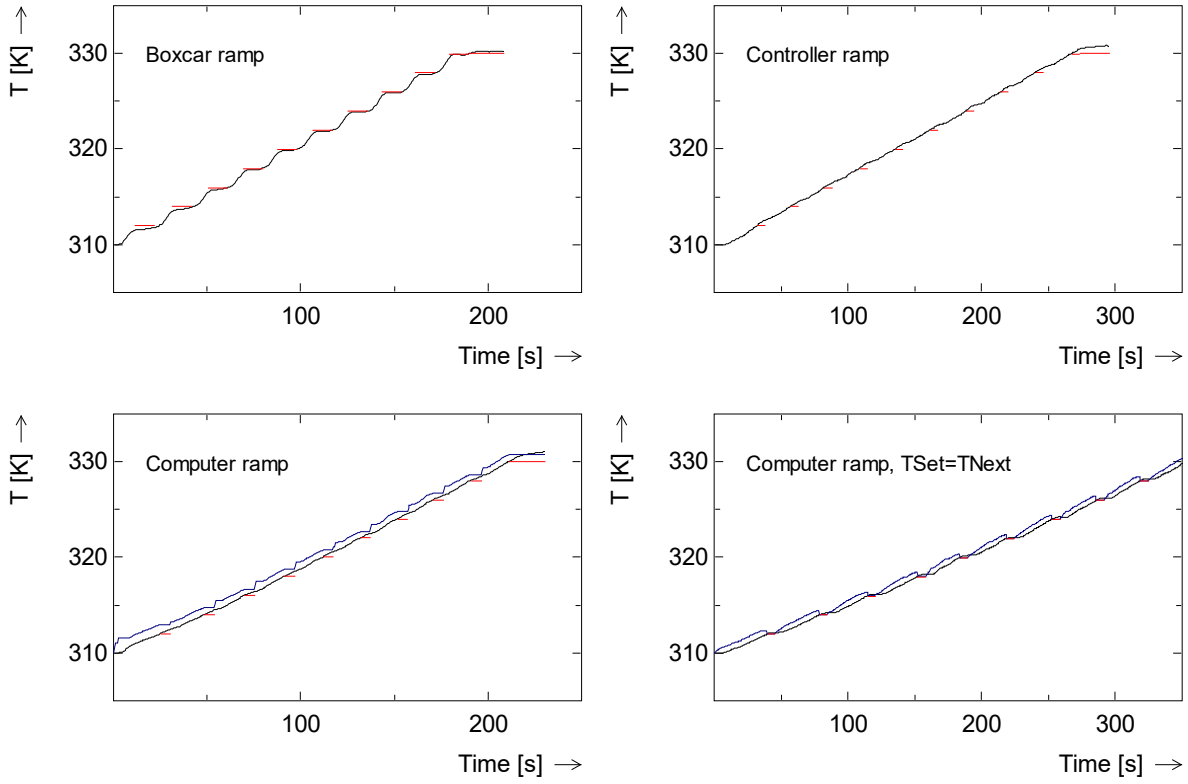
The **ramp params** as ramp rate and cryo times are already described above.
If activating **show regulation steps** then the temperature will not be measured only at the boxcar steps but also between these steps. **Show TSet** shows in the plot the temperature set points by a default blue line. **Mark steps temps** shows in the plot the boxcar temperature steps by a read line. You can also get some additional **info in status line**.

Tip: After cryostat installation adapt first the PID parameters, see chapter H3. Then make 4 temperature tests with the boxcar, controller and computer ramp; for the last make tests without and with 'TSet=TNext' (chapter 2.4.6.2.3). Use standard cryo times and a ramp rate of 0.1K/s. Select 8s wait time at step for the boxcar ramp, 5s for the other ramps. If necessary change the PID parameters and repeat the tests. Compare the 4 results and select then the best ramp mode for your measurements. If 'TSet=TNext' yields to better results you have to activate it for every cryo times. You can improve the temperature stability by optimizing the cryo parameters, this must be done for all cryo times.

After you have finished the measurement you get the standard plot. Yo can save it in the presentation plot program. Other plots are available when clicking onto the **alternative plot** button.
If using 2 sensors then the temperature of one or both sensors or the difference of both sensors can be plotted. You can mark the temperature steps and show TSet at the computer ramp.
The plot 'Difference at step' shows the temperature difference at the boxcar steps. For this the last temperature of each step will be subtracted from the other temperatures at this step. So you can check how stable the temperature is at these steps.
For a better overview here a special time axis will be used which separates all wait time at steps by 1s. If activating 'without fix hold wait time' then only points will be shown which relative time is bigger than 0.2/TR resp. (t_C+t_M)/2.



The following picture shows measurements for the 3 different ramp modes. The computer ramp was used without and with the flag 'TSet=TNext at measure'. The black lines represent the temperature measurements, the read lines the boxcar steps and the blue lines TSet at the computer ramp. The temperature should be nearly constant during the boxcar step (red line). It is not so important to reach here the exact (destination) temperature.
For the boxcar ramp (top left) you can estimate the wait time until a measurement should be started. The best results give here the computer ramp with 'TSet=TNext' (bottom right).
The 'hold command' don't work here fine at the controller ramp. An additional criterion is the effective ramp rate. This example is not representative for all cryostats and controllers! It gives you only a hint how you to use this tool.



Tip: You can also check the temperature stability of a tempscan measurement by the difference temperature before – after measurement, see chapter 3.4.4.6.

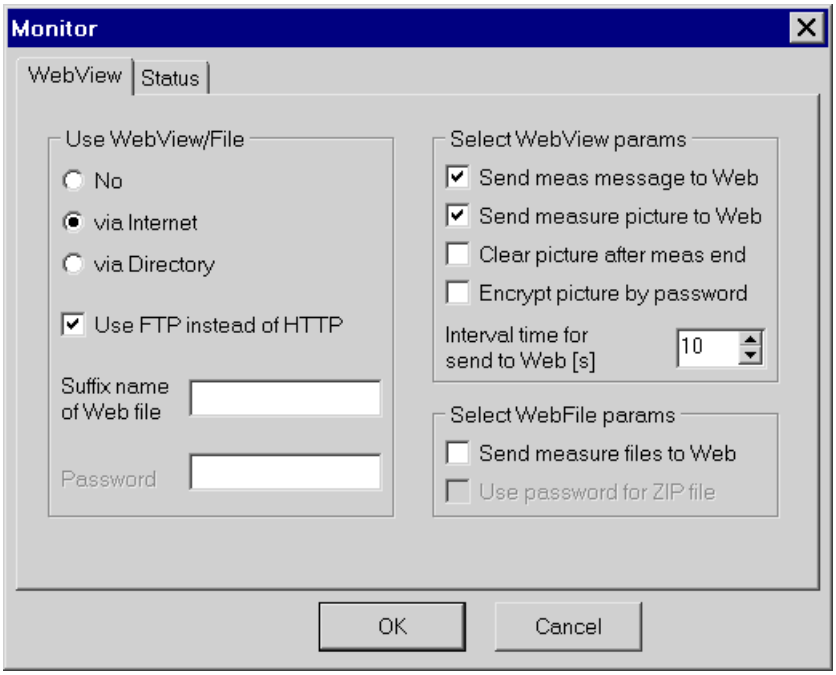
2.4.7 Monitor

The Monitor allows a WebView and monitoring of the measurement action. At user class 6 you get additional input sheets for checking the communication with the hardware and a Tool button for some diagnose tools. Extended diagnose tools are only available when calling the Monitor from the Utils menu of the Base tools. Be careful with the diagnose tools, especially the initialization of the measurement hardware and sending manually measurement commands.

2.4.7.1 WebView input sheet

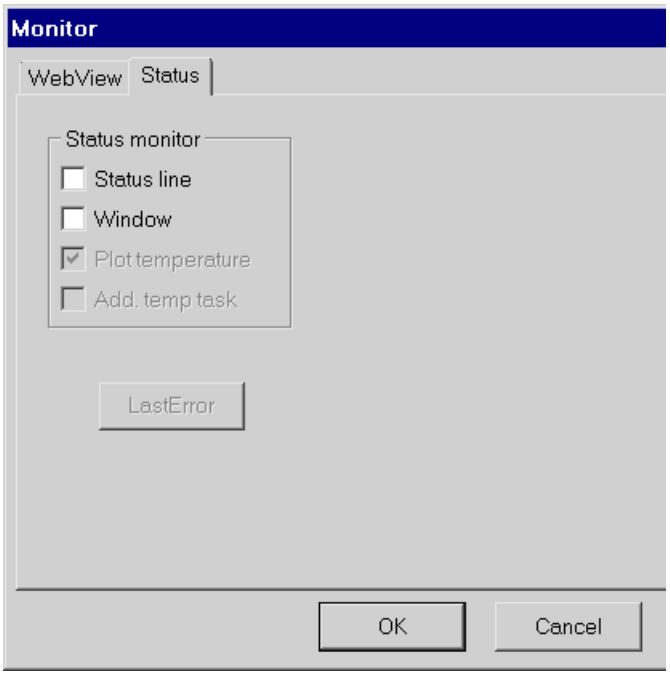
The **WebView** allows to monitor the measurement via internet or a network directory. This input sheet is only visible in the isothermal or tempscan measurement module. It is only for long temperature depending measurements. With this option a HTML file will be created at the end of measurement or, for example every10 s, with measure message or/and measure picture.
You can load your monitor HTML file by every browser or with the program **WebWatch** in the directory Dlts\Bin. You can copy this program to another computer and run there without installation. If you encrypt your measure pictures by a password you need the WebWatch program. This program can also poll in a time interval for the new monitor file, for example to get a message for the end of measurement.

At **Internet** the monitor file will be saved at a hidden directory on the PhysTech server. At **Directory** you can define a network directory for these files.
If you use FTP instead of HTTP for upload you must be sure that FTP is enabled on your computer.
By defining an additional **suffix** name of Web file nobody knows the complete name of your web file. You see the complete monitor file name at leaving this dialog in the status line.



You can also send all new files with measurement data to the Web or your directory. These files will be packed into one ZIP file. You can encrypt this file by a password. The name of the ZIP file is the same as for the Web file (you see it in the status line) but has the extension ZIP instead of HTM.

2.4.7.2 Status input sheet



The status monitor gives some information about the status of the measurement. You can show this information in the **status line** or/and in a separate **window**, see next picture.

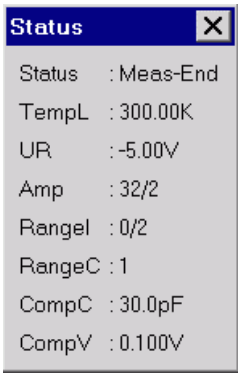
'**Plot temperature**' expands the status windows and plots the last temperatures. By activating **Additional temp task** the temperature will be measured every 5 s and updated in the status line or status window.

If an error has occurred then you can get information about this error by the **LastError** button.

By clicking onto the '**List status line**' you get a list of the last 100 texts shown in the status line.

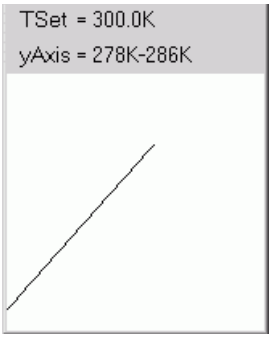
At user class 6 you can create a report file by the **Report** button and use an error monitor.

The following shows an example for the **Status window:**



Status denotes the current action, TempL shows the last measured temperature, UR the applied reverse bias voltage. Amp lists the actual amplification and only here behind a '/' the pre-amplifier. Usually the pre-amplifier will be listed together with the range, see chapter 3.2.3.1. The first value of RangeI is the actual current range. Except at I- and Q-DLTS the current amplifier will be switched off after the current measurement. This will be denoted as range 0. Therefore the last used real current range will be listed after a '/', in this example it is 2. RangeC the actual capacitance range, CompC the compensation capacitance and CompV the compensation voltage.

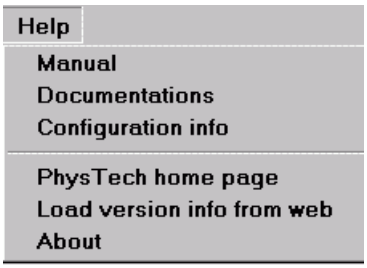
By activating 'Additional temp task' the current temperature will be shown and updated instead of the last temperature. The label is in this case 'Temp' instead of 'TempL'.



By the flag '**Plot temperature**' the last measured temperatures will be shown in a plot at the bottom of the Status window. The range of the x-axis is always 20s. The minimum and maximum values of the y-axis will be listed above the plot. These are the values of the white plot window and not of the black curve (data) inside of the plot.
The current temperature set point TSet will also be listed. If the temperature controller is not in the 'Set-Control' mode, for example at using the linear ramp of the controller, then the control mode will be shown here.

Note: The Status monitor shows only the temperatures of the first (control) sensor when using 2 temperature sensors.

2.5 Help menu



By the menu **Manual** the software manual will be opened at the page of the current program module.

At some help menus there is sometimes '**Manual for data**'. This opens the manual page for an explanation of the data or plot and not for the current program part, for example in the Standard Plot Program.

The **Configuration info** gives an overview about your software configuration. There you can also edit your user file, especially the maximum user class, see chapter 1.1.5.

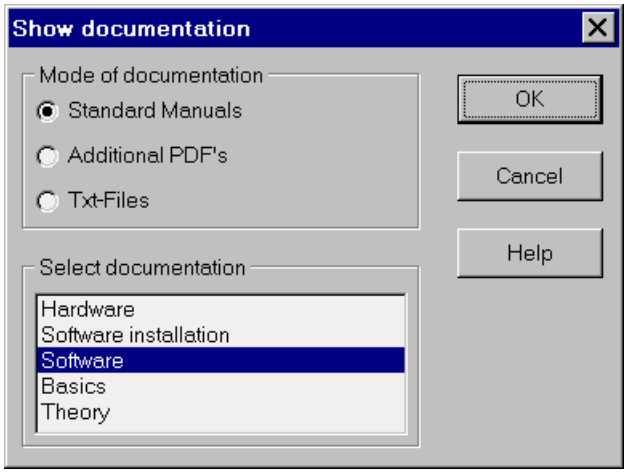
PhysTech home page opens the home page of PhysTech.

Load version info from web checks your version and the newest version at the PhysTech server.

About gives an information about your software version.

At **Documentations** you can select one of the 5 **Manuals** (Hardware, Software installation, Software, Basic, Theory) or additional important information or publications by **Additional PDF's.** In **Txt-Files** there are very special information about the software, for the normal user it is not important.

You need a **PDF viewer** for showing help files by the F1-key or Help-button (navigating to a defined page).
At the installation resp. SetUp Configuration program you can select between the Adobe Acrobat Reader, an ActiveX control of the Adobe Acrobat reader, the PDF viewer of your browser, the FoxitReader (Portable) or the SumatraPDF. For more details see chapter 3.2 of the Installation Manual.



Calling Manual in the Help menu or using the Help button or F1-key the PDF viewer opens normally the manual at a defined page. The Adobe reader saves internally your last opened page. If you start the Adobe reader again with the same defined page (same help point) it opens your old page. If you start with a new defined page (new help information) it opens the new page.

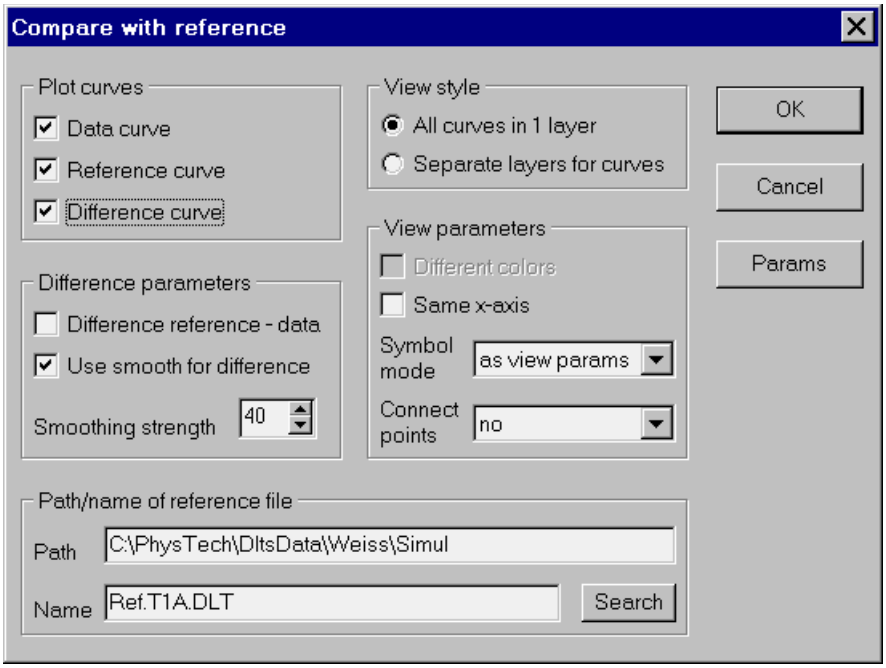
In the most menus and input windows you get help information by the **F1-key**. At some input windows there is a help button. It have the same function as the F1-key. You get help information by the F1-key also if there is no help button!
In some input windows you get by the F1-key different help information depending on the selected input group. For example if there is an input group for interpolation then you get the help text of chapter 2.7.1 if activating this input group and pressing the F1-key.
At many buttons and inputs you get a hint by moving the mouse to this position.

Note: All help and information files are in the sub directory Dlts\Sys\Doc.

2.6 Others

The following common functions come from the other menus Edit, List, Plot and Evaluate.

2.6.1 Compare reference



At the plot menu it is possible to compare the current data with a reference file. By the params button you can select the curve to compare, this depends on the program module. At the **plot curves** input group the curves for plotting will be selected: Data (current), reference or/and difference curve. **Difference parameters** are available if showing the difference. The difference will be formed by 'data – reference' or, if the flag is activated, by 'reference – data'.
If activating **Smooth** for difference then the data and the reference curve will be smoothed by splines for the forming of difference. The difference itself and the data and reference curve in the plot will not be smoothed by activating this flag! If data and reference curve have not the same x-axis then the x-axis will be interpolated to the x-axis of the data curve.

As **View styles** you can define to show all curves in one layer or to use for every curve a separate layer.

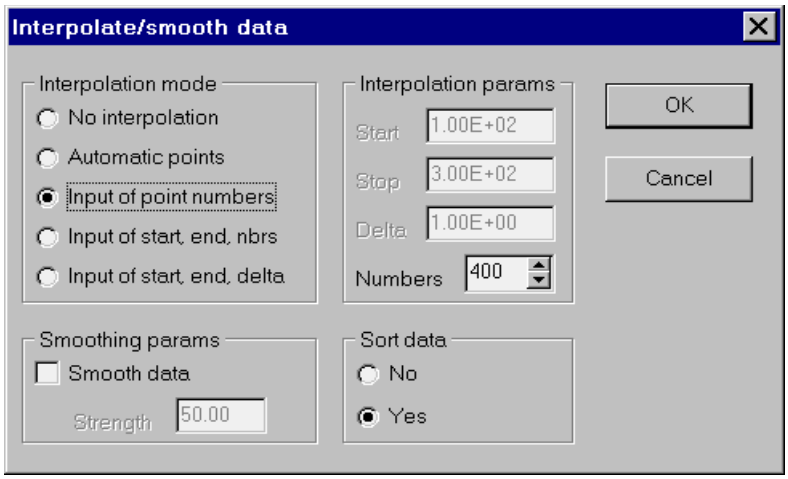
In **View parameters** you can activate to use different colors for every curve instead always the same if selecting separate layers.

For the symbols in the plots following **modes** are possible:

standard symbol: For all curves the standard symbol will be used.
as view params: The symbols will be set as defined for compare and difference symbols in the global plot parameters, see chapter 2.3.3.
as many curves: The symbols will be set as defined for curve 1 to 3 in the global plot parameters.
2 symbols, 1 line: The data curve uses the symbol for curve 1, the reference curve uses the symbol for curve 2, the difference curve will be shown by a line.
only lines: All curves will shown by lines.

Connect points will be explained in chapter 2.7.2.

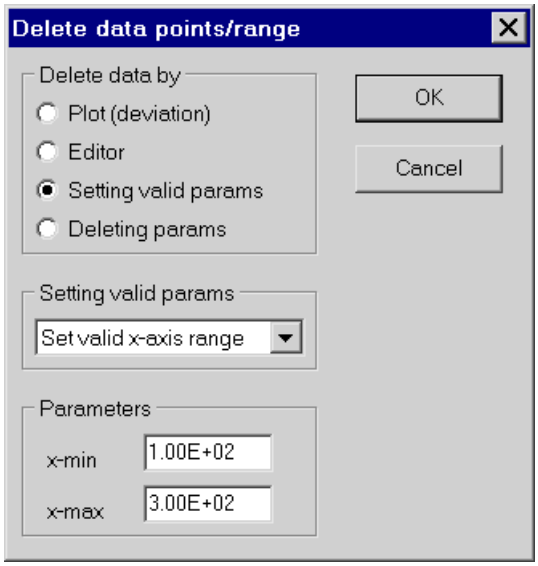
2.6.2 Approximation



In the Edit menu of some program modules there is at user class 5 the menu point Approximation. It means that all possible measurement data can be interpolated and/or smoothed. Smoothing will be made by splines, the input of strength is possible. Additionally the data can be sorted.
If activating interpolation then a new x-axis with equidistant steps will be calculated, following **interpolation modes** exist:

No interpolation: The data will not be interpolated.
Automatic points: Interpolation with automatic setting of interpolation points (new data numbers), see chapter 2.3.3.6.
Input of start, end, nbrs: For the interpolation you have to input the x-start and x-end value and the numbers of interpolation points.
Input of start, end, delta: For the interpolation you have to input the x-start, x-end and x-delta value.

2.6.3 Delete data



In the Edit menu of some program modules there is at user class 5 the menu point Delete data points/range. The data arrays/records will be internal in the memory modified, not in the file. This function deletes not only points of one curve but the full data record of the marked points. Not all functions are always possible.

Delete data by defines the base delete mode. The first both modes use x- and y-data. In 'Plot as y-axis' you must select the data (curve) for using as y-axis. This input depends on the current program module.

Following modes exist:

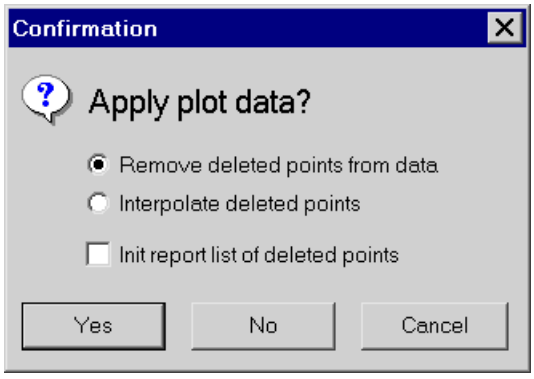
Plot (deviation): The x- and y- data will be shown in a special plot program in which you can delete one or more points by the mouse, see chapter 5.3.2.6.1.

Editor: The x- and y-data will be listed in a grid. In the menu Edit you can 'delete' a grid line. The line will not be really deleted in the grid but only marked as deleted by setting the x-axis value to -1E100, for more details look in chapter 5.4.1.2 You can also change there the values for the x-axis. A change of the y-values will not be applied.

Setting valid params: Only data with a given valid criterion will be applied. This criterion can be the last index, the index range or the x-axis range. Index mean the index of the data arrays, starting from 1 to numbers of data. The valid parameters will be defined in the Parameters input group.

Deleting params: Data will be deleted by given parameters. You can delete an index range, an x-axis range or not valid data. Not valid data for example are such data which x-values are -1E100. For a temperature as x-axis all x-values smaller than 2 are not valid.

If 'Plot' was selected as mode, you have to confirm the applying of the new data after leaving the special plot program.



By **Cancel** you stay in the plot program, by **No** you leave it without changing the data.

By **Yes** the new x-data will be applied. The data which has been marked as deleted will either be **removed** from the data arrays/records, or for these x-values new data will be **interpolated** over the valid points. The interpolation will be done for the old x-values, so that the x-axis remains. This option is not in all cases available.

'**Init report list of deleted points**' applies the current deleted points as new report list. If this flag is not activated, these points will be appended to the report list. This report list can be used for deleting the same points at new data, more details will be given in chapters 5.3.2.6.1 and 3.4.2.3.

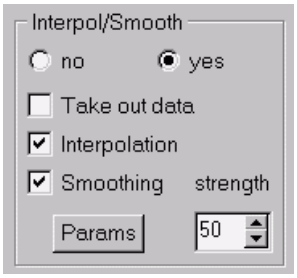
2.7 Common input parts

This chapter don't describe menu functions but only parts of input windows which will be used in some input windows.

2.7.1 Interpolation/Approximation

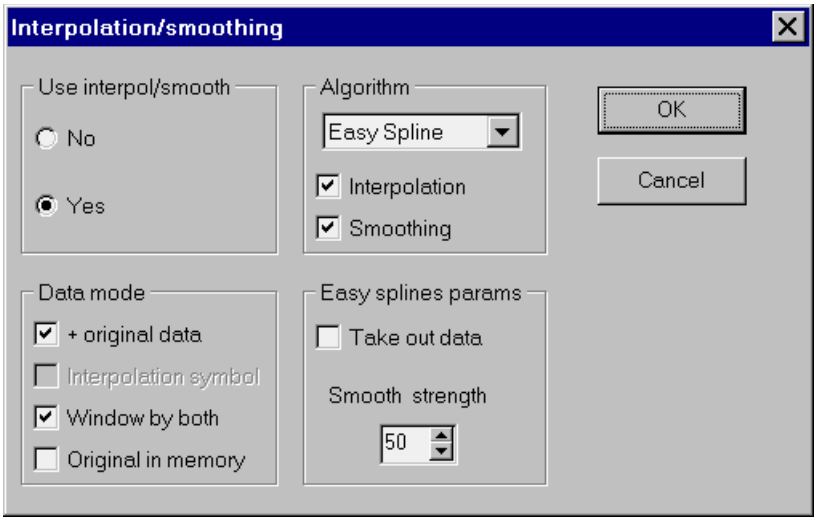
Interpolation means that additional data to the existing data will be created and shown in plots. In detail, at an interpolation a new x-axis will be defined with more than the existing x-values. The new x-axis contains equidistant x-values, the new y-values will be calculated from the original curve. The calculation will normally done by an interpolating and not approximating cubic splines. This means if a point of the new x-axis have the same value as the original curve then the calculated y-value has the same value as the original curve. The interpolation curve hits the original curve. The number of interpolation points will be defined in chapter 2.3.3.6.
By approximation (smoothing) the new curve don't hit the original curve. The y-values for the same x-values are different for the original and the approximated curve.

The standard input group for interpolation and approximation (smoothing) looks like:



Yes enables the interpolation and approximation. By activating **Interpolation** the plot data will be interpolated.
Smoothing activates the approximation of the curve. **Strength** defines how strong the smoothing is. 0 means no, 99 is maximal smoothing. A medium smoothing is 50, this is the default. The spline strength is normalized in respect to the x-axis data, so that same strengths have similar effects at different x-axis data.
If activating **Take out data** then not all original data will be used for the approximation. A special algorithm search 'bad' data. To simplify matters, if data points have a too big difference to the approximated data these data points will be neglected in calculation the smoothed data.

The input group below contains the main parameters, in some input windows these are the only inputs, in other inputs there is a **Params** button, which opens an input window with more possibilities, see picture below. In special cases, for example differentiation of data, there are only the inputs for smoothing.



In the **Data mode** input you can define if additionally to the new (interpolated/approximated) the **original data** should be shown. If using only the new curve you can select if the new curve has the plot symbol from the original curve or the special defined **interpolation plot symbol,** see chapter 2.3.3.1.
At activating **Window by both** the plot window will be calculated from the original and the new curve, in the other case only from the new curve.

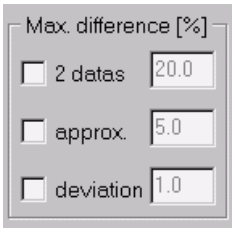
Original in memory means that the original curve instead the new curve will be used for further calculations, for example for applying into the Presentation Plot Program.

At the **Algorithm** you can activate interpolation and smoothing and select the algorithm:

Easy Spline:	Use natural cubic splines, inputs are easier and less as Splines.
Spline:	Use natural cubic splines, full inputs with strength as a real value.
Gauss:	Use a Gauss smooth with sigma as smoothing parameter, for the interpolation the Aitken or Lagrange interpolation will be used.
Polynomial:	Use a polynomial with the polynomial order as smoothing parameter, all points are smoothed.
Bezier:	Use Cubic or N Bezier curves for smoothing, all points are smoothed and interpolated. Cubic Bezier yields only to slight smoothing.

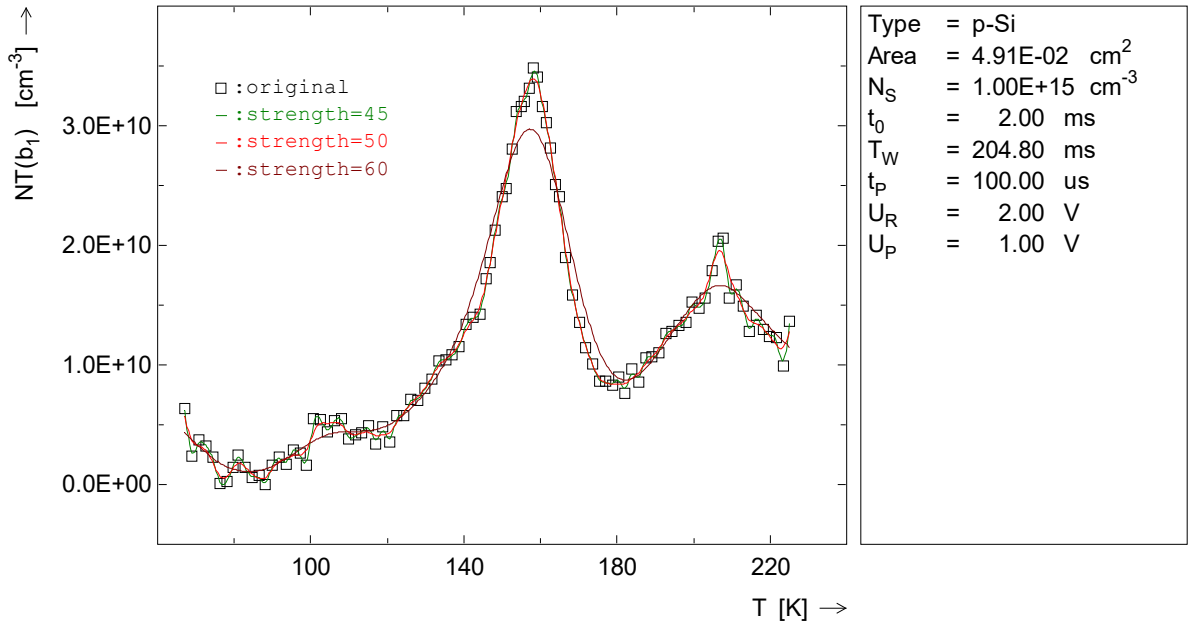
The next input group depends on the selected algorithm.
Strength defines how strong the smoothing is. 0 means no, 99 is maximal smoothing. A medium smoothing is 50.

If activating **Take out data** then not all original data will be used for the approximation.
You get at the right a new input window except Easy Spline was selected.
Here you can define the maximum differences for taking out data.
There are 3 checks. The checkbox activates the check.
2 data means the difference between 2 data in percentage.
Approx. means the difference of the original curve and the first approximation before taking out data.
Deviation means the difference of the first approximation before taking out data and a second approximation after taking out data.
The final approximation will be done by the original valid data which were not taken out.



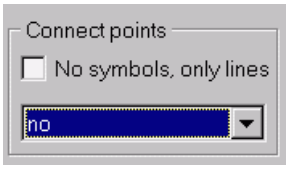
Note for tempscan: The smoothing of temperature curves is equivalent to the output filter of an analog DLTS system and allows comparison between our results and conventional analog systems. Smoothing is essential because it is not possible to avoid the output filter in an analog system.
The smoothing strength can be handled as different output filter time constants.
The anti-aliasing filter and the use of low frequency coefficients as b1 (digital filtered by Fourier transformation) have an effect only on the transient. There is no filtering of the temperature curve, if approximation/smoothing is switched off. This means every b1(T) point is independent from the other in opposite to the analog system. So it could be that analog DLTS temperature curves seems to be without noise or jumps because they were strongly filtered. For a comparison of a digital and analog system you have to smooth the digital temperatures curves in similar strength.

The following picture demonstrates the influence of the **smoothing strength**. The squares denote the original measurement data without smoothing. The lines are the by Splines interpolated and smoothed curves of these data. The smoothing strength are 45 (weak) for the green line, 50 (medium) for the red line and 60 (heavy) for the maroon line.
At strong smoothing the peak height increases, at overlapping of peaks also the peak position can change here.



2.7.2 Connect points

The plot uses the default plot symbol (chapter 2.3.2.1) or the symbols for curve (chapter 2.3.3.2) at plots with many curves. At some input windows there is the input group Connect points. It means that the points (symbols) can be connected by lines.



Following **connecting modes** are possible:

no:	The points (symbols) will not be connected by lines.
connect:	The points (symbols) will be connected by lines, no interpolation or approximation will be done.
connect + clip:	As above but the lines will be clipped. Clipping of lines means that if a point (symbol) is outside the plot window then the line will be drown to the plot window and at the window cut off. In the other case only the visible points inside the plot window will be directly connected.
interpol:	The points will be connected by interpolated lines. The interpolation for the connection line will be done by splines without smoothing.
interpol + clip:	As above but the lines will be clipped.
approx:	The points will be connected by interpolated smoothed lines. The interpolation will be done by splines with weak smoothing strength 45.
approx + clip:	As above but the lines will be clipped.
medium approx:	The points will be connected by interpolated smoothed lines. The interpolation will be done with medium smoothing strength 50.
medium + clip:	As above but the lines will be clipped.
cubic Bezier:	The points will be connected by interpolated slightly smoothed lines using cubic Bezier curves.

Activating the flag '**No symbols, only lines**' shows only the connection lines but not the symbols for the original data.

3. Measurement program modules

The five measurement program modules are Static, Transient, Isothermal, Tempscan and Equilibrium. They have a similar menu structure. The File, View, Tools and Help menus were already explained in chapter 2, also the common functions of the measurement menu.
In the following the menus Edit, List, Plot, Evaluate and the special functions of the Measure menu will be explained separately for every program module.
These menus depend on the kind of sample (Schottky diode or MIS capacitor), the selected transient evaluation (see chapter 2.4.4.2) and the user class. Especially the Edit menu gives much more possibilities at user class 5 and 6. In this chapter the menus for a Schottky diode with an exponential evaluation will be described up to user class 4.

The data during the measurement will be shown on the main canvas, after measurement or if you open a data file the standard plot resp. evaluation will be placed on this main canvas. On the main canvas there are no changes possible. By a click onto the button 'Plot Program' you see this plot in the plot program where you can change a lot of plot parameters and, depending on the kind of data, in some cases do a manual evaluation.

The **data** in the file contains a common file header and the measurement data array. The file header is similar for all measurement modules, the measurement data array are specific for the program module. At the list menu you see in 'File header' some main parameters of this header, see chapter 3.4.3.1 for an example. The sample parameters, also stored in the file header, will be shown in the sample parameters input window, see chapter 2.4.4.
The measurement data array of the static program contains the voltages and the capacitance resp. current values, the transient program contains the transient data points (capacitance, voltage, current, charge). The measurement data array of the tempscan and isothermal program contains a record for every temperature resp. x-axis data point. This record contains coefficients, equilibrium values and measurement parameters. A description of this record will be given later.
You can convert single curves or the complete file to ASCII data in the Edit menu 'Edit ASCII curve' or 'Edit ASCII file'. For this you need user class 5 or 6. You can also use the external program 'Convert data to ASCII'. You find it in your program folder.
A description of the data files and data structure will be given in Data.Txt.

The **temperature** will be measured before and after the measurement of a static curve or transient. The averaged value will then called temperature, Temp or 'T'; the temperature before will be called 'TB' in the software. Both values will be saved into the data file. The difference of temperature before and after measurement will be called TempD or 'TD'.
If the cryo system have 2 temperature sensors (see installation manual) the temperatures of both sensors will be measured before and after measurement. Then the values will be averaged. Sensor 1 is the control sensor for setting the temperature, sensor 2 for the sample temperature. The value of sensor 2 will be further called temperature and will be used for the plots and evaluations. The value of the control sensor 1 will be called TempC or 'TC' and will also be saved into the data file. The difference between sensor 2 – 1 will be called TempV or 'TV', see also chapter 1.3.6.
In the list menu 'Full data' you can see T, TD and TV. So you can check whether the temperature was stable enough during the measurement. The 'Equilibrium plots' in the plot menu of the isothermal and tempscan module allow to show the different temperatures

3.1 Static program

This module enables you to measure C/V or I/V curves on Schottky or p-n diodes or MIS capacitors at different temperatures. The data can be saved and the evaluation will give the shallow concentration, doping profile, oxide capacitance etc..
A C/V or I/V curve is measured by several 'single value' measurements under systematical variation of the voltage. 'Static' in this case means that the measurements are done slowly compared to any relaxation and emission processes of the sample (Schottky diode).

The first character of the data extension is 'K' for the static measurement files. The second data extension character (chapter1.3.3) denotes this **kind of measurement**:
B: C/V and G/V curves
C: C/V HF curve
D: Drain-Source I/V curve for FET
G: Conductance G/V curve.
I: I/V curve, Gate-Source I/V curve for FET
P: C/V pulse curve

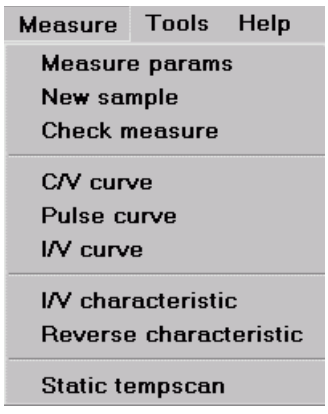
The voltage curves will be called C/V resp. I/V curves. The voltage in the equations will be denoted by a 'U', the reverse bias is UR. So V and U means the same. In our manuals no difference will be done between both notifications.

In the View menu at 'Params for standard plot' you can select whether the evaluation should be shown in the standard plot after measurement or reading data. The default value is 'auto'. It shows then the evaluation when the flag 'Evaluation plot' was activated at the measurement for the current data, see 'Other params' at chapter 3.1.1.1. If no evaluation is possible for such plot (data) then you get an error message at reading data, but it is no problem of the data file. In this case you should switch off the automatic evaluation.

The Static program module is not necessary for preparation measurements. For these you can make static measurements by the 'Check measure' menu of every measurement program module. There you can also save the C/V curve. Only the shallow doping concentration Ns is necessary for DLTS measurements.

3.1.1 Measure menu

The measurement menu contains the 3 common functions and the static measurements.

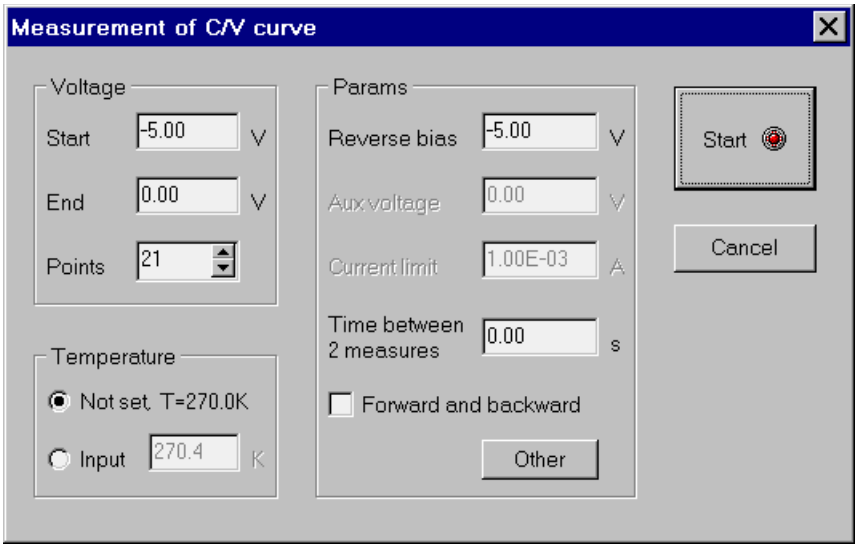


The input window for the different kinds of static measurements is always very similar, see next chapter.
Measurements of C/V and I/V curves can be made with more freedom for the voltage as the selection of the reverse bias. At the reverse bias should be the leakage current below 1 uA.
The pulse curve will normally be used for MIS samples, so the explanation is in the MIS chapter.
I/V characteristic is a separate measurement in forward and bias direction with evaluation of n-factor.
The Reverse characteristic combines C/V and I/V measurements in reverse bias direction.
If the bridge allows the conductance measurement, G/V curves can be measured.
Static curves can be measured at automatic variation of temperature (tempscan).

3.1.1.1 C/V curve

The C/V curve will be measured with a 1 MHz AC signal and will give you the so called HF curve. The main application of the measurement of a C/V curve is the calculation of the shallow concentration.

At the **Voltage** input box there are the **Start** and **End** voltage of the measurement and the number of **Points** per curve. The measurement direction (high to low or low to high voltages) and the voltage range (+-20V) are normally not limited. **Negative** voltages are reverse bias at n-type samples, **positive** voltages are reverse bias at p-type samples.



At the **Temperature** input box you can input a new temperature or apply the current temperature. In the first case a new set point will be set to the temperature controller, normally the program waits until the temperature is stable. In the second case (not set) no command will be send to the controller, the measurement starts immediately.

Following inputs are possible in the **Parameter** input box:

Reverse bias: This voltage is set to the sample after the C/V curve measurement has been finished.

Aux voltage: This input is only activated in special cases, for FET samples you can define here a second voltage, the Drain-Source voltage.

Current limit: This input is only available at current measurements. The current limit is a only a stop condition. The current will not be set but measured. So if the absolute measured current is higher than this value the measurement stops.

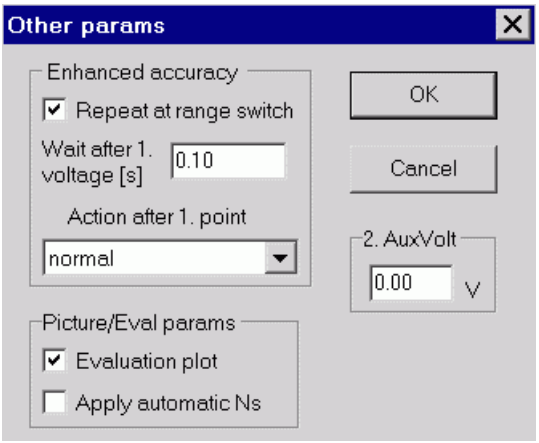
Time between 2 measurements: An additional waiting time between two data points can be defined to make the measurement slower, so that slow processes (e.g. oxide states) can be observed. The software waits between setting the voltage and the measurement.

Forward and backward: Enables a two direction measurement from Start to End and from End to Start voltage to check hysteresis effects (due to surface or oxide states).

The button **Start** starts the measurement cycle.
The button **Cancel** cancels the input window, all inputs are lost.

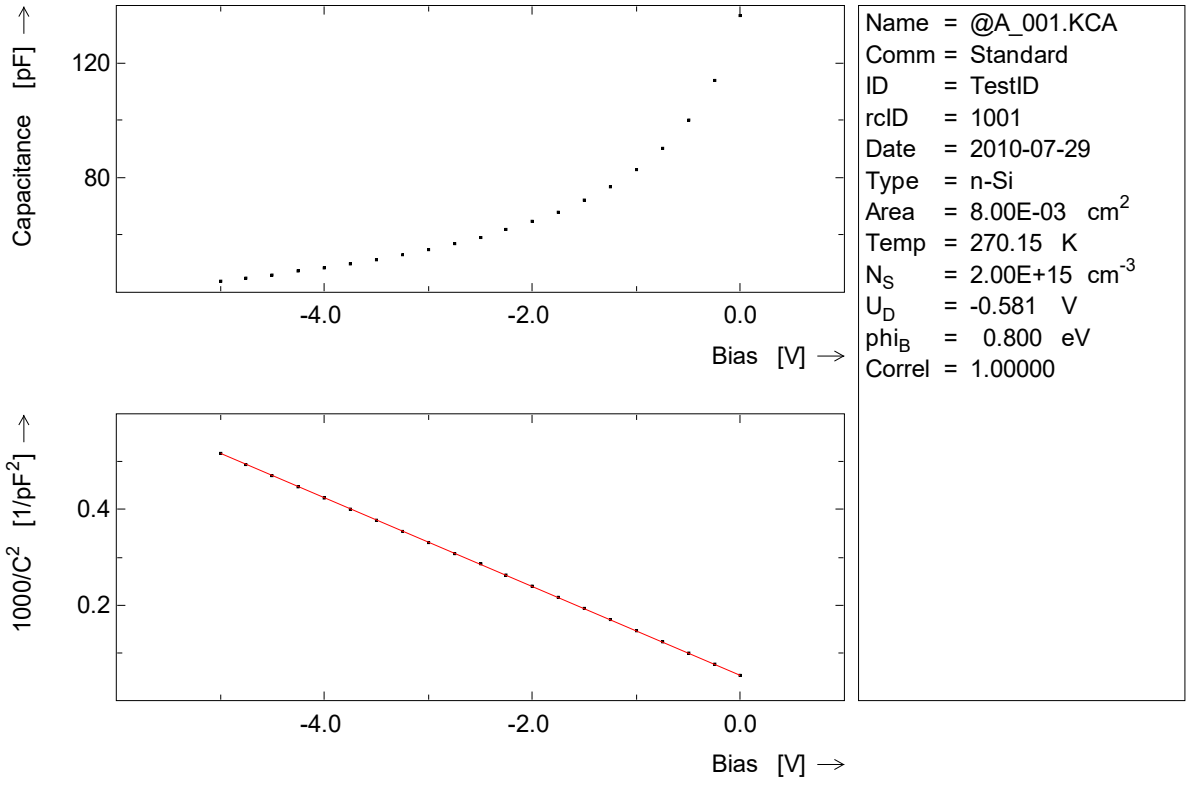
The button **Other** opens an additional input window: If using a second auxilary voltage for general purpose, the input of its value is here possible.

In the **Enhanced accuracy** group you can define that the measurement of a data point of the C/V will be repeated after switching the range.
An additional waiting time after setting the first voltage of a C/V curve is available.
You may define that no smaller range will be set during the full C/V curve after measurement of the first point. If selecting 'no higher sensitivity' additionally no higher amplification will be used.



Activating **Evaluation plot** shows automatically after the measurement and after reading C/V data a plot with the evaluation, in the case of C/V curve the 1000/C^2 plot, see next picture. Different flags exist for a C/V, I/V and HF-C/V-MIS evaluation. This flag is also important for the standard view and for the question for applying Ns at saving data. It will be saved into the file header, there it is specific for each file.

After a measurement or reading C/V data you see a **picture** with two plots on the main canvas. The upper plot shows the measured data, the second one (if required) gives the evaluated data, see equation 1.4 to 1.6 of Theory Manual. The text box at the right contains some sample parameters and the calculated data. The linear regression will be automatically made and the shallow doping concentration Ns calculated. Note that the accuracy of the result will depend upon the accuracy of the area of the device in the sample parameters menu. UD is the diffusion voltage and phiB the barrier height. Correl means the correlation factor for the linear regression line used for the evaluation. It is a quality factor for the linearity of the $1/C^2$ versus bias plot.



If the measured data are too noisy, change filter mode in 'Measure params', as described in chapter 2.1.2.2.

Apply automatic Ns defines whether the shallow doping concentration calculated from a C/V measurement is automatically saved into the sample parameters set or not. You can save it manually in the evaluate menu of plot program resp. 'check measurement', in the data tasks and after the measurement by the save question, see chapter 1.3.2.

The calculated **Ns** value from the 1/C^2 curve can be **applied** in several ways into the sample parameter set:

- **Automatic** if activating the flag 'Apply automatic Ns', see above. This flag can also be changed in the Program parameters, see chapter 2.4.2.2.
- At **saving data** after the measurement you get a question for it, see chapter 1.3.2. The flag is here only visible if an evaluation will be shown after the measurement (defined in the View menu) and if 'Apply automatic Ns' is deactivated, see above.
- In the **Evaluate menu** of the plot program or of 'check measurement' there is the item 'Apply as sample params'.
- You can activate this by the menu item '**Apply to EvalBank**' in the Evaluate of the plot program, chapter 5.1.5.3.
- In the **data tasks** menu by 'Apply sample params', see chapter 2.2.3.
- At the **new sample** procedure with C/V curve, see chapter 2.1.1.1.

Ns will also be listed in the text header of plots without a Ns calculation. Here Ns means its value from the sample parameter set. If an evaluation plot will be shown where Ns will be calculated, Ns is the newly calculated value. If this value will here not be automatically applied and this value differs from that one of the sample parameter set, then **N_{SP}** will be shown in the plot header. N_{SP} denotes Ns of the sample parameter set.

Tip: If you see N_{SP} then the Ns calculation was not applied and Ns differs from N_{SP}.

Note: If the both flags 'Apply automatic Ns' and 'Evaluation plot' are deactivated then you don't get after the measurement the question for applying Ns. If calling the evaluation from the menu then the Ns calculation will not be automatically applied. In this case you have to do it manually as described above.
After a C/V curve in the check measurement tool you don't get a question for saving data and for applying Ns. If 'Apply automatic Ns' is deactivated then you have to do it manually or to save the file by the data task item.
If the automatic Ns calculation is not accurate then don't save the data after the measurement but call the evaluation menu and correct it manually. Here you can save the data and apply Ns by the data task item.

3.1.1.2 I/V curve

The main application of measuring an I/V curve is either to check the leakage current in reverse bias or to estimate the ideality of the Schottky diode (n-factor) in forward voltage. In the next chapter you see on the left top an example for the first case, on the bottom one for the second case.
The **current limit** which can be set is only a stop condition and not a hardware limit. The hardware current limit is 10 mA. The C-meter will be automatically disconnected at current measurements.

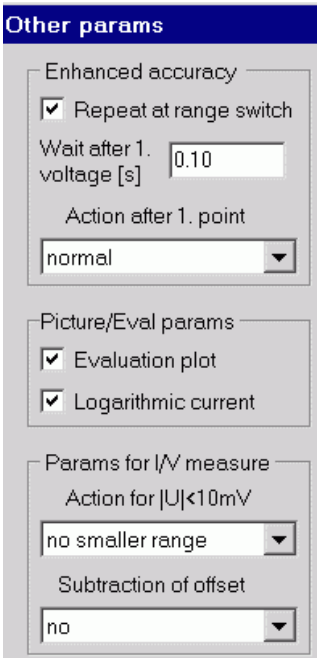
If you make measurements in forward direction and if you have activated 'Evaluation plot' at the other parameters then you get automatically an evaluation plot as the bottom right plot in the next chapter.

At the measurement you see as voltage axis **Bias***, this is the uncorrected Bias. After the full measurement the voltage will be corrected by the internal resistance and shown:

Bias = Bias* - Current * RB.

RB is the internal resistance of the bias source, normally 110 Ohm. For more information look in the Hardware Manual.
You can show the original I/V curve with the not corrected bias* axis in the plot menu. Select there 'Resistance plots → I % Bias*'.

Note: Don't wonder when the voltage axis is reduced at the final I/V plot.



The 'Other' button opens an input window similar as for C/V measurements.
Now you can select that the current will be shown in a logarithmic window.
Very small bias voltages may be a problem for the I/V curve because the current goes to zero and the smallest (most sensitive) current range may here be necessary. To avoid these range switches following actions for **voltages below 10mV** exist:

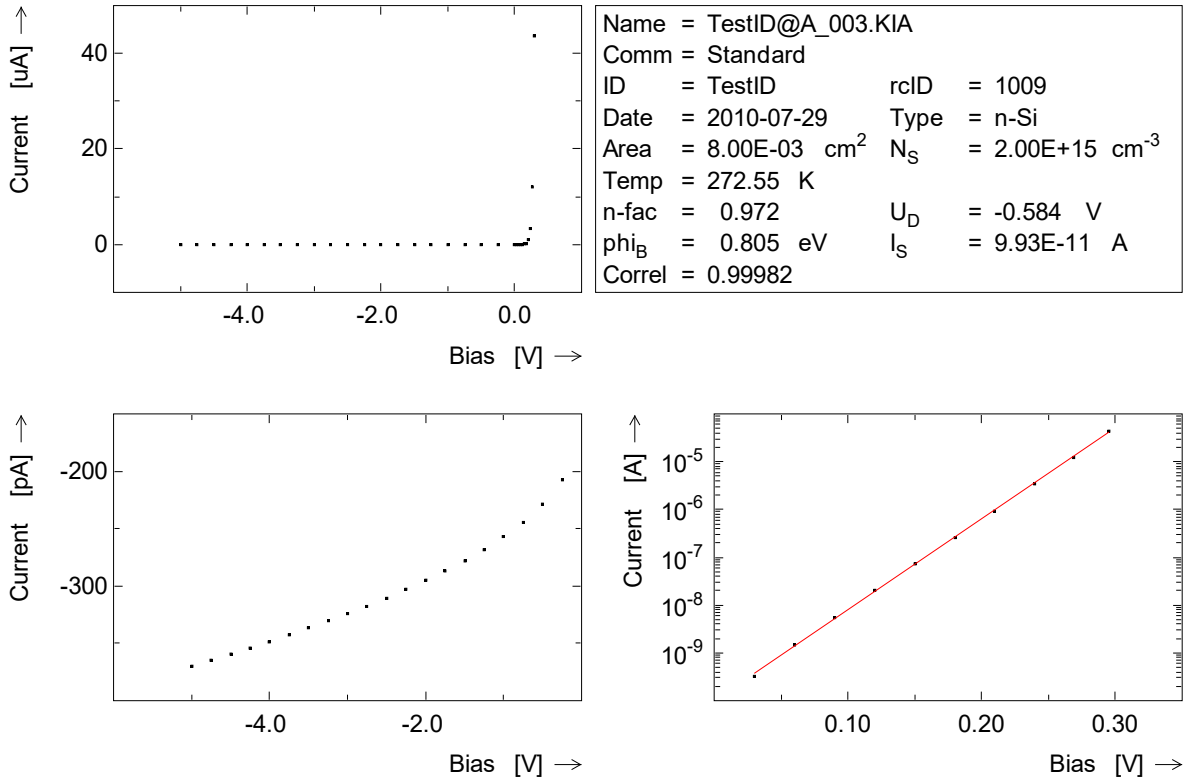
- **normal:** These voltages will be treated as all other voltages.
- **no smaller range:** No smaller current range will be set at these voltages.
- **no higher sensitivity:** Additionally no higher amplification will here be set.
- **avoid these voltages:** No measurement will be done for absolute voltages below 10mV.

The hardware and software offset of the current measurement is usually calibrated. But it may be possible that it is not accurate enough at very small currents. So it is here possible to **subtract the offset** of the I/V curve:

- **no:** No special subtraction will be done.
- **measure at 0V:** An additional measurement at 0V will done and this current will be subtracted from all I/V data points.
- **inter/extra-polate:**The current at 0V will be calculated from the I/V curve and then subtrated from all measured current values.

3.1.1.3 I/V characteristic

This measurement mode combines the two main applications of the I/V curve, see 3.1.1.2. So you have to define that the end voltage is in forward direction. The measurement goes from reverse to forward direction. The defined numbers of points N is only for the reverse direction. In the forward direction additional N/2 data points will be measured. Reverse and forward direction will be defined by the n- or p-type doping in the sample parameters.



The top left plot shows all measurement data, in reverse and forward voltage direction, the bottom left only in reverse direction (n-type sample). The bottom right plot is the evaluation plot in forward direction. The current data are logarithmic, from the slope of the linear regression you get the ideality of the Schottky diode, called n-factor, from the intersection you get the **saturation current** IS. From IS you can calculate the barrier height phiB and the diffusion voltage UD, see equations 1.15 to 1.20. A value as close as possible to one should be aimed for the n-factor.

3.1.1.4 C/V and G/V curves

The CGI-Meter FT-1235 allows to measure the capacitance C and the conductance G. C/V and G/V curves can be measured at the menu entry 'C/V and G/V curve'. In its input window is now an additional input box. You can measure only the C/V or G/V curve or C/V and G/V curves together by defining '**Conduct. measure**':

No, only C:	Only the capacitance C will be measured.
Yes, only G:	Only the conductance G will be measured but not the capacitance C.
C+G: together:	C and G will be measured together. At one voltage first C then G will be measured. Then the voltage will be increased.
C,G: 2 cycles:	First the complete C/V curve will be measured, then the complete G/V curve.
I' = Gp*U:	G will be measured and the 'current' G*U will be shown in the plot.

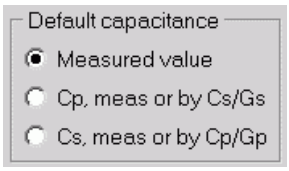
When measuring C/V and G/V both curves will be saved into one data file. This data file will be treated as a C/V curve for the standard plots and evaluations, but additional plots and evaluations exist. The capacitance can be Cs or Cp, see below. In the Edit menu it is possible to restore this data in a C/V data file.

Following is valid for the **simulation**: The simulated conductance is Gp which will be calculated by Cs and Gs, the sample thickness is necessary for Gs. The simulated static capacitance is Cs and not Cp as at a real measurement. The exception is the mode 'C+G together'. Here Cp will be calculated by Cs (equ. 1.1 of Theory Manual) and Gs.

The bridge measures always the parallel capacitance Cp and, if available, the parallel conductance Gp. If you have both values, you can calculate the series capacitance Cs, the series capacitance Gs and the quality Q. The resistance Rp resp. Rs is the inverse of Gp resp. Gs. When Rs is small (Q is much bigger than 1), the measured capacitance Cp is equal to the real sample capacitance Cs. In the other case the measured capacitance differs from Cs. For more details look in chapter H5 of the Hardware Manual or in the Boonton 7200 manual.

Tip: Measure C/V and G/V curve and check the quality Q. Values of Q<1 can yield to errors and problems at DLTS measurements.

The 'Other' button opens an additional input window as described before but when measuring CV and G/V curves there is the additional input for the '**Default capacitance**':

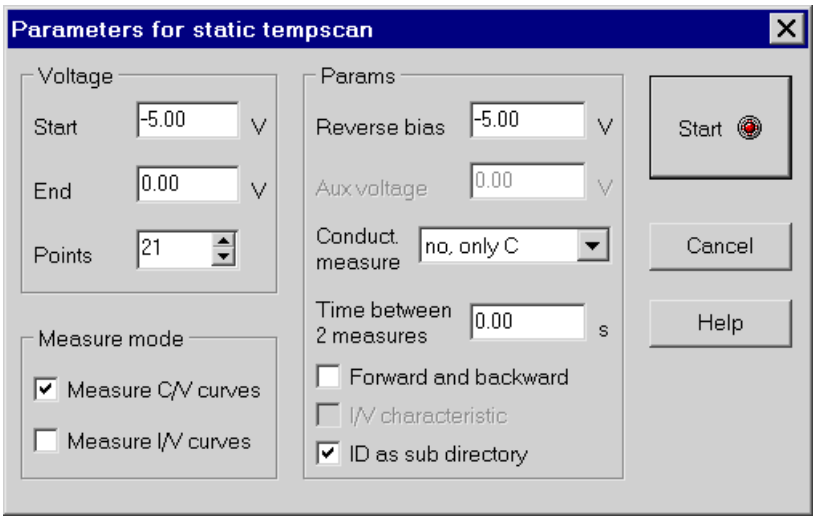


- **Measured value:** For all plots and evaluations the measured capacitance will be used, except there is a special selection for the capacitance. The FT-1235 and the Boonton 7200 measures Cp. At the Keysight 4980A you can select between Cp and Cs.
- **Cp, meas or by Cs/Gs:** The parallel capacitance Cp will be shown, either measured or calculated. The FT-1235 measures Cp, so it is the same mode as before.
- **Cs, meas or by Cp/Gp:** For all plots and evaluations the series capacitance Cs will be used. It will be calculated by the measured values Cp and Gp for the FT-1235.

This input is also possible at 'Params for standard plot' in the View menu. This input is also valid for the C/V curves in the 'Define menu' of the sub program 'Static Temperature Evaluations', see chapter 4.4.

3.1.1.5 Static tempscan

Static curves can be measured at automatic variation of the temperature.



You can measure C/V, I/V or both curves.
The other inputs are similar to that one in chapter 3.1.1.1.
So you have to define the **Start** and **End** voltage of the measurement and the number of **Points** per curve. Activating 'I/V characteristic' measure I/V curves as in chapter 3.1.1.4 described.

If the capacitance bridge allows the measurement of the conductance G then the input of the kind of **G measurement** is available as explained in the previous chapter.

The input 'Probe variation' is only visible at using the sample switch box, chapter 6.5.5.3.

After clicking 'OK' a start window opens similar to that one of chapter 3.4.1.4.

If activating '**ID as sub directory**' then the static files will be saved into a sub directory with the sample ID as directory name, as selected it for the automatic file name, described in chapter 2.4.5. It is only enabled if there 'ID as file name' was selected.
If this flag is not activated then in opposite to the measurements of static curves together with tempscan files here the static files will be saved directly in the given directory without a new sub directory.

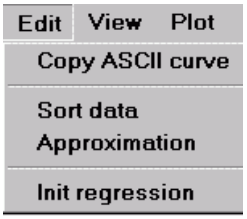
In the following example with 15 temperature data points is the base file name input ID@A_00T001.KCA.DLT. The sub string 'T001' is a must.

Created files:ID@A_00T001.KCA.DLT → C/V curve at 1. temperature
ID@A_00T002.KCA.DLT → C/V curve at 2. temperature
….....
ID@A_00T015.KCA.DLT → C/V curve at 15. temperature

Note: Usually temperature depending C/V curves will not be separately measured in the static program but during the tempscan, see chapter 3.4.1.1.7. There is an automatic creation of the QC?-file and an automatic restoring of the tempscan files(s) possible. Use the separate C/V measurements if these would affect the transients.

3.1.2 Edit menu

By the edit menu it is possible to edit and modify the data in the memory. The file itself will not be changed. After reading the file again you lose the changes. For changes of the file you have to save the file, here you get a question for overwriting.



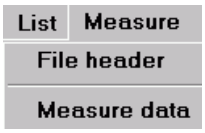
Copy ASCII curve copies the voltage and the capacitance resp. current data line by line in an ASCII format to the clipboard. You can define the delimiter and the exponential format in the menu ASCII parameters. You find it in Tools of the plot or list program.
Sort data sorts the data by the voltage, normally not necessary.
Approximation was already explained in chapter 2.6.2.
Init regression deletes the old regression, for example used by the 1000/C^2 curve, and calculates the regression again by a new evaluation plot. This can be helpful if you have set the regression range manually. If you change data, for example by deleting, then the regression will be automatically initialized.

At user class 5 here are: Edit ASCII curve, Simulate, Delete data (see chapter 2.6.3). If measured forward and backward you can select in Edit tools one of this branch. When measuring C/V and G/V curves in one data file, you can make a standard C/V data file from these both curves. This can contain either the measured Cp or the calculated Cs, see chapter 3.1.1.4.

At **user class 6** here are: Edit ASCII file, Edit curve by plot, Paste ASCII curve, Edit Tools. Edit ASCII file means that the complete file will be shown in an ASCII editor, here you can edit all data (header and data arrays). After leaving the editor the changes will be applied for the memory data but not for the file itself. Use this option very careful because there is no data check. You find a description of the data structure in the file Data.Txt. You can use also the program **DataConv** for converting one or more binary data files into ASCII files. You find it, called 'Convert data to ASCII', in your Dlts\Tools program folder. A description of the data structure will be given in Data.Txt.

3.1.3 List menu

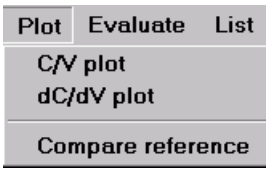
By the list menu it is possible to list the file header and the measure data.



A similar list of the file header will be shown in chapter 3.4.3.1.
The measure data will be listed as lines and columns. In the first line there is the first voltage and capacitance resp. current and so on. Three kinds of view here are possible: the data grid, the image without and with header and the ASCII editor, for more details see chapter 5.4.

At **user class 5** exist a list of a manual scan if the contact string (sample parameters, see chapter 2.4.4) has 2 characters.

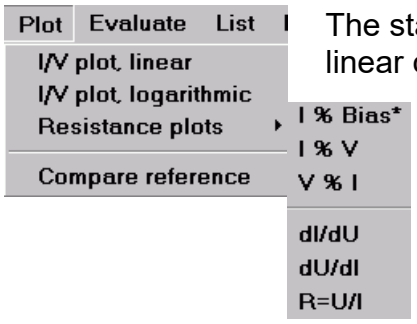
3.1.4 Plot menu



C/V plot shows the standard C/V curve without evaluation.
dC/dU is the deviation of the capacitance by the voltage. The data can be smoothed before the deviation.
Compare reference compares the current data with a reference file, see chapter 2.6.1.
'Conductance plots is visible' when the data file contains a G/V curve.
If the static file comes from a data set with many files then here is a menu entry to read and plot the different curves as described in chapter 5.1.7. See in chapter 2.4.5 for defining manually a set of temp variations. The various files of current measurement have different x-axis because the voltages will be corrected by the internal resistance, but it is possible to reduce all curves to the same x-axis.

At **user class 5** and a contact string length of 2, then a plot of a manual scan is possible.

The plot menu has a little bit other face for **I/V curves**.



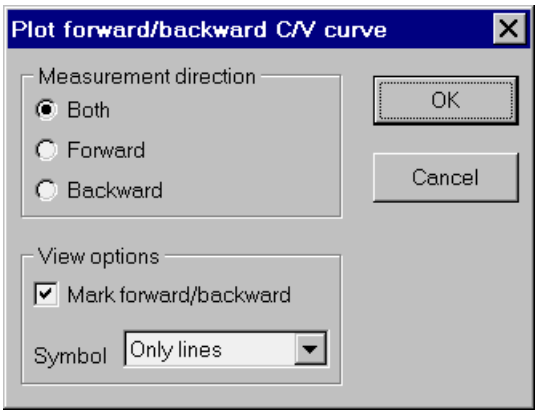
The standard I/V curve without evaluation can be shown with a linear or logarithmic current axis.

The resistance plot shows the I/Bias* (chapter 3.1.1.2), I/V or V/I curve, the deviation dI/dU or dU/dI, or the resistance without deviation R=U/I. For the last 3 possibilities you can select a linear, an absolute or logarithmic y-axis. 'Linear' means data with sign, 'absolute' means a linear axis with absolute y-values. Absolute y-values will be formed for the logarithmic axis.
The data can be smoothed before deviation. Be careful with the interpretation of the first and last point of a deviation. Because the left resp. right point is missing for the deviation, the edge points can show artefacts.

Note: The current versus voltage curve will be called I/V curve. The voltage in the equations will be denoted by a 'U', the reverse bias is UR. So V and U means the same. In our manuals no difference will be done between both notifications.

3.1.4.1 C/V plot

A special input window exist for the C/V plots if measuring in forward and backward direction. Forward means here the first measurement, backward the second measurement branch. It don't denote the voltage direction.



Here you can select the **measurement direction**:

Both: Plots all data.
Forward: Plots only the first direction.
Backward: Plots only the second direction.

If selecting both directions then you can **mark** the forward and backward direction by using separate colors for the different directions. The forward (first) direction uses the color for curve 1 (usually black), the second direction uses the color for curve 2, see chapter 2.3.3.1.
The voltage direction will be explained by arrows. So '→' means from smaller to bigger voltages, '←' means the opposite. The first (forward) measurement direction will be explained in the first line, the backward direction in the second line.

You can also select the **symbol** for both directions:

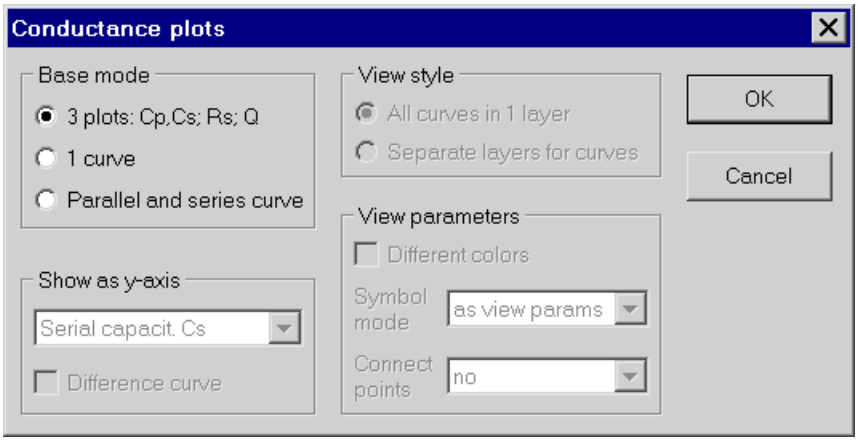
Standard symbol: The standard symbol, usually the 3x3 points will be used for both directions:
Connect by lines: As above but the symbols will be connected by lines.
Only lines: The data points will only be connected by lines.
Lines and points: The first direction will be shown by lines, the second by points.

3.1.4.2 Conductance plots

When the data file contains only a G/V curve, this curve will be shown without any inputs. If it contains a C/V and a G/V curve then the following input window appears.

The **base mode** defines the kind of plot:

3 plots: Cp,Cs; Rs, Q:
This standard plot shows in one plot window (layer) the parallel and series capacitances Cp and Cs, in the second plot the series resistance Rs and in the third plot the quality Q. This plot will be shown as standard plot after measuring or reading data when the flag 'Evaluation plot' is not activated, see other input window of chapter 3.1.1.1

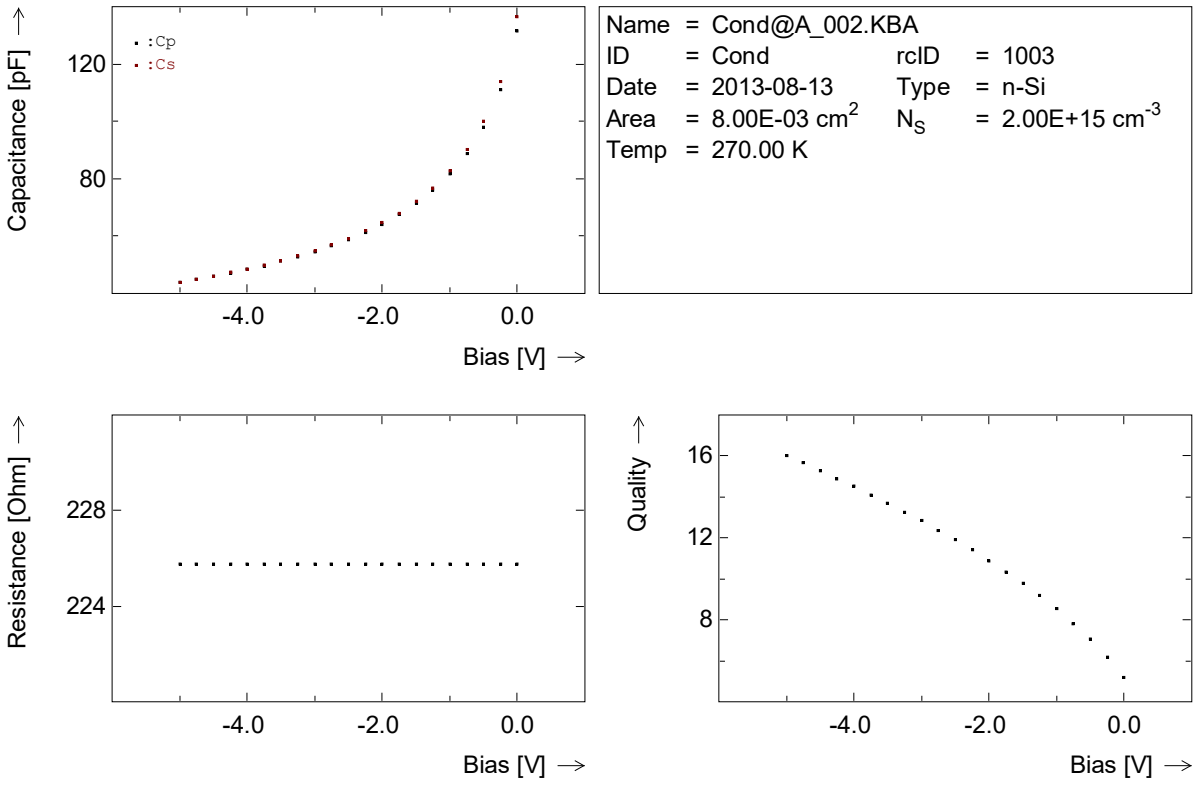


The base mode **'1 curve'** has following possibilities where an explanation of the curves will be given in chapter 3.1.1.4:

1. Parallel capacitance Cp (measured)
2. Series capacitance Cs
3. Parallel conductance Gp (measured)
4. Series conductance Gs
5. Parallel resistance Rp
6. Series resistance Rs
7. Quality
8. 1/Quality
9. Cs/Cp

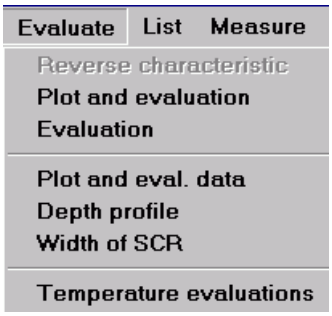
The base mode '**Parallel and series curves**' shows both curves of capacitance (Cp,Cs), conductance (Gp,Gs) or resistance (Rp,Rs). Optionally the difference of both curves can be shown. The curves can be plotted one layer or in separate layers.

The following picture shows the standard conductance plot of a simulation. The sample thickness was set to 10mm because the quality should not too good with the parameters of chapter 3.1.1.1. The simulation mode 'C+G together' was selected, therefor Rs is constant.



3.1.5 Evaluate menu

The possibilities of the evaluation depend on the kind of sample (Schottky diode or MIS capacitor) and the measurement. The following menu will be shown for a Schottky diode and C/V measurement.



Reverse characteristic is only enabled if C/V and I/V curve exist. Plot and evaluation shows the standard picture as in 3.1.1.1, see there for **applying Ns**. Evaluation shows only the 1000/C^2 plot. At user class 5 you can here select the capacitance mode, for example the C0-correction as explained in chapter 2.4.4.2. Plot with eval. data shows the C/V curves and lists in the text header additional evaluation data like the maximum width of space charge region.

Depth profile will be explained below. Width of SCR shows the depletion width versus V. Temperature evaluations are the evaluations of C/V or I/V curves at many temperatures. The results will be saved into an equilibrium files, a description will be given in chapter 4.4.

If measured **forward/backward** you can select the direction for the evaluation curve. The C/V curve shows here always both directions. For the C/V curve of 'Plot and evaluation' you can select the symbol and mark the direction. Its style will also be used for the standard plot on the main canvas. The inputs are similar as explained in chapter 3.1.4.1.

3.1.5.1 Depth profile

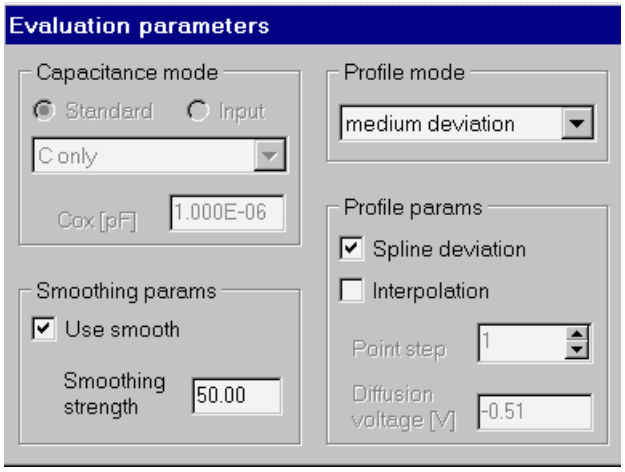
The depth profile shows the distribution of the shallow concentration Ns versus the depth in the space charge region starting from the contact. For more details see in the Theory Manual chapter 1.1.3.

4 **Profile modes** exist. The systematic errors differ from mode to mode, so you have to test, which one is the best for your sample:

medium profile: Equ. 1.9, input of diffusion voltage necessary.
medium deviation: Equ. 1.10, standard mode, work correct in most cases.
deviation with VD: Equ. 1.11, input of diffusion voltage necessary.
deviation without VD: Equ. 1.12 in the Theory Manual, literature reference 7.

The **deviation** can be done by cubic splines or by building differences point by point. In the last case you can select the point step.
You can **smooth** the data by splines before the deviation. Here is also an interpolation available.

The **x-axis** is usually the width of space charge region, the bias as x-axis is available for the medium profile.



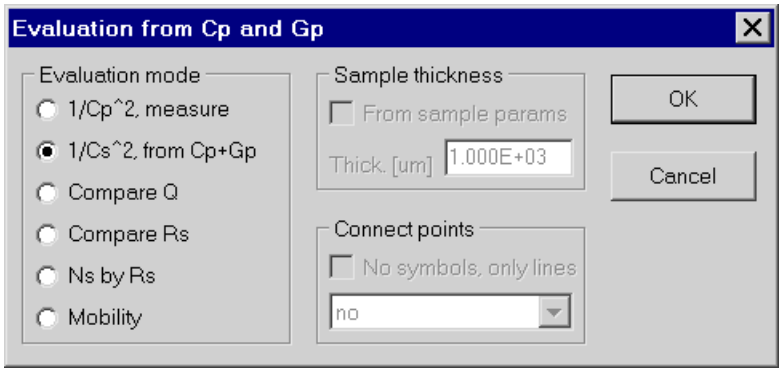
3.1.5.2 Capa + conductance

When existing C/V and G/V curve in the data file, the Evaluate menu has the additional feature 'Capa + conductance'. An explanation of the base values as Cp, Cs and so on es will be given in chapter 3.1.1.4.

Following **evaluation modes** exist here:

- **1/Cp^2, measure:** The standard evaluation with the C/V curve and the 1000/C^2 versus voltage curve will be shown. The evaluation of the last plot yields to Ns and UD. The measured parallel capacitance Cp will be used as capacitance.
- **1/Cs^2, from Cp+Gp:** Similar as above but the series capacitance Cs calculated by Cp and Gp will be used.
- **Compare Q:** Compares the quality Q calculated by the measure values Cp and Gp with the analytical Q. The last one will be calculated by the analytical values of Cs (equ. 1.1 of Theory Manual) and Rs.
- **Compare Rs:** Compares Rs calculated by Cp and Gp (measure) with the analytical value of Rs, see below.
- **Ns by Rs:** Calculates Ns from Rs, needs the mobility from the material parameters.
- **Mobility:** Calculates the mobility by comparison of Ns calculated by Rs with Ns of the sample parameter set.

The last 4 evaluations need the **sample thickness**. You can either apply it from the sample parameter set or input here a local value.



Rs can be calculated by Cp and Gp, see chapter H5 of the Hardware Manual.
On the other hand the **analytical** equation of the series resistance Rs of a homogenous semiconductor is given by:

$$Rs = d / F \;\; 1/(Ns\, q\, \mu)$$

d is here the thickness of the sample, F the area, Ns the shallow concentration, q the elementary charge and μ the mobility. So we can calculate Ns or μ by Rs.

3.2 Transient program

This module enables you to measure the time dependent change (transient) of the capacitance or current of a diode or MIS structure. The transient measurements is in opposite to the static measurements a non equilibrium measurement.
The analog signal will be measured by an analog digital converter (ADC) in N discrete equidistant times td. td will be called sampling interval, Tw=N*td is the period width. N denotes the number of transient points and is a power of 2. The transient values start from index 0 up to index N (y[0]...y[N]), so the 'really' numbers of transient points are 1 higher than N. From these transient values the discrete Fourier coefficients are formed by numerical Fourier transformation.

The evaluation values will be calculated using the measured Fourier coefficients and analytical equations for exponential, logarithmic or linear time laws, see Theory Manual. Time constants, trap concentrations, lifetimes (Zerbst) and so on can be calculated. It gives also a quality factor (named class) for the transient. This class takes into account the quality of the measurement as well as the quality the transient follows the given time law. This type of evaluation will be called DLTFS (**D**eep **L**evel **T**ransient **F**ourier **S**pectroscopy).

Transients can be measured and saved at different temperatures, reverse bias, pulse voltages and pulse widths. Single transients can be transferred to a tempscan file, the last 3 characters of the file names must be here a number, for example TestT001.YEA.DLT, TestT002.YEA.DLT and so on. If you want to create a tempscan with a constant period width Tw shouldn't be changed in the different transients. For a variable period width tempscan you can optimize Tw. A transient can also be saved as a single tempscan point (user class 5).

The first character of the data extension is 'Y' for the transient files. The second data extension character (chapter1.3.3) denotes this **kind of measurement**:

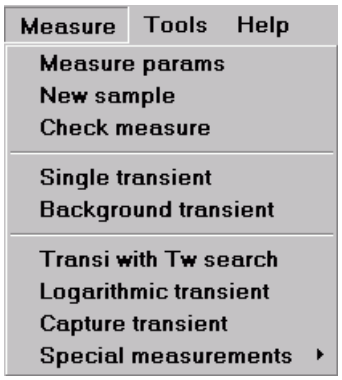
C: Capture transient
D: Difference transient of measurement with 2 parameters
E: Emission transient, standard
L: Logarithmic time-axis transient
P: Capture transient with logarithmic time-axis
Q: Quasi-logarithmic transient
R: Raw data of oversampling logarithmic transient
U: Background transient
W: from isothermal 1 oversampling transient
0: from isothermal program module
1..9: from tempscan program module

In the View menu at 'Params for standard plot' you select the plot after a measurement. 'Automatic' defines the plot depending on the measurement. Or the program will show always the transient, the spectrum or both together.

The Transient program module is not necessary for preparation measurements. For these you can make transient measurements by the 'Check measure' menu of every measurement program module.

3.2.1 Measure menu

The measurement menu contains the 3 common functions and transient measurements.



The input window for the different kinds of transient measurements is always similar, see next chapter.
The single transient is the standard measurement for emission processes. The background transient is a measurement without pulse for checking the noise spectrum.
Transi with Tw search adapts automatically the period width.
The logarithmic time axis transient is helpful for the HERA evaluation, for this measurement you need the HERA option and the new transient recorder. A special menu entry exist for the measurement of capture transients.
Special measurements are for checking the recovery time or shape of pulse, and for 2 transients with one different parameter. At user class 5 there is also a manual measurement for tests.

3.2.1.1 Single transient

The main application of the measurement of a transient is the emission transient with the calculation of the amplitude and time constant. A single transient measurement is normally the emission transient.

3.2.1.1.1 Main input window

Period width/time input box:

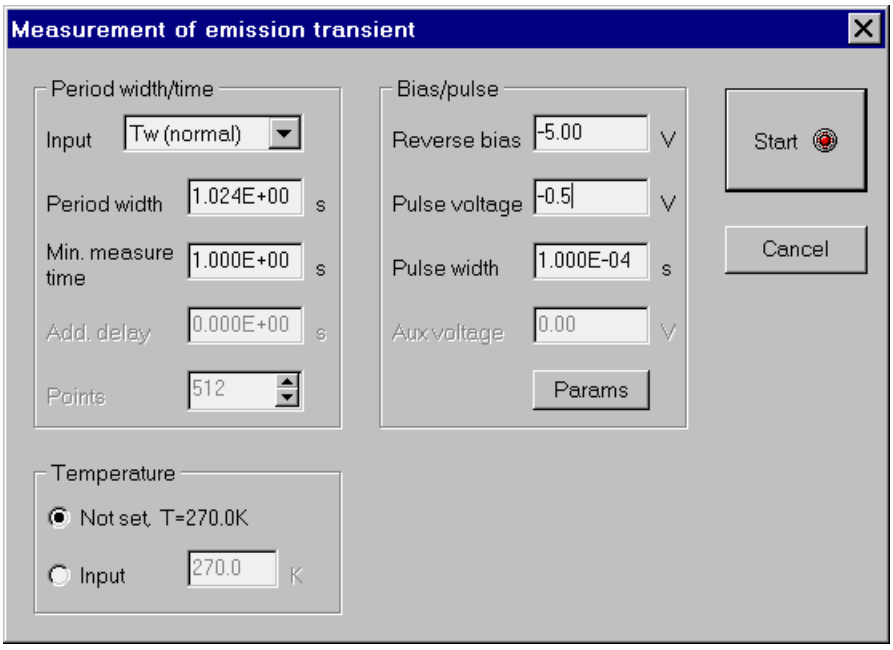
Input defines which variables can be modified:

Tw (normal): The period width Tw and the minimum measure time tM can be defined, this should be used as a standard. The number of points per transients is 512 if possible.
Tw,N: In addition to the standard inputs also the number of points per transient N can be defined.
Tw,N,t0+: In addition to above an additional time for the delay time t0 can be defined.

The **Period width** is the main and dominating variable of the transient measurement. Tw=N*td, where N is the number of transient points and td the sampling interval.

Minimum measure time tM defines the total time of the measurement tMt. It includes the period width Tw, the delay time after pulse t0, the pulse width tP and the number of averages Na. The software calculates from tM the number of averages Na=tM/(Tw+t0+tP) by roundness. The minimum number of averages (transient measurements) is 1, so the input is not the measure time but the minimum measure time. Na*Tw defines the signal noise ratio and not only the period width, the SNR is proportional to the square root of Na*Tw. For an example, if tM=1s and neglecting t0 and tP, then is valid:
Tw=10ms → tMt=1s, Na=100
Tw=1s → tMt=1s, Na=1
Tw=10s → tMt=10s, Na=1

The **Additional delay** time $t0_{Add}$ increases the automatic calculated delay time t0. t0 depends from the recovery time of the bridge $t0_{Bridge}$ and the anti-aliasing filter $t0_{Filter}$. The additional time should be used if measured transient show at the beginning a not monotonous behavior or a small maximum. The reason can be the pulse recovery time of the capacitance bridge or a high leakage current of the sample, see Basics Manual.



The frequency f_{Filter} of the analog filter depends on the sampling interval td. We set our Bessel filter to $f_{Filter}=1/(4*td)$ and use $t0_{Filter}=1.5/f_{Filter.}$ Therefore it is valid:

t0 = $t0_{Bridge}$ + 6*td + $t0_{Add}$

$t0_{Bridge}$ is per default 600 us for C-range 1 of the FT-1235.

Points defines the number of points N per measured transient. Normally the standard definition of 512 points is the best. Only for some background measurements (transient measurements without pulse for noise detection) we suggest 1024 points. For period width scans (Isothermal transient measurements under variation of the period width) we suggest 64 points.

Note: Different transients can be combined only if they have the same Tw, t0 and N.

At the **Temperature** input box you can input a new temperature or apply the current temperature. In the first case a new set point will be set to the temperature controller, normally the program wait until the temperature is stable. In the second case (not set) no command will be send to the controller, the measurement starts immediately.

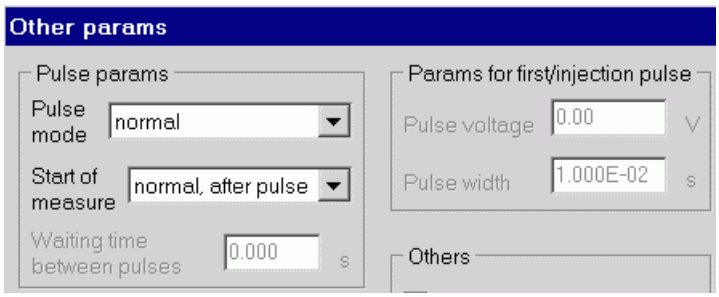
The button **Start** starts the measurement cycle.
The button **Cancel** cancels the input window, all inputs are lost.

Following inputs are possible in the **Bias/pulse** input box:

Reverse bias: This voltage UR is the voltage at the transient measurement. Its is also the equilibrium voltage for compensation, the sample stays at this voltage after measurement.
Pulse voltage: This is the voltage during pulse, called UP.
Pulse width: This is the length of one pulse, called tP.
Aux voltage: This input is only activated in special cases, for FET samples you can define here a second voltage, the **D**rain-**S**ource voltage.

The **Params** button leads to inputs for additional pulse and measurement parameters. This window resets also the under range check and the compensation (2.1.2.2, 2.1.2.3).

3.2.1.1.2 Params input window



Pulse params input group

There are two independent pulses: The injection (first) and the standard (second) pulse. Both can be electrical or optical. The measurement starts normally after the standard pulse.

Params for first/injections pulse are enabled if you have selected one of the double pulse modes. This additional pulse is designed as an injection pulse in forward bias. There is no current limitation!

Pulse mode opens a list of available pulse modes. The list is enhanced if optional pulse sources (optical interface or external pulse generator) are installed:

0) without pulse: Transient measurements are done without a pulse. This pulse mode is meant to use for noise checks at measurement conditions (sample attached, UR set).

1) normal: Transient will be measured with a pulse, this is the standard mode.

2) double pulse: The transient measurement is done in that way, that the first pulse voltage (called injection pulse voltage) for a given time is supplied and then the standard pulse voltage UP. There is no time or different voltage between these pulses tPi and tP. This mode is not possible at using the auxiliary (FET-DS) voltage, see chapter 2.1.2.1.

3) fast pulse: The external fast pulse generator will be used, this is necessary if you need very short pulse widths. Make sure that the sample and the external pulse generator is correctly connected, see chapter H2.2 of the Hardware Manual. Look in chapter H5.2 for the pulse shape at small pulse widths.

5) optical: Instead an electrical an optical pulse will be used, if available (tPo).

6) elec. & optical: Electrical and optical will be used together as 'one' pulse (tPb).

7) elec., optical: The first (injection) pulse is the electrical, the second the optical. In the plot header these will be denoted as tPi and tPo.

8) optical, elec.: The first (injection) pulse is an optical, the second the standard electrical. These will be denoted as tPI and tP.

9) opt., elec-fast: Similar as (8) but with the fast pulse generator.

10) optical DLOS: Special mode only for the variable laser option.

12) double, opt.: Similiar as (7) but uses as first pulse an electrical double pulse.

The available pulse modes depend on your hardware and software licence. Depending on the pulse mode there are additional inputs. If using another pulse as the normal one, the pulse mode will be denoted in the caption of the 'Bias/pulse input group'.
The different pulse values will be marked by different suffixes:

tP = electrical pulse width, **tPi** = width of the electrical injection pulse,
tPo = optical pulse width, **tPw** = waiting time at a pulse.
tPb = wdth of electrical and optical pulse width (mode 6)

The **optical pulse** modes will be more explained in chapter 6.4.3.

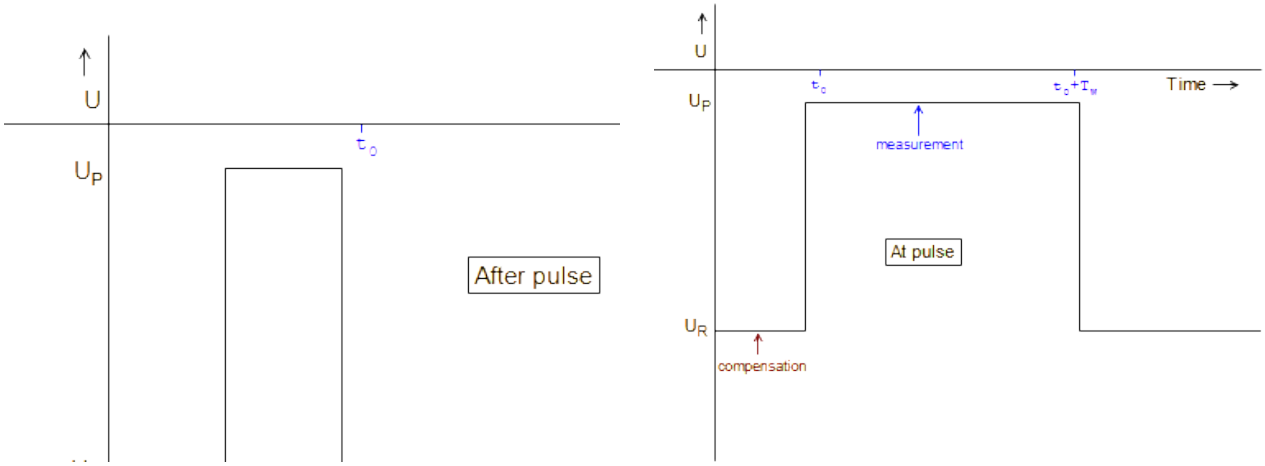
Start of measurement:

The start of the transient recorder will be defined here:

- **normal, after pulse:** Starts the transient recorder directly after the end of pulse.
- **at pulse, Tw=tP:** Starts the transient recorder at the beginning of the standard pulse. The pulse width tP is set to the value of the period width Tw. The capacitance is measured as a function of time during the pulse. Especially at an optical excitation this mode is useful to see the capacitance change during the pulse. The pulse voltage will be denoted as UP*.
- **at pulse, tP input:** Starts the transient recorder as above with the pulse. But Tw and tP can be defined independently from each other. The capacitance is now measured during and partly (as defined) after the pulse. It enables the measurement of the recovery behavior of the circuit including the sample. Because the capacitance variation is quite high during this kind of measurement, the range low limit for transients have to be increased to 3 or 4. This feature needs user class 5.

'At pulse' is not available for CC-DLTS and at the pulse modes 0 and 3 (without, fast). When using one of the double pulse modes (2, 7, 8, 9, 12), then here the measurement starts during the main pulse, that is the second one.

The following diagram illustrates the differences. The disadvantage of 'at pulse' is that the compensation (at UR) will not be done at the same voltage (capacitance) as the measurement (UP). There is a big difference between CR and CP, so you have to select a higher bridge range to avoid over range errors. So you lose sensitivity.



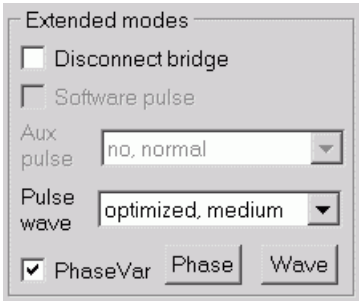
The selecting 'at pulse' as start of measurement enables the input '**waiting time between pulses**'. When repeating the transients because averaging or bad range or bad amplification then the software waits before the next pulse for this time. This can be important if this mode will be selected for capture processes. If the emission process after the caption process is not finished then a new filling pulse starts with the already filled traps. The waiting time between the pulses can avoid this problem. If this time is bigger than the emission time, each measurement starts always with empty traps.

User class 5 allows to set such a waiting time also for the mode 'normal, after pulse'. Normally here is no waiting time necessary because the traps of most levels are filled at pulse widths of 100 us. So the emission process starts usually with full filled traps. But at an indirect capture measurement (chapter 3.3.6.1) the above discussed problem must be considered. The waiting time used for 'after pulse' takes into account the period width. For example, if the waiting time is 3s and Tw=1s then the software waits 2s between each pulse. The software waits not only between the averages but also when repeating the transient because bad range or amplification. Additional times (for example for the compensation) will be taken into account, you can say it is an 'active' waiting tine.

The waiting time will also be used between each tempscan file and between each parameter change of the isothermal measurement. For the isothermal program module (chapter 3.3.1.2) and the capture transient measurement (chapter 3.2.1.5) separate variables for this waiting time will be used instead the global value. Its input here is forbidden.

Note: You can identify the pulse mode and start of measurement in the file header list and in the text header of a plot. Without pulse there are no values for UP and tP. Measurement at pulse will be denoted as UP*. An injection pulse will be denoted by tPI, an optical pulse by tPo or tPb. The standard electrical pulse is tP. UP represents always the standard electrical pulse. So there is no UP entry if using only an electrical pulse.

Extended modes input group:



'**Disconnect bridge**' means that the bridge is not connected to the sample during the pulse. The bias will be switched by relays directly to the sample during the pulse, so that the bias doesn't go through the bridge to the sample as in the standard pulse mode. During the pulse no HF voltage is applied to the sample. Look also in chapter H5 of the Hardware Manual.
For I-DLTS a similar flag exist called '**Disconnect I/V-Amp**'.

Usually the pulse will be triggered by the hardware. It is also possible to set the voltage up and down by single software commands, we call this '**Software pulse**'. If this flag is labeled by 'Software pulse and trigger' then also the measurement will be started by software. In the other case the measurement starts as at a hardware pulse by a hardware trigger. Starting the measurement by software yields to a not well-known t0 for short Tw's.
'First pulse as software pulse' may be helpful at long double pulses.

The **limits** of the hardware pulses are 12000s for each pulse and 42000s for all pulses together including wait times. The limit is about 100h at software pulses. But use the software pulse only at long pulses and long period widths because the accuracy is here only some ten or hundred milliseconds.

The **Auxiliary** resp. UDS voltage, here called UAux, will usually only be applied to the sample, but not pulsed. You may also pulse this voltage, see H1.4 of Hardware Manual. Following is possible for the UAux pulse and for the start of data collecting by ADC:

no, normal:	The Aux voltage is fix, only standard Bias pulse
pulse before meas:	UAux pulse, no Bias pulse, measure starts after UAux pulse
pulse during meas:	UAux pulse, no Bias pulse, measure starts with UAux pulse
before standard pulse:	UAux pulse, then Bias pulse, measure start as Bias pulse
during standard pulse:	UAux pulse and Bias pulse simultanous, start as Bias pulse

3.2.1.1.3 Pulse wave and PhaseVar

The new Bias source of the FT-1230 allows arbitrary **pulse wave** forms. The old standard pulse is a rectangular pulse. This has the advantage of a fast rising time but the disadvantage of oszillations and overshoots. The overshoot may yield to problems, especially around zero voltage. Forward voltage with big leakage current may occur during the pulse. See pictures below and chapters H5.2 to H5.4 of the Hardware Manual.
We have predefined following pulse wave forms:

rectangular (std): That is the old standard pulse.

Gauss, fast: Uses a Gauss distribution as pulse wave form with fast rising times.

Gauss, medium: Gauss wave form with medium rising times.

Gauss, slow: Gauss wave form with slow rising times.

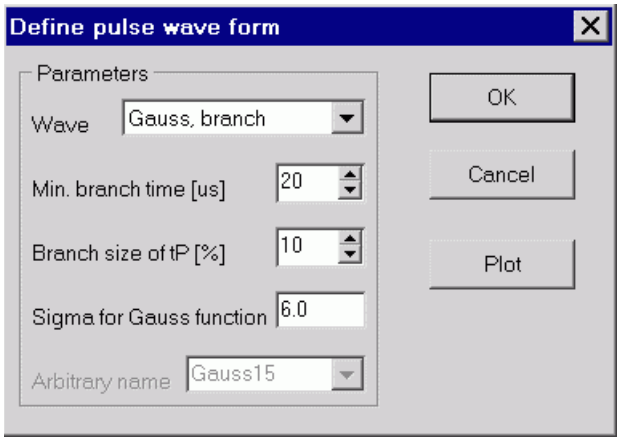
optimized, medium: Our prefered pulse wave form, combines a sin90 and a Gauss depending on tP. This is the new default mode.

Gauss, branch: A Gaussian pulse wave form with customer inputs of rising time and of sigma for the Gauss function.

sin180, branch: Uses a half period of a sinus function, customer inputs.

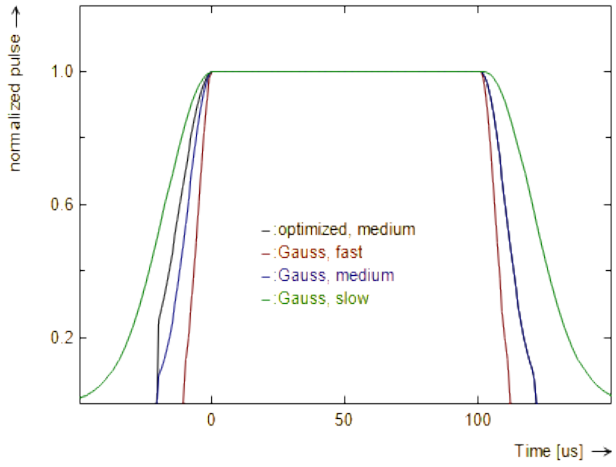
sin90, branch: Uses a quarter period of a sinus function, customer inputs.

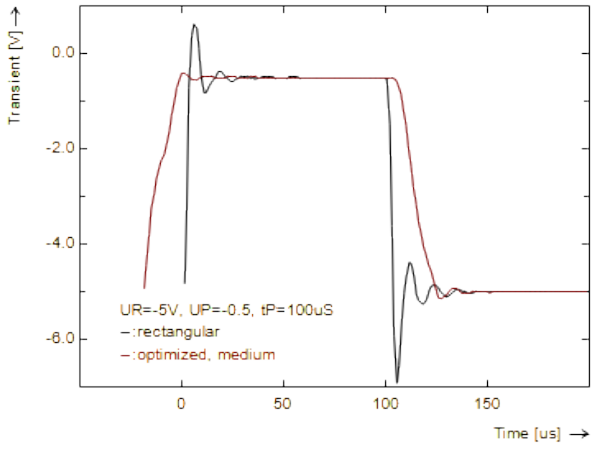
The input window shown on the right opens after clicking onto the 'Wave' button:
Here you can define the wave form and the **rising times** if selecting a wave form with 'branch'. These times will be defined by an absolute minimum time and a percentual time relative to the pulse width tP (Branch size of tP). For the Gauss function there is also the input of sigma. A bigger value yields to a bigger width of the Gauss curve.



A click onto the '**Plot**' button shows the theoretical pulse curve, as shown in the picture below left for some wave forms.

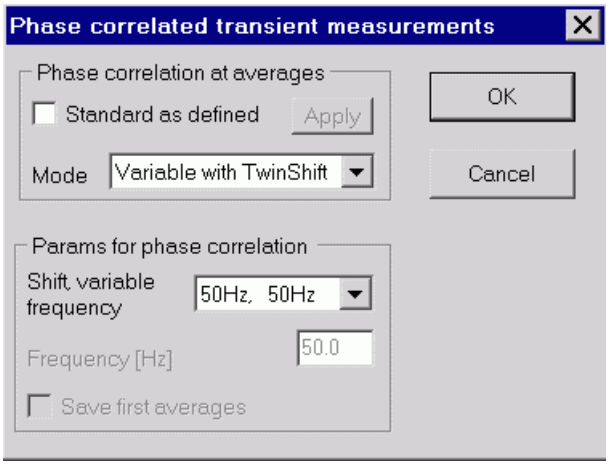
The following picture on the right shows the **real pulse** at a sample. You see the oszillations and overshoots into forward voltage for the rectangular pulse by UP=-0.5V. This is neglectable at the 'optimized' pulse. The 'longer ' pulse time will be taken into account at starting the measurement.





The **Phase variation** is a new option which will be introduced with the FT-1230. It means that at averaging transients the time between the transients is defined by the software and is not randomly or given by the electronic. So it is possible to suppress peaks in the back-ground spectrum which based on the power line frequeny or its hardmonics. These peaks have a fix frequency and a fix phase. The new option yields in the practice to a better density because especially low frequencies have an influence to the transient.

You may switch on/off this option by the 'PhaseVar' box, clicking onto the 'Phase' button opens an input window:



'**Standard as defined**' applies the values which PhysTech has defined for your hard-ware (bridge, I/V-converter). Clicking on the 'Apply' button shows the predefined values. In the other case you may define the mode:

'**Variable with TwinShift**' means that each second transient will be measured with a shift of 180grad to the frequency of the line power. The time between 2. and 3. transient will also be varied by a schema.

At '**Random with TwinShift**' the time bet-ween 2. and 3. transient is really randomly.

'Random phase' sets a really random time between all transients.

In the following the label **50Hz** is only a synonym for the power line frequency. You may define this frequency by the Set_Conf program, see chapter I3.3 of the Installation Manual. The same is valid for the harmonic waves. So a 100Hz label means here 120Hz at a powerline frequency of 60Hz.

For the first mode you have to select the **shift** (1.value) **and variable frequency** (2.value):

- 50Hz, 50Hz
- 50Hz, 100Hz
- 50Hz, 150Hz
- 100Hz, 50Hz
- 100Hz, 100Hz
- 100Hz, 200Hz
- input, 50Hz
- input, 100Hz

The following example should explain the both first selections. We assume a powerline frequency of 50Hz, means 20ms powerline period time, and averaging of 4 transients. Period width, pulse time and data collecting should be smaller than 100ms. The first transient starts always at 0ms.

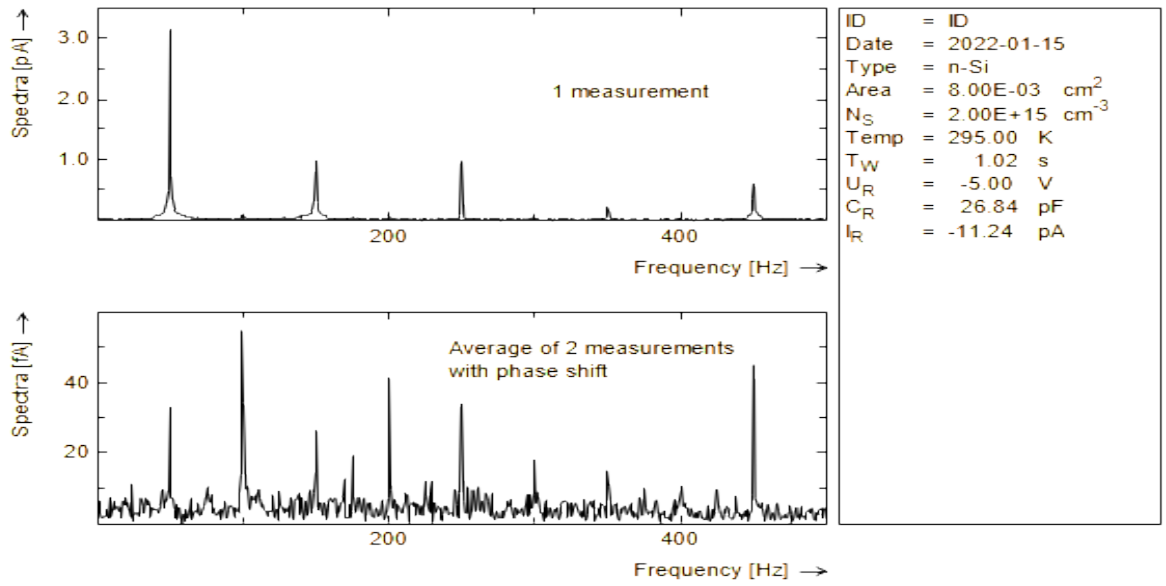
50Hz/50Hz: 2. transient at 110ms, 3. transient at 220ms, 4. transient at 230ms.

50Hz/100Hz: 2. transient at 110ms, 3. transient at 215ms, 4. transient at 225ms.

The variable frequency has only a meaning at averaging of 4 or more transients. The num-bers of **averaging** will be calculated by Tw, tP and the minimum measurement time. If activating the flag 'PhaseVar' only even numbers of averages will be used. Except the minimum measure time is too small, then no averages (we call it one average) will be done. The PhaseVar option has without averaging no meaning.

The phase variation is only possible at not too small period widths. The reason is the **latency time** of the USB bus, it is about 1ms. The software starts the measurement via an USB command.
The latency time of the USB is also the reason that the results of the reduction of the powerline peaks (or its harmonics) changes at repeating the measurement. Sometimes the 180grad phase shift is perfect, in worst case the phase shift has an error of some milli-seconds. So a reduction factor of 100 is possible for the 50Hz peak, but also only a factor of 5 may occur. If some harmonic waves of the power frequency exist in the transient spectrum, then only 2 frequencies can be well reduced.
Without activating the flag 'PhaseVar' the phase at averaging will be given by the electronic and PC. So the results of averaging are accidentally for peak with fix frequency and fix phase. Nevertheless averaging with or without phase shift reduces statistic noise.

The next pictures shows the spectrum of two Current-DLTS transient measurements. The transient was only 1-times measured (no averaging) at the top curve. Two transient are measured with phase shift and averaged for the bottom curve. The 50 Hz peak is about 3pA without averaging, it is about 35fA for averaging with phase shift. So the phase shift averaging is especially important for I-DLTS. You should use it.



Note: 2 averages means in the whole manual that 2 transients were measured and these will then be averaged. **1 average** means that only 1 transient was measured, no average then will be done because not possible.

3.2.1.1.4 Measurement notes and tips for Schottky diodes:

a) Voltages: The reverse bias direction will be in the negative voltage direction for n-type samples, in positive voltages for p-type sample. Select UR so that you have a wide space charge region and the leakage current is not high, typically it should be smaller than 1uA. UP should be selected a little smaller than zero volt, take into account the HF voltage of the bridge (normally 100mV effective). Don't use forward voltages or UP=0. Typical voltages for n-type samples are UR=-7V to -5V and UP=-0.5V.

b) Pulse width: For standard samples select 100us as tP. This time is enough to fill the most traps. Longer pulse widths can yield to longer recovery times. Only in special cases at extreme small capture cross section it can be necessary to use longer pulse widths. Smaller pulse widths don't give an advantage.

c) Period input: The selection of 'Tw (normal)' is in most cases sufficient. 512 transient points are in most cases enough. An additional delay is only necessary if you see you recovery signals at the start of the transient.

d) Period width: Select, if possible by time, Tw so that the transient goes at the end to its equilibrium value, for more details see next chapter. The period width should not be too small because recovery time of the bridge. For an overview you can use the measurement 'Transients of 3 periods'. A good value for the minimum measure time is 1s. If Tw is also 1s (default) then the transient will not be averaged.

e) Temperature: Select the temperature as necessary and important. If an adaption of Tw is not possible or favorable then decrease or increase the temperature to get a slower or faster emission time constant. It can take some time until the sample (not the temperature sensor!) has reached the defined temperature. You should repeat the transient measurements at big temperature changes. If you want to make some measurement at the same temperature, it can be an advantage to select the mode 'Not set' at the repetitions. Some temperature controller 'lose' its temperature if setting the same temperature again.

f) Params button: Normally there are no changes necessary at the Params input window.

g) Fast pulse: Use the fast pulse only for small pulses below 50us because relays of the fast pulse interface will be switched on and off at each pulse. Too many switches may damage the relays. Look in the file Dlts\Work\Relay.Cfg for the current number of switches.

h) HF-voltage: A higher HF-voltage yields to a higher sensitivity because the signal related to the noise is higher. But note that the peak to peak voltage is about 3-times higher than the effective voltage. A big HF voltage may yield to recharging and to forward current around 0V. A high HF voltage is especially a problem for MIS capacitors.

3.2.1.1.5 Period width adaption

For a good evaluation by the **DLTFS** (**D**eep **L**evel **T**ransient **F**ourier **S**pectroscopy) method, see chapter 3.3 of Theory Manual, it is necessary that the period width will be adapted to the emission process of the transient. At the evaluation list, see next chapter, you get for this a hint by the relations **tau/Tw** and **ts/Tw**. ts is the time when the transient has decreased to the ADC resolution.
A good Tw adaption is if ts/Tw=1. In this case the full relevant transient will be measured. If ts/Tw<>1 then you have to multiply your old Tw with this ratio to get at the next measurement ts/Tw=1. For standard amplitudes this value corresponds to tau/Tw=0.15.
At higher recovery times, drift problems or overlapping of levels it can be necessary to select another value. So 'ts/Tw>1' measure only the first part of transient. ts/Tw should be selected in such way that the evaluation class is so high as possible, see chapter 1.3.4. The exponential class should be near at 1.
Instead modifying Tw you can also change the temperature to fit the period width.

For an overview you can use the measurement 'Transients of 3 periods'. The transient will be measured using 3 different period widths which will cover a wide range of Tw. Another possibility is the measurement 'Transi with Tw search' as explained in chapter 3.2.1.3.

Note: ts/Tw=1 yields normally to the best results. But this value is not exactly necessary. There is normally a wide range of ts/Tw for getting good evaluation values.

3.2.1.1.6 Transient offset

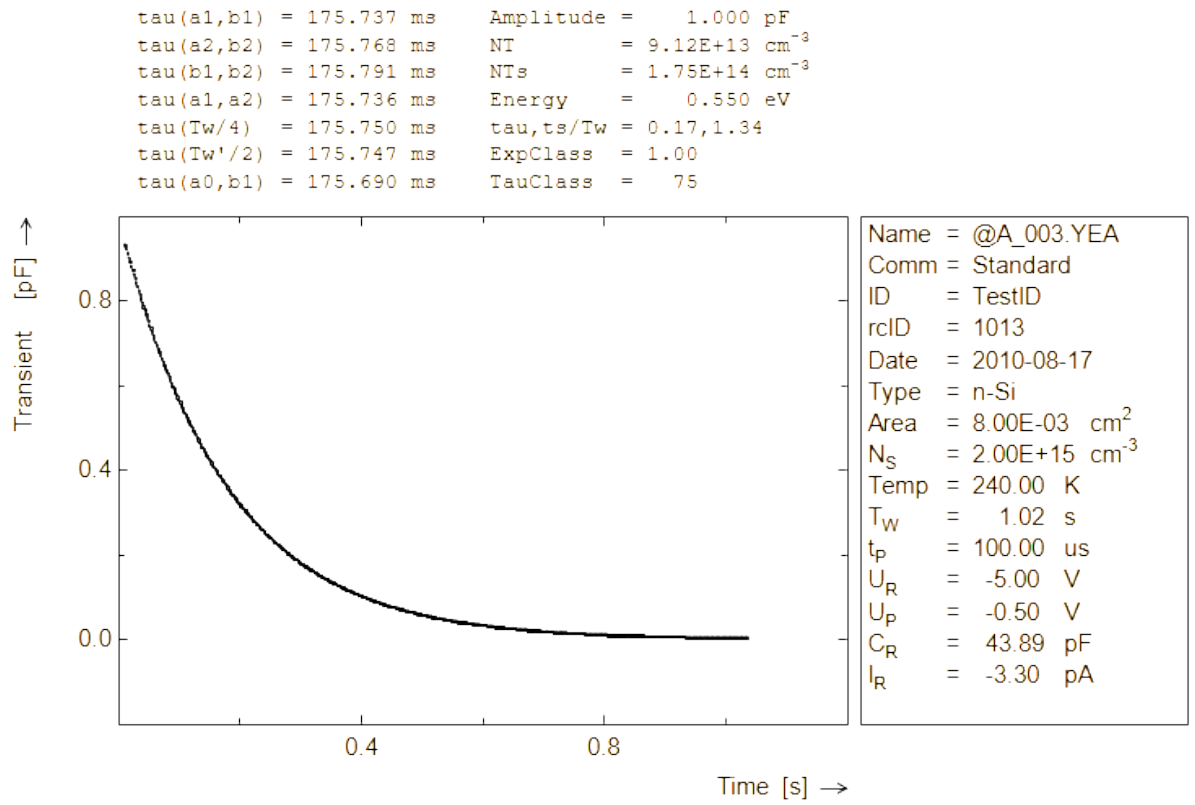
Sometimes you see in the transient an offset, means that the transient doesn't fall to zero but to a constant value. Reasons for this transient offset can be:

1. A not perfect compensation to zero
2. Not finished emission at compensation
3. Sample drifts during the measurement
4. Temperature drifts during the measurement
5. Not complete filling by one pulse, addition by average

The offset can origin from a transient measurement before when measuring many files in one temperature cycle and the emission of the transient before is not finished (2).
We measure the offset after the compensation before the transient measurement. We call this value also DC, see list of next chapter. Because 3 to 5 the true offset can vary from the measured one. But a transient offset, also a 'wrong' measured one, is not a problem and yields not to wrong results. You see the offset only in a0, the other coefficients, for example b1, will not be effected by an offset. Please don't mismatch a transient offset with a tempscan offset.

3.2.1.1.7 Plot after measurement

After measurement or reading transient data you see on the main canvas a picture with a **plot** and with a list of data. The plot in the middle displays all capacitance versus time data as measured. The text box at the right contains some sample and measurement parameters and results of the static (single value) measurements, for an explanation see chapter 1.3.4. On the top the results of the direct evaluation of this transient are shown.



The following explains the result list of the **direct evaluation**:

tau(a1,b1): Time constant calculated by a1 and b1, will be used as tau.
tau(a2,b2): Time constant calculated by a2 and b2.
tau(b1,b2): Time constant calculated by b1 and b2.
tau(a1,a2): Time constant calculated by a1 and a2.
tau(Tw/4): =tau(a1L,b1L), time constant calculated at the first quarter of Tw.
tau(Tw'/2): =tau(a1M,b1M), calculated by tau(a1,b1) with Tw'=Tw/2, t0'=t0+Tw/16.
tau(a0,b1): Time constant calculated by a0 and b1.
Amplitude: Amplitude of the transient.
NT: Trap concentration, standard approximation. Ns is necessary for this value.
NTs: Trap concentration, calculated with the space charge region.
Energy: Calculated from tau and from in the sample parameters defined capture cross section.
tau/Tw: Time constant divided period width.
ts/Tw: ts is the time when the transient has decreased to the ADC (Analog Digital Converter) resolution.
ExpClass: a1/a2 * b2/b1, is 1 for a single exponential transient.
TauClass: Classification of the tau calculation, see chapter 1.3.4.

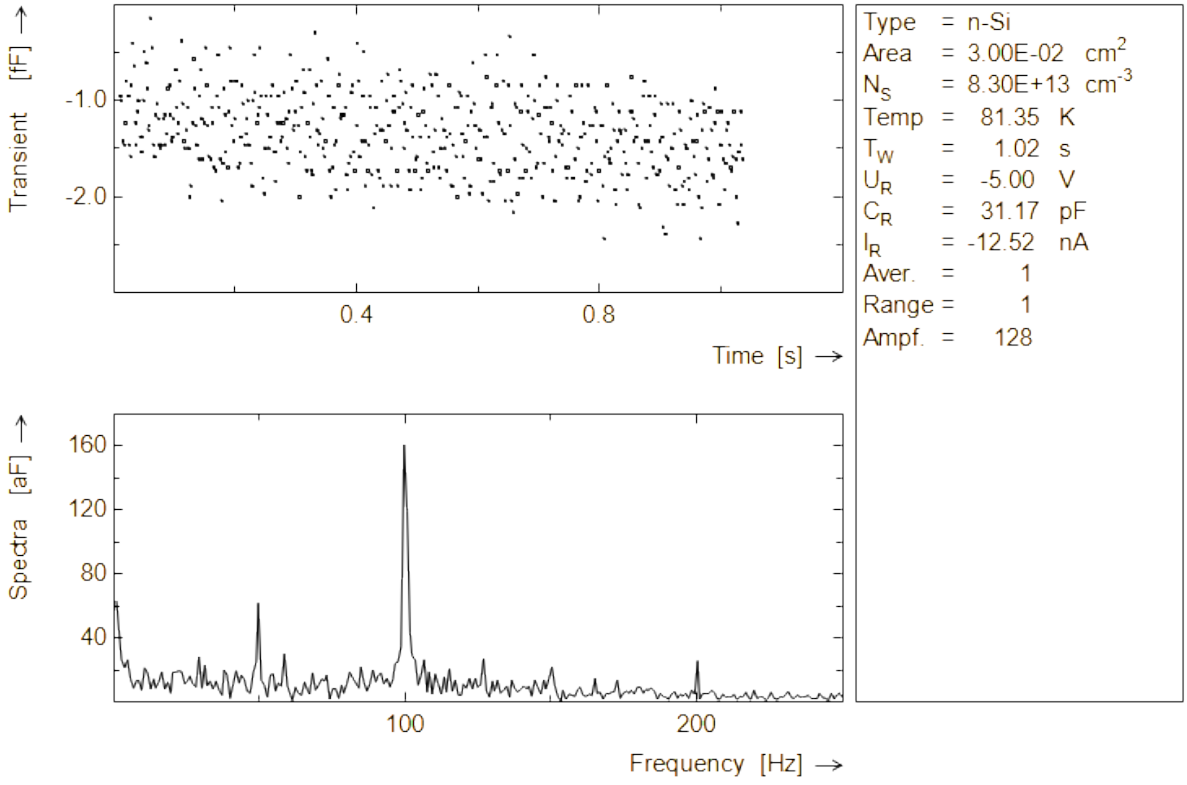
3.2.1.2 Background transient

The main application of the background transient measurement is the noise check.

In the Period width/time input box there are additional possibilities for the **Input** mode:
Tw = 20 ms: This is the standard fast period width, N=512, f_{Filter}=6.25kHz.
Tw = 200 ms: This is the standard middle period width; N=512, f_{Filter}=625Hz.
Tw = 2 s: This is the standard slow period width, N=512, f_{Filter}=62.5Hz.
Low spectrum: Tw = 1.024 s, N=1024, special for background, f_{Filter}=250Hz.
High spectrum: Tw = 10.24 ms, N=1024, special for background, f_{Filter}=25kHz.
Low spect, PhaseVar: as low spectrum but 2 averages and PhaseVar, see 3.2.1.1.3.

The Input of pulse voltage and pulse width is not available. By default the pulse mode 'without pulse' will be used.

After a background measurement you see a **picture** with two plots. The top plot shows the transient data, the plot on the bottom the frequency spectra. The spectra are explained in the theory manual. The number of averages, the capacitance range (and there behind a colon the pre-amplifier if >1) and the amplification will be listed in the text box. At the following measurement was f_{Filter} = 125 Hz.



3.2.1.3 Transi with Tw search

This is a single transient measurement with automatic search of the period width.
At the main input window there you can define how the **Tw search starts**, either by the input of Tw or by testing 3 period widths of 10 ms, 300 ms and 10 s.
The **Params** button opens an input window with parameters for the search. As mode you can select 'tau/Tw', 'ts/Tw' or 'ts/Tw,no eval'. The last uses no evaluation, the others the transient evaluation. The tau/Tw resp. ts/Tw value defines the Tw adaptation of the search.

3.2.1.4 Logarithmic transient

Theoretically there are 3 possibilities to get a transient with a logarithmic time axis:

1. The direct measuring of transient points with logarithmic steps.
2. Measurement of many equidistant transient points and then selecting points in a logarithmic step.
3. Measurement of some equidistant transients with different period widths and then forming from these transients a new curve/transient with a logarithmic time axis, we call it quasi-logarithmic transient.

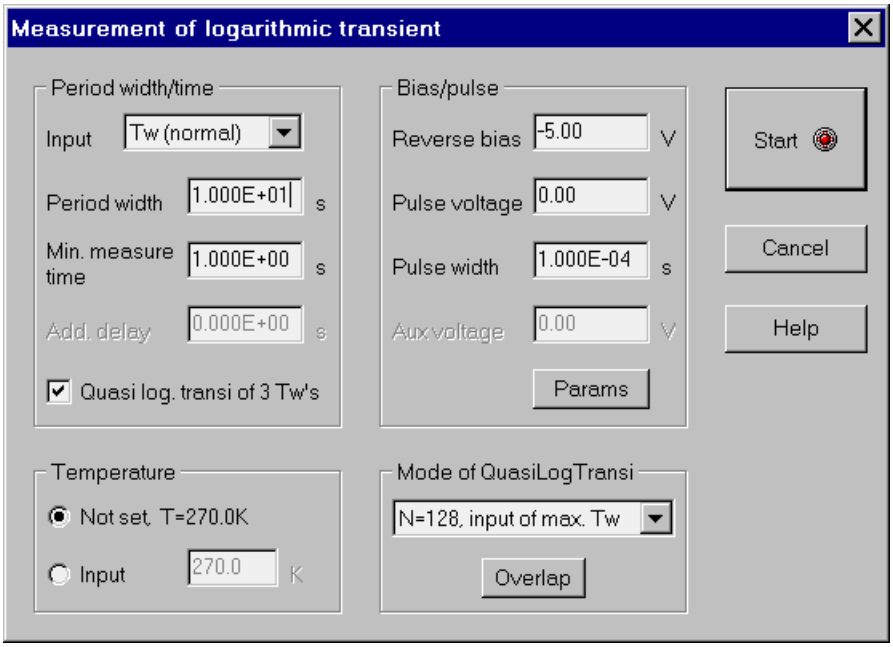
Method 1 and 2 are similar and yield to a very bad SNR (**S**ignal **N**oise **R**atio). The filter frequency of the anti-aliasing must be high and an average is not possible because the long measurement time. Method 3 avoids these disadvantages. Here is the anti-aliasing filter frequency optimal for each transient, an averaging is for the small Tw's individual possible. Our DLTS system offers method 2 and 3, we prefer 3 because the big advantages.
At method 2 our system use up to 65000 transient points.

In the transient and tempscan module the **quasi-logarithmic** curve (method 3) will normally be constructed from 3 transients of different period widths with each 128 points, at the isothermal module many transients of different Tw's each of 32 points will be used. The transients must overlap on the time axis, for more details see in chapter 3.3.4.5.
Problems may occur when the pulse width is too small, so that not all traps will be filled by one pulse, see chapter 6.1.5.

The new quasi-logarithmic curve can contain only **original** measured data points or, at a logarithmic time axis, interpolated **equidistant** points (transient). The isothermal and tempscan module use only original data points, for the transient module equidistant points are necessary.

The input groups for temperature and Bias/ pulse are the same as in chapter 3.2.1.1.
The input group for period/with time is similar as there. Here is an additional flag for selecting the measurement method. Activating of **quasi log. transi of 3 Tw's** use method 3 instead of 2.

An additional input group exist, different for method 2 and 3.



At **method 2** you can select the number of logarithmic points and a filter (no, weak, medium, heavy) for creating these points from the up to 65000 measured transient points. At user class 6 all these raw data can be saved and plotted.

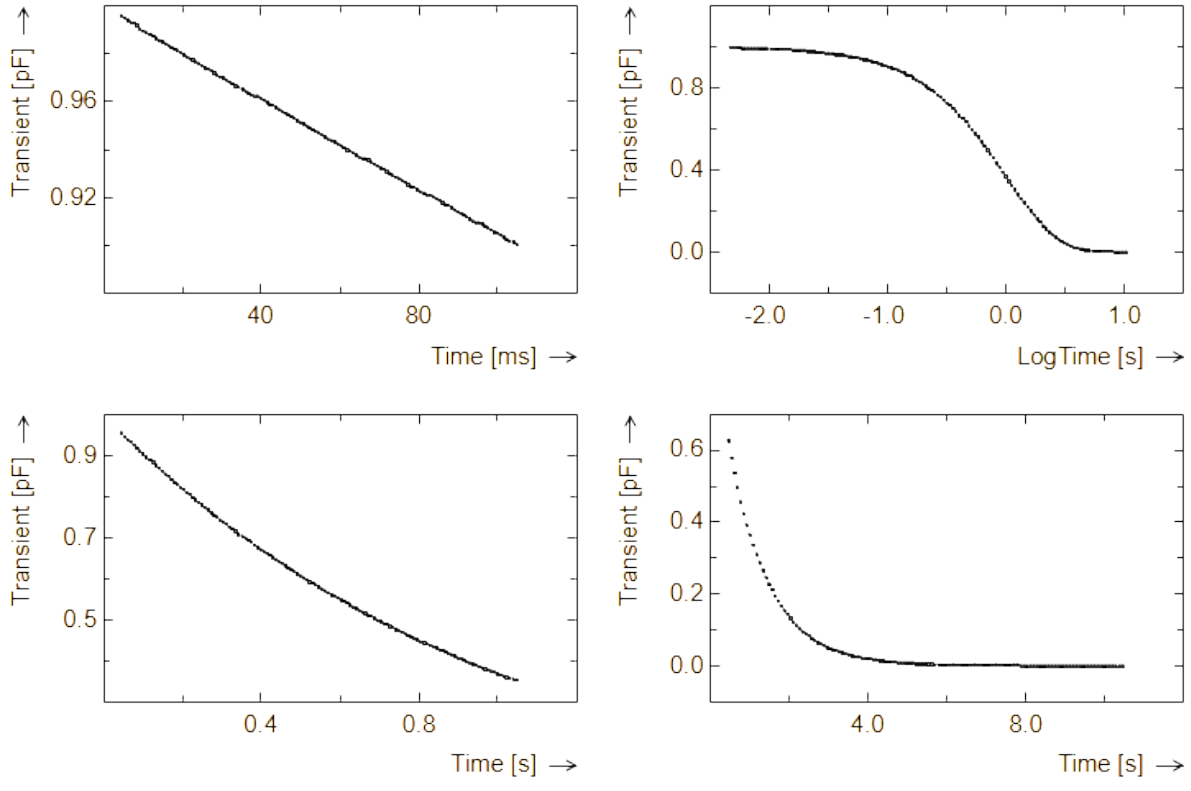
At **method 3** the quasi-logarithmic transient will be constructed from 3 transients of different period widths with each 128 or 512 points. The **quasi-logarithmic** transient will always have 128 data points.
You can select a **mode** for the construction/measurement:

as check meas 3 Tw's: 3 transients with each 128 points; maximum period width is 10s. Same procedure as in 'Check measure → Transients of 3 Tw's'.
as HERA tempscan: 3 transients with each 128 points, maximum period width 1.9s. Same procedure as the HERA standard routine measurement in the tempscan module.
N=128, input of max. Tw: 3 transients with each 128 points; input of the maximum period width, this is also the period width of the constructed transient.
N=512, input of max. Tw: 3 transients with each 128 points; input of the maximum period width, this is also the period width of the constructed transient.

The **Overlap** button opens a window with the construction parameters (chapter 3.3.4.5).

At the transient module the data will be interpolated so that the quasi-logarithmic transient has 128 equidistant, on a logarithmic time axis, points.
Here at the transient module the x-axis will not be shown as time in a standard logarithmic window with many ticks. A new x-axis expression will be created, we call it **LogTime**. Then this transient has equidistant points similar to the standard transients with a linear time axis. All plots and evaluations can be done also with the quasi-logarithmic transient because the data structure is the same as the standard transient.
For the LogTime is valid: LogTime = log10(Time).

At the measurement you see the 3 origin transients in 3 small plots. After the measurement the quasi-logarithmic transient will be shown.
The next picture shows 3 transients and the constructed quasi-logarithmic (top right):



3.2.1.5 Capture measurements

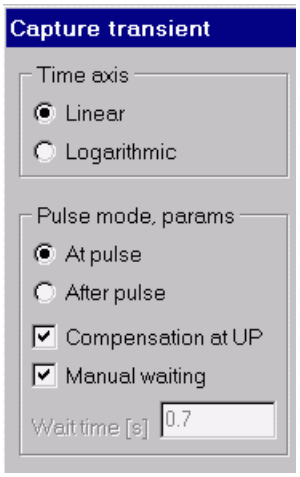
Two techniques exist for observing directly the capture process:

- Set 'Start of measure' to '**at pulse, Tw=tP**', see chapter 3.2.1.1.2. The disadvantage is that the compensation will be done at UR but the measurement at UP. There is a big difference between CR and CP, so you have to select a higher bridge range to avoid over range errors. The pulse voltage in the text header will be denoted as UP* because this is not the normal pulse but the voltage during the measurement.
- Set 'Start of measure' to '**after pulse**' and **swap** reverse bias and pulse voltage. The disadvantage is that the sample will be hold at UP, that means the sample is already filled before the capture measurement. You should select the pulse width in such way that all emission is finished when the measurement starts.

Both techniques measure directly the transient of the capture process. In the practice this is for discrete levels not helpful because the capture process is normally very fast. The direct capture measurement by the transient recorder can start about after 100 us because the recovery time of the bridge. Better is the indirect measurement of a capture transient, see chapter 3.3.6.1. The direct measurement can be helpful or necessary at slow oxide states, see chapter 6.3.6.3.
You can use both techniques for all transient measurements, for example by 'Single transient' in the Transient Measurement Module. But usually the Single transient will be used for observing the emission process.

In the Transient Module the special measurement '**Capture transient**' exist to avoid changing always the 'Start of measure' or swapping the voltages. Additionally here is a possibility to compensate at UP when using the 'at pulse' technique. The 'Start of measure' will be set here temporary. UR and UP are always the values for the emission, it will here be automatically swapped if necessary. After the measurement the values will be switched back to the old ones. A special evaluation exist for capture transients. At CC-DLTS it may be better not to use this feature but to swap manually UR and UP as described above.

Before the standard input window (chapter 3.2.1.1.1 resp. 3.2.1.4) opens with some restrictions the following first input window appears:



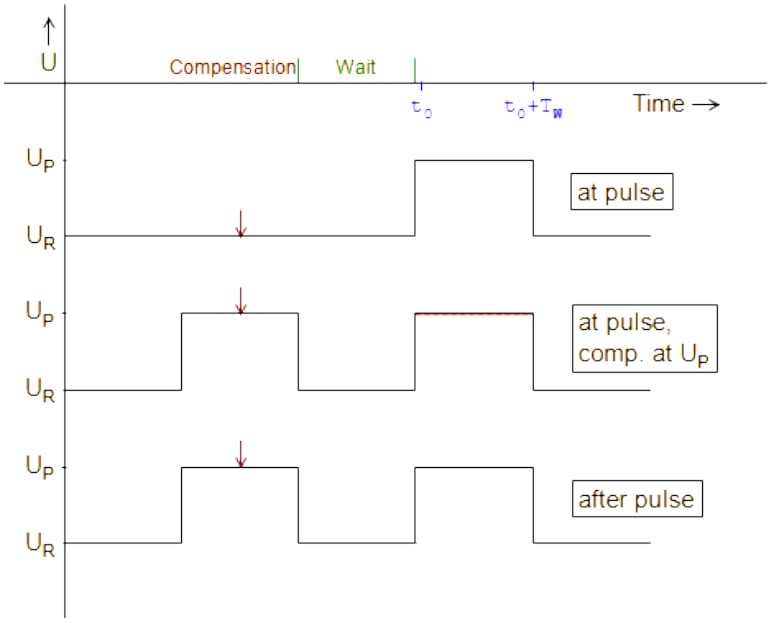
The capture measurement can be done with the standard **linear time axis** or with a **logarithmic** one.

As discussed above the 2 techniques '**at pulse**' and '**after pulse**' are possible. For the first one a special mode exist if activating the flag '**Compensate at UP**'. Then the compensation will not be done at UR but at UP. This avoids the discussed disadvantage. So totally 3 different techniques are possible.
An input of 'fast pulse' mode will be ignored, the software uses then the standard pulse. The 'optical pulse' mode allows here only 'at pulse'. The 'at pulse' technique' is not available for CC-DLTS. At CC-DLTS a compensation will be done at UP and after the measurement the 'CC-init' flag will be set, see chapter 6.2.1.3.2.

You can define a **wait time** before the measurement starts. It will also be used at repeating of the transient and replaces the global input, see chapter 3.2.1.1.2. When using 'at pulse' and 'Comp. at UP' there is the flag **Manual waiting**. If activating it then the reverse bias capacitance will be permanently shown in a plot until you start the measurement.

The following **time/voltage diagrams** illustrate the 3 different techniques:

- The top curve denotes the simple technique 'at *pulse*', the compensation will be done at UR.
- The medium curve represents also 'at *pulse*' but here the compensation will be done at UP because the flag '*Comp. at UP*' was activated.
- The bottom curve shows the diagram for 'after *pulse*'.



The red dot lines mark the pulse while the dark red arrows mark the compensation. The measurement will be done between t0 and t0+Tw, marked by the 2 short blue lines.

The measurement waits at UR for the given wait time (green marker) before the first measurement starts except at the top curve. The software waits at both 'at pulse' techniques when the measurement will be repeated because averaging or bad amplification. At the mode 'after pulse' the wait time is the pulse width. So the program waits for each measurement (pulse) the same time.

Following fact is **important**: The emission must be finished (all traps must be empty) when starting or repeating the measurement. A measurement will be repeated at averaging or if the amplification of the amplifier is too low or too high. If this fact is not fulfilled then the time axis is not correct for a capture evaluation. Consider following **tips**:

- Select the **wait time** long enough.
- If possible select the **period width** so that the emission is finished at the end of Tw. For an exponential emission this is valid for tau/Tw<0.15.
- **Don't average**, select a bigger Tw so that no average is necessary. For no averaging you have to set the minimum measure time tM to Tw or to zero. Remember that the SNR depends only on the product Na*Tw, see chapter 3.2.1.1.1.

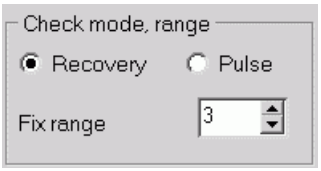
Summary: The top diagram has the disadvantage that the compensation will be done at UR. The medium and the bottom diagrams are very similar. The advantage of the medium mode is that you can wait manually until a possible emission process is finished. Therefor we prefer this as direct technique.

Note: You have to input here always UR and UP for the emission process. If using 'after pulse' then the voltages will be automatically swapped for the measurement. At the plot then the not swapped values (as the input) will be listed. The pulse voltages will be denoted as 'UP*', so that you know that measurement was done at the shown value of UP. The old pulse mode will be restored after the measurement. Be carefully when reading capture transients and applying the measurement parameters because the capture pulse mode will be applied.

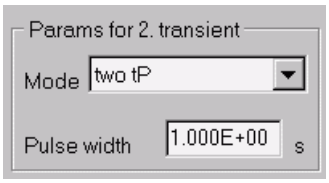
3.2.1.6 Special measurements

Check recovery/pulse enables 2 applications:

- Check of **recovery** behavior of the circuit including the sample. The start of measurement is 'normal, after pulse', see chapter 3.2.1.1.2. The difference to the normal emission is that the measurement starts immediately after the pulse and doesn't take into account the recovery times of bridge and filter. So you can observe the recovery times.
- Check of **pulse** shape. The start of measurement is 'at pulse, tP input', no averages are possible. You see the increase of the pulse and, depending on your Tw and tP input, the decrease of pulse and the recovery times. This can be helpful especially at small pulses. So the slew rate of the internal pulse generator is 1 V/us. But you don't see here the pulse but the capacitance output of the bridge. Chapter H5.3 of the Hardware Manual describes how to observe the voltage during the pulse.



The automatic setting of the transient range and of the compensation range is here disabled. So you have here to set locally this range. The reason is that the capacitance or current variation is quite high during this measurement. Therefor the range should here usually 1 range higher than at the standard measurement. An optional additional delay shifts the start time of measurement.



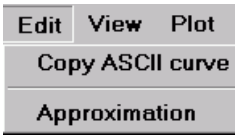
Two parameters means a measurement of 2 transients with one different parameter. In the main input window you can select as this parameter a second UR, UP or tP. If the second parameter is UP, this method will be called DDLTS or Double correlation DLTS. The different pulse voltage defines the different depletion region that will be recharged, see chapter 3.3.6.2.
After the 2 measurements the first transient will be subtracted from the second one. This difference transient is then the new 'transient' and will be used for saving or evaluation. The second measurement parameter will be listed at the text header, for example tP2. The second parameter should be selected in such way that the second transient has the bigger signal.

If saving data then additionally to the difference transient (YD?) the measured first (YI?) and second (YJ?) transient will be saved. In the list and plot menu there is an entry to compare the difference and original transients (Compare 2 transi).

2 double pulse measures 2 transients with an electrical double pulse. The first transient will be measured with the defined parameters for the first (injection) and second (clear) pulse. These pulse parameters (voltage and width) will be swapped when measuring the second transient. So here the first pulse has the values of the clear pulse and the second pulse has the values of the injection pulse. After the 2 measurements the first transient will be subtracted from the second one as described above. This method is similar to Double-Double-DLTS (DD-DLTS).

3.2.2 Edit menu

By the edit menu it is possible to edit and modify the data in the memory. The file itself will not be changed. After reading the file again you lose the changes. For changes of the file you have to save the file, here you get a question for overwriting.



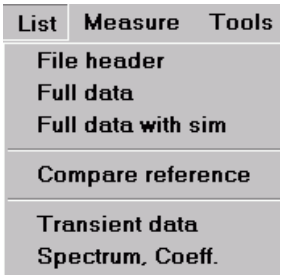
Copy ASCII curve copies the time and transient values line by line in an ASCII format to the clipboard. You can define the delimiter and the exponential format in the menu ASCII parameters. You find it in Tools of the plot or list program.
Approximation was already explained in chapter 2.6.2.

At **user class 5** here are: Edit ASCII curve, Save to buffer, Simulate, Change data, 'New CR, CP, Ns'. The last function is similar to that one for the isothermal file, see chapter 3.3.2.1.

At **user class 6** here are: Edit ASCII file, Edit curve by plot, Paste ASCII curve, Edit Tools. Edit ASCII file means that the complete file will be shown in an ASCII editor, here you can edit all data (header and data arrays). After leaving the editor the changes will be applied for the memory data but not for the file itself. Use this option very careful because there is no data check. You find a description of the data structure in the file Data.Txt.

3.2.3 List menu

By the list menu it is possible to list the file header, the full data and the measure data.



A similar list of the file header will be shown in chapter 3.4.3.1.
The full data list and the full data with simulation will be explained in the next chapter. Both show the sample and measurement parameters and the evaluation.
The transient will be listed as lines and columns. In the first line there is the first time and transient point and so on. Three kinds of view here are possible: the data grid, the image without and with header and the ASCII editor, for more details see chapter 5.4.
The **spectrum** data will be listed similar to the transient data, it shows the frequency, the spectrum and the cosine and sine coefficients.
At **compare reference** you have to input the file name of a reference file. The list is similar to the full data list, but only the 2. block (starting with Tw) and the 4. block (starting with tau) will be shown for the main (current) and the reference data. Additionally the difference can be listed. Additionally the difference can be listed, here you can define to take the difference from reference – data or the opposite.

At **user class 5** the ratio of coefficients can be listed. Data in a manual scan order can be listed if the contact string (sample parameters, chapter 2.4.4) has 2 characters.

3.2.3.1 Full data

```
Name    = TestID@A_003.YEA
Comm    = Standard
ID      = TestID          rcID    = 1013
Date    = 2010-08-17      Type    = n-Si
Area    = 8.00E-03 cm²    NS      = 2.00E+15 cm⁻³

Tw =   1.024 s    t0 =  12.000 ms  N  =     512     T  = 240.00 K
UR =  -5.000 V    CR =  43.865 pF  IR =  -3.302 pA  DT =   0.00 K
UP =  -0.500 V    CP =  98.679 pF  tP = 100.000 us
y0 =    1224 D    yN =       4 D   DC =       0 D
Av =       2      Rg =       2     Af =      64

              a0/2-DC = 159.830 fF
b1 = 159.374 fF  a1 = 147.800 fF
b2 = 121.991 fF  a2 =  56.556 fF

tau(a1,b1) = 175.737 ms     Amplitude =    1.000 pF
tau(a2,b2) = 175.768 ms     NT        = 9.12E+13 cm⁻³
tau(b1,b2) = 175.791 ms     NTs       = 1.75E+14 cm⁻³
tau(a1,a2) = 175.736 ms     Energy    =    0.550 eV
tau(Tw/4)  = 175.750 ms     tau,ts/Tw = 0.17,1.34
tau(Tw'/2) = 175.747 ms     ExpClass  = 1.00
tau(a0,b1) = 175.690 ms     TauClass  =   75
```

The **full data list** contains the relevant sample and measurement parameters and the results of the direct evaluation:

Name : Base file name without ID and data extension DLT.
Comm : Comment
ID : Sample identification, see in 2.4.3
rcID : Record ID in the file data base
Date : Date of measurement
Type : Material name and type of doping (n- or p-type).
Area : Area of sample contact
NS : Shallow doping concentration

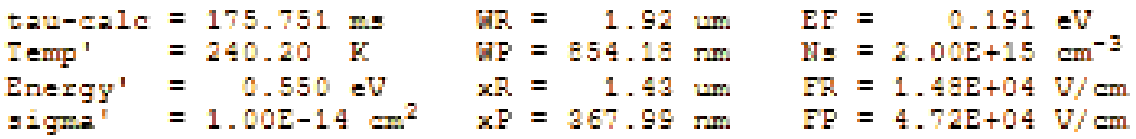
Tw : Period width = Time of one transient, start at t0
t0 : Time between end of pulse and first transient data point
N : Numbers of sampling (transient) points
T : Temperature (average before/after measurement)
UR : Reverse bias voltage
CR : Capacitance at reverse bias
IR : Leakage current at reverse bias voltage
TD : Temperature difference after – before measurement
UP : Pulse voltage
CP : Capacitance at pulse voltage
tP : Pulse width
TV : Temp. difference sensor 2 (sample) – 1 (control), visible at 2 sensors
y0 : First transient value in digits
yN : Last transient value in digits
DC : Transient offset in digits

Av : Numbers of averages
Rg : Range of capacitance bridge or current amplifier; if pre-amplifier > 1 then it will be listed here as 2. value, for example 2,8 for pre-amplifier 8
Af : Amplification of transient amplifier

an : n-th cosine coefficient
bn : n-th sine coefficient

tau(a1,b1) : Time constant calculated by a1 and b1, will be used as tau.
tau(a2,b2) : Time constant calculated by a2 and b2.
tau(b1,b2) : Time constant calculated by b1 and b2.
tau(a1,a2) : Time constant calculated by a1 and a2.
tau(Tw/4) : =tau(a1L,b1L), time constant calculated at the first quarter of Tw.
tau(Tw'/2) : =tau(a1M,b1M), calculated by tau(a1,b1) with Tw'=Tw/2, t0'=t0+Tw/16.
tau(a0,b1) : Time constant calculated by a0 and b1.
Amplitude : Amplitude of the transient.
NT : Trap concentration, standard approximation. Ns is necessary for this value.
NTs : Trap concentration, calculated with the space charge region, see 2.4.2.2.
Energy : Calculated from tau and from in the sample parameters defined capture cross section.
tau/Tw : Time constant divided period width.
ts/Tw : ts is the time when the transient has decreased to the ADC (Analog Digital Converter) resolution.
ExpClass : a1/a2 * b2/b1, is 1 for a single exponential transient.
TauClass : Classification of the tau calculation, see chapter 1.3.4.

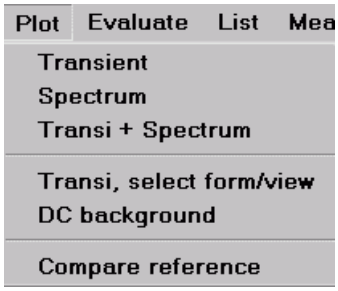
At **full data with simulation** the emission time constant and some other values will be calculated from the input of activation energy and capture cross section sigma. At the input you can select to take these values from the local fit parameters, the sample parameters or the simulation levels. Following will be shown at the top of list instead of the first block:



tau-calc : tau calculated by the measured temperature and from the given energy and capture cross section.
WR : Width of space charge region at reverse bias UR.
EF : Fermi level.
Temp' : Temperature calculated by the evaluated tau(a1,b1) and the given energy and sigma.
WP : Width of space charge region at pulse voltage UP.
NS : Shallow doping concentration.
Energy' : Energy calculated by the measured temperature, the evaluated tau(a1,b1) and the given sigma.
xR : Cross point with fermi level at UR.
FR : Field strength at UR.
sigma' : sigma calculated by the measured temperature, the evaluated tau(a1,b1) and the given energy.
xP : Cross point with fermi level at UP.
FP : Field strength at UP.

3.2.4 Plot menu

By the plot menu it is possible to plot the measure data.

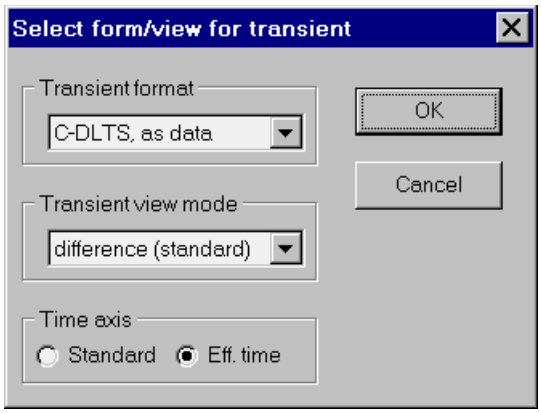


Transient shows the transient without evaluation. In the Evaluate menu of the plot program there are menu entries for Fit and Library. Fit compares the current transient with a simulation curve, library compares it with levels in the library. The inputs are similar as in chapter 3.4.4.8 described.
Spectrum is the plot of the frequency spectrum.
By Transi + Spectrum both will be shown as in chapter 3.2.1.2.
A plot with selection of transient format and view is possible.
DC background shows the transient which was measured for calculation the DC offset.
Compare reference compares the current data with a reference file, see chapter 2.6.1.

If the transient file comes from a data set with many transients then here is a menu entry to read and plot the different curves as described in chapter 5.1.7.

At **user class 5** here are: Special plots (logarithmic axis, …), Coefficients (a_n, b_n, ratio), Fit transient, ITS transient, Averaged/first transient, Plot manual scan, Compare C/U-transients. For the fit you have to input the numbers of levels and each amplitude and time constant. Then the current transient and the simulated transient will be plotted. The manual scan is available if the contact string length is 2.
At user class 6 and N>=2048 a spectrum about parts of time axis is possible.

3.2.4.1 Transient with selection of form/view



For this transient plot you can select the **transient format**, depending from the DLTS mode:

C-DLTS, as data:	CR-C, this is the standard.
CR^2/C-CR:	MIS inversion.
CR^3/C^2-CR:	MIS inversion.
(CR-C^2/CR)/2:	It is also called C^2-DLTS.
U-DLTS:	calculated

Following **transient view modes** exist:

absolute:	The absolute capacitance, not the difference from CR will be shown.
difference:	The difference CR-C will be shown, this is the standard.
difference, text:	The difference CR-C will be shown, at the y-axis of the plot this will be denoted as CR-C(t) instead Transient.
without DC:	The difference will be shown without the measured DC offset.
without yLast:	The difference will be shown, from all transient points the last transient point will be by subtracted.
digits:	The transient will be shown in digits of the ADC.

The **time axis** can be the standard one or the effective time. Effective time subtract from the time axis the phase delay of the bridge and the analog anti-aliasing filter. Evaluations use internal the effective time.

3.2.4.2 DC background

A background transient without pulse will be measured before the real transient measurement. This background transient uses normally the same sample interval as the real transient except it is too low or too high. The DC value will be calculated from this transient by averaging. The availability of this plot feature depends on your hardware.

Following **plot modes** exist:

All, digits: Shows all data points of the DC background transient. In opposite to the next modes the dimension of the y-axis is digits and not the absolute dimension.

All points: All data points of the DC background transient will be shown.

Used for DC: Only those points will be shown which will be used for the DC calculation. The measurement time is here normally a multiple of the reciprocal power frequency, for example 120 ms at 50 Hz power frequency.

Power of 2: A power of 2, means 32, 64 or 128 data points will be shown.

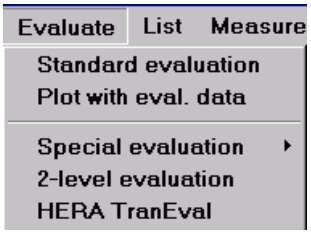
33 points: Only those 33 data points, which will be used for the internal tempscan transients, will be plotted, see also chapter 3.3.4.5.1.

Spectrum: The spectrum of the DC background transient will be shown.

Compare: Compares the standard transient (transient symbol) with the DC background transient (line symbol).

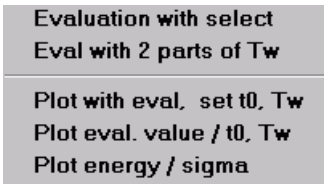
3.2.5 Evaluate menu

The possibilities of the evaluation depend on the kind of sample (Schottky diode or MIS capacitor) and the selected transient evaluation (sample parameter menu). So the Zerbst menu appears if the sample was selected as MIS sample. All measured data points will normally be used for the calculation. If the tau class for the used time law is better than 55 no other evaluation is necessary. The following menu will be shown for a Schottky diode and exponential evaluation.



The standard evaluation list the data as shown in 3.2.3.1.
Plot with evaluation data shows transient and main evaluation as at the main canvas, described in chapter 3.2.1.1.
The 2-level evaluation is a special technique to evaluate 2 overlapping exponential transients by the DLTFS method.
HERA TranEval will be explained in the HERA chapter.

Special evaluation opens a sub menu.



Evaluation with select gives the possibility to select the transient format (chapter 3.2.4.1) and the evaluation mode (2.4.4.2).
An evaluation compares the results over the full period width, the first quarter and the medium quarter of Tw.

A plot and evaluation by manual selection the t0 and Tw range is possible. So only a part of the measured transient can be evaluated separately. t0 and Tw must be marked by the mouse after calling 'Set t-start/end' in the evaluate menu of the plot program. The new Tw' will be corrected by the software because Tw=N*td and N must be a multiple of 32. The new used t0' and Tw' will be marked in the plot by a cross and listed in the header.
This method enables you to avoid or to evaluate separately two time laws appearing in the measured transient. This is only possible if the different time laws are not overlapping over the total period width. For example, two exponential time laws with time constants of 10 ms and 100 ms can be separated, two of 40 ms and 50 ms not.

A plot tau versus t0 or Tw shows the influence of t0 or Tw to the evaluation.
A plot energy versus sigma shows the energy calculated by the time constant, the temperature and the various capture cross sections.
At user class 5 there is the possibility to list some statistic data of transient and evaluation.

A special evaluation exist for direct capture transients. The inputs are similar as for the indirect capture measurement as described in chapter 3.3.6.1.4, except that you can not select the data origin and y-axis. All other physical calculations in the Transient Module are for the emission process, for example the calculation of energy at the evaluation list.

Note: The evaluation takes into account the phase delay of the bridge $t0_{PhaseBridge}$ = 30 us and of the anti-aliasing filter $t0_{PhaseFilter} = 0.5/f_{Filter} = 2*td$. td is the sampling interval. The corrected time will be called effective time. For the evaluation then the effective t0 will be used: $t0_{eff} = t0 - t0_{PhaseBridge} - t0_{PhaseFilter}$.

Tip: Use 'Evaluation with select' for temporary checking the results of another evaluation mode as selected in the sample parameters.

3.3 Isothermal program

This module enables you to do isothermal transient measurements under systematic variation of one measurement parameter. This measurement parameter can be the period width, the pulse with, the reverse bias, the pulse voltage or another special value. From the Fourier transform we get coefficients to every transient, so we get for example a plot b1(Tw).
Variation of the period width is the most used application, it will be called **period scan** or frequency scan or ITS (**I**sothermal **T**ransient **S**pectroscopy). From the period with scan b1(Tw) we get by numerical normalization a plot versus time constant, b1-norm(tau). Tau and the amplitude of the emission process will be calculated from the maximum position, similar to the conventional tempscan. Period scans at different temperatures yields to an Arrhenius plot which gives trap energy and capture cross section. This method may aid deep level separation.
Variation of the pulse width at a fix period width yields to a special evaluation for the capture cross section. Variation of reverse bias or pulse voltage enables a deep level profile evaluation.

User class 5 enables a parameter variation at a variable period width. This means Tw change for every new parameter, for example UP. A plot b1 versus UP makes here no sense, this kind of measurement is only for the evaluation values tau and amplitude.

From the data **structure** the isothermal module is very similar to the tempscan. Here a parameter like Tw or tP is the x-axis instead the temperature. The period scan is most comparable with the tempscan, here is the period width or calculated from this the time constant the x-axis. In the total chapter 3.3 the period scan will be described as the standard. Only at chapter 3.3.1 (measure) and 3.3.5 (evaluate) the other isothermal kinds will be explained. Because this module is similar to the tempscan module often only a short explanation will be given, for more details have a look in chapter 3.4, for example the selection of coefficients. At period scans often a1 instead of b1 will be used by default because the better energy resolution.

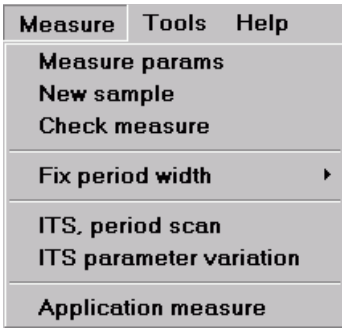
Isothermal data files are only comparable for same kind of measurements. The first character of the data extension is 'P'. The second data extension character (chapter 1.3.3) denotes this **kind of measurement**:

A: Variation of auxiliary voltage, special option
C: Variation of time
D: Variation of drain source voltage
F: Variation of pulse width, linear steps
H: Variation of reverse bias and pulse voltage
I: Variation of optical intensity, special option
L: Variation of pulse width, logarithmic steps
O: Variation of optical wave length, special option
P: Variation of pulse voltage
U: Variation of reverse bias voltage
W: Variation of period width

After measurement or reading data the standard plot will be shown on the main canvas. You can select the face of the standard plot in the menu 'View → Params for standard plot'. The inputs are the same as described in chapter 3.4.4.2.

3.3.1 Measure menu

The measurement menu contains the 3 common functions and isothermal measurements.

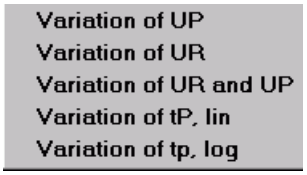


Fix period width means here transient measurements with a fix period width by variation of UR, Up, tP and so on.
At user class 5 the same is possible by a variable period width.
ITS, period scan is the variation of the period width Tw, this is the most used application. You get here the time constant and amplitude of the level(s). Period scans at different temperatures yields to an Arrhenius plot.
ITS parameter variation are ITS (period scan) measurements at variation of an additional parameter, normally the temperature.
Application measure are measurements for a special application with easy inputs.
User class 5 enables a double pulse variation.

During the measurement you see at the top of the main canvas the current transient and at the bottom b1 versus the variation parameter. The parameter list includes the current maximum temperature difference TempX, see chapter 3.3.3.

3.3.1.1 Fix period width

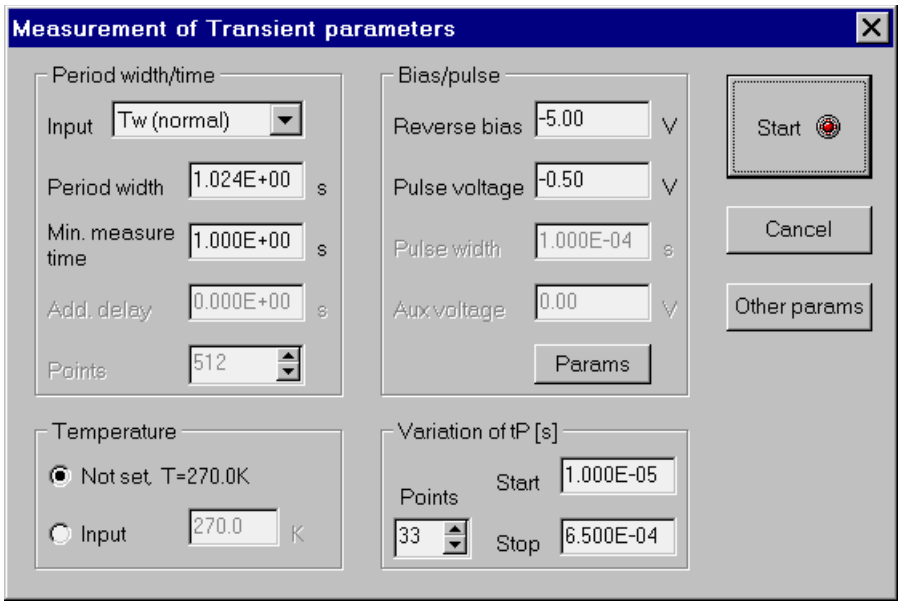
The following gives an overview of the main modes and the main applications:



Variation of pulse voltage **UP**: NT profile, tau versus field
Variation of reverse bias voltage **UR**: tau versus field
Variation of **UR and UP** at fix pulse height: NT profile
Variation of pulse width **tP, linear** steps: indirect capture transient
Variation of pulse width **tP, logarithmic** steps: oxide states

As an example for the variation of a measurement parameter at a fix period width here the variation of the pulse width will be shown.

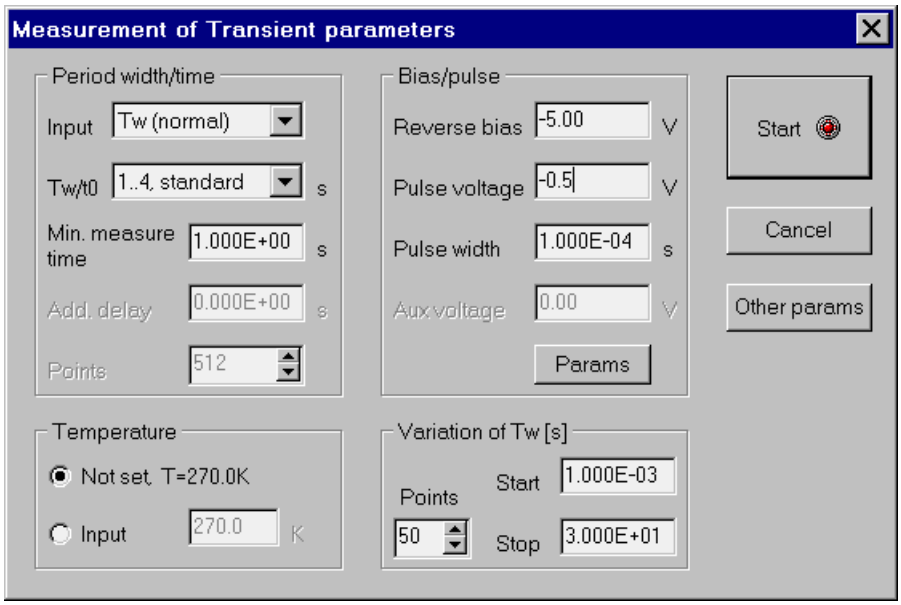
The input groups for period width/time, temperature and Bias/pulse are the same as in chapter 3.2.1.1 explained. The parameter, which will be varied (here the pulse width), is not enabled in the Bias/pulse input group. For the **variation parameter** there is a new input group. You can input the number of points (variations) and the start and stop value.



Other params opens an input window, similar as that one for the period scan.

3.3.1.2 ITS, period scan

Period scans or called ITS (Isothermal Transient spectroscopy) is the variation of the period width Tw. This is the most used application for isothermal measurements.



The input groups for temperature and Bias/ pulse are the same as in chapter 3.2.1.1.
The input group for period/with time is similar as there. Instead of the period width here is an input box for the **Tw/t0** ratio. For the calibration of the Tw-axis to a tau-axis it is necessary that Tw/t0 is constant, see Theory Manual and chapter 3.3.4.1. In detail, Tw/t0_eff which includes the phase delay must be constant. Because the recovery time of the bridge and anti-aliasing filter and the phase delay this is not possible. A small change will be compensated by the tau calculation. The oversampling enables a good phase correction.
Tw/t0 has an influence to the smallest usable Tw (because the recovery times) and to the peak height and so to the SNR (signal noise ratio). Tw/t0 must be small for starting at small period widths, it must be big for a good SNR.

Neglecting the phase delay following compromise modes exist for the **Tw/t0 ratio**:

=1, Dlts optimal: Optimal for the 3 Dlts signals (differences of 2 points, t2=2*t1) but bad for the Fourier coefficients because bad SNR.

=4: Fix ratio with good compromise between smallest Tw and SNR. Only small change of Tw/t0_eff, best for unknown time laws of transient.

