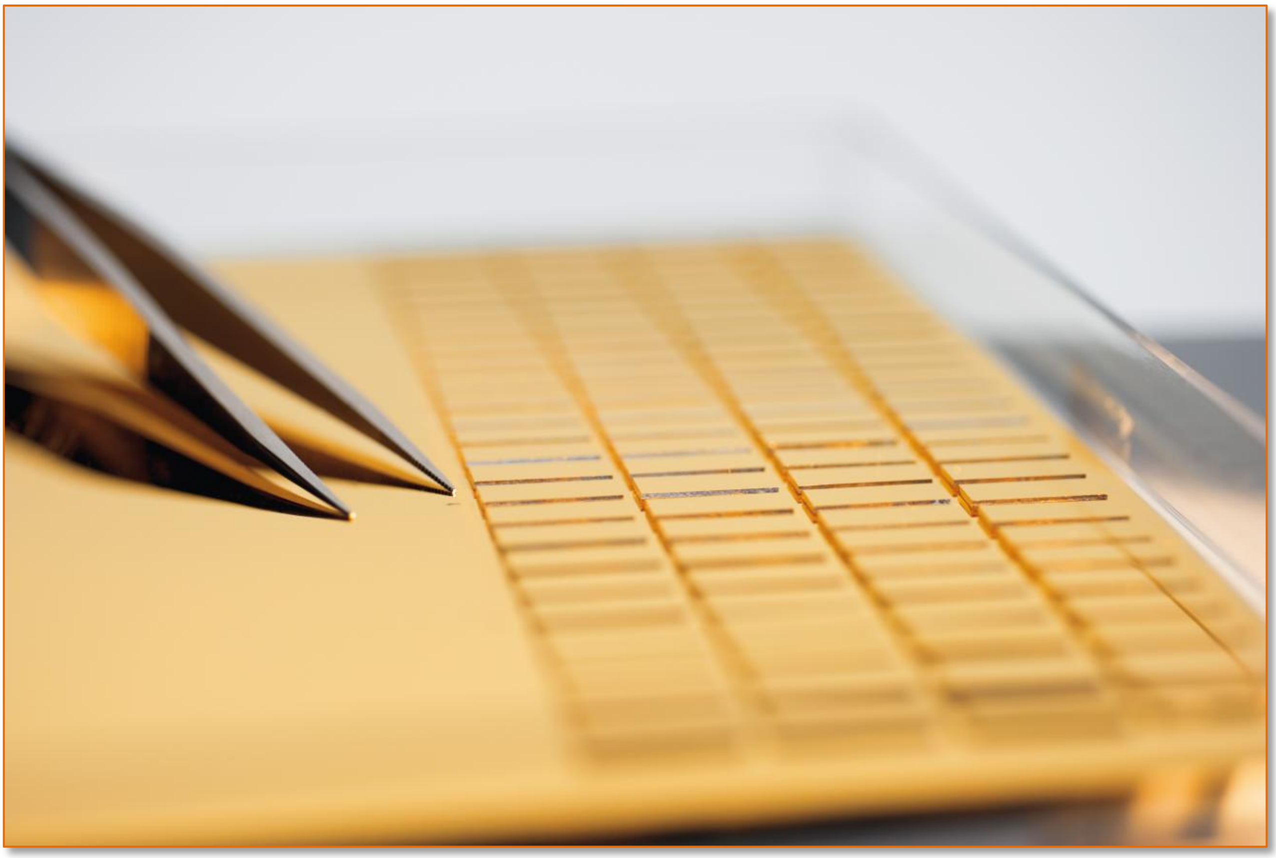
MATRIX 3.2 Application Manual for Scanning Probe Microscopy

Version 3.2 • 04 November 2014



Help Line:
German Headquarters and Service Centre:
Scienta Omicron GmbH
Limburger Str. 75
65232 Taunusstein, Germany
Tel.: +49(0) 61 28 / 987-230
Fax: +49(0) 61 28 / 987-33-230
E-Mail: services@scientaomicron.com

PN05323

scientaomicron

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Preface

This document has been compiled with great care and is believed to be correct at the date of print. The information in this document is subject to change without notice and does not represent a commitment on the part of Omicron NanoTechnology GmbH.

Notice

Some components described in this manual may be optional. The delivery volume depends on the ordered configuration.

Notice

Product names mentioned herein may be trademarks and/or registered trademarks of their respective companies.

Notice

This documentation is available in English only.

Attention

Please read the safety information in all related manuals before using the instrument.

Copyright

No Third Party Additions for Omicron Instruments

Attention

Third party equipment can destroy your Omicron instrument. If connecting other than Omicron supplied equipment please make sure this is compatible with your Omicron instrument, particularly with respect to power rating, maximum voltages, currents and impedances as well as fault handling and safety shutdown.

Omicron shall refuse any warranty claims in case of non-compliance.

Notice

Omicron cannot guarantee compliance with CE directives in case of changes to the instrument not explicitly agreed by Omicron, e.g. modifications, add-on's (including third party equipment), or the addition of circuit boards or interfaces to computers supplied by Omicron.

Normal Use

The **Omicron MATRIX system** is a microscope control system comprising software, computer hardware, digital and analogue I/O electronics. MATRIX is determined for instrument control, data acquisition and image visualisation in Scanning Probe Microscopy (SPM) and Electron Spectroscopy (ESP).

The Omicron MATRIX SPM system consists of the following subunits

1. MATRIX Control Unit (MATRIX CU)
2. MATRIX Power Supply
3. MATRIX rack
4. Windows XP computer
5. Mobile computer desk
6. MATRIX SPM control software

optional:

7. AFM-SPU
8. HC 1100 for direct sample heating

The **Omicron MATRIX system** must always be used

- **complete** and with Windows XP PC, MATRIX CU, and AFM CU (if applicable) being rack integrated with all screws tightly fixed to ensure proper grounding
- in combination with SPM heads which are explicitly specified for this purpose by Omicron
- with original Omicron cable sets which are explicitly specified for this purpose
- with all cabling connected and secured, if applicable, and all electronics equipment switched on
- in combination with the up-to-date software release
- in an indoor research laboratory environment
- by personnel qualified for operation of delicate scientific equipment
- in accordance with all related manuals.

Conditions of CE Compliance

Omicron instruments are designed for use in an indoor laboratory environment. For further specification of environmental requirements and proper use please refer to your quotation and the product related documentation (i.e. **all** manuals, see individual packing list).

The **Omicron MATRIX system** complies with CE directives as stated in your individual delivery documentation if used unaltered and according to the guidelines in the relevant manuals.

Limits of CE Compliance

This compliance stays valid if repair work is performed according to the guidelines in the relevant manual and using original Omicron spare parts and replacements.

This compliance also stays valid if original Omicron upgrades or extensions are installed to original Omicron systems following the attached installation guidelines.

Exceptions

Omicron **cannot** guarantee compliance with CE directives for **components** in case of

- changes to the instrument **not explicitly agreed by Omicron,** e.g. modifications, add-on's, or the addition of circuit boards or interfaces to computers supplied by Omicron.

The customer is responsible for CE compliance of entire **Experimental setups** according to the relevant CE directives in case of

- installation of Omicron components to an on-site system or device (e.g. vacuum vessel),
- installation of Omicron supplied circuit boards to an on-site computer,
- alterations and additions to the Experimental setup not explicitly approved by Omicron

even if performed by an Omicron service representative.

Spare Parts

Omicron spare parts, accessories and replacements are not CE labelled individually since they can only be used in conjunction with other pieces of equipment.

Notice
CE compliance for a combination of certified products can only be guaranteed with respect to the lowest level of certification. Example: when combining a CE-compliant instrument with a CE 96-compliant set of electronics, the combination can only be guaranteed CE 96 compliance.

Safety Information

Caution

Important:

- Please read this manual and the safety information in all related manuals before installing or using the instrument or software.
- The safety notes and regulations given in this and related documentation have to be observed at all times.
- Check for correct mains voltage and grounding/earth before connecting any equipment.
- Do not cover any ventilation slits/holes so as to avoid overheating.
- The electronics may only be handled by authorised personnel.

Warning

Warning: Lethal Voltages!!

- Adjustments and fault finding measurements as well as installation procedures, repair work and SPM Experiments in environments other than UHV may only be carried out by authorised personnel qualified to handle lethal voltages.
- Lethal voltages may be present on parts of the SPM head during operation.
- Lethal voltages are present inside the control unit/computer (if applicable).

Caution

Always

- All connectors which were originally supplied with fixing screws must always be used with their fixing screws attached and tightly secured.
- Always disconnect the mains supplies of all electrically connected units before
  - ⇨ opening the vacuum chamber or a control unit case,
  - ⇨ touching any cable cores or open connectors,
  - ⇨ touching any part of the in-vacuum components (except for tip and sample exchange as described in this manual).
- Leave for a few minutes after switching off for any stored energy to discharge.

Caution

This product is only to be used:

- indoors, in laboratories meeting the following requirements:
  - ⇨ altitude up to 2000 m,
  - ⇨ temperatures between 5°C / 41°F and 40°C / 104°F (specifications guaranteed between 20°C / 68°F and 25°C / 77°F)
  - ⇨ relative humidity less than 80% for temperatures up to 31°C / 88°F (decreasing linearly to 50% relative humidity at 40°C / 104°F)
  - ⇨ pollution degree 1 or better (according to IEC 664),
  - ⇨ overvoltage category II or better (according to IEC 664)
  - ⇨ mains supply voltage fluctuations not to exceed ±10% of the nominal voltage
- Condensation of humidity, particularly on water-cooled equipment, must be avoided.

1. Introduction

Welcome

Welcome to the MATRIX software package which will provide you with the tools and information necessary to successfully run your Omicron MATRIX system as well as handle and visualise your obtained data.

Notice
This manual will only cover the predefined Projects as supplied by Omicron.

The Software

The Omicron MATRIX software package runs on a Windows XP or Windows 7 Personal Computer.

All Windows computers allow a user account management concept which requires

- users to have a unique user name and a password
- a system administrator for general system management jobs like creating new user accounts etc.

In the most simple case there are two types of users

- normal users, i.e. those who use the system but do not care about its administration and management
- an administrator who is responsible for user and disk management, system configurations and for the installation of new software and software updates.

A "user" in this context is not a physical person but rather like a numbered account: one physical person can have several accounts and an account can be used by everyone who knows the account name and the corresponding password. So, please keep passwords safe and secret.

When you receive a software update you will find information on how much software installation is necessary in the release notes which go with it. Usually only MATRIX has to be installed. In very rare cases a Windows operating system installation will be necessary.

Notice
When you receive your Windows PC from Omicron, all software is already installed. Additional software installation **is neither recommended nor necessary.**

Notice

Please read the Windows PC Manuals before switching on the computer.

Notice

The MATRIX software will keep project and experiment descriptions, experiment structures, and other information in a folder hierarchy in the <*RootDir*> directory. (The exact location of this folder hierarchy is determined by the %APPDATA% environment variable, see also chapter **MATRIX File Path Systematic** on page 138f.)

Since the <*RootDir*> directory is actually part of the user profile maintained by the operating system, the data stored by MATRIX is subject to user profile restore operations.

As a result, on networked systems, MATRIX files might experience changes when the user profile information has not been stored correctly on the server (e.g. because the computer was switched off instead of shutdown properly) but the networked profile is nevertheless loaded upon the next login. In such a case, the more recent local user profile will be replaced by the older networked profile, destroying all changes to MATRIX data that took place in the meantime.

Please take care that on a networked computer system the user profile information will be stored on the server correctly by adhering to the logout and shutdown procedures of the Windows operating system. If this is not possible (e.g. because the computer crashed or was accidentally switched off), always choose to use the more recent user profile stored locally instead of using the older profile data stored on the network server when the system prompts you to choose between profiles.

Otherwise, changes to projects, experiments, and maybe also result data will be lost.

2. Starting MATRIX

MATRIX consists of one or several control units and a software package. For successful communication between hardware and software to be established it is essential to stick to the following power-on routine:

- Check the cabling. Make sure all power cables are connected to the same wall socket to avoid ground loops.

- Switch on the MATRIX rack.

- On your MATRIX PC press Crtl + Alt + Del to log in as **MATRIX User**, giving the correct password (initially without password). You may want to create a less privileged user for normal SPM operation using the User Manager in the Administrative Tools sub-menu.

- Make sure the MATRIX Power Supply and Control Unit (MATRIX CU) are switched on before starting the MATRIX Software.

- The PC software will automatically detect the MATRIX CU configuration and determine the layered software modules required for experiment operation. These modules will be transferred to the MATRIX CU. (As this process may take up to 25 seconds, a progress bar will indicate the status of the transfer process.)

- As soon as the MATRIX application main window is available, the system is ready for operation.

If you are upgrading from a previous version of the MATRIX software, or if your system was originally shipped before 1st June 2008, you must contact the Omicron service organisation for obtaining a valid Product Authorisation Key (PAK). Upon start-up you will be presented with the following message:

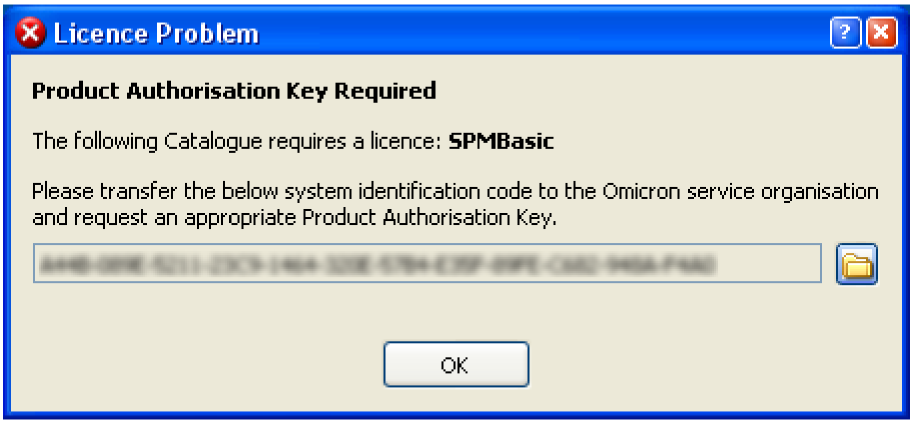


Figure 1. Licence Required message.

In this case use the folder button to save the system identification code and email it to Omicron to obtain your Product Authorisation Key. Copy the obtained licence file(s) to folder

```
...\Omicron NanoScience\MATRIX\<version>\Licences
```

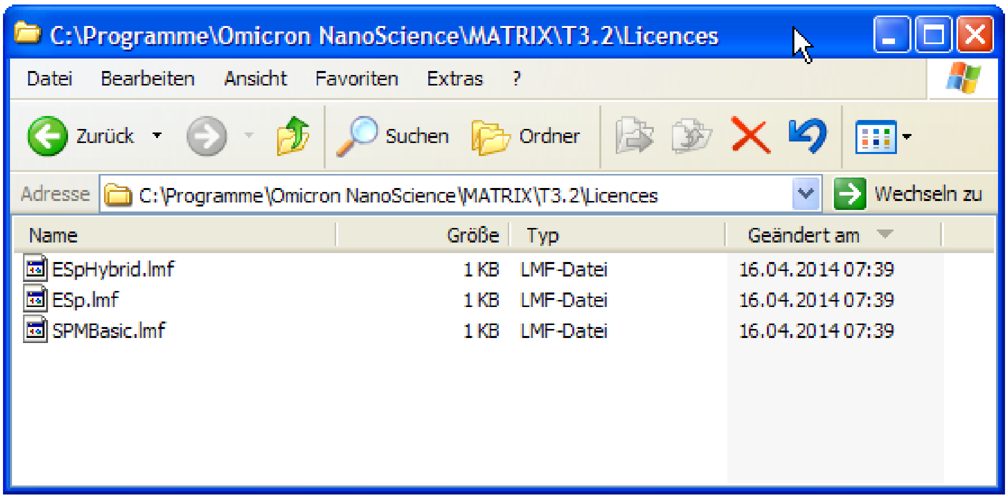


Figure 2. MATRIX licence folder, example shown.

Note that for new MATRIX systems this is normally not necessary as Omicron-installed systems come with a licence key in place.