=16, good SNR: Good SNR, but start only at bigger period widths possible, so it is bad for fast emissions.

1..4, standard: The standard mode don't use a fix ratio but a compromise. At small period widths it is 1 for using small Tw's, at bigger Tw's it goes to 4 to get a better SNR. Normally the tau-axis calculation from the Tw-axis can compensate this change.

For the HERA transient evaluation it is not necessary that Tw/t0 is fix, this ratio is here not important. Select as ratio 1 or 1..4 to observe fast transients. The HERA coefficient deconvolution should have a fix ratio but 1..4 is also good enough.

Note: At the period scan normally 64 instead 512 points of a transient will be measured. The reason is the Tw/t0 ratio. Don't change this value.

For the **variation of Tw** there is a new input group. You can input the number of points (variations) and the start and stop value. The variation will be done with logarithmic steps.

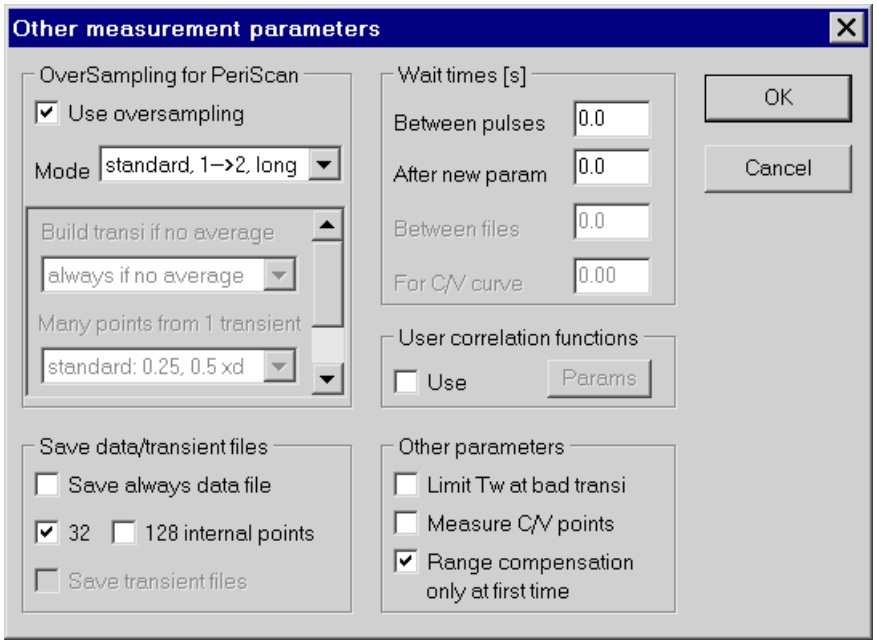
The button **Other params** opens a new input window.

If activating **Save always data file** then you can input the file name at the main window above. The data will be saved then automatically after the measurement without a question. In the other case you get the question for saving. If this flag is activated, you have the possibility to save the complete transients in separate files.

32, **128** or up to **512** transient points can be saved in the isothermal file, called **internal points**. At the period scan normally only 64 transient points will be measured. So here it is unreasonable to save the complete transients in separate files, 32 internal points are enough.

Depending on the kind of isothermal measurements different **wait times** are possible:

- Between the pulses
- After a new parameter (between each data point)
- Between isothermal files at a parameter variation
- Between the single points of a C/V curve



Some separate variables exist for the first 2 times depending on the kind of variation. A separate variable for the first wait time exist at a period scan with tM<=100us (no averaging). The wait time 'between pulses' replaces here the global input value of chapter 3.2.1.1.2, the global input is forbidden in the isothermal program.
Remember that the software waits this time not only at averaging (between the pulses) but also when repeating the transient measurement because bad amplification. It will also be used between each data point and takes into account Tw. This waiting can be important especially when the pulse width is not big enough to fill all traps (particularly at a period scan) or at variations of the pulse width (capture measurement).

C/V points at voltages which will be used at the isothermal measurement can be directly measured without compensation. At the period scan these are only UR and UP. At a variation of UR or UP this is a complete C/V curve.
The **range compensation** (bridge) can be done only at the first transient instead at every transient. If not varying UR this is the default value.
Limit Tw at bad transients means that the measurements breaks when all transient measurements until 5% of stop Tw are bad. This saves measurement time.

The **user correlation functions** will be explained in chapter 3.4.6.3.

If you have the HERA option and the special hardware then you can here activate the **oversampling** for the period scan. This is a very important feature:
Instead of 64 points the transient oversampling measurements uses up to 65000 points. From these big transients are many transients with 64 points will be formed by digital filtering. These give also many b1 versus Tw points from one oversampled transient. In opposite to a logarithmic transient the SNR is good because at small period widths (smaller as the minimum measure time tM) transients will be averaged. A reduction of the total measurement time down to 10% is possible.

Following **oversampling modes** exist:

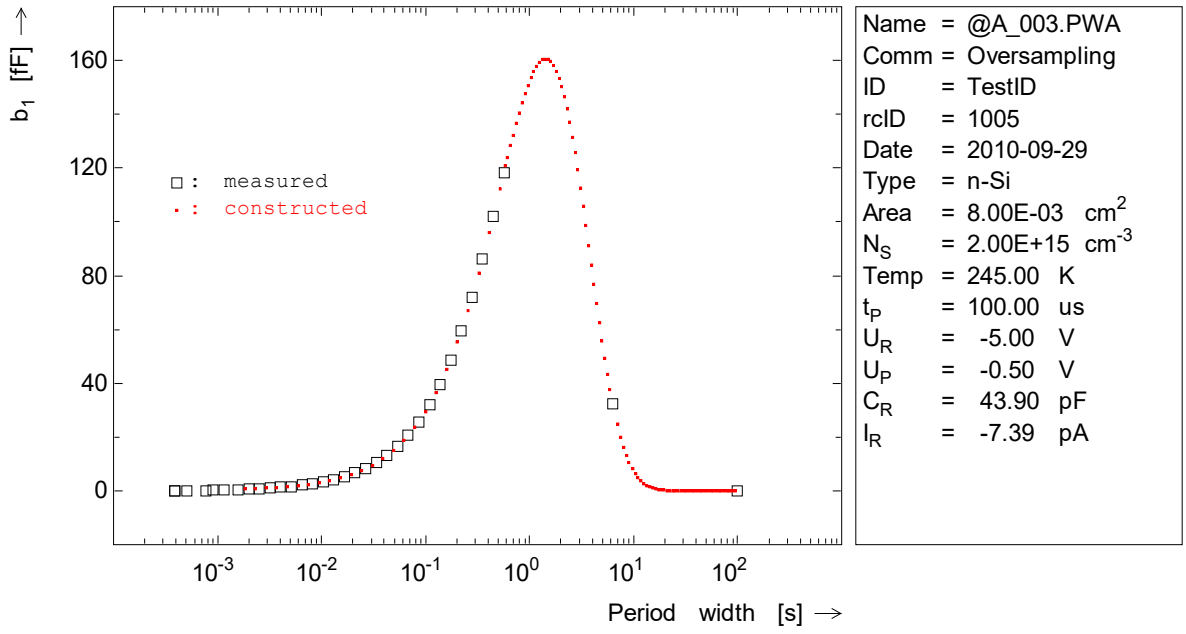
use 1 long transi: If Tw>tM, that means no averaging, then at the end 1 long big transient will be measured and from this the transients with big Tw's formed.

long transients: If Tw>tM all transients will be formed from long big transients. Depending on tM and the stop value for Tw this can be 1 or more big long transients.

standard, 1-->2, long: For Tw>tM as before. If Tw<tM and Tw>10* $t0_{Bridge}$ then 2 or 3 transients will be formed from one measured. Whether this is possible, depends on Tw, t0 and number of points. Takes into account the phase delay. This is the standard mode.

input of parameters: More input possibilities, only for experts.

The following picture illustrates the standard oversampling mode. The big black squares denote the oversampled measured transients, the small red symbols denote the constructed transients.



The simulation above shows also the influence of the Tw/t0 ratio to the peak height. Here the standard mode (1..4) was used, in the peak maximum this ratio is 4. The amplitude of the simulation was 1 pF. At bigger Tw/t0 ratios you get about 250 fF for the b1 maximum, here at Tw/t0=4 it is only 160 fF. The time constant of the simulation was 1 s, the peak of b1 is at about 1.4 s.
The phase correction will be shown only after and not during the measurement**!**

Use the oversampling method always if possible to save measurement time and to get more points in the isothermal plot. Only if you have slow statistic drift problems it could be better to switch off this option.

If the levels are not completely filled by the used pulse width then **jumps** in the period width scan may occur when using oversampling. If working in long oversampling mode (big Tw's) then you don't average so that you have only 1 pulse. At averaging (small Tw's) you have more pulses. The number of averages depend on Tw because the fix measurement time. At too small pulse widths this adds the amplitude if the emission process is not finished. Even without averages the amplitude will be added at the next Tw if the emission process is not finished and the traps will not completely be filled by one pulse. The jumps in the b1/Tw plot come then from the different emission amplitudes.
This effect has also an influence on the measurement without oversampling. Also there are jumps possible. But without averaging you don't see here often a jump, the amplitudes change continuously from Tw to Tw. You can see the influence of averaging by comparing b1 with b1T (chapter 3.4.4.3).
To avoid the 'jumps' problem try bigger pulse widths. Then every measurement at the various Tw's start with a complete filled level. This may be not possible especially at oxide states. Waiting times can often help, see the description at the beginning of this chapter.
When using oversampling at not complete filled levels then use as oversampling mode 'use 1 long transi' or, better, use standard oversampling without averaging, means setting 'Min. measure time' tM to zero.

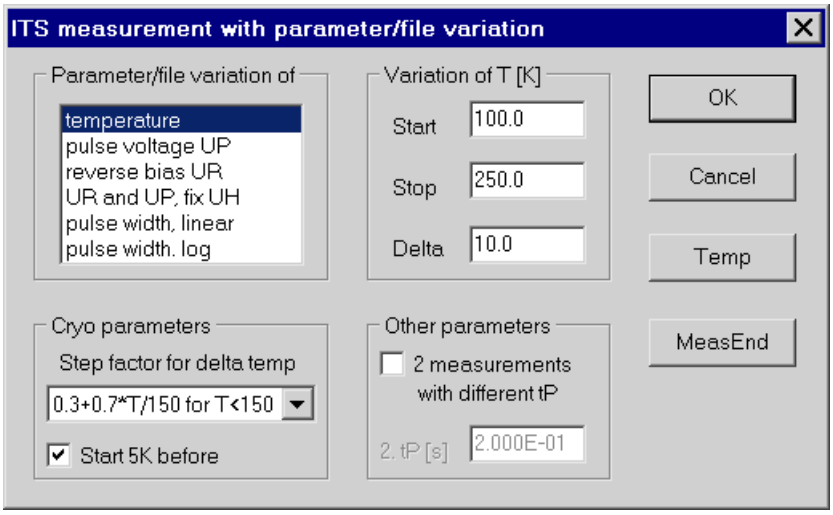
A **special feature** exist when using the standard oversampling and setting the 'Min. measure time' tM to zero. The transients will here be constructed by 3 or 4 long measurements with each one pulse. The long measurements overlap so that in the overlap region 2 transients with the same Tw can be build from 2 measurements. For example, the last constructed transient of measurement 1 has the same period width as the first of measurement 2. If the level is not completely filled and the emission is not finished, the 2. measurement has a bigger amplitude. The two transients of the overlap region with the same Tw enable a **filling calibration** of measurement 2, the calibration factor is the ratio of both b1. The coefficients of all constructed transients of measurement 2 will be multiplied by this factor. This will be done automatically after the period scan but you can undo it, see chapter 3.3.2.2.
No calibration is available by the input 0<tM<=100us, but all transients will also be build from some long oversampling measurements.
When not averaging and constructing all transients from oversampling measurements, the SNR is for small Tw's not so good as with averaging. Nevertheless each constructed transient will be digitally filtered optimal in respect to its sample interval.

As a **summary**, 3 types of period scan measurements cover the most applications:

- **Standard oversampling:** Tw/t0=1..4, standard oversampling mode, phase correction, tM=1s. This standard mode allows a wide range of Tw with a good SNR and a small total measuring time.
- **Filling calibration:** Tw/t0=4, standard oversampling mode, phase correction, tM=0, no average. This allows an amplitude calibration and has a fix Tw/t0 which avoid normalization problems at unknown time laws. The disadvantage is the bad SNR for short Tw's. It is especially for oxide states, see chapter 3.3.1.4 and 6.3.6.3.
- **No oversampling:** Tw/t0=1..4, no oversampling and no phase correction, tM=1s. This classic mode can be helpful at statistic drift problems but needs a long time.

3.3.1.3 ITS parameter variation

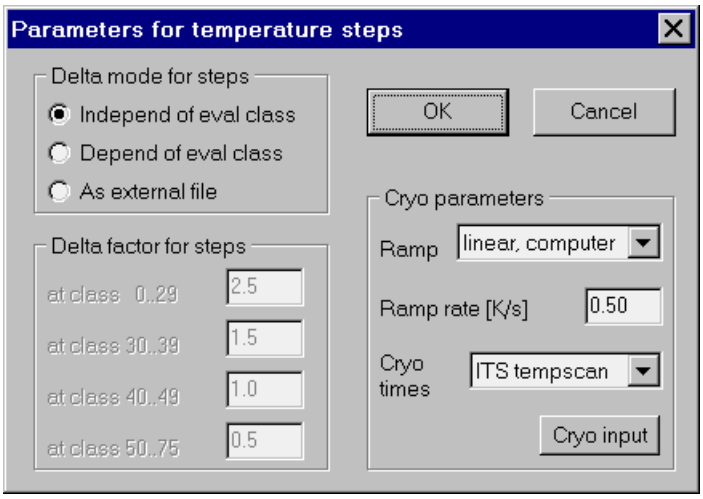
ITS parameter variation are period scans measurements at variation of an additional **parameter**, normally this is the temperature. Instead the temperature you can select UP, UR, UR and UP, tp in linear or logarithmic steps. The inputs of this window depends on this parameter. The picture on the right shows the input for the temperature variation.



Activating a flag then **2 measurements** with different pulse widths are available for every temperature. This can be helpful to separate 2 levels with a big difference of capture cross section. After the measurement you can subtract the corresponding isothermal files to get the emission of the level with the small capture cross section. The second pulse width should be bigger than the first to reduce an influence of the first period scan to the second one.

You have to define the start, stop and delta temperature for the **variation**.
The cryo parameters input group and the input window opened by the 'MeasEnd' button will be explained in chapter 3.4.1.4.

The **Temp** button opens a new input window for further temperature/cryo parameters.
The **Delta mode** for the temperature steps is normally independent from the evaluation class, for more details have a look in chapter 3.4.1.1.2.
The ramp mode (boxcar, linear controller, linear computer) will be explained in chapter 3.4.1.4.
The **ramp rate** defines the velocity of the temperature ramp.



Cryo times selects the parameter set for the cryo system:

isothermal: Parameter set for the standard isothermal measurement.
ITS tempscan: Parameter set for a ITS tempscan, this means ITS parameter variation of the temperature. This mode should be used here.

The button **Cryo input** allows to modify the selected parameter set, see chapter 2.4.6.2.

After the first parameter input window you get the standard input window of the period scan as described in chapter 3.3.1.2. The input of the temperature is there not possible. Additionally there is the input for the first isothermal **file name**, separated in path and base file name.

In the following example with 15 temperature data points is the base file name input ID@A_00T001.PWA.DLT, the files will be saved into the defined subgroup. The sub string 'T001' is a must.

Created files: ID@A_00T001.PWA.DLT → period scan at 1. temperature
ID@A_00T002.PWA.DLT → period scan at 2. temperature
….....
ID@A_00T015.PWA.DLT → period scan at 15. temperature

If saving complete transients, then these transient files will be saved into a sub directory as explained in chapter 3.4.1.4.

3.3.1.4 Application measure

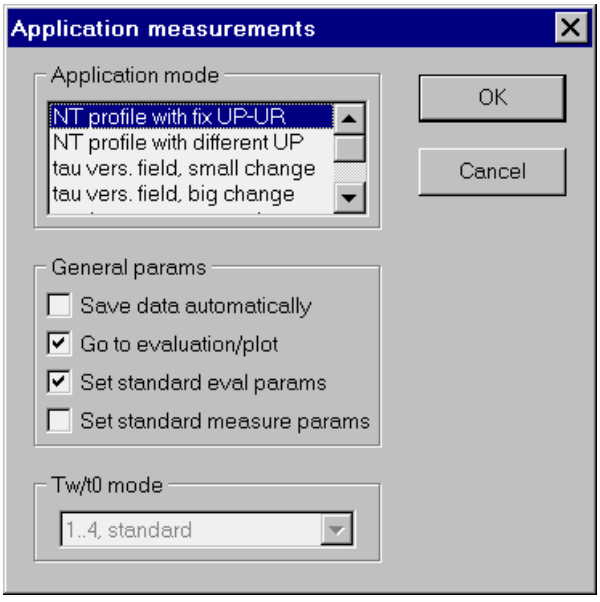
These are measurements for a special application with easy inputs. Applications exist for the deep level profile, for the field dependence of time constant, for the calculation of capture cross section by capture measurements and for the period width scan.

In detail following **application modes** exist:

NT profile with fix UP-UR:	Fix Tw and variation of UR and UP with a fix pulse height. Use this for small changes of deep level profile.
NT profile with different UP:	Fix Tw and variation of UP. Theoretically the best but high sensitivity necessary because differentiation.
tau versus field, small change:	Fix Tw and variation of UP, only possible at small changes of tau.
tau versus field, big change:	Variable Tw and variation of UP, also possible at big changes of tau.
capture measurement:	Fix Tw and variation of tP in linear steps. This gives an indirect capture transient with the capture cross section as result.
tau maximum by period scan:	Period scan, jumps to the ITS plot (chapter 3.3.4.2).
deconvolution by period scan:	Period width scan, jumps to the HERA coefficient deconvolution plot.
MIS period scan, 2 tp's:	2 period scans with Tw/t0=4, no averaging, filling calibration and different pulse widths. The 2. pulse should be the larger one. It is especially for oxide states.

More information for the specific measurement and evaluation will be given in chapter 3.3.4.2, 3.3.6 and 6.3.6.3.

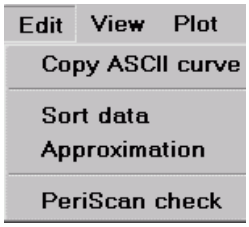
If activating **Save data automatically** then you can input the file name at the main input window. The data will be saved then automatically after the measurement without a question.
Go to evaluation/plot jumps after the measurement to the standard evaluation or plot.
Set standard eval params sets newly the standard parameters, in the other case the current values will be used.
If activating **Set standard measure params** the parameters for the measurement will be set to standard values.



The inputs depend on the application mode. The main input window for isothermal measurements opens after clicking OK.

3.3.2 Edit menu

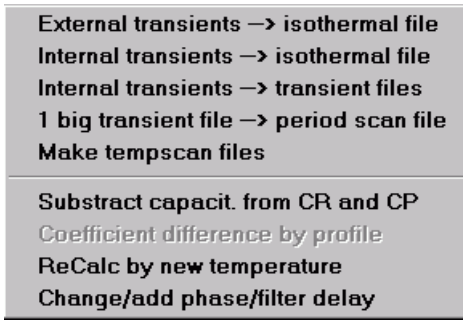
By the edit menu it is possible to edit and modify the data in the memory. The file itself will not be changed. After reading the file again you lose the changes. For changes of the file you have to save the file, here you get a question for overwriting.



'Copy ASCII curve' copies the x-axis data and one selected coefficient or other measured value line by line in an ASCII format to the clipboard. You can define the delimiter and the exponential format in the menu ASCII parameters. You find it in Tools of the plot or list program.
'Sort data' sorts the data by the x-axis, normally not necessary.
'Approximation' was already explained in chapter 2.6.2.
'PeriScan check' makes the filling (re)calibration, if available, and delete data with Tw/t0<>const. of a period scan.

At **user class 5** here are: Edit ASCII curve, Simulate, Delete data, Change data, 'New CR, CP, Ns', Edit Tools. The common functions of 'Delete data' function were described in chapter 2.6.3, many of the additional features for the tempscan are also valid for the isothermal data, see chapter 3.4.2.3.

At **user class 6** here are: Edit ASCII file, Edit curve by plot, extended Edit Tools.
Edit ASCII file means that the complete file will be shown in an ASCII editor, here you can edit all data (header and data arrays). After leaving the editor the changes will be applied for the memory data but not for the file itself. Use this option very careful because there is no data check. You find a description of the data structure in the file Data.Txt.



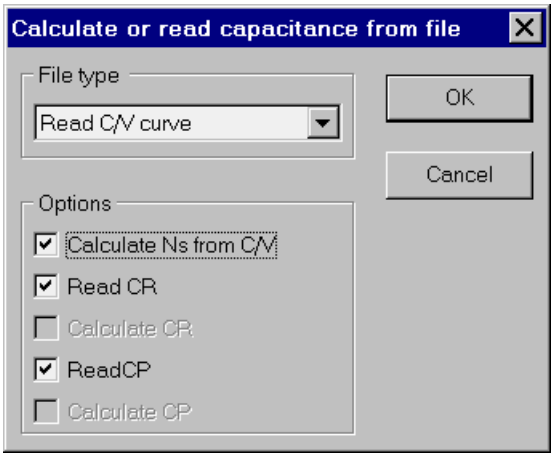
The extended tools give at user class 5 and 6 depending on the data extended possibilities. So transient files can be saved into an isothermal file and the opposite. Temperature depending period scans can be transferred into tempscan files with one to 5 different period widths which enables a tempscan maximum analysis. But for the HERA transient evaluation use better the quasi-logarithmic transient of the isothermal analysis, see chapter 6.1.3.4.

All these features and the other features at user class 5 or higher are only for user with much experience.

3.3.2.1 New CR, CP, Ns

This tool applies CR, CP or Ns from a C/V curve into the isothermal data file. The reason for applying these values will be discussed in chapter 6.4.2. This tools here is similar to that one for the tempscan. But here only one C/V curves is necessary because all isothermal measurements were done at the same temperature.
Because different isothermal files exist there can be some differences. So have the PP, PU and PH-files various UR or/and UP. Normally here an applying of CR and CP is not good because these values come from an automatic C/V curve before the isothermal measurement. This tool here is more for the period scan.

Following **options** exist:



'**Read CR**' and '**Read CP**' from a C/V curve.

'**Calculate CR**' and '**Calculate CP**' with the current isothermal data. These options are only enabled if 'Read CR resp. CP' is not activated.

By '**Calculate Ns from C/V**' Ns will be calculated from the selected C/V curve and applied as new sample parameter. Be careful a little with this option because the regression range will be set automatically. Instead of this option you can also input a new Ns value into the sample parameter.

Following **file types** are available:

Read C/V curve: A C/V curve will be read, CR and CP at UR and UP can be applied.

Read C+G/V curve: Reads C/V and G/V curve from a file (extension KB?) and calculates the serial capacitance. Serial capacitances CR and CP at UR and UP can be applied.

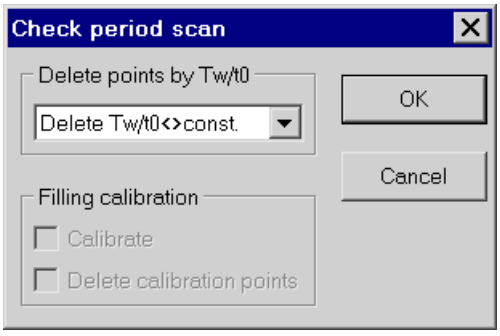
Last C/V curve: As the first file type but the last measured C/V curve will be used.

Paste C/V curve: As above but ASCII x/y-data will be pasted as C/V curve from the clip-board. The x- and y-data must represent U and C.

No file, only calculation: No additional file will be used, CP can be re-calculated. It can be helpful if you have changed Ns. You can also calculate CR.

3.3.2.2 PeriScan check

Sometimes it can be necessary to have only data with same Tw/t0 resp. similar Tw/t0_eff ratio, see discussion in chapter 3.3.4.1 and 3.3.4.3.



'**Delete Tw/t0<>const.**' deletes all data points which Tw/t0 ratio differs from that of the last data point (biggest Tw). The phase delay will here not be taken into account. If Tw/t0=1..4 was selected at the measurement, the first data points will be deleted (Tw/t0<4).

'**Delete Tw/t0_eff<>const.**' deletes all data points where Tw/t0_eff differs more than 5% from the last data point. The phase delay will here be considered. This avoids eventual artifacts of the normalization.

'**Delete too big Tw/t0_eff**' deletes all data points which Tw/t0_eff is more than 3% bigger than that from the last data point.

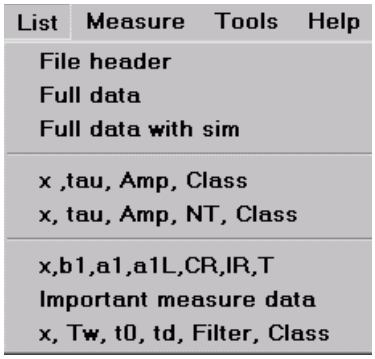
'**Delete bad Tw/t0_eff**' delete points with jumps in the Tw/t0_eff ratio. These jumps may also be visible in b1 versus Tw, usually not in norm. b1 versus tau.

Chapter 3.3.1.2 describes also a period scan measurement with a **filling calibration**. The plots show then the calibrated coefficients but not the calibration points. These are the data which Tw has the same value as the data point before. Nevertheless the data array contains these points. You can undo (**recalibrate**) this calibration when already done. Then also the calibration points will be shown, all data are not calibrated. A new calibration is possible after an undo.

'**Delete calibration points**' deletes those data which Tw has the same value as the data point before (overlapping region). This action disables a new (re)calibration.

3.3.3 List menu

By the list menu it is possible to list the file header, the full data and selections of measure parameters, coefficients and evaluation data.



A similar list of the file header will be shown in chapter 3.4.3.1.
The maximum temperature difference between all transients, called TX or TempX, will be listed additionally in the isothermal program. It is a hint for the temperature stability and must be small to avoid misinterpretations. So a change of the coefficients can also be based on the change of temperature. 'Temp' means here at the file header not the temperature of a single transient but the averaged temperature over all transients.

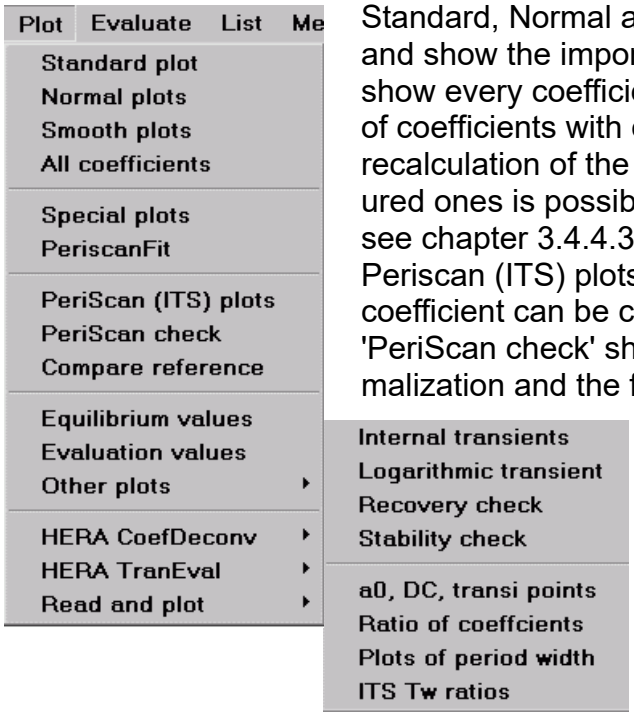
A similar explanation of the full data list and the full data with simulation will be given in chapter 3.2.3.1. This list will be shown for each data point.
The other possibilities will be listed as lines and columns. In the first line there is the first data point and so on. Three kinds of view here are possible: the data grid, the image without and with header and the ASCII editor, for more details see chapter 5.4. The most abbreviations are explained in chapter 1.3.4. t0-fil means the phase time of filter and bridge.

'**Important measure data**' lists the temperature, CR or IR, the range of the capacitance or current (Range), the amplification of the transient recorder (Amplif) and the absolute maximum of the transient data in digits (MaxDig). When the amplification of the pre-amplifier is bigger than 1, this amplification will be listed behind the range. So range '2,4' means range 2 and pre-amplifier 4. An additional column called 'Flag' may give some additional information. If invalid data exist, these will be shown only in this list function. Then two additional columns exist, for more details look in chapter 3.4.6.4.

At **user class 5** there is a sub menu for the 2-level and for the HERA transient evaluation. Here is also a user defined list possible by manual selecting of the values for the listing.

3.3.4 Plot menu

The plot menu shows single or more coefficients, equilibrium or evaluation values, HERA plots and internal saved transients. The plots will be shown in the Standard or Application Plot program. The input groups Interpol/Smooth and Connect points are already explained in chapter 2.7, see especially note in 2.7.1.
The plots, especially for the period scan, are very similar to the tempscan plots in 3.4.3. So not all plots will be explained here but only in the tempscan module. Instead the temperature as x-axis here the period width or, calculated from this, the correlating time constant is the x-axis. The inputs are the same, additionally here is an input for the selection of the x-axis, see chapter 3.3.4.1. The selection of coefficients, the normalization and the logarithmic y-axis will be explained in chapter 3.4.4.1. Additionally a so called ITS-signal exist.

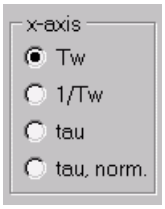


Standard, Normal and Smooth plots have the same input window and show the important coefficients. 'All coefficients' allows to show every coefficient. Special plots show important collections of coefficients with optional energy axis. At the PeriscanFit a recalculation of the coefficients and comparison with the measured ones is possible (exp. evaluation) similar to the TempFit, see chapter 3.4.4.3.
Periscan (ITS) plots shows one or more coefficients versus tau. A coefficient can be compared with one from a reference file. 'PeriScan check' shows Tw/t0, its influence on the amplitude normalization and the filling calibration.

Other plots opens a sub menu. Internal transients shows the transients in the data file. One tool checks whether the used recovery time is too long. The stability check helps to detect contact problems. The first or last transient point, the offset and some other values can also be shown in this sub menu. The forming of a quasi-logarithmic transient from many transients of a period scan will be described in 3.3.4.5.

Equilibrium values are CR, CP and son on, Evaluation values are tau, amplitude ...
The HERA plots will be explained in the HERA chapter.
For isothermal files of a data set exist a sub menu to read and plot the different curves.

3.3.4.1 x-axis and normalization of period scan



If showing a plot with a coefficient, then you get at the period scan additionally to the inputs at the tempscan module the input for the x-axis.

Following modes for the **x-axis** exist:

Tw: The measured period width will be taken as x-axis.

1/Tw: The reciprocal period width will be taken. This will be called frequency because this is the base frequency.

tau: The Tw axis will be numerically calibrated to a tau-axis. The time constant is only valid for the peak maximum. The peak denotes a level with the corresponding emission time constant.

tau, norm.: As before but additionally the y-axis will be normalized to the amplitude. This has also influence on the x-axis because small Tw/t0_eff changes can be corrected. Therefore use this mode instead of 'tau'.

The main evaluation of a period scan is the maximum analysis; time constant and amplitude of a level will here be determined. This needs a plot b1-norm versus tau, therefore the last mode above of x-axis will be used here. From the period width scan b1(Tw) we get by numerical normalization a plot versus time constant, b1-norm(tau), see next chapter.

The **normalization** to the tau-axis and normalized y-axis will numerically be done because no analytical solution exist for the Fourier coefficients. A simulation of the analytical coefficients under variation of tau will be done for each data point. Then the maximum of the coefficient versus tau curve will be searched. The time constant will be applied from the maximum position, the amplitude factor will be calculated by the peak height and the given amplitude of the simulation. These simulations and maximum search will be done for each data point of the period scan. This calculation takes into account that Tw/t0_eff changes with Tw. So the normalization factors for tau and amplitude depend usually on Tw because Tw/t0_eff changes with Tw.
When Tw/t0_eff $t0_{eff}$ would be constant then only one normalization factor of tau would exist for the total period scan, means tau/Tw=const. The same is valid for the amplitude, means b1_norm(Tw)/b1(Tw)=const.
If Tw/t0_eff changes only marginally from one data point to the next, the software doesn't calculate newly the normalization but takes the values from the previous data point.

While t0 includes only the recovery times of bridge and filter (chapter 3.2.1.1.1 and 3.2.5) t0_eff, also named $t0_{eff}$, includes additionally its phase delays. **Tw/t0_eff** can not be 100% constant for the whole period scan. Very small changes of this ratio have no influence, small changes will be compensated by the normalization. Oversampling with phase correction reduces changes in the Tw/t0_eff ratio.

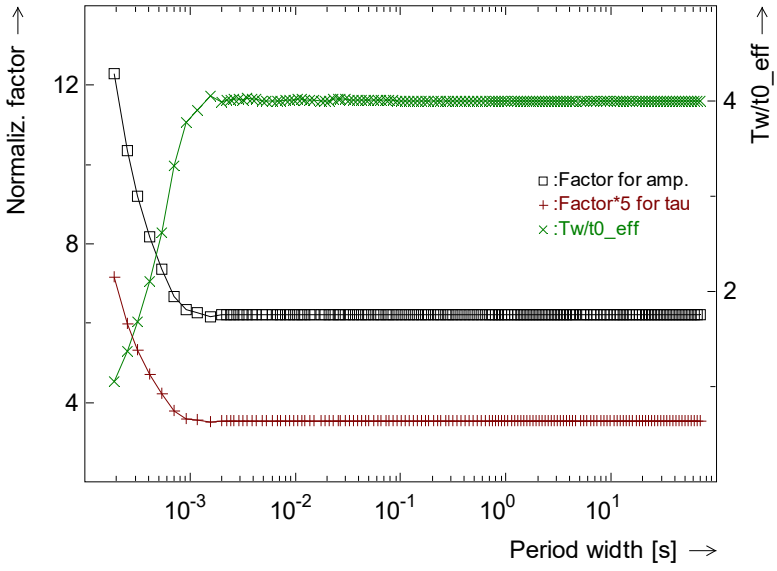
At **small Tw's** resp. tau's the normalization is not perfect and deviations can be visible. When Tw/t0_eff shows bigger jumps or discontinuities, then jumps or discontinuities are visible in the period scan b1(Tw). You have a curve b1(Tw,Tw/t0_eff) instead of b1(Tw) at an evident change of Tw/t0_eff. b1 versus Tw can then be misinterpreted. But the jumps or discontinuities should not be visible in the normalized view because the normalization considers Tw/t0_eff. But effects may also be visible in b1-norm(tau) at very big jumps because the normalization is not perfect, especially when the transient don't follow 100% the expected time law.

The normalization technique needs the correct time law of the transient, here the exponential one. Deviations from the used time law yield to a wrong normalization. Its error is here 'only' a factor for a fix Tw/t0_eff, but a strong change of Tw/t0_eff can give a wrong structure of b1-norm(Tw).
Remember that the described calculation for an exponential time law is only valid in a peak, it will be used in the isothermal and tempscan maximum analysis.

Summary and comparison period scan with and without normalization:

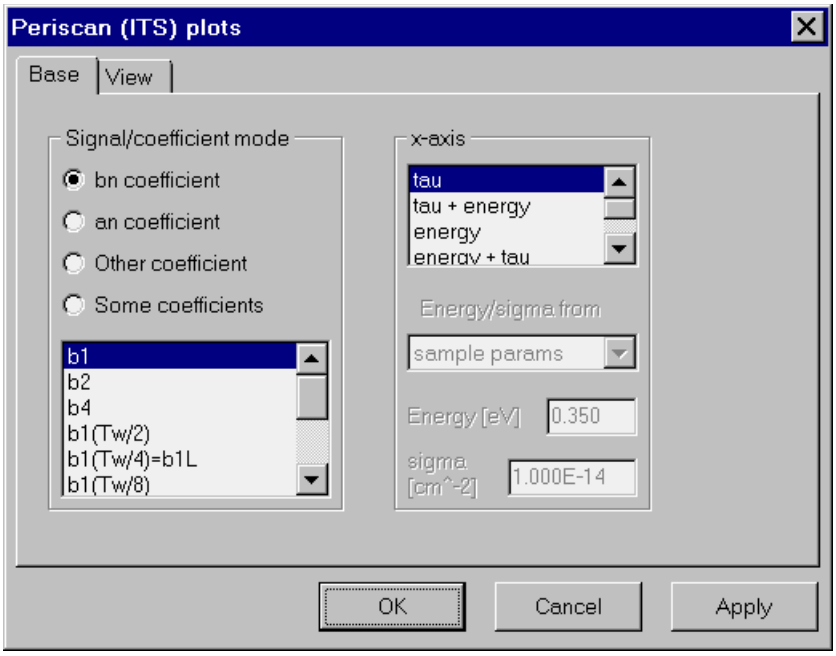
- When Tw/t0_eff is constant then period scan without and with normalization are similar. There is only a factor between both for the x- and y-axis.
- If Tw/t0_eff changes significantly, you have a curve b1(Tw,Tw/t0_eff) instead of b1(Tw). So a reason for a change in the b1(Tw) curve can be the transient (other Tw) or/and a change in the Tw/t0_eff ratio. The normalized curve b1-norm(tau) should be okay.
- The numerical calibration from Tw to tau is only exact if Tw/t0_eff is constant.
- Consider especially the not normalized curve for Tw<10*$t0_{Bridge}$ (2ms) with care because here is a strong change of Tw/t0_eff.
- The Tw/t0_eff ratio is in most cases not a big problem, only Tw's under 2ms can be effected. When using oversampling with phase correction the Tw/t0_eff change is marginal for Tw>2ms.
- The normalization compensates usually the Tw/t0_eff change at known time laws.
- At unknown time laws of transient use the fix ratio Tw/t0=4 for the measurement, see chapter 3.3.1.2. The disadvantage is that the smallest Tw is bigger than 1ms.

The right plot shows the normalization of a period scan with oversampling and phase correction. The black squares denote the normalization factor for the amplitude, the right crosses for tau multiplied by 5 because better overview (tau/Tw*5). The green curve with the right y-axis shows Tw/t0_eff versus Tw. Tw/t0_eff will be constant for Tw>1.5ms.
If not using oversampling and phase correction the ratio Tw/t0_eff changes more, also at high Tw, see example in 3.3.4.3.

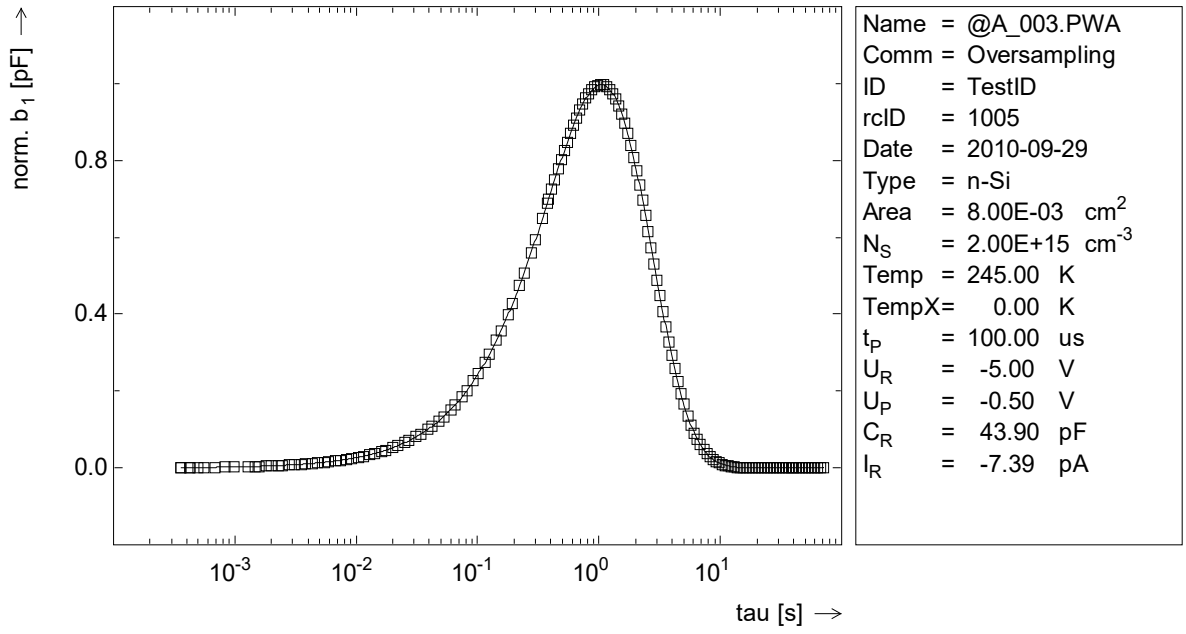


3.3.4.2 PeriScan (ITS) plots

This shows one or more coefficients. Following possibilities exist for the **x-axis**: tau, tau with top energy, energy, energy with top tau, sigma.
For the input of energy or sigma you can decide from which parameter set this value should be applied, either from local fit parameters or from the sample parameters or from one of the simulation levels.
The **View** input sheet contains the input groups for Data/axis (normalization), Interpol/Smooth and Connect points.



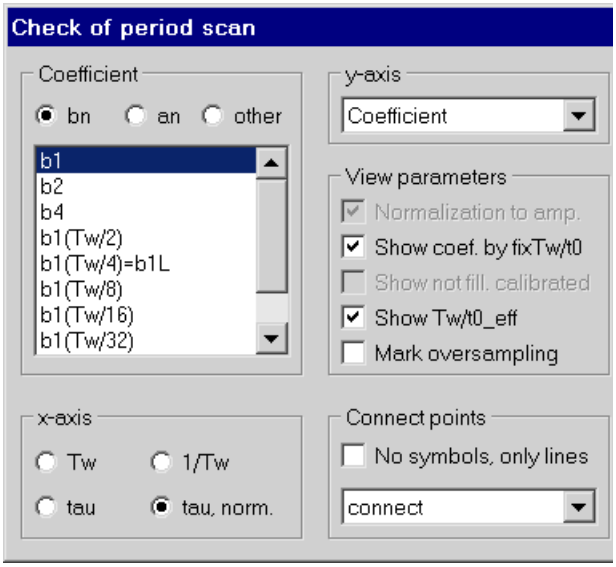
The following picture shows the simulation from chapter 3.3.1.2 now in a normalized view with tau as x-axis:



b1 in this plot will be normalized to the amplitude of an exponential time law. Then the maximum of the period scan denotes the transient amplitude. An advantage is that all coefficients should have theoretically the same peak height.
'TempX' in the right parameter list is the maximum temperature difference between all transients, 'Temp' is the averaged temperature over all transients. For more details see chapter 3.3.3.

3.3.4.3 PeriScan check

A change in the Tw/t0_eff versus Tw curve can be visible in the b1(Tw) and, more rarely, in the b1-norm(Tw) curve, see discussion in chapter 3.4.4.1. So a reason for a change in the b1(Tw) curve can be the transient (other Tw) or/and a change in the Tw/t0_eff ratio. Therefore the following tool exist to check a correlation between an unusual period scan and the Tw/t0_eff curve, use it especially at jumps in the period scan and for Tw<2ms.



The x-axis can be selected as in chapter 3.4.4.1 described.

The **y-axis** can be:

- **Coefficient:** This is the standard.
- **Tw/t0_eff:** Shows this ratio.
- **Factor for amplitude:** This is the normalization factor between amplitude and coefficient height in the peak, for example b1-norm/b1.
- **Factor for tau:** This is the factor for the calculation of tau from Tw, means tau/Tw.

Depending on the x- and y-axis following view parameters are available:

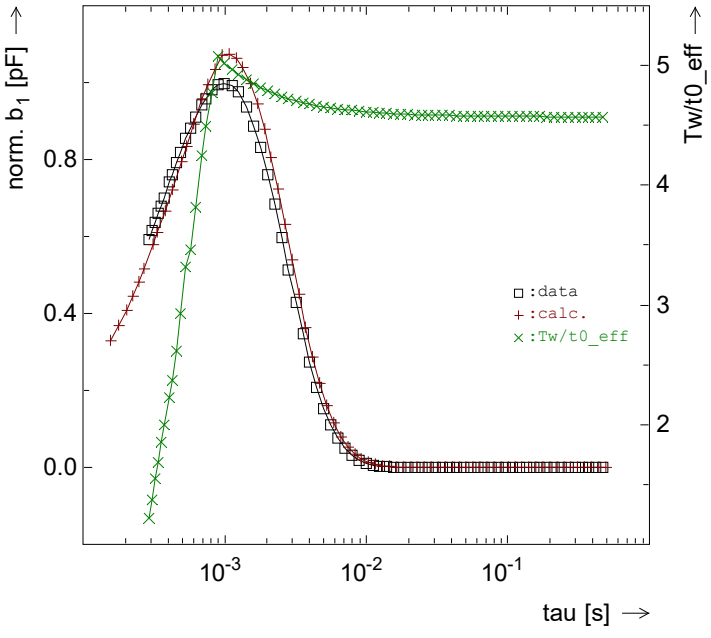
Show coef. by fix Tw/t0: An additional curve will be calculated and shown, it uses for the normalization the Tw/t0_eff ratio of the last data point (biggest Tw). This curve is direct proportional to the not normalized curve b1(Tw) because the normalization factor is fix.

Show not fill. calibrated: An additional period scan curve will be shown which doesn't use the filling calibration, explained in chapter 3.3.1.2.

Show Tw/t0_eff: This ratio will be plotted as an additional curve with a right y-axis.

Mark oversampling: The measured (not constructed) data points with oversampling will be marked.

The plot on the right is an extreme example without oversampling, the time constant was 1ms. The black squares denote the normalized period scan. The red curve was be calculated by a fix ratio of Tw/t0_eff. The green curve with the right y-axis shows Tw/t0_eff versus Tw.
If this curve shows a jump or a big discontinuity, you see this also in b1(Tw). The biggest changes of this ratio are at small Tw's because the recovery times. Here are the biggest differences between the red (wrong, fix ratio) and black curve. You have to consider the change of Tw/t0_eff when showing the not normalized curve b1(Tw).



3.3.4.4 ITS/ICTS signal

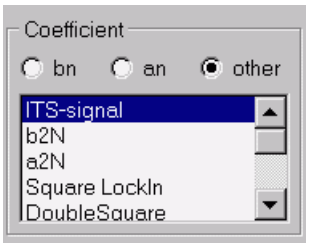
The period scans or also called ITS (Isothermal Transient spectroscopy) measurements allow the selection of the same coefficients as in the tempscan program module, see chapter 3.4.4.1. Additionally a so called ITS signal exist. If the capacitance transient will be measured then it is the well known **ICTS** (Isothermal capacitance transient spectroscopy) signal.

The general definition of the ITS-signal is: $-t\,df(t)/dt$, where f(t) is the transient signal. For C-DLTS it is then $-t\,dC(t)/dt$. If using the so called C^2-DLTS, see last C-transi mode in chapter 2.1.2.1, then it is $-t\,dC^2(t)/dt$. That is the original definition for the ICTS-signal.

The disadvantage of the ITS signal is that it needs a **differentiation**. This yields to an unfavorable signal to noise ratio. The differentiation will be made at the medium transient point of every internal saved transient of the period scan. So one transient yields to one ITS signal data point. For a better signal noise ratio the differentiation will not be done pointwise but by a digital FIR filter with a differentiation function. 33 transient points will be used, each 16 left and right from the medium point. 3 filtering levels are possible: weak, medium, heavy. You find this input only at the Isothermal program in 'Tools → Program parameters → Other'. This input needs user class 5. The ITS-signal will not be saved into the data file, it will be calculated from the internal saved transient points.

The result is a ITS-signal versus tau or Tw curve similar as b1 versus tau or Tw. The normalized view versus tau contains all corrections so that the maximum position gives the time constant and the amplitude of the level as by the 'normal' coefficients. This is valid for all DLTS modes, also for C^2-DLTS.

You can select the ITS signal at every coefficient input window by selecting the 'Other coefficients' input group.



Usually there is no reason to use the ITS signal. The coefficients have a better signal noise ratio and a better energy resolution. But the ICTS signal is well known in the literature.

3.3.4.5 Logarithmic transient

The direct measuring of a transient with a logarithmic time axis or the measurement of 65000 equidistant transient points and then selecting points in a logarithmic step yields to a very bad SNR, because the filter frequency of the ant-aliasing must be high and an average is not possible because the long measurement time. Better is the combination of some transients with different period widths. For every transient is here the anti-aliasing filter frequency optimal, an averaging is for the small Tw's individual possible. We call the forming from some equidistant transients to a new curve/transient with a logarithmic time-axis **quasi-logarithmic** transient. At the transient and tempscan module transients of 3 Tw's a' 128 or 512 points will be used, at the isothermal module many transient of different period widths a' 32 points.

The new quasi-logarithmic curve can contain only **original** measured data points or, at a logarithmic time axis, interpolated **equidistant** points (transient). In the 2. case the data can be saved in a transient data format (Standard plot → Evaluate → Save eval as file).

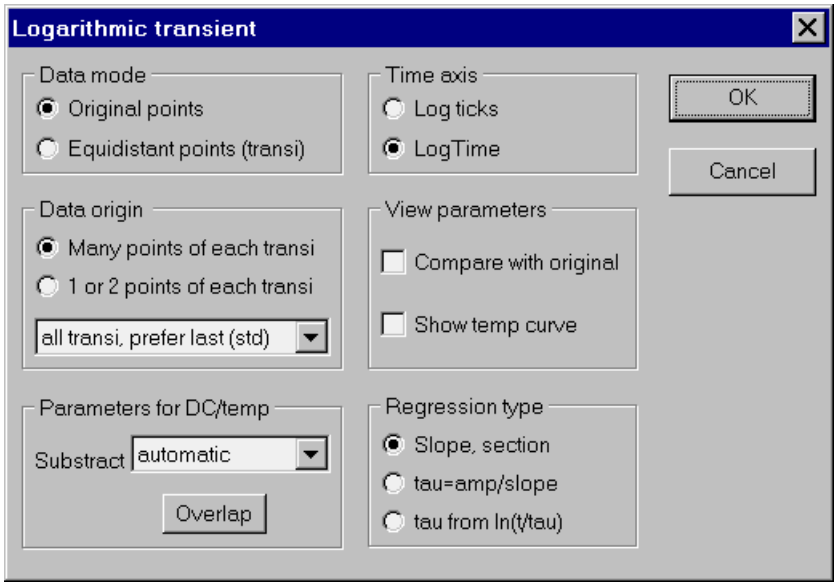
The new curve can be formed by **1 or 2** points or by **many points** of each transient. In the first case you can select the point(s), for example y[0] and y[N]. The second case (many) is the standard one. Here you can select the **data origin**:

from one oversampling: All transients formed from first long oversampling transient will be used.

all transi, prefer first points: All isothermal transients will be used. If possible then the new curve will be formed from the first points of each transient, at big Tw' also from the last points.

all transi, prefer last (std): All isothermal transients will be used. If possible then the new curve will be formed from the last points of each transient, at small Tw' also from the first points. This is the standard mode.

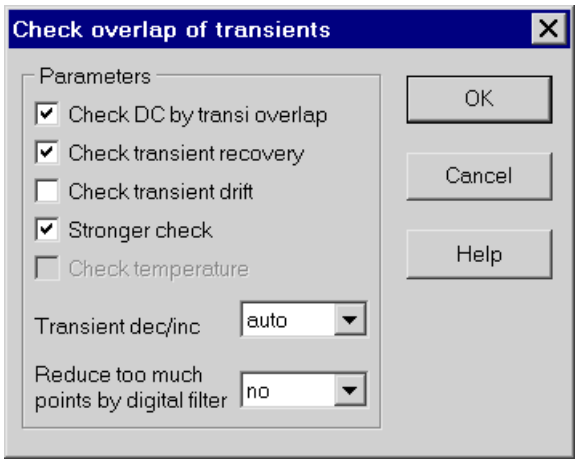
The **time axis** of the plot can be an axis with logarithmic ticks or a linear called LogTime axis.
It is possible to **compare** the new curve with all original transients in one plot.
A second bottom plot with the **temperature** of every transient point gives the possibility to check whether the temperature was stable during the measurement.
If making a linear regression over the new curve, the **regression** type is selectable.



The **DC** offset can be subtracted from the new curve:

no: The DC will not be subtracted.
yes: The DC of each transient will be subtracted.
DC of 1. transi: The DC of the first transient will be subtracted.
automatic: Subtract the DC of each (normally) or of the first transient.

For constructing of the quasi-logarithmic curve there is an **overlapping** of the 3 or many transients necessary. So each transient could have an unknown different offset. Then a combination of these transients would give jumps in the new curve. To avoid this behavior there are some checks and corrections.
The button **Overlap** opens an input window for checking the overlap of transients.



Check DC by transi overlap search the overlapping time range of each 2 transients and synchronizes the transient offsets.

Check transient recovery avoids points which can come from a recovery signal, these are points at start of transient start which y-values increase/decrease instead of decreasing/ increasing. The check is limited to Tw/4.

Check transient drift avoids points which can come from a transient drift, these are points at transient end which y-values increase/ decrease instead of decreasing/increasing. Be careful with this option because especially noise can yield to bad detections.

'**Stronger check**' defines the strength and algorithm of recovery and drift check. The software tries to detect the noise and takes it into account, but too much noise can yield to bad results. The tolerance for noise at the check is lower if 'Stronger check' is activated. Then more recovery points may be detected.

The recovery and drift times are limited for checking the DC because here an overlapping time range is necessary. But this is not valid for the construction of the quasi-logarithmic transient. There recovery and drift times are only limited to the first rep. last quarter of Tw.

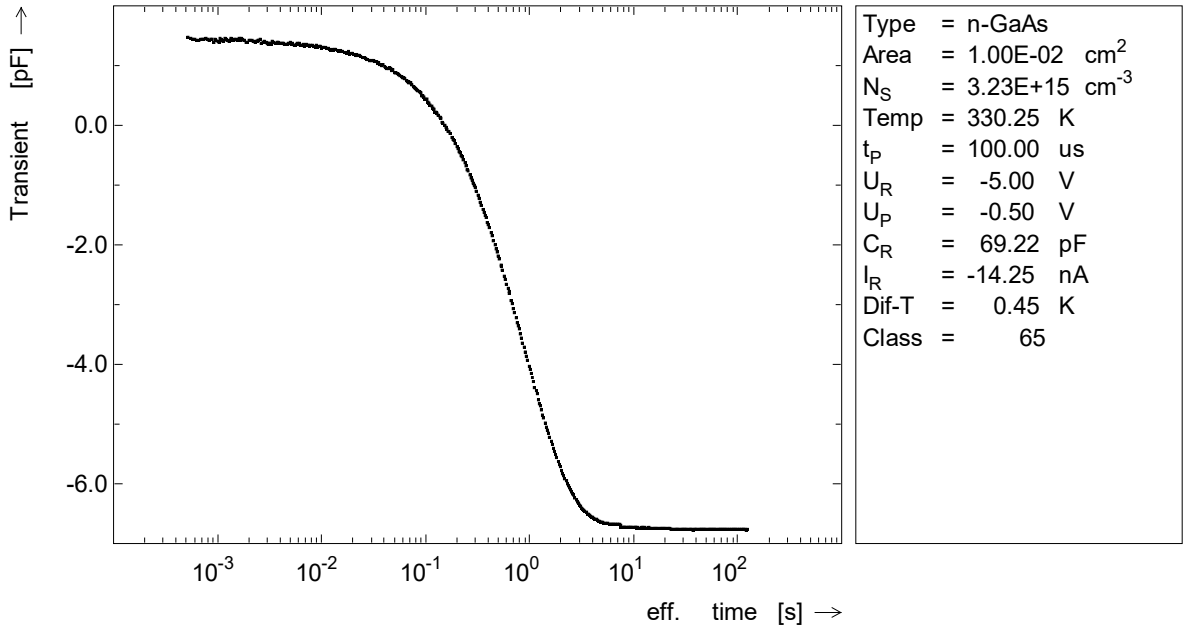
Check temperature is only for tempscan data where 2, 3 or 4 overlapped transients of different files will be used. If activating this flag, the software controls whether these transients has been measured together. This can be important when a data point in one file was removed. Additionally, the maximal temperature difference must be smaller than 1K.

Transient dec/inc defines whether the transient decreases or increases. At 'auto' the program decides this by the transient data.

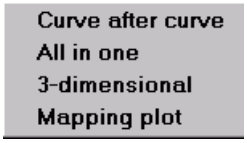
When constructing a quasi-logarithmic transient of 256 points by 3 equidistant transients of 512 points, then not all these 3*512 points will be used. Therefor a special option exist for this case of 512 internal saved transient points. This option is always visible but has no significance at lower point numbers. We call this option '**Reduce too much points by digital filter**' because the 512 points can be reduced and filtered to a lower number of points. The strength of filtering can be selected: *no*, *fast*, *weak*, *medium*, *strong*.
'No' doesn't use a digital filter but reduces the point numbers by selection of each second or fourth point. The advantage of the filtering is the higher sensitivity by reducing the noise. The disadvantage is the recovery time of the digital filter which yields to losing of the first transient points. This means that your quasi-logarithmic transient starts later when filtering. The recovery time is bigger at stronger filtering. The mode 'fast' uses additional to the filtered points the unfiltered points until the recovery time. So you don't lose the fast time range. But the problem can occur that you see a jump or transition from the unfiltered points to the filtered points.

Note: The quasi-logarithmic curve is very important for the HERA transient evaluation. In the transient module equidistant points are necessary, in the isothermal and tempscan module only original points will be used. The time axis is always corrected by the phase delay (see chapter 3.2.5) and so will be called effective time.

In the following picture of a quasi-logarithmic transient, measured by oversampling, you see in the text header the maximal temperature difference during the measurement and the maximal evaluation class of all original transients.

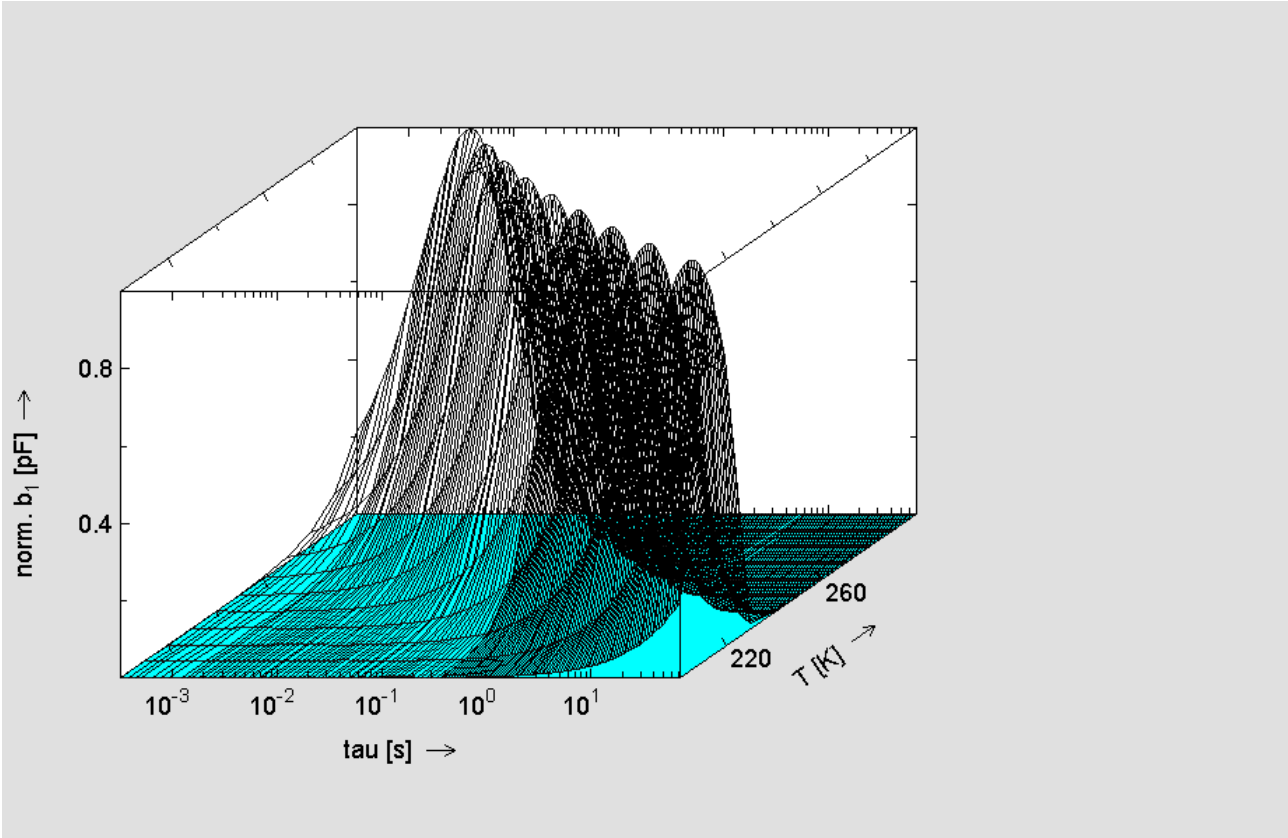


3.3.4.6 Read and plot



If the isothermal file comes from a data set (e.g. temperature variations) then here is a sub menu to read and plot the different curves as described in chapter 5.1.7. The mapping plot needs user class 5.

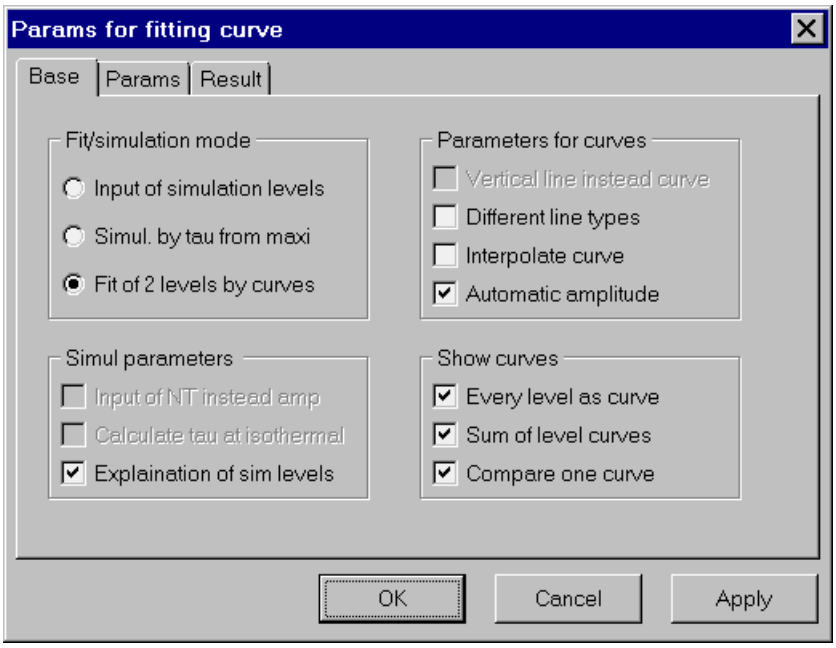
The following picture shows the 3-dimensional plot of period scans at variation of the temperature. The 3rd dimension z-axis gives the varied parameter, here the temperature. You see that the peaks of higher temperatures occur at faster time constants.



3.3.4.7 Fit and library

If using 'All coefficients' and tau selected as x-axis or 'Special plots' or 'PeriScan (ITS) plots' of the plot menu then it is possible to **fit** this curve by simulation levels (as PeriFit) or to compare the curve by existing levels in the **library**. You find these both possibilities in the menu 'Evaluate' of the plot program. If the fit or library search was done then the menu entry will be marked by a hook. First you have to define the peak maximum by the mouse or vertical marker. Then opens an input window. The library will be explained in a separate chapter.

Fit means here an analytical recalculation of the coefficient by given simulation parameters. It is not a smooth! The simulation parameters will be defined in the input sheet SimLevel. You can input NT instead of the amplitude if activating this flag.
The next picture shows the base input sheet for the fit.



Fit/simulation modes:

Input of simulation levels:
The fit curve will totally be defined by the simulation parameters. The definition of the peak temperature position has no effect.

Simul by tau from maxi:
This fit mode simulate the fitting curve by the tau value defined in the maximum, no inputs for the simulation levels are necessary.

Fit of 2 levels by curve:
This fit is for 2 strong overlapping levels. This means you see only 1 peak which exist of 2 peaks.
The input sheet 'Params' contains parameters for the fitting of the 2 amplitudes and the 2 time constants.

Parameters for curve:
By activating a flag only a vertical line at the fit maximum position will be drawn instead the fitting curve. It is possible to use different line types for the fitting curve, the fitting curve can also be interpolated. If activating 'Automatic' amplitude then the fitting height will be normalized to the peak height defined by the mouse.

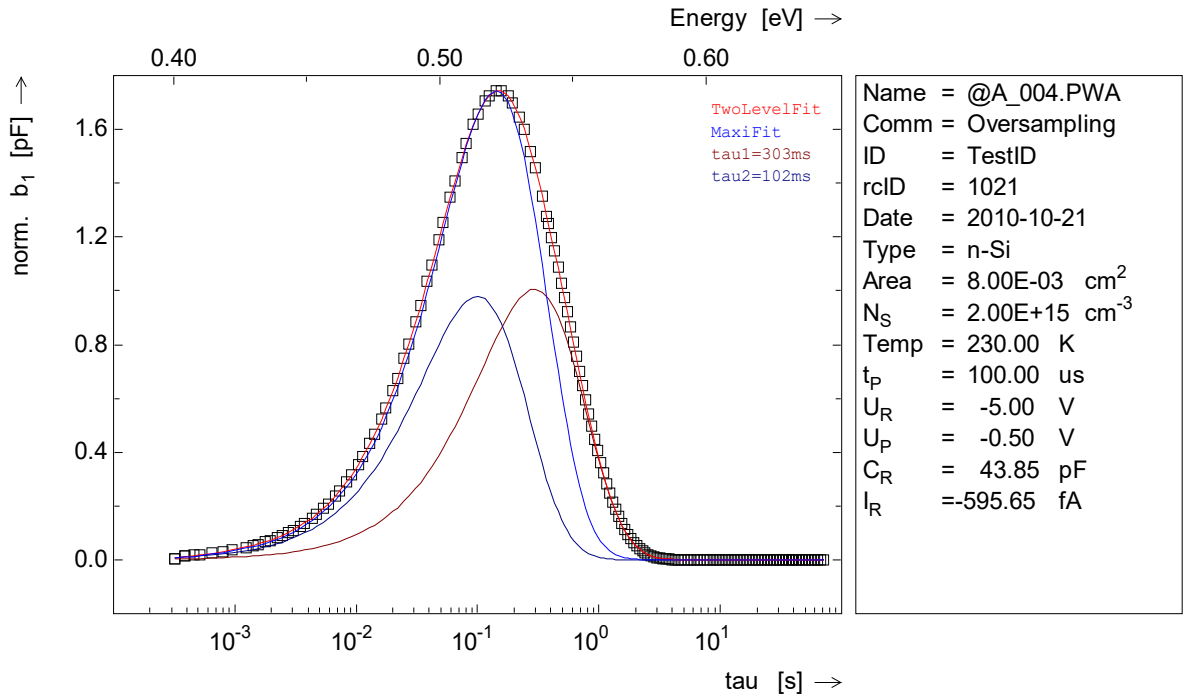
Show curves:
At the first and third simulation mode you can show the curves of every level or/and the sum of curves of all levels. This is for mode 1 only possible at 2 or more levels. At selecting 1 simulation level you can compare the simulation curve (Energy, sigma) with the curves (Energy', sigma) and (Energy, sigma'), see in the list below for the explanation. For this user class 5 and activating of 'Calculate tau at isothermal' is necessary. At the third simulation mode you can compare the data with simulation of mode 2. This curve will be called 'MaxiFit'.
An explanation of the simulation curves is possible by activating a flag.

The tab sheet **Compare** is only visible for the first fit mode. It compares the given simulation parameters by recalculated values. These makes only sense if atcivating 'Calculate tau at isothermal'. The values will be calculated at clicking onto this tab sheet. Following list will be shown:

Energy: Energy of the simulation level.
Energy': Energy calculated by sigma, tau and temp.
sigma: sigma of the simulation level.
sigma': sigma calculated by energy, tau and temp.
tau: Time constant defined for the peak maximum.
tau': tau calculated by energy, sigma and temp.
Temp: Temperature measured.
Temp': Temperature calculated by energy, sigma and tau.

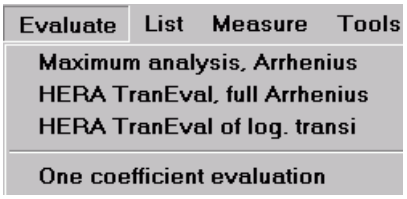
Clicking 'OK' starts the simulation, 'Cancel' break and delete it.

The next picture shows a simulation with 2 overlapping levels with time constants of 100 ms and 300 ms. The amplitudes were 1 pF. The top energy axis is only for demonstration. The red line is the 2 level fit by mode 3. The results for the time constants are 102 ms and 303 ms. The curves with the smaller peaks are the curves of the single levels. The blue curve 'MaxiFit' is the fit by mode 2.



3.3.5 Evaluate menu

The possibilities of the evaluation depend on the kind of isothermal measurement (period scan, …), kind of sample (Schottky diode or MIS capacitor) and the selected transient evaluation. The following menu will be shown after a period scan for a Schottky diode and an exponential evaluation.



The Arrhenius plot made by the maximum analysis is an important evaluation. This will be explained in chapter 4.2. There you can also use the HERA coefficient deconvolution for the Arrhenius plot.
The Arrhenius plot done by the HERA transient evaluation will be described in chapter 6.1.3.4. The HERA transient evaluation of a logarithmic transient will be explained in chapter 6.1.3.3.
The one coefficient evaluation is similar to this one from the tempscan module, the description will be given in chapter 4.6.

Evaluations of other kinds of isothermal measurements (not period scan) will be explained in chapter 3.3.6.

3.3.6 Special applications

3.3.6.1 Capture measurement and evaluation

In chapter 3.2.1.5 a transient measurement was introduced for the capture process. This method is in the practice for discrete levels not helpful because the capture process is normally very fast. The direct capture measurement by the transient recorder can start about 100 us after pulse start because the recovery time of the bridge.

So in the following an indirect method will be introduced. It based on the fill pulse width of the emission amplitude.
The DLTS technique assumes that the filling pulse tP is of sufficient duration to fully occupy the traps, see equation 1.48 of the Theory Manual. Then you get the correct trap concentration NT.
If the filling pulse width is reduced, only some of the traps will become occupied. The concentration of filled traps depends on the pulse width and the trap's capture cross-section. Equation 1.54 describe the capture process. The measured emission amplitude will be multiplied with the term (1-exp(-tP/tau_C)). The measurement of the emission transient at different tP gives a curve amplitude versus tP, this can be used as capture transient. The emission amplitude can be calculated by the DLTFS technique. A coefficient of the Fourier transformation over the emission transient can also be used instead of the amplitude. Then b1 versus tP represents also the capture transient.
This technique allows also to calculate the capture cross section of MIS surface states.

3.3.6.1.1 Capture cross section

As result of the capture measurement you get the capture time constant tau_C and by equation 1.55 the capture cross section.
The Arrhenius plot yields also to the capture cross section but this is not the pure value. Sigma-Arrhenius includes the entropic factor XT. We distinguish between the capture cross section evaluated from Arrhenius plot (sigma Arrhenius) and that one evaluated from direct capture measurements **Sigma-Capture**. These two are related by the Entropic factor XT as:

Sigma_Arrhenius = XT*Sigma_Capture

In the software Sigma_Capture will be denoted as $sigma_C$.

3.3.6.1.2 Measurement

Before you start with the capture measurement you must search a temperature where you can observe the emission process. Further you have to adapt the period width in respect to the emission time constant to get good results for the DLTFS evaluation, see chapter 3.2.1.1.4. Make sure that the evaluation class is good enough.
For an indirect capture measurement following fact is **important**: The emission must be finished when starting the next measurement (at the next pulse width and when repeating because averaging). If the traps are not completely empty then the tP-axis of the constructed capture transient is not correct. The best is to select Tw so that tau/Tw<0.15, then the exponential emission is about finished at the end of Tw. In the other case you have to dispense with repeating or to use a wait time between pulses (chapter 3.3.1.2 and 3.2.1.1.2).

For the capture measurement you have to select 'Fix period width' and in its sub menu 'Variation of tP, linear'. Then you get the main input window as shown in chapter 3.3.1.1. As the capture process is very fast you have normally to use a fast pulse generator, see chapter 3.3.6.1.2. For its use you have to select by the software the fast pulse mode. If not done, click onto the 'Params' button in the Bias/pulse group and select there the fast pulse mode as described in chapter 3.2.1.1.2.
After this define the start and pulse width in the main window. The steps, that means the delta value between 2 pulse widths, are fix. The start value should be selected so small as possible, but it will be corrected by the end value and the number of points because the start value must be a multiple of the delta value. The pulse end value should be selected that all traps are filled. A similar argumentation as for an optimized emission transient measurement can be used. Approximate 7 time constants, in this case capture time constants, should be measured to get an optimized capture transient. The number of points should be a power of 2 plus 1 because a Fourier transformation will be done over tP. If you use not a power of 2 plus 1, then the additional points will not be used for the Fourier evaluation.

By default the capacitance at UR and UP will be directly measured without the bridge once before the measurement starts.

During the measurement you see on the top the transient at various pulse widths and at the button the curve b1 versus pulse width.

3.3.6.1.3 Fast pulse generator

Measurements with pulse widths below 10 us requires the use of an external pulse generator and a Fast Pulse Interface, for more details see chapter 3.5.2.
For conventional DLTS measurements in which the aim is to fill the deep levels completely, the speed response of the capacitance bridge does not represent a limitation on the measurement. However for capture cross section measurements in which the filling rate is essentially time resolved, the bridge speed may limit measurements, especially in moderately and heavily doped semiconductors.

The capture time constant depends mainly on the capture cross section, the desired measurement result, and the shallow doping NS (chapter 1.3 of Theory Manual). Large capture cross sections can only be determined in low doped samples. For that, not every capture cross section can be measured in every sample because the fastest pulse is limited to 10ns or 20ns by the fast pulse generator.
It's an experience that smaller pulse widths, even if the pulse generator can supply it, does not completely reach the sample through standard BNC cables. The pulse voltage may not reach the defined value and the pulse shape may not be rectangular. This can yield to artifacts in the b1 versus tP plot. So b1 can rapidly increment at small pulse widths because the effective pulse voltage on the sample depends on tP. Be careful with pulse widths below 100ns. For more details look in chapter H5.2 of the Hardware Manual.

3.3.6.1.4 Evaluation

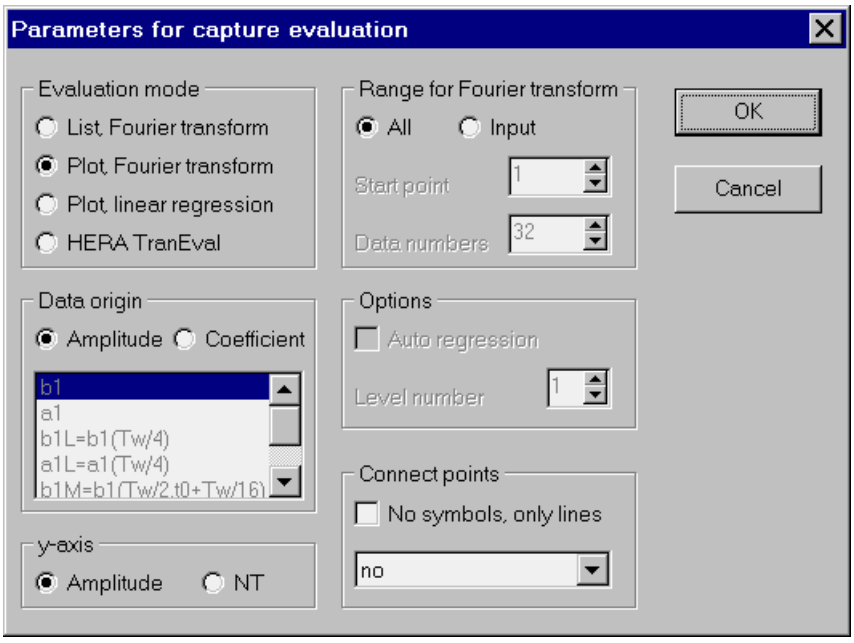
Select 'Capture evaluation' in the Evaluate menu. The evaluation will be done by the emission amplitude versus tP curve or by one coefficient versus tP curve, the used equations are in the chapter 1.3.2 of the Theory Manual. See chapter 3.3.6.1.1 for the capture cross section.

There are some ways of obtaining the capture time constant, called **evaluation modes:**

List, Fourier transform: The evaluation will be done by the DLTFS technique, see Theory Manual, and the results will be listed.
Plot, Fourier transform: The evaluation will be done by the DLTFS technique and the selected data curve plotted with a list of the main results.
Plot, linear regression: The data will be plotted in a special way, see below, and a linear regression yields to the results.
HERA TranEval: The HERA transient evaluation gives the results.

The best method is the Fourier transform over the amplitude. But the transform method requires equidistant pulse widths and so it is not possible to remove some points if the data is not perfect. If amplitudes for some data points not exist you get an error message. Use in this case a coefficient instead of the amplitude. This can also be necessary if the data are very noisy or at overlapping of levels.

The regression method needs as y-axis log(Amp-Amp(tP)) and requires the measurement to go to saturation (Amp). This is not always possible, especially because the Edge layer effect.



The **Data origin** provides the Amplitude option, plus a list of coefficients. The **amplitude** option selects only data points that have a good class value, thus improving the accuracy of the calculation. The amplitude was calculated by the DLTFS technique for every emission transient at the various pulse widths. So it could be that at one data point, that means at one pulse width, the evaluation of the amplitude is not possible or the class is too bad. Amplitude is only calculated if the data class is greater than 40, but this is the only check on the quality of the data. The amplitude is required to calculate the correct trap concentration.

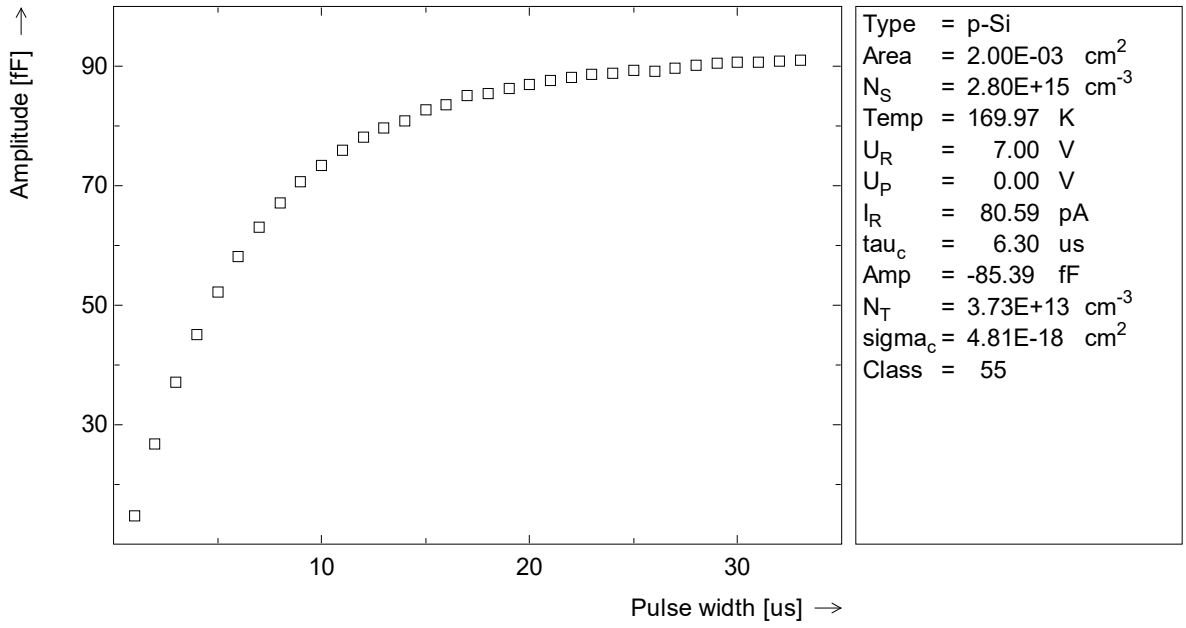
Selection of a specific **coefficient** provides access to the actual measured data and will include all the measured points regardless of their nature. Following choice exist:

b1, a1, b2, a2, b1(Tw/4), a1(Tw/4), b1M, a1M, b1T.

If a coefficient is chosen to be plotted, then a plot will be generated of coefficient against tP. In this case, because the coefficients depend on tP and the emission time constant, it will theoretically not be possible to calculate NT from the capture process. To avoid this disadvantage we normalize the coefficients to the amplitude. This will be done by the best emission time constant of the various transients. This method can lead to a wrong NT calculation. But the capture time constant and therefore the capture cross section can be always correctly calculated by using one coefficient.

For using the Fourier transform you can select to use all data points or only a defined range. The plots can show as y-axis the amplitude resp. the normalized coefficient or the trap concentration.
If selection 'Auto regression' then the plot starts with an automatically done linear regression.

The following picture shows a measurement with a small capture cross section so that no fast pulse generator was necessary. This plot represents the capture transient. The evaluation values were calculated by the **DLTFS** (**D**eep **L**evel **T**ransient **F**ourier **S**pectroscopy) method. In the header list there are the results of the capture process: time constant, amplitude, trap concentration, capture cross section and evaluation class.

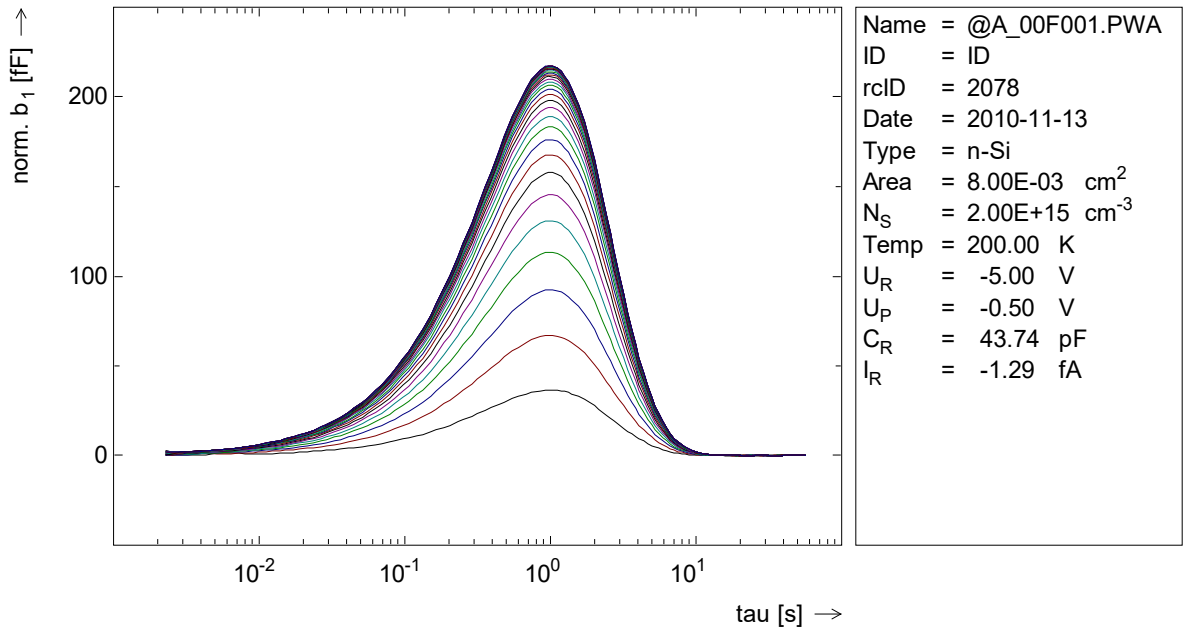


In the practice the capture transient is not always exponential and don't go to the saturation (flat line). There is a logarithmic transient superposed. This effect will be called **Edge Layer effect**, see literature reference 6 in the Theory Manual. You can minimize this effect by using a big space charge region and the first part of capture transient. For the Fourier transform method this is not a so big problem as for the linear regression.

3.3.6.1.5 Period scan at various pulse widths

Capture cross sections can also be calculated by period scans at various pulse widths. For this select in the measurement menu 'ITS parameter variation', see chapter 3.3.1.3, with linear pulse width variation. For the pulse width range the is same valid as described above. After the parameter input window you get the standard input window for the period scan. If using 33 different pulse widths then 33 period scan files will be saved, named for example ID@A_00F001.PWA.DLT to ID@A_00F015.PWA.DLT, see chapter 3.3.1.3 for more details.
This type of measurement takes a longer time as the measurement introduced in chapter 3.3.6.1.2. The advantage is that also overlapping levels can be observed.

The following picture shows a simulation at pulse widths from 1 us to 33 us. Each curve represents a period width scan. The smallest peak refers to the smallest pulse width.



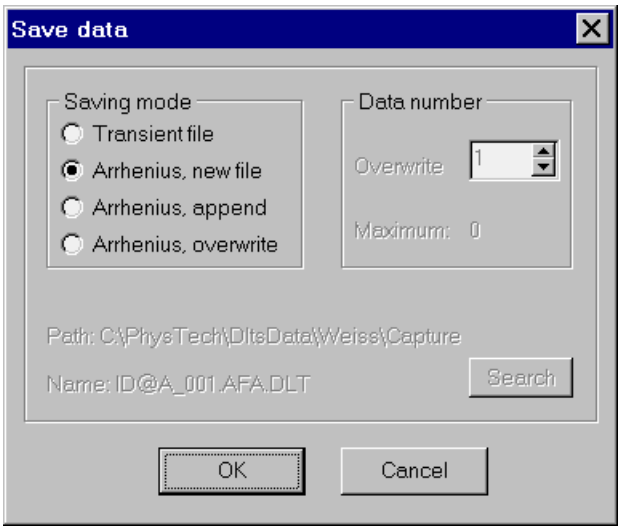
There are tow possibilities to get the capture cross section from this plot:

1. A **vertical plot** is the easiest way. Call in the isothermal plot menu 'Read and plot → All in one'. Then call in the View menu of the plot program 'Vertical evaluation' (not Vertical plot!). As described in chapter 5.1.7.2 you have to mark the tau-position by a vertical marker line. All y-values, this means here b1, to this tau-value will be applied for a curve b1 versus pulse width, this is the capture transient. The program jumps then with this data into the evaluation as described in the previous chapter.
2. A **maximum analysis** allows the x/y-definition for every curve. As result you get also the capture transient with the evaluation of the previous chapter. For the maximum analysis see chapter 4.2.3.

3.3.6.1.6 Temperature depending capture cross section

It is possible that the capture cross section is temperature dependent and thermal activated. You can examine such behavior by capture measurements at different temperatures. The measurements can be done as described before by a variation of tP or by a period scan with parameter variation of tP.

Each capture time constant at a measured temperature has to be saved into an **Arrhenius file**. You find this option during the capture evaluation (chapter 3.3.6.1.4) in the evaluate menu of the standard plot program under 'Save eval as file'.
Here you can save the data as transient or as Arrhenius file. For Arrhenius files you can create a new file, append or overwrite the data record. For a new Arrhenius file you get the standard file dialog, in the other case the used Arrhenius file name will be displayed at the bottom. You can change it by the 'Search' button. At overwriting you can input the data position.



In the maximum analysis, chapter 4.2, you can read the Arrhenius file and can calculate a thermal activation of the capture cross section. The Arrhenius file for the temperature depending capture measurements has as second character of the data extension a 'F', see chapter 1.3.3.
Then there is at the inputs for the Arrhenius plot the input box shown on the right. If selecting 'for capture' the **kinetic** for the capture process will be used, that means for the y-axis of the Arrhenius plot 'tau*v_{th}*NS'. In the other case the global defined kinetic will be used, normally for the emission process this is 'tau*v_{th}*$N_{C/V}$'. For more details see chapter 2.4.2.1.

3.3.6.1.7 Others

You can save the curve amplitude or coefficient versus pulse width curve in the transient data format. Then you can read this file in the transient module. You find this option in the file menu of the isothermal program and in the evaluate menu of the standard plot program under 'Save eval as file'.

At **user class 5** there is the possibility to calculate the capture cross section from the logarithmic part of the capture process. For this you have to make a pulse width variation with logarithmic steps. The evaluation is not so easy and the results are not very good. It gives more the range of the capture cross section. The only advantage is that here the fast pulse generator is not necessary because the edge layer effect is visible also at longer pulse widths.

3.3.6.2 Deep level profiling

A profile of the deep level trap concentration through the depletion region can provide useful information about the type of defect and its uniformity, and is often used to investigate ion implantation damage or to identify diffusion tails.

The profiling measurement is based upon the Integration of Poisson's equation which provides the relationship between the applied voltage to the point where the trap crosses the Fermi Level. In early DLTS systems the measurement was made by scanning over a deep level peak using a different set of bias or pulse voltage conditions for each scan (DDLTS).

The FT 1030 profiling option is fully computer controlled and is made at a single temperature from within the isothermal software. Transients under variation of the reverse bias, the pulse voltage or both voltages will be measured at fix period width.

3.3.6.2.1 Measurement

Select in the measurement menu 'Fix period width', then a sub menu opens with the selectable variations. After selecting the variation mode an input window similar to that one described in chapter 3.3.1.1 opens. For the selection of Tw the same is valid as discussed in chapter 3.3.6.1.2.
The **profile** is obtained by varying the position of the observation window. This can be achieved in three ways:

1. **Variation of UP** (*.PP? files)**:** Changing the pulse voltage with the reverse bias held constant, see chapter 1.2.3.a of Theory Manual. You have to input UR and the start and end value for UP. Changing the pulse voltage changes the depletion width and hence capacitance. The region of the depletion region that is recharged with each pulse changes and at the point at which the pulse height is high (close to the reverse bias) the region of observation will be close to the width of the transition region and therefore the effect of the Debye tail may become significant.
   The difference of 2 transients yields to a small effective space charge region, that means a small observation window. This is a big advantage for the profiling.

2. **Variation of UR** (*.PU? files)**:** Variation of the reverse bias whilst the pulse voltage is fixed, see chapter 1.2.3.b of Theory Manual. You have to input UP and the start and end value for UR. Changing the reverse bias changes the depletion width and the initial capacitance for each measurement point in addition to changing NT(x). The relevant charges are at the intersection Fermi/trap level. All this complicates the measurement and may introduce errors. Don't use this method for profiling.

3. **Variation of UR and UP** (*.PH? files): Variation of reverse bias at constant pulse height, see chapter 1.2.3.c of Theory Manual. You have to input the pulse height (UP-UR) and the start and end value for UR. This option overcomes the limitations of both preceding options. This keeps the pulse height fixed, the reverse bias and the pulse bias are both varied. This ensures that a similar depth of the depletion region is sampled each time and that the region never approaches the width of the transition region.
   Building differences is here not possible and not necessary. The space charge region, that means the observation window, depends on the pulse height. Is it not small enough, then this method gives only an averaged profile.

In **summary**, the physical best method is the first with making difference of transients. But in practice it could be that making differences between transients is not possible because noise or less density. Then the method 3 with bigger pulse heights gives not the exact but better results.
From the physics it is better to make **U-DLTS** (CC-DLTS) instead of capacitance DLTS measurements for the profiling. Then the space charge region is constant during the emission process, see chapter 6.2.1 and Theory Manual.

By default the equilibrium capacitance values at all used UR and UP will not be measured with the compensation before the transient but as a separate C/V curve before the isothermal measurement starts.
At 'Other params' you can activate 'sqrt variation of U'. Then the variations of UR or UP should have more similar changes in the space charge region.

Note: By DLTS you can only determine 'big' profile changes, for example a change of factor 10 or more. A factor of 1.5 is too small.

3.3.6.2.2 Evaluation, method 1 (UP variation)

The calculated trap concentration used in the profile evaluation is the NTs concentration as referred in other chapters, so here NT or NT(x) means NTs. The capture therefore takes the transition (space charge) region into account, which is possible because UR and UP are measured for each point. The differences will be formed from the coefficients and not from the transients. But the result is the same. The following equations refer to the Theory Manual, chapter 1.2. LR and LP denote there xR and xP.

Select 'Depth profile' in the Evaluate menu and a window with two input sheets opens.

3 **profile data modes** for the UP variation exist:

1. **Direct profile:** NT will be calculated directly from every isothermal data point with given UR and UP, equ. 1.34. Although this option allows a plot of NT(x) to be made without building differences this normally gives rise to a large error because of the large space charge region (LR-LP in fig. 1.2 of the Theory Manual, means xR-xP).

2. **Difference between 2 points:** The difference of 2 data points (transients) will be formed and the trap concentration will be calculated from the difference, equ. 1.45. For this is only the effective space charge region relevant, this is in fig.1.2 LPj-LPi.

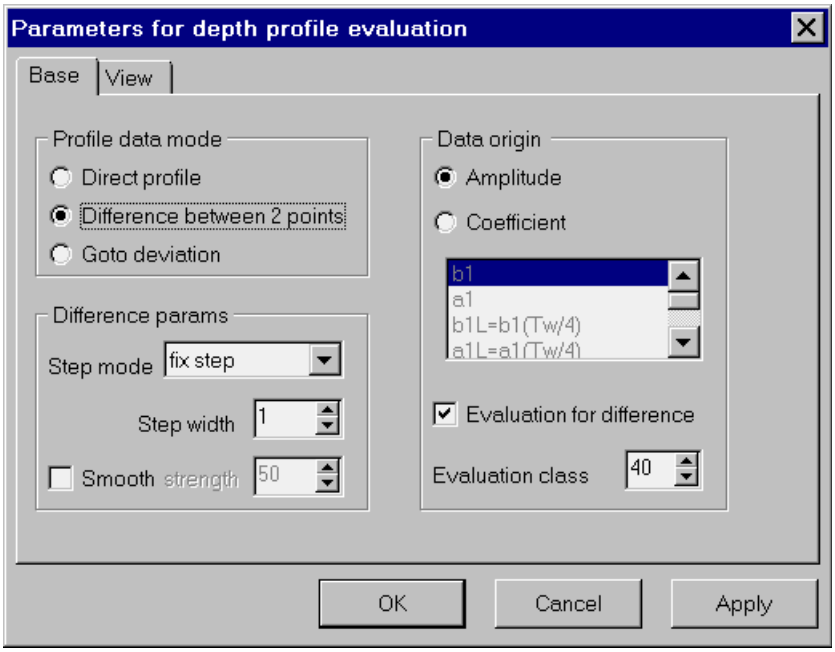
3. **Goto deviation:** A special evaluation, similar to that one as for the Ns-profile. Replace in equ. 1.12 all Ns by NT. The averaged NT will be get by mode 2. For more information see in the Goto publication, literature reference 7.

If selecting profile mode 1 then the **x-axis** can be selected:

Depth width:	(xR+xP)/2, standard
WP:	Width of space charge region at UP
xP:	Fermi intersection at UP
xR-xP:	Effective space charge region = transition region

3 **step modes** exist for the building of differences at mode 2:

fix step: The step width corresponds to the data number.
same xd: The program searches for a similar width of effective space charge region.
same density: The program searches for a similar factor NT divide amplitude in equ. 1.45.



The **step width** is the difference of the data numbers or a factor for the search.
You can **smooth** the coefficients by splines before the difference building.
The **deviation** for mode 3 can be done by splines or by difference building.

The **Data origin** provides the Amplitude option, plus a list of coefficients. For both a minimum evaluation class can be defined. Only data points equal or better this class will be used for the profile.
The **amplitude** was calculated by the DLTFS technique for every emission transient at the various pulse voltages. So it could be that at one data point, that means at one pulse voltage, the evaluation of the amplitude is not possible. The amplitude is required to calculate the correct trap concentration.
Selection of a specific **coefficient** can include all the measured points regardless of their nature. If a coefficient is chosen to be plotted, then a plot will be generated of coefficient against UP. In this case, because the coefficients depend on UP and the emission time constant, it will theoretically not be possible to calculate NT. To avoid this disadvantage we normalize the coefficients to the amplitude. This will be done by the best emission time constant of the various transients. This can lead to a wrong NT calculation.

In the **View** tab sheet you can define the activation energy. It is necessary for the lambda calculation, equ. 1.27, which are necessary for the xR and xP calculation.
The y-axis (NT) can be selected as linear or logarithmic. It is possible to show the profile plot together with the standard plot, for example amplitude or b1 versus pulse voltage. Smoothing, interpolation and the connection of points can also be selected at this input sheet.

3.3.6.2.3 Evaluation, method 3 (UR and UP variation)

Here you get a similar input window as described in the previous chapter. Only the profile modes 1 and 3 are available because a difference building is not possible. The standard mode 'direct profile' uses equ. 1.46 for the evaluation. The accuracy of the profile calculation depends on the width of effective space charge region xR-xP.
As x-axis you can select additionally to chapter 3.3.6.2.2 WR and xR.

3.3.6.2.4 Period scan at various bias or pulse voltages

A depth profile can also be calculated by period scans at various pulse voltages or at UR and UP variation. For this select in the measurement menu 'ITS parameter variation', see chapter 3.3.1.3, the corresponding variation. An analog consideration is valid for these measurements as done in chapter 3.3.6.1.5. So you can get the new data curve by a vertical evaluation or by the maximum analysis. With this data the evaluations described above are possible.

3.3.6.3 Field depending time constant

The emission can depend on the electrical field as described by the Poole-Frenkel effect. If the time constant changes not so strong (smaller than a factor of 10) by the electrical field, then you can select 'Fix period width' in the measure menu. In the other case select 'Variable period'. User class 5 is necessary for the variable period width option. Here Tw will be automatically adapted by the change of the emission time constant. In both cases appears a sub menu. Select there 'Variation of UP' or 'Variation of UR'. The variation of UR is the best method.

The inputs for the measurement are the same as described in chapter 3.3.6.2.1 for method 1 and 2.

After the measurement select 'tau % field' in the Evaluate menu. Then a window opens similar to this one described in chapter 3.3.6.2.2.
The field data mode is similar to the profile data mode, except that the Goto deviation don't exist. The y-axis of the plots is the time constant calculated by the DLTFS technique. Therefore the data origin is not enabled.
The x-axis of the following plot is the square root of the electrical field.

Period scans at various UR or UP variation yields also to a plot time constant versus field. For this select in the measurement menu 'ITS parameter variation' the corresponding variation. An analog consideration is valid as in chapter 3.3.6.1.5.

3.4 Tempscan program

This is the main DLTS measurement program module. It enables you to measure transients as a function of temperature, the so called tempscan. Up to 18 different measurement parameter sets can be measured and saved in one temperature scan, every measurement in one separate tempscan file.
The digitized transient data will be reduced by using Fourier transformation and several correlation functions. Up to 30 Fourier coefficients resp. correlation functions, including Box-car and conventional DLTS rate windows, will be calculated per file, in chapter 3.4.4.1 you get a list of these. Automatic calculated Arrhenius plots can be shown during the measurement as well as different coefficients and transients.
The main evaluation are the maximum analysis and the Arrhenius plot. From this you get the energy, the capture cross section and the trap concentration of the deep levels.

It exist tempscan files with constant period width and files with variable period width. The files with variable period width are a DLTFS (**D**eep **L**evel **T**ransient **F**ourier **S**pectroscopy) speciality. The period width will automatically be adapted to the temperature depending emission time constant. So you get the best results for every temperature. The evaluation will be done by the direct DLTFS transient evaluation and yields, for example, to the Arrhenius plot. With the variable period width is only an evaluation possible, a temperature curve plot as b1 versus temperature makes no sense, a traditional DLTS spectrum is not produced, a maximum analysis is not possible. So files with variable period width should be only additional files to the tempscan with constant period width.
Tempscan files with constant period width are comparable with the conventional DLTS. You obtain an overview DLTS spectrum, for example b1 versus temperature. The b1 coefficient is similar to the conventional DLTS signal. The maximum analysis is possible. In opposite to the conventional DLTS is also the direct DLTFS evaluation possible with the files of constant period width.
The curve coefficient versus temperature will also be called temperature curve.

The open function in the file menu is only for files with constant period width and linear time axis. Use the menu 'Read vari/log Tw' to read files with variable period width or logarithmic period width.

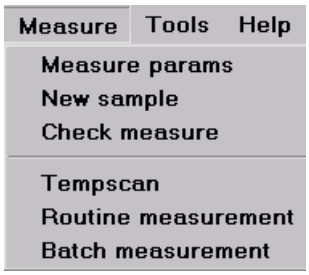
If comparing the peak position of 2 different files you must select the same coefficient, and both files must have the same t0 and Tw. In the other case the peak position shifts.

By the 'Read special' procedure you can read the difference of 2 tempscan files. The difference of files with different pulse voltage gives a DDLTS (Double correlation DLTS) file.

After measurement or reading data the standard plot will be shown on the main canvas. You can select the face of the standard plot in the menu 'View → Params for standard plot'. The inputs are the same as described in chapter 3.4.4.2.

3.4.1 Measure menu

The measurement menu contains the 3 common functions and tempscan measurements.



Tempscan means here a tempscan measurement with manual input of all parameters, up to 18 data files can be designed with a special parameter set. Routine measurement starts a tempscan with a selected standard set of parameters.
Batch measurement repeats different temperature cycles by changing some measurement parameters.

3.4.1.1 Tempscan

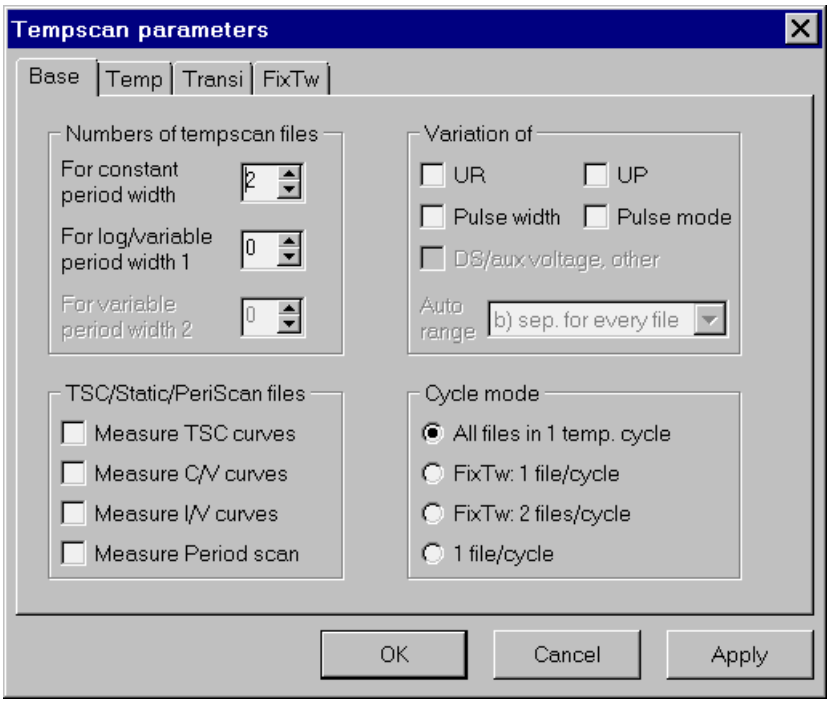
The Tempscan with manual parameters input enables you to create up to 18 different parameter sets for tempscan measurements.

You get first a window with some input sheets. Which tab sheets are visible depends on your options and on the selected parameters at the base input sheet:

- The **Base** input sheet defines the number of files, the kind of variation, the temperature cycle mode and additional measurements.
- The **Temp** input sheet defines options for the temperature delta.
- The **Transi** input sheet defines parameters for all transient measurements like saving transients points or files and for the global UR, UP and tP.
- The **FixTw** input sheet defines the parameters for all files with constant period width like the plot during the measurement, the minimum measure time, the period width of every file and the parameters of variation.
- The **VarTw1** input sheet defines the parameters for all files with variable period width1 or with logarithmic period width.
- **VarTw2** input sheet defines the parameters for all files of variable period width 2.
- The **TSC** input sheet defines the parameters for additional TSC/TSCAP measurements.
- The **Static** input sheet defines the parameters for additional C/V and I/V curves.
- The **PeriScan** input sheet defines the parameters for additional period width scans.

The second window is the **start input window** with the temperature parameters (start, stop, delta), it will be explained in chapter 3.4.1.4.

3.4.1.1.1 Base input sheet



In the input box **Numbers of tempscan files** you define how many files should be created and measured. Specific parameters must be entered for each of the files created. There are different inputs for files resp. measurements with:

- Constant (fix) period width, this is the standard, necessary for the maximum analysis
- Logarithmic or variable period width 1
- Variable period width 2, these files have another Tw as period width 1

In the **TSC/Static/PeriScan files** you can select if additional files should be measured. TSC (Thermal stimulated current) resp. TSCAP (Thermal stimulated capacitance) give file(s) which will be measured before the tempscan. Measure C/V, I/V or Period scan means that these measurements will be done during the tempscan in a defined temperature distance. This yields to one file per temperature.

'Variation of' defines the input possibilities of measurement parameters for the files:
UR, UP, tP, pulse mode, DS voltage
So activating of 'Variation of UP' means that you have to input the pulse voltage UP for every file. If not activating all files have the same pulse voltage. An input of the period width is always possible.

If you select variation of UR, there is a local input for the **auto range**, only valid for the tempscan with UR variation:

a) comm. Compens.: One common capacitance compensation for all tempscan files. Check of over range, that means transient measurement will be repeated at an over range of the capacitance bridge.
b) sep. for every file: Separately compensation for every file, check of over range.
c) a, check underrange: As a), additional check of under range.
d) b, check underrange: As b), additional check of under range.

You should make an UR variation in separate temperature cycles, especially at MIS.

The **Cycle mode** defines how much temperature cycles are necessary for the tempscan files, that means how often the cryostat must be cooled down resp. heated up:

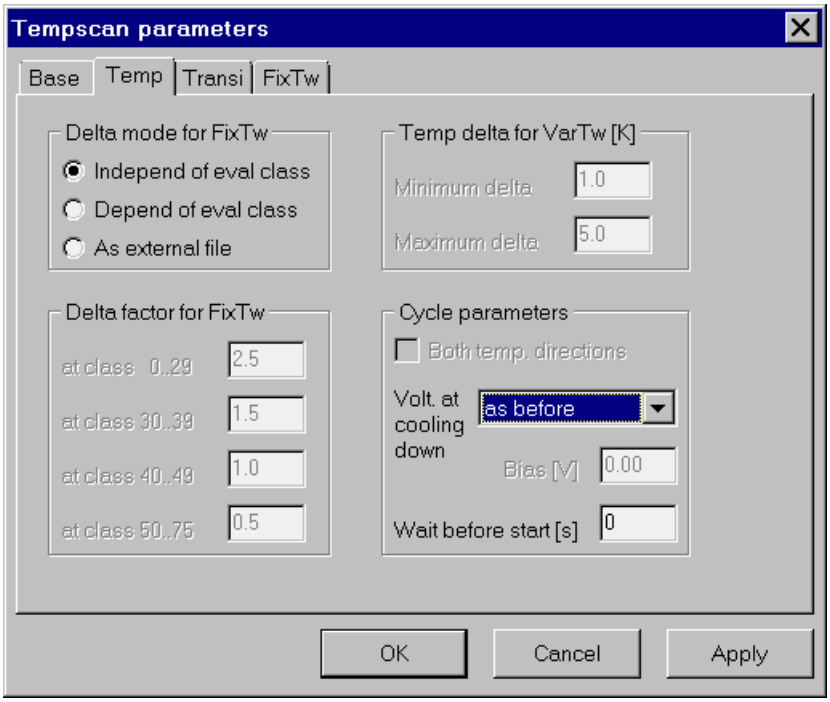
All files in 1 temp. cycle: All tempscan files will be measured together (one after the other at one temperature), only one temperature cycle is necessary. This is the standard mode. Selecting one of the other modes can be necessary if the measurement of one file influence the measurement of the others.

FixTw: 1 file/cycle: All files of the constant (fix) period width will be measured in separate temperature cycles. So the number of cycles are the numbers of files with constant period width. All files with variable Tw would be measured in the first cycle. This mode can be useful at variation of UR because compensation at different voltages.

FixTw: 2 files/cycle: Always two files of the constant (fix) period width will be measured in a separate temperature cycle. These 2 files should have different period widths but the same other measuring parameters. This mode can be useful at a variation of UR and two different period widths per 'different UR'.

1 file/cycle: All files will be measured in separate temperature cycles.

3.4.1.1.2 Temp input sheet



The temperature delta (increment/decrement) between two measurements will be set in the start input window, see chapter 3.4.1.4. The **Delta mode for FixTw** defines whether this delta is fix for files with constant period width:

Independ of eval class: The temperature delta is independent of the evaluation

Depend of eval class: The delta temperature depends on the evaluation class. This mode enables the input for 4 ranges of class.

As external file: Measurements will be made only at temperatures given in an external ASCII file without header, see chapter 3.4.6.2. Every temperature must be in the first column of a line, an optional waiting time after setting temperature in the 2. column. This mode enables you to measure only at temperatures which are interesting for your sample. This decrease the measuring time.

At the **Delta factor for FixTw** you define a factor for multiplying with the temperature delta if selecting 'Depend of eval class'. At higher evaluation class (quality of transient) the temperature steps should be smaller:

at class 0..29: Factor in case of very bad signals, no transient, only noise.
at class 30..39: Factor in case of bad signals.
at class 40..49: Factor in case of quite well signals. There is a transient, but the time law of the transient do not follow the expected ones. For example not exponential but double exponential (two overlapping levels) or linear or a very noisy transient.
at class 50..75: Factor in case of a very well signal. The measured transient will follow definitely the expected time law. A direct Arrhenius evaluation is possible.

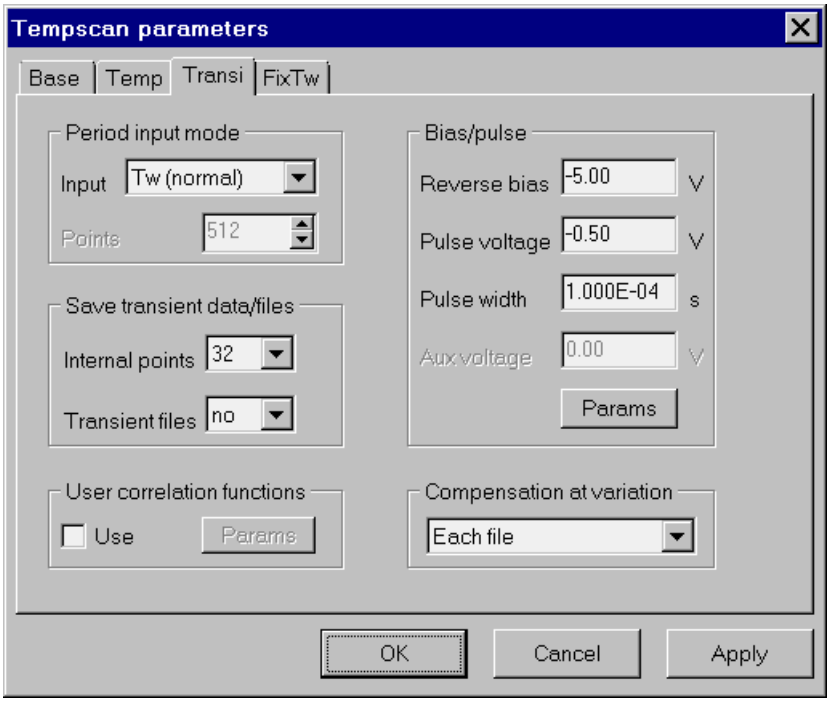
Temp delta for VarTw defines the temperature steps for the files with variable period width. The software calculates here the temperature increment with respect to the evaluation class between the limits defined in 'Minimum' resp. 'Maximum delta'.

In **Cycle parameters** there are parameters for different temperature cycles.
If there is more than 1 cycle you can use the defined or **both temperature directions** (cooling down and heating up).
Before the first cycle and between the cycles you can set a **waiting time** before start.

You can define the **voltage at cooling down**:

zero: Zero voltage will be set to the sample.
before: The voltage will not newly set, the applied voltage will be kept.
global UR: The global reverse bias will be set to the sample.
l**ocal UR:** At variation of UR the local voltage for this file will be set.
input: Enables an input for this voltage.

3.4.1.1.3 Transi input sheet



Period input mode defines which variables can be modified:

Tw, N=128: Similar as next but the numbers of transients points is 128. This is helpful at using 3 Tw's for constructing a quasi-logarithmic transient (HERA).

Tw (normal): The period width Tw and the minimum measure time tM can be defined, this should be used as a standard. The number of points per transients is 512 if possible.

Tw,N: In addition to the standard inputs also the number of points per transient N can be defined.

Tw,N,t0+: In addition to above an additional time for the delay time t0 can be defined.

Note: Normally we use 512 transient points as default. This gives a better signal to noise ratio (SNR) for the coefficients than 128 points. But you should select 128 points for the HERA transient evaluation because here the transient data and not the coefficients are necessary. The saving of internal transient points is limited to 512, but this enlarges the file size. If measuring 512 transient points and saving 128 points only every 4. point will be saved. You lose a factor of 2 for the sensitivity. If measuring and saving the same number of points you get the best available SNR for the transient. On the other hand 128 transient points are enough for the HERA transient evaluation because you build from 2 or 3 files a quasi-logarithmic transient. For more information look in chapter 6.1.4.1.

Save transient/data files:

Included in the tempscan file you can save **32**, **128** (default) or up to **512** transient points. Complete separately **transient files** as in the transient module can be saved in defined temperature distance (Temp-delta). You can select whether saving transient files only for the **main file of FixTw** or for all tempscan files. A definition of a minimum evaluation class for saving transient files is possible. The input group will be expanded for this.

If activating **User correlation functions** you get by the button an input window for the numbers of user correlations (weighting) functions and their names, see chapter 3.4.6.3.

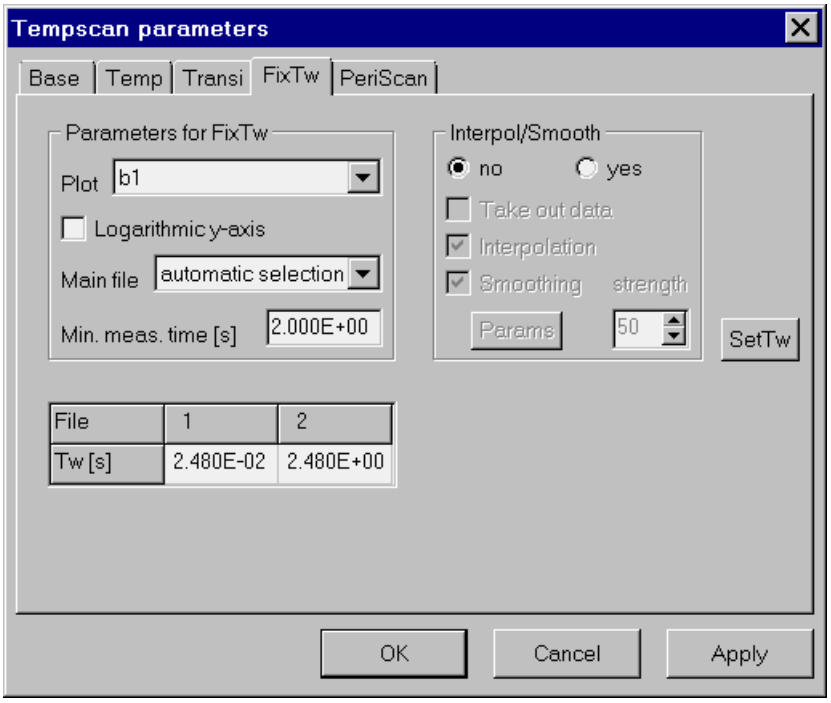
Following inputs are possible in the **Bias/pulse** input box:

Reverse bias: This voltage UR is the voltage at the transient measurement. Its is also the equilibrium voltage for compensation, the sample stays at this voltage after measurement.
Pulse voltage: This is the voltage during pulse, called UP.
Pulse width: This is the length of one pulse, called tP.
Aux voltage: This input is only activated in special cases, for FET samples you can define here a second voltage, the Drain-Source voltage.

These inputs are only enabled if not selected the variation of this value in the base sheet. The **Params** button leads to an input window for additional pulse and measurement parameters, see chapter 3.2.1.1.

The **range compensation** (or bias regulation at CC-DLTS) can be done at the first file, at the first Tw block or at each file. The second means that if only Tw changes but no other parameter at one temperature point the compensation will not be done. In the example tip at the end of the next chapter the compensation would then only be done for file 1 and 3.

3.4.1.1.4 FixTw input sheet



Plot defines the Fourier coefficient(s) which will be shown during the measurement as a function of temperature:

b1: First sine coefficient, similar to the standard Dlts rate window
a1: First cosine coefficient
b1, b1(Tw/4), a1(Tw/4): 2 similar, 1different coefficient
b1, a1, b2, a2: 4 different coefficients
b1 or a1, normalized: The height of b1 resp. a1 will be normalized to the amplitude of the exponential time law.
NT of b1 or a1: b1 resp. a1 will be normalized to the trap concentration. The normalization is only valid for a peak maximum.

Activating **Logarithmic y-axis** takes the logarithm of the coefficient above for the plot.

By **Interpol/Smooth** the coefficient plot will be interpolated or smoothed, see chapter 2.7.1 for the explanation of these parameters.

You can select the **Main file** of the constant period width:

Automatic, first or last Tw of first block, first or last Tw of last block.

First/last block means the first/last parameter variation, see also tip at the next page. If there is no parameter variation then there is no difference between first and last block. Automatic means last Tw at heating up and first Tw of last block at cooling down. Usually the first period width is the smallest one. The coefficient plot uses the main file while transients of all files will be shown.

Minimum measure time tM defines the total time of the measurement tMt. It includes the period width Tw, the delay time after pulse t0, the pulse width tp and the number of averages Na. The software calculates from tM the number of averages by Na=tM/(Tw+t0+tP). The minimum number of averages (transient measurements) is 1, so the input is not the measure time but the minimum measure time. The total measure time tMt defines the signal noise ratio and not the period width.

For a example, if tM=1s and neglecting t0 and tP, then is valid:

Tw=10ms → tMt=1s, Na=100
Tw=1s → tMt=1s, Na=1
Tw=10s → tMt=10s, Na=1

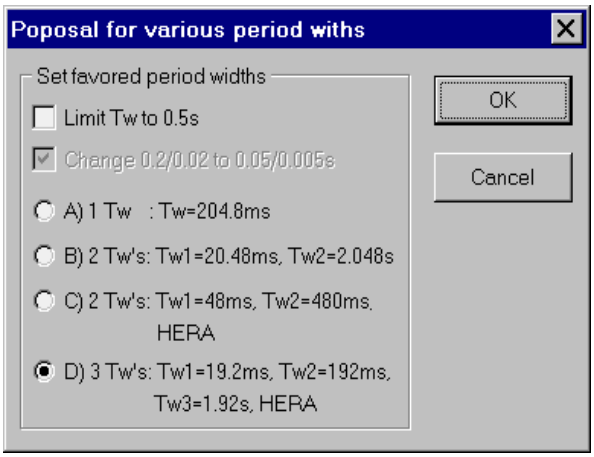
The input for the **variations** are in the grid at the bottom. Entries must be made for every specified file of constant period width. In all cases you have to define the period width for every file/measurement. If selected 'Tw,N,t0+' as period input mode then there is in the grid the input for the additional delay time. If activating UR, UP or tP as variation then these inputs are in the grid.

Note: We prefer definite period widths. This have the advantage that files are comparable and combinable (subtraction, addition) if they have the same period width. So if you make 2 measurements with same Tw on 2 samples then the peaks of the temperature curves appear on the same temperature position if the levels in the 2 samples are identical.
If using 1 period width this is 204.8 ms, for 2 different period widths we use 20.48 ms and 2.048 s. This selection of the 2 period widths yields to a wide range in the Arrhenius plot without overlapping and without a gap. If the large period width of 2.048 s is too big because drift problems we use 5.12 ms and 512 ms, but 5 ms is only possible if you see no recovery signal at Tw=5ms. The number of transient points for all these files is 512.
For the HERA transient evaluation we use 3 period widths with 19.2ms, 192ms and 1.92s, the number of transient points is 128. These 3 transients have an overlapping so that you can build a quasi logarithmic transient. The 128 transient points can be saved into the tempscan file.

The following lists our **favored period widths**, in brackets are the alternative values:

A) 1 Tw: N=512, Tw=204.8 ms
B) 2 Tw's: N=512, Tw1=20.48ms (5.12ms), Tw2=2.048s (0.512s)
C) 2 HERA: N=128, Tw1=48ms, Tw2=480ms
D) 3 HERA: N=128, Tw1=19.2ms (4.8ms), Tw2=192ms (48ms), Tw3=1.92s (0.48s)

The button **SetTw** simplifies the input of period widths.



Here you get the question to set 1, 2 or 3 of our favored period widths in the grid. For example if you have 4 files and you select 2 favored period widths, then file 1 and 3 get Tw1, file 2 and 4 get Tw2. The Tw's and N will be defined by the standard values as described above. If selecting '2 HERA' or '3 HERA' then 128 transient points will be internally saved, in the other case 32.

The selection of a '**Limit Tw to 0.5s**' gives the possibility to limit the period widths if they are too big because drift problems. This flag has only an effect for selection B and D. If activated then Tw2 from B and Tw3 from D will be set to its alternative value.
If this limit is activated then also a flag with the caption **Change 0.2/0.02 to 0.05/0.005s** is enabled. Activating of this flag sets also for the other period widths of selection B and D its alternative values.

Arguments for the selection of period width:

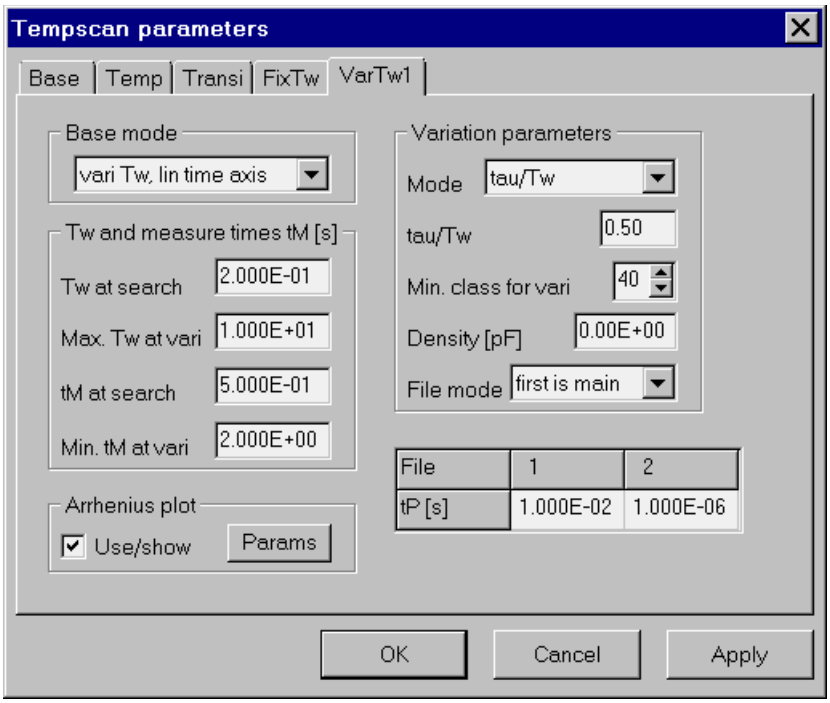
- 1 period width is enough for only an overview.
- 2 period widths are necessary for a good maximum analysis.
- 3 period widths are necessary for a good HERA transient evaluation. Then a quasi-logarithmic transient can be build with a large time range.
- A and B are optimized for the coefficients, C and D for HERA.
- Select B if your priority are the coefficients, select D if your priority is HERA.
- If possible don't use the alternative values.
- A limit of Tw to 0.5s can be necessary at drift problems or temperature oscillations.
- If you limit Tw to 0.5s then use also the alternative values for the other period widths. This change has the advantage that there is not too much overlapping in time constants. A wide overlapping decreases the range of the Arrhenius plot and of the time axis of the quasi-logarithmic transient.
- Period widths of 5ms are only possible if you see no recovery signal at Tw=5ms.
- Select C if the priority is HERA and Tw must be limited and Tw=5ms is not possible.

Tip: At a variation of the period width and a parameter you should first measure all period widths of the first parameter value and then all period widths of the next parameter value. For example, if using 2 Tw's and 2 tP's, then the file (measure) order should be:

1: Tw1,tP1; 2:Tw2,tP1; 3:Tw1,tP2; 4:Tw2,tP2

This has the advantage that the influence of the parameter is always similar for the corresponding Tw's, for example if the traps are completely filled by tP2 but not by tP1. The other advantage is that the software can easier detect the corresponding Tw's and files.
The last parameter value should be so that it gives a bigger transient signal as the first parameter value, in the example above tP2>tP1. This has the advantage that the influence of measurement with tP1 is not so big to measurement with tP2 when the emission process is not finished after transient measurement.

3.4.1.1.5 VarTw1 input sheet



The **Base mode** defines the kind of use:

var Tw, lin time axis: Variable period width with linear time axis, standard mode.
vari Tw, log time axis: Variable period width with logarithmic time axis
fix Tw, log time axis: Constant period width with logarithmic time axis

In the following only the **standard mode** with the linear time axis will be explained. For the logarithmic time axis is the HERA option necessary, an explanation will be given at the end of this chapter.

Variable period width 1 means the period width Tw will be calculated and regulated during the measurement according to the transient time constant of the main measurement file for the variable period width 1. All other specified files with variable period width1 will be measured with this period width and their particular parameter sets. This enables you to use the differences of these files.
Differences of measurement files are only possible with files of the same period width at the same temperature.
The combination of variable period width 1 and 2 enables you to optimize the measurement conditions on two different emission time constants (a slow and a fast one), and so to separate overlapping levels even with the variable period width measurement mode.

Tw and measure times:

Tw at search defines the default period width for the Tw search. Search means here that no good transient signal was found and the software tries different period widths.
Max. Tw at vari is the maximum period width for the variation of Tw. Variation of Tw means here that the software has found a good transient signal and now regulates the Tw for this transient.
tM at search is the minimum measure time at Tw search, the definition is similar to this one for the constant period width.
Min. tM at vari is the minimum measure time at Tw variation.

The **Variation parameters** specify some parameters, that are important for the regulation of the variable period width:

Mode for the Tw regulation:

tau/Tw: Ratio between the time constant tau of the measured transient and the period width Tw. For example, 0.2 means the measured time was 5 times higher than the effective time constant of the signal. This assures you, that the measurement time was long enough for calculating the correct time constant. Value should be in the range 0.1 < tau/Tw < 0.8.

ts/Tw: Ratio between the time ts taken for the signal to fall below the ADC sensitivity and the period width Tw. For example, 1.5 means 1/3 of the measured transient is measured in the ADC noise level. It assures you that the transient has really decreased to zero and the measurement time was satisfying. Value should be in the range 1.1 < ts/Tw < 2.

ts/Tw, mid Tw: As above, but instead of the full period width only the middle part of the transient will be used.

ts/Tw, no eval: No evaluation model (exponential) will be used for the ts calculation only an extrapolation.

external file: An external ASCII file defines the period width and the temperatures where the measurements of variable period width should be done. The ASCII file must not have a header. Every temperature must be in the first position (column) of a line, Tw must be in the 2., t0 in the 3. column, an optional waiting time after setting temperature in the 4. column.

The **tau/Tw** resp. **ts/Tw** value defines the Tw regulation.

Minimum class for a transient measurement is used to filter data used for the calculation of the regulated period width. If the measured data is below the specified class then no regulation will be done, in which case the starting period width will be used. Default value for this minimum class is 40.

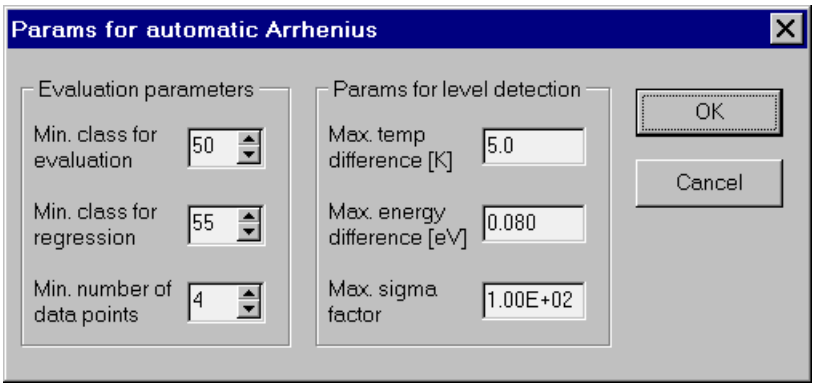
Density defines the minimum signal height for regulating the period width.

File mode defines the main file which will be used for the Tw regulation. The other files have the same period width. You can select 'First', 'Last', 'First-last' and 'Last-first'.

If activating variation of tP and so on you see at the right bottom the **input grid** for these parameters. File 1 means here the first file of variable period width.

By activating use/show **Arrhenius plot** the software shows the Arrhenius plot during the measurement. The energy and capture cross section is calculated automatically. The range for the linear regression is automatically selected by the class of the measured data. The results will be used for the next variation of Tw.

The button **Params** opens an input window for the DLTFS Arrhenius plot. Special parameters for automatic distinguishing of several trap levels values for the automatic direct Arrhenius plot analysis can be



defined. The parameters are only valid for the showing of the automatic Arrhenius plot during the measurement.
Input of the **minimum class for evaluation** that shall be used for the Arrhenius plot. The default value is 50. Data with a class lower this value will not be shown in the Arrhenius plot.

Input of the **minimum class for regression** that shall be used for the regression line and so for the energy calculation of the Arrhenius plot. Data with a class lower that this value will be plotted in the Arrhenius plot, but not used for the regression line calculation. The default value is 55.

Input of **min. number of data points** (measured and calculated time constants with satisfying class) that shall be necessary for calculating and showing an Arrhenius plot level.

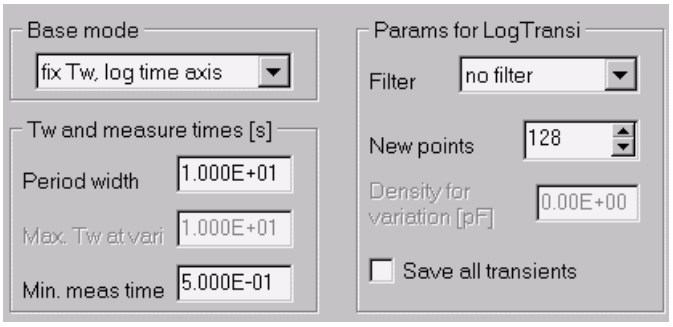
Max temp difference defines the temperature difference between two measured time constants that will be used for calculation of one trap level. If the temperature difference between two time constants (with satisfying class) is higher than this value the last measured time constant and all following ones will be used for evaluation of a new level.

Max energy difference defines an energy value used to distinguish trap levels. If the calculated energy of the last number of measured time constants will differ more than this value from the energy calculated from all measured time constants for this trap level, a new trap level will be defined and the last measured time constants and all following ones will be used for evaluation of this new level. This level definition is only valid during the measurement.

Max sigma factor similar to above, but in this case the criterion for differentiation between levels is the capture cross section.

Fix Tw, log time axis:

This type of logarithmic transient will be measured by many equidistant transient points and then selecting points in a logarithmic step, see chapter 3.2.1.4.



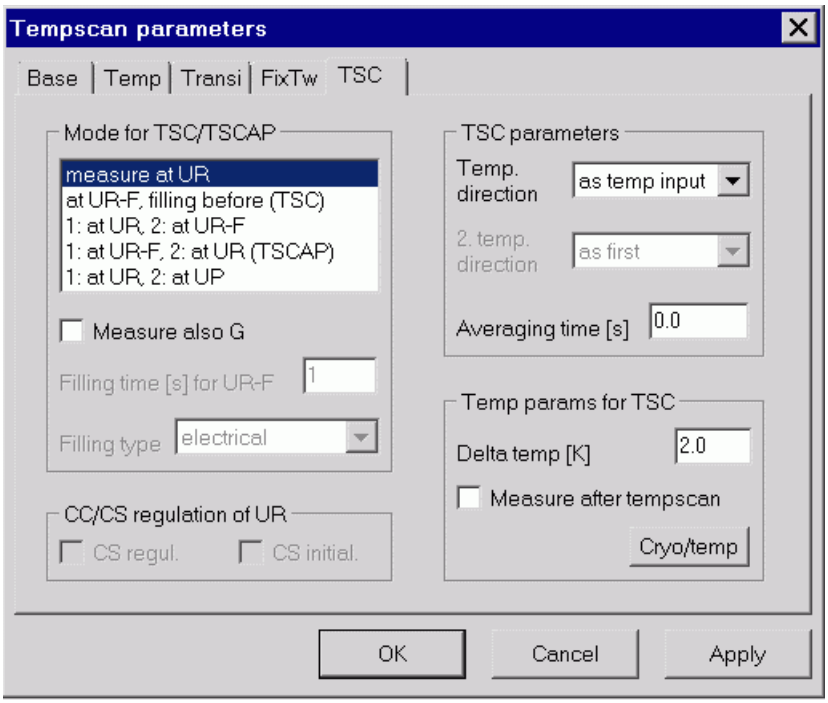
'**Period width**' Tw and 'Min. meas' tM time have the same meaning at the linear time axis. Usually now Tw is bigger than tM so that the number of averages is only one.

You can select the number of logarithmic points (**New points**) and a digital **filter** (no, weak, medium, heavy) for creating these points from the up to 65000 measured transient points. It is possible to save the logarithmic transients in separate files, this will be selected on the transi input sheet. If there is 'main file of FixTw' activated then here the flag 'Save all transients' will be enabled.

3.4.1.1.6 TSC input sheet

The TSC mode and equilbrium parameters will be explained later in chapter 3.5.

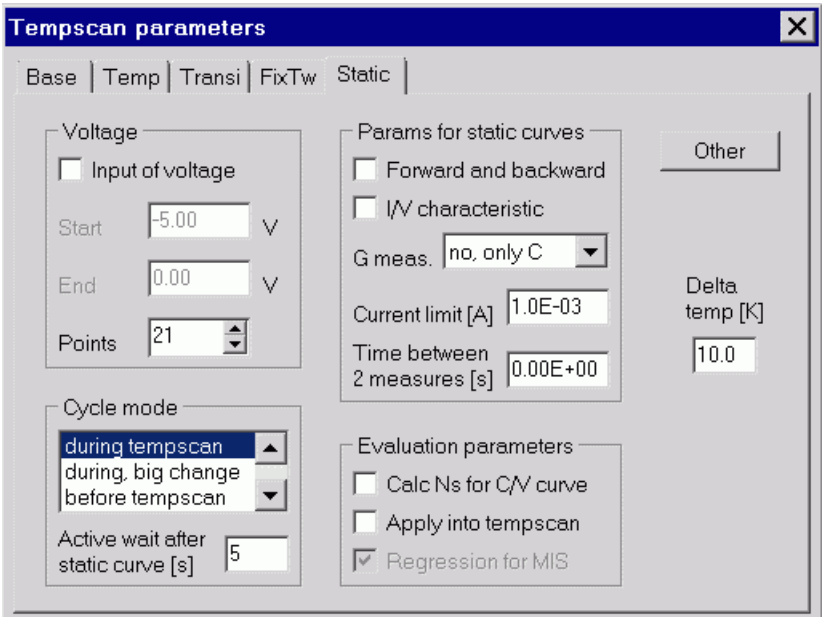
The voltages UR and UP will be taken from the 'Transi' input sheet.
There are separate inputs for the cryo resp. temperature parameters of the TSC measurements. These inputs are similar to the inputs for the tempscan files, explained in chapter 3.4.1.4, and only valid for TSC. TSC needs normally a temperature ramp.
Usually the TSC measurements will be done in a separate temperature cycle before the tempscan, by activating a flag it can also be done after all tempscans.



3.4.1.1.7 Static input sheet

The measurement of static curves can be helpful to observe their temperature dependence or to calculate Ns at various temperatures. The capacitance will here directly be measured by the bridge without compensation. Usually CP will only be calculated at a transient measurement.

The static input sheet is similar to that one in chapter 3.1.1.1.



If not activating **Input of voltage** then the reverse bias and pulse voltage will be used as start and end voltage.

Activating I/V characteristic measure I/V curves as in chapter 3.1.1.3 described.

'Temp-delta' is the fix temperature step.

'Calc Ns for C/V curve' calculates Ns from the new C/V curve and apply it in the sample header.

Apply into tempscan means that CR, CP and Ns from the temperature depending C/V curves will be applied into the tempscan files for each temperature, see chapter 3.4.2.2. The Ns(T) flag in the sample parameters will be activated, chapter 2.4.4.2.

Regression for MIS optimizes the regression range of the Ns calculation for MIS samples.

The **cycle mode** defines when the static curves should be measured:

during tempscan: The static curves will be measured during the tempscan (standard).

during, big change: The static measurements will be done at start and end temperature and at big changes of CR resp. IR.

before tempscan: The static curves will be measured in a separate temperature cycle before the tempscan. This can be necessary form the physic to avoid that the change of voltage affects the transient. A button 'cryo/temp' will be visible which contains parameters as ramp and so on, similar to chapter 3.4.1.4.

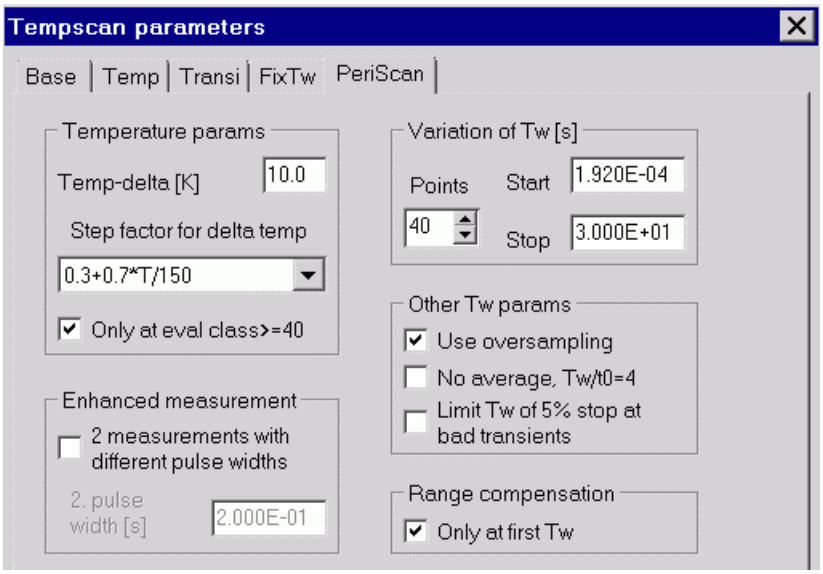
after tempscan: As above, but after all tempscans.

A waiting time after a complete C/V or I/V curve can be necessary before measuring transients. '**Active wait after static curve**' defines such a waiting time. It is not a fix time but takes into account the time for increasing the temperature. '5s' means that the next transient will not be measured before 5s after the static curve. This time is especially helpful at slow emission processes which depend on the pulse width.

If the capacitance bridge allows the measurement of the conductance G, then the input of the kind of **G measurement** is available as explained in chapter 3.1.1.4.

3.4.1.1.8 PeriScan input sheet

There are special inputs for the temperature parameters for the period scan measurements. These inputs are similar to the inputs for the tempscan files explained in chapter 3.4.1.4.



Activating **Only at eval class >=40** means that the period scan will be done only if the evaluation class of one transient is same or bigger as 40.

Activating a flag then **2 measurements** with different pulse widths are possible. This can be helpful to separate 2 levels with a big difference of capture cross section. After the measurement you can subtract the corresponding isothermal files to get the emission of the level with the small capture cross section. The sub file name of the period scan for the second pulse width starts with a 'B' instead of a 'T', for the name conventions have a look in chapter 3.4.1.4.
The pulse width of the first (main) period scan is always the global pulse width which you can input in the separate 'Params' input window of the Transi input sheet.
The measurement of the 2. period scan starts after the main period scan, so its period width should be bigger than that one of the first. This reduces a possible influence of period scan 1 to period scan 2, see tip in chapter 3.4.1.1.4.

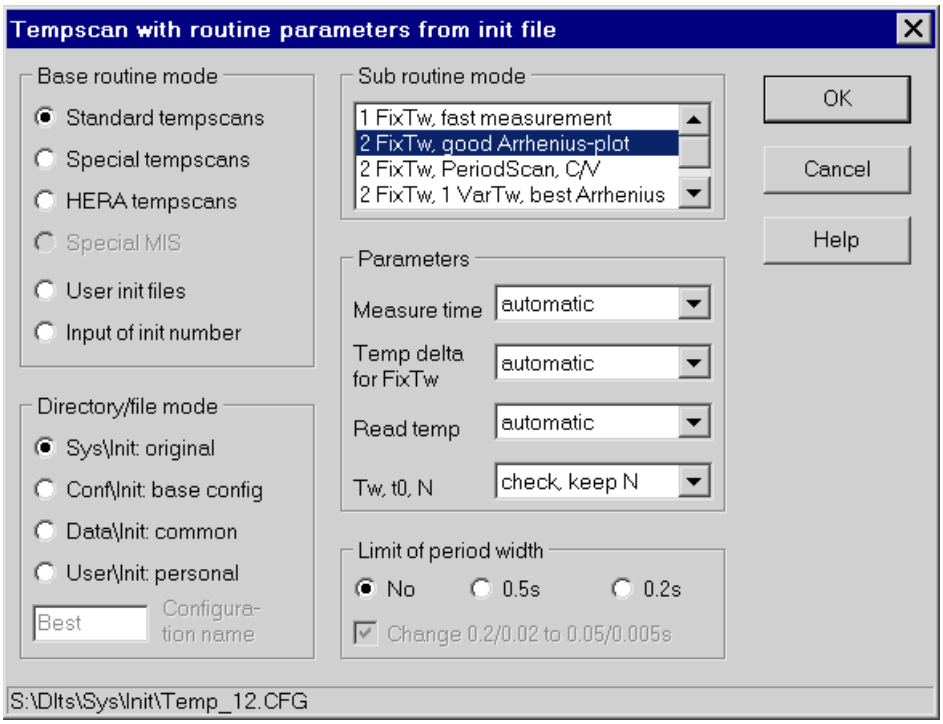
The other inputs are explained at the period scan in chapter 3.3.1.2.

The **oversampling** is a main feature of the HERA system and should be activated.

Activating of '**No average, Tw/t0=4**' sets the Tw/t0 ratio to a fix value and doesn't average the transients. It is only enabled when using oversampling. Activate this flag for the measurement of oxide states, for more details see chapter 6.4. In the other case (standard) it should be deactivated. Then Tw/t0 is 1 to 4 and the number of averages will be calculated by the 'Min. measure time' (input sheet FixTw) as in the isothermal module.

Limit Tw of 5% stop at bad transients means that the period scan stops at 5% of the Tw stop value if all evaluation classes are smaller than 40 until this period width. This save measurement time.

3.4.1.2 Routine measurement



The routine measurements starts a tempscan with standard parameters in which only a few inputs are necessary. This permits rapid measurement, and is convenient for new users. You can select between several sets of parameters. The main difference in these sets are the period width and the numbers of files. The parameter sets are prepared for different applications and saved in special initialization files with name Temp_XX.CFG. XX is the number of the init file and is specific for the parameter set. Additionally to the pre-defined init files the user can create his own, see chapter 3.6.1.

For a better overview the selection is divided into base and sub routine mode. The **Base routine mode** is a 'caption' and defines which input of sub routine mode is visible:

Standard tempscans: This is the standard.

Special tempscans: Tempscans for level separation by tP.

HERA tempscans: Tempscans optimized for the HERA transient evaluation, see chapter 6.1.4.1. So all 128 transient points will be saved.
A quasi-logarithmic transient can be build by 2 or better 3 files.

Special MIS: Special tempscans for MIS samples.

User init files: Opens a selection of init files which was made by the user. This standard one is Temp_71.CFG.

Input of init number: Input of the number of the initialization file which should be loaded, so 91 gives Temp_91.CFG.

In the following means FixTw a tempscan with constant period width, VarTw with variable period width. The number denotes the number of these files. Tw is the period with at FixTw, TwMax is the maximum period width at VarTw, tM is the minimum measurement time. The number of transient points N is normally 512. The internal saved transient points NI are usually 32. The following list gives a short overview. The first number denotes the init file number. A detailed explanation will be given below.

Sub routine modes of **standard tempscans**:

11) 1 FixTw, fast measurement:	Tw=204.8ms, tM=2s
12) 2 FixTw, good Arrhenius plot:	Tw1=20.48ms, Tw2=2.048s, tM=2s, standard
13) 2 FixTw, PeriodScan, C/V:	as 12, period scan, C/V curves at big CR change
14) 2 FixTw, 1 VarTw, best Arrhenius:	Tw1=20.48ms, Tw2=2.048s, TwMax=10s, tM=2s
15) quick overview measurement:	Tw=204.8ms, tM=1s

Sub routine modes of **special tempscans:**

21) 1 FixTw, 1 VarTw, one level :	Tw=204.8ms, TwMax=30s, tM=2s,
22) 2 FixTw, 2 pulse widths:	Tw=204.8ms, tM=2s, tP1=1us, tP2=1ms
23) 4 FixTw, 2 pulse widths, 2 Tws:	Tw1=24.8ms, Tw2=2.048s, tM=2s, tP1=10us, tP2=1ms
24) 2 FixTw, 3 VarTw, 2 pulse widths:	Tw=204.8ms, TwMax=10s, tM=2s, tP1=1us, tP2=1ms

Sub routine modes of **HERA tempscans:**

31) 2 FixTw, HERA TranEval:	Tw1=48ms, Tw2=480ms, tM=2s, N=128, NI=128
32) 3 FixTw, HERA TranEval:	Tw1=19.2ms, Tw2=192ms, Tw3=1.92s, tM=2s, N=128, NI=128
33) 3 FixTw, HERA, PeriScan, CV:	as 32, period scan, C/V curves at big CR change
34) 4 FixTw, HERA TranEval:	Tw1=6.4ms, Tw2=55.04ms, Tw3=473.6ms, Tw4=4.096s, tM=2s, N=128, NI=128
35) 1 FixTw, log. time axis:	Tw=10s, tM=2s

Sub routine modes of **special MIS :**

41) 1 FixTw, Nss only:	Tw=204.8ms, tM=2s
42) 2 FixTw, 2 tP, oxide states:	Tw=204.8ms, tM=2s, tP1=100us, tP2=100ms
43) 4 FixTw, 3 tP, oxide states, taps:	Tw=512ms, tM=0.2s, tP1=20us, tP2=2ms, tP3=200ms, Tw2=20.48ms for tP=20us, tM=0.5s, NI=128
44) VarTw, Zerbst transients:	Saving of transients for Zerbst plot with automatic adaption of period width

Equilibrium and **static** curves will be measured together with the tempscan or alone in the equilibrium resp. static program module. If the batch measurement should measure only separate equilibrium or static curves, a routine init file is necessary. Therefor some such init files were defined, which can also be called by the input of init number:

51) CR and IR at UR:	One file (QR?) with C- and I-measurement at UR
52) TSC/TSCAP at UR and fill:	One file (QR?) at UR and one (QF?) with 1s filling, uses mode IV of chapter 3.5.1.1
53) CR/IR and CP/IP:	One file (QR?) at UR and one (QP?) at UP
61) C/V curves:	C/V curves between 2 voltages, check the voltages at 'Params' button of start window.
62) I/V curves:	I/V curves between 2 voltages
63) C/V and I/V curves:	C/V and I/V curves between 2 voltages

Detailed explanation of main routine tempscans:

11) 1 FixTw, fast measurement:
Measurement of one file with constant period width. The period width has the medium value of 204.8ms. The emission time constants at the maximum temperature of the different coefficients are between 2.8ms and 155ms. Here you don't get very good results for the activation energy because the temperature range in the Arrhenius plot is too small.

12) 2 FixTw, good Arrhenius plot:
This is the standard initialization file. Measurement of two files with different constant period width. The first period width (main file) is 20.48ms and the second one 2.048s. The emission time constants at the maximum temperature of the different coefficients are between 0.36ms and 1.5s. By this measurement you get very good results for the activation energy because the large temperature range of the Arrhenius plot made by the maximum analysis.
This parameter set can be used at several trap levels that emission rates will superpose. The variable period width measurement will not work in this case. Therefore such files will not be measured. All evaluations have to be done with constant period width files.
Application: Discrete levels, superposition.

13) 2 FixTw, PeriodScan, C/V:
Similar to 12 but additional isothermal period scan every 10K. 40 period widths from 1ms up to 30s will be measured. C/V curves will be measured at start and end of tempscan and when CR changes more than 10 %.
Application: Discrete levels, unknown sample, extended test.

14) 2 FixTw, 1 VarTw, best Arrhenius:
Similar to 12 but additional measurement of variable period width. Without superposition of levels you get a very good Arrhenius plot by the direct evaluation (DLTFS) of the variable period width. The restriction of the maximal period width to 10s, that will be used for following an emission time constant, will enable the measurement system not only to follow one trap level but to look for other ones. So the system can switch from one emission rate measurement optimization to another one. The variable period width is only working correctly if there is no superposition of traps. By the maximum analysis of the two constant periods you get good results for the activation energy because the large temperature range of the Arrhenius plot.
This parameter set can be used at several trap levels that emission rates can superpose. It will give an accurate energy for levels with only little superposition (using the variable period width analysis), and gives possibilities for separation of overlapping signals.
Application: Discrete levels, perhaps superposition, very accurate Arrhenius plot.

15) quick overview measurement:
Very fast overview tempscan with one file with constant period width of 204.8ms. All parameters are optimized for quick measurements. In practice it is not the measurement time, but the cooling/heating rate of the cryostat which limits the tempscan completion time. The results are only useful insofar as they provide an indication of the temperature at which a trap emission transient will be seen; accurate trap concentration analysis is not possible. Trap energy analysis by Arrhenius plot from this measurement is not useful in most cases, because the quick heating and cooling will cause systematical errors of more than 10 % of the real energy! A correct energy evaluation has to be done with a measurement at very slow heating or cooling rates.
Application: Rapid overview, search of interesting temperature range.

21) 1 FixTw, 1 VarTw, one level:
Measurement of one file with a constant period width of 204.8ms and of one file with a variable period width of maximal 30s. Without superposition of levels you get very good results for the activation energy. In this case the measurement of variable period width gives an excellent Arrhenius plot because the temperature range is there very large.
If there are several but isolated trap levels (or the emission amplitudes of the other ones are negligible, smaller than a factor of 100) this parameter set can be used. It will give a very accurate energy of all levels (using DLTFS for the variable period width).
Application: Discrete levels, no superposition.

22) 2 FixTw, 2 pulse widths:
Two files with constant period width of 204.8ms will be measured using identical parameters except for the pulse width. The first file will be measured with a small pulse width of 10us (standard pulse generator), the other one with a 1ms pulse. Uses standard DLTS pulse width separation evaluation, and should be used in cases where there are several traps levels with emission that will be superimposed.
If there are several trap levels that emission rates will superpose and the capture cross sections of these levels are very different (eg 10^-15 and 10^-19) and one capture cross section is very small (<<10^-17cm^-2), this parameter set can be used.
The long pulse width measurement will collect every transient, while the short pulse will only collect the emission signal from the large capture cross section level. The difference between these measurement files will give the signal of the small capture cross section level. Difference building is possible in the file menu (see chapter 2.2.2) and automatically in the maximum analysis.
Note: If you have an external fast pulse generator you should use smaller pulses than 10us, for example 10ns to 100ns.
Application: Superposition, 1 small, 1 big capture cross section.

23) 4 FixTw, 2 pulse widths, 2 Tws:
Similar to 22 but four files with two different constant period widths of 20.48ms and 2.048s will be used. With this is a good maximum analysis possible.
Application: Superposition, 1 small, 1 big capture cross section, good Arrhenius plot.

24) 2 FixTw, 3 VarTw, 2 pulse widths:
This (only on digital systems with direct analysis useable) mode for level separation will measure 2 constant period width files and 3 files with 2 different variable period widths. The files with fix Tw are similar to 22, but uses 1us and 1ms pulse width. This pulse width separation will use the variable period width for level separation. It will work if:

1. The capture cross sections differ more that factor of 1000.
2. There are only two main levels.
3. One capture cross section is smaller than 10^-17cm^-2 or a fast pulse interface and an external pulse generator is used.

The variable period widths will be optimized on the (depending from tp) effective emission time constant this will also separate levels with totally overlapping tempscan signals.
File 1 of VarTw: Variable period width 1, tp=1us
File 2 of VarTw: Variable period width 2, tp=1us
File 3 of VarTw: Variable period width 2, tp=1ms
File 2 and 3 will have different period widths than file 1 because of different regulation parameters. Use file 1 for energy analysis of the large capture cross section and the difference between file 3 and 2 for the small capture cross section analysis.
Application: Extreme superpos., 1 small, 1 big capture cross section, very good Arrhenius.

31) 2 FixTw, HERA TranEval:
2 tempscans optimized for the HERA transient evaluation, similar to 32 but here only 2 files with 48ms and 480ms period width will be measured. A quasi-logarithmic transient can be formed by these 2 files but covers only a smaller time range than with 3 period widths. So use these routine init file instead of number 32 only if the Tw=1.92 is to long (temperature oscillation problems) and Tw=4.8ms is to fast (recovery signal).
Application: HERA transient evaluation, fast and slow period widths not possible.

32) 3 FixTw, HERA TranEval:
This is the standard file for HERA TranEval measurements. 3 tempscans optimized for the HERA transient evaluation (chapter 6.1.4.1) with constant period widths of 19.2ms, 192ms and 1.92s will be measured. Here 128 points per transient will be measured and internally saved. This gives the best signal noise ratio for the HERA transient evaluation. The reason for the selection of 128 points was explained in the note of chapter 3.4.1.1.3. A quasi-logarithmic transient can be formed by these 3 files and covers a large time range. A maximum analysis of the coefficients, the direct DLTFS analysis and the HERA deconvolution is also possible.
If Tw=1.92s is to long because temperature oscillation problems, limit the period width to 0.5s as described at the end of this chapter. Change there also the other periods widths to 0.05s/ 0.005s. Then measurements at period widths of 480ms, 48ms and 4.8ms will be done.
Application: Standard HERA transient evaluation, superposed levels, large time range.

33) 3 FixTw, HERA, PeriodScan, C/V:
Similar to 32 but additional isothermal period scan every 10K. 40 period widths from 1ms up to 30s will be measured. C/V curves will be measured at start and end of tempscan and when CR changes more than 10 %.
Application: HERA transient evaluation, unknown sample, extended test.

34) 4 FixTw, HERA TranEval:
Similar to 32 but 4 period widths of 6.4ms, 55.04ms, 473.6ms and 4.096s will be measured. This covers a little bit bigger tau range.
Application: HERA transient evaluation, extended time range.

35) 1 FixTw, log. time axis:
Measurement of many equidistant transient points and then selecting points in a logarithmic step. The disadvantage is the bad SNR, see chapter 3.2.1.4. Only the HERA transient evaluation is possible but not the other evaluations. Use this routine file only if there are problems with the quasi-logarithmic measurements.
Application: Only HERA transient evaluation, big amplitudes.

41) 1 FixTw, Nss only:
Only 1 file with constant period width of 204.8ms will be measured, similar to 11. One file is enough for the Nss evaluation. It can also be used for a linear inversion process.
Application: Nss evaluation or inversion process at a MIS sample.

42) 2 FixTw, 2 tP, oxide states:
2 files with a constant period width of 204.8ms and pulse widths of 100us and 100ms will be measured. Oxide states should show a strong dependence from the pulse width. 2 files enable a special oxide states evaluation.
Application: Oxide states at a MIS sample.

43) 4 FixTw, 3 tP, oxide states, traps:
3 files with a constant period width of 512ms and pulse widths of 20us, 2ms and 200ms will be measured without averaging. Oxide states should show a strong dependence from the pulse width. 3 files enable three times a special oxide states evaluation, so a check of results is possible. Additionally a file with Tw=20.48ms and tP=20us will be measured. If there are additional traps then a maximum analysis with 2 period widths and a HERA evaluation with a quasi-logarithmic transient are possible.
Application: Oxide states and traps at a MIS sample.

44) VarTw, Zerbst transients:
All transients will be saved into separate files. The period width will be automatically varied in this way that the transient reaches its equilibrium value in the observation time at every temperature. This gives reasonable values for the Zerbst evaluation. For more details see chapter 6.3.8.2 and 4.3.
Application: Temperature depending Zerbst evaluation at a MIS sample.

Following arguments can be used for the **parameter set** selection:

- The variable period widths will only work well if there is very little or no superpositioning of multiple trap levels.
- If there is a working variable period width, theoretical there is no need for an evaluation of a constant period width. In most cases however it is useful to have a constant period width measurement, both for comparison with analog DLTS systems and to obtain an overview DLTS spectra. This is because the variable period width measurement do not provide tempscan signals so the traditional DLTS spectrum is not produced.
- If there are definitely two or more trap levels with similar time constants (superposition of the transients) it is beneficial to have two or more constant period width tempscans with a factor of 100 in the period widths. This will help to create period width separation of the traps; this is similar to the more traditional separation observed through rate windows.
- The HERA transient evaluation can be necessary for very closed levels. You should use here 3 period widths for constructing a quasi-logarithmic transient.

In **summary**, not only a variable period width should be used. In most cases are 2 FixTw files as in sub mode 12 sufficient. Therefore this is the standard, also for overlapping levels. Here you can use the DLTFS evaluation and the maximum analysis to get the Arrhenius plot. For single discrete levels without super-positioning number 14 is better because the additional VarTw. For very closed levels there should be made a HERA evaluation by the use of 32. A traditional maximum analysis is here also possible.

The **Directory/file mode** defines from which directory the initialization file will be loaded:

Sys\Init; original:	Loads an original init file, coming with the software.
Conf\Init; base config:	Use the base configuration directory for init files
Data\Init; common:	Use the init directory of the common data directory.
User\Init; personal:	Use the personal init directory, if the user name is UserX and the program version is 3.2 then this directory is UserX\Init\32.

There is no other search strategy for the init files. After installation only the original init files exist. At the common and personal init directory you have to input the configuration name. In the **status line** you see the full initialization file name. There you get also a hint if the file don't exist.

Every parameter can be read from the init file. This enables you to recreate completely the measurement conditions for similar samples. At the **Parameters** input window you can select if the temperature limits and increments and the measurement times have to be read from this file or not.

In **Measure time** you can select the minimum measurement time tM for the constant and variable period width:

as file:	tM will be read from the selected init file.
automatic:	tM=2s, for the quick overview 1s; standard.
as global:	tM will be overtaken from the current global input value.
density:	tM=10s, means slow measurement.
fast measure:	tM=1s

Temp delta for FixTw define the Delta mode for FixTw and the Step factor for delta temp:

as file:	Both modes will be read from the selected init file.
automatic:	Except the fast measure time the Delta mode is independent of evaluation class and the step factor is 0.3+0.7*T/150 for T<150.
indep. of class:	Delta mode is independent of eval class, the step factor is constant.
depend of class:	Delta mode depends on the evaluation class, the step factor is 0.3+0.7*T/150 for T<150.
external temp file:	Use of an external ASCII file for temperature steps.

Read temp defines the temperature parameters of the start window, see chapter 3.4.1.4:

all params:	All temperature parameters will be read from the selected init file.
automatic:	All temperature parameters without temperature start and stop will be read from the selected init file. The cryo times will be selected by the measure time mode. As density slow cryo times will be selected, as fast measure fast and at the other cases normal cryo times.
no:	The temperature parameters will not be read from the selected init file.

Tw, t0, N defines whether the period width Tw, the delay time t0 and the number of transient points will be overtaken exactly after reading from the selected init file:

keep from file: Tw, t0 and N will be exactly overtaken without a check of validity.
check, keep N: Tw and t0 will be checked and corrected, for example if t0 is not possible with the global selected recovery time of the bridge it will be corrected. N will be kept from the init file.
enable new: similar as above, but if necessary also N will be changed.

We prefer **definite period widths** for constant period widths. This have the advantage that files are comparable and combinable (subtraction, addition) if they have the same period width. If using 1 period width this is 204.8ms, for 2 different period widths we use 20.48ms and 2.048s. This selection of the 2 period widths yields to a wide range in the Arrhenius plot without overlapping and without a gap. For the HERA transient evaluation we use 3 period widths with 19.2ms, 192ms and 1.92s.

The selection of a **Limit of period width** gives the possibility to limit the constant period widths if they are too big because drift problems:

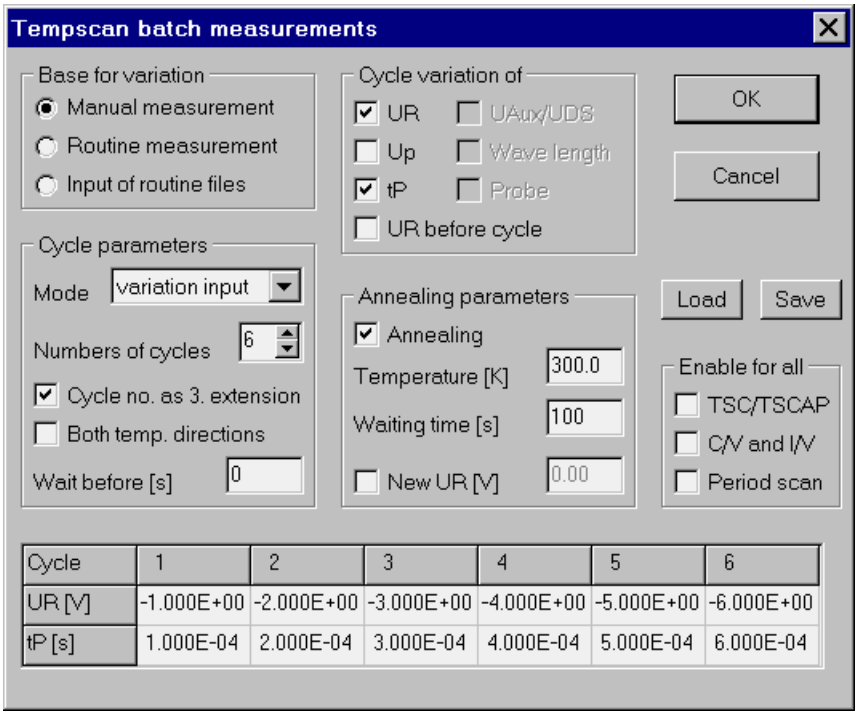
No: There is no limit of the period widths, they will be taken as in the init file.
0.5s: The period width is limited to 0.5s.
0.2: The period width is limited to 0.2s.