Window Management

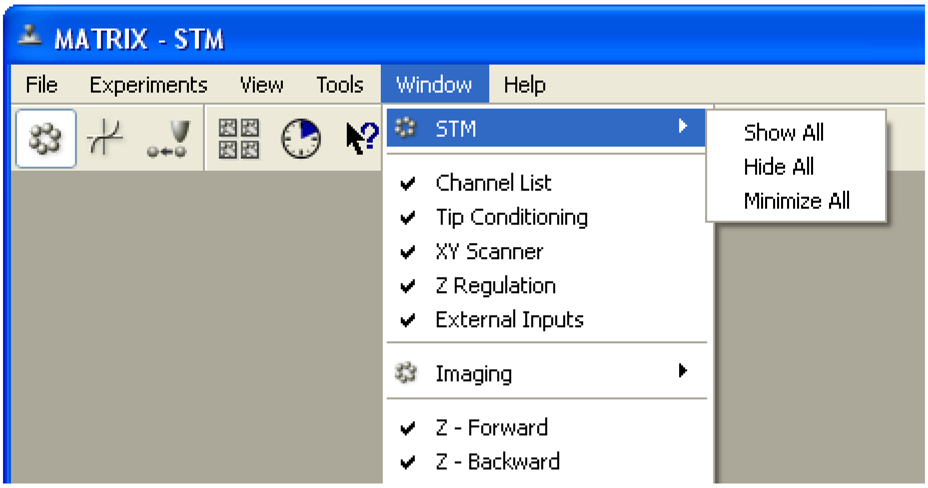


Figure 3. *Window* menu options.

All experiments come with a large number of windows, some for parameter settings and measurement control and others for data display of the various channels. The *Window* menu can help you organise all those windows. For example you can show or hide single windows by ticking or un-ticking them in the list.

In your drop-down menu the windows are grouped into categories. Apart from single windows you can also organise entire categories as a whole, i.e. you can

- Show all windows at the same time. This will result in overlapping windows as there are so many.

- Hide all windows. The result is the same as if you would click  (close) at the top right of every single window.

- Minimise all windows. The result is the same as if you would click  (minimise) at the top right of every single window.

Minimised and hidden windows can be restored and brought to the front by selecting them from the windows list.

3. A Notice on Concepts

MATRIX distinguishes between *Projects* and *Experiments*. These will be explained below. You may also want to refer to the glossary on page 158 for a short description of special words.

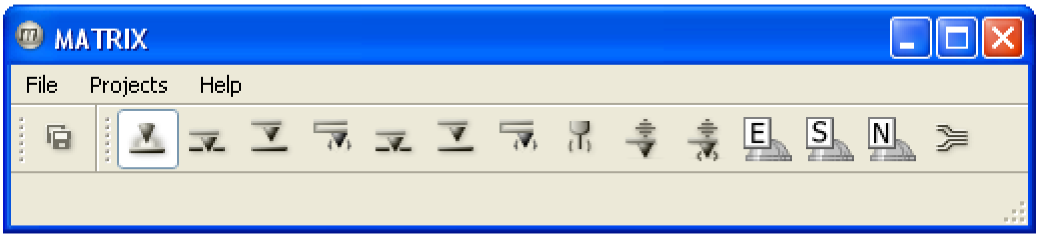


Figure 4. The MATRIX main window.

Projects and Experiments

A *Project* is a container for a collection of *Experiments*. It can be used much like a sub-folder in a file system. It is up to you to define which *Experiments* go into which *Project*. Every Omicron SPM comes with at least one pre-configured *Project*, but you can create as many as you want. *Projects* can be opened from the main window, see figure 4 on page 18.

An *Experiment* is an executable Element of a *Project*, similar to a computer program. It includes Views, Experiment Structure, Parameters, the graphical user interface (GUI) and, possibly, Scripts. Experiments can be started from within the Project windows, see for example figure 44 on page 54.

For every Omicron SPM there are a number of Experiments, all of which are already grouped into *Projects*. Changing the Parameter set may well be all you need in order to customise these *Experiments* and *Projects*. However, you can also assemble new *Projects* from existing *Experiments* or create entirely new *Experiments*.

Window Schemes

MATRIX supports different configurable window schemes. A scheme defines the position, size and visibility information for all windows on an *Experiment*. Currently two window schemes are available: all windows as sub-windows of the *Project* window (Regular) or all windows as independent single windows (Dual Monitor). The window scheme can be selected from the *View* menu.

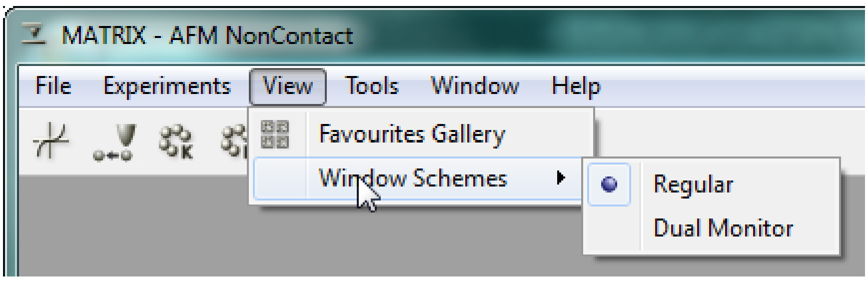


Figure 5. *Window schemes.*

Data

The data concept allows arbitrary - even non-rectangular - areas of interest (in future versions of MATRIX). The acquired data can be made visible during the scan process in flexible Views defined or customised by the user.

Online data displays can also be used to evaluate parameters that are then fed back into the system for parameter optimisation or for changing the area of interest. All *Experiment* data will be saved in a special MATRIX format.

A result file or result file chain records log information and data information in different blocks: parameter blocks, data file references, time stamp etc. It is not possible to modify or delete single blocks later-on as every file carries a signature. This allows detailed analysis of the experiment as a whole, including all parameter changes and other events. Data manipulation is thereby excluded. Single chain elements cannot be deleted without corrupting the entire chain.

File Organisation

MATRIX stores the acquired data on a per-channel basis. The data resulting from one scan cycle will be stored in a separate file for each channel supported by an experiment.

The result file chain itself does not contain acquired data, but stores other experiment information. In addition, the result file chain will keep references to the "external" data files in order to allow the association of acquired data with experiment calibration information, experiment run incident data, and similar information.

Note that for later data access the entire **RESULT** file chain must be preserved together with the files storing acquired data because the data processing software needs to access the result files even when loading selected data files only. You may however safely delete **DATA** files that you consider obsolete.

Attention

If you delete a result file from a chain, or even the entire chain, all data generated during the respective experiment runs will be lost, even if the data files produced are still available. Without the information provided by a result file chain, a correct interpretation of acquired data is impossible.

Saving Data

The channels to be saved can be selected in the *Channel List* window, see figure 20 on page 35. In order to save disk space, data recording can be switched off for all channels in the *XY Scanner* window, see figure 18 on page 33. Channels selected in the *Channel List* window will therefore only be saved if the checkbox in the *XY Scanner* window is also ticked.

Notice

Note that images moved to the *Favourites Gallery* are always saved to disk regardless of the checkbox settings.

Active channels will automatically store data acquired through them as long as you do not disable data saving for the respective active channel explicitly.

Prophylactic Data Storing

MATRIX allows automatic storing of a temporary "snapshot" of the data acquired by a progressing experiment. This option is referred to as Prophylactic Data Storing.

The MATRIX software will store an acquired data object as soon as the associated operation "completes", which usually means that a scan sweep of some kind has finished. However, for certain experiments (such as Volume CITS on dense grids) completing a scan sweep can take a very long time—from hours to several days—so access to the acquired data will not be possible during that period (simply because the data will not be stored until a scan sweep completes). In addition, experiments running for long time spans increase the risk of accidental data loss due to power failures, software errors and similar issues.

Prophylactic Data Storing can help to circumnavigate both problems outlined above:

- You can access the result data acquired as soon as the Prophylactic Data Storing option saves a data snapshot for the first time.
- In case the experiment gets interrupted, data loss is minimised: you can still access the most recent data snapshot.

Data snapshots created by the Prophylactic Data Storing option must be integrated into the result file of the respective experiment before you can use them; see section "Agglutinate Utility" below for more information on this topic.

Notice
Prophylactic Data Storing cannot be used if you have enabled the *Embedded Measurement Data* option of the result file preferences.

Data snapshots can be created manually by right-clicking the disk symbol to the right of the experiment state control buttons and selecting Store now from the context menu, or automatically at configurable intervals. For using the automatic snapshot creation variant, select *Settings…* from the Project window's *Tools* menu and check the *Prophylactic Data Storing* control. The Interval entry field determines the interval at which the Prophylactic Data Storing option creates data snapshots; the supported time range is 5 minutes to one hour.

Agglutinate Utility

The Prophylactic Data Storing option will not associate the created temporary data files with the result file chain because the log structure of a MATRIX result file does not support "volatile" data files. Thus, any data file created by the Prophylactic Data Storing option must be "bound" to its parent result file before you can access its contents.

Associating a data file created by Prophylactic Data Storing with its parent result file is an automated process that you can control by means of the utility software Agglutinate.

Launch the utility by selecting Programs -> Omicron NanoScience -> MATRIX V3.x -> Tools -> Agglutinate from the Microsoft Windows *Start* menu. Associating data files created by the Prophylactic Data Storing option with their parent result files requires three simple steps reflected by the user interface of the Agglutinate utility.

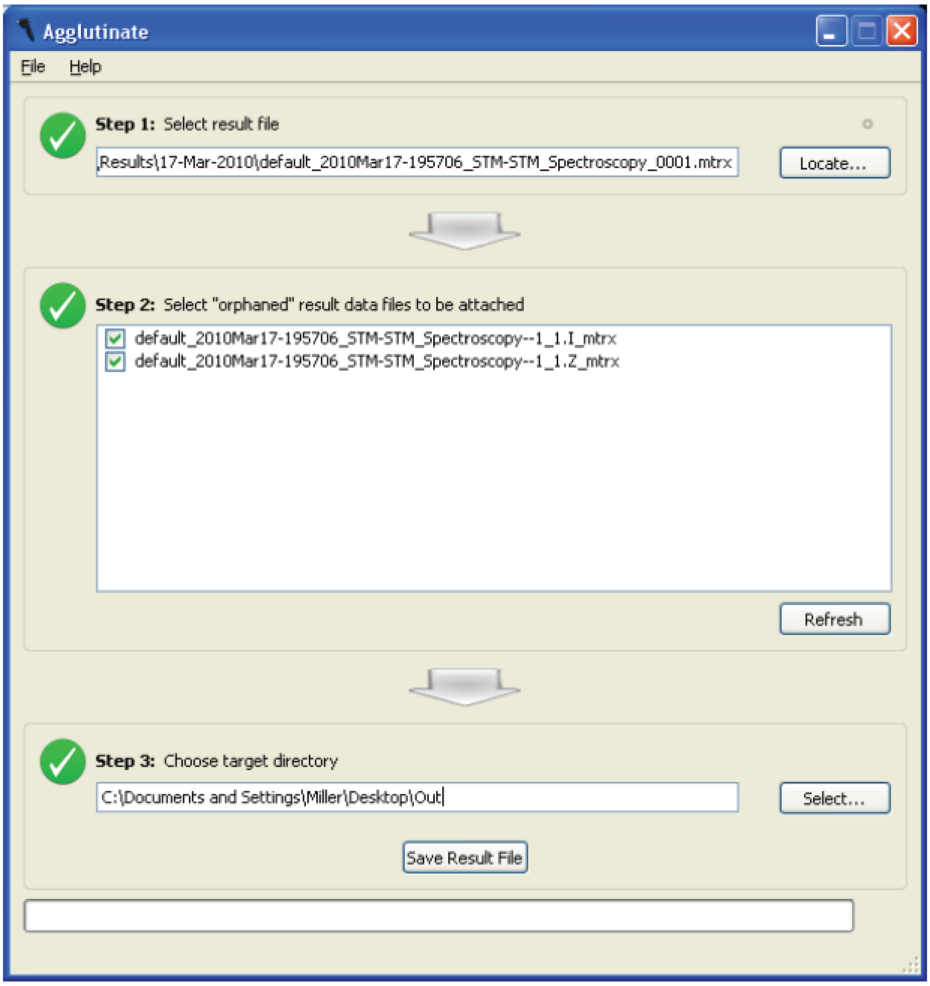


Figure 6. Agglutinate user interface.

To bind "orphaned" data files created by Prophylactic Data Storing to the corresponding result file, please follow the procedure outlined below:

- Click the *Locate…* button and select the parent result file or drag the parent result file icon into the text field at the top of the *Agglutinate* window.
- The utility will check if there are any unreferenced data files that match the specified result file. If so, these files will be shown in the list box at the centre of the *Agglutinate* window. Tick the checkboxes of the files you want to associate with the parent result file.
- Select a target directory for storing the result set. The *Agglutinate* utility will store a copy of the result file and all data files (including those you have ticked in the list box) in this directory. Note that the target directory must not be identical to the directory storing the original result file and data files.

If you are using the Prophylactic Data Storing option for creating result file "snapshots" during a progressing experiment, you can keep the *Agglutinate* utility running and continuously use its *Save Result File* (and the *Refresh*) buttons for updating the combined files in the target directory.

Scan Raster Interpretation

In a straight-forward scan interpretation scheme, a mapping issue causes a discrepancy between the expected and the actual scan area dimensions as well as a problem with the data acquisition when oversampling data resulting from a spatial scan operation (such as tunnelling current or Z information). Figure 7 on page 22 illustrates this issue; for more information on oversampling please refer to page 34.

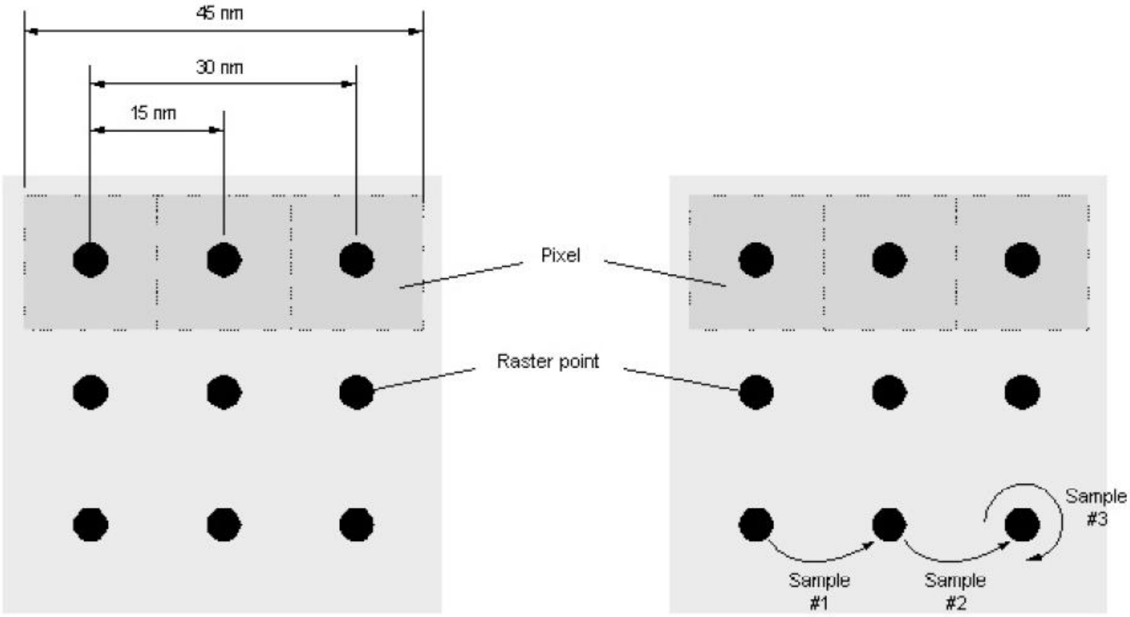


Figure 7. Scan raster interpretation without auxiliary raster points.

Figure 7 on page 22 shows a scan area of 3 x 3 raster points; the width and height chosen is 30 nm each. Using this configuration would have resulted in the following observations:

- Distance between two raster points: 15 nm. (One may have expected a distance of 10 nm.)
- As the raster point is considered to be the centre of a square data pixel, a distance of 15 nm between two raster points would have resulted in a scan area size of 45 nm x 45 nm rendered by the data displays (instead of the expected 30 nm x 30 nm.)
- With oversampling enabled, the first two samples would have been taken while moving from raster point #1 to raster point #2, and from raster point #2 to raster point #3. However, while taking the third sample, the probe would not have been moved at all.

While the resulting error is probably negligible in many scenarios, the scan generation processes have been adapted to remedy the problem as depicted in Figure 8 on page 23.

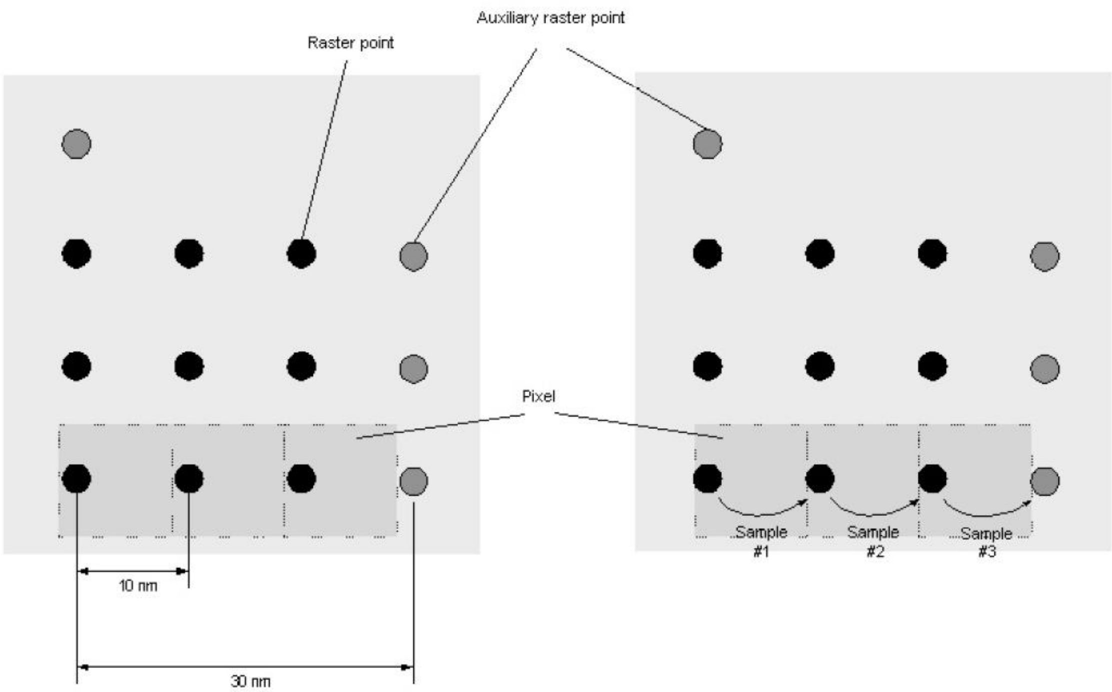


Figure 8. Scan raster interpretation with auxiliary raster points.

As illustrated above, MATRIX will configure a raster point distance of 10 nm covering a scan area size of 30 nm x 30 nm. The "auxiliary" raster points in X-axis direction allow a different interpretation of the data pixels, thus the scan area width and height as shown by the displays does not exceed the actual size. (The single auxiliary raster point in Y-axis direction is generated only to ensure symmetric piezo deflection.) Finally, all samples will be taken while moving the probe from one raster point to the next without exception.

Data Acquisition Location

As a result of the scan raster interpretation with auxiliary raster points, the location of raster points at which data acquisition is triggered can be different during the forward and backward sections of a scan line sweep. As depicted in Figure 9 on page 24, the data acquisition process gets triggered simultaneously with the scan movement generation; hence, the first data acquisition location on the backward sweep is actually marked by the auxiliary raster point at the end of each line. While this behaviour is correct with oversampling enabled (because data will be continuously sampled between two raster points then), it will cause the system to sample data at different raster points when a single sample is acquired during each raster time period. Actually, the locations at which data samples will be taken appear to be shifted by one raster point in forward and backward direction.

To remedy this, two different data acquisition location policies are possible:

The policy *no exact match* designates the system to trigger a data acquisition operation each time the probe gets relocated during the scan process. As a result, as described above, the raster points at which data gets sampled will differ between the forward and backward sections of a scan line sweep. Omicron adopts this data acquisition location policy for all scans.

At the cost of an additional raster time period, the policy *exact match* applies a different scan algorithm causing the data sample operations to run at identical raster point locations in forward and backward directions. This policy can be useful with oversampling disabled if you need to sample the exactly same locations on forward and backward sweeps.

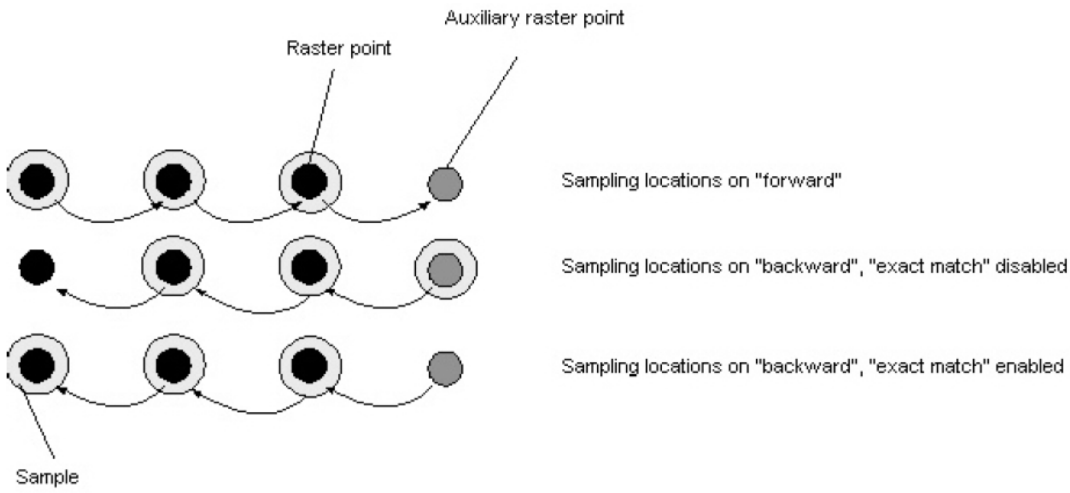


Figure 9. Data sampling locations with oversampling switched off.

If you need to employ the *exact match* policy please contact Omicron Service for instructions on how to do that.

Experiment Comment

A fine-grained comment system allows specifying additional information on result sets, experiments, and acquired data. The sample name, data set name, and creation comment can be entered by means of a dedicated dialogue that will open automatically as soon as a new result file is created, i.e. when you upload an experiment to the controller unit.

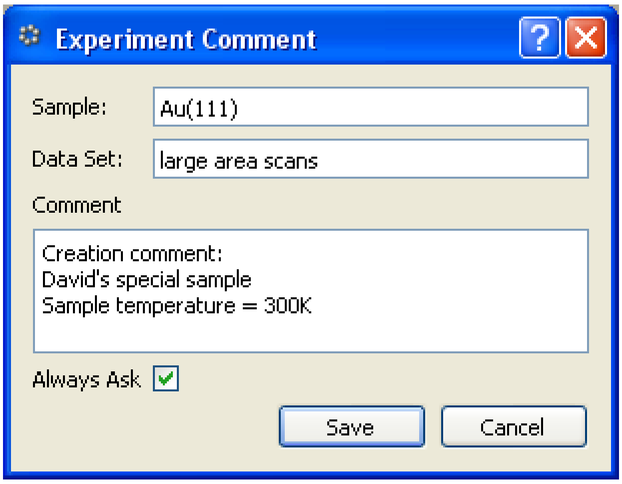


Figure 10. Comment field for additional notes.

- The *sample name* is an arbitrary text you may use for identifying the sample. The sample name gets attached to all data acquired. Each experiment supports only one sample name; changing the sample name while using an experiment (which should be a rare case, actually) causes the new name to be attached to the data objects acquired subsequently while all previous data remain associated with the original name.

- The *data set name* is an arbitrary name that you can use for assigning a name to several result sets generated by different experiments, or by experiments in different sessions. A data set name can be helpful for identifying data objects that are related even when they are stored in different result files. Similar to the sample name, the data set name gets attached to all data acquired; changing the data set name while using an experiment causes the new name to be attached to the data artefacts acquired subsequently while all previous data remain associated with the original name.

- The *creation comment* is an arbitrary text that gets attached to all data objects (curves, images, Volume CITS sets, etc.) acquired while using a particular experiment. As with the data set name and the sample name, if you change the comment text while using an experiment, the new text will be attached to the data acquired subsequently while all previous data remain associated with the original text.

To prevent MATRIX from opening the dialogue each time you upload an experiment, uncheck the *Always Ask* control, see figure 10 on page 24. You can manually open the dialogue at any time by clicking on the book symbol to the right of the experiment state control buttons.

MATRIX will remember the current sample name, data set name and creation comment so you can reuse them when changing experiments. In addition, the sample name and data set name will be saved when you store the session state by e.g. selecting *Save All* from the *File* menu. These names will be also available in subsequent MATRIX sessions.

Data Comments

- In addition, a *data comment* can be assigned to a particular data object such as an image or a curve in the channel display window. You may add as many data comments as you require. Data comments are always "private" to the data object you associate them with.

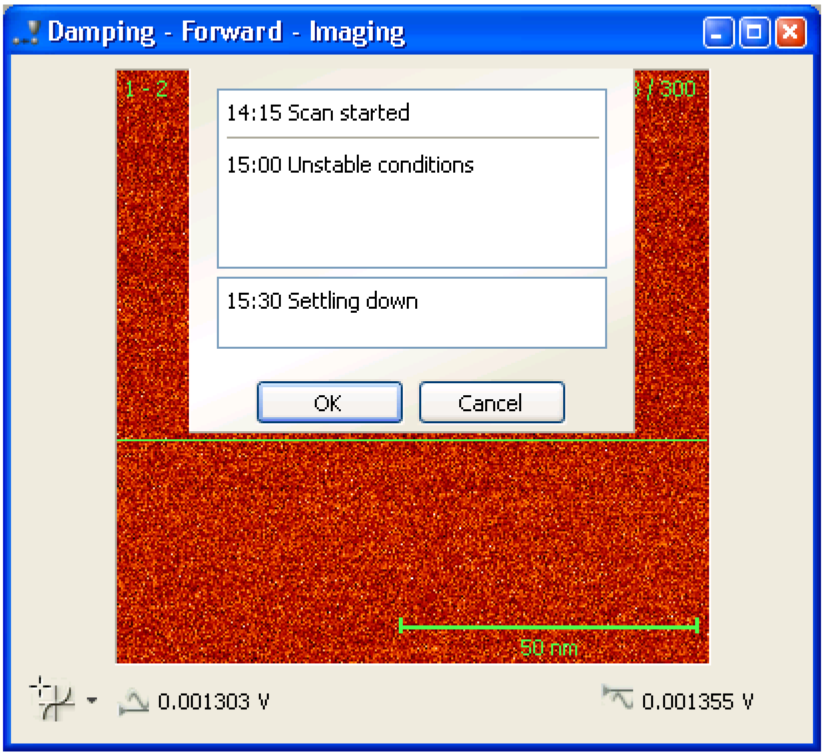


Figure 11. Data comments added while scanning. The upper field shows previous comments entered for this data object. Enter your new comment in the lower field.

Data-specific comments can be entered by right-clicking the display showing the data to be commented and selecting *Add Comment…* from the context menu. As depicted in figure 11 on page 25, a comment entry field will open, allowing you to type an arbitrary text that gets added to the set of data comments associated with the respective image or curve.

Data comments are particularly useful when viewing result sets using the Omicron Vernissage software. Vernissage offers a sophisticated sorting and filtering facility that you can use for browsing and previewing result data. Filter categories are provided for all supported types of comments (sample name, data set name, creation comments, and data comments), allowing you to restrict the result data presented by Vernissage to curves and images associated with a specific sample name, comment part, and other information.

Favourites Gallery

The *Favourites Gallery* allows a direct selection of images to be processed, rather than loading the entire data file into the data processing software. It stores images that have been marked as being of interest for processing and presents these images in a concise way. You can then transfer either a single image, or a group of images from the *Favourites Gallery* to the data processing software.

Images can be marked by right-clicking on the channel display which shows the image of interest: select *Add to Favourites* from the context menu, see figure 30 on page 43.

The *Favourites Gallery* window can be opened directly from the icon bar  or by selecting *Favourites Gallery* from the *View* menu of a *Project* window.

The *Favourites Gallery* window comprises:

- An area displaying thumbnail representations of the images that have been marked.
- A button for transferring images of the *Favourites Gallery* to the data processing software.
- A slider for adjusting thumbnail size.

You can select images to be transferred by clicking on the respective thumbnail representations. A right-click reveals another context menu for directly analysing or deleting the respective image.

The size of the thumbnail images can be adjusted by means of a dedicated slider control. In addition, the thumbnail images can be enlarged by pressing the Ctrl/+, and shrunk by pressing the Ctrl/– keyboard shortcut. (You may also use the mouse wheel while pressing and holding the Ctrl key for adjusting the thumbnail image size.)

The *Favourites Gallery* will clear all entries automatically when an experiment gets unloaded in order to reflect that changes to the entry rating or the gallery contents are no longer allowed because the underlying result file has been closed. You can add a new entry to the gallery when an experiment has been stopped but the source data display still shows the curve or image to be added. (Note that the gallery will nevertheless refuse to add an entry if the raw data associated with a curve or an image has not been saved to disk.)

Data Rating

With data rating, you can assign an abstract "level" to acquired data such as images or curves, and use the Vernissage software for filtering data according to such levels. You may use either of the following options for adding an image or a curve to the *Favourites Gallery*:

- Select *Add to Favourites* from the context menu of a display without placing the mouse cursor over the star symbols to the right of the menu entry, or press Ctrl + F (or Ctrl + 0) while the display window is active. In either case, the respective image or curve is transferred to the *Favourites Gallery* without rating.

- Select *Add to Favourites* from the context menu of a display, and point the mouse cursor to the first, second, or third star symbol to the right of the menu entry. When clicking the left mouse button, the respective image or curve is transferred to the Favourites Gallery with the respective rating assigned. Alternatively, you can press the keyboard shortcuts Ctrl + 1 through Ctrl + 3 for rating the image or curve from the active display window, and transferring it to the *Favourites Gallery*.

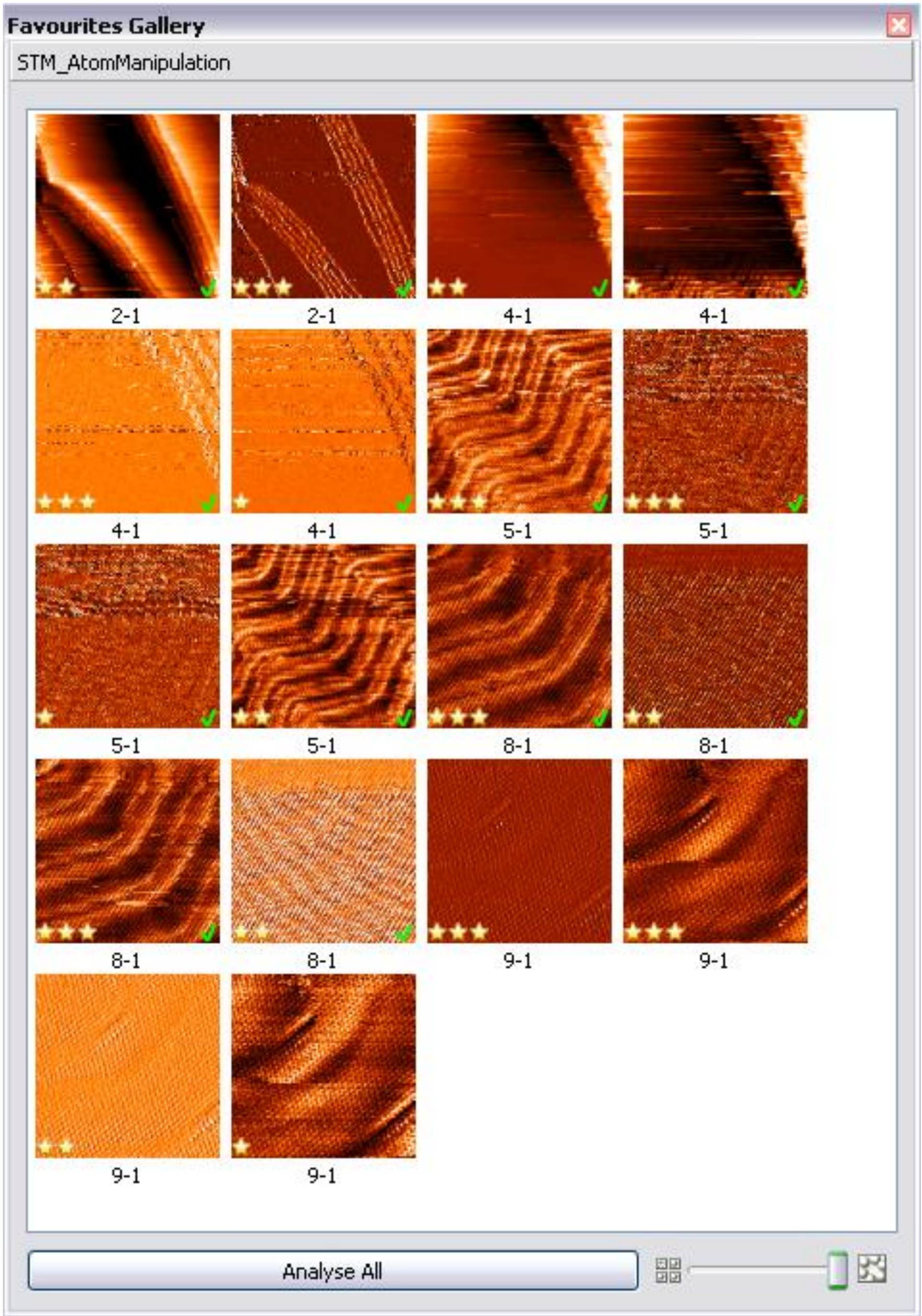


Figure 12. *Favourites Gallery*.