At limiting period width there is a flag enabled with the caption **Change 0.2/0.02 to 0.05/0.005s**. Activating this flag means that a period width of 204.8ms, read from the init file, will be changed to 50ms for the measurements. Period widths of 20.48ms will be changed to 5ms. Similar is valid for the values of period widths used by HERA. The change of the period widths has the advantage that there is not too much overlapping in time constants if using 2 period widths. This increases the range of the Arrhenius plot. Period widths of 5ms are only possible if you see no recovery signal at Tw=5ms.

After clicking on the **OKAY** button the tempscan start window opens where you can change the temperature parameters. There is also a Params button which opens the input sheets of the tempscan with manual parameters as explained in chapter 3.1.1.1. Here you can view or modify your parameters loaded from the initialization file. Normally no view or change is here necessary.
If you have not already defined the reverse bias you get before the tempscan start window an input window for the global reverse bias and pulse voltage.

Tip: You can also use the routine tempscan to simplify the inputs. That means you select that routine init file which covers best your intended tempscan. Then you click onto the 'Params' button of the tempscan start window. This opens all manual inputs as described in chapter 3.4.1.1.

3.4.1.3 Batch measurement



The batch job measurement repeats different temperature cycles by changing some measurement parameters, so it works similar as a 'batch' job. A manual or routine measurement can be the base for the batch measurement. This measurement contains all parameters. The batch measurement then repeats this measurement by variation of one or more parameters. Every repetition will be done in a separate temperature cycle. We call this temperature cycle here batch cycle to avoid confusions. The base measurement, that means in this case one batch cycle, can contain also different temperature cycles as shown in the previous chapters. A temperature cycle of the base measurement will here be named as base cycle.
Three possibilities for the **base for variation** exist:

1. **Manual measurement:** A manual measurement as explained in chapter 3.4.1.1 is the base for the batch. After clicking on the 'OK' button these input sheets open and you have to define the parameters for the base of measurement.
2. **Routine measurement:** A routine measurement as explained in chapter 3.4.1.2 is the base for the batch. After clicking on the 'OK' button the routine input window opens and you have to select the routine file. Then this file will be loaded.
3. **Input of routine files:** You can define for every batch cycle a separate routine file by input of an individual routine file number in the cycle grid. After clicking on the 'OK' button the routine input window opens, as described in chapter 3.4.1.2. Here you can not define a routine file number but the other parameters. The directory mode will be used to construct the various routine file names.

In the cycle parameters input group you can define the cycle **mode**:

variation input: This standard mode enables the input of **numbers of cycles**, up to 10 are possible. For each you can input the parameters in a grid.
2. as C-DLTS: 2 cycles while the first use the actual DLTS mode, the 2. the C-DLTS.
all samples: Available with the sample switch box (chapter 6.5.5) and sets the number of probes/samples to the numbers of cycles. Then every cycle is valid for the corresponding probe number.

If activating '**Cycle no. as 3. extension**' then the data file name for each batch cycle will be constructed with the help of the cycle number. For this the file name which you have input will be used and the 3. character of the data extension will be set to the batch cycle number. For example ID@A_001.T12 for the second batch cycle. Remember that the second data extension character will be set by the base measurement resp. base cycle.
If this flag is deactivated then the file name will be automatically set if the automatic file name option will be used, see chapter 2.4.5. For example, if the input of file name was ID@A_001.T1A, then the file name is ID@A_002.T1A for the second batch cycle.

Note: The program checks before starting the measurement whether files which will be created during the first batch cycle already exist. If one file exist then you get a warning and a question to overwrite all these files or to cancel the measurement. There is no check for the files of the further batch cycles! So make sure that you don't overwrite existing files. Usually there is no such problem when activating the '3. extension' flag therefor we prefer this option.

If activating **both temperature directions** then cooling down and heating up will be used for the various batch cycles. In the other case all batch cycles will be done only in the same temperature direction (cooling or heating) as defined at the tempscan start.
Wait before defines a waiting time directly before starting the measurement.

Up to 7 flags can be activated for the batch **cycle variation**. By activation of a flag the corresponding value can be input in the grid at the window bottom:

1. **UR:** The reverse bias voltage can be input for each batch cycle.
2. **UP:** The pulse voltage can be input for each batch cycle.
3. **tP:** The pulse width can be input for each batch cycle.
4. **Uaux/UDS:** Input of the auxiliary resp. the Source-Drain voltage if used.
5. **Wave length:** The wave length of a laser can be input if enabled.
6. **Probe:** Input of the probe number if using the sample switch box.
7. **UR before cycle:** You can define how UR will be set before a new cycle, that means also between the cycles. 4 possibilities exist: zero, UR, pulse, optic. 'Zero' means that UR will be set to 0V before the measurement. This will done immediately after the previous batch cycle is finished. 'UR' means that the reverse bias stays. 'Pulse' means that if the start temperature is reached the bias will be set for 1s to 0V, 'optic' sets here an optical pulse for the time defined by 'wait before'.

A further input box contains **annealing parameters**. By activation of this option the software sets after each batch cycle a defined temperature and wait here a defined time. Therefore we call it annealing but you can also go to lower temperatures. If activating 'New UR' then the software sets a new user defined reverse bias, for example 0 V, before it sets the annealing temperature. It applies the old voltage (or zero if you have select 'UR before cycle = zero') when the annealing process is finished and the program has reaches the old temperature where the annealing process has started.

By '**Enable for all**' you can enable the additional measurements for all batch cycles and not only for the first. 3 separate flags exist for equilibrium measurements (TSC/TSCAP), static curves (C/V and I/V) and isothermal period scans. Usually it is senseless to repeat the static and equilibrium measurements in all cycles. An exception is when using different samples by the sample switch box.

Two **buttons** exist for load or save a batch configuration file. If clicking onto these buttons then a file dialog opens. After such a file was loaded the program comes back to batch input window and sets all inputs new.

As discussed above the base measurements can also contain different temperatures cycles, called base cycles. The base measurement can also vary measurement parameters like UR, independently whether in one or more temperature cycles. The variations of the base measurement has a higher priority. For example if varying UR in the batch cycles and in the base measurement then the value of UR in the base measurement dominates because before starting the base measurement its UR will be applied.

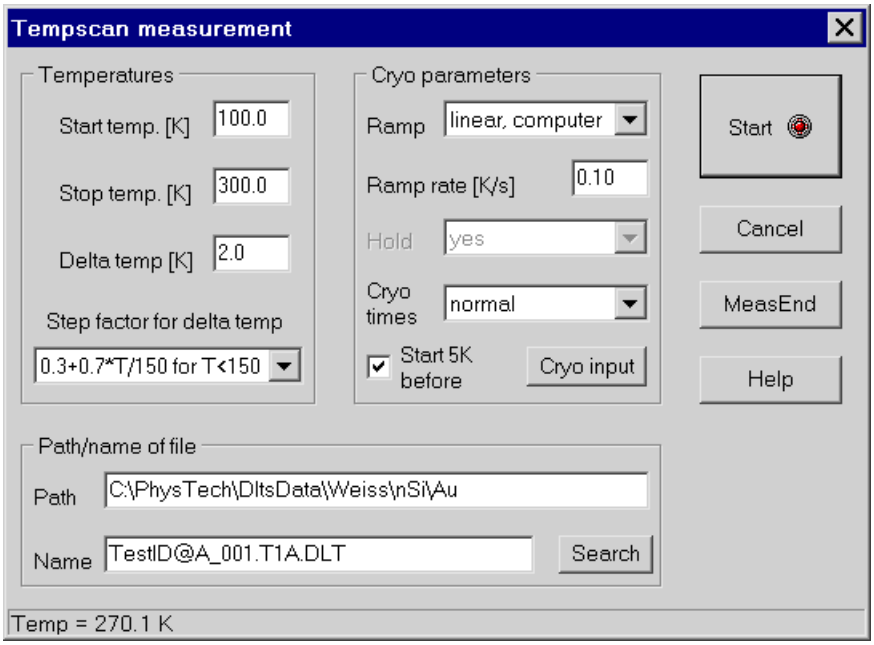
The **order** of one batch cycle illustrates the batch work:

1. Set cycle parameters as UR, tP, ….; set UR=0 if 'UR before cycle'=zero
2. Start annealing procedure if selected
    1. Set new annealing UR if selected
    2. Set annealing temperature
    3. Wait defined time at annealing temperature
    4. Go to old temperature and set previous UR if new annealing UR selected
3. Set new cycle start temperature and wait until this temperature is reached
4. Set UR=0 for 1 s if 'UR before cycle'=pulse or
   set optical pulse for time 'wait before' if 'UR before cycle'=optic
5. Set UR to global or cycle defined value
6. Wait defined time before measurement
7. Read routine file if base mode 3
8. Base measurement including all base cycles and base parameter variations

Following can given as a **comparison** of base and batch cycles:

1. Base measurements can be done in one or more temperature (base) cycles, batch cycles will always be done in separate temperature cycles.
2. Variations in one temperature cycles are much faster than in different temperature cycles. But from the physic is can be necessary to make measurements separately especially if a measurement affects the other ones.
3. The base cycles offers more flexibility, so the period width can only here be varied.
4. The batch cycles have easier inputs for many files, especially in combination with a base cycle.
5. The base cycles are limited to 18 files, however the batch cycles offers up to 9 temperature cycles with each up to 18 files.
6. The base cycles can have maximum 2 files per temperature cycle if using more than one temperature cycle.
7. If you want only one temperature cycle you must not use the batch cycles.
8. If you want to change only the period width you must use the base cycles and should do it in one base (temperature) cycle. This is the standard measurement.
9. If you change UR then it can be helpful to do it in separate temperature cycles. If you then want 3 period widths for each UR so you must use the batch cycles with UR variation and one base cycle with 3 Tw variations.
10. Usually you should combine the batch cycles only with one base cycle, so that you have only one kind of temperature variation.
11. At using the sample switch box it can be helpful to measure each sample in its own batch temperature cycle.

3.4.1.4 Tempscan start window



Temperatures defines the start and stop temperature of the tempscan. The delta temperature (difference between 2 tempscan data points) is only valid for the constant period width files. This delta temperature can be constant or depending on the current temperature, it will be defined by the **Step factor for delta temp**:

- **constant**: The given value is valid for the whole temperature range.
- **0.3+0.7*T/150 for T<150:** For temperatures below 150K the delta value will be multiplied with 0.3+0.7*T/150. At temperature below 150K you get a smaller temperature distance, above 150K the given delta value will be used.
- **0.3+0.7*T/150, 0.5 – 2:** Similar to above, but the equation is valid for all temperatures. The factor for multiplying the delta temperature is restricted, the minimum is 0.5 (low temperatures), the maximum 2 (high temperatures).
- **0.3+0.7*T/150:** Similar to above, but no restriction of the factor.

The real difference will often be reduced by dT_S resp. TOfs, see chapter 2.4.6.2. So the delta temperature must be higher than 0.5K for dT_S=0.5K.

The **cryo parameters** define the work with the temperature controller of the cryo system. A main parameter is the temperature **ramp mode**:

boxcar: The temperature for the measurement is set to the cryo system, the software pauses until the sample has reached the temperature and then starts the transient measurement. After that the next measurement temperature is set.

linear, controller: The value for the temperature ramp is transferred to the cryo system. The controller is calculating and controlling by setting the temperature. The transients will be measured during the temperature is ramped. Not all controllers support this option.

linear, computer: The software emulates a linear controller ramp. It increases the temperature set point of the controller in a loop. Only very small differences, normally 0.1 K, will be used in a given time, defined by the ramp rate. During the transient measurements no new set point will be set, so the temperature will be 'hold'. If this ramp don't work well optimize the regulation parameters, see explanation in chapter 2.4.6.2.3.

Note: Theoretically the boxcar mode, also called rectangular ramp, should be the best one because the transients should be measured at constant temperature. But in the practice it is a problem for the controller to get a stable regulation in the full temperature range. Oscillations and recovery times are possible so that the transient will not be measured at a constant temperature. This changes the equilibrium capacitance and can be visible in the transient. An additional problem can be that the temperature don't reach the set point (chapter 2.4.6.2.1) at bad PID parameters, the program waits then endless.
The linear ramps are quicker than the boxcar and work very well. The ramp should not be too fast. At the controller ramp the temperature is normally not fix during the transient measurement. Don't use this mode for extreme sensitivity by large measurement periods. If activating the hold option, see below, then the temperature should be stable enough at transient measurement. In most cases you get the best results with the linear ramp set by the computer. At the transient measurement the temperature should be stable enough. It depends on the parameters, selected by Cryo times, given by the cryo input button.

Arguments for the **selection of ramp** mode:

- Box car ramps yield often to oscillations especially at big temperature steps. But if it works fine then you can save a lot of time.
- The controller ramp can be the best for fast overview and TSC measurements.
- Don't use controller ramps without 'Hold' for sensitive measurements or slow Tw's.
- The computer ramp is in most cases the best one.
- The computer ramp should be also the best for very sensitive measurements or long period widths, but an additional temperature stability check procedure with long waiting times is here necessary, for more details see chapter 2.4.6.2.3.

The **ramp rate** defines the velocity of the temperature ramp.

Hold means that the current temperature will be hold at the linear controller ramp during the measurement, is not available at all controllers and don't work well at all controllers:

no:	The ramp don't hold.
long time, CV:	The ramp holds at long measure times of variable period width and at C/V measurements.
yes:	The ramp holds at every measurement.

Cryo times selects the parameter set for the cryo system:

normal:	Parameter set for a standard tempscan.
slow:	Parameter set for a slow tempscan, this yields to high density and accurate temperatures but takes a long time for the tempscan.
fast:	Parameter set for a fast tempscan, not high density because less temperature data points and fast ramp rate.
very fast:	Parameter set for a very fast tempscan, should be used only for overview measurements.
init file:	The parameters set will be taken from the current initialization file.

The selection of the right parameter set is **important** because it determines the temperature stability (optimization of regulation) and the velocity (waiting times), especially at the computer ramp.

The button **Cryo input** allows to modify the selected parameter set, see chapter 2.4.6.2. The inputs there depend on the selected ramp mode and are individual for each parameter set selected by 'Cryo times'.

Activating **Start 5K before** avoids a problem of controllers at temperature start if there is a big change of temperature set point. For example, if the current temperature is 300K and you want to start the measurement at 100K many controllers oscillates after they have reached the 100K. Then the first measurements are not good. By activating this option the set point will be set to 95K. Then the temperature will be set to 100K in small steps.

If you come from the Routine tempscan you see a button '**Parameters**'. This button opens the input sheets of 3.4.1.1.

In the status line you see the current temperature.

The **Start** buttons starts the measurements, normally first opens the wait for temperature window, see chapter 1.3.6.

Path and **name** define the first file of the tempscan. At automatic file names, this is the default mode, you get a proposal. The file names of the other tempscan files will be created by numbering the 2. data extension character. Additional static or transients files will be saved into a sub directory named by the tempscan name, the file names are T001, T002 and so on.
Before starting the tempscan the program check if one of the to created file names already exist. In this case you get a question to overwrite or to cancel.

In the following examples for the created files is the file name input ID@A_001.T1A.DLT, the files will be saved into the defined subgroup.

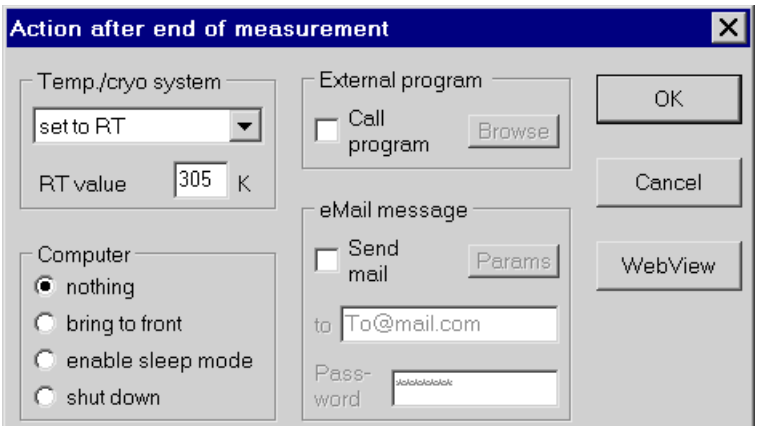
Example 1: 2 FixTw
Created files: ID@A_001.T1A.DLT → FixTw1
ID@A_001.T2A.DLT → FixTw2

Example 2: 2 FixTw, 2 VarTw1, all external transients, PeriScan, TSC, I/V, C/V, Ns(T)-file
Created files: ID@A_001.T1A.DLT → FixTw1
ID@A_001.T2A.DLT → FixTw2
ID@A_001.V1A.DLT → VarTw1
ID@A_001.V2A.DLT → VarTw2
ID@A_001.QRA.DLT → TSC
ID@A_001.QFA.DLT → TSC
ID@A_001.QCA.DLT → C(T),Ns(T)-file
ID@A_001\T001.Y1A.DLT → 1. transient of FixTw1
ID@A_001\T001.Y2A.DLT → 1. transient of FixTw2
ID@A_001\V001.Y1A.DLT → 1. transient of VarTw1
ID@A_001\V001.Y2A.DLT → 1. transient of VarTw2
ID@A_001\T001.PWA.DLT → 1. period width scan
ID@A_001\B001.PWA.DLT → 1. period width scan, 2. tP
ID@A_001\T001.KCA.DLT → 1. C/V curve
ID@A_001\T001.KIA.DLT → 1. I/V curve

Example 2 is an extreme example only for explaining the created file names. Only the first files are listed in the sub directory. There are also the files T002, T003 and so on.

Note: Internal transient points (up to 512) will not be saved as external transient files but internal in the tempscan data file, for example in ID@A_001.T1A.DLT.

If you click onto the '**MeasEnd**' button the input window shown on the right opens. Here you can define the temperature and additional actions after the end of tempscan measurement.



Temp/cryo system defines what the temperature controller makes after a tempscan, not all options are available for all cryostats:

Nothing: No special action will be done.
Last temp: The current temperature will be set to the controller.
Set to RT: The set point of the controller will be set to room temperature, the RT value can be input here.
Heater/pump: Heater and pump (LN2 or He refrigerator) will be switched off.
All off: The cryo system will be switched off.
Heater off: The heater will be switched off.
Pump off: The pump will be switched off.
Set to RT + off: Sets the set point to RT and switches off pump, heater, cryo system.

The **Computer** input group defines the computer action after the complete measurement:

no: The sleep mode is disabled, see chapter 1.3.8.
bring to front: Maximizes the DLTS program and brings it to the front of the screen.
enable sleep mode: The program deletes the disabling of the sleep mode. If the sleep mode was defined by the Windows configuration, the computer goes into this mode after the defined time.
shut down: The program closes and shuts down Windows. This feature don't work at all Windows user configurations, special rights may be necessary. All other users must be logged off.

The program does the actions above only after a normal tempscan end. If the measurement was stopped by an error or by the user, these actions will not be executed.

Note: When the computer has gone into the sleep mode, some drivers may not be loaded at wake-up, for example the drivers for the hardlock key or for the measurement hardware. Close the program and reboot after the sleep mode.

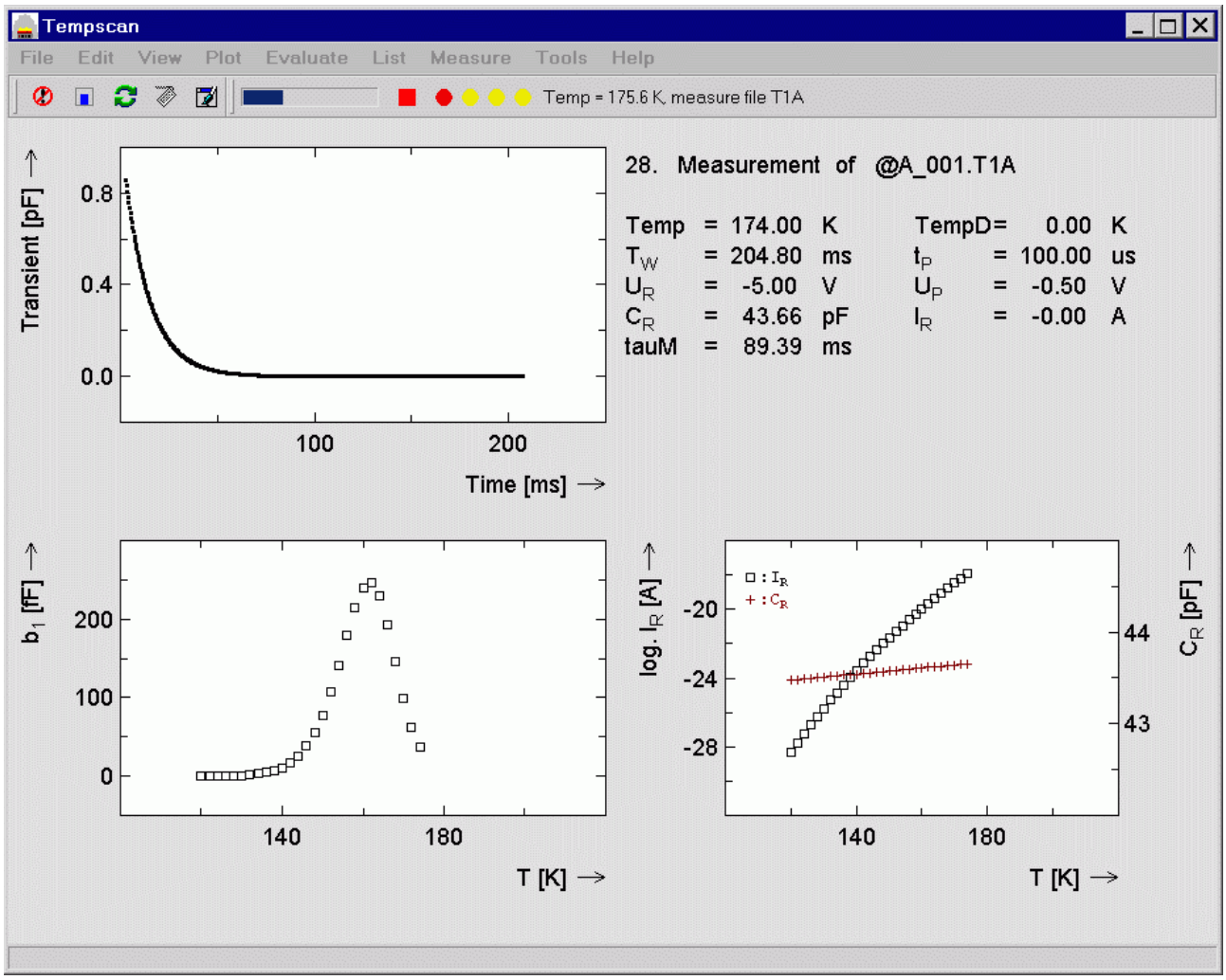
When the tempscan is finished, then the software can call an external program or send an eMail. These actions will not be done if the user breaks the measurement. You have to input the eMail address of the receiver (to) and password and further parameters (Params button) of the eMail account of the sender. Have a look in your eMail program.

The inputs for the computer action, for calling an external program, for sending an eMail and for the password will not be saved when leaving the DLTS program. That means you must activate these options after each program start, even after a hot start.

Clicking onto the **WebView** button allows to monitor the measurement via internet or via a network directory. This feature will be explained in chapter 2.4.7.1.

3.4.1.5 During the tempscan

During the tempscan measurement you see the following picture:



In the line with the progress bar there are the transient state and range (chapter 1.3.7), the current or the measurement temperature and the data extension of the measured file.
The **top left** plot shows the transient, the **bottom left** the temperature curve b1 versus temperature. In the plot at the **bottom right** there are the logarithmic current (black square symbols) and the capacitance (red cross symbols) versus temperature.
The **top right** quarter of the picture gives a list of relevant data. It starts with the number of the measurement and the last part of the tempscan file name. The main abbreviations are already explained in chapter 1.3.4. **tauM** is the time constant valid in the tempscan maximum for the temperature curve shown in the bottom left plot. If there are more than 2 files with constant period widths, then the temperature curve will only be shown from the main file, defined in the FixTw input sheet. tauM will only be listed for this main file.

If static curves will be measured during the tempscan, these curves will be shown on the top left quarter of the screen.
When a period width scan will be measured, its transients will be shown on the top left. The period scan itself will be plotted at the bottom right. During the period scan measurement its text header will be shown at the top right instead of the tempscan text header.

The buttons, especially the Break button, were explained in chapter 1.3.7.

If you click onto the **Input button** during the measurement, you get an input window for changing the temperatures parameters, for example the stop temperature. The inputs are parts of the inputs in 3.4.1.4. Additionally you can reset the values at which temperature and voltage the compensation was done, see chapter 2.1.2.3.
If you there click onto the 'Permanent' button (user class 6), the measurements will be permanently done. These permanent measurements will be stopped by clicking again onto the input button.

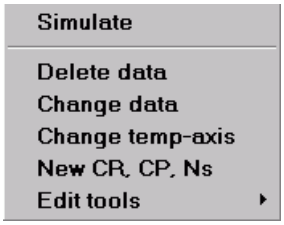
Tip: If you must break the tempscan, perhaps because sample contact problems, then it is not always necessary to start again at the old start temperature. You can also start at the temperature where the contact was lost. By 'Read Special' you can append two files without overlap range (chapter 2.2.2). Because the first file has some bad points it is better to read first the good file (2. measurement) and then append the bad file (1. measurement). If the new contacting yields to another capacitance because other contact area (same contact!), the amplitude of the emission process change and therefore you see a jump in the combined tempscan. At user class 5 you get tools in 'Edit → Change data' to normalize a part of the tempscan.

3.4.2 Edit menu

By the edit menu it is possible to edit and modify the data in the memory. The file itself will not be changed. After reading the file again you lose the changes. For changes of the file you have to save the file, here you get a question for overwriting.

Copy ASCII curve copies the temperature and one selected coefficient or other measured value line by line in an ASCII format to the clipboard. You can define the delimiter and the exponential format in the menu ASCII parameters. You find it in Tools of the plot or list program.
Sort data sorts the data by the temperature, normally not necessary.

Approximation was already explained in chapter 2.6.2. If invalid data exist (see chapter 3.4.6.4), you can here interpolate new values only for the invalid data by activation of 'Interpolate invalid data'. These interpolated points will not be used for the HERA transient evaluation.



At **user class 5** here are: Edit ASCII curve, Simulate, Delete data, Change data, Change temp axis, 'New CR, CP, Ns'. In Edit Tools are transient files ↔ tempscan file. A new tempscan file can be calculated from the internal transients. Here t0/td may be changed, user correlation functions can be used.

Edit ASCII curve' allows to select one data arrays, for example b1. You can edit this data array together with the temperature in a data grid.

'**Simulate**' makes a tempscan simulation either with the current temperature data or with a new temperature axis. The simulation data can be applied as new data or combined with current (old) data.

'**Delete data**' deletes full data records and not only points of one curve. The data arrays/ records will be modified in the memory, not in the file. The base functions were already described in chapter 2.6.3, chapter 3.4.2.3 introduces the special features for the tempscan.

'**Change temp axis**' allows to restore the temperature axis and to make a temperature correction, see next chapter.

'**New CR, CP, Ns**' applies measure and evaluation values from a Q-file into the tempscan data array.

At **user class 6** here are: Edit ASCII file, Edit curve by plot, Paste ASCII curve, extended Edit Tools. The Edit tools give similar possibilities as in the isothermal program module, for example saving transient files into a tempscan and the opposite.
Edit ASCII file means that the complete file will be shown in an ASCII editor, here you can edit all data (header and data arrays). After leaving the editor the changes will be applied for the memory data but not for the file itself. Use this option very careful because there is no data check. You find a description of the data structure in the file Data.Txt.

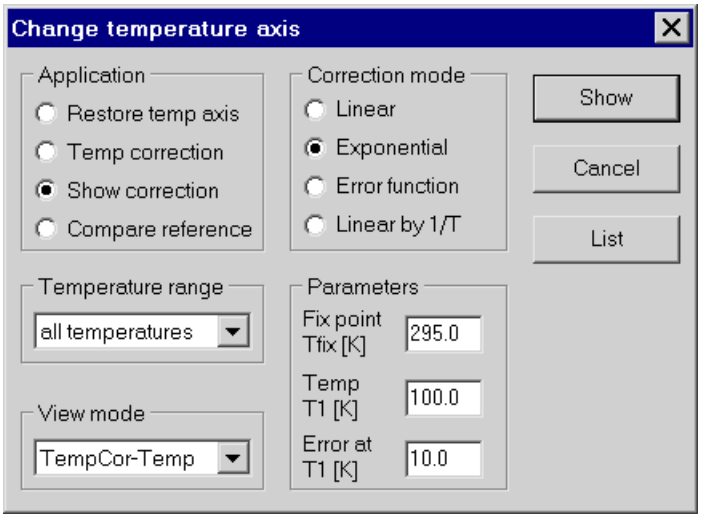
3.4.2.1 Change temp axis

This procedure has 4 **applications**, user class 5 is necessary:

1. **Restore temp axis:** Normally the used (work) temperature is the average of the temperature before and after measurement. Here you can apply one of these values as new work temperature. If using 2 temperature sensors, also the control sensor 1 can be applied.
2. **Temp correction:** You can correct the used (work) temperature by a given formula. Plot the selected correction (next point) before changing the temperature data.
3. **Show correction:** This shows the influence of a temperature correction. The curve can be plotted in various styles and some values can be listed.
4. **Compare reference:** This compares temperature, time constant or Arrhenius plot of the measured level with a reference level.

The correction is not for an error of the temperature controller, for example by the cables of a Pt100. This problem must be corrected in the temperature file. There you can define a temperature or resistance offset or use a temperature table, see chapter 2.4.6.1.

The following correction should be used only if you know or assume a difference between the measured temperature and the real temperature in the sample, based on a bad thermal contact between sample and cryostat. The correction changes each temperature by a given formula.



If the data will be restored, then a restoring to the original values is not possible. If saving the restored data into a file, you should use another file name. The data will be applied only by the 'OK' button but not by the 'Show' button. The 'Show' button plots only the selected curve.
The 'OK' button is visible instead the 'Show' button at application mode 1 and 2, the 'List' button is enabled at mode 2 and 3.

The **temperature range** defines whether the correction will be done for all temperatures or only for such ones which are smaller or bigger than the selected fix point Tfix.

Following **correction modes** exist:

- **Linear:** A linear correction will be done. The correction is zero at the fix point Tfix. Terr is the percentage temperature error per K. So if it is 5%, then the wrong temperature is 5K at that temperature which is 100K lower than Tfix. Additionally you can input a constant offset temperature.
- **Exponential:** An exponential correction will be done. The correction will be stopped to zero at the fix point. You have to define a temperature point T1 and the absolute temperature error at this point.
- **Error function:** This correction uses an exponential function in a special way so that it has a likeness to an error function. It goes to zero at the fix point. You have to define a temperature point T1 and the absolute temperature error at this point. This value is the half of the maximum error temperature.
- **Linear by 1/T:** Similar as 'Linear' but for 1/T.

The **view mode** defines for application mode 3 the kind of y-axis while the x-axis is the measured temperature:

TempCor, Temp: The corrected temperatures (black squares) and the measured ones (red line) will be shown in one plot.

TempCor-Temp: The difference of corrected and measured temperatures will be shown. This difference should be positive or zero below room temperature and should go to zero at room temperature.

tau(TCor)/tau(T): The ratio of the time constants calculated by the corrected and measured temperature will be plotted. Here you have to input the energy and capture cross section (sigma). Only values for a tau range of 100us to 10s will be drawn. The curve should be smaller or equal 1 below room temperature.

Energy difference: The difference of the energies calculated by the corrected and measured temperature will be plotted. Here you have to input the time constant and sigma. The difference should be positive or zero below room temperature.

The last 2 plots give you a hint for the influence of a 'wrong' temperature, especially the plot of energy difference.

At application mode 4 no temperature correction will be done. Here a measured level will be compared with a reference level. The **compare mode** defines the type of plot:

Temp difference: You have to input each 2 values for energy and sigma. A time constant will be calculated by the first ones (measured) for each temperature. Then the software calculates the temperature by this tau, the reference energy and sigma (2. line at the inputs) and shows the difference of this one and the original temperature.

Compare tau: The time constants for the measured and reference level will be calculated and plotted in one picture. Only time constants between 100us and 1s will be shown. This time range is typical for an evaluation.

Arrhenius-plot: Similar as before but both levels will be compared in an Arrhenius-plot.

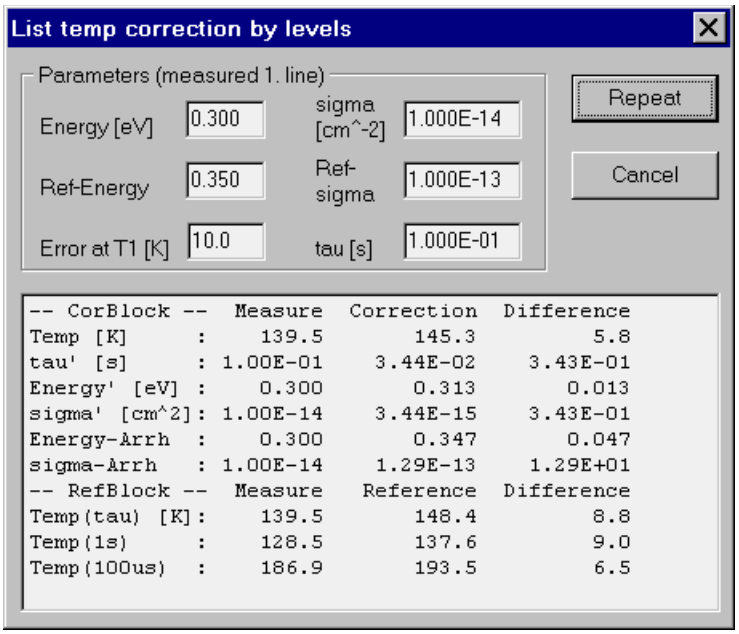
The first plot can be a help if you have got 'bad' results for a level and you assume that these come from a bad thermal contact. Then you can input energy and sigma of the 'bad' and of a reference level. This plot shows then how big the temperature difference (error at the measurement) must be that both levels are identical.

The **List** button opens a new window. On the top there are input fields, on the bottom a memo field which shows some calculations. Here you see also the influence of a 'wrong' temperature. In the 'CorBlock' measured values will be compared with values calculated by the selected temperature correction. The 'RefBlock' compares the measured level with a reference level without a temperature correction.

If you click on the 'List' button, the results will be immediately shown. The 'Repeat' button on this new window repeats the calculation with the current values. So you can observe the influence of the input parameters to the shown calculations.
You have to input the activation energy and the capture cross section sigma for the measured and for the reference level. The input of an example emission time constant is also necessary. The error temperature can be input here again.

The 1. column contains values which were been calculated without correction, denoted as 'Measure'. The 2. column shows the results calculated with the temperature correction resp. by the reference level. Therefore it will be denoted as 'Correction' resp. 'Reference'. The 3. column lists the difference or ratio (for tau and sigma) of 1. and 2. column.

The results are divided in 2 blocks.



We call the first block '**CorBlock**' because it contains calculations which use the temperature correction, followings will be listed here:

Temp : Temperature calculated by tau, energy and sigma. This is the measured one, the corrected one will be calculated from this by the correction.
tau' : tau calculated by measured resp. corrected temperature, energy and sigma.
Energy' : Energy calculated by temperature, tau and sigma.
sigma' : sigma calculated by temperature, tau and energy.
Energy-Arrh: Energy calculated by the regression over 2 points of an Arrhenius-plot. The 2 used temperatures will be calculated by time constants of 100us and 1s and the given energy and sigma. The same will be done with the corrected temperatures.
sigma-Arrh : sigma calculated by the Arrhenius plot above.

The Energy' and the Energy-Arrh calculation for the correction differs much. The reason is the different kind of calculation. At Energy' you assume a known correct capture cross section which will be used for the energy calculation. But that is not the reality, normally you don't know sigma. If you make an **Arrhenius** evaluation and the temperatures are wrong, you get a wrong energy and sigma, both values will be effected by wrong temperatures! Its correction shows the real error. Energy' is more a hint for the influence of a wrong temperature. If you know the exact sigma then it is correct. An analogue reflection is valid for sigma'.

The '**RefBlock**' contains each 3 temperatures for the measured and reference level, calculated by its respective energy and sigma. The given tau, a tau of 100us and a tau of 1s will be used for these 3 temperatures. The both last are the typical minimum and maximum used time constants in an Arrhenius evaluation.

Tip: If you assume that an Arrhenius evaluation has yielded to 'wrong' results based on a bad thermal contact, you can estimate by the RefBlock how big the temperature difference must be that measured and reference level are identical. In the example above the temperature must be wrong between 9K and 6.5K. A hint for a bad thermal contact is a low value for the capture cross section.

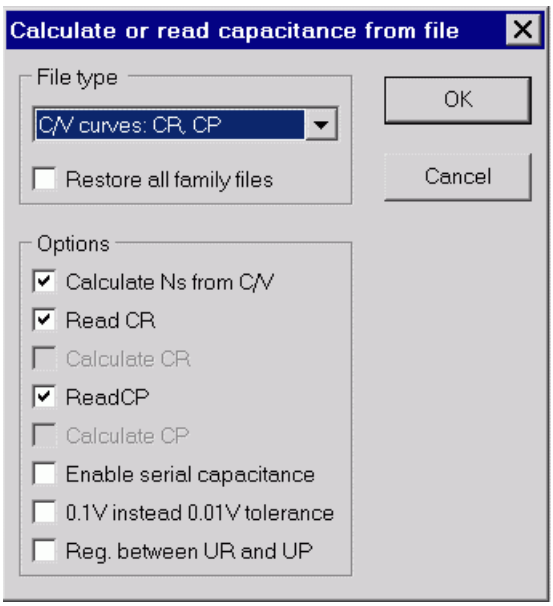
Note: The calculation of the temperature by tau, energy and sigma is not so accurate as the other calculations because it is not analytical possible and will be done iterative.

3.4.2.2 New CR, CP, Ns

Usually CR of a tempscan will be measured with the compensation. This is a little bit more less precise as the direct measurement without compensation, as it will be done at C/V curves.
The pulse capacitance CP will normally only be calculated for a tempscan. This calculation will be done by CR, UR, UP and Ns. It needs also the dielectric constant of the defined material. If the shallow concentration Ns is not temperature depending, this calculation is fine. A shift on the bias axis during the temperature change has no influence on this calculation. But when Ns changes strongly or the C/V curve have an unusual behavior, then this calculation can be not correct.
The evaluation uses by default only one not temperature depending Ns but it can be activated that the software uses a temperature depending shallow concentration. This can be a big advantage.

A more precise value of CR and especially CP can be necessary for the calculation of the trap concentration which takes into account the space charge region, called NTs.

Due to the facts above we have developed a tool which can apply CR, CP and Ns either from Q-files, explained in chapter 3.5, or from a complete set of temperature depending C/V curves. The conductance, if exist, will not be applied.



The possibilities depend on the **file type**:

QC-file: CR, CP, Ns (std.): This is the standard file type, it gives all possibilities. Use this type if UR and UP are not temperature depending. So don't use it for CC-DLTS.

QR/QF/QP: CR/CR/CP: Uses separate files for CR and CP. You can input the QR- or QF-file name for CR and the QP-file name for CP. If using CR and CP then the other file will be automatically loaded.

QU-file: CR, CP: The QU-files contain UR and UP for fix CR and CP. There are also saved CR(T) and CP(T) for a fix UR0 and UP0. Use this file for CC-DLTS, see chapter 4.4.1.5.

C/V curves: CR, CP: Uses a complete set of temperature depending C/V curves. CR, CP and Ns can be applied from these curves.

no file: CR, CP: No additional files will be used, CP can be re-calculated. It is necessary if you have changed Ns. You can also calculate CR.

If activating '**Restore all family files**' then the current file and all its corresponding files which were measured together will be changed and saved. In the other case the current data will only be restored but not the file saved. Corresponding files means here only a change of Tw but not of another parameter.

Following **options** for reading or calculation exist:

'**Read Ns from QC-file**' applies for every temperature the shallow concentration. The sample parameter flag 'Ns(T)', see chapter 2.4.4.2, will be activated. The evaluation, for example the NT-calculation, uses then not further the fix Ns value of the tempscan header but a separate array for Ns which contains the Ns values of the different temperatures.

'**Calculate Ns from C/V**' means that Ns will be calculated from the C/V curves, similar as the flag above. This flag is only visible at using C/V curves and hides the previous flag. Be careful a little bit with this option because the regression range will be set automatically.

'**Read CR**' applies the reverse bias capacitance from the file for each temperature.

'**Calculate CR**' calculates CR with the current tempscan data UR, Ns and UD, only enabled if 'Read CR' is not activated.

'**Read CP**' applies the capacitance at UP from the file for each temperature.

'**Calculate CP**' calculates CR with the current tempscan data UR, UP and CP, only enabled if 'Read CP' is not activated.

'**Enable serial capacitance**' calculates the serial capacitance from the measured parallel capacitance and conductance, see also chapter 3.1.1.4. It is valid for CR and CP. This option requires that the data file contains additionally the conductance. This flag has no effect without the conductance.

'**0.1V instead 0.01V tolerance**' increases the maximum tolerated difference between the voltage of the tempscan and of the Q-file, see below, may be necessary at CC-DLTS.

'**Reg. between UR and UP**' means that not the whole C/V curve but only the voltages between UR and UP will be used for the linear regression to calculate Ns.

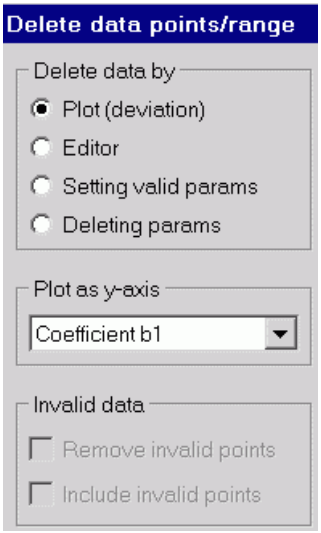
'**Regression for MIS**' optimizes the regression range of the Ns calculation for MIS samples. This flag is only visible for MIS samples if using C/V curves, it hides the next flag. The reason for this flag is that the linear regression range at MIS samples is often smaller than at Schottky diodes. If activating this flag then the 'Min. range for auto regression' will be set to 30% and the search mode to 'prefer correlation', see chapter 2.3.3.6. This flag is a global for the linear regression of MIS samples. This input is only visible at MIS-samples and file type 'C/V curves', the input '0.1V tolerance' is not visible.

The program check whether the data can be applied. At Q-files UR will be checked for CR, UP for CP. That means UR of the Q-file and of the tempscan file, for a given temperature point, should be identical. The software accepts a maximum tolerance of 0.01V resp. 0.1V. At C/V curves the voltage will be interpolated. This enables an applying also if UR or UP of the tempscan file changes with the temperature.
The applying of a value read from a file will be done for each temperature data point of the tempscan. The QC-file for example contains a CR versus temperature curve. This curve will be interpolated to each temperature of the tempscan. So the temperature range of the Q-file and the tempscan should be similar.

This tool to applying CR, CP and Ns can also be used for an **Arrhenius** file which come from a maximum analysis or from a HERA transient evaluation in the isothermal and tempscan program module. All discussed facts above are also here valid. The flag 'Restore all family files' is here not enabled. The software applies the values separately for each level.

3.4.2.3 Delete data

The common functions were described in chapters 2.6.3, but additional features exist for the tempscan. So data can be selected which have a minimum evaluation class. Select there 'Delete by class' as 'Deleting params'. Invalid data can be included (Setting valid params) or removed from the data array (Deleting params).



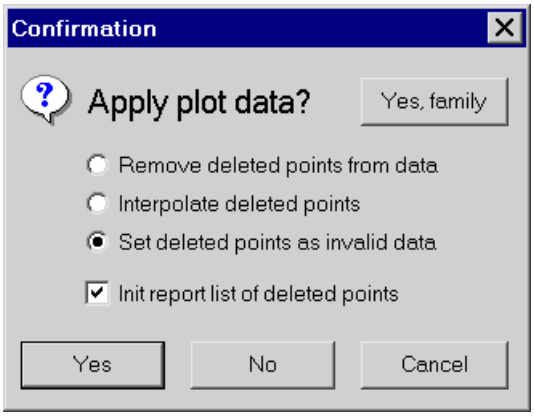
If selecting 'Plot' or 'Editor'. you have to select the **y-axis** data:

b1, a1, UR, CR, leakage current (linear or logarithmic), temperature difference TempD.

CR is here not the standard CR but the real measured value, see chapter 3.4.4.7.

If **invalid** data exist, these data can here be included in the plot and for the editor. Existing invalid data points can be removed automatically after leaving this function. This option forbids the including of the invalid data. The invalid data can be shown in the plot of 'Delete data by deviation' by red diamonds. Select there 'Tools → Show invalid data'. The meaning of invalid data will be explained in chapter 3.4.6.4.

Its is not only possible to delete points, but also the values of the x-axis can be changed by the editor. In the plot you have to call the editor by the Tools button. Changes of the y-axis values will not be applied.



After leaving the deleting by plot function, you have to confirm the applying of the new data. By **Cancel** you stay in the plot program, by **No** you leave it without changing the data.

Yes applies the new data with 3 possibilities:

- **Remove** deleted points from data: The data which has been marked as deleted will be **removed** from the data arrays/records. If only single files will be used or when deleting the same points of all related files, select this mode.
- **Interpolate** deleted points: For the deleted values new data will be interpolated over the valid points. The interpolation will be done for the old x-values, so that the x-axis remains. The advantage is that no points are missing, this could be important at combing different files.
- Set deleted points as **invalid** data: The deleted points remain in the data array, but these points will be denoted as invalid by setting the evaluation class to 8, see chapter 3.4.6.4. The advantage is that the data number order will not be changed, this may be important at combing different files. And no data will be removed, you can activate later the invalid data.

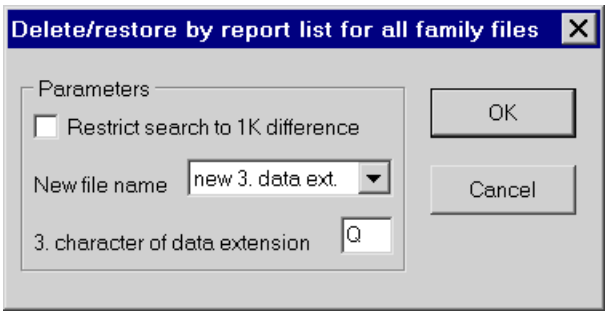
Remember that the data will be modified only in the memory but not in the stored file. If you store manually the file, you can keep the Windows file date by 'File → Overwrite'. The file date of the data header will never be changed.

Clicking onto the '**Yes, family**' button yields to an extended possibility. The deleting which you have done for the current data file will be applied for all family files. These are temp-scan files measured together in one temperature cycle. The same temperatures points will be deleted for all these files. This can be helpful especially at problems of sample contact during the measurement. The advantage is that all family files keep the same relative data number order.

All family files will not only be modified in the memory but also restored on the disk.
Following possibilities exist for the **New file name**:

- *Overwrites* the current file name without a question. By activating a flag the Windows file date can be kept.
- Changes the third character of the *data extension* by a new defined one, for example *.T1A.DLTS → *.T1Q.DLTS
- *Adds* a given character to the file name, ID@A_001.* → ID@A_Q001.*

When deleting points of the other family data, a temperature point will be searched for each defined deleted temperature. This will be the nearest temperature, a 100% match is not necessary. By activating a flag this **search** can be restricted to a maximum difference of 1K.

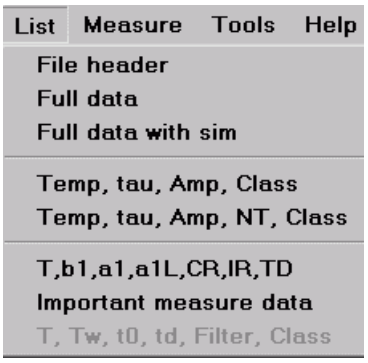


Another possibility exist to delete the same points of different files. This can be done by the automatic generated **report list** of the deleted points, see chapter 5.3.2.6.1. So first delete the points of your current file by the plot deviation function. At leaving this function apply the changes and initialize the report list. Save you current data, load new data and call the delete data function again. There you can mark the existing points of the report list for a check. If it is okay, call 'Delete by report' by the Tools button.

If **invalid data** exist, you can interpolate new valid data only for the invalid points in 'Edit → Approximation'. Interpolated points coming from invalid data will never be used for the HERA transient evaluation. These data points have in the 'Info' column the value 'S=2', see chapter 3.4.4.5.3.

3.4.3 List menu

By the list menu it is possible to list the file header, the full data and selections of measure parameters, coefficients and evaluation data.



The file header will be shown in the next chapter.
A similar explanation of the full data list and the full data with simulation will be given in chapter 3.2.3.1. This list will be shown for every temperature data point.
The other possibilities will be listed as lines and columns. In the first line there is the first temperature point and so on. Three kinds of view here are possible: the data grid, the image without and with header and the ASCII editor, for more details see chapter 5.4. The most abbreviations are explained in chapter 1.3.4.
'**Important measure data**' lists the temperature, CR, IR, the temperature difference TD, the absolute maximum of the transient data and DC offset in digits (MaxDig), the range of the capacitance or current (Range) and the amplification of the transient recorder (Amplif). When the amplification of the pre-amplifier is bigger than 1, this amplification will be listed behind the range. So range '2,4' means range 2 and pre-amplifier 4. An additional column called 'Info' may give some additional information, see chapter 3.4.4.5.3. If invalid data exist, these will be shown only in this list function. Then two additional columns exist, for more details look in chapter 3.4.6.4.

At **user class 5** there is a sub menu for the 2-level and for the HERA transient evaluation. A user defined list is also possible. Here you select the values for the listing.

3.4.3.1 File header

The **file header list** contains the relevant file, sample and measurement parameters, the second block is similar for all data formats, the third block is specific for the data format. At the end of the second block there may be additional information about numbers of temperature sensors, pulse mode, start of pulse or CC-regulation parameters.
Remember that UP* means that the measurement was done at UP and not at UR.

The next list shows an example of a tempscan file:

```
Name    = TestID@A_001.T1A
Comm    = Standard
ID      = TestID          rcID    = 1A11
Date    = 2010-07-27      Type    = n-Si
Area    = 8.00E-03 cm^2   N_S     = 2.00E+15 cm^-3

DataVers = 3.2              FileVers = 3.2
x-Axis   = Temp             y-Axis   = Capacitance
x-Start  = 1.000E+02        x-End    = 3.988E+02
DataNbrs =  154             Sensors  = 1
CorFct   = standard

Tw =  20.480 ms  t0 = 440.000 us  N  =     512
UR =  -5.000 V   CR =  43.414 pF  IR =  -0.000 A
UP =  -0.500 V   CP =  93.646 pF  tP = 100.000 us
td =  40.000 us  tF =   0.000 s   w0 = 4.655E+01
```

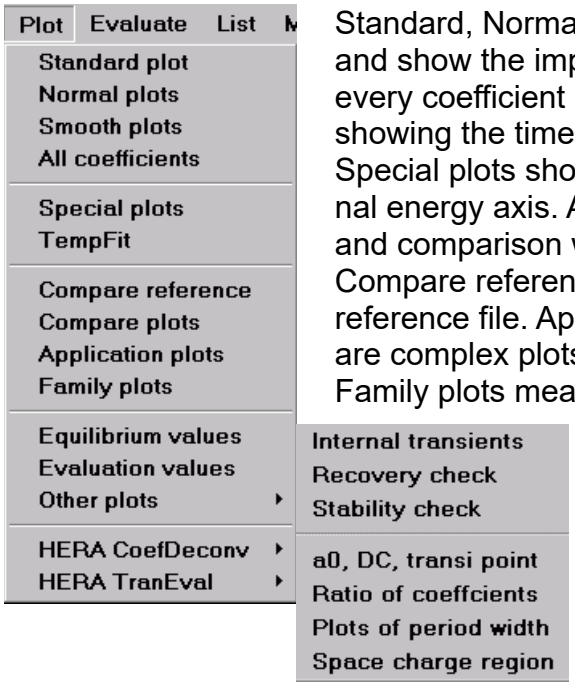
Name : Base file name without ID and data extension DLT.
Comm : Comment
ID : Sample identification, see in 2.4.4
rcID : Record ID in the file data base
Date : Date of measurement
Type : Material name and type of doping (n- or p-type).
Area : Area of sample contact
NS : Shallow doping concentration

DataVers : Program version of the data at measurement
FileVers : Program version of the saved file
x-Axis : Data used as x-axis, at the tempscan this is the temperature
y-Axis : Type of measured y-axis (transient)
x-Start : Start value of the x-axis data
x-End : End value of the x-axis data
DataNbrs : Numbers of data/records, here the number of temperature points
Sensors : Temperature sensors; 1 means only 1 sensor; 2,1 means 2 sensors with sample temperature at sensor 2, set temperature (control) at sensor 1.
CorFct : Type of used correlation functions

Tw : Period width = Time of one transient, start at t0
t0 : Time between end of pulse and first transient data point
N : Numbers of sampling (transient) points
UR : Reverse bias voltage
CR : Capacitance at reverse bias voltage, from the 1. data point
IR : Leakage current at reverse bias voltage, from the 1. data point
UP : Pulse voltage
CP : Capacitance at pulse voltage, from the 1. data point
tP : Pulse width
td : Sampling interval, time between 2 transient points
tF : Phase time of filter and bridge (see chapter 3.2.5), also called t0-Fil
w0 : Tw/(t0-tF)

3.4.4 Plot menu

By the plot menu it is possible to show single or more coefficients, equilibrium or evaluation values, HERA plots and internal saved transients. The plots will be shown in the Standard or Application Plot program. The input groups Interpol/Smooth and Connect points are already explained in chapter 2.7, see especially Note in 2.7.1.

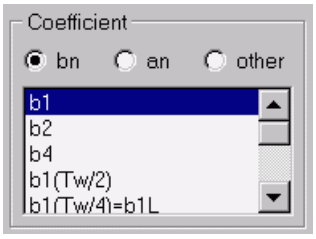


Standard, Normal and Smooth plots have the same input window and show the important coefficients. 'All coefficients' allows to show every coefficient as described in 3.4.4.1. You can here activate showing the time constant valid at a peak maximum.
Special plots show important collections of coefficients with optional energy axis. At the TempFit a recalculation of the coefficients and comparison with the measured ones is possible.
Compare reference/plots compares a coefficient with one from a reference file. Applications plots show coefficients of some files or are complex plots with more pages showing additional C/V curve. Family plots means data measured together in one cycle.

Other plots opens a sub menu. 'Internal transients' shows the transients in the data file. One tool checks whether the used recovery time is too long. The stability check helps to detect contact problems. The first or last transient point, the offset and some other values can also be shown in this sub menu.

Equilibrium values are CR, CP and son on, Evaluation values are tau, amplitude …
The HERA plots will be explained in the HERA chapter.

3.4.4.1 Selection of coefficients



At many plots you get the following selection of coefficients. bn denotes the sine, an the cosine coefficient, other are other coefficients and correlator signals. Some coefficients have a better energy resolution, other a better signal noise ratio. You get more information in chapter 3.4.6.3, in the Theory Manual and in the menu 'Plot → Other plots → Info about weighting functions'. For this you need user class 5. All coefficients except b2, b4, a2, a4, a1(Tw/8), b1T and Square Lockin will be used for the maximum analysis.

bn coefficients:

b1	: First sine coefficient, similar to the standard Dlts rate window
b2	: Sine coefficient of 2. order
b4	: Sine coefficient of 4. order
b1(Tw/2)	: b1 with Tw'=Tw/2, only first half of period width will be used
b1(Tw/4)=b1L	: b1 with Tw'=Tw/4, it will also be called b1L
b1(Tw/8)	: b1 with Tw'=Tw/8
b1(Tw/16)	: b1 with Tw'=Tw/16
b1(Tw/32)	: b1 with Tw'=Tw/32
b1M=b1(Tw/2,t0+Tw/16)	: b1 with Tw'=Tw/2, t0'=t0+Tw/16
b1H=b1(Tw/2,t0+Tw/2)	: b1 with Tw'=Tw/2, t0'=t0+Tw/2, last half of Tw will be used
b1T	: b1 over the first transient at averages, exist not always

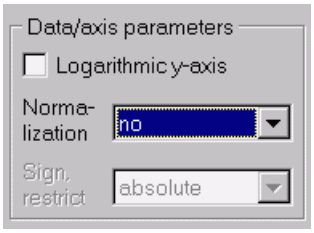
an coefficients:

a1	: First cosine coefficient
a2	: Cosine coefficient of 2. order
a4	: Cosine coefficient of 4. order
a1(Tw/2)	: a1 with Tw'=Tw/2, only first half of period width will be used
a1(Tw/4)=a1L	: a1 with Tw'=Tw/4, it will also be called a1L
a1(Tw/8)	: a1 with Tw'=Tw/8
a1(Tw/16)	: a1 with Tw'=Tw/16
a1(Tw/32)	: a1 with Tw'=Tw/32
a1M=a1(Tw/2,t0+Tw/16)	: a1 with Tw'=Tw/2, t0'=t0+Tw/16
a1H=a1(Tw/2,t0+Tw/2)	: a1 with Tw'=Tw/2, t0'=t0+Tw/2, last half of Tw will be used

other coefficients:

b2N	: Similar b2 but 2. part is mirrored
a2N	: Similar a2 but 2. part is mirrored
Square LockIn	: Lock-in using a square instead sine function, similar to b1
DoubleSquare	: Lock-in which use a double square as correlation function
DoubleSquare(Tw/4)	: DoubleSquare from the first quarter of Tw
Dlts-slow	: Dlts-signal of 2 transient points, end of transient
Dlts-mid	: Dlts-signal of 2 transient points, mid of transient
Dlts-fast	: Dlts-signal of 2 transient points, start of transient
User-1	: 1. user correlation function, exist if made by user
User-2	: 2. user correlation function, exist if made by user
User-3	: 3. user correlation function, exist if made by user

At many coefficient plots there is following input group for Data/axis parameters:



Normalization defines whether the coefficients should be shown in a normalized view:

no: The pure coefficients will be shown, different coefficients have different peak (maximum) heights.

amplitude: The coefficients will be normalized to the amplitude of an exponential time law. Then the maximum of the temperature curve denotes the transient amplitude. The advantage is that all coefficients should have theoretically the same peak height.

NT: The coefficients will be normalized to the trap concentration. The normalization is only valid for a peak maximum.

Note: The not normalized b1-coefficient has, similar to the conventional Dlts signal, a maximum which is about 4 times smaller than the amplitude of an exponential transient. For example, if the amplitude is 1000 fF then the b1-peak height is 250 fF, the peak height of the normalized b1 is 1000 fF. The peak height depends on the Tw/t0 ratio, so at small ratios, the height is smaller.

If activating **Logarithmic y-axis** then the logarithm will be formed from the coefficients resp. y-data. You can define how this will be done in the input **Sign, restrict**:

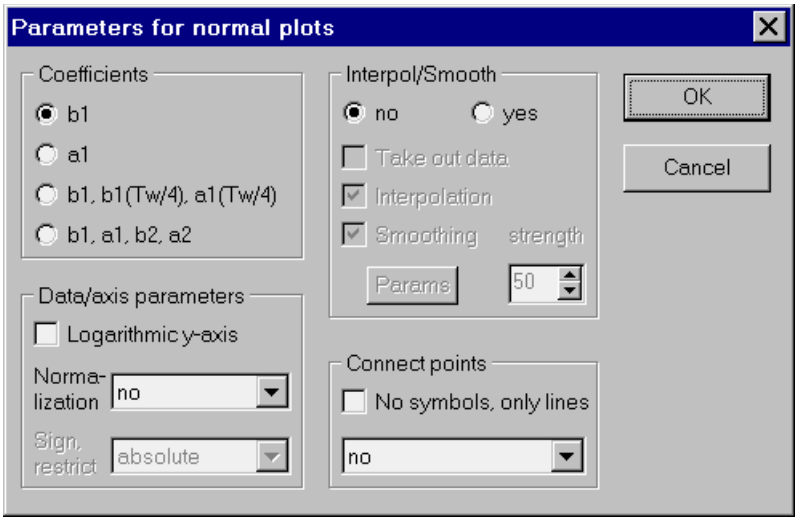
absolute: The absolute value of y-data will be used.
only >0: Only positive y-data will be used.
only <0: Only negative y-data will be used.
abs, min. window: Use the absolute value of y-data, small values are not shown.
>0, min. window: Use only positive y-data, small values are not shown.
<0, min. window: Use only negative y-data, small values are not shown.

3.4.4.2 Coefficient, special and tempfit plots

3.4.4.2.1 Standard, Normal and Smooth plots

These 3 menus have the same input window but different parameter sets:

By the **Standard plot** menu you get directly the plot without an input window. The input window for this is in 'View → Params for standard plot'. These inputs are also valid for the standard plot on the main canvas.
The difference between **Normal** and **Smooth** plots are that Smooth plots use smoothing and interpolation by default.
The Data/axis parameters will be explained in the chapter before**.**



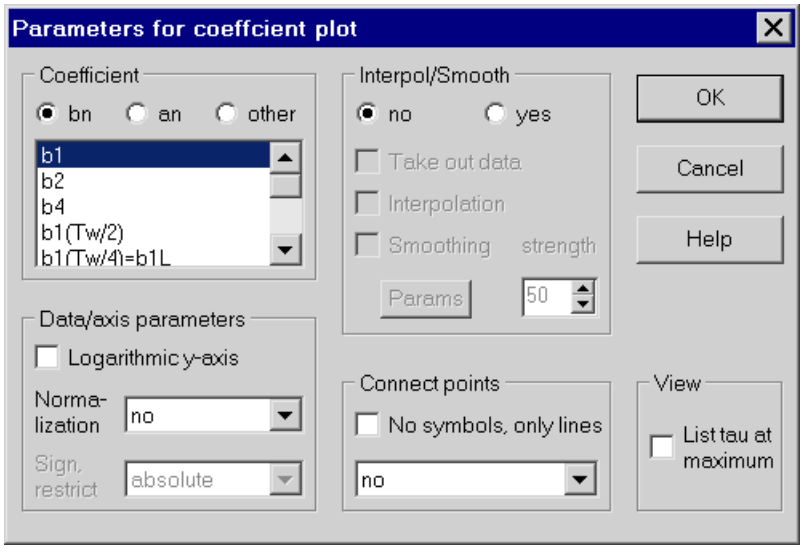
The input group Coefficients defines what should be shown:

b1:	First sine coefficient, similar to the standard Dlts rate window
a1:	First cosine coefficient, better energy resolution as b1
b1, b1(Tw/4), a1(Tw/4):	2 similar, 1different coefficient; peak maximum are at different temperatures; amplitude normalized view
b1, a1, b2, a2:	4 different coefficients; useful for not exponential transients

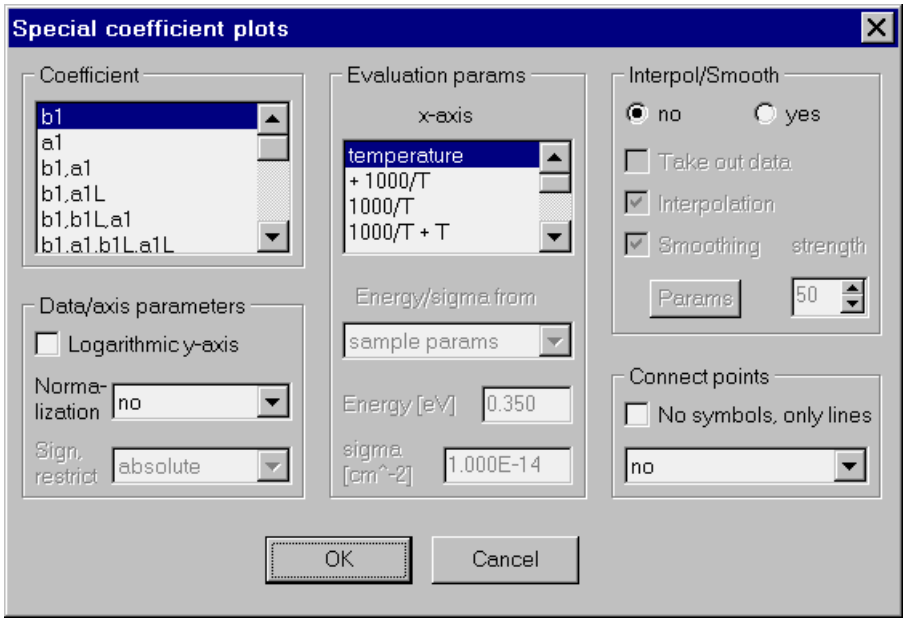
3.4.4.2.2 All coefficients plots

All available coefficients can be plotted here. The inputs were already explained in chapter 3.4.4.1, 2.7.1 and 2.7.2.

The activation of '**List tau at maximum**' shows the time constant of the selected coefficient on the plot text header. This time constant is only valid in the maximum of the coefficient versus temperature curve, see Maximum Analysis.



3.4.4.2.3 Special plots



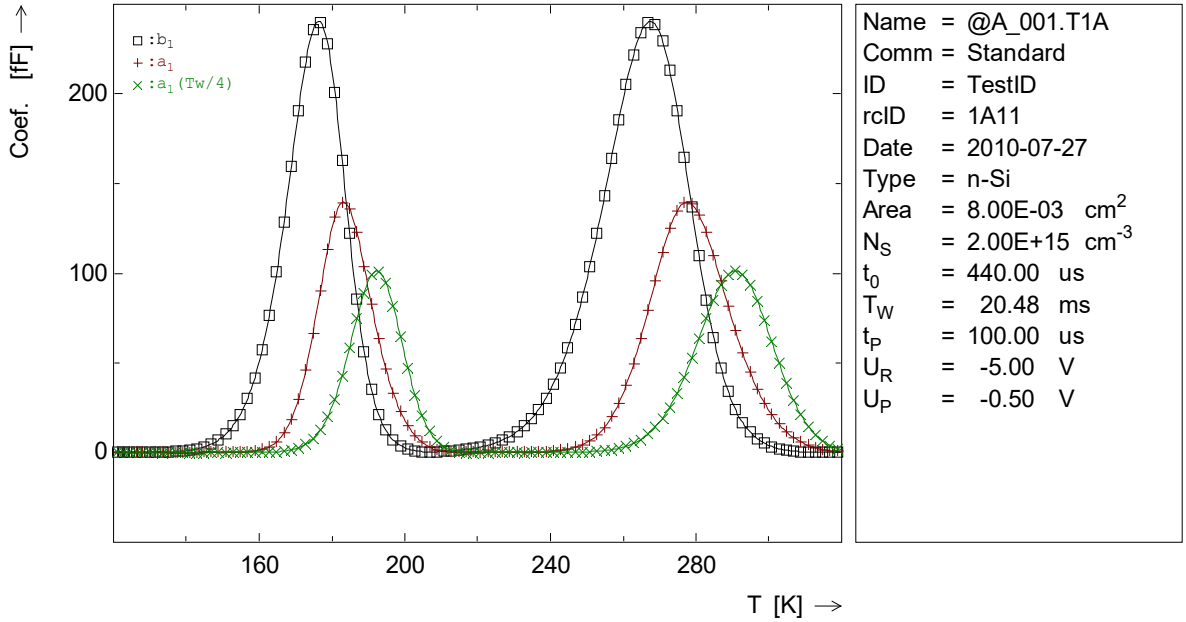
Here you can select one or more coefficients for the plot. They are already explained in the chapter before. The plot of 2 or more coefficients is helpful to compare the position and the height of the peaks. For example b1, b1(Tw/2) and b1L=b1(Tw/4) are the same coefficient but with different period widths. Some coefficients have a better energy resolution, other a better signal noise ratio.
The comparison of b1 and b1T shows the influence of averaging.

In the **Evaluation params** you can select the **x-axis** for the plot, especially an additional top x-axis:

Temperature:	Bottom temperature axis.
+ 1000/T:	Bottom temperature, top 1000/T axis.
1000/T:	Bottom 1000/T axis.
1000/T + T:	Bottom 1000/T, top temperature axis.
+ energy:	Bottom temperature, top energy axis. The energy axis will be calculated by the temperature, the emission time constant tau (valid in the peak maximum) and the given sigma.
energy:	Bottom energy axis
energy +:	Bottom energy, top temperature axis,
sigma emission:	Bottom x-axis is the capture cross section calculated for the emission process by temperature, tau and given energy.
sigma capture:	Bottom x-axis is the capture cross section calculated for the capture process by temperature, tau and sample Ns.
sigma variation:	3-dimensional plot with variation of sigma as z-axis and calculated from this the energy as x-axis.

For the input of energy or sigma you can decide from which parameter set this value should be applied, either from local fit parameters or from the sample parameters or from one of the simulation levels.
If more than 1 coefficient was selected then a temperature and energy axis together are not possible because different coefficients have different time constants.

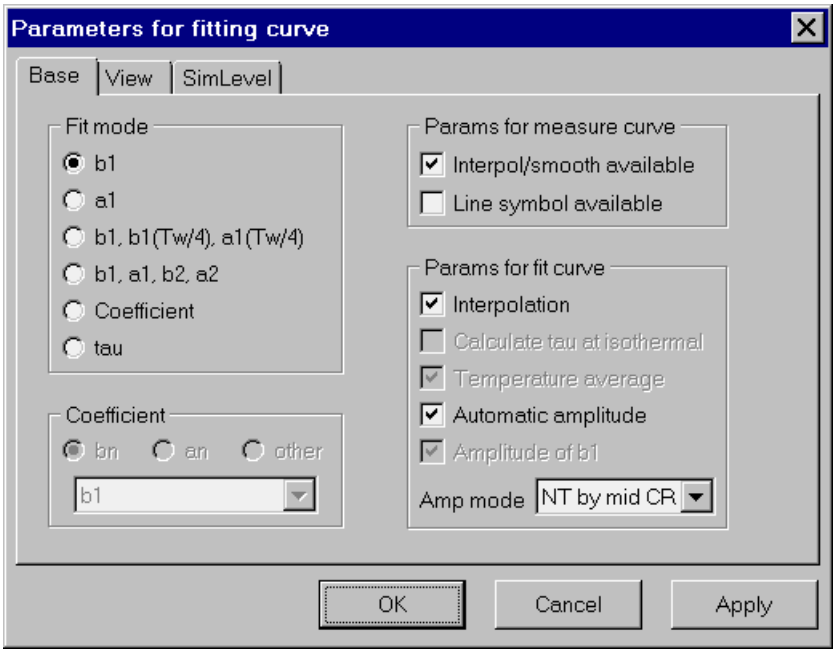
In the following picture you see that the peaks of the different coefficients and period widths are at different temperatures. The peak heights depend also on the kind of coefficient. A normalized view should give same heights. The peaks of a1 and a1(Tw/4) have here different heights because the Tw/t0 ratio was not the same. If using the same coefficient from 2 files with different Tw's but same Tw/t0 then the peak height is the same.



3.4.4.2.4 TempFit

At the TempFit a recalculation of the coefficients and comparison with the measured ones is possible when the exponential evaluation mode was selected.

The **Base input sheet** defines the base parameters for fitting. At the Fit mode you can select one or more coefficients to fit. Coefficients enables the input window as in chapter 3.4.4.1. If selecting tau then the time constant calculated by the direct DLTFS evaluation will be fitted.
In **Params for measure curve** you can enable the input groups for Interpol/ smooth and Connect points (line symbol) at the View tab sheet.



At **Params for fit curve** there are some parameters for the fitting curve:

Interpolation: If activating this flag then simulation values will be calculated not only at the given temperatures but additionally at interpolated temperatures.

Automatic amplitude: If activating then the amplitude (peak height) will be normalized automatically to the measured one, measured and fitting curve have then the same maximum. In the other case you must input the correct amplitude resp. trap concentration of the simulation levels.

Amplitude of b1: This flag is only available if more coefficients to fit and automatic amplitude is selected. From the theory it must be able to fit all curves with the same fitting parameter for amplitude resp. trap concentration. In the practice this is not always possible.

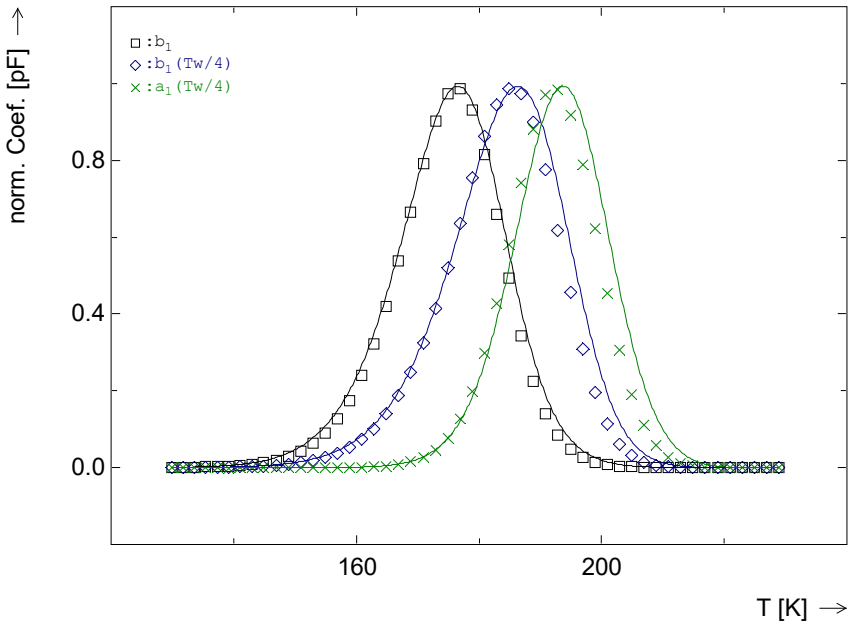
The **Amp mode** defines which value you have to input for the simulation levels, either the maximum of b1, or the amplitude of the exponential transient or the trap concentration NT. The simulation works internal with the amplitude. The factor of maximum height to the transient amplitude can be calculated numerically, for calculating the amplitude from NT an over all temperatures averaged CR will be used.

At the **View input sheet** there are the well known input groups for Data/axis parameters, Interpol/smooth and Connect points. Additionally here you can activate to show the measurement curve and the difference curve measurement – fit. The difference curve is only available if the interpolation flag on the first tab sheet is not activated.

At the **SimLevel input sheet** you define the numbers of simulation levels and the parameters for each level. You can apply the results of an Arrhenius plot as simulation level parameters, see chapters 3.4.4.3 and 5.1.5.3.

The next picture shows a simulation with one level and its tempfit. The energy was 0.35eV, the capture cross section 1E-14 cm^2. The squares and crosses denote three coefficients of these given values. The tempfit curves will be analytically calculated by the SRH model with the input values in 'SimLevel'. The curves will not be fitted by a Gauss curve.

The lines are the curves of the tempfit. For the demonstration a wrong energy of 0.326eV and a wrong capture cross section of 2E-15cm^2 were used for calculating the fitting curves. The results show that is important to fit more than one coefficient or period width. While b1 will be fitted quite good by the 'wrong' level, there are bigger deviations at the other coefficients.



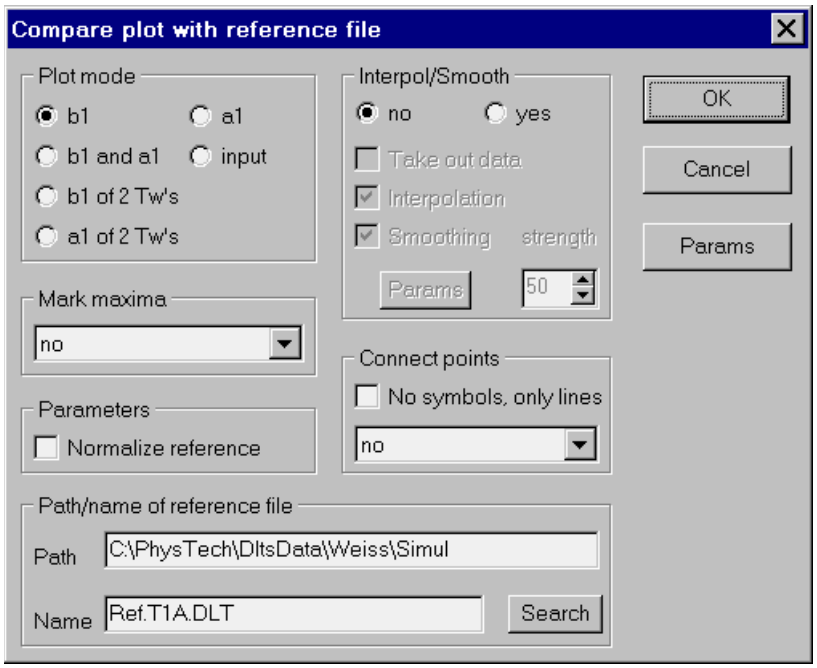
3.4.4.3 Compare, application and family plots

Compare reference was already explained in chapter 2.6.1.

3.4.4.3.1 Compare plots

Here one or two coefficients will be compared with one from a reference file.

The **plot mode** defines the coefficient(s) to show: b1, a1, b1 and a1 together, b1 or a1 of 2 different Tw's. Selection of 'Input' opens by the Params button an input window as described in chapter 3.4.4.1. Plots for 2 Tw's are only possible if different period widths exist for the family data.



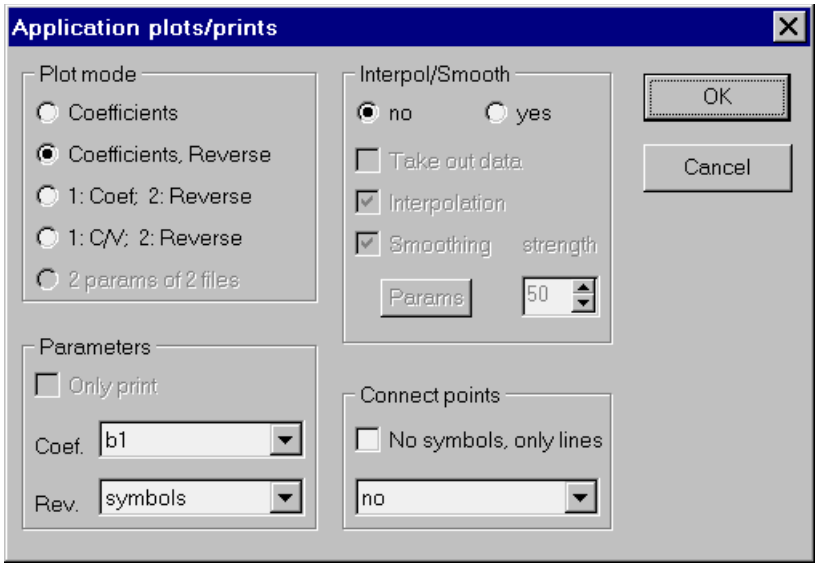
By '**Mark maxima**' the maximum peaks will be marked by a vertical line. Either only the main (highest) maximum or all peaks with a minimum height of 20% or 50% of the absolute maximum can be marked.

By activating **Normalize reference** then the reference curve will be normalized to the current data curve. That means both curves have the same maximum height.

3.4.4.3.2 Application plots

Applications plots show coefficients of some files or are complex plots with more pages showing additional C/V curve.

By activating the flag **Only print**, available at plot modes with 2 pages, the program jumps after clicking OK directly to the print dialog.



Following **coefficients** are selectable for the plot:
b1; a1; b1,a1; b1,a1(Tw/4)
b1,b1(Tw/4),a1(Tw/4)
b1 of all Tw's; a1 of all Tw's
b1 or a1 of all Tw's are only helpful if files with different period widths exist.

The **plot mode** defines the type of plot and numbers of plots:

Coefficients: One plot with one or more selected coefficients versus temperature.

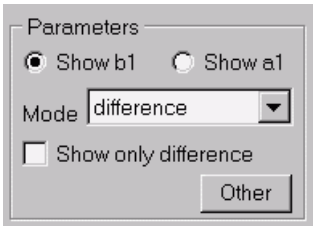
Coefficients, Reverse: Coefficient plot at the top, CR and IR versus temperature plot at the bottom. The leakage current IR will shown in a logarithmic view, the y-axis is from this. The capacitance CR at reverse bias will be shown in the same plot without showing its own y-axis. The CR minimum and maximum value will be listed in the text header.

1:Coef, 2:Reverse: At the first page there is the coefficient plot. At the second page there is at the top the CR (called EquiCapa) versus temperature curve, at the bottom the leakage current.

1:C/V, 2:Reverse: At the first page there is at the top the C/V curve, at the bottom the 1000/C^2 curve with evaluation. At the second page there is at the top the CR, at the bottom the IR curve. This plot is only possible if a C/V curve was saved before tempscan start, for example done in the menu 'New sample'.

2 params of 2 files: Coefficient or difference plot for family data. For this 2 or more files of same Tw but different other parameter likes tP must exist.

The plots with the **reverse** values CR and IR can be shown with symbols, lines or both.



Selecting **2 params of 2 files** yields to another input group of parameters. The possible and visible modes depend on the type of data. The main **modes** are:

all files of this Tw: b1 or a1 of all family data files with the current period width will be plotted.

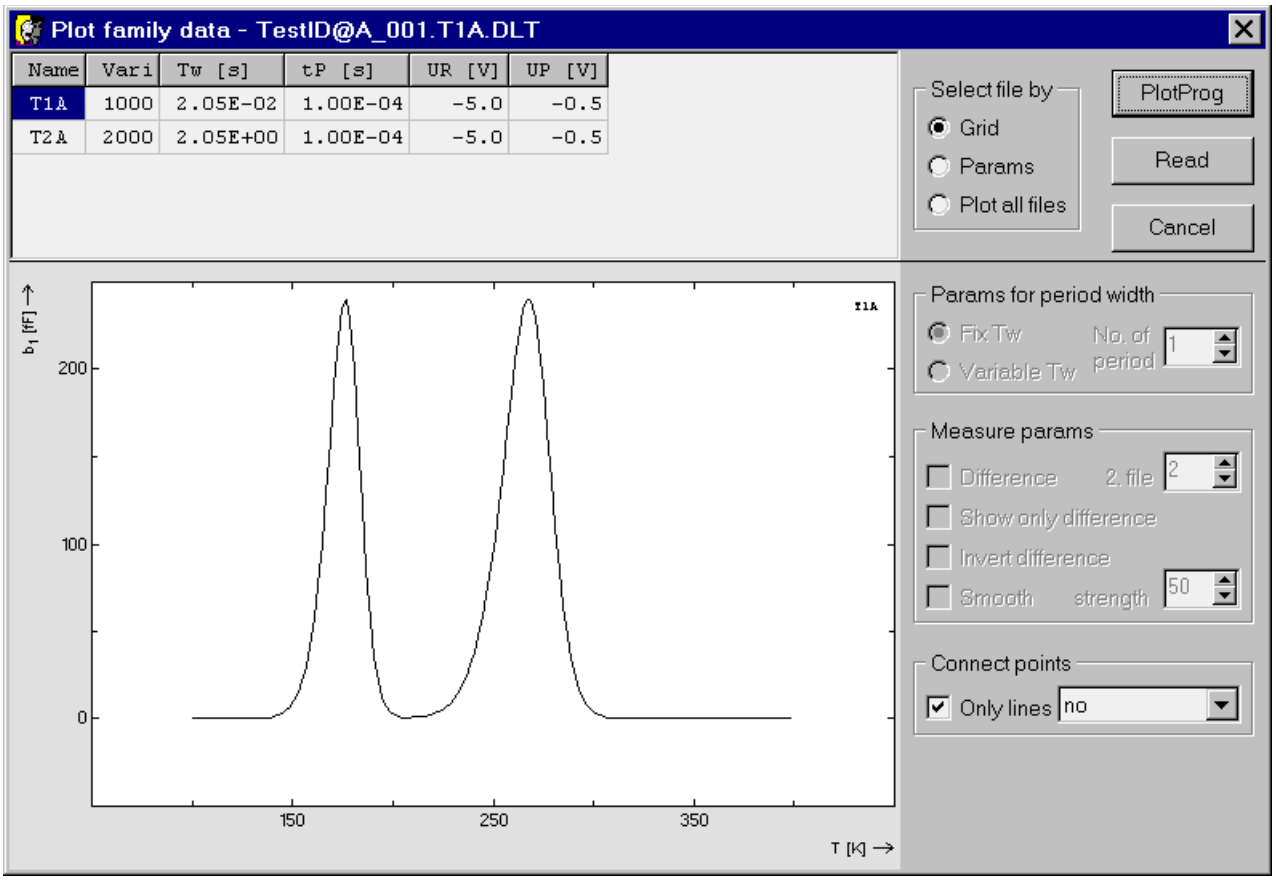
file at small param: Only the file with the small parameter, for example small pulse width, will be shown.

file at big param: Only the file with the big parameter will be shown.

difference: The difference or/and the single curves will be shown. At the Other button you get an input window similar to chapter 2.6.1. Activating the 'Show only difference' flag hides the other button and shows only the difference with a possible smoothing.

3.4.4.3.3 Family data

'Family data' means tempscan data measured together in one temperature cycle. Up to 18 different (constant period width or variable one) files using different measurement parameters can be measured together as a file family with automatically created file names (file data extensions T1A to TIA).
The current file is shown and a list of the family data is given above. The list contains all important measurement parameters to give the information about what has been changed between the different measurements.
In the grid there are the data extension as **name,** a short string for the kind of measurement variation (**Vari**), the period width **Tw**, the pulse width **tP**, the reverse bias voltage **UR** and the pulse voltage **UP**.



The input at '**Select file by**' defines which file of the family data group will be shown:
Grid: The marked file in the grid will be shown in the plot.
Params: The file will be selected by the parameters in the input group below.
Plot all files: All files of family data group will be plotted.

In some cases, for example same Tw and different UP, there is the possibility to show and read the differences between two files. For this you have to activate the box 'Difference'. The difference of 2 UP's files gives a DDLTS (Double correlation DLTS) file.

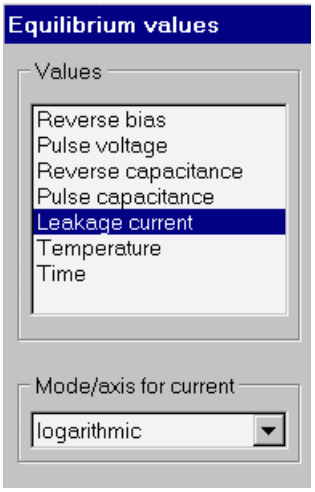
Explanation of **Vari characters**:

1) Number of period width
2) Variation (0:no, 1:UP, 2:UR, 4:tP, G-K:more)
3) Mode (0:normal; 1,2:main-+; 3,4:mainMany-+; 5,6:many-+; 7,8:largeMany-+)
4) Number of reference file (for difference or Tw)

By **PlotProg** the program jumps with the marked file to the standard plot program.
By the **Read** button the marked file will be read and the program goes back to the tempscan main menu.

If coming from the Tools button of the **Read/View** menu then you see a similar picture but with other buttons:
By the **Read** button the marked file will be read and the program leaves the Read/View procedure.
By **Open** you get the Windows file open dialog and after input of a new file name the new family data will be shown.

3.4.4.4 Equilibrium and evaluation plots



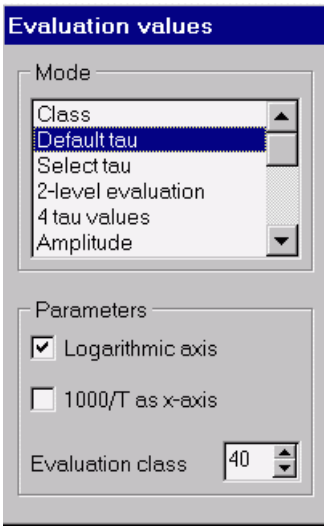
At **equilibrium plots** reverse bias UR, pulse voltage UP, reverse capacitance CR, pulse capacitance CP and leakage current IR can be plotted as a function of temperature. The y-axis of IR can be linear, logarithmic or similar to a Richardson plot.

At showing the **temperature** you can select its value, see 1.3.6:

T: (TA+TB)/2, average of before and after measurement
TB: before measurement
TA: after measurement
TD: TB-TA, difference before - after measurement
T-T[1]: average temp - first average temp
No.: temperature versus data number
TC: sensor 1 (control), if using 2 sensors
TV: T-TC, sensor 2 (sample) -sensor 1 (control)

Time means the time when the measurement was done. It is the time after each measurement point, time zero is the start of the tempscan.

If the **conductance** was also measured, then Cp, Cs, Gp, Gs, Rp, Rs, Q and Cs/Cp can be plotted, see '1 curve' in chapter 3.1.4.2. Additional Ns by Rs and the mobility can be calculated as described in chapter 3.1.5.2.



At **evaluation plots** the evaluation values of the direct DLTFS evaluation, like tau, amplitude, NT, class and so on, can be plotted as a function of temperature or 1000/T if activating this flag. The y-axis can be linear or logarithmic. The type of tau calculation can be selected, a plot with 4 different tau calculation is possible.

An **energy** can be calculated by the temperature, the emission time constant tau and a given sigma. A capture cross section for the emission can be calculated by temperature, tau and given energy. A capture cross section for the capture process can be calculated by temperature, tau and sample Ns.

The **Evaluation class** denotes here (exponential time low) the minimum tau class. All data points that have a class value greater than or equal to the specified value will be included in the plot. Good classes start from 50. If you use lower values you must take care when interpreting the data. 40 is the default to have an overview. For more information have a look in chapter 1.3.4.

3.4.4.5 Internal transients, recovery and stability check

3.4.4.5.1 Internal transients

If transients points were saved into the tempscan data file at each temperature, this will be called Internal transients. You can save 32, 128 or up to 512 internal transient points, the default is in most cases 32. These transients can be shown here. The data index goes from 0 to 32, 128 or 512. Saving 512 internal points needs the enhanced software option.

Base View defines the plot view:

curve after curve: Only one curve will be plotted. It starts from the first transient. You can navigate to the next transient by the button 'Next data'. In the file menu there is the sub menu 'Next datas' with the functions Next data, Previous data and Input of data number. You can also navigate by the PageDown (next) and PageUp (previous) key.

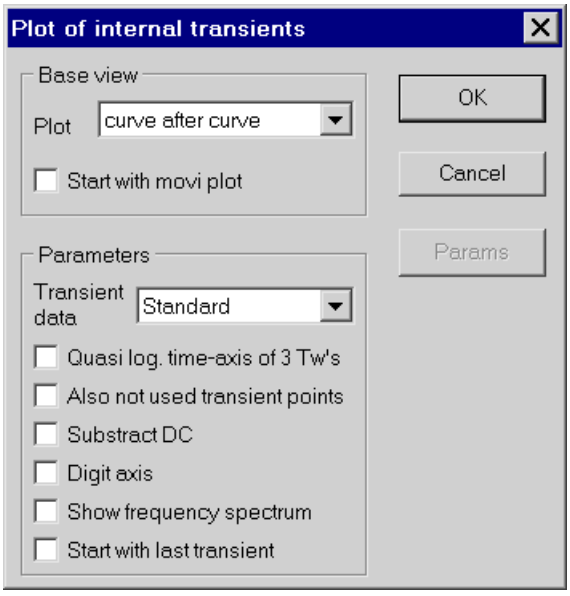
all curves in 1 plot: All transients will be shown in one plot, lines with different colors will be used.

3-dimensional: A 3-dimensional plot will be shown with time as x-axis and temperature as z-axis.

When 2 or 3 Tw's were measured, a transient with a **log. time axis** can be constructed, the parameters are explained in chapter 3.3.4.5.

The flag **All transient points** is visible at 32 points. If activating it then additionally points calculated from the 3 Dlts signals (differences of transient points) will be shown.

If saving 128 or 512 points in a tempscan file with a fix period width, then the transients will be measured longer than necessary and 3 (128 internal points) resp. 31 additional internal points will be saved. These allows to change t0 after the measurement and to recalculate the coefficients for the new t0. If activating the flag '**Also not used transient points**' then also the saved points before t0 and after t0+Tw will be shown.

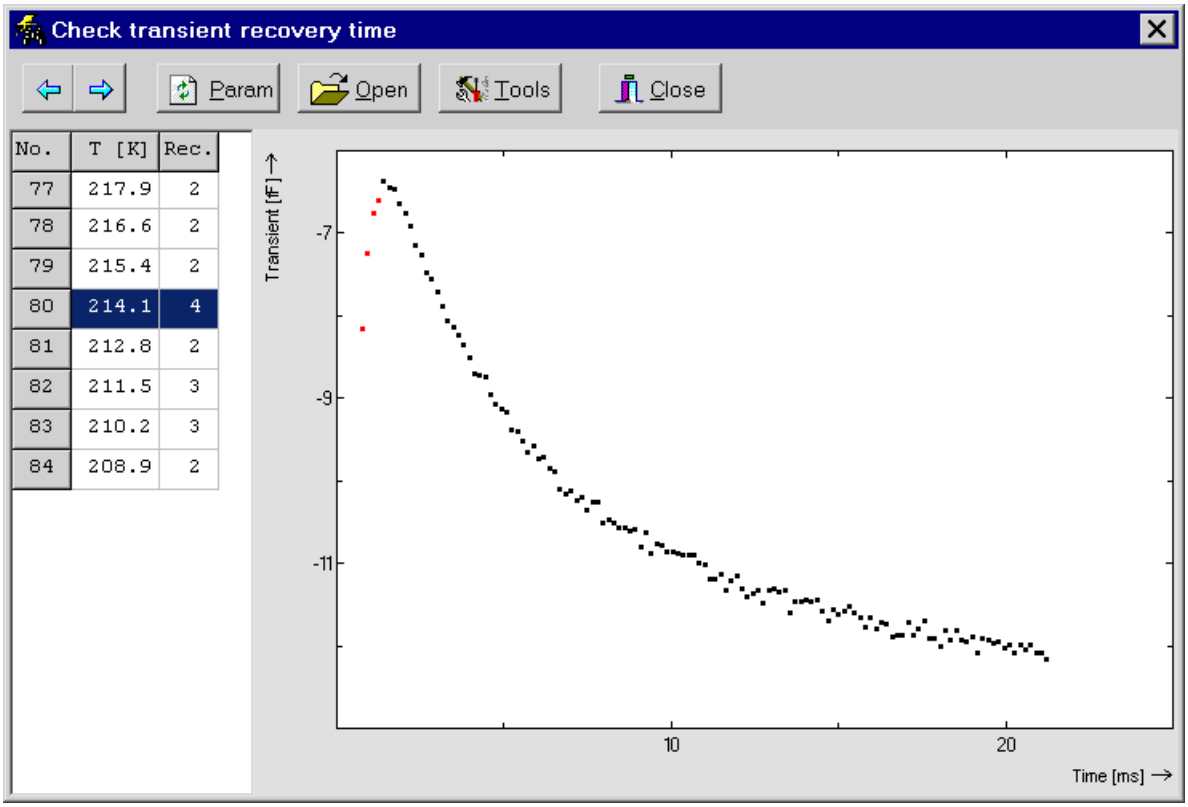


Activating **Subtract DC** then the measured offset will be subtracted from the transient.
By activating **Digit axis** the transient y-axis will be shown as digits of the ADC, in the other case the absolute dimension will be used as fF. The digit axis may be inverted.
It is possible to show the **frequency spectrum** instead the transient.

A **background** transient without pulse will be measured before the real transient measurement. This background transient uses normally the same sample interval as the real transient except it is too low or too high. The DC value will be calculated from this transient by averaging. If saving 128 or 512 transient points then 15 resp. 33 points of the background transient will be internally saved. Depending on your hardware, this background transient can be selected at **Transient data**. The real (emission) transient will be called 'Standard' in this input. You can also plot standard and background transient together.

3.4.4.5.2 Recovery check

This tool checks whether recovery points of the internal transients exist. These are points at start of transient which y-values increase/decrease instead of decreasing/ increasing. Use this option when the tempscan show an unusual behavior, especially negative values for the coefficients. A recovery can yield to negative coefficients, the cosine coefficients will be more effected by recovery points because the cosine function weights more the first part of the transient. Only one recovery point has no influence on the sine coefficients. b1M and a1M are not so sensitive on recovery points because t0 is expanded by Tw/16. The data detected with recovery points will be listed in a grid, the transients can be shown one after the other. The grid contains the data point number, the temperature and the number of recovery points. In the status line you see the number of found recovery transients and the maximum number of recovery points.
The plot below shows a 'bad' measurement with some recovery points and relative much noise. The noise complicates it to identify the correct recovery time. Therefor you should control manually the detected transients.



You can plot the previous/next transient by the **left/right button**. This function is also possible by the left/right cursor and top/down key when the grid has the focus. Clicking into the grid shows the marked transient.

The **Param button** opens an input window with parameters for checking the recovery:

By '**1 point tolerance**' transients with only 1 recovery point will not be shown.

It is possible also to **check for drift**, these are points at transient end which y-values increase/decrease instead of decreasing/increasing. Then the additional column labeled by 'Dri.' lists the number of drift points.

'**Stronger check**' defines the strength of check and was explained in chapter 3.3.4.5.

If activating '**Increment transient**' then a transient will be assumed which y-values increment with time, in the other case a decrement transient will be checked (standard).

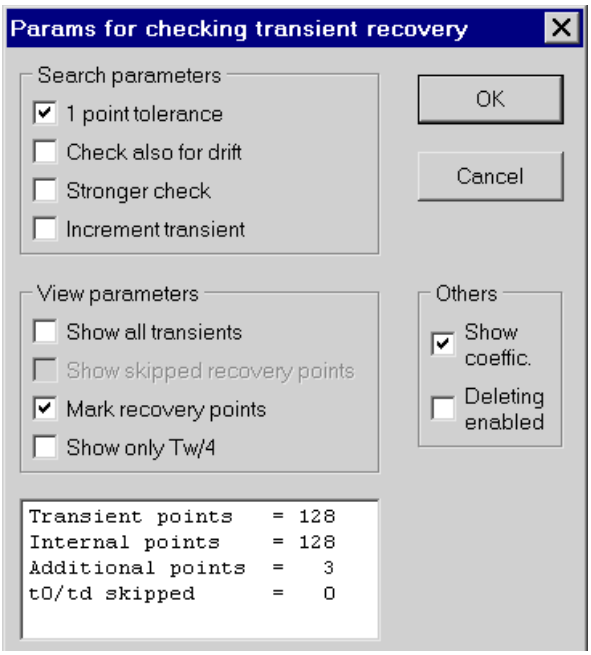
You can **show all transients** of the tempscan instead of only these with recovery points.

If the transients contain already **skipped recovery points** at the transient start, these points can additionally be shown.

Usually you will **mark recovery points** by small red squares.

For a better overview it can be helpful to show only the first **quarter** of transient period width.

A **coefficient** versus temperature (tempscan) can be shown below the transient, the corresponding point of the current transient will be marked by a filled red square. Coefficients which come from transients with recovery or drift will be marked by dark red squares.



If '**Deleting**' is enabled, an additional column in the grid gives the possibility to delete this data point. A click into this column toggles between a '+'-cross (deleted), a 'x'-cross (not used for HERA) and an empty cell (valid data). The deleted data will be marked by blue crosses in the tempscan curve. The points not used for HERA will be marked by blue squares, these points will not be deleted but only not used for the HERA transient evaluation. The 'Del' column will be initialized at starting the recovery check. It may be that that a '-' sign exist in the 'Del' column, it denotes a data point which comes from an interpolation. This point will never been used by the HERA transient evaluation, therefor an empty 'Del' column is here not allowed. After leaving the recovery check the software asks you to apply the deleting. The '+'-marked data points will not be removed from the data array but will be set as invalid data, for more details look in chapter 3.4.6.4.

At the bottom of the input window there is a list with significant **transient parameters**: Number of transient points, internal saved transient points, additional internal saved transient points (see previous chapter) and already t0/td skipped points. The last are points at the transient start which will not be used for the calculation of coefficients.

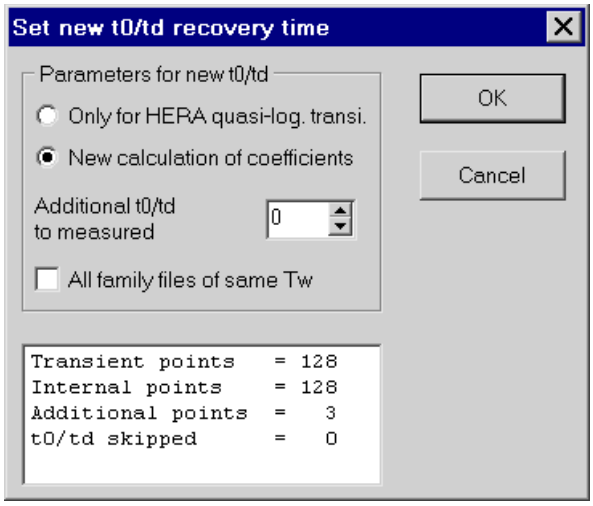
You get following functions by the **Tools button**:

- **Refresh** of the plot.
- Lists the **measure data** in a grid similar as shown in the next chapter. Additionally the recovery and, if activated, the drift points will be listed.
- Plots the **transient** in the standard plot program
- Plots a **coefficient** versus temperature and marks the 'bad' points which were shown in the grid by red squares. The coefficient can be selected.
- Plots a **coefficient** versus temperature on the top and the **transient** on the bottom.
- **Compare t0/td:** Here coefficients will be calculated from the internal transients by an additional t0/td. So if the additional t0/td value is 2, the first 2 points will not be used (skipped) for the Fourier transformation. The new coefficients will be compared with the old t0/d ratio. This feature needs additional saved internal points, see above.

- **Set new t0/td:** The coefficients will be newly calculated from the internal transients by an input of an additional t0/td value (relative to the used t0/td at the measurement). This feature needs additional saved internal points and is only available when the number of transient points is identical to the number of internal points. Then the new calculation is reversible, that means you can make later a calculation with the original t0/td. You don't lose sensitivity by using the internal transients. If only 128 points from a transient with 512 points would be saved, then the SNR would be a factor of 2 smaller by using the internal transients. Therefor this is here not allowed.

The input window on the right shows some options for the last feature. Instead a new calculation of coefficients you can define the additional t0/td only for the construction of a quasi-logarithmic transient. If the flag 'all family files of same Tw' is activated, all tempscan files measured together which have the same Tw as the current one will be automatically restored and saved. Otherwise the changed data will not automatically be stored on the disk.

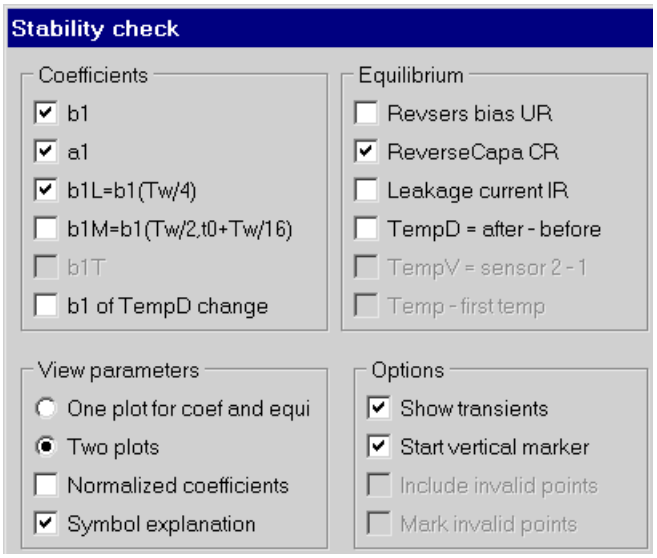
Note that b1T can not be calculated from internal transients, see chapter 3.4.4.1.



You have more possibilities to set a new t0/Tw in 'Internal transients → Tempscan file' of the Edit menu. There you can also use your own correlation functions.

3.4.4.5.3 Stability check

This plot is a big help to check whether there was a sample contact problem during the measurement. Use this check if you see jumps in the tempscan or other unusual behavior. This plot shows up to 6 coefficients together in one plot and up to 6 equilibrium values either in a separate plot (two plots) or in the lower part of the same window (one plot).



Up to 5 standard **coefficients** can be plotted together: b1, a1, b1L, b1M, b1T. Remember that b1L is b1(Tw/4) and b1M is b1(Tw/2,t0+Tw/16). If there is a single level then the peaks of b1 and b1M and the peaks of a1 and b1(Tw/4) should have similar temperature positions. The order, from low to high temperatures, should be: b1, b1M, a1, b1L.
Problems of the transients, for example jumps or recovery effects, have different influence to these 4 coefficients.
a1 weights especially the first part of the transient while b1M don't use the first transient points. On the other hand b1L doesn't use the last ¾ of the transient. b1 use the total transient but weights the first points not so strong as a1. A complete linear transient, which can come for example from a drift, has no influence to the cosine coefficient a1. b1T is b1 over the first transient at averages. All these can give you a help to decide what the origin of the problem is.
The coefficients may also be plotted normalized to the amplitude. In this case all coefficients would have the same peak height at one discrete level.

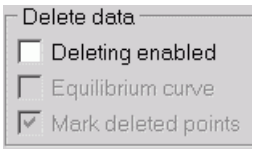
Following **equilibrium** values can be selected:

- **Reverse bias UR:** It is only helpful at CC-DLTS.
- **Reverse capacitance CR:** This is the main equilibrium value because a sample contact problem should be visible in this curve. CR is here not the standard CR but the real measured value. Usually both are the same but you can restore CR by a QC or QU file, see chapter 6.4.2. Here the not restored value will be shown.
- **Leakage current IR:** The logarithmic of the absolute current will be shown.
- **TempD = after - before:** Shows the difference of temperatures which will be measured after the full transient measurement and before.
- **TempV = sensor 2 - sensor 1:** Shows the difference of temperature sensor 2 (sample sensor) and sensor 1 (control sensor), only available at 2 sensors.
- **Temp - first temp:** This is the difference of the temperature of each isothermal data point and the temperature of the first data point. This curve characterizes the temperature change during the whole measurement while TempD is only the temperature difference at one data point. It's only enabled for isothermal measurements.

When using only one equilibrium curve in a separate plot window, the original y-axis will be shown. Otherwise all equilibrium curves will be normalized to plot these in the same plot window. If using a separate plot window (two plots), then the normalized y-range goes from 0 to 1. The minimum and maximum values will be listed in the plot header.

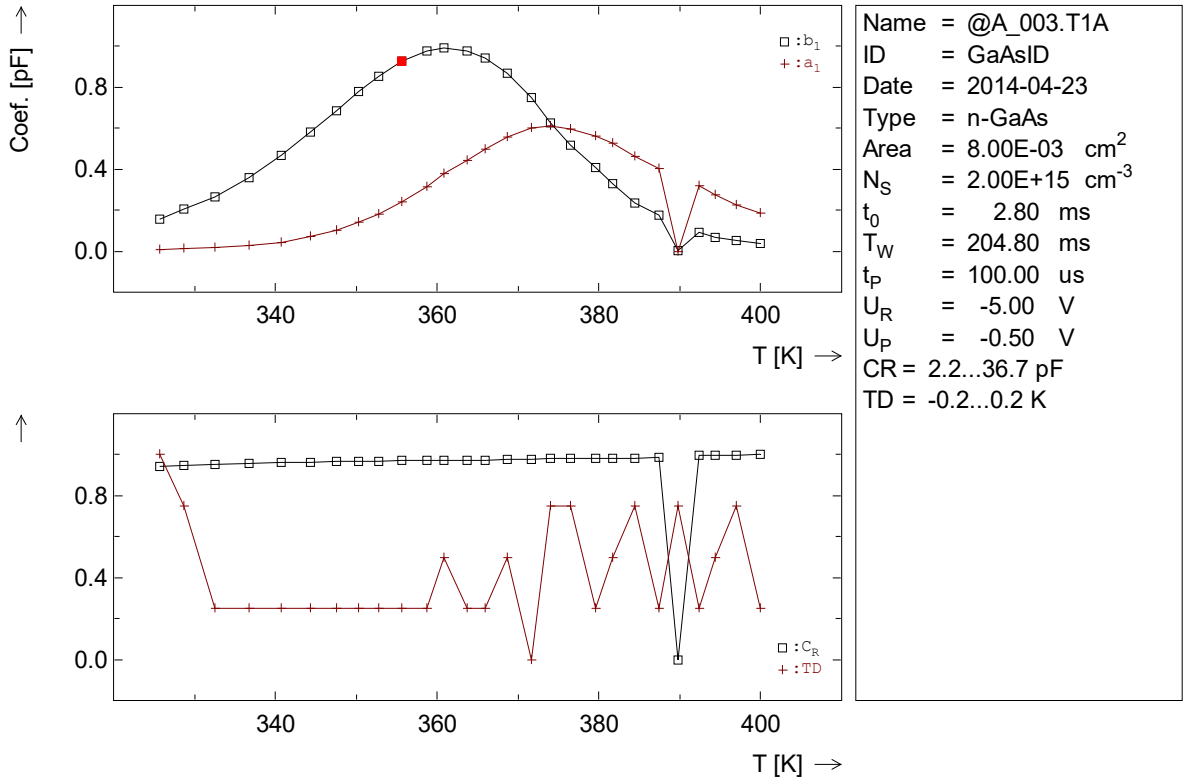
The plot may start with a vertical **marker** (from the Tools menu, chapter 5.1.6.5) movable by mouse or cursor keys. This allows to identify coefficient(s) and equilibrium value(s) of same temperature (data point). So for example, if the behavior of b1 is unusual and CR has a big jump at this point, the reason is in many cases a contact problem.

If **invalid data** exist (see chapter 3.4.6.4), you can *include* these data points into the plot as normal data. When activating the flag '*Mark invalid points*', these will be shown as additional points with red diamond symbols.

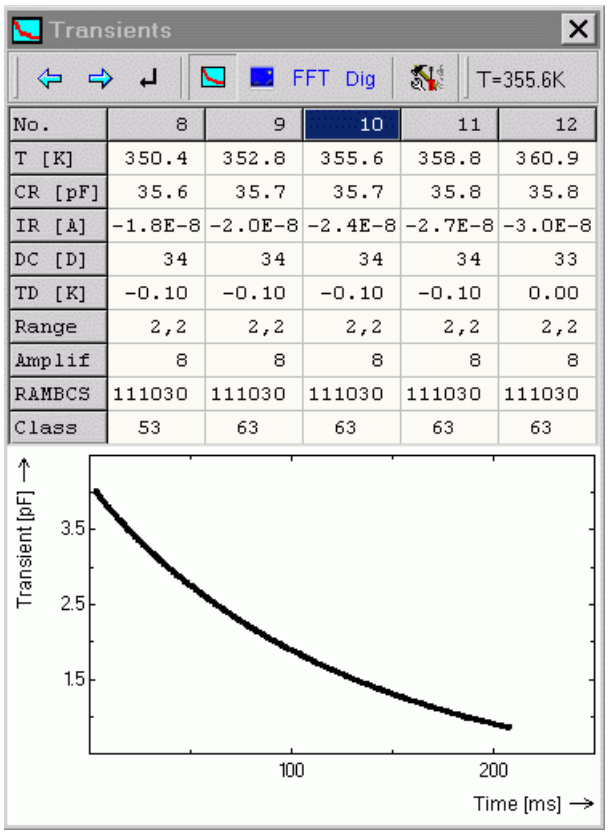


If activating '*Deleting enabled*' in the **Delete data** input group, you can delete data points by the marker or mouse. Then the item 'Delete data point' exist in the Edit menu of the plot program. For deleting you have to mark a point of the first coefficient curve, usually b1. By activating '*Equilibrium curve*' the first equilibrium curve will be used. The deleted points can be *marked* by a blue '+'-cross symbol. The full data record of the marked point (temperature) will be deleted. If you exit the plot, you get a question whether you want to apply the deleting. The deleted points can be removed, replaced by an interpolation or be set as invalid. For more details look in chapter 3.4.2.3, an extended delete function will there also be explained. The deleting will only be done in the memory but not in the file. You can delete a data point also in the separate transient window as explained on the next page.

The next picture shows an example. On the top there are the coefficients b1 and a1. On the bottom there is CR and the temperature difference TD (TempD). As explained above the bottom y-axis is normalized. So CR goes from 2.2pF to 36.7pF which will be listed on the right text header. The filled red square marks the temperature of the shown transient. At T=390K CR falls down and both coefficients have here (at the same temperature!) a jump to zero. The reason was a contact problem.



The **transient** of a selected data point can be shown in a separate plot window when activating a special flag in the 'Options' input group. On the top there is data grid with 5 data columns. Each column contains the main measurement data of one data point. The data point which corresponds to the transient at the bottom is in the third data column and will be marked in the 'No.' line. The corresponding point in the tempscan curve will be marked by a red filled square. The meaning of the data will be explained on the next page.



The offset, labeled by '**DC**', will be given in digits. It is the value directly measured by the ADC. The transient will be shown usually in absolute dimensions, for example in pF. Depending on the DLTS mode, this transient may be inverted. When showing the transient in digits, the values measured by the ADC (not inverted) will be shown. So the DC value can only be compared with the transient in digits.

The **toolbar** contains following buttons:

Plots the **previous** transient.

Plots the **next** transient.

Applies the data number from the vertical **marker** of the stability plot.

Shows the **transient**, selection of plot type.

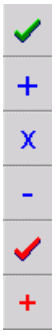
Shows the **background** transient, only visible if exist.

Shows the **spectrum**, only enabled for N>=128 transient points.

Selects **digits** as y-axis of the transient.

Opens the **Tools** menu: Refresh of the transient window, Input of data number for transient, List of measure data.

If '**Deleting**' is enabled, an additional grid line and tool button shows the deleting state. A click on this button toggles between a '+'-cross (deleted), a 'x'-cross (not used for HERA) and a green 'okay' resp. empty cell (valid data). The deleted data will be marked by blue crosses in the tempscan curve. The points not used for HERA will be marked by blue squares, these points will not be deleted but only not used for the HERA transient evaluation. The 'Del' line will be initialized at start. It may be that that a '-' sign exist, it denotes a data point which comes from an inter-polation. This point will never been used by the HERA transient evaluation, therefor an empty 'Del' line is here not allowed. If you have included invalid data, these data will be marked by a red cross symbol on the button. When you set such a point as valid, it will be marked by a red cross.



Clicking onto the '**List** of measure data' menu of the Tools button creates a separate window with a data grid. It is a little bit similar to the grid in the transient window, but contains now measure data for all data points. It shows the temperature, reverse bias capacitance, leakage current, the temperature difference TempD=TD, the absolute maximum of the transient data and DC offset in digits (MaxDig), the capacitance resp. current range, the amplification, the 'RAMBCS' column, and the evaluation class.

No.	T [K]	CR [pF]	IR [A]	TD [K]	MaxDig	Range	Amplif	RAMBCS	Class
1	325.7	34.8	-3.267E-09	0.20	-1181	2,2	8	111030	42

If invalid data exist, there is the column 'dNo.' when the invalid data were not included (see flag above). This number denotes the data position in the total data array (valid and invalid points). If invalid data exist and these were included in the stability plot, there is the additional column 'vNo' which denotes the number of valid data point valid.

One column is labeled by '**RAMBCS**'. It reports some events during the measurement of transient and gives some helpful information for an expert:

R = Numbers of range loops: 1..3

A = Numbers of amplification loops: 1..4 at R=1; 1..2 otherwise

M = Break test
- 0: no
- 1: test on over range
- 3: test on under and over range
- 9: break by input

B = Break done
- 0: no
- 1: Break by under range
- 2: Break by over range
- 3: Break by under and over range
- 9: Break by input

C = Compensation report
- 0: nothing changed
- 1: Variable capacitor moved directly before measurement
- 2: Variable capacitor changed
- 3: Variable capacitor moved and changed
- 4: Fix capacitors changed

S = Switch of capacitance range: 0: no, 1: yes directly before measurement

So R=1 means that the transient was measured in one range loop, the measurement was not repeated for switching a lower or higher range. R=3 means that 3 or more loops were necessary.

You get this list, but not as separate window, also in the Tools menu of the main stability plot by clicking onto the 'List measure data' item.

The grid may contain the additional column '**Info**' which shows 'B,S' with:

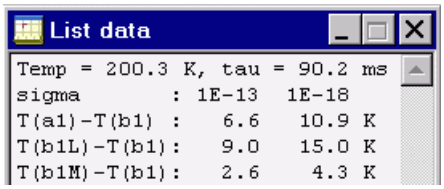
B: Bit 0: Problems at slow regulation

S: 2: interpolated point, 3: manually not used for HERA transient evaluation

Some calculations:

A special 'coefficient' is **b1 of TempD change**. This curve will be calculated from the reverse bias capacitance CR and the temperature difference TempD before and after the measurement at one temperature (data) point. This calculation is only a rough approximation. It uses the capacitance change during the whole tempscan and calculates from this a capacitance change per Kelvin. This change will then multiplied by TempD. You can consider this value as the amplitude of a transient. At the standard exponential evaluation we consider this transient as exponential and define its time constant so that b1 would be maximal. That means we divide this value through the amplitude factor of b1, which is about 4 for an exponential time law. For a linear time law this factor is ¶. So this curve is more comparable to b1. If the flag 'Normalized coefficients' is activated, the y-values of this curve will not be divided by the amplitude factor.
A calculation with the help of the local change of CR in the near of the data point is not possible because CR will be measured with the compensation.
At U-DLTS the reverse bias UR will be used for this calculation instead of CR. At I-DLTS this curve is a very rough approximation because the current changes normally logarithmic by the temperature. So for this curve the logarithmic absolute value of IR will be used.

Clicking onto the '**List data**' item in the evaluate menu of the plot program yields to a window which shows the temperatures differences of a theoretical peak. The temperature of the vertical marker will be used to calculate an energy by the time constant of b1. All calculations will be done for 2 extreme capture cross sections, 1E-13 and 1E-18 cm^-2. With these data the peak maximum temperature of b1, a1, b1L and b1M will be calculated. Then the difference between the last 3 temperatures and that one from b1 will be listed.



You see an example at the right. You can use this list to check whether the peaks of your measurement come really from one single level. Remember that the time constant of b1, given by the period width, and the temperature, defined by the marker, changes the results. Temperature and time constant will be listed in line one.

You can check the real temperature differences of the peaks compared to the theoretical ones by the vertical marker. Its current x-value, means the temperature, will be shown in the status line. The peak temperature defined for b1 is in the first line of the list window.

Tip: If you see an unusual behavior in the tempscan, have also a look into the internal transients or into the recovery check. Here you can detect recovery effects and drifts. Read also chapter H3 of the Hardware Manual about isolation problems.

3.4.4.6 Fit and library

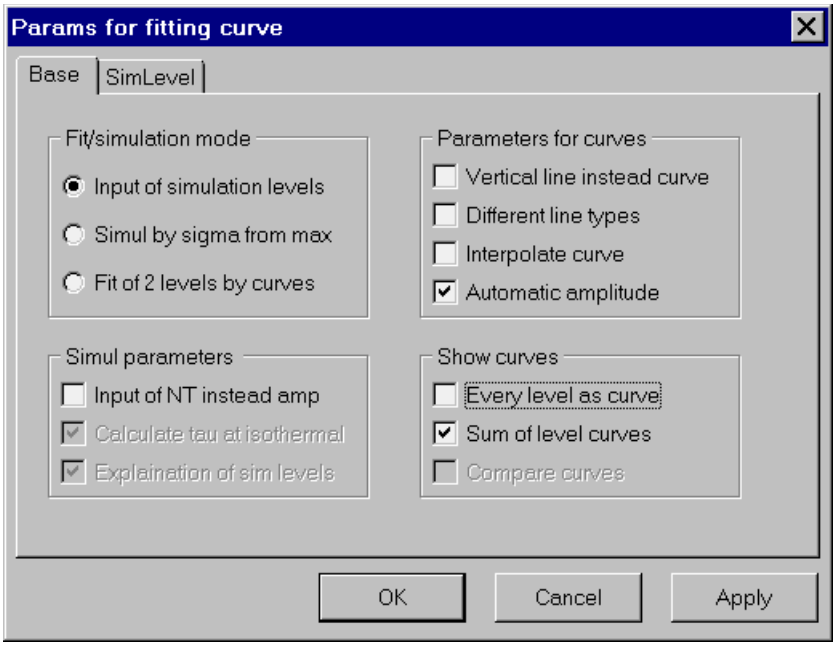
If using 'All coefficients' or 'Special plots' of the plot menu then it is possible to **fit** this curve by simulation levels (as tempfit) or to compare the curve by existing levels in the **library**. You find these both possibilities in the menu 'Evaluate' of the plot program. If the fit or library search was done then the menu entry will be marked by a hook. First you have to define the peak maximum by the mouse or vertical marker. Then opens an input window. The library will be explained in a separate chapter.

Fit means here an analytical recalculation of the coefficient by given simulation parameters. It is not a smooth! The simulation parameters will be defined in the input sheet SimLevel. You can input NT instead of the amplitude if activating this flag.
The next picture shows the base input sheet for the fit.

3 **Fit/simulation modes** exist:

- **Input of simulation levels:** The fit curve will totally be defined by the simulation parameters. The definition of the peak temperature position has no effect.
- **Simul by sigma from maxi:** The fitting curve will be calculated by a calculated energy and the given sigma. This energy will be calculated from the time constant of the coefficient (only valid in the maximum), the defined temperature at the fit peak and the given sigma.
- **Fit of 2 levels by curve:** This fit is for 2 strong overlapping levels. This means you see only 1 peak which exist of 2 peaks. The fit of 2 separated levels is with this method not possible, you set only 1 peak position by the marker. A direct fit of 2 levels is for a tempscan not possible because there are 6 unknown parameters: 2 energies, 2 capture cross sections and 2 amplitudes. Therefore a special 2 level fit base on the HERA deconvolution will be used.

Parameters for curve:
By activating a flag only a vertical line at the fit maximum position will be drawn instead the fitting curve. It is possible to use different line types for the fitting curve, the fitting curve can also be interpolated. If activating 'Automatic' amplitude then the fitting height will be normalized to the peak height defined by the mouse.



Show curves:
At the first simulation mode you can show the curves of every level or/and the sum of curves of all levels. This is only possible at 2 or more levels. At selecting 1 simulation level and user class 5 you can compare the simulation curve (Energy, sigma) with the curves (Energy', sigma) and (Energy, sigma'), see in the list below for the explanation.

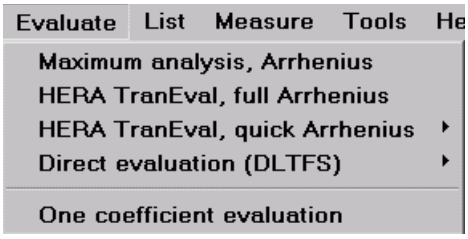
The tab sheet **Compare** is only visible for the first fit mode. It compares the given simulation parameters by recalculated values. The values will be calculated at clicking onto this tab sheet. Following list will be shown:

Energy: Energy of the simulation level.
Energy': Energy calculated by sigma, tau and temp.
sigma: sigma of the simulation level.
sigma': sigma calculated by energy, tau and temp.
tau: Time constant of the coefficient, valid in the peak maximum.
tau': tau calculated by energy, sigma and temp.
Temp: Temperature defined by the mouse at the peak maximum.
Temp': Temperature in the peak maximum calculated by energy, sigma and tau.

Clicking 'OK' starts the simulation, 'Cancel' break and delete it.

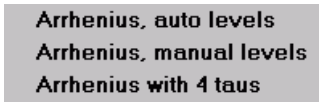
3.4.5 Evaluate menu

The possibilities of the evaluation depend on the kind of sample (Schottky diode or MIS capacitor) and the selected transient evaluation. The following menu will be shown for a Schottky diode and an exponential evaluation.



The Arrhenius plot made by the maximum analysis is the most important evaluation for many users. This will be explained in chapter 4.1. There you can also use the HERA coefficient deconvolution for the Arrhenius plot.
The Arrhenius of the HERA transient evaluation will be explained in chapter 6.1.4.3 (quick) and 6.1.4.4 (full).
The One coefficient evaluation will be explained later.

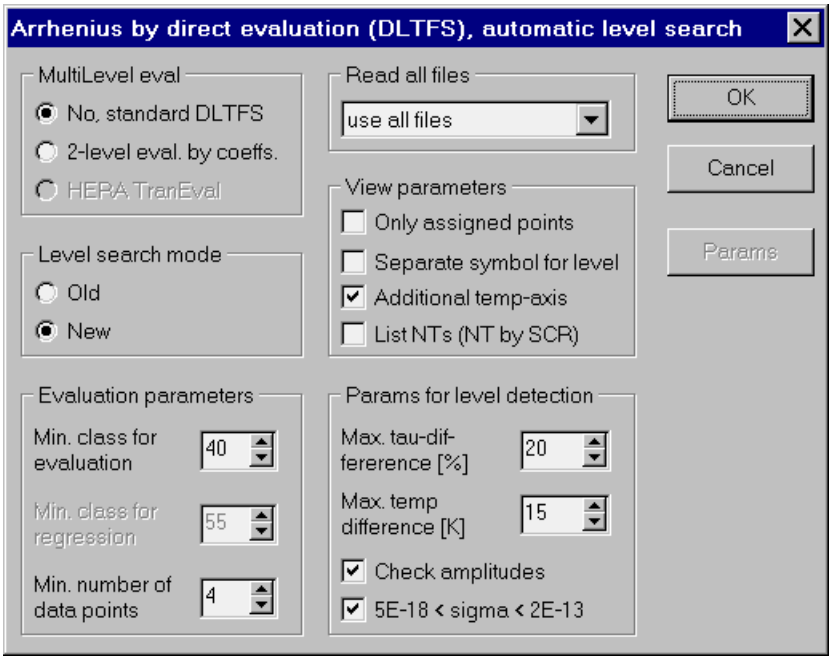
In the following the Arrhenius plot for the direct evaluation of **DLTFS** (**D**eep **L**evel **T**ransient **F**ourier **S**pectroscopy) will be explained, more details are in the Theory manual.



Arrhenius with auto levels try to detect the numbers and the corresponding data points of levels automatically. At manual levels the user has to define the numbers and the linear regression range of the levels.

3.4.5.1 Arrhenius, auto levels

The software tries here to detect the numbers and the corresponding data points of levels automatically. The sorting of the data points to the levels are done by the software. The linear regression will be done level by level about the data points of the level. There is no mismatch possible, even at an overlapping, if the automatic sorting is successful. Points that are not assigned to a level will be shown as a small square.



The **standard DLTFS** and a special 2-level evaluation is possible. Normally the new **level search mode** will be used. At the old mode the input group for 'Params for level detection' will be replaced by inputs as described in 3.4.1.1.5 and the input of minimum class for regression is enabled.

All points that have a class value greater than or equal to the **minimum class** for evaluation will be included in the displayed Arrhenius plot, see chapter 3.4.5.4 for an explanation of the class.

In the **View** input box there are some parameters for the view of the plot:

Only **assigned** points shows only Arrhenius points which are assigned to a level.
It is possible to use different **symbols** for different levels and to show an additional **temperature axis** at the top of the plot.
NTs, this is NT corrected by the space charge region, can be listed.

It is possible to collate information from more than one tempscan file into the Arrhenius plot, using files that were collated at the same time (family data). This yields to a bigger 1000/T-range with many points and so to a higher accuracy. The options for **reading all files** include constant and variable period widths:

only current file: Only the current file will be used for the Arrhenius plot.
use all T/V-files: If the current file is a file with constant period width (T-file) then all T-files will be used. If it is a file with variable period width (V-file), then all V-files will be used.
use all T-files: All files with constant period width that were collected simultaneously will be used.
use all V-files: All files with variable period width will be used.
use all files: All files will be used.
all V-files, auto diff.: All V-files will be used, automatic differences will be made at files with different measurement parameters like pulse width.

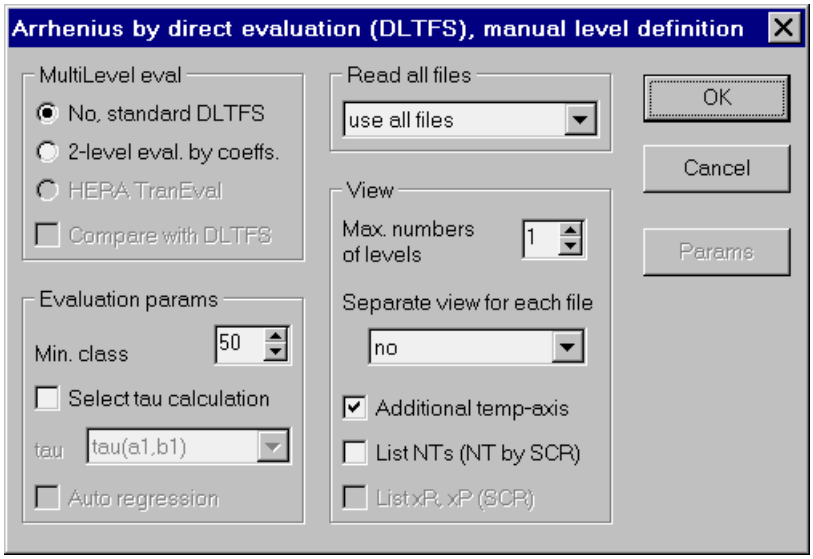
The **Params for auto detection** define criterions for the validity of a level:

A **Minimum number of data points** is in the Arrhenius plot necessary for each level.
There is a **maximum percentage difference** possible between the time constant and the regression line of the Arrhenius plot.
The gap between 2 points of the same level is restricted by the maximum temperature difference, it is a relative value to 150 K as the last mode of step factor in chapter 3.4.1.4.
By **Check amplitudes** all amplitudes of each level will be checked. If the difference is too big then this point can not belong to this level.
The capture cross section can be limited to **5E-18 < sigma < 2E-13**.

3.4.5.2 Arrhenius, manual levels

Here the user has to define the numbers and the linear regression range of the levels.
If there was already done a linear regression then you can start with this if activating the flag **Auto regression**.
All defined Arrhenius data will be used without level separation. A regression can be done about all data. The **maximum numbers of levels** will be defined in the input window. This is not the really numbers of levels. It defines for how many levels you can make here an evaluation, it is not necessary that all levels exist. It defines also where the results will be shown, for one level at the right text header, for two or more in a top list box inside of the Arrhenius plot. It reserves also enough space for the result list.
In this mode all data points will be used as one array, there is no **separation** by levels. If levels overlap in the x-axis then you can not separate the levels for the linear regression by setting x-start and x-end point. It is possible that you make the linear regression about the data of 2 'real' levels. In this case you should use the so called manual regression with setting the x/y-start and the x/y-end point. It will be described in the chapter 5.1.5.2.

Inputs already described in the chapter before will here not be explained.



Normally tau will be calculated by tau(a1,b1). If activating a special flag then the **tau calculation** can be selected:
tau(a1,b1), tau(a2,b2),
tau(b1,b2), tau(a1,a2)
tau(a0,b1), tau(a1L,b1L)
tau(a1M,b1M), tau(a1H,b1H)

If using more than one file you can select **separate** symbols, separate colors or both for each file.
In order to improve on the accuracy of results calculated using just one file, make the regression across the whole range of data collected using all different period widths files. Ideally the data in the constant period width files should cover a tau range factor of 100. 2 or more files can be a help especially at overlapping of levels. Then you see better the transition between the two levels.

Note: Choice of the different coefficients can enhance the energy discrimination because the coefficients with H subscripts use the latter half of the transient for the calculation of tau.

3.4.5.3 Arrhenius with 4 taus

Since the class is calculated from different tau calculations an Arrhenius plot with 4 tau calculations can be used to assess data quality. For good data the different tau calculations should lie close together. If the DLTS peaks overlap, which can produce lower class values, then the tau curves will be displaced from each other, although some may still be coincident. The inputs are the same as in the previous chapter except the selection of tau calculation.
This Arrhenius plot can be a help especially at overlapping of levels.

3.4.5.4 Evaluation class

The class is a very important parameter. It classifies the evaluation in respect to the measuring quality (signal to noise ratio, single events during a transient measurement), measurement parameters (period width in respect to the actual transient) and evaluation parameters like the type of the transient evaluation (exp, log, lin). This parameter gives a very good tool to distinguish between data fitting very well to the expected signal (e.g. exponential transient for trap emission processes) so that the wanted evaluation can be done without seeing the physical background.

Classes>=60 fulfill all conditions, probably classes between 50 and 59 represent also the based theory. Therefore 50 is the default value for the class.
If you lower this value you must take care when interpreting the results. Data with classes between 40 and 49 do not fulfill every conditions for the evaluation, but can be used for plotting the data and for a manual evaluation. These classes can occur at overlapping of levels. Data with classes<40 should not be used for the evaluation.

For an exponential evaluation the evaluation class will also be called tau class.
Following **classification** is valid for the class:

1 – 6 : Error during measurement
7 – 9 : Transient is not taken into account
10 : No evaluation was done
11-29 : No signal suitable for evaluation
30-39 : Coefficient ratios don't correspond to the assumed transient type or shape
40-49 : There is an evaluable signal but the shape is not assignable
50-59 : Probably the transient is of the assumed type
60-75 : The transient is of the assumed type

3.4.5.5 Regression, fit and library

The Arrhenius plots will be made in the plot program, for more details see chapter 5.1.
You can change the start and end point of the **linear regression** for each level. Use the toolbar button or the F8-key for setting the range of the linear regression. This mode will also be called auto regression. After setting the right point the results will be calculated again. The correlation factor provides an indication of the deviation of the data from the regression.
The current level number can be changed by a mouse click onto the level number button in the toolbar, it toggles then between first and last level.
In the Evaluate menu you can select a manual regression, see chapter 5.1.5.2. Here you can set the x/y-start and the x/y-end point. This method is especially important at overlapping levels without level sorting.

You can compare the results with existing levels in the **library**. You find this option in the Evaluate menu of plot program. The library will be explained in a separate chapter.

It is also possible to **fit** the Arrhenius plot by simulation levels, this option is also in the Evaluate menu of plot program. At the input sheet SimLevel you can define the simulation parameters. At 2 or more levels you can select the colors for the lines of the simulation levels. Taking the global color for fit or separate colors for each fitting lines are possible. The lines can be drawn from start to end point (simple line or dots), by interpolation or from data to data point. The last can give problems if many arrays will be used.
Library and fit are only available if the linear regression was done.

3.4.5.6 NT calculation at Arrhenius

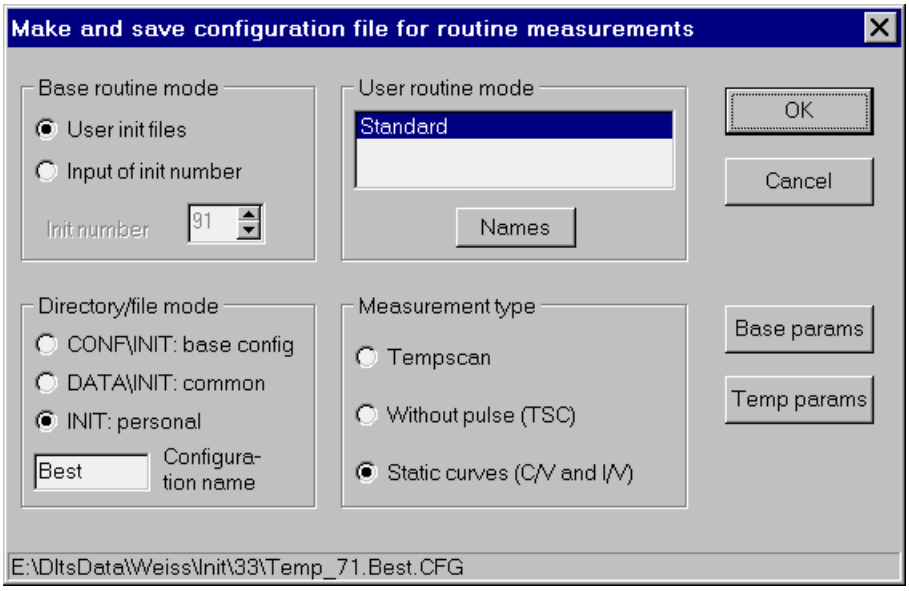
The Arrhenius plot shows also the trap concentration NT. It will not be calculated from the x- and y-array of the Arrhenius plot but from the amplitude and other arrays. The software links these arrays to the Arrhenius points so that only those data will be used for NT which Arrhenius points contribute to the linear regression of the level. The average of all these points yields then to the shown NT value.

3.4.6 Others

3.4.6.1 Make routine init file

Here you can make personal configuration files for the routine measurements. These files can there be loaded, the measurement will the done by this file. This enables you to have totally the same measurement conditions for similar samples or to create a big measurement task for an unknown sample as an overnight measurement. The software option 'Routine' is necessary for making personal configuration files.

The **Base routine mode** is similar to that one as the routine measurements. User init files are init file numbers 71 to 79, which will be named and selected by the **User routine mode**. By the button 'Names' you can define the names. The other possibility is to input the number of the init file. Numbers 91 to 99 should be used here. In the status line you see the full initialization file name.



The **Directory/file mode** defines to which directory the initialization file will be saved:

Conf\Init; base config: Use the base configuration directory for init files, need user class 5 or higher.
Data\Init; common: Use the init directory of the common data directory.
User\Init; personal: Use the personal init directory, if the user name is UserX and the program version is 3.2 then this directory is UserX\Init\32.

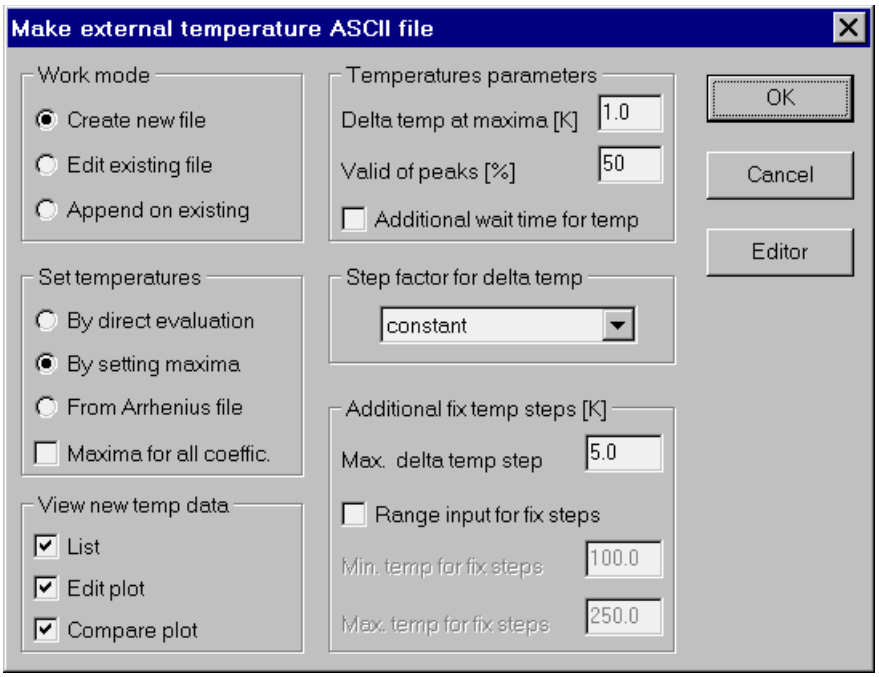
At the common and personal init directory you have to input the configuration name.

In **Base params** there are the inputs for the measurement. These inputs depend on the measurement type. For the tempscan the input sheet window will be opened as described in chapter 3.4.1.1.
The **Temp params** button opens an input window as described in 3.4.1.4.

3.4.6.2 Make external temperature file

As described in chapter 3.4.1.1.2 it is possible to make tempscan measurements only at user defined temperatures which are interesting for your sample. This decreases the measuring time. The defined temperatures must be saved in an external ASCII file without a header. Every temperature must be in the first position (column) of a line, an optional waiting time after setting temperature in the 2. column. You can set these temperatures manually by an ASCII editor or from existing tempscan files by the menu 'Tools → Make external temp file'.

The following input window opens if using this automatic tool. It is only enabled if a tempscan file was loaded. The software option 'Routine' is necessary for this feature.



By the '**Work mode**' you can select to create a new temperature file, to edit an existing one or to append temperatures on an existing file.
By the '**Edit**' button you can edit an existing file by the internal ASCII editor.

Set temperatures defines how the temperatures should be calculated from the tempscan:

1. **By direct evaluation:** All temperatures with a evaluation class equal or bigger than a minimum class will be applied. If selecting 'Use all files of Tw's' then all family tempscan files will be used.
2. **By setting maxima:** You have to define the maxima of the b1-temperature curve in a special plot. If the tempscan is part of family data then all b1 curves of different period widths will be plotted. The list right of the plot shows your defined maximum temperatures. The software calculates from these points temperatures around the maximum. If activating the flag 'Maxima for all coeffic.' then not only temperatures points for b1 but for all coefficients will be searched.
3. **From Arrhenius file:** An analytical tempscan curve will be calculated for every valid point of an Arrhenius file. Points around the maximum with a minimum height of 95% will be applied, similar to mode 2. If you have already read an Arrhenius file then this file will be used by default. In the other case or if you activate the flag 'Load new Arrhenius file' you have to input the file name.

Tip: If you want to compare only the amplitudes with a reference file and use the One coefficient evaluation then select mode 2 without activating of its flag. If you want to make a maximum analysis then select mode 2 and activate the flag 'Maxima for all coefficients'.

The '**Temperatures parameters**' input group depends on the set mode, the input window above is for mode 2:

'**Delta temp at maxima**' is the difference of the temperature points around the maximum. This delta temperature can be constant or depending on the current temperature, it will be defined by the **Step factor for delta temp**, see chapter 3.4.1.4.
'**Valid of peaks**' means that all b1-values around the maximum which are greater than this percentage value will be applied for the temperature file. For this not the b1-curve of the tempscan will be used but an analytical curve.
If activating '**Additional wait time for temp**' then the temperature file contains a second column. It defines an additional waiting time in seconds after reaching the temperature and before starting the transient measurement. By default this value is 0. You have to edit it manually.

Additional fix temperature steps are possible:

The '**maximum delta temp step**' restricts the delta temperature. For example, if this value is 5 K, then a new temperature point will be inserted if the difference between 2 temperatures would be bigger than 5 K. If you don't want this option input a big value.
By activating of '**Range input for fix step**' only points in the defined temperature range would be inserted.

'**View new temp data**' defines how the defined temperatures will be shown. Different views one after the other are possible:

'**List**' shows the temperatures in a list view, either in a grid or in the ASCII editor. You can edit, delete or insert data.

'**Edit plot**' shows the temperatures versus temperature in the edit plot program. You can there change the points. This option is only available if the flag 'Additional wait time for temp' is not activated.

'**Compare plot**' shows the b1-tempscan as a line with marking the defined temperatures by symbols. If the tempscan file is part of family data then all tempscan files with different period widths will be shown.

The described ASCII temperature file above is for tempscans with constant period width. If a tempscan with a variable period width was loaded then the created file has another structure. In the 1. column is the temperature, in the 2. the period width and optional in the 3. an additional delay time t0+.

3.4.6.3 User correlation functions

Additionally to our standard coefficients and correlator signals, see chapter 3.4.4.1, also user defined correlation functions are possible. Instead correlation functions also the expression weighting functions will be used. From the transient values you get with the help of a correlation function the correlator signal. A Fourier coefficient can also be treated as a correlator signal. You get more information in the Theory Manual. The reason for a user defined signal can be that some correlation functions have a better energy resolution, other a better signal to noise ratio.

2 different **kinds of working** with user correlation functions are possible:

- The DLTS program uses an ASCII file which contains the y-values of the correlation function. The time constant and amplitude valid for the maximum will be calculated numerically by the software. The user has only to create the ASCII file, see below. You find an example in Dlts\Sys\Doc\Dll\UserFct.Txt. The ASCII file name must have the extension Txt and 8 or less characters. If using 8 characters then last must not be a 'D'. The file will be first searched in the personal base init directory, for example DltsData\UserX\Init. If not found there, it will be searched in Dlts\Conf\Init.
- The DLTS program calls a DLL which was written by the user. Here are calculations possible which are more complex that a correlator signal. You find an example in Dlts\Sys\Doc\Dll\UserFct.dpr. The DLL name must have the extension DLL and 8 characters, where the last character is a 'D'. The search strategy is the same as for the ASCII file.

The **ASCII file**, necessary for the first kind, must contain M or M+1 equidistant points of the correlation function, similar as the transient. The lines represent the different points, in the last column must be the y-values, the x-axis will be skipped if exist. The transient points start from the index 0 and go to N, means y[0], y[1], …, y[N], where N is a power of 2. M must be N or a power of 2 bigger than N. Usually M should be 512, this is the standard for the tempscan. If M is 512 for the correlation function and N is 128 for the transient then only every fourth point of the correlation function will be used. If M<N then the correlation signal will be set to zero. If the file contains only M values, means h[0] to h[M-1], the additional point h[M]=0 will be appended.

If M=N, that means the correlation function h goes from h[0] to h[N], then the correlator signal d will be calculated by:

$$d = \sum_{k=0}^{N} h_k * y_k * w_k$$

y[k] are the transient values and h[k] the correlation function values from your ASCII file. w[k] is a normalization function which will be set by the software. If an additional first line of the ASCII file contains the text 'normoff' then no normalization will be done, means w[k]=1. In the other case the software defines w[k].
The reason for the introduction of the normalization w[k] is that then the user correlator signals are better comparable with our standard Fourier coefficients and correlator signals while h[k] is between -1 and 1. We use by default an edge correction for the Fourier transformation, that means the Fourier coefficients will be calculated like an integration by the trapezium rule:

$$d = 2/N * (h_0 * y_0/2 + h_N * y_N/2 + \sum_{k=1}^{N-1} h_k * y_k)$$

The **automatic normalization** of w[k] distinguishes between 3 cases:

1. Only **2** points with h[k]<>0: w[k]=1, correlation function of the standard Dlts signal.
2. ASCII file contains **M** values: w[k]=2/N.
3. ASCII files contains **M+1** values: w[k]=2/N for 0<k<N and w[0]=w[N]=1/N. This case will be used for the standard Fourier coefficients with edge correction.

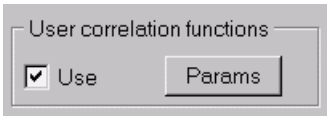
The explanation above is only a simplification. The software takes into account which range of N will be really used. So it replaces N by N/4 for b1(Tw/4). And the edge correction in case 3 will be done for the first and last used point. But bear in mind that the SNR of b1(Tw/4) is worse than of b1 although these have similar peak heights.

Note: The normalization is only a visual effect. It has no influence on the calculation of amplitude and time constant. The numerical evaluation takes into account a normalization.

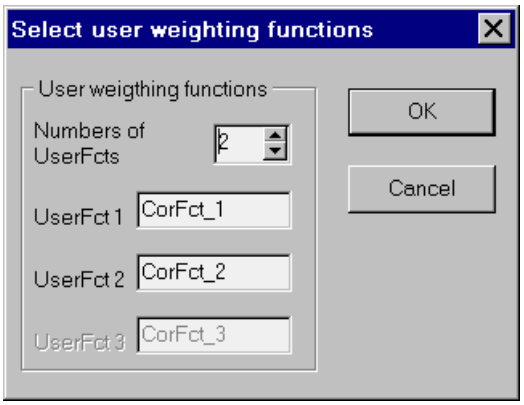
The easiest way to create a correlation function is to use the Edit Plot Program, especially if calling from the transient program module. Alternatively work with an ASCII editor or another program which can save ASCII data.
User correlation functions can be used in the isothermal and tempscan program module. The user correlator signals can be calculated during the measurement or, if saved the transients, after the measurement.

For the calculation **after the measurement** is user class 5 necessary. You find it in 'Edit → Edit tools'. There are the 2 possibilities 'Internal transients → tempscan (isothermal) file' and 'External transients → tempscan (isothermal) file'. This feature gives you the possibility to try many user correlation functions on the same data.

For calculation **during the measurement** you have to activate a special flag. In the tempscan module you find this flag on the transient input sheet, see chapter 3.4.1.1.3, for the isothermal module see chapter 3.3.1.2.



Clicking onto the 'Params' button opens a new input window. There you have to define the numbers of user defined correlation functions, 1 to 3 are available in one tempscan or isothermal file. For each function you have to define its name. It is also the name of the ASCII file or the DLL without extension. For the names remember the convention above.



After creating the user correlator signal you can use these data as our standard coefficients. For plotting you have to select 'other coefficients' and then 'User-1' to 'User-3', see chapter 3.4.4.1. At the maximum analysis you can define by 'Select Arrhenius points' the use of these data, see chapter 4.1.5.1.

3.4.6.4 Invalid data points

The isothermal and tempscan data may contain so called **invalid data points**. An invalid data point will not be taken into account at the evaluation or at showing the data. The reason for an invalid data point is either a measurement error or a manual deleting by the user. The evaluation class gives a hint to the reason. Evaluation **classes** between 1 to 8 denote an invalid data point:

1) System error
2) Overflow of ADC
3) Over range of bridge
4) Compensation error
5) Break of measurement
6) Error at reading temperature
7) Data point was manual deleted by the user
8) Hidden data point, may be used for special calculations

Usually the invalid data points are hidden and will not be used for the evaluation, plot and list of data. There are some exceptions:

- **List imp. measure data**: If invalid data points exist, these will here always been shown. Then 2 additional columns exist. A 'vNo.' labeled column shows the number of data point which would be used only for valid data points. The column labeled by 'Inval' shows the invalid class as explained above, 0 denotes a valid data point.
- **Stability plot**: You may include or mark invalid data, see chapter 3.4.4.5.3.
- **Edit ASCII curve** and Edit curve by plot: Invalid points can be included.
- **Delete data** in Edit menu: You can include invalid points, see chapter 3.4.2.3.

If invalid data exist and will not be shown (this is the standard!), the shown number (for example the grey 'No.' column in a grid) denotes the number of valid data points, and not of all (valid and invalid) data points. At 'List → Important measure data' the grey 'No' column shows the real data number of valid and invalid points, this is also the real position in the data file. The 'vNo.' column shows here the number of valid data points, which will be shown in the grey 'No' column of the other list functions (only valid data). A '0' in the 'vNo.' column means that this data point is invalid.
At listing the file header, 'DataNbrs' shows the number of data points. If no invalid data exist, there is only one number. Otherwise the first value denotes only the numbers of valid data points, the second value the total numbers of valid and invalid data.
The minimum class for valid data can be input at user class 6 in the program parameters, see chapter 2.4.2.3. But you should keep its value at 10. Invalid data can be removed from the data array in 'Edit → Delete data, see chapter 3.4.2.3
The reason for keeping invalid data is, that these data points could be necessary when combining data of different files. One example is the construction of the quasi-logarithmic transient by 3 files of different period width. The transients of the correct data points (same temperature) have to be merged. If one point is missing (removed) in only one data file, the 3 files don't have the same order. But the software usually find the correct data when activating 'Check temperature', see chapter 3.3.4.5. If one of the 3 transients is invalid or missing, the quasi-logarithmic transient will not be shown.
Invalid points will not be used at an interpolation or approximation. The invalid data will be deleted by an interpolation to a new x-delta, these will be usually kept at an interpolation to a given reference x-axis. Optionally you can interpolate new values for invalid data.

Note: Usually the data don't contain invalid data points.

3.5 Equilibrium program

This chapter describes the equilibrium files, also called '**Q-files**'. The software option 'equilibrium' is necessary for this feature. These files contain one or two temperature depending equilibrium values, for example the reverse bias capacitance CR or the leakage current IR. TSC, TSCAP and TSV measurements are also a part of this feature.

Two ways exist to get a Q-file:

1. **Measurement:** The QR, QF, QP, QB and QV-files will be made by special measurements in the equilibrium and tempscan module.
2. **Made by static curves:** The QC and QU-files will be made by C/V curves, the QI-files by I/V curves. That means you have to measure these static curves by different temperatures in the static or tempscan program module. The QC, QU and QI-files will then be made in the static program module. More details gives chapter 4.4.

So 2 program parts exist for the equilibrium files:

- **Equilibrium program module**, explained in the following**.**
- **Equilibrium sub program** of the static program module, explained in chapter 4.4.

Both programs are very similar with 3 **exceptions**:

1. Measurements of **QR**, **QF, QP, QB** and **QV-files** are only possible in the equilibrium and tempscan program module.
2. The **TSC/TSCAP/TSV** evaluation is only possible in the equilibrium program.
3. The making of **QC**, **QI** and **QU**-files from C/V resp. IV/V curves is only possible in the static program module.

The menu of both equilibrium programs are similar. Differences base on the 3 exceptions. So the equilibrium program has no 'Define menu'. On the other hand a measurement menu exist here and the evaluation menu is expanded by the menu item 'Energy evaluation' for TSC/TSCAP/TSV.
You can read all Q-files in both program parts. Usually QR, QF, QP, QB and QV-files will be read here in the equilibrium program, therefor these will be explained in the following. The QC, QI and QU-files will be explained in chapter 4.4.

Three purposes of these Q-files can be listed:

1. **Temperature behavior:** For example, it can be interesting to plot CR or Ns versus temperature to check its temperature change.
2. **Applying into tempscan:** As explained below it can be helpful to apply for example CP or Ns(T) from a Q-file into a tempscan file, see chapter 3.4.2.2.
3. **Evaluation of the Q-file:** Here the equilibrium value itself versus the temperature will be evaluated. Examples are the TSC/TSCAP evaluation and Richardson plot.

The first character of the data extension is 'Q' for the equilibrium files. The second data extension character (chapter1.3.3) denotes the **kind of file resp. measurement**:

R: Measurement of CR and IR at UR, will be used for TSCAP.
F: Measurement of CR and IR at UR, before start of measurement a fill pulse UP will be applied, used for TSC resp. TSCAP.
P: Measurement of CP and IP at UP.
B: CC or CS regulation of the bias UR, can be used for TSV.
V: As 'B' but with a fill pulse before measurement start, will be used for TSV.
C: Made by C/V curves, contains CR and CP, means capacitance at UR and UP. Saves also Ns and UD of each C/V curve.
I: Made by I/V curves, contains IR and IP, these are the currents at UR and UP. Saves also n-factor and saturation current of each I/V curve
U: Made by C/V curves, contains UR and UP, means voltages for a fix CR and CP. It can be used for CC-DLTS measurements, see chapter 6.2.1.2.1.

The different file types save different equilibrium values in dependance of the temperature:

- The **QR, QF** and **QP**-files contain the capacitance and current at a given voltage, either at UR or UP. If the measurement will be done without the capacitance bridge then there is only the current value.
- **QB** and **QV**-files contain the regulated UR, and the measured IR and CR. CR should be constant because the CC resp. CS regulation.
- The **QC** and **QI**-files contain either the capacitance or the current at UR and UP. Additionally there 2 evaluation values will be saved which come from the linear regression of each static curve.
- The **QU**-file contain UR, UP, C(UR0), C(UP0), C(UR-UR0+UP0), where UR0, UP0, CR and CP are fix values. For more details look in chapter 4.4.4.2

The data may contain the conductance which enables the calculation of the serial capacitance Cs. You can select between Cs and the measured parallel capacitance in some inputs.

3.5.0 TSC/TSCAP/TSV

TSCAP is an abbreviation for **T**hermally **S**timulated **Cap**acitance spectroscopy and bases on the measurement of the equilibrium reverse bias capacitance versus temperature.
TSC is an abbreviation for **T**hermally **S**timulated **C**urrent spectroscopy and measures the leakage current at UR in dependance of temperature.

Both methods base on the emission of traps due to the increasing of temperature which has an effect to the equilibrium capacitance and current. Both give the approximate thermal activation energy of traps and under dedicated circumstances the trap concentration. The DLTS method gives usually more accurate results. But at some applications, especially at high leakage current, this method can have advantages. For more details of TSC/ TSCAP have a look in the literature, following 2 publications:

- Z-Q. Fang, D.C. Look et al., Material Science Forum, Volumes 527 – 529 (2006)
- C.T. Sah et al., Appl. Phys. Lett. 20, 193 (1972)

2 different **initial conditions** exist for the measurement start:

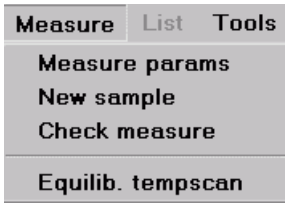
1. The reverse bias UR will be applied on the sample at room temperature. Then the sample will be cooled down. The measurement starts from low temperature to high temperature. At low temperature the traps are **empty**. During a linear temperature ramp with a constant rate (in K/s) the capacitance or/and current will be measured at UR. This type of initially empty condition describes the normal dependance of the capacitance on the temperature. This data file will be called QR-file, CR and IR are the measured values. It can be used to subtract this curve from the true TSCAP/ TSC curve (described in the next point) but an evaluation is also possible without this empty curve.
2. At the second initial condition the sample will also be cooled down to a low temperature. Then the traps will be **filled**. This can be done either by an electrical or by an optical pulse. Then the reverse bias will be applied and the measurement starts from low to high temperature while recording capacitance or/and current at UR and various temperatures. This is the true TSCAP/ TSC measurement and yields to the QF-file, we call its values CF resp. IF. An evaluation can be done alone by this curve or by the difference of CF-CR curve.

The QR- and QF file contain capacitance and current. But a TSC measurement will usually be done without the capacitance bridge because the sensitivity. So in the practice you make either TSCAP or TSC measurements. TSCAP measurements will usually be done by the 2 measurements, TSC only at condition 2.

TSCAP measures the equilibrium capacitance at a fix voltage. We introduce now a new variation of this method which we call **Thermally Stimulated Voltage** spectroscopy, abbreviated **TSV**. Here the static capacitance will be kept constant by regulation of the bias voltage UR, as the bias regulation for CC- and CS-DLTS.
The measurement and evaluation is similar to TSCAP. The new **QB**-file corresponds to the QR-file, the new **QV**-file to the QF-file. The new files contain the regulated UR, and the measured IR and CR. CR should be constant because the CC resp. CS regulation. The TSV measurement needs the software option 'Enhanced'.

3.5.1 Measure menu

The measurement menu contains the 3 common functions and an entry for the temperature depending measurements, called here also tempscan. The measurement will also be called 'measurement with no pulse'. During the measurement CR and IR will be plotted versus temperature.



Not only TSCAP/TCP are possible but also a usual measurement of capacitance and current at a defined voltage.
TSV measurements are available at CC- or CS-DLTS and bias regulation mode B2.

3.5.1.1 TSC/TSCAP measurements

Five measurement **modes** are possible:

I. **measure at UR:** Static C- and I-measurements at UR will be done at various temperatures in one temperature cycle. The results will be saved into one QR?-file. This file can be second file of the two files for TSC/TSCAP. This mode corresponds to initial condition 1 (empty) of the previous chapter.

II. **at UR-F, filling before (TSC):** Static C- and I-measurements at UR will be done at various temperatures. The defined pulse voltage will be set for the filling time to the sample before the measurement starts. The results will be saved into one QF?-file. This file can be the first file of the two files for TSC/TSCAP. This mode corresponds to initial condition 2 (filled). This is the standard mode for TSC.

III. **1: at UR, 2: at UR-F:** Similar as the next mode but the order is reciprocal, means first the QR-file will be measured, then the QF one.

IV. **1: at UR-F, 2: at UR (TSCAP):** Static C- and I-measurements at UR will be done at various temperatures. The defined pulse voltage will be set for the filling time to the sample before the first temperature cycle starts. The results of this cycle will be saved into one QF?-file. After this cycle the sample will be again cooled down. Then a second temperature cycle will be started which C- and I-measurement results will be saved into a QR?-file. This is the classic TSCAP measurement.

V. **1: at UR, 2: at UP:** Static C- and I-measurements at UR will be done at various temperatures in one temperature cycle. The results will be saved into one QR?-file. Then a second temperature cycle will be started with C- and I-measurements at UP and saving into a QP?-file. This mode has nothing to do with TSC/TSCAP.

The C-measurement will only be done if the bridge is connected. At current DLTS it is normally disconnected, see chapter 6.2.2. The QR, QF and QP- files contain in this case only the current.

Mode **I** is a normal measurement at one voltage, usually the reverse bias. But you can also create 2 QR-files with different voltages. This is mode is also one part of the full TSC/ TSCAP modes III or IV.

Mode **II** is a special for TSC/TSCAP and gives a QF-file. Before starting the measurement an electrical or optical filling pulse will be applied on the sample. Depending on your TSC/ TSCAP evaluation it can be enough to have only the QF-file. This is mode is also one part of the full TSC/ TSCAP modes III or IV.

Mode **III** is a full TSC/TSCAP measurement with first measuring a QR-file as in mode I and then measuring a QF-file as in mode II. It has the reciprocal order as the classic mode IV but enables the same evaluation.

Mode **IV** is the classic full TSC/TSCAP measurement with first measuring a QF-file as in mode II and then measuring a QR-file as in mode I. You can either evaluate only the QF-file or both files, especially by forming of the difference.

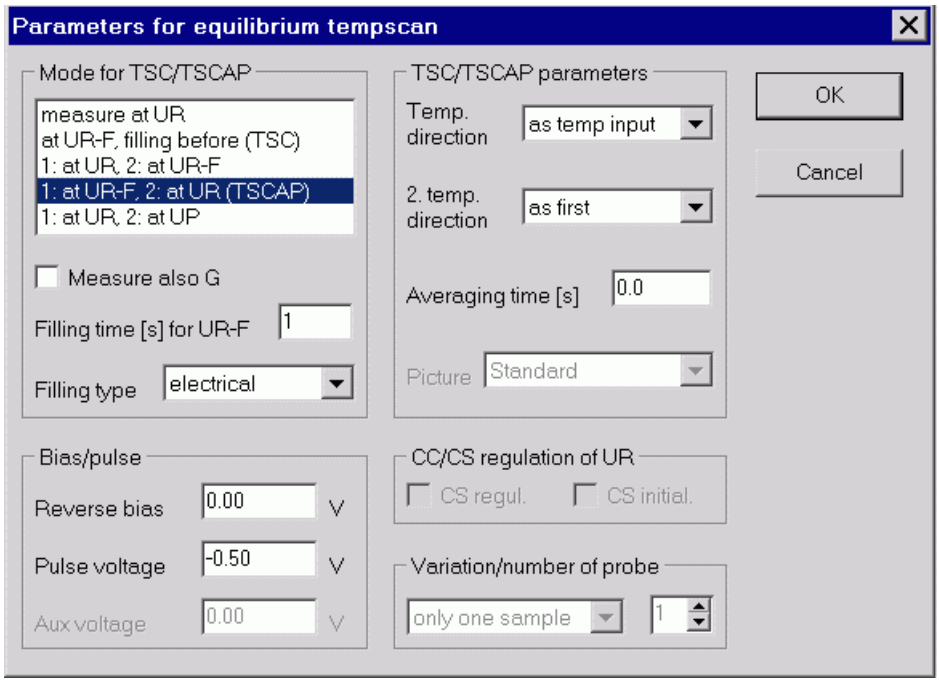
Mode **V** is not a TSC/TSCAP mode. Here you get capacitance and current at the 2 voltages UR and UP. Then you can compare both temperature curves and build the difference. Normally it is better to measure complete C/V or I/V curves and then to make a QC or QI- file for 2 voltages. Use this mode of 2 separate temperature cycles for UR and UP only if one measurement would have an effect on the other one at a measuring in one cycle. In the Edit menu you can make from both files a QC or QI-file.