Rated gallery entries will be marked by one to three stars, depending on the rating level chosen. The rating level of gallery entries can also be modified at any time by means of the context menu of the Favourites Gallery, or by means of the keyboard shortcuts Ctrl + 0 through Ctrl + 3 while the *Favourites Gallery* window is active. The purpose of the data rating feature is to provide an additional parameter for filtering images and curves when reviewing acquired data with the Vernissage software.

Time Estimation

Click the clock button from the *Project* window menu and point for example on the *Start* button in the *XY Scanner* window to show the estimated scan cycle duration.

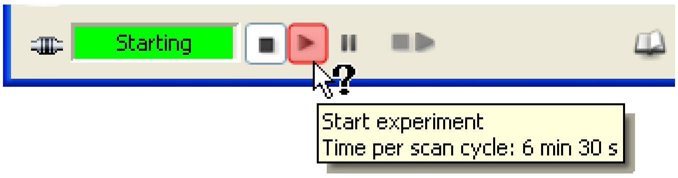


Figure 13. Estimated scan cycle duration for a spectroscopy experiment, example shown.

Although the software can only provide approximate figures, the computed periods are often helpful for understanding the impact of certain experiment parameters on the total duration of a particular operation.

Operation duration hints are provided on a per-experiment basis, i.e. for which operation time estimation support is actually provided may differ between experiments. In general, the experiment state controls as well as the mouse tool selectors are "sources" for time estimation information.

If you are already familiar with the control elements that are "sources" for operation duration hints, the simplest way of obtaining time estimations is to let the mouse cursor hover above the respective control; the estimated time and a short description will be displayed together with the usual brief onscreen help text. The MATRIX software will highlight all control elements that are capable of initiating time estimations.

Alternatively, you can also use the following procedure for obtaining an operation duration hint:

- Click on the clock icon in the toolbar of the *Project* window.
- Choose *Time Estimation* from the *Help* menu of the *Project* window.
- Press the key combination *Shift* + *F2* on the keyboard.

Notice

MATRIX will always compute time information for an entire operation, i.e. from the start of the operation until its termination. As a result, the time estimation feature cannot be used for obtaining hints on the *remaining* time a progressing operation will presumably take.

Numerical Value Control

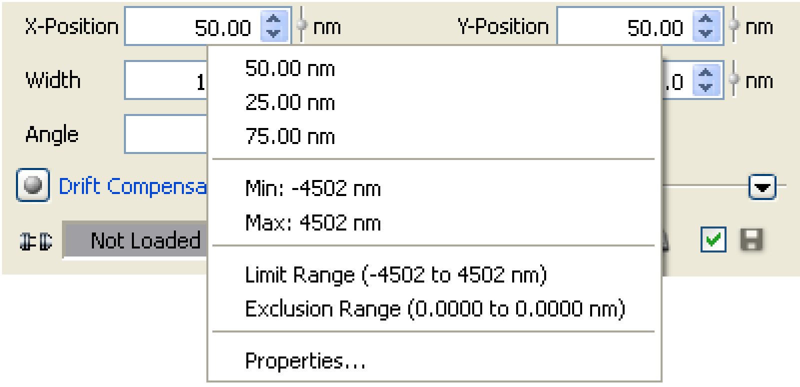
A numerical value control consists of a label (e.g. "Height"), a number field (e.g. "100") and a unit (e.g. "nm"). The latter is selectable via drop-down field in some cases. There are different methods for data input into a numerical value control:

- Click on the number field to enter numerical values. The integer and decimal fraction parts of a floating point figure can be selected separately: double-clicking the integer or decimal fraction section will select the respective part; clicking three times will select the entire figure. For direct numerical input always press *Return* to accept the typed value.

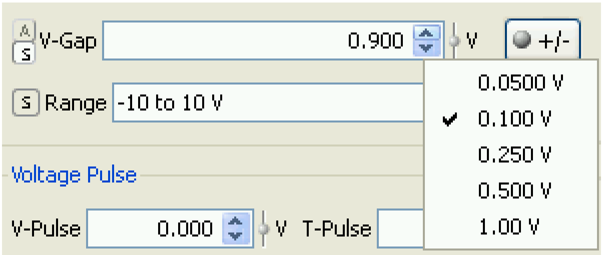
- Recent values: reselect previously applied values from the top section of the value field context menu. Note that this section is empty initially. From the second section the min and max values can be selected directly.

- Range limits and possibly an exclusion range constraint are displayed. These can activated/deactivated via mouse click and may be configured via the *Properties* window.

- Properties: configure the properties of the numerical value control, e.g. range, raster, handling, formatting.



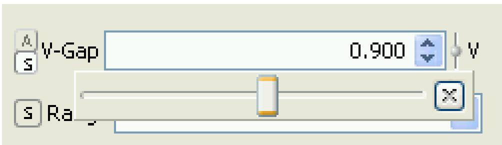
- Use the up-down control buttons (step size can be adjusted with a right-click).



- Use the mouse wheel while the cursor is hovering over the entry field.

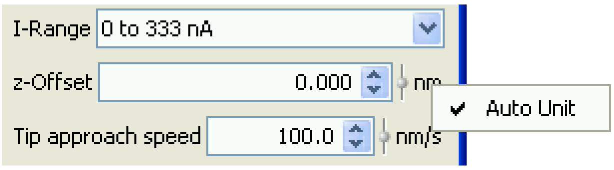
- Use the up and down arrow keys on your keyboard.

- Click on the slider button next to the numerical value control field to unfold a slider for convenient value adjustment. This works with all numerical value control fields. Close the slider by clicking the little [x] on the right.



- Right-click on the slider or slider button to unfold the context menu: Snap slider to raster. This allows rastered values for slider input (same raster as for up-down control). It can facilitate input if you want rounded values only. The raster size is the same as for the up-down buttons and can be configured via Properties in the numerical field context menu.

- Units context menu: Auto Unit allows the automatic adaptation of the unit when entering very large or very small numbers (10000 nm will be displayed as "10 µm").



Out of Range Conditions

- If a user-defined minimum value, maximum value, or value exclusion range constraint has been set up for a particular parameter, and a value violating such a constraint is being entered, numerical value entry fields will visualise this condition by displaying a red "overflow/underflow" symbol on the left hand side of the input area.

- Under rare circumstances, a parameter value can violate the supported range although accepted during entry. (For example, a correct scan area offset may become invalid after changing the scanner used by the experiment.) Because in such a scenario some manual value correction is often required, the numerical value entry field associated with the respective parameter will display its value on a striking yellow background to indicate the out-of-range situation.

- Any ongoing edit operation can be cancelled by pressing the *Escape* (Esc) key.

Properties

The *Properties* window is available from the context menu of numerical value controls. Depending on the context this window may present different options. The screen shot below shows an example for the STM Scanner I-Setpoint control.

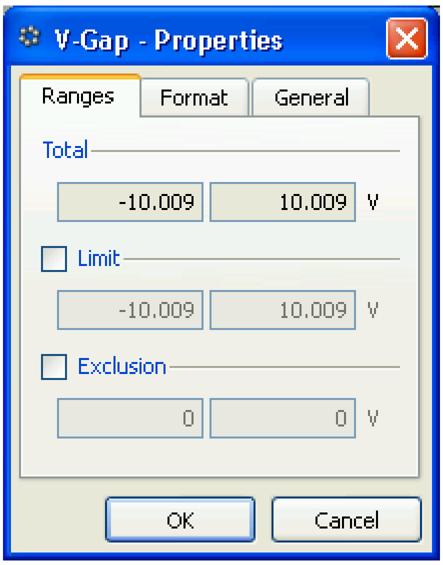
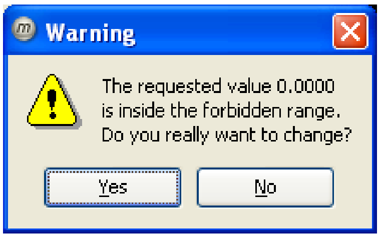


Figure 14. STM Scanner *V-Gap Properties* window: Ranges.

The *Range* tab in this case shows the total parameter range provided by the software and allows setting the value control limits and a forbidden value range that you want to exclude from data input, e.g. zero.

Notice

When using the numerical value control a parameter value within the forbidden range will be displayed in red digits. However, this value will nevertheless be set on the hardware, if the related query is answered with *Yes*.



On the *Format* tab choose from a number of formatting strategies for the displayed numbers, e.g. the number of leading and decimal digits.

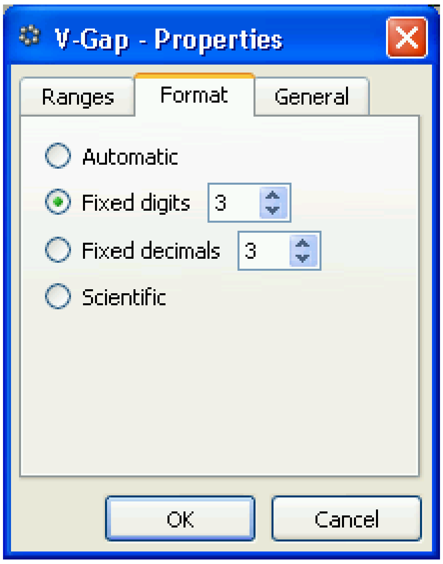


Figure 15. STM Scanner *V-Gap Properties* window: Format.

On the *General* tab you can switch the *Automatic unit* and *Snap slider to raster* features on/off and set the *Raster step size*.

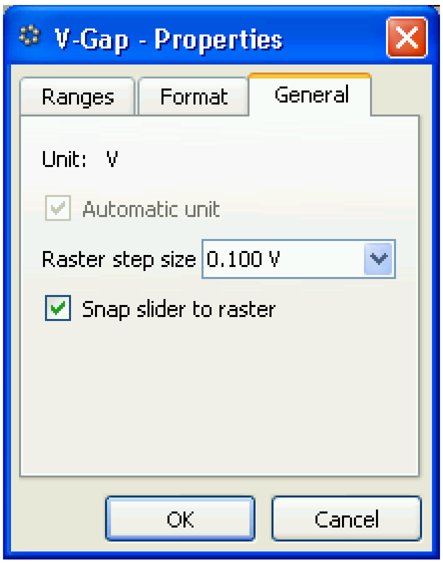


Figure 16. STM Scanner *V-Gap Properties* window: General.

Notice

The function *snap slider to raster* may lead to problems if the raster step size is unsuitable for the given situation.

External Inputs

The window *External Inputs* allows controlling the input signals V-MOD, V-EXT and Z-EXT. It is available in all experiments. The external input signals can be enabled or disabled and the low-pass filter can be configured.

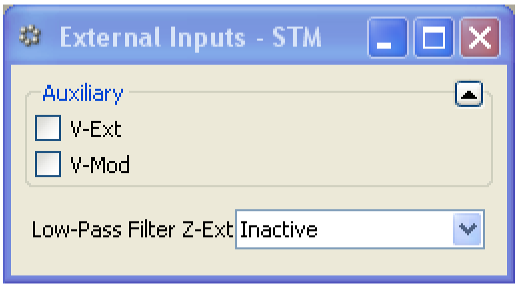


Figure 17. *External Inputs* window.

Low-Pass Filter Z EXT

Set low pass filter for external input Z-EXT on the DRB/SCAR board. Note that setting "inactive" means: no signal connected. Use this filter setting to deactivate external input Z-EXT.

Attention

Changing the cut-off frequency of the Z-EXT input signal low-pass filter causes significant peaks in the output signal Z Out controlling the Z-axis position. As a result, when using *n*-type scanner equipment, the probe/sample distance will spontaneously decrease, probably causing a tip crash.

To prevent potential tip crashes, the Z-Ext input signal state should not be changed when the probe is in close proximity to the sample; in this **case you should neither change the cut-off frequency of the associated low-pass filter, nor should the signal be enabled or disabled** manually or by means of the signal modulation support for spectroscopy operations.

Uploading - Controlling Experiment State

Each Experiment has a "master"-window which contains dedicated controls for the state of the *Experiment*. In the standard configuration this is the *XY Scanner* window, see figure 18 on page 33.

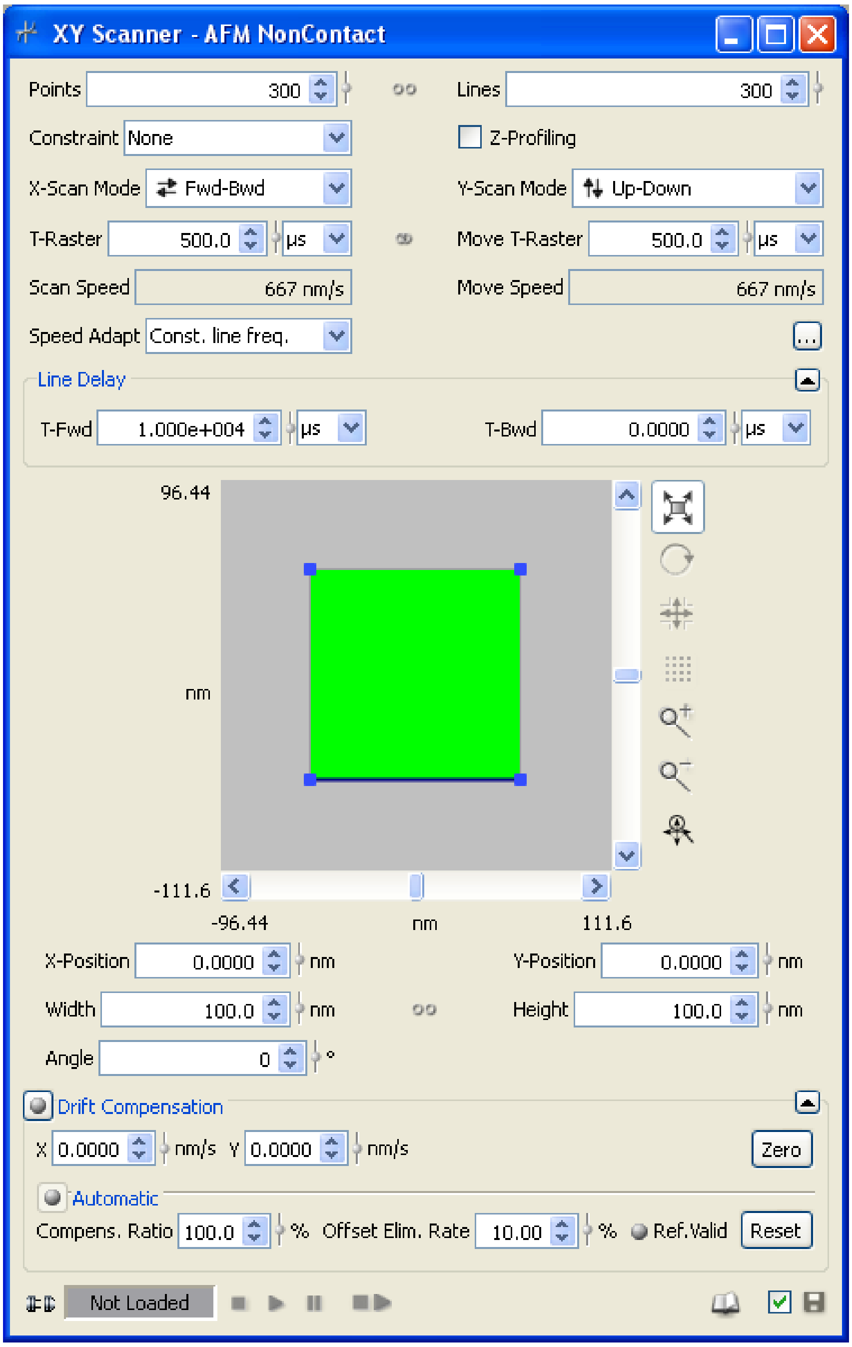


Figure 18. The *XY Scanner* window.

The experiment state controls consist of a symbol button, a display and four radio buttons, see figure 19 below.