TSCAP evaluation will usually be done by the difference of the QR- and QF-file, so the standard is here mode III or IV. **TSC** needs only the QF-file for the evaluation, so its standard is mode II.

The conductance G can be measured additionally to capacitance and current when using the FT-1235 CGI-Meter or the Boonton 7200.

At measuring mode II, III and IV a fill pulse will be applied to the sample before starting the measurement at UR. Therefore we abbreviate this by UR-F.

You can type in the **filling time**, what means the filling pulse width.



Depending on your hardware you can select the **filling type**:

- **electrical:** An electrical pulse with the pulse voltage UP will be applied.
- **optical:** An optical pulse will be applied on the sample.
- **electrical & optical:** Electrical and optical pulse will be together applied.

The **reverse bias** is that voltage at which the measurement will be done.
Pulse voltage is either the voltage of the electrical pulse at measuring mode II, III and IV, or the voltage of the second measurement at mode V.

TSC/TSCAP parameters contain parameters for the **temperature direction**, what means measuring from low to high temperatures or from high to low temperatures:

as temp input: The temperature direction will be defined by the given start and end temperature. If the start temperature for example is smaller than the end temperature then the measurement will be done from low to high temperatures.

Cooling: Independent from you start and end temperature the measurement goes from low to high temperatures. If the start temperatures is higher than the end temperatures so in practice these both values will be swapped.

Heating: The measurement goes always from high to low temperatures. If the start temperatures is lower than the end temperatures so in practice these both values will be swapped.

The **2. temperature** direction is for the 2 temperature cycle:

as first: The second measurement will be done in the same way as that for the first temperature cycle. So if the first measurement goes from low to high temperatures then second one goes also from low to high temperatures. That means that the sample will be cooled down or heated up between the temperature cycles.

reverse: The second measurement will be done in the reverse direction as at the first one. So if the first measurement goes from low to high temperatures then second one goes from high to low temperatures.

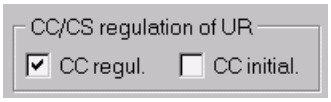
Setting an **Averaging time** bigger than zero gives the possibilty for a better sensitivity. The TSC measurement time will be defined by the filter of the Static C-measurements, see chapter 2.1.2.2. The default value is the medium time of 100ms. If you set the TSC averaging time to 1s, then the standard measurement of 100ms will be repeated 10-times and the results averaged. The input of zero yield to only 1 standard measurement of 100ms.

Note: TSCAP/TSC measurements must always be done from low to high temperatures for the QR- and QF-file. Use other temperature directions only for other measurements.

3.5.1.2 Equilibrium voltage measurement

The **Thermally Stimulated Voltage** (TSV) measurements are similar as for TSCAP. Most of the description there is also valid for TSV, especially the measurement modes.
TSV measurements are available at CC- or CS-DLTS and bias regulation mode B2, see chapter 6.2.1 and 6.2.2. The measurement mode V must not be selected.

Then the input group for **CC/CS regulation of UR** is enabled. If activating the flag **CC-regul**. resp. CS-regul. then TSV measurements will be done instead of TSCAP.



The **measurement modes** I to IV are similar to that ones for TSCAP, therefore only a short description will be given here:

I. **measure at UR:** The static capacitance will be kept constant by changing the bias voltage UR. The results will be saved into one QB?-file. This mode corresponds to initial condition 1 (empty) of the chapter 3.5.0.
II. **at UR-F, filling before:** Similar as mode I but a defined pulse voltage will be set to the sample before the measurement starts. The results will be saved into one QV?-file. This mode corresponds to initial condition 2 (filled).
III. **1: at UR, 2: at UR-F:** Similar as the next mode but the order is reciprocal, means first the QB-file will be measured, then the QV one.
IV. **1: at UR-F, 2: at UR (TSV):** Use as first mode II. The results of this cycle will be saved into one QV?-file. After this cycle the sample will be again cooled down. Then a second temperature cycle will be started which results will be saved into a QV?-file. This is the classic TSV measurement.

If activating **CS-initial**. resp CC-initial. then the input of UR is possible and it will be set at the measurement start. The software tries then to keep this initial capacitance constant during the whole measurement. If this flag is not activated then the 'old' defined capacitance CR will be kept constant.

This flag must be deactivated for a TSV evaluation. Before the first TSV measurement set UR at room temperature (high temperature) and define here the initial capacitance. You can do this by the compensation at the bias regulation (chapter 6.2.1.2.3). Both measurements keep in this case the same CR constant and the UR versus temperature curves of the QB and QV-file go at high temperature to the same value.

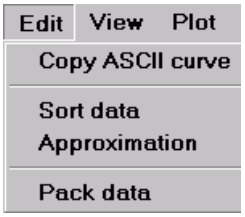
If the flag is activated then UR of the QB and QV-file starts at the same UR but diverge then, they keep different values of CR constant.

The initialization flag is similar as that one used for the CC- resp. CS-transient measurements, see chapter 6.2.1.3.2, but it will be used only for the equilibrium measurements. That means the corresponding flag for the transients will not be effected.

While the standard equilibrium measurements will be done without the capacitance compensation, the **CC/CS-regulation** will be done with the capacitance compensation as used for CC/CS-DLTS.

3.5.2 Edit menu

By the edit menu it is possible to edit and modify the data in the memory. The file itself will not be changed. After reading the file again you lose the changes. For changes of the file you have to save the Q-file, here you get a question for overwriting.



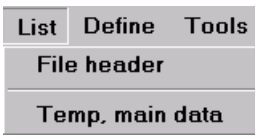
Copy ASCII curve copies the temperature and one selected result or other value line by line in an ASCII format to the clipboard. You can define the delimiter and the exponential format in the menu ASCII parameters. You find it in Tools of the plot or list program.
Sort data sorts the data by the temperature, normally not necessary.
Approximation was already explained in chapter 2.6.2.
Pack data means that not valid points (see note at the previous chapter) will be deleted.

At **user class 5** here are: Edit ASCII curve, Change temp axis (see chapter 3.4.2.1), Merge to CQ/QI-file. The last one merges 2 files (QR, QF, QP) of different voltages to one QC or QI-file.

At **user class 6** here are: Edit ASCII file, Edit curve by plot.

3.5.3 List menu

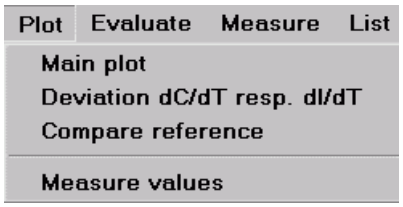
By the list menu it is possible to list the file header and the temperature with the main data. The most abbreviations are explained in chapter 1.3.4.



The main data depends on the file format. At a QR, QF and QP-file the main data are capacitance C and current I.
At user class 5 is a user defined list possible. Here you select the values for the listing.

3.5.4 Plot menu

By the plot menu it is possible to plot all values of the equilibrium data array.



The main plots shows CR or IR. A linear or logarithmic axis is possible for the current.
The deviation of capacitance or current by the temperature can be shiown. The data curve can be smoothed for the deviation.

Compare reference compares capacitance, current resp. voltage with that one from a reference file, see chapter 2.6.1.
Measure values are the data of the main plot and the temperature and the time.

At a QR, QF and QP-file you can select between capacitance and current. If the measurement was done without bridge then here only the current is available. At QB and QV-files UR or IR is available.
If the data file contains also the **conductance** then 'Conductance plots' is visible. There you can plot the parallel or serial capacitance, conductance and resistance. The possibilities and the input window are similar as shown in chapter 3.1.4.2.
If there is no question for parallel or serial capacitance (Cp or Cs), the measured parallel capacitance will be used. It is the default one in this sub program.

3.5.4.1 Measure values

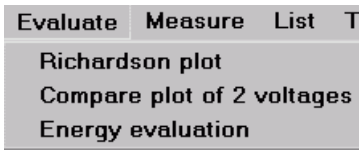
This plot shows the measure values. Depending on the data format following **modes** exist:

- **CR, IR or UR**
- **Conductance GR when exist**
- **Temperature**
- **Time**

For more details look in chapter 4.4.4.1.

3.5.5 Evaluate menu

The evaluate menu depends on the data format. 'Compare plot of 2 voltages' compares the capacitance, current or voltage with the value of the corresponding second file. Additionally the difference of both curves can be plotted. All curves can be plotted together in one plot or in separate plots. The inputs are similar as described in chapter 2.6.1 but here is no reference file necessary.



The Richardson plot will be explained in chapter 4.4.5.2.
The energy evaluation is the main evaluation for TSC/TSCAP and TSV measurements.

When existing capacitance Cp and conductance Gp in the data file, the additional feature 'Conductance evaluation' exist, see chapter 4.4.5.1.

3.5.5.1 TSC/TSCAP energy evaluation

TSC and TSCAP give the approximate activation energy of traps, TSCAP additionally the trap concentration NT. For this the equilibrium curve versus temperature will be plotted.

At the first you have to define the **input/evaluation** mode:

Manual inputs: Here you can input all parameters.
Standard evaluation: A standard evaluation and plot as described below will be done. Not all parameters are available, these will be set automatically.

The standard evaluation is following:

- **TSCAP:** The difference of the capacitance of the QR and QF will be normalized plotted versus temperature. The y-axis is (CR^2-CF^2)/CR^2. This difference falls to high temperatures to zero. You have to search the half of the curve. On this point you can calculate the energy and trap concentration. It is only valid for one level. For more levels it will be more complex. At this case a differentiation of this curve can give hints for the energies.
- **TSC:** only the QF-file will be used for the evaluation. The current versus temperature shows for every trap level a peak, the energy can be calculated at the peak temperature.

You have to select the **data** for evaluation:

Capacitance: The capacitance will be used, means TSCAP evaluation.
Current: The current will be used, means TSC evaluation. The y-axis can be linear or logarithmic.

The **file mode** defines whether the actual file or 2 files will be used:

Actual file: The actual data will be used.
2 files: The QF and QR file will be used, 2 curves will be shown.
2 files, difference: The QF and QR-file will be used and the capacitance or current difference of the 2 files will be formed, means CR-CF and IF-IR.

For the capacitance the normalized difference **(CR^2-CF^2)/CR^2** can be build. At MIS samples C^2 will be replaced by 1/(1/C^2-1/Cox^2).

Following algorithms for the **energy evaluation** are possible:

E = kT*ln(T^4/B): An approximation as introduced by Fang will be used, see literature 1 above, only available for TSC.

Sah, prefactor = 1E12: A calculation as described by Sah with the pre-exponential factor of 1E12 will be used, see literature 2 above.

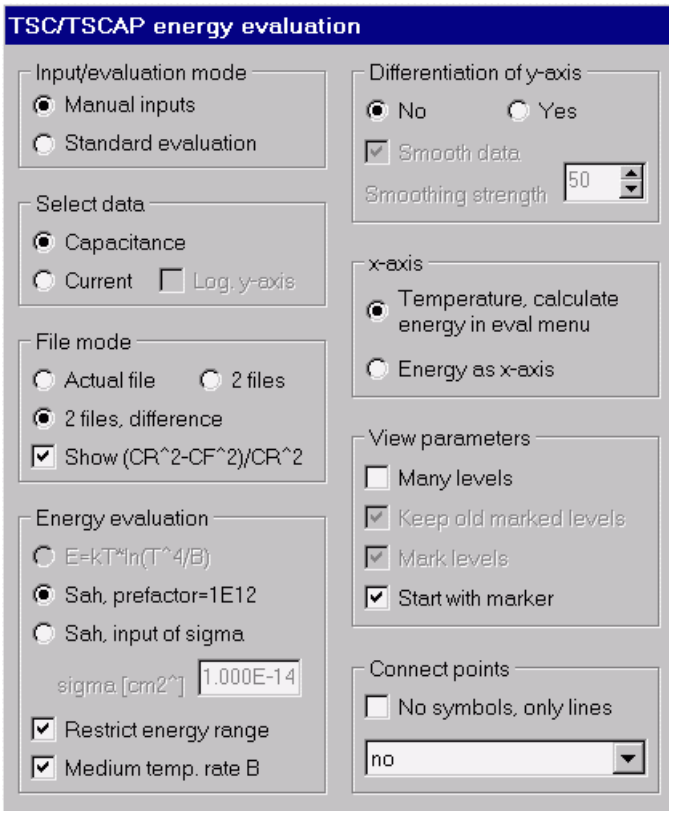
Sah, input of sigma: As before but we calculate here the prefactor by vth*Nc*sigma instead to take a constant value of 1E12. This calculated value is for n-Si, T=150K and sigma=1E-14 about 7.9E11.

The last two calculation modes needs iterations which we do by the Regula Falsi. You can restrict the energy range for these calculations.

Medium temp. rate B means that not the individual rate at each temperature will be used but a value calculated from the first and last temperature data point. If the ramp is constant then both methods are equal.

A **differentiation** of the y-axis can be done. Here the data can be smoothed, the smoothing strength can be input. At the capacitance the differentiation values will be inverted with the aim to get a maximum and not a minimum peak.
A differentiation is normally not necessary and only for a view but not for an evaluation. At TSCAP it can be used to get peaks but the peak position don't mark the correct energy.

When the data contains additionally the conductance, you can select between Cp and Cs, see chapter 3.1.1.4.



The evaluation will be done by a user defined temperature position. At TSC this is the position of the peaks, at TSCAP the half of the difference curve. A vertical marker helps to mark the peak or the half value position. For the last you can use an additional horizontal marker to find the half value of difference, see chapter 5.1.6.5.
The trap energies will be calculated from the defined temperatures by the selected algorithm. The energies will be marked and shown in a list. TSCAP lists also NT if the normalized difference will be used.

2 possibilities exist for the type of **x-axis** of plots:

Temperature: This is the standard mode. The energy will be calculated in the evaluation menu of the plot program, there you see the item 'Calculate energy'. Its activates the horizontal marker. You can move the marker line by the cursor keys or set it by a mouse click, chapter 5.1.6.5.

Energy: An energy will be calculated for each temperature data point and used as x-axis for the plot. But the energy is only valid at the maximum of a TSC peak, at TSCAP the axis can be only a hint.

View parameters are parameters for the energy list and the marker. If selecting energy as x-axis then only 'Start with marker' is enabled.

If activating '**Many levels**' then more than one temperature and so many levels can be defined. The level number in the toolbar increases automatically after defining a temperature. A list will be shown with the temperature and energy of each level. The calculation of NT of each level is not possible. Instead of this the total concentration of all traps, called NTT, will be shown in the text header. NTT will be calculated by the total capacitance difference similar as C^2-DLTS. NT for each level can be estimated from NTT by the proportionate capacitance difference.
If not activating this flag then only one level is available which values will be listed in the text header beside the plot, at TSCAP also NT. The flag can be deactivated for the evaluation of only 1 level, usually at TSCAP.

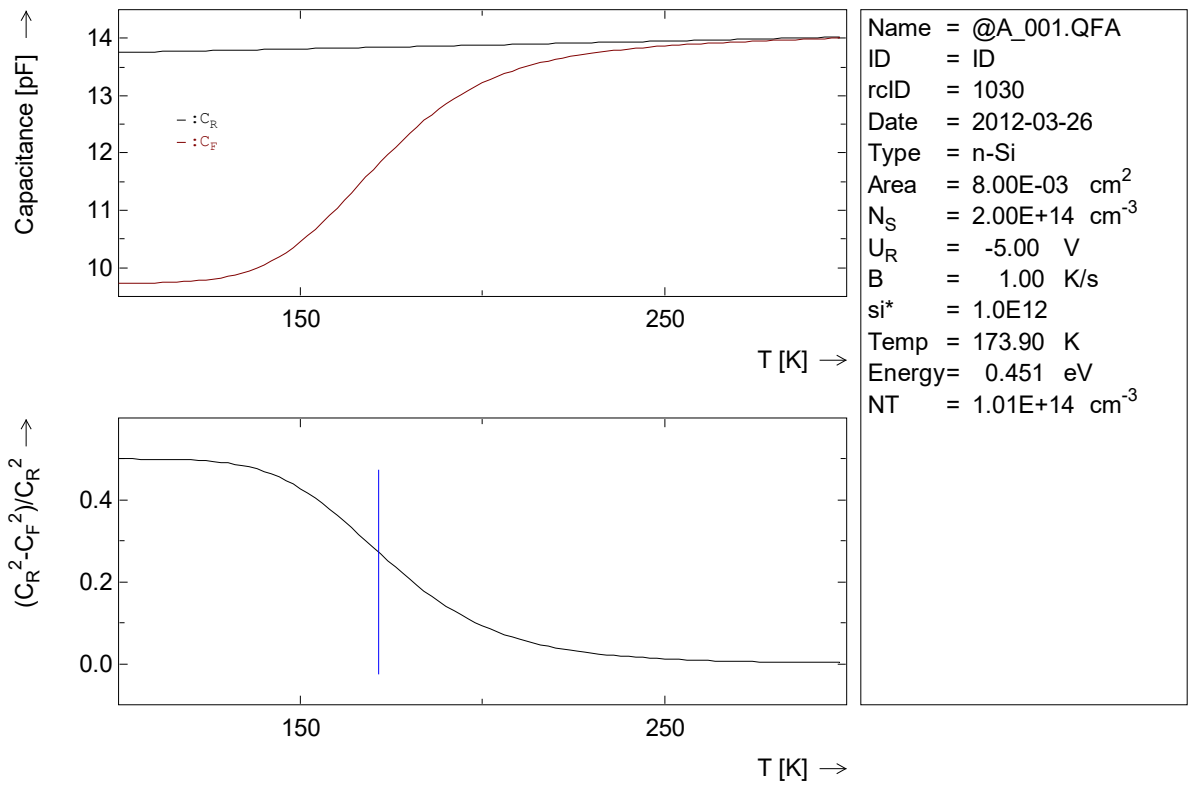
Keep old marked levels starts the plot with already defined levels.

By activating **Mark levels** the defined position of each level will be marked by a vertical line which color is by default blue.

Start with marker means that the plot immediately starts with a marker. So it is not necessary to go into the evaluation menu for the first level. If selecting the TSCAP difference then additional a horizontal line will be drawn at the half of the y-data.

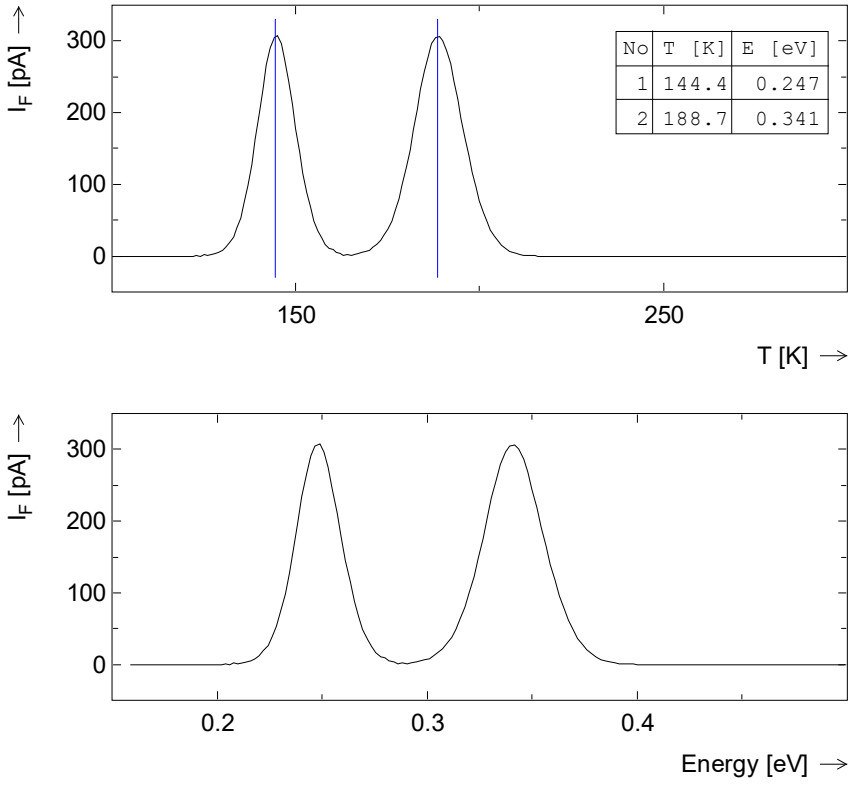
Note: The marker will be cleared at a plot refresh. For the evaluation marker you have to call again 'Calculate energy' in the evaluate menu, the other markers can be created in 'Tools → Marker tools', see chapter 5.1.6.5. The horizontal marker there can be a help for TSCAP.

Following both pictures show a TSCAP and a TSC simulation using some approximations. The TSCAP simulation was done with one QR and QF-file, the TSC with only one QF-file. The Text header denotes the algorithm of energy calculation. si*=1E12 means algorithm 2, that is the original from Sah. If sigma is listed then the modified 3. algorithm was used. 'Calc = kT*ln(T^4/B)' denotes the calculation by Fang.
The medium temperature rate B will also be shown. 'B*' means that not the medium but an individual rate for each temperature was used.
If not using 'many levels' then these will be written in the text header, as you see it for the TSCAP simulation. There are the temperature where the evaluation was done, the activation energy and, for TSCAP, the trap concentration.



The plot above shows a TSCAP simulation. The top plot shows CR and CF of the QR and QF-file. CF means the reverse bias capacitance with a filling pulse at measurement start. The bottom plot shows the normalized difference of both curves. The blue line marks the temperature where the normalized difference is 1/2.

The picture on the right demonstrates a TSC simulation with 2 levels. The top plot shows the current IF versus temperature. IF is the reverse bias current with a filling pulse at measurement start. The algorithm by Fang was used to calculate the energy at the temperature of the peak maximum.
The plot on the bottom shows IF versus energy calculated for every temperature point. Remember that the energy is only valid at the peak maximum.

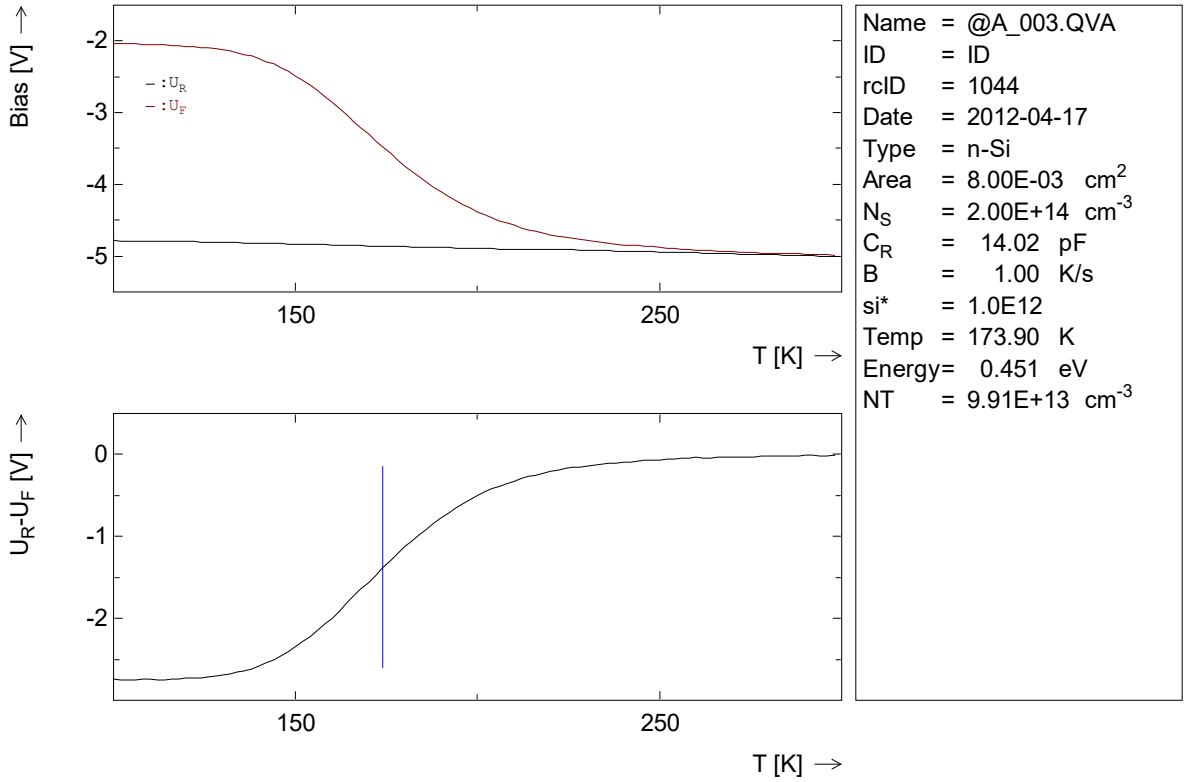


3.5.5.2 TSV evaluation

The TSV evaluation is similar to TSCAP but uses the difference of the regulated UR of the QB and QV-file. This difference goes to high temperatures to zero, at n-type doping it starts from negative differences, at p-type from positive ones. You have to search the half of the curve. On this point you can calculate the energy and trap concentration. It is only valid for one level. The NT calculation takes into account the oxide capacitance at MIS samples. For more levels it will be more complex.

Theoretically you can make also a current evaluation at QB- and QV-files. But the current of different temperatures will not be measured at the same voltage. Current measurements will usually be done without the capacitance bridge because the sensitivity. So this evaluation is not relevant in the practice.

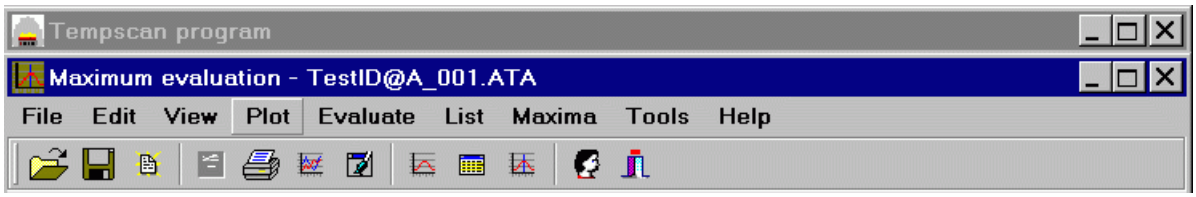
The following picture shows a simulation with the same level parameters as used in the TSCAP simulation. The fix capacitance CR was defined at -5V at 300K. The top plot shows UR and UF of the QB and QV-file. UF means the reverse bias voltage with a filling pulse at measurement start. The bottom plot shows the difference of both curves. The blue line marks the temperature where the normalized difference is 1/2. The results are the same as got from TSCAP.



4. Sub programs

Some program modules have sub programs with his own data files. The sub program has his own window with menu bar and toolbar. The plot or list will not shown on the main canvas but on the canvas of the sub window.

Normally this window will be shown under the caption line of the main window or as a kind window, see chapter 2.3.1. The following shows as an example the sub program Arrhenius by tempscan maximum analysis:



The menu is similar to the measurement program modules. The big difference is that here is no menu for measurements. Instead of this here is a menu for creating the files of the sub program, in the case of maximum analysis the menu Maxima.

At the file menu there is no sub menu to change to another measurement program module. The 'Exit' entry was replaced by 'Close'. By 'Close' you don't exit the DLTS program but you close only the sub program and go back to the measurement program. The same will be done by clicking onto the additional 'Close' button in the toolbar or by pressing 'Alt+F4'.

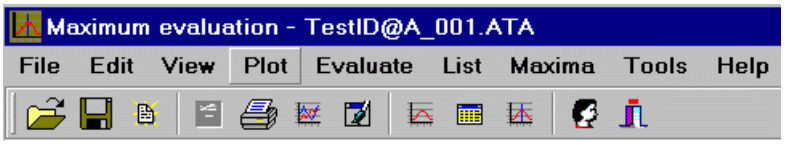
The standard evaluation will be shown on the canvas of the sub program. If calling a function of the plot menu then the window of the sub program will be replaced by the window of the plot program. So only one sub window is visible, dialogs not considered. The plot program has a similar window as a sub program, also with a Close button. To distinguish both windows the Close button of a sub program has a red top rectangle. If you see this button then you know that the main canvas of the sub program will be shown. By closing this window you leave the sub program and go back to the measurement program.

All data and evaluations will be buffered at leaving the sub program.

At the View menu are missing the functions 'Form and panel styles' and 'New size'. The Help menu contains only the important entries.

4.1 Arrhenius by tempscan maximum analysis

The perhaps important evaluation of the temscan is the maximum analysis. The emission time constant will be calculated from the maximum peak of the coefficient versus temperature curve, for these the tempscan files with constant period width are necessary. After defining of all peaks you get an Arrhenius plot with trap energy, capture cross section and trap concentration for each level. The new data can be saved into the Arrhenius data file format with the data extension AT?. The sample parameters of the Tools menu refers here to the Arrhenius and not to the tempscan data file.
The standard Arrhenius plot with all levels will be shown on the main canvas of this sub program.



The menu bar is similar to the measurement program modules. Instead the menu Measure here is the menu Maxima.

Most of the toolbar buttons have the same meaning as in the measurement programs, following have a different meaning:

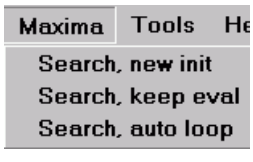

Plot equilibrium values as CR, IR and so on.


List amplitude, time constant and so on.


New **search** and definition of the peak maxima.

4.1.1 Maxima menu

By these functions the peak maxima will be searched and defined. You can use the current tempscan data or read new tempscan files.
At the same time resp. one Arrhenius file 9 levels with each 5 blocks (files, period widths) and each 22 until 25 coefficients can be evaluated, see chapter 4.1.1.7 for the list.
The coefficients in the maximum analysis will normally be plotted amplitude-normalized. This means, that the y-axis is quasi the amplitude of the transient for the coefficient maximum. A plot with a normalizing to the trap concentration is also possible. Amplitude and trap concentration correspond to the transient only in the peak maximum of the coefficient! An advantage of normalization is that all various Fourier coefficients should have the same height in the tempscan for an exponential transient.
For a better energy resolution is also a HERA deconvolution of the temperature curves possible, this will be described in the HERA chapter.



The search will normally be done with a **new** initialization, that means old definitions and results will be deleted. If you have already done a search or a file read then you can **keep** the old definitions and evaluations. A new definition of a level of one temperature curve will only overwrite this one data point in the Arrhenius data array.
At Search with **auto loop** the peak maxima will be automatically searched and defined. After this you get a question how the maxima shall be sorted, see chapter 4.1.2.

4.1.1.1 Inputs

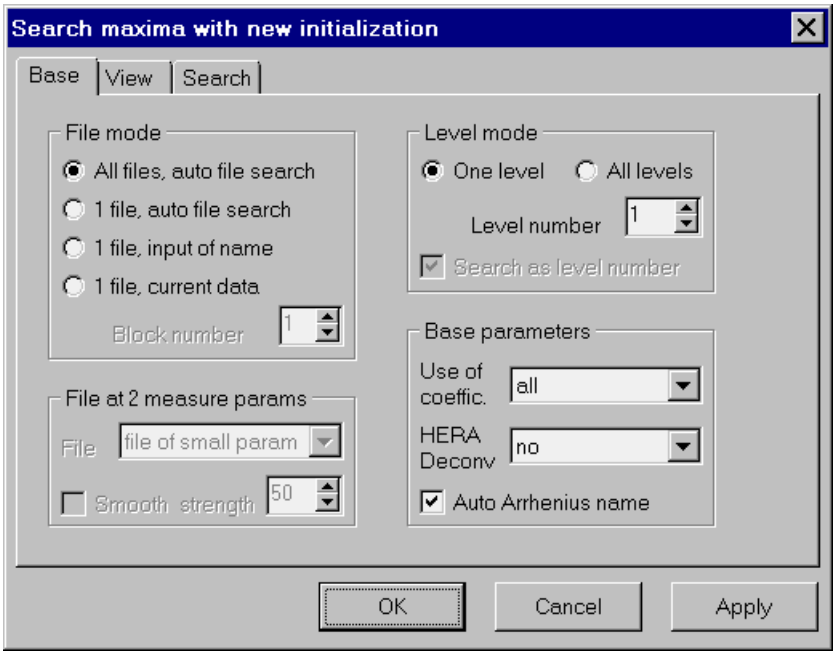
Base input sheet:

The **file mode** defines which files will be used for the determination of the peak maxima:

- **All files, auto file search:** All tempscan files will be used one after the other. The file name search will be automatically done from the name of the current tempscan file as in family data. This is the standard mode. 2 files with different period widths are necessary for a high accuracy. If there are variations of tP, UP and so on, check by the shown names whether the automatic search works as you expect it.
- **1 file, auto file search:** One tempscan file will be used. The file name search will be automatically done from the name of the current tempscan file as in family data. Which file will be loaded depends on the input of the block number.
- **1 file, input of name:** One tempscan file will be used, you can select the file name.
- **1 file, current data:** The current tempscan data will be used.

If you don't use 'All files' then you have to input the **block number**, that means the saving position of the data. You can use up to 5 blocks, normally blocks correspond to the period width number.

Note: The software keeps the current transient evaluation mode except at '1 file, input of name'. If you have made other changes of the tempscan data but not saved the file, these changes will here not be applied except you use the mode 'current data'.



File at 2. measure params is enabled if files with different UR, UP or tP exist. Then you can select the files with small or big parameters or its difference. At 'current params' files with the parameters of the current file will be loaded.

The **level mode** defines whether only one level should be evaluated or all together:

- **One level:** The peak maximum of only one level will be defined at the following maximum search. For this you have to type in the level number. If activating 'Search as level number', available at level number higher than 1, the order of the searched peak is the same as the level number. In the other case the program starts with the first peak. You can use the 'One level' mode also for the evaluation of more levels. For the first level start with 'New init' of maxima search and define the first level. Then select 'Keep eval' a level number 2 and repeat the search for the 2. level and so on.
- **All levels:** All levels will be defined together in one search. You get the question for the numbers of levels at showing the first coefficient. Then you have t to define the peaks of all levels for every coefficient.

Use of coefficients defines which coefficients will be used for the maximum evaluation:

all:	All 22 until 25 coefficients can be used.
most:	All without Dlts and user correlation functions.
main:	The main will be used, attribute M in chapter 4.1.1.7.
b1 at various Tw:	Only b1 coefficients of various period.
an or similar:	Only cosine or similar coefficients with high energy resolution.
only Dlts, user-fct:	Only the 3 conventional Dlts signals and, if exist, until 3 user defined correlation functions.

b1(Tw/32) and a1(Tw/32) will not be used at 128 transient points except the mode 'all'.

If activating **Auto Arrhenius name** then the proposed name of the Arrhenius data file will be set from the tempscan file name.

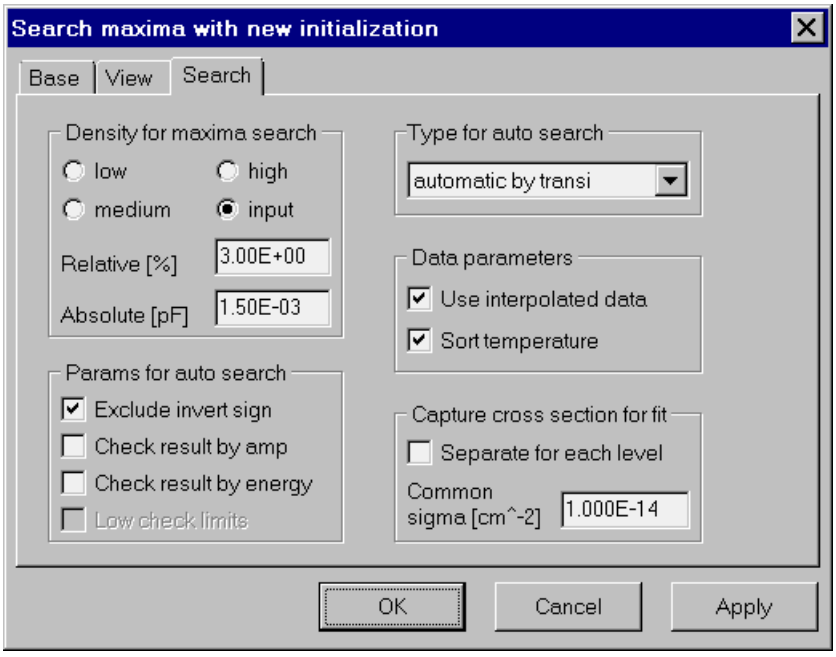
At the **View input sheet** are the standard inputs for Data/axis parameters, Interpol/smooth and Connect points.

'Show preview/reference' gives an additional small plot window with an Arrhenius preview and the results of a reference coefficient.
Activating **Full plot size** list the important values not at the right of the plot but in the status line and use the full window for the plot.

At **Top axis** you can select to show an additional axis or information on the top of the plot:

no top axis:	No top axis will be plotted.
mark b1 position:	The temperature position of the b1-peak for each level will be marked as a short vertical line. Additionally the position of the coefficient defined before will be marked.
1000/T:	The 1000/T axis will be shown as a top x-axis.
energy:	A top energy axis will be calculated by the temperature, the time constant tau and the given sigmaI.

At the **Search input sheet** there are the parameters for the maximum search.
The **Density** for maxima search defines a minimum height of the peak. You can select low, medium, height or input. At low density only peaks with a big height will be automatically found. At height density also peaks with a small maximum will be found. At input you can define the minimum relative peak height in respect to the total maximum and the minimum absolute peak height, see next chapter.



Params for auto search are further parameters for the automatic detection of a peak:
Exclude invert sign means that the absolute height must be positive for a maximum and negative for a minimum.
By **check result** by amplitude and energy the result of the found maximum will be checked to which level order this result belongs. **Low check limits** give stronger limits for this check.

Searching of a minimum or maximum will be set by the **Type for auto search:**

automatic by transi:	Depending of transient decrease or increase the program search a maximum or minimum.
only maxima:	The program search only maxima.
only minima:	The program search only minima.
maxima and minima:	Maxima and minima will be searched.

Use interpolated data means that if temperature curves will be interpolated these interpolated data will be used for the automatic search instead of the original data. The position of the peak maximum will be always interpolated.

The **capture cross section** sigma is necessary for **fitting** the temperature curves. You can type in a common capture cross section for all levels or separate ones for each level.

4.1.1.2 Peak search

There are 2 principle problems of an automatic peak search:

1) **Peak detection:** It is not so easy to say doubtless that this is a peak. It could be that it is only noise or that there are jumps in the temperature curves because sample contact problems. On the other hand 2 peaks can be very closed together that a separation is difficult, one peak can also be a 'shoulder' of the other.
2) **Level order:** If you have more levels, it is necessary to set in order the peaks for the different levels. Different coefficients resp. correlation functions have their peaks at different temperatures. The energy resolution is better at lower temperatures for levels with same capture cross section. So it could be that at one temperature curves 3 levels were found at another curve only 2. An order is necessary because calculation must be done separately for each level. A separation by the temperature range is not possible because these ranges can overlap.

At the Search input sheet of the previous chapter there are some parameters to reduce these two problems.
The input of a **density** can avoid to find only peaks produced by noise. The absolute input is normalized to a measure time of 1s. At the maxima plot, see chapter 4.1.1.3, the value DensA will be listed. DensA=Height*sqrt(Tw*Na). Height is the height of the peak (not normalized to amplitude), Tw the effective period width for the coefficient and Na the number of transient averages. A peak can be found when DensA is bigger than the input of Absolute [pF]. The absolute value relates to the not normalized coefficient!

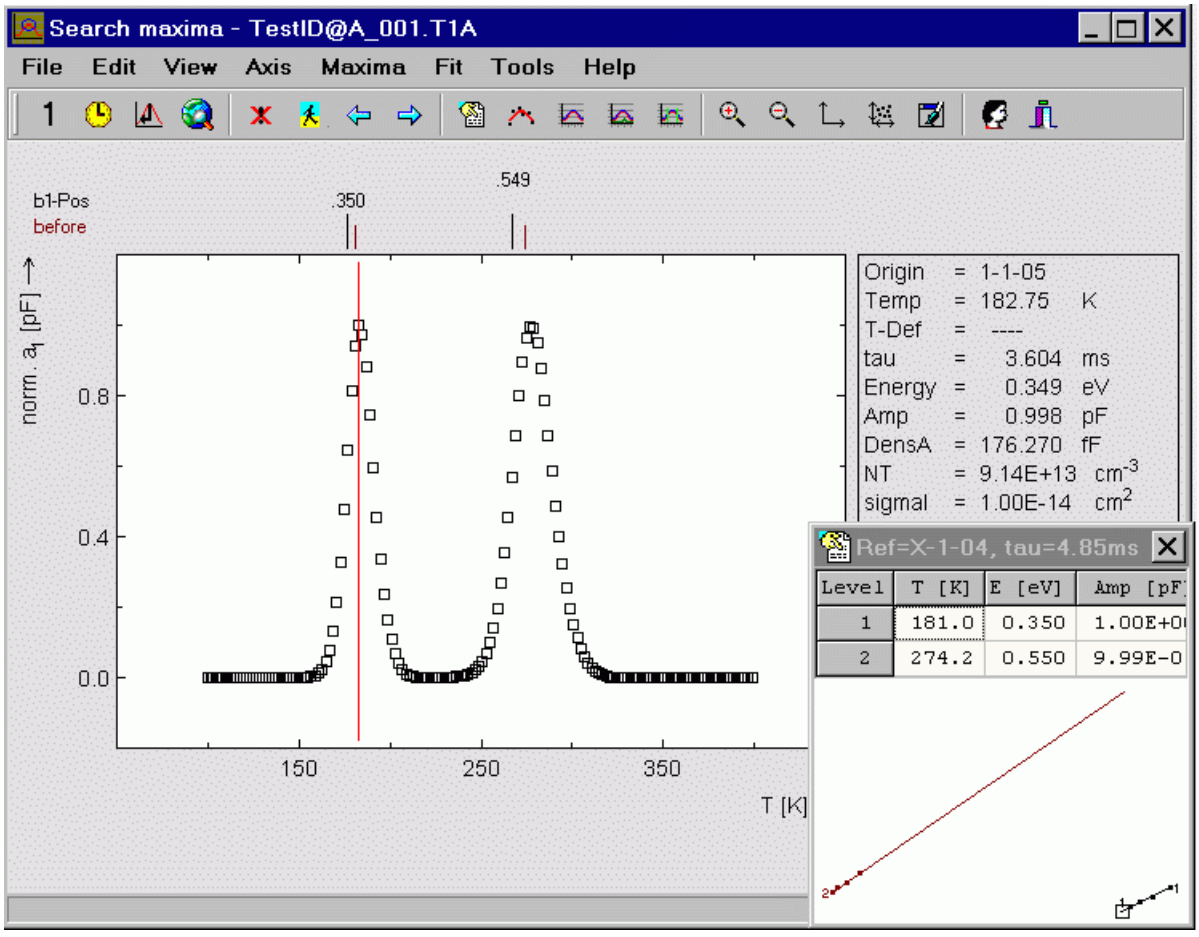
Note: If you see a peak but the software don't detect it, the density could be too low. Set the density to 'high' or input a lower value.

The position of the peak maximum will always be interpolated and not only taken by the original data values.

If you start the maxima search with 'new init' or 'keep eval' the program search peak for peak but these are only proposals. You have manually to confirm the found peak or you can change the position. You can also change the number of level to which this peak belongs.
If you start 'search auto loop' the peak maxima will be automatically defined. After the complete run the maxima will be sorted. Here the program try to sort the related results for the levels by the Arrhenius plot. Isolated values, perhaps found because noise, can be taken out. A manual sort is also possible.

4.1.1.3 Maximum plot

The following picture shows the plot at the maxima search. Under the top menu bar there is the toolbar. At the right there is a list with the important parameters and results. At the right bottom there is an Arrhenius preview and a list of the current and reference values. The current peak position will be marked by a vertical red line, it will be called peak marker. The current level number will be shown in the first left button of the toolbar.
At the top of the plot, outside of the plot window, are the **marks** and energies for the b1 coefficient and the marks for the coefficient defined before. These marks give a help to order the levels. The coefficient before has a bigger time constant so that it should peak at lower temperatures. If the time constant is smaller, calc(b1) will be marked. It denotes the theoretical peak position of the current coefficient calculated by the b1 definition.



List of important parameters and results:

Origin:	Origin of the current peak, gives also the record position in the Arrhenius data array. The 1. number denotes the level, the 2. the block and the 3. the coefficient number. For the coefficient see chapter 4.1.1.7.
Temp:	Temperature at the position of the peak marker.
T-Def:	Temperature already defined for this peak level, '----' means that no definition was done.
tau:	Emission time constant for the coefficient, only valid in a peak maximum. This value was numerical calculated by an analytical simulation curve.
Energy:	Calculated energy at the peak marker position, calculated by temperature, tau and sigmal.
Amp:	Calculated amplitude at the peak marker position, only valid in a maximum.
DensA:	Normalized density at the peak marker, see chapter before.
NT:	Calculated trap concentration at the peak marker position.
sigmal:	Capture cross section, defined by the sigma input.

Explaining of the **toolbar**:


Current **level number**, toggles between first and last level by mouse click.


Apply, go on by **timer.** Automatic peak determination until break.


Define maximum, go on. If no maximum was found here is the Go on button.


Search next maximum, F7 key is shortcut.


No maximum, go on to the next maximum or coefficient. F9 key is shortcut.


Go on to next maximum or coefficient, no definition will be done or deleted.


Go to previous data (coefficient), PageUp key is shortcut.


Go to next data (coefficient), PageDown key is shortcut.


Show reference list and Arrhenius preview.


Interpolation of the temperature curve.


Standard fit.


Special fit.


Two level fit.


Zoom in this data (coefficient).


Zoom out.


Axis mark for setting a new plot window by mouse marker.


Axis rescale to the initialization plot window.


Refresh the plot, F5 key is shortcut.


Personal user button.


Close the maximum search.

The **peak marker** will be set automatically, by the mouse or by the cursor keys. A click onto the left mouse button sets the marker to the mouse position. Left and right cursor keys move the marker slowly along the x-axis to the left resp. right, Up and Down moves it in big steps to the left resp. right.
The **ENTER** key have the same effect as the Define maximum button. The marker position will be recorded as a maximum point for the selected level. Then the software goes on to the next level or to the next coefficient. If there was no maximum found, it goes on without a maximum definition.
A click onto the right mouse button has the same effect as the ENTER key.
If the software has not found a maximum it replaces the 'Define maximum' button by the 'Go on' button. If you move the peak marker then the 'Define maximum' button will be shown again. If the last peak was defined then the Close button will be shown on this button position.
In mot cases you can confirm the results only by the ENTER key.
The **Origin** in the header list shows the current data position.
Depending on the numbers of levels the peak search plots after the last level the next coefficient (temperature curve). If selecting 'All files' as file mode then the next file will be loaded after the last coefficient.

4.1.1.4 Menus at the maxima search

The important actions can be done by the mouse or keyboard. More possibilities are given in the menus.

The main menu is the **Maxima menu**:

Number(s) of levels: Input of the total numbers of levels and of the current level number. Levels can be excluded at the automatic setting of level.
Apply, go on by timer: Automatic peak determination until break is pressed. Before starting there is an input window similar to the search input sheet. A delay time between the detection of 2 maxima can be given.
Apply maximum, go on: The marker position will be recorded as a maximum point for the selected level resp. data position. Then the software goes on to the next level or to the next coefficient (data position).
Search next maximum: Locks the marker onto the successive maxima points, one each time if this function was called.
Apply maximum: Applies the maximum and stays here.
No maximum, go on: Define that there is no maximum for this data position. Goes on to the next level or coefficient.
Go on: Go on to the next level or to the next coefficient (data position) without defining or clearing a maximum.
Go to defined position: Sets the peak marker to the defined temperature if this data position was already defined.
Set pos. by reference list: Sets the marker to the temperature of the reference coefficient in the reference list.
Go to previous coef./data: Go to the previous coefficient (data).
Go to next coef./data: Go to the next coefficient (data).
Input of coef/data: Go to the coefficient (data) which was selected by an input.

Edit menu:

Copy page: Copy the graphic into the clipboard.
Copy ASCII data: Copy the temperature curves as x and y ASCII data into the clipboard.
Paste ASCII data: Paste x and y ASCII data from the clipboard and show this curve. This can be useful for a comparison.
Base line correction: A base line will be subtracted from the current temperature curve, see below.
Delete maximum, current level: Delete the maximum of the current level for the current coefficient.
Delete maximum, all levels: Delete the maxima of all levels for the current coefficient.

Base line correction: The base line correction contains some lines. You have to define the points for these lines by the mouse. The software shows these lines. After defining the last point press the ESC key to proceed. Then the temperature curves will be shown without this base line. At the text header there is the additional text 'Data = BL'. The base line is only valid for the current coefficient.

Note: A base line correction is normally not necessary. An DC offset gives no offset in the temperature curves! A fix positive or negative offset in the temperature curves origins from a fix transient signal, for example from a fix recovery signal. A fix background has only an influence for the trap concentration but not for energy and capture cross section.

Some points of the **View menu** are the same as in the plot program. Only the new ones will be explained here:

Other params: Opens a window with the View and Search input sheet.
Use cross marker: Instead the vertical peak marker a cross will be used for setting x- and y-position. This is important for the peak height and therefore for the trap concentration.
Interpolation: The temperature curve will be interpolated.
Plot b1 as reference: b1 will be additionally plotted.
Show reference list: Show reference list and Arrhenius preview, see next chapter.

Some points of the **Axis menu** are the same as in the plot program.

If **zooming** then there are 3 possibilities for the validity: for this level, for this coefficient or for all coefficients. In the first case the plot will automatically zoomed out if going to another maximum. In the last case the zoom will be applied for all coefficients.

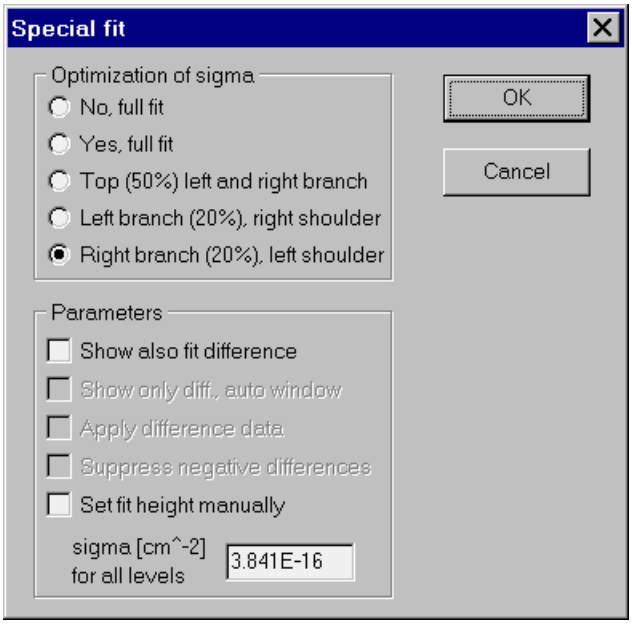
For the **axis window** at plotting a new coefficient (data) there are 3 modes:
New x,y-axis: A complete new plot window for the x- and y-axis will be set, this is the default one.
New y-axis: Only the y-axis will be set by the new coefficient. If you want to restrict the x-axis for all coefficients, use this mode.
Old axis: The current x-and y-axis will be taken over for all coefficients.

In the **Tools menu** you can list the results for all evaluated coefficients.

By the **Fit menu** you can recalculate the current temperature curve. The fit will done by the current peak temperature, the time constant and the capture cross section (either by input or by optimization). The height of the fit curve will be normalized to the temperature curve at the peak. In opposite to the fit buttons on the toolbar there are inputs if using the fit menu.

For the **standard fit** is only the input of the capture cross section sigmaI necessary. If activating 'separate for every level' then you get a grid for the sigma inputs.

The **Special fit** opens an input window. Some options can be activated at Parameters.
Show also difference shows also the difference between data and fit curve.
Show only diff. shows only the difference curve.
Apply difference data applies the difference as new temperature curve.
Suppress negative differences means that points of the difference curve will not be shown for negative values.
At **Set fit height manually** you have to set the peak height of the fit by mouse or marker.



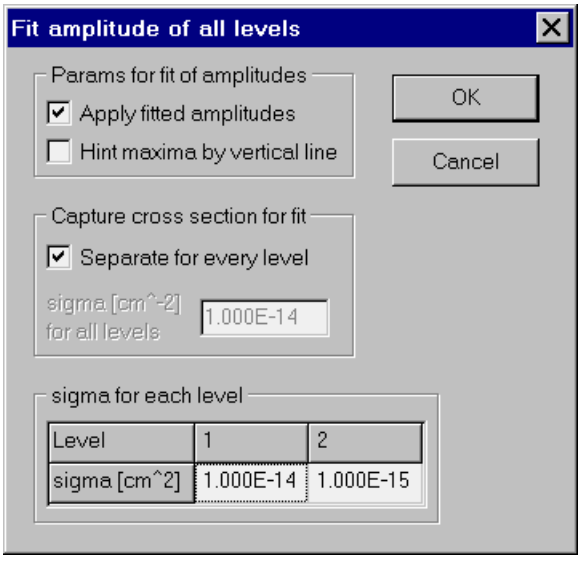
Sigma can be calculated by an **optimization** of the fit by variation of sigma. After optimization the new value will be applied also for the input value:

No, full fit: No optimization, sigma will be applied from the input.
Yes, full fit: The optimization uses all data of the peak.
Top (50%) left and right branch: The optimization uses only values which are higher than 50% of the peak height.
Left branch (20%), right shoulder: The optimization uses only the left branch with values which are higher than 20% of the peak height. This mode should be used if at the right branch a shoulder exist coming from another level.
Right branch (20%), left shoulder: The optimization uses only the branch with values which are higher than 20% of the peak height. This mode should be used if at the left branch a shoulder exist coming from another level.

The special fit can be used for a so called **shoulder analysis**. At overlapping of 2 levels it is possible that the temperature curve shows a shoulder in the branch of a peak. Fitting this peak and then subtraction the fitting curve from the data gives a difference curve which shows the peak of the second level. Be careful with this method because deviations of the fit can yield also to peaks in the difference curve!

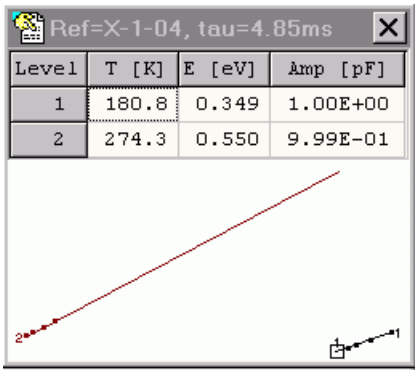
Fit amp of all levels fits the amplitudes of all defined levels of the current coefficient. So you have first to define all levels of the current coefficient. At the last level you must call from the menu only 'Apply maximum' instead 'Apply maximum, go on'. Then the peak marker stays on the last level position and the software don't go to the next coefficient. In opposite to the standard or special fit a transient amplitude for each level will be searched by **amplitude variation**. Those amplitudes which fits the data curve as best will then used. The advantage is that at overlapping levels the amplitude and so the trap concentration can be exactly calculated by this method. Taking the amplitudes from the peak heights gives at overlapping wrong values because both levels have an effect to the peak height.

In the following input window was **Separate for every leve**l activated for the capture cross section. Here you get an input grid. By deactivating this flag the grid is not visible, you have only to input the sigma for all levels.
By activating **Apply fitted amplitudes** these amplitudes will be applied in the Arrhenius data array and used for the calculation of NT.
By activating **Hint maxima by vertical line** the position of the defined temperature of every level will be marked by a vertical line. The height of this line corresponds to the found amplitude.



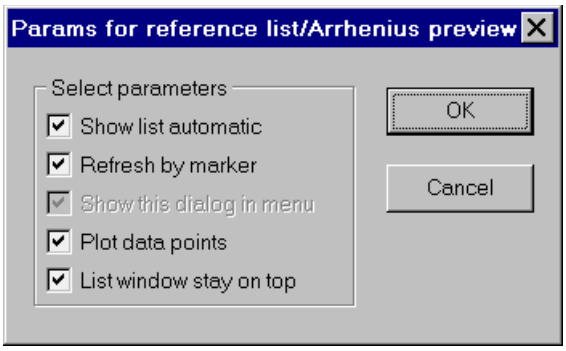
4.1.1.5 Show reference list, Arrhenius preview

If selecting 'Show reference list' in the view parameters you get after the first defined maximum a **reference list**. At the top there is denoted the origin of the reference coefficient. So Ref=X-1-04 means Level X, block 1, coefficient number 4. The time constant tau, valid in the peak maximum, for this coefficient will also be shown.
The **grid** contains the maximum temperature T, the energy E and the amplitude Amp of the reference coefficient. The values are listed for every level. The energy was calculated by T, tau and given sigma. The energy for a level can change with the temperature because not the true capture cross section of the trap will be used.



After 2 Arrhenius points a small **Arrhenius preview** will be plotted below the grid. All already defined data points are shown and denoted by the level number. Different colors will be used for different levels. The current data point, not yet applied, is plotted as a bigger symbol and marked by the current level number. The symbol depends on the level number. The lines in the plot are calculated by a linear regression of corresponding levels points, they will be extrapolated for a better overview. Not all points are visible to all times because there is an automatic plot window. If moving the peak marker then the bigger symbol moves in the Arrhenius plot.
Don't use the Arrhenius preview for the fixing of the peak position! It is only a help to order the levels and to check the results during the maximum analysis.

If you click onto the symbol of the reference list, you get a short menu. There you can select **parameters** for the reference list. The same you can do in the View menu or in the toolbar.



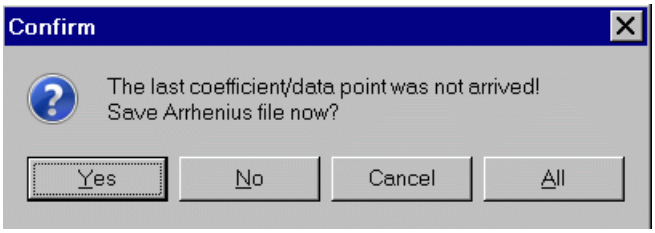
Show list automatic means that the list and the preview will be shown automatically for every coefficient. In the other case you have to call it for every coefficient by the menu.
If activating **Refresh by marker** then the big symbol in the Arrhenius plot will be moved if the peak marker will be moved along the x-axis.
Show this dialog in menu is only enabled if the list will not automatically shown. Activating this flag means that you get always this input window if you select this function in the View menu or toolbar. If this flag is not activated, then the list will be shown without an input.
By **Plot data points** all Arrhenius points will be plotted, in the other case only the lines and the current data point.
By **Stay on top** has this window the highest priority for the visibility.

Note: The window of the reference list resp. Arrhenius preview is a separate Windows form. You can change its position and size.

4.1.1.6 After the maximum search

If you close the maximum search you get a question for saving the results to an Arrhenius file if you have start a new maximum analysis. You should save the file because you lose the results if exit the program or start a new maximum search.

If you close the search before arriving the last possible coefficient you get this confirmation window. Normally you should do the maximum analysis for all coefficients.



Yes opens here the save file dialog, save the results and leaves the search. The program stays in the maximum analysis and shows the standard Arrhenius plot.
No leaves the search without saving.
By **Cancel** you stay in the maximum search and can go on with further coefficients.
All opens the data task window, as described in chapter 2.2.3. Here you can save and print the data, save results into the evaluation database and apply results as sample or simulation parameters.

At Search with **auto loop** you get after the automatic search a question whether and how the maxima shall be sorted. A 'No' keeps here the current sort order, that means all defined points will be applied. Then the Arrhenius plot with the new order will be shown. After this you get a question for applying the new level order or to retry, if you have select a new sort. Then the software asks for saving the Arrhenius data. The procedure and questions are the same as in 'Sort data by levels' of the View menu, chapter 4.1.2.1. Only the detection mode 'Edit by grid/plot' is here not possible.

4.1.1.7 Coefficient order in the Arrhenius data

The following list shows the order of the coefficients at the maximum analysis. Number (No) is the number in the Arrhenius data array:

No)	Coefficient	Class'	tau/Tw	Attributes
1)	b1	75	0.44	-BESM
2)	b1H	71	0.79	-BE-M
3)	b1M	72	0.29	---SM
4)	b1(Tw/2)	73	0.22	-B-SM
5)	a1	72	0.17	A--SM
6)	a1(Tw/2)	72	0.087	A--SM
7)	a1(Tw/4)	74	0.048	A-ESM
8)	b1(Tw/16)	69	0.037	-B--M
9)	b1(Tw/32)	69	0.024	-B--M
10)	a1(Tw/16)	70	0.017	A-E-M
11)	a1(Tw/32)	70	0.011	A-E-M
12)	a1H	62	0.37	A-E--
13)	b2N	62	0.18	A-E--
14)	b1(Tw/4)	61	0.17	-B---
15)	a1M	60	0.13	A----
16)	DoubleSqr	62	0.12	A-E--
17)	a2N	62	0.086	A-E--
18)	b1(Tw/8)	65	0.064	-B-S-
19)	DoubleSqr(Tw/4)	62	0.034	A-E--
21)	Dlts-slow	50	0.73	
22)	Dlts-mid	50	0.12	
23)	Dlts-fast	50	0.015	
28)	User-1	52		
29)	User-2	52		
30)	User-3	52		

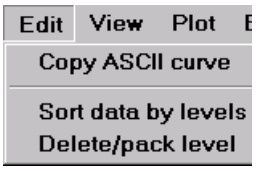
tau/Tw is a normalized relation for the time constant, valid in the peak maximum, and gives a hint for the position of the peak. The value depends also from the Tw/t0 ratio. The list above is for Tw=204.8ms and t0=2.8ms.
Class' is not the evaluation class! It is only for the internal use and describe the coefficient type. Class' must be bigger or same than 50 for validity.

Attributes give hints for the origin and properties:

A: Cosine or similar coefficient, all have a good energy resolution
B: Sine coefficient
E: Coefficient with good energy resolution, used for special selection (chapter 4.1.1.1)
S: Coefficient with good signal/noise ratio, used for special selection
M: Belongs to the group 'main' coefficients, all here have different tau/Tw

4.1.2 Edit menu

By the edit menu it is possible to edit and modify the data in the memory. The file itself will not be changed. After reading the file again you lose the changes. For changes of the file you have to save the Arrhenius file, here you get a question for overwriting.



Copy ASCII curve copies the temperature and one selected result or other value line by line in an ASCII format to the clipboard. You can define the delimiter and the exponential format in the menu ASCII parameters. You find it in Tools of the plot or list program.
Sort data and Delete level will be explained below.

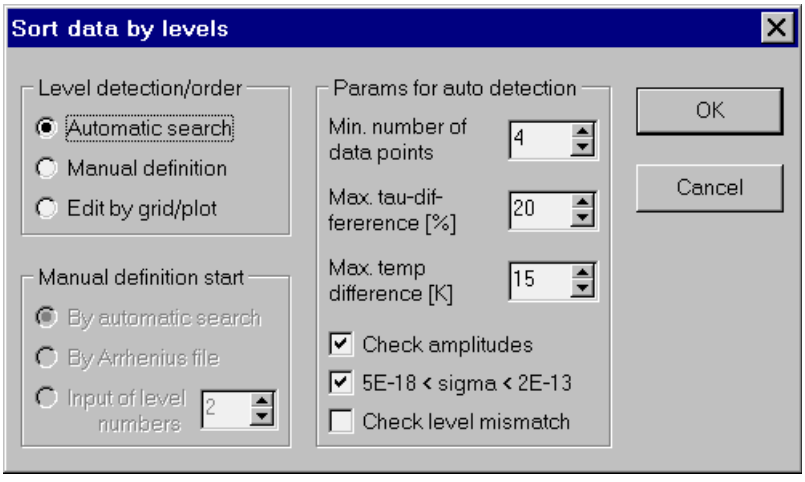
At **user class 5** here are: Edit ASCII data, Change temp axis (as chapter 3.4.2.1), 'New CR, CP, Ns' (see chapter 6.4.2).

At **user class 6** here are: Edit ASCII file, Edit curve by plot.
Edit ASCII file means that the complete file will be shown in an ASCII editor, here you can edit all data (header and data arrays). After leaving the editor the changes will be applied for the memory data but not for the file itself. Use this option very careful because there is no data check. You find a description of the data structure in the file Data.Txt.

4.1.2.1 Sort data by levels

If you have made a manual maximum analysis then you have ordered the results to levels. At auto loop the results were automatically sorted. Here you can change this sort order or delete points. Some of the coefficients are inherently more suited to yielding better signal to noise ratios, whilst others provide improved better energy resolution.

At an automatic search the software try to detect different levels and order the corresponding Arrhenius results to the different levels. It is possible that some points in the Arrhenius plot are isolated (shown by small squares), that means these are not assigned to a level.



The base mode is the **Level detection/order:**

Automatic search: The software searches and sorts the levels by the 'Params for auto detection'.

Manual definition: The search starts by the mode given in 'Manual definition start'. Then the Arrhenius plot will be shown. After this you define a maximum deviation for the Arrhenius plot points, see chapter 4.1.2.1.2. As start mode you can select the automatic search, the current order of the Arrhenius file or input the level numbers. In the last case the software try to order the results to the given levels.

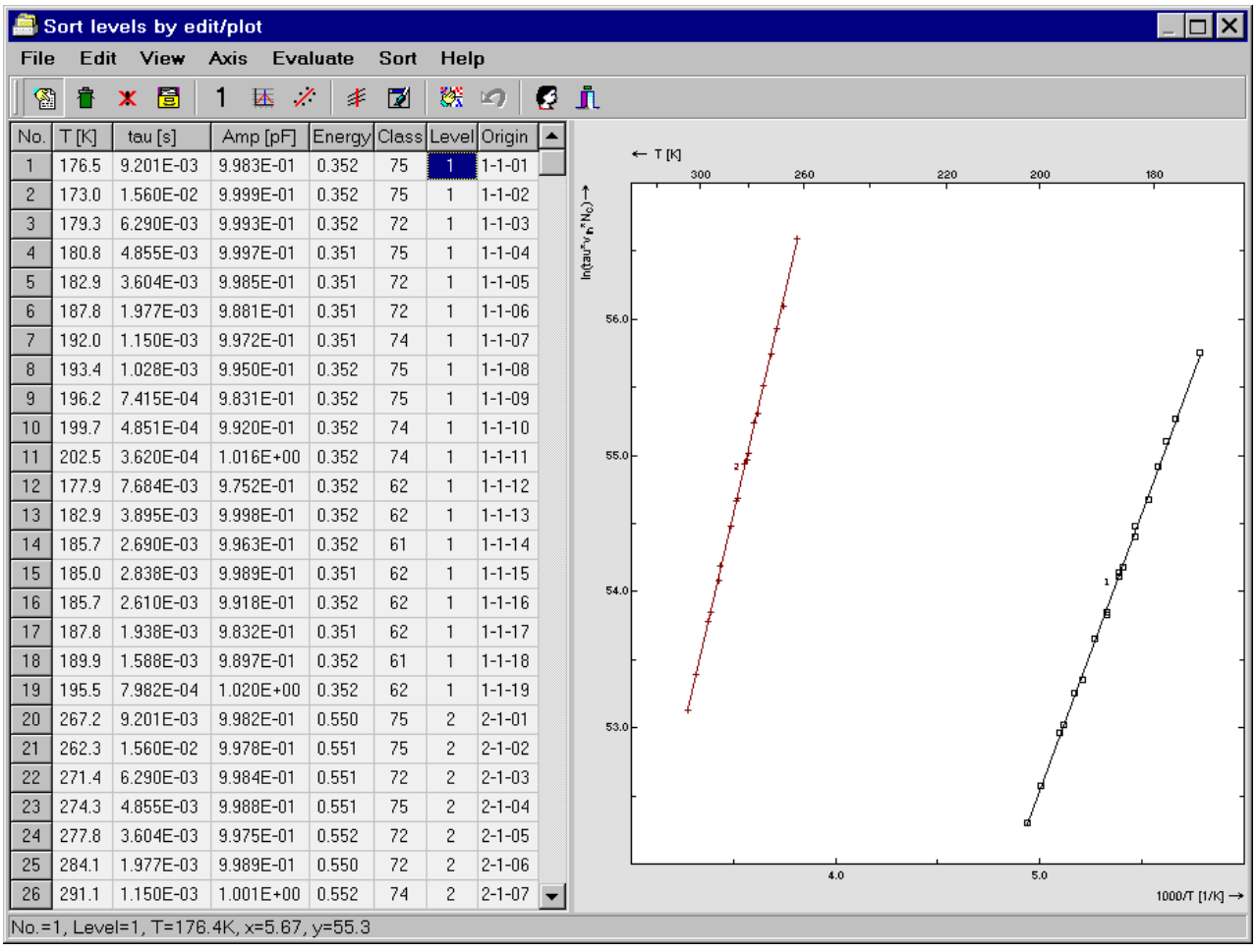
Edit by grid/plot: No inputs are necessary. The sort will be done manually by a combined grid/plot window, see chapter 4.1.2.1.1.

The **Params for auto detection** define criterions for the validity of a level:

A **Minimum number of data points** is in the Arrhenius plot necessary for each level.
There is a **maximum percentage difference** possible between the time constant and the regression line of the Arrhenius plot.
The gap between 2 points of the same level is restricted by the **maximum temperature difference**, it is a relative value to 150 K as the last mode of step factor in chapter 3.4.1.3.
By **Check amplitudes** all amplitudes of each level will be checked. If the difference is too big then this point can not belong to this level.
The capture cross section can be limited to **5E-18 < sigma < 2E-13**.
Check level mismatch checks whether the storing position in the file is wrong.

4.1.2.1.1 Edit by grid plot

Here is at the left a grid with the results and at the right the Arrhenius plot. The grid list shows temperature, time constant, amplitude, energy, class, level and origin. The energy was calculated from temperature, tau and sigma calculated by the linear regression of all points of level. So all points of the same level should have the same energy value. 'Class' is only for the internal use, it is not the evaluation class! Origin denotes level number, block and coefficient. This column can not be changed or marked.
Editing the level number in the level column gives a new level order. Level number 0 represents a deleted level, negative level numbers are unassigned points (shown by small squares). At the menu File you can apply the changes in the grid without leaving. Then the plot will be newly drawn.



A **sort** is also possible by the **plot.** For these there are 4 **work modes**, selectable in the Edit menu and in the toolbar:

Mark: By clicking onto a symbol in the Arrhenius plot this point will be marked in the grid and shown in the status line.

Delete: By clicking onto a symbol in the Arrhenius plot this point will be deleted in the plot and marked as delete in the grid (level number 0).

Unassign: By clicking onto a symbol in the Arrhenius plot this symbol will be replaced by a small square and marked as unassigned (negative level number).

Define: By clicking onto a symbol in the Arrhenius plot this data point will be assigned to the current level number, shown in the toolbar symbol. The plot symbol will be replaced by the new symbol and the level number will be set in the grid. It is possible that another data point will be set as unassigned because 2 data points can not have the same origin.

Explanation of the toolbar:

Mark is work mode.

Delete is work mode.

Unassign is work mode.

Define is work mode.

Current **level number**, toggles between first and last level by mouse click.

Show **level evaluation**, calculates energy and sigma for the current level.

Manual **regression line** by setting left and right point by mouse.

Activate/deactivate a **vertical line** at marked point.

Refresh the plot, F5 key is shortcut.

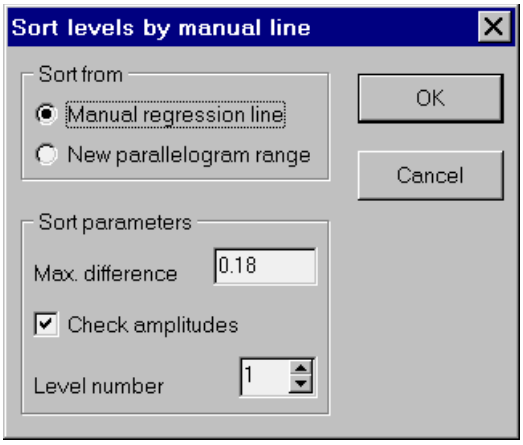
Sort levels by manual line or parallelogram.

Undo the sort done by the sort button.

Personal user button.

Close the maximum search.

An additional method for sorting is to **sort** levels by **manual line** in the Arrhenius plot. Here a maximal y-difference between the data points of the selected level and the line is necessary, in the other case these points will be marked as unassigned. A check of the amplitudes is also possible. Instead the deviation from the line you can select only data which are inside of a **parallelogram**. You have to define the left top, the right top, the right bottom and the left bottom point of this parallelogram by the mouse.



All functions of the toolbar are possible in the menu. There you have additional features.

At the **File menu** you can apply the changes and save the grid in an ASCII file with header (ASCII text) and without header (ASCII data).

In the **Edit menu** you can copy the grid data into the clipboard and select the work mode. You can also delete all data which class is smaller than an input minimum class.

At the **View menu** you can select the grid font, activate the vertical line, refresh the plot and define personal shortcuts. There you can also define whether and how '*Regression lines'* will be shown: No lines, All points, Search best range. At the second mode all data points of the level will be used for the linear regression.

At the **Axis menu** you can select the plot slice. All levels, level 1 until 6 or level 4 until 9 are possible. The selected will be marked by a hook. You can plot the points for all, low or high temperatures.

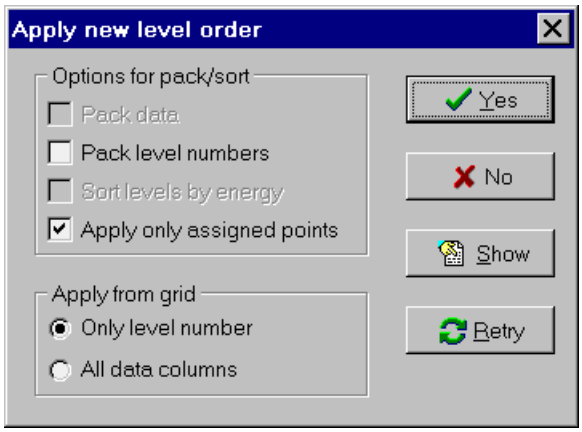
In the **Evaluate menu** it is possible to call the manual regression, to show the level evaluation in the status line, to input the current level number and to calculate the energy in the grid. The energy will be here calculated by sigma of the level, calculated by the Arrhenius plot, and not from a given sigma.

In the **Sort menu** you can start the sorting by a manual line or call its Undo function.

4.1.2.1.2 Apply new level order

After sorting you get a dialog to confirm. **Yes** applies the changes, **No** leaves the data unchanged, **Show** plots the changes in an Arrhenius plot and asks again and **Retry** calls the sort dialog again without changes.

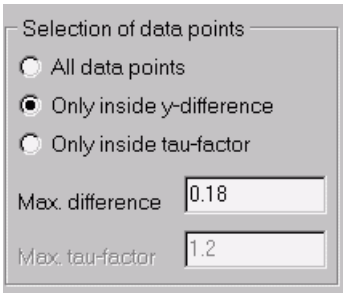
The following window is for the Edit by grid/plot.



Pack level numbers means that level numbers will be sorted if there is a gap in the used levels.
Sort level by energy is only enabled if 'Pack level numbers' is activated.
Apply only assigned points delete results in the Arrhenius data array which are not assigned to a level, not at all data format enabled.

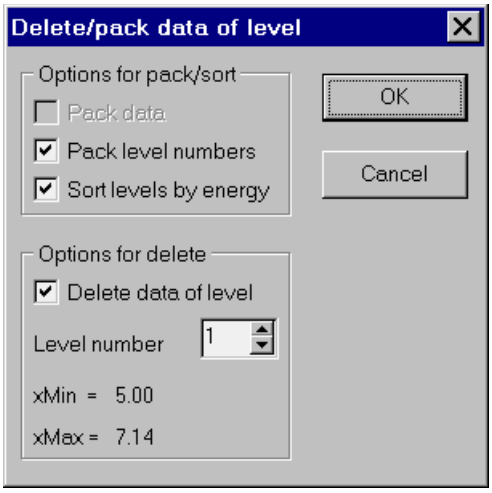
You can **apply from the grid** only the level number or all data columns, for example also the temperature.
If using the **automatic search** as level detection then the 'Apply from grid' box is not visible.

If using the **manual search** as level detection then the following input box is visible instead the 'Apply from grid' box.
You can select only data points with a maximal difference between data point and linear regression line in the Arrhenius plot. Instead the maximal y-difference you can also input a maximal factor for the deviation between time constant of data point and time constant calculated from the linear regression of the level.



4.1.2.2 Delete/pack level

Here are following possibilities to delete and pack levels:

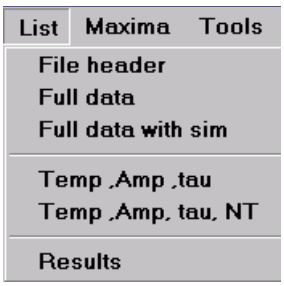


Pack level numbers means that level numbers will be sorted if there is a gap in the used levels.
Sort level by energy is only enabled if 'Pack level numbers' is activated.
Delete data of level means that all data of this level will be deleted in the Arrhenius data array. You can input the level number for deleting. The software lists the x-axis range (xMin, xMax) of the Arrhenius plot for which data of the selected level exist.

At user class 6 there is the option to pack the data. Packing means that only the valid results will be saved into the Arrhenius file. The disadvantage is the loosing of the origin information. This option is not for all types of Arrhenius data available, for example not for the data extension AT? and AP?.

4.1.3 List menu

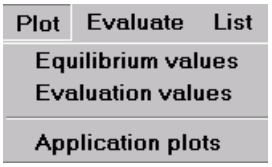
By the list menu it is possible to list the file header, the full data and selections of measure parameters, coefficients and evaluation data. The most abbreviations are explained in chapter 1.3.4.



A similar list of the file header will be shown in chapter 3.4.3.1.
A similar explanation of the full data list and the full data with simulation will be given in chapter 3.2.3.1. This list will be shown for every temperature data point.
Temp, Amp, … shows all valid data of the Arrhenius data array. The data will be listed as lines and columns. In the first line there is the first temperature point and so on.
Results list all relevant data of the levels. In opposite to the Arrhenius plot all data inside the regression range will be used.
At user class 5 is a user defined list possible. Here you select the values for the listing.

4.1.4 Plot menu

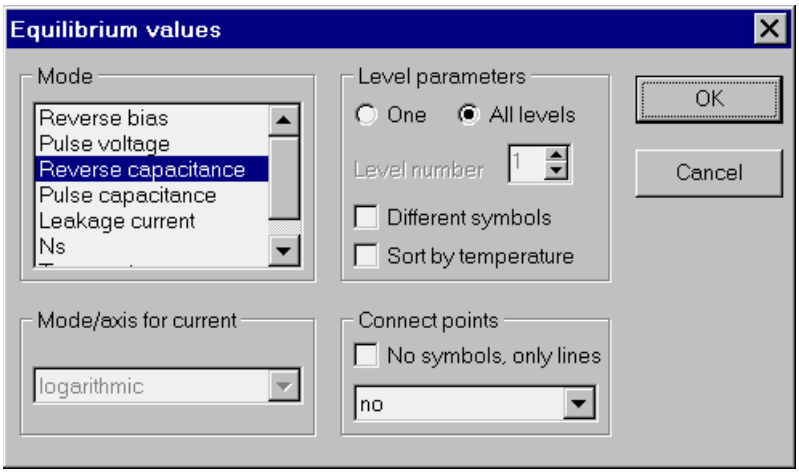
By the plot menu it is possible to plot all values of the Arrhenius data array.



Equilibrium values are CR, CP and son on, Evaluation values are tau, amplitude …
Applications plots shows the Arrhenius plot, the coefficients of the original tempscan files and an additional C/V curve.

Values of the space charge region can be plotted at user class 5.

4.1.4.1 Equilibrium and evaluation plots



At **equilibrium plots** reverse bias UR, pulse voltage UP, reverse capacitance CR, pulse capacitance CP and leakage current IR can be plotted as a function of temperature.
The y-axis of IR can be linear, logarithmic or similar to a Richardson plot.

You can show the data of **one** selected level or of **all** levels. The data can be sorted by temperature.
If using all levels then data can be plotted with the same symbol and color or with different symbols and colors for each level. The data of each level will in the last case be treated as a separate curve.

At **evaluation plots** the evaluation values of the Arrhenius file, like tau, amplitude, NT and so on, can be plotted as a function of temperature or 1000/T if activating this flag. The y-axis can be linear or logarithmic.

4.1.4.2 Application plots

Applications plots show the Arrhenius plot, the coefficients of the original tempscan files and complex plots with more pages showing additional C/V curve.

The **plot mode** defines the type of plot and numbers of plots:

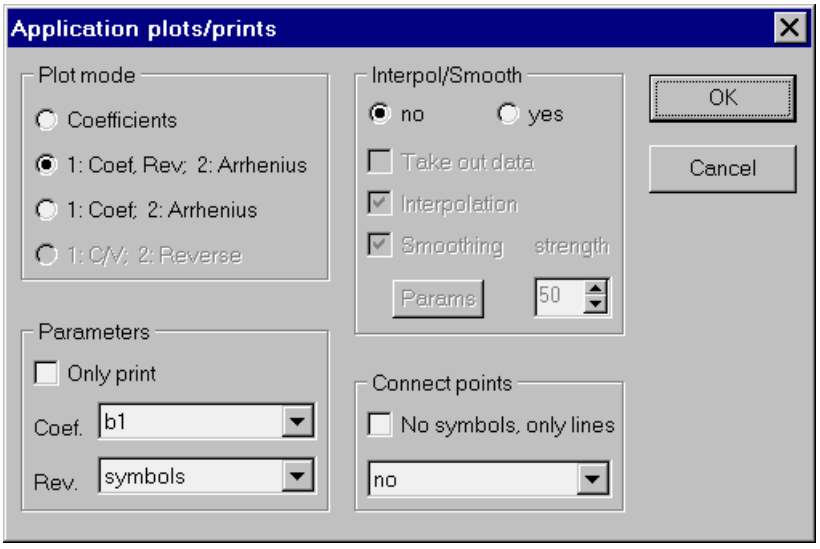
Coefficients: One plot with one or more selected coefficients versus temperature.
1:Coef,Rev; 2:Arrhenius: At the first page there is the coefficient plot at the top, CR and IR versus temperature plot at the bottom. The leakage current IR will shown in a logarithmic view, the y-axis is from this. The capacitance CR at reverse bias will be shown in the same plot without showing its own y-axis. The CR minimum and maximum value will be listed in the text header. The second page shows the Arrhenius plot.
1:Coef, 2:Arrhenius: At the first page there is the coefficient plot, at the second page is the Arrhenius plot.
1:C/V, 2:Reverse: At the first page there is at the top the C/V curve, at the bottom the 1000/C^2 curve with evaluation. At the second page there is at the top the CR, at the bottom the IR curve. This plot is only possible if a C/V curve was saved before tempscan start, for example done in the menu 'New sample'.

By activating the flag **Only print**, available at plot modes with 2 pages, the program jumps after clicking OK directly to the print dialog.

Following **coefficients** are selectable for the plot:

b1; a1; b1,a1; b1,a1(Tw/4)
b1,b1(Tw/4),a1(Tw/4)
b1 of all Tw's; a1 of all Tw's

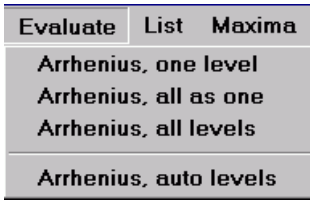
b1 or a1 of all Tw's are only helpful if files with different period widths exist.



The plots with the **reverse** values CR and IR can be shown with symbols, lines or both.

4.1.5 Evaluate menu

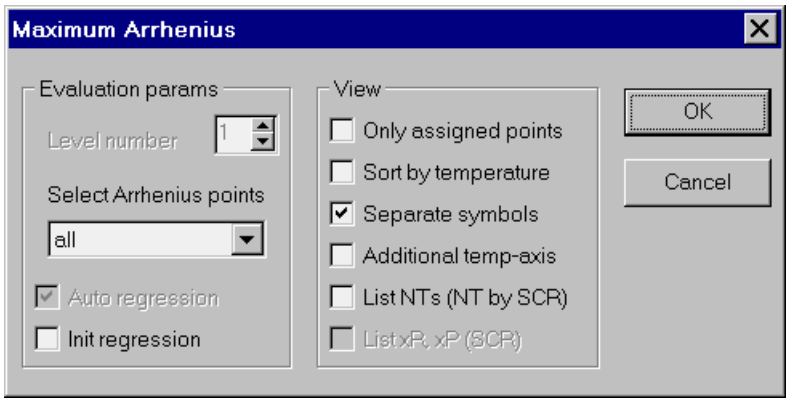
The evaluate menu shows the Arrhenius plot in different kinds.



You can plot the Arrhenius plot by selecting one level or selecting all data which will be used as for one level. The standard is the Arrhenius plot for all levels with the level order of the file.
At auto levels an Arrhenius plot is possible with a new automatic detection and sorting of the levels.

4.1.5.1 Arrhenius for all levels

The following shows the inputs for the standard Arrhenius plot for **all levels**. The sorting of the data points to the levels were taken from the Arrhenius file. The linear regression will be done level by level about the data points of the level. There is no mismatch possible, even at an overlapping.



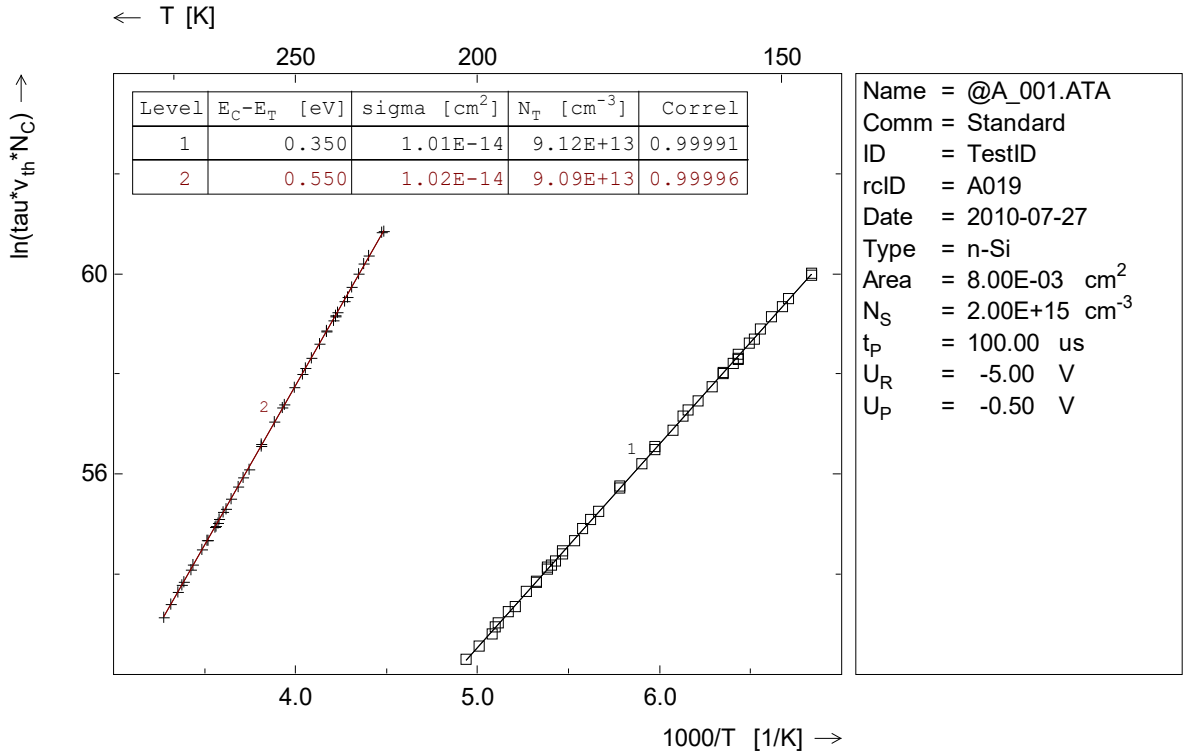
Activating **Init regression** makes a new initialization of the linear regression, that means the x-axis range used for the linear regression will be set newly, in the other case the range will be taken from the file. Energy, sigma and so on will be always newly calculated.

Select Arrhenius points define which data points (coefficients) will be used (for plot and evaluation):

- **all:** All 22 until 25 coefficients can be used. Because some have similar time constants, points are at the same place in the Arrhenius plot, plot symbols overlap.
- **most:** All without Dlts and user correlation functions.
- **Main:** The main will be used, attribute M in chapter 4.1.1.7. All coefficients have different time constant,s so the Arrhenius plot looks more nice. There are no overlapping symbols of one level.
- **energy resolution:** Only coefficients with a high energy resolution, attribute E.
- **good signal/noise:** Only coefficients with a good signal/noise ratio, attribute S.
- **b1 at various Tw:** Only b1 coefficients of various period.
- **an or similar:** Only cosine or similar coefficients with high energy resolution.
- **only Dlts, user-fct:** Only the 3 conventional Dlts signals and, if exist, until 3 user defined correlation functions.

In the **View** input box there are some parameters for the view of the plot:
Only **assigned** points shows only Arrhenius points which are assigned to a level.
It is possible to **sort** the data by temperature, to use different **symbols** for different levels, to show an additional **temperature axis** at the top of the plot.
NTs, this is NT corrected by the space charge region, and the **xR** and xP values of the space charge region can be listed.

The following picture shows an Arrhenius plot with an additional top temperature axis. All data points (coefficients) will be used, so that some plot symbols overlap. You get a more nice look if selecting only the main Arrhenius points. Two tempscan files with different period widths yield to the big 1000/T-range with many points and so to a high accuracy. Points that are not assigned to a level would be shown as a small square. The list shows the level number, the activation energy of the trap level, the capture cross section, the trap concentration and the correlation of the linear regression.



4.1.5.2 Arrhenius for all as one level

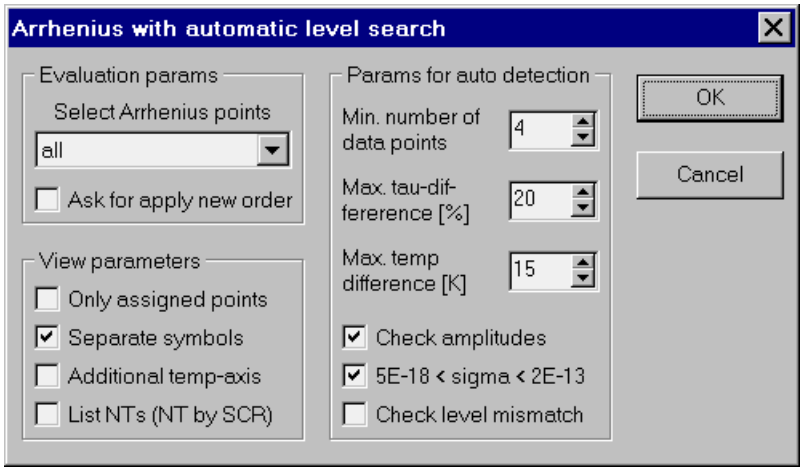
All defined Arrhenius data will be used without level separation. One regression can be done about all data. The **maximum numbers of levels** will be defined in the input window. This is not the really numbers of levels. It defines for how many levels you can make here an evaluation, it is not necessary that all levels exist. It defines also where the results will be shown, for one level at the right text header, for two or more in a top list box inside of the Arrhenius plot. It reserves also enough space for the result list.
In this mode all data points will be used as one array, there is no **separation** by levels. If levels overlap in the x-axis then you can not separate the levels for the linear regression by setting x-start and x-end point. It is possible that you make the linear regression about the data of 2 'real' levels. In this case you should use the so called manual regression with setting the x/y-start and the x/y-end point. It will be described in the chapter 5.1.5.2.

4.1.5.3 Arrhenius with one level

At the Arrhenius plot with one level there can be selected the level number. Only the data points of this level will be shown.
Activating **Auto regression** starts the plot with an automatic linear regression.

4.1.5.4 Arrhenius with auto levels

A new automatic detection and sorting of the levels will here be done before showing the Arrhenius plot. After the plot the software asks for **applying** the new level order if this flag was activated. In the other case is the new order only temporary. 'Select Arrhenius points' and 'View parameters' are already explained in the chapter before. The 'Params for auto detection' are explained in chapter 4.1.2.1.



Note: The selection of Arrhenius points defines also which points will be used for the calculation of energy, NT (see 3.4.5.6) and so on. This can give a difference to the result list of the list menu, see 4.1.3. There all points inside the regression range will be used.

4.1.5.5 Regression, fit and library

The Arrhenius plots will be made in the plot program, for more details see chapter 5.1. You can change the start and end point of the **linear regression** for each level. Use the toolbar button or the F8-key for setting the range of the linear regression. This mode will also be called auto regression. After setting the right point the results will be calculated again. The correlation factor provides an indication of the deviation of the data from the regression.
The current level number can be changed by a mouse click onto the level number button in the toolbar, it toggles then between first and last level.
In the Evaluate menu you can select also manual regression, see chapter 5.1.

You can compare the results with existing levels in the **library**. You find this option in the Evaluate menu of plot program. The library will be explained in a separate chapter.

It is also possible to **fit** the Arrhenius plot by simulation levels, this option is also in the Evaluate menu of the plot program. At the input sheet SimLevel you can define the simulation parameters. At 2 or more levels you can select the colors for the lines of the simulation levels. Taking the global color for fit or separate colors for each fitting lines are possible. The lines can be drawn from start to end point (simple line), from data to data point or by interpolation.
Library and fit are only available if the linear regression was done.

Note: The Arrhenius plot gives only energy differences. The doping type (n or p) defines, whether EC-ET or ET-EV will be used as text in the Arrhenius result box. This has also influence on the y-axis because the effective mass of electrons or holes are different. The energy (slope) is independent from the doping type, the result for the capture cross section (intersection of y-axis) depends on the doping type. For minorities (negative peaks) change the doping type to get the correct text and the correct capture cross section.

4.2 Arrhenius by isothermal maximum analysis

The isothermal maximum analysis is very similar to the tempscan maximum analysis of chapter 4.1. Therefore only a small explanation will be given here and the differences described.
For this maximum analysis period width scans files at different temperature are necessary. One period width file gives only one maximum and therefore only one Arrhenius data point per level. Using different coefficients of one file should give the same result for the time constant and amplitude.
After defining of all peaks you get an Arrhenius plot with trap energy, capture cross section and trap concentration for each level. The new data can be saved into the Arrhenius data file format with the data extension AW?. The data are not packed after the creation.

4.2.1 Maxima menu

By these functions the peak maxima will be searched and defined. You can use the current isothermal data or read new period scan files.
At the same time resp. one Arrhenius file 9 levels with each 150 data numbers (period scan file) can be evaluated.
The coefficients in the maximum analysis will be plotted amplitude-normalized. This means, that the y-axis is quasi the amplitude of the transient for the coefficient maximum. A plot with a normalizing to the trap concentration is also possible. Time constant, amplitude and trap concentration correspond to the transient only in the peak maximum of the coefficient!
For a better energy resolution is also a HERA deconvolution of the isothermal curves possible, this will be described in the HERA chapter.

4.2.1.1 Inputs

Base input sheet:

The **file mode** defines which files will be used for the determination of the peak maxima:

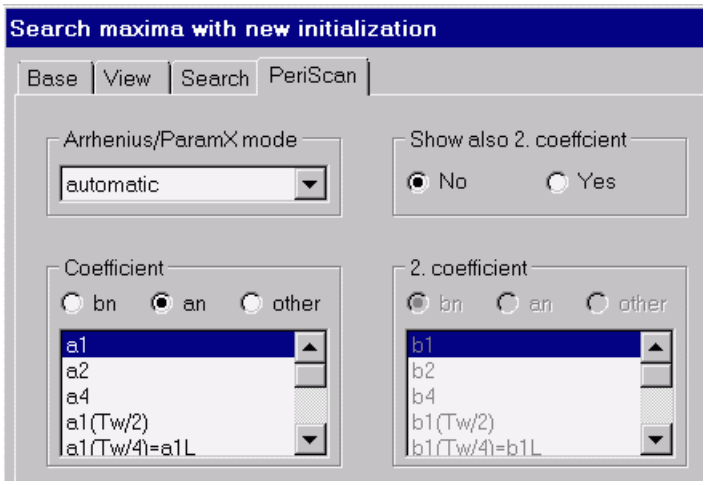
All files, auto file search: All isothermal files will be used automatic one after the other. The file name search will be automatically done from the name of the current file by searching the last 3 numbers before the data extension.
1 file, auto file search: One isothermal file will be used. The file name search will be automatically done from the name of the current file by searching the last 3 numbers (characters). Which file will be loaded depends on the input of the data number.
1 file, input of name: One isothermal file will be used, you can select the file name.
1 file, current data: The current data will be used.

If you don't use 'All files' then you have to input the **data number**, that means the saving position of the data.

PeriScan input sheet:

Additionally to the tempscan here is an input sheet for the selection of coefficient.

The **Arrhenius/ParamX mode** defines which parameter was varied, normally this is the temperature. At automatic the software select it.
You can use all available **coefficients** for the maximum analysis. The default one is a1, first cosine, because the better energy resolution. You should use for all Arrhenius point the same coefficient.
It is possible to show simultaneously a **second coefficient** to compare the results.



4.2.2 Differences between tempscan and isothermal Arrhenius

There are some more differences between Arrhenius files coming from tempscan files and Arrhenius files coming from isothermal files. The data numbers of the isothermal Arrhenius files don't correspond to a special coefficient order as described in chapter 4.1.1.7. All used data are saved one after the other. If deleting one point you can pack the data. At tempscan Arrhenius files this point will internally only be marked as deleted.
At the Arrhenius plot you can not select the Arrhenius points, all points will be shown.

It is also possible to make Arrhenius files without period scans, for example at the capture evaluation at different temperatures, see chapter 3.3.6.1.5. The second data character is here 'F'. You can read these Arrhenius data in the maximum analysis. Therefore the maximum menu is visible although no maximum analysis is possible.

4.2.3 Maximum analysis for other parameters

A period scan maximum analysis is also possible at others variations instead of the temperature. This can be variations of UR, UP or tP and so on. The maximum analysis will be done in the same way as described above. At the result you get not an Arrhenius plot but the corresponding evaluation. Additionally you get a plot time constant or amplitude versus variation parameter. The data will also be saved into the so called Arrhenius file. The second character of the data extension is 'O', see chapter 1.3.3. This file you can read in the same way as a 'true' (temperature depending) Arrhenius file. The software detects automatically the kind of data.

Especially the **pulse width** variation is important for calculating the capture cross section, see chapter 3.3.6.1.4. Then you get as result the capture transient evaluation. Making this variation at some temperatures yields to some 'AO?' files. Each capture time constant at a measured temperature can be saved into a new (true) Arrhenius file with 'F' as second character of the data extension. You find this option during the capture evaluation in the evaluate menu of the standard plot program under 'Save eval as file'. Reading this file yields to a special input for the kinetic of the Arrhenius plot, see chapter 3.3.6.1.5.

The first character of the data extension of an **Arrhenius file** is always 'A'. The second data extension character (see chapter 1.3.3) denotes this **kind** of data. All Arrhenius files except that one with 'O' have the temperature as x-axis. The following list gives an overview of all Arrhenius files by this character:

E: from single emission transients of the transient module
F: from capture transients of the isothermal module, done by pulse variation
M: from HERA transient evaluation in the transient module, all levels and records
P: from HERA transient evaluation in the tempscan module, packed levels
O: from period scans of other variations (not temperature) in the isothermal module
T: from standard maximum analysis in the tempscan module
W: from period scans of the isothermal module
X: from isothermal xy-scan
Z: from Zerbst evaluations at various temperatures in the transient module

4.3 Temperature depending Zerbst analysis

The Zerbst technique for MIS samples will be explained in chapter 6.3.8. At one temperature it is only capable of identifying whether deep level generation or surface state/diffusion effects dominate an inversion process (gm or Gb rate).
The Zerbst evaluation of transients at different temperatures gives additional information. Similar as an Arrhenius plot you get activation energies for gm and Gb. The generation processes which are contributing to the inversion may be assessed from these energies. If the activation energy is Eg (bandgap) then the dominant process is the diffusion from the bulk, if the energy is Eg/2 then the dominant process is from deep level generation. Most commonly there will be a contribution from both processes.

You find the temperature depending Zerbst analysis in the Evaluate menu of the Transient program module. This function is similar to the Arrhenius plot via maximum analysis as described in chapter 4.1 but here the transients will be evaluated and not the coefficients. The results and the data structure is that of an Arrhenius file with the data extension AZ?, so this function runs in this sub program.
The menu bar is similar to the maximum analysis of chapter 4.1. Instead the 'Maxima' menu here is the 'Define' menu. In the following only the Define and Evaluate menu will be described because the other menus are similar to chapter 4.1.

4.3.1 Define menu

In the Define menu the Zerbst plot and its evaluation will be shown for every temperature. It contains 2 sub menus:

The evaluation will normally be done with a **new** initialization, that means old definitions and results will be deleted.
If you have already done an evaluation or an Arrhenius file read then you can **keep** the old definitions and evaluation.

4.3.1.1 Inputs

Base input sheet:

The **file mode** defines which files will be used:

All files, auto file search: All transient files will be used automatic one after the other. The file name search will be automatically done from the name of the current file. This is the standard mode.

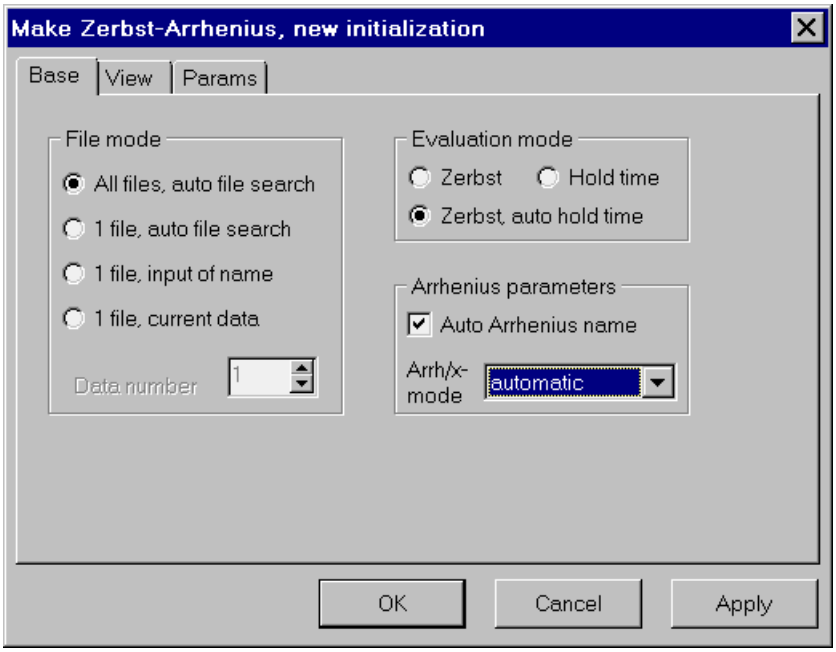
1 file, auto file search: One transient file will be used. The file name search will be automatically done from the name of the current file. Which file will be loaded depends on the input of the data number.

1 file, input of name: One transient file will be used, you can select the file name.

1 file, current data: The current transient data will be used.

Tip: For automatic reading of the various transients the file names must include a running number. So the last 3 characters before the data extension must be a number, see also tip c) at chapter 6.3.8.2.

The **evaluation mode** defines whether a standard Zerbst evaluation or the calculation of the transient hold time will be done. At the first two modes only one of this evaluation will be done. The evaluation resp. regression will be done automatically, but can be changed manually. If selected 'Zerbst, auto hold time' then additionally to the Zerbst analysis the hold time of the transient will be calculated automatically without showing the transient.



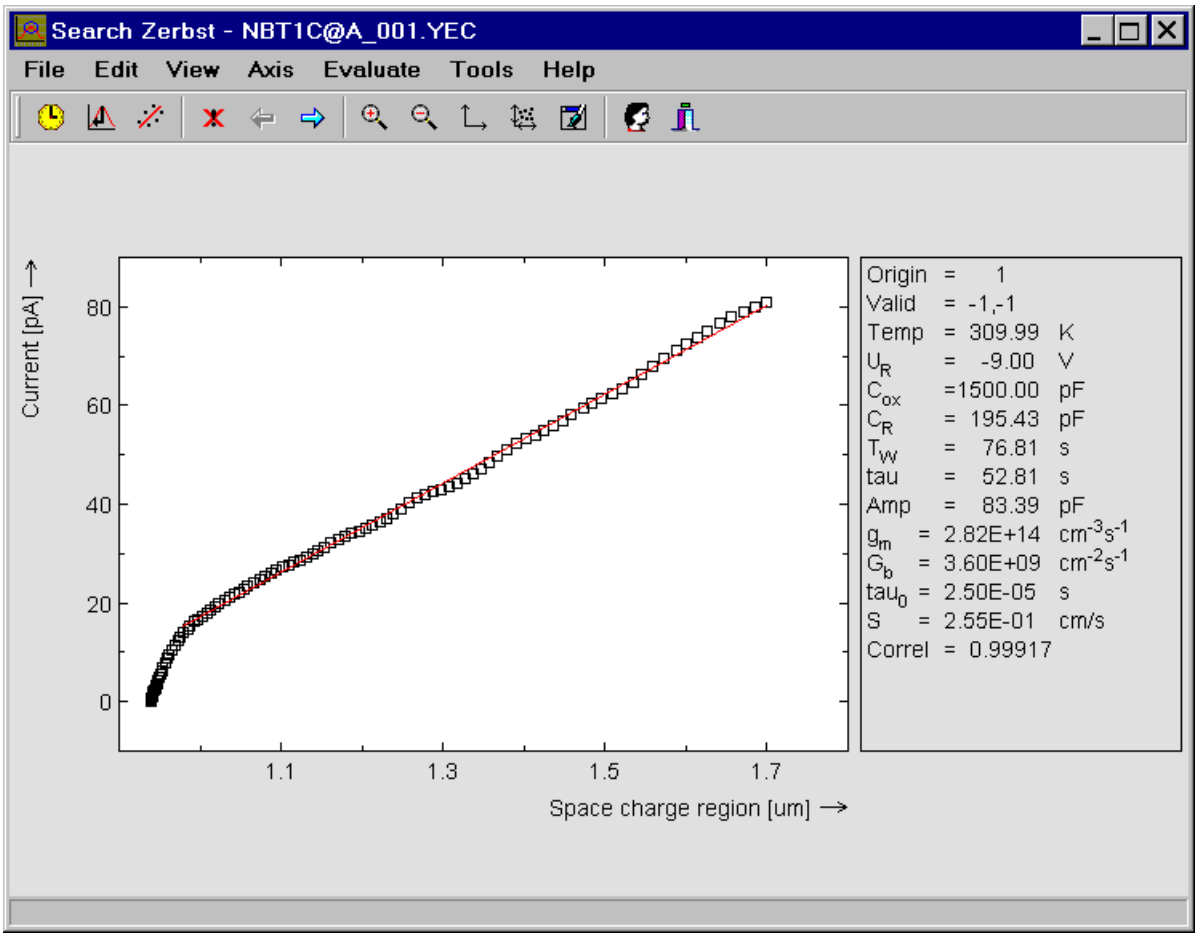
Note: For the calculation of the hold time tauH the period width must be bigger than tauH. Use manual evaluation of hold time if you suspect that transients were not measured to completion; this will enable you to identify them as being invalid. So if you want to use the tauH evaluations select in this case first 'Define, new init' and evaluation mode 'Zerbst'. Then select 'Define, keep eval' and evaluation mode 'Hold time'.

If activating **Auto Arrhenius name** then the proposed name of the Arrhenius data file will be set from the transient file name.
The **Arrhenius/ParamX mode** defines which parameter was varied, normally this is the temperature. At automatic the software select it.

The other input sheets will be explained in chapter 6.3.8.3.

4.3.1.2 Zerbst plots

The following picture shows the Zerbst plot after calling the Define menu. Under the top menu bar there is the toolbar. At the right there is a list with the important parameters and results.



List of important parameters and results:

Origin: The origin number shows the record position in the Arrhenius data array, in many cases this is also the number of the transient.

Valid: The first number denotes the Zerbst evaluation, the second one the hold time evaluation of the current transient. A '-1' means that no evaluation was done, a '0' that this data point will not be used. Other values represent valid points.

Temp: Temperature at the measurement.

tau: Hold time of the transient.

Amp: Amplitude of the transient.

gm: Depletion width dependent generation rate.

Gb: Depletion width independent generation rate.

tau0: Life time, calculated from gm.

S: Surface recombination velocity, calculated from Gb.

Correl: Correlation coefficient of the linear regression over the Zerbst plot.

Explaining of the **toolbar**:

Apply, go on by **timer.** Automatic regression resp. evaluation until break.

Define evaluation, go on. If no evaluation is possible here is the Go on button.

Manual regression, F8 key is shortcut.

No evaluation, go on to the next transient. F9 key is shortcut.

Go to previous transient, PageUp key is shortcut.

Go to next transient, PageDown key is shortcut.

Zoom in this data (transient).

Zoom out.

Axis mark for setting a new plot window by mouse marker.

Axis rescale to the initialization plot window.

Refresh the plot, F5 key is shortcut.

Personal user button.

Close the defining of transients.

The **ENTER** key have the same effect as the Define button. Then the software goes on to the next transient. If there was no evaluation possible, it goes on without a definition. If the last transient was defined then the Close button will be shown on this button position.
In mot cases you can confirm the results only by the ENTER key.

4.3.1.3 Menus at the Define menu

The important actions can be done by the mouse or keyboard. More possibilities are given in the menus.

The main menu is the **Evaluate menu**:

Apply, go on by timer: Automatic evaluation until break is pressed. Before starting there is an input for a delay time.
Apply regression, go on: The current evaluation will be applied. Then the software goes on to the next transient.
Auto regression: Automatic regression.
Manual regression: Calling the manual regression, see chapter 5.1.5.2.
Params for ManuRegress: Input of the parameters for the manual regression.
Init regression: New initialization of the linear regression.
Apply regression: Applies the regression rep. evaluation and stays here.
No regression, go on: Define that there is no evaluation for this data position. Goes on to the next transient.
Go to previous data: Go to the previous transient.
Go to next data: Go to the next transient.
Input of data number: Go to the transient which was selected by an input.

Some points of the **Axis menu** are the same as in the plot program.

If **zooming** then there are 2 possibilities for the validity: for this data (transient) or for all data (transients). In the first case the plot will be automatically zoomed out if going to another transient. In the last case the zoom will be applied for all transients.

For the **axis window** at plotting a new transient (data) there are 3 modes:

New x,y-axis: A complete new plot window for the x- and y-axis will be set, this is the default one.

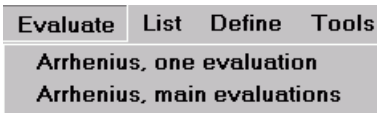
New y-axis: Only the y-axis will be set by the new transient. If you want to restrict the x-axis for all transients use this mode.

Old axis: The current x-and y-axis will be taken over for all transients.

In the **Edit menu** there you copy the graphic into the clipboard and delete the linear regression. In the **Tools menu** you can list the results of all evaluated transients. The items of the **View menu** are described in the plot program.

4.3.2 Evaluate menu

The evaluate menu shows the Arrhenius plot of the different evaluation values.



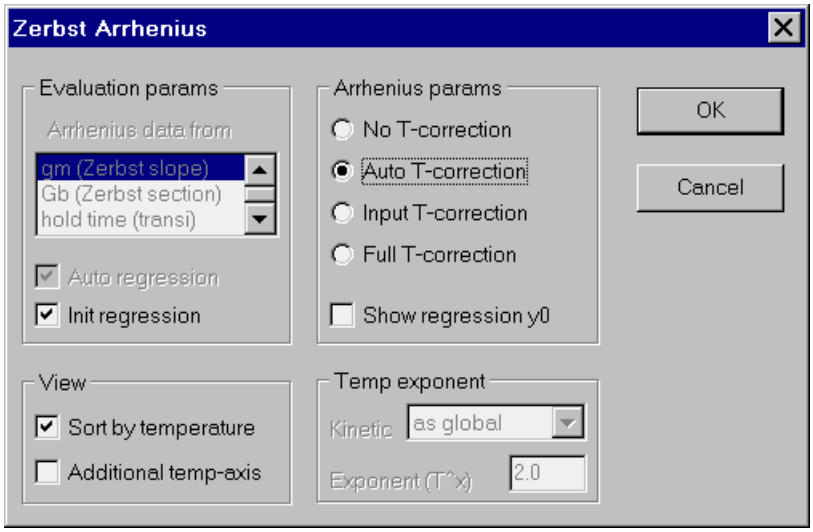
You can plot the Arrhenius plot by selecting one of the evaluation values. Main evaluations shows the 3 main evaluations (gm, Gb, tau) in one plot. This is the standard evaluation.

If using the 'one evaluation' mode then you can select from which the **Arrhenius data** come: from the Zerbst plot the slope gm or the section Gb; or from the transient the hold time tau or the amplitude or combinations of tau and amplitude. From gm and Gb a 'time constant' tau will be calculated for the Arrhenius plot: tau =1E15/gm resp. tau = 1E9/Gb.

Auto regression means that the plot starts with doing an automatic linear regression.

Activating **Init regression** makes a new initialization of the linear regression, that means the x-axis range used for the linear regression will be set newly, in the other case the range will be taken from the file.

It is possible to **sort** the data by temperature and to show an additional **temperature axis** at the top of the plot.



In the **Arrhenius params** input box you can select the T-correction, for more details see chapter 2.4.2.1, and the y-axis:

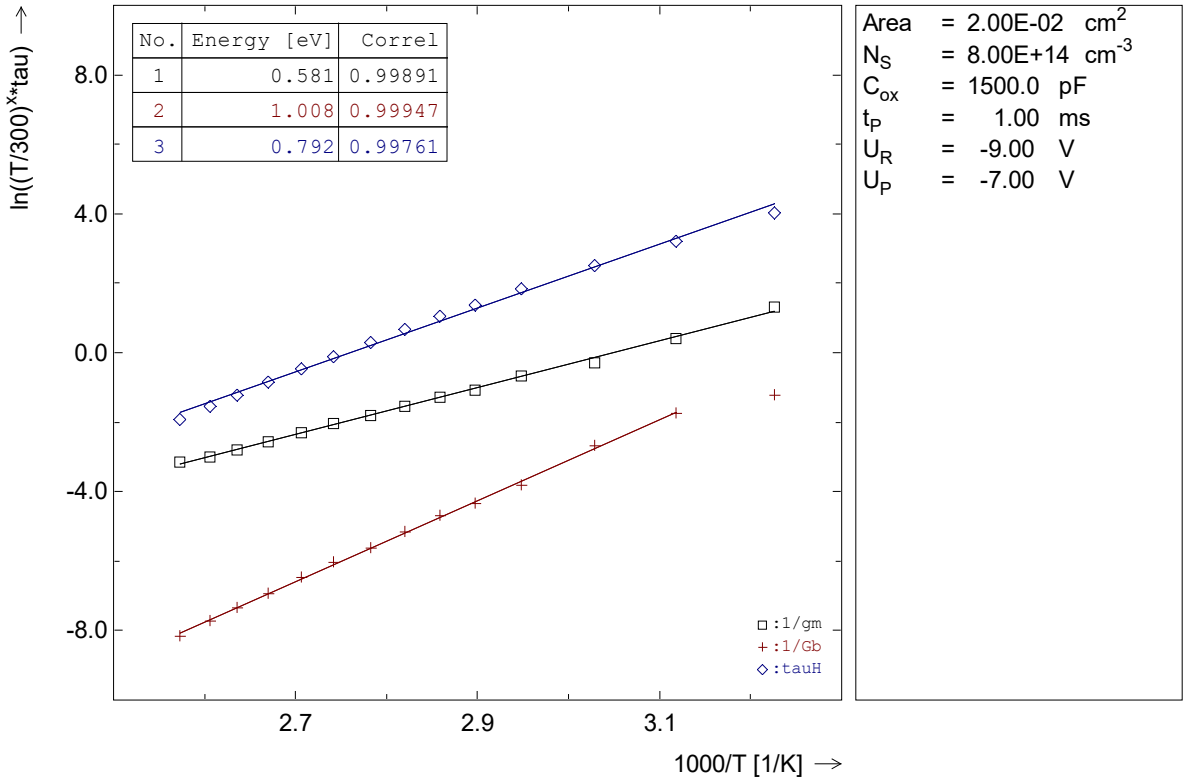
No T-correction: y = ln(tau)
Auto T-correction: y = ln(tau*T^x), where x is the exponent of the T-correction and will be set automatically depending on the kind of data: x=1.5 for gm, x=3.5+0.5*x_my for Gb, x=2 otherwise. x_my is the temperature exponent of the mobility, see chapter 2.4.3.
Input T-correction: y = ln(tau*T^x), the T-correction will be selected by the kinetic input.
Full T-correction: y = ln(tau*vth*Nc) for example; not only T^x will be used for the y-axis but the full kinetic with all factors. In the y-axis the factors without T^x will normally be denoted as 'C'.

Activating '**Show regression y0**' shows not only the slope (energy) but also the section of the y-axis of the Arrhenius plot calculated by the linear regression. The dimension is [s]. This feature is not enabled at full T-correction.

In the **Temp exponent** input box you can select the kind of **kinetic** or input directly the exponent of T-correction:

as global:	Use the kinetic as selected in 'Physics input sheet', chapter 2.4.2.1.
emission:	Emission kinetic vth*Nc, x=2.
minority:	Emission for minorities, x=2.
capture:	Capture kinetic vth*Ns, x=0.5.
inv. band mid:	Inversion from bandmid kinetic sqrt(Nc*Nv), x=1.5.
inv. Diffus.:	Inversion from diffusion kinetic Nc*Nv, x=3.
Ns:	Shallow concentration, x=0.
T-exponent:	Direct input of the temperature exponent x.

The next picture shows the **Zerbst Arrhenius plot** of a measurement, calculated with an automatic T-correction. The black squares represent the calculation from gm, the red crosses come from Gb and the blue diamonds denote the hold time. 0.581 eV calculated by gm is about the half bandgap. So this process comes from a volume generation by deep levels. The energy calculated by Gb is in the near of the bandgap, so the dominant part here is the bulk diffusion. The energy calculated from the hold time is between the other 2 values because tauH is a result of gm and Gb. At this sample both processes are important at the observed temperatures. At other samples is Gb the dominant process at higher temperatures so that the energy of tauH goes here to this value.



As **summary**, the different kinds of Arrhenius data allow evaluation for different processes:

- **gm** gives an indication of whether the inversion process has come from deep levels. If so, the energy value will be approximately half the bandgap.
- The **Gb** energy will approximate to the bandgap if the inversion process is from diffusion. Take care with this as the diffusion process may come from two different processes so it may be necessary to split the regression and check.
- The **hold time** is a result of gm and Gb processes and gives an overlapping result.

4.4 Static temperature evaluations

In the evaluation menu of the static program module there is the menu point 'temperature evaluation'. This sub program allows to evaluate temperature depending static curves. The evaluation for each temperature point is the standard evaluation for C/V resp. I/V curves which was already described in the static program module. The results can be saved into a new data file which we call **'Equilibrium'** file or **Q-file**. A detailed explanation of these files was already given in chapter 3.5. The different file types save different equilibrium values in dependance of the temperature.

Here usually a **QC-file** will be made by C/V curves. It contains the shallow concentration Ns and the diffusion voltage for various temperatures. The linear regression for each C/V curve can be done automatically or manually. Additionally CR and CP of a fix UR and UP will be saved into this file. The purpose of this file is to show the temperature behavior of all these values, especially the shallow concentration, and the applying into a tempscan, see chapter 6.4.2.

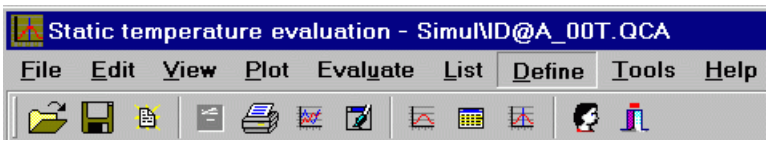
You can also create a **QU-file** from temperature depending C/V curves. It can be used for CC-DLTS measurements. It will be explained in chapter 4.4.1.5.

Temperature depending I/V curves yield to a **QI-file** which contains the n-factor, the saturation current and the currents at UR and UP. The saturation current versus temperature is the **Richardson plot**. Here you get the barrier height more exactly as from a C/V curve.

You can read here also the QR, QF, QP-files but the full **TSC/TSCAP** evaluation is only possible in the equilibrium program module. If you read here such a file then instead of the plot at UR and UP you can select between capacitance and current at one voltage.
A **QB** and **QV-file** can also be read here or in the equilibrium module. The static capacitance was kept constant by changing the bias voltage UR (CC- or CS-DLTS) at this measurement. Only UR, the capacitance CR, which should be constant, and the current IR can be shown. The **TSU** evaluation is only possible in the equilibrium module.

In the following the QC, QI and QU-files will be explained while the other Q-files were described in the equilibrium program module, see chapter 3.5.

The standard equilibrium plot resp. evaluation will be shown on the main canvas of this sub program.



The menu bar is similar to the measurement program modules. Instead the menu Measure here is the menu Define.

Most of the toolbar buttons have the same meaning as in the measurement programs, following have a different meaning:

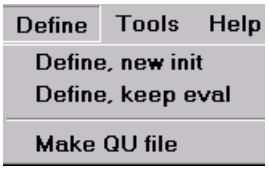

Plot equilibrium values as CR, IR and so on.


List main data.


Define the curve and evaluation for each temperature.

4.4.1 Define menu

The menu bar is a little bit similar to the maximum analysis of chapter 4.1. Instead the 'Maxima' menu here is the 'Define' menu with 3 sub menu items:



The evaluation will normally be done with a **new** initialization, that means old definitions and results will be deleted.
If you have already done an evaluation or an equilibrium file read then you can **keep** the old definitions and evaluation.

The first two sub menu items are for making QC- or QI-files. The third is '**Make QU-file**'. That is a special case and will be explained in chapter 4.4.1.1.5. In the following 4 chapters only making of QC- and QI-files will be described.
The define menu uses Cp or Cs for C/V curves as explained in chapter 3.1.1.4.

4.4.1.1 Inputs

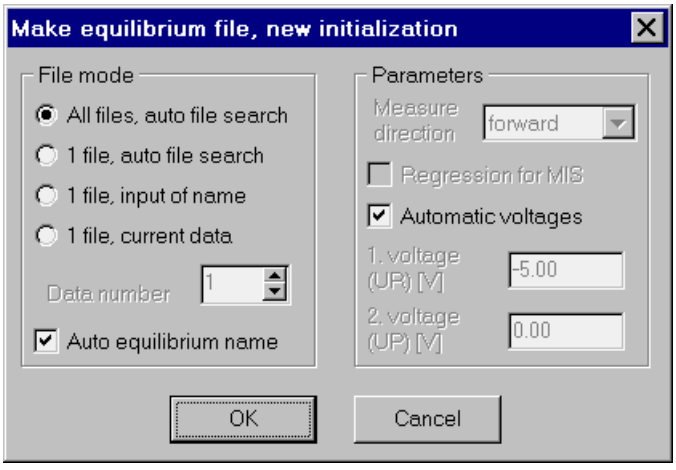
The **file mode** defines which files will be used:

All files, auto file search: All static files will be used automatic one after the other. The file name search will be automatically done from the name of the current file. This is the standard mode.

1 file, auto file search: One static file will be used. The file name search will be automatically done from the name of the current file. Which file will be loaded depends on the input of the data number.

1 file, input of name: One static file will be used, you can select the file name.

1 file, current data: The current static data will be used.



For automatic reading of the various static curves the file names must include a running number. So the last 3 characters before the data extension must be a number, see chapter 6.4.1.

If activating **Auto equilibrium name** then the proposed name of the equilibrium data file will be set from the static file name.

If measured forward/backward then you can select the **measure direction**:

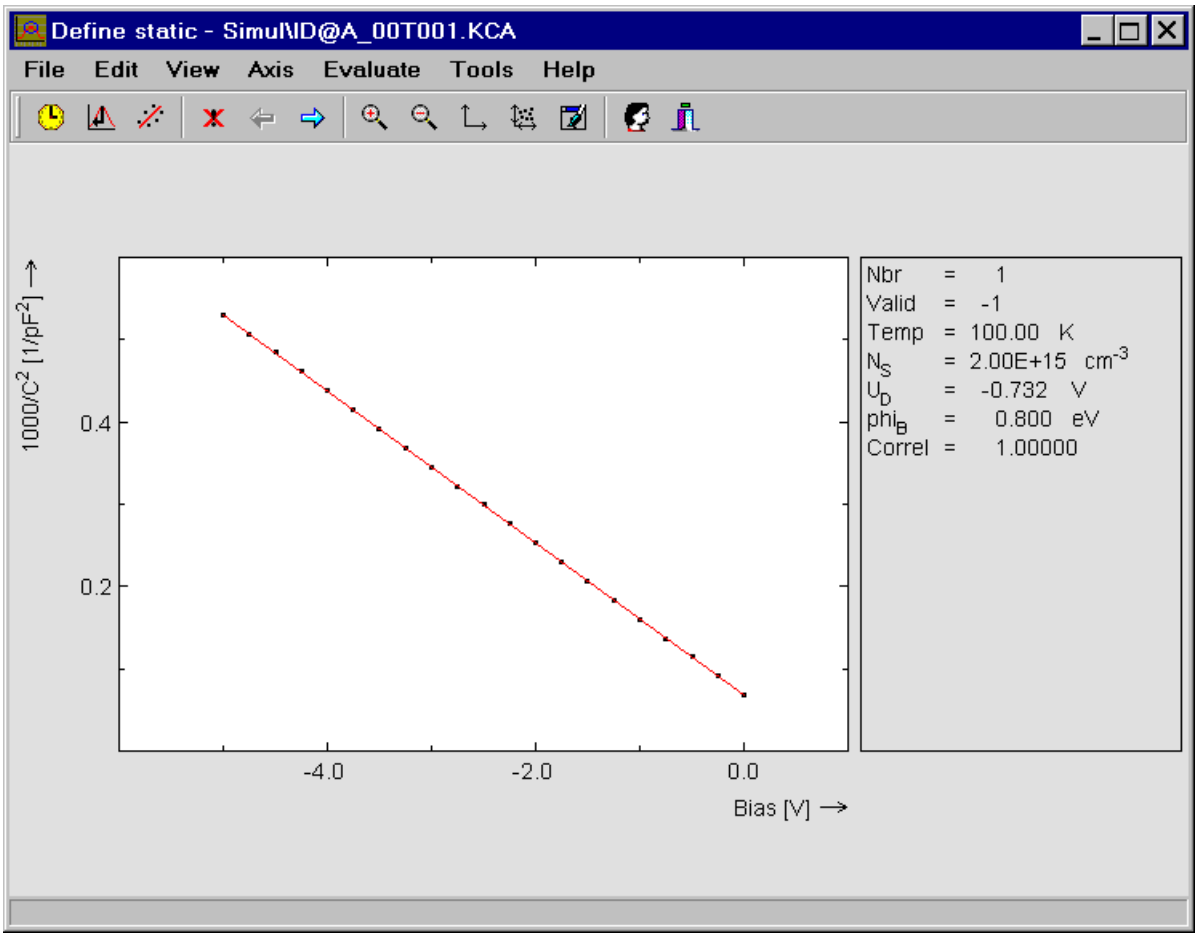
Both: Plots all data.
Forward: Plots only the first direction.
Backward: Plots only the second direction.

As explained above the capacitance resp. current at 2 voltages (called UR and UP) will be saved into the equilibrium file. If **automatic voltages** is activated then the software takes minimum and maximum as UR and UP, in the other case you can input these 2 voltages. If applying CR and CP into a tempscan (chapter 6.4.2) then you must set UR and UP as the tempscan. The capacitance resp. current at this values will be applied from each static curve by interpolation. If using 'Define, keep eval' then the old UR and UP will be kept.

'**Regression for MIS**' optimizes the regression range of the Ns calculation for MIS samples. This flag is only enabled for MIS samples if using C/V curves. The reason for this flag is that the linear regression range at MIS samples is often smaller than at Schottky diodes. If activating this flag then the 'Min. range for auto regression' will be set to 30% and the search mode to 'prefer correlation', see chapter 2.3.3.6. It is a global flag for MIS.

4.4.1.2 Evaluation plots

The following picture shows the evaluation plot for a C/V curve after calling the Define menu. Under the top menu bar there is the toolbar. At the right there is a list with the important parameters and results.



List of important parameters and results:

Nbr: The number shows the number of static curve.
Valid: This value denotes the evaluation resp. linear regression. A '-1' means that no evaluation was done, a '0' that this data point will not be used. Other values represent valid points. At entering a new curve the value is '-1' because the evaluation was not applied at this time. After applying (and going on to a new curve) it will be set (for the old curve).
Temp: Temperature at the measurement.
Ns: Shallow concentration which comes from the slope of linear regression.
UD: Diffusion voltage, comes from the intersection of the linear regression.
phiB: Barrier height calculated by UD.
Correl: Correlation coefficient of the linear regression over the static curve.

Explaining of the **toolbar**:

Apply, go on by **timer.** Automatic regression until break.

Define evaluation, go on. If no evaluation is possible here is the Go on button.

Manual regression, F8 key is shortcut.

No evaluation, go on to the next curve. F9 key is shortcut.

Go to previous curve, PageUp key is shortcut.

Go to next curve, PageDown key is shortcut.

Zoom in this data.

Zoom out.

Axis mark for setting a new plot window by mouse marker.

Axis rescale to the initialization plot window.

Refresh the plot, F5 key is shortcut.

Personal user button.

Close the defining of static curves.

The **ENTER** key have the same effect as the Define button. Then the software goes on to the next curve. If there was no evaluation possible, it goes on without a definition. If the last curve was defined then the Close button will be shown on this button position.
In mot cases you can confirm the results only by the ENTER key.

Tip: You can make an automatic defining by the first button. There you can set the waiting time between 2 curves to 0s.

4.4.1.3 Menus at the Define menu

The important actions can be done by the mouse or keyboard. More possibilities are given in the menus.

The main menu is the **Evaluate menu**:

Apply, go on by timer: Automatic evaluation until break is pressed. Before starting there is an input for a delay time.
Apply regression, go on: The current evaluation will be applied. Then the software goes on to the next curve.
Auto regression: Automatic regression.
Manual regression: Calling the manual regression, see chapter 5.1.5.2.
Params for ManuRegress: Input of the parameters for the manual regression.
Init regression: New initialization of the linear regression.
Apply regression: Applies the regression rep. evaluation and stays here.
No regression, go on: Define that there is no evaluation for this data position. Goes on to the next curve.
Go to previous data: Go to the previous curve.
Go to next data: Go to the next curve.
Input of data number: Go to the curve which was selected by an input.

Some points of the **Axis menu** are the same as in the plot program.

If **zooming** then there are 2 possibilities for the validity: for this data or for all data. In the first case the plot will be automatically zoomed out if going to another curve. In the last case the zoom will be applied for all curves.

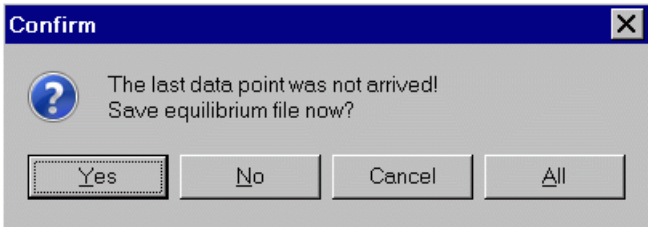
For the **axis window** at plotting a new curve (data) there are 3 modes:

New x,y-axis:	A complete new plot window for the x- and y-axis will be set, this is the default one.
New y-axis:	Only the y-axis will be set by the new curve. If you want to restrict the x-axis for all curves use this mode.
Old axis:	The current x-and y-axis will be taken over for all curves.

In the **Edit menu** there you copy the graphic into the clipboard and delete the linear regression. In the **Tools menu** you can list the results of all evaluated curves. The items of the **View menu** are described in the plot program.

4.4.1.4 After the defining

If you close the defining you get a question for saving the results to an equilibrium file if you have start a new defining. You should save the file because you lose the results if exit the program or start a new defining.



If you close the search before arriving the last possible static curve you get this confirmation window. Normally you should do the evaluation for all curves.
Yes opens here the save file dialog, save the results and leaves the defining. The program stays in the static temperature evaluation and shows the standard plot.
No leaves the defining without saving.
By **Cancel** you stay in the defining and can go on with further curves.
All opens the data task window, as described in chapter 2.2.3. Here you can save and print the data, save results into the evaluation database and apply results as sample or simulation parameters.

Note: The data will not be packed in the equilibrium data array resp. file. That means if you have for example 20 static curves but the evaluation of curve number 2 will not be applied (Valid=0), then you have nevertheless 20 data points in the equilibrium data but with 1 not valid point. You don't see this point in a plot. This behavior has the advantage that you can start the evaluation again with keeping your old results. All curves then have the same data position as before. You can pack the equilibrium data in the Edit menu but then a repetition of the evaluation with keeping the old results gives problems.

If the C/V curves contain also the **conductance**, Cp or Cs will be shown and evaluated in the C/V curves, as selected in the Static Program, see chapter 3.1.1.4. But always Cp and Gp at UR and UP will here be saved into the QC-file.

4.4.1.5 Making a QU-file

Here you can create a **QU-file** from temperature depending C/V curves. It can be used for CC-DLTS measurements. The voltages for 2 fix user defined capacitances CR and CP will be searched and saved. This feature needs the 'Enhanced' software option.

The difference between QC- and QU-data can be demonstrated if you plot all C/V curves in one plot. For the QC-data you define 2 fix voltages UR and UP for which you search the CR(T) and CP(T) values. This will done by a **vertical** marker/plot. For the QU-data you define 2 fix capacitances CR and CP for which you search the UR(T) and UP(T) values. This will done by a **horizontal** marker/plot.

The QU-file contain additionally 3 capacitance values at the various temperatures. For this 2 fix voltages UR0 and UP0 will be defined. The capacitances for these voltages will then be applied as for a QC-file. Additionally a temperature depending voltage UR(T)-UR0+UP will be local constructed and for this the capacitance applied. UR-UR0+UP0 means a pulse voltage which differs by the fix pulse height UP0-UR0 from UR.

UR0 and UP0 will be automatically defined from the first or last C/V curve. It is the value at which this curve hits CR resp. CP.

One application of the 3 capacitance values is the applying into a tempscan. The first two values are for C-DLTS with a fix UR and UP. The third value is for CC-DLTS with mode B2+P2, means fix CR and fix pulse height but temperature depending UP and CP.

So at a **summarize** following temperature depending values are saved in the QU-file:

UR, UP, C(UR0), C(UP0), C(UR-UR0+UP0)

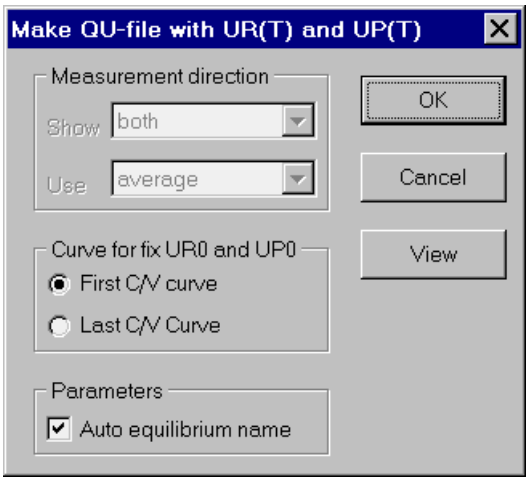
The fix values CR and CP will be listed at QU-plots on the right text header while the fix values UR0 and UP0 only at the file header list will be shown.

If measured forward/backward then you can select the **measure direction** which will be shown:

Both: Plots all data.
Forward: Plots only the first direction.
Backward: Plots only the second direction.

If using both directions then you must define which data (direction) should be **used** for applying into the QU-file:

Average: Uses the average of forward and backward data.
Forward: Uses only the first direction.
Backward: Uses only the second direction.



You can select the **curve for fix UR0 and UP0**: First or Last C/V curve is available.

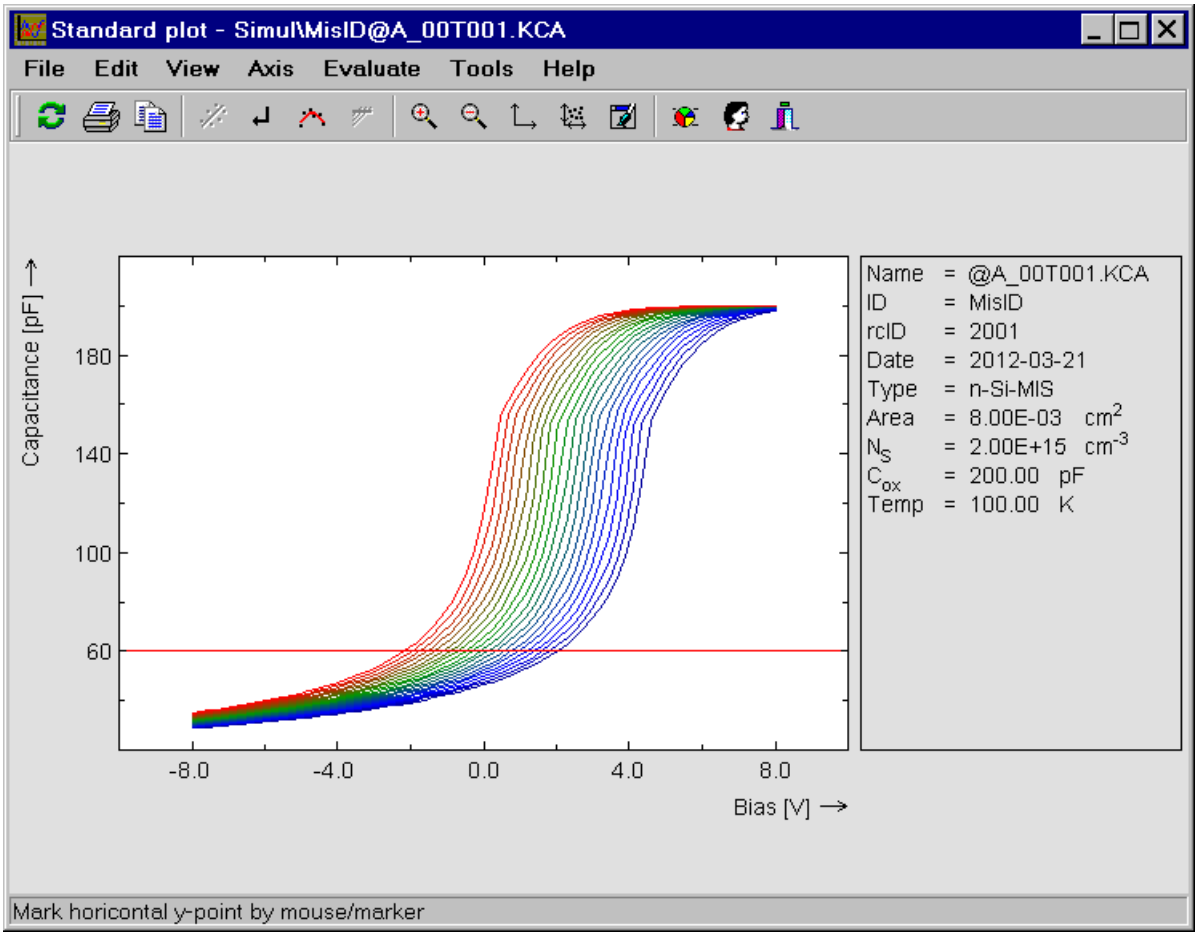
The button '**View**' opens the input window for showing all curves in 1 plot, see chapter 5.1.7.2. Some inputs there has now no influence.

The following shows a simulation of C/V curves with a bias shift. All curves will be drawn in one plot by different colors.

The software starts with the following text in the status line: 'Define reverse bias capacitance by horizontal marker'. Now you have to click onto the horizontal marker button  in the tool bar. You get then the following text: 'Mark horizontal y-point by marker'.
The red horizontal marker line will be set. If it is the first use of a horizontal marker then it will be set to the plot window minimum, in the other case to the old value. The plot shown below describes this time point.

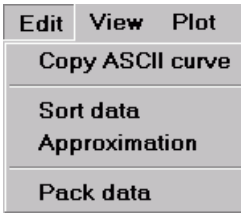
Now you can move the marker line by the cursor keys or set it by a mouse click. Look in chapter 5.1.6.5 for more details of using the marker. During the marker movement you see the capacitance value in the status line as first value. For applying the marker position and going on you have to click onto the 'Apply/Enter' button or to press the 'Enter' key. If you are working by the mouse then a left mouse click sets the marker at the mouse position, applies this position and the software goes on.

Now the reverse bias capacitance CR was defined and you see in the status line: 'Define now pulse capacitance by horizontal marker'. Go on with the same procedure as you have done for CR. After applying CP the software closes the plot window and searches UR, UP and the 3 capacitance values as explained above. Then you get a question for saving the QU-file. At the end the bias versus temperature will be shown.



4.4.2 Edit menu

By the edit menu it is possible to edit and modify the data in the memory. The file itself will not be changed. After reading the file again you lose the changes. For changes of the file you have to save the Arrhenius file, here you get a question for overwriting.



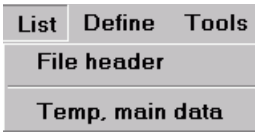
Copy ASCII curve copies the temperature and one selected result or other value line by line in an ASCII format to the clipboard. You can define the delimiter and the exponential format in the menu ASCII parameters. You find it in Tools of the plot or list program.
Sort data sorts the data by the temperature, normally not necessary.
Approximation was already explained in chapter 2.6.2.
Pack data means that not valid points (see note at the previous chapter) will be deleted.

At **user class 5** here are: Edit ASCII curve, Change temp axis (see chapter 3.4.2.1), Merge to CQ/QI-file. The last one merges 2 files (QR, QF, QP) of different voltages to one QC or QI-file.

At **user class 6** here are: Edit ASCII file, Edit curve by plot.

4.4.3 List menu

By the list menu it is possible to list the file header and the temperature with the main data. The most abbreviations are explained in chapter 1.3.4. The file header shows at a QU-file also CR and CP for which UR(T) and UP(T) was applied. Additional the fix 2 voltages UR0 and UP0 will be listed for which 2 capacitance values in dependence of the temperature are saved in the data file.

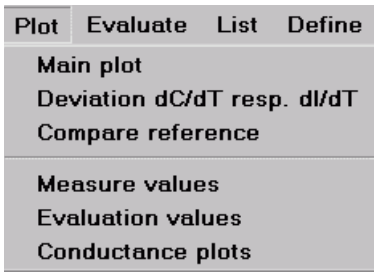


The main data depends on the file format. At QC-files there are CR, CP, Ns and UD; at QI-files there are IR, IP (means current at UR and UP), n-factor and the saturation current. QU-files list UR, UP, CR0, CP0. This list will be shown for every temperature data point.
At a QR, QF and QP-file the main data are capacitance C and current I.

At user class 5 is a user defined list possible. Here you select the values for the listing.

4.4.4 Plot menu

By the plot menu it is possible to plot all values of the equilibrium data array.



The main plots shows, depending on the file format, CR and CP, IR and IP, UR and UP or UR and IR. A linear or logarithmic axis is possible for the current.
At QR, QF, QP, QC and QI- files the deviation of capacitance or current by the temperature is possible. The data curve can be smoothed for the deviation.
Compare reference compares capacitance, current resp. voltage with that one from a reference file, see chapter 2.6.1.
Measure values are the data of the main plot and the temperature and the time.
Evaluation values depend on the file format. That are Ns, UD and phiB for QC-files, n-factor, UD, phiB and the saturation current IS for QI-files. The values can be plotted with a linear or logarithmic axis, the x-axis can be the temperature or the reciprocal temperature. For QU-files such a plot is not possible. There exist a plot called 'Plot 2 curves'.

If the data file contains also the **conductance** then 'Conductance plots' is visible. There you can plot the parallel or serial capacitance, conductance and resistance. The possibilities and the input window are similar as shown in chapter 3.1.4.2. You can select between values at voltage UR or UP at a QC-file.
If there is no question for parallel or serial capacitance (Cp or Cs), the measured parallel capacitance will be used. It is the default one in this sub program. This is not valid for the C/V curves in the Define menu. The definition of the Static Program is here valid.

At the QC-plots **Ns0** will be listed at the data header. Ns0 denotes the shallow concentration saved in the data header.

Note: If you have measured I/V curves in forward direction then perhaps the voltage axis is limited because the current limit. Especially the IP value can then be wrong because it don't exist for UP. IP will then not found by an interpolation but by an extrapolation.

4.4.4.1 Measure values

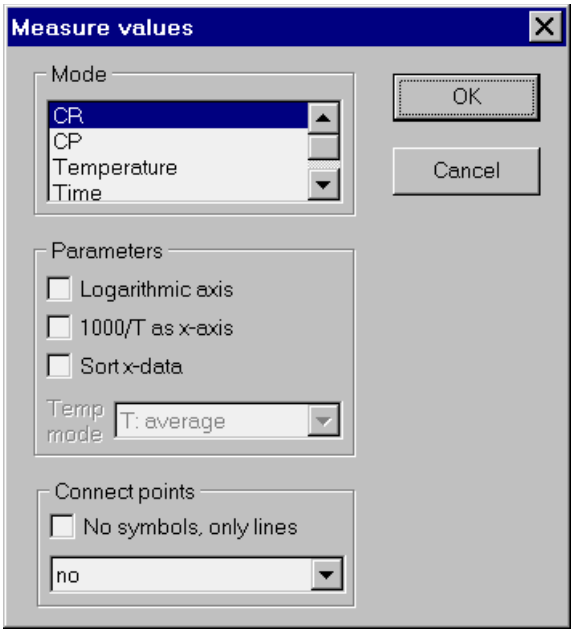
This plot shows the measure values. Depending on the data format following **modes** exist:

- **CR, IR or UR**
- **CP, IP or UP**
- **Conductance GR and GP when exist**
- **Temperature**
- **Time**

At **QU-files** additional values are possible, an explanation will be given in the next chapter:
C(UR0), **C(UP0), C(UR-UR0+UP0)**

At showing the **temperature** you can select its value, see chapter 1.3.6:

T: (TA+TB)/2, average of before and after static curve measurement
TB: before measurement
TA: after measurement
TD: TB-TA, difference before - after
T-T[1]: average temp - first average temp
No.: temperature versus data number
TC: sensor 1 (control), if using 2 sensors
TV: T-TC, sensor 2 (sample) -sensor 1 (control)



Time means the time when the static measurement was done, time zero is the start of the first static curve. Following time modes exist:

time: Plots the time versus temperature.
time difference: Plots the time difference means the difference from one data point to the next versus temperature.
time diff % nbr: Plots the time difference versus data point number.
d(time)/dT: Plots the deviation time by temperature.
dT/d(time): Plots the deviation temperature by time.
dT/d(time) smooth: As above but smooth the data curve before the deviation.

The values can be sorted and plotted with a linear or logarithmic axis, the x-axis can be the temperature or the reciprocal temperature.

4.4.4.2 Plot 2 curves

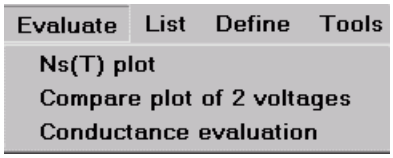
This plot exists only for QU-files. These files can be used for CC-DLTS, the making and data structure of these files was explained in chapter 4.4.1.5.

2 or 3 curves versus temperature in one plot will be shown here:

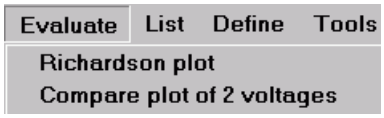
- **UR and UP:** Shows UR and UP which was defined for a fix CR resp. CP.
- **C(UR0) and C(UP0):** Shows the capacitance for a fix UR0 resp. UP0.
- **C(UR0), C(UP0), C(UR-UR0+UP0):** As before but shows additionally the capacitance at UR-UR0+UP0. So this curve can describe at CC-DLTS the pulse capacitance of a fix pulse height. While UR changes with the temperature is UR0 and UP0 and so the pulse height UP0-UR0 constant. UR-UR0+UP0 is the pulse voltage.

4.4.5 Evaluate menu

The evaluate menu depends on the data format. Only the menu item 'Compare plot of 2 voltages' is for all files possible. There you can select the capacitance, current or voltage itself at UR and/or UP. Additionally the difference of both curves can be plotted. All curves can be plotted together in one plot or in separate plots. The inputs are similar as described in chapter 2.6.1 but here is no reference file necessary. If you have read here a QR, QF, QP, QB or QV-file then for this comparison the corresponding second file will be read.



The picture on the left shows the evaluate menu for QC-files. The Ns(T) plot shows the evaluated value shallow concentration versus temperature. An evaluation, similar to an Arrhenius plot, is with this curve not possible. If the conductance is available then special evaluations exist.

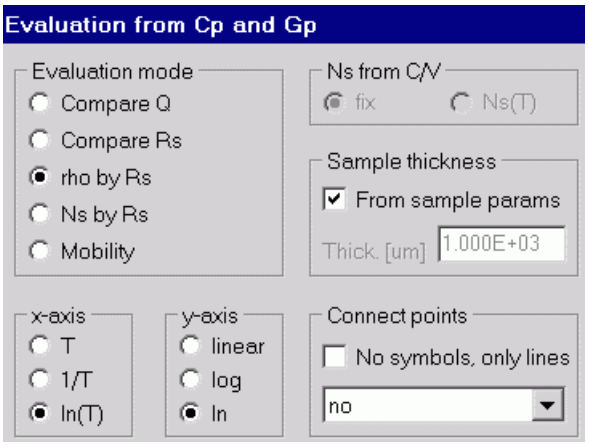


The picture on the left shows the evaluate menu for QI-files. The temperature depending saturation current IS allows an evaluation similar to the Arrhenius evaluation, it will be called Richardson plot.

4.4.5.1 Conductance evaluations

When existing capacitance Cp and conductance Gp in the data file, the Evaluate menu has the additional feature 'Conductance evaluation'. Following **evaluation modes** exist:

- **Compare Q:** Compares the quality Q calculated by the measure values Cp and Gp with the analytical Q. The last one will be calculated by the analytical values of Cs (equ. 1.1 of Theory Manual) and Rs.
- **Compare Rs:** Compares Rs calculated by Cp and Gp (measure) with the analytical value of Rs.
- **Rho by Rs:** Calculates the specific resistance by measured Rs.
- **Ns by Rs:** Calculates Ns from Rs, needs the mobility from the material parameters.
- **Mobility:** Calculates the mobility by comparison of Ns calculated by Rs with Ns from a C/V measurement.



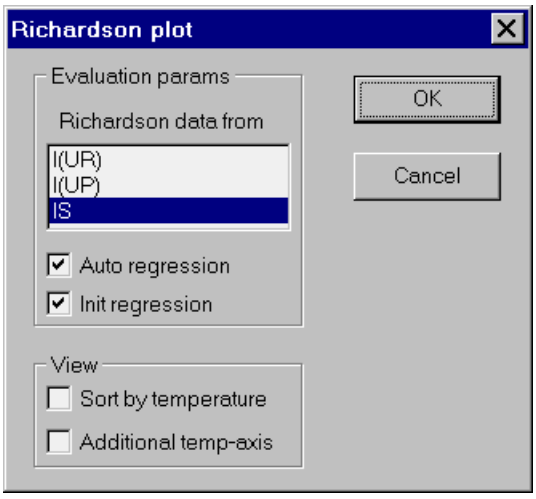
The **x-axis** can be: T, 1000/T, ln(T).
The y**-axis** can be linear, logarithmic or ln(y).
The analytical calculation of Rs and the evaluation of mobility needs **Ns** from the C/V measurement. This value can be applied from the sample parameter set (fix=T-independent) or, at a QC-file', from the temperature depending evaluation values Ns(T).
The evaluations need the **sample thickness**. You can either apply it from the sample parameter set or input here a local value.

The last 3 evaluations allows a linear regression over the data. When selecting ln(T), ln(y) and rho or mobility you get as slope the temperature exponent of mobility.

4.4.5.2 Richardson plot

You can define from which the **Richardson data** come from:

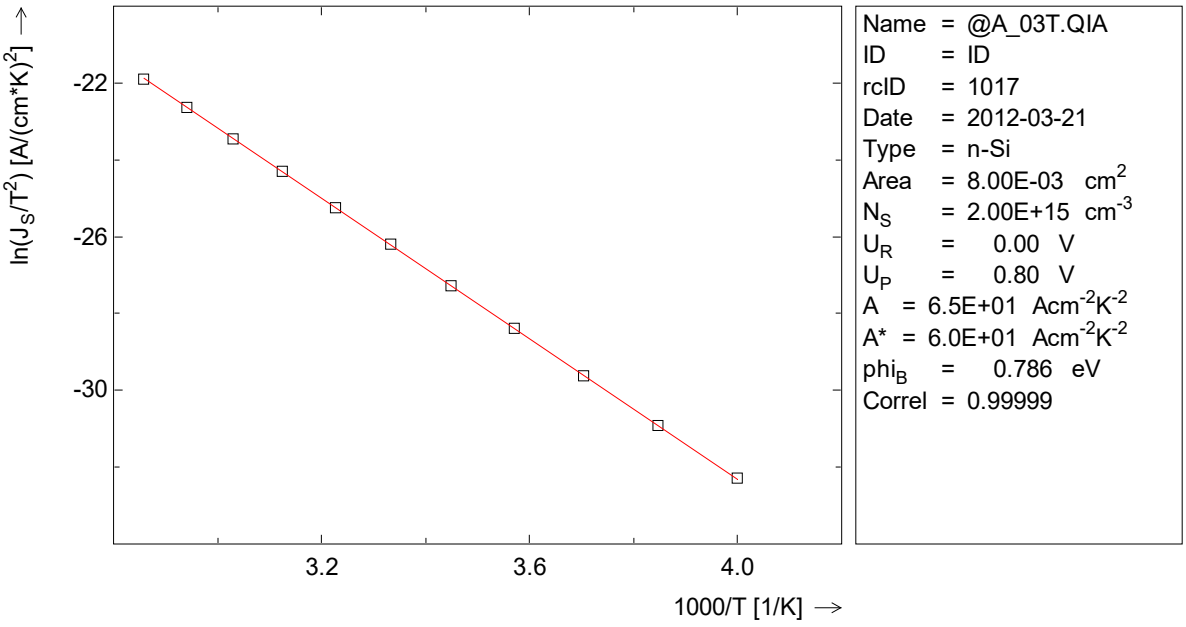
I(UR): Current at UR, not a true Richardson plot.
I(UP): Current at UR, not a true Richardson plot
IS: Saturation current, that is the origin Richardson plot.



Activating **Auto regression** starts the plot with an automatic linear regression.
Activating **Init regression** makes a new initialization of the linear regression, that means the x-axis range used for the linear regression will be set newly, in the other case the range will be taken from the file.
It is possible to **sort** the data and to show an additional **temperature axis** at the top of the plot.

The Richardson plot makes an evaluation of the current versus the reciprocal temperature. From the slope with get the barrier height and from the intersection the Richardson constants A and A*. For more details see chapter T1.1.5 of Theory Manual.

The following plot shows a simulation.



Note: Using I(UR) or I(UP) gives not a true Richardson plot. The barrier height which was calculated from the slope can be okay but not the Richardson constant which comes from the intersection. The reason for these possibilities is to compare it with 'Richardson' likes plots of the leakage current in the tempscan module, see chapter 3.4.4.6.

If a Q-file was read which contains the saturation current then the standard Richardson plot will be drawn on the main canvas. This plot uses always the saturation current and will be shown as application plot.

5. Common program modules

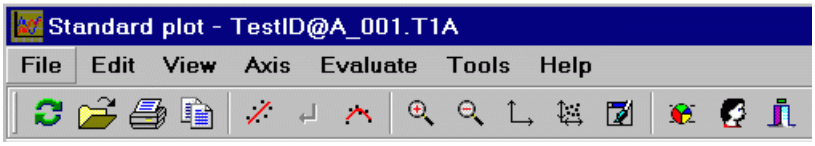
Depending on the kind of work which you do in the main program modules you can call further common program modules (tools), so different plot programs, list programs and the database. These tools will be explained in the following chapters.

Program tools have his own sub window with menu bar and toolbar. The plot or list will not shown on the main canvas but on the canvas of the sub window.
Normally this window will be shown under the caption line of the main window or as a kind window, see chapter 2.3.1.
The 'Exit' entry at the file menu was replaced by 'Close'. By 'Close' you don't exit the main program but you close only the program tool and go back to the measurement or previous program. The same will be done by clicking onto the additional 'Close' button in the toolbar.

If calling a function of another common program module the current window will be replaced by the window of the called program module (tool). So only one sub window is visible, dialogs not considered.

5.1 Standard plot program

The most used common program module is the Standard Plot Program. If you select a plot or an evaluation the program shows this plot normally by the standard or application plot program. In the standard plot program you can change the axis of the plot window, the plot symbol, the linear regression (if possible) and so on.
Many parameters in this plot program are only local, this means if leaving and entering again this program tool then these parameters will be set to the default ones. The global plot parameters are an exception, see chapter 2.3.3.
Some options are not enabled if more than one curve will be shown. The 'plot software option' is necessary for some functions, e.g. for the Tools menu.
This plot program has no own data type. You can also here open the measurement data without leaving the plot program.
Which menu entries and tool buttons are visible and enabled, depend on the kind of data.



The following buttons of the **toolbar**, except for the regression, are visible in most cases:

Repeat the inputs of plot.

Open a measurement data file.

Print the plot on a printer.

Copy page to clipboard.

Linear regression, sets start and end value by mouse and calculate regression.

Apply the selected plot and so on, for example for the linear regression.

Interpolate plot points by a line.

Zoom-in the plot window.

Zoom-out the plot window.

Axis input parameters for the plot window.

Axis rescale to the standard window.

Refresh the plot**.**

Call the **Presentation plot program.**

User button is a user definable button, see chapter 2.3.4.

Close the standard plot program and goes back to the previous program.

The following buttons only visible in special cases:

Shows **Next** file or data point.

Data tasks for saving and printing data, save evaluation to database.

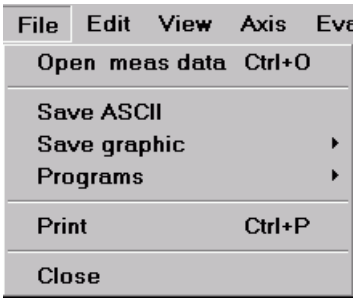
Current **level number**, toggles between first and last level by mouse click.

Following **shortcuts** exist for the menu, but not all are always possible:

F1:	Help information, opens this manual at the corresponding chapter.
F2:	Repeats the inputs of plot.
F5:	Refresh the plot.
F7:	Calls the library.
F8:	(Automatic) linear regression, sets start and end value by mouse.
Ctrl+F8:	Starts the manual linear regression.
F11:	Personal hot key 1, see chapter 2.3.4.
F12:	Personal hot key 2, see chapter 2.3.4.
Ctrl+C:	Copy page to clipboard in the bitmap format.
Ctrl+O:	Opens a measurement data file.
Ctrl+P:	Print the plot.
Ctrl+S:	Save the current measurement data.
Ctrl+V:	Paste a bitmap graphic from the clipboard.
Enter:	Apply the selected plot and so on, as Apply button.
PageUp:	Shows previous file or data point.
PageDown:	Shows next file or data point.
Alt+F4:	Close the standard plot program.

5.1.1 File menu

The standard plot program has no own data type. If coming from a measurement or sub program, you can also here read the (measurement) data and show the last selected plot. It is not necessary to leave the plot program, read the measurement data and then to call the plot program again. For this option you must have read measurement data or saved the last measurement. If not saving the last measurement, you can here save these data. If not saving data or if an evaluation is possible, then here the Data task entry is visible. Several tasks, so saving and printing the data and saving evaluation values into the database, can here done.



Save ASCII data saves the current x,y plot values line by line in an ASCII format to a text file. This option is only enabled if one curve will be shown. You can define the delimiter and the exponential format in the ASCII parameters of the Tools menu.
Print opens a dialog for printing the plot. If installed a HPGL printer (I3.2) then here is a special entry for its use.
By 'Close' the standard plot program will be closed and the software goes back to the previous program.

Programs opens a sub menu for further program tools. If calling one of these tools the software jumps to this tool and don't come back to the standard plot program. If closing this tool, the software goes back to the previous program module, normally one of the measurement or sub programs. If more than one curve will be shown, only the presentation plot program is enabled.

ListData lists the data in a grid, image or ASCII editor (chapter 5.4)
EditData enables to edit the x/y-data in a grid or ASCII editor (5.4)
EditPlot enables to change, read and plot the x/y-data (5.3.2)
CompPlot compares in a plot the current data with saved data (5.3.6)
PresPlot opens a new complex plot program with many features (5.2)

The presentation plot program is here the perhaps most important program tool. It gives the possibility to show curves of (manually loaded) different files. You can also show different plots (layers) in one picture. There you can also save the full picture without a graphic format.

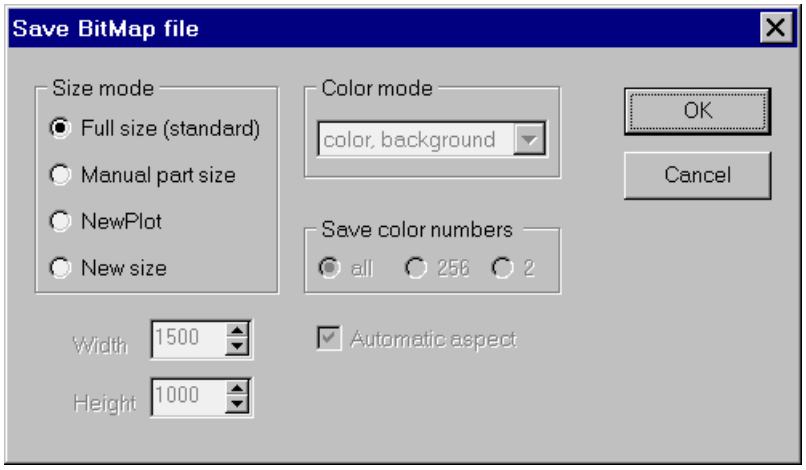
If showing curve by curve from many data points or files (e.g. I/V curves at many temperatures), a **Next datas** sub menu exist for navigating to next or previous data or to input the data number, for more information see chapter 5.1.7.1.

5.1.1.1 Save graphic

Save graphic opens a sub menu for saving the plot in a graphic file format. Bitmap and vector formats exist: BMP, PCX, GIF, JPEG; PLT, HPGL, WMF / EMF, EPS, ACAD. Before saving you get a special dialog for some parameters and the standard Windows dialog for saving data. For saving into the PDF format use a virtual PDF printer.