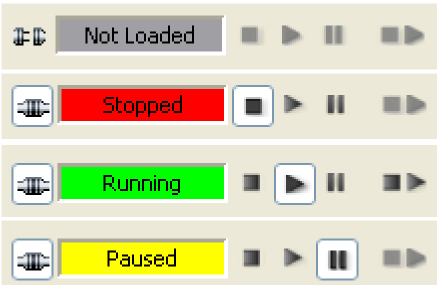


Figure 19. Experiment state control field in different states of operation.

The symbol shows a plug and socket pictogram . Click this button to upload or unload the *Experiment* (including all its components and parameters).

After uploading, the symbol changes to a closed link pictogram and the radio buttons become active. The display field then indicates the current state. e.g. "Stopped".

The pictograms on the radio buttons are well-known from multi-media applications, tape recorders etc. They have the following symbolism (from left to right): Stop, Start, Pause, Restart.

The display field indicates the current state: Not Loaded, (Loading,) Stopped, Running, (Stopping,) Paused... Temporary states like Loading, Stopping, etc. are not shown in figure 19 on page 33.

A comment button allows writing down additional information regarding the sample or experiment. When you place the mouse cursor on the book symbol, MATRIX will display a tool-tip text containing the current creation comment entered. For more details on comments please refer to page 24.

A checkbox allows enabling or disabling automatic storage of measurement data. In order to save disk space, data recording can be switched off for all channels. To do so make sure the box next to the diskette symbol is not ticked. In this case the result file only records log information, parameter changes, etc. Note that the channels to be saved can be selected in the *Channel List* window, see figure 20 on page 35. Channels selected there will be saved only if the above mentioned checkbox is ticked.

Notice

Note that images moved to the *Favourites Gallery* are always saved to disk regardless of the checkbox settings.

Oversampling

Channel displays support MATRIX CU-based oversampling and filtering during data acquisition. When oversampling, a channel will actually acquire several samples when it is triggered, see also page 22. It will then filter the acquired data by running a simple averaging algorithm on the sampled values. The result of this filtering operation will be delivered by the channel as outcome of the sample process. This process is used to eliminate statistical spikes. The oversampling factor must be a power of two up to 128 and a multiple of 128 above that; other values will automatically be corrected to the closest allowed value.

- A data point is taken as a number of different single measurements and averaging over the result. The number of single measurements per data point can be selected using the parameter **oversampling factor** accessible from the channel list, see figure 21 on page 36.

$$\text{data point} = \frac{\sum_{1}^{\text{oversampling factor}} \text{single measurement}}{\text{oversampling factor}}$$

- A single measurement takes a fixed time of 2.5 micro seconds.

- The next data point is taken after one raster time, see also figure 86 on page 87. Consequently, the raster time must be longer than the combination of initial delay and data acquisition time, i.e.

$$\text{raster time} > \frac{\text{oversampling factor}}{400\,\text{kHz}} + \text{initial delay}$$

- In Auto Oversampling mode (default) the software ensures that this requirement is adhered to. We recommend to always set the raster time first. With Auto Oversampling disabled an auto correction function during input makes sure that all times are correctly matched.

When enabled, the auto oversampling mechanism will maximise the sample count with respect to the raster time and initial sample delay configured. Note that both, oversampling and filtering, will be executed by a MATRIX CU, i.e. the processes are completely transparent to the MATRIX PC software. By default, oversampling will be enabled for all channels. The oversampling function can be switched off by removing the tick at Auto Oversampling and setting the Oversampling Factor to "1".

Channel List and Sensor Control

As detailed on page 19 MATRIX stores the acquired data on a per-channel basis. The channels to be saved can be selected in the *Channel List* window, see figure 20 on page 35. In order to save disk space, data recording can be switched off for all channels in the *XY Scanner* window, see figure 18 on page 33. Channels selected in the *Channel List* window will therefore only be saved if the checkbox in the *XY Scanner* window is also ticked.

Figure 20. *Channel List* window, example shown.

- A window with tick boxes and buttons allows selecting/deselecting the respective channel. A channel that is not ticked will not be saved to file. A channel with a greyed out ball symbol will have an empty display and no data acquisition takes place.

- Note that you can also choose to display a channel but not save it.

- MATRIX will automatically balance the number of active channels with respect to the available hardware resources. The channels that have been activated last will be the first to be switched off in case of hardware resource problems.

Notice

Note that in AFMHybrid systems Aux1 is used for the AFM regulation signal. This is wired internally so that an input signal connected to the Aux1 socket on the MATRIX CU has no effect in this case.

Notice

Note that images moved to the *Favourites Gallery* are always saved to disk regardless of the checkbox settings.

Note also that channels can be switched off completely using the ball icon next to its name 

.

When you open the *Channel List* entries the sensor control settings become available. These define the initial delay and oversampling conditions. (For details on the oversampling settings please refer to page 34.)

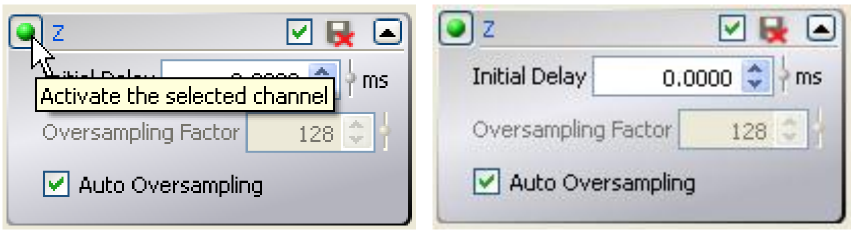


Figure 21. Channel list single item with options open.

Initial Delay

The initial delay is the delay between channel trigger and first single measurement, specified in seconds. The parameter value defines the initial delay time before the sample operation(s) are started. After every trigger the initial delay ensures stable conditions before the first single measurement takes place.

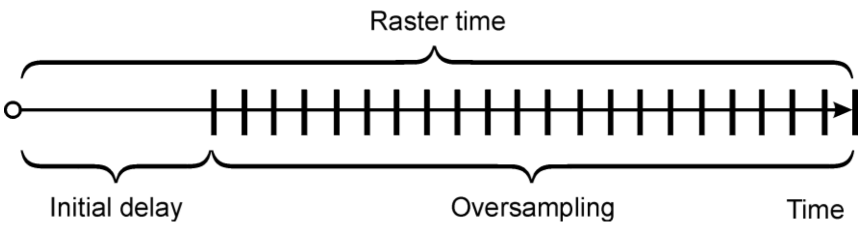


Figure 22. Initial delay and oversampling for a single data point.

In spectroscopy delay times **T1 to T4** are applied before and after each curve while the **initial delay** is applied before every single data point within a curve to ensure stable conditions before the spectroscopy single measurement takes place. Note that the spectroscopy raster time must be longer than (sample count/sample rate) + initial delay. Always set the raster time value in the *Spectroscopy* window first. For a more detailed description you may want to refer to page 86.

Auto Oversampling

Normally the channel computes the sample count and oversampling rate on the basis of the specified initial delay and raster time, fitting in as many samples per data point as possible. To increase the sample count you can fall back on slower scanning, i.e. increase the raster time in the *XY Scanner* window or the *Spectroscopy Settings* window.

- The auto oversampling mechanism can be enabled and disabled using the checkbox shown in figure 21 on page 36. When enabled, the auto oversampling mechanism will maximise the sample count with respect to the raster time and initial sample delay configured.

- Use oversampling to increase bit resolution.

- The data acquisition rate (samples per second) or sample rate is 400 kHz .

Notice
The raster time must be longer than (sample count / sample rate) + initial delay. Normally the Auto Oversampling function takes care of this. If switching this function off, always set the raster time value first and make sure to match the parameter values.

Oversampling Factor

Specifies the number of sample operations that take place for every data point when a channel is triggered (oversampling). Minimum number is 1, i.e. a single sample will be acquired. This parameter is normally taken care of by the Auto Oversampling function.

Notice
The oversampling/filtering facility imposes a restriction regarding the sample count: the actual amount of samples acquired during a raster time period must be a power of two up to 128 and a multiple of 128 above that. The maximum number of samples is 7,600,000. If you enter an oversampling factor that cannot be met, the MATRIX software will automatically adjust the factor to a suitable value.

The Auto Approach

In Auto Approach mode the Control Unit performs an automatic approach procedure. On the remote box press the AUTO button to start the Auto Approach procedure. If the tip surface distance is close enough for the feedback regulation to become active or if the FORWARD button is pressed the Auto Approach stops and the FORWARD menu becomes active. A beep gives an acoustic signal for the end of Auto Approach and the number of coarse steps is displayed for another 3 seconds. Note: this display can be stopped by pressing any button, e.g. press BACKWARD to directly jump to the BACKWARD menu. If any button (except FORWARD) is pressed, the Auto Approach procedure will be aborted and the BACKWARD menu becomes active. Pressing FORWARD takes you to the FORWARD-menu.

The *Auto Approach* settings can be accessed in the *Regulator Options* window ( button to the right hand side of the *Z-metre*). Note that the settings and procedures are different for STM and AFM setups.

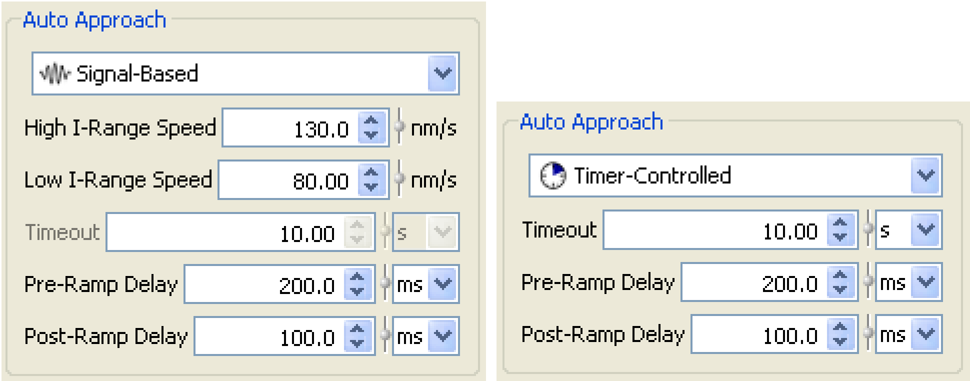


Figure 23. *Auto Approach* settings for STM (left) and AFM (right) experiments.

Mode

For experiments using the tunnelling current signal for controlling (or, in case the dual feedback loop branch option is active, contributing to the determination of) the Z-position of the probe two different Auto Approach strategies are provided. Alternatively a timer controlled strategy is also possible.

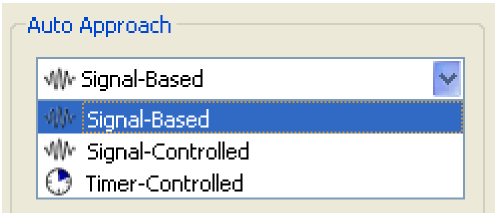


Figure 24. Auto Approach modes.

- *Signal-Based*: this strategy switches the feedback mode off and uses dedicated signal comparator mechanisms for determining whether the probe is in feedback loop proximity. In this mode, the velocity of the probe during the approach phase of each Auto Approach cycle can be controlled by means of dedicated parameters. This is the "traditional" STM Auto Approach strategy, it is not available for AFM experiments.

- *Signal-Controlled*: this strategy also uses the signal comparator mechanisms for determining whether the probe is in feedback loop proximity, but the entire operation will be run with the feedback loop enabled. As a result, the probe movement in Z-direction depends on the feedback loop gain characteristics instead of the configured approach velocity. This strategy is not available for AFM experiments.

- *Timer-Controlled*: in this strategy the feedback loop is also active all the time. Here the Auto Approach stops if, at the end of the timeout period (see figure 23 on page 38), the tip has still not reached the end of the ramp. It will then be assumed that a working point has been detected (WPD) along the ramp as shown in figure 25 on page 40. Note that the timeout timer is restarted with every tip approach ramp. This is the default mode in AFM experiments.

Attention
Note that in AFM experiments the Auto Approach will also stop if the approach speed is so slow that the break-off criterion ("has not reached the end of the ramp after timeout") is met even if no working point has been detected. In this case increase the loop gain or the timeout setting.

Speed Settings

For Auto Approach operations based on the tunnelling current signal, the velocity of the probe during the approach phase of each Auto Approach cycle can be controlled by two parameters:

- *High I-Range Speed*: This parameter determines the velocity of the probe during the approach phase of an Auto Approach cycle if the tunnelling current preamplifier has been switched to the "high" range (e.g. 0 ... 333nA in case of an SPM PRE 4 preamplifier), i.e. the velocity at which the probe approaches the sample.

- *Low I-Range Speed*: This parameter determines the velocity of the probe during the approach phase of an Auto Approach cycle if the tunnelling current preamplifier has been switched to the "low" range (e.g. 0 ... 3.3nA in case of an SPM PRE 4 preamplifier), i.e. the velocity at which the probe approaches the sample.

The parameter value has to be specified in meter per second.

Procedure

- The fine control Z-piezo moves the tip towards the sample (or vice versa in some instruments) with a fix ramp speed and after a delay of a few milliseconds by superimposing a linear ramp to the regulator output.

- In STM without feedback loop the ramp speed as well as a pre-ramp and post-ramp delay can be adjusted. In STM with feedback loop and in AFM experiments the ramp speed depends on the selected loop gain and on the feedback signal strength.

- If no feedback signal is detected, the tip (or sample) is retracted with a retraction speed of 10 mm/s by the fine control Z-piezo. For a timing diagram see figure 25 on page 40.

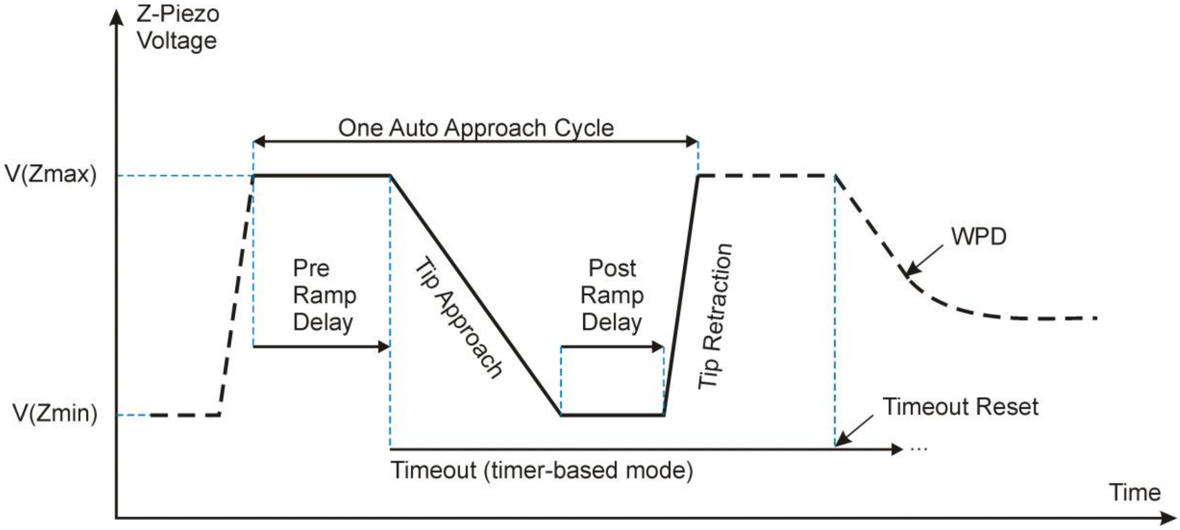


Figure 25. Auto Approach times, schematic diagram. WPD = working point detected.

- The coarse approach step motor drive then moves a specified number of steps forward (1-10, selectable in the settings menu). The tip moves towards the sample (or vice versa) by this number of steps (step size is adjustable, default = DIAL for most heads).

- The tip is then again ramped towards the sample by the fine control Z-piezo. If no working point is detected (WPD in figure 25 on page 40), this sequence will be repeated automatically.

Twin Regulator Options

- With the twin regulator option active the control for selecting the feedback loop branch used for conducting Auto Approach operations is located prominently below the weighting slider of the twin regulator. To set the "left" or "right" branch as Auto Approach control entity, simply click on the respective radio button.

- The twin regulator option supports all Auto Approach modes that are available for its single-branch regulator counterpart. The mode for both of the branches can be configured by means of two dedicated drop-down menus below the Auto Approach branch selection buttons.

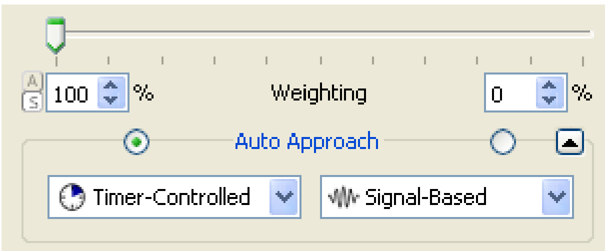


Figure 26. Auto Approach selection and twin regulator weighting.