Tip: WMF or EMF is the standard format for saving plots. If you need a bitmap format use GIF. The JPEG format is not suitable for plots.

5.1.1.1.1 Bitmap formats



Depending on the bitmap graphic format (BMP, PCX, GIF, JPEG) you get similar inputs. The following input is for the BMP format. For PCX and JPEG files you can select the compression.

The enabled inputs depend on the **Size mode:**

Full size: This is the standard mode. The graphic will be saved as shown on the screen.
Manual part size: You can select a part of the plot by the mouse.
NewPlot: You can select the color mode and the saved color numbers.
New size: You can select a new pixel size and the color mode. At activating 'Automatic aspect' is only the input of width necessary.

The **color mode** defines the background color and the use of a color plot:

mono, white lines: Monochrome plot with white lines and symbols.
mono, black lines: Monochrome plot with black lines and symbols.
256 grey scales: 256 grey scales, no background color.
color, transparent: Color plot, transparent background.
color, no background: Color plot, no background color (white background).
color, background: Color plot, background is as on the screen, including the special background inside the plot window.

Save color numbers defines the numbers of colors: 2, 256 or all.
If the data were interpolated then there is the additional input **Print data** (chapter 2.2.4).

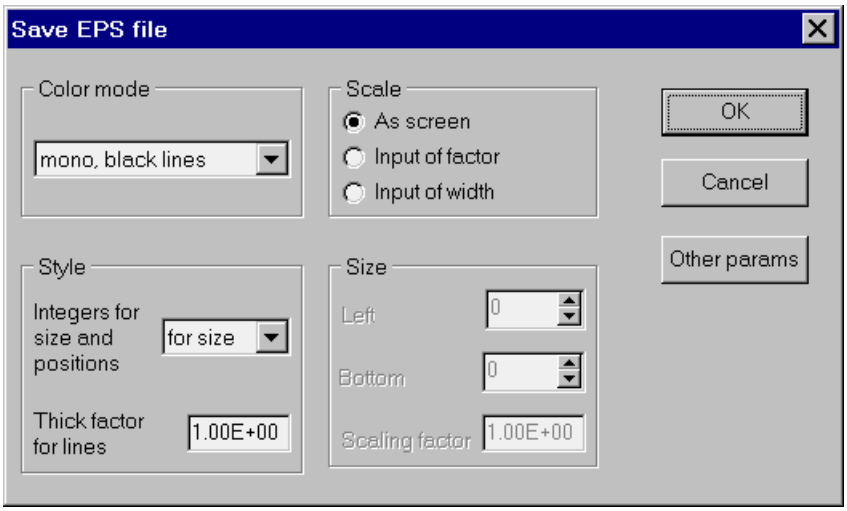
5.1.1.1.2 Vector formats

At PLT and HPGL you get similar input windows as for printing, see chapter 2.2.4.
At **Windows meta files** you can select the color mode and between Aldus (WMF) and Enhanced (EMF) meta file. The EMF format is the newer and better one. If possible use this format for saving vector graphics.
Only monochrome ACAD files are possible.

5.1.1.1.3 EPS format

The EPS (**E**ncapsulated **P**ost **S**cript) format is also a vector graphic:

The color mode is as above but without the transparent mode.
The values for size and positions (coordinates) can be saved in the file as integers or as real numbers.
A factor can be defined for the thickness of lines.



For the **scaling** from plot coordinates or sizes to the values in the EPS file there are 3 possibilities:

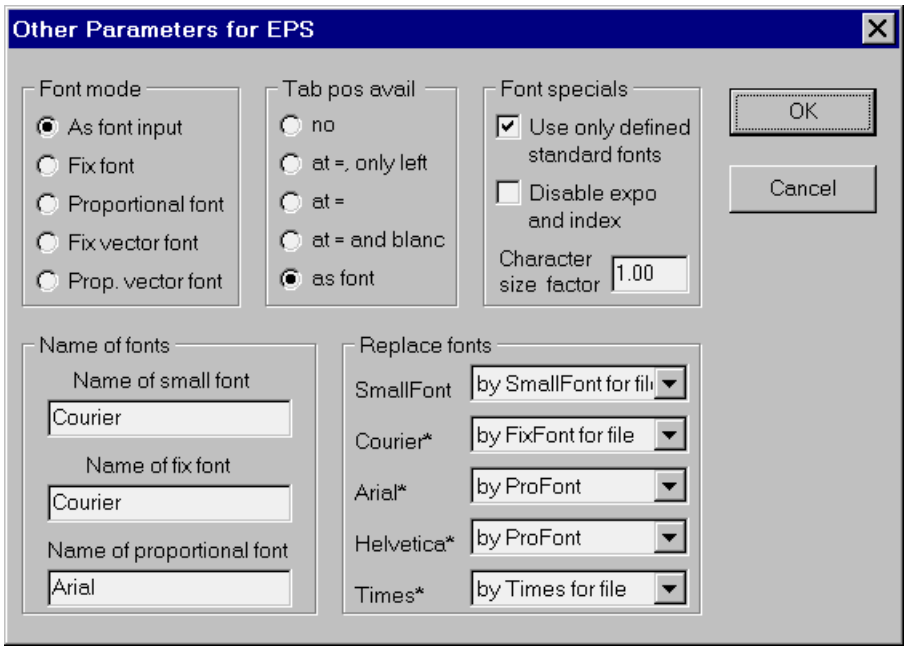
As screen: The same values as for the screen will be used.
Input of factor: All plot positions, sizes and so on will be multiplied with a user defined scaling factor. For the plot positions there can be defined a left (x) and a bottom (y) offset.
Input of width: All plot positions and sizes will be scaled to a given maximum width. For the positions there can be defined a left (x) and a bottom (y) offset.

Other params opens a new input window which will be used in similar way also for the printer and other graphic formats:

The used fonts can make problems if using an EPS file with another program like GhostScript. Most PostScript interpreter don't know the Windows fonts Courier New, New Times Roman or Arial. Some EPS interpreters break then the plot, some ones give a warning, others ones go on without a warning. If the interpreter don't break but don't know the used font, it will replace this font by another one. The size of this font can be different as the original in Windows used one. Then positions and style of the text may be bad, especially at right centering text because this centering needs the exact text length.

Normally you use for the **font mode** 'As font input', that means for the EPS file the same fonts will be used as for the screen. You can also select a fix or a proportional Windows font for all used fonts. The vector fonts are old fonts and should only be used if absolute necessary.

Tab. pos avail means where a tabulator for EPS is available if there is a tabulator in the text. After a tabulator the text will be broken. For the start of the text after the tabulator a new x-position will be calculated by a medium character width. So you can center a text for a table. The tabulator is only helpful at proportional fonts (variable character width), for fix fonts (fix character width) as Courier New this is not necessary.



The modes for the available **tabulator** positions are:

no:	Don't use tabulators.
at =, only left:	At a '=' is a tabulator available, the new text position starts directly at the '=' sign.
at =:	At a '=' is a tabulator available, blanks directly after the '=' sign will be treated as a tabulator.
at = and blank:	At a '=' and every ' ' is a tabulator available.
as font:	The tabulator is available as defined for the used font (chapter 2.3.3).

To avoid the EPS font problems discussed above there is the option to **use only defined standard fonts**. If activating this option then you can define the files using for the EPS file. The 3 font names at the left bottom window part are the names for the standard small, fix and proportional font in the EPS file. Use only fonts which your EPS interpreter knows! At the bottom right window part there are the names and modes of Windows fonts which you will be replaced by the EPS standard fonts. 'Courier*' means all font names which contain the string 'Courier', for example Courier New.

Following modes exist for 'Arial*', other inputs are similar:

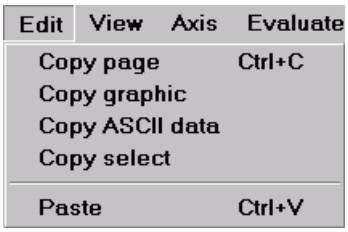
no:	No replacement of the 'Arial*' fonts.
by Arial:	The font name will be replaced by 'Arial'.
by ProFont:	The font name will be replaced by the name of proportional font.
by Arial for file:	As above, but only valid for saving into a file.
by ProFont for file:	As above, but only valid for saving into a file.

Note: At EPS there is no difference between the mode 'only valid for saving into a file' and the other mode because EPS is only possible for saving into a file. At HPGL it is also possible to send the graphic directly to a HPGL printer.

At the **font specials** input there are some other options. So you can disable exponent and index in the text. The character size for the fonts can be multiplied with a factor. This can be helpful if the EPS interpreter replaces unknown fonts by unfavorable standard fonts.

5.1.2 Edit menu

By the edit menu it is possible to copy a graphic or the data into the Windows clipboard.



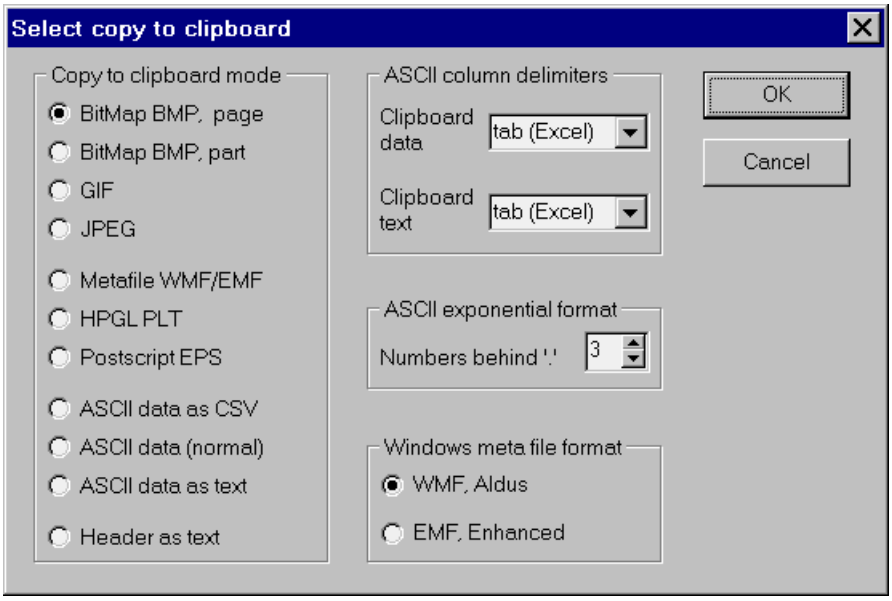
'Copy page' copies the graphic as a bitmap into the clipboard,
'Copy graphic' as a Windows meta file (WMF or EMF).
'Copy ASCII data' copies the current x,y plot values line by line in an ASCII format, only enabled at one curve.
'Copy select' asks for the format before copying.
'Paste' shows a bitmap graphic from the clipboard on a definable position of the screen.

5.1.2.1 Copy select

Some different types of **copy modes** exist:

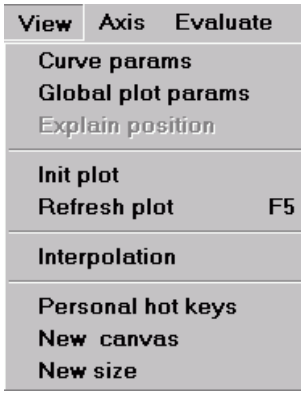
1. Bitmap graphics
    1. BitMap BMP, full page as on the screen
    2. BitMap BMP, part of the plot defined by the mouse
    3. GIF
    4. JPEG
2. Vector graphics
    1. Windows meta file, WMF (Aldus) or EMF (Enhanced) selectable
    2. HPGL / PLT
    3. Postscript EPS
3. ASCII data, only enabled if one curve is been shown
    1. as CSV (comma separated values)
    2. normal ASCII data, special column delimiter
    3. ASCII data as text with data number and caption
4. Plot header as text

Separate **ASCII column delimiters** exist for clipboard data and clipboard text. Following delimiters are possible:
blank, double blank, comma, semicolon, tab, &, “;”, “tab”, cr, lf, cr+lf.
Many programs use a blank or a comma as a separator, Excel uses the tabulator character, DBase the semicolon.
The ASCII data will be saved in the exponential format, you can define the numbers behind the point.



5.1.3 View menu

In the view menu you can set the window and canvas size, curve and global plot parameters and personal short cuts.



'Curve params' are the local params for the shown curve. 'Global plot params' were already explained in chapter 2.3.3.
If different curves will be explained then you can change the default explain position.
'Init plot' makes a new window/axis initialization, 'Refresh' plots the plot again.
'Interpolation' opens a input window as described in chapter 2.7.1.
'Personal hot keys' and 'New size' were already explained in chapter 2.2.4 and 2.2.5.
'New canvas' defines manually the canvas size instead to set it from the form size. The inputs are similar to 'New size'.

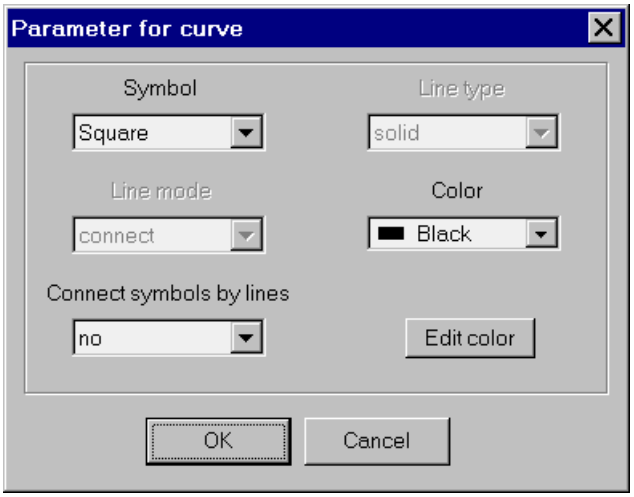
5.1.3.1 Curve params

5.1.3.1.1 One curve

If only **one curve** was shown in the plot then the following input window opens. All these parameters are only local, this means if leaving and entering again this plot program then these parameters will be set to the default ones.

Following **symbols** are available:

1. Square
2. Cross +
3. Diamond
4. Cross x
5. Triangle
6. Circle
7. Full square
8. Full circle
9. 3x3 points
10. Point
11. Line



If selecting the line then you can set the **line mode**, for an explanation see below:

1. connect
2. connect + clipping
3. interpolation
4. interpolation + clipping
5. approximation
6. approximation + clipping
7. medium approximation
8. medium approximation + clipping
9. approximation by cubic Bezier curves
10. vertical line to the window minimum
11. vertical line → 0

Following **line types** are available: solid, dash, dot, dash-dot, dash-dot-dot.

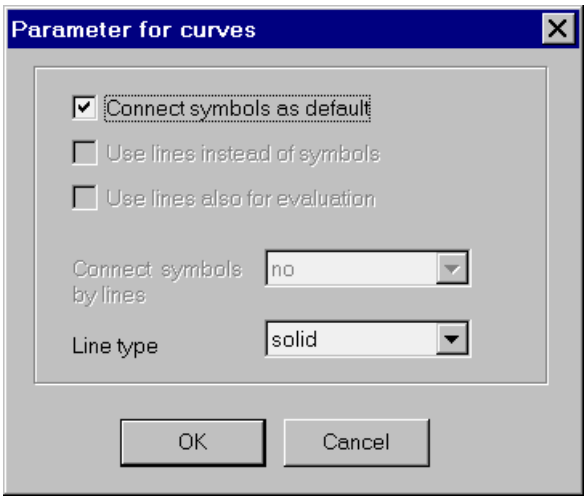
Following **connecting modes** are possible if the selected symbol is not the line:

no:	The points (symbols) will not be connected by lines.
connect:	The points (symbols) will be connected by lines, no interpolation or approximation will be done.
connect + clip:	As above but the lines will be clipped. Clipping of lines means that if a point (symbol) is outside the plot window then the line will be drawn to the plot window and at the window cut off. In the other case only the visible points inside the plot window will be directly connected.
interpol:	The points will be connected by interpolated lines. The interpolation for the connection line will be done by splines without smoothing.
interpol + clip:	As above but the lines will be clipped.
approx:	The points will be connected by interpolated smoothed lines. The interpolation will be done by splines with weak smoothing strength 45.
approx + clip:	As above but the lines will be clipped.
medium approx:	The points will be connected by interpolated smoothed lines. The interpolation will be done with medium smoothing strength 50.
medium + clip:	As above but the lines will be clipped.
cubic Bezier:	The points will be connected by interpolated slightly smoothed lines using cubic Bezier curves.

At **color** you can select one of the standard colors as listed at the right. If the old selected value was not a standard color then this color will be listed in the standard color dialog as 'Other'. The **Edit color** button opens the Windows dialog for editing the color. There you can select all possible colors.

5.1.3.1.2 Some curves

If **some curves** were shown in the plot then the following input window opens:

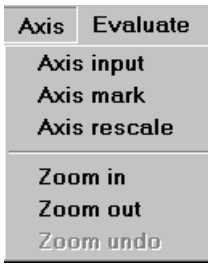


If activating a flag then the symbols will be **connected** as default defined. In the other case you can select the connecting mode for all curves as described in chapter 2.7.2. These inputs here are local.

The **symbols** and **colors** for each curve can not be local defined. For these the symbols and colors for curve 1 to 6 of the global plot parameters will be used, see chapter 2.3.3.1 and 2.3.3.2.

5.1.4 Axis menu

This menu enables to set the axis of the plot and a new plot window. This can be done by an input, by the mouse or by the zoom function.

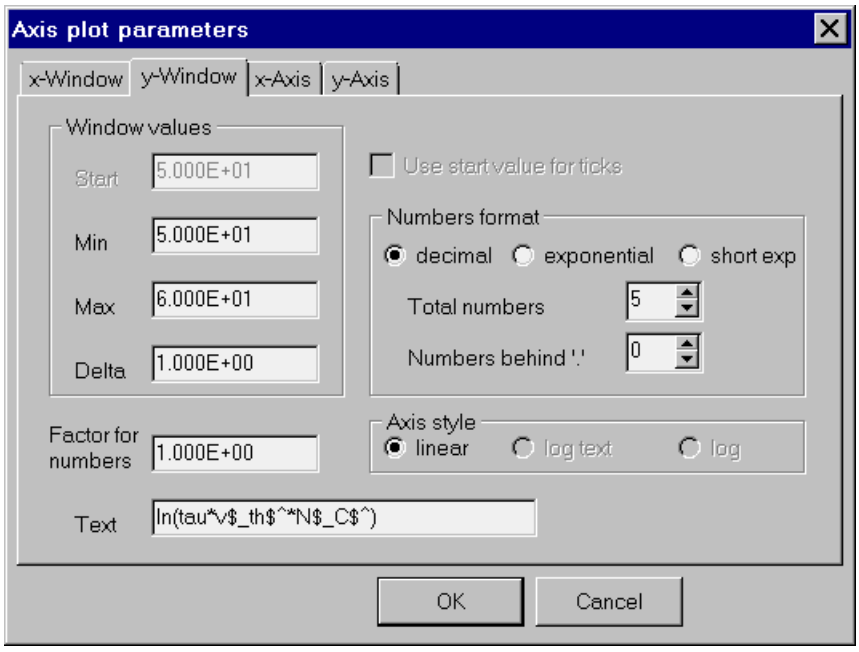


'Axis input' opens an input window for the x,y-axis parameters.
'Axis mark' enables to set a new plot window by marking the left/bottom and right/top point. You can define points inside of the plot window (zoom) or outside, but the defined points must be inside of the canvas.
'Axis rescale' restores the standard plot window.
'Zoom in, out and undo' are the standard zoom functions. For zooming-in you have to mark the center point by the mouse.

5.1.4.1 Axis input

Separate input sheets exist for the x- and y-axis, at 3-dimensional plots additionally for the z-axis. In the following only the inputs for the y-axis will be explained.

5.1.4.1.1 Window input sheet



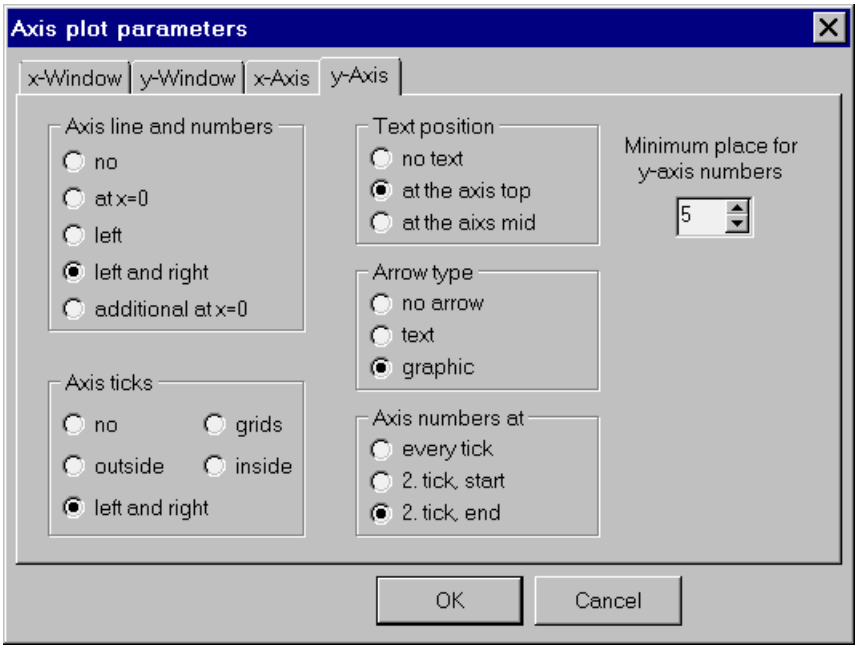
The **Window values** input group contains the inputs for the minimum, maximum and delta value of the axis. The numbers of intervals (axis ticks) will be set by the delta value.
The x/y data are always in the base dimensions (see chapter 1.3.5), for example V for the voltage. Nevertheless it is possible to show the axis as mV. The **factor for numbers** is for this use. In the example of mV the factor must be set to 1000, then all numbers at the axis will be multiplied with this factor. But the inputs for the window values must be in the original dimension V.

Text is the axis caption text, it can contain characters for index ($_) and exponent ($^). For the end of the index text use $^.

The **numbers format** for the axis numbers can be decimal (1.23), exponential (1.23E+00) or short exponential (1.23E0). You can define the total numbers and the numbers behind the point.
If the **axis style** is linear, no change is possible in the standard plot program. Is it logarithmic, then you can select between logarithmic text, for example log. voltage, and logarithmic axis ticks.

5.1.4.1.2 Axis input sheet

The window around the plot will be defined by **Axis line and numbers.** If selecting bottom and top for x-axis and left and right for y-axis then a full window will be drawn around the plot and on the bottom and left axis line there is the numbers and axis text. 'Additional at x=0' is as left and right, and draws a vertical line at x=0. You can also select the kind of **axis ticks**. Left and right means that the ticks are inside of the left and right axis line. Other possibilities are left inside or outside of the axis line, or grid lines.

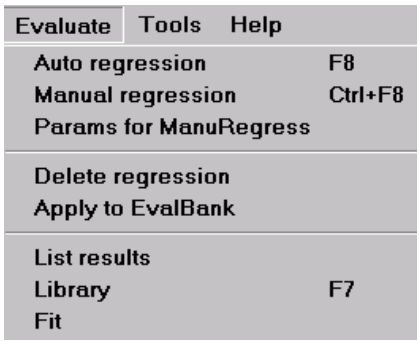


Text position defines the position of the axis text.
Top means that the y-axis ends at the top line.
The **arrow type** behind the axis text is only a text string or a graphic arrow.
Axis numbers at defines when at the axis the number will be printed. It can be done at every tick or every 2. tick. At start/end means that there is at the first/last tick a number.

For the y-axis there is also the input of the **Minimum place for y-axis numbers**. This means that software reserves the place for the selected numbers. This shifts the left axis line and change the size of the plot. This can be important if you compare different plots on a paper.

5.1.5 Evaluate menu

The possibilities of this menu depend on the kind of data. An evaluation by a linear regression is not always available. To apply the evaluation in the evaluation database (EvalBank) is only possible if an evaluation is available and was done. In some cases you can list the evaluation results in a special data grid or text window.



'Auto regression' is the standard linear regression, the 'Manual regression' can be started directly and with inputs of its parameters.
You can also delete a done linear regression. Then no regression line and no results will be shown.
If there are more levels available then in the Evaluate menu is the entry 'Level number' to set the current level number for the regression. In the toolbar you can then also see and change the current level number. A mouse click onto the level number button in the toolbar toggles between first and last level. Instead of 'Delete regression' the entry 'Delete level' exist which deletes only the evaluation/regression of the current level.

If calling the library or the fit, then the curve or evaluation will be compared with other curves coming from the library or the fit function. Have a look in the corresponding chapters for these functions. Library and fit are only available for special plots/evaluations of the DLTS software. The shown fit or library will be denoted by a hook left on the menu. To clear this function call it again and click onto the Cancel button in the input window.
'Save eval as file' exist sometimes to save the plot curve into a measurement data file.

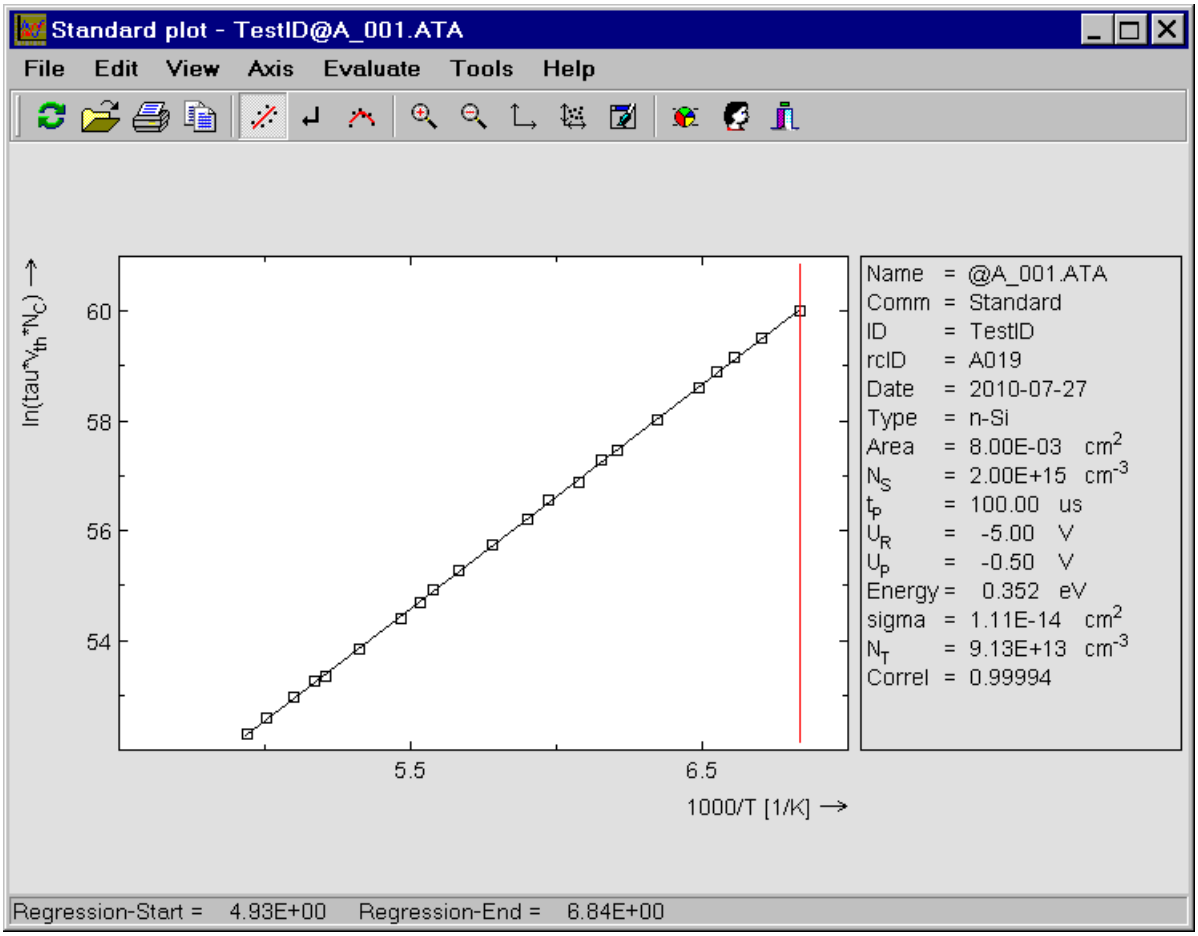
5.1.5.1 Auto regression

Auto regression is the standard linear regression, sometimes it will be called only regression. You have to set the **x-start** and **x-end** value of the range, which are used for the linear regression, by mouse or vertical marker (marking line). Left and right cursor keys move the marker slowly along the x-axis to the left resp. right, Up and Down move it in big steps to the left resp. right. The regression-start resp. -end value will be shown in the status line during the movement. The arrow in the marker denotes that the start or end value have to be set. Instead a new definition of start and end value you can apply the old (predefined) values by the 'Enter' key or button.
After setting the right point (end value) the evaluation results will be calculated again and then drawn by a straight line and shown in the text header or evaluation data grid. The old result text will be deleted but not the old regression lines. So you can compare the influence of different regression ranges. For deleting the old lines refresh the plot.

At the application plot the regression will be **done automatically** at calling the plot. In this case the regression line is normally red instead of black. You can change the color of the regression line in 'Global plot parameters', see chapter 2.3.3.1. The (red) regression line of the application plot program will there be called 'Application regression', the other (black) 'Standard regression'.

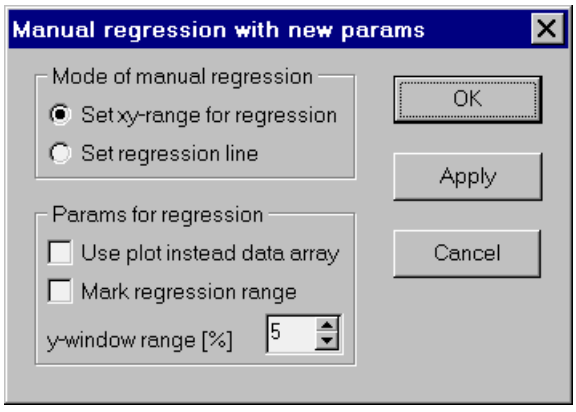
The **correlation** factor provides an indication of the deviation of the data from the regression. But be careful with the interpretation because the correlation factor is not very sensitive. You find a value of 0.99 in many cases.

The following picture shows an example for the auto linear regression:



5.1.5.2 Manual regression

For the manual regression you have to set the x/y-start (left) and -end (right) point by mouse or cross marker (see chapter 5.1.6.5). How this option works, depends on the following parameters:



For all modes is valid that only plot/data points will be used for the linear regression which x-values are inside the selected x-range.
The first mode is '**Set xy-range for regression**'. If not activated 'Mark range' then only points will be used which y-values deviate less as a given maximum difference from a line calculated by the x/y-start and end value. For the maximum difference you have to input the per cent y-window range. If activating '**Mark regression line**' then you have not to input a value but to define a 3. point for the maximum y-difference.
To use the plot instead the data array is normally not necessary.
In the first manual regression mode only the used points for the linear regression will be selected. The calculation of the linear regression and so the drawn line will be done in the normal way.

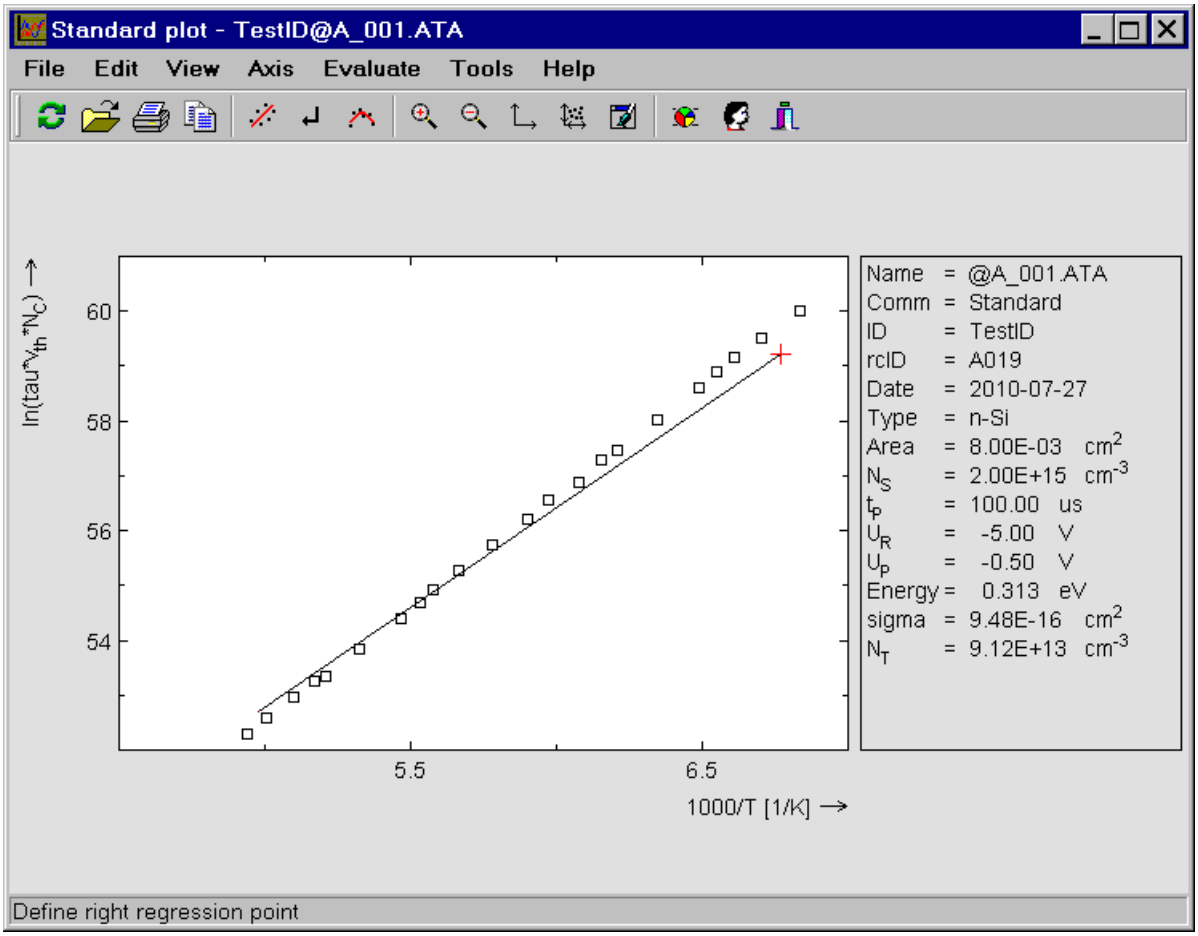
The second mode is '**Set regression line**'. In this case you define directly the line by the left and right point. This means the 'regression line' goes through these 2 points. No linear regression will be calculated for the line and results. The results will be calculated from the slope and offset of the defined line. Normally no correlation factor will be calculated and shown in the text. It is also possible to show 1.0 for the correlation value, see chapter 2.3.3.6. Another option is to activate the flag '**Calculate correlation factor**'. Then the correlation factor will be calculated from the given line and all data which x-values are inside the selected x-range.

In special cases there is an input for selecting the **NT value**. NT will not be calculated from the x/y values in the plot program but by special values of the main program! NT can be calculated by the average of all points of the used regression range, or by marking a point and searching of the corresponding NT value.

Note: The manual regression can be necessary at using many levels. If levels overlap in the x-axis then you can not separate the levels for the linear regression by setting x-start and x-end point. It is possible that you make the linear regression about the data of 2 'real' levels. Setting the x/y-start and the x/y-end point solves this problem.

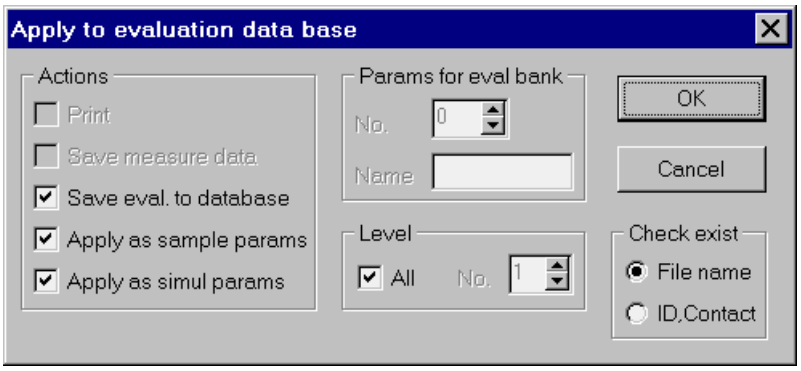
The **menu** entry 'Manual regression' starts directly this regression, the entry 'Params for ManuRegress' opens the input window with the parameters. The 'Apply' button there applies only the inputs, the 'OK' button starts additionally the manual regression.

The following picture shows the manual regression with the mode 'Set regression line':



5.1.5.3 Apply to EvalBank

You can save the evaluation results in the **evaluation database**.
If the evaluation gives a sample parameter likes Ns, it can be applied as sample parameter and for the simulation.
If the evaluation was already saved in the database, you get the question, whether you want to delete the existing record.



If saving Arrhenius data in the evaluation database a selection of **level** is possible.
At some evaluations and deactivating 'All levels' you can define a **number** and **name** of evaluation. The name is only for searching in the database (eval bank). The number is only for an easier comparison of results in the database. So you can restrict at the database your search of results by selection of an evaluation number.

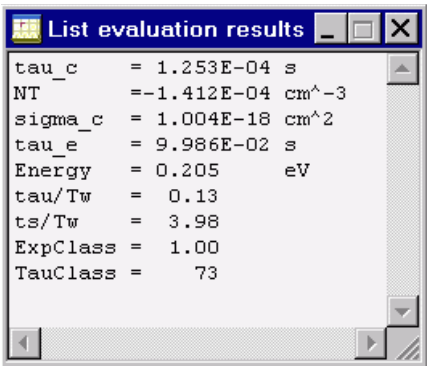
'**Apply as sample params**' applies the results into the sample parameter set.
'**Apply as simul params**' applies the results as simulation parameters. When 'all levels' is activated, the number of levels will also be defined.

Check exist search if the new **file name** or the **ID and contact** already exist in the database.

5.1.5.4 List results

In some cases you can list the evaluation results in a special data grid or text window. It is a non-modal window which may not be closed by an 'OK' or 'Cancel' button. This window will be closed at leaving the plot program or by a refresh of the plot. It can be separately moved on the screen, the program saves its position for the next call. If you click onto the left top icon of this window you get additionally to the standard Windows menu entries 'Minimize, Close ...' some special options.

An example will be shown on the right. For this text window the following additional options exist:



'StayOnTop' means that this window is visible in front of all other windows.
'Font' enables the selection of the text font and size.
'Copy' copies the text into the Windows clipboard.
'Editor' calls the integrated ASCII editor with the evaluation text.
'Image' calls the List Image program.

If activating 'StayOnTop' then this window will not be closed at refreshing the plot. So it stays during the total plot program until you close it explicitly or leave the plot program. You can also mark the text and then copy it into the clipboard by the Ctrl-C key.

5.1.6 Tools menu

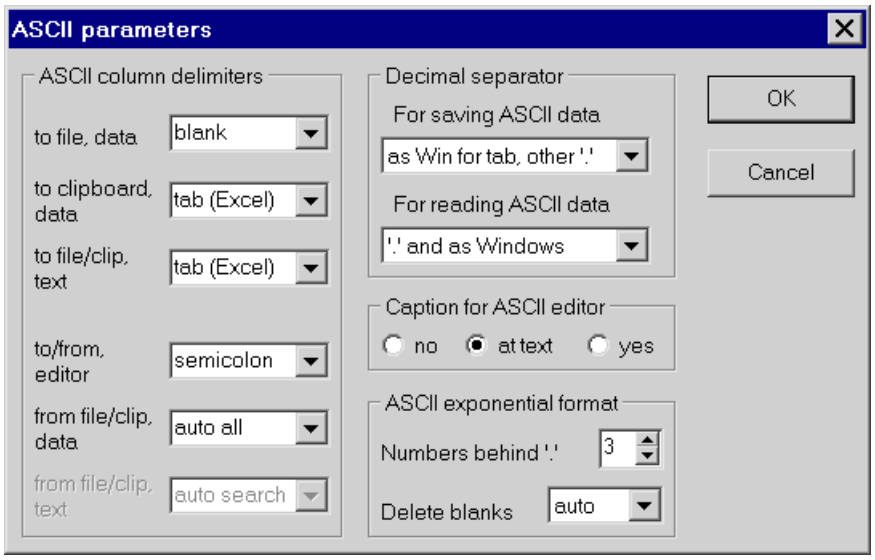
This menu contains some different functions.

User class was already explained in chapter 2.4.1.
ASCII parameters contains parameters for copying, saving and reading ASCII data.
List data lists the x/y-data as lines and columns.
Compare data compares the current data with other ones from an ASCII file or clipboard.
It is possible to create an extra window with a plot or data grid of the current data.
Marker tools are a help to identify a point or get its position.

At **user class 5** there are ActiveX/OLE tools. ChartFX is a chart plot program, Formula One a spread sheet. You can call Excel (Microsoft) or Calc (OpenOffice) with the current data or save into the Excel or Calc format.

5.1.6.1 ASCII parameters

The parameters for copying, saving and reading ASCII data are in this input window.



The first input group contains the **ASCII column delimiters**, following delimiters are possible: blank, double blank, comma, semicolon, tab, &, ";", "tab", cr, lf, cr+lf.
Many programs use a blank or a comma as a separator, Excel uses the tabulator character, DBase the semicolon,Tex/ Latex the "&" sign.
At reading ASCII data/text there is the possibility 'auto search' and 'auto all'.
The first mode takes the first valid delimiter as delimiter for all columns, the second mode accepts all valid delimiters for every column.

Different **delimiter inputs** exist for:

1. Save ASCII data into a file.
2. Save ASCII data into the Windows clipboard.
3. Save ASCII text into a file or into the clipboard.
4. ASCII data or text to the editor or from the editor.
5. Read ASCII data from a file or from the clipboard.
6. Read ASCII text from a file or from the clipboard.

There is no big difference in ASCII data or text. ASCII text contains as first line the caption for x and y. Normally ASCII data will be used.

The **decimal separator** can be selected for saving and reading ASCII data. This separator can be the point (standard English) or that one defined in the Windows operating system. At saving ASCII data there is the option: **as Win for tab, other "."**. This option means if the column delimiter is a tab, then the decimal separator is as in Windows defined, in other cases it is a point. This can be helpful when copying to Excel with local country definitions. At reading ASCII data there is the option: **"." and as Windows**. This option means the point and the decimal separator as in Windows defined will be accepted.

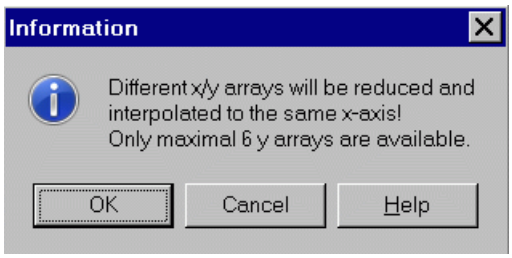
Caption for ASCII editor means when using the internal ASCII editor, the first line contains the caption for x and y. The caption is available only for ASCII text or for text and data (yes).

The ASCII data will be saved in the exponential format, you can define the **numbers** behind the point. **Leading blanks** can be deleted but then negative and positive values have different lengths. While this doesn't lead to a nice structure, it may be necessary for foreign programs when using a blank as delimiter. The mode 'auto' deletes leading blanks only at saving data into a file or clipboard if the delimiter is a blank.

5.1.6.2 List data

List data lists the x/y-data as lines and columns. Three kinds of view here are possible: the data grid, the image without and with header and the ASCII editor, for more details see chapter 5.4. In opposite to the call of the ListData program in the sub menu 'File → Programs' here the software comes back to the plot program.
If only one curve will be shown, that means only x and y data exist, the program jumps directly to the last used kind of ListData program.

If **some** (many) **curves** exist, that means more than one y data column, you get the following information:

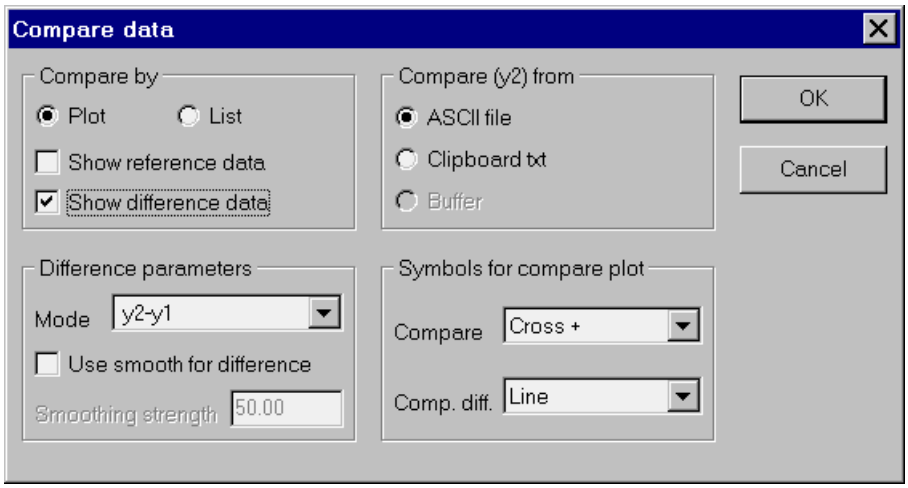


At some curves it can be that the curves have similar but not the same x-values. But in the data list is only one x-array possible. So the software reduce and interpolate all arrays to the same x-axis. This is the first x-axis and takes into account the range of the other x-axis. If all have the same x-axis then the interpolation gives the original x-and y-values because the data will not be smoothed.
For more information see Note in chapter 2.2.2.
Only one x-array and maximal 6 y-arrays can be listed.

In some cases the curves have a total different x-axis. Then you get the following message: Different x/y arrays will be concatenated!
Here the different curves will be concatenated to one curve with a total x/y-array.

5.1.6.3 Compare data

This function compares the current data with other ones from an ASCII file or clipboard.



You can **compare** the data by a plot or a list. At a plot you can also show the reference curve. For plot and list is the showing of the additional difference data possible. Following **difference** modes exist:

1. y1+y2
2. y1-y2
3. y2-y1
4. y1/y2
5. y2/y1
6. y1*y2
7. (y2-y1)/y1

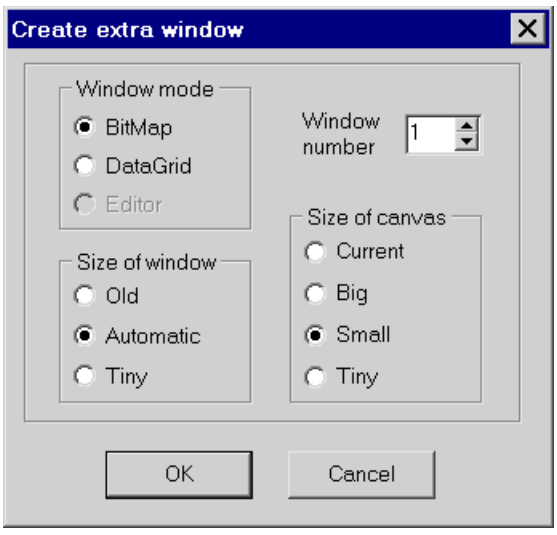
y1 are here the current y-values, y2 the reference (compare) y-values.
The data can be smoothed for the difference forming. The shown current or reference data are then not smoothed.

The **reference** (compare, y2) data can be read from an ASCII file or from the clipboard. These data must be ASCII x/y-data in columns and lines. For the delimiters see chapter 5.1.6.1. It is not necessary that the x-values of the current data and of the reference curve are identical. At the plot both curves will be shown with its own x-axis. For the difference forming and for the list, both x-axis will be reduced to the same axis as described in the second part of chapter 5.1.6.2.
You can define the **symbols** for the reference (compare) and for the difference curve. More possibilities gives the program tool 'Compare data' of the file menu.

5.1.6.4 Create extra window

It is possible to create an extra window with a bitmap (plot) or data grid of the current data. These are separate windows which you can place on the screen. These can be helpful to compare data. Note, that such a window may stay on top, see chapter 1.2.4. You can create some windows defined by the window number.
The **size** of the bitmap window can be:

Old: The old defined size will be used.
Automatic: Depending on the selected canvas size the window size will be set.
Tiny: Very small size.



The size of the **canavs** can be the current canvas size of the plot program or big, small or tiny.

5.1.6.5 Marker tools

At marker tools there is a **vertical**, **horizontal** and **cross** marker. You can set these markers by mouse or move by the cursor keys. After setting or during movement by the cursor keys you get in the status line the absolute value of the position in axis dimension and percentage of the axis. If the axis was multiplied with the axis factor for numbers, see chapter 5.1.4.1.1, additionally the original data value without this factor will be shown.

Example: On the x-axis is a voltage (base dimension V), the axis text is mV and the axis factor for numbers is 1000. On the status line will be shown:
xAxis,Data,Perc = 5.000E+00, 5.000E-03, 80.0
That means the x-axis value is 5 mV, the data value is 5.0E-3 V and the position is 80 % of the total x-axis size.

The vertical marker shows the x-position, the horizontal marker the y-position and the cross marker x- and y-position. You can move the markers by the cursor keys. The following description of movement is also valid for other program parts:

Horizontal marker:	Cursor left/right	→ slow along the x-axis to the left/right
	Cursor up/down	→ fast along the x-axis to the left/right
Vertical marker:	Cursor left/right	→ slow along the y-axis to the top/bottom
	Cursor up/down	→ fast along the y-axis to the top/bottom
Cross marker:	Cursor left/right	→ slow along the x-axis to the left/right
	Cursor up/down	→ slow along the y-axis to the top/bottom
	Cursor + Ctrl-key	→ fast movement

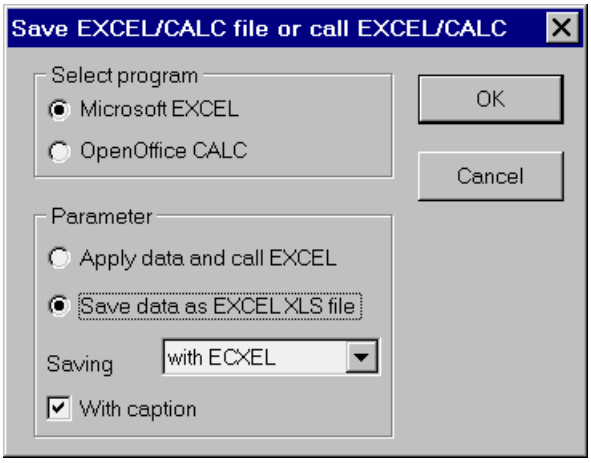
At the marker tools there is also the **mouse marker**. The x- and y-position of the mouse will be shown in the status line during the mouse movement. Normally for the mouse marker a cross will be used. But you can switch off this cross and show the original mouse cursor, see chapter 2.3.3.7.

If selecting a new marker the cross and mouse marker will be deleted but not the vertical and horizontal ones. So you can have a vertical and horizontal marker at the same time. You can also combine these both markers with the standard marker used for linear regression, vertical and horizontal plots and so on. These both markers have a special color (fix marker). In the marker sub menu there is an entry for deleting the marker. All markers will be deleted by refreshing the plot.

Mouse and marker, general: At many tools and functions you can mark and apply a point by the mouse and vertical or cross marker, for example at the linear regression. The movement of the markers was explained above.
In most cases the left mouse click sets the marker at the mouse position, applies the point/data and the software goes on. The cursor keys move only the marker. For applying the point/data of the marker position (after cursor movement) and going on you have to click onto the 'Apply/Enter' button or to press the 'Enter' key or to do a right mouse click. 'Enter' don't apply the mouse position but the marker position!
In some cases (e.g. maximum analysis) the left mouse click sets only the marker but don't apply the point. For applying the point/data and going on then you have to click onto the 'Apply/Enter' button or to press the 'Enter' key or to do a right mouse click.

5.1.6.6 Excel/Calc

As spread sheet **program** you can at user class 5 select Microsoft Excel or OpenOffice Calc.



You can apply the data and **call** Excel resp. Calc. For this you must have installed it on your computer. Another mode is to **save** the x/y-data in the Excel/Calc format.
For Excel are 3 possibilities for saving:

1. with Excel
2. without Excel
3. with the program Formula One

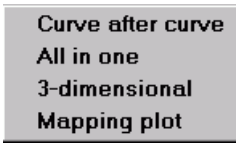
The format differs by these modes. The best is the first one but you need Excel on your computer. Formula One supports only the old Office 97 format.
You can also save the column captions.

Note: Normally it is better to copy/save the ASCII data and paste/read them in Excel/Calc.

5.1.7 Many curves

Sometimes a measurement data file contains curves at many data points, for example the tempscan contains internal transients at each temperature. It is also possible that a file is part of a file set, for example transients or V/I curves at different temperatures. The temperature is in both examples the parameter for the single curves.

For these both cases you get in the plot menu of the main program an entry to read and plot these curves (as shown on the right) or you can select the base view in an input window. The mapping plot is only available at user class 5.



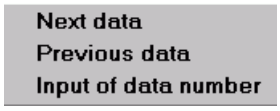
Four **base views** are possible:

Curve after curve:	Only one curve will be plotted. It starts from the first curve. You can navigate to previous or next curve, see chapter 5.1.7.1
All curves in 1 plot:	All curves will be shown in one plot, see chapter 5.1.7.2.
3-dimensional:	A 3-dimensional plot will be shown with the parameter as z-axis, see chapter 5.3.3,
Mapping-plot:	A color mapping area plot will be shown, see chapter 5.3.4.

If selecting 'Curve after curve' from an input window, the flag 'Start with movi plot' is visible. Its activation starts a slide show of the single curves. For the other 3 base views a button exist which leads to the special parameters of the selected view.

5.1.7.1 Curve after curve

In the file menu of the standard plot program there is the sub menu **Next datas** for navigating between the files or data points:



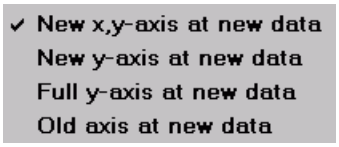
Shows the curve of the **next** file or data point.
Shows the curve of the **previous** file or data point.
Input of file or data point **number**, first or last can directly be called by clicking onto the 'Min' or 'Max' button.

You can also navigate by the PageDown (next), PageUp (previous), Home/Pos1 (first), End/Pos2 (last number) key and by the NextData button in the toolbar.

Depending on the kind of evaluation it can be that the 'Next datas' sub menu has another face. So the next data entry can be called 'Next data, apply'. This means the curve resp. the evaluation will be applied for further use or for other files. There can also be the entry 'Next data, not valid F9'. This means the current curve will not be applied and the next curve will be shown. F9 is a shortcut for this. Sometimes a menu entry for inputs of parameters exist.

In the file menu there is the menu entry 'MoviPlot program' for starting a slide show, see chapter 5.3.5.

The '**Axis menu**' is expanded by the following 4 entries which defines whether the x- and y-axis will be set newly or kept at plotting new data:



Sets a **new x- and y-axis** at new data, this is the standard.
Sets only a **new y-axis** at new data, keeps the x-axis.
As before but the y-axis considers also the hidden points.
Keeps the **old x- and y-axis** at showing new data.

The Marker tools (sub menu of Tools) contains the additional entry '**Permanent marker**'. Its activation shows a permanent vertical marker. It stays also on its position when loading new data.

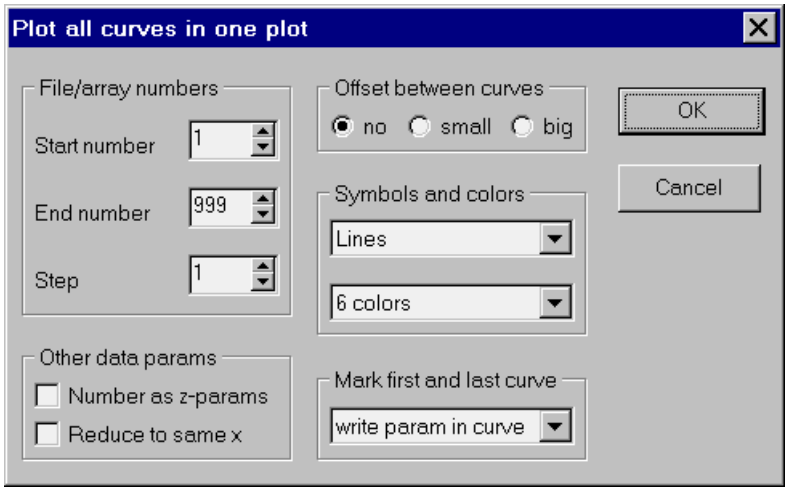
If the measurement data file contains curves at many data points then the caption of the plot program is: data point N – file name. If the file is part of a file set then the caption is the current file name.

Note: If showing curve by curve from many data points or files then the 'Next datas' menu is visible as described above. Files will be loaded here without opening the file dialog. But if files exist from a variation (e.g. I/V curves at many temperatures) and you call in the plot menu of the main program any function else as a curve by curve plot, then the file dialog opens at 'Next data' with the new name as proposal. The 'Input of data number' is not visible in the 'Next datas' sub menu.

5.1.7.2 All curves in 1 plot

All curves will be shown in one plot. An input window with some parameters for this plot exist. Either this window is the main input window after calling the menu entry or it is a (sub) parameter window of the main input window where you can select the base view.

You can define the start and maximal end **number** of files or data points. Normally the end number is 999 so that all files or data points will be used. **Step** means whether every file (step 1) or every second (step) and son on will be used. Sometimes the curves are very closed together, so you can define a y-**offset** between the curves for a better overview. The offset can be small or big.



Normally the parameter which was varied (for example the temperature) is the parameter for the **z-axis**. You can also select the file resp. data point number as z-parameter. This parameter will be used at this plot only for the horizontal or vertical plot.
If the curve have different x-axis, it is possible to reduce all curves to the **same x-axis**.

You can select as **symbols** the standard symbol, lines, interpolated lines or different symbols. Different symbols use the symbols for curve 1 to 6.

The symbols or lines of the different curves have always different **colors**:

- **6 colors:** The colors for curve 1 to 6 will be used, see chapter 2.3.3.1.
- **Blue-red palette:** The colors start from dark blue and go over green to bright red.
- **Blue-yellow palette:** The colors start from dark blue and go over green to yellow.
- **Rainbow palette:** Uses the rainbow spectrum.

The z-parameter for the **first and last curve** can be shown in the plot:

- **No:** Doesn't show the z-parameter of first and last curve.
- **Write param in curve:** Writes the z-parameter on the first and last curve.
- **By squares and text:** Marks the first and last curve by small squares and lists the z-parameter in the symbol explanation.

Following menu entries are not enabled at many curves: Save/Copy ASCII data, ActiveX/ OLE tools and the programs ListData, EditData, EditPlot and CompPlot. The listing of the data is restricted as in chapter 5.1.6.2 described.

Tip: Use the 3-dimensional plot for the list or export of all y-columns. There is no restriction to 6 y-columns and all x/y-arrays will be interpolated to the same x-axis.

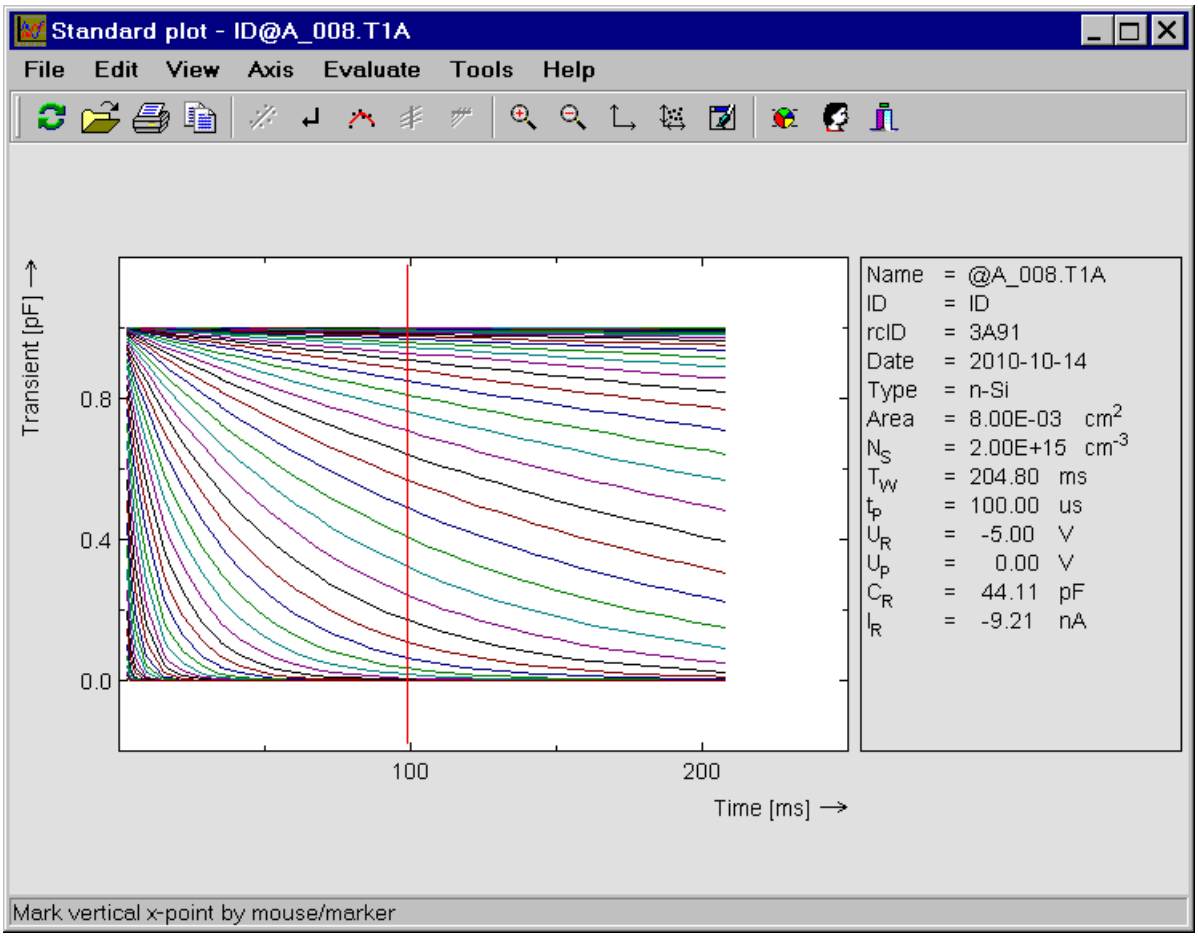
In the **View menu** there are additional entries for Vertical and Horizontal plots, in the toolbar there are also buttons for these plots. In special cases there is a menu entry for Vertical evaluation. Normally the vertical plot is more important than the horizontal.

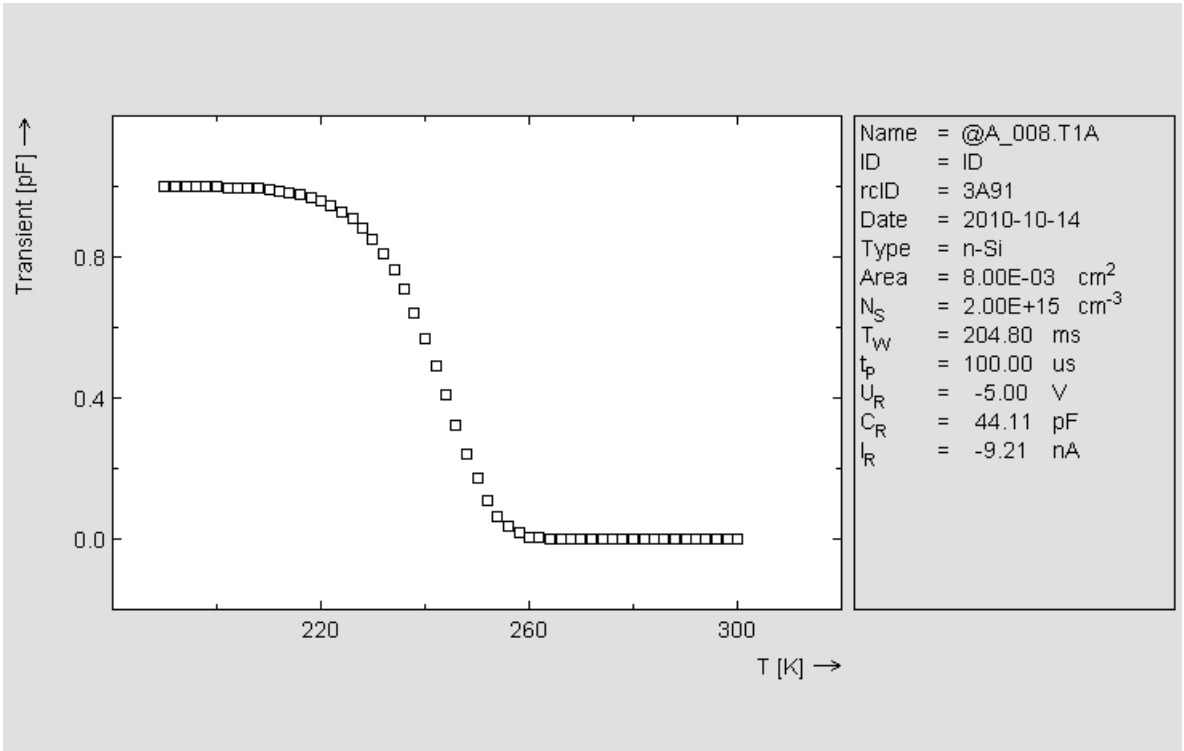
Vertical plot means that you mark by the vertical marker a point on the x-axis. For this x-point (x0) the y-value of all curves will be searched and applied for a new plot with only one curve. If the x0 point don't exist at a curve (only important at curves which have not exactly the same x-axis) then the curve will be interpolated. The new x-axis is here the parameter of the old z-axis parameter, for example the temperature. The new y-axis is the y-value of all curves at x0.

The **horizontal plot** is similar to the vertical plot. Here you use the horizontal marker to mark a y0 on the y-axis. The new y-axis is the x-value of all curves at y0. Each y/x-curve will be interpolated to find the x-value to the given y0. This works only correctly when only 1 x-value exist for 1 y-value (bijective).

Vertical evaluation uses the data of the vertical plot for a special evaluation. The kind of evaluation depends on the data.

The following picture on the top shows some curves at different temperatures in one plot. The picture on the bottom is the vertical plot of the first picture at about 100 ms.





5.2 Presentation plot program

The greatest flexibility in data presentation is provided by the option Presentation Plot Program. This chapter describes the functionality provided by this optional program.
The presentation plot program allows data from different curves resp. files to be plotted on the same axes for a direct comparison. The axes are auto scaled to ensure that all of the selected plots fit into the correct axes. In addition to comparing curves it is also possible to compile a picture from different types of plots with independent axes for each plot, that means to make multiple plots per picture. We call the different plots in one picture 'layers'. Up to 4 layers per picture are possible. Every layer can have many curves. A curve means one x/y-data array.
Annotation of the plots is also possible, you can draw text and graphics in the plot. All parameters as the plot axis, symbols and so on will be set automatically but can be changed manually. You can save the full picture with all data arrays and parameters in its own data format without using a graphic format, the data extension is F??.

Some menus are similar to the standard plot program, others have extended features. Which menu entries and tool buttons are visible and enabled, depends on the kind of data.

The following buttons of the **toolbar**, except for the regression, are always visible:

Open a presentation data file.

Save a presentation data file.

Print the plot on a printer.

Copy page to clipboard.

Active **layer number**, toggles between first and last layer by mouse click.

Show only **one layer**, the active one. The face changes at a one layer plot.

Input of all **plot parameters**.

Call input of **last parameters**.

Linear regression, sets start and end value by mouse and calculate regression.

Apply the selected plot and so on, for example for the linear regression.

Zoom-in the plot window.

Zoom-out the plot window.

Axis input parameters for the plot window.

Refresh the plot**.**

Call the **Edit plot program.**

User button is a user definable button, see chapter 2.3.4.

Close the Presentation plot program and goes back to the previous program.

Following **shortcuts** exist for the menu, but not all are always possible:

F1:	Help information, opens this manual at the corresponding chapter.
F2:	Call input of last parameters.
F5:	Refresh the plot.
F8:	(Automatic) linear regression, sets start and end value by mouse.
Ctrl+F8:	Starts the manual linear regression.
F11:	Personal hot key 1, see chapter 2.3.4.
F12:	Personal hot key 2, see chapter 2.3.4.
Ctrl+C:	Copy page to clipboard in the bitmap format.
Ctrl+O:	Opens a presentation data file.
Ctrl+P:	Print the picture.
Ctrl+S:	Save the current presentation data.
Ctrl+V:	Paste a bitmap graphic from the clipboard.
Enter:	Apply the selected plot and so on, as Apply button.
Alt+F4:	Close the presentation plot program.

Tip: Sometimes it is necessary to go several times through the same input window. Use then the button 'Last parameters' or its shortcut. It calls that input window which you have opened at last by the menu or toolbar.

Base syntax and definitions:

Picture means a complete picture on the screen with one or more plots.
Layer means one plot of the picture. A picture can have up to 4 layers. Every layer can have many curves and objects. An additional special layer 0 exist, which can contain only objects but not curves.
Curve means a x/y-array.
Objects are text or graphic elements of a layer, layer 0 is also possible.
Transferred plot means the plot which should be transferred into the presentation plot.
Current plot means here usually the same as transferred plot.

The **parameters** will be divided in 3 groups:

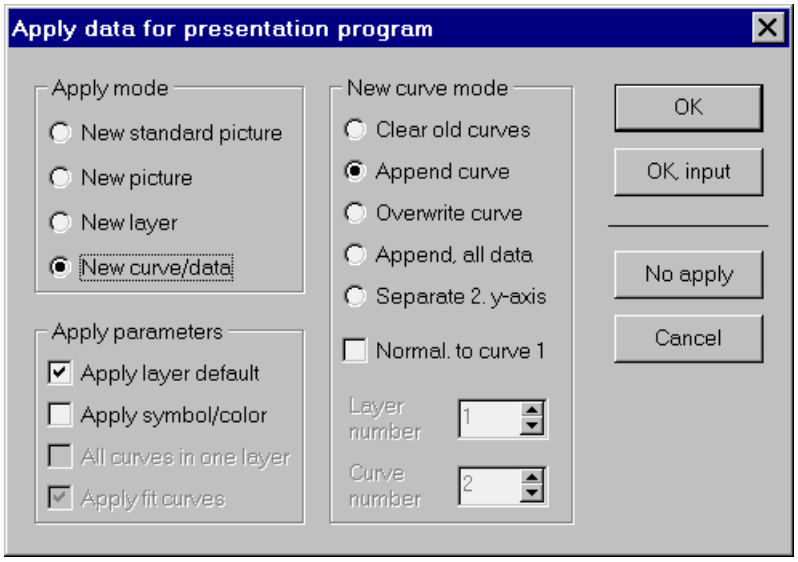
All layers:	The parameters are valid for all layers (the total picture). These are the parameters for applying, the header and so on.
One layer:	The parameters are valid only for one layer. These are the plot axis, the regression mode, objects and so on.
One curve:	The parameters are valid only for one curve. These are the plot symbol and color and so on.

5.2.0 Entering the Presentation Plot Program

The Presentation Plot program can be called from another plot program (Standard, Application, Edit, 3-dimensional) or from the Base Tools. This sub program applies the current total plot (picture), also called transferred plot, with all layers, curves (data), evaluation and text.

5.2.0.1 Main window

If entering the presentation plot program the following main window occurs for transferring the current plot data into the presentation plot program.
If you confirm with '**OK**' then the data will be applied and the new picture will be shown.
At '**OK, input**' additional the extended input window of chapter 5.2.0.2 opens.
If leaving with '**No apply**' the current plot will not be applied. Then you hold the old picture resp. data of the presentation plot program.



You can apply the current plot as a new picture. In this case the old data of the presentation plot will be deleted. You can also compile a new picture by the new and old data.

The **Apply mode** defines the kind of applying the current plot:

New standard picture: This is the standard mode. The current plot with all layers and curves as new picture resp. data. If more than one current layer exist then only this input is possible.

New picture: Similar as before but default apply parameters for the standard picture will not be set. The inputs for the 'layer mode' occurs, see below. Select a special layer mode or confirm with 'OK, input' and go through the extended input window.

New layer: A new layer can be created by the current plot or an old layer can be overwritten. For the last you have to input the layer number. The inputs for the 'layer mode' occurs. You must select a special layer mode or confirm with 'OK, input' and select in the extended window a new layer position.

New curve/data: You can keep all existing data of the presentation plot. The 'new curve mode' defines how a new curve (or all) will be applied. You have to input the layer number. This mode is only possible if the transferred plot contains only one layer.

The header can only be applied at the modes 'New (standard) picture'.

If selecting a new layer you can define the layer position in the extended window. An easier way is to set the size and position of layer by the **Layer mode**:

Extended select:	You have to go through the extended input window.
2 layers:	The new picture contains 2 plots. The layer number defines the layer position. Layer 1 will be shown on the top, layer 2 on the bottom.
3 layers:	As before but with 3 layers: left-top, left-bottom, right-bottom.
Layer in layer:	A small layer 2 will be drawn inside on the right top of the big layer 1.

The **New curve mode** defines how the new curves will be transferred to a existing layer:

Clear old curves:	The existing curves of the selected layer will be deleted. The layer contains then only the new curves.
Append curve:	This is here the usual standard mode. The new data will be append as new curve(s) to the layer. The software increases automatically the curve number.
Overwrite curve:	An existing curve will be overwritten. You have to input this curve number.
Append, all data:	The data will be append to an existing array (curve). Old and new data are saved in one array. By the flag 'No overlap' only new data which x-data are not in the x-range of the old data will be applied.
Separate 2. y-axis:	The new curve uses a separate 2. y-axis. The y-axis of the current plot will be transferred as a 2. y-axis of the selected layer.

If activating '**Normal. to curve 1**' then the new curve(s) will be normalized to curve 1. That means the minimum and maximum values of the new and the first curves are the same.

The **Apply parameters** input group contains flags for the applying of data and parameters:

'**Apply layer default**' sets the default parameters for a new layer. In the other case the main parameters of the first layer will be used. These parameters are not the axis, curves and objects.

'**Apply symbol/color**' applies the symbols and colors of the transferred curves, only enabled if setting the previous flag. In the other case the symbols and colors are associated with the curve number.

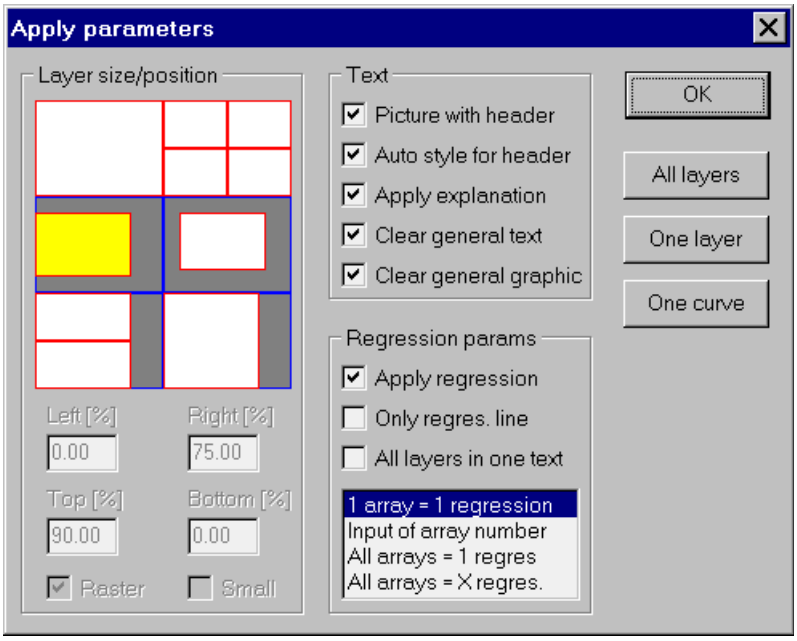
If the current plot contains similar curves in various layers then '**All curves in one layer**' transfers all these curves in one layer of the presentation plot.

If the current plot contains additional fitting curves then these curves can be applied by activating '**Apply fit curves**'.

Tip: Activate 'Apply symbol/color' at many curves. If this flag is not activated and a symbol explanation will be applied from the current plot then the symbols and colors of the explanation differ from that ones of the curves. If the current plot has only one curve you should usual deactivate this flag. There are different flags for one and many curves.

5.2.0.2 Extended window

The following input window opens if you click in the main window on the 'OK, input' button. It contains extended apply parameters.



The main parameter here is the **Layer size/position**. This setting is necessary for manual compiling of a picture with multiple plots. The white area denotes size and position on the screen, the selected will be yellow colored. You can select it by mouse. Following possibilities exist:
Full, Left-top, Left-bottom, Right-top, Right-bottom, Standard, Manual, Left, Bottom, Big.
If selecting '**Manual**' then you have to input the per cent left, right, top and bottom position of the layer, relative to the canvas. In 'View → Positions' you can use the mouse for this, see chapter 5.2.3.6.
The flag '**Raster**' sets the positions to a virtual raster as described in chapter 2.3.5.
If activating '**Small**' then small symbols will be used for the curves, see chapter 2.3.3.4.

The input group **Text** contains parameters for the picture style and for text/graphic objects.
'**Picture with header**' applies the text header and shows it on the right side of the plot.
'**Auto style for header**' sets the style and position of the header by the layer position.
'**Apply explanation**' applies a symbol explanation of the current plot.
'**Clear general text**' clears the text, which was defined for all layers, called layer 0.
'**Clear general graphic**' clears the graphic, which was defined for all layers, called layer 0.

For the parameters of the linear **Regression** exist a separate input group:
'**Apply regression**' means that the regression mode and range will be applied.
'**Only regres. line**' defines as regression mode 'Only line' so that only the regression line will be shown but not the results. If the current plot lists the results in the text header box this evaluation text will be integrated in the text header.
'**All layers in one text**' lists the regression/evaluation results of all layers in one text box.
One of the 4 regression **array modes** can be selected, see chapter 5.2.5.

3 separate **buttons** call the parameters for all layers, for the active layer and for the active curve. It is similar as described in 5.2.3.1 but not all input sheets are here visible.

Note: If selecting 'Standard picture' in the main window then some text and regression parameters will first be set from 'Default from standard picture', chapter 5.2.3.2.

5.2.0.3 First call

As discussed in chapter 1.1.1 and 1.1.2 some initialization files will be loaded at program start or first call of the measurement module. The configuration mode, see chapter 1.1.1, defines which set of initialization files will be loaded. The presentation plot program has also an init file for its configuration. In opposite to the other initialization files here you will be asked at the first call whether you want to use the original file or the file defined by the configuration mode. The reason is that it could be that you have leaved the program after a very special work in the presentation plot program. At a hot start you would load these very special parameters.

Following modes for reading the **configuration init file** exist:

No, read original init file: Independently from the selection of the configuration mode the original init file PresProg.Cfg from Sys\Init will be loaded.

Only apply params: The init file defined by the configuration mode will be loaded, for example that one for a hot start. But only the parameters for applying data will be used from this file. The other parameters come from the original file.

Only apply/base params: As before, but additionally the base parameters will be used.

Yes, read all params: All parameters of the init file defined by the configuration mode will be read.

5.2.0.4 Compiling a picture

Usually you enter the presentation plot program with the apply mode 'New standard picture'. The whole picture with all layers and all curves will be transferred. Then you can change the axis or evaluation or add objects as text to the plots to achieve best results. The presentation plot program will also be used for compiling a new picture. So you can show different curves in one plot for a comparison. The program also allows data from multiple files of different types, such as a tempscan file and a corresponding Arrhenius file, to be plotted into the same picture. In this case each set of data will be plotted on an independent set of axes which can be independently moved around.

The common **sequence** for compiling a picture is the following:

1. Select in your main program your **first plot** and call then the presentation program.
2. For showing different curves in one plot (application example 1) use the **apply mode** 'New standard picture'. In the other case use 'New picture' and define the layer mode or/and go through the extended window.
3. **Leave** the presentation program.
4. If necessary read in your main program data form a new file. Select in your main program your second plot and enter the presentation plot program again.
5. Use the **apply mode** 'New curve' or 'New layer'.
6. Repeat steps 3 to 5 until the picture is finished.
7. If necessary, make changes (axis, symbols...) and add objects.

5.2.0.5 Special applications

This section describes the compiling of a new picture for some special applications. The common sequence will be described in the previous chapter. The following arabic numeral refers to the sequence number. You can normally leave the main window by 'OK'.

I. Different curves in one plot: Data from different temperature scans, different samples, different coefficients or different V/I curves may be plotted on the same axes. The program will automatically scale the axes so that all of the data will fit in. It is however possible to override this and to set your own axes. The different curves must be similar. This means that the x- and y-axis of all curves must be identical, for example that all curves have the temperature as x-axis.

(2) For the first curve or curves use the apply mode 'New standard picture'.
(5) For the next curves use apply mode 'New curve' and curve mode 'Append curve'.

II. Multiple plots per page, one curve: It is possible to display up to four separate plots on a single page and have them positioned automatically by the software. Each plot is still treated as separate layer and may have different axes from the other plots. So one layer can contain a tempscan, another one the Arrhenius plot. The standard multiple plots per page consist of 2 or 3 layers. Then you have additional space for the text header. The following describe the sequence for 2 layers.

(2) For the first layer select apply mode 'New picture' and layer mode '2 layers'.
(5) For the second layer use apply mode 'New layer' and keep the layer mode.

III. Multiple plots per page, many curves: Every layer can contain many curves. As the current plot have many curves then all these curves will be applied in example II. You can also add manually a curve. The following describe the sequence for 2 layers with 2 curves in layer 1.

(2) For the first layer select apply mode 'New picture' and layer mode '2 layers'.
(5) For curve 2 of layer 1 use apply mode 'New curve' and curve mode 'Append curve'.
(5) For the second layer use apply mode 'New layer' and keep the layer mode.

IV. Layer in layer: A small plot can be drawn inside on the right top of a big plot. Each plot is referred to as a layer. An example will be shown at the end of this chapter.

(2) For the big layer select apply mode 'New picture' and layer mode 'Layer in layer'.
(5) For the small layer use apply mode 'New layer' and keep the layer mode.
(7) Usually the picture is not perfect. Set the best size and position of the small layer in 'View → Plot params for → Position'. Optimize also the axes.

V: 2 different y-axis: One plot can contain 2 curves with different y-axis, for example curve 1 shows the current and curve 2 the capacitance versus temperature. This layer has then 2 y-axes. An example will be shown at the end of this chapter.

(2) For curve 1 use the apply mode 'New standard picture'.
(5) For curve 2 use apply mode 'New curve' and curve mode 'Separate 2. y-axis'.

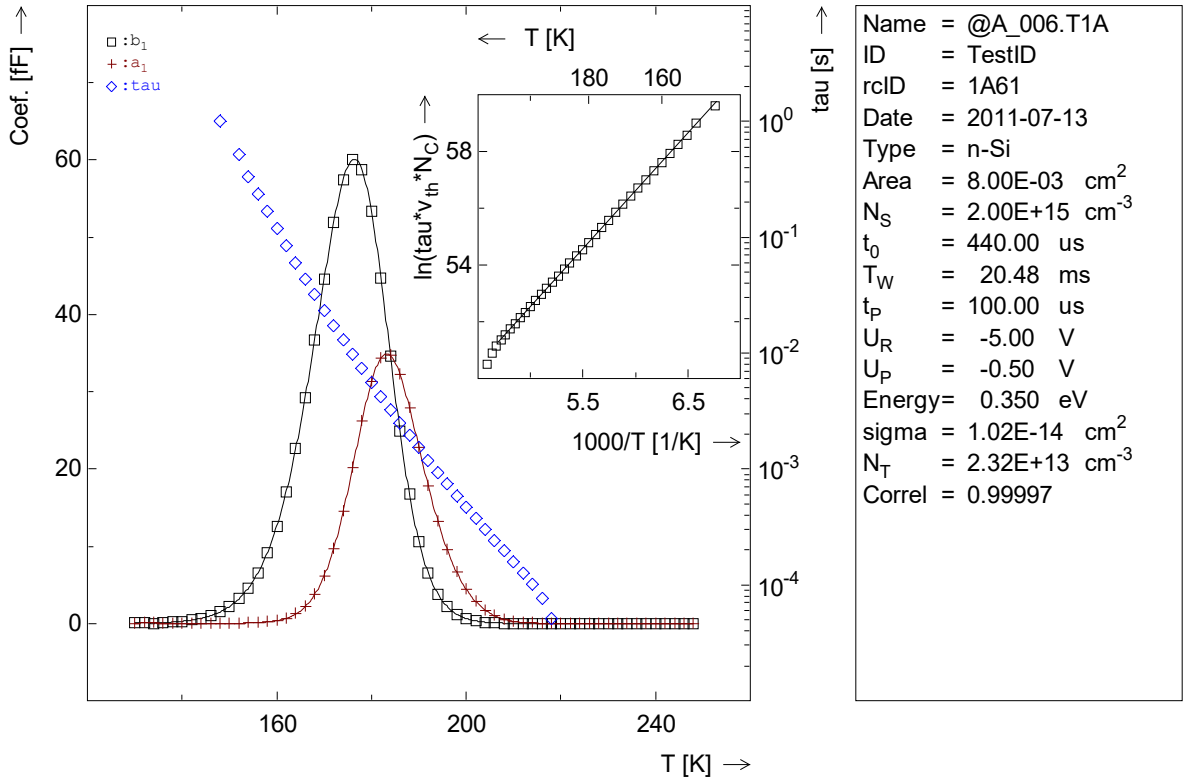
VI. Difference of 2 curves: It is possible to show 2 curves and its difference in 1 or 3 plots. For this create a picture with 1 layer and 2 curves as explained in example I. Then go to the Edit menu and select 'Make difference'. By 'Restore layer' you can there restore the 1-layer plot into 3 separate layers with each 1 curve.

VII: 3-dimensional plots: You can manually make a 3-dimensional plot by many curves. For this transfer many curves with the same x-axis into one layer of the presentation plot. Apply many curves in one step from a current plot or/and curve by curve. Look in 'Apply input sheet' of chapter 5.2.3.2 for applying the z-values. A 3-dim plot can be temporary created in 'View → One layer plots' (chapter 5.2.3) or be set as default for the current picture. For the last set in 'Params for one layer → input sheet Base' the axis mode to '3-dim', see chapter 5.2.3.X. The button '3d params' defines the parameters of the 3-dim plot.

VIII: Regression: The linear regression will be applied from the current plot. Sometimes it can be important to calculate the regression over different parts of the curve(s). In other cases you want to calculate one or more regressions over all curves. Compile the plot and define in the extended entering window the regression array mode. You can change it also in the Evaluate menu. Chapter 5.2.5 gives more information.

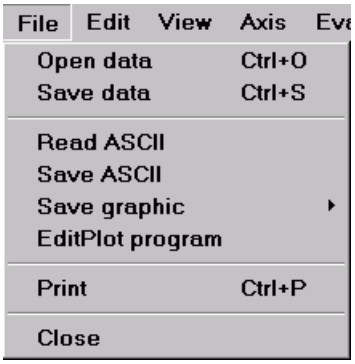
IX: Additional text: You can add objects like text, lines, symbols, boxes and graphics to the layers. For a new text call 'Objects → New text'. See chapter 5.2.7.X for a detailed explanation.

The following picture shows 2 layers. The first contains 3 curves. The 3. curve has a separate y-axis. The small layer is inside of the big layer 1 and has 1 curve. Additional text and graphics are included in this picture. So this is an example for application I, IV, V and IX.



5.2.1 File menu

The presentation plot program has its own data type, so you can read and save files of the presentation plot program.



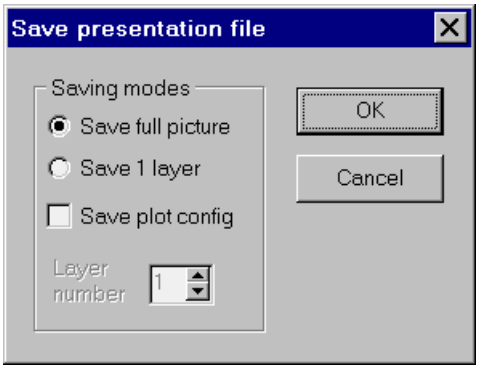
Save ASCII data saves one or more x,y curves line by line in an ASCII format to a text file. Read ASCII data reads one or more curves from an ASCII file.
Save graphic opens a sub menu for saving the plot into a graphic file format. Bitmap and vector formats exist: BMP, PCX, GIF, JPEG; PLT, HPGL, WMF / EMF, EPS, ACAD. An explanation was given in chapter 5.1.1.1.
By calling EditPlot program the program jumps with one selected curve to the edit plot program and comes then back.
Print opens a dialog for printing the plot. By 'Close' the presentation plot program will be closed and the software goes back.

5.2.1.1 Read and save presentation data

If reading a presentation file then you can select after the input of the file name the **reading mode**:

- **Read full picture:** All layers from the file will be read. The new picture consists of only the read layers. If the plot configuration was saved with this file then you can activate to read it here.
- **Read 1 layer:** Only one layer from the file will be read. Then you get the input window for applying the data of file to compiling a new picture, see chapter 5.2.0.
- **Read 1 curve:** Only one curve will be read.

If saving a presentation file then you can select after the input of the file name the **saving mode**:



- **Save full picture:** Parameters and data of all layers will be saved. The data extension is F0?. By activating a flag the plot configuration will be saved into a separate file, see below. Then the data extension is F9?.
- **Save 1 layer:** Only one selectable layer will be saved. The data extension is F1? for layer 1 and so on.

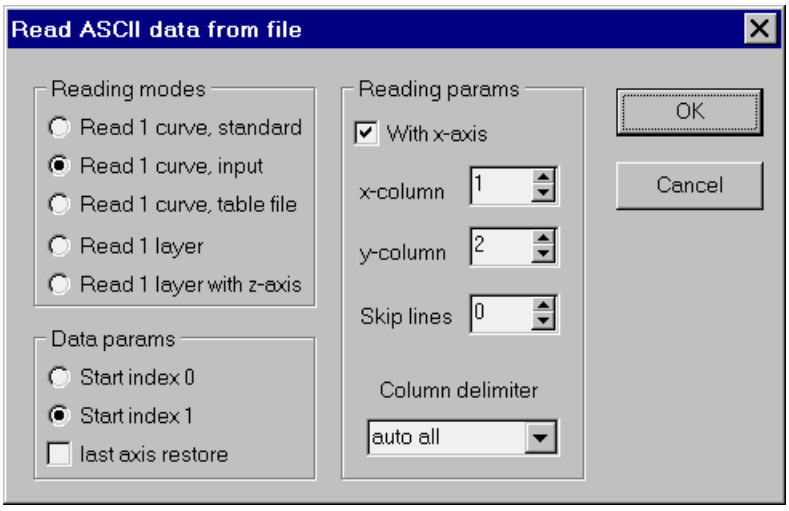
The presentation plot program uses some parameters of the current **plot configuration**, for example the color for the regression line and the definitions of the axis fonts. If you change these global plot parameters and read later an old presentation data file you don't get the same view as at that time at which you have saved the file. Therefore you have the possibility to save also the plot configuration into a separate file if saving the presentation data. This configuration file has the name as the presentation file but instead the program extension the extension CFG. This file has the structure of the initialization file Plot.CFG from the program directory Sys\Init. After leaving the presentation plot the program asks you for restoring the old global plot configuration.

5.2.1.2 Read and save ASCII data

If reading ASCII data from a text file you can select the **reading mode**:

1. **Read 1 curve, standard:** This is the standard mode. 1 curve will be read, x must be in the 1. column, y in the 2.
2. **Read 1 curve, input:** 1 curve will be read, you have to input the column number for the x and y-data. When selecting column 1 for x and y, x will be read from the odd lines (1,3,5,..), y from the even lines.
3. **Read 1 curve, table file:** 1 curve of a special table file will be read, for example a temperature calibration file.
4. **Read 1 layer:** Read all columns of file. The first one is x, the second y1, the third y2 and so on.
5. **Read 1 layer with z-axis:** As above but the first line contains the z-axis values, necessary for 3-dimensional plots.

At read mode 2, 4 and 5 you can **skip lines** of the file, necessary if the file has a header.
At these modes you can also deactivate the flag '**With x-axis**'. Then the x-data will not be read but will be set to data (line) number.
If selecting -1 as x- or y-column, the old x- or y-values will be kept. The number of old and new data points must be identical! This feature needs user class 5.



Starts index means the first index of data array, normally it starts from 1, so you have data x[1],...x[N], where N is the numbers of data points.

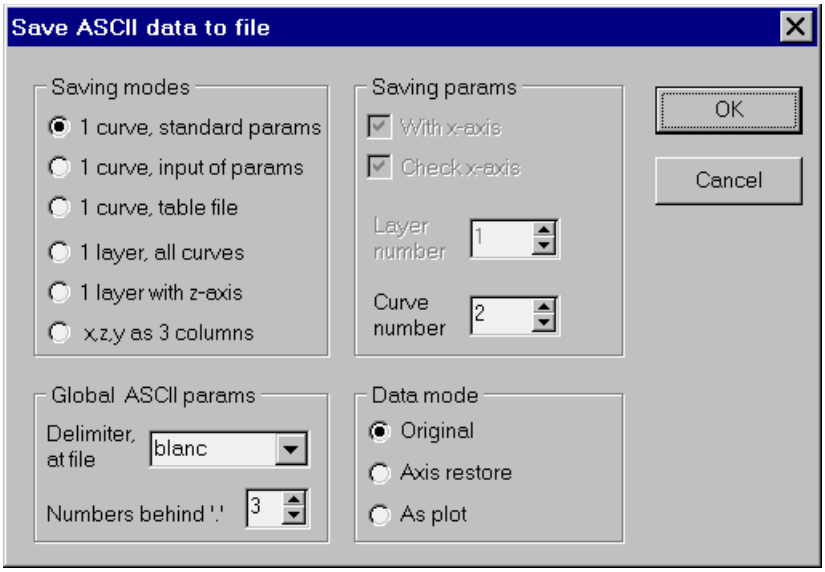
If activating '**Last axis restore**' then the ASCII data will be restored in respect to the axis restore (change) mode of the layer, see 'View → Params for layer → Array → Change x/y-axis'.
The **delimiter** between the columns can be selected, for more details see chapter 5.1.6.1.

After confirming the window above you get the inputs for compiling a new picture, see chapter 5.2.0.

If saving ASCII data into a text file you can select the **saving mode**:

1. **1 curve, standard params:** This is the standard mode. 1 curve will be saved, x into the 1., y into the 2. column.
2. **1 curve, input of params:** 1 curve will be saved, you have to input the column number for the x and y-data.
3. **1 curve, table file:** 1 curve will be saved into a special table file.
4. **1 layer, all curves:** Save all curves of one layer. x will be saved in the 1. column, y1 in the 2., y2 in the 3. and so on.
5. **1 layer with z-axis:** As above but the first line contains the z-axis values, necessary for 3-dimensional plots.
6. **x,z,y as 3 columns:** All x-data of all x-arrays will be saved into the first column, x-array after x-array. Ally-data will be saved into the third column. The second column contains the z-data, it will be applied from the value for z-axis of every curve.

At save mode 2, 4 and 5 you can deactivate the flag '**With x-axis**'. Then the x-data will not be saved.
If saving all curves of a layer you can activate a flag for '**Check x-axis**'. In this case all x-arrays of the layer will be checked. If these are different, the common x-range will be used and all y-arrays will be interpolated to the x-array of the first curve.
If more than one layer exist, you have to select the **layer number**. For the modes 1 to 3 you have also to input the **curve number**.



The **delimiter** between the columns can be selected, for more details see chapter 5.1.6.1. The ASCII data will be saved in the exponential format, you can define the **numbers** behind the point. Both inputs are global and valid for the total program.

The **data mode** decides how the data will be saved:

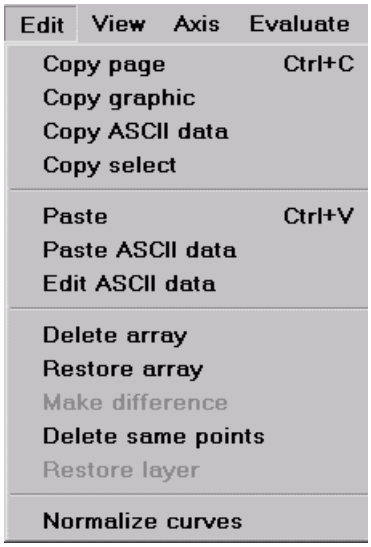
Original: The original data without interpolation and so on will be saved.

Axis restore: If the data will be changed in respect to the axis, see above, or the data will be combined by 2 curves then these 'calculated' data will be saved.

As plot: The curve will be saved as you see it in the plot. If interpolating then the interpolated data will be saved. An axis restore will be taken into account.

5.2.2 Edit menu

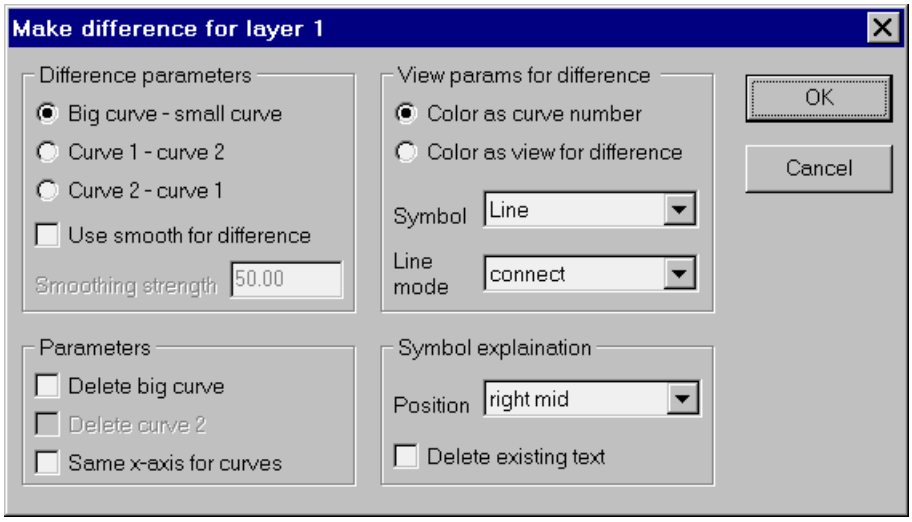
By the edit menu it is possible to copy a graphic or the data into the Windows clipboard, to paste a graphic or ASCII data, to edit data, to delete arrays and to restore arrays or layers.



'Copy page' copies the graphic as a bitmap into the clipboard, 'Copy graphic' as a Windows meta file (WMF or EMF).
'Copy ASCII data' copies one or more selectable x/y-arrays line by line into an ASCII format, similar to chapter 5.2.1.2.
'Copy select' asks for the format before copying, see 5.1.2.1.
'Paste' shows a bitmap graphic from the clipboard on a definable position of the screen.
'Paste ASCII data' read ASCII data form clipboard similar to chapter 5.2.1.2.
'Edit ASCII data' load one selectable array (curve) or all arrays of a layer into the grid or text editor. There you can edit these data and apply the changes into the presentation plot.
'Normalize' all plotted curves to one reference curve.
'Delete array' removes one selectable curve from the plot.
By 'Restore array' one or all arrays of a layer will be used for compiling a new picture. The main window for entering opens as described in chapter 5.2.0.1.
'Make difference' is enabled if the active layer has 2 curves, or if 2 layers with the same numbers of arrays exist and a 3-dim or mapping plot will be shown.
'Delete same points' deletes same points of all curves of a layer.
'Restore layer' restores one layer into 2/3 layers, or restores all curves into one layer.
'Apply vertical' is visible at a vertical plot was done and apply this plot a new layer.

5.2.2.1 Make difference

If the active layer has 2 curves, then you can build a difference between the 2 curves and store this new curve as a 3. curve of the layer. If there was already a difference formed, so that the layer has yet 3 curves, then you can call this function again and the old 3. curve will be overwritten.



At the **Difference parameters** you can select how the difference should be formed:
At '**Big curve – small curve**' the curve with the biggest y-value will be searched, the other (small) curve will then be subtracted from this one. At '**Curve 1 – curve 2**' curve 2 will be subtracted from curve 1. The opposite is also possible. 1 and 2 denote the curve numbers of the layer. If activating a flag then the curves can be **smoothed** before difference forming. The smooth is only valid for the difference forming, the original curves will not be changed. You can input the strength of the spline smooth, see also chapter 2.7.1.

In the **Parameters** input group you can activate some flags:
So you can **delete** the big curve at the first difference mode, curve 1 and curve 2 at the other both difference modes. 'Delete' means that this curve(s) will not be longer in the plot. The layer contains then 1 resp. 2 curves.
'**Same x-axis**' means that the x-arrays of the original curves will be checked. If these are different, the common x-range will be used and the y-array of the 2. curve will be interpolated to the x-array of the first curve. This flag is only valid for the original data and changes so these data. The difference forming uses always this check.

View parameters define the symbol, line mode (see chapter 5.1.3.1.1) and color of the difference curve. The color is either the color for curve 3 or the special color for a difference curve, see chapter 2.3.3.1.

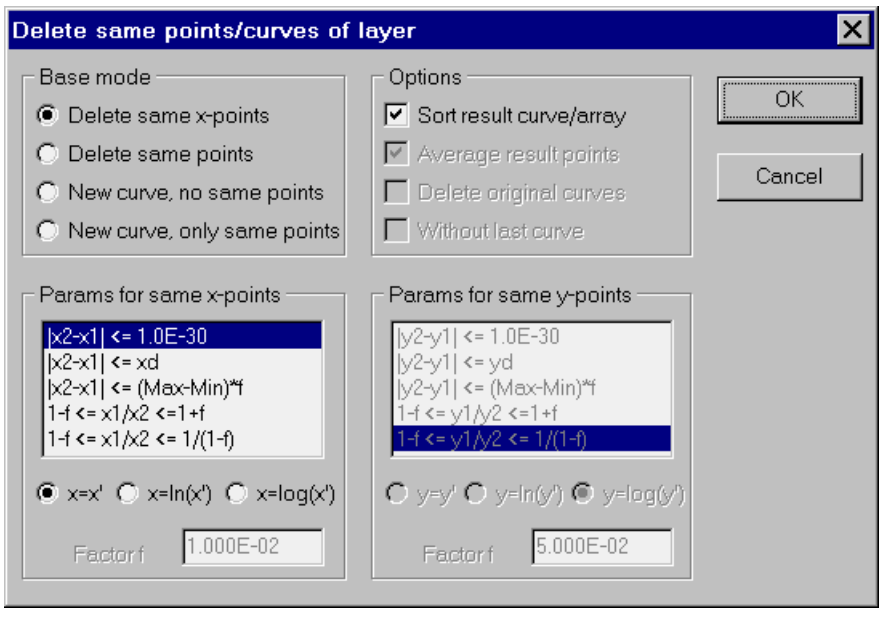
Symbol explanation defines the position of a text which explains the origin of the curves: left top, left bottom, right bottom, right top, right mid, right down. No additional text will be shown by 'no explanation'. Activating 'Delete existing text' delete all text objects of the active layer, except the selected symbol explanation.

5.2.2.2 Delete same points

This function deletes same points of a curve in various ways. Each curve of the active layer will be checked. Following **base modes** exist:

Delete same x-points:	Only the x-array of each curve will be checked. If a curve contains data points with the same x-value then the 'double' points will be deleted.
Delete same points:	As before, but if a curve contain points with the same x and y values then the 'double points' will be deleted.
New curve, no same points:	A new additional curve will be created by using all data points of all curves. This new curve will then be checked for same points.
New curve, only same points:	As before, but the new curve contains only data points which exist in all curves.

The **Params for same x-points** define criteria when 2 values will be treated as 'same'. Depending on this you can input a maximum difference or a factor. The last criterion allows also a logarithmic check for logarithmic data. By activating x=ln(x') is valid: |x2-x1|<=xd, where xd=-ln(1-f) and f is the factor by input.
If checking not only the x-value but points, then the y-parameters are enabled.



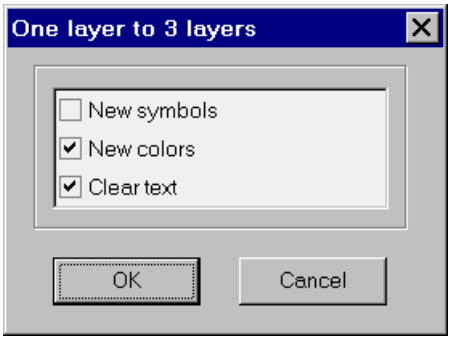
Some **options** exist. So the curves can be sorted. At the last base mode the result points can be averaged over the same points. The original curves can be deleted at the last 2 base modes, so that the layer contains only the new curve. If one of the last 2 base modes was already done then the flag 'Without last curve' is enabled. That means the new curve will not be used at a repetition.

5.2.2.3 Restore layer

This procedure restores one layer with many curves into 2 or 3 layers, or restores all curves of all layers into one layer.

The first case is only available if one layer with 2, 3, 4 or 6 curves exist. Then 2 or 4 curves of layer 1 will be restored into 2 layers with each 1 or 2 curves, 3 or 6 curves of layer 1 will be restored into 3 layers with each 1 or 2 curves. The plot window of each new layer is the same as the old one.

You get the following input window. If activating 'New symbols' and 'New colors' then the symbols and colors correspond to the new curve number in the new layers, see chapter 2.3.3.1. In the other case the old symbols and colors will be kept.
If activating 'Clear text' means that all text objects of the first layer will be deleted. In the other case the first text object, usually the symbol explanation, will be splitted into 2 resp. 3 parts.

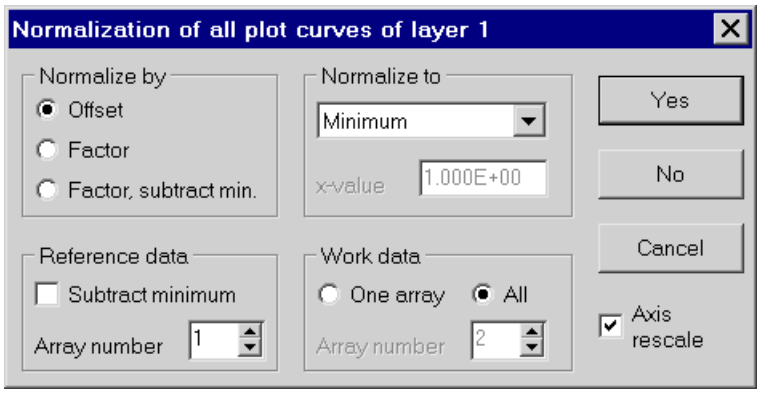


If more than one layer exist then all curves of all layers can be restored into one layer. The input window is the same as in the first case.

5.2.2.4 Normalize arrays

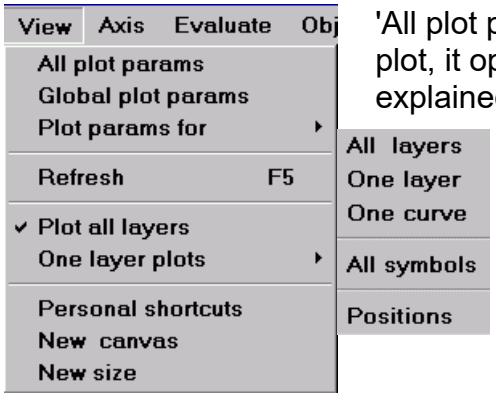
This procedure normalizes one or all plotted curves to one reference curve. It will be done only at the plot, the data itself will not be modified. The flag 'Plot with offset', array input sheet of chapter 5.2.3.3, will be activated by using the 'Yes' button. It will be deactivated by clicking onto the 'No' button. The flag 'Axis rescale' rescales the axis for the next plot.

The normalization can be done by setting an offset or factor for each curve. At the first mode the curves will only be shifted on the y-axis. At the last mode, additionally the minimum value of each curve can be subtracted. The normalization can be done to the first/last data point, the minimum/maximum or to a given value of the reference curve. The number of the reference array can be selected, its y-minimum value can be subtracted.



5.2.3 View menu

In the view menu you can set the window and canvas size, personal short cuts, global and all presentation plot parameters.

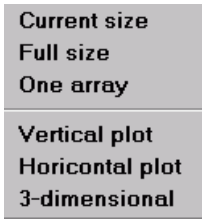


'All plot params' are the parameters for the active presentation plot, it opens a general input. 'Global plot params' were already explained in chapter 2.3.3. 'Refresh' plots the plot again.

'Plot params for' opens a sub menu for the presentation parameters for all layers and for the active layer and curve, similar to 'All plot params'. Special inputs allow to set the layer position and 3-dim parameters.

'New canvas' allows to define manually the size of the canvas instead to set it bythe form size.

'Plot all layers' shows all layers on the screen. This is the standard mode. If selecting a one layer plot, the face of the fifth button in the toolbar changes. This button toggles the view between 'Plot all layers' and 'One layer plot'.



In the sub menu of 'One layer plots' you can also select a special view for the active layer. At 'Current size' the active layer will be shown in its size, at 'Full size' it will be shown in the full screen size.
'One array' shows only the active curve. Navigate by the PageDown (next) and PageUp (previous) key and by the Next button in the toolbar. You can make a vertical or a horizontal plot from the active layer, as described in chapter 5.1.7.2. The active layer can be shown as a 3-dimensional plot.

'Restore plot cfg' restores the old plot configuration, it is visible if you have load a new plot configuration from file, see chapter 5.2.1.1.

5.2.3.1 All plot params

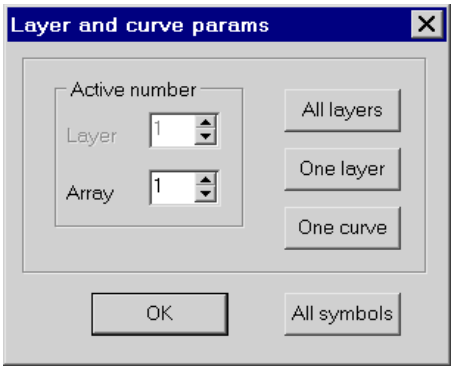
This is the most important input window for the parameters of the presentation plot. As described above these are divided in 3 groups:

All layers: The parameters are valid for all layers (the total picture). These are the parameters for applying, the header and so on.

One layer: The parameters are valid only for one layer. These are the plot axis, the regression mode, objects and so on.

One curve: The parameters, as plot symbol and color, are valid only for one curve.

Here you can select the active layer and the active curve number of this layer.
The 3 buttons opens the different input sheets for the parameters for all layers, for the active layer and for the active curve of this layer. The main inputs will be described in the next chapters. The axis and object input parameters are also available in special menus and will be explained there.
'**All symbols**' changes the symbol, line mode and color of each curve of the selected layer by one dialog.

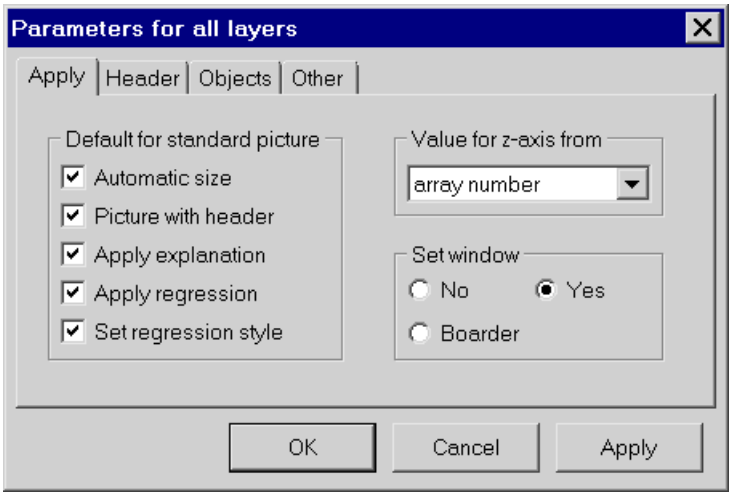


5.2.3.2 Plot params for all layers

These parameters are valid for all layers, the inputs are grouped in 4 input sheets.

Apply input sheet:

Here are the parameters for applying a plot into a presentation plot.



The input group '**Default for standard picture**' contains parameters for applying if using the apply mode 'New standard picture', see chapter 5.2.0.1.

If 'Automatic size' is activated, the size of the plot, which will be transferred into the presentation plot, will be applied.

The flags 'Picture with header', 'Apply explanation' and 'Apply regression' were already explained.

'Set regression style' deactivates the flags 'Only regres. line' and 'All layers in one text' and sets the regression array mode, usually to '1 array = 1 regression'. For more details look in chapter 5.2.0.2.

'**Set window**' will be used at apply mode 'New curve' for setting a new plot window:

No: The layer window of the presentation plot will be kept.
Boarder: The layer window will be changed if the boarder (axis) of the plot which will be transferred into the presentation plot is bigger.
Yes: If the new curve(s) contain data which are outside of the layer window then the layer window will be expanded.

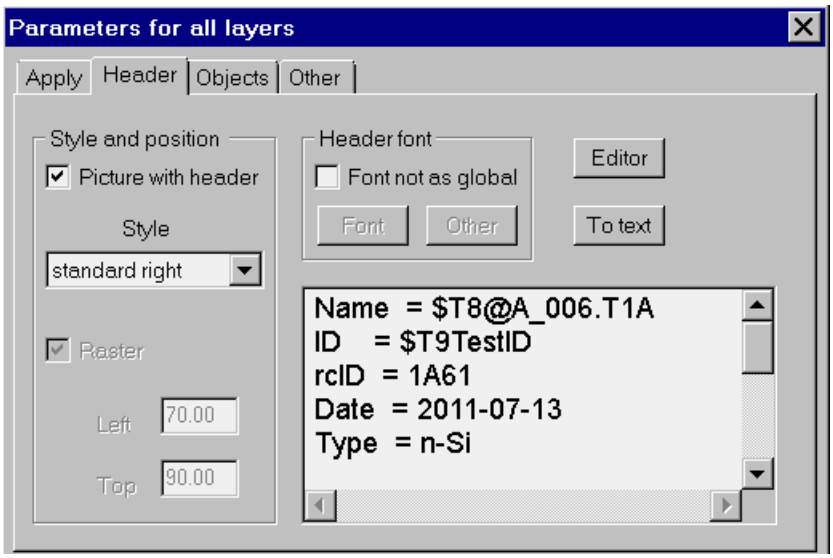
'**Value for z-axis from**' defines which value (parameter) will be set for an optional z-axis, which will be used for 3-dimensional and mapping plots. The standard is 'array number', is the number of curve will here be applied as z-value. Another possibility is the temperature, additional possibilities depend on your program. When using the z-axis define this mode before applying data into the presentation plot program. Click for this at entering the presentation program onto the 'Ok, input' button (chapter 5.2.0.1) and then onto the 'All layers' button (chapter 5.2.0.2). You can later edit the z-data in the 'Other' input sheet of 'Params for one layer', see chapter 5.2.3.3. The z-axis text will automatically be defined by applying a new picture or a new layer. This mode has no effect when starting the presentation plot program from a 3-dimensional or mapping plot or from 'all curves in one plot'.

Header input sheet:

Here are the parameters for the text header. The flag 'Picture with header' enables the showing of the text header. Following header **styles** resp. positions are available:

mid: The header will be shown in the mid.
top: The header will be shown on the top.
top and right: 2 lines will be shown on the top, the other on the right.
standard right: The header will be shown on the right besides the plot boarder.
quarter, 2 columns: The header will be shown in the left-right quarter.
manual: Input of left and top position in per cent canvas coordinates.
manual, 2 columns: As above, but the header will be shown in 2 columns.

If changing the style from one with 2 columns to a style with 1 column then you will be asked for making a header with 1 column. In this case the text control commands for a 2. column, $TT, will be deleted. The opposite happens if changing from 1 column to 2 columns style. The flag '**Raster**' sets the manual defined positions to a virtual raster as described in chapter 2.3.5.



Usually the global defined header **font**, see chapter 2.3.3.3, will be used. By activating a flag you can locally define a font for the header.

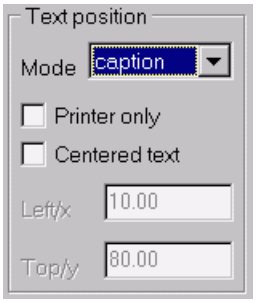
The memo **text** field allows to edit the header text. The text control commands will be explained in chapter 5.2.7.X. Clicking onto the 'Editor' button calls the integrated standard editor. The 'To text' button copies the header into a text object.

Objects input sheet:

Here you can define whether text and graphic objects are available for layer 0. These objects don't belong to a normal plot layer. The standard application here is a caption of the picture. If text or graphic objects exist then you can reduce its numbers.

3 buttons exist for opening the input window for 'New text', 'Text' and 'Graphic'. These inputs are similar to those described in chapter 5.2.7.

The setting of the **text position** is restricted. Following modes exist:



manual: Input of left and top text position in per cent canvas coordinates.
caption: The text will be shown on the bottom of the picture.
screen top: The text will be shown on the top of the picture.
scr top+: As above, but the x-position is at the plot boarder, the y-position is a little bit lower.
screen left: As above, but the x-position is at the picture start.

If using the caption mode then it is possible to plot the text only on the printer and not on the screen. The text can here also be shown centered in the x-mid of the picture.

Other input sheet:

Here you can restrict the maximum numbers of layers.
The **size for one layer plots** can be defined here: Full, Big, With header. The first modes don't show the header, the last shows the header and uses a big screen size.

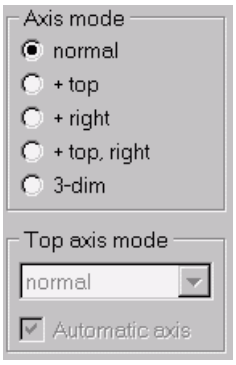
5.2.3.3 Plot params for one layer

These parameters are valid for the selected layer, the inputs are grouped in 6 input sheets.

Base input sheet:

Here are the parameters for the **layer size/position**, as described in chapter 5.2.0.2.

A plot has normally 2 axes, the x- and the y-axis. The software allows the use of additional axes, so that you can have for example 2 curves in 1 layer with 2 different y-axis. If it is an independent axis then you can define it separately in the axis menu.
Following **axis modes** exist:



normal: Only one x- and one y-axis exist.
+ top: An additional x-axis on the top of the boarder exist.
+ right: An additional y-axis on the right exist.
+ top, right: An additional top x-axis and right y-axis exist.
+ 3-dim: The plot will be shown in a 3-dimensional style, that means with an additional z-axis. This needs many curves.

At an additional top axis you can select the **top axis mode**:

normal: The top axis is an independent full definable axis.
1/T → T: Not an independent axis, the top axis will be calculated from the standard x-axis. The application is an additional top temperature at an Arrhenius plot.
T → 1/T: As before but shows on the top a 1000/T axis, the x-axis must be T.
T → E: As before but calculates from the temperature (x-axis) an energy with the help of energy and capture cross section of the physical parameters.
tau → E: As before but calculates from the time constant (x-axis) an energy with the help of temperature and capture cross section of the physical parameters.
E → T: Opposite to T → E
E → tau: Opposite to tau → E

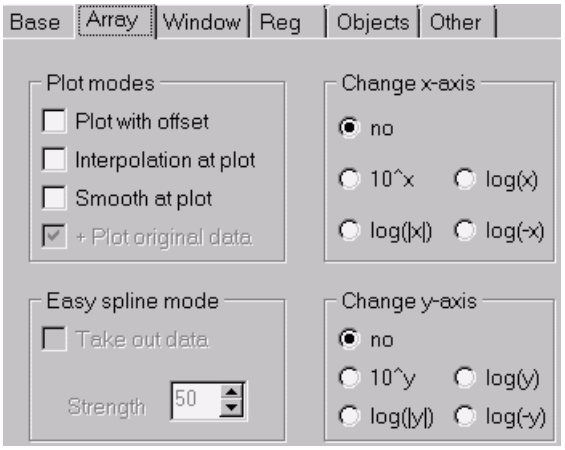
If not defining the normal top axis mode then the flag '**Automatic axis**' is enabled. This means the text, steps and so on will be automatically set. In the other case you can input these values in the axis menu as x2-axis. The window minimum and maximum will not be used for this axis but calculated from the standard x-axis.

If using the **3-dim** axis mode then a button for the 3-dimensional parameters and the flag 'Check x-axis' will be visible. By not activating of this flag, the software don't check whether all curves of the layer have the same x-axis. In the other case the software test it and interpolate the curves to one common x-axis if necessary, similar as saving ASCII data of all curves, see chapter 5.2.1.2.
The 3-dim plots shows an additional z-axis. The data for the z-axis come from 'Value for z-axis' of each curve and will be automatically set by entering the presentation plot. You can change this value separately for each curve in the 'Other' input sheet of parameters for one curve or commonly for all curves in the 'Other' input sheet of parameters for all curves.

If using an axis mode with an independent additional axis, except the 3-dim axis mode, then you have to define for every curve which axes the curve uses. This must be done in the 'View' input sheet of parameters for one curve, see chapter 5.2.3.4.

Array input sheet:

Here are the common parameters for all arrays (curves) of the selected layer.



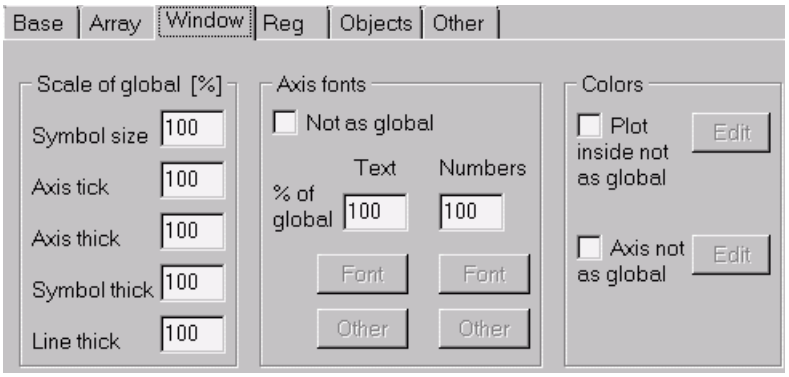
The **plot modes** input group contains flags for showing the curves with different y-offsets, see 'View' input sheet in chapter 5.2.3.4, and for interpolation and approximation (smooth).
If **smoothing** the curves then you can also plot additionally the not smoothed original data. The approximation will be done by the Easy spline mode, see chapter 2.7.1. You can select the smoothing strength and the taking out of data.

The scaling of both axes may be changed independently from linear to logarithmic and reverse. For the logarithmic you can use only negative or positive values or the absolute value.

Note: All functions here don't change the original data arrays, only the curves will be plotted in the selected kind.

Window input sheet:

Here are style parameters for the layer window and some other style parameters.



You can select a per cent **scale** of the global size for:
size of symbols and axis tick and the thickness of axis boarder, symbols and lines.

Usually the global defined **axis fonts**, see chapter 2.3.3.3, will be used. By activating a flag you can define locally fonts for the axis text and numbers. In the other case a per cent size of the global fonts is selectable.

In the **Colors** input group you can define whether the color for the plot inside and for the axis will not be used as global defined, see chapter 2.3.3.1. In this case you can select the color by the 'Edit' button.

Regression input sheet:

This input sheet contains the parameters for the linear regression of the selected layer.

The regression mode defines which evaluation will be done by the linear regression. Further evaluation values will be calculated by the slope and section of the linear regression. Usually the regression line through the curve(s) will be drawn and the results listed. Following **regression modes** exist in all main programs:

No regression: No linear regression resp. evaluation will be done.
Only line: Only the regression line will be drawn but not the results listed.
Slope: Only slope and intersections of the linear regression will be listed.
Energy: Arrhenius evaluation with listing only the energy.
Arrhenius: Arrhenius evaluation, shows energy and capture cross section.
Richardson: Calculates barrier height and Richardson constant.
V/I resistance: Calculates resistance from a V/I (voltage versus current) curve.
I/V resistance: Calculates resistance from a I/V curve.
n-factor: Calculates n-factor from a I/V curve of a diode.
Ns by C/V: Calculated shallow concentration from a 1000/^C2 versus V curve.

At the **DLTS** program are additional following modes available:

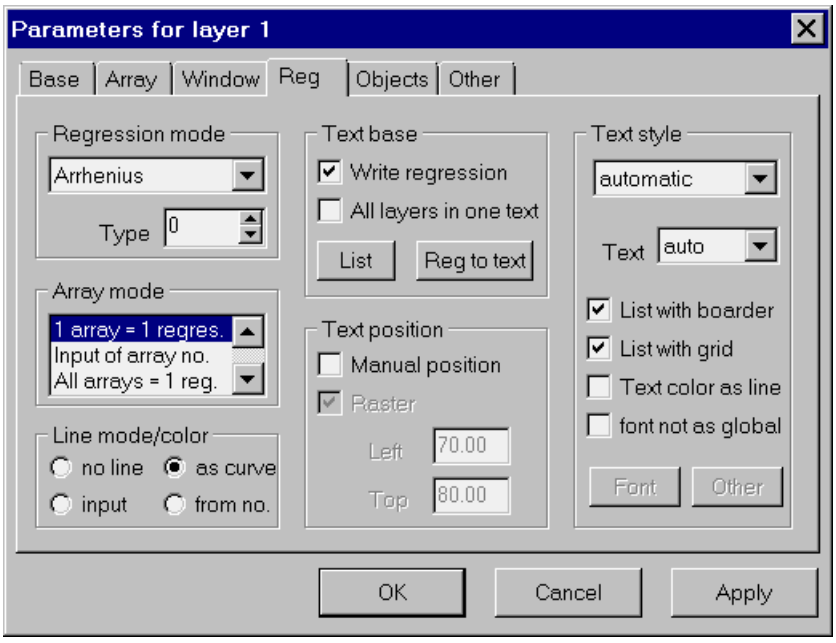
Arrhenius with NT: Similar to Arrhenius but additional the value for NT will be listed, but this value can not be calculated by the presentation plot program. It will be applied from the transferred plot at the entering.
Zerbst: Zerbst evaluation of a transient.
Nss: Calculates the capture cross section from a Nss plot.
Capture: Calculates the capture cross section at a capture process.

At the **Hall** program are additional following modes available:

Magnet: Calculates Rh and concentration at a field variation.
Seebeck: Calculates Seebeck constant.

The **regression type** is a sub mode for the regression mode. So its meaning depends on the regression mode but also on the data. The input is only a number. It will be set as the regression mode by the transferred plot.

The regression **array mode** defines how the regression will be done over the different arrays, it will be later explained in chapter 5.2.5. You can set it also in the Evaluate menu.



The **line mode/color** defines the color of the regression line:

no line: No regression line will be drawn.
input: You can input the color for each line, see chapter 5.2.3.4 input sheet 'Reg'.
as curve: The line has the same color as the curve.
from no.: The color will be defined by the regression (level) number. Here the global plot parameters will be used.

'**Write regression**' write the results either in the header or in a separate text box.
'**All layers in one text**' lists the regression/evaluation results of all layers in one text box. This input is valid for all layers.
The '**List**' button opens the integrated editor and list all regression/evaluation results of the selected layer.
The '**Reg to text**' button copies all regression results into a text object.

You can set the position of the regression text box by activating '**Manual position**'. Then you have to set the left and top position in per cent canvas coordinates. '**Raster**' sets the manual defined positions to a virtual raster.

The **text style** input group contains parameters for the regression text box and defines the use and main style of the text list box:

automatic: Sets the style automatic. If only one regression number resp. level exist then the results will be listed in the text header.
hori, no dim: Lists the results in a separate horizontal text box. Horizontal means that all results of 1 regression number (level) will be listed in 1 line. No dimensions of the values will be shown in the caption for saving space.
horizontal list: As before but shows also the dimensions.
vertical list: As before but the all results of 1 level are in 1 column.

For the Arrhenius regression mode you can select the energy text.
'**List with boarder**' draws a boarder around the list text box.
'**List with grid**' shows the list text box with a grid.
'**Text color as line**' uses the same color for the text as for the line, depending on the regression number. In the other case the color is black.
'**Font not as global**' allows to select a separate font for the regression text box. In the other case global defined data font will be used.

Objects input sheet:

Here you can define whether text and graphic objects are available for the selected layer. If text or graphic objects exist then you can reduce its numbers.

3 buttons exist for opening the input window for 'New text', 'Text' and 'Graphic'. These inputs are similar to those described in chapter 5.2.7.

Other input sheet:

Here you can restrict the **numbers of curves** and regressions. If a linear regression is available then the numbers of regression correspond usually to the numbers of curves, see previous chapter.

The plot shows normally the boarder and the curves. By deactivating a flag the boarder or the curves will not be plotted.

The button '**Axis**' allows the access to the axis inputs as in the Axis menu.
The button '**Edit z-val**' opens the grid editor for editing the z-values of all curves.

An input group contains **Physical parameters**: Temperature, time constant tau, energy, capture cross section sigma. These parameters are valid for all curves of the selected layer. Normally they are not necessary, but will be used for an additional top axis, see 'Base' input sheet of this chapter. 'Temperature' exist also separately for each curve. For the linear regression this value will be used.

If the layer comes from a plot with **many curves**, see chapter 5.1.7, then an additional input window is visible. The dimension of the z-parameter can be input. The z-parameter for the first and last curve can be written into the curves or be marked by squares with explanation text.

5.2.3.4 Plot params for one curve

These parameters are valid for the selected curve, the inputs are grouped in 4 sheets.

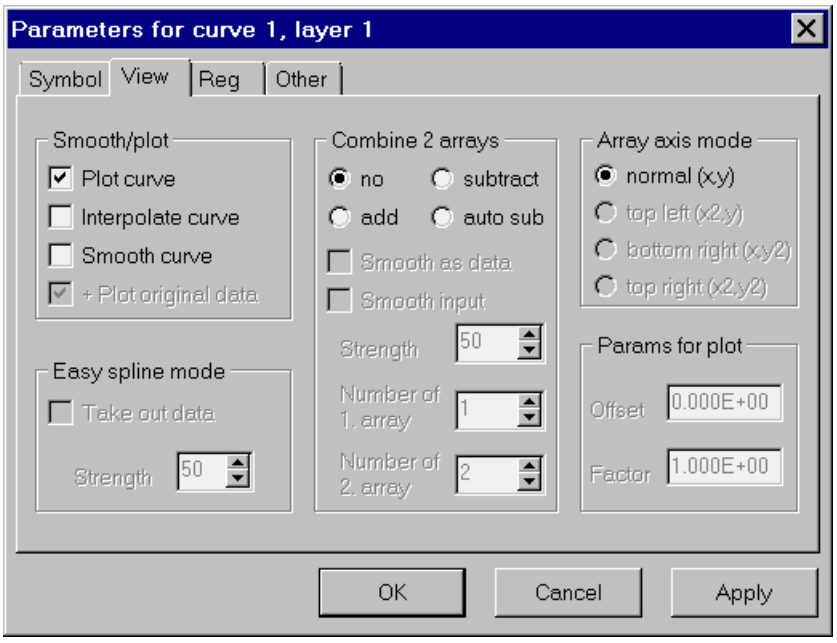
Base input sheet:

Here are the parameters for the **symbol** and color of the curve, as described in 5.1.3.1.1. An additional input for the scale size of symbols exist. The default is 100%, this means the symbol size is as global defined and used in the other plot programs.

View input sheet:

Here are parameters for showing the curve.

The **Smooth/plot** input group contains flags for showing, interpolating and smoothing the curve.
If **smoothing** the curves then you can also plot additionally the not smoothed original data. The approximation will be done by the Easy spline mode, see chapter 2.7.1. You can select the smoothing strength and the taking out of data.
All functions here and in the following don't change the original data arrays, only the curves will be plotted in the selected kind.



You can **combine 2 arrays** by addition or subtraction. 'Auto sub' means that from the curve with the biggest y-value the other curve will be subtracted. For the combination you have to input both array numbers, except in the mode 'auto sub' and the curve number N is bigger than 2. In this case the curves N-2 and N-1 will be used.
The arrays which will be used for the combination can be smoothed. This smoothing is only valid for the combining, it don't change the curves itself. You can smooth the combined curve as in 'Smooth/plot' or input a separate strength. Independently from the approximation both arrays will be reduced to the same x-axis at the combination, similar as explained in chapter 5.2.1.2.

The combined array replaces the selected curve at the plot but don't change the original data. It don't create a new curve, the curve which belongs to this array number will not be shown. If you want to show all original curves and additional a combined curve you have to create a new curve. For this select in 'Edit → Restore array' as curve mode '1 curve, standard params' and then as apply mode 'New curve/data'. For the difference of 2 arrays it is easier to call 'Edit → Make difference'.

The **array axis mode** is enabled if you have the selected an independent 2. axis, see axis mode of 'Base' sheet in chapter 5.2.3.3. Then you must define to which window axes the selected x- and y-array refers:

normal (x,y):	The curve uses the standard bottom x-and left y-axis.
top, left (x2,y):	The curve uses as x-axis the top x2-axis.
bottom right (x,y2):	The curve uses as y-axis the right y2-axis.
top right (x2,y2):	The curves uses the top x2- and the right y2-axis.

If activating 'Plot with offset', see 'Array' input sheet of chapter 5.2.3.3, then you can here define an **offset** and factor for each curve. This is only for showing the curve, the y'-values of the shown curve are calculated by y'=y*Factor+Offset.

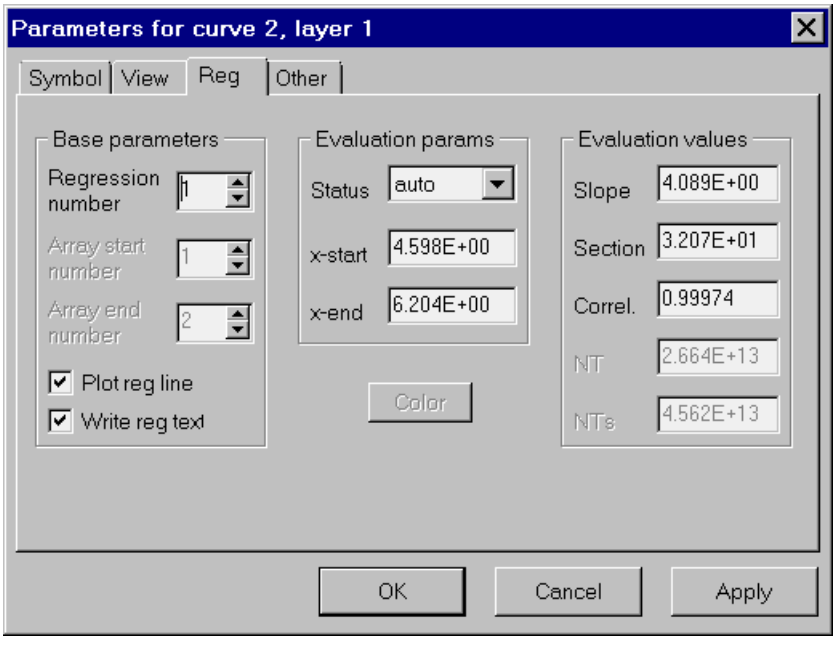
Regression input sheet:

This input sheet contains the parameters for the linear regression of the selected regression number. It is only visible if the regression mode of the layer is not 'no regression'.

If there is more than one regression possible, see regression array mode in chapter 5.2.5, then you can here input the regression (level) number. The **regression number** may not refer to the curve number. So if you have 2 curves and 3 regressions you can at every curve edit the regression by selecting the regression number. How to create a new regression number will be explained in chapter 5.2.5. A change of the regression number fills all inputs with the corresponding values.

If the regression array mode is 'Input of array no.' then you can here input the **array** start and end number over which the regression will be done. The input is also in the Evaluate menu possible. An array can be excluded in the 'Other' input sheet of its curve.

'**Plot reg line**' draws the regression line for the selected regression number '**Write reg text**' writes the results either in the header or in a separate text box.



The **color** button is enabled if you have selected 'input' for the color of the regression line, see 'Reg' input sheet of chapter 5.2.3.3.

In the **Evaluation params** you can change the x-start and x-end of the linear regression. Normally these values will be set by the transferred plot or manually in the Evaluate menu. The **status** denotes how the regression was done:

not init: No regression calculation was done.
auto: An auto regression was done, see chapter 5.1.5.1.
manu-range: A manual regression was done with the mode 'Set xy-range for regression', see chapter 5.1.5.2.
manu-line: As above but with the mode 'Set regression line'.
manu-plot: As above but no new calculations.

The status defines also whether the standard evaluation values slope, section and correlation will be new calculated at the plot. If selecting 'auto' these 3 values will be new calculated. An input of these values makes then no sense. The manual regression keeps the values for slope and section. The correlation factor will be new calculated at 'manu-range' and, if global enabled as described in chapter 2.3.3.6, at 'manu-line'.
Slope and section are the direct values from the line. At the result list not these values but evaluation values calculated from these will be shown. For example, at an Arrhenius evaluation the energy will be calculated from the slope. The 'Arrhenius with NT' evaluation can have 2 additional values. Here you can input both, these will not be new calculated.

Other input sheet:

Here you can restrict the first and last **array** index of the curve and edit the x- and y-array by the integrated grid or text editor.

The **regression** can be disabled for the selected curve. The flag here belongs to the curve and not the regression (level) number. The regression number may not refer to the curve number. So for example, you can have a regression number 2 which uses curve 3, while curve number 2 will not be used for the regression. This flag can also be important for the regression array mode 'Input of array no.' if you want to exclude an array of the selected array range.

The value for **z-axis** can here be changed, it is only important for 3-dim and mapping plots. It is normally this parameter which is varied when many curves are to be plotted together.

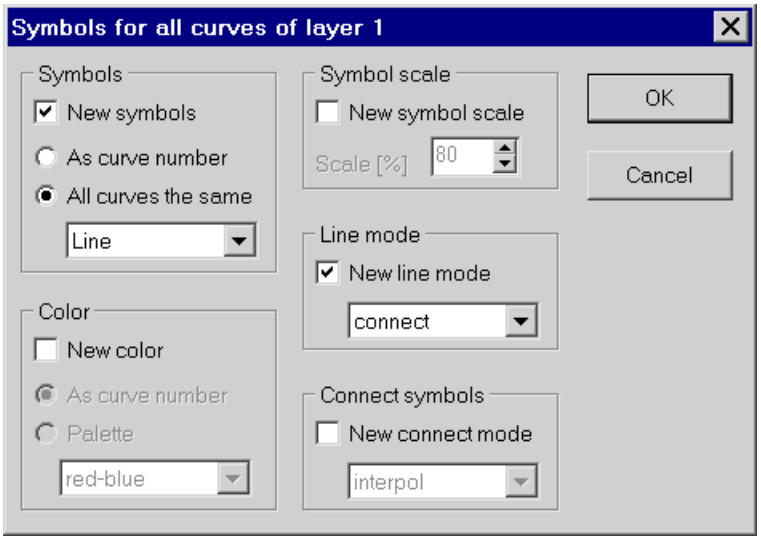
An input group contains **Physical parameters**: Temperature and doping type. These parameters are valid only for the selected curve and will be used for special evaluations, that means regression modes. So the doping type will be used at the Arrhenius evaluation for the labeling of the energy. A change of the doping type here changes only this label but not the data and evaluation results!

5.2.3.5 Symbols for all curves

Here you can change the symbol, line mode and color of each curve of the current layer by one dialog. So a line can be set as symbol for each curve by 'one click'. If the flag 'New symbols' is not activated, the current symbols of the curves will not be changed.
Each of the following **possibilities** have to activate by a separate flag called 'New …':

- **Symbols:** 2 possibilities exist for setting a new symbol for each curve:
  - 'As curve number' sets the symbol by the curve number. Curve 1 gets the square, curve 2 the cross and so on, for more details look in chapter 5.1.3.1.1. Only the symbols 1 to 8 will be used.
  - 'All curves the same' defines for each curve the same selectable symbol.
- **Color:** 2 possibilities exist for setting a new color for each curve:
  - 'As curve number' sets the color by the curve number as explained in chapter 2.3.3.1. Only up to 8 colors will be used.
  - 'Palette' applies the color either from the blue-red or the rainbow palette, see chapter 5.1.7.2. Curve 1 gets the first color (blue), the last curve gets the last color (red). An inverse order is also available.
- The **Symbol scale** size for all curves can be input. 100% means the symbol size is as global defined.
- The **Line mode** can be set as described in chapter 5.1.3.1. This has only an influence when a curve will be drawn by lines.
- **Connect symbols** by lines can be set as described in chapter 5.1.3.1.

After clicking onto the 'Ok' button the selected actions will be done. The new symbols, colors and so on will then applied as new curve parameters. If a flag is not activated, this parameter will not be changed. The action will be done for all existing curves of the current layer. If you add later a new curve to the layer, the parameters of the new curve will not automatically be changed. You have to call this dialog again. All flags are deactivated after a program start.



5.2.3.6 Position

Here you can change the positions of the layer, the header and the list text box of the regression results. These inputs are also in other input windows possible and are already explained, see chapter 5.2.0.2, 5.2.3.2 (Header) and 5.2.3.3 (Reg). There you can only input the position value or, for the layer, select predefined position types. Here you can additionally set the coordinates by mouse clicks on the screen plot.

For this you have to select in the input box 'SetPos for' for which you want to set the position by mouse: layer, header, regression. The selection for each mode is only enabled if the manual position was activated for it. The 'SetPos' and 'Show' button, see below, is only enabled if one mode of 'SetPos for' is enabled.

For the layer you have to set the left top and the right bottom corner by mouse, for the header and regression only the left top point. All coordinates are in per cent canvas coordinates.

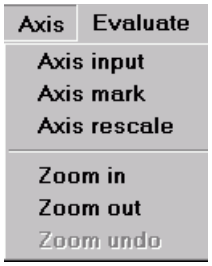
There are 3 additional smaller buttons:

- **SetPos:** Shows the full plot and marks the current setting of point. After defining of the new point(s), the program goes back to the 'position' input window.
- **Show:** Similar as above, but the full plot with the new position will be shown after defining the new point(s). The program goes only back to the input window after pressing a key or a mouse click.
- **Refresh:** No new setting by mouse, the current plot will be shown. The program goes back to the input window after pressing a key or a mouse click.

Note: Activating of the 'Raster' flags sets the coordinate values to a virtual raster as described in chapter 2.3.5. So the final positions may not identical with these ones you have set by mouse or input.

5.2.4 Axis menu

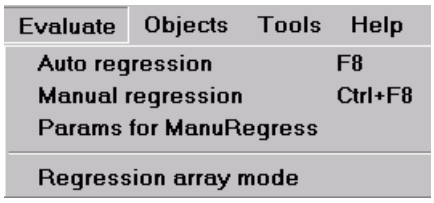
This menu enables to set the axis of the plot and a new plot window. This can be done by an input, by the mouse or by the zoom function. The functions are the same as in the standard plot program, an explanation was given in chapter 5.1.4. The axis refers to the active layer, selectable in the View menu and shown in the toolbar as a button caption.



'Axis input' opens an input window for the x,y-axis parameters.
'Axis mark' enables to set a new plot window by marking the left/bottom and right/top point. You can define points inside of the plot window (zoom) or outside, but the defined points must be inside of the canvas.
'Axis rescale' restores the standard plot window.
'Zoom in, out and undo' are the standard zoom functions. For zooming-in you have to mark the center point by the mouse.

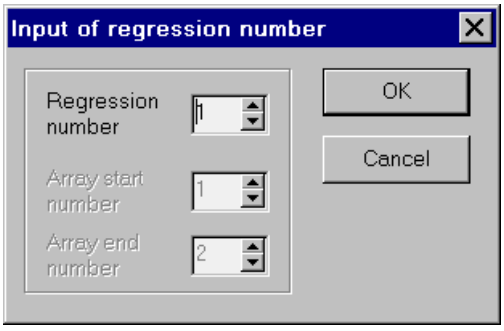
5.2.5 Evaluate menu

The possibilities of this menu depend on the kind of data. An evaluation by a linear regression is not always available. Look in chapter 5.1.5 for a description of the automatic and manual regression.



'Auto regression' is the standard linear regression, the 'Manual regression' can be started directly and with inputs of its parameters.
'Regression array mode' defines how the regression will be done over the different arrays.

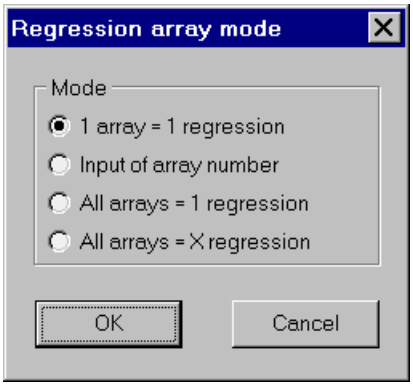
The regression refers to the active layer. If there is more than one curve you get normally the input for the **regression number**:



You have to input the regression number. In the standard case this number corresponds with the curve (array) number for which the automatic or manual regression should be done. The kind of inputs depends also on the 'Regression array mode'. You can change it in the Evaluate menu, explained at the end of this chapter. If the array mode 'Input of array no.' is selected then you have here to input the array start and end number over which the regression will be done.
At this mode and at the mode 'All arrays = X reg.' you can also create a new regression number. The maximum numbers of regressions resp. evaluations is 9.

In the regression input sheet at 'View → Plot params for → One layer → input sheet Reg', see chapter 5.2.3.3, you find further parameters for the linear regression and evaluation which are valid for all curves of the selected layer. The regression parameters for a special curve are in 'View → Plot params for → One curve → input sheet Reg', see 5.2.3.4. There you can also delete the regression.

The **Regression array mode** defines how the linear regression resp. evaluation will be done over the different arrays resp. curves of the active layer:

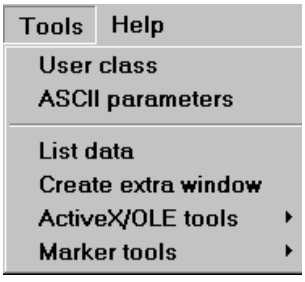


- 1 array = 1 regression: This is the standard mode. The linear regression will be done separately for each curve. The regression number refers to the curve number. At calling the regression you get a question for the regression number if more than one curve exist, see above. But it is not necessary to do it for all curves, only regressions done will be drawn. You can also deactivate a regression number, see chapter 5.2.3.4.
  Application:1 curve with 1 regression or many curves with each 1 separate regression.
- **Input of array number:** This mode has the greatest flexibility. Regression number and array number are independent. You create a regression number and define which array range will be used for the calculation. For one array range are many regressions possible. You can exclude arrays of the array range at the 'Other' input sheet of 'Params for one curve'.
  Application: Many regressions over the same or different arrays ranges, or not using all arrays for the regression.
- **All arrays = 1 regression:** Only 1 regression is possible, all curves will be used. There is no input for the regression number or array range necessary.
  Application: 1 regression over all curves.
- **All arrays = X regression:** All curves will be used and you can define many regressions over all curves.
  Application: Many regressions over all curves.

Note: At some evaluations the regression number will also be denoted as level number.

5.2.6 Tools menu

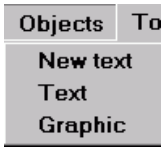
This menu contains some different functions. The functions are similar as in the standard plot program, for more information see chapter 5.1.6.



ASCII parameters contains parameters for copying, saving and reading ASCII data.
List data lists the x/y-data as lines and columns. You have to select layer and curve number in a similar input window as the second one in chapter 5.2.1.2.
You can create an extra window with a plot of the active layer. For the creating a separate data grid window you have to select layer and curve number in a similar input window as in 5.2.1.2.
Marker tools are a help to identify a point or get its position.
The ActiveX/OLE tools with its sub menu is only visible at user class 5. ChartFX is a chart plot program, Formula One a spread sheet. You can call Excel or Calc with the current data or save into the Excel or Calc format.

5.2.7 Objects menu

This menu allows to create and edit objects and to insert these in the plot. Objects are text or graphic elements of a layer. The inputs here are valid for the active layer. Objects for layer 0 can only be created and edit in the 'Params for all layer', see chapter 5.2.3.2.

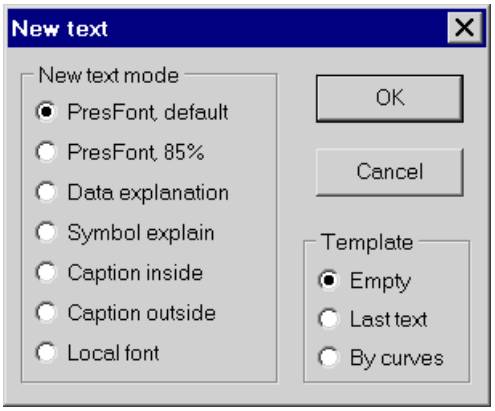


'New text' create a new text object with default parameters and opens then 'Text' input window. Here you can edit the existing text objects or create or delete an object.
'Graphic' allows to create a new graphic object or to edit an existing one.

5.2.7.1 New text

The 'New text' function is similar as the 'Text' function. But before it opens the normal text function, you get an input window for the new text mode. It defines the default font for a new text and some other parameters. Following **new text modes** exist:

PresFont, default: This is standard mode. The so called presentation font will be used. It is global defined, see chapter 2.3.3.3.
Application: Standard text inside the plot.
PresFont, 85%: As above but sets the font scale to 85%.
Data explanation: Uses the data font.
Application: Data grid inside of the plot.
Symbol explain: Uses the symbol font in simple mode, see next chapter.
Application: Explanation of plot symbols inside of the plot.
Caption inside: Uses the caption font with font scale 75%.
Application: Caption inside of the plot window.
Caption outside: Uses the caption font and activates the canvas coordinates system.
Application: Caption at the top or bottom outside of the plot window.
Local font: Uses not a global font as the other modes but a local font which you have to define.



If not otherwise denoted above, the new text mode sets also following default parameters:

- Activation of the axis coordinates system instead of the per cent canvas coordinates.
- Setting of the font scale to 100 %.

The input of the new text mode is valid for all layers except layer 0.

The new text can be filled by a **template**:

Empty: The new text is empty.
Last text: The text of the last input will be used.
By curves: The template contains an explanation of symbols and colors of each curve.

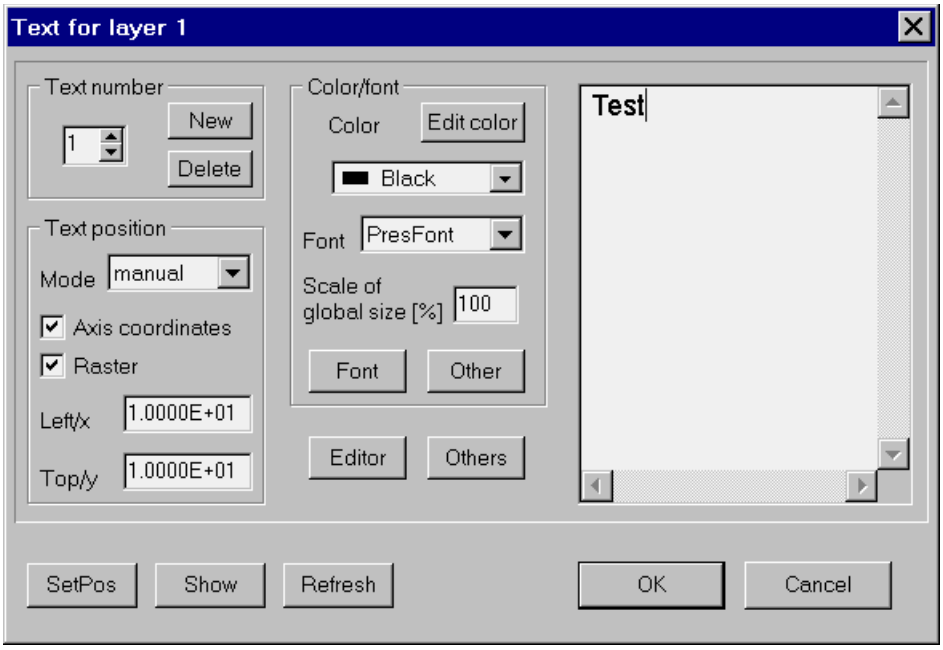
A new text object will be created after setting the new text mode. For this the maximum number of text objects will be incremented. The parameters of the last text object, if exist, will be copied to the new object. The default parameters as the font will then be set for the new text object. Then the input window for 'text' opens as described in the next chapter.

5.2.7.2 Text

Here you can create a new text object or edit an existing one.

The **text number** is the number of the text object. Up to 50 text objects per layer are possible. You can select one of the existing text objects. A change of the text number fills all inputs with the corresponding values.

You can create a new text object by the '**New**' button. The parameters of the last text object, if exist, will be copied to the new object. Here the default parameters will not be set by the new text mode as described in the previous chapter.
The '**Delete**' button deletes the selected text object. The text numbers will then be reorganized.



Following modes for the **text position** exist:

manual:	Input of the left and top text position, can be set also by mouse.
left/top:	Left top inside of the plot window.
left/bot:	Left bottom inside of the plot window.
right/bot:	Right bottom inside of the plot window.
right/top:	Right top inside of the plot window.
right/mid:	Right middle top inside of the plot window.
right/center:	Right center inside of the plot window. The text is centered around the middle of the y-axis.
out/top:	On the top outside of the plot window.
reg. list:	Left top inside of the plot window, optimized for a regression list text.
caption:	The text will be shown on the bottom of the picture.
screen top:	The text will be shown on the top of the picture.
scr top+:	As above, but the x-position is at the plot boarder, the y-position is a little bit lower.
screen left:	As above, but the x-position is at the picture start.

Activating of '**Axis coordinates**' uses the axis (world) coordinates system of the selected plot (layer) instead the per cent canvas coordinates system.
'**Raster**' sets the manual defined positions to a virtual raster. Then the final positions may not identical with these ones you have set manually, but usually it likes nicer.
The **Left/x** and **Top/y** coordinates (axis or per cent canvas) are enabled at the manual text position. You have to define the left top corner of the text.

The text **color** can be selected by the color input box or by the standard color dialog.

The **font mode** defines the text font:

PresFont:	The so called presentation font will be used. *Application*: Standard text inside the plot.
Header font:	The header font will be used: *Application*: Usually only for the header.
Data font:	Uses the data font. *Application*: Data grid inside of the plot.
Symbol font:	Uses the symbol font.
Symbol, simp.:	Uses the symbol font in simple mode. Scale, color and 'Others' parameters are not enabled, optimized for symbol explanation. *Application*: Explanation of plot symbols inside of the plot.
Local font:	Uses a local font which you have to define.
Caption:	Uses the caption font. 'Others' parameters are not enabled. *Application:* Caption inside and outside of the plot window.

Except the local font, the fonts are global defined, see chapter 2.3.3.3. The input windows which open by the '**Font**' and '**Other**' button change the global valid parameters of the global font. So here these inputs are forbidden for the header, data and symbol font. The inputs for the presentation, caption and local font are allowed because the presentation and caption font will not be used automatically from the software, they are reserved for the presentation plot program. The local font is only local valid for this text number.
The **scale of global size** sets the font size relative to the global selected size of the global font.

The memo **text** field allows to edit the text. Clicking onto the 'Editor' button calls the integrated standard editor. The command characters will be described in the next chapter. The 'Others' button will be described on the next page.

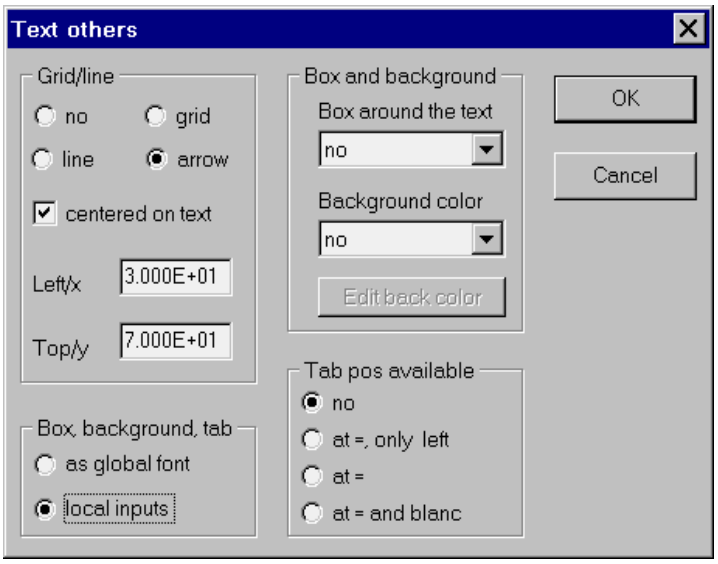
If selecting the **manual position** then you can set the left top corner of the text also by a mouse click or by cursor keys. For this there are 3 additional smaller buttons:

- **SetPos:** Shows the full plot and marks the current setting of point and draw the text on the old (current) position. No refresh of the plot will be done, so you can compare the old and new position. After defining the new point, the program goes back to the 'text' input window.
- **Show:** Similar as above, but the plot will be refreshed and while marking the old (current) position the text will not be drawn. And the full plot with the new position will be shown after defining the new point. The program goes only back to the input window after pressing a key or a mouse click.
- **Refresh:** No new setting by mouse, the current plot will be shown. The program goes back to the input window after pressing a key or a mouse click.

In the **status line** you get normally the information 'Mark left/top point by mouse/marker'. If drawing a line or arrow with the text then you have here also define its end point. So you get in the status line first the hint 'Mark start point', this is the text position, and then the hint 'Mark end point', this is the position of line resp. arrow end.

Note: The left top position is not the real start (left top corner) position of an individual character. A virtual cell size independently from the character will be used.

The '**Others**' button opens an additional input window .



A grid, line or arrow can be drawn with the text.
For the **line** and **arrow** you have to define the end point of the line resp. arrow, either by input or by mouse. The coordinate system is the same as for the text. The start point will be calculated by the text position in such way, that the line don't go through the text. By activating 'centered on text' starts the line from the middle of the top, bottom, left or right of a virtual box around the text. In the other case a vertical or horizontal line will be drawn from the text to the end point. If this is not possible then the start point of the line is a corner of the text.
You can also draw the text with horizontal and vertical **grid** lines. The text columns must be separated by semicolons. Usually you should here use a 'grid with boarder'.

2 modes exist for the **box, background and tab** of the text:

as global font: The input is here not available, the parameters of the global font will be used, see 2. input window of chapter 2.3.3.3.

local inputs: Local inputs here are available, they are only valid for the current text number and replace only for this the corresponding global values.

The inputs for the local font are always possible, they are here the same as in the 'Other' button above. The local font is only valid for the current text number!

Following possibilities exist for a **box** around the text: normal box, shadow, 3-dim box.

Following modes for the **background color** of the text or the box are possible:

no: No background color.

text, color input: Background of the text, color input by the 'Back color' button.

box, color input: Background of the box, color input by the 'Back color' button.

box, plot color: Background of the box, the color is the global color 'Plot background', see chapter 2.3.3.1.

box, inside color: Background of the box, the color is the global color 'Plot inside'.

Tab pos available means after which character the software can set a tabulator and starts a new position. This is useful at proportional fonts for list of data with text and values. A more detailed description was given in chapter 5.1.1.1.3.

Tip: If the text includes a '=' character and another tab mode as 'no' is selected, this is the default by the data and header font, then spaces between the words can occur. To avoid this sets the tab mode locally to 'no' or switch it off by control commands. These commands allow on the other hand also to set the tab mode as explained in the next chapter.

5.2.7.3 Control characters

The text objects and the header can contain control characters. These are characters resp. character groups which will not be shown but control the face of drawing the text, for example for drawing an index or exponent. We use as control character only the **dollar** sign '$', followed by other characters which yields to a control character group. These are composed of the '$' and one base sign, in some cases followed by other character.

In the following list denotes 'N' a 'character number' that means if the number is 0 to 9 then N is '0' to '9', if the number is 10 then it is 'A' and so on. This is similar to the hexadecimal system. The important **control character groups** are:

$$: Shows only the **dollar** sign.
$^: **Exponent**, draws the following text a little bit higher.
$_: **Index**, draws the following text a little bit lower.
$<: **Left**, sets the following text one character size to the left.
$F: **Font**, toggles between the standard font character set and the greek charset 161.
$AN: **Angle**, draws the next text rotated, N denotes here the angle:
0..9: 0..90 degree, A: 180, B: 270.
$CN: **Color**, draws the next text or symbol with the color defined by N. For '0' to 'F' denotes N the global color number, see chapter 2.3.3.1:
1..6: color for global curve number 1..6; 7: color for fit curve, and so on.
For 'K' to 'Z' is N the color of the base color dialog:
K:black, L:maroon, M:green, N:olive, O:navy, P:purple, Q:teal, R:gray, S:silver, T:red, U:lime, V:yellow, W:blue, X:fuchsia, Y:aqua, Z:white.
'a'..'t': Sets the color of the curve number 1..20 of the current layer, only valid for a text object in the presentation plot program.
$SN: **Symbol**, draws a symbol defined by N. N is the symbol:
1:square, 2:+, 3:diamond, 4:x, 5:triangle, 6:circle, 7:full square, 8:full circle, 9:3x3 points, A:point, B:horizontal line, C..E:longer line, F:dash line, H:dot line, H:dash-dot, I:dash-dot-dot, J:space.
$TN: **Tabulator** control. Meaning of N:
0: disables the tabulator control for the whole following text.
0..3: as the input in the previous chapter,.
5: sets only on the current text position a tab.
8: disables tabulators and the control characters.
9: disables the control characters.
T: tabulator for a header with 2 columns.

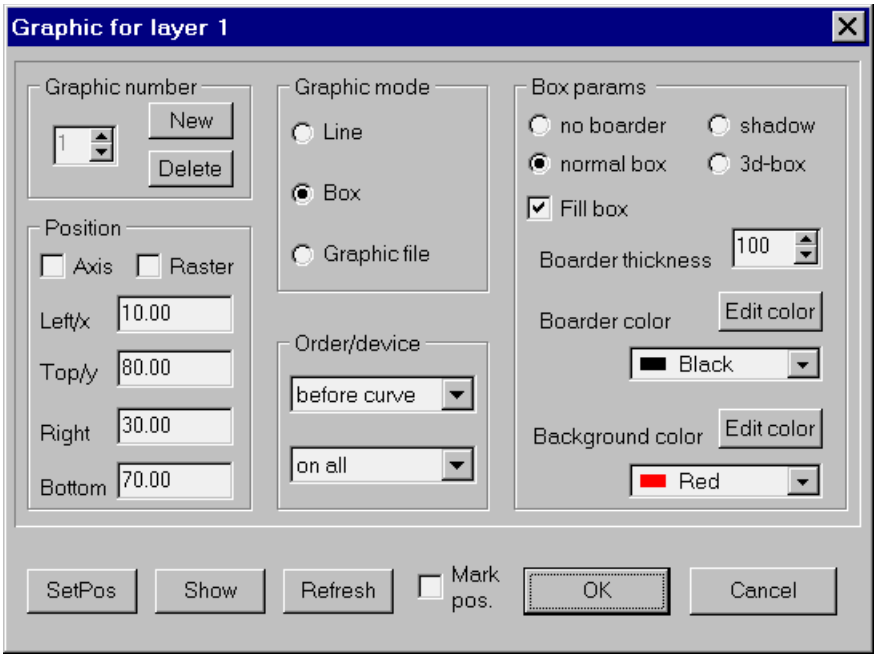
Tip: For a manual symbol explanation use only one text object with several text lines and not some text objects with each one line. Start line 1 with $Ca, line 2 with $Cb and so on, then the text will be drawn in the color of the curves. A symbol will be drawn by $SN where N is the symbol number. For the tabulator see tip above.

Note: If using an index (exponent), don't forget to insert an exponent (index) after the character group. For example, use N$_S$^.

5.2.7.4 Graphics

Here you can create a new graphic object or edit an existing one of the active layer. A graphic object belongs as a text object to a layer.

The graphic **number** is the number of the graphic object. Up to 50 graphic objects per layer are possible. You can select one of the existing graphic objects. A change of the graphic number fills all inputs with the corresponding values.



You can create a new graphic object by the '**New**' button. The parameters of the last text object, if exist, will be copied to the new object. The '**Delete**' button deletes the selected object. The graphic numbers will then be reorganized.

The left, right, top and bottom **position**, in per cent canvas coordinates, of the graphic is necessary. '**Axis**' uses the axis coordinates instead the canvas coordinates. '**Raster**' sets the positions to a virtual raster.

3 **graphic modes** are available, the parameters on the right depends on this:

Line: A line will be drawn. Parameters are the line type, the thickness and the color. The line can have an arrow on its end. A horizontal or vertical line will be drawn by the option 'horizontal/vertical'. The software draws here a horizontal line by (x1,x2,y1) if |y2-y1|<=|x2-x1|, in the other case a vertical line.

Box: A box will be drawn. Parameters are the type, thickness and color of boarder. The box can be filled with a background color.

Graphic file: A saved graphic can be loaded and drawn, the program supports BMP, JPG, GIF, WMF and EMF file formats. You can draw the graphic in original size or stretch it into the marked size. The graphic can also be shown transparently. The graphic will not be saved into HPGL, PLT, EPS and DXF files.

The steps by showing a layer are: start of layer, draw curves, draw texts, layer end. The graphic **order** defines when a graphic should be drawn: layer start, before curve, before text, layer end.

You can select on which **devices** the graphic will be shown:

on all: The graphic will be shown on all devices.
not printer: The graphic will be not shown on a printer, opposite to the next mode.
as printer: The graphic will be shown only on a printer and similar output devices a printer or HPGL file.

The **buttons** has the same meaning as in chapter 5.2.7.2. Here you have always to set 2 points, first the left-top and then the right-bottom corner.

At user class 6 there is the additional flag 'Mark pos', which also exist in the input window for the text object. This option means that the positions of all text and graphic objects will be marked by a big cross (+). It is only for testing. The flag is global and is valid for all layers and all objects. It will not be saved into the presentation data file.

5.3 Other plot programs

This chapter describes not complete new plot programs but modifications or extensions of the standard plot program or other common parts of the plot programs.

5.3.1 Application plot program

The Application Plot Program is only a modification of the standard plot program. In some cases the plot opens the application instead of the standard plot program.

There are 3 **differences** resp. reasons for an application plot:

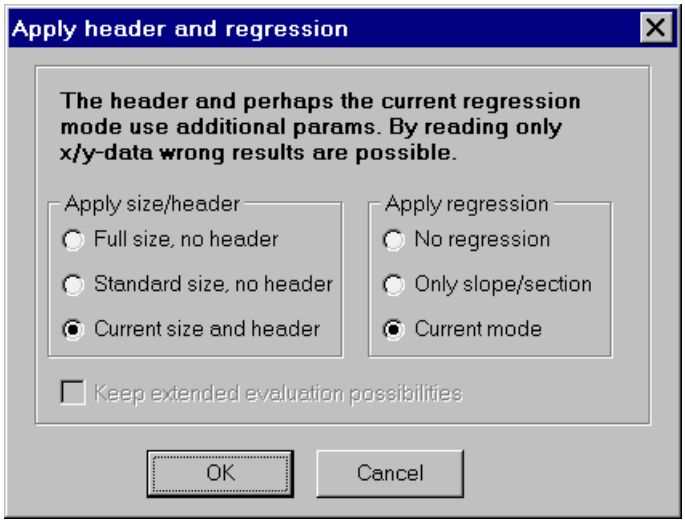
- The linear **regression** can be done automatically at calling the plot. Sometimes there is in the input window before doing the plot, a question for starting with the 'Auto regression'. In all these cases the regression line is normally red instead of black. You can change the color of the regression line in 'Global plot parameters', see chapter 2.3.3.1. The automatic (red) regression line will there be called 'Application regression', the other (black) 'Standard regression'.
- The application plot can contain more than one **layer**, that means more than one plot per page. In this case it not possible to change the windows of the various plots. For this use the presentation plot program.
- The picture can even be composed of 2 canvas (screen) **pages**. Between the 2 pages you get the information box 'Plot next page'. Usually these 2 canvas pages will be shown on one paper page by a printer.

If there are 2 pages then is in the View menu the entry 'Page number'. Here you can define to show only the first or the second page or both pages.

5.3.2 Edit plot program

The Edit Plot Program is an extended version of the standard plot program. In opposite to this the edit plot program can modify the data and can load data from ASCII files. You can call it from the standard plot program if the plot contains only one curve, means only one x/y-array. It can also be called from the presentation plot program or from the Base Tools. The edit plot program can save the x/y-array and read these from an ASCII file. But only the pure ASCII data will be saved or loaded, not the parameters for the window and so on as the presentation plot program will do.
The *application* for the edit plot program is to edit (modify) the x/y-data and then to plot it or to apply it into the presentation plot program.
The menus and the toolbar are similar to the standard plot program, in the following only the new possibilities will be explained.

If **entering** the edit plot program from the standard or application plot the following window occurs. The current x/y-array will always be applied.
You can also apply the current header and the current regression mode. But this may yield to problems by reading x/y-data from a file because the header will not be saved. It will be taken from the current global data. So it can happen that the header don't belong to your x/y data. Some regression modes don't use only the x/y-array but additional parameters which will also not be saved in the edit plot program.



Following modes exist for applying the **size/header**:

Full size, no header:	The plot uses the full (possible) canvas size, no text header will be shown.
Standard size, no header:	The plot has the standard size but without showing the text header.
Current size and header:	The edit plot uses the current size and header position of the standard plot program.

Following modes exist for applying the **regression** mode:

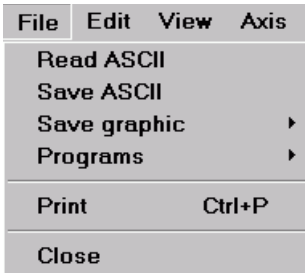
No regression:	No linear regression is available.
Only slope/section:	A linear regression with calculating only slope and intersection x0 with the y-axis and y0 with the x-axis is available.
Current mode:	The current regression mode of the standard plot will be applied.

You can change also later the size/header in 'View' and the regression mode in 'Evaluate'.

The additional flag 'Keep extended evaluation parameters' is only enabled at user class 5. If activated then all possibilities of the Evaluate menu of the standard plot program are further on available, as 'Fit', 'EvalBank', 'Data tasks' and so on. Be careful with this option because a lot of problems can occur.

5.3.2.1 File menu

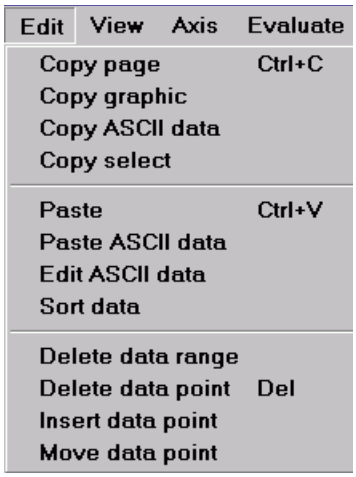
The edit plot program has no own data type. You can only save the x/y data into an ASCII file or load these data from an ASCII file.



If reading ASCII data an input windows opens similar as described in chapter 5.2.1.2. The old data will be overwritten. The option 'Reset plot axis' sets the axis of the plot window by the new data. In the other case the old window will be kept.
'Save ASCII' data saves the current x,y plot values line by line into a text file. The input is similar as described in chapter 5.2.1.2. By an additional option it is possible to save the data in the decimal format instead of the standard exponential format.

5.3.2.2 Edit menu

The Edit and the Data menu are perhaps the most important menus of the edit plot program. Here you can edit the x/y-data points.



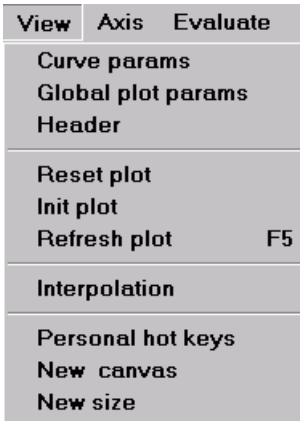
'Paste ASCII data' pastes ASCII data from the Windows clipboard and overwrite the current data. The x-array will be taken from the first, the y-array from the second column. The plot window will not be reset.
'Edit ASCII data' opens the grid or ASCII editor for editing the x/y-data, see chapter 5.4.1.
'Sort data' sorts the data by the x-array.
You can delete single data points or a data range, new points can be inserted and existing points be moved. These can be done by mouse or marker. In the 'special 'edit' mode the deleted data remain in the data array with setting x to -1E100, see chapter 5.4.1.2.
A powerful tool to delete points is 'Delete by deviation' in the Data menu, see chapter 5.3.2.6.1.

5.3.2.2.1 Delete, insert, move

At all the following functions you can use the mouse or the cursor marker. The mouse click marks the point and calls then the action. If using the marker you have to go to the point by the marker and then to press 'Enter' for applying the point and calling the action.

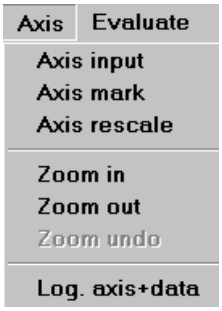
Delete data range: The left and right marked data range will be deleted.
Delete data point: The marked point will be deleted. For deleting a further point you have first to click onto the menu. You can delete some points with only each one mouse click by 'Delete by deviation', see chapter 5.3.2.6.1.
Insert data point: Inserts on the marked position a new data point. This point will be append on the existing ones. There is no automatic sort.
Move data point: Allows marked data point to be moved to a new x/y position. First you have to mark an existing point and then the new position.

5.3.2.3 View menu



By 'Header' you can define the plot size type and whether the header should be shown. It is the same as at entering the edit plot program, see start of chapter 5.3.2. 'Old auto size and header' means here the 'current size and header' at entering the edit plot.
'Refresh' plots the plot again.
'Init plot' makes a new window/axis initialization.
'Reset plot' makes more than 'Init plot'. It sets additionally the standard values for the boarder and window face, deletes the axis text and sets the regression mode to 'slope'.
'Interpolation' interpolates also here only the curve at drawing but not the x/y-data array if selecting 'Original in memory', see chapter 2.7.1. For interpolating or smoothing of the data you must disable this flag or select 'Data → Smooth, Devi, Int'.

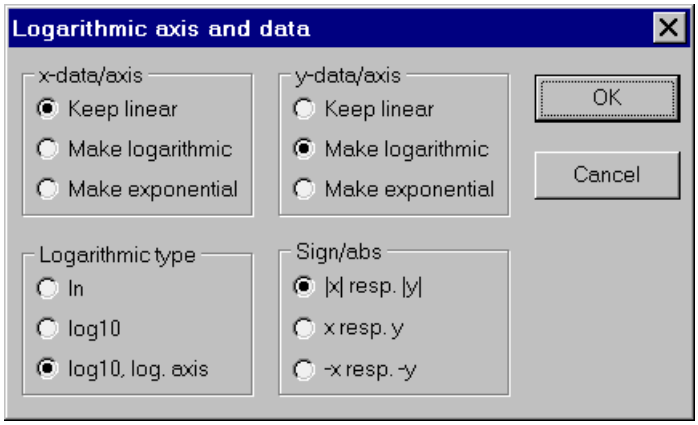
5.3.2.4 Axis menu



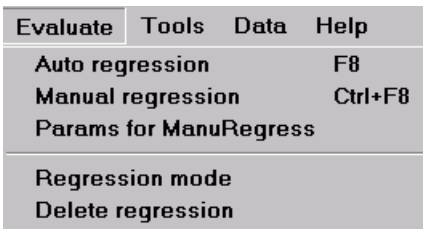
'Log. axis+data' forms linear data to logarithmic data and reverse. The scaling of axis will be set automatically to the data type. x- and y-axis (array) may be changed independently from the other, as the input window below shows. If the data/axis is linear then you can select as **data/axis** 'Keep linear', 'Make logarithmic' or 'Make exponential'. The last is usually not necessary because the software tries to detect the current face. If the data/axis is logarithmic then you can select between 'Make linear', 'Keep logarithmic' and 'Make logarithmic'. By leaving with 'OK' the plot axes will also be newly initialized.

Following **logarithmic types** exist:
ln, log10, log10 with log. axis.
At the first 2 possibilities only logarithmic data will be formed, the axis is linear with the text prefix 'ln' resp. 'log'. At the 3. type the axis will be shown in a logarithmic face.

For the logarithmic '**Sign/abs**' you can use only negative or positive values or the absolute value.



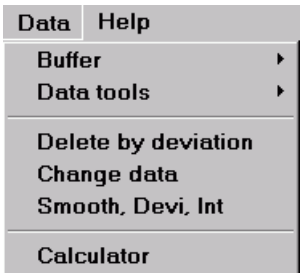
5.3.2.5 Evaluate menu



Normally the extended evaluation menus as 'EvalBank' are not visible in the edit plot program, see 'entering' at start of chapter 5.3.2.
The regression mode can be selected. The input is the same as explained in chapter 5.2.3.3. Usually it will be automatically defined at entering the edit plot program.

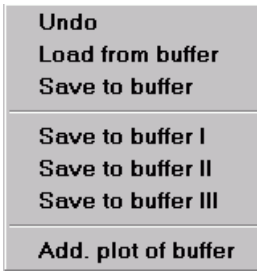
5.3.2.6 Data menu

This is a sub menu with a lot of possibilities to change the x/y-data. Only a short description will be given here.



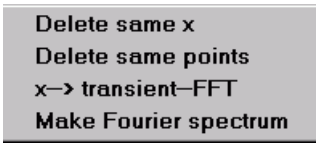
'Buffer' opens a sub menu to load/save data from/to buffers,
'Delete by deviation' is an important tool for deleting data points by plot and will also be used in similar way from some measure program modules.
'Change data' and 'Smooth, Dev, Int' are also important functions of the Data menu. The last allows a smooth (approximation), interpolation, deviation and integration of data.
'Calculator' calls a semi-conductor calculator, needs user class 5.

Following possibilities exist for working with the buffers:



'Undo' restores the data from the Undo buffer.
Data can be saved to *the* (main) buffer or load from it. If loading then the current plot data will be overwritten.
Three additional buffers I, II and III exist for saving the current data into these buffers. The buffers can then be used later.
'Add. plot of buffer' shows in all plots of the Edit plot program additionally the data of the buffer.

'Data tools' opens a sub menu with following tools:



'Delete same x resp. points' are described in chapter 5.2.2.2.
'x → transient FFT' restores the data by interpolation in such way that it can be used for the FFT (Fast Fourier Transform). That means the new x-data will be equidistant and the numbers of points are a power of 2.
'Make Fourier spectrum' calculates the FFT and applies the spectrum as new data.

5.3.2.6.1 Delete by deviation

This is an important tool for deleting data points by plot and will also be used in similar way from some measure program modules, see chapter 2.6.3. This function opens a combined input and plot window. The inputs are on the left side, on the right is the plot. Some buttons and plot parameters are above the plot.

Following **buttons** exist:

Do: Do the selected action with the current data, means for example the deleting of an array range. It shows the result plot and applies its data as the current data.

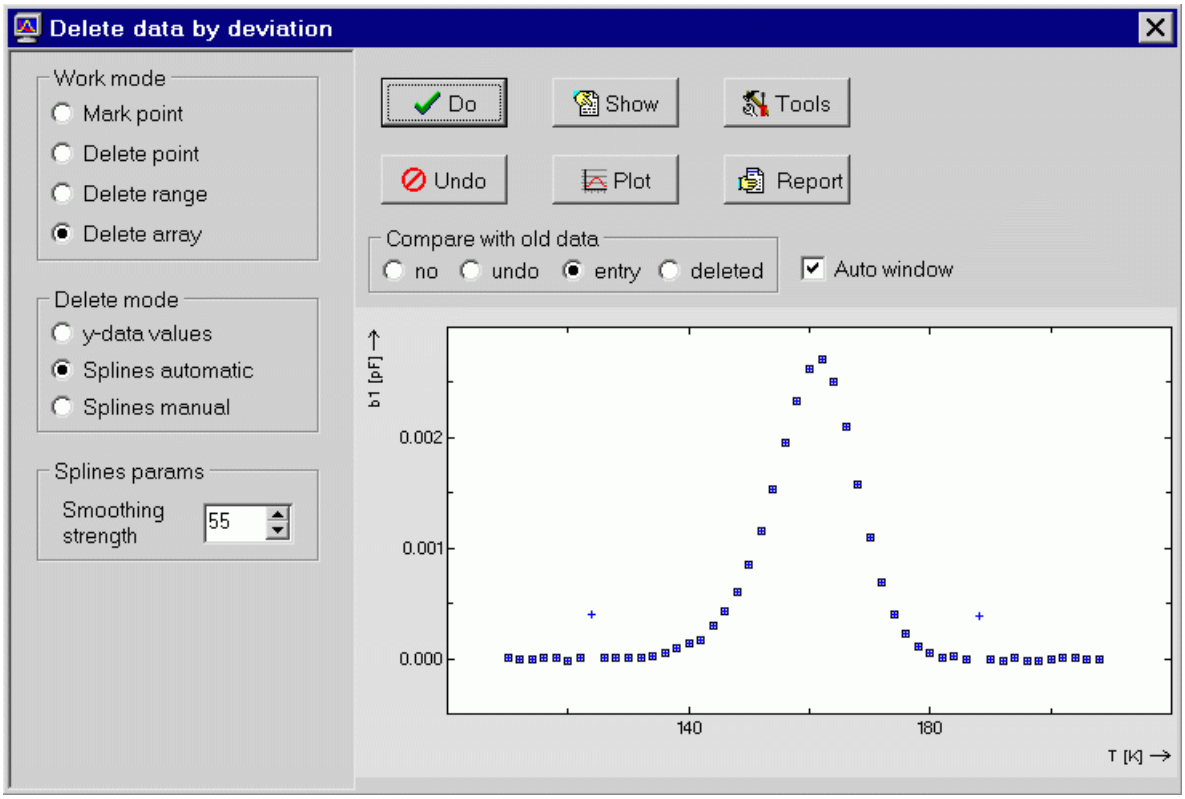
Undo: Undo the last action.

Show: Do the action and shows the result plot, but don't apply the data.

Plot: Plots the current data, it don't refresh the 'Show-plot'.

Tools: Input of curve and axis parameters, copies ASCII data, lists and edits the plot data in a data grid or in the ASCII editor, lists the deleted data. Loads the entry data or buffers data as current data, saves the plot data in a buffer. The x- and y-values can be changed by calling the editor.

You can **compare** the current data in the plot with the undo, entry or deleted data. 'Undo' data are the data before clicking onto the Do-button, 'entry' data are the data at starting this menu point. 'Deleted' data are these points which were already deleted. By activating '**Auto window**' the plot window will be set automatically.



The deleting of data can be done in several ways, called **Work mode:**

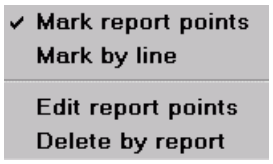
Mark point: The mouse marks a data point. Only one point can be marked. You can delete the point by the 'Delete' button which hides the 'Do' button.
Delete point: A mouse click onto a point delete it.
Delete range: The left and right marked data range can be deleted by the 'Do' button.
Delete array: The program searches the full data array for 'bad' points.

The **Delete mode** defines criteria for the work 'Delete array':

y-data values: You can delete all points with y=0, y<0 or y>0.
Splines automatic: Calculates a smoothed spline with a given strength and checks then the difference between smoothed and origin y-value. If it is too big, the corresponding point will be deleted.
Splines manual: Similar as above but you can define manually the maximum difference between original and smoothed y-values. The inputs are the same as explained in chapter 2.7.1 for 'Take out data'.

The x-values of the deleted points from earlier sessions will be saved into a **report list**. This enables to delete the same x-values in many curves (files), click onto the 'Report' button for this feature. The report list contains only points of earlier sessions but not of the current session. When leaving the current session, you can reset this list by a flag.

The points of the report list can be marked (shown) in the plot by green 'x'-crosses. The report list contains only x-values and searches the nearest y-values for the plot. It may be, that the points of the report list don't match the y-values of the current data. Therefor it is possible to mark the points of the report list by vertical lines instead of symbols. But a 'bad' y-value is no problem for deleting data by the report list because only the x-values are here necessary.



A small menu opens by clicking onto the **Report** button:
Marks the data of the report list in the plot, uses a vertical line for the marked points, edits the points of the report list or deletes the current data by the report list (see above and note).

Note: When deleting by the report list, a point of the current data will be searched for each x-value of the report list. This will be the nearest x-value, a 100% match is not necessary. Don't call this function 2-times because then additional points will be deleted. When using this function, call it first after the entry. If necessary, delete then additional points by the work modes. Don't call this function after deleting points by the work modes.

The following input window appears if leaving the 'Delete by deviation' function. It defines whether the changed data should be applied.

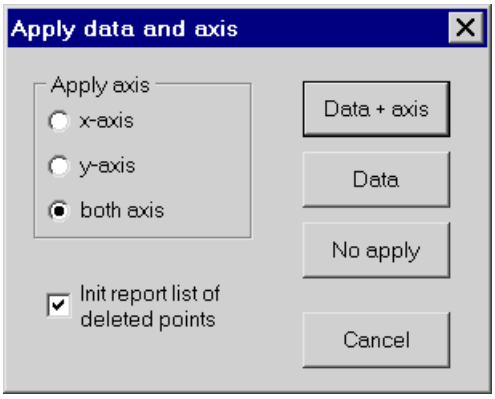
Following buttons exist:

Data + axis: The new data and the new plot axes will be applied. A separate input defines whether only the x-axis, the y-axis or both axes should be applied.

Data: Apply only the data but not the plot axis.

No apply: The changed data will not be applied, the program restores the entry data.

Cancel: Goes back to the 'Delete by deviation'.

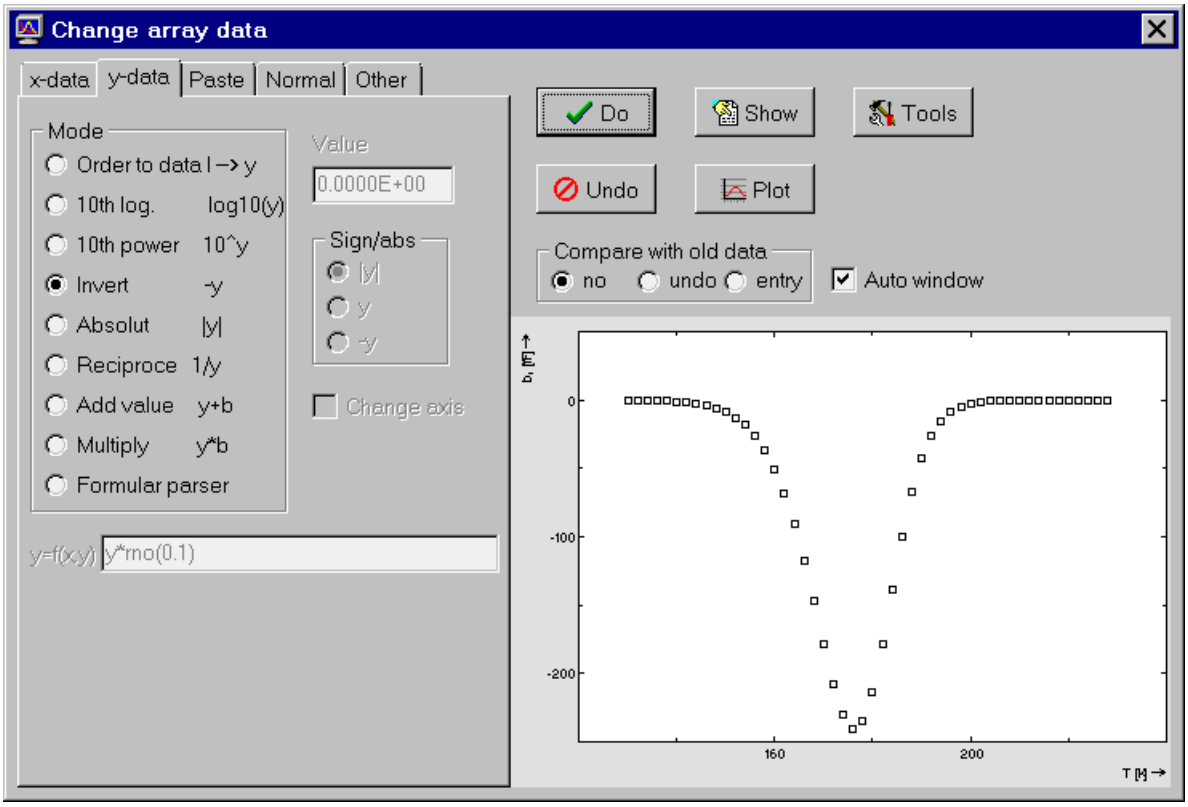


'**Init report list of deleted points**' resets the report list and applies the current deleted points as new report list. If this flag is not activated, these points will be appended to the report list.

When this tool will be called from a measure program module and not from the edit plot program, you get a different input window at leaving. This may allow additional features, for more details look in chapter 2.6.3 or in the corresponding description of the measurement program.

5.3.2.6.2 Change data

This function uses as a similar kind of combined input and plot window as introduced in chapter 5.3.2.6.1. But the inputs are divided in 5 input sheets: x-data, y-data, Paste, Normal, Other. The action depends on the selected input sheet. So the y-data of the current plot array will be changed by 'y-data'. At 'Paste' you can paste ASCII data from the clipboard or read from an ASCII file. These data can be combined with the existing ones, for example addition, subtraction or appending.



The buttons are also similar as in the previous chapter.
But the **Tools** button has extended possibilities:

- Input of curve and axis parameters
- Copy, Paste, Save and Read ASCII data
- List and edit the plot data in a data grid or in the ASCII editor
- Load the entry data or buffer data as current data, save the plot data in buffers
- Compare the current data in a list with the entry, undo or buffer data

5.4 List and Edit data programs

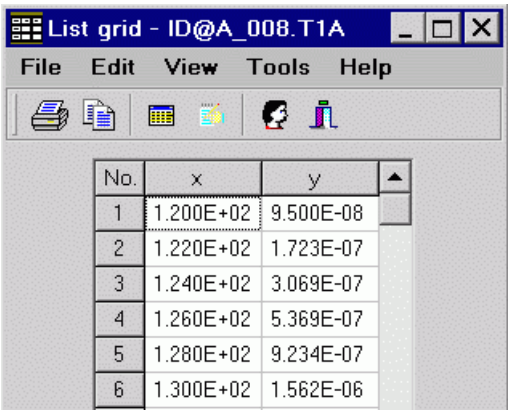
This chapter describes the list and edit data programs. The edit data programs base on the list data programs, but are extended in the file and edit menu.

3 views exist for the list programs:

1. **List grid program:** The data will be shown in a grid.
2. **List image program:** The data will be shown on a canvas image.
3. **ASCII editor:** The data will be listed in an ASCII editor.

Not all views exist in all cases. The image view doesn't offer an edit possibility. The grid view is available only for x/y data, the list view may show additionally a header, the ASCII editor shows either x/y data or a header. Often you can switch between the 3 views, the last selection will be stored when possible. A list program will be opened either automatically by the list menus or manually in 'Tools → List data' of the plot programs (chapters 5.1.6.2 and 5.2.6). The list and edit data program can also be called from the Standard Plot program (see chapter 5.1.1). The possibilities of the list programs depend on this origin.

5.4.1 List/Edit grid program



The list/edit grid program is the grid view of the list data program. The x/y-data will be shown in a grid with a caption. The fix (grey) column denotes the number of data point. If more than one curve (y-array) exist, the grid contains one column for each y-array. If coming from a list menu, the columns will be labeled by its meaning. A data header can not be shown in the grid program. The caption 'List grid' or 'Edit grid' distinguishes between list and edit data program (list or edit mode).

The following buttons of the **toolbar** are not visible in all cases:

Repeat the inputs of list parameters, if available.

Open a measurement data file, if available.

Shows **Next** file, if available.

Print the grid on a printer.

Copy data to clipboard.

Jumps to the list **image** program.

Jumps to the ASCII **editor**.

User button is a user definable button, see chapter 2.3.4.

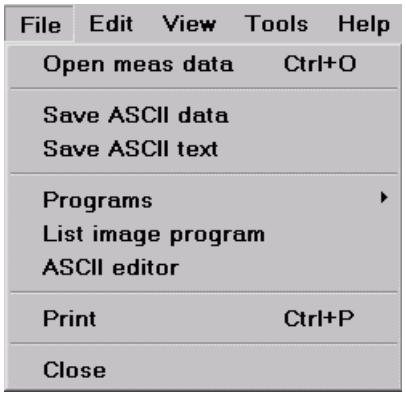
Close the list program and goes back to the previous program.

Following **shortcuts** exist for the menu, but not all are always possible:

F1: Help information, opens this manual at the corresponding chapter.
F2: Repeats the inputs of plot.
F11: Personal hot key 1, see chapter 2.3.4.
F12: Personal hot key 2, see chapter 2.3.4.
Ctrl+C: Copy ASCII data into the clipboard.
Ctrl+O: Opens a measurement data file.
Ctrl+P: Print the data.
Ctrl+V: Paste ASCII data from the clipboard.
Ctrl+Del: Delete a line (data point) in the grid.
Alt+F4: Close the list plot program.

5.4.1.1 File menu

The entries of the file menu depend on the origin of the data. When coming from a list menu, you can read here the (measurement) data and list these as before. If there was an input of parameters, you can repeat this input by 'Repeat'. If not saving the last measurement, you can here save these data.

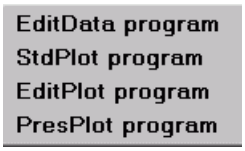


'Save ASCII data' saves the current x,y values line by line in an ASCII format to a text file. In opposite to the Standard Plot Program, many y-arrays (columns) can be saved here. You can define the delimiter and the exponential format in the ASCII parameters of the Tools menu.
'Save ASCII text' saves additionally the grid caption in the first line and, if selected for the grid, the number of data point in the first column. Separate column delimiters and decimal separators exist for this special saving mode.
'Print' opens a dialog for printing the data.

You can jump with the current data to the list image program or the ASCII editor.
By 'Close' the program will be closed and the software goes back to the previous program.

If showing curve by curve from many data points or files (e.g. I/V curves at many temperatures), a 'Next datas' sub menu exist for navigating to next or previous data or to input the data number, for more information see chapter 5.1.7.1.

Programs opens a sub menu for further program tools, it is only visible when coming from a list menu. If calling one of these tools, the software jumps to this tool and don't come back to the list program. If closing this tool, the software goes back to the previous program module, normally one of the measurement or sub programs.



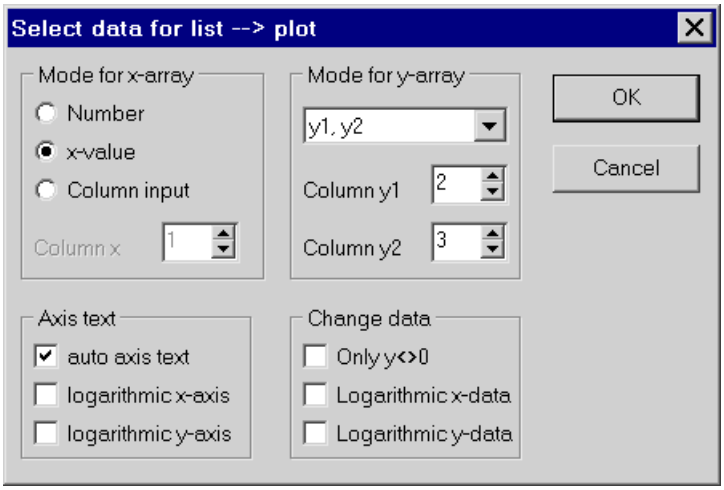
EditData enables to edit the x/y-data, switches to the edit mode.
Shows the x/y-data in the standard plot program.
EditPlot enables to change, read and plot the x/y-data (5.3.2).
PresPlot opens a new complex plot program with many features (5.2). It may be better, to call first StdPlot and from there PresPlot.

If selecting '**StdPlo**t' or '**EditPlot**' program and more than one curve are shown, the following input window opens, where you have to select the x- and y-data.

'**Mode for y-array**' defines which array(s) will be applied as y-data(s):

- one y-array
- y1, y2
- y2-y1
- y2/y1
- (y2-y1)/y1
- (y2-y1)/x
- all y-arrays

'y1, y2' and 'all arrays' are not allowed for the Edit plot program. You have to input the column number(s) of the grid for y1 (and y2).



'**Mode for x-array**' defines which data will be applied as data for the x-axis:

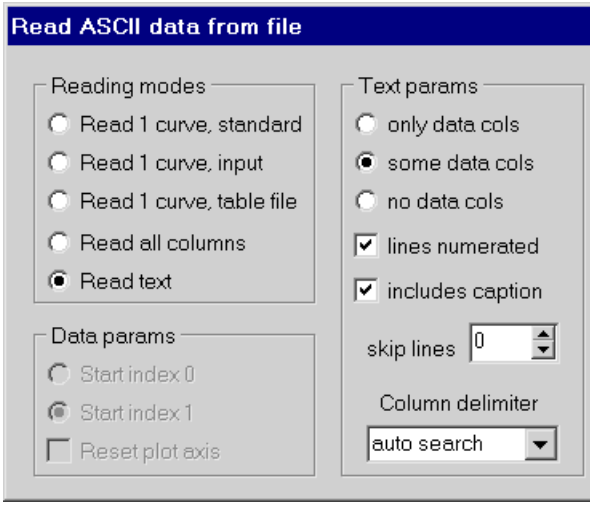
Number: The number of data point will be applied as new x-data.
x-value: The x-column of the grid will be used as x-data for the plot (standard).
Column input: You can input the column number of the grid.

Column number 1 means the x-data of the grid, column number 2 means the (first) y-data array of the grid. The grid column with the data number will be denoted as column 0.

The **axis text** of the plot will be applied from the grid header by activating 'auto axis text'. 'Logarithmic x- or y-axis' defines a logarithmic axis style, but doesn't change the data. Special flags exist for the logarithmic calculus of the x- or y-data, the logarithmic axis style will here automatically be set. The activation of 'Only y<>0' selects only y-data which are unequal zero.

The entry '**Read ASCII data**' is visible in the edit mode, it opens an input windows similar as described in chapter 5.2.1.2. The **reading modes** 1 to 3 were already explained there:

1. **Read 1 curve, standard**
2. **Read 1 curve, input**
3. **Read 1 curve, table file**
4. **Read all columns** of the ASCII file
5. **Read text**

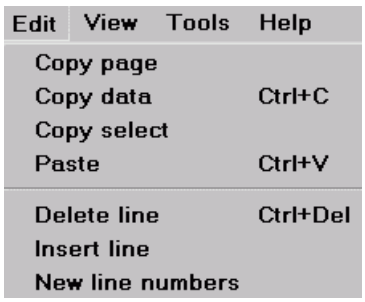


The special mode 5 treats the ASCII file as text and applies directly the file columns into the grid columns. At the other modes the file columns will be converted into numbers. The input group 'Text params' appears for mode 5. The information that the text file contains 'only/some/no' real data (not text) columns is for searching the decimal separator.

You have to inform the software when the text file includes numerated lines or a caption. Look in chapter 5.1.6.1 for the column delimiter.

5.4.1.2 Edit menu

Here it is possible to copy the data into the Windows clipboard or to paste data from there.



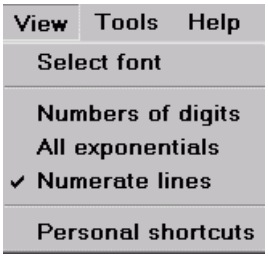
'Copy page' copies the grid as a BMP graphic into the clipboard.
'Copy data' copies the grid data line by line in an ASCII format.
'Copy select' asks for the format before copying, see chapter 5.1.2.1. But now only the BMP and ASCII modes are enabled.
'Paste ASCII data' pastes ASCII data from the clipboard and overwrite the current data, see previous page for the input dialog. This feature is only visible in the edit mode.

You can **edit** the data cells of the grid in the edit mode (caption Edit grid). Click onto the cell and input the new value. You can go to the next cell by the 'Tab' key. A line in the grid, means one data point, can be deleted by 'Ctrl+Del'. You may insert an empty line at the current row position. A marked (blue) cell can be edited by a right mouse click.

In rare cases a **special edit** mode exist where the line will not immediately be deleted, but only marked as deleted. Its value for the first column (x-value) will be set to -1.0E+100 or -2.0E+99. The reason is that other data columns in the calling program will also be deleted. The deleted lines will not be applied when saving ASCII data or calling a plot program from the Tools menu. These data remain in the data array when calling the list image program or ASCII editor. Don't change at the special edit mode the numbers of lines in the ASCII editor, mark a line as deleted by setting x to -1E100.

5.4.1.3 View menu

Here you can set parameters for the view of the grid, so the font and its size.



'Numbers of digits' defines the precision at an exponential view, it is the numbers behind the point. For example, 1.123E-10 has 3 digits. It may be that values of some columns will be shown in a fix decimal format. By activating 'All exponentials' all columns will be shown in the exponential view.
The lines can be numerated in an own grey column, labeled by 'No'. This column will not be taken into account at 'Save ASCII data', but at 'Save ASCII text'.

The 3 menus above are not enabled in the **edit mode**, the lines are always numerated.

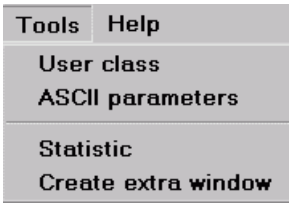
If coming from a **3-dimensional** plot, the grid contains on the top an additional line with the z-values, as shown on the right. The view menu is then expanded by 3 entries:

No.	x	1	2
z	0.000E+00	1.200E+02	1.220E+02
0	2.800E-03	2.357E-02	2.359E-02
1	4.000E-03	2.357E-02	2.359E-02
2	5.600E-03	2.357E-02	2.359E-02

You can numerate the columns as shown in the example. Then the z-values will also be saved when saving ASCII data.
The x- and z-axis can be inverted. The x-values will then be shown in the first line, the z-values in the first column. Then the z-order can be inverted, means the last z-value will be shown on the top.
In the edit mode lines and columns are numerated, x- and z-axis can't be inverted.

5.4.1.4 Tools menu

This menu contains some different functions.

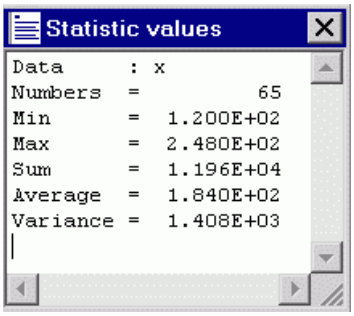


User class was already explained in chapter 2.4.1.
ASCII parameters contains parameters for copying, saving and reading ASCII data, see chapter 5.1.6.1.
It is possible to create an extra window with a plot or data grid of the current data, see chapter 5.1.6.4.

At **user class 5** there are ActiveX/OLE tools as described in chapter 5.1.6.

In the **edit mode** you can usually jump here to the standard, edit and presentation plot program. For this you have to select the x- and y-data as explained above. The software comes back to the edit program after closing the plot program but doesn't apply changes of data.

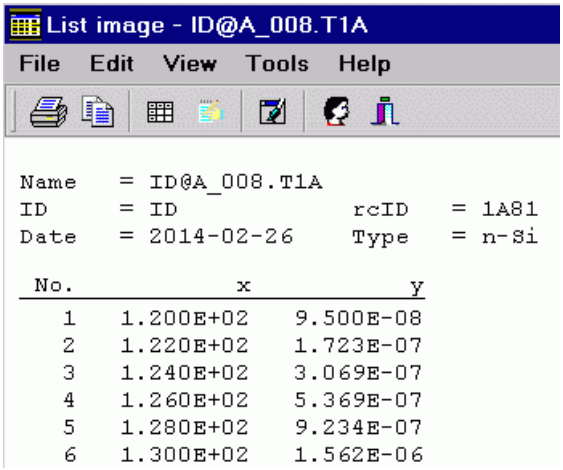
Statistic shows some important values of the selected column: Numbers of data points, minimum value, maximum value, sum, average, variance.



5.4.2 List image program

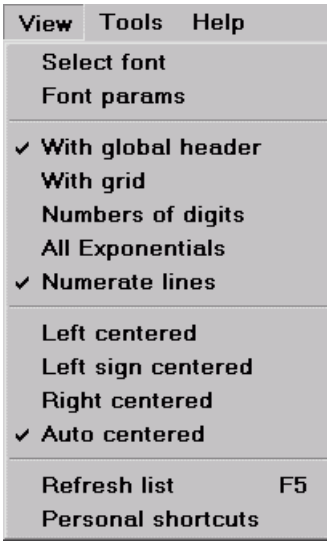
The list image program is the image view of the list data program. The data will be shown on a canvas image. The possibilities of the image view are similar to the grid view, therefor only a short description will be given. But, additionally to the style of view, there are 2 big differences:

- The image view has no edit mode.
- The image view may show additionally a header, as shown on the right.



The header may be a special data header or a global sample header with the most important sample parameters. It is also possible that no x/x-data exist but only a data header.
The toolbar contains a button for refreshing the canvas.
The PageUp and PageDown key may show previous resp. next file.

Based on the different view, the **View menu** of the image program differs from that one of the grid program.



The font, the font parameters used for the canvas, as explained in chapter 2.3.3.3, and the background color of the canvas can be selected.
If a data header or the global sample header is here available, the list can be shown without or with this header on the top. This flag is disabled when no header or no x/x-data exist.
A grid can be drawn around the lines and columns.
'Numbers of digits', 'All exponentials' and 'Numerate lines' were already be explained in chapter 5.4.1.3.
These flags and the center group is not enabled if no x/a-data exist.
'Refresh' draws again the canvas of the list image program.
If coming from a 3-dimensional plot, the menu contains three special entries as shown in chapter 5.4.1.3.

The data in the columns can be **centered** in various ways in respect to the caption:

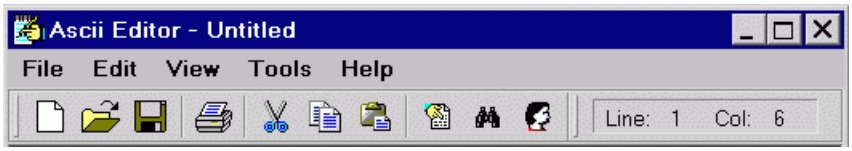
- *Left centered:* First character of caption and column string has the same position.
- *Left sign centered:* First character of caption and column string has the same position, a minus sign will not be taken into account.
- *Right centered:* Last visible character of caption and column string has the same position, space characters at the end of the string will be deleted.
- *Auto centered:* Last character of caption and column string has the same position (default), as shown in the example above.

5.4.3 ASCII editor

The ASCII editor will not be used only for data but also for pure text or to list or edit ASCII files. x/y-data will be shown as a ASCII text in lines and columns, text files as saved in the file. There is no formatting, except of space (blank) characters and empty lines. The ASCII editor can be in the list or edit mode. The default data type has the extension 'Txt', but in the file dialogs you can select another one.
The ASCII editor has following **functions**:

- **Editor view** of the list/edit data program. When x/y-data exist, an additional header will not be shown, but a pure text header without x/y-data will be shown
- **Integrated editor**, in the main or tool programs, to list or edit ASCII text.
- **Separate editor** (program), which can be called from the program Tools. Here it is always in the edit mode and has the most possibilities, so an additional Tools menu.

The menus and possibilities depend on this function resp. on the origin of the text. So changing the text or reading an ASCII file is only available in the edit mode.



The following buttons of the **toolbar** are not visible in all cases:

New text, delete all text, only enabled in the edit mode.

Open an ASCII file, only enabled in the edit mode.

Save data into an ASCII file

Print the text on a printer.

Cut marked text into the clipboard, edit mode.

Copy marked text to the clipboard.

Paste text from the clipboard, edit mode.

Mark the full text, edit mode.

Find (search) a text string.

Jumps to the list **image** program, only at list/edit data program.

Jumps to the list/edit **grid** program, only at list/edit data program.

Shows **Next** file, if available.

User button is a user definable button, see chapter 2.3.4.

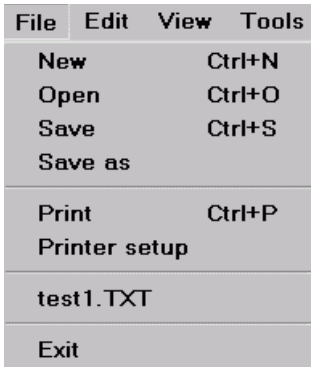
Close the program and goes back, not visible for the separate editor.

The current line and column number will be shown behind the toolbar, you can move the position of this display in the toolbar.

Following **shortcuts** exist for the menu, but not all are always possible:

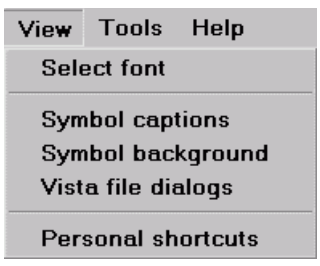
F1:	Help information, opens this manual at the corresponding chapter.
F3:	Repeats the search of a text string.
F11,F12:	Personal hot key 1 and 2, see chapter 2.3.4.
Ctrl+A:	Marks the full text.
Ctrl+B, E:	Marks the begin or end of a text block.
Ctrl+C, X:	Copies or cuts the marked text into the clipboard.
Ctrl+F:	Finds (searches) a text string.
Ctrl+H:	Replaces a text string.
Ctrl+N:	Deletes all text and starts a new document.
Ctrl+O:	Opens a text file.
Ctrl+P:	Prints the text.
Ctrl+S:	Saves the text into an ASCII file.
Ctrl+V:	Pastes text from the clipboard.
Ctrl+Z:	Undoes the last new, paste or cut operation. Undo of Undo by 2. call.
Ctrl+Del:	Deletes marked text.
Alt+F4:	Closes the program.

The **File menu** starts a new text document, opens an existing text file or saves the current text. If no file name exist or by 'Save as', you have to input the file name before saving.



You can print the text and open the printer setup dialog. The names of the last 5 used files will be shown in the file menu. You can read one of these by clicking onto its name (here test1.txt).
If the editor will be used as list/edit data program, you can jump here with the current data to the list image or grid program.
When starting the editor by the Editor button of the Set_Conf program (chapter I3.6), the entry 'Cfg dirs' changes the default directory to the customer configuration directories 'Conf, 'Conf/Base' or 'Conf/Init'. The default extension is then 'CFG'.

The **Edit menu** enables to cut or copy a marked text range. You can paste ASCII text from the clipboard, mark the full text or delete a marked text range.
'Find' opens the Windows standard dialog for searching a text and starts the search from the cursor position. 'Repeat search' starts the search without an input dialog at the current cursor position. 'Replace' replaces a text string by another one.
The entry 'Edit mode' exist only in special cases, it switches from the list to the edit mode.



In the **View menu** you can select the font and the style of the toolbar. The symbols can have a caption and the toolbar a background.
'Vista file dialogs' uses the new file dialogs under Windows Vista, Seven and 8.X.
Personal shortcuts was explained in chapter 2.3.4.

6. Specials

This chapter describes special options and program parts. These are not sub programs or program tools with his own sub window, no own data types exist. These Specials are options or parts of one or more measurement program modules. So the DLTS mode is valid in all measurement modules, the HERA evaluation exist for the transient, isothermal and tempscan program.

Some Specials need a special software option or/and a special hardware.

6.1 HERA transient evaluation

The **H**igh **E**nergy **R**esolution **A**nalysis (HERA) uses quite new or well known mathematics algorithms for the separating of several overlapping emission processes. All procedures base on the exponential law of time. The transient is a sum of some exponential functions with different time constants and amplitudes. The HERA evaluation is especially suitable for the detection and separation of very closed time constants. The energy resolution is much better than at the maximum analysis.
HERA needs a special hardware and a special software option.

We divide the HERA evaluation into 2 types. The first uses directly the transient values, the second the coefficients versus period width resp. temperature. In this chapter 6.1 the first type will be explained, the HERA transient evaluation.

We can sort all our DLTS evaluations in two ways. The first sort order prefers the data, the second the evaluation technique.

Evaluations **sorted by data**:

1. **Transient evaluation**
    - 1.1 Direct evaluation by DLTFS (Deep Level Transient Fourier Spectroscopy)
        - 1.1.1 Constant period width
        - 1.1.2 Variable period width
    - 1.2 HERA Transient Evaluation
        - 1.2.1 Discrete
        - 1.2.2 Contin (inverse Laplace transform)
2. **Coefficient evaluation**
    - 2.1 Standard maximum analysis
        - 2.1.1 Period width scan
        - 2.1.2 Tempscan
    - 2.2 HERA Deconvolution
        - 2.2.1 Period width scan
        - 2.2.2 Tempscan

Evaluations **sorted by technique**:

1. **DLTFS** (Deep Level Transient Fourier Spectroscopy)
    - 1.1 Constant period width
    - 1.2 Variable period width
2. **Maximum analysis**
    - 2.1 Period width scan
    - 2.2 Tempscan
3. **HERA** (High Energy Resolution Analysis)
    - 3.1 HERA Transient Evaluation
        - 3.1.1 Discrete
        - 3.1.2 Contin
    - 3.2 HERA Deconvolution
        - 3.2.1 Period width scan
        - 3.2.2 Tempscan

6.1.1 Common

In this chapter the software and the basics will be discussed which is common for all program modules.

6.1.1.1 Basics

This type of HERA uses directly the transient values for the evaluation.

We have implemented 2 different kinds of **algorithms**:

1. **DISCRETE** is a multi exponential transient fit. It gives directly the time constants and amplitudes of the transient.
2. **CONTIN** and **FTIKREG** base on the inverse Laplace transform. It gives not directly the results but a contribution versus time constant. There the peak positions yield to the time constants. The peak search will be automatically done by the algorithm and the DLTS program. A determination of the amplitude is by the Laplace transform not possible.

DISCRETE and CONTIN are algorithms of S. Provencher and are freeware. For more details of these algorithms and its parameters call www.s-provencher.com.
For calling the algorithm, we use the original Exe files or our own DLL's based on the corresponding source code. The communication (data, parameters, results) between the algorithm and our DLTS program will be done by ASCII files.

The inverse **Laplace transform** is given by:

$f(t)=\int F(s)\exp(-st)dt$ where f(t) is the transient and F(s) the spectral density.

CONTIN and FTIKREG base on the Tikhonov regularisation. The Laplace algorithms give only the time constants but not the amplitudes. The heights of the peaks of the distribution don't correspond to the amplitudes! For HERA we have combined the Laplace algorithm with our DLTFS evaluation. So we can also here determine the amplitudes.

For a real multi-exponential transient with noise usually not only one solution exist. The problem for the algorithm is to find the best solution. Parameters given by the user help at this search. The combination of the algorithms with our DLTFS gives the possibility to check the results by an evaluation class.

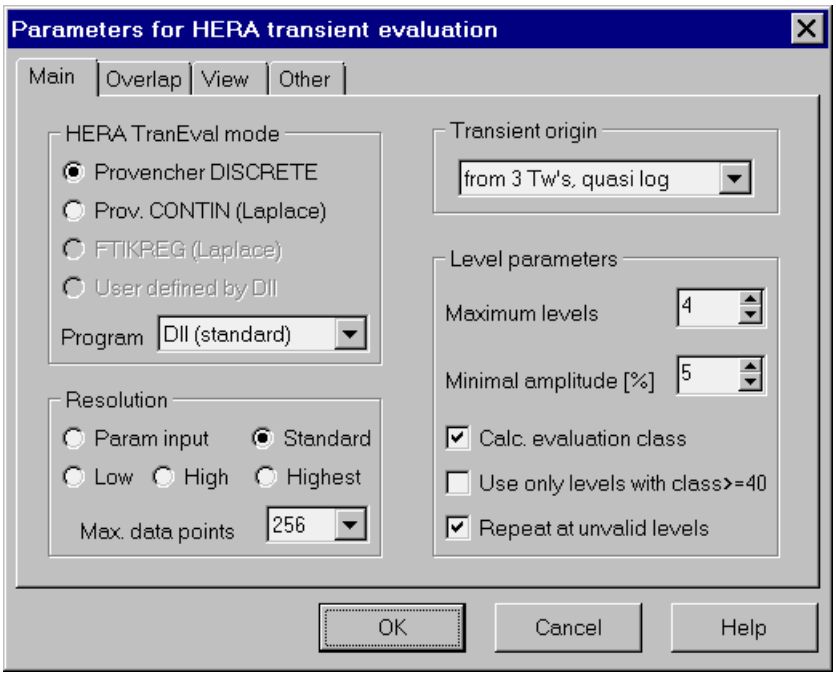
The HERA transient evaluation is available in the transient, isothermal and tempscan module. It works with linear and logarithmic time axis. It is not necessary that the x-axis is equidistant. The logarithmic time axis covers a wide range of time constants, so you should use this one. The best way for this is to construct a **quasi-logarithmic transient** from transients of different period widths. The advantage of this type of logarithmic transient is the good signal/noise ratio (SNR), see chapter 3.2.1.4. The logarithmic transient is especially important for the use of the Arrhenius plot because the time constants vary strongly with the temperature.

Our HERA transient evaluation with one of the algorithms, combined with DLTFS and used a quasi-logarithmic transient, gives also in the practice the possibility to separate 2 or more very closed time constants resp. levels.

6.1.1.2 Common inputs

Because the HERA main inputs are similar for all program modules the main input window will be explained here for the tempscan program. After calling a HERA menu point you get the following input sheets either directly or, if another input window appears, by clicking there onto a button with the caption 'HERA' or 'Params'.

6.1.1.2.1 Main input sheet



Up to 4 HERA transient evaluation **modes** are possible:

DISCRETE: This mode uses the 'DISCRETE' algorithm of S. Provencher. Usually it is for DLTS a little bit better than 'CONTIN'. For more details of the algorithm call www.s-provencher.com.

CONTIN: This mode uses the 'CONTIN' algorithm of S. Provencher. It bases on the inverse Laplace transform.

FTIKREG: This mode uses the 'FTIKREG' algorithm. It bases also on the inverse Laplace transform and is similar as 'CONTIN'. It is not a free software so we support it only but you must have the FTIKREG.EXE file. You can get the Fortran source code from www.cpc.cs.qub.ac.uk**.**

User: This allows a user definable algorithm via a DLL. For more details ask PhysTech and have a look in Dlts\Sys\Doc\Dll\UserHera.dpr.

The 'DISCRETE' algorithm gives directly the time constants and amplitudes of the transient. The Laplace based algorithms (CONTIN, FTIKREG) give not directly the results but a contribution versus time constant. There the peak positions yield to the time constants. A determination of the amplitude is by the Laplace transform not possible. So we combine our DLTFS evaluation with these algorithms to calculate the amplitude.

The implemented algorithm (**program**) can be called by different way:

Exe file: This calls the corresponding EXE file, for example 'Discrete.Exe'. We use the original file but you can change it by your own compilation. These files are stored in Dlts\Bin. The call of an external EXE file takes a longer time than using a DLL, especially in the tempscan program. The Exe file must be loaded for each call.

Dll (standard): This calls a DLL. The DLL's base on the Fortran code of Provencher with some small modifications. It is much faster than calling the external EXE file.

Dll multi process: Uses also the DLL's but supports up to 8 cores or CPU's. It is only important at tempscan evaluations.

All algorithms try to find the time constants of the transient. How it works, how good the resolution of closed time constant is and which errors can occur, depends on some parameters. These parameters have also an influence on the results if the exponential functions are not perfect because noise, small amplitudes, deviations from an ideal exponential law of time, very closed time constants and so on. Resolution means here the resolution of closed time constants. We call also predefined parameters sets as **resolution**:

Param input: Opens a tab sheet for parameters of the selected algorithm.

Standard: Defines the parameters in a standard way for a medium resolution. The results are in most cases sure.

Low: Only very good exponential functions will be detected.

High: Allows the detection of closed time constants but errors are possible.

Highest: Use this with caution. It allows the detection of very closed time constants but artifacts are possible.

Depending on the selected algorithm you can define the maximum number of **data points** (transient points). More points can give better results but needs more calculation time.

Transient origin defines from which files the transient data will be used. This input depends on the program module and the current data. In the transient module only the data from the current transient can be used. The possibilities for the isothermal module are the same as explained in chapter 3.3.4.3.

The main possibilities for the *tempscan module* are:

- **from internal transients:** Uses the transient points saved in the current tempscan.
- **from 3 Tw's, quasi log:** Uses 3 (2 to 4) tempscan files of different period widths and constructs a quasi logarithmic transient. For more details see chapter 3.2.1.4 and 3.3.4.4. This is the best method because covering a wide range of time. A special measurement is necessary, see chapter 3.4.1.2.

If using a quasi logarithmic transient, the '**Overlap**' tab sheet is visible which allows the inputs for checking the overlap of transients, see chapter 3.3.4.5.

Note: Normally 3 transient width different period widths will be used for the construction of a quasi-logarithmic transient. It is also possible to do it with 2 period widths (tempscan files) which reduces the time range and with 4 files which can expand the time axis. Nevertheless it will be called 'from 3 Tw's' at the input. An overlap on the time axes is in all cases necessary.

Some important inputs are available in the **Level parameters** input group:

You can define the **maximum numbers of levels** (time constants) which the algorithm uses for its calculation. Don't mismatch the level number for one transient (at one temperature) with the number of levels in the Arrhenius plot (many temperatures).

Only levels which have a **minimum amplitude**, in percentage to the sum of amplitudes of all found levels, will be used by the DLTS program.

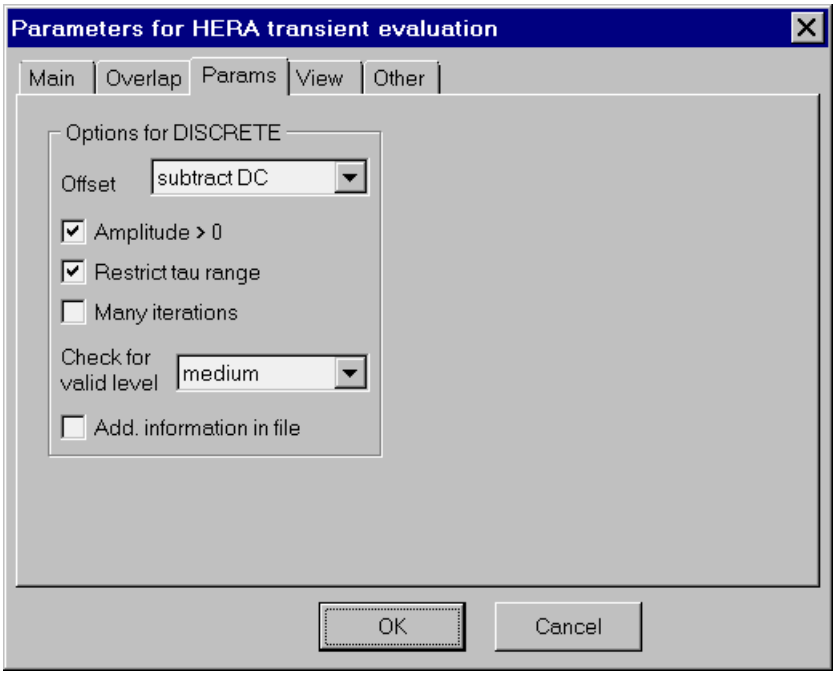
Calculate evaluation class means that the results of the selected algorithm will be used for a DLTFS evaluation with many levels. Then the DLTFS class for each level will be calculated.

Use only levels with class>=40 selects only these results which evaluation class is equal or better than 40. 40 represents a medium class.

The algorithm gives the results to the DLTS program. This selects the levels by amplitude and class. So levels found by the algorithm can be marked as not valid by the DLTS program. If activating '**Repeat at invalid levels**' the search by the algorithm will be repeated if the DLTS program marks found levels as not valid. The maximum numbers of levels and the tau range will be adapted for the repetition.

6.1.1.2.2 Params input sheet for DISCRETE

This input sheet is only visible if selecting the DISCRETE algorithm and 'Param input' at the main input sheet.
It contains parameters for the detection and resolution of the time constants of the transient.
'Amplitude>0' and 'Many iterations' are direct parameters for the DISCRETE algorithm.
By 'Add. information in file' the ASCII result file contains more information.
The other parameters are from the DLTS program.



A transient DC **offset** can be subtracted from the transient data points. This will only be used for the algorithm but not for the plot:

normal:	No offset will be subtracted.
subtract DC:	The measured DC will be subtracted from the transient data.
subtract, no calc.:	The measured DC will be subtracted and the DISCERTE algorithm get the information that there in no offset in the used data.
set y>0:	The measured DC will be subtracted. If then data points exist with y<=0 then the minimum value will be subtracted so that all data points are a bigger zero.

If activating a flag, only levels with **amplitude > 0** will be calculated by DISCRETE. Positive amplitudes means that the data decrement with time. This refers to the data used for the algorithm but not to the original transient, see View tab sheet.

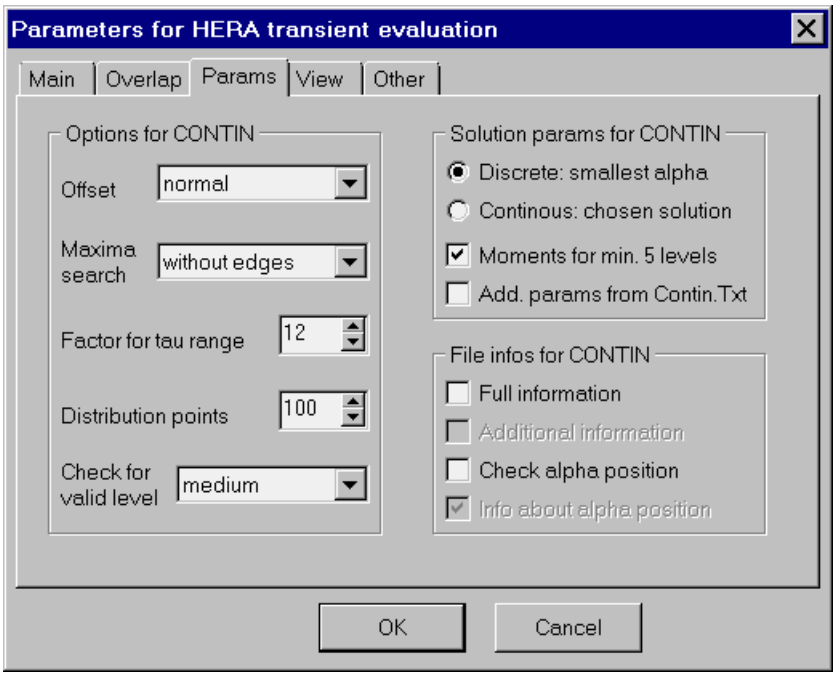
By activating '**Restrict tau range**' only time constants are valid which are not too far outside of the transient time.

'**Many iterations**' increments the numbers of iterations in the algorithm.

'**Check for valid levels**' checks the error values given by DISCRETE. If the error value is too high of a time constant then this time constant (level) will be marked as not valid. Following strengths of check exist: no, weak, medium, heavy.

6.1.1.2.3 Params input sheet for CONTIN

This input sheet is only visible if selecting the CONTIN algorithm and 'Param input' at the main input sheet.
It contains parameters for the detection and resolution of the time constants of the transient.
Most parameters are directly for the CONTIN algorithm.
'Offset' and 'Check for valid level' are the same at DISCRETE.
Additional user defined parameters are possible in a special text file, but this is only for experts of CONTIN.



The inverse Laplace transformation gives as a result a distribution versus time constant. A peak corresponds there to a level. The peak position yields to the time constants. So an automatic peak search is necessary. Following types of **maximum search** exist:

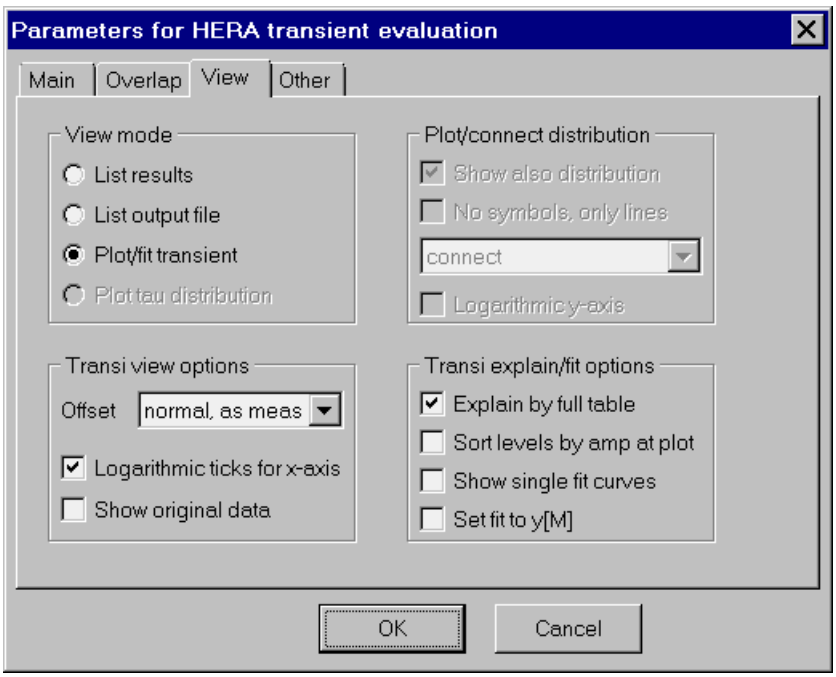
all maxima:	All peaks found by CONTIN will be taken over.
without edges:	As before but peaks at the tau-axis edges will not be taken over.
big maxima:	As before but a relative minimum peak height is necessary.
full maxima:	Uses a DLTS peak search similar to the maximum analysis. The amplitudes can not been calculated by CONTIN.
full big maxima:	As before but only peaks with a relative minimum height are valid.

Factor for tau range defines the tau axis of the distribution relative to the minimum and maximum time of the transient.
The number of **distribution points** has also an influence on the accuracy of the results. But more points need a longer calculation time.

An important flag is whether the solution is optimized for discrete delta like peaks or for a continuous distribution. For the other parameters look in the description of CONTIN.

6.1.1.2.4 View input sheet

The view input sheet is only visible if the transients for one or each temperature will be shown. If only a calculation will be done without showing the single transients then it is not visible. One example for this case is the automatic Arrhenius plot by the HERA transient evaluation.



The **view mode** defines the kind of view after the calculation:

List results:	Only the results (time constants and amplitudes) will be listed.
List output file:	The output file given by DISCRETE or CONTIN will be listed.
Plot/fit transient:	Plot the transient and a transient fit calculated by the results.
Plot tau distribution:	Shows the distribution versus tau, only for Laplace algorithms.

Transient view options define how the transient will be shown. These are parameters only for the plot not for the calculation.

A transient DC **offset** can be subtracted from the transient data points:

normal, as meas:	No offset will be subtracted.
subtract measure:	The measured DC will be subtracted from the transient data.
subtract calculated:	The DC calculated by HERA will be subtracted.
subtract y[N]:	The last transient value will be subtracted.

If using a logarithmic time axis then it can be plotted with **logarithmic ticks** for the x-axis.

If constructing a quasi logarithmic transient from 3 or more period widths then additionally the **original data** (transients) can be shown. At the isothermal module there is a button which allows to show the original transients.

At the Laplace algorithms there are parameters for **plot/connect the distribution**:

If activating a flag the distribution will also shown at the view mode 'plot/fit transient'.
The distribution points can be connected by lines, or only lines can be plotted.
A logarithmic view of the y-axis of the distribution is possible.

Following transient **explain/fit options** exist:

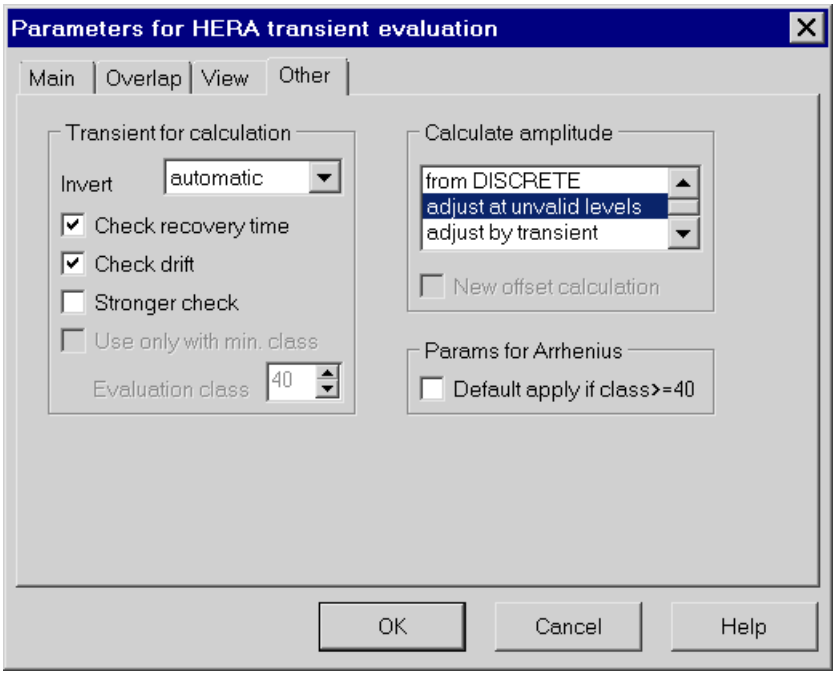
Explain by **full table**: A table with all results will be shown inside the transient plot. In the other case only a short symbol explanation will be given.

Sort levels by amp at plot: The table will be sorted by the amplitudes. The biggest amplitude will be listed in the fist row.

Show single fit curve: Shows at more levels the calculated transient of each level, additionally to the total fit transient.

Set fit to y[N]: Shifts the fitted (calculated) transient on the y-axis, so that its last point is identical with the last point of the measured transient.

6.1.1.2.5 Other input sheet



The transient data can be changed before transferring to the algorithm. This is only valid for the algorithm but not for the plot of the transient. The input group **Transient for calculation** contains these parameters.

Following possibilities exist to **invert** the transient:

- **no:** The transient will not be inverted.
- **yes:** The transient y-data will be inverted, that means multiplied with -1.
- **automatic:** The software looks whether the transient increases or decreases with time. If the transient increases, it will be inverted so that the data transferred to the algorithm always decrease. Then only positive amplitudes should exist.

Activating '**Check recovery time**' deletes transient data (only for the algorithm) at the begin of the transient if these data come from a recovery signal. This means that a decreasing transient the first data points may not increase.

Activating '**Check drift**' deletes transient data at the end of the transient if these data come from a drift. This means that a decreasing transient the last data points may not increase.

'**Stronger check**' defines the strength and algorithm of recovery and drift check, for more details see 3.3.4.5.

Use only with min. class is only enabled for transients at many temperatures. It means that only those temperature points will be used at which the DLTFS evaluation class is equal or higher than the selected minimum evaluation class.

The mode '**Calculate amplitude**' depends on the selected algorithm. For DISCRETE there are following possibilities:

- **from DISCRETE:** The amplitudes will be calculated by the DISCRETE algorithm.
- **adjust at invalid levels:** As before, but if levels found by DISCRETE are not valid (for example too small amplitude), the amplitudes of the other levels will be adjusted to the transient.
- **adjust by transient:** The amplitudes calculated by DISCRETE will be adjusted to the transient by a ±10% variation.
- **from transient:** The amplitudes will be calculated by fitting the transient.
- **from coefficients:** Calculation from the Fourier coefficients by DLTFS technique.

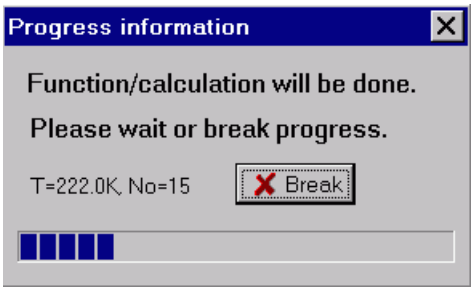
Only the time constants of DISCRETE will be used at the last 2 possibilities. If not activating here 'New offset calculation', the DC will also be applied from CONTIN.

CONTIN has similar possibilities. If calculating from CONTIN means not from the distribution but from them 0. moment, see CONTIN publication.

A special flag exist if making manually an Arrhenius plot from the HERA evaluation or if saving level results into the evaluation database. If activating '**Default apply if class>=40**', only the check boxes of levels which have an evaluation class equal or bigger 40 will be marked for applying. In the other case all will be marked independent of class.

6.1.1.3 Progress information

Usually the calculation of the algorithm is very fast. It can take some seconds or longer when calculating for many temperature points. Then you see the progress bar with the temperature and data number. Especially here the use of a DLL is much faster. Here also more cores of the CPU can be used and accelerate the calculation. The calculations for the different temperature points will be divided to the cores.



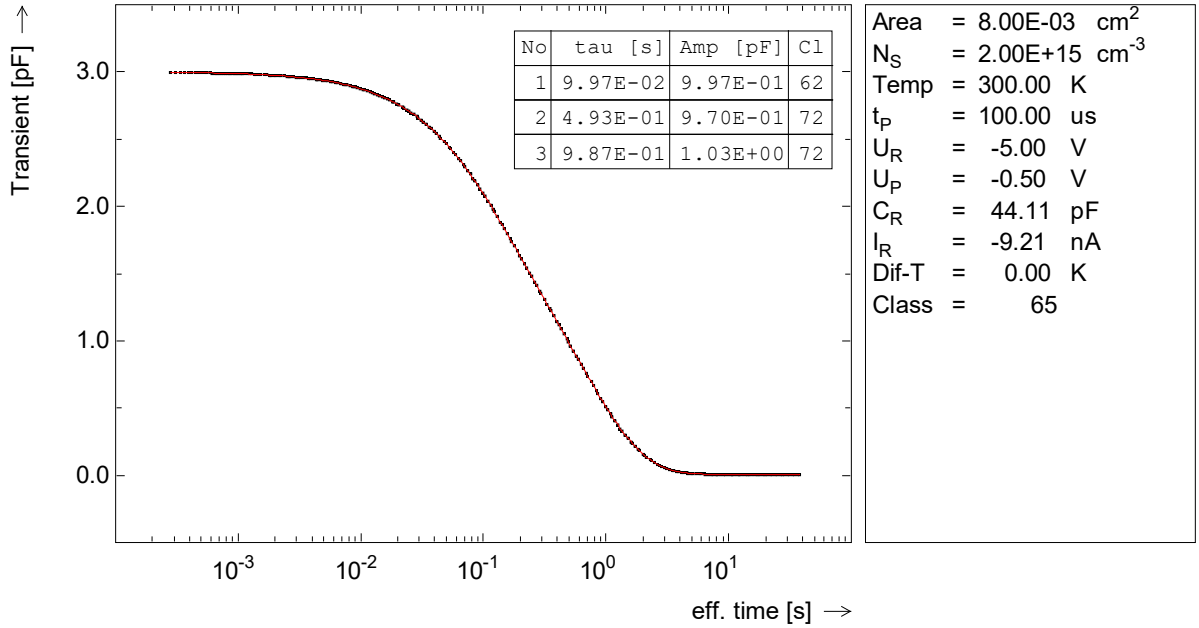
6.1.1.4 Example for DISCRETE and CONTIN

In the following an example will be given for the result plot of DISCRETE and CONTIN. It will be done in the isothermal module but it is in similar way also valid for the transient and tempscan module. A logarithmic time axis will be used to cover a wide time range.

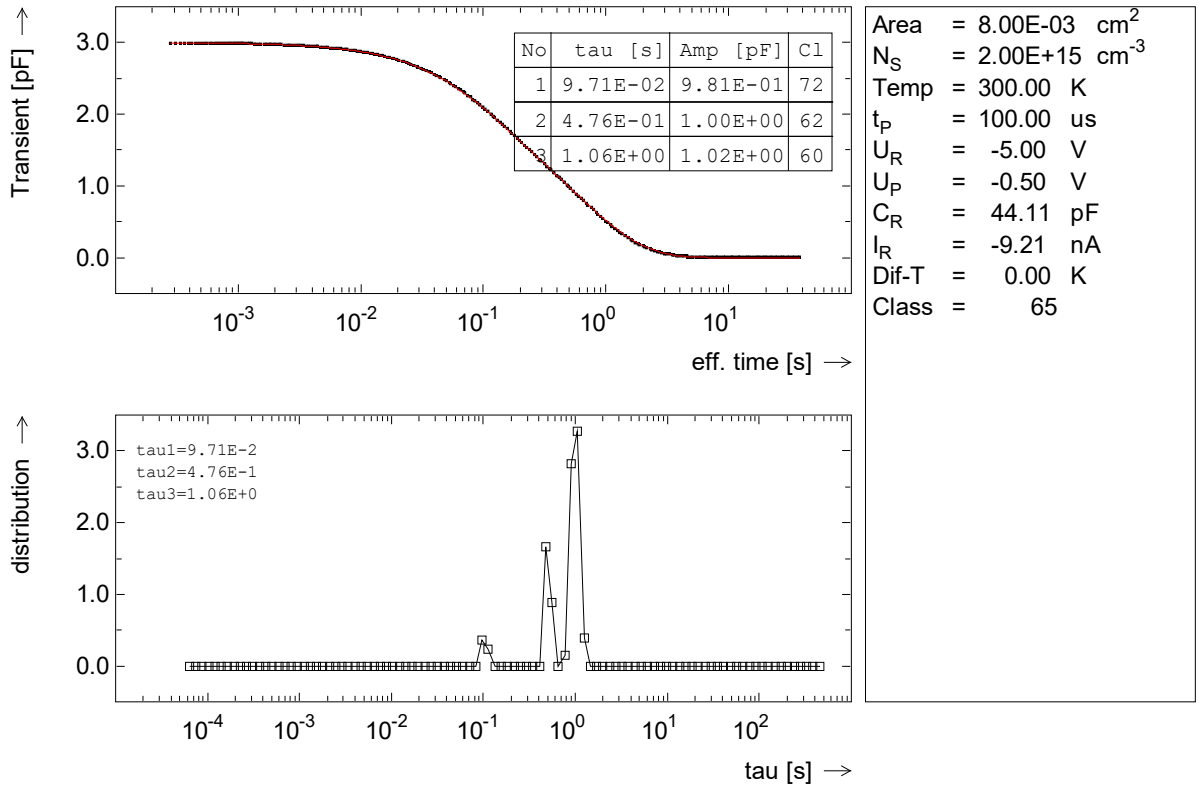
For the next 2 pictures a period scan of 3 levels was simulated. The time constants were 100 ms, 500 ms and 1 s, all amplitudes were 1 pF. A quasi-logarithmic transient will be constructed from all transients of the period scan as explained in chapter 3.3.4.4. Its x-axis takes into account the phase delay and will therefore be called effective time.

In the text header you see additionally the maximal temperature difference Dif-T between the used transients and the maximal DLTFS evaluation class of all original transients.

The next picture demonstrates the **DISCRETE** algorithm. It shows the quasi-logarithmic transient (small black squares), the list of results and the transient fit (red curve). The fit curve was calculated by the results of DISCRETE. The result list shows the time constant, amplitude and evaluation class, abbreviated by 'Cl' and done by DLTFS, for each level. The determination of the 3 closed time constants is very good.



The next picture demonstrates **CONTIN**. The top picture is similar as for DISCRETE. The bottom picture shows the distribution of the inverse Laplace transformation. The results were calculated by this distribution. You see that the peak height doesn't correspond to the amplitude.



6.1.2 Transient program module

At the transient program module every transient can be evaluated by the HERA transient evaluation. There is no special measurement.

So you can use the menu point 'Single transient' in the **Measurement** menu. Then you get a transient with a linear time axis. This transient covers only a small time range. Therefore the HERA calculation covers also only a small range of time constants. This can be helpful if you want to separate 2 or 3 very closed time constants. Then select the period width in this way that all time constants are included in the time range.
Generally it is better to cover a bigger tau range. This is possible by a transient with a logarithmic time axis. Select for this measurement 'Logarithmic transient' and activate there the flag 'Quasi log. transi of 3 Tw'. A detailed description of this measurement was given in chapter 3.2.1.4. In opposite to the isothermal and tempscan program module here not all possible points of the 3 original transients will be used. The data will be interpolated so that the quasi-logarithmic transient has 128 equidistant, on a logarithmic time axis, points.

In the **Evaluate** menu you find 'HERA TranEval'. It plots and fits the current transient and list the results. The inputs are explained above. The plot is similar as shown in chapter 6.1.1.3. The time axis is linear or logarithmic depending on the current transient.

6.1.3 Isothermal program module

Here usually for HERA a standard period scan will be measured and evaluated by 'HERA TranEval of log. transi' in the Evaluate menu.

6.1.3.1 Measurement

At the isothermal program module every period scan can be evaluated by the HERA transient evaluation. The saving of the internal transient data points must be activated. Internal transients means that these data are included in the isothermal file. 32 points are here enough. This is the default value. From all internal transients a transient with a logarithmic time axis can be constructed, see chapter 3.3.4.4 for more details.

6.1.3.2 Plot menu

At the plot there is the menu 'HERA TranEval' with following sub menu entries:

tau evaluation: Shows all calculated time constants versus period width.
Curve by curve: Shows the transient, fit, results and at Laplace algorithms the distribution for every period width, curve after curve.
Distribution: Shows either the Laplace distribution versus tau for each period width curve after curve, or all distributions in one plot. An example of the input window will be shown at the end of chapter 6.1.4.2.

All these plots use the internal transients of the various period widths. That means the calculation will be done for every transient (linear time axis) at various period widths. Here not the constructed quasi logarithmic-transient will be used.

If the period scan comes from a temperature variation, that means the automatic measurements of period scans at various temperatures, then following additional menu entries are in the sub menu:

tau, all temps: Shows all time constants of the quasi logarithmic transients versus temperature. At more one level then some time constants exist. The minimum class is necessary separately for each tau (level).
Curve, all temps: Shows the transient, fit, results and at Laplace algorithms the distribution for every temperature, curve after curve.
Distribution, all temps: Shows the Laplace distribution versus tau for all temperatures. The distribution can be shown curve after curve, all in one plot, as a 3-dimensional plot or as a mapping plot.

All these plots use the quasi logarithmic transients, constructed at each temperature by all internal transients. That means the calculation will be done for every constructed transient (logarithmic time axis) at various temperatures.

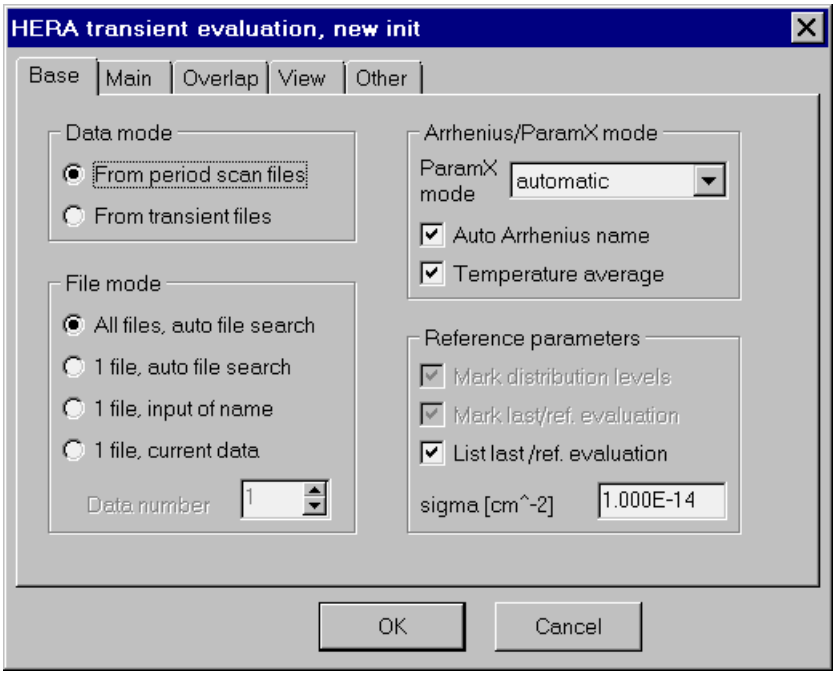
6.1.3.3 Standard evaluation

The standard evaluation is 'HERA TranEval of log. transi' in the Evaluate menu. From all internal transients a transient with a logarithmic time axis will be constructed. Here all possible data points of the original transients will be used. 'Possible' means not twice in the overlapping time range. The constructed quasi-logarithmic transient is not equidistant. For more details look in chapter 3.3.4.4, data mode 'original points'.
An example for this HERA evaluation was given in chapter 6.1.1.3.

6.1.3.4 Full Arrhenius

In the Evaluate menu there is also the entry 'HERA TranEval, full Arrhenius'. An Arrhenius plot will here be done by a manual, automatic or semi-automatic HERA transient evaluation of period scans at various temperatures. This function is similar to the Arrhenius plot via maximum analysis as described in chapter 4.2 but here the transients will be evaluated and not the coefficients. The results and the data structure is that of an Arrhenius file, so this function runs in this sub program. The function is also very similar to the Arrhenius plot done by a HERA transient evaluation of tempscan files as described in chapter 6.1.4.4. Therefore only a short explanation will be given here. But the Arrhenius data are always not packed after creation in the isothermal module, the data extension is AW?.

After calling one of the 'Define' menu entries you get the common HERA input sheets and an additional BASE input sheet.



The **data mode** decides from which the transients come from. Usually the internal transient points of the period scan files will be used.
'Temperature average' means that the temperature will be averaged over all measured temperatures of the period scan.
The Reference parameters will be explained in chapter 6.1.4.4.2, the other parameters are already described in chapter 4.2.

6.1.4 Tempscan program module

Here usually for HERA a routine measurement with 3 Tw's will be done and the manual Arrhenius plot used by 'HERA TranEval, full Arrhenius' in the Evaluate menu. The easiest way is there calling '*Automatic*' in the Define menu, but the '*Manual*' definition of each transient is more flexible and give better results. We think a good compromise is there the 'S*emi-automatic*' mode.

6.1.4.1 Measurement

At the tempscan program module the HERA transient evaluation can be done for every tempscan data file if internal transient data points are saved. Internal transients means that these data are included in the tempscan file. By default only 32 points are included. Normally 512 transient points will be measured, and then, if activated, from these 32 or 128 will be saved into the tempscan data file. For the HERA transient evaluation it is better to measure only 128 points of a transient and then to save all 128 points into the tempscan data file. The accuracy will be better when the internal transient has more points, 128 are the maximum. If measuring 512 transient data points but using only 128 for the HERA transient evaluation, then you lose sensitivity.

3 different kinds of measurements and using transients are possible:

1. Only one transient with a fix period width for each temperature of the current data file will be used. This covers only a small range of possible time constants.
2. A tempscan with a variable Tw will be measured. This gives not so good results by the HERA transient evaluation because Tw can be optimized for only one level.
3. The best is the use of a logarithmic time axis. This covers a wide range of time constants. The best method here is the quasi-logarithmic transient constructed from 3 transients of different period widths, for more details see chapter 3.2.1.4.

For the **quasi-logarithmic transient** you have to measure a tempscan with 3 different fix period widths, so you have 3 tempscan data files. The period widths must be selected in this way that there is an overlapping of the time axis. Measure only 128 transient points and include all 128 points as internal transients in the data file. You can change the inputs manually. But it easier to use the tempscan **routine measurement**. Select there:

Base routine mode → HERA tempscans
Sub routine mode → 3 FixTw, HERA TranEval

The use of 3 period widths is the standard mode and is normally enough. At the routine measurements there is also a predefined configuration with 4 period widths. This covers a little bit bigger tau range. 2 period widths can be useful if Tw is limited, see chapter 3.4.1.2. The construction of the quasi-logarithmic transient can be done when reading one of these 2, 3 or 4 files. The other data will be loaded automatically, identified by the file names. Problems may occur if the transient amplitudes differ because different filling (averaging).

All other evaluations are also possible with these special tempscan measurements. So following **evaluations** are possible:

1. DLTFS evaluation with the Fourier coefficients.
2. Maximum analysis of the Fourier coefficients.
3. HERA deconvolution of the Fourier coefficients.
4. HERA transient evaluation of the internal transients.

6.1.4.2 Plot menu

At the plot there is the menu 'HERA TranEval' with following sub menu entries:

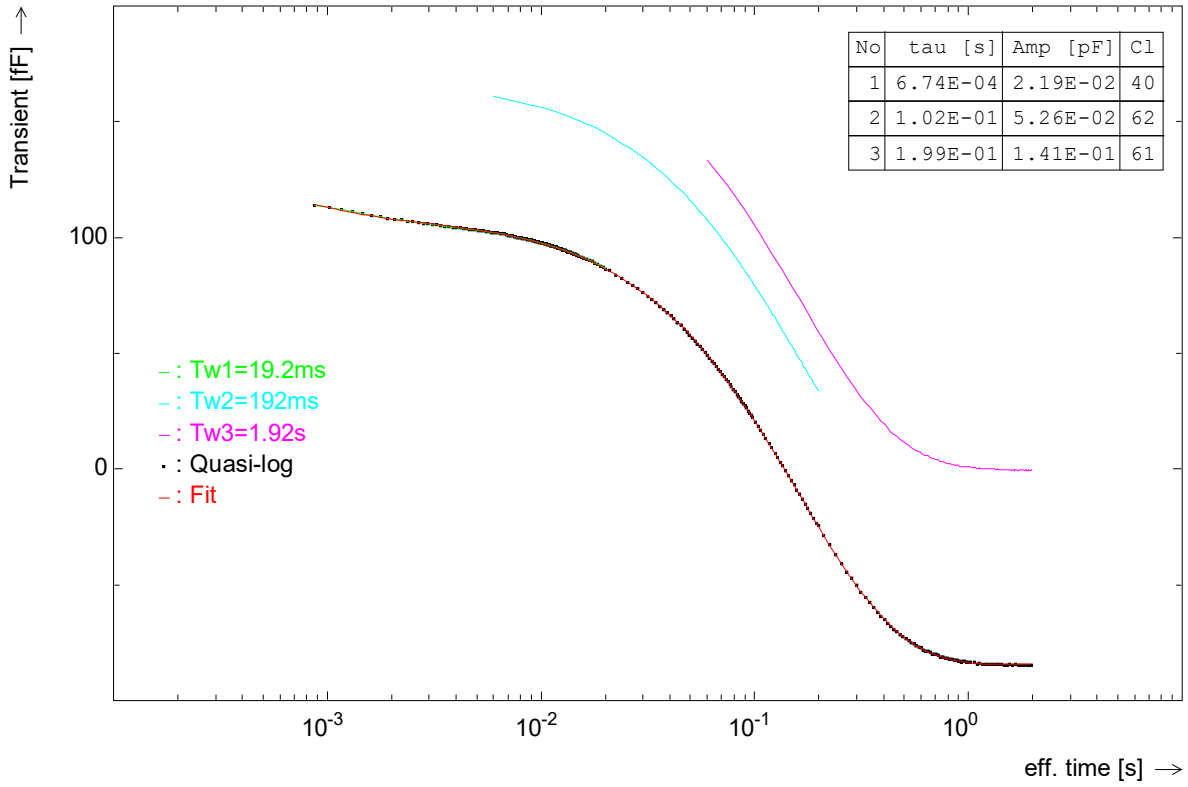
tau evaluation: Shows all calculated time constants versus temperature. This plot and HERA amplitudes are also available in 'Plot → Evaluation values'. A comparison with DLTFS and simulation data is there possible. When selecting 'Different symbols' then different symbols and colors and separate data arrays will be used for each level.

Curve by curve: Shows the transient, fit, results and at Laplace algorithms the distribution for each temperature, curve after curve.

Distribution: Shows the Laplace distribution versus tau for all temperatures. The distribution can be shown curve after curve, all in one plot, as a 3-dimensional plot or as a mapping plot. An example of the input window will be shown at the end of this chapter.

From 2 up to 4 internal transients a transient with a logarithmic time axis can be constructed. Here all possible data points of the original transients will be used. 'Possible' means not twice in the overlapping time range. In opposite to the transient module, see chapter 3.2.1.4, here the constructed **quasi-logarithmic transient** is not equidistant and has more than 128 points. The search of the used transient starts with the current transient and its parameters.

The following picture shows a quasi-logarithmic transient (small black squares) at one temperature constructed from 3 measured transients with different period widths. These original transients will be represented by the lime, fuchsia and aqua lines. These have different DC offsets, nevertheless the quasi-logarithmic transient can be constructed without jumps because the DC will be checked in the overlapping time range. So transient 2 and 3 will be set to the DC of transient 1. The picture shows also the results by the DISCRTE algorithm. With these values the transient will be recalculated and plotted (red line). This fit is very good.



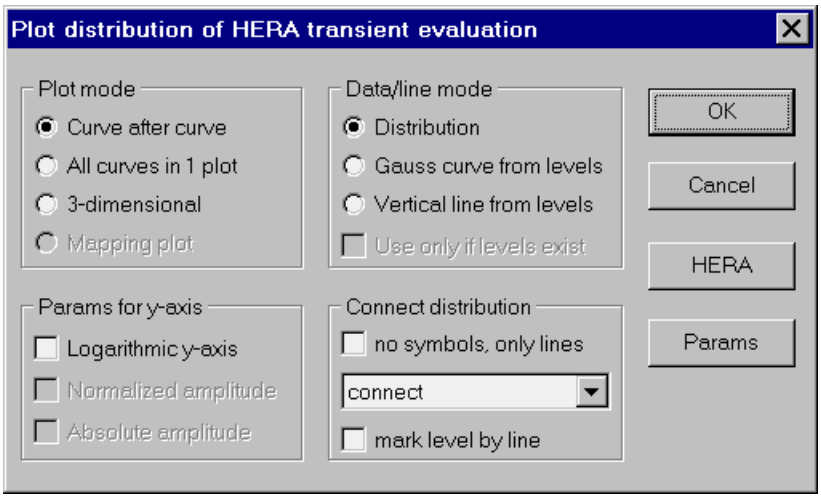
No	tau [s]	Amp [pF]	Cl
1	6.74E-04	2.19E-02	40
2	1.02E-01	5.26E-02	62
3	1.99E-01	1.41E-01	61

Plot Distribution:

This menu shows the distribution, a Gauss curve or a vertical line versus tau for all temperatures. If using a Laplace algorithm then the result distribution can be shown. At the DISCRETE algorithm there is no distribution, so this option is not possible.

The **plot mode** defines whether the distribution will be shown curve after curve, all curves in one plot, as a 3-dimensional plot or as a mapping area plot. The last mode needs user class 5.

The 'Params' button opens the parameter window for the selected plot mode, the HERA button opens the HERA parameter window.



The y-axis of the plot can be linear or logarithmic.

Normalized amplitude is not for the Laplace distribution available. It means that the height of the Gauss peaks or vertical lines corresponds relative to the amplitude of the level. So the peak height of the biggest amplitude is 1, the other heights are smaller. If not activating this flag then all peaks heights are 1. If activating '**Absolute amplitude**' then the peak heights are the amplitudes of the levels.

The **data/line mode** defines the type of plot:

Distribution:	Shows the result distribution of the inverse Laplace transform versus tau, not possible for DISCRETE.
Gauss curve:	A Gauss curve at the time constants of each level will be drawn. So you get a plot amplitude 'distribution' versus time constant.
Vertical line:	Similar as Gauss curve, but draw a vertical line at each time constant.

'**Use only if levels exist**' means that only distributions with one or more time constants will be used for the plot. This option is not available for the plot mode 'curve after curve'.

If selecting the Laplace distribution then you can connect the distribution points by lines and mark the level (time constant) by a vertical line. At the Gauss curve you can input the numbers of curve points and the sigma for the Gauss function.

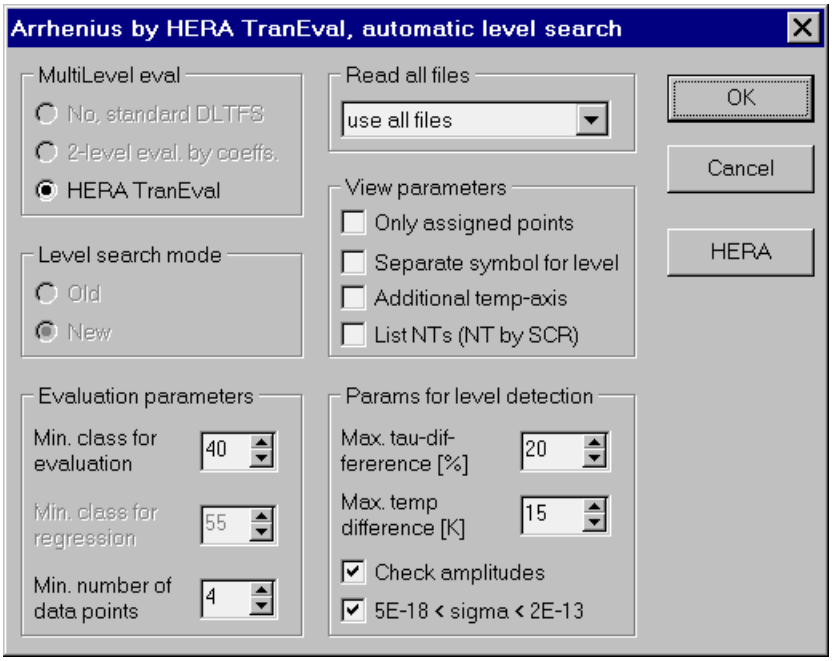
6.1.4.3 Quick Arrhenius

In the Evaluate menu there is the entry 'HERA TranEval, quick Arrhenius'. An Arrhenius plot will be done by an automatic HERA transient evaluation. Here the evaluation will be done in the background without showing the transients. The sorting of the levels will not be saved, it is only temporary. 2 possibilities exist:

1. **Arrhenius, auto levels:** The results will be automatically sorted to various levels. You have only to define parameters for the sort order.
2. **Arrhenius, manual levels:** You have to define the number of levels and then select the temperature range for the linear regression of each level.

At the **automatic level search** the software tries to detect the numbers and the corresponding data points of levels automatically and sorts the data points to the levels. The linear regression will be done level by level about the data points of the level. There is no mismatch possible, even at an overlapping, if the automatic sorting is successful. Points that are not assigned to a level will be shown as a small square.

Clicking onto the 'HERA' button opens the HERA inputs. The other inputs are the same as in chapter 3.4.5.1.
It is possible to collate information from more than one tempscan file. But here this mode is not independently from the HERA parameter 'Transient origin'. If you use there '3 Tw's, quasi log', the corresponding tempscan files with different period widths will be loaded and **'Read all files'** is disabled.
You should not use files with variable Tw for HERA.



The **Params for auto detection** define criterions for the validity of a level:
A **Minimum number of data points** is in the Arrhenius plot necessary for each level.
There is a **maximum percentage difference** possible between the time constant and the regression line of the Arrhenius plot.
The gap between 2 points of the same level is restricted by the **maximum temperature difference**, it is a relative value to 150 K as the last mode of step factor in chapter 3.4.1.3.
By **Check amplitudes** all amplitudes of each level will be checked. If the difference is too big, then this point can not belong to this level.
The capture cross section can be limited to **5E-18 < sigma < 2E-13**.

The Arrhenius plot with **manual level search** is similar to that one of DLTFS. For more details see chapter 3.4.5.2. Here an additional comparison between HERA transient evaluation and DLTFS evaluation is possible.

Note: In opposite to the *Full Arrhenius* the shown data are restricted by the minimum evaluation class. Levels found by HERA may have only a class between 30 and 40.

6.1.4.4 Full Arrhenius

In the Evaluate menu there is also the entry 'HERA TranEval, full Arrhenius'. This is the main application for the HERA transient evaluation in the tempscan module. An Arrhenius plot can here be done by a manual HERA transient evaluation of a tempscan. 'Manual' means that the transient for each temperature will be shown and the HERA results listed, the user defines then whether the found results are valid and to which levels these belong. But the 'semi-automatic' mode is more convenient for the user.
This function is similar to the Arrhenius plot via maximum analysis as described in chapter 4.1 but here the transients will be evaluated and not the coefficients. The results and the data structure is that of an Arrhenius file, so this function runs in this sub program. In the following only the differences and additional features will be explained. For more details look in chapter 4.1. At the full Arrhenius the results and the sorting can be saved into an Arrhenius data file. It is not only temporary as in the 'Quick Arrhenius'. If using the standard pack mode 'Level common' then the data extension is AP?, in the other case AW?.
The standard Arrhenius plot with all levels will be shown on the main canvas of this sub program.

6.1.4.4.1 Define menu

The menu bar is similar to the maximum analysis of chapter 4.1. Instead the 'Maxima' menu here is the 'Define' menu with its 4 sub menus:

The search will normally be done with a **new** initialization, that means old definitions and results will be deleted.
If you have already done an evaluation or a file read then you can **keep** the old definitions and results. This is only possible if the existing Arrhenius data are not packed.

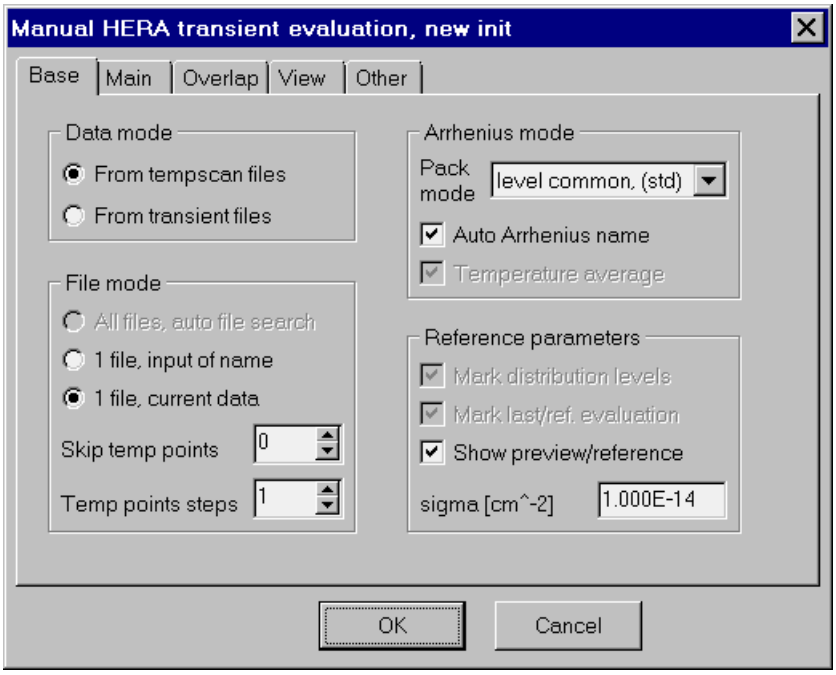
3 different kinds of searching and sorting (defining) of levels here exist:

1. At the **Manual** mode the algorithm calculates the time constants and amplitudes but the user decides which result is valid and to which level it belongs. The manual definition of each transient is more flexible and gives better results than the automatic definition. But it can be a lot of work and sometimes complicate to sort the levels.
2. At **Automatic** the levels will be automatically searched and defined, as described in the chapter before. After the search you get a question how the results shall be sorted. This the easiest way to get the HERA Arrhenius.
3. The **Semi-automatic** mode is a good compromise between easy use and flexibility. Here the levels will be first automatically searched and defined. Then you can change the sorting and control the results.

The define button in the tool bar means here the semi-automatic sorting. 

6.1.4.4.2 Manual defining

Manual defining, input



After calling one of the 'Define' menu entries you get the common HERA input sheets of chapter 6.1.1.2 and an additional BASE input sheet.

The **data mode** decides from which the transients come from. Usually the internal transient points of the tempscan files will be used. 'From transient files' means external transients have must be saved, one for each temperature.

The **file mode** defines which files will be used for the HERA evaluation:

1 file, input of name: One tempscan file will be used, you can select the file name.
1 file, current data: The current tempscan data will be used.

If '3 Tw's, quasi log' is selected as HERA parameter 'Transient origin', then all corresponding tempscan files with different period widths will be loaded if exist.

You can **skip temperature points** at the start and you can select the **temperature point step**. If it is 1 then all temperature points will be used, if it is 2 then only every second temperature will be used.

The **Reference parameters** give helps for the detection and sorting of the levels, the first options are only enabled if using a Laplace algorithm:

'**Mark distribution levels**' draws a vertical red line at the peak position of the Laplace distribution.

At '**Mark last/ref. evaluation**' a blue vertical line will be drawn at the distribution peak position of the last valid (done before) resp. reference evaluation. Additionally the level number of this reference peak will be written above this line.

'**Show reference list**' gives an additional small plot window with an Arrhenius preview and a grid with the last valid resp. reference results, for more details see chapter 4.1.1.5.

Sigma is necessary for calculating the energy from tau and temperature, for example in the reference list.

If activating **Auto Arrhenius name** then the proposed name of the Arrhenius data file will be set from the tempscan file name.

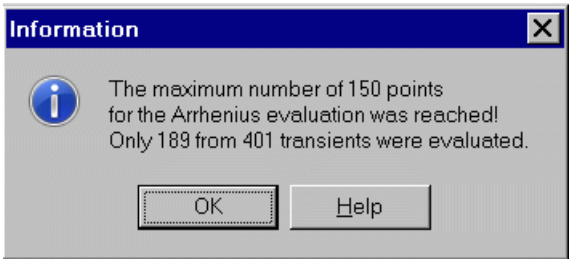
The result data in the Arrhenius file can be packed. Following **pack modes** exist:

No packing: A data record will be reserved for every temperature, independently if there is a result or not. Maximum 150 data points per level are possible. During manual defining you can go back to all data points. The Define mode 'Keep' is only here available.

Level common: If there is a valid result for one level at the temperature point (transient), space for all levels will be reserved. This is here the standard packing mode. This keeps the valid origin, it means that you can determine which level results come from the same transient. Maximum 150 data points with up to 9 valid levels are possible. During manual defining you can only go back to data points with valid results.

Level separately: This full packed mode needs user class 5 and saves only the valid results into the Arrhenius file. You should not use it because you lose the origin information. A check of level mismatch is not possible. It is the same mode as packing in chapter 4.1.2.2. Maximum 150 valid data points per level are possible.

The pack mode decides also how many data points can be evaluated. If you have many tempscan data points with transients with valid results, then the maximum number of Arrhenius points can be reached before all transients were evaluated. In this case you get the following message on the right.

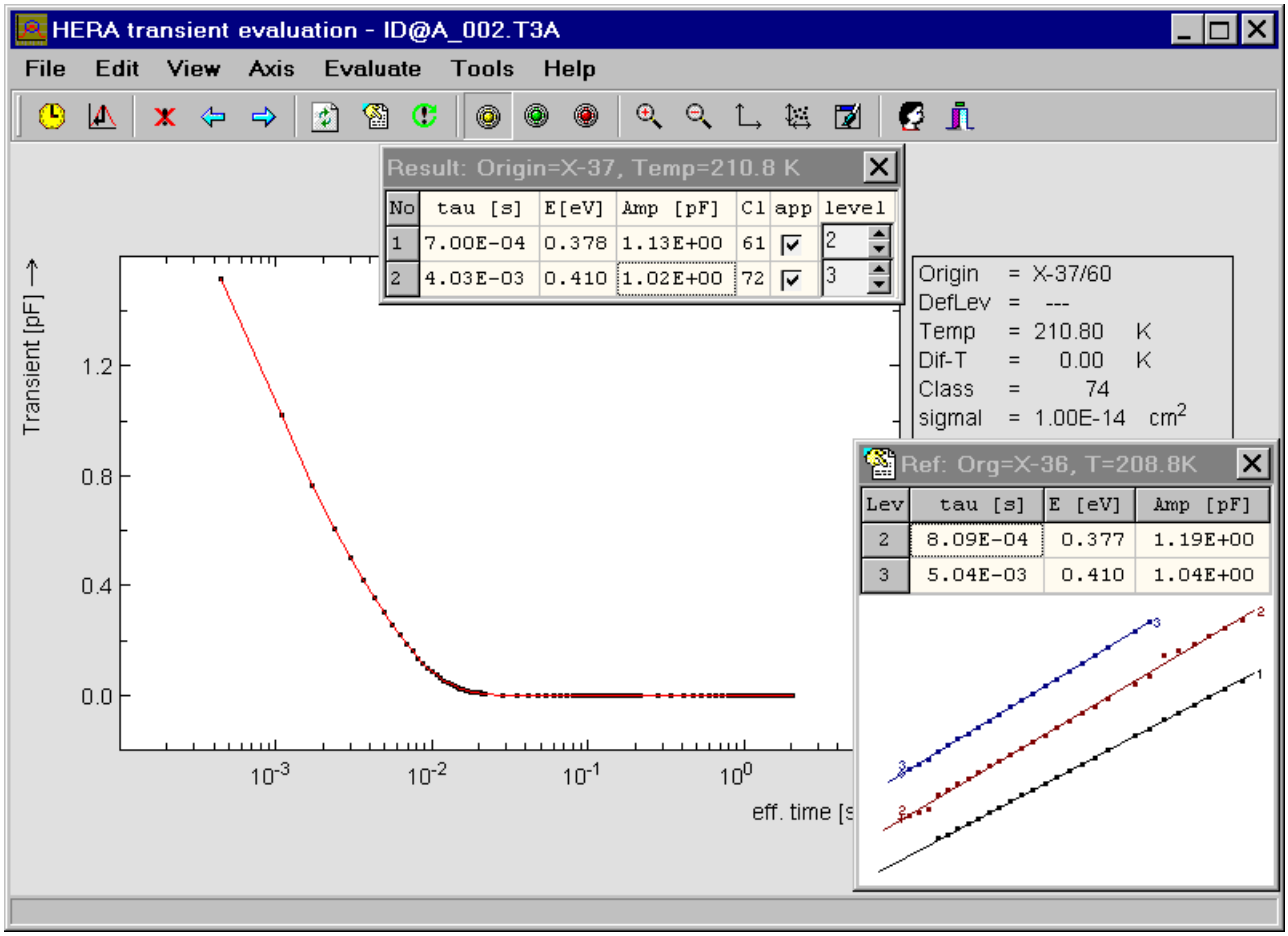


Following possibilities exist to avoid this problem:

1. Use only transients with a **min. class** of 40 or higher. It means that only those temperature points will be used at which the DLTFS evaluation class is equal or higher than the selected minimum evaluation class. You find this option at the input sheet 'Other'.
2. Make **2 Arrhenius files**, one for the first, the other for the last levels. For the second Arrhenius file skip temperature points at the start. You can also set a temperature step bigger than 1 to reduce the data numbers.
3. Use the pack mode '**Level separately**'.

Manual defining, plot

The following picture shows the plot at the defining of levels using the DISCRETE algorithm. The plot shows the current quasi-logarithmic transient of the current temperature. Under the top menu bar there is the toolbar. At the right there is a list with the important parameters. At the right bottom there is an Arrhenius preview and a list of the current and reference values. Below the toolbar there is the result list for the current transient, done by the selected algorithm. You can change the position of result list and Arrhenius preview.



List of important parameters:

Origin: Origin of the current transient, gives also the record position in the Arrhenius data array. 'X' means one of the level numbers, the 2. number is a running order of valid data and the 3. is the temperature point number.
DefLev: Lists the level numbers which were defined for the current transient, '----' means that a definition was not yes done.
Temp: Temperature at the measurement.
Dif-T: Maximal temperature difference between the used transients.
Class: Maximal DLTFS evaluation class of all original transients.
sigmal: Capture cross section, defined by the sigma input.

In the **Edit menu** there you copy the graphic into the clipboard and delete all levels of the current transient**.** The **Axis menu** is the same as in the plot program. In the **Tools menu** you can list the results of all evaluated transients.

Some points of the **View menu** are the same as in the plot program, new ones are:

HERA TranEval params: Opens the HERA input sheets as described in chapter 6.1.1.2.
Reference params: Input of the reference parameters of the Base input sheet.
Show reference list: Show reference list and Arrhenius preview, see next chapter.

The main menu is the **Evaluate menu**:

Apply, go on by timer: Automatic sorting until break is pressed. Before starting there is an input window for the delay time between 2 transients.
Apply levels, go on: The defined levels numbers will be applied. Then the software goes on to the next transient (data position).
No levels, go on: Define that there are no valid results for this transient. Goes on to the next transient.
Go to previous data: Go to the previous transient (data position).
Go to next data: Go to the next data.
Input of data: Go to the data position which was selected by an input.
Resolution as input: Makes an evaluation with the resolution which was selected for the algorithm at the main input sheet.
Standard resolution: Makes an evaluation with the standard resolution parameters.
Highest resolution: Makes an evaluation with the highest resolution mode.
New eval by used levels: The numbers of the valid levels for the current transient will be used as the maximum level numbers for a new evaluation.

Explaining of the **toolbar**:

Apply, go on by **timer.** Automatic sorting until break.
Apply levels, go on. If no valid results were found here is the Go on button.
No levels, go on to the next transient. F9 key is shortcut.
Go to previous data, PageUp key is shortcut.
Go to next data, PageDown key is shortcut.
Params for HERA TranEval.
Show reference list and Arrhenius preview.
New evaluation by used levels.
Resolution as input.
Standard resolution.
Highest resolution.
Zoom in.
Zoom out.
Axis mark for setting a new plot window by mouse marker.
Axis rescale to the initialization plot window.
Refresh the plot, F5 key is shortcut.
Personal user button.
Close the level defining.

Manual defining, work

The algorithms give only time constants and amplitudes for each transient. There is no sorting to the physical level number, that means no connections between the results at different temperatures. At one temperature it can be that you see 3 time constants, at the next only 2 because one of the levels is too fast for detecting. But at higher temperatures a new level may appear. So it can be necessary that 2 found levels must be sorted to the level number 3 and 4. The situation will be more complex if the transients are not pure exponential or at bigger noise. Then the algorithms don't work perfect and detect perhaps at similar temperatures 3 resp. 4 levels.
The software sets the level number to the result number plus a level offset. The level offset will be set only by the user. For example if there are 3 time constants found in the transient then the fast will be set to level 1 and the slowest to level 3. At higher temperatures only 2 time constants can be found, these are from the physical levels 2 and 3. But the software defines these as 1 and 2! So you have to change the level numbers manually to 2 and 3. This situation shows the picture above. Then the software knows that there is a level offset of 1 and will add it at the next transient. The software takes the offset from the first number (line) of the result list.
Some helps will be given by the software for the manual sort.

The **result list** shows in the caption the origin with the running order of valid data and the temperature. The grid lines contain the important parameters for each level found by the algorithm. The time constant, amplitude and class will be listed. An energy calculated by tau, temperature and given sigma will also be shown. 'No.' is a running number of the result for the current transient given by the algorithm, it is not the level number!
A checkbox, called 'app', decides if this result will be applied as a physical level. The level number behind the box defines to which level this result belongs. At one temperature only one result can belong to one level. You can activate or deactivate the applying of a result and you can change the sorting by defining new level numbers in the result list.

The **reference list** is also a help. Its caption shows the origin of the reference and their temperature. 'Reference' means here the last transient with valid results. In the grid lines are the level number, tau, energy and amplitude for each level. The energies and amplitudes in the result and reference list give you further hints. Both values must correlate more or less between the result and reference list. The energies of the result and reference list were not calculated by the Arrhenius plot. Therefore it is possible that the energies differ by temperature, how much depends how much the true capture cross section differs from the given sigma.
The evaluation class can also be a help. At the HERA transient evaluation this class was calculated by the DLTFS technique, so it has a similar meaning, see chapter 3.4.5.4.

The **Arrhenius preview** gives you a further help. After 2 Arrhenius points a small preview will be plotted below the grid. All already defined data points are shown and denoted by the level number. Different colors will be used for different levels. The current data point, not yet applied, is plotted as a bigger symbol and marked by the current level number. The symbol depends on the level number. The level number corresponds to the level number in the result list defined by the software. You can change the level number in the result list but the new number will not be drawn in the preview.
The lines in the plot are calculated by a linear regression of corresponding levels points, they will be extrapolated for a better overview. Not all points are visible at all times because there is an automatic plot window, for more details see chapter 4.1.1.5.

6.1.4.4.3 Automatic defining

The easiest way is the automatic search. Then the sorting will be done automatically. If the Arrhenius plot is not so good by this automatic work, you can later change the criterions for sorting or automatic detection of levels. If this is not successful, you can sort the Arrhenius points manually, also after the automatic search. See chapter 4.1.2.1 for more details.

The input is similar as for the manual defining. The reference parameter have here no meaning.

For all kinds of defining the input sheet '**Other**' is expanded:

Use only with min. class is now enabled in input group 'Transient for calculation'. It means that only those transients (temperature points) will be used at which the DLTFS evaluation class is equal or higher than the selected minimum evaluation class.
Don't mismatch this feature with 'Use only levels with class>=40' from the Main input sheet. Activating this flag applies only those HERA results which evaluation class is equal or better than 40.

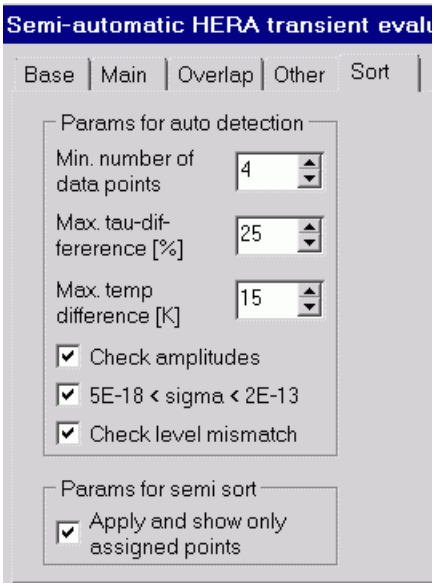
The option '**Default apply if class>=40**' exist for the manual defining. When activating it, only the check boxes of levels which have an evaluation class equal or bigger 40 will be marked for applying. In the other case all will be marked independent of class.
The option '**Apply only if class>=40**' exist for automatic and semi-automatic. When activating it, only levels which have an evaluation class equal or bigger 40 will be applied. In the other case all levels independent from the class will be applied.
Both options are a little bit similar to 'Use only levels with class>=40' from the Main input sheet. This feature is valid not only for the Arrhenius plot and may repeat the calculation at invalid levels. Prefer, if necessary, the special option for the Arrhenius data from the 'Other' input sheet.

After the automatic search the software asks you how the results shall be sorted. A 'No' keeps here the current sort order, that means all defined points will be applied. Then the Arrhenius plot with the new order will be shown. After this you get a question for applying the new level order or to retry, if you have select a new sort. Then the software asks for saving the Arrhenius data. The procedure and questions are the same as in 'Sort data by levels' of the View menu, chapter 4.1.2.1. Only the detection mode 'Edit by grid/plot' is here not possible.

6.1.4.4.4 Semi-automatic defining

The **Semi-automatic** mode is a good compromise between easy use and flexibility. Here the levels will be first automatically searched and defined. Then you can change the sorting and control the results.

The input is similar as for the manual mode. The input sheet 'Other' is the same as for the automatic mode.



There is the additional input sheet 'Sort'. The **Params for auto detection** define criterions for the validity of a level:

A **Minimum number of data points** is necessary in the Arrhenius plot for each level.

There is a **maximum percentage difference** possible between the time constant and the regression line of the Arrhenius plot.

The gap between 2 points of the same level is restricted by the **maximum temperature difference**, it is a relative value to 150 K, see chapter 4.1.2.1.

By **Check amplitudes** all amplitudes of each level will be checked. If the difference is too big, then this point can not belong to this level.

Check level mismatch checks whether the storing position in the file is wrong. So at one temperature only one result can belong to one level.

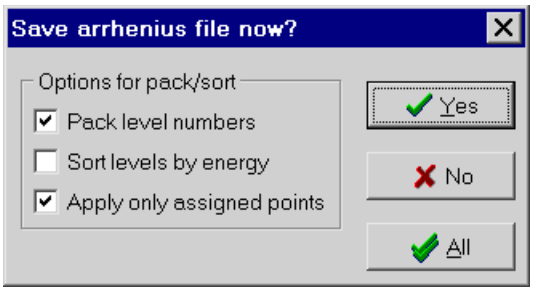
The capture cross section can be limited to **5E-18 < sigma < 2E-13**.

'Apply and show only **assigned points**' deletes results in the Arrhenius data array which are not assigned to a level. These points will not be shown in the following function 'Edit by grid plot'. If this flag is not activated, such points will be shown as small squares. You can assign such a point to a level, after the plot you can delete the not assigned points.

After the automatic levels search the software jumps to the function '**Edit by grid plot**'. There you can delete points and change the level order. You can do this in the grid or in the plot. Editing the level number in the level column gives a new level order. Level number 0 represents a deleted level, negative level numbers are unassigned points. You find a detailed explanation in chapter 4.1.2.1.1.

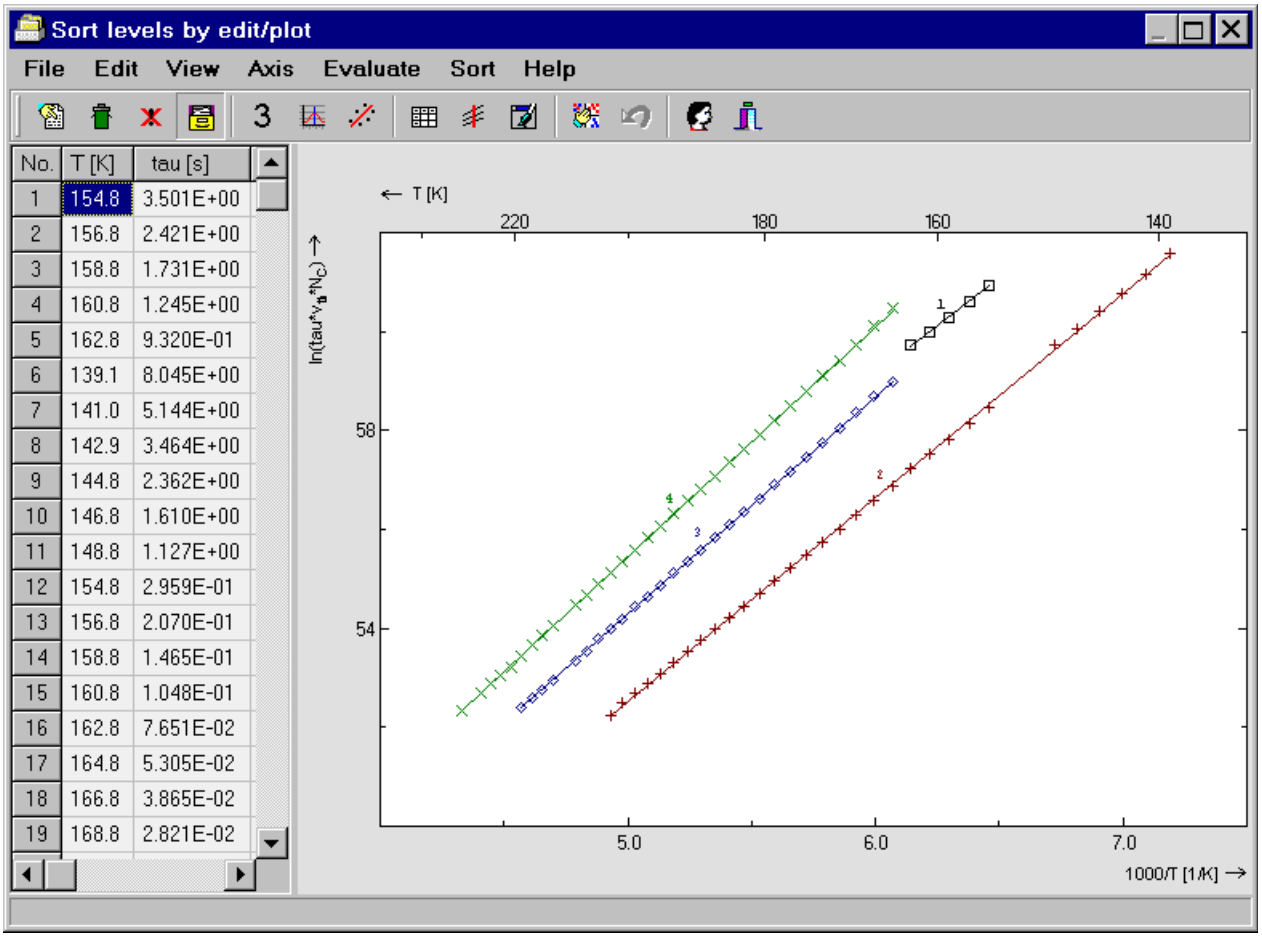
After leaving this function the software asks you for saving and packing data:

Yes opens here the save file dialog and saves the results into the Arrhenius file.
No don't save the data but packs the data in the arrays as defined in the options.
All opens the data task window of chapter 2.2.3.



Pack level numbers means that level numbers will be sorted if there is a gap in the used levels.
Apply only assigned points deletes results in the Arrhenius data array which are not assigned to a level. This function is no enabled at pack mode 'Level separately'.

The following shows a simulation with a non perfect automatic level sort. The easiest way is to change the level numbers of the wrong sorted data. For this select the work mode 'Define' and select as level number 3. Then mark all points in the plot which were sorted to level 1 but belongs to level 3. Then these points will be applied as level 3 and no points for level 1 will exist. If closing this window then you get the dialog as described on the previous page. Activate there 'pack level numbers' to numerate the levels from 1 to 3.



The origin denotes here now the level and a running order of the valid data. If the data are not packed, the 2. number is the temperature point number. The origin column can not be changed or marked. The energy was calculated from temperature, tau and sigma calculated by the linear regression of all points of level. So all points of the same level should have the same energy value. Class here is not the EvalClass of the DLTFS technique (in opposite to the Quick Arrhenius) but depends on it: Class = 50 + EvalClass DIV 10. You can delete all data with too small class in the Edit menu. It is not necessary that the first level number is 1. Before storing the data in the Arrhenius data array the level numbers can be packed.

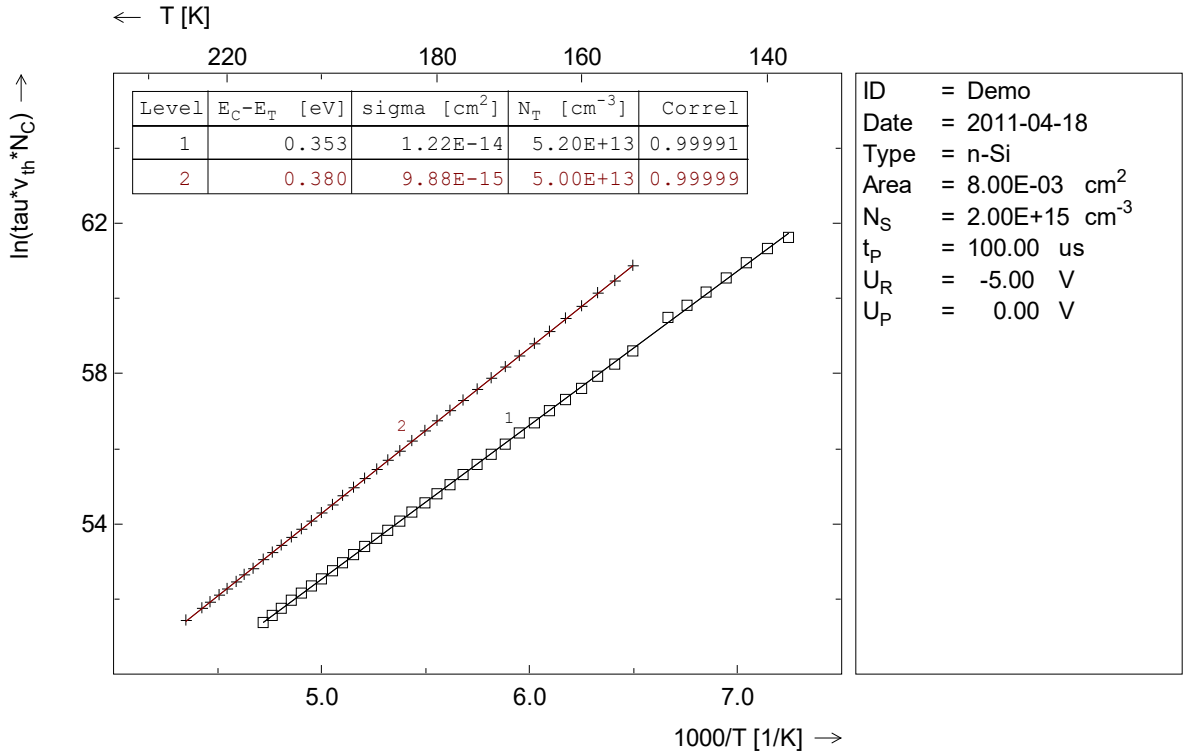
The menus and the toolbar were already explained in chapter 4.1.2.1.1. After the semi-automatic search there are 2 further possibilities:

In the Sort menu you find '**Sort by new params**'. It opens an input window with the 'Params for auto detection' as described above and start then a new sort. All manual changes will be deleted except you have called 'Apply changes' in the File menu!

In the View menu and in the toolbar you can activate '**Sort grid by origin**'. Normally the grid shows first all points of the first level, then of the second and so on. If activating this flag the grid shows first all levels of origin point 1, then all levels of origin point 2 and so on.

6.1.4.4.5 Arrhenius plot

Except the Define menu, all menus and possibilities of the 'full Arrhenius' are the same as in the maximum analysis, explained in chapter 4.1. So you find here in the Evaluate menu also 'Arrhenius, all levels'.
The next picture shows a simulation with 2 closed levels. The energies are 0.35 eV and 0.38 eV, the capture cross section is 1E-14 cm^2 for both. The levels are not separable by the conventional maximum analysis. But the HERA evaluation detect both levels with a good accuracy.

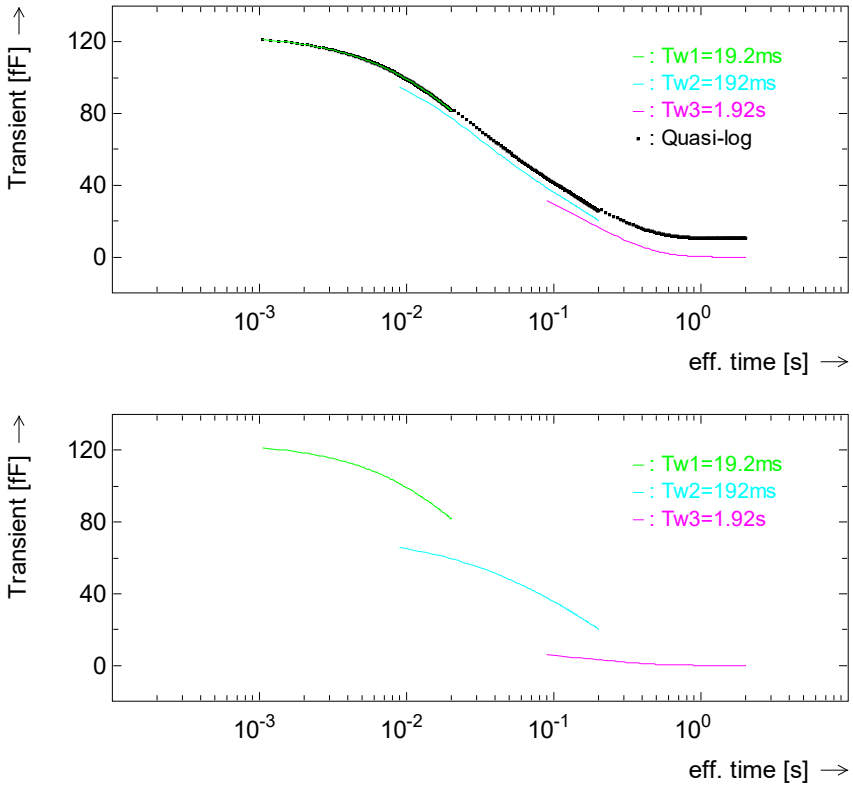


6.1.5 Artifacts and special notes

The construction of the **quasi-logarithmic transient** bases on the assumption that all transients have the same time-law and the same amplitude.

Problems may occur if the **pulse width** is too small (means capture cross section is to small for given tP) then not all traps will be filled by one pulse. The 3 or more different Tw's will usually be measured at different averages. This yields here to different amplitudes because each pulse (average) fills the trap more and more. The construction will be wrong or not possible as the simulation below shows.

Both plots show the 3 transients of different period width and different averages. The defined capture cross section of the top plot was bigger so that the effect of averages is not so strong as in the bottom plot. The transient at Tw=19.2ms was 100 times averages while the transient at Tw=1.92 was only one times measured. That means the effective pulse width of the fast transient can be up to 100 times higher. The construction of the quasi-logarithmic transient gives at the top plot only a small error while this construction is not possible for the bottom plot.

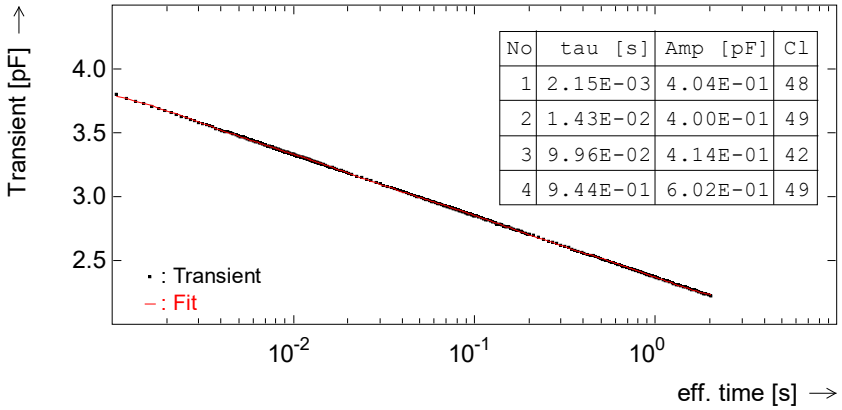


A quasi-logarithmic transient yields usually to problems at oxide states which depend very strong from the pulse width. Look also in chapters 3.2.1.5, 3.3.1.2 and 6.3.6 for the problem of not filled traps and how to reduce this problem. The logarithmic transient made by one measurement don't have this problem but has a bad SNR.

A similar problem is possible at the quasi-logarithmic transient when using **CC-DLTS**. The maximum voltage output depends there from the CC-amplification (see chapter 6.2.1.1.4). If this is too small then the transient will be limited. Usually the transient has at small times a higher voltage, so that this influence is bigger at faster transients. It could be that only the transient with the small Tw will be limited but not the other ones.
At not complete emission, which is typically for oxide states, and averaging it could be that you don't see the constant voltage limit in the transient but a decreasing line. The reason is that the first measurements are not in the limit but only the last ones. The average yields to a line with a wrong slope.
At CC-DLTS it is also important that all 3 transients are measured at the same voltage. So don't use a separate regulation for each tempscan file as explained in chapter 6.2.1.3.2. But take into account the limited voltage when regulating only before the 1. file.

The HERA evaluation will be used for the calculation of time constants of an exponential time law. The time axis can be linear or logarithmic. The surface or oxide states emission follow a **logarithmic time law** which amplitude depends on the temperature. If you use here the HERA evaluation the results are fix time constants over the whole temperature range. The reason is that a transient with a logarithmic time law can be well fitted by an overlapping of some exponential functions. Don't confuse here the logarithmic time axis with the logarithmic time law which can be expressed as '*Amplitude*ln(t/tau)*'. At a conclusion, usually the HERA evaluation makes no sense for a logarithmic law of time.

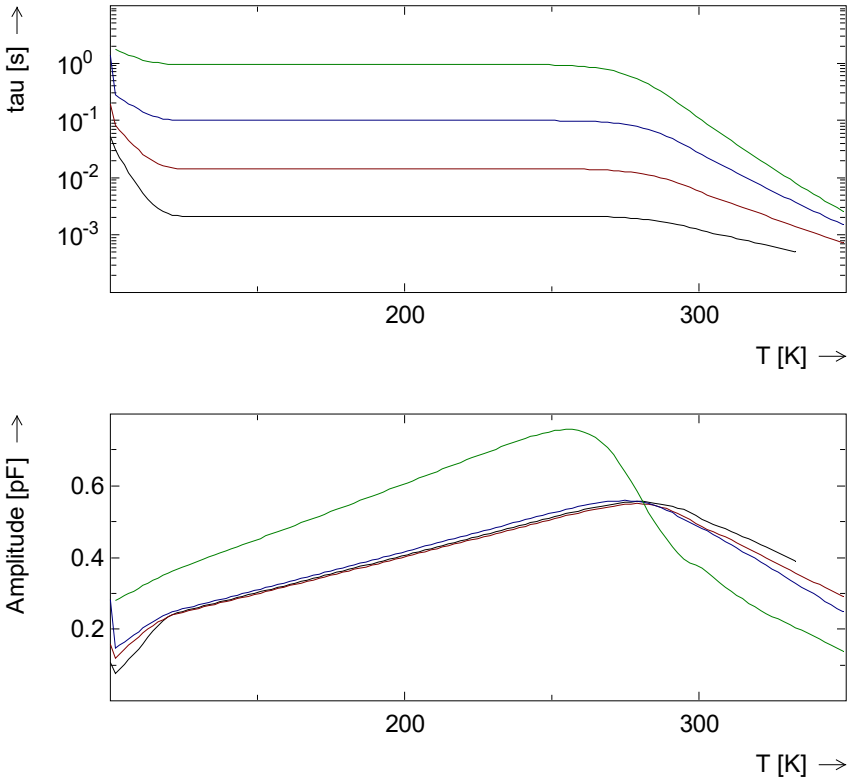
The plot on the right shows a transient with a logarithmic time law (black points). The time axis was logarithmic so that it yields to a linear curve. These data were fitted by the results of the HERA evaluation (red line). Only 4 exponential functions was used for a better overview, that means the maximum number of levels was restricted to 4.



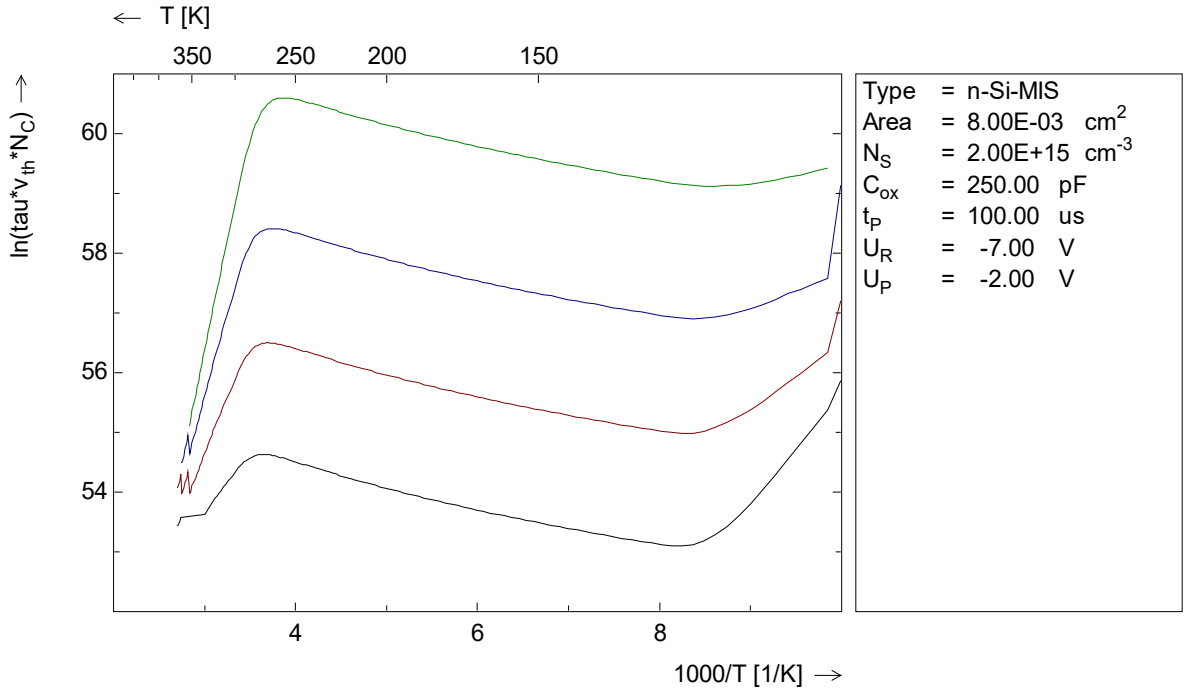
No	tau [s]	Amp [pF]	Cl
1	2.15E-03	4.04E-01	48
2	1.43E-02	4.00E-01	49
3	9.96E-02	4.14E-01	42
4	9.44E-01	6.02E-01	49

The next picture demonstrates the HERA evaluation for the tempscan simulation of surface states in chapter 6.3.4.3. The tempscan there shows that b1 (amplitude) increases between 120K and 270K linear with the amplitude. At the edges the curves falls because reaching EFR and EFP.

The top plot shows the results for the 4 time constants, the bottom plot the corresponding amplitudes. In the range 120K to 270K the results for tau are fix while the amplitudes increase linear with the temperature. At the edges we have no longer a full logarithmic time law, 'some exponential functions are missing'. First the amplitude of the slow time constant (green curve) falls above 270K. We may see a more complex behavior at oxide states because the logarithmic time law is there more complex because the influence of tP.



At a temperature independent time constant you get in the **Arrhenius plot** a straight line which decreases with 1000/T (increases with T) because v_{th}*N_C on the y-axis increases with the temperature.
The next picture shows the top plot above as Arrhenius plot. In the medium range, which corresponds to a temperature between 120K and 270K, the y-values decreases a little bit because the temperature dependence of v_{th} and N_C while tau is here constant. At small 1000/T values (high temperatures) the y-values increases because tau falls down here by reaching the Fermi level $E_{FR.}$ These straight lines can be misinterpreted as an Arrhenius straight line. So the evaluation of the green curve would give here an energy of 0.67eV and a capture cross section of 5E-15 cm^2. But that is wrong, it is only a fake.



6.2 DLTS modes and FET

The **DLTS mode** defines which kind of transient will be measured and which evaluations are possible:

Capacitance: C-DLTS, capacitance transients will be measured, it is the standard mode.
Voltage: U-DLTS, voltage transients will be measured. This mode will also called CC-DLTS because the **C**apacitance will be kept **C**onstant.
Current: I-DLTS, current transients will be measured.
Charge: Q-DLTS, current transients will be measured and from these the charge transients calculated by numerical integration.

The DLTS mode defines also the dimension of the Fourier coefficient.
It will automatically uncover and hide any other relevant menus. You can select the DLTS mode in 'Measure → Measure params → ' at the Base tab sheet, see chapter 2.1.2.1.
The chapter 2 and 3 of the Software Manual describe normally the C-DLTS.

6.2.1 Voltage-DLTS (CC-DLTS)

For CC-DLTS (U-DLTS) you have to connect the 'CC' output of the bias board with the 'V' input of the amplifier board, use a short BNC cable. Once the CC cable has been connected it will not be necessary to disconnect for standard C-DLTS. All other options will work correctly.

6.2.1.1 Basics

Voltage transients will be measured here while the capacitance of the transient will be kept constant. This mode is used when the deep level trap concentration is close to the doping concentration for example when the condition NT << NS/10 is violated.

6.2.1.1.1 Theory

The depletion region of the device under test is kept constant during the emission process by the use of a feedback loop which adjusts the bias applied to the device in order to keep the capacitance constant, see equation 1.3. The transient that is produced by deep level emission through this process is seen as a voltage transient, when monitored using constant capacitance feedback high trap concentrations can be determined accurately. The voltage transient will be more close to an exponential than the capacitance transient and therefore conventional style analysis can be applied, see Theory Manual.
The benefit of using the constant capacitance technique is that the analysis using an exponential transient is exact irrespective of the trap concentration. The position of the deep level traps is well controlled and defined throughout the measurement; this is especially useful when investigating the spatial distribution profile of a deep level.
Capacitance changes that occur in a diode under test of applied reverse bias are monitored closely and the output signal from the capacitance meter is used to control the applied reverse bias so that the capacitance is kept constant. This may be done by either comparison to a reference capacitor or by comparison with a reference voltage. The transient that is monitored is the change in voltage, as the voltage is changed in order to keep the capacitance constant. Obviously the feedback of the capacitance must be fast.

CC-DLTS is not generally used as a standard measurement method because it is more complex to set up than C-DLTS. The operator must set the amplification up manually. This can be time consuming but once set for one sample type can be used for others.

Summary: The advantage of U-DLTS is the exponential transient, no overlapping of levels assumed, even if NT is close to NS. The disadvantage is that it is more complex, especially the setting of the best amplification is not easy. A further disadvantage is the smaller sensitivity, but U-DLTS measurements will be done at high concentrations.
CC-DLTS needs a **voltage dependent capacitance**. If the C/V curve is flat in the region of UR then it is not possible, for example at MIS samples in accumulation and deep inversion. Take care this fact especially for **MIS** samples.

6.2.1.1.2 Regulation modes

We distinguish at the **CC-regulation** between fast and slow regulation.

1. The **fast regulation** is the regulation during the transient and keeps the capacitance transient constant during the emission process, that means C(t)=constant. So this regulation can also be called 'transient regulation'. The fast regulation will be done by a hardware loop. The fast regulation is always necessary for CC-DLTS. Normally the fast regulation is only on during the transient measurement. If it is permanently on, then CR(T) will be kept constant by this regulation. But the fast regulation can only regulate a special voltage range depending on the CC-amplification, see next chapter.
2. The **slow regulation** keeps the equilibrium capacitance constant between the transients during a tempscan, that means CR(T)=constant. So this regulation can also be called 'reverse bias capacitance regulation'. The slow regulation will be done by changing the reverse bias in a loop. This can yield to a problem because the reverse bias can go to the limits, especially at a flat C/V curve, and destroy the sample. If it goes to zero voltage then only a small pulse height is possible.
   Slow regulation is not so important for measuring Schottky diodes as for MOS samples. It is possible to make CC-DLTS measurements without slow regulation.

Two **base regulation modes** are possible:

I. CC-DLTS with a **fixed reverse bias** and pulse voltage: Only use of fast regulation during the transient measurement. This measurement is more complicated as C-DLTS with respect to the capacitance amplification as the higher capacitance must be carefully regulated, this can cause problems with MOS devices where inversion processes are occurring. Only the transient capacitance is regulated with this option. This mode is sufficient to get an exponential transient at high trap concentrations. This kind of regulation don't use the slow regulation menu and make the measurement much simpler and more likely to produce a successful measurement. Regulation mode 1 belongs to this base mode.

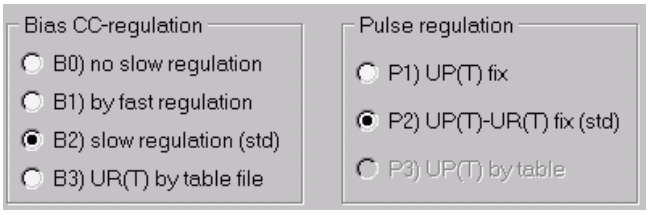
II. CC-DLTS with **constant depletion region WR**: Use of fast and slow regulation. Both the transient capacitance and the reverse bias capacitance are regulated. In this option the width of the depletion region is kept constant, this option obviously is the best condition so that the traps under evaluation are always those in the same region, i.e., the spatial distribution of the deep levels is best defined. Theoretically also WP and so CP, capacitance at UP, should be constant. A hardware regulation of CP is not possible. So we have introduced the regulation modes 3 to 5.

Note: CC-DLTS introduced in the literature uses normally only the fast regulation. This is the origin regulation, also called CC regulation. The slow regulation is only a help. It makes in principle a voltage compensation so that the fast regulation can always work in its optimal operating range. Big offsets voltages are possible without slow regulation.

We have introduced 7 regulation modes. For a better overview we have separated the input in **2 types**:

Bias CC-regulation: Defines how the bias will be regulated.
Pulse regulation: Defines how the pulse voltage will be regulated.

The right window shows the input for these 2 types. It will be used in the 'Parameters menu', see chapter 6.2.1.2.1. Not all combinations are possible. The bias regulation modes will be abbreviated by 'B0' to 'B3', the pulse modes by 'P1' to 'P3'.



All following regulation modes use the fast regulation. So the capacitance during the transient measurement will be kept constant, that means C(t)=constant. At the bias mode B1 the fast regulation is permanently on, the other modes switch it on only during the transient and while making the slow regulation. B0 and B1 don't use the slow regulation automatically but you can do it manually in CC-DLTS menu. Mode B2 and B3 make automatically the slow regulation before every transient measurement. The first text in the following list denotes which physical value will be kept constant.

Following **Bias regulation modes** exist:

B0) **No slow regulation:** No slow regulation, bias and pulse voltage are fix. The capacitance compensation will be done before every transient measurement, CR changes with the temperature. This option is simplest and involves using a fixed reverse bias whilst regulating the transient by the application of a bias, this is not true CC-DLTS. Making this measurement is fine for Schottky devices but not okay for MOS devices. Selection of this kind of regulation only makes the measurement much simpler and more likely to produce a successful measurement.

B1) **By fast regulation:** No slow regulation, fast regulation is permanently on. It is a special case and don't belong to base mode I or II. The fast regulation try to keep CR(T) constant. But it can regulate only a special voltage range depending on the CC-amplification, see next chapter. As mode B0, the advantage of this mode is that it don't use the slow regulation. This makes the measurement simpler. In opposite to mode B0 also CR(T) will be kept constant if possible. The disadvantage is that the voltage range can be too small at big changes of capacitance. Then you get a big transient offset or an ADC overflow error.

B2) **CR(T): slow regulation (std):** The reverse bias capacitance will be kept constant by changing UR. This is the standard bias regulation mode. The advantage is that CR(T) is constant, the disadvantage the possible problems at the slow regulation.

B3) **UR(T) by table file:** The reverse bias capacitance will be kept constant by changing UR by a table. The table can come from temperature depending C/V curves. One advantage is that no regulation problems can occur, it can also be used if the C/V curve has a flat range (inversion). An important feature is that also CP(T) can be kept constant by a table during the tempscan and. The disadvantage is that the table file and so C/V measurements are necessary.

Following **Pulse regulation modes** exist:

P1) **UP(T) fix:** The pulse voltage is fix during the tempscan. The disadvantage is that the pulse capacitance changes with the temperature.

P2) **UP(T)-UR(T) fix (std):** UP will be changed in the same way as UR, so that the pulse height UP-UR is fix. This is an approximation for a fix CP and space charge region. It is especially important when the C/V curves shifts on the voltage axis by the temperature. This mode is the standard pulse regulation mode. The advantage is the approximate fix CP, the disadvantage that UP can go to its limits.

P3) **UP(T) by table:** The pulse capacitance will be kept constant by changing UP by a table. The table can come from temperature depending C/V curves. This feature is the only way to keep also CP completely constant during the tempscan. The difference to mode P2 depends on the behavior of the sample.

Summary: Each of the available modes has different assumptions and benefits associated with it. Mode B0 is the easiest one. It is enough to get exponential transients at high trap concentrations. If the SCR (space charge region) must be constant, at MIS devices or at NT depth profiles, then select mode B2+P2. If the slow regulation makes problems then mode B1 can be a good compromise. For a true fix space charge region use B3+P3. This has the additional advantage that no regulation problems can occur.

The regulation modes B3 and P3 need the 'Enhanced' software option.

6.2.1.1.3 Defining of CR

How to define the value for **CR** which should be kept **constant**? For this you have to make a compensation. Then the slow regulation keep the last compensated capacitance constant. You can do this compensation manually in the compensation window (see chapter 6.2.1.2.3) or in the Measure Utils or automatically before the transient measurement. For the last case there is a flag which will be activated by defining a new sample. It will also be activated at opening a table file (mode B3). You can also activate it manually, see chapter 6.2.1.3. After a compensation this flag will be deactivated. The slow regulation (mode B2) will also be done after a new automatic compensation.

It is important that the compensation will be done after switching to CC-DLTS and not before. If you have not selected the CC-DLTS mode then normally the compensation will be done by capacitance and voltage compensation. This can yield to an error or big offsets at CC-DLTS because CC-DLTS don't 'see' the voltage compensation. If selecting the CC-DLTS mode then only the capacitance compensation will be used.

Note: At CC-DLTS the applied voltage at the sample is not only the **reverse bias**. It is UR plus the regulation voltage. At the tempscan plots you can show UR or UR+DC, the last one is the applied voltage if the emission process is finished.

6.2.1.1.4 Regulation parameters

Two important regulation parameters are the bridge range and the CC-amplification. Both together are the total regulation-amplification. This amplification defines how good the fast regulation is, this means how constant the capacitance is during measurement.
If the amplification is too small then the capacitance changes a little bit more or less. Then you see a mix of a C-DLTS and of a U-DLTS transient. If the amplification is set too high then oscillations will be seen on the transient.

Change to one bridge **range** lesser yields to a higher total amplification but a lower C-range gives more sensitivity. In most cases range 2 is the best, range 1 max be possible at small capacitance values. Range 3 is necessary for a big capacitance. The general rule may be to use one range higher as at C-DLTS but sometimes the same range is also okay.

The **CC-amplification**, used for the fast and slow regulation, allows only some values and defines also the maximal output voltage of the fast regulation. So you have to define two values: the **maximum fast regulation voltage** and the amplification. Both values are not independent. If you change the first value, then another range of possible amplification values will be shown in the input window. The maximum voltage which can be regulated by the fast regulation is a delta voltage and is applied on the sample additionally to the reverse bias. It is bipolar, so it can have negative and positive sign. The maximum regulation voltage must be higher than the transient amplitude. In the other case the U-DLTS transient goes into a saturation.

The possible input voltages and amplifications for the CC-regulation are depending from the bias range. At higher bias ranges only higher amplifications are possible. The best bias range is the **20V bias range** resp. 40V range at the 40V bias option. The 10V range is the fastest one but it may be too fast for CC-DLTS measurements. On the other hand the **100V** option allows only big amplifications, also if you restrict the limit to 40V. Oscillations may be the result. If you need here a lower total regulation-amplification, you have to increase the capacitance range.

The regulation, especially the possibility of oscillations, depends also on the use of pre-amplifier. For an effective 'slower' regulation, deactivate the pre-amplifier for U-DLTS measurements. For this the flag '**Reduce CC-amplif**' exist in the enhanced bridge parameters, see chapter 2.1.2.5.

So at all following parameters define the **effective regulation**:

Capacitance range and limit,	Bias range and speed,
Max. regulation voltage,	Regulation amplification,
Pre-Amplifier	

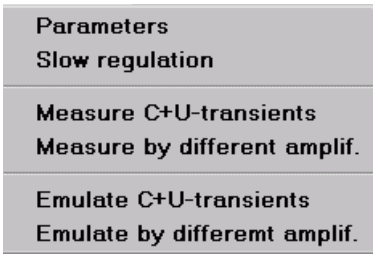
Factors which need to be assessed by the user for the measurement are:

1. The regulation mode must be selected.
2. The capacitance bridge range must be set manually.
3. Amplification and maximum regulation voltage must be set manually.
4. Bias values must be limited manually to protect the device.

There are tools within the software which will assist the user in setting these parameters correctly, see next chapter.

6.2.1.2 CC-DLTS menu

If selecting U-DLTS then the following sub menu will be visible in the 'Check measurements' menu. It contains the parameters and tools for CC-DLTS.



'**Parameters**' contains the inputs for the regulation.

'**Slow regulation**' is a tool for doing the slow CC-regulation.

'**Measure C+U-transients**' measures C- and U-DLTS transients and compare both and the 'regulation error'.

A transient measurement by **different amplifications** helps to find the best amplification.

The parameters are also in 'Measure params' as a separate input sheet. How and when to call the single tools will be described in chapter 6.2.1.3.

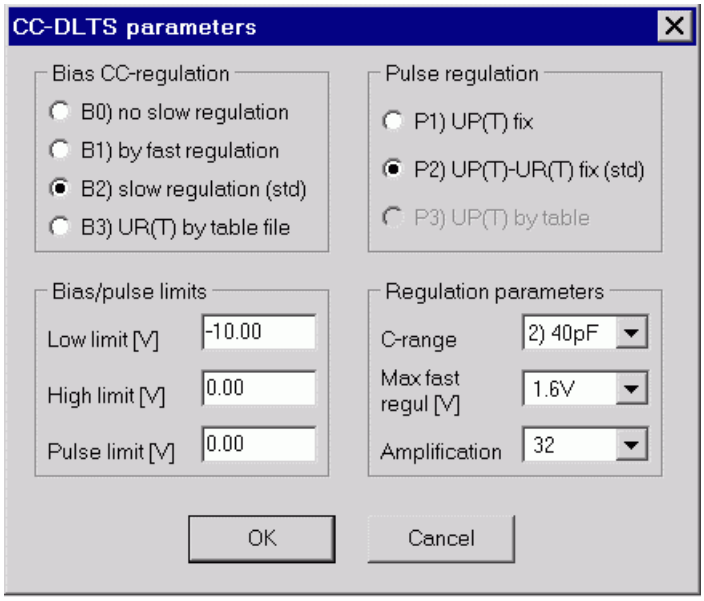
6.2.1.2.1 Parameters

The parameters window contains the inputs for the CC-regulation, these parameters are also available in 'Measure params' as a separate input sheet.

The regulation modes were already explained in chapter 6.2.1.1.2. For a better overview we have separated the regulation mode input in 2 types:

Bias regulation: Modes B0 to B3, defines how the bias will be regulated.

Pulse regulation: Modes P1 to P3, defines how the pulse voltage will be set.



The regulation parameters are already described in the previous chapter. For the **C-range** (also called bridge range) you should start with range 2. If it works, you may try range1. If it doesn't work, select range 3.

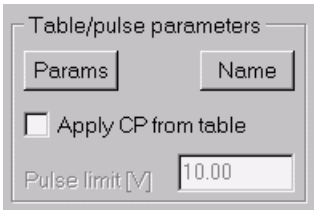
Following **max. fast regul** voltages exist for the 20V bias range: 0.8V, 1.6V, 3.2V, 6.4V. You transient amplitude must by smaller than this value. For the 1.6V value following **CC-amplifications** are possible: 16, 32, 64, 128.

If using the slow regulation, this means mode B2, then inputs for the bias low and high **limit** are enabled (including sign). Mode P2 enables also the pulse limit. At n-type sample this is a high limit, at p-type a low limit. The pulse low resp. high limit is given by UR. For example, UR can be regulated between -10V and -0.5V with the shown values in the input window. At regulation mode P2 UP would be maximal 0V.

The limits must be considered from the I/V curve and also when selecting the temperature scan direction. When scanning up in temperature do not set the starting reverse bias close to the limit of the device because the device capacitance will increase with temperature and the regulation voltage will need to be increased to accommodate it.

Note: At MIS samples especially the pulse limit should allow forward voltages because a possible shift of the flat band voltage.

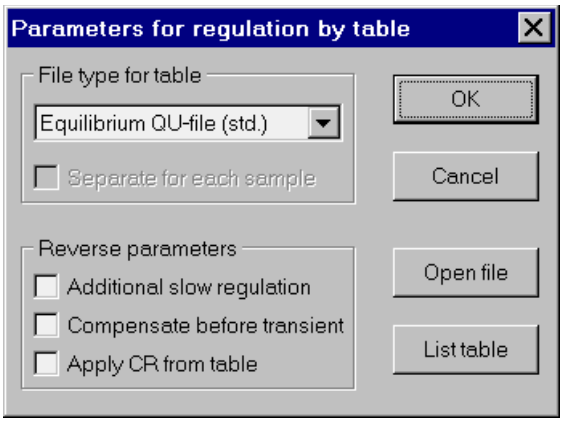
If selecting mode B3, that means UR will be read from a **table file**, then mode P3 will be enabled and the limits input window changes as shown on the right.



Activation of '**Apply CP from table**' applies the pulse capacitance from the table file. In the other case it will usually be calculated, see chapter 2.1.2.3.

The button '**Name**' opens the Windows dialog for the input of the table file name.

The button '**Params**' opens an additional input window for the regulation by a table file, as shown on the right.



The button '**Open file**' opens here the Windows dialog for the input of the table file name.
The button '**List table**' lists the temperatures, UR, UP and so on of the table file in a grid.

The **file type for table** defines the type of table file and so the type of values used from this file and the possibilities:

- **Equilibrium QU-file (std.):** This is the standard mode, an equilibrium QU-file made by temperature depending C/V curves will be used, see chapter 4.4. This file contains T, UR, UP, CR and CP. It allows the most possibilities.
- **ASCII text file with T, UR:** Uses an ASCII text file which must contain line by line the temperatures T in the 1. column and UR in the 2. column. The regulation mode P3 is here not possible.
- **ASCII file with T, UR, UP, CR, CP:** Similar as above but contains additionally UP in the 3., CR in the 4. and CP in the 5. column. This makes mode P3 possible and allows to apply CR and CP from the table. If you don't know CR or CP fill these columns by 0 and don't apply CR or CP from the table.

At all file types UR will be read at all temperatures from the table file and then set. It is not necessary and possible that the table contains all used temperatures. The program interpolates UR for the used temperature. Regulation mode P3 sets also UP by the table.

Reverse parameters contains additional parameters for the bias:

'**Additional slow regulation**' means that after UR will be set by the table, an additional slow regulation will be done. The advantage is that this mode keeps also CR constant if the sample has changed its C/V behavior after making the table file. Possible regulation problems are the disadvantage. Usually this option is not necessary.