Customising the Channel Display

During scanning the incoming data will be displayed on the computer screen. MATRIX provides you with a separate window for every channel configured in the *Experiment*. The window headline shows the name of the currently displayed channel. The window display can be adjusted using the controls from the context menu.

Image Mode Controls

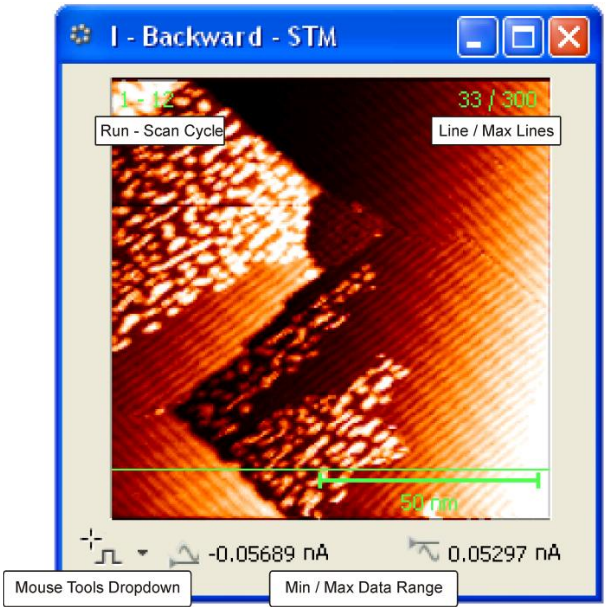


Figure 27. Channel display in image mode.

If a channel display shows a topography channel in the Image mode, the display includes the following elements:

- A bird's eyes view shows the different measured values (e.g. Z or I) as different colours.
- At the top of the image four numbers inform about experiment progress and help locating a particular image for data analysis, see page 45.
- A scale gives an idea of the size of the scanned surface. Available scale models are bar, axes and none.
- A dropdown list gives access to a number of mouse tools.
- A data range display below the image by default shows the minimum and the maximum of the incoming data. The relative scale values are determined after slope and offset correction have been performed.

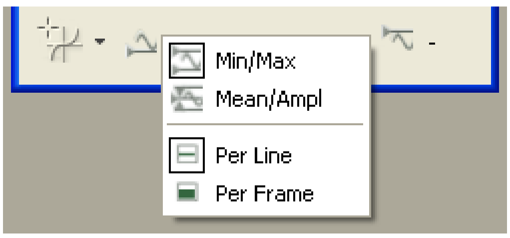


Figure 28. Data range context menu.

- The data range display can show minimum/maximum values or mean value and amplitude – either per line or per frame. The display mode can be selected from a separate context menu available upon right-clicking the data range display.

- The display colour table is automatically adapted to the incoming data in order to cope with changing data ranges. On samples with a slope in Y-direction this may result in a flickering appearance when the colour table needs frequent adjustment. This feature can be switched off in the *Properties* window available from the context menu, see figure 31 on page 44. In this case the colour table can be adapted manually by pressing *Reset*.

Curves Mode Controls

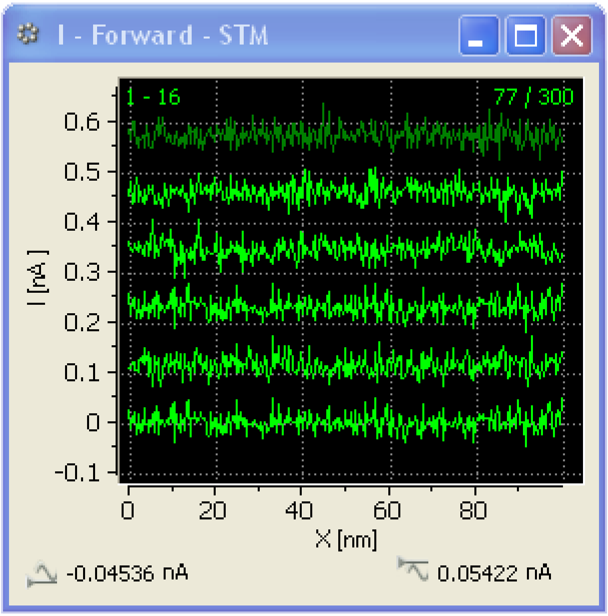


Figure 29. Channel display in Curves mode.

If a channel display window is switched from Image mode to Curves mode you get a plot representation of the incoming data and some elements of the window change.

- The data range display shows the minimum and the maximum of the incoming data line.

- There are no mouse tools in a curve display.

- Trace curves are displayed in green, retrace curves are displayed in yellow, i.e. in a forward channel display all curves will be green, in a backward channel display all curves will be yellow. For force-distance curves and spectroscopy curves with the retrace option enabled you will have both colours in the same channel with an optional colour legend that can be switched on or off, see also on page 47.

Channel Display Layout

The layout of a channel display window depends on the type of channel which is displayed (e. g. topography or spectroscopy) and on the display mode actually selected. Channels can be deactivated individually. A deactivated channel will not deliver data and the display will stay empty. It can be closed manually. We recommend that you deactivate all channels you do not need in order to increase performance and minimise result file size and count.

Notice

Drag-and-Drop Support for Display Data

Display data can be used as "background" for the scan area visualisation and configuration control (field with green rectangle). For details on this feature please refer to section **Navigation Assistance** on pages 61f.

For copying the contents currently shown by an image or curve display to **third party software**, place the mouse cursor on the respective display contents, press and hold the Alt key, then press the left mouse button and drag the mouse cursor to the third party software's document window. When you release the mouse button, the display contents will be copied into the respective document.

Please note that for using this function, the target software must be capable of receiving graphics by means of the Drag & Drop mechanism.

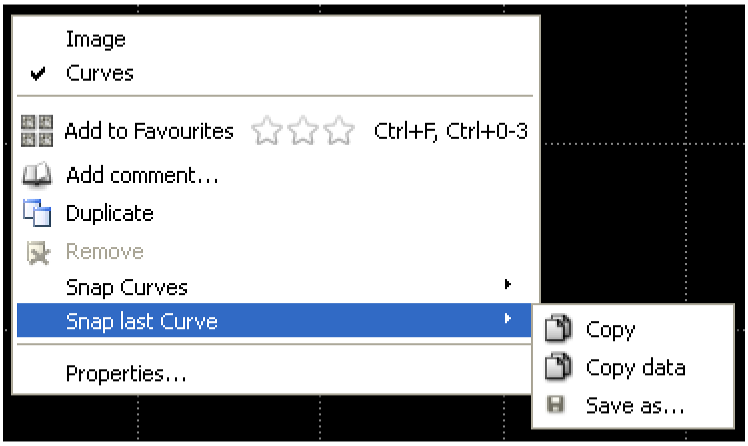


Figure 30. The channel display context menu. Top: Image mode; bottom: Curves mode.

The context menu allows

- Switching between Image and Curves mode
- Adding the current image to the favourites list, see figure 12 on page 27 with or without rating.
- Adding a comment to the current image. Note that image comments are not to be confused with data set comments added via the button in the *XYScanner* window or at experiment upload. For more information on comments please refer to page 24.

- Duplicating the channel display (e.g. for viewing the same channel in different modes at the same time)

- Removing a display that had previously been duplicated (i.e. removing a copy)

- *Snap Image* either to the clipboard or save it to harddisk (image formats supported: BMP, PNG, JPG, TIFF). MATRIX will automatically add axes, axis labels and channel information to the image.

- *Snap Curves* has the same options as *Snap Image*.

- *Snap Last Curve* has an additional option *Copy Data* that yields an X/Y table including header, e.g. X [nm] I [nA]. Here, Save As offers the format SVG only.

- Invoking the *Properties* window. Note that there will only be one *Properties* window for all channels. It normally displays the settings of the currently selected channel display but can also be switched to other channels by means of a dropdown menu.

The *Display Properties* window consists of two parts, a *Visualisation* tab and a *Processors* tab.

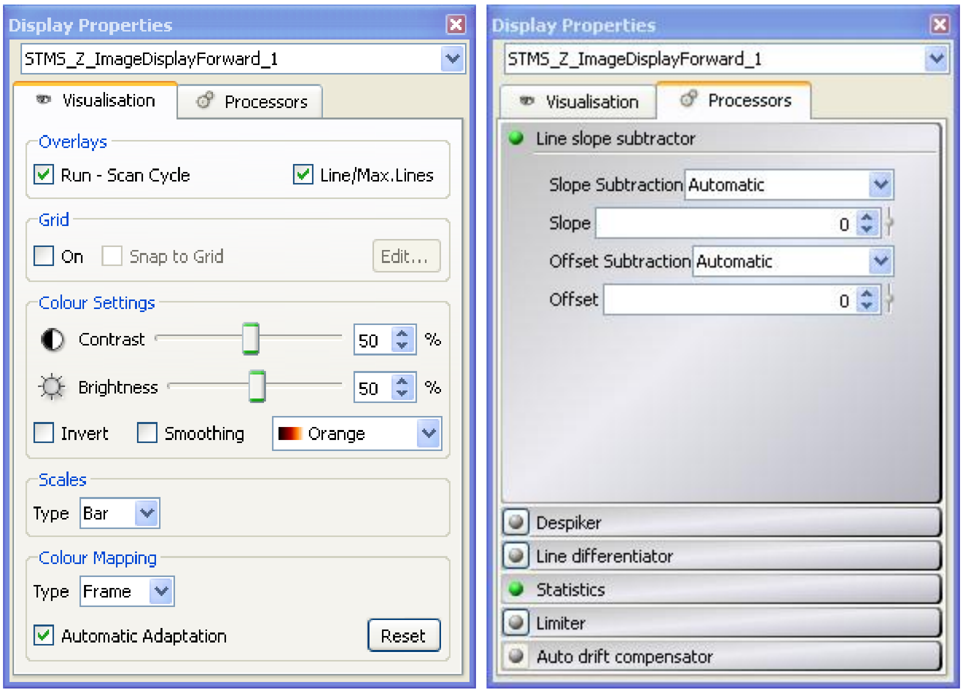


Figure 31. *Display Properties* windows, examples shown.

Notice

The Processor options provided here are for display only. They do not affect the data taken: saved data are always true raw data.

Result Data Rating

With data rating, you can assign an abstract "level" to acquired data such as images or curves, and use the Vernissage software for filtering data according to such levels. You may use either of the following options for adding an image or a curve to the *Favourites Gallery*:

- Select *Add to Favourites* from the context menu of a display without placing the mouse cursor over the star symbols to the right of the menu entry, or press *Ctrl* + *F* (or *Ctrl* + *0*) while the display window is active. In either case, the respective image or curve is transferred to the Favourites Gallery **without** rating it.

- Select *Add to Favourites* from the context menu of a display, and point the mouse cursor to the first, second, or third star symbol to the right of the menu entry. When clicking the left mouse button, the respective image or curve is transferred to the Favourites Gallery with the respective rating assigned. Alternatively, you can press the keyboard shortcuts *Ctrl* + *1* through *Ctrl* + *3* for rating the image or curve from the active display window, and transferring it to the *Favourites Gallery*.

Rated gallery entries will be marked by one to three stars, depending on the rating level chosen. The rating level of gallery entries can also be modified at any time by means of the context menu of the *Favourites Gallery*, or by means of the keyboard shortcuts Ctrl + 1 through Ctrl + 3 while the *Favourites Gallery* window is active.

The purpose of the data rating feature is to provide an additional parameter for filtering images and curves when reviewing acquired data by means of the Vernissage software. Vernissage is able to present (or hide) only those images and curves of a particular rating level, thus allowing you to quickly filter large amounts of data.

Information Overlays

At the top of the channel display four numbers inform about experiment progress and help locating a particular image for data analysis. These are called Information Overlays. They can be switched on or off in pairs.

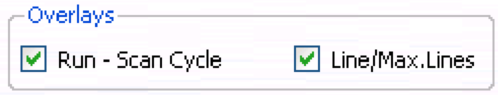


Figure 32. Information overlays panel of the *Display Properties* window.

Run	The run cycle count gets incremented each time you start a new a data acquisition operation. Topography and similar channels will indicate a new run count each time the scan process is restarted, while a channel acquiring single point spectroscopy curves increases the run count for each new single point spectroscopy operation initiated.
Scan Cycle	Shows the number of times a full scan cycle has been finished (e.g. one up and one down for a topography channel or the repetition for a spectroscopy curve).
Line	The current scan line within the cycle
Max. Lines	The maximum number of scan lines within a cycle

Grid Overlay

An image display grid overlay that can be used as an alignment aid, e.g. for atom manipulation operations. The grid can be configured for different purposes and supports a Snap to Vertices mode for restricting Mouse Tools.

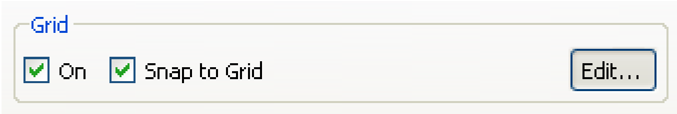


Figure 33. Display properties: Grid.

To show or hide the grid, use the checkbox in the *Grid* panel of the *Display Properties* window. Check *Snap to Grid* for restricting mouse tool operations to the vertices of the grid. To open the grid properties panel click the *Edit*… button, see also figure 34 below.

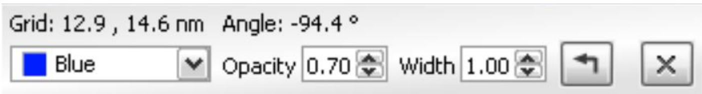


Figure 34. Grid configuration panel with controls and numerical information.

With the grid properties panel visible you can configure the grid position, cell spacing and line angle by pressing and holding the left mouse button with the mouse cursor hovering over one of the grid control points, and dragging the mouse afterwards. While the angle and spacing control points can be used for adjusting the form and spacing of the grid cells, the position control point allows moving the grid.

The grid properties panel also supports the configuration of the grid colour, opacity and line width. Click the reset button  to revert to the default grid configuration easily. Note that the grid configuration, including colour, line width, opacity, etc. will be saved when you store the session state e.g. by selecting *Save All* from the *File* menu of the MATRIX main window.

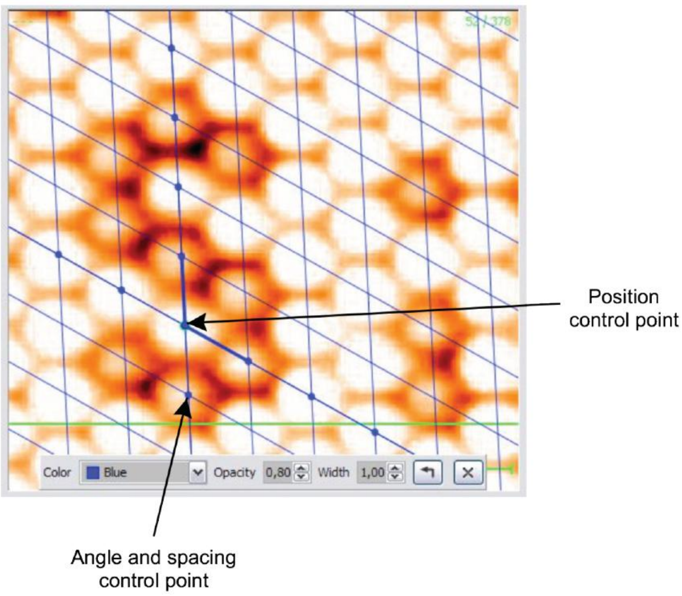


Figure 35. Image display showing grid overlay with grid properties panel.

The standard Mouse Tools for initiating experiment operations, configuring scan area dimensions etc. will be disabled while the grid properties panel is displayed. Close the panel for re-enabling the standard Mouse Tools.

Visualisation Colour/Curve

The *Visualisation* tab has different appearances depending on the selected display mode of the related channel display, see figure 36 on page 47.

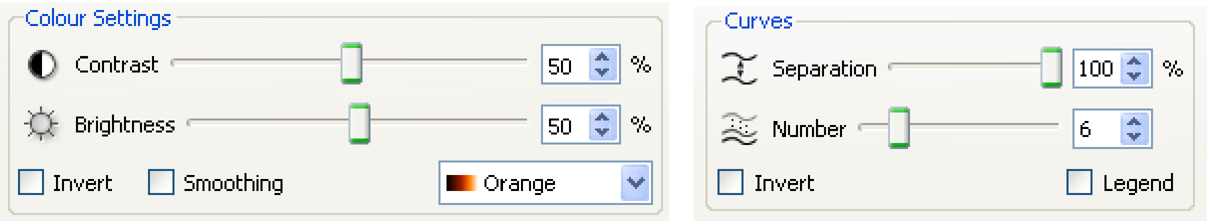


Image mode Curves mode

Figure 36. Display tools *Visualisation* tab, example shown.