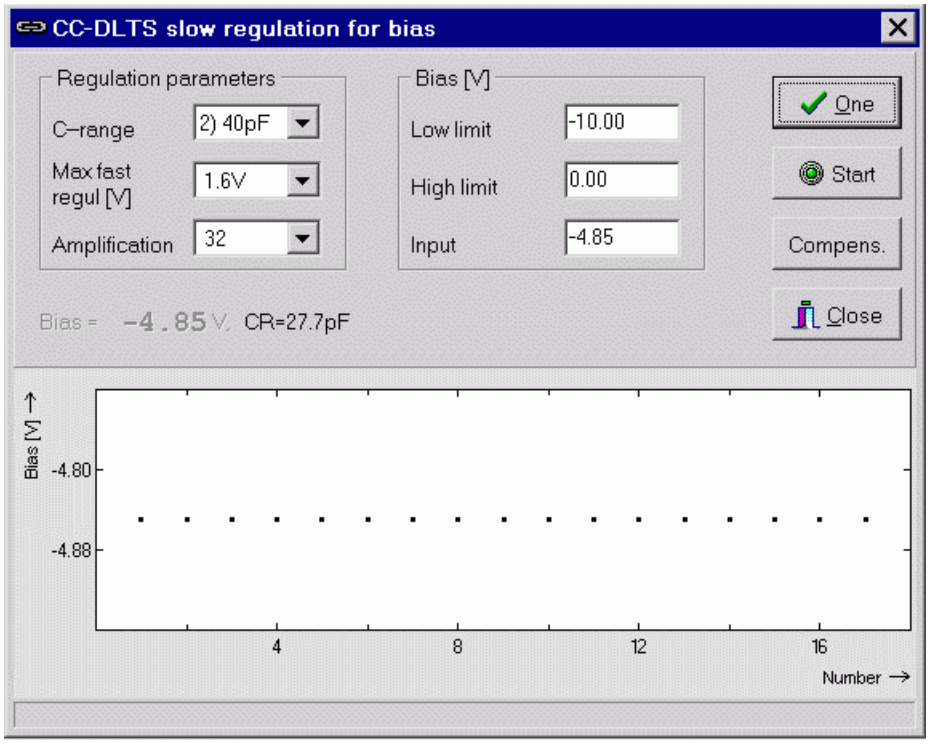
'**Compensate before transient**' makes after setting UR by the table a capacitance compensation. This avoid DC offsets if the sample has changed its C/V behavior after making the table file, but then CR is not completely constant. Usually this option is not necessary.

'**Apply CR from table**' applies CR from the table file instead to measure it. It can be more accurate because CR will be normally measured with the compensation. If you activate this option the capacitance at UR will be measured additionally and saved into the variable 'MeasReverseCapa' but not used as CR.

6.2.1.2.2 Slow regulation

Bias regulation mode B2 makes automatically the slow regulation before every transient measurement. By default here maximal 5 loops will be done until no further changes of UR are necessary for a constant reverse bias capacitance.

This tool here allows to call the slow regulation manually. It is only necessary for mode B2. At user class 6 it can be used for tests also at other modes.
The fast regulation will be switched off when entering this tool, but it will be switched on during slow regulation. Here are also the inputs for C-range, CC-amplification, low and high limit. Additionally you can input the global reverse bias, labeled here as 'Input'.



Following **buttons** exist:

One: Starts one loop of slow regulation.
Start: Starts a permanent regulation.
Compens.: Makes a capacitance compensation and defines ('fixes') CR. You can make the compensation automatically or by a given CR, see next page.
Close: Breaks the regulation if running and exit this tool.
Break: Breaks a permanent regulation, only visible if permanent regulation runs.

During the regulation the new **bias** will be listed and plotted versus the regulation number. It should be constant after a new compensation and if the temperature don't change. Don't worry about the fact that the bias is perhaps not exact the value at which you have done your compensation. The compensation will be done by fix capacitors. It is not always possible and not necessary to compensate it totally to zero. Remember that at C-DLTS there is an additional voltage compensation which regulates the rest to zero. The slow regulation of CC-DLTS measures the voltage input of the regulation loop.
A not complete compensation to zero yields to a small offset on this input. The slow regulation takes this offset to set a new reverse bias with the purpose to get zero volt at the input. This is necessary to avoid offsets during the CC-transient measurements.

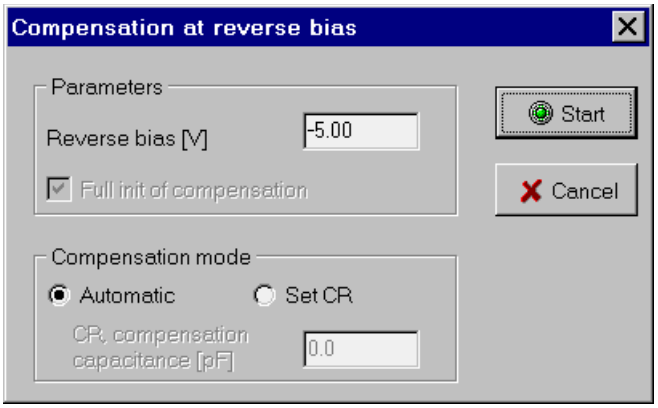
CR will be shown right from the new bias value. It is a fix value and denotes the capacitance at the last compensation, means that value which should be kept constant. It will be called 'CR-comp.' in the list which will be shown after calling the compensation. In the manual it will also be called initial capacitance.

The **compensation** should be done one times if not already done. It is used to identify the reverse bias capacitance which is to be kept constant. This means the regulation tries to keep this capacitance constant at which the compensation was done. If the reverse bias is changed by the input then the reverse bias capacitance must be re-compensated. The compensation must be done after switching into the U-DLTS mode. Regulation mode B0 compensates the capacitance before every transient.

The '**Compens**' button allows here 2 compensation modes:

Automatic: Input of UR and then automatic compensation.

Set CR: Input of UR and CR-comp. (compensation capacitance) and then setting of UR and the compensation capacitors by CR, offsets will be taken into account here. Due to offsets the really compensated capacitance can differ a little bit from the given value.



After the compensation you get a **list** which shows 2 capacitance values. 'CR-direct' was measured directly by the bridge without compensation. 'CR-comp.' is the compensation capacitance which was measured with the compensation capacitors, see chapter 2.1.1.4.

The last compensation capacitance will also be listed in 'Check measure' → 'Measure' → 'Utils' → 'List ranges'. It will be called there 'Compens capacitance'. There you see also the value 'Compens capacitors'. Both values mean not the same. The last one denotes the physical capacitors (fix and variable) which were used for the compensation. The first one takes also offsets into account. The offsets can come from the bridge (separately for each range), the relays (fix capacitors) and the cables.

Tip: For testing the regulation, input a new bias value and start without compensation. The slow regulation should then go to the old bias value at which the compensation was done.

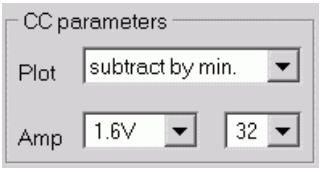
The permanent regulation should constantly adjust the voltage to maintain the compensated reverse bias capacitance.
After 5 slow regulations the bias should be constant. If it goes to the limits then the CC-amplification is too high or the bridge range is too low or the C/V curve is flat at UR.

6.2.1.2.3 Measure C+U-transients

This tool makes a test measurement of the transient regulation, so it measures C- and U-DLTS transients and compare both and the 'regulation error'.

Select a transient resulting from deep level emission and ensure that there is a good capacitance transient go to the maximum transient signal value for a given period width. Have a look in chapter 3.2.1.1.3 for the adaption of Tw. By doing this you will be able to set up the correct amplification for the sample under test. You should also be aware of the necessary voltage limits which apply to the device under test.

The inputs are similar as for the single transient, see chapter 3.2.1.1.1. Additionally you get the input group shown on the right. You can input the CC-amplification and the kinds of transients which the **plot** shows. 3 or 4 curves can be shown in one plot depending upon whether zero-line normalization is selected:



- **Subtract by min.:** C-DLTS, U-DLTS, C(U-DLTS), C-C(U-DLTS). 4 curves will be plotted, where the minimum value of each transient will be subtracted so that the minimum of all shown curves will be zero. The benefit of this plot is that the plot will be clearer, however the absolute transient will not be observed and the ADC offset will not be seen.
- **All in 1 plot:** C-DLTS, U-DLTS, C(U-DLTS) in 1 plot without subtraction of minimum value. The advantage of this plot is that it is possible to observe the absolute transient value and the ADC output, this can be important for assessing ADC overflow errors in U-DLTS.
- **3 separate plots:** C-DLTS, U-DLTS, C(U-DLTS) as above but in 3 separate plots.

The **curves** are described below:

1. **C-DLTS** this shows the normal capacitance DLTS transient, black line by default.
2. **U-DLTS** this is the CC-DLTS transient, red line. For axis calibration see below.
3. **C(U-DLTS)** this is the non-regulated capacitance signal or the error that is found during CC DLTS measurement, blue line by default. It will also be called 'regulation error' or 'error signal'. At a 100% regulation it should be zero.
4. **C-C(U-DLTS)**, means C-DLTS minus C(U-DLTS), this shows the regulated capacitance signal from a CC-DLTS measurement (green curve by default). It was not measured but formed by a difference. At a 100% regulation it should be the capacitance transient C-DLTS.

The dimension of U-DLTS is V, the others are pF. The first 2 plot modes show the U-DLTS curve together with the other curves in one plot. Therefore a calibration of the voltage axis to a capacitance axis is necessary. In the status line you get the information how much voltage corresponds to 1pF.
Each of the 3 plots can be shown after the measurement by the 3 alternative plots, see chapter 2.1.1.

When **saving** the transient, the U-DLTS transient will be saved under the given name. Additionally the curves 1 to 3 will be saved (as used in plot 2) with the suffix 'C', 'U' and 'N' before the data extension. Curve 2 (U-DLTS) will here be calibrated to curve 1 in pF. Then you can call the 3 plots above in 'Plot → Other plots → Compare C/U-transients' of the Transient Program Module.

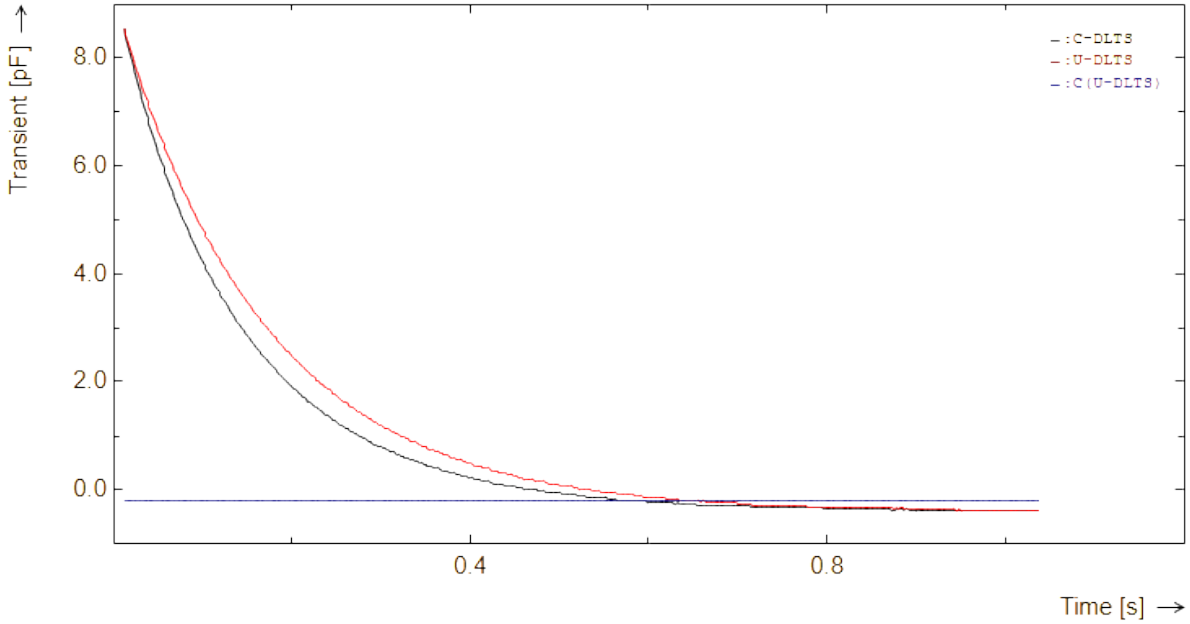
The CC-amplification is assessed through the amplification curve, see previous chapter. Normally start with this value. For testing start with a smaller value and gradually increase it until either oscillations or ADC overflow message appears.

Note: The ADC has a range of -10V to +10V and the DAC has a range of -20V to +20V.

When measuring large U-DLTS transients ADC overflow problems are likely. This can be rectified by reducing the amplification and repeating the test measurement.

Caution: A too high CC-amplification yields to oscillations. In this case a forward voltage can be applied at the sample and so damage the sample.

The following picture shows a measurement with a good regulation. The evaluation class of the C-transient was 65, the class for the U-transient 75; this is the highest class. The U-DLTS transient is a little bit 'more exponential'.



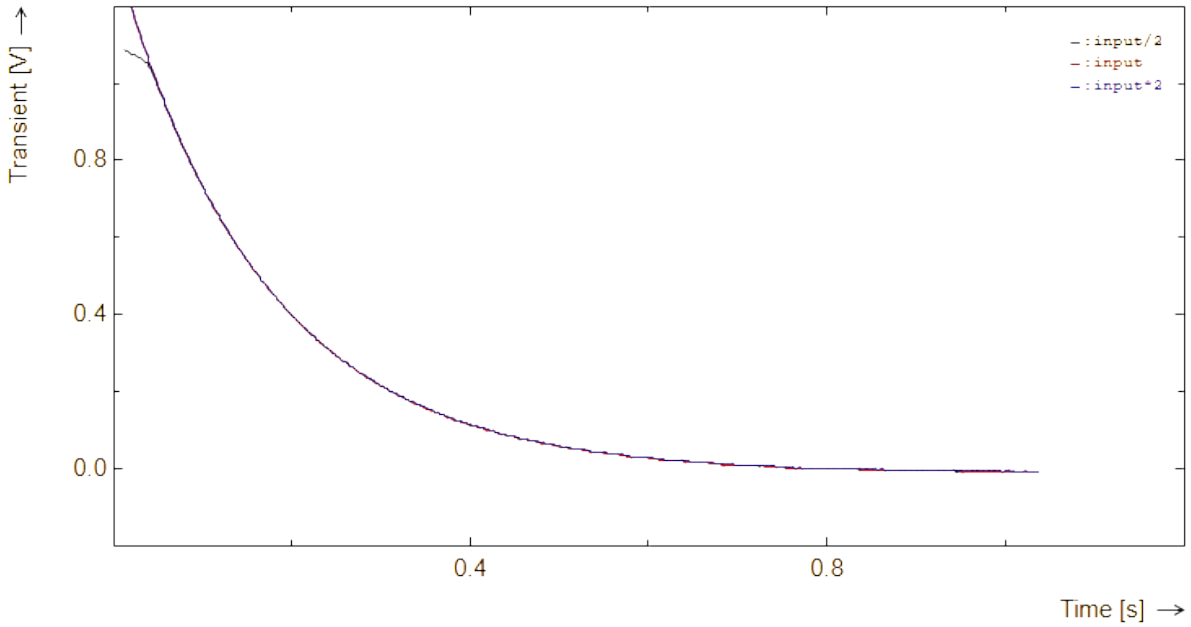
For a **good fast regulation** is valid:

1. The error signal C(U-DLTS) should represent no more than 10% of the C-DLTS transient.
2. C-DLTS and U-DLTS transient should have in plot mode 1 a similar height.
3. The difference C-C(U-DLTS), only shown in plot mode 1, should be similar to the C-DLTS transient.
4. If there is one level with a high trap concentration then the U-DLTS transient should be more exponential as the C-DLTS one and the evaluation class should be higher.
5. No oscillations, especially at the beginning of the transient, are visible.

6.2.1.2.4 Different amplifications

This tool measure CC-transients by different amplifications and helps to find the best amplification. Call this tool if you are not sure that the amplification is high enough for a good regulation (more than 90%). The inputs are similar as for the single transient, see chapter 3.2.1.1.1. Additionally you can input the CC-amplification.

The plot compares 3 transients at user defined CC-amplification, at the half and at the twice. The curves will be called input, input/2 and input*2. If the selected amplification (input) is high enough then the curves 'input' and 'input*2' should have similar heights. In the other case increase the amplification. If you see oscillations of the transient at one curve, decrease the amplification. Keep in mind that a high amplification could give problems at other temperatures.
The following picture shows a measurement at 3 different amplifications. The CC-amplification, called here input, was not selected as the best but as the half of the best. This was done for showing a special effect of this curve. The regulation here is good enough after 50 ms, but you see at the begin of the transient a smaller signal as at the other amplifications. The reason is that the CC-amplification of 'input/2' was 0.1 and so the output voltage was limited to 1.3 V, see chapter 6.2.1.1.3.



6.2.1.3 Measurements

The Software will allow data interpretation using all the methods available to standard DLTS. The transient and the coefficients resp. correlation function signal will be displayed in Volts. Sou can make measurements as usual.

6.2.1.3.1 General

The only thing is that some **preparations** and tests are necessary. The CC tools are a help for this. First you have to switch on the U-DLTS mode as described above. Then go to the 'Check measurement' menu. Not all following steps are necessary in all cases.
You should call the **CC tools** in the following order:

1. Input '**Parameters**' contains the inputs for the above discussed regulation parameters. Decide which mode of regulation is necessary and possible. Type in the voltage limits. The call is only necessary after changing to U-DLTS.
2. '**Measure amplification from C/V**' measures the C/V curve and gives a hint for the best CC-regulation amplification. Don't forget to input the C-range. The proposal of best amplification depends on this range. This call is helpful if you don't know the best amplification.
3. '**Slow regulation**' is a tool for doing the slow CC-regulation. There you can also input the main parameters. If you have not input the reverse bias, here you can do it. *Compensate* the capacitance at the selected reverse bias. If you use the slow regulation, adjust the regulation until the value displayed during permanent regulation remains constant.
4. '**Measure C+U-transients**' measures C- and U-DLTS transients and compare both and the 'regulation error'. This measurement should always be done. Take the temperature so that there is a good transient, adapt the period width as discussed. Check the amplification, the error signal should represent no more than 10% of the C-DLTS transient. For testing increase the amplification until either oscillations or an ADC error message appear.
5. A transient measurement by **different amplifications** helps to find the best amplification. The plot compares transients at user defined amplification, at the half and at the twice. Call this tool if you are not sure that the amplification is high enough for a complete regulation.

Tip: If you know the sample and you have already set the regulation parameters (point 1 above) then you can also directly start a transient or tempscan measurement. The compensation can be done one times automatically before the transient measurement by activation of a special flag, see next chapter. Remember that you can set the regulation parameters also in 'Measure params' in a separate input sheet. It is not necessary to call the CC-tools.

After these preparations make a **tempscan** as usual. The evaluation and tempscan are carried out as for normal DLTS except that the output is in Volt. If using the slow regulation, check after the tempscan the reverse bias and capacitance versus temperature curves. You find them in 'plot menu → equilibrium values'. CR must be constant over the whole temperature range, UR should not go to the limits. You find there also the possibility to plot UP, UP-UR and UR+DC.

Note: If CR changes very strong with the temperature then a slow regulation is not possible during the whole tempscan. This can happen if the effective carrier concentration and so CR will be dominated by a trap level. CR changes here very strong at that temperature at which this trap will be activated. If making compensation at big CR with activated traps then the slow regulation tries to keep this CR. If changing temperature and the traps are not activated then CR falls down to a small value. Then it is not possible to reach the old big CR by changing voltage because the C/V curve has been changed very strong by the temperature. Remember that the slow regulation works on the C/V curve. In this case try a measurement width regulation mode B0, that means no slow regulation.

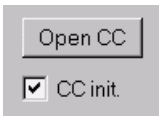
If using regulation mode B3 then make sure that the table file exist. If it don't exist then you get an error message and the measurement goes on without regulating UR and UP.

Tip: 3 ways to **repeat** a CC-DLTS tempscans with the same UR versus temperature:

1. Set the same UR and make the compensation at that temperature as before.
2. Start the tempscan with the same compensated CR. You can input this value for a manual compensation, 'compens.' button in chapter 6.2.1.2.3.
3. Use regulation mode B3 and load UR from an ASCII file. You can create this file by an existing tempscan. Plot UR versus temperature (chapter 3.4.4.6) and save then the curve as ASCII file (chapter 5.1.1).

6.2.1.3.2 Differences

As discussed above the compensation must be done one times to define the CR value which should be kept constant, except mode B0. This can be done by activating a special flag, called '**CC init.**' because it initializes CR. You find it in the 'Other params' input window, see chapter 3.2.1.1.2. You can call it by the 'Params' button of the bias/pulse input group of the transient, isothermal and tempscan measurement.
At CC-DLTS the input window is expanded by the inputs shown on the right. The button 'Open CC' is only visible at mode B3 and opens the dialog for the table file name. The 'CC-Init' flag will be set automatically at defining a new sample, switching to CC-DLTS mode or opening a table file. After doing the compensation it will be deactivated. A slow regulation (mode B2) will also be done after a compensation.

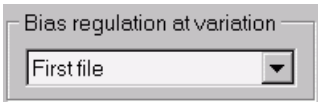


At the tempscan measurement you get the flag by the tab sheet 'Transi'. Additionally the tempscan start window (chapter 3.4.1.4) is expanded by the following flags of the input group **CC-initialization**, shown on the right:

Now: It is the CC-init flag discussed above. After the compensation is done the flag will be deactivated.
Temp cycle: Makes a compensation at each temperature cycle. This flag will not be automatically switched off but saved into your configuration.
Batch cycle: Makes a compensation at each batch cycle, only enabled at batch measurements.

If the CC-init flag is not activated (means compensation was already done) then the input of **reverse bias** is not available in the standard measurement input windows of the transient, isothermal and tempscan program. Activating this flag enables the UR input. The UR input is not enabled at the bias regulation mode B3 because UR will be read from a file.

For a comparison of files (for example different Tw or tP) and for the construction of the quasi-logarithmic transient it is important that all tempscan files are measured at the same UR. In the tab sheet 'Transi' you can define whether the **Bias regulation** will be done separately for each file in a temperature cycle:



First file: The bias regulation will be done only before the measurement of the first file at a temperature.
First Tw: It will be done only at the first Tw block, see chapter 3.4.1.1.3.
Each file: It will be done separately for each file.

A separate bias regulation yields to problems especially at long emission processes (surface or oxide states). Here the emission of 1. file is not finished while the regulation would be done for the 2. one. At worst case regulation mode B3 (UR table) can be necessary. But take into account UMax (chapter 6.2.1.1.4) when regulating only before the 1. file.

If selecting the pulse regulation mode P2 then the **pulse height** UP-UR instead of the pulse voltage must be input in the standard measurement input windows. No input of pulse voltage or pulse height is enabled at the mode P3.

CC-DLTS forbids the UR variation of the **tempscan** base measurement, chapter 3.4.1.1.1. A variation of UR is here only allowed at the batch tempscans (chapter 3.4.1.3) except the regulation mode B3. Additionally to UR you have here to define the CC-amplification separately for each batch cycle because this amplification can depend on UR.

CC-DLTS tempscans can be done in one temperature cycle with different pulse voltage or height. At variation of UP and mode P2 the pulse height, abbreviated by UH, must be input in the variation grid. At mode P3 the UP variation is not enabled.

Specials notes are necessary for CC-DLTS measurements in the **isothermal program** module. For the period scan or the variation of pulse width is the same valid as for a CC-DLTS measurement in the transient program module.

For the variation of UP and UR are specials valid. Some regulation modes would here be absurd, so that the software changes the mode:

- **Variation of UP, fix UR:** Regulation mode B3 is not allowed and will be switched to B2, mode P2 and P3 will be set to P1. All that means you can always select UR (remember to set the CC-init flag at new UR except at mode B0) and you have to input UP for the variation. The slow regulation (mode B2) and an eventual compensation will only done by the first transient except you have deactivated the flag 'Range compensation only at first time', see chapter 3.3.1.2.
- **Variation of UR, fix UP:** All regulation modes will be set to B0. That mean you can select UP and have to input UR for the variation. The compensation will be done before each transient, no slow regulation will be done.
- **Variation of UR, fix UH:** As before but you have to select UH instead of UP.

In summary, the inputs for these 3 isothermal variation modes are the same as at the capacitance DLTS mode. After the measurement the old regulation mode will be restored.

The used regulation modes will be listed at the file header (chapter 3.4.3.1).
A fix UR and UP value will be listed also on the tempscan header of CC-DLTS measurements. Depending on the regulation mode it is possible that it is only the start value for UR and UP and gives you only a hint.

6.2.1.3.3 Special notes

a) Recovery time: The recovery time will be increased for CC-DLTS measurements, the software adds by default 200 us to the normal recovery time (bridge + filter), see chapter 3.2.1.1.1. You can change this value in the menu 'Measure → Measure params → Range', there is for U-DLTS the additional input 'Additional CC-recovery time'. You can also define an additional delay time at the transient input as described in chapter 3.2.1.1.1.
The use of a delay time can assist with the removal of oscillations that may be seen at the start of the transient.

b) Voltage limits: The reverse bias capacitance regulation can be limited to ensure that the device is not damaged during regulation by selecting high and low limits to the voltage, these voltages may be assessed from the I/V curve and the limiting values input in the CC-parameters menu. If the reverse bias goes to the limit then is no further slow regulation possible. It is also possible that then UR=UP.

c) Caution: A too high CC-amplification yields to oscillations. In this case a forward voltage can be applied at the sample and so damage the sample.

d) CC-amplification: Amplification for hardware regulation is achieved through the use of the C/V curve, although it should be noted that the values obtained by this method are usually not the maximal values. High amplification could give problems at other temperatures. Correct amplification can be checked by taking the sample temperature to the region of emission of a deep level and making a test transient measurement. Incorrect amplification is obvious from oscillations and noisy data. It is also possible that an ADC overflow error may be obtained, this is indicative of too high amplification. Begin by reducing the amplification by 50%. The CC-amplification depends also on the maximum regul. voltage.

e) Range: The capacitance range has also an influence on the CC-amplification, a smaller range gives a bigger total CC-amplification. So range 2 has a 10-times bigger amplification than range 3. Select range 2 or 3. Range 1 is only in some cases at small capacitance values possible, for more details see also chapter 2.1.2.3. The automatic range is disabled at CC-DLTS. The compensation range is the transient range.

f) Reverse bias: If the reverse bias is changed then the reverse bias capacitance must be re-compensated manually, for example 'Check measurements → Measure → Utils → Compensation' or in 'Slow regulation'. This is not necessary for regulation mode B0.

g) Doping type: Ensure that the doping type is correctly input in the sample parameters menu. The technique will not work if the doping type is incorrect.

h) Regulation (simplification): The fast regulation refers to the regulation of the emission transient and the slow regulation refers to the regulation of the reverse bias in order to maintain the reverse bias capacitance at a constant value (see C/V curve).

i) U-DLTS? It can be helpful to make first a conventional C-DLTS measurement and then to asses whether a constant capacitance measurement is needed, i.e., does NT exceed 0.1*NS at a Schottky diode? Normally CC-DLTS will be used only at big transient signals. For depth profiles it is in most cases helpful. If NT is closed to NS then CR can change very much by the temperature without CC-DLTS. A fix CR over all temperatures is then with CC-DLTS not possible because a change of UR on the C/V curve can not compensate the big change of CR.

6.2.2 CS-DLTS

CC-DLTS (U-DLTS) measures the voltage transients while the capacitance of the transient will be kept constant. Usually also CR and CP and so the space charge region (SCR) with WR and WP will be kept constant as discussed in the previous chapter.
It is also possible to keep CR and CP constant at C-DLTS. In this case the space charge region will be kept constant in the equilibrium, therefore we call it **C**onstant **S**pace Charge region DLTS. Here are only the equilibrium (static) values CR and CP constant but not the capacitance during the transient! We use CS-DLTS usually at C-DLTS but it is also possible to combine it with I-DLTS.
You can select the CS-DLTS mode in 'Measure → Measure params → ' at the Base tab sheet, see chapter 2.1.2.1. The software option 'Enhanced' is necessary.

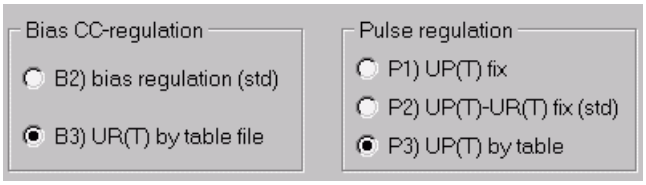
6.2.2.1 Basics

U-DLTS has as discussed advantages at big trap concentrations but the disadvantage is that it is more complex and not so sensitive as C-DLTS because the smallest range is 2. The smaller sensitivity is at Schottky diodes usually not a problem because it will here be used at big signals. But sometimes it would be helpful to have a constant space charge region also at small signals. U-DLTS is here often not necessary because the transient follows a pure exponential time law also at C-DLTS (NT<<NS, Schottky diode).
For this case we have introduced our **CS-DLTS**. It is more sensitive and not so complex as U-DLTS because it is C-DLTS but nevertheless it keeps the space charge region constant in the equilibrium. It can also be interesting for MIS samples, especially if the V/V curve shifts on the bias axis during the tempscan. CS-DLTS can be kept CR and CP and therefore the emission region constant. If applying CR and CP form a table then no regulation problems exist.

Something what was described in the CC-DLTS chapter is here also or similar valid. But the measurement is easier because the CC-amplification is here not necessary. A fast regulation don't exist (because it is C-DLTS!) but a bias regulation exist also.
CC-DLTS sets the bias in a loop and regulates the offset of the U-input to zero. CS-DLTS measures CR in a loop (usually with the compensation) and sets the bias so that CR will be that value which was defined at one temperature. This fix CR value will be defined at a capacitance compensation, in the same way as at CC-DLTS. At CS-DLTS are also bias regulation problems possible, especially at a flat C/V curve.
It is also possible to work without this regulation loop and to set the bias and also the pulse voltage by a table file. This has the advantage to avoid regulation problems.

As at CC-DLTS we separated the input for the regulation modes in **2 types**:
Bias CC-regulation: Defines how the bias will be regulated.
Pulse regulation: Defines how the pulse voltage will be regulated.

The right window shows the input for these 2 types. It will be used in the 'Parameters menu', see next chapter. Not all combinations are possible. The bias regulation modes will be abbreviated by 'B2' and 'B3', the pulse modes by 'P1' to 'P3'.



Following **Bias regulation modes** exist:

B2) **CR(T): bias regulation (std):** The reverse bias capacitance will be kept constant by changing UR in a loop, This is the standard bias regulation mode. The advantage is that CR(T) is constant, the disadvantage the possible problems at the regulation.

B3) **UR(T) by table file:** The reverse bias capacitance will be kept constant by changing UR by a table. The table can come from temperature depending C/V curves. One advantage is that no regulation problems can occur, it can also be used if the C/V curve has a flat range (inversion). An important feature is that also CP(T) can be kept constant by a table during the tempscan and. The disadvantage is that the table file and so C/V measurements are necessary and the sample must not be changed by the measurements.

Following **Pulse regulation modes** exist:

P1) **UP(T) fix:** The pulse voltage is fix during the tempscan. The disadvantage is that the pulse capacitance changes with the temperature.

P2) **UP(T)-UR(T) fix (std):** UP will be changed in the same way as UR, so that the pulse height UP-UR is fix. This is an approximation for a fix CP and space charge region. It is especially important when the C/V curves shifts on the voltage axis by the temperature. This mode is the standard pulse regulation mode. The advantage is the approximate fix CP, the disadvantage that UP can go to its limits.

P3) **UP(T) by table:** The pulse capacitance will be kept constant by changing UP by a table. The table can come from temperature depending C/V curves. This feature is the only way to keep also CP completely constant during the tempscan. The difference to mode P2 depends on the behavior of the sample.

We prefer for CS-DLTS the modes B3+P3.

How to define the value for **CR** which should be kept **constant**? For this you have to make a compensation. Then the bias regulation keeps the last compensated capacitance constant. You can do this compensation manually in the compensation window (see chapter 6.2.2.2.3) or in the Measure Utils or automatically before the transient measurement. For the last case there is a flag which will be activated by defining a new sample. It will also be activated at opening a table file (mode B3). You can also activate it manually, see chapter 6.2.1.3. After a compensation this flag will be deactivated. The bias regulation (mode B2) will also be done after a new automatic compensation.

It is important that the compensation will be done after switching to CS-DLTS and not before, as explained in chapter 6.2.1.1.3.

6.2.2.2 CS-DLTS menu

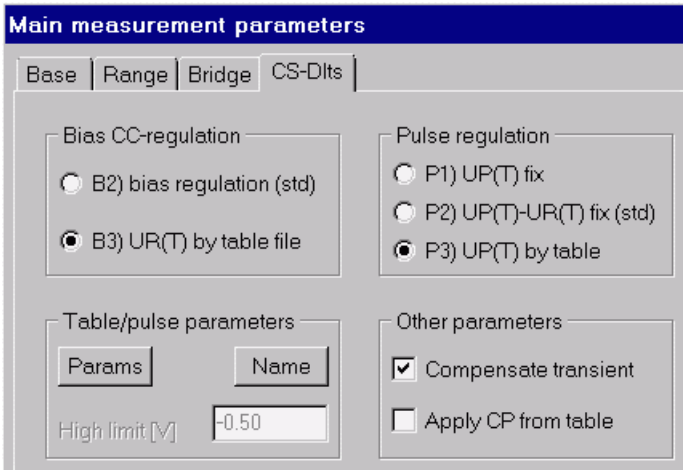
If activating CS-DLTS then the following sub menu will be visible in the 'Check measurements' menu. It contains the parameters and tools for CS-DLTS.

'**Parameters**' contains the inputs for the regulation.
'**Bias regulation**' is a tool for doing the bias Cs-regulation.
The parameters are also in 'Measure params' as a separate input sheet.

The **parameters window** contains the inputs for the CS-regulation, the parameters are very similar to the CC-regulation parameters in chapter 6.2.1.2.1. For all details look in this chapter. These parameters are also available in 'Measure params' as a separate input sheet as the following shows.

The regulation modes were already explained in chapter 6.2.2.1. For a better overview we have separated the regulation mode input in 2 types:

Bias regulation: Modes B2 and B3, defines how the bias will be regulated.
Pulse regulation: Modes P1 to P3, defines how the pulse voltage will be set.



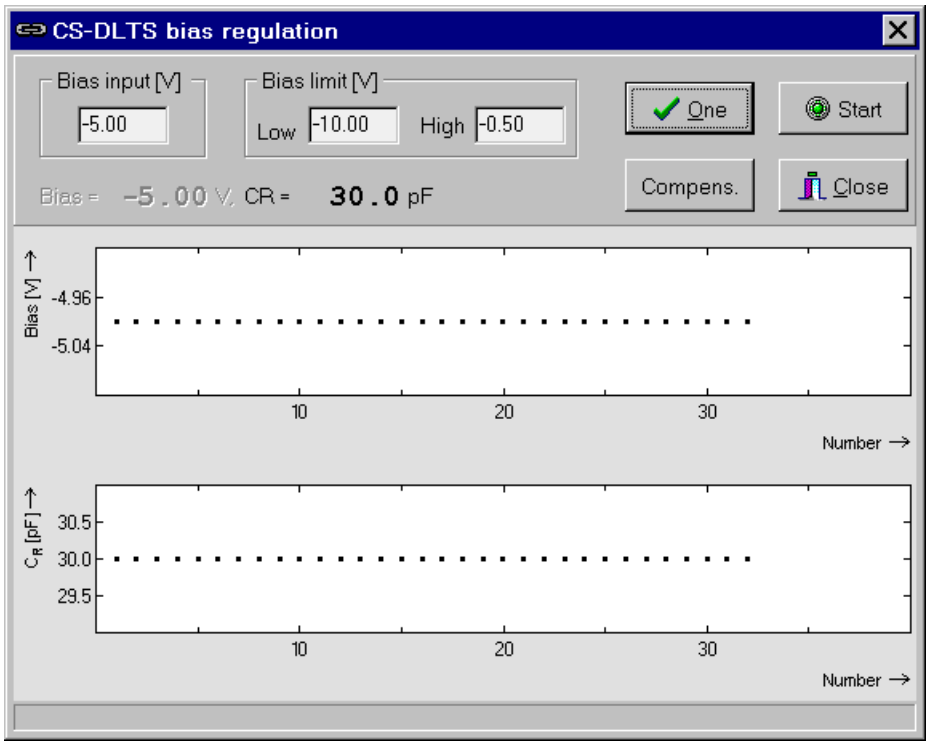
If using the bias regulation B2, then inputs for the bias low and high **limit** are enabled. Mode P2 enables also the pulse limit. At n-type sample this is a high limit, at p-type a low limit. The pulse low resp. high limit is given by UR.

In opposite to CC-DLTS is here always an additional capacitance **compensation** before the transient possible and will be used by default. At a good bias regulation it should not be necessary. The avoiding of compensation can spend measuring time.

If selecting mode B3, that means UR will be read from a **table file**, then mode P3 and special inputs for the table file will be visible resp. enabled.
Activation of '**Apply CP from table**' applies the pulse capacitance from the table file.
The button '**Name**' opens the Windows dialog for the input of the table file name.
The button '**Params**' opens an additional input window for the regulation by a table file, see chapter 6.2.1.2.1.

Bias regulation mode B2 makes automatically the regulation before every transient measurement. By default here maximal 5 loops will be done until no further changes of UR are necessary for a constant reverse bias capacitance.

This tool here allows to call the bias regulation manually. It is only necessary for mode B2. At user class 6 it can be used for tests also at other modes.
Here are also the inputs for low and high limit. Additionally you can input the global reverse bias, labeled here as 'Bias input'.



Following **buttons** exist:

One: Starts one loop of bias regulation.
Start: Starts a permanent regulation.
Compens.: Makes a capacitance compensation and defines ('fixes') CR. You can make the compensation automatically or by a given CR.
Close: Breaks the regulation if running and exit this tool.
Break: Breaks a permanent regulation, only visible if permanent regulation runs.

During the regulation the bias and CR will be listed and plotted versus the regulation number. The top plot shows the bias, the bottom plots shows CR. **CR** denotes at the regulation the actual measured capacitance and should be constant. If entering this tool or after the compensation CR denotes the capacitance at the last compensation, means that value which should be kept constant. It will be called 'CR-comp.' in the list which will be shown after calling the compensation.

The **compensation** should be done one times if not already done. It is used to identify the reverse bias capacitance which is to be kept constant. This means the regulation tries to keep this capacitance constant at which the compensation was done. If the reverse bias is changed by the input then the reverse bias capacitance must be re-compensated. The compensation must be done after activating the CS-DLTS mode.

Tip: The last compensation capacitance will be listed if you entering this tool. You see this value also in 'Check measure' → 'Measure' → 'Utils' → 'List ranges'.

6.2.2.3 Measurements

The measurements are much easier than CC-DLTS because there is no special parameter as the CC-amplification. The only thing is to check the bias regulation if using regulation mode B2. So only these **preparations** are necessary:

1. Set the regulation **parameters** in 'Measure params' or in 'Parameters' of the CS-menu. Decide which mode of regulation is necessary and possible. Type in the voltage limits for mode B2, define the table file name for mode B3. The call is only necessary after new activation of to CS-DLTS.
2. '**Bias regulation**' is a tool for doing the bias CS-regulation. It is not necessary and available at regulation mode B3. If you have not input the reverse bias, here you can do it. *Compensate* the capacitance at the selected reverse bias. If you use the bias regulation, adjust the regulation until the value displayed during permanent regulation remains constant.

If you know the sample and you have already set the regulation parameters (preparation point 1) then you can also directly start a transient or tempscan measurement. The compensation can be done one times automatically before the transient measurement by activation of a special flag, see chapter 6.2.1.3.1.

The measurements can be done as usual C-DLTS measurements. There is no special evaluation.
All what was already explained in the CC-DLTS chapter 6.2.1.3.1 and 6.2.1.3.2 is also here in principle valid. That means especially the compensation, the restrictions and differences to standard DLTS. 'CC init' will now be called 'CS init'.

6.2.2.4 CS-Regulation with I- and Q-DLTS

CS-DLTS will in most cases be used at C-DLTS but it is also possible to combine it with current and charge DLTS. These DLTS modes work normally without the capacitance bridge. So it is not possible to measure the capacitance and regulate it to a constant value. Therefore the bias regulation B2 is here not allowed. Only the bias regulation mode B3 which reads UR from a table file is possible. All pulse regulation modes P1 to P3 are available.

If using I- or Q-DLTS with the CS option then you should also read CR and, if possible, CP from the table file. This has the advantage that then CR is a measured value. In the other case CR will be calculated if not using the capacitance bridge. For this calculation NS and the diffusion resp. flatband voltage will be used. This calculation is less precise as the calculation of CP from CR which uses only NS. On the other hand CR is necessary for the calculation of the trap concentration NT.

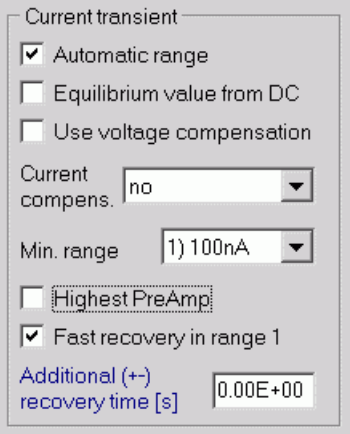
6.2.3 Current and charge DLTS

Current transients will be measured at I- and Q-DLTS. The connections at the CGI-Meter are the same as for C-DLTS. The Bias will be internally directly switched to Sample High, the current will not be measured through the bridge as at older DLTS systems. So it is not necessary to disconnect manually the bridge.

If activating 'Disconnect bridge', see chapter 2.1.2.1, then no capacitance measurements will be done. The reverse bias capacitance CR, for example used for the evaluation, then will be calculated by equ. 1.3 with Ns and UD of the sample parameters. You can also read CR for a tempscan from a Q-file (chapter 6.4).

The I/V converter of the FT-1235 has 6 **ranges** with maximum currents of 100nA, 1 uA, 10 uA, 100 uA, 1 mA and 10 mA. The recovery time and phase delay time of the I/V-converter will be described in chapter H1.3 of the Hardware Manual. Read also at the next page the meaning of 'Additional recovery time'.

Most of the inputs of the **range input sheet** in 'Measure params' are similar to these at C-DLTS and were already explained in chapter 2.1.2.2.



Equlibrium value from DC means that there is no separate measurement of the reverse bias current. This value will here be calculated from the DC underground values of the transient measurement.

Use voltage compensation increases the voltage resolution of the ADC because higher amplifications are possible. Don't mismatch this option with a current compensation.

The FT1235 allows a **Current compensation**. If there are big leakage currents, then a higher current range with smaller sensitivity is necessary. A current compensation applies an additional current with opposite sign to the reverse bias current. Sou you can measure in the most sensitive range. This increases your density of current transients. Various possibilities for the density mode exist. At a low density the compensation is not so exact. The resulting current is then not zero. Because this rest current the smallest range may be not possible. Furthermore the difference of range number of the not-compensated and of the compensated current is limited. The resulting current goes more to zero by a higher density mode. It may be that you switch from range 5 (1mA, not-compensated) to range 1 (100nA, compensated). The advantage of a higher density mode is a higher sensitivity of the measurement, the disadvantage is a longer measurement time and perhaps effects by instabilities.

Highest PreAmp uses additional amplifiers for the measurement. This may increase the sensitivity and the current resolution but increases the measurement time. Use this option only if necessary.

Fast recovery in range 1 time reduces the recovery time in range 1 from 12ms to 4ms. On the other hand the noise suppression may decrease a little bit by this option.

Additional (+-) recovery time: The meaning is similar as described in chapter 2.1.2.2 for C-DLTS. But at I-DLTS the recovery times depend directly on the current range. It is not so clearly to define a recovery time of a special range, because it depends on the sample and the pulse. And it depends on the definition at which current the recovery stops, means what is the maximum current between the end of recovery and the base line. A small recovery at starting the transient measurement **(t0**) is not a problem at big current signals, but at small amplitudes you may see the influence of a too short t0. On the other hand, if t0 is bigger than necessary, you 'loose' the first time of the transient.

The pre-defined recovery times are specific for each range. At each range these are the same or smaller than in a lower range. The recovery times decreases with a rising range, at I-DLTS it may be a factor up to ten for one range higher. Therefor the recovery time will at 'automatic range' not be selected by the actual range but by the **minimum** range, selected by the user. So the used recovery time is during all measurements the same independently of the range. That is especially important for tempscan measurements with fix period widths because t0 must not be fix here. On the other hand, if a low range is not necessary or possible, a higher minimum range yields to a smaller recovery time and therefor to a smaller t0. Use this behaviour.

The **pre-defined** recovery times, see chapter H1.3, are for standard applications. So it is reasonable to set the additional recovery time. Remember that negative values decrease the total recovery time and t0. For example, the pre-defined value of range 2 of the FT-1235 is 2ms. But if a recovery time of 1.5ms would be enough for your measurement, select -500us for the additional recovery time.

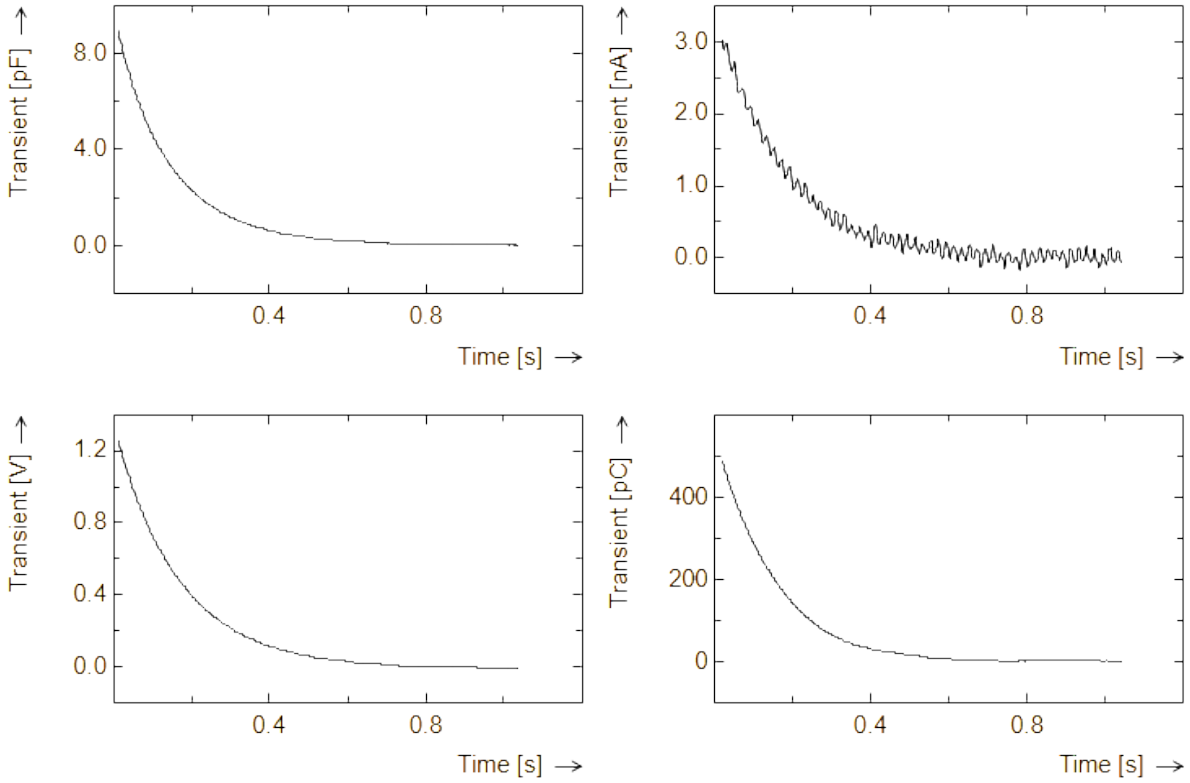
The **transient** measurement is similar as at C-DLTS. But the evaluation is a little bit more complicate. The emission time constant is also a reciprocal factor in the amplitude of the exponential law of time, see equation 3.33 of Theory Manual. So the current amplitude is temperature depending. This yields to an error in the conventional DLTS maximum analysis but not in our maximum analysis because we calculate the maximum position numerically. It is also no problem for the DLTFS and HERA evaluation, see Theory Manual. The DLTFS evaluation shows in the result list, chapter 3.2.1.1.4 and 3.2.3.1, 2 values for the amplitude. The 1. is the total amplitude in [A], the 2. is the amplitude multiplied with the time constant in [As]. This kind of 'amplitude' should be not temperature depending.
The dimension of the Fourier coefficients and correlation functions is Ampere.

The sensitivity of current DLTS is also temperature depending because the amplitude depends on the temperature. An additional disadvantage is the approximation for NT. An advantage of current DLTS may be the smaller recovery time.

At **charge DLTS** also current transients will be measured and from these the charge transients calculated by numerical integration. The advantage is that the amplitude is not temperature depending as at current DLTS. The disadvantage is that the integration needs the correct current offset. If the offset is not correct then an additional linear 'signal' overlaps. At the selection of the DLTS mode there is the flag 'Check DC by yLast at I → Q'. This means that the software checks the offset, used for the integration, by the first and last transient value. This check gives good results if the measured offset is correct or the transient has decreased to the ADC resolution within the used period width.

6.2.4 Comparison of DLTS modes

The picture show following transients: C-DLTS on the left top, U-DLTS on the left bottom, I-DLTS on the right top, Q-DLTS on the right bottom.



DLTS mode	***C***	***U***	***I***	***Q***
tau [s]	0.144	0.167	0.170	0.183
NT [cm^-3]	1.54E15	1.18E15	3.63E15	3.64E15
NTs [cm^-3]	3.80E15	2.93E15	–	–

The table on the left shows the DLTFS evaluation of the transients, NS was 6.25E15 cm^-3. The measurements were done on a Gas sample.

Summary: The advantage of C-DLTS is the sensitivity and capacitance compensation, U-DLTS yields even if not NT<<NS to an exponential signal and keeps the SCR fix, I- and Q-DLTS have a smaller recovery time. Analytical solutions of kinetic equations exist for U-DLTS, only approximations are possible for C-DLTS. The disadvantage of U-DLTS is the complicate measurement, I-DLTS have a bad sensitivity. I- and Q-DLTS must be measured without bridge, so that no simultaneous capacitance measurement is possible.

DLTS mode	***C***	***U***	***I***	***Q***
Sensitivity	+	o	-	o
Recovery time	-	-	o	o
Offset compensation	+	+	-	-
Measurement	+	o	+	o
Exponential	o	+	+	o
NT calculation	+	+	o	o
NTs, depth profiles	o	+	-	-

The table on the left makes a **simplified comparison** with '+' as good, 'o' as medium and '-' as bad.

6.2.5 FET

The **F**ield **E**ffect **T**ransistor has 3 contacts: **G**ate, **D**rain and **S**ource. You can make standard measurements, static and transients, between gate and source with the drain-source voltage as a parameter. The FET measurement mode will also be called 3-Terminal DLTS.

6.2.5.1 Connection and transient measurement

The FET measurements need a second voltage, also called auxiliary voltage, for the drain source voltage. You have to connect the Bias with Gate-Source and the Aux with Drain-Source. So the bias UR is now UGS and the auxiliary voltage is UDS.

The cables coming from the CGI-Meter and DLTS electronic must be connected as following:

Sample Low → **S**ource
Sample High → **G**ate
Aux-B (A) → **D**rain

The FT-1230 with the FT-1235 have 2 different **Aux-BNC connectors**, labeled by Aux-A und Aux-B. At default Aux-B will be used as UDS for SD-FET measurements. The BNC connector labeled by 'Aux-A' will be used as a second voltage source for general purpose, called as '2. Aux' in the software. Look in chapter H1.4 of the Hardware Manual for the selection of the Aux connectors.

Normally the current of the FET will be measured. For using this mode, called **FET mode**, you have first to switch to the **Current DLTS** mode. You can change the DLTS mode in the menu 'Measure → Measure params' at the Base tab sheet, see chapter 2.1.2.1. Select then there '**FET DS (standard)**' as **Aux mode**.

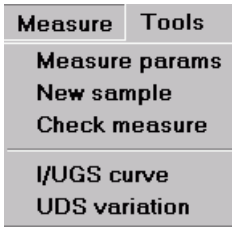
When measuring without bridge (normally not necessary) activate the flag '**Disconnect bridge**'. Then no capacitance measurements will be done.

In the software then the bias is the gate-source voltage (**UR=UGS**) and will in most cases be called UGS. The auxiliary voltage is the drain-source voltage (**UAux=UDS**) and will be called UDS.

The mode above is the standard one for FET's. But you may also select **FET-GS voltage** as Aux mode. This mode uses the aux voltage as a **G**ate-**S**ource voltage, the aux inputs will be renamed to GS voltage. The standard bias is then the **D**rain-**S**ource voltage. Compared to the standard FET mode UDS and UGS are swapped. So you have also to swap the bias and aux cable at your sample.

Make DLTS measurements with UGS in the same way as with Bias at Schottky diodes. The UDS voltage is then an additional parameter. Setting this value depends on the FET type. At wrong UDS values you don't see a transient.
You can set this parameter in all measurement modules, for example at the transient measurement in the Bias/pulse input group, see chapter 3.2.1.1. At the isothermal program module you can vary UGS or UDS. In the tempscan module you can set both values independently for different measurement files. UDS is permanently on the sample.

6.2.5.2 Static measurement

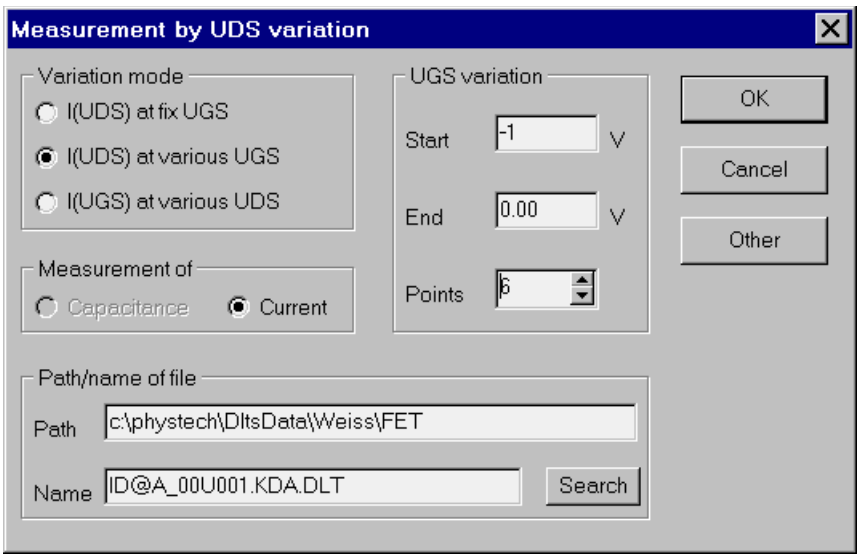


If selecting the FET mode as described above, you see at the static program module the measure menu as shown on the left.
The I/UGS curve is the same as the standard I/V curve with the reverse bias as x-axis, see chapter 3.1.1.2.
The UDS variation is an additional possibility. You can there measure I/UDS or parameterized I/V curves.

The **UDS variation** has 3 variation modes:

I(UDS) at fix UGS: The curve I versus UDS will be measured with a fix UGS.
I(UDS) at various UGS: Some curves I versus UDS will be measured at various UGS. This is the standard mode for UDS variation.
I(UGS) at various UDS: Some curves I versus UGS will be measured at various UDS.

The 2. mode was selected at the input window on the right. Here you have to input the values for the UDS parameter variation. Additionally there is the input for the **file name** of the first I/V curve, separated in path and base file name. At a parameter variation (mode 2 and 3) every I/V curve will be saved into a separate file.



The 2. character of the data extension, chapter 1.3.3, is 'D' for I(UDS) and 'I' for I(UGS).

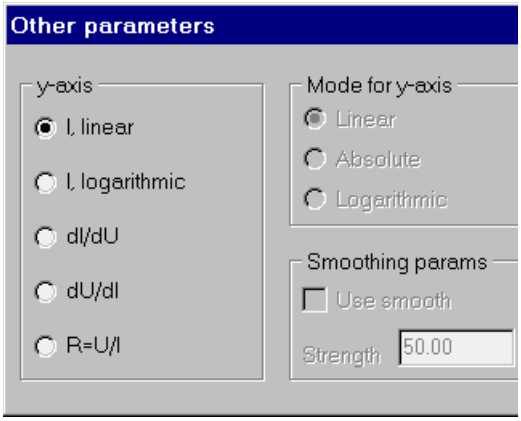
In the following example with 6 values for the UGS variations is the base file name input ID@A_00U001.KDA.DLT; the files will be saved into the defined subgroup. The sub string 'U001' is a must for the 2. variation mode.

Created files: ID@A_00U001.KDA.DLT → I(UDS) at 1. UGS (-1V)
ID@A_00U002.KDA.DLT → I(UDS) at 2. UGS (-0.8V)
.....
ID@A_00U006.KDA.DLT → I(UDS) at 6. UGS (0V)

For the 3. variation mode is the sub string 'D001'.
The 1. variation mode is only a single I/V curve, so here is not an input of file name necessary. You can save it after the measurement.

The '**Other**' button is enabled at variation mode 2 and 3 and opens following input window:

The **y-axis** can be the current with a linear or logarithmic axis, the deviation dI/dU or dU/dI, or the resistance without deviation R=U/I. For the last 3 possibilities you can select as **mode for y-axis** linear, absolute or logarithmic. 'Linear' means data with sign, 'absolute' means a linear axis with absolute y-values. Absolute y-values will be formed for the logarithmic axis.
The data can be smoothed before deviation. For the definition of the smoothing strength have a look in chapter 2.7.1.



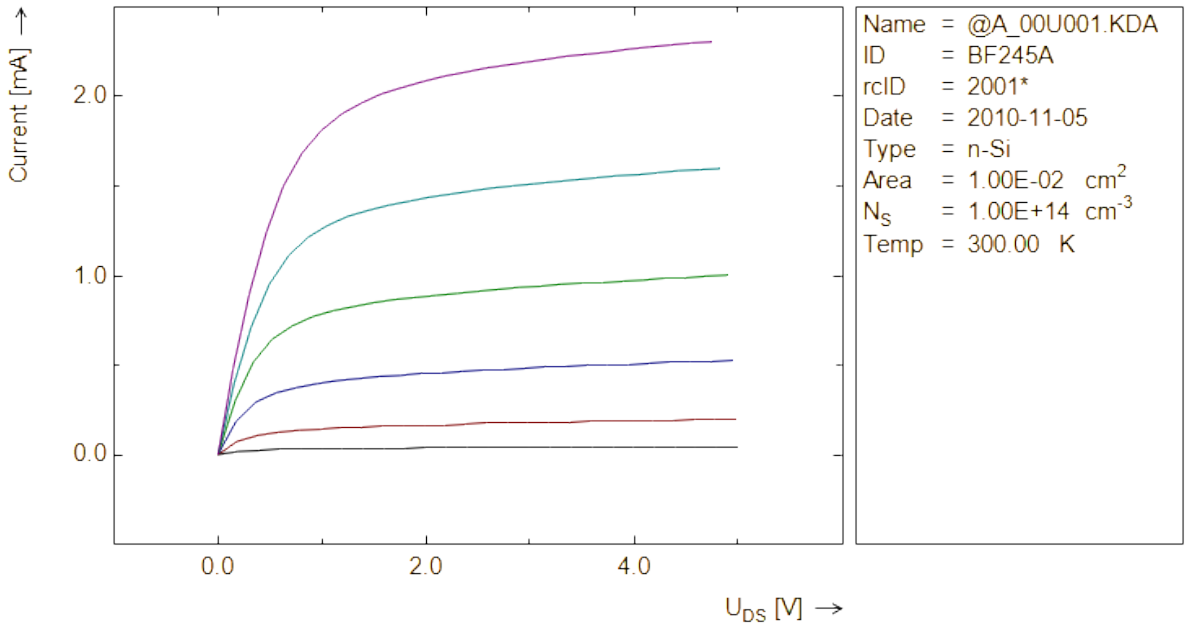
After clicking '**OK**' the standard input window for I/V curves opens as shown in chapter 3.1.1.2. For the 1. and 2. variation mode you have here to input the UDS start and end values, for the 3. variation mode the UGS values. These inputs will be denoted as UDS resp. UGS.
The input of the reverse bias value, Params input group in chapter 3.1.1.2, will be called further on '**Revere bias**' but it is UGS. This UGS voltage is set to the sample before the I/V curve measurement starts and after the I/V curve measurement has been finished. The UDS value of this input group will be applied to the sample before and after the I/V curve. That means, this **global UDS** voltage will also be set after a UDS variation.

During the measurement of UGS variation (mode 2) you see at the top the curves current versus UDS at various UGS. At the bottom you see the extremal current of every curve versus UDS. Extremal means the lowest or highest current, calculated by the highest absolute value. Similar is valid for variation mode 3.
UGS* resp. UDS* shown during the measurement is not corrected by the internal resistance. After the full measurement the voltage will be corrected by the **internal resistance:**

UGS = UGS* - Current * RB resp. UDS = UDS*-Current*RB.

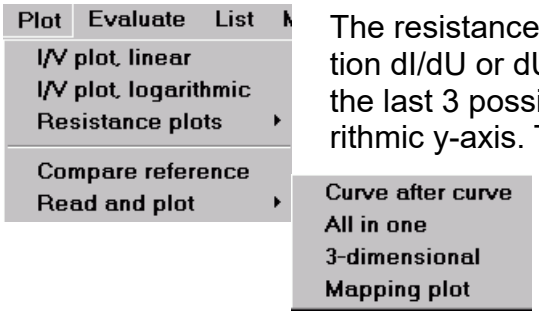
RB is the internal resistance of the bias resp. auxiliary source, normally 110 Ohm.

The following picture shows a measurement of a Junction-FET at UGS variation (mode 2) from -1 V to 0 V.



The UDS end voltages of the different curves are not the same because the voltage was corrected by the internal resistance.

The plot menu is similar as for standard I/V curves. The standard I/V curve can be shown with a linear or logarithmic current axis.



The resistance plot shows the I/Bias*, I/V or V/I curve, the deviation dI/dU or dU/dI, or the resistance without deviation R=U/I. For the last 3 possibilities you can select a linear, an absolute or logarithmic y-axis. The data can be smoothed before deviation.

If the I/V curve comes from variation mode 2 or 3 then here is a sub menu to read and plot the different curves as described in chapter 5.1.7. The mapping plot needs user class 5. The y-axis can be selected as in the 'Other params' input window of chapter 6.2.4.2.

Note: The current versus voltage curve will be called I/V curve. The voltage in the equations will be denoted by a 'U', the reverse bias is UR. So V and U means the same. In our manuals no difference will be done between both notifications.

6.2.5.3 Special notes

a) Internal resistance: UGS (UR) and UDS at Aux-B have an internal resistance of 100 Ohm, UDS at Aux-A (standard) 50 Ohm. The I/V-amplifier contains a resistor of 10 Ohm. At the measurement you see as voltage axis the uncorrected UDS or UGS. After the full measurement the voltage will be corrected by the internal resistance and shown. This is done by subtracting the voltage drop across these resistors from the applied voltage after acquisition: U = U* - Current * RB. RB is the full internal resistance of the bias or auxiliary source, normally 110 Ohm resp. 60 Ohm.

b) Maximum current: The current at the auxiliary terminal is specified to be10 mA.

c) Zero voltage: At UDS = 0 V there is no current flowing. With UGS = 0 V the FET acts as a small resistor between the drain and source terminals. The I/V-converter of the DLTS system has a small but nonzero offset voltage U0. This offset is amplified by the ratio of the internal feedback resistor RFB (which is large) and the FET drain source resistance RDS (which is small). In this case (no current) the output voltage of the I/V-converter is given by Uout = U0 * (1 + (RFB / RDS)). If the FET reaches it's cut-off voltage and now RDS is large compared to RFB then Uout = U0.

d) Offset of I/V converter: The offset of the I/V converter is properly adjusted. Due to the temperature dependence the offset voltage will never be perfectly zero. Additionally to the offset of the I/V converter the UDS (Aux) offset has to be considered. UDS has been adjusted to be within +/- 1mV of the specified voltage, e.g. at UDS = 0 the actual voltage at the Aux terminal is between -1mV and +1mV. This offset is temperature dependent with a specification of max. 0.24mV per °C, i.e. a temperature variation of 10°C can lead to an offset drift of 2.4mV.

e) Recovery time: The recovery time of the I/V-converter is 5 ms in range 1 and 50 us in range 2 or higher. The default recovery time values used for the software are these hardware values. You can change the software values and the minimum range in 'Measure -> Measure Params -> Range', see chapter 6.2.2.

f) Capacitance at FET: If the samples leakage current is excessive, the capacitance meter won't give reliable measurements of the samples capacitance.
Don't worry about the output resistance of the bias supply during capacitance measurements (U = R x I).

g) Evaluation: We don't use special evaluations for the FET mode but only the standard equations for current DLTS of Schottky diodes as described in the Theory manual.

e) Global UDS: This value (see above) is permanently on the sample. It will be set also after a variation of UDS.

f) Current: The measured current is always IDS+IGS. Because usually IDS>>IGS, the effective current is IDS.

g) Transient: At the standard connection (bias to gate) UGS will be pulsed. If selecting 'FET DS-voltage' as Aux mode, the current transient will be evaluated by Amp*exp(-t/tau) instead of Amp/tau*exp(-t/tau).

6.3 MIS

MIS (**M**etal **I**nsulator **S**emiconductor) or MOS (**M**etal **O**xide **S**emiconductor) device physics are extensively covered in most widely available semiconductor physics textbooks and papers and will only be covered briefly here. For literature have a look in the Theory Manual.

During **sample set-up** the device type should be specified as MIS; this will automatically make the MIS/MOS options available, according to the user level which is selected as the default level. It is normally expected that users making MIS measurements will already be familiar with the software. At the sample parameters there is also the input for the oxide capacitance, called Cox. This values will also displayed at every plot for a MIS sample.

6.3.1 Theory

Processes which occur to affect MIS device characteristics are:

- Deep levels
- Surface states, sometimes called interface states
- Oxide states, also called isolator states
- Inversion (minorities)

The effect of the presence of any of these defects may be seen in the behavior of the C/V curves and transients.

Inversion occurs when the intrinsic energy level (midgap) crosses the Fermi level and the number of minority carriers at that position and beyond is greater than or equal to the number of majority carriers in the bulk. For the consideration of MOS devices we will consider an n-type semiconductor. Inversion can occur by a number of different processes all of which may overlap in some way. The evaluation of these different processes is achieved by measuring and evaluating transients as a function of different bias and pulse conditions and temperatures. Fourier evaluation has additional benefits over other evaluation and measurement techniques which will be explained in more detail below.

Accumulation occurs when a high forward bias is applied to the metal gate causing a build up of electrons at the oxide interface.

In between inversion and accumulation exists a **depletion** state where the capacitance varies similarly to a Schottky device with applied bias.

Deep levels can be seen in **C/V curves** when their concentration is 10 to 20% of NS by influencing the reverse bias region of the curve. Interface states can affect the C/V curve by effectively adding a fixed value onto the Cox value in addition to increasing the inversion processes.

MIS **transients** are produced from different processes than those observed in Schottky diodes. In Schottky diodes the transients are produced from deep level emission which depends almost solely upon the reverse and pulse bias values, but with MIS devices it is the position of the Fermi level with respect to the intrinsic level which controls emission processes from deep and interface states.

There is also the possibility that if there is a very high number of interface states then the Fermi level will be pinned and therefore its position will not be changed with a change in the applied bias. The energy window described applies equally to the oxide states, but for each energy unit change more than 1 oxide state may be recharged.

HF voltages of 20, 40, 100, 200 and 400mV effective voltage are available for the FT-1235 **capacitance bridge**. The 100mV bridge is the most used HF voltage as it produces greater sensitivity, up to 7 times better than the 20mV one. The noise level of both levels is similar but the 20mV can offer better accuracy when measuring the high frequency C/V curve because its signal is smaller. When in reverse bias in an MIS device where inversion processes can dominate use of the 100mV HF can cause inaccuracies in the calculation of the shallow doping concentration.

Transient and tempscan for MIS **evaluation** is much the same as for Schottky diodes. The transient is digitized and Fourier transformation is applied. The transient is tested for the form of the time law by the evaluation.

6.3.2 C/V curves

The **Low Frequency** curve is formed as the inversion process occurs and requires a 1 kHz test signal. This curve is not available with the FT 1230.

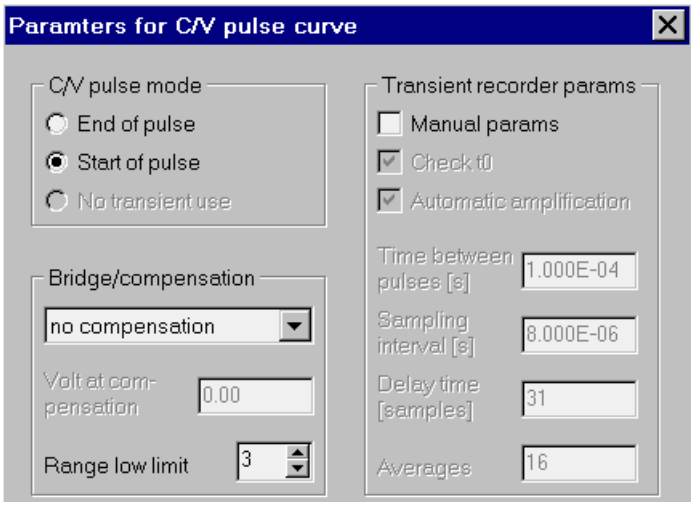
The so-called **High Frequency** curve uses a 1MHz signal. Inversion processes cannot respond to this high frequency signal and so no Inversion occurs. This option is standard C/V measurement. From the software it is possible, the MIS evaluations also from the HF curve but you should use the pulse curve because inversion process.
The HF curve has an own flag for using 'evaluation plot' as standard, see 'Other params' in chapter 3.1.1.1, especially the note there. Cmax will be listed after a measurement.

6.3.2.1 Pulse curve

The **Pulse curve** is measured very fast in order to prevent inversion from occurring and so only the 'semiconductor' C/V curve is seen. It is from this that we can obtain the shallow doping concentration. The device is pulsed from accumulation into progressively more reverse bias. This curve is available in the Static measurement menu.

The main input window is similar as for the HF curve, see chapter 3.1.1.1. Additionally there are the input for the accumulation voltage, called Uac in the next diagrams, and the '**Pulse**' button.

The Pulse button opens a window for the specific parameters of the pulse curve, shown on the right.
In the following the different C/V pulse modes will be discussed, the common 'Transient recorder params' will be explained in chapter 6.3.2.1.4.



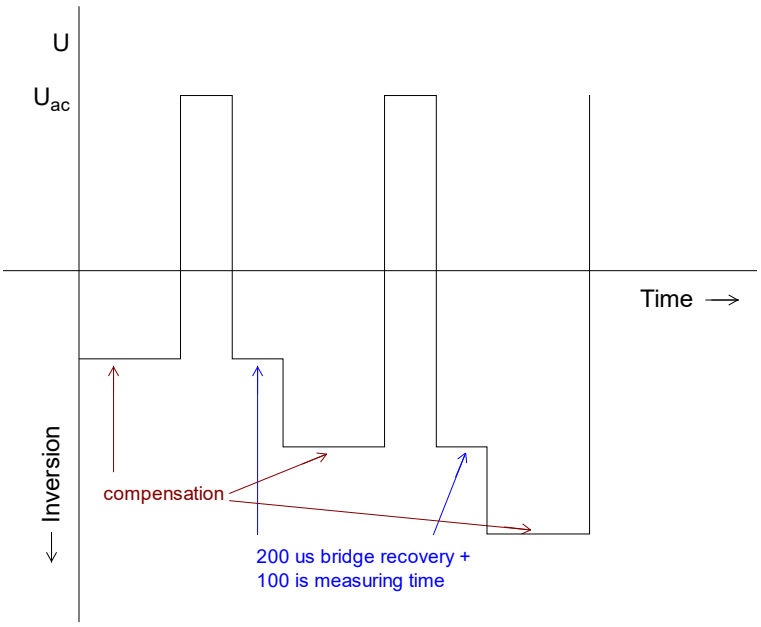
There are, in principle, three different measurement options which are selected through the **C/V pulse mode:**

End of pulse: Measurement at the end of a pulse (after pulse), similar to the transient measurement with normal pulse mode 'end of pulse'.
Start of pulse: Measurement at the start of a pulse, similar to the transient measurement with pulse mode 'at pulse', see chapter 3.2.1.1.2.
No transient use: Capacitance will be measured directly from C-meter without a transient, similar to a standard C/V measurement, needs user class 5.

6.3.2.1.1 End of pulse

This method is unique to the FT 1230. It exploits the compensation procedure, allowing highly sensitive measurement whilst minimizing the chance of inversion beginning. This C/V pulse mode is the best one.

The pulse sequence is illustrated schematically on the right side, showing the compensation and measurement phases. This figure is not to scale.
The device is held at reverse bias (in inversion) at which the measurement is to be made. The device is compensated at this voltage, then pulsed further towards accumulation voltage for 100 us. This is enough to clear the inversion process, after which the voltage is dropped to the required level and the measurement is made.
Measurement of the complete C/V curve takes a few minutes, depending on how many points are to be collected.



However, maximum sensitivity is obtained because of the compensation. There are four **compensation options**, available at user class 5 and above, associated with this C/V pulse mode:

- No compensation.
- One compensation at UR before start of measurement.
- One compensation before start, input of voltage.
- Compensate for every pulse voltage.

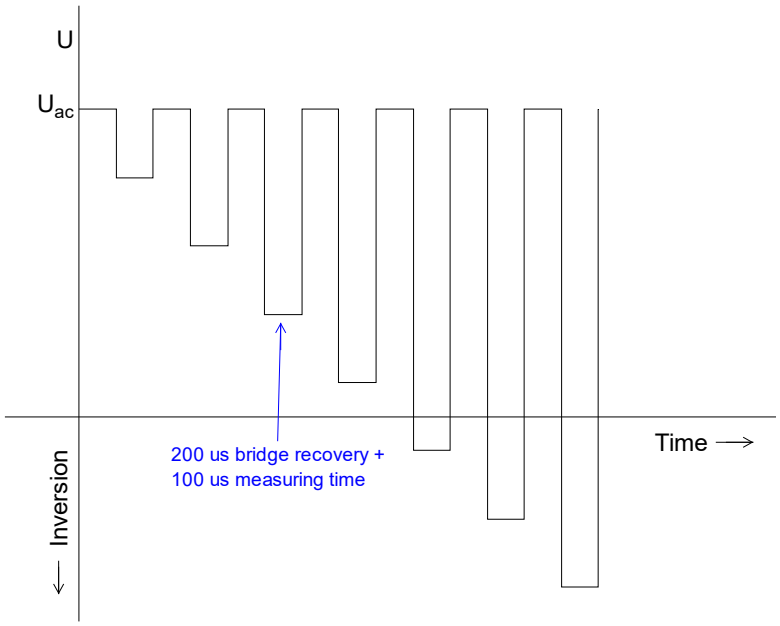
There is normally no benefit to choosing either of the first three options for this mode.

Set the **range low limit** of the bridge so low as possible for a high sensitivity.

6.3.2.1.2 Start of pulse

The static bias is held at a preset level in accumulation, and the sample is pulsed to the different bias values to obtain the curve. The pulse width is approximately 100 us. This C/V pulse mode is the default one.

The pulse sequence is illustrated schematically on the right side. Advantages of this method are that it is possible to average the measurement, and that the measurement time is only 100 us to 200 us compared to 100ms above. Too much averaging will, however, allow inversion to begin.



Theoretically it is possible to compensate these measurements to improve the sensitivity, but in practice this is likely to allow inversion.
If higher sensitivity is required, the range low limit of the bridge should be changed.
To take an extreme case as an example: if the accumulation capacitance is 1000 pF, measurement in range 4 would be necessary; however if the depletion region of the curve has a capacitance of order 10pF this should ideally be measured in range 2. To measure such a sample, no compensation should be specified. This does not, however, provide yield sensitivity.

It is possible to improve sensitivity by compensating before the measurement begins. There are three **compensation options**, associated with this C/V pulse mode:

- No compensation.
- One compensation at Uac before start of measurement.
- One compensation before start, input of voltage.

If using compensation then you should select the last one, but the voltage at which compensation is to made must be specified. This option must be chosen with care, if the compensation does not work, ADC Overflow errors may be reported during the measurement. 'Volt at compensation' should be set to a value that is a good compromise for the different voltages at which the measurements will be done. The average between start and end voltage should be sufficient. New users should not do this, accepting the reduced measurement sensitivity until they have the experience necessary to choose measurement conditions effectively. Generally, use no compensation for measure at start of pulse.

6.3.2.1.3 No use of transient

The first both C/V pulse modes use internal a transient measurement with pulse. The third mode don't use this dynamic transient measurement, but change static the voltage. This method is only valid if the inversion process is very slow as the sample is held at the pulse voltage and the measurement is made over a number of averages. The measurement will take about 60 ms per point and so the correct capacitance is not observed. This method is not strictly a pulse measurement. The voltage diagram is similar as in chapter 6.3.2.1.2, but here are no pulses but direct changes of the reverse bias. So the total measurement time need 50 ms filter recovery time and 10 ms pure measurement time.
You can define the time during accumulation voltage and an additional time before measurement at measurement voltage.

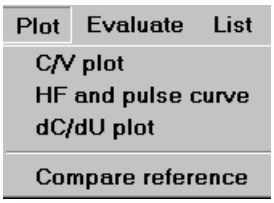
6.3.2.1.4 Transient recorder params

The transient recorder parameters can be specified so that the data will be collected as the user wishes if activating the flag 'Manual params':

- Activating of Check t0 corrects the start point of the measurement, this means the delay time, if it is too small because recovery times.
- Automatic amplification sets the best amplification for the ADC at every measurement. This is the default but increase the measurement time.
- The Time between pulses can be specified at C/V pulse mode 1. This is the time at accumulation voltage.
- Sampling Interval is the time between measured points.
- Delay time is measured an integer number of sampling intervals and gives the value before the first point is measured, called delay numbers.
- Numbers of averages allows the user to balance the trade-off between a greater number of averages and an increased chance that Inversion may begin before the measurement has been made. It is expected that the user has a good feel for the devices being measured and can asses the number of averages that can be safely made. The minimum number of averages is 16.

The effective 'pulse width' is: (Delay numbers + Average numbers) * Sampling interval.
It is **important** to understand the implications of changing any parameter.

6.3.2.2 Static plot menu



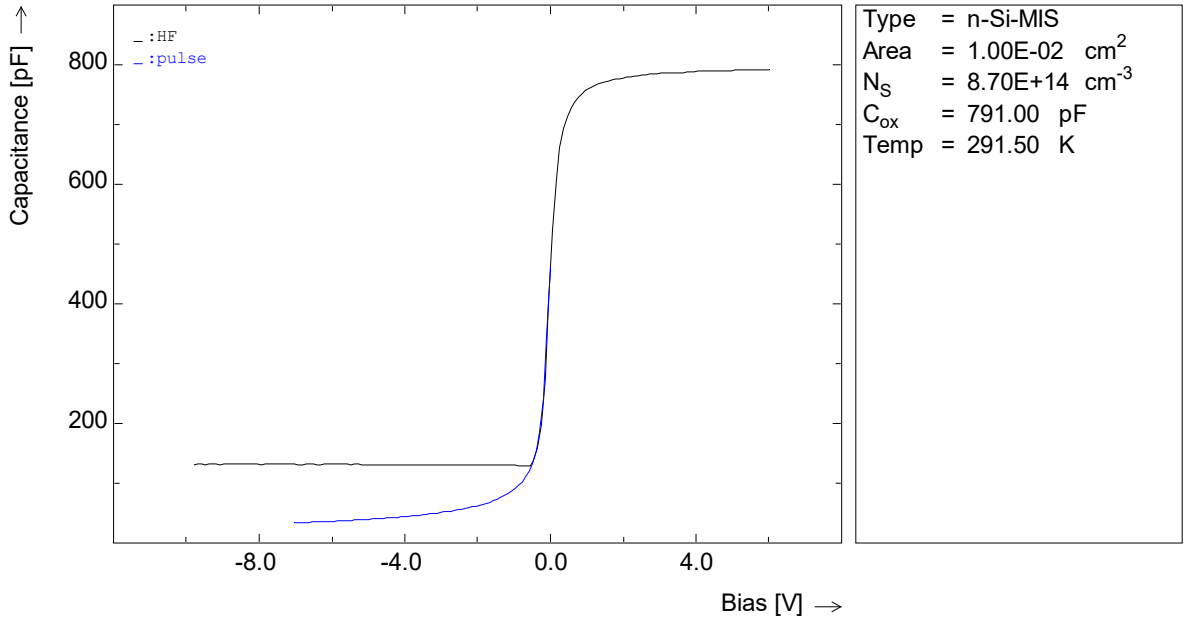
If a HF or pulse C/V curve exist for a MIS sample then the additional entry 'HF and pulse curve' exist is in the plot menu. The second file name will be automatically searched by the current file name and the 2. character of the data extension, see chapter 1.3.3. The data extension for HF curves is 'KC?', for pulse curves 'KP?'. If measuring forward and backward and showing the difference of HF and pulse curve then only the first branch will be shown as difference.

6.3.2.2.1 HF and pulse curve

It is possible to hold both the pulse and high frequency curves in memory so that both curves can be overlaid. The curves should be coincident in accumulation but should differ in the reverse bias region where Inversion is seen.
It is possible to observe hysteresis by measuring the curve in both forward and reverse directions, to illustrate different degrees of inversion.

Before showing both curves you get an input window similar as that one for comparing a reference file, described in chapter 2.6.1, except that here no input of file name exist. The second curve will be read temporary.

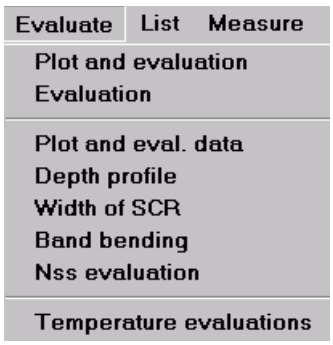
In the following picture shows the black line the high frequency C/V curve, the blue line shows the pulse C/V curve. An evaluation of the shallow concentration is only possible by the pulse curve, the HF capacitance is fix at the inversion voltage.



Note: In many cases U-DLTS can be helpful for the determination of Nss. At the voltage where the C/V curve is flat there is no CC-DLTS possible because one capacitance value belongs to many voltages.

6.3.2.3 Static evaluate menu

This menu has for MIS the 2 additional entries 'Band bending' and 'Nss evaluation'. All evaluations which needs NS or gives NS as result should use the pulse curve. These are 'Plot and evaluation', 'Evaluation', 'Depth profile' and 'Width of SCR'. If you use here the HF curve then you get errors because the inversion. The other menu entries, especially the Nss evaluation, should use the HF curve.

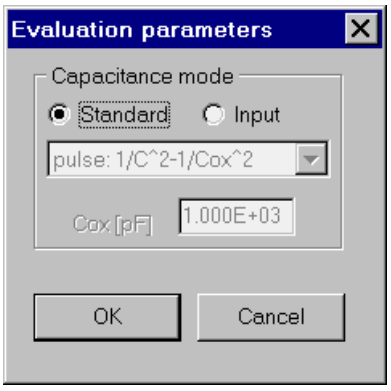


'Plot and evaluation' and 'Evaluation' are for calculating NS. These are similar as for Schottky diodes but uses 1000/C^2-1000/Cox^2 as y-axis, see MIS theory. Cox is the oxide capacitance. The results list now NS, UFB and Wms. UFB is the flat band voltage which is the same as the diffusion voltage at Schottky diodes, Wms is the work function. Use a pulse curve measurement for this evaluation.
'Plot with eval. data' has now additional inputs and shows the C/V curve and list in the text header the significant values of a MIS capacitor.
'Evaluation', 'Depth profile' and 'Width of SCR' allow at user class 5 the input of the capacitance mode.

6.3.2.3.1 Evaluation (pulse curve)

From the pulse curve, a linear regression can be made and the shallow donor concentration, flat band voltage and work function obtained. The equations for calculating NS from the MIS C/V curve vary according to the measurement mode employed. For example using the pulse curve the equation is: 1/C^2 = 1/Cox^2-1/Csc^2, where Csc is the capacitance of the semiconductor and C the measured capacitance of the pulse curve.

With user class 5 it is possible to specify the capacitance terms that will be used in the calculations. This **capacitance mode** defines the y-axis for the evaluation. The standard is for a Schottky diode 1/C^2, for a MIS sample 1/C^2-1/Cox^2 from the pulse curve. As input you can select the mode:



C only:	The standard for a Schottky diode, the y-axis is 1000/C^2.
parallel: C-Cp:	Subtracts a parallel capacitance.
serial: 1/C-1/Cs:	Subtracts a serial capacitance.
pulse: 1/C^2-1/Cox^2:	The standard for a MIS sample, evaluation from a pulse curve.

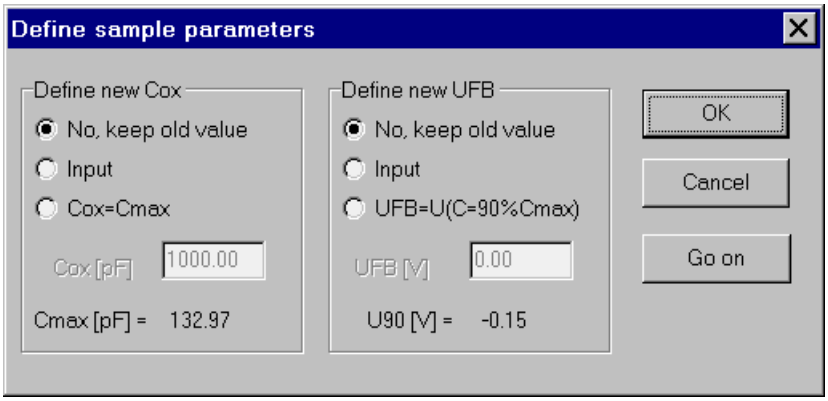
At 'Input' you can also define the parallel, serial or oxide capacitance.
It is possible to use the 'abnormal' C/V evaluation when there is an additional capacitance within the sample. Users at this level are expected to have a good understanding of the device and any 'extra' capacitance values.

Note: For a MIS sample you get only the correct shallow concentration NS when using the pulse curve with the standard capacitance mode. The correct oxide capacitance is necessary for this evaluation.

6.3.2.3.2 Plot with evaluation data (HF curve)

The value for Cox is usually taken from the high frequency C/V curve. If you call 'Plot with eval. data' then you get the following input window.
3 modes exist for defining the oxide capacitance **Cox**:

- No, keep old value
- Input of Cox
- Cox=Cmax with maximum capacitance of C/V curve



There are 3 possibilities for defining the flat band voltage **UFB**:

- No, keep old value
- Input of UFB
- UFB will be taken from this voltage at which the capacitance is 90% of Cmax

If you click onto the '**OK**' button then the selected actions will be done and the C/V curve shown. The '**Go on**' button skips the actions and shows directly the C/V curve.

The text header lists the **significant values** of a MIS capacitor:

NS:	Shallow doping concentration [cm^-3]
Cox:	Oxide capacitance [pF]
Cmin:	Minimum capacitance of the C/V curve [pF]
Cmax:	Maximum capacitance of the C/V curve [pF]
Wmin:	Width of space charge region at Cmin [cm]
Wmax:	Width of space charge region at Cmax [cm]
Qox:	Oxide charge per area [C/cm^2]
dox:	Thickness of oxide [cm]
UFB:	Flat band voltage [V]
Wms:	Work function [eV]
CFB:	Capacitance at UFB [pF]
ni:	Intrinsic concentration [cm^-3]

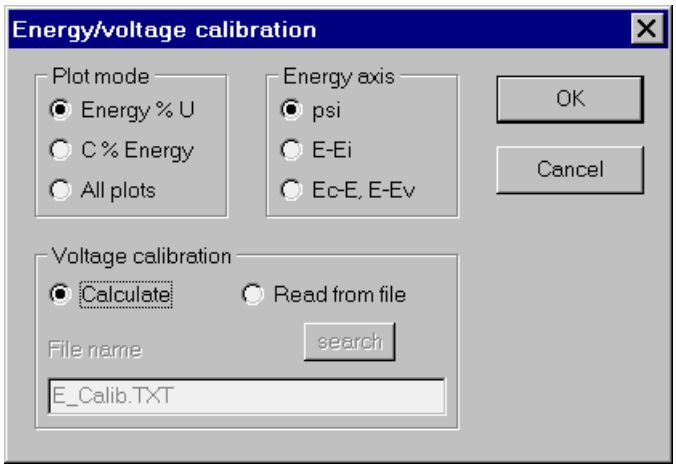
At the 'Evaluate menu' of the standard plot program you can select 'Define sample params'. Then the previous input window opens again for a new definition of Cox and UFB.

6.3.2.3.3 Band bending

The base of this option is the transferring of the voltage axis to an energy axis. The theory for this will be explained in some papers.

Following **plot modes** are possible:

- Energy versus voltage
- Capacitance versus energy
- All plots: C/V, C versus energy, energy versus voltage



You can select as **energy axis**:

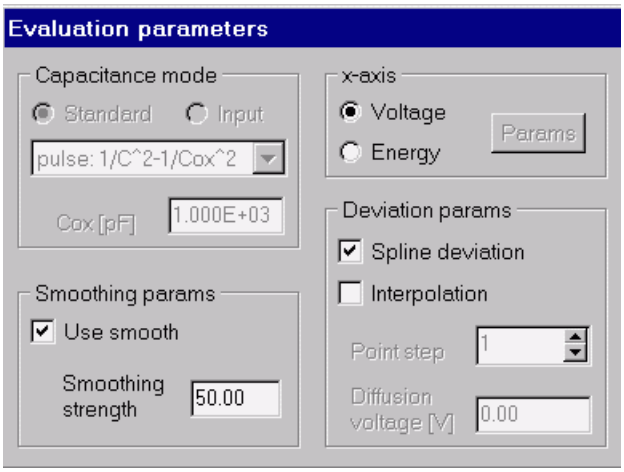
- Potential function psi
- E-Ei, with Ei as intrinsic level
- Ec-E resp. E-Ev

The **voltage calibration** will be explained in chapter 6.3.5.3.

6.3.2.3.4 Nss evaluation

The density of surface states can also be calculated from a C/V curve, but this calculation is not very accurate. For the equations look in MIS papers.

You can select as **x-axis** the voltage or the energy. By clicking onto the 'Params' button opens the input window of the previous chapter.



A C/V **deviation** is necessary for the calculation, therefore you can select between a Spline or a step by step deviation. In the first case you can smooth and interpolate the data, in the second case you can define the point step.

As result you get a plot Nss versus voltage or energy.

6.3.2.4 Notes and tips for static curves

Two values are important at MIS C/V curves:

- The **oxide capacitance** Cox. There are 2 ways:
  - If you know Cox input it in the sample parameter set, chapter 2.4.4.1.
  - Take it from a HF C/V measurement in accumulation and input it then.
- The **shallow concentration** Ns, its calculation needs Cox.

Depending on the **area input** mode different variables have to be input for **Cox**:

Area input: **area:** Contact area and oxide capacitance.
diameter: Contact diameter and oxide capacitance.
area, thick: Contact area and oxide thickness.
diameter, thick: Contact diameter and oxide thickness.
thick, Cox: Oxide thickness and capacitance, contact area will be calculated.

If you input the oxide thickness then the oxide capacitance, or in the last case, the contact area will be calculated. This requires the dielectric constant of the oxide, see chapter 2.4.3.

You see Cox in a **HF** (not pulse) C/V curve. The capacitance should go in forward voltage (accumulation)) to a fix value, this is the oxide capacitance. After a C/V measurement the software lists the maximum capacitance Cmax one times, after a plot refresh it is not visible. Yo can use this value to check your defined Cox. Cmax should be identical to Cox at complete accumulation. Cmax will also be listed in a plot with evaluation data as described in chapter 6.3.2.3.2. In the 'Check measurements' menu you get this plot in the View menu as alternate plot 4. If necessary input Cox here or in the sample parameters inputs. If you don't know Cox you should first call the plot with evaluation data.

The **Ns** calculation should be done by a **pulse** C/V curve as explained in the previous chapters, similar to a Schottky diode. Remember first to input Cox. Look at the last page of chapter 3.1.1.1 how to apply Ns into the sample parameter set.

A pulse C/V curve is sometimes complicate. Try here to get Ns by a **HF curve**, this is possible especially if you don't reach deep depletion. Then you have a small or not so large voltage range for the Ns evaluation. As explained in 3.1.1.1 the standard view depends on the flag 'Evaluation plot'. This is deactivated by default for HF C/V curves at MIS samples because Ns should be calculated by pulse curves. 'Apply automatic Ns' is by default also deactivated. So you don't get by default the question to apply Ns at saving data after a measurement. One possibility is to change one of these flags, the other one to apply Ns manually as described in 3.1.1.1.

Tip: Don't save the C/V curve directly after a HF measurement but call the evaluation. Check here the voltage range used by the linear regression for the Ns calculation. The automatic defined range may not be optimal at a HF curve. Save then the data and apply Ns by the data task item of the plot program.

C/V HF curves at MIS samples will be often measured in **forward** and **backward** direction. For the Ns evaluation you should select only one branch because both 1000/C^2 curves may be shifted, this yields to an error in the linear regression. The 2 directions can be marked in a C/V plot. How to do all these was already explained in chapter 3.1.4.1 and 3.1.5.

Normally don't use the automatic bias search for MIS samples but select the **bias** by the C/V curve and what you want to observe, for example inversion or Nss.

6.3.3 Traps and Arrhenius plot

3 kinds of traps with a discrete energy level are possible in MIS samples:

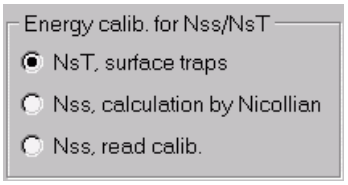
- **Bulk traps** (deep levels) in the space charge region of the semiconductor, the concentration is N_T in cm^-3.
- **Surface traps** (interface traps) at the surface, the concentration is N_{sT} in cm^-2.
- **Oxide traps** (also called isolator traps) in the oxide (isolator), the concentration is N_{IT} in cm^-3. It will be described not here but in chapter 6.3.6.4.

Measurement and evaluation of the first 2 kinds of deep levels are similar to that one for Schottky diodes. First you have to calculate time constant and amplitude of the transient at different temperatures. The final results will be calculated by the Arrhenius plot in the Isothermal or Tempscan program module, either done by the maximum analysis or by the direct DLTFS evaluation.

For **bulk traps** you have to select 'Exponential, discrete levels' as transient evaluation mode, see chapter 2.4.4.2. The evaluations are the same as for Schottky diodes. The software takes into account the oxide capacitance at the calculation of NT.

For **surface traps** you have to select 'Exp., surface states/traps' as transient evaluation mode, see chapter 2.4.4.2.

The type of this evaluation (called Energy calib. for Nss/NsT) must now be set to 'NsT, surface states'. You find this input in Tools → Program params → Eval, see chapter 2.4.2.2. Here you can define whether the defined evaluation is for surface states traps (NsT) or for surface states with a small energy interval (Nss), see also chapter 6.3.5.



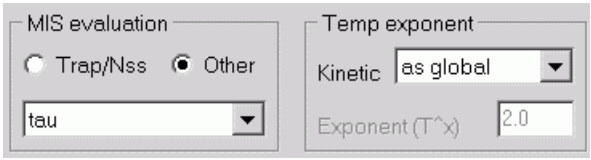
If selecting NsT then the evaluation is similar as for Schottky diodes. The only difference is that the surface concentration N_{sT} instead of N_T will be calculated form the amplitude. This concentration will always be shown instead of N_T, the calculation of N_{TS} makes here no sense. All other evaluations and plots are the same as for Schottky diodes.

You can not **distinguish** between bulk and surface traps by a transient, period scan or tempscan. The only difference is the dependence from reverse bias and pulse voltage. You can observe this in an isothermal measurement by variation of UP and plotting amplitude or b1 versus UP.
The number of charged bulk traps increases by a bigger space charge region (by a bigger UR and smaller UP). If you change UP at a fix UR then the amplitude increases with decreasing UP. Changing of UR at fix UP is more complex because the amplitude depends also on CR.
The number of surface traps are always the same if you have selected UR and UP so that the trap energy ET is between EFR and EFP. EFR and EFP are the Fermi levels at UR and UP. If you change UP at a fix UR you don't see a signal if EFP is below ET. EFP increases while decreasing of UP. If EFP is bigger than ET you see a transient with a fix amplitude. Further increasing of UP don't change the amplitude. The b1 versus UP plot should show a jump from zero to a fix value. Changing of UR at fix UP is more complex because the amplitude depends also on CR.

When using the **maximum analysis** or HERA evaluation it can be necessary to change the transient evaluation mode for the trap (Arrhenius) evaluation. If this mode saved in the tempscan file is 'Log, surface/oxide states' then change it in the sample parameter input window of the tempscan main program, not in the maximum analysis. The software keeps this change until a new file will be read. It keeps it in the maximum analysis also when reading automatic family files. Only at the file mode '1 file, input of name' the evaluation mode will be read from the new file (see chapter 4.1.1.1). You can use also a special MIS mode for surface traps and states in the maximum analysis, see chapter 6.3.4.4.3

You can make an **Arrhenius plot** not only for discrete levels but also for an inversion process with a linear transient or for surface states with exponential transients, see chapter 2.4.4.2 for choose of the transient evaluation. Arrhenius plots for surface and oxide states with logarithmic transients will be described in chapter 6.3.4.4.2 and 6.3.6.2.2.

Because the different evaluation possibilities for MIS there is at user class 5 an additional input group at the **Arrhenius input** windows:



By default the **Trap/Nss** button is activated. Then here are no inputs possible or the option for calculating sigma0 of oxide states is visible, see chapter 6.6.6.6. The time constant tau and the global selected kinetic will be used. If activating the **Other** button then the evaluation value and the type of kinetic can be selected.

The possibilities for the **evaluation value** depend on the kind of data and the user class:

tau:	Time constant from exponential or linear transient.
Hold time, 95%:	Defines a hold time: tau*3 for exponential, tau*0.95 for linear transient.
tau/Amp:	Ratio of tau and amplitude.

Note: tau and the hold time is not the same as those used in the Zerbst evaluation of chapter 6.3.8.3. Here tau will be calculated from the coefficients or the maximum analysis. An exponential or linear law of time is necessary for the transient.

The y-axis is y = ln(tau*T^x*C). T^x describes here the T-correction, see chapter 2.4.2.1. The kinetic factors without T^x will be denoted as 'C'. The kind of T-correction has also an influence on the energies calculated by the Arrhenius plot. Smaller values for x give higher energies.

In the **Temp exponent** input box you can select the **kinetic** including the T-correction or input directly the exponent x of T-correction:

as global:	Use the kinetic as selected in 'Physics input sheet', chapter 2.4.2.1. The y-axis is here normally y = ln(tau*vth*Nc).
emission:	Emission kinetic vth*Nc, x=2.
minority:	Emission for minorities, x=2.
capture:	Capture kinetic vth*Ns, x=0.5.
inv. band mid:	Inversion from bandmid kinetic sqrt(Nc*Nv), x=1.5.
inv. Diffus.:	Inversion from diffusion kinetic Nc*Nv, x=3.
Ns:	Shallow concentration, x=0.
T-exponent:	Direct input of the temperature exponent x.

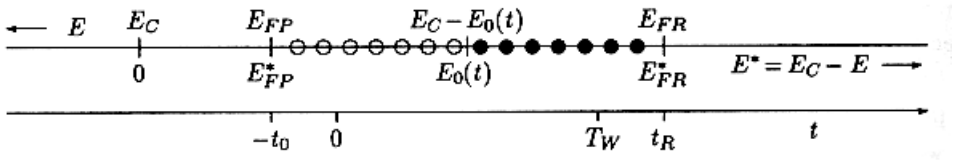
6.3.4 Nss evaluation from logarithmic transient

The Nss evaluation of a logarithmic transient is possible in the Transient, Isothermal and Tempscan measurement program module. For using this option select as Transient evaluation 'Log., surface/oxide states'. You find it in 'Sample parameters → Evaluation input sheet', see chapter 2.4.4.2. The wanted result plot is Nss versus energy.

6.3.4.1 Theory

A logarithmic emission transient is formed if the interface distribution is uniform throughout the 0 to Tw time frame. The transient amplitude will decrease with temperature, but its time constant will not change. The time frame, or observation window, is determined by the pulse and reverse bias voltages, and is in fact an energy window as illustrated below. The tempscan measurement in effect monitors the transient amplitude changes with temperature and will decrease linearly for a homogenous distribution of states which is integrating the transient over the energy range with temperature. The energy window is dependent on both temperature and time Tw. The Fermi level needs to be forced as low as possible in the conduction band to ensure that enough surface states are within the energy window and available for recharging. However if too big a reverse bias is applied then it is possible that the device will be forced into Inversion. Additionally if the Fermi level is pinned to the Nss then it is not possible to alter the position of the Nss with respect to EF. Generally EF is varied by pulsing into accumulation. If the effective width of the energy window is smaller than 0.1 eV (T=250K) you don't get a logarithmic transient but an exponential or an overlapping of 'some' exponential transients.

The following picture shows the energy and time axis of the Nss emission process with a logarithmic transient. In the software energy means E_C-E for n-type, E-E_V for p-type.



The medium energy EC-E0, see next chapter, will often be called in the software only E0. The same is valid for EFR and EFP. So means an input of EFR in the software EC-EFR resp. EFR-EV.

6.3.4.2 Transient evaluation

An interface state transient is composed of the emission of carriers from a large number of interface states distributed uniformly through the bandgap. Each state emits carriers with an exponential time law. The overlapping of many exponential transients forms a transient which approximates to a logarithmic transient. The density of surface states Nss is proportional to the temperature and each Fourier coefficient, for example b1, divided by a correction factor. This correction factor b1' takes into account the times and the type of coefficient. It will be numerical done by integration and searching the expected (mean) value in the b1 versus Tw curve, similar as described in 3.3.4.1, but not the maximum. From the physics this is the correctest way because the coefficients are not symmetrical.

Following equation is valid for C-DLTS (chapter T2 of Theory Manual):

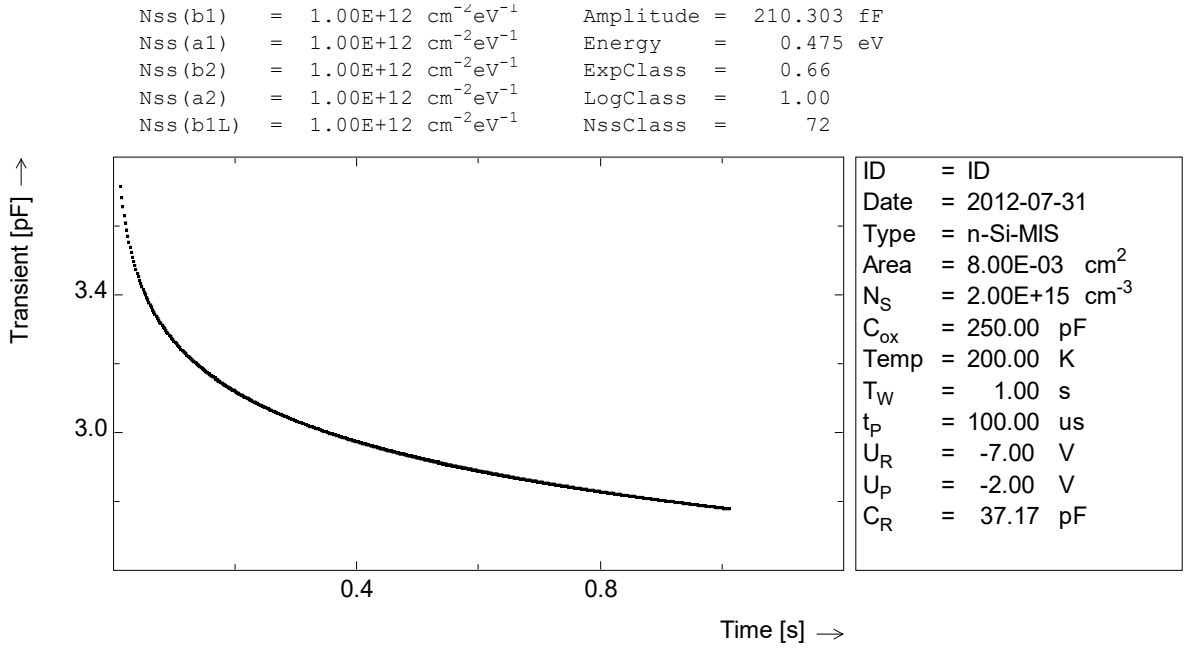
$$Nss(b_1) = \epsilon F N_S C_{ox} / (C_R^3 kT) * b_1 / b_1'$$

The medium energy for Nss at one temperature will be calculated by the expected (mean) value of tau, called tau' or <tau>, of the b1 versus Tw curve as explained above:

$$E_C - E_0 = kT * \ln(v_{th} N_C \sigma \tau')$$

The software can evaluate the transient and assign a class value to each throughout the temperature range in a manner similar to Schottky diode DLTS evaluation for an exponential transient. A good logarithmic transient will have an evaluation class value of 50 or greater. This class will be called here as NssClass. It is similar to the TauClass.

The following picture shows a simulation of a logarithmic transient and its evaluation. Five different calculations of Nss will be used. The capacitance difference between first and last transient point is amplitude*(ln(t0+Tw)-ln(t0)). The energy will be calculated by the capture cross section of the sample parameters. The ExpClass is the class for an exponential transient, see chapter 1.3.4. LogClass is a1/a2 * b2/b1 *fn and is 1 for a logarithmic transient; fn contains the normalization factors all 4 coefficients.

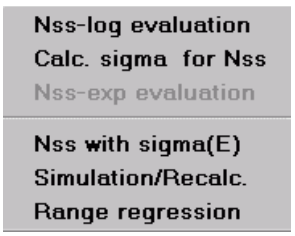


6.3.4.3 Tempscan and Nss(E)

The tempscan will be used to obtain a Nss(E) plot. You evaluate a logarithmic transient, that means a continuous distribution of exponential transients. The evaluation will be done with the help of the Fourier transformation. From the transient amplitude you get Nss, from the medium time constant with the help of capture cross section the energy.
A tempscan for a Nss evaluation will be done usually at one fix period width. At the routine measurement there is the special MIS mode 41 '1 FixTw, Nss only'. It uses the medium Tw of 204.8 ms. Many period widths give normally no additional information except at traps or when calculating sigma by the maximum analysis. Select in this case routine mode 12.
The bias conditions should not permit any, or only very little inversion and should pulse into accumulation. Response rates of interface states vary over a wide range and if a long Tw is used then it is likely that inversion processes will be observed. The UR and UP value will define the position of the Fermi level and it may be that no recharge is observed. Don't make an UR variation in one temperature cycle when oxide states exist.

You can plot Nss versus temperature in the Plot menu at 'Evaluation values'. There you can also select NF=Nss*kT as y-axis. NF is the concentration of charged interface states per area, its dimension is cm^2. It is Nss without temperature normalization, so its behavior is very similar to the amplitude. In the most coefficient plots you can define as normalization: no, amplitude, Nss-log, NF.

At the **Evaluate menu** there is a sub menu 'Surface states evaluation':



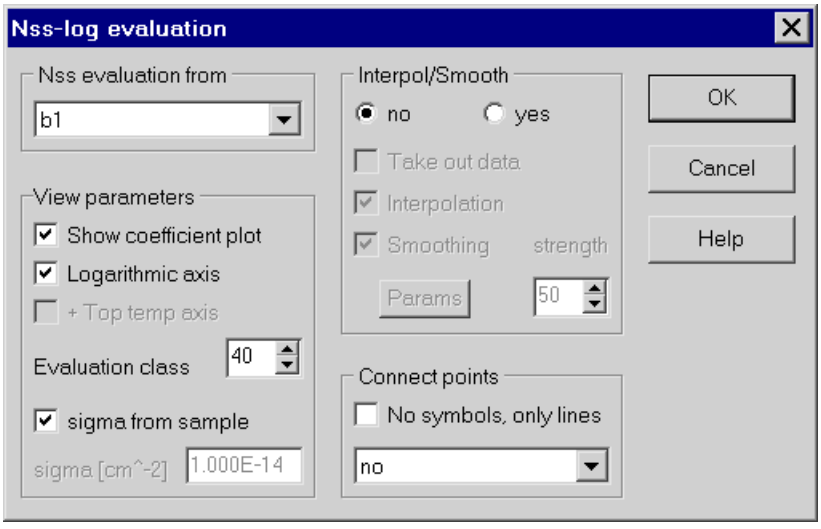
Nss-log evaluation shows Nss versus energy, this is the main application, see below. The capture cross section is necessary for the energy axis. Some possibilities for this will here be introduced. The last 3 menu entries are for a Nss evaluation with an energy depending capture cross section. It is only for special experts. The simulation and the range regression can also be used for the standard Nss-log evaluation with an energy independent sigma.

Except 'Calc sigma for Nss' all functions are also possible in the isothermal program module.

The **Nss-log evaluation** can be shown from one or three coefficients:

1. b1
2. a1
3. b1, b1(Tw/4), a1(Tw/4)
4. b1, b1(Tw/2), b1(Tw/4)
5. a1, a1(Tw/2), a1(Tw/4)
6. 3 Dlts signals

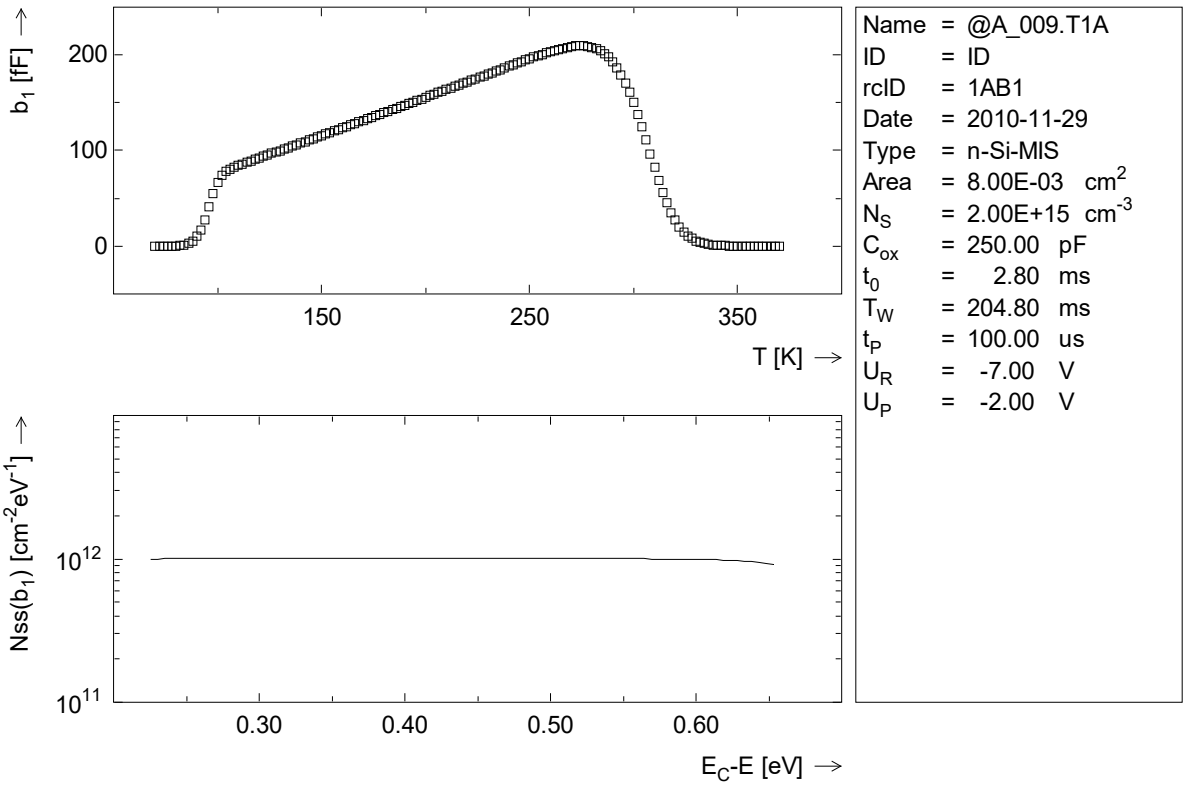
All 3 curves have different x- and y-axis. At no big changes in Nss(E) all 3 curves should be similar.



If activating '**Show coefficient plot**' the selected coefficient, only b1 or a1 is possible, will be shown versus temperature at the top of the picture; Nss(E) will then plotted at the bottom. All other inputs of this input window are only valid for the Nss(E) plot.

The Nss axis can be linear or **logarithmic.** It is possible to show an additional **temperature axis** at the top of the plot. All points that have an evaluation class, in this case it is the NssClass, greater or equal to the defined value will be included in the displayed Nss(E) plot. The capture cross section **sigma** of the sample parameters or of a local input is necessary for the energy calculation.

The following picture shows a simulation with EFP=0.2eV, EFR=0.7eV, sigma=1E-14cm^2 and Nss=1E12cm^-2eV^-1. At the top there is b1 versus temperature, at the bottom Nss versus energy.



The tempscan shows a fast increment, then a linear part and at last a decrement. This is typical for a constant (homogenous) Nss distribution. A period scan shows instead the linear part a plateau with a fix value.
The tempscan data will be bounded by EFP and EFR. In this example the medium energy of the energy window is smaller than 0.2 eV (EFP) below 100 K and bigger than 0.7 eV (EFR) above 300 K. The effective width of the energy window below 100 K and above 300K is less than 0.1 eV and falls to zero. The effect of these boundaries is that the tempscan curve 'falls down' when it goes below the 0.1 eV width. The 'fall down' may be observed by plotting the Nss concentration versus energy and specifying a class value lower than 50 as used in the picture above. This fall down is not a result of a change in the interface state distribution but a direct result of the measurement parameters.

6.3.4.4 Capture cross section

Following **methods** exist for calculating the capture cross section of the surface states at a logarithmic emission transient:

1. The **capture** process of the surface states yields to an exponential transient. You can calculate sigma by a capture measurement as described for a Schottky diode in chapter 3.3.6.1. This is the best method.
2. If Nss(E) shows a distribution with a distinct **maximum**, a maximum analysis yields to the capture cross section and the energy of the maximum.
3. Same as 4 but uses the increasing at **EFP**. Select UP so that you see this increase.
4. From the '**fall down**' of the Nss(Coef) versus temperature curve because reaching of **EFR** you can define a time constant. You have to search the temperature where Nss(Coef) reaches 50% of its value. Physically this is more correct as using directly the coefficient maximum because the coefficients increase with temperature. You can do this evaluation in the maximum analysis. Select UR so that you see this decrease.
5. In the '**maximum**' of the temperature curves because reaching of **EFR** you can define a time constant. Using different temperature curves (coefficients) you get an Arrhenius plot and as result the capture cross section. This search is easier than method 4 but it is physically not correct because the coefficients increase with the temperature. Therefor we use here a numerical correction which corrects the time constant for the maximum.
6. The use of **2 coefficients** yields to 2 curves with different energies. States of the same energy interval must have the same Nss. So the Nss of the 2 coefficients will be plotted versus temperature. Temperatures T1 and T2 will be defined at which both curves have the same given Nss value. Because both temperatures represent the same energy interval you can calculate sigma. This method don't work if Nss is about constant. For a better control of the result we use 3 coefficients and get so 3 values for sigma. All 3 calculations should give about the same value.
7. Sigma can be calculated with the help of **a0** if Nss about constant in the observed temperature range. This method is much complicate and only for experts. You find this method in the same menu as method 6 at user class 5.

For method 1 you need a capture measurement in the transient or, better, in the isothermal program module. The other methods will be done on tempscan files with constant period width. Method 6 and 7 will be done in 'Calc. Sigma for Nss' while method 2 to 5 will be done in the Maximum Analysis. For method 2 to 5 it is helpful to have 2 tempscan files width different period width. Then the accuracy is better because the longer temperature range in the Arrhenius plot.

6.3.4.4.1 Sigma by capture measurement

The following describes method 1. The capture transient of surface states follows an exponential time law, similar as for Schottky diodes. A direct measurement of the capture transient as discussed in chapter 3.2.1.5 is usually not possible because the capture process is usually to fast. So you have to do an indirect measurement of a capture transient as introduced in chapter 3.3.6.1.

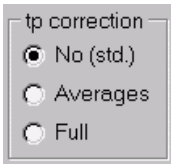
This measurement will be done in the Isothermal Program Module. Select as transient evaluation 'Log., surface/oxide states', make the isothermal measurement 'Fix period width' → 'Variation of tP, linear' and call the capture evaluation. This evaluation is also valid for surface states. Some evaluation inputs (chapter 3.3.6.1.4) are now not available. Here it is only a visual difference to select 'amplitude' or 'b1' as data origin because the amplitude of a logarithmic transient will be calculated only by b1.

The big difference to a Schottky diode is that now the emission transient of surface states follows a **logarithmic time law** instead of an exponential one. The capture transient will be constructed by the coefficients or amplitude of the logarithmic transient. The logarithmic emission transient yields here in the practice to a **problem**: The emission must be finished when starting the next measurement (at the next pulse width and when repeating because averaging). If the surface states are not completely empty then the tP-axis of the constructed capture transient is not correct. Usually you can not select the period width of a logarithmic transient in such way that the emission is finished at the end of Tw.

Following techniques exist to avoid or to minimize the problem of not **complete emission**:

- Set **EFR** by UR in such way that the emission process is not to long. Select Tw so that the Nss class is high enough.
- Select a **wait time** between transients until the emission is empty (chapter 3.3.1.2). A separate variable exist for this at a tP variation and logarithmic evaluation.
- **Don't average**, select a bigger Tw so that no average is necessary. For no averaging you have to set the minimum measure time tM to Tw or to zero. Remember that the SNR depends only on the product Na*Tw, see chapter 3.2.1.1.1.
- If averaging is necessary select a **wait time** between the pulses, chapter 3.2.1.1.2.
- Use **b1T** for evaluation, it is b1 over the first measured transient at averages.
- Make a **tP correction** as described below. Be careful with this correction because it is not exact, it is more an estimation for seeing the influence of the emission.

The software offers a **tP correction** which correct the tP-axis at a non complete emission:

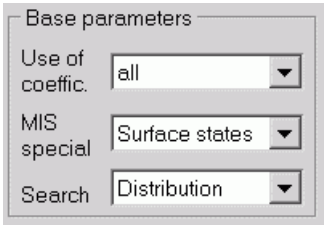


No (std.): No correction of the pulse width axis, this is the standard.
Averages: Only correction at averaging. The software uses the ratio total emission charge to charge at Tw for adding a part of the cur - rent pulse width.
Full: As before but makes additionally a correction by the previous pulse widths. That is not very accurate because a repeating of measurement (bad range or amplification) can not be taken into account.

6.3.4.4.2 Sigma by Maximum Analysis and Arrhenius plot

You can define an emission time constant in the **distinct maximum** of a Nss(E) distribution (method 2), from the increase at **EFP** (method 3), from the '**fall down**' of Nss(Coef) versus temperature (method 4) and from the **maximum** of temperature curves because reaching of **EFR** (method 5). Using different temperature curves (coefficients) in the maximum analysis you get an Arrhenius plot and from this the capture cross section and the method depending energy. It is the energy in the maximum of distribution or EFP or EFR. The accuracy of evaluation increases by using 2 period widths.

For this method call the maximum analysis, see chapter 4.1. The easiest way is here to select the **MIS special** mode on the Base input sheet.



No, as usual: No special mode will be set, you have select manually the correct y-axis and search type for the different methods.

Surface states: Special evaluation for surface states, enables a second input for the search by the various methods, see below. All these methods use the expected tau value of a logarithmic transient for the time constant.

Oxide states: Special mode for oxide states, see chapter 6.3.6.2.2.

Surface traps: Special mode for surface traps with a discrete energy. NsT will be plotted versus temperature, the transient evaluation mode will be set to exponential.

Oxide traps: Special mode for oxide traps with a discrete energy.

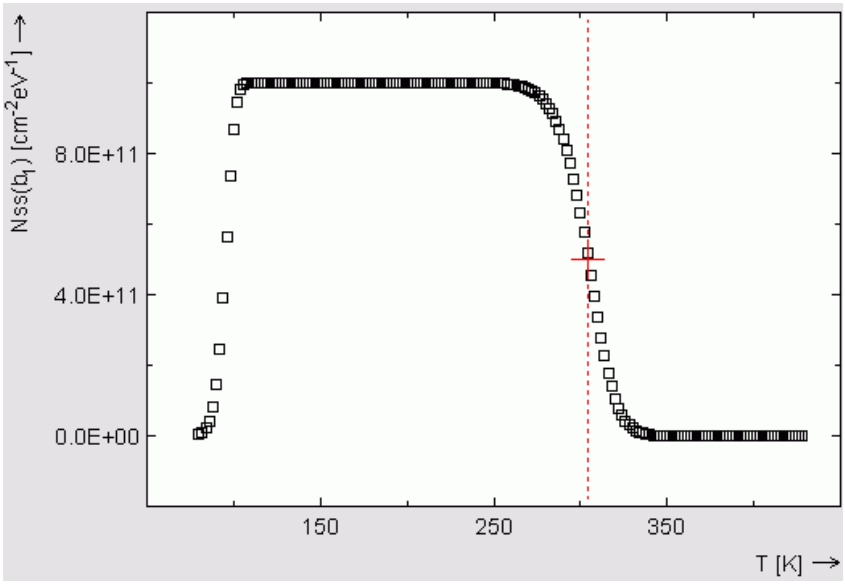
For the mode 'Surface states' following **search** modes exist:

Distribution: This is method 2 in the list of chapter 6.3.4.4. Each coefficient will be shown temperature normalized (means Nss(Coef)) versus temperature. The maximum of the curves must be defined similar as at a trap level. The Arrhenius plot yields to sigma and the energy in the maximum of the Nss(E) distribution. This evaluation is only valid when a distinct maximum in the Nss(E) distribution exist.

Increment at EFP: Method 3 is similar to method 4 but here the temperature to the 50% increase of the Nss(Coef) curve will be defined. In the plot above it is at about 100K. The results are the sigma and EFP.

Dec. at EFR, 50%: At method 4 you have to define the temperature where the Nss(Coef) curve falls down to 50%. A cross marks the position where the y-value is 50% of the maximum, starting from high temperatures. The results are sigma and EFR. This method is more accurate as method 5 because it is physically more correct. The disadvantage is that it can be difficult to find the 50% point, the searching of a maximum is easier.

Dec. at EFR, maxi: Method 5 is similar to the standard maximum analysis. You search the maximum of NF(Coef)=Nss*kT versus temperature for each coefficient. These curves are the coefficients normalized by amplitude and CR, but not by the temperature. You see here a maximum, as in the not normalized temperatures curves. This evaluation is easier than method 4 but it is physically not correct because the coefficients increase with the temperature. Therefor we use here a numerical correction which corrects the time constant for the maximum.



The picture on the left uses **method 4** and shows Nss(b1) of the example of chapter 6.3.4.3. When using 2 Tw's of 20ms and 2s then you get for sigma=1.03E-14 and for EFR=0.704eV. This is in good agreement with the simulation parameters. EFR will be called 'energy' in the Arrhenius plot.
A maximum analysis of the coefficients (without correction as used in method 5) get sigma=1.15E-14 and EFR=0.643eV.

If you make only a standard maximum analysis with searching the maximum of the not temperature normalized temperature curves, you get bad results. This evaluation is physically not correct because the coefficients increase with the temperature. This corresponds to method 5 without correction of time constant. EFR will be calculated with an error of about 5% to 10%. The error of the capture cross section is tolerable because the energy calculation E0 for Nss depends in a logarithmic way form sigma, see equ. 2.6 of Theory Manual. The results depend on the 'Selected Arrhenius point' because different kind of coefficients.

The input for the **Arrhenius plot** contains at user class 5 an additional input group, as described in chapter 6.3.3. If visible select here Trap/Nss. At the Evaluation 'Arrhenius, one level' there is an input group for calculating sigma0 of oxide states visible, see chapter 6.3.6.2.2. Select here 'No' for surface states.

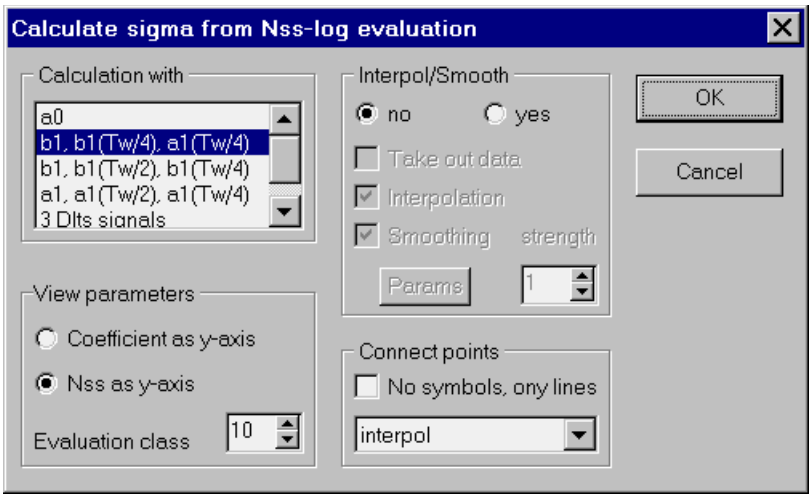
6.3.4.4.3 Sigma by 2 Nss calculations

In the following method 6 will be introduced. You find it in 'Calc sigma for Nss'.

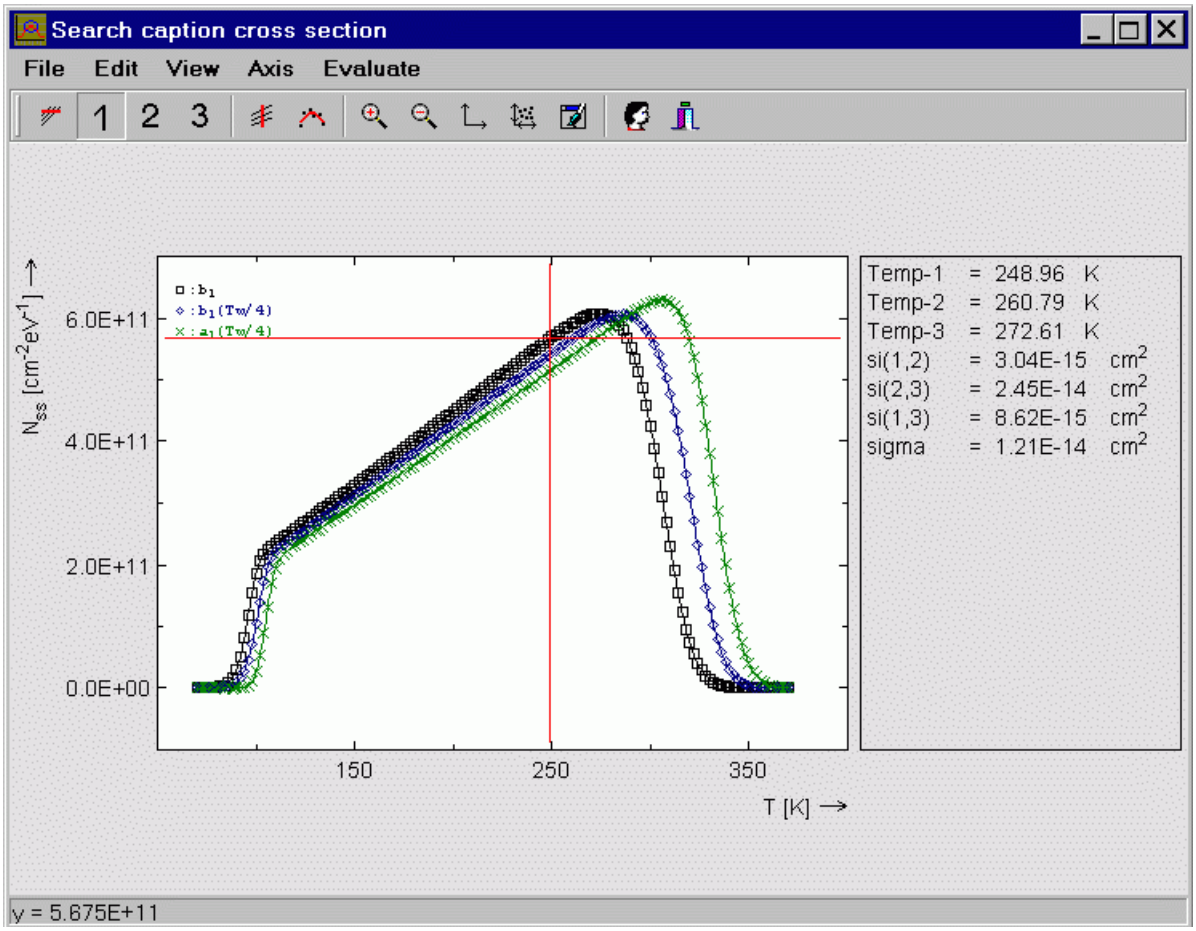
'**Calculation with**' selects the 3 coefficients:

b1,b1(Tw/4),a1(Tw/4)
b1,b1(Tw/2),b1(Tw/4)
a1,a1(Tw/2),a1(Tw/4)
3 Dlts signals

Selecting a0 yield to method 7. Nss should be selected as **y-axis** because you must define a common Nss value. If selecting coefficient as y-axis then the curves are not temperature normalized. Evaluation class 10 uses all data points.



The following picture shows a simulation with a square Nss distribution with a given sigma of 1E-14 cm^2. The horizontal line denotes the defined common (same) Nss value for all 3 curves. The temperatures Temp-1to Temp-3 are the corresponding temperatures. The common Nss value should be defined in such way that the differences between the curves are big. si(1,2) denotes the capture cross section calculated form curve 1 and 2, and so on. The 3 sigma calculations give different values because the accuracy for this method is not big. A difference with a factor of 3 is not unusual. The averages of the 3 calculations will be called sigma. After leaving this program part you get the question for applying the capture cross section. There you can select one of the 3 calculations or the average.



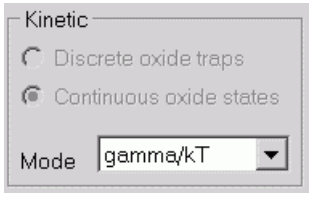
The Evaluate sub menu and the first 5 tool buttons are specially for this method. The other sub menus and tool buttons are part of the standard plot program. The active marker will be selected in the Evaluate sub menu or at the are the first 5 **tool buttons**:

	Set horizontal marker, activates the marker for the common Nss value.
1	**Marker for coefficient 1**, activates the vertical line marker for curve 1.
2	**Marker for coefficient 2**, activates the vertical line marker for curve 2.
3	**Marker for coefficient 3**, activates the vertical line marker for curve 3.
	Set new temperatures, searches temperatures of common Nss for all 3 curves.

The marker itself, and so the common Nss value or the temperature Temp-1/2/3, will be set by the mouse or the cursor keys. After moving one vertical marker line, the corresponding 2 sigma calculations will be refreshed.

6.3.4.5 Energy depending capture cross section

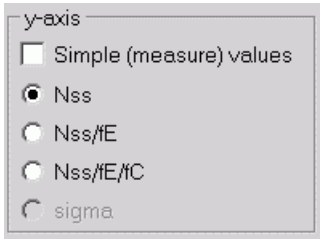
The Nss evaluation with an energy depending capture cross section is only for special experts. See in the Theory Manual for more details. The simulation and the range regression can also be used for the standard Nss-log evaluation with an energy independent sigma. The inputs are a little similar to that ones for oxide states (chapter 6.3.6.1) so that here only a short explanation will be given.



At the Kinetic input sheet there is the input for the **kinetic mode**:

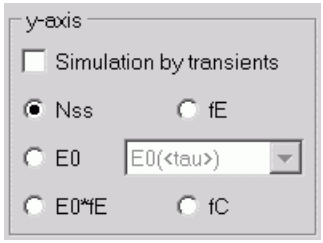
simple: sigma is energy independent, standard Nss.
1/Esigma: Input of Esigma, tau depends exp. on 1/Esigma.
gamma/kT: Input of gamma, tau depends exp. on gamma/kT.
only tauC: As before but only tauC is energy dependent.
only tauE: As before but only tauE is energy dependent.
special: Should only be used for simulations, as 'simple' for evaluations.

In the following is fE=1/(1+gamma) the emission kinetic factor. fC is the capture factor which can only numerically approximated at an energy depending sigma. Its calculation needs EFR and EFP and is not accurate. For simple Nss is fC=1-exp(-tP/tauC).
If the x-axis is the energy, then the energy can be corrected by fE.



The **y-axis** at the Base input sheet of 'Nss with sigma(E)' defines which value will be calculated and shown:

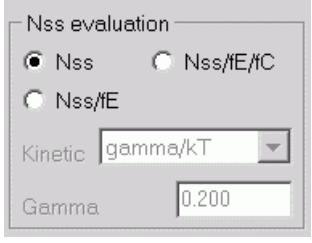
- **Nss**: Shows the standard Nss calculation without respect to an energy dependence of the capture cross section.
- **Nss/fE**: Shows Nss divided by the factor fE.
- **Nss/fE/fC**: Shows Nss divided by the factors fE and fC.



The **y-axis** at the Base input sheet of 'Simulation/Recalc.' defines which value will be calculated and shown:

- **Nss**: Shows the standard Nss calculation.
- **fE**: Shows the emission factor fE.
- **E0**: Shows the medium energy EC-E0.
- **E0*fE**: Shows the medium energy corrected by fE.
- **fC**: Shows the capture factor fC.

At the 'Range regression' one coefficient or NF=Nss(Coef)*kT will be plotted versus temperature. If the distribution is homogenous, you should see a linear increasing in a temperature range. The slope yields to Nss, here called Nss0.



The **Nss evaluation** can be selected:

- **Nss**: Uses the standard Nss calculation without respect to an energy dependence of the capture cross section.
- **Nss/fE**: Corrects Nss by the emission factor fE.
- **Nss/fE/fC**: Corrects Nss by fE and fC.

6.3.4.6 Notes and tips

a) Isothermal: You can obtain a Nss(E) plot also from isothermal data of a period width scan, similar to the tempscan evaluation. But here is the energy range smaller than at a tempscan. With the simulation parameters of chapter 6.3.4.3, you get by period widths from 0.3 ms to 100 s only an energy range of about 0.2 eV. Changing EFR and/or EFP shows the influence of the energy window. If the effective width of the energy window is smaller than 0.1 eV you see only a peak in the b1 versus tau curve.

b) Inversion: To measure the interface state density it is important to minimize inversion processes. Therefore the voltages that are selected for the tempscan should ensure that you work in the accumulation region of the C/V curve. However it may be possible that only a few interface states will be recharged and it may be necessary to work closer towards Inversion.
Inversion occurs more slowly at lower temperatures. As interface processes such as recharging are fast and the pulse is going into accumulation, if a small Tw value is used, observation of Inversion will be minimized. Additionally at lower temperatures the mid gap deep levels are likely to be frozen and their contribution to any signal will also be minimized.

c) Nss or NT: If verification is required to show that fall down is not caused by a deep level trap or a non-homogenous distribution of interface states then:

- Change evaluation to exponential (NT). This may still give a poor class due to overlap with interface states.
- Change the reverse bias conditions to shift the energy window. The fall down point NT should not be sensitive to bias shifts.
- Observe fall down in different coefficient plots.

For the Nss versus energy plot the program requires a capture cross section input. This may be either a simple reference, or it may be directly calculated using the capture cross section measurement in the isothermal software.
Three Nss coefficients may be overlaid to look for variations within the tempscan to try to extract more information. It is also possible to plot EFR - E0 where E0 is the mid point of energy window. The fall down temperature will be different for each coefficient because the maximum of each coefficient occurs at a different temperature.

d) Nss or oxide states: Separation of the two may be achieved by using different pulse widths, for more details see chapter 6.3.6. They can be distinguished especially at the kind of T-decrement and by the dependence of pulse width.

e) Nss or inversion: A linear or a hyperbolic transient will yield specific peak shapes and combinations from different Fourier coefficients. With the first order coefficient one peak is formed, and two peaks are formed with the second order coefficients. For more details see chapter 6.3.7.

f) U-DLTS: In many cases U-DLTS can be helpful for the determination of Nss because the equations are easier and there are less approximations. But at a reverse bias where the C/V curve is flat there is no CC-DLTS possible.

g) Time law: Interface states have usually a logarithmic emission and an exponential capture transient while the capture transient of oxide states is logarithmic.

6.3.5 Nss evaluation from exponential transient

6.3.5.1 Theory

A Nss evaluation is also possible from an exponential transient. The exponential method is more difficult than the logarithmic one. You need a small energy range so that you see about an exponential transient and not a logarithmic one. This kind of Nss evaluation is not the standard one. The wanted result plot is also Nss versus energy.

The following table gives an approximation of the energy width (interval). The calculation was done by an overlapping of many exponential transients with a given tau range. Overlapping of many transients with a wide range of time constants yields to a logarithmic transient. The period width in the example was 1 s. The calculation from tau to an energy assumes a capture cross section of 10^-14 cm^2 and a temperature of 250 K.

Transient	Logarithmic	Exponential
tau range [s]	0.01 – 1.0	0.06 – 0.17
Energy range [eV]	0.513 – 0.612	0.552 – 0.574
Energy width [eV]	> 0.099	< 0.022
ExpClass	0.69	0.91

The ExpClass of an ideal logarithmic transient must be 0.66 for this example, the ExpClass is 1.0 for an ideal exponential transient.

So you see that for a good logarithmic transient a minimum energy width of about 0.1 eV is necessary. The energy width must be smaller than about 0.02 eV to get an exponential transient. The calculation is valid for a temperature of 250 K. At lower temperatures the energy width is smaller, at higher temperatures it is bigger. The energy width is the width of the energy interval from which the emission process will be done.

You have to select a small voltage range, for example UR=-5V and UP=-4.5V, so that you get only a small energy range and see about an exponential transient and not a logarithmic one. Variation of UR and UP in the Isothermal Program Module gives the Nss(E) plot. This **isothermal** measurement and evaluation is the standard one. You find here in the evaluation menu the menu point 'Nss-exp evaluation'. The inputs are similar as described in chapter 6.3.5.3.

The energy can be calculated by: $E = E_F + q*psi$, where psi is the potential function.
The problem is to calibrate the voltage axis to a psi-axis resp. energy axis. It is to complex to explain it here in the software manual. There are some methods in the software and literature, keywords are: psi → energy, Nicollian.

The calibration gives the energies E(UR) at reverse bias and E(UP) at pulse voltage. The medium energy is the average of these energies:

E_{mid}=(E(UR)+E(UP))/2

The width of the energy is:

ΔE=ABS(E(UR)-E(UP)).

Note: 'Energy' means in the software E_C- E_{mid} for n-type, E_{mid}-E_V for p-type samples.

This exponential Nss evaluation is possible in the Transient, Isothermal and Tempscan program module. For using this option select as Transient evaluation mode 'Exp., surface states/traps'. You find it in 'Sample parameters → Evaluation input sheet' (chapter 2.4.4.2).

This evaluation mode will also be used for surface traps, see chapter 6.3.3. The type of this evaluation (called Energy calib. for Nss/NsT) defines whether NsT or Nss will always be shown. You find this input in Tools → Program params → tab sheet Eval.
Following **evaluation types** are possible:

NsT, surface traps: Shows always the evaluation for surface traps.

Nss, Nicollian: Shows Nss and calculates the energy by Nicollian.

Nss, read calib: Shows Nss and read an energy calibration file, see chapter 6.3.5.3.

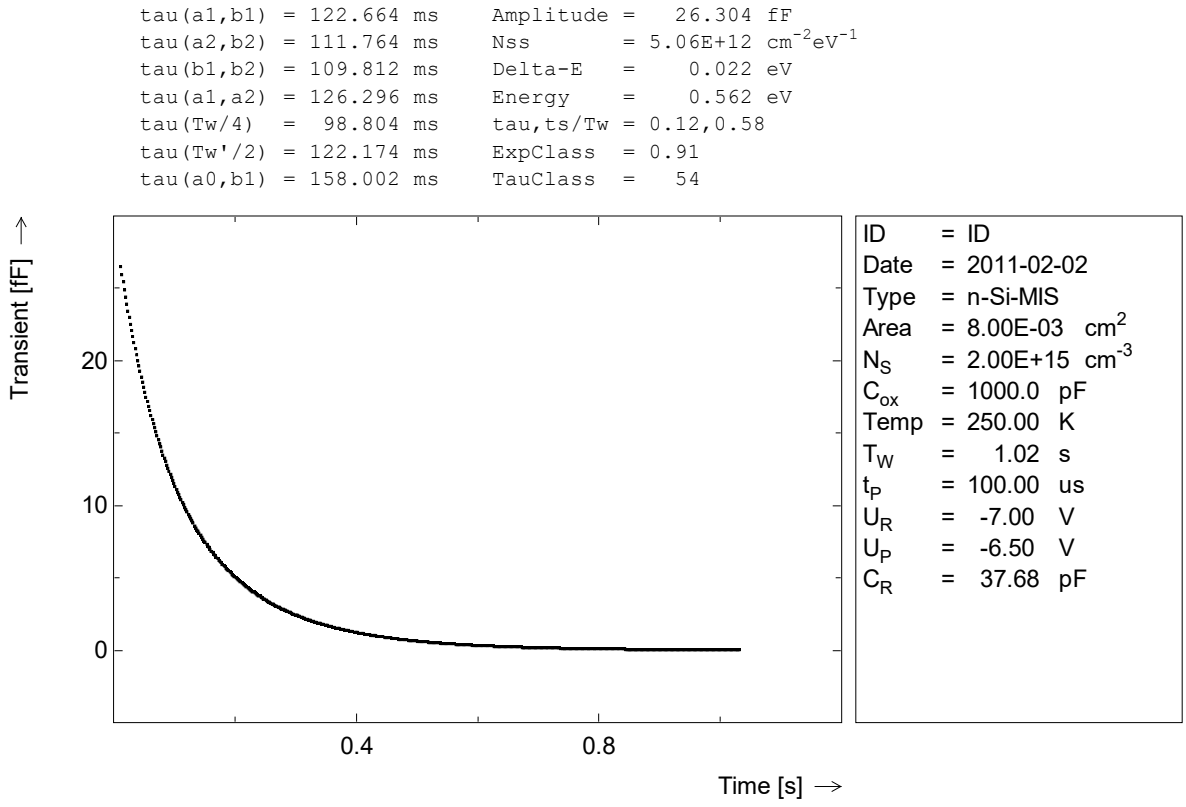
If selecting a Nss type (2. or 3. one) then, for example, you can plot Nss versus temperature in the tempscan plot menu at 'Evaluation values'. The special 'Nss-exp evaluation' in the isothermal and tempscan evaluation menu is also possible at selecting 'NsT'.

6.3.5.2 Transient evaluation

The density of surface states Nss is proportional to the amplitude Amp of the exponential transient. Following equation is valid for C-DLTS:

$$Nss = \epsilon F N_S C_{ox} / \left(C_R^3 \Delta E \right) * Amp$$

ΔE is the width of the energy interval, also called here energy width or Delta_E.
The transient evaluation is similar to that one described in chapter 3.2.1.1.4. Here now Nss, Delta_E and the medium energy will be listed.

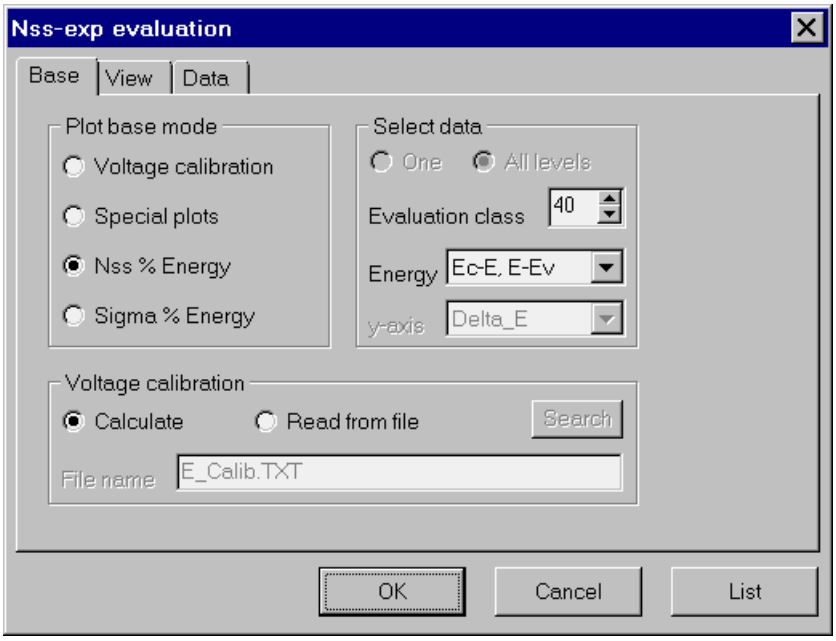


6.3.5.3 Tempscan and Nss(E)

The tempscan can be used to obtain a Nss(E) plot. It is similar as described in chapter 6.3.4.3. The tempscan measurement for this Nss evaluation will be done only at one fix period width. At the routine measurement there is the special MIS mode 41 '1 FixTw, Nss only'. It uses the medium period width 204.8 ms. Select UR and UP so that you get only a small energy range and see an about exponential transient.

In the Evaluate menu there is the menu 'Surface states evaluation → **Nss-exp evaluation**'.
It shows Nss versus energy and some other plots.

The input sheet shown on the right opens.



The **plot base mode** defines which plot will be shown:

Voltage calibration: Shows E(UR), E(UP), E_{mid} or Delta_E versus temperature.
Special plots: Shows the x-and y-data as defined in 'Select data'.
Nss % Energy: Shows Nss versus medium energy $E_{mid.}$
Sigma % Energy: Shows the capture cross section, calculated from the medium energy, versus energy.

The kind of **energy** axis can be selected:

- Potential function psi
- E-Ei, with Ei as intrinsic level
- Ec-E resp. E-Ev

All data points that have an **evaluation class** value greater than or equal to the specified value will be included in the plot.

The **voltage calibration**, that means the transfer from the voltage axis to the potential psi (and then to an energy axis) of the MIS device, can be calculated or read from an ASCII text file. Here the voltage must be in the first column, the potential psi in the second column of the text file. The program searches the voltage line by line and interpolate if necessary. This is the best way if you know the potential function and voltage calibration of your sample. The calculation mode must be considered with caution.

At the **View input sheet** you can define some parameters for the view of the plot:
Sort, Logarithmic axis, Connect points, Interpolation, Approximation.

At the **Data input sheet** you can restrict the plot data by an axis range.

The **List** button yields to a list of the evaluation data.

6.3.6 Oxide states

The evaluation for oxide states bases on the Nss evaluation. For using this option select as Transient evaluation 'Log., surface/oxide states'. The standard plots have no special evaluation for oxide states but show as evaluation value Nss. You can interpret this value as N_I*d_x where N_I is the concentration of oxide states in cm^-3eV^-1, $d_x=d_0*\ln(tP/tau_{SC})$ and d_0 the tunnel constant, d_x denotes the filling depth at tP. For more details look in chapter T2.1.3 and T2.2 of the Theory Manual. In the isothermal and tempscan program module there is in the 'Evaluate' menu a special evaluation for oxide states.

Oxide (isolator) states and impurities within the oxide can cause complications to the measurement of interface states. The presence of mobile charges can cause the movement of the C/V curve and thus prevent any measurement at all. Therefore when making C/V measurements, the measurement should be repeated several times and the plots overlaid to ensure that the curve is stable. If this is not the case and the Cox value shifts it is not worth persevering with the measurement.

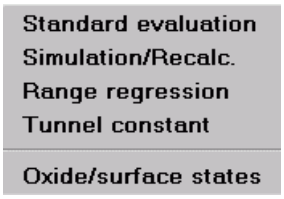
Typically, interface states respond to changes in bias and pulse quicker than oxide states. Separation of the two may therefore be achieved by using different pulse widths. To investigate interface states use tempscan with pulse widths in the region of 10 to 100 us and to investigate oxide states use additional pulse widths of 100 ms up to 1 s.
Additionally, the isothermal module can be used to examine the behavior of the device when the pulse width varies, by using the variation of pulse widths in logarithmic steps.

The emission transient formed by charge of oxide states follows a logarithmic time law but it is much more complex at as surface states. We can make here a distinction between e different ranges. The emission amplitude and therefor the Fourier coefficients of the emission transients show a strong dependence from the pulse width until saturation.
The capture transient of oxide states is also logarithmic. Plotting the capture transient versus logarithmic time yields to a straight line until saturation. From the slope, calculated by a linear regression, we get NI*d0, while the capture cross section can be calculated from the intersection.
The used equations will be given in chapter T2 of the Theory Manual, for more details see also in (10) of the literature list.

6.3.6.1 Tempscan and oxide states

The tempscan module can be used to calculate N_I and to separate out the influence of surface and oxide states by collecting two fix period width files with two pulse widths. At the **routine measurement** there is the special MIS mode (42) '2 FixTw, 2tP, oxide states'. It uses the medium period width 204.8 ms and pulse widths of 10 us and 100 ms. 2 different period widths are only necessary for the Arrhenius evaluation of an additional trap level.
You get a little bit more information when using 3 different pulse widths. The tempscan routine mode 43 creates 3 files with a constant period width of 512ms and pulse widths of 20us, 2ms and 200ms. Select there as measure time 'automatic', then these 3 measurements will not be averaged. 3 files enable three times a special oxide states evaluation, so a check of results is possible. Additionally a fourth file with Tw=20.48ms and tP=20us will be measured. If there are additional traps then a maximum analysis with 2 period widths and a HERA evaluation with a quasi-logarithmic transient are possible. A HERA evaluation only for oxide states is not helpful.

In the Evaluate menu there is the sub menu '**Oxide states evaluation**':

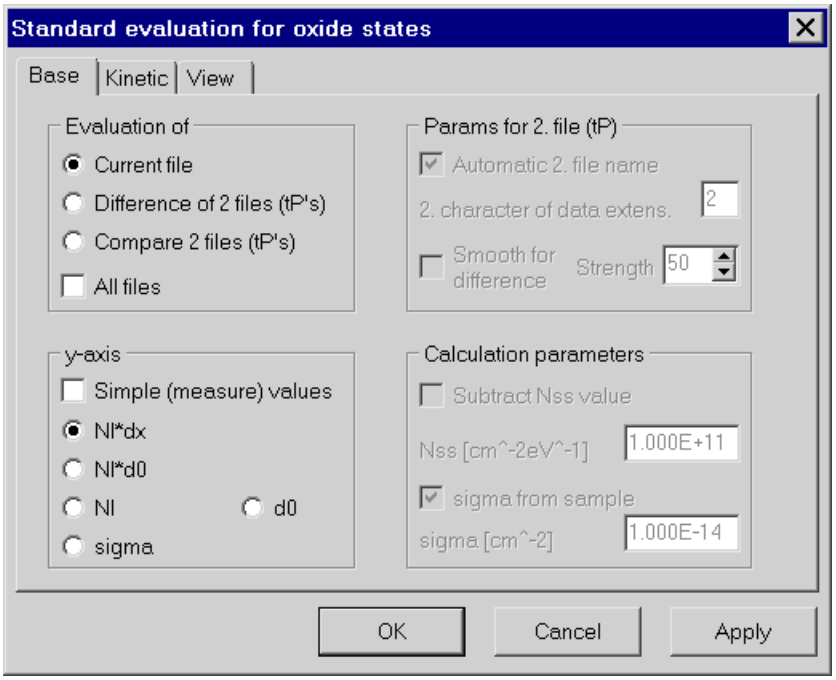


'Standard evaluation' shows NI or sigma versus temperature or energy. The next menu entry allows to recalculate the curves.
A special plot calculates the 'tunnel constant' by the saturation tP.
'Range evaluation' calculates NI*d0 or EFR by a linear regression over different kinetic ranges. 'Oxide/surface states' tries to separate between oxide and surface states.

6.3.6.1.1 Standard evaluation

'Standard evaluation' shows NI, sigma and other results versus temperature or energy.

The main inputs will be done on the **Base input sheet**.



The current file, 2 files, the difference of 2 files or all (maximal 4) family files can be evaluated. Family files are files which were measured together and differs in the file name only by the second character of data extension.
The difference evaluation is similar to the calculation of the capture cross section of the next chapter. But here you have only 2 tP points for the linear regression (curve).

'Evaluation of' defines the use of family files:

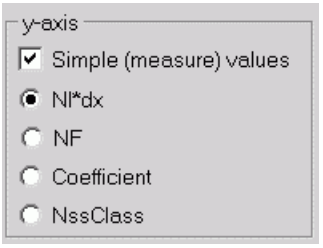
- **Current file** evaluates the current file.
- **Difference of 2 files (tP's)** calculates the results by the coefficient difference of 2 files with different pulse width. We assume that these 2 points per temperature are a part of a linear curve with a logarithmic tP-axis. NI*d0 will be calculated from its slope, sigma from the intersection. It is the best method because it needs no further parameters, the NI*d0 calculation will not be influenced by surface states.
- **Compare 2 files (tP's)** show the results of 2 files with different tP and its difference.

Activation of **All files** shows the results of all files or the differences of maximal 3 files.

The **y-axis** defines which value will be calculated and shown:

- **NI*dx**: This is the standard, needs no further inputs. It is more a normalization but an evaluation, see chapter T2.2.
- **NI*d0**: Calculates NI with the input of sigma. If using 'Difference of 2 files' then sigma is not necessary.
- **NI**: As NI*d0 below, you have to input d0 or to calculate from the tunnel barrier.
- **d0**: As NI*d0, you have to input NI.
- **Sigma**: Calculates the capture cross section, needs NI*d0 if not difference building.

If activating '**Simple (measure) values**' the following possibilities exist for the y-axis:



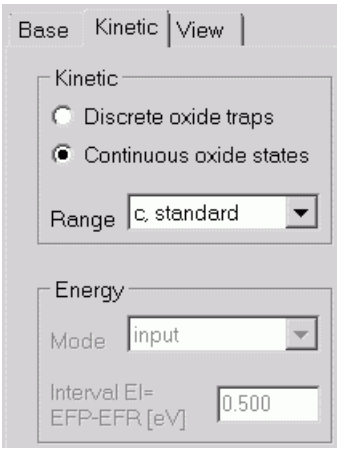
- **NI*dx** as explained above.
- **NF=NI*dx*kT** is the concentration of charged oxide states per area, its dimension is cm^2. It is NI*dx without temperature normalization, therefor its behavior is very similar to the selected coefficient.
- **Coefficient** shows the selected coefficient.
- **NssClass** shows the evaluation class.

When using 2 files (tP's) then the **2. file name** can be searched automatically by the software, or you have to input the 2. character of the data extension. For example, if the current file is ID@A_001.T1A and the 2. file should be ID@A_001.T3A then input here '3' . The 2 files must have the same period width and different pulse widths. You can smooth the data before the difference building.

The **calculation parameters** input group contains parameters for the evaluation and simulation. Depending on the x- and y-axis you have to input NI*d0, NI, d0 and sigma. Sigma can also be applied from the sample parameter set.
You can **subtract** a given **Nss** value for the sigma calculation. Surface states give a coefficient value which is independent from tP (at higher pulse widths) and yield to wrong results for the capture cross section.

Tip: Use 'Compare oxide/surface states', chapter 6.3.6.1.5, to check whether the emission comes only from oxide states or also from surface states.

At the **Kinetic input sheet** you have to define the kinetic model:



- **Discrete oxide traps** (NIT) with a discrete energy level, see also chapter 6.3.6.4.
- **Continuous oxide states** with an energy distribution (NI), the standard mode.

If selecting 'oxide states' then depending on the selected y-axis the selection of the **emission range** may be possible:

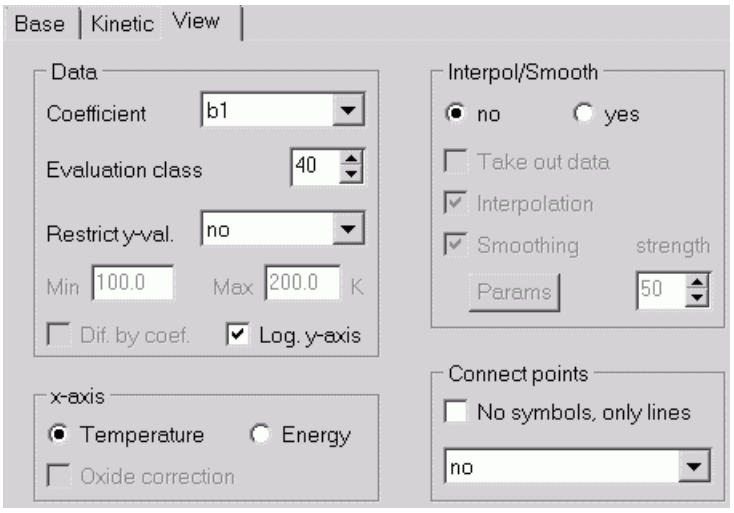
- **b, increment:** Strong increment of temperature curves because EFP.
- **c, standard:** Temperature curves increases only by temperature, this is the standard and easiest mode.
- **d, plateau:** The temperature curves are about constant.
- **e, decrement:** Decrement of temperature curves because EFR.

Look in the Theory Manual and on the next plots for a more detailed explanation.

Range b, d and e needs the **energy** EFP, EFP-EFR or EFR. This value can be input or be calculated, the selection of this input mode is similar as shown on chapter 6.3.6.2.

Usually tempscans will be measured in this way that the emission will be observed. Here NI*dx will be normalized by the energy kT. If tempscans were measured under caption kinetic then you have to input the energy interval EFP-EFR.

At the **View input sheet** you can select the used coefficient:
b1, a1, b2, a2, b1(Tw/4), a1(Tw/4), b1M, a1M, b1T.
The minimum evaluation class can be input. The y-axis can be linear or logarithmic.
If using the **difference** of 2 files then the difference of all coefficients can be build with a new calculation of the evaluation class. In the other case only the difference of the selected coefficient will be formed without new calculation of evaluation class.



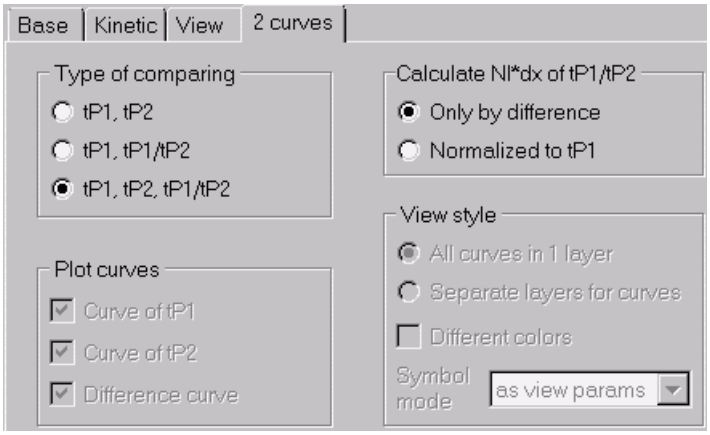
You can **restrict** the y-values by searching the right maximum (at high temperature):

no: All y-values will be shown.
min. 10%: All y-values will be shown which values are 10% or higher of the maximum.
l**inear temp:** Selects all y-values which increases resp. decreases linear with the temperature from the right maximum.
sqrt temp: Similar as above, but with a square root temperature dependence.
sqrt, slope: As above but checks also the slope between 2 points.
MinT,MaxT: Input of a valid temperature range.

As **x-axis** you can choose for oxide states the temperature or the energy. When using the energy you should activate the flag '**oxide correction**', then the medium energy as defined in equ. 2.20 of the Theory Manual will be used. In the other case the energy will be calculated as for surface states.

If activating 'Compare 2 tP's' the **2 curves input sheet** is visible.

Type of comparing selects 2 or 3 curves. tP1 and tP2 are the curves of file 1 and 2, tP1/tP2 is the difference curve of file 1 and 2.
When using only 2 curves then you can plot curve 1, 2 and/or the difference. In this case you can select the view style as already explained.

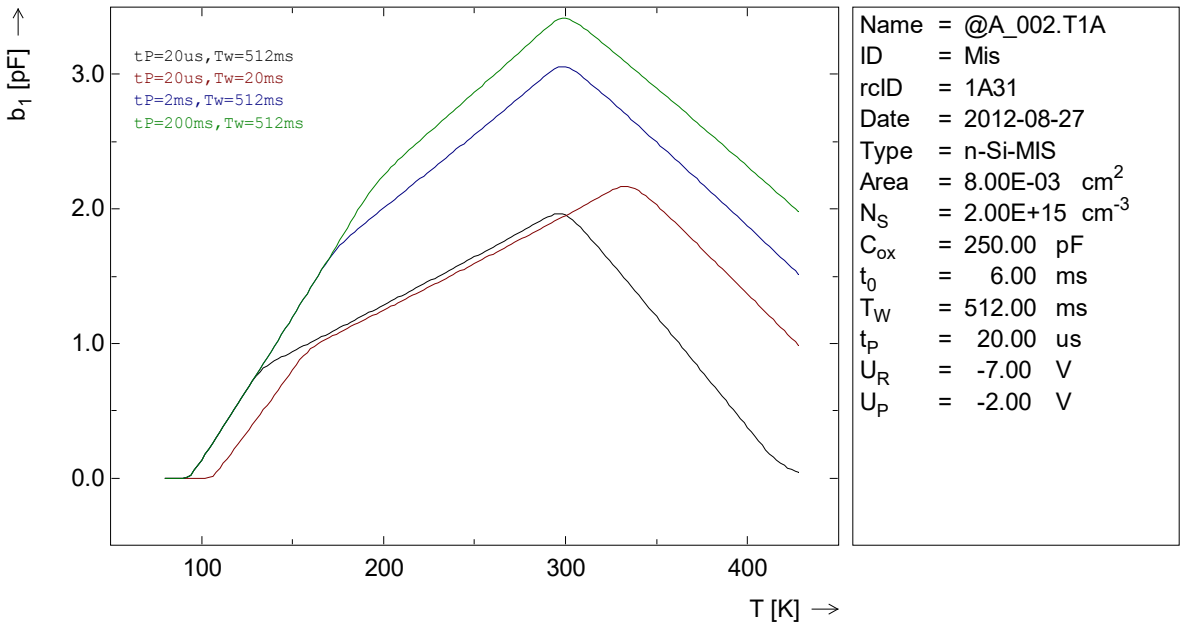


At 'NI*dx' as y-axis you can define how to **calculate NI*dx of tP1/tP2**:

- **Only by difference**: It is only the difference from the curves with tP1 and tP2.
- **Normalized to tP1**: First the difference from curves with tP1 and tP2 will be formed. Then this curve will be normalized to tP1. If the data come only from oxide states then this NI*dx curve should cover the curve of tP1. The normalized curve will be denoted as tP1/2N in a plot. You must know sigma for the normalization.

Using the normalized difference is similar to the standard mode in chapter 6.3.6.1.5.

The following picture shows a **simulation of oxide states** done by routine init file 43, see above. The simulation parameters are a little bit similar as in chapter 6.3.4.3: EFP=0.2eV, EFR=0.7eV, sigma=1E-14, NI*d0=1E12, d0=8nm, dox=116nm.



The top plot shows b1 versus temperature of the 4 files. We observe **3 ranges**:

- b1 increases because E0>EFP, it starts with the oxide states near at the interface.
- The slope of increment will be smaller. All states in the whole filled oxide region contribute to the amplitude, the emission rate is here constant and the amplitude increases only by the temperature.
- b1 falls after reaching EFR because some oxide states are already empty and can not emit. First the states at the interface are empty.