- The contrast and brightness controls have sliders which allow settings between zero and 100%. Defaults for brightness and contrast are 50% as shown above.
- The separation slider changes the range of the displayed ordinate and hence the displayed size of the corrugation. The vertical scale adjusts automatically when the amplitude is changed.
- The number of lines displayed on the screen can be adjusted with the *Lines* field. The vertical scale adjusts automatically when the number of lines is changed.
- The *Invert* checkbox reverses the raw data representation of an image in order to show an inverted image. This can be useful for current images with negative currents to make the more negative currents look brighter than the less negative currents. The physical values are not affected, the negative current is accounted for when converting raw data into physical data, anyway.
- The *Smoothing* checkbox activates an interpolation routine to smooth the appearance of the image in the channel display. Please note that this routine does NOT affect the acquired data, it is applied for display purposes only.
- The *Legend* checkbox for curve displays enables or disables the exhibition of a colour legend at the bottom right of the display. This can be very useful for force-distance curves and spectroscopy curves with retrace enabled.
- The colour table drop-down field provides a choice of colouring options for the display in image mode.

Figure 37. Colour table drop-down field in display properties.

Colour Map (Image Mode)

The colour table used for channel display data representation can be adapted to the actual range of the incoming data.

- Select *Frame* or *Line* to spread the colour table across the current frame or to the current scan line. We recommend activating the *Despiker* processor, see page 49, when selecting Line.

Figure 38. Display properties: Colour Mapping.

- Check *Automatic Adaptation* to automatically adapt the colour table for every displayed frame/line. Note that the colour table adaptation is reset when a new frame/line is started, e.g. when changing the scan direction.

- Click *Reset* to manually reset the colour table adaptation to the actual data range at any time. The *Reset* button can be used with Automatic Adaptation on or off.

Scales (Image Mode)

A scale representing the scan area can be set to Bar (displayed inside the data frame) or Axes (displayed around the data frame). It can also be switched off entirely.

Ordinate (Curves Mode)

The ordinate for the curve display can be adapted to the incoming data. There are two strategies available.

- Automatic: the ordinate is adapted automatically to the incoming data.

  In automatic mode smart adaptation allows the data to go above and fall below the current ordinate limits before axis rescaling. This reduces the rescaling frequency and "axis jitter" of the ordinate especially with high data throughput.

- Manual: the ordinate minimum and maximum values can be specified using numerical input fields.

Figure 39. Ordinate panel in Curves mode display properties.

- *Adapt now*: Press this button to calculate the appropriate ordinate limits based on the effective data (only lines in light green/yellow taken into account). This function is not available in Automatic mode without smart adaptation.

Processors

Display Properties include a number of processors which provide channel display processing options in order to improve the scan image appearance on the fly, i.e. while scanning. Please note that these image manipulations are **for display purposes only** and do not manipulate the recorded raw data. In special cases you may want to use the *Snap Image/Snap Curve* functions described on page 44 for reference purposes. The provided display processors are applied to the incoming data in the order of appearance on the tab.

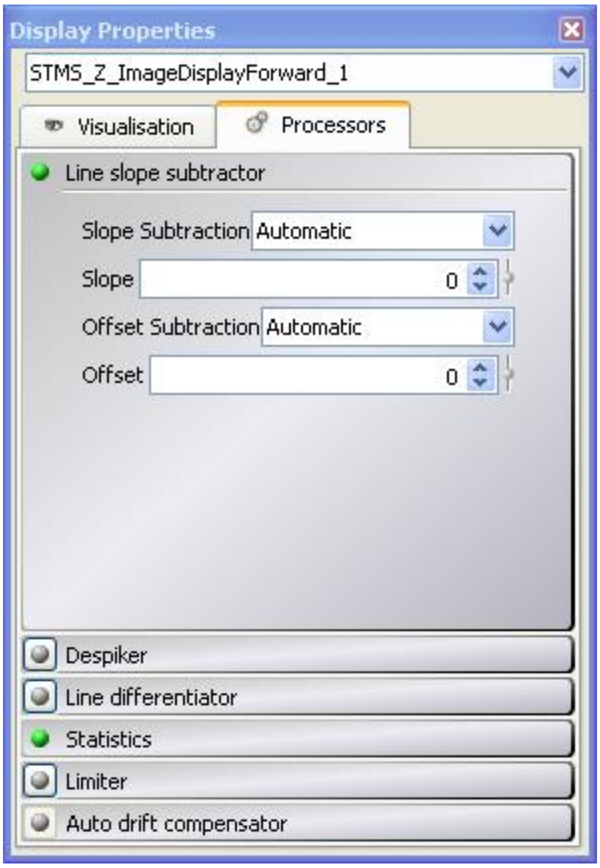


Figure 40. *Display Properties Processors* tab, example shown.

Line Slope Subtractor

The *Line Slope Subtractor* fits a straight line through the data values of a scan line. Two subtraction options are available: slope subtraction and offset subtraction. Slope subtraction eliminates slopes along the scan lines, e.g. due to a sample tilt. Offset subtraction reduces a possible offset, i.e. the full colour range is made available for each scan line. Effectively this reduces a slope perpendicular to the scan line. Both options can be used in an automatic or manual mode, separately or in combination.

Despiker

If *Despiker* is active, spikes will not be considered for the minimum and maximum value of the channel display. The Despiker processor cuts off a certain percentage of extreme data per line. In the default setting the upper and lower 1% of the incoming data will be cut off, i.e. the display range will be cut to the centre 98% of the incoming data. The percentage of data cut-off can be set between 1% and 50%.

Line Differentiator

The *Line Differentiator* superimposes the local derivative on every data point. The percentage of the derivative mixing can be selected. The corresponding formula is:

$$result = (1-q) \cdot original + q \cdot \frac{\partial}{\partial x}(original)$$

Mixing data with their derivative can help finding fine structures on a roughly corrugated or stepped surface as it enhances short range variation over long range variation, e.g. pronounces atomic structure over gentle slopes. The resulting appearance is similar to an illumination effect. Keep in mind, however, that height scaling is no longer correct with a differentiated image.

Statistics

The *Statistics* function is for display purposes only. Here you can see the number of analysed data points, as well their mean value and root mean square.

Limiter

The *Limiter* cuts off all data outside the given data range.

Auto Drift Compensator

Activate the *Automatic Drift Compensation* and choose if you want to broadcast this signal to other scanners (if applicable). For details on automatic drift compensation please refer to page 63.

Curve Averager

For repeated Force Curves and single point spectroscopy (SPS) curves you can activate the *Curve Averager* to display averaged curves in the channel display. The averaging will be reset when you click a new SPS position in the display or click Start in the Force Curve display. Click Reset to restart averaging during a repetition cycle without taking the previous curves into account.

> **Notice**
>
> Please remember that all processor generated image improvements are for display purposes only and do not manipulate the recorded raw data. In special cases you may want to use the Snap Image/Snap Curve functions described on page 44 for reference purposes.

Power Spectrum

This *Fast Fourier Transformation* (FFT) processor is available for data displays dedicated to rendering continuous signal curves only. It can run in different modes, supports a number of window functions, and is capable of computing signal characteristic indicator values for total power as well as power spectral distribution. The processor can be set to the following modes.

- *Amplitude:* This mode performs an FFT operation on the signal "slice" represented by the number of samples configured.
- *Amplitude-log:* As *Amplitude*, but the processor will apply an additional logarithmic conversion to the FFT-processed signal.
- *PSD:* Similar to mode *Amplitude*, but with the amplitude of the FFT-processed signal normalised to the width of the frequency window.
- *PSD-log:* As *PSD*, but the processor will apply an additional logarithmic conversion to the FFT-processed and normalised signal.

The data processor supports the window functions Hamming, Hann, Blackman and Uniform for signal analysis selectable from a drop-down menu in the processor display properties.

The *Power Spectrum* data processor is capable of computing signal characteristic indicator values for total power and power spectral distribution; the latter value is particularly useful as a measure for the noise density of the acquired signal. The two values are defined as shown in table 1 below.

Value	Definition	Value Display Label
Total Power (Amplitude signal: A)	$P = \sqrt{\sum_i A_i^2} \quad [V_{pp}]$	sqrt(Total Power)
Power Spectral Distribution (Amplitude signal: A, sample period: T)	$P = \sqrt{\frac{\sum_i A_i^2}{\Delta \frac{1}{2T}}} \quad \left[\frac{V_{pp}}{\sqrt{Hz}}\right]$	sqrt(Power per Frequency)

Table 1. Power spectrum signal characteristic indicators.

Mouse Tools

The channel display offers a number of mouse tools. These can be selected from a drop-down list or via their designated shortcuts, see figure 41 on page 51.

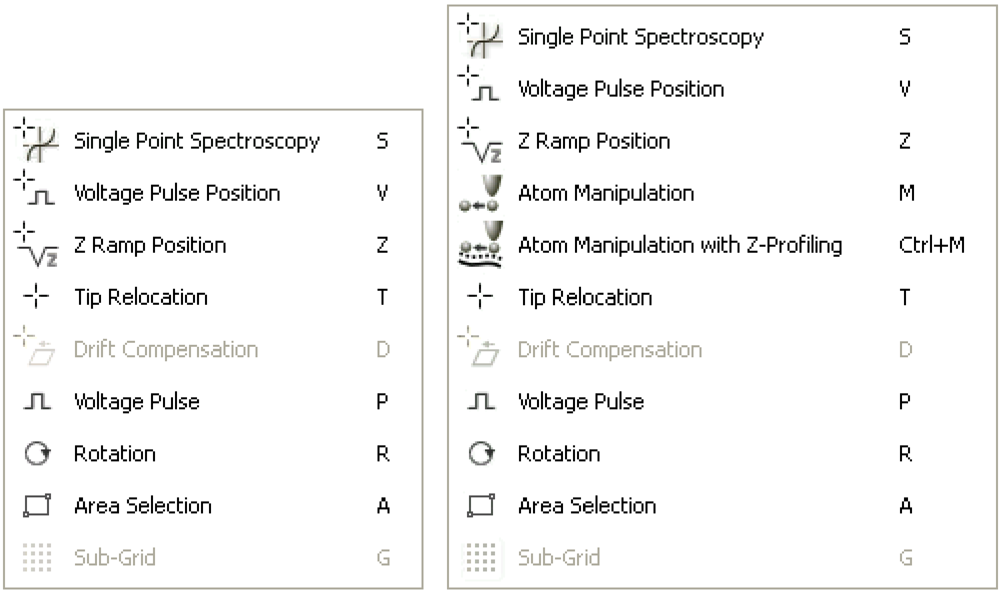


Figure 41. Channel display mouse tools and their shortcuts, examples shown. Note that the list adapts to the loaded experiment.

Additional shortcuts:
ESC Reset scan area
RETURN Apply scan area changes

Repeat

Some of the mouse tools also allow repeating the previous action by providing a special *Repeat* button.

Figure 42. Repeat function provided in some channel display mouse tools.

Tip Movement Visualisation

When changing the tip location, e.g. during atom manipulation or single point spectroscopy, the movement of the tip is shown as a moving green diamond in the channel displays *Z-Forward* and *I-Forward* (and as a red dot in the scan area control of the *XY Scanner* window). Once the tip has arrived its destination location the dot is switched back off.

Continuous Signal Channels

Data channels dedicated to continuous signal acquisition show oscilloscope-type signal displays. They are supported by all available MATRIX experiments. In general, such channels are provided for topography information— i.e. *Z(t)*—and for the various feedback loop input signals—such as $I_T(t)$ or $\Delta f(t)$—as well as for selected unspecific auxiliary signals. From a user perspective, the continuous signal acquisition feature is represented by dedicated data displays showing the acquired signal as a scrolling curve and some associated parameters.

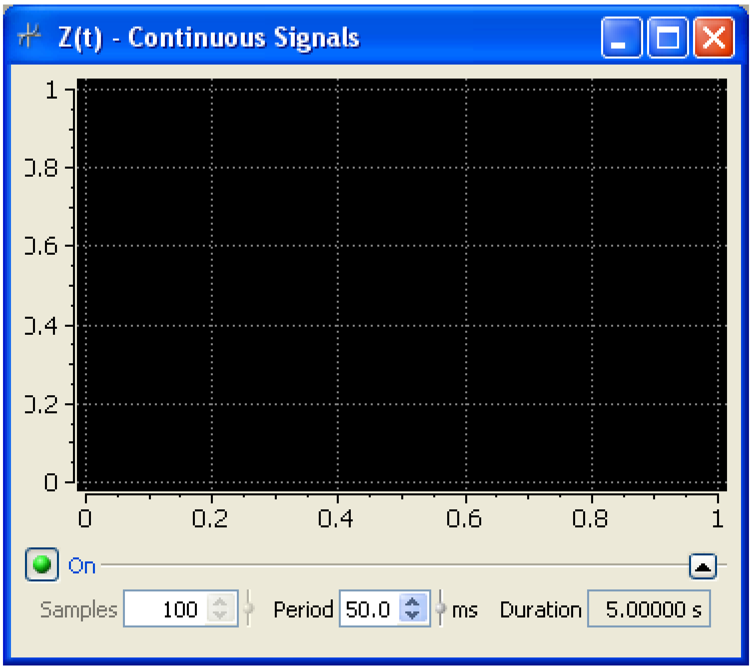


Figure 43. Continuous signal channel with parameters and controls.

For enabling the continuous sampling of a specific signal, two distinct steps are required:

- In the *Channel List* window of the experiment, enable the respective data channel e.g. *Z(t)*. Optionally, you may also enable data storing by marking the checkbox labelled with the diskette symbol.
- In the *Z(t)* display window, start the clock generation by clicking the *On* button.

For disabling the continuous sampling of a specific signal, it is sufficient to stop the clock generation by clicking the respective *On* button again. Note that the parameter *Samples* can only be set with continuous sampling switched off.

- *Samples* determines the number of samples a "scan cycle" will consist of; the Matrix software uses this parameter primarily for sizing the data files storing samples from the acquisition process.

- *Period* is equivalent to the various "Raster time" experiment parameters and determines the time spend on acquiring a single data sample. The value range of the parameter is 5 microseconds to 10 seconds; as usual, data will be actually acquired at a rate of 400 kHz during the specified period, the data item resulting from the sampling process represents the average of all samples acquired during the specified period.

- *Duration* represents the *cycle duration,* i.e. the "length" of a data file expressed in seconds. The value is calculated from the acquisition period specified and the number of samples per "scan cycle".

If you choose to store data acquired through a continuous signal-sampling channel, the MATRIX software will generate result data files containing the number of samples specified by means of the *Samples* parameter. The Omicron Vernissage software is capable of automatically concatenating the data from such files so that you can view the acquired curve in full length.

Data displays dedicated to continuous signal-sampling channels present information by rendering scrolling curves. The ordinate scale of such a display adapts automatically to increasing signal amplitudes; however, the data display will not shrink the axis scale autonomously. If you need to rescale the ordinate according to the amplitude range of the signal section currently displayed, you may use either of the following options.

- In the Ordinate section of the *Display Properties* window (*Visualisation* tab) click on the *Adapt Now* button for rescaling the ordinate manually.

- Use the Auto Adapt option in the Ordinate section of the *Display Properties* window (*Visualisation* tab) for configuring rescale operations that are repeated periodically.

Finally, you can specify the value range to be represented by the ordinate manually by selecting the option Manually on the *Range* pop-up menu, and entering suitable minimum and maximum amplitude values into the respective value entry fields.

4. The STM Project

The STM project is opened from the main window, see figure 4 on page 18, using the  icon.

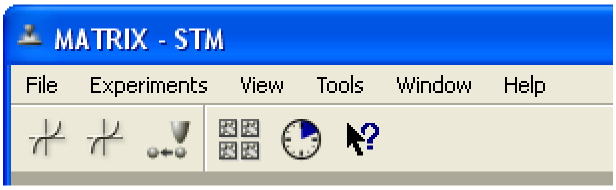


Figure 44. MATRIX – STM project window controls.

The STM project provides the following Experiments:

 STM topography & spectroscopy

 STM topography & spectroscopy QPlus

 STM Atom Manipulation

In the following we will explain the main elements of these Experiments starting with STM. Note that many components of all Experiments are very similar or identical to those of the STM Experiment, e.g. Regulator, Scanner and Channel displays. In later chapters we will therefore only describe the Project/Experiment specific GUI panels.

Scanner

The *Scanner* window (see figure 18 on page 33) is the main measurement control feature provided by the MATRIX software. In the STM experiment it is the primary (master-) component which contains the experiment start/stop controls.