These 3 ranges refers to the ranges b, c and e in 'P. van Staa, H. Rombach, R. Kassing, J. Appl. Phys. 54, 4014 (1983)'. Range c is the standard range where we can do the best evaluation, equ. 2.19 of the Theory Manual describes it.

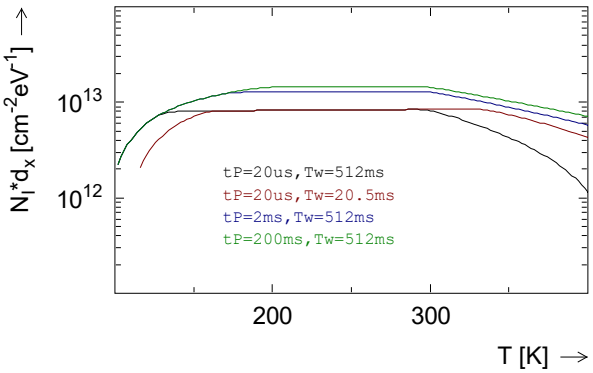
When comparing 2 files with different Tw but same tP (black and red curve) we see that the curve with the smaller Tw increases and decreases later because its medium energy reaches later EFP and EFR. Curves of the same Tw but different tP start at the same temperature (EFP) and reaches at the same temperature its maximum (EFR) because these have the same energy at the interface. The transition from range b to c is for bigger pulse widths at higher temperatures because oxide states deeper in the oxide contributes later to the emission.

b1 increases with the pulse with by ln(tP). Curves of same tP but different Tw should have in the range c the same value. At the example (black and red curve) it differs a little bit because the different Tw/t0 ratio. The difference between tP=200ms and tp=2ms (green and blue curve) is much smaller than the difference between 2ms and 20us (blue and black curve). The reason is that the saturation pulse width is reached before 200ms. As the capture plot in the next chapter shows the saturation pulse width is about 9ms at 250K. Evaluation of this green curve yields to wrong results.

A maximum analysis of the maximum yields to EFR=0.7eV. A 'maximum' analysis of the transition temperature yields to EFP.

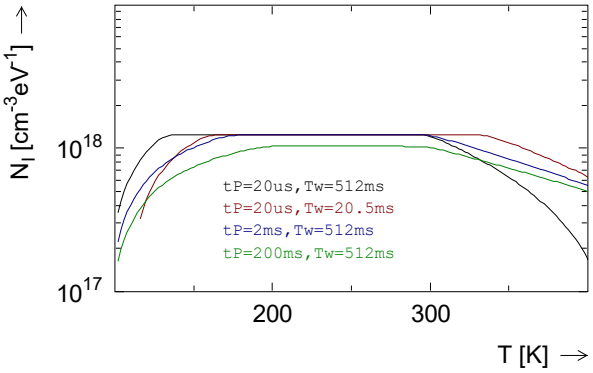
The next picture shows NI*dx versus temperature of all 4 curves.

Curves of same tP but different Tw (black and red) have in range c the same value. In this range NI*dx seems to be constant. But if you select a non logarithmic view then you see a small increment because the small temperature dependence of the capture time constant. The difference between green and blue curve is very small because the saturation is already reached at tP=200ms. Therefore its value is in range c constant.



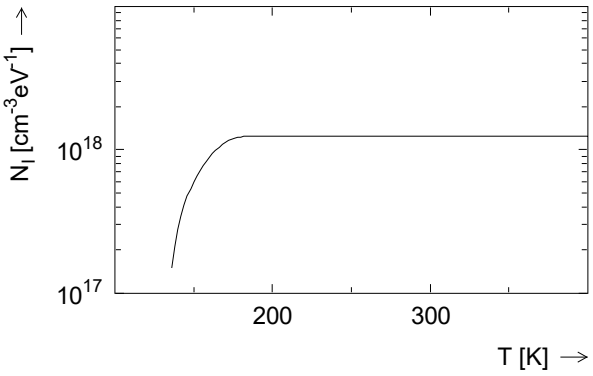
The next picture shows the NI evaluations from NI*dx, it needs sigma and d0.

All curves except the curve at tP=200ms show in range c the same value for NI, here it is really constant. The green curve is already in the saturation so that the normalization by 200ms is too strong. In the both other ranges the calculated NI value decreases. This evaluation is only valid in range b and when not reaching the saturation. An advantage of using 3 pulse widths is the checking of the saturation. If surface states are overlaid then this NI calculation is also wrong.

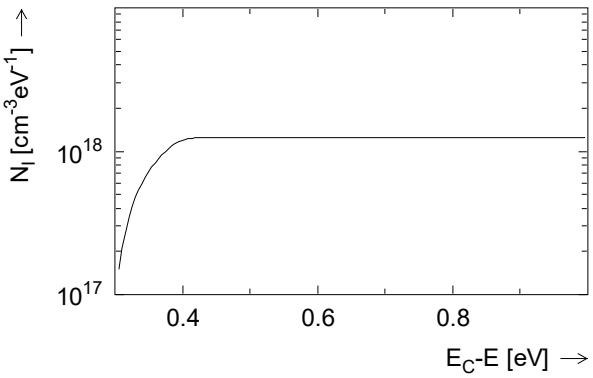


The next plots show NI calculated by NI*d0 from tP1=20us and tP2=2ms.

In opposite to the calculation method above the evaluation from the difference of 2 curves with different pulse widths is also valid in range e. Only if one curve is in range b the calculation is wrong. Further advantages of this method are that you need not the capture cross section and that additional surface states don't yield to bad results. Surface states would give an offset which will be eliminated by the difference. Each curve must not be in saturation.

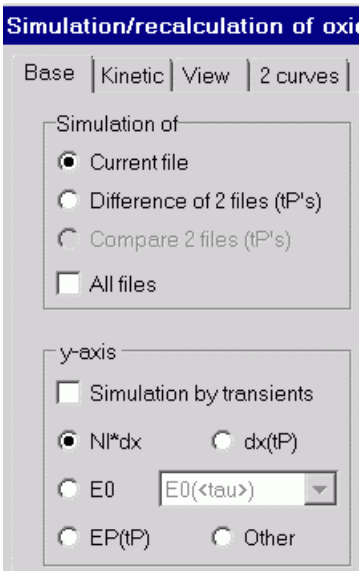


The right picture shows this NI versus the energy. For a better comparison with the Nss plot of chapter 6.3.4.3 here the standard energy by equ. 2.33 instead the medium oxide energy by equ. 2.20 will be used. The oxide correction gives a 0.1 to 0.2eV smaller energy. The maximum of b1 corresponds to an energy of 0.7eV. The NI curves calculated by NI*dx fall after this value. You need sigma for the energy calculation. If you don't know d0 take the NI*d0 plot.



6.3.6.1.2 Simulation/recalculation

Here you can simulate NI*dx and compare it with the measurement. The inputs are similar as for the standard evaluation.



'Simulation of' defines the use of family files:

- **Current file** makes a simulation with the parameters of the current file.
- **Difference of 2 files (tP's)** makes a simulation by the coefficient difference of 2 files with different pulse width as explained above.

Activation of **All files** shows the results of all files but only NI*dx is available as y-axis.

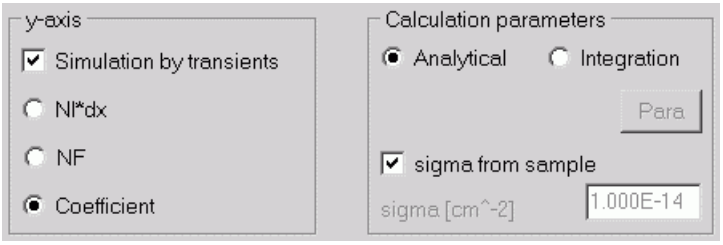
The **y-axis** defines which value will be calculated and shown:

- **NI*dx**: This is the standard.
- **E0**: Calculates the energy at the interface.
- **EP(tP)**: Calculates the energy at the maximum depth within the oxide filled by tP, it is E0-E0c(tP).
- **dx(tP)**: Calculates the maximum depth within the oxide filled by tP.
- Other: Calculates dx/d0, tP/tauC, sigma(dx/2) or the emission range. Here range (a) to (e) will be represented by 1 to 5.

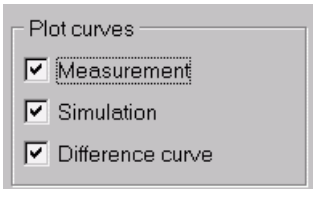
For E0 and EP(tP) following possibilities exist: E0(<tau>), E0(t0), E0(t0+Tw). E0(<tau>) is the standard energy for the expected tau value without oxide correction.
At EP(tP) additionally E0c(tP)=kT*ln(tP/tauC) and E0-E0c/2 can be shown. The last one is the standard energy with oxide correction.

If activating '**Simulation by transients**' the calculation will be done by transient simulation with oxide and surface states and oxide, surface and bulk traps; simulates all ranges of oxide states kinetic. A selected coefficient or from this NI*dx or NF can be calculated.

The tab sheets 'States' and 'Traps' will be visible for the simulation parameters. The calculation can be done analytically or by an integration over an energy and depth range. The last allows the definition of a Nss(E) and NI(E,x) distribution, look in chapter 2.4.2.4 for more information.



If not activating 'All files' then the '2 curves' input sheet is visible. You can plot the measurement, the simulation and/or the difference curve. The view style can be selected as already explained.

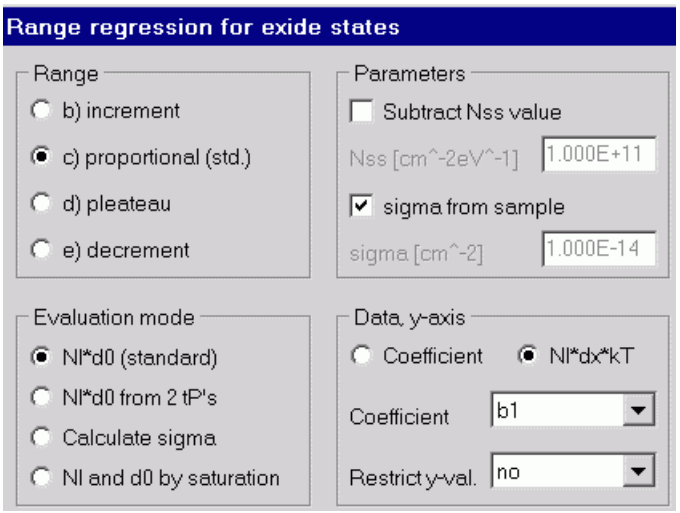


6.3.6.1.3 Range evaluation

The previous sub chapters use for the evaluation only emission range (c) or, at a difference building, range (e). The evaluation was done for each temperature point, so you get for an example a NI*d0 versus temperature curve. The following range evaluation uses for each range a special evaluation which will be done by a linear regression. So you get for the whole range one evaluation value, for example NI*d0. It is only valid for oxide states but not for discrete oxide traps. For more details look in the Theory Manual.

The main input is the selection of **range**, for the definition see next plot:

b) increment: NI*d0, EFP
c) proportional (standard): NI*d0
d) plateau: EFR-EFP
e) decrement: NI*d0, EFR

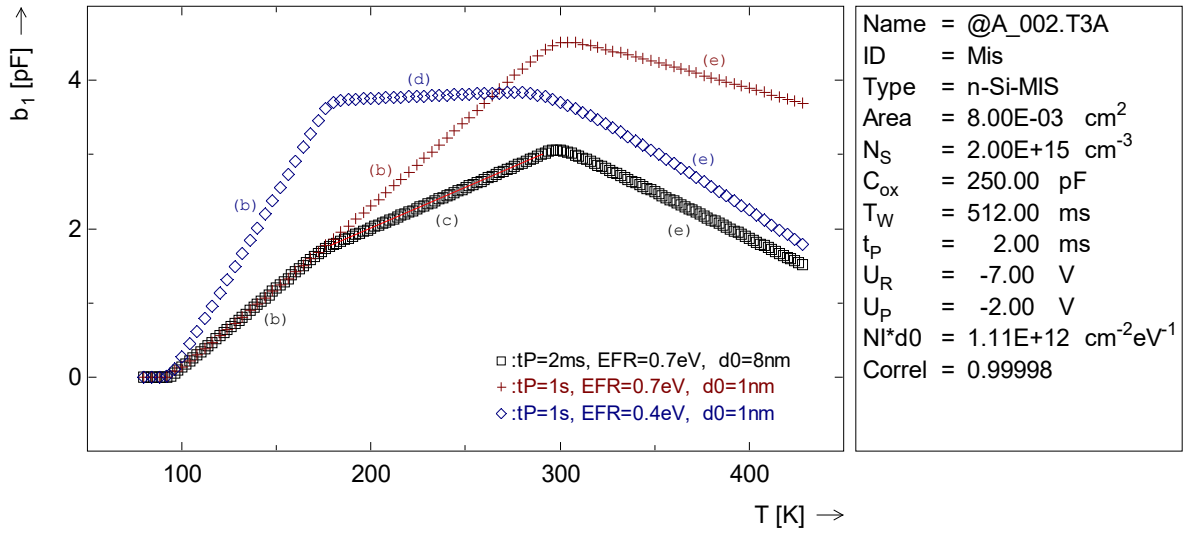


The evaluation values coming from the linear regression were listed behind the double point. Depending on the range special **evaluation modes** exist, for range (c) followings:

- **NI*d0 (standard):** NI*d0 comes directly from the linear regression.
- **NI*d0 from 2 tP's:** NI*d0 will be calculated by the difference of 2 files.
- **Calculate sigma:** Sigma will be calculated with the input of NI*d0.
- **NI and d0 by saturation:** When in saturation you can separate NI and d0.

The 1. and 3. mode is available for range (b), the 1. and 2. for range (e). Using mode 2 you can evaluate over range (c) and (e).
The **y-axis** can be a coefficient or better NF=NI*dx*kT which contains changes of CR.

The following plot shows 3 simulation curves with different tP, EFR and d0. Not all ranges are always visible, it depends on the measurement and sample parameters. The range will be denoted in brackets. A linear regression over range (c) was done for the black curve (bright red line). The results are not 100% accurate because a temperature range contain also contributions of the other emission ranges.



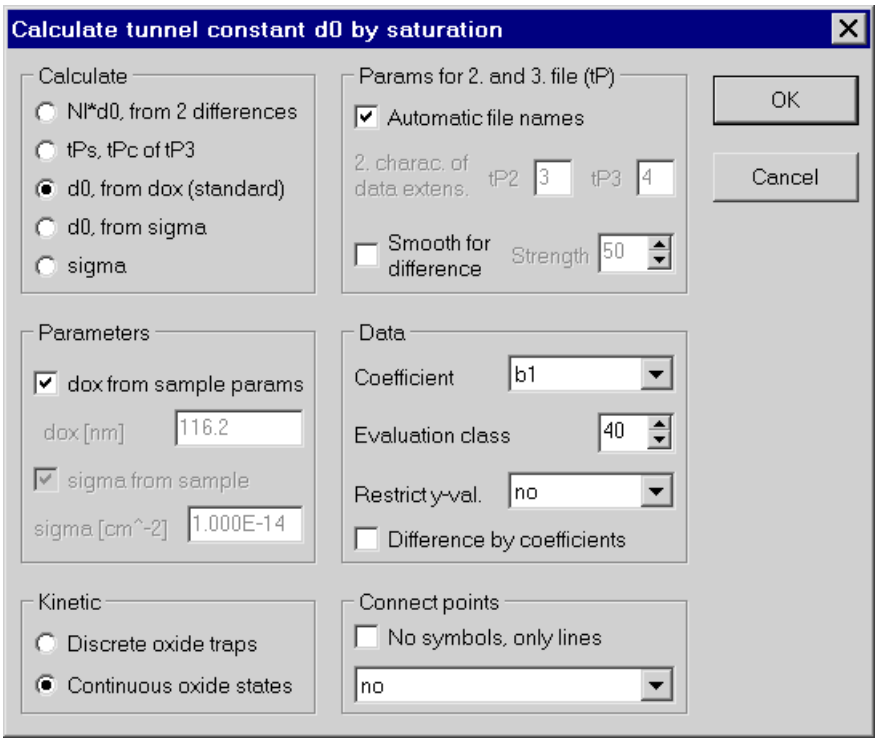
6.3.6.1.4 Tunnel constant

The 'tunnel constant' d0 can be calculated by the saturation pulse width tPs. 3 files with different pulse widths are necessary, tP3 must be bigger than tPs. Then the difference of tP1/2 gives the correct value for NI*d0. The difference of tP2/3 must be smaller because tP3 is bigger than tPs, this yields here to a 'wrong' calculation of NI*d0. We can normalize this difference to that one from tP1/2 by calculating a special value for tP3. This value is tPs because we assume that the 3. file is in saturation. At the saturation is NI*dx=NI*dox. We can calculate d0 by NI*d0 from the difference tP1/2.

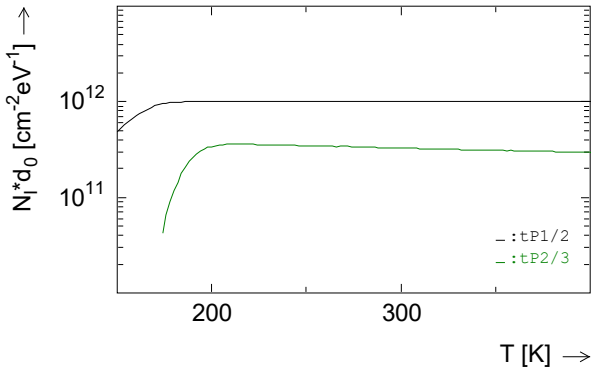
Calculate defines the shown value:

- **NI*d0, from 2 differences**: Compares the difference of tP1/2 with that from tP2/3.
- **tPs, tPc of tP3:** Shows the calculated saturation pulse width of tP3.
- **d0, from dox (standard)**: Calculates the tunnel constant by dox as explained above, this is the standard and best method.
- **d0, from sigma**: Calculates d0 by NI*d0*ln(tPs/tauC), needs sigma. It is not so accurate and more for a comparison.
- **sigma**: Similar as before but calculates the capture cross section.

The other parameters are similar as above. You can input the thickness dox or apply it from the sample parameters, see chapter 6.3.2.4.
When selecting tPs as y-axis you can activate a special flag. Then only calculated tPs values (tPc) will be shown which are smaller than 0.5*tP3. This restriction will be used always for the standard d0 calculation



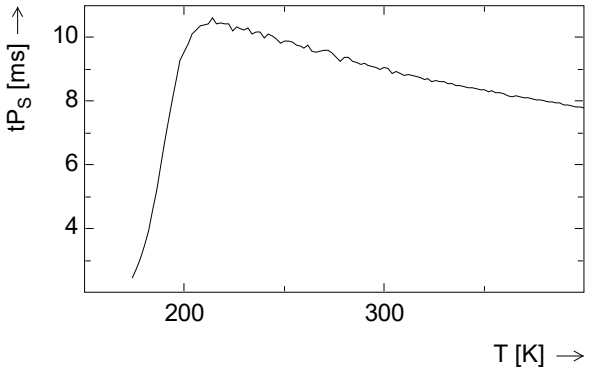
The next plots use the simulation from chapter 6.3.6.1.1 with tP1=20us, tP2=2ms and tP3=200ms.

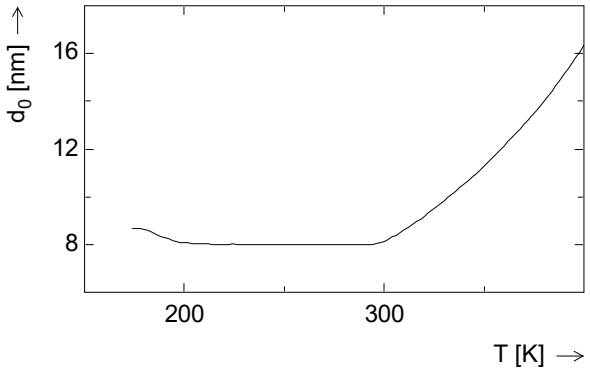


The left plot shows NI*d0 by the differences tP1/2 and tP2/3. The 2. (green) curve is smaller than the first one because tP3 is bigger than tPs. Only the first curve matches the given NI*d0 value. The calculation is only valid in the range (c) and (e) but not in range (b) at low temperatures.

The top plot on the right shows the calculated saturation pulse width tPs versus temperature. The calculation is also valid only in the ranges (c) and (e). The increment below 210K is an artifact because the calculation was done here in range (b). You can avoid showing the artifacts by the y-restriction.

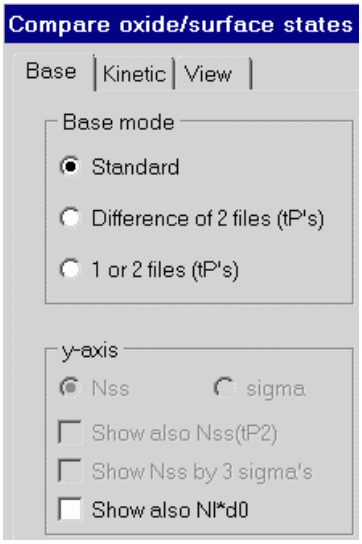
The bottom plot shows the standard calculation of the tunnel constant d0 versus temperature, the given value was 8nm. The calculation is only valid in range (c) because it uses the NI*dx curve of tP3, see green curve in chapter 6.6.6.1.1. It is the temperature range from 210K to 300K. The increment above 300K comes from the 'wrong' evaluation of range (e). A calculation of d0 with a given sigma is also valid in range (e) but is in the practice not so accurate.





6.3.6.1.5 Compare oxide/surface states

This is an important tool to separate oxide states and surface states and to check this results. 2 tempscan files with same Tw but different pulse width are necessary. Many inputs are similar as for the standard evaluation.



The **base mode** defines the comparison or the type of check:

- The **Standard** mode calculates NI*d0 by the difference of 2 tP's, this result will not be effected by surface states. NI*dx of tP1 will be calculated by this result. The difference of this calculated and the measured curve is Nss of the surface states. NI*d0 can optionally be shown.
- **Difference of 2 files (tP's)** calculates Nss or sigma by the coefficient difference of 2 files with different tP's as explained in the standard mode. The input of sigma resp. Nss is necessary. This mode is better than the next.
- **1 or 2 files (tP's)** calculates Nss or sigma from 1 or 2 files width different pulse width. The input of NI*d0 and of sigma resp. Nss is necessary.

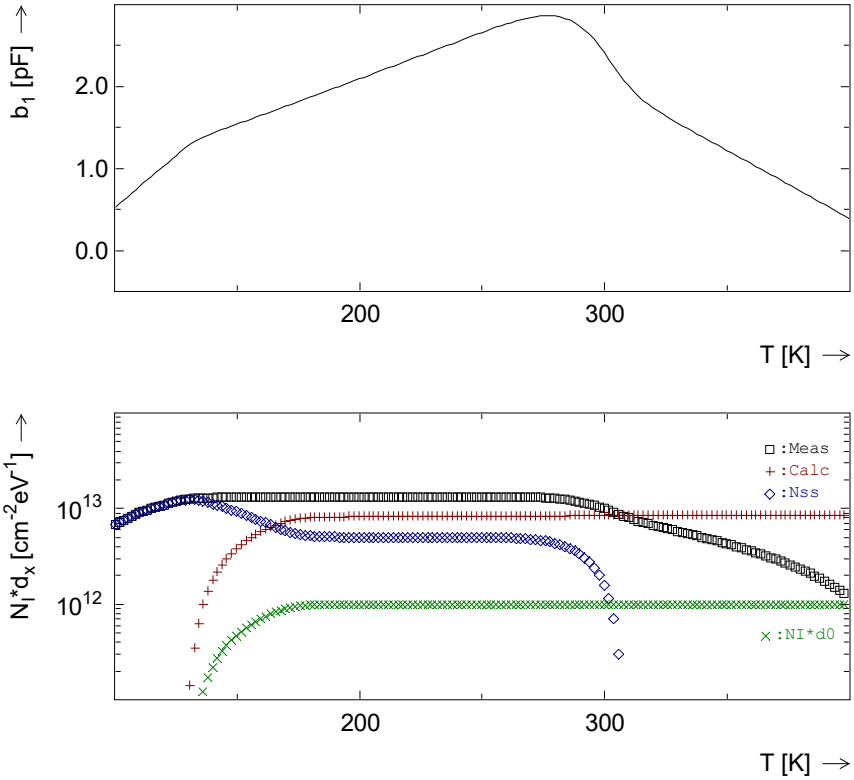
The standard mode shows how Nss was calculated. The other both modes enable a check of the Nss calculation. Here you can select Nss or sigma as **y-axis**.

When selecting **Nss** then you can compare Nss(tp1), means Nss calculated by tP1, with **Nss(tP2)**. Both should be identical but you have as input parameter the capture cross section. When this is wrong you get bad results. The option '**Show Nss by 3 sigma's**' demonstrates the influence of sigma on the Nss calculation. Nss(tP1) and Nss(tP2), when selected, will be shown by a calculation of 3 different capture cross sections. The 2 additional sigma's are a factor of 10 smaller resp. bigger as the input value. Optionally you can select 2 fix values of 1E-17cm^2 and 1E-13cm^2.

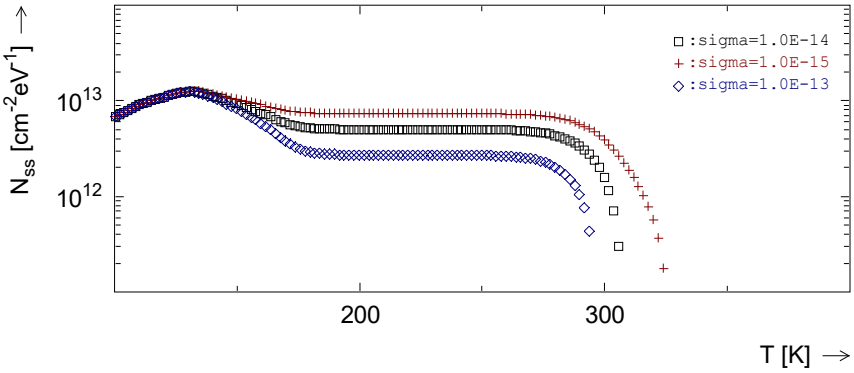
Sigma is necessary for the NI*dx and therefor for the Nss calculation. Calculating of sigma can be helpful to check the results for Nss. You can compare sigma(tp1), means sigma calculated by tP1, with **sigma(tP2)**. Both should be identical but you have as input parameter Nss. Start with the Nss value from the standard mode and check then how sigma changes by another Nss input. Is sigma in a physical sensible range? The option '**Show sigma by 3 Nss's**' shows sigma(tP1) and sigma(tP2), when selected, by a calculation of 3 different values for Nss. The 2 additional sigma's are a factor of 2 smaller resp. bigger as the input value. Optionally the 2 additional Nss values can be a factor of 5 smaller resp. bigger.

The next plots are a simulation with oxide and surface states, where NI*d0=1E12, Nss=5E12 and sigma=1E-14. The parameters are the same as used in chapter 6.3.6.1.1.

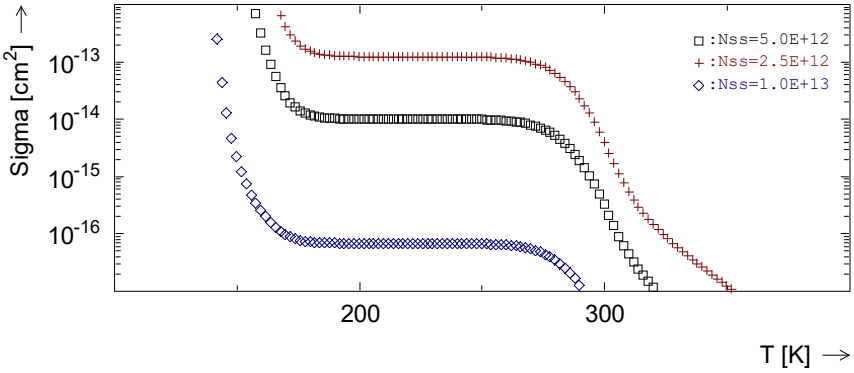
The top plot shows b1 versus temperature. The bottom plot is the standard mode for the separation of oxide and surface states as explained above.
The black squares denote NI*dx of the measurement of tP1, the red crosses are NI*dx calculated by NI*d0 and tP1.The difference of both curves are the surface states Nss (blue diamonds). Additionally the calculated oxide states NI*d0 will be shown by green crosses.
The Nss calculation is only valid in emission range (c) while NI*d0 is also correct in range (e).



The top plot on the right demonstrates the influence of sigma on the Nss calculation, 3 values of sigma will be compared: 1.0E-14 (black squares), 1.0E-15 (red crosses), 1.0E-13 (blue diamonds).



The next plot is for checking the results of the Nss calculation. Sigma was calculated by Nss coming from the standard mode (black squares) and then varying by a factor of 1/2 (red crosses) and 2 (blue diamonds). Bigger variations yield to not sensible values of sigma.



6.3.6.2 Capture cross section

Following **methods,** similar to chapter 6.3.4.4, exist for calculating the capture cross section of the oxide states at a logarithmic emission transient:

1. The **capture** process of oxide states yields to a logarithmic transient. You can calculate sigma by a capture measurement as described below. This is the best way.
2. If NI(E) shows a distribution with a distinct **maximum**, a maximum analysis yields to the capture cross section and the energy of the maximum.
3. Same as 4 but uses the increasing at **EFP** (range b).
4. From the '**fall down**' of the Nss(Coef) versus temperature curve (range e) because reaching of **EFR** you can define a time constant. Search the temperature where Nss(Coef) reaches 50% of its value. Physically this is more correct as using directly the coefficient maximum because the coefficients increase with temperature.
5. In the '**maximum**' of the temperature curves because reaching of **EFR** (range e) you can define a time constant. Using different temperature curves (coefficients) you get an Arrhenius plot and as result the capture cross section. This search is easier than method 4 but it is physically not correct because the coefficients increase with the temperature. Therefor we use here a numerical correction which corrects the time constant for the maximum.

For method 1 you need a capture measurement in the isothermal or in the transient program module. The other methods will be done on tempscan files with constant period width in the Maximum Analysis. Here it is helpful to have 2 tempscan files width different period width because the longer temperature range in the Arrhenius plot. Select in method 3 UP and in methods 4 and 5 UR so that you see the increasing resp. decreasing.

6.3.6.2.1 Sigma by capture measurement

As shown in the Theory Manual the capture transient of oxide states follows a logarithmic time law. So you have to measure a **logarithmic capture transient**, 2 possibilities exist:

- **Direct** measurement of the capture transient in the transient module as explained in chapter 3.2.1.5. Problems in accumulation at MIS are possible.
- **Indirectly** by measurement of the emission amplitude at a logarithmic variation of pulse width in the isothermal module. The principal is similar as described in chapter 3.3.6.1 but for oxide states you need a logarithmic variation of tP.

Usually we prefer the indirect method but at oxide states it has the problem of the very slow emission. A measurement point of the isothermal variation can be effected from that ones before because the not complete emission. For more details and how to minimize this effect look in chapter 6.3.4.4.1. For the indirect method select in the isothermal measurement menu 'Fix period width' → 'Variation of tP, log'.

The direct method avoids this effect. Use here as time axis 'logarithmic' and as pulse mode 'at pulse' and 'compensation at UP'. Don't average, measure until the pulse width saturation if possible. Wait manually with the measurement start until the emission, done by the compensation at UP, is finished. The disadvantage of the direct method is that you should know the energy interval. But it is only necessary for the calculation of the concentration but not for the calculation of the capture cross section.

But at MIS samples there is an additional disadvantage of the direct measurement, it may not be possible in accumulation (flat C/V curve). The capacitance will here be dominated by the oxide capacitance. A change in the transient is here not really visible. On the other hand a pulse voltage in accumulation is usually necessary. So here you have to compare direct and indirect measurement and to decide whether the direct measurement works.

After you have done a capture measurement you have in the 'Evaluate' menu the entry **'Capture evaluation'.** The face of its input window differs a little bit when making the direct measurement in the transient module or the indirect one in the isothermal module. The following example is from the isothermal module.

At the **Kinetic** input you have to decide between oxide traps and states:

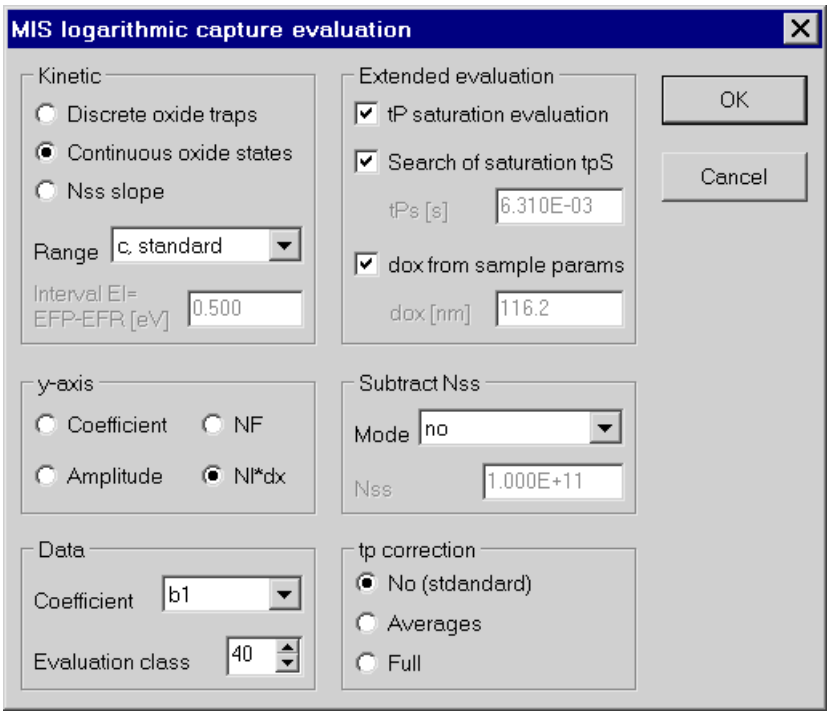
- **Discrete oxide traps** (NIT) with a discrete energy level, see also chapter 6.3.6.4.
- **Continuous oxide states** with an energy distribution (NI), the standard mode.
- **Nss slope** calculates only slope, offset y0 and tau by a linear regression. It will be calculated for ln(tP) not for log10(tP) as the shown curve.

The kinetic input group differs between the indirect and direct method (see below). The emission kinetic will be used at the indirect method.

Select the emission range where the transient comes from. The standard is range (c). If the emission comes from range (e), this is the decrement in the tempscan, then NI*d0 and EFR can be calculated but not sigma.

You can select as **y-axis**:

- Coefficient
- Amplitude
- NF=NI*dx*kT
- NI*dx (default)



Select in '**Data**' the coefficient for the calculation and the minimum evaluation class. The data and tP correction input group are not visible at the direct method.

An extended evaluation is possible by activating '**tP saturation evaluation**'. Then the pulse width tPs where the curve goes into the tP saturation will also be used for the evaluation which enables the separation of NI and d0. Either the software searches tPs or you input it. For this calculation the oxide thickness dox is necessary. You can input it or it will be calculated (taken) from the sample parameters, see chapter 6.3.2.4.

If surface states overlay the oxide states then your calculation of capture cross section is wrong because it will be calculated from the offset of the linear curve. The calculation of NI*d0 is further correct because it uses the slope of the linear regression. In the case of overlaying surface states try to **subtract a Nss** (means NI*dx) value from the curve:

- **no** value will be subtracted, this is the standard mode.
- **input of Nss** resp. NsT value which will be subtracted.
- **input of tP**, the value at this pulse width will be subtracted from all points.

The software offers a **tP correction** which correct the tP-axis at a non complete emission:

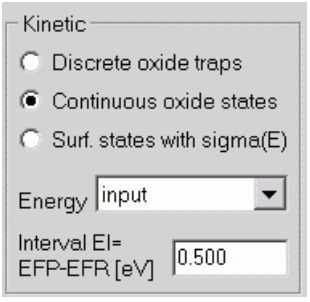
- **No (std.):** No correction of the pulse width axis, this is the standard.
- **Averages:** Only correction at averaging. The software uses the ratio total emission charge to charge at Tw for adding a part of the current pulse width.
- **Full:** As before but makes additionally a correction by the previous pulse widths. That is not very accurate because a repeating of measurement (bad range or amplification) can not be taken into account.

Be careful with this correction because it is not exact, it is more an estimation for seeing the influence of the emission. This correction is only available for the indirect measurement method, for the direct method it is not necessary.

For the indirect capture measurement select UP and UR so that your emission is for all oxide states between EFP and EFR, this yields to the emission range c as explained in the previous chapter. A correct calculation is only possible in this range. Try to measure until pulse width saturation. Select the period width so big that an average is not necessary. Don't activate the flag 'Measure C/V points' for MIS samples, see chapter 3.3.1.2!

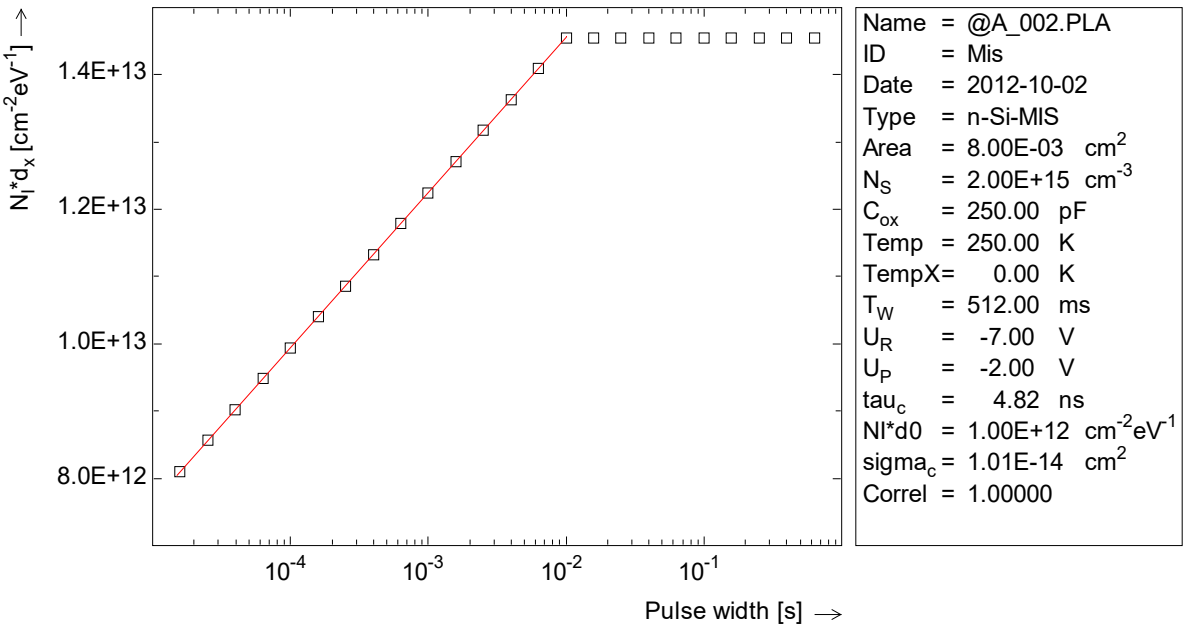
At the direct method the capture kinetic will be used and the Kinetic input group shown on the right is visible. When selecting the kinetic for continuous oxide states then you have to input the **energy mode** which defines the energy interval EFP-EFR:

- **1 eV**, it selects a normalized view.
- **input of EI**, input of the energy interval EFP-EFR.
- **Nicollian calcul.**, calculation of EFR and EFP by Nicollian, see chapter 6.3.5.3.
- **read calib table**, see chapter 6.3.5.3.



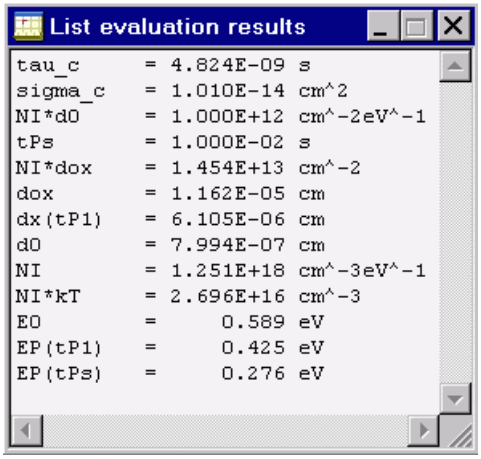
Tip: Use the direct capture measurement for the calculation of the capture cross section but it may not be possible in accumulation. So compare direct and indirect measurement. Measuring until saturation is the only way to calculate d0 and so to separate NI*d0. Usually you don't know the energy interval, so that you can not calculate NI at the direct measurement. For the NI calculation use an emission transient or tempscan.

The following picture shows an indirect **capture simulation of oxide states**. The simulation parameters are as in the previous chapter. The temperature was 250K so that emission range c will be used. The measurement was done until the saturation, this enables the extended evaluation.



NI*dx versus the logarithmic pulse width gives a linear curve which can be evaluated by the linear regression. From the slope we get NI*dx, from the intersection the capture time constant and therefore the capture cross section. Saturation will be reached at about 9ms. dx is about dox at the saturation. In opposite to the capture of surface states a capture cross section of 1E-14 cm^2 can be measured without fast pulse generator because the capture of oxide states follows a logarithmic time law.

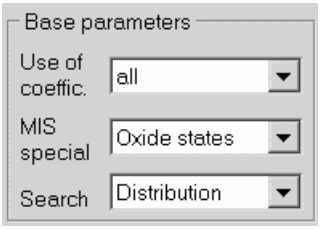
If selected the extended evaluation then you get all evaluation values in a special text window. For this option select in the Evaluate menu of the plot program 'List results', see chapter 5.1.5.
Additionally to the text header of the plot NI and d0 will here be calculated with the help of the saturation pulse width tPs. dox will be taken from the input or sample parameter set. dx(tP1) denotes the filling depth within the oxide at the first pulse. E0 is the medium energy at the interface, EP(tP1) is the energy at dx(tP1) and EP(tPs) is the energy at dx(tPs)=dox.



6.3.6.2.2 Sigma by Maximum Analysis and Arrhenius plot

You can define an emission time constant in the **distinct maximum** of a NI(E) distribution (method 2), from the increase at **EFP** (method 3), from the **'fall down'** of Nss(Coef) versus temperature (method 4) and from the **maximum** of temperature curves because reaching of **EFR** (method 5). Using different temperature curves (coefficients) in the maximum analysis you get an Arrhenius plot and from this the capture cross section and the method depending energy. It is the energy in the maximum of distribution or EFP or EFR. The accuracy of evaluation increases by using 2 period widths. At method 2 to 4 the y-axis for the maximum analysis is Nss(Coef), means Nss calculated from the selected coefficient. It will be called Nss but it means here NI*dx and is identical with NI*dx as explained in 6.3.6.

For this method call the maximum analysis, see chapter 4.1. The easiest way is here to select the **MIS special** mode on the Base input sheet.



No, as usual: No special mode will be set, you have select manually the correct y-axis and search type.

Surface states: For surface states, see chapter 6.3.4.4.2.

Oxide states: Special mode for oxide states, enables a second input for the search by the various methods, see below. All these methods use the expected tau value of a logarithmic transient for the time constant.

Surface traps: Special mode for surface traps, see chapter 6.3.4.4.2.

Oxide traps: Special mode for oxide traps with a discrete energy. Search the temperature where the increasing of NF=Nss*kT=NIT*dx reaches 50% of the plateau value, see chapter 6.3.6.5.

For the mode 'Oxide states' following **search** modes exist:

Distribution: This is method 2 in the list of chapter 6.3.6.2. Each coefficient will be shown temperature normalized (means Nss(Coef)) versus temperature. The maximum of the curves must be defined similar as at a trap level. The Arrhenius plot yields to sigma and the energy in the maximum of the Nss(E) distribution. This evaluation is only valid when a distinct maximum in the Nss(E) distribution exist.

Increment at EFP: Method 3 is similar to method 4 but here the temperature to the 50% increase of the Nss(Coef) curve will be defined. In the plot above it is at about 100K. The results are sigma and EFP.

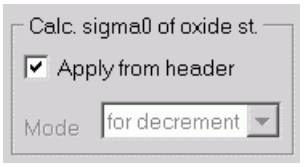
Dec. at EFR, 50%: At method 4 you have to define the temperature where the Nss(Coef) curve falls down to 50%. A cross marks the position where the y-value is 50% of the maximum, starting from high temperatures. The results are sigma and EFR. This method is more accurate as method 5 because it is physically more correct. The disadvantage is that it can be difficult to find the 50% point, the searching of a maximum is easier.

Dec. at EFR, maxi: Method 5 is similar to the standard maximum analysis. You search the maximum of NF(Coef)=Nss*kT versus temperature for each coefficient. These curves are the coefficients normalized by amplitude and CR, but not by temperature. You see here a maximum, as in the not normalized temperatures curves. This method is easier than method 4 but it is physically not correct because the coefficients increase with temperature. Therefor we correct here numerically the time constant for the maximum which needs some time.

The **Arrhenius plot** of method 5 gives the correct capture cross section sigma0 which is independent from the pulse width.

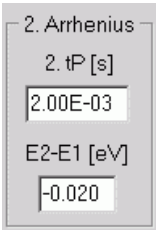
Method **2** to **4** yields to a bad capture cross section which depends on tP and is much smaller than sigma0, we call it here sigma(tP). Unfortunately it is not sigma(dx/2) where dx=ln(tP/tauC) and sigma(x)=sigma0*exp(-x/d0), see Theory Manual. Nevertheless we assume first that sigma(tP) is sigma(dx/2). From this we can calculate numerically sigma0. The calculated value is often too high but much better than sigma(tP). Generally the error is smaller at shorter tP's. If you make the maximum analysis by the MIS special mode, this sigma0 value will be listed additionally to the original sigma value, means here sigma(tP).

When using method 2 to 4 of the special MIS mode the corresponding correction will be automatically done at all Arrhenius plots. At the Evaluation 'Arrhenius, one level' there is an input group for **calculating sigma0 of oxide states** visible. 'Apply from header' sets the correction mode by the used method in the maximum analysis. If this flag is deactivated, the correction mode can be input:



No: Sigma0 will not been shown.

Correct energy: Energy and sigma correction by 2 Arrhenius plots at different tP. The current plot must use the smaller tP. You have to input additionally the 2. tP and the energy difference between Arrhenius plot 2 and 1, it can be negative or positive. Sigma0 will also be shown. Put in the full energy difference at method 2 but only the half at method 3 and 4. Use this correction only at bigger E2-E1 values.



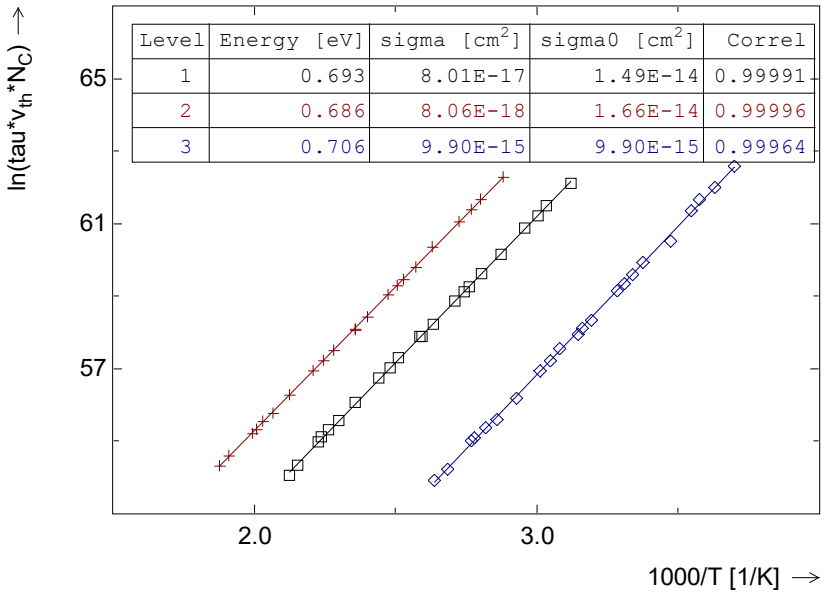
For distribution: Use it at an energy distribution, calculates sigma0 by sigma(dx/2).

For increment: For method 3, sigma0 as above and additional correction.

For decrement: For method 4, sigma0 as above and additional correction.

Note: When you don't have sigma0 but only sigma(tP), then don't use the oxide correction for the energy, see chapter 6.3.6.1. The energy with oxide correction and input of sigma0 is the same as the energy without oxide correction and input of sigma(dx/2).

The next plot demonstrates methods 4 and 5. The data are as in chapter 6.3.6.1.1. The black squares denote method 4 with tP=20us, the red crosses method 4 with tP=2ms and the blue diamonds method 5 with tP=20us. Sigma directly coming from the Arrhenius plot is much smaller than the given value of 1E-14. The error in sigma and energy is higher at longer tP's. The best result yields method 5. sigma is here about the given value, a sigma0 correction will not be done.



Level	Energy [eV]	sigma [cm^2]	sigma0 [cm^2]	Correl
1	0.693	8.01E-17	1.49E-14	0.99991
2	0.686	8.06E-18	1.66E-14	0.99996
3	0.706	9.90E-15	9.90E-15	0.99964

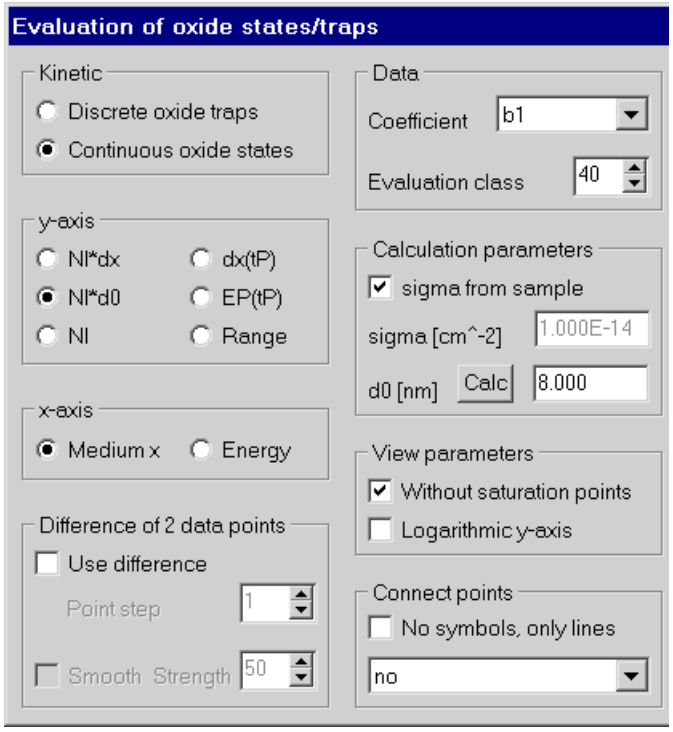
6.3.6.3 Isothermal oxide states evaluation

When measured a logarithmic capture transient, you can make a capture evaluation, as described in chapter 6.3.6.2.1, or an '**Oxide states evaluation**'. You find this function in the evaluation menu of the isothermal and transient program. Here not the capture cross section will be calculated but NI*d0 or other values shown versus energy or depth x in the oxide. Following input window opens in the isothermal program module.

Select as **y-axis**:

- **NI*dx**: Shows NI*dx versus tP.
- **NI*d0**: Shows NI*d0 versus dx/2 or E0-E0c/2.
- **NI**: Shows N versus dx/2 or E0-E0c/2, needs the input of d0.
- **dx(tP)**: Calculates the maximum depth within the oxide filled by tP.
- **EP(tP)**: Calculates the energy at the maximum depth within the oxide filled by tP.
- **Range**: The emission range (a) to (e) will be represented by 1 to 5.

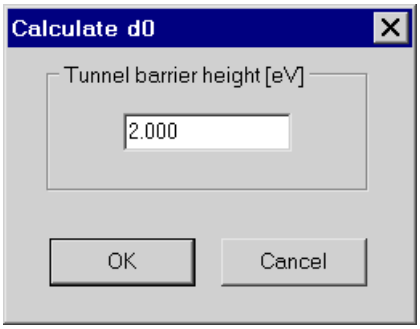
If selecting NI*d0 or NI, then the **x-axis** can be the medium x-distance from the interface, means dx/2, or the medium energy E0-E0c/2, see equ. 2.20. The last one is the standard energy with oxide correction. When measuring directly a capture transient the x-axis is only dx. The x-axis for the last 3 plots is the pulse width.



It is possible to build point by point the **difference** of 2 data points. The distance or energy is then the medium value between these 2 points. The point step defines how many data points are between these each 2 points. You can smooth the data before the difference building.

'Without saturation points' don't show data points which are in saturation.

The **tunnel constant** d0 is necessary for calculating dx. You can directly input this value or click onto the 'Calc' button. Then opens a window with the input of the tunnel barrier height. d0 will be calculated from this value by clicking onto the 'OK' button.

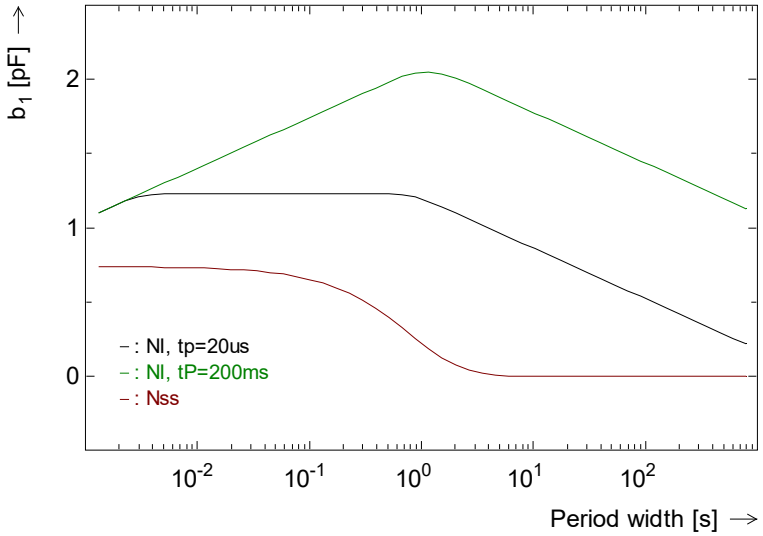


6.3.6.4 Period scans at oxide states

An important isothermal measurement could be the **period scan**. But as described in chapter 3.3.1.2 problems can occur because the not complete filling and the different numbers of averages. To reduce these problems use waiting times, mode Tw/t0=4 and oversampling without averaging, means setting 'Min. measure time' to zero. Then only 3 or 4 'big' transients will be really measured while the other ones will be created from these. Such an application measurement with 2 pulse widths is predefined (chapter 3.3.1.4).

The isothermal period scan evaluation for oxide states is similar as for tempscans described in chapter 6.3.6.1. For using this option select as Transient evaluation 'Log., surface/oxide states'. The standard plots have no special evaluation for oxide states but show as evaluation value Nss which is NI*dx. In the Evaluate menu are the sub menus 'Surface states evaluation' and 'Oxide states evaluation'. In the last are: Standard evaluation, Simulation/recalculation, Range regression, Oxide/surface states.
The plots are similar as at tempscans. The x-axis is either the expected tau-value or the energy. But here the energy range is much smaller than at a tempscan.

The plot on the right shows a simulation which compares period scans of oxide states (black and green curve) and surface states (red curve). The parameters are similar as in the previous chapters but now EFR=0.6eV and EFP=0.3eV.

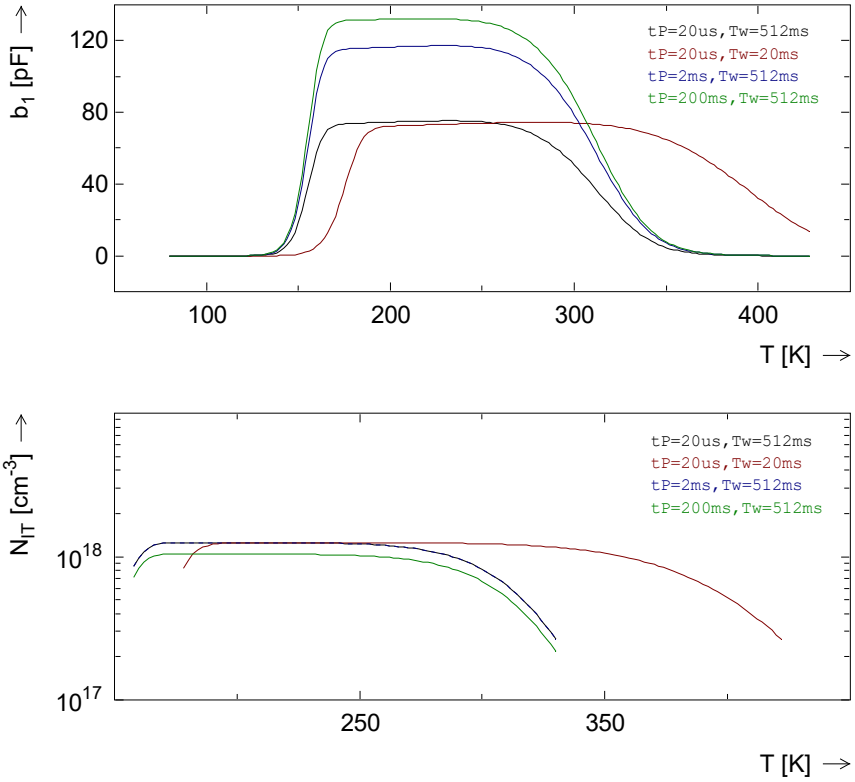


6.3.6.5 Oxide traps

Oxide traps can be treated as a special case of oxide states. These have a discrete energy level, its concentration is N_{IT} in cm^-3. The emission and the capture transient fallows a logarithmic time law. The evaluation can be done analog to the oxide states as discussed before, you have only to select as **kinetic** 'Discrete oxide traps'. Nss (resp. NI*dx) plots are not valid for oxide traps because the temperature division. Select here NF=Nss*kT which is here NIT*dx. Tempscan measurements should be done by 2 or more pulse widths and 2 period widths, routine mode 43 covers oxide states and traps.

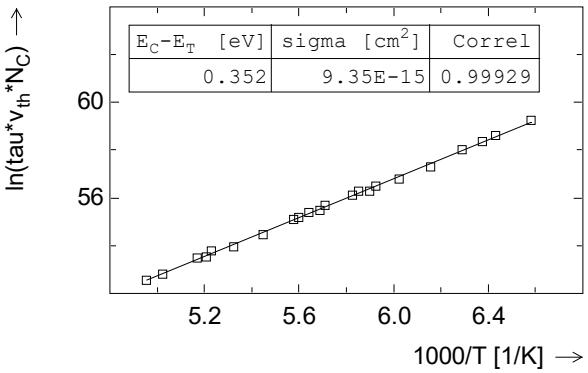
The following oxide traps **simulation** uses similar parameters as for oxide states, the trap energy EC-ET is 0.35eV.

b1 'jumps' to a plateau value when the medium energy is bigger than 0.35eV. The red curve with the smaller Tw increases later because its energy reaches later EC-ET. The plateau height depends on the pulse width. b1 increments a little bit at the plateau except the green curve which is in saturation.
The bottom plot shows NIT calculated for all 4 curves. The curves with tP=20us and tP=2ms are identical. Calculation from the difference of these 2 curves yields also to the same result, use this because the discussed advantages.



The trap energy can be calculated by the **maximum analysis**. Because there is no maximum you have to select as type for auto search 'left 50%' (chapter 4.1.1.1). Then the software takes the temperature where the left branch (jump) has 50% of the plateau value. The easiest way is to select 'Oxide states' as MIS special mode, see chapter 6.3.6.2.2.

The results of the Arrhenius plot done by maximum analysis are quite good. The capture cross section is not so accurate as a maximum analysis of a bulk trap because the selection 'left 50%' is only an approximation to the theory. In opposite to oxide states sigma coming from the Arrhenius plot don't depend on tP, so it is sigma0.
Don't select as normalization 'Nss-log' and as search 'maximum'. This gives a maximum because the temperature division but the energy is 10% too high.



6.3.6.6 Comparison

Emission transients of oxide states have **2 properties** which can yield to problems:

- The **emission time** is very long. This is also at surface states but at oxide states it is usually stronger. So the emission is not finished after measuring the transient.
- The amplitude depends on the **pulse width** also at long pulses. The oxide are usually not filled by one pulse. When averaging then the oxide states will be more filled by each repetition.

These 2 facts can give **problems** especially at:

- If comparing 2 Tw's then the number of averages differs because the fix maximum measurement time. The 'effective' pulse width can be up to 100-times higher for a 100-times smaller Tw.
- By 2 or more files in one temperature cycle the measurement of the 2. file can be effected by the 1. one. Use as first the smallest pulse width to reduce this effect.
- Capture measurements need not a fast pulse generator but the data points of the indirect measurement can be effected from that ones before.
- A period scan can show jumps because the different numbers of averages.
- A separate bias regulation at CC-DLTS tempscans yields to problems because the emission of 1. file is not finished while the regulation would be done for the 2. one.

How to reduce or avoid these problems look into the corresponding chapters.

In this manual we call surface states also interface states. In some publications means interface states as well surface states as oxide states. We distinguish between oxide states and oxide traps. In most publications no distinction will be done for both expressions. Oxide states will also be called isolator states.

Traps, surface states/trap and oxide states/trap have different **time laws** for the transient and other properties. The following table is only a short approximation:

Type	Conc. [dim.]	Cap.	Emi.	Tempscan	PeriScan	tP>100us	UR,UP
Bulk traps	N_T [cm^{-3}]	exp	exp	peak	peak	const.	inc
Surface traps	N_{ST} [cm^{-2}]	exp	exp	peak	peak	const.	jump
Surface states	N_{SS} [$cm^{-2}eV^{-1}$]	exp	log	inc*, inc, dec*	plateau	const.	shift
Oxide traps	N_{IT} [cm^{-3}]	log	log	plateau	plateau	inc	jump
Oxide states	N_I [$cm^{-3}eV^{-1}$]	log	log	inc*, inc, dec	inc*, fix, dec	inc	shift

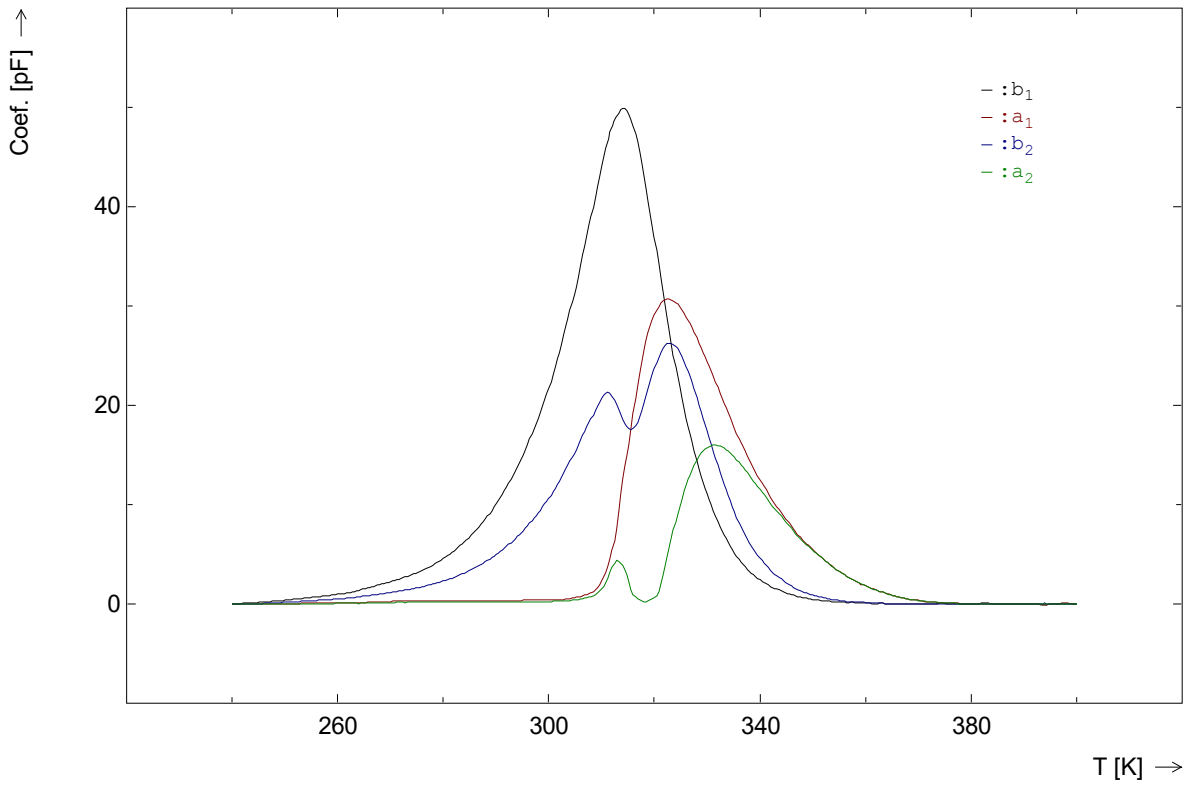
'Plateau' means a fast increment to a fix value where it stays at T resp. Tw range, after this it decreases. 'Inc.' denotes an increment with T, tP, UR or UP where '*' denotes a strong increment. A 'jump' means a strong increment to a fix value where it remains. 'Shift' denotes a jump but the point of jump depends on UR resp. UP. At the tempscan 3 ranges were listed. 'tP>100us' marks an influence of the amplitude for tP>100us. It is not valid for very small capture cross sections.

The emission of oxide states is complex and may not follow a pure logarithmic time law but in most cases the transient is a logarithmic one or likes a logarithmic one. Oxide states are often be overlaid by surface states.

6.3.7 Inversion and linear transients

The Fourier transformation evaluation of transients for DLTS can, in addition to being able to assist with the classification of transients for different time laws, provide further information when evaluating linear transients. Linear transients are formed from processes such as inversion by diffusion from the bulk. A linear transient will yield specific peak shapes and combinations from different Fourier coefficients. With the first order coefficient one peak is formed, and two peaks are formed with the second order coefficients. So, if two peaks are observed in the a1 or b1 coefficient plots then it is possible to determine that there are either two levels or contributory processes. However, only one peak in the a1 or b1 coefficient but two in the a2 or b2 plots indicates that inversion processes dominate the generation.
At the routine tempscan measurement there is the special MIS mode 41 '1 FixTw, Nss only'. It can also be used for the linear inversion process.

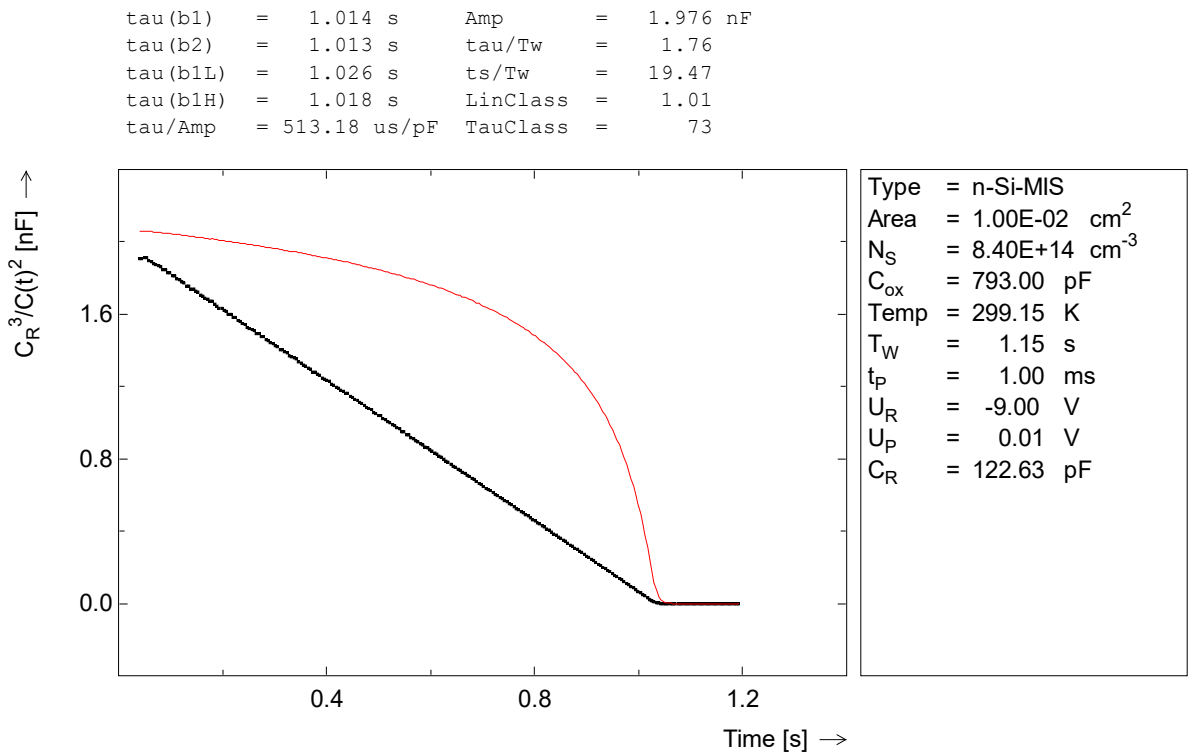
The following picture shows a tempscan with an inversion process which yields to **linear transients** (volume generation). You see one peak in the first order coefficients b1 (black line) and a1 (red line). Two peaks occur in the second order coefficients b2 (blue line) and a2 (green line).



Diffusion from the bulk yields to a hyperbolic law of time for the transient. The tempscan is a little bit similar as for linear transients in the picture above. b1 and a1 have one peak, b2 and a2 have two peaks. In addition a1 and a2 have negative peaks. The first order cosine coefficient has one negative peak and the second order coefficient has two smaller negative peaks. This allows an identification of diffusion from the bulk.

Normalization of the **hyperbolic transient** (1/C^2) will yield a linear transient. This normalization can be done for a single transient in the transient program module in 'Edit → Edit tools → Restore transient formats'. In the Plot (→ Transi, select form view) and Evaluate (→ Special evaluation → Evaluation with select) menu there is also a temporary normalization possible which is only valid for the plot resp. evaluation. A global normalization for all transients is possible in 'Measure → Measure params'. At the base input sheet you can select the C-transi mode, see chapter 2.1.2.1. You must select CR^3/C^2-CR to get a linear curve from a hyperbolic transient.

The next picture shows the normalization (small black square symbols) from a hyperbolic transient (red line). The y-axis is not valid for the red line, this curve is only for comparison.



The evaluation was done from the first half of the normalized transient. This is a pure linear curve. You get the time constant, the amplitude, the slope and the evaluation class. tau has here the meaning of a hold time. The time constant takes into account the effective time. The transient is tested for the form of the time law by the ratio of sine coefficients: bn /bk = k/n, where n and k are integers and represent the order of the coefficient. The cosine coefficients are zero for a purely linear transient. This is not valid if the transient falls to zero and the period width is bigger than this time! In the plot above this would be if taking the full period width.
If diffusion from the bulk transient is normalized in the measurement params menu then the negative peaks in the tempscan will not be seen, but one peak in the first order and two peaks in the second order for both sine and cosine coefficients will be seen as in the linear evaluation discussed above.

Tempscan bias conditions must be chosen carefully because they strongly influence what will be observed and which processes dominate the shape and form of the transient. On the other hand, tempscans differentiate by separating inversion, deep level traps, interface states and most importantly bulk diffusion processes by adjusting UR and UP.

6.3.8 Inversion and Zerbst

6.3.8.1 Theory

Inversion means the generation of minority carriers in the depletion region. Discussion of inversion processes involves the work of Zerbst, who originally described two processes which contribute to inversion:

- Generation from deep level traps in the mid band gap region **gV**.
- Surface state generation **GS**.

Other processes have since been identified as contributing to inversion:

- Diffusion from the bulk, **GD**.
- Light generated carriers which can diffuse into the depletion region, **GP**.
- Lateral generation from surface states, **gSL**.
- Back contact generation, which will not be considered further here.

These processes may be categorized into two groups, those that are dependent on the depletion region depth and those that are not. This can be re-stated as processes that may be affected by changes in reverse bias and those that are not:

- **Depletion width independent: Gb = GS + GD + GP**
  The units for the total generation are cm^-2 s^-1 for the purpose of this discussion. Photon generated processes will not be discussed further.
- **Depletion width dependent: gm = gV + gSL**
  The units are cm^-3 s^-1.

So following is valid for the generation current:

$$I_G(t)=\frac{-q\epsilon F^2 N_S}{2C_{ox}}\frac{d}{dt}\left(\frac{C_{ox}^2}{C^2(t)}\right)=qF\left(g_m(W(t)-W_R)+G_b\right)$$

Gb and gm are generation rates per area and time respective per volume and time. Following approximation is valid for the generated minority concentration per area if gm and Gb are time independent:

$nG(t)=Gb*t+\int_0^t (W(t')-WR)dt'$, W(t)-WR is the length of the generation region.

The values gm (slope) and Gb (intercept) are both obtained from the Zerbst plot; however it should be remembered that these processes are each the result of more than one process and the contributing processes cannot be obtained from Zerbst plots. It is possible therefore, from the Zerbst measurement and evaluation to say that the inversion process is formed from either predominantly deep levels or interface states and diffusion from the bulk. The dominant process depends upon the device quality and its history. For good devices it is possible that the interface state density can be neglected. It is however possible to make further tests to find out which process dominates

In the last plot of chapter 6.3.7 CR^3/C^2 against time is plotted. This normalizes the transient and can be used as a test plot. If the transient is dominated by Interface state processes or diffusion from the bulk the plot in this mode will be linear. It is not possible to separate these processes here except by changing the temperature.

The Zerbst evaluation of transients at **different temperatures** gives additional information. Similar as an Arrhenius plot you get activation energies for gm and Gb. These give you a hint of the inversion processes. The evaluation of Zerbst plots at different temperatures will be described in chapter 4.3.

In most cases gV is composed directly from deep level generation processes and therefore gm=gV will be set. The definition of gV is:

gV = ni/(2*tau0)

tau0 is the life time and is normally of the order of us. A small value for gV will yield a larger lifetime.

The generation rate for surface states is given by:

GS = ni*S.

The surface recombination velocity **S** is due mostly to surface states and so a high value for S implies high Nss density. S normally has a value around 1 but may be higher if there are a lot of surface states present.

NT = 1/(tau0*vth*sigma) is the concentration of deep level states, must be considered with care as the value is calculated with a fixed valued for the capture cross section. This value should be used as a reference for comparison purposes.

If Gb is dominated by diffusion from the bulk then Gb=GD will be set. For GD is valid:

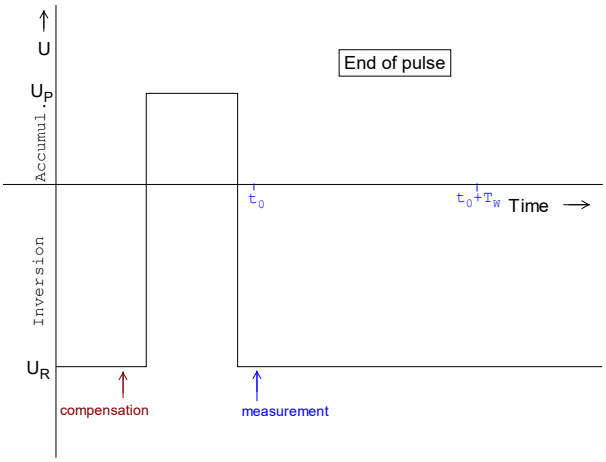
GD = ni^2*Dp/(Ns*lp), with lp = sqrt(Dp*tau0D) and Dp = diffusion constant

tau0D is the diffusion lifetime and will be calculated only at user class 5 or higher.

6.3.8.2 Measurement

The capacitance transient is formed by setting a reverse bias on a device and pulsing the device into accumulation, then switching from the pulse bias back to the reverse bias. Two methods may be used to accumulate the data. The first is preferable as it takes advantage of the compensation routine to provide improved sensitivity. The second mode enables direct comparison with other systems, and the emulation of the original Zerbst measurements in which only one point was collected per pulse because that was all that the available equipment could achieve. This second method is effectively a faster version of the original Zerbst style.

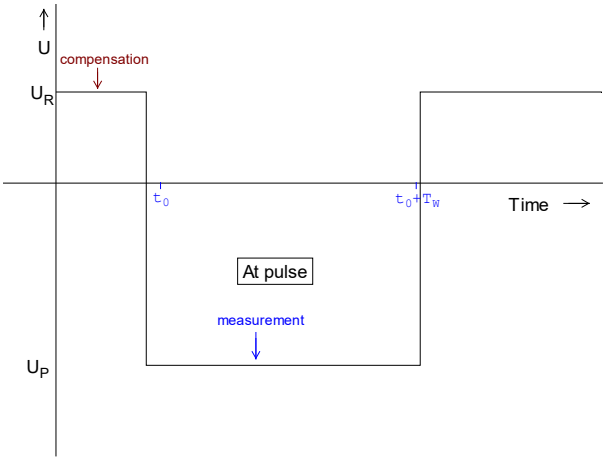
Start measurement at end of pulse



The device is held at a reverse bias which does not change for the duration of the measurement. The device is compensated at this bias and is then pulsed (example pulse width 1 ms) to the required pulse bias. The bias is then returned to the reverse bias value and measurement of the transient is made inversion begins. The diagram on the right side shows this mode. This mode is the normal start of measurement also used for emission transients, called 'end of pulse' in chapter 3.2.1.1.2.

For this type of measurement select in the Transient measurement menu 'Zerbst measurement'. Then the pulse mode will be set automatically. After this measurement the Zerbst plot will be shown as described in the next chapter.

Measurement during pulse



The pulse mode is illustrated at the next diagram. Note that the bias which remains static is in accumulation not in the inversion region as in the previous method. The device is pulsed into inversion and measurement begins immediately. For using this measurement call in the Transient measurement menu 'Single transient'. Select there UR and UP so that UR is in accumulation and UP is in inversion! This is the opposite from the normal mode. Take care by switching the biases and pulsing from accumulation to inversion. Click then on the Params button of the Bias/pulse input group to select the pulse mode. It will there be called 'at pulse', see chapter 3.2.1.1.2. This mode has the disadvantage that the compensation will not be done at the same voltage resp. capacitance as the measurement. This yields to a lower sensitivity.

The original Zerbst pulse routine is in principle the same as the mode 'during pulse' but it takes a long time. In principle each pulse width gets successively longer and only one measurement point is available per pulse.

Measurement notes and tips:

a) Transient: Select in the Transient measurement menu 'Zerbst measurement'. This the standard mode and provides an instant evaluation including plots of gm and Gb which are not produced directly if only a single emission transient is measured. Select the voltages so that UR is in inversion, UP in accumulation. The measurement should be kept within the inversion region in order to minimize the contribution to the transient from deep levels.

b) Period width: The period width for the measurement will vary according to the length of time taken for full inversion and must be evaluated by the user. If possible by time, select Tw so that you measure the transient to it's end, that means till the inversion process has finished and the capacitance keeps constant again.

c) Temperature: The inversion transient is temperature dependent and can be measured at different temperatures. To collect manually data for a temperature depending Zerbst evaluation (chapter 4.3) the inversion transients must be collected and saved at temperature intervals of a few degrees. It is important that the file names follow a strict protocol so that the files may all be read automatically into the calculation module in order to form a Zerbst Arrhenius plot. The last 3 characters before the data extension must be a number, for example ID@A_001.YEA.DLT. If using automatic file names this is given. Better it is to activate the option 'Set of temp variations' in the data base, see chapter 2.4.5. Then the proposals of the file names are for example ID@A_00M001.YEA.DLT and so on.

d) Tempscan: It is possible to measure automatically transients at different temperatures in the tempscan module. Select there 1 file with variable period width 1. Select 'All files' in the Transi input sheet, and 'ts/Tw, no eval' as variation parameter at the VarTw1 input sheet. ts/Tw should be between 0.6 and 0.8. Then the transient reaches its equilibrium value in the observation time. This gives reasonable values for the Zerbst evaluation. For the DLTFS linear transient evaluation then the half period width can be used. This part of transient should be pure linear.

e) Routin tempscan: The easiest way to get automatically transients at different temperatures is to use the routine tempscan measurement. There is the special MIS mode 43 'VarTw, Zerbst transients'. All parameters, except the voltages, will be set automatically as described in (d).

f) Zerbst Arrhenius: The Zerbst technique at one temperature is only capable of identifying whether deep level generation or surface state/diffusion effects dominate an inversion process (gm or Gb rate).
The Zerbst evaluation of transients at different temperatures gives additional information. Similar as an Arrhenius plot you get activation energies for gm and Gb. These give you a hint of the inversion processes. This type of evaluation will be explained in chapter 4.3.

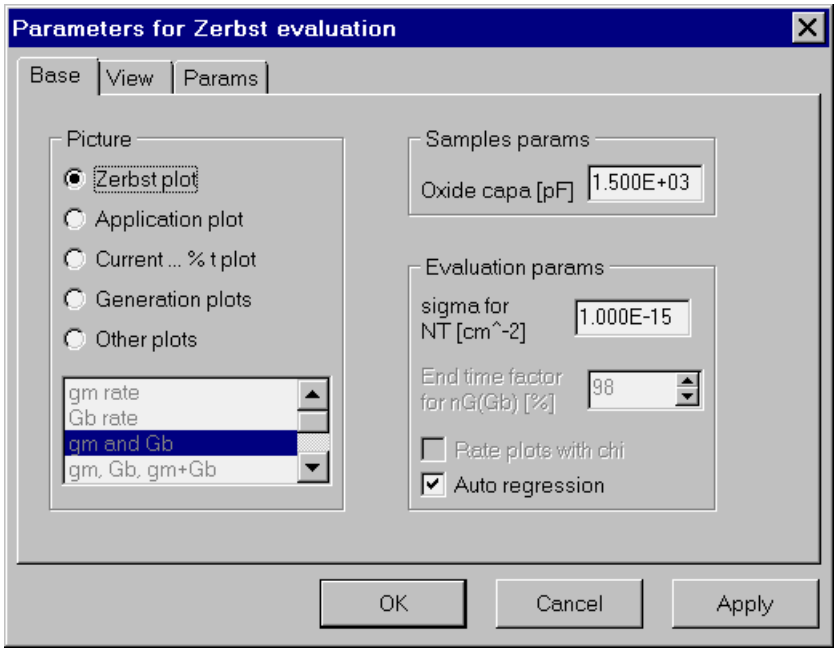
g) General: Tempscans differentiate by separating inversion, deep level traps, interface states and most importantly bulk diffusion processes. This is achieved by varying the reverse bias and the pulse voltage. Prior to commencing a tempscan, identify the dominant generation elements from the Zerbst menu and then adjust the tempscan bias and pulse values accordingly.

6.3.8.3 Zerbst plot

The standard evaluation for generation processes is the Zerbst evaluation in the Evaluate menu of the transient program module. This menu appears only on MIS samples.

6.3.8.3.1 Base input sheet

The base input sheet defines the kind of picture, the oxide capacitance and the capture cross section sigma (used for the NT calculation). If the flag 'Auto regression' is activated then the linear regression for the Zerbst plot will be done automatically at start of the plot.



Following possibilities exist for the kind of **picture**:

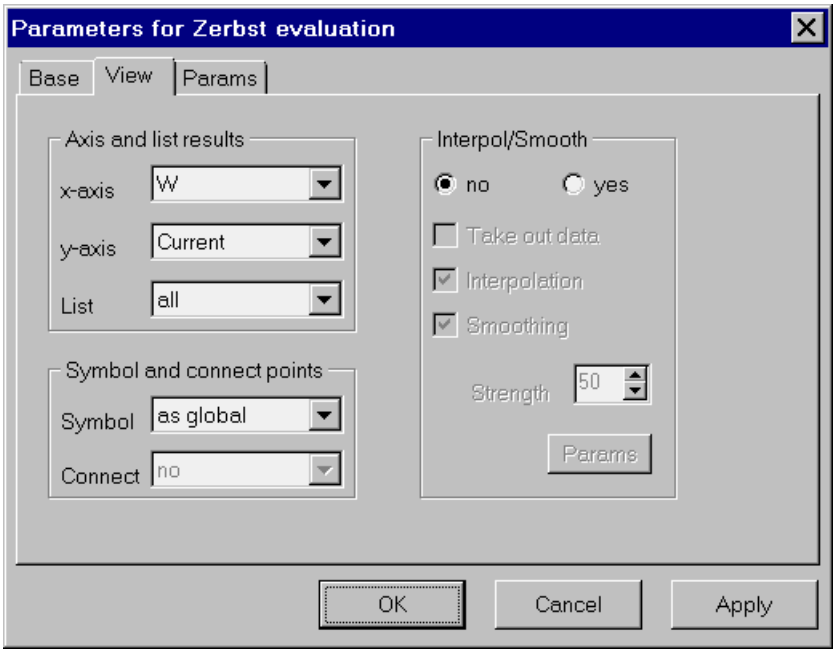
Zerbst plot:	Shows the Zerbst plot.
Application plot:	3 plots with transient, nG(t) of gm and Gb and Zerbst plot.
Current … % t plot:	Shows the calculated current or similar data versus time. The y-axis will be defined in the view input sheet.
Generation plots:	Shows the generated minority concentration of gm and/or Gb.
Other plots:	Additional plots, depends on the user class. The standards are the transient and the space charge region versus time.

Following plots are possible for the **generation plots**:

gm rate:	Generated minority concentration nG(t) of gm.
Gb rate:	Generated minority concentration nG(t) of Gb.
gm and Gb:	Generated minority concentration nG(t) of gm and Gb.
gm, Gb, gm+Gb:	Generated minority concentration nG(t) of gm, Gb and gm+Gb.
gm, Gb, transi:	nG(gm), nG(Gb) and transient normalized to nG maximum.
all rates, transi:	nG(gm), nG(Gb), nG(gm+Gb) and transient normalized to nG.
rates, W, transi:	nG(gm), nG(Gb) and W(t) and transient normalized to nG.

The regression/evaluation of the Zerbst plot is necessary for the generation plots. So you have to do the Zerbst plot before if the Zerbst evaluation is not saved in the transient file.

6.3.8.3.2 View input sheet



The values that may be plotted on the **x-axis** are all comparable and are included because different users have preferences and may wish to compare data plots with plots from other publications. Data may also be normalized, again according to the user preference. The x-axis is a normalized capacitance or a depletion width. Detailed options are:

CR/C, CR/C-1, W, W-WR

Since $C = \epsilon A / W$ it is possible to plot either the capacitance or the depletion region width. Also it is equally valid to plot either CR/C or CR/C-1 according to preference. W-WR is equivalent to CR/C-1 and has the added advantage that the plot begins at zero. It is also possible at user class 5 to input a factor 'chi' into the equation for instances when the transient is not being produced from the whole of the depletion region. The result of the Zerbst plot will not be affected by the choice of the x- or y-axis.

Following possibilities exist for the choice of the **y-axis**:

Zerbst: d(Cox/C)^2/dt, this is the original axis of Zerbst plot.
Current: Generation current.
Current density: Generation current normalized with area.
Generation rate: Generation rate G in [cm^-2 s^-1].

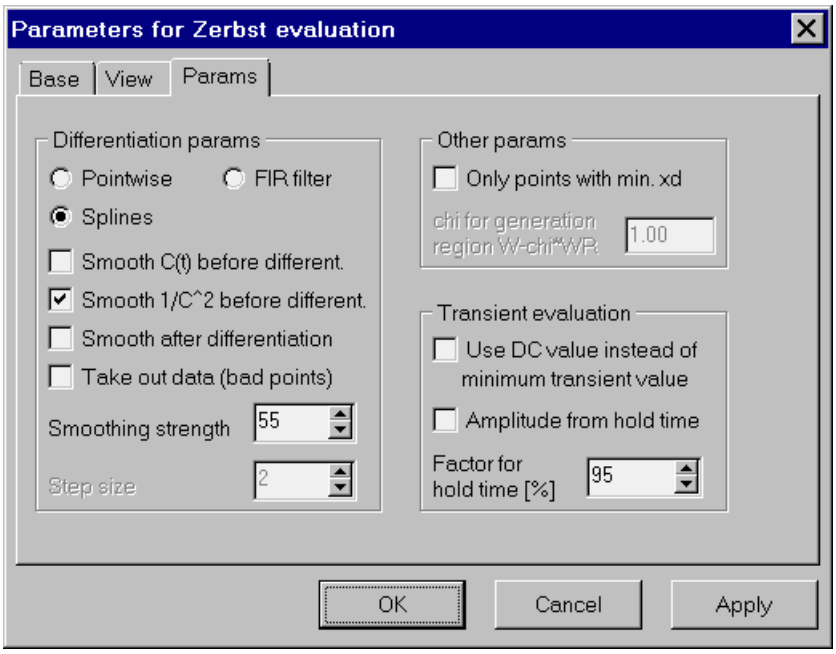
The **list** option defines which kind of evaluation values will be shown at a Zerbst plot:

only rates: Only the generation rates gm and Gb will be listed.
+ tau0, S: List additionally the life time tau0 and the surface recombination velocity S.
+ hold time: Shows rates and the time constant (hold time) and amplitude of transient.
all: Shows rates, tau0, S, hold time tau and amplitude.

Tip: You get all evaluation values discussed above and some ones more, depending on the user class, in a special text window. For this option select in menu of the plot program 'Evaluate → List results', see chapter 5.1.5. An example will be shown later.

The symbols of the Zerbst plot can be selected: as global, 3x3 points, points, line. 'As global' means the standard symbol for evaluation, see chapter 2.3.2.1. The option '**Connect points**' is only available for the picture modes 'Current plot' and 'Other plots'.
It is possible to interpolate or smooth the plot curve. This option here is not for the Zerbst curve. For this there is a separate option at the Params input sheet.

6.3.8.3.3 Params input sheet



The first input group contains the options for the **differentiation** d(Cox/C)^2/dt of the Zerbst plot.
Following **differentiation modes** are possible:

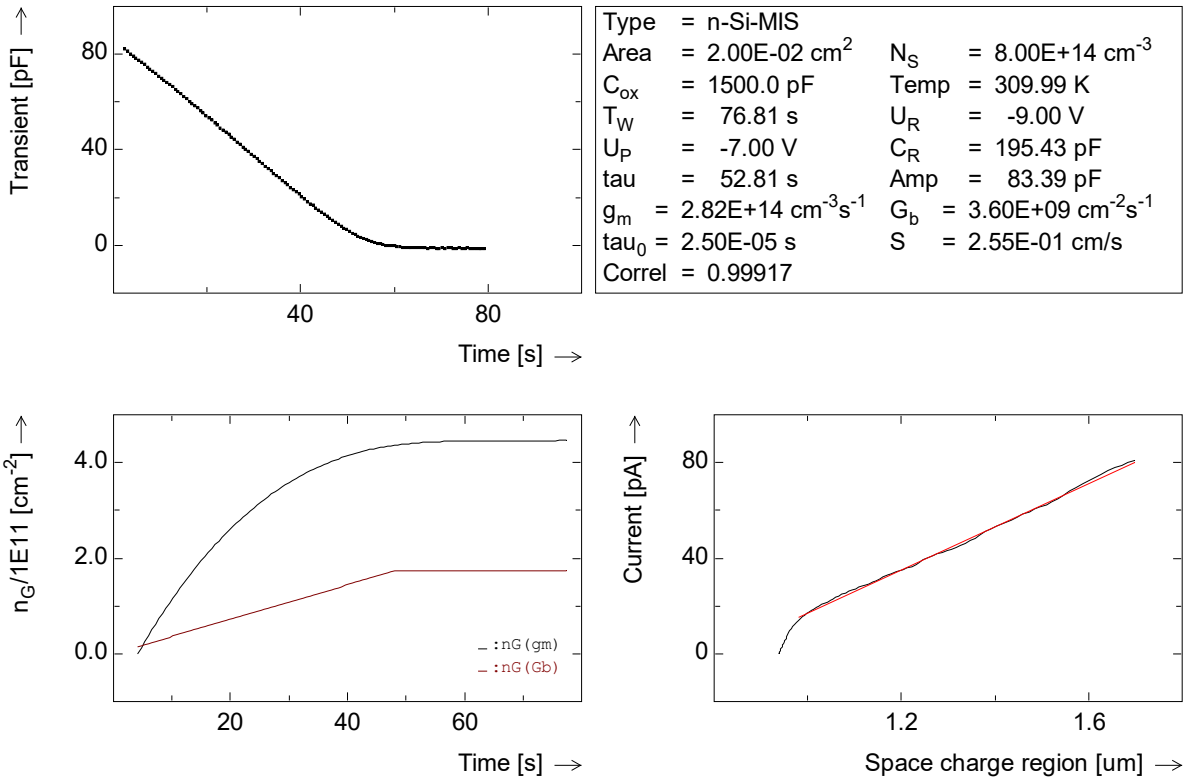
Pointwise: The differentiation will be done point by point. This requires the input of step size. This mode yields to much noise by small steps and without smoothing.
FIR filter: Uses a digital low-pass filter for differentiation.
Splines: Uses cubic splines for the differentiation. The 1/C^2 curve should be smoothed with a medium strength before differentiation. This mode gives usually the best results.

It is possible to **smooth** the C(t) and the 1/C^2(t) curve before differentiation and the result curve after differentiation. Bad data points can be taken out before differentiation as explained in chapter 2.7.1.
If activating 'Only points with min xd' then only these transient points will be used which are not closed together on the x-axis. That means the data will be selected in such way that a minimum distance on the x-axis, for example the space charge region W, is given.

The input group '**Transient evaluation**' defines parameters for the evaluation of the transient and not of the Zerbst plot. The **hold time** will normally be set to this time when the transient reaches its minimum value. By activating a special flag the time will be used when the transient goes to the measured DC value. By default the hold time is not the time when transient has fallen to the defined value but 95% of this time. You can change the factor for the hold time.

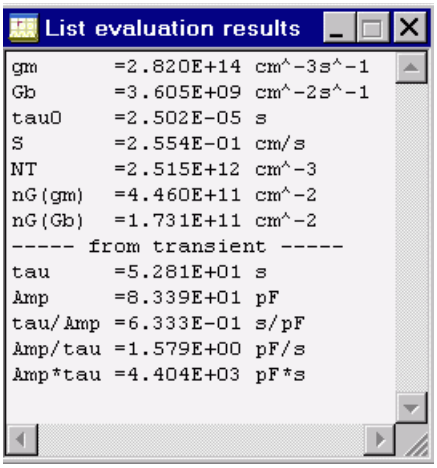
Normally the transient **amplitude** will here be set to the difference of maximum and minimum value of the transient. If activating a special flag then the amplitude will be calculated from the hold time.

6.3.8.3.4 Example of a Zerbst plot



The picture above shows the Zerbst application plot an example measurement. The transient will be shown at the left top, the minority concentration nG of gm and Gb at the left bottom and the Zerbst plot on the right bottom. The x-axis of the Zerbst plot is the space charge region W, the y-axis the calculated current. At the right top there are some sample parameters and results. The rate gm will be calculated from the slope of the Zerbst plot (red regression line), Gb from the intercept. The life time tau0 will be calculated from gm, the surface recombination velocity S from Gb.
nG(Gb)=Gb*t will be set to a fix value for t>tG. This time tG will be calculated from the time when nG(gm) reaches its maximum and goes into the saturation. By default it is 98% of the maximum of nG(gm) but can be changed in the base input sheet, called 'End time factor for nG(Gb) [%]'.
The hold time tau and the amplitude will be calculated directly from the inversion transient.

Note: tau is the end of the transient and not the period width. The period width is the measurement time which must be longer than the end of the transient, i.e. the transient must have decayed to zero before Tw because it is not possible to calculate a transient which has not fallen to zero i.e. C=0. tau is not the same as those used in the normal transient evaluation of Schottky transients. It will be calculated from the transient values but not by the DLTFS evaluation, no special law of time is necessary. Dont' confuse tau with tau0. The hold time tau has nothing to do with the Zerbst evaluation.



As discussed in the tip above you get all results in a special text window of the plot program. Depending on the user class here more values will be listed as in the text window of the plot, for example the diffusion life time tau0D.

6.4 Hardware options

This chapter describes options which needs additional hardware. For installation and connecting of the hardware see in the Hardware Manual and Software Installation Manual.

6.4.1 100 Volt option

This option amplifies the voltage of the standard bias source by a factor of 2.5 resp. 5, so that the maximum bias and pulse voltage is +- 100 V. **Exercise care** when using the 100V power supply. The high voltage is very **dangerous**. Remove the bias from the sample before removing the sample. Use at the test of contact only the voltage mode 'U=0', see chapter 2.1.1.2. Click there onto the 'Set' button to set immediately 0 V to the sample.

6.4.2 Fast pulse option

Measurements with pulse widths below 10 us requires the use of an external pulse generator and a Fast Pulse Interface, which is included in the CGI-Meter FT1235. The aim of this combination is to prevent the capacitance meter from being plunged into a severe overload condition. Recovery from an overload condition is slow and without the Fast Pulse Interface the recovery speed limits the measurement.
For conventional DLTS measurements in which the aim is to fill the deep levels completely, the capacitance meter speed response does not represent a limitation on the measurement. However for capture cross section measurements, see chapter 3.3.6.1, in which the filling rate is essentially time resolved, the C-Meter speed may limit measurements, especially in moderately and heavily doped semiconductors.

The fast pulse Interface overcomes the C-Meter speed limitation by switching the diode from the bridge to a pulse generator for the fill pulse phase, and then returning it to the C-meter for the measurement phase of the DLTS cycle. The Interface timing is controlled by the Software and the sequence is timed so that the diode is never allowed to float open circuit. This clamping of the diode to either the fill voltage or the reverse voltage is essential to the integrity of the measurement.

The fast pulse generator will be used if selecting the pulse mode 'fast pulse'. You can select the pulse mode in the 'Params input window', see chapter 3.2.1.1.2. Depending on the fast pulse generator the minimum and maximum bias values can be limited. The fast pulse generator defines these values at the fast pulse mode. You have to connect and to switch on the pulse generator before starting the DLTS program. How the fast pulse interface works will be explained in chapter H2.2 of the Hardware Manual.
Followings must be considered at using the fast pulse:

1. After the end of the pulse the system needs an additional recovery time of 700 us before a transient can be measured. This time will be automatically taken into account at the evaluation (t0) and saved into the data files.
2. The useful pulse width and the pulse slew rate is in the practice limited because the samples are not ideal. Usually pulse widths smaller 20 ns can not be completely, that means with the defined voltage, applied on the sample. The pulses reach completely the defined voltages from 20 ns. But the slew rate of the pulses is here also be taken into account.

6.4.3 Optical pulse option

This option needs a light source as a LED or a laser. It allows to use an optical pulse instead an electrical one. Combinations of both pulse types are also possible. You can select the pulse mode in the 'Params input window', see chapter 3.2.1.1.2.

Following **optical pulse modes** exist:

5) optical: Instead an electrical an optical pulse tPo will be used.

6) elec. & optical: Electrical and optical will be used together as 'one' pulse tPb.

7) elec., optical: The first (injection) pulse is the electrical, the second the optical. In the plot header these will be denoted as tPi and tPo.

8) optical, elec.: The first (injection) pulse is an optical, the second the standard electrical. These will be denoted as tPI and tP.

9) opt., elec-fast: Similar as (8) but with the fast pulse generator.

10) optical DLOS: Special mode only for the variable laser option, see chapter 6.4.4.2.

12) double, opt.: Similiar as (7) but uses as first pulse an electrical double pulse.

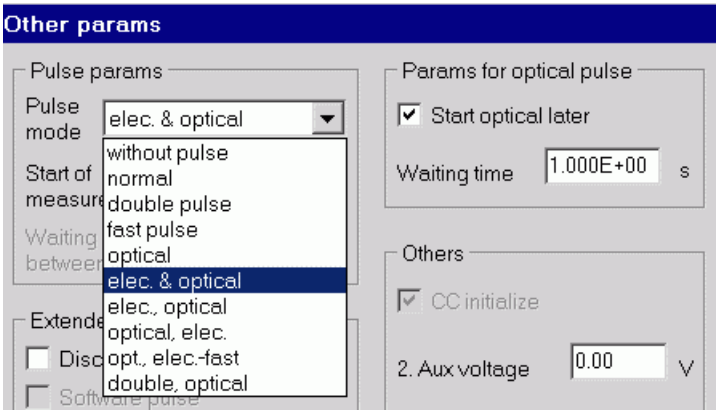
The different pulse values will be marked by different suffixes:

tP = electrical pulse width, **tPi** = width of the electrical injection pulse,
tPo = optical pulse width, **tPw** = waiting time at a pulse.
tPb = wdth of electrical and optical pulse width (mode 6),

A permanent use of the optical source is also possible. You can switch it permanently on in the Base input sheet of the 'Main measurement parameters', see chapter 2.1.2 and the picture in 6.4.5.1. Any optical or fast pulse is then forbidden. The software doesn't switch on permanently the optical excitation after program start, so you have to activate this option manually after a new program start. An optical pulse mode will be 'buffered' by a program hot start. You get a warning at activating the permanent option first time after program start. Be careful with the permanent option because laser light is dangerous! Switch the laser off when working on the cryostat or contacting the sample.

New double optical pulse mode:

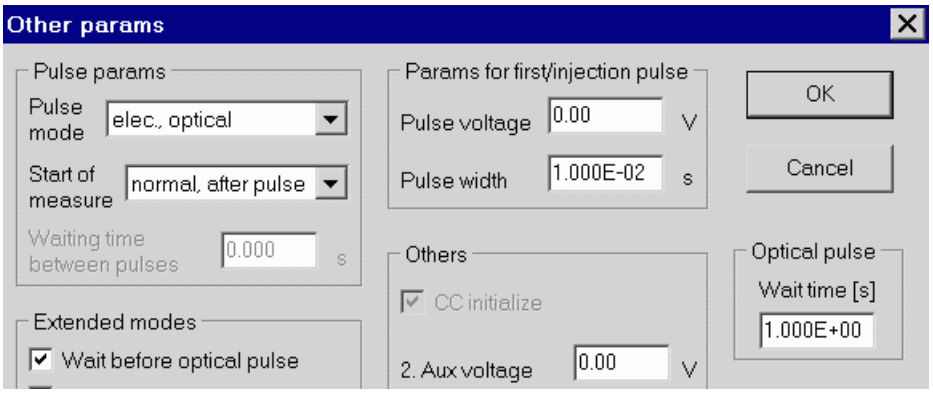
The new optic pulse option contains one new pulse mode and 2 expanded existing pulse modes. These 3 modes will be described in the following.
The pulse numbers are the internal numbers for the pulse modes, saved on the data header.
You can select these modes as before in the params input window of the pulse/bias params group of each transient input window.



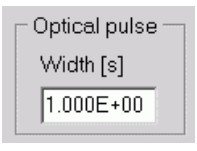
These 3 **pulse modes** are:

6) Elec. & optical: Electrical and optical pulse will be used together as 'one' pulse. Now there is the option to start the optical pulse later, see input window above. In this case the electrical pulse starts without the optical pulse. After the waiting time tPw the optical pulse starts. After the time tp both pulses terminate.
In the standard case is tPw=0. Selecting the start of measurement as 'at pulse, tp=Tw' yields to tP=Tw. That means the optical pulse width has the same length as the period width Tw. Therfor the input of tP is then not available because it is Tw.

7) Elec., optical: The first (injection) pulse is the electrical, the second one the optical. The optical pulse is the main pulse (uses tP as input). Now there ist the possibility to wait before starting the optical pulse. So the bias goes first to the pulse voltage UP and falls after the time tPi back to the reverse bias. The optical pulse starts then after the waiting time tPw and stops after time tP.
In the standard case is tPw=0. Selecting the start of measurement as 'at pulse, tP=Tw' yields to tP=Tw. The optical pulse width has then the same length as the period width.
The picture on the right shows the inputs for this enhanced mode.

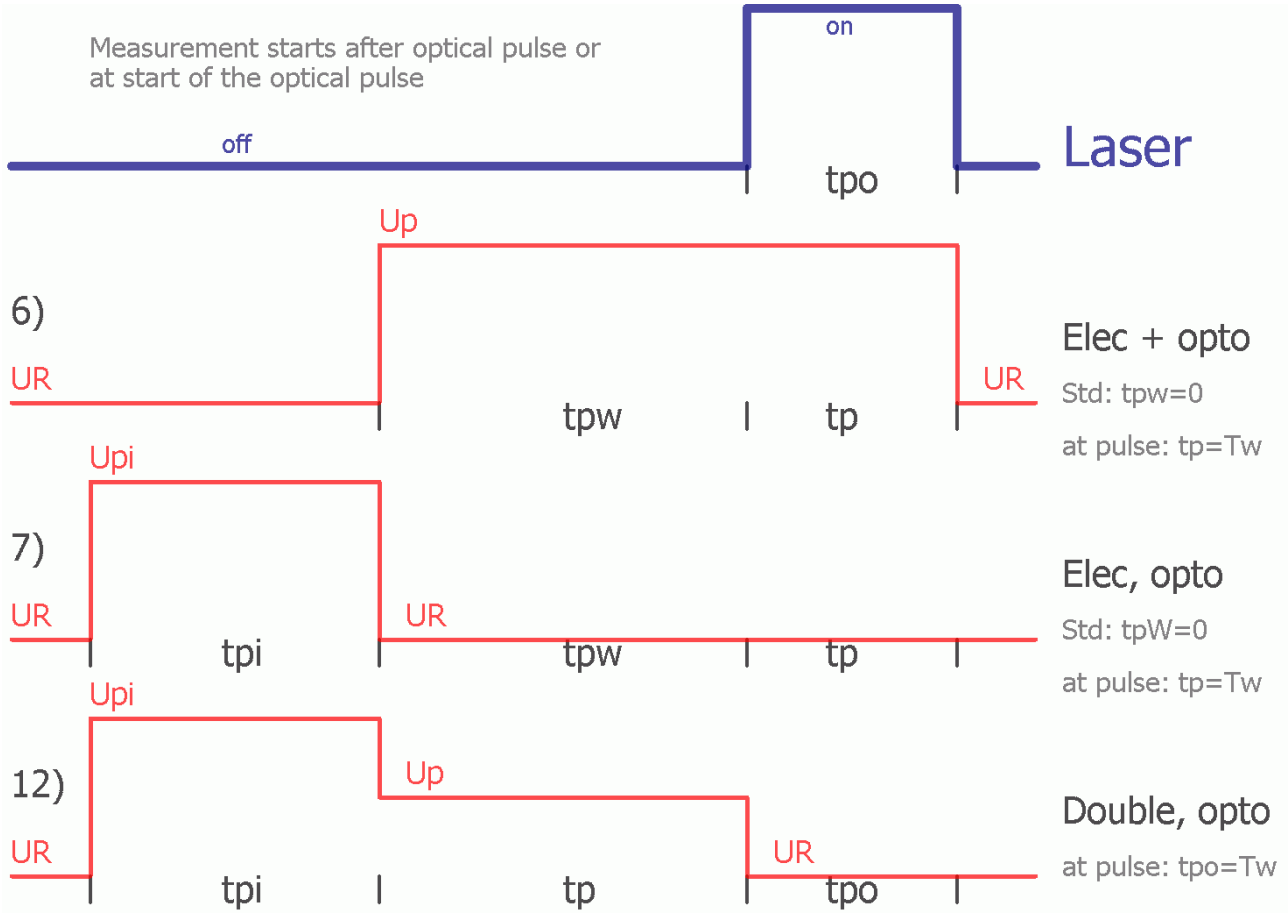


12) Double, optical: This is a new pulse mode. It combines an electrical double pulse with an optical one. The 2. electrical pulse is the main pulse. The first pulse voltage (called injection pulse voltage UPi) will be spupplied for a given time tpi and then the standard pulse voltage UP will be supplied for the time tP. After tPi+tP the voltage falls back to the reverse bias and the optical pulse starts for the optical pulse width tPo.
If both electrical pulses have the same voltage, means UP=UPi, then there is by default no voltage change during the electrical pulse. In this case this pulse mode is as pulse mode 7 with waiting time. But the inputs are different, see different meaning of tP in the timing diagram below.



Selecting the start of measurement as 'at pulse, tP=Tw' yields to tPo=Tw. That means the optical pulse width has the same length as the period width. Therfor the input of tPo is then not available because it is Tw.

The next picture shows the **timing diagram** for these 3 pulse modes.



Notes and tips:

1) The measurement (collecting of transient data) **starts** after optical pulse (if selecting 'Normal, after pulse' as start of measure) or at start of the optical pulse (if selecting 'At pulse' as start of measure). In the 2. case ('at pulse') the measurement will also be done at reverse bias UR if using pulse pulse modes 7 and 12. Compensation and measurement may be done at the same range. At pulse mode 6 measurement will be done at UP.

2) If varying the pulse width in the **isotherma**l module, always the time tP (main pulse) in the timing diagram above will be varied. When using pulse mode 7, the optical pulse length will be varied. At pulse mode 12 the length of the 2. electrical pulse will be varied. In the case of UP=UPi you can use this fact to vary different time parameters.

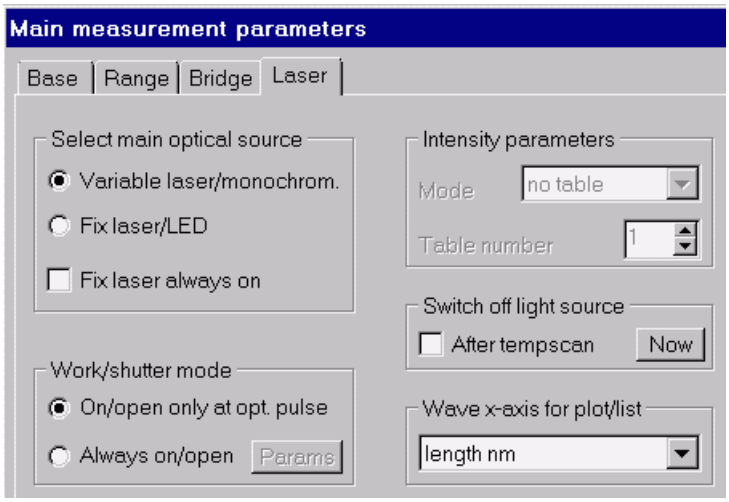
3) At the **period scan** with selecting 'At pulse' usually tP (main pulse) will be varied as Tw, except pulse mode 12. Here tPo=Tw will be varied.

6.4.4 Optical with variable wave length

This option, also called variable laser, means that you can change the wave length of your optical excitation. It can be a laser, a monochromator with a grid or a series of LED's. The intensity can also be selected if the optical hardware supports this feature. We have no standard equipment for this optical option, the solutions are special for each customer. The installation will be described in chapter I3.3 of the installation manual.

6.4.4.1 Main parameters

The main parameters for this option are in a separate input sheet, called Laser, of the main measurement parameters, see chapter 2.1.2. You get these parameters in the measure menu of each measurement program module. The visible and enabled parameters depend on your optical hardware. Usually these optical parameters here will not often be changed. The wave length and intensity can be set also before the measurement, see next chapter.



If using 2 optical sources you can select the **main optical source**:

- **Variable laser/monochromator**: This is the source at which you can select the wave length, usually this is the main source.
- **Fix laser/LED**: It is an additional source with a fix wave length, similar to the standard optical excitation, see previous chapter.

At 2 optical sources you can activate a flag which switch additionally the other (not as main selected) optical source permanently on. So if using the first possibility, you can switch additionally the **Fix laser always on**, in the other case the variable laser.

The Work/shutter mode defines how the main optical source will be used:

- **On/open only at optical pulse**: This is the standard mode, the optical excitation is on (the shutter is opened) only during an optical pulse. In the other case it is off (the shutter is closed). It means it is off before the measurement, after the measurement and between the pulses of an averaging. It is also off at an electrical pulse.
- **Always on/open**: The optical excitation is permanently on (the shutter is opened). That means it is on before, after and during the measurement. An optical pulse can not be selected at this mode.

If selecting 'Always open' and the main optical source is 'Variable laser' the **Params** button yields to an input window for the wave length, similar as described in 6.4.4.2.
If selecting 'Always on' for the main or other optical source, then it will be switched on after leaving the measurement parameters input window by the 'OK' button. A change of wave length will also be set at this time. If changing from 'Always on' to 'On only at optical pulse' the optical source will be switched off by the 'OK' button.

The software doesn't switch on permanently an optical excitation after program start, so you have to activate this option manually after a new program start.
Depending on your hardware it is possible to select the **intensity mode**. Then the intensity will be changed with the wave length by the hardware or by a table. A table number can be input. The name of table file depends also on the material name, the doping and the grid number. LasI_Si_n102.Txt is an example for n-type silicon, grid number 1 and table number 2. The file must be in your Dlts\Conf directory. It must be an ASCII file with 2 columns. In the first column is the wave length in [cm], in the second an intensity factor with which the intensity will be multiplied. The wave length will be interpolated.
If using more than one grid then it can be necessary to calibrate the wave length by a **calibration file**. The syntax for the file name is LasC_NNX.Cfg, where NN is the laser type (laser file name) and X the grid number. This file must be in Dlts\Conf or in Dlts\Sys\Meas. See in LasC_211.Cfg for the syntax. The data section contains 2 columns. In the first column is the wave length in [cm] and in the second the difference wave length in [cm] for it. The wave length will be interpolated.

Some excitation hardware allows to **switch off the light source** to extend the lamp life. This feature don't mean the shutter. By the button 'Now' the lamp light will be immediately switched off. If activating a flag then it will be automatically switched off after a tempscan measurement. If it is off and the optical excitation will be used then the program switch the lamp automatically on.

You can select the **x-axis** for the variable optic option (variation of wave length). This mode will be used for plots and listing data:

- Wave length in cm for list data, in nm for plots
- Wave length in nm
- Energy in eV
- Frequency in Hz
- Kaiser in 1/cm

6.4.4.2 Fix wave length

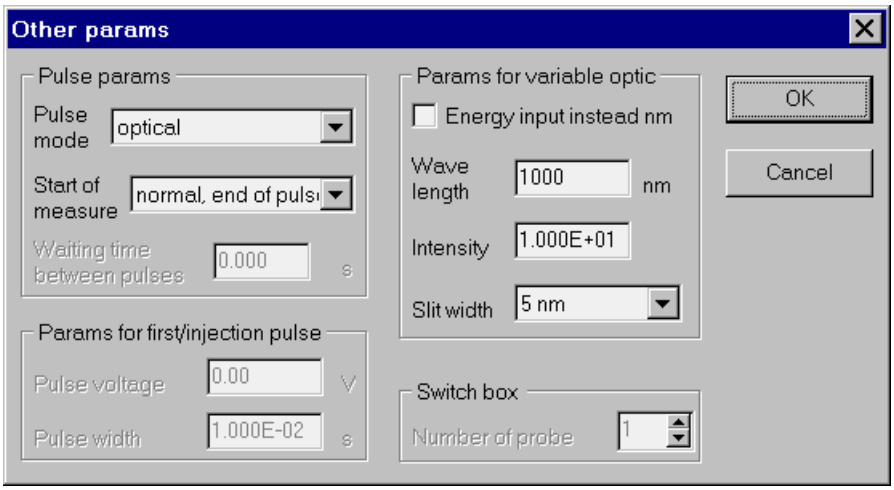
A transient measurement using the optical excitation can be done if using the mode 'always on' or if selecting an optical pulse. In the transient, isothermal and tempscan program module then a transient will be measured at a fix wave length.

You can input the pulse mode, the wave length and, if possible, the optical intensity in the 'Params input window' of the bias/pulse input group, see chapter 3.2.1.1.2. You find this input group at the measurement inputs of the transient, isothermal and tempscan program module. If the 'variable laser option' exist then this input window is extended. You have additional input groups but not all are always enabled. If the laser is always on then you can input the wave length also at the main measurement parameters.

The optical pulse modes were already explained in chapter 3.2.1.1.2 and 6.4.3.

A special pulse is the **optical DLOS:** The main optical source uses the pulse mode (5), the standard optical. During the measurement the other optical source will be switched on, after the measurement it will be switched off. This feature needs 2 optical sources. The other optical source has not to be switched always on.

The optical parameters are in the 'Params for variable optic' input group. These are only enabled if an optical pulse mode was selected or your optical excitation is permanently on, see above. The optical parameters will be set before the measurement, except a change of the grid**.**



If activating '**Energy input instead nm**' then the **wave length** must be input in eV, in the other case in nm.

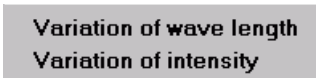
The optical **intensity** can be selected if the optical hardware supports this. The range and the dimension depend on the used hardware.

If using more than 1 **grid** then you can select the grid number.

Some monochromators allow to select the **slit width**. A change of slit width changes usually the minimum and maximum value for the intensity.

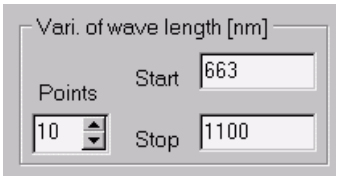
6.4.4.3 Wave length scan

In the isothermal program module there is the possibility for a wave length scan, this means the measurement of transients at a systematic variation of the wave length. From the Fourier transform we get coefficients to each transient, so we get for example a plot b1 versus wave length, see chapter 3.3. Such scans will be used for **DLOS** (Deep Level Optical Spectroscopy).



You find this feature there in the sub menu 'Fix period width' of the measurement menu.

At the isothermal measurement parameters you get an input group for the start and stop wave length and for the numbers of data. The input of wave length can be in nm or in eV, this selection was explained in the previous chapter.



A variation of the optical intensity is also possible if the hardware supports this feature. Depending on the optical hardware this variation will be done in linear or logarithmic steps.

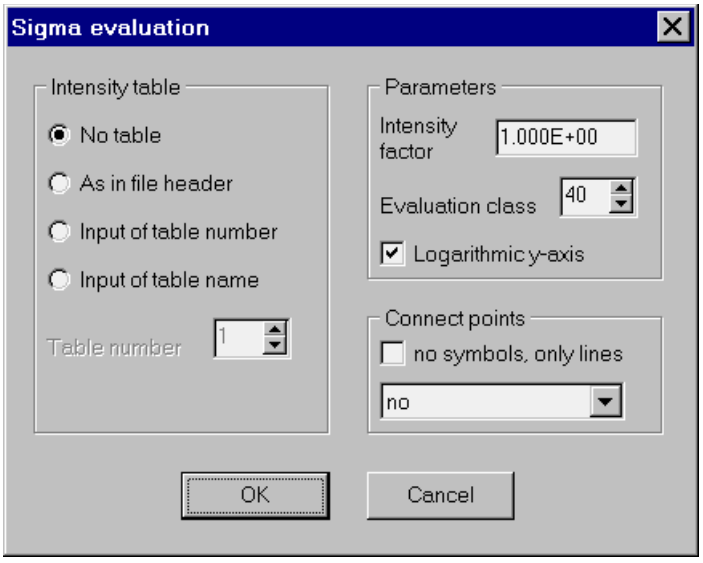
The optical scan options are only possible at the work mode 'always on' or at using an optical pulse mode. In the other case these menu entries are enabled but the software asks for selecting an optical pulse mode.

6.4.4.4 Plot and evaluation

All isothermal standard plots are possible, for example coefficients, time constant or amplitude versus wave length.

A special evaluation shows the optical **capture cross section** sigma versus wave length. Sigma will be calculated by the time constant multiplied with the optical intensity and a given intensity factor. The time constant can be calculated by DLTFS evaluation or by the maximum analysis. For this you have to make a period width scan with a parameter variation of the wave length. Then you have to go the isothermal maximum analysis.

The saved intensity can be calibrated by an **intensity table** as explained in chapter 6.4.4.2 at the intensity mode. The intensity factor should normalize the calculation to a capture cross section. If setting to 1 then sigma is only a relative value.
If coming from the DLTFS evaluation then a minimum evaluation class for the data can be input.
Sigma can be plotted in a linear or logarithmic axis.

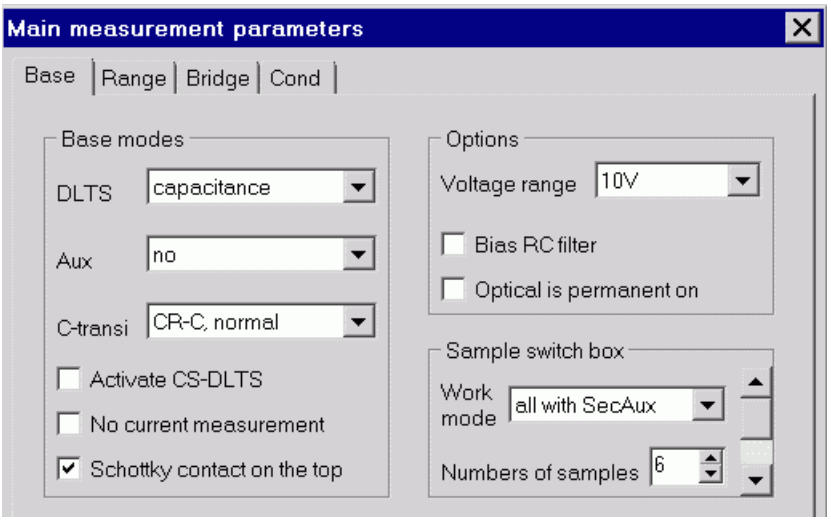


6.4.5 Multi-Sample switch

The Multi-Sample switch option has been developed to measure several samples during one temperature scan. Up to 6 samples can be connected to this option and automatically switched to the DLTS measurement system for transient measurements. The Ohmic contacts of the samples are all connected to the LOW sample input of the CGI-meter. Only the HIGH input of the CGI-Meter meter is switched to the particular sample. Only then also the bias voltage and the pulse voltage is supplied to the sample. To all the other samples that are still not selected for a measurement either no voltage (open diode) can be supplied or a collective bias voltage. This bias voltage is supplied by the 2. Aux output of the DLTS electronics and (if selected) automatically set to the (general) bias voltage value, see chapter I3.3 of the Installation Manual.

6.4.5.1 Base parameters

You find the main parameters for the sample switch box in 'Main measurement parameters' of the 'Measure' menu of every measurement program module. The base input sheet here is extended if using the sample switch box.



You have to define how the switch box works and how it apply voltages for those samples which are not selected. The possibilities for this **work mode** depends on the selected installation mode, see chapter I3.3 of the Installation mode. If using there 'yes, connected with 2. aux', this is the standard, then following work modes exist:

no switch box: The switch box will not be used.

1 sample: The switch box will be used, but only 1 sample can be measured. An input for the probe/sample number occurs below the work mode. This input is only here possible.

all, open: All samples/probes can be used. The selection of the used sample can be done in the 'Other' input window of all main measurement input windows, see next chapter. The voltage will only be applied to the selected sample. There is no voltage on the not selected samples. The voltage at the Schottky diode of these samples is floating after one of it has been measured as long as it is selected for the measurement again. The not selected samples are not connected together.

all with SecAux: Similar as 'all, open' but the not selected samples are connected together and set to an additional voltage. This voltage is set by the DLTS software. It is supplied at **Aux-A** output of the bias/pulse board. The software will set the voltage at the 2. Aux (usually Aux-A output) automatically to the global **bias voltage**. This is the standard mode for using the switch box.

The **numbers of samples** defines how much samples are connected to the switch box.

The **file mode** input is hidden in the picture above, use the scroll bars to show it. It defines how the file name resp. the proposal for the file name will be build:

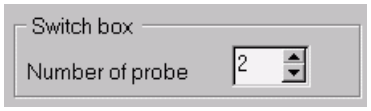
no. as 3. extens.: The probe number will be used as third data extension character, for example ID@A_001.YE2.DLT for probe 2.
separate ID: The file name will be build by the separate ID of each sample.
no. and plate ID: The file name will be build by the common plate ID and the probe number, for example Plate@2_001.YEA.DLT for probe 2 and the plate ID 'Plate'.

Independently for the file mode each sample can have an individual sample ID. At the third file mode a common plate ID exist. For more details see chapter 6.4.5.4.

6.4.5.2 Selection of probe

Probe number means the number of connection at the switch box, labeled there by S1 to S6. So you can also call it sample number but it is not a number which comes from the sample itself. It denotes only the connection position at the switch box.

The used sample will be directly defined before a measurement in the Static, Transient and Isothermal program module. Only the number of the probe has to be defined in addition to the measurement without the sample switch box.



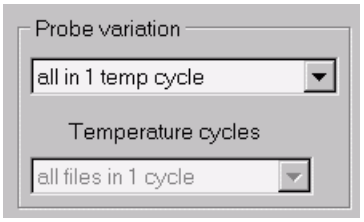
You can select the probe number in the 'Params input window' of every measurement, it is now extended.

The sample of the selected probe is measured and (if available) evaluated data like the shallow doping is saved into the sample parameters under this probe number. The proposal of file name will be constructed as defines in the 'file mode' of the previous chapter.

At the Static program module there is the additional menu point '**C/V of all samples**'. Here all samples connected to the switch box will be automatically measured, evaluated and saved one after one. Before starting the measurement you have to confirm or to change the proposal of the file name for the first probe. The other file names will then build by the 'file mode' definition.

6.4.5.3 Tempscan measurements

Different kinds of probe variation can be selected for a tempscan if you have selected in the base parameters 'all' as work mode. From one tempscan of one sample with a defined probe to an automatic variation of the probes during one temperature variation all possibilities are selectable. The selections can be done for the **manual tempscan** in the parameters base input sheet. Instead the cycle mode you get there the input group 'Probe variation'.



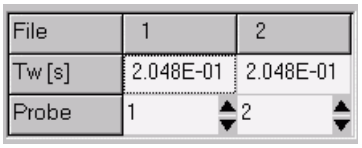
Following possibilities for the **Probe variation** exist:

only one sample: Only one probe is measured. The probe number is given in the 'Params' window of the transient input sheet, similar as described in the previous chapter.

all in 1 temp cycle: All probes (1 up to 6, defined in 'numbers of samples, chapter 6.4.5.1) are automatically measured in one temperature cycle. Reverse bias, period width and so on are always the same for all samples.

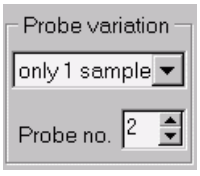
all in diff. cycles: All probes are automatically measured in different temperature cycles. The measurement can be done (similar to the measurements of different files) always during the heating or cooling cycles dependent on the temperature definition before the tempscan start. Both direction measurements (one probe during the heating the next during the cooling cycle) can be defined in the Temp input sheet (flag 'Both temp directions', see chapter 3.4.1.1.2).

all, full input: The full parameter input for all files and probes. The probes are handled similar to other parameters like pulse voltage or period width. For every constant period width file the probe number can be defined. This input mode allows to measure selectable probe that must not be measured in a row and not all probe must be measured.



If selected 'all, full input' then the input for the mode of **temperature cycles** is enabled. It is the same as the cycle mode, described in chapter 3.4.1.1.1.

If you use the **routine tempscan** then you find the input for the probe variation on the main routine window. There you have the same possibilities as in the manual tempscan. The input for the probe variation don't come from the routine file! If you select 'all, full input' you don't get here the input for the temperature cycles. This parameter comes from the routine file.



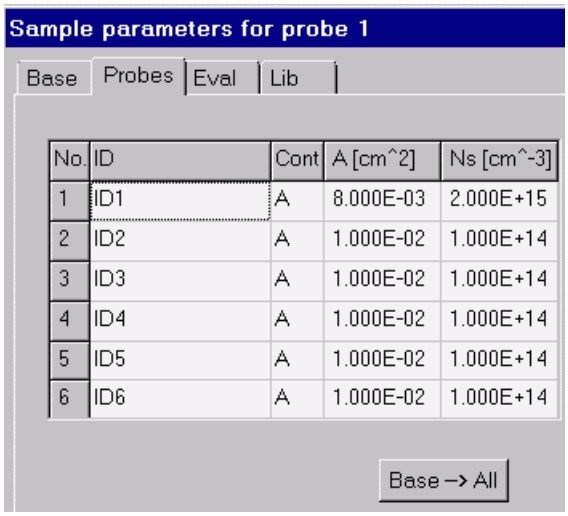
If using the **batch tempscan**, see chapter 3.4.1.3, then you can also vary the probe in the batch cycles. There you can set each cycle to the corresponding probe number or input the probe number for every cycle separately. A sample variation is also possible in the base cycle (at one or more temperatures). This might lead to confusions but the base cycle has a higher priority. To avoid misunderstandings it is the best to vary the probe number only in the batch cycle. For this select as probe variation (valid for the base cycle) 'only one sample'. You find this input as explained above.

The variation mode 'all, full input' is not enabled if measuring only **TSC** or temperature depending C/V curves.

Before starting the measurement you have in the tempscan start window, chapter 3.4.1.4, to confirm or to change the proposal of the **file name** for the first probe. The other file names will then build by the 'file mode' definition.

At the batch tempscan there are confusions with the file name syntax possible if varying the probe number in the batch and base cycles or if using 2 batch cycles for 1 sample. It depends also on the file mode. In such cases you should activate 'Cycle no. as 3. extens.' in the manual tempscan window. Then the 3. character of the data extension represents the batch cycle number and not the probe number.

6.4.5.4 Sample parameters



In the sample parameters the new input sheet **Probes** is visible. The ID, contact and the contact area can be defined for every sample. The shallow doping Ns can either directly be defined or measured, evaluated and transferred into this sample parameters set.

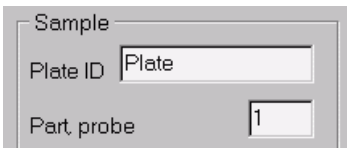
All other parameters like material, type of the diode and so on meant to be the same for all samples.

Nevertheless you can also define for example the area on the 'Base' input sheet. This input is only valid for the selected sample/probe.
A change there on the Base input sheet changes also the value on the Probes input sheet. The same is valid for the opposite.

The button '**Base** → **All**' transfers the values from the Base input sheet to all samples.

Only these parameters above are separately for the different samples. The sample switch box is meant to measure different, but similar samples. It is important that the sample does have the same material and similar diode characteristics. Totally different samples should not be measured together. It might be much better in that case to measure these separately in different temperature scans.

If selecting as file mode '**no. and plate ID**', see chapter 6.4.5.1, then the Base input sheet differs a little bit.



Instead the sample ID and the contact of the current probe there is an input for a common plate ID. This plate ID is valid for all samples. Nevertheless an individual sample ID for each sample exist further on, now abbreviated as 'S-ID' on the 'Probes' input sheet.

Instead the contact input is on the Base input sheet the input 'Part, probe'. 2 characters are here allowed, the last will be set automatically to the selected probe number. You can input an individual contact on the Probes input sheet.

At this file mode the file name will be build by the common plate ID and the part/probe number. The plate ID and the S-ID together with the contact will be listed at plots.

6.4.6 Multi frequency bridge

This chapter describes the additional options of the CGI-Meters FT-1241/43/44/45. Not all options are available for each CGI-Meter. The options may vary for different customers.

6.4.6.1 Main working parameters

6.4.6.1.1 Bridge range/frequency mode

The access to the selection of the main working modes (frequency …) is possible by clicking onto the ‘HF, Others’ button of the bridge input sheet of the main measurement parameters, see chapter 2.1.2.3. An input window opens as shown below.

For the next description it is important to know how our CGI-Meters meters work. At all modes 2 oscillators generate two sine HF-voltages (standard 1MHz). One is a reference signal, the other branch goes into the sample. At the end both signals will be multiplied in a lock-in correlator. Each oscillator contains a DDS (Direct digital synthesis) with adjustable frequency and phase. 2 complete different methods resp electronic parts exist:

Resonator capacitance bridge: This works as a classic capacitance bridge, for example the Boonton 72B and the Boonton 7200. The sample signals goes into one of more resonator circuits (depending on range and frequency), then the signal passes a CR high pass filter, then it will be amplified by 4 AC amplifiers (amplification variable), goes together with the HF reference signal into the lock-in correlator, the DC output signal of the lock-in will then be amplified and measured.

Measurement of HF-current: This is a bit similar as a LCR-meter works. The sample signal goes directly or via a transformer into a trans-impedance amplifier. Its HF output voltage corresponds to the HF current through the sample. This HF voltage will then be amplified by 4 AC amplifiers, goes together with the HF reference signal into the lock-in correlator, the DC output signal of the lock-in will then be amplified and measured.

Usually the DDS (**D**irect **D**igital **S**ynthesis) will be used for creating the HF-voltage. This has the advantage that the phase for all ranges, amplifications and HF-voltages can be adapted for optimal work. And the frequency may be changed a little bit to avoid noise, see pitch control. The phase at the analog oscillator can be changed only in some steps by hardware, so it is not always optimal. And the frequency is fix. An advantage may be a better suppression of high HF-frequencies. This is only important if the capacitance compensation is not good and some pF will not be compensated. The 1MHz-Fix is only available for the FT-1245 and only for the mode ‘Standard’, see below.

The **bridge connection** defines how the sample will be connected to the bridge:

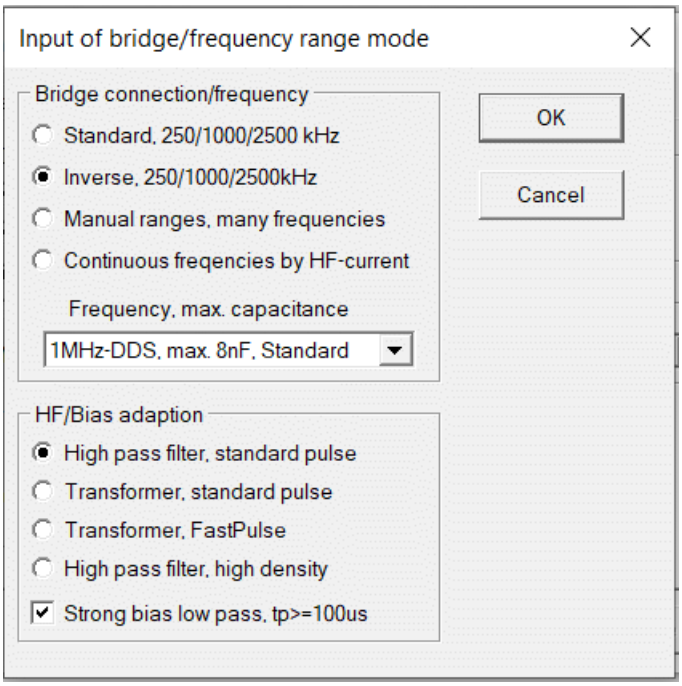
Standard: C-Meter at **HighSample**. This is the standard mode for resonator bridges, the Boonton bridges use also this mode. The input of the bridge will be connected with Sample High. Additionally the bias high voltage will be connected via a LC low pass filter to this point. The HF voltage of the oscillator will be connected to Sample Low. Bias low and oscillator low are on the same ground. The CR high pass filter in the bridge blocks the DC in the bridge. The LC low pass filter at the bias avoids that the HF voltage goes into the bias source.

Inverse: C-Meter at **LowSample:** This is the inverse mode, LCR-meters use it. The HF-voltage of the oscillator will be added to the bias high voltage and then connected to Sample High. Sample Low will be connected via a transformer to the input of the bridge.

Both modes have advantages and disadvantages. The problem at the inverse mode is the addition of DC voltage and HF voltage. It will be done either by a high pass filter or by a transformer. The capacitance of the filter has to be much bigger than as the capacitance of the sample. This yields to a big time constant which forbids small pulse widths. A too small capacitance yields to an error of the capacitance measurement. The impedance especially of the bias source is a problem at the transformer. Overall the inverse mode reduces the maximum available capacitance and may yield at resonator bridges to a bigger non-linearity. The advantage is the smaller recovery time, 100us versus 600us in range 1 for 1MHz. The reason and a further advantage is that the DC doesn't go into the resonator. It will be blocked via a transformer. So the resonator doesn't see directly a voltage change by a DLTS pulse but only the capacitance change. An additional advantage is the direct use of a fast pulse generator without switching relays. At high bias voltages this mode is also more stable. At the standard mode the most high voltage amplifiers show oscillations at the DC voltage.

In the following input windows you can select the measurement method, the bridge connection and the frequency or the type of frequency selection.

- **Standard, 250/1000/2500kHz:** Uses the resonator circuits and the standard connection.
- **Inverse, 250/1000/2500kHz:** Uses the resonator circuits and the inverse connection.
- **Manual ranges, many frequencies:** Uses the resonator circuits and the standard connection. You have to select a special frequency and a fix range for the measurement. More details for this mode will be given later in this chapter.
- **Continuous frequency by HF-current:** Uses the measurement of the HF current and the inverse connection. You select a frequency of a frequency range.



To abbreviate the selection (methods) above we call it '**bridge mode**'. These are:
Standard, Inverse, Manual ranges, HF-current.

For selection 1 and 2 (Standard/Inverse) following frequencies may exist:

- **1MHz-Fix**, max. 8nF, 4 ranges plus sensitive range: Analog oscillator with a fix frequency of 1MHz.
- **1MHz-DDS**, max. 8nF, 4 ranges plus sensitive range: This is the standard mode and frequency.
- **2.5MHz-DDS**, max. 400pF, 3 ranges: High frequency, restricted capacitance.
- **250kHz-DDS**, max. 80nF, 5 ranges: Low frequency for big capacitance, smaller sensitivity.

Following modes for the **HF/Bias adaption** exist at the 'Inverse' bridge mode:

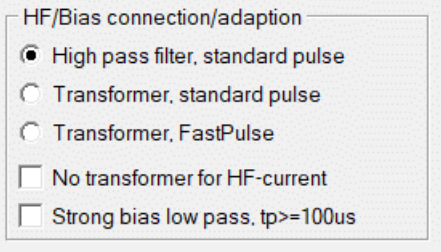
- **High pass filter:** The HF voltage will be added via a high pass pass filter to the DC bias.
- **Transformer:** The HF voltage will be added via a transformer to the DC bias. The maximum capacitance is a little bit restricted.
- **Transformer, fast pulse:** The fast pulse generator will also be used for the bias. At the fast pulse mode there is no switching between standard bias source and fast pulse generator. So the recovery times are smaller. Selecting '**tp>=100ns**' decreases the recovery time. The maximum capacitance is 400/200/4000pF for 1000/2500/250kHz.
- **Transformer, high density:** The HF voltage will be added via high pass filter to the DC bias. The signal height is twice of the other modes because a 2:1 transformer will be used for coupling the sample signal into the resonator. But the accuracy is not so good.

The bias source output has a low pass RC filter. Because the high cut-off frequency the influence of this filter is minimal. Activating the option '**Strong bias filter**' increases the filter influence, but the minimum pulse width is 100us. This option may increase the sensitivity.

At the 'Standard' bridge mode only the option 'Strong bias filter' is available.

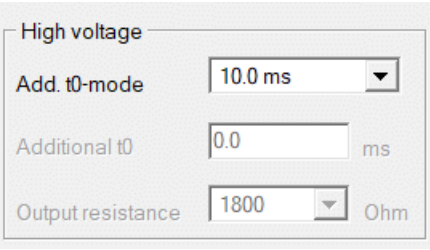
At the 'HF-current' bridge mode following input window for the **HF/Bias adaption** is visible:

- **High pass filter:** The HF voltage will be added via a high pass pass filter to the DC bias.
- **Transformer:** The HF voltage will be added via a 1:1 transformer to the DC bias.
- **Transformer, fast pulse:** The fast pulse generator will also be used for the bias.



The HF-current signal goes usually through a transformer to the trans-impedance amplifier (TIA). Selection of '**No transformer for HF-current**' avoids this transformer. Then HF-current and DC-current go directly into the TIA. A transformer has the advantage that DC-currents have no influence to the output voltage of the TIA. In the other case a high offset voltage may occur which reduce the possible impedance amplification and so the sensitivity. The minimum usable frequency of our transformer is 100kHz. At lower frequencies it can not be used. So here you have to into account the offset current.

If using the **external high voltage** option (500V or 1000V) the input window shown on the right is visible. Some high voltage amplifiers need a resistance between amplifier and sample, integrated in the CGI-Meter. Without this resistance oscillations may occur. The disadvantage is a big additional recovery time. By default the standard time will be set. But you may select other values.

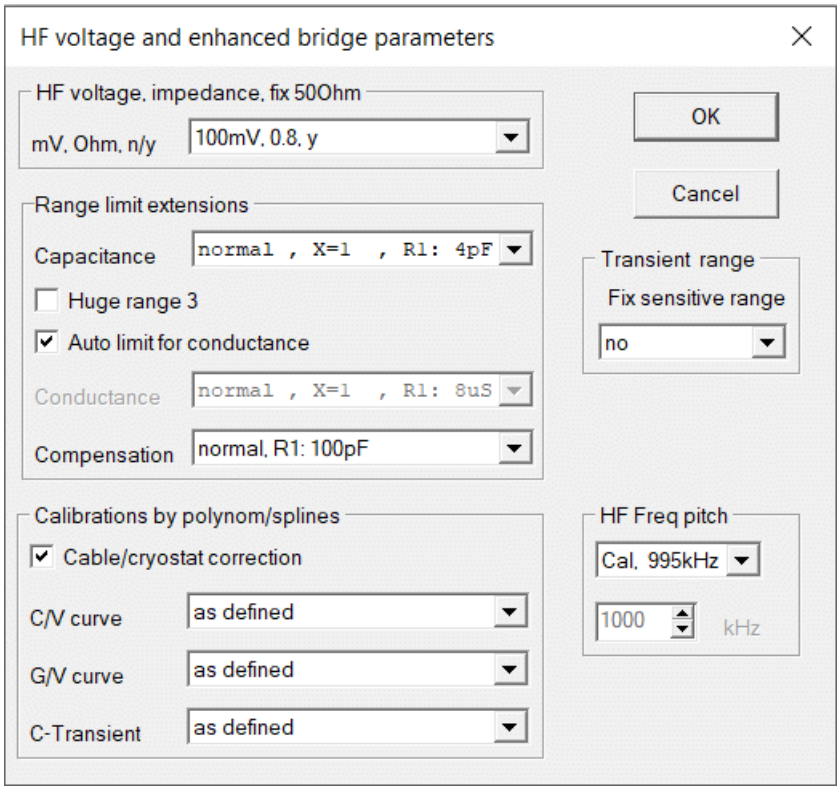


A **VarParams** button is only available for bridge mode 'Manual ranges'. Then here the ranges for the frequency scanning will be set. It is similar to the inputs for 'Manual ranges'.
The 'Okay' button opens yet another input window described in the following chapter.

6.4.6.1.2 Standard and inverse bridge mode

Most of these inputs were already explained in chapter 2.1.2.5. One or two new input inputs are available for the FT-124X CGI-Meters.

There is one range more at the FT-1243/44/45 for 1MHz. This is a special **sensitive range** for small capacitances. This range is only available for transient measurements, not for static curves. It will not be selected automatically. If you use the sensitive range, it will replace the standard range 1. The two limit extension 2pF and 4pF exist. The 2pF limit has the highest sensitivity but the signal has to be smaller than 2pF, amplitude plus offset.



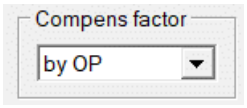
HF Freq pitch allows to change the selected frequency a little bit. There are following possibilities, example for 1MHz:

Cal. 995KHz: Frequency at which the calibration was done, best selection.
Alt 1000kHz: Alternative frequency.
Min 970kHz: Minimum frequency.
Max 1020kHz: Maximum frequency.
Input kHz: Input of frequency in kHz is available.
Input Hz: Input of frequency in Hz.

The best is to select the frequency where the calibration was done. The calibration factor will also be calculated for the alternative, minimum and maximum frequency. At other values it will be interpolated. But the linearity may be not so good in all these frequencies except at the calibration frequency. But it may be that the noise is smaller at an other frequency. That is the reason that we use 995 kHz instead of 1MHz. Often there is an interference with other frequencies of the PC, perhaps from the USB, so that we see a peak at low frequencies at 1MHz HF voltage. So, if you see a peak or big noise in the background spectrum, change the HF frequency a little bit. But aware that the linearity of the capacitance measurement may decrease.

The calibration by **frequency table** for C and G is only visible when such a table exist.

As shown in chapter 2.1.2.5 a 100mV and a 1000mV **HF voltage** exist with a direct output of the operation amplifier (**OP**). Because there are no transformers the output has a very low resistance and impedance. This output exist not only for the sample signal but also for the capacitance compensation. The compensation for the 1000mV level will always done by an OP output.



If selected the 100mV OP, the signal output comes always directly from the OP. But the capacitance compensation can use either also an OP output or a standard transformer output. 4 possibilities exist at the 100mV OP level for the compensation level, an additional input window occurs for the **Compensation factor**:

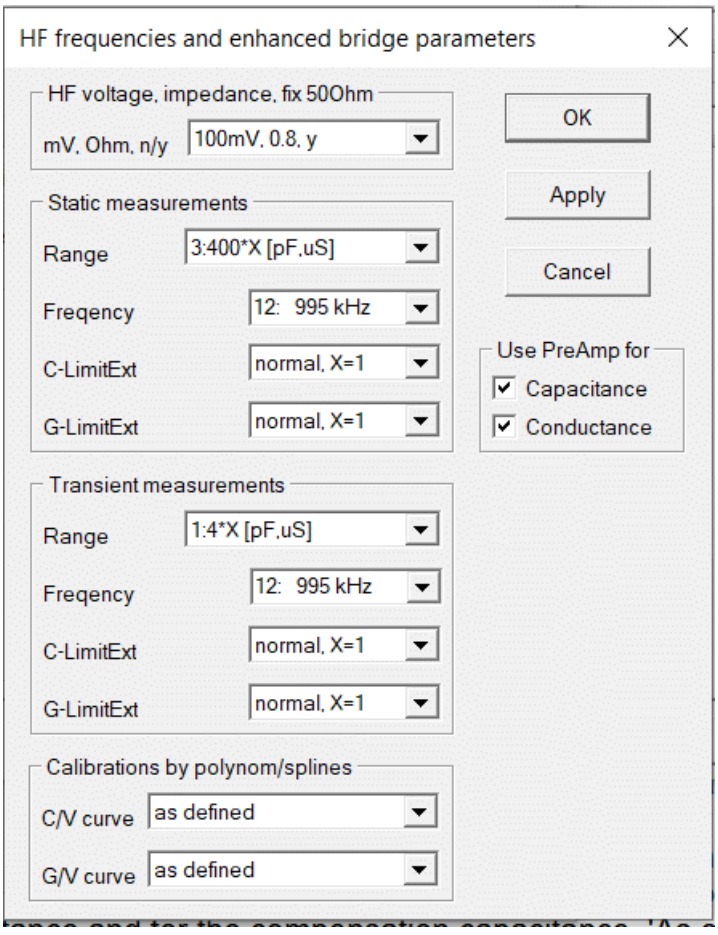
by OP: An OP output with 100mV HF voltage will be used for the capacitance compensation and for the sample signal.

1, 100mV: The standard 100mV HF voltage will be used for the compensation, sample and compensation HF voltages have the same height.

0.5, 200mV: The standard 200mV HF will be used, the capacitance of the used compensation capacitors are half of the sample capacitance.

2.5, 40mV: The standard 40mV HF will be used, the capacitance of the used compensation capacitors are a factor of 2.5 bigger than of the sample.

6.4.6.1.3 Manual ranges



The input window for the 'Manual ranges' bridge mode differs from that one before. Some inputs are the same as in chapter 2.1.2.5, so these will not be explained here.

In this mode the capacitance range will not be set automatically. You have to select a special frequency and a fix range for the measurement, separately for C and G and for static and transient measurements. Select for static measurements a **range** which fits your sample capacitance. Transients will be measured with capacitance compensation, so that usually range 1 is the best, except at big transient amplitudes. Select then a **frequency** at which your measurements should be done. Use similar frequencies for static and transient measurements. But it is not necessary that it is the same frequency. The reverse bias capacitance will normally be measured with the transient range at transient measurements. In range 1 you have usually 25 frequencies between 150kHz and 5MHz. Up to 25/25 frequencies between 150kHz and 2.5/3MHz are available at range 2/3. Up to 15 frequencies exist for range 4, only 5 for range 5. Range 6 is a special range. Here you have a very sensitive mode of about 1MHz, and some low frequencies for a big capacitance. The exact frequencies in all ranges depend from your hardware.

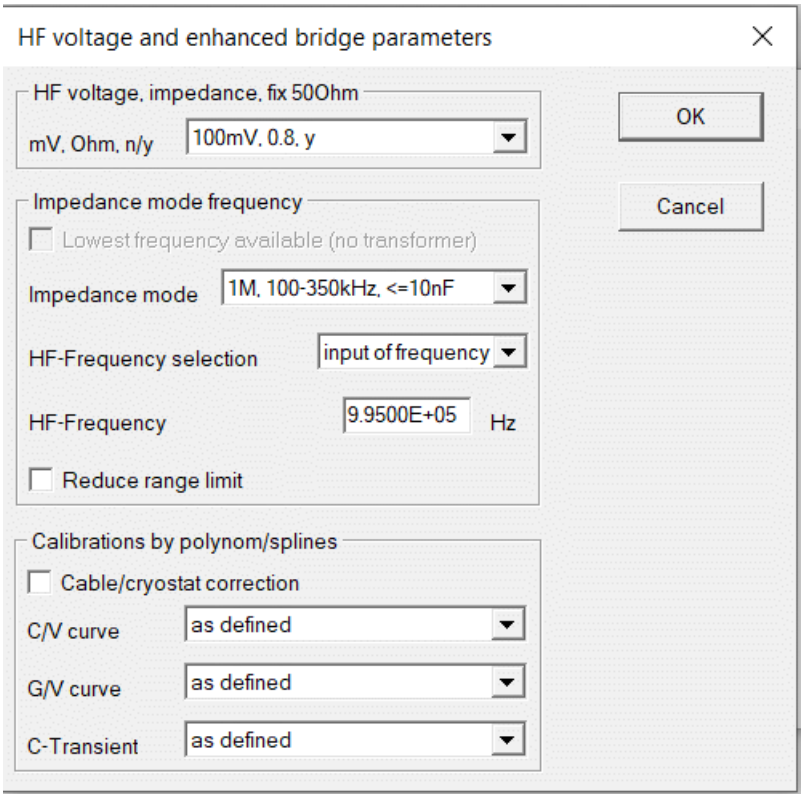
A calibration by **frequency table** for C and G is visible when such a table exist. The calibration can be done by the frequency number or by the frequency. Different tables exist for limit mode 1 and 2/3. In the Base Tools menu 'Calib → Service calibrations → Edit frequency Factors' you can create and edit such a table. User class 6 is necessary.

6.4.6.1.4 Continuous frequency by HF-current

Most inputs of this bridge mode were already explained in chapter 2.1.2.5 and 6.4.6.1.2. Only the 20mV, 100mV, 100mV-OP (FT-1243/44/45) and 200mV HF levels are possible.

The inputs for 'Impedance mode frequency' are new. The **impedance mode** means the trans-impedance amplification in range 1 and defines also the frequency range and the maximum capacitance. Up to 6 single impedance modes and 1 automatic mode exist:

0) auto, 30-5000kHz (100-2500kHz)
1) 10M, 30-125kHz, <=30nF
2) 1M, 100-350kHz, <=10nF
3) 1M, 300-550kHz, <=2nF
4) 100k, 500-1100kHz, <=2nF
5) 10k, 1100-2500kHz, <=500pF
6) 1k, 2500-5000kHz, <=100pF



Only mode 2 up to 5 are possible at the FT-1241. The maximum capacitance depends also on the HF level voltage. In the automatic mode the impedance mode will be selected by the used frequency. The frequency limits for the FT-1241 are 100-2500kHz.

The 10M impedance mode with the low frequencies is only possible for the 100mV OP HF-level. No transformer here is possible, also not the transformer ahead the TIA. So you have to respect a possible DC current offset, see chapter 6.4.6.1.1. You have to activate 'Lowest frequency available' to use this impedance mode at selected automatic mode.

The HF-Frequency selection defines how you are select the frequency:

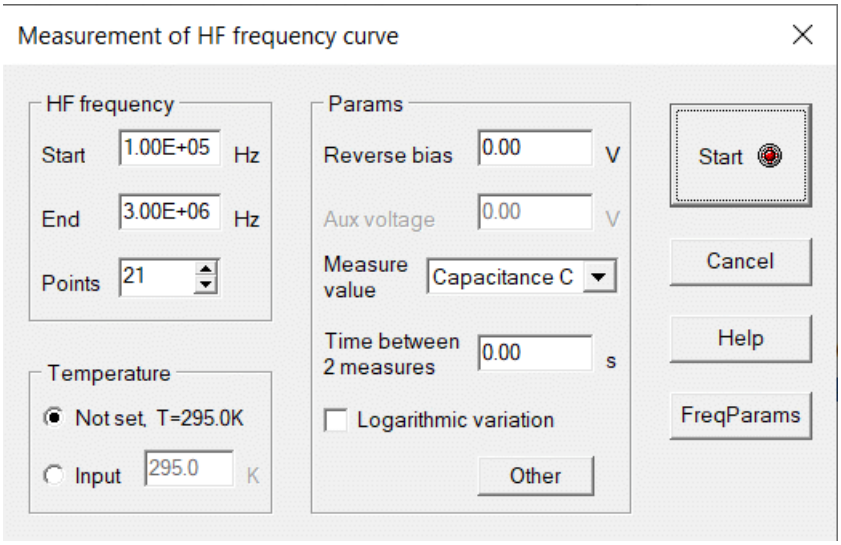
- **Calibration frequency:** The fix full calibration frequency of the impedance mode: 100kHz, 245kHz, 495kHz, 995kHz, 2500kHz, 5000kHz
- **Main frequencies:** Only the main frequencies which are calibrated for the used impedance mode: 1: 30,40,50,75,100,125 kHz
  2: 100,125,150,200,245,300 kHz
  3: 300,350,400,450,495,550 kHz
  4: 495,600,700,800,900,995,1100 kHz
  5: 1100,1300,1500,1750,2000,2250,2500 kHz
  6: 2500,3000,3500,4000,4500,5000 kHz
- **Input of frequency:** You may input each frequency of the selected frequency range. The calibration values for these frequencies will be interpolated by the calibration of the main frequencies.

No limit extension exist for this bridge mode. But you can **reduce the range limit** without changing the AC and DC amplifiers. The reduction depends on the HF level, it is 50% for the 20 and 100mV levels, 25% at the 200mV HF level.

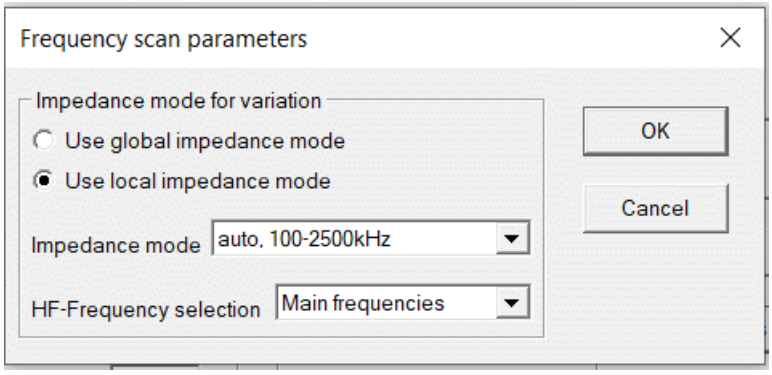
Note: Measurements for frequencies above 1MHz are not 100% calibrated at this time. And the influence of cables and connectors increase at higher frequencies and with bigger capacitance values. Generally the error at a frequency scan (changing the frequency) may be 1% or less at lower frequencies and more than 1% at frequencies above 1MHz. Measurements in a cryostat may lead to a bigger error. The reason are the cables and the manipulators in the cryostat. The error increase significantly for capacitance values bigger than 1nF at 1MHz. The influence of the cryostat decreases at lower frequencies.

6.4.6.2 HF Frequency and phase scans for static curves

In the static measurement menu there is the new entry '**C versus HF frequency**'. The capacitance or/and the conductance can be measured versus the HF frequency. The inputs are similar as for a C/V curve. Here you have to input the HF frequency, the measurement will be done at reverse bias. The variation of the frequency resp. the frequency-x-axis of the standard plot is either linear or logarithmic.



The 'FreqParams' button opens for the mode 'HF-current' the input window shown on the right.

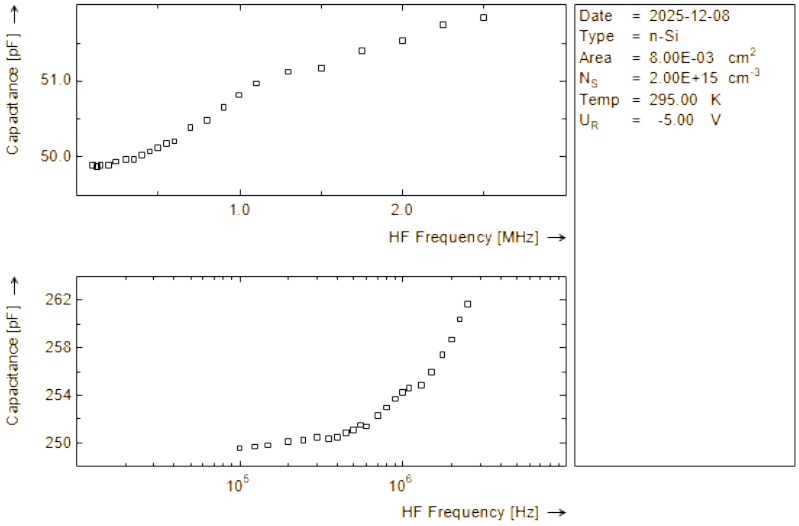


You may use the selected global impedance mode (see chapter 6.4.6.1.4) or only for the frequency scan a local impedance mode.

The **HF-Frequency selection** defines also which frequencies are possible:

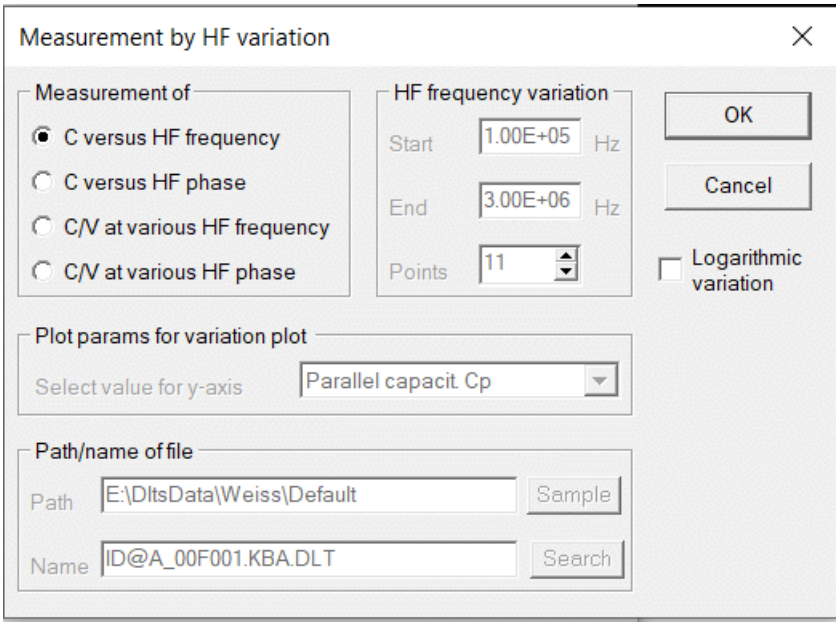
- **Main frequencies:** Only the main (calibrated) frequencies for the selected impedance mode are available, see chapter 6.4.6.1.4. At auto impedance mode all main frequencies may be used, restricted by selected min. and max. frequency.
- **Match main frequencies:** If a frequency is near a main frequency, this frequency will be used.
- **All frequencies available:** The frequencies will only be defined by the min. and maximum frequency and the number of points.

The picture on the right shows at the top a measurement of a capacitor with about 50pF at 1MHz. The measurement on the bottom was done at a capacitor with about 250pF, the frequency axis here is logarithmic. The curve should be independent of the frequency. But the capacitor was build-in into a small aluminum box with BNC connectors. This yields to a not ideal capacitor. The deviation is bigger at the 250pF capacitor, as expected.



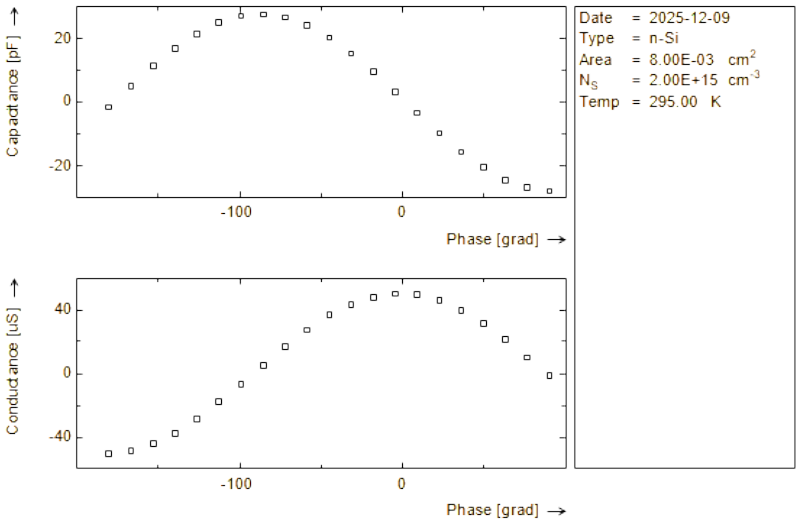
The measurements were done in the bridge mode ‘HF-current’.

In the static measurement menu there is also the new entry ‘**HF variation**’. Here you can measure C or G versus the HF frequency (as above) or versus the HF phase. Or you measure C/V or G/V curves by variation of the HF frequency or of the HF phase. At the variation you have here to input the parameters for the frequency or phase. If measuring C and G you may select the value for the y-axis of the plots. The inputs are similar as already explained in this manual for the static program module.



The top picture on the right shows the capacitance of a Zener diode at -5V at different HF phase. The maximum is at about -90 grad, so this device has here the behaviour of a good capacitor.

The picture on the button shows the conductance of a 20kOhm resistor at different phases. As expected the peak is at 0 grad.



A frequency variation is also possible in the **equilibrium** program module. At one temperature the capacitance will be measured at different frequencies. Then the program goes to the next temperature and the capacitance will be measured again at different frequencies. As result different Q-files (CR versus T) will be created measured at different frequencies.

6.4.6.3 HF Frequency variation for transients

In the isothermal program module you have 2 possibilities for transient measured at different frequencies:

Variation of HF frequency: You find it in the measurement sub-menu of ‘Fix period width’. Here transients at different frequencies will be measured, a PK? file with the frequency as x-axis will be created at saving data. The coefficients, for example b1, will then been shown versus the frequency.

Parameter variation of HF frequency: You find it in the input window for the measurement ‘ITS Parameter variation’. Then period scans will be measured at different frequency. First a complete period scan will be measured at one frequency, then the frequency will be changed and the next period scan will be measured. As result you get for each frequency a period scan file. Plots with a single period scan, plots with all period scans or 3-dimensional plots are possible.

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