Raster Settings

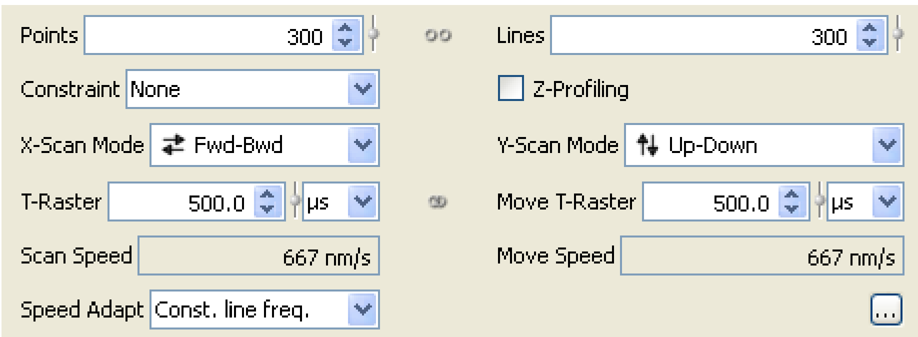


Figure 45. Scanner: raster settings. Note that Z-Profiling is only available in non-contact AFM/SFM experiments.

Scan Resolution

- The scan resolution (raster) can be set with the *Points/Lines* control fields. Note that these two parameters can be linked using the  button. In this case *Points* is always equal to Lines.

Constraint

The *Constraint* setting restricts the field of action within the given points and lines raster.

- **Line Mode** can be used for repeated scanning of a single line (first line of the specified scan area, i.e. Y=0)

- **Point Mode** can be used for sampling without moving the tip (first point of the specified scan area, i.e. X=0 and Y=0). The point mode option is particularly useful for stability assessments.

Scan Mode

- The scanning mode can be selected using a drop-down field. **Up Mode** stands for scanning a normal frame.

- Note that the **Up-Down Mode** allows frame scanning while avoiding the long-distance move of the tip between the end of the first frame and the beginning of the second. Instead, the second scan is run from top to bottom, the third again from bottom to top.

Notice
A small **offset** which may occur between UP-scans and DOWN-scans is a hysteresis effect due to piezo creep and **not a drift effect**.

Raster Time

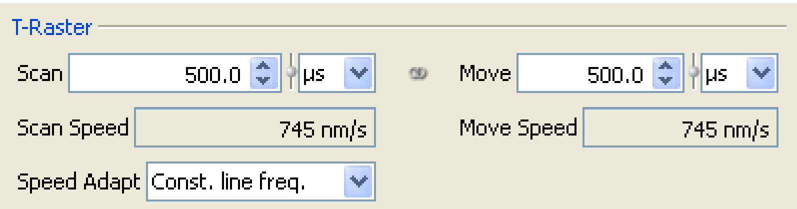


Figure 46. T-Raster control field.

- The raster time is the time between two adjacent data points. Note that data acquisition is handled by a separate component (channel) and will therefore not slow down a scanner.

- Different raster times can be specified for Scan and Move. (Here, "move" means non-scan tip movements such as tip relocation in case of point spectroscopy.) The related scan speed and move speed are also stated. A dedicated parameter constraint ensures that both parameters have identical values by default; however, you may toggle the state of the constraint by clicking on the "wedding rings" control button located between the two input fields.

- Lower limit: apart from the fact that scanner and electronics system have natural speed limitations the minimum raster time supported is currently 5 µs.
- Upper limit: the maximum raster time (i.e. minimum scan speed) supported is 500 ms.

Notice

The raster time is not necessarily identical to the data acquisition time per data point. For a graphical representation please refer to figure 86 on page 87.

The limits given above are standard values valid for standard Omicron SPM electronics equipment. For special electronic setups, e.g. for non-standard preamps, the hardware setup in the program may be different and lead to different limits.

Estimated Scan Speed/Move Speed

The scan/move speed, i.e. the travelling speed of the tip, depends on a number of settings. For a simple setting with Z-data acquisition only it can be calculated directly from raster time, raster width and length of the scan line. However, many Experiments define additional actions, such as spectroscopy or intentional waiting times, which make speed calculation a difficult subject. The value given in this display field is estimated according to your settings above, it is not a measured value.

Speed Adapt

The *Speed Adapt* setting tells MATRIX how to handle scan size changes while a scan is in progress.

- **Constant line frequency:** By default, the MATRIX software will keep the raster time constant when the scan area dimensions get modified during a scan. As a result, the line scan frequency does not change when resizing the scan area.
- **Constant scan speed:** When enabling the constant scan speed mode, the MATRIX software will attempt to adjust the raster time after resizing the scan area in order to keep the scan speed constant.

Scan Area

The scan area can be positioned inside the maximum positioning area using numerical value controls or mouse tools.

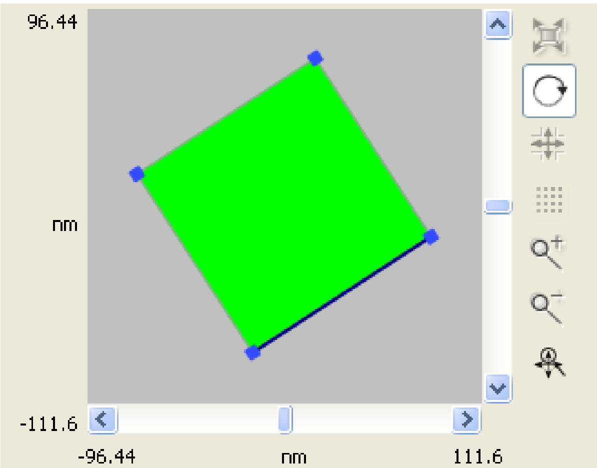
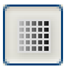
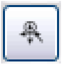


Figure 47. STM Scanner: scan area control.

When changing the tip location, e.g. resizing or rotating the scan area, the movement of the tip is shown as a moving red dot in the scan area control of the *XY Scanner* window. This is also the case when relocating the tip for certain experiments, e.g. single point spectroscopy. Once the tip has arrived its destination location the dot is switched back off.

	Resize area at constant aspect ratio (grip corner handles).
	Rotate area (grip corner handles)
	Move area freely
	Move area along axes
	Raster on/off (0.5 width / 0.5 height) for move area
	Optical Zoom in
	Optical Zoom out
	Automatic centre

The scan area is normally indicated as a green rectangle on a grey background which in turn characterises the maximum positioning area.

- When the selected scan area touches the border of the maximum positioning area (normally this only happens when you turn a rectangle close to the border), its colour turns red, indicating that parts of the specified scan area cannot be reached by the piezo.

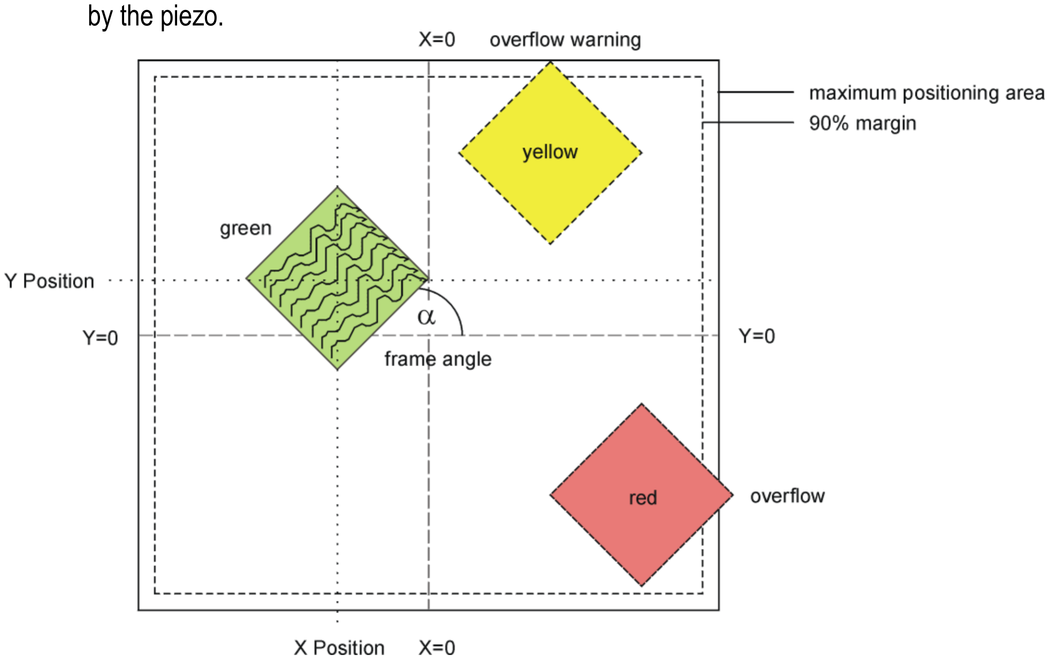


Figure 48. Frame positioning parameters.

- The first scan line is indicated in dark blue. Note that the default tip position is always at the beginning of the first scan line (scan area origin).

- The lateral position and scan size can be adjusted using the mouse. You can pan the frame in the direction of its edges or along the co-ordinate axes with respect to the centre of the scan area by activating the corresponding buttons and using the provided controls.

- The eyeglass buttons allow optical zoom-in and zoom-out functions. This can be helpful if you have specified a very small scan area which is displayed as a small spot within the positioning area. Press the eyeglass until the scan area is displayed at a reasonable size. There will be sliders for accessing the full positioning area.

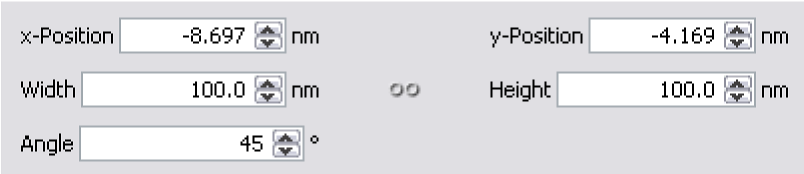


Figure 49. STM Scanner: scan area numerical controls.

- The size and lateral position of the scan area inside the maximum positioning area can also be adjusted with the **X/Y Position, Width/Height** and **Angle** controls. Note that width and height can be linked for a constant aspect ratio using the button.

Probe Relocation Speed Warning

Be aware of a potential caveat regarding the move speed: If the scan area size is changed, the system will often be forced to modify several DACs simultaneously in order to relocate the probe correctly. As a result, the relocation speed can drop significantly below the scan speed under certain circumstances, resulting in travelling times substantially longer than the configured raster time suggests. The following parameters can be used to control the system behaviour in such a case.

Note that these parameters cannot be modified via the graphical user interface but must be configured by editing the scanner parameter file of the respective experiment.

- `Relocation_Time_Limit` specifies the maximum time acceptable for probe relocation, default is 40 sec for all Omicron supplied experiments. If this time has elapsed before a particular relocation operation is completed, the MATRIX software will automatically accelerate the movement by increasing the tip step size, i.e. reducing the number of intermediate points on the relocation vector, thus increasing the distance between these points.
- Increasing the tip step size as described above can cause the Z-axis regulation to fail in case the actual feedback loop parameters are not sufficient for the resulting relocation speed. To compensate, the parameter `Relocation_Step_Limit` specifies the maximum distance between two intermediate points on the relocation vector. By default, this maximum distance is 0.5 Å, which is considered suitable for most feedback loop settings.

In order to prevent tip damage, Omicron recommends not to change these parameters unless the default settings are utterly unacceptable for a specific experiment.

Zoom, Pan and Rotation

There are two fundamentally different approaches to this subject.

- One approach is to **focus on the scan area** and directly manipulate it by move or rotation operations. Use the controls in the *XY Scanner* window to manipulate the scan area. When you rotate or pan the scan area in this window, MATRIX will directly change the parameters to match your choice. Note that the obtained image will consequently rotate or move the other way.

- Alternatively, you can **focus on the obtained image**, i.e. on the features of a scanned part of the sample. Use the controls in the channel display to manipulate the obtained image. When you rotate or pan the image in this window, MATRIX will calculate parameters such that the result matches your choice. Note that the scan area will consequently rotate or move the other way.

While the first approach gives you direct control over the scan area, the second approach allows you to concentrate on interesting features of a sample without bothering about scan parameters.

In the latter case, you can zoom into the contents of a channel display, rotate the contents of the channel display, or move the contents around until the channel display shows the section of interest of a scanned portion of the sample. The MATRIX software then allows you to automatically configure the scan area parameters such that the selected channel display contents will be (re-)scanned.

In any case, the MATRIX software supports zooming into the contents of an image display without changing the scan area. In addition, you can also move around (pan) the contents of an image display without changing the scan parameters. This way you can pre-select interesting features and afterwards direct the MATRIX software to set up the scan parameters for scanning these features.

Zoom

Do not confuse the optical zoom feature (eyeglass buttons) provided for optical magnification, with the zoom feature that changes the size of the scan area.

- One way to zoom into the scan area is to adjust the width and height settings. This can be done before or while scanning.

- Alternatively with your mouse pointer in the channel display window use the wheel button for zooming (scroll forward to zoom in and backward to zoom out). Once you are happy with the appearance click the *Apply* button at the bottom right corner of the channel display to activate the new scan parameters.

	Click the *Apply* button to activate the new scan parameters. Click the *Reset* button to return to the original parameters.

Pan

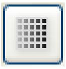
There are several possibilities to move the image or the scan area. You can either use the pan buttons in the channel display to manipulate the obtained image or use the respective mouse tool in the *XY Scanner* window to manipulate the scan area.

Pan and Rotation Numerical Value Controls

An offset set using the numerical value control will be applied after pressing return.

Pan Button in *XY Scanner* Window

Use the pan and rotation buttons in the *XY Scanner* window to directly move or rotate the scan area. Note that the lateral movement can be restricted to movements parallel to the scan area edges. The coordinate system rotates with the scan area.

	Move area freely
	Move area along axes
	Move area along grid

Pan Function in the Channel Display

The pan functions in the channel display are WYSIWYG (What You See Is, What You Get). This means that you can move the image the way you want it to look and the software takes care of calculating the necessary parameters accordingly.

- Click the image with the mouse wheel button, hold the button down and move the image freely.
- Once you are happy with the appearance click the *Apply* button at the bottom right corner of the channel display to activate the new scan parameters.

Rotation

There are several possibilities to rotate the image or the scan area. You can either use the rotation function in the channel display (shortcut R) to manipulate the obtained image or use the respective mouse tool in the *XY Scanner* window to manipulate the scan area.

Rotation Numerical Value Controls

A rotation angle set using the numerical value control will be applied after pressing return.

Rotation Button in *XY Scanner* Window

Use the rotation button in the *XY Scanner* window to directly move or rotate the scan area. Note that the lateral movement can be restricted to movements parallel to the scan area edges. The coordinate system rotates with the scan area.

	Rotate area (grip corner handles)

Rotation Function in the Channel display

The rotation function in the channel display is WYSIWYG (What You See Is, What You Get). This means that you can rotate the image the way you want it to look and the software takes care of calculating the necessary parameters accordingly.

- Select the *Rotation* function (shortcut R). Click the image with the left mouse button and rotate as desired.

- Once you are happy with the appearance, release the mouse button to activate the new scan parameters.

Figure 50. Channel display *Rotation* mouse tool.

Notice
The number shown when rotating the image is the parameter **change** that will be applied when releasing the mouse button. It is NOT the final rotation angle as indicated in the *XY Scanner* window if the image had been rotated before.

Area Selection

After activation (shortcut A), the mouse tool allows you to determine a rectangular area representing the new scan region. Once you are satisfied with the size and position of the area, click on the *Apply* button at the bottom right of the respective image display to direct the MATRIX software to take the marked region as the new scan area.

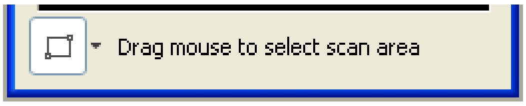


Figure 51. Channel display *Area Selection* mouse tool.

Navigation Assistance

In addition MATRIX allows navigating samples by using the contents of image displays as "background" for the scan area visualisation and configuration control (field with green rectangle in figure 47 on page 56). You can transfer the contents of any image display to the control. The respective image will be shown at the location where the image data was actually acquired, and with the run cycle and scan cycle information included.

Figure 52 shows the scan area control element after the results of scanning two different sample regions have been inserted from a tunnelling current image display. MATRIX supports two options for transferring image data to the scan area control.

- Transfer images by *Drag & Drop*: place the mouse cursor on the display contents you want to transfer, press and hold the *Alt* key, then press the left mouse button and drag the mouse cursor to the scan area visualisation and configuration control. Release the mouse button when the + symbol appears next to the mouse cursor.

- Transfer images by *Copy & Paste*: place the mouse cursor on the display contents you want to transfer, press the right mouse button and select *Snap Image* → *Copy* from the context menu. Then right-click the scan area visualisation and configuration control and select *Paste Image* from the context menu.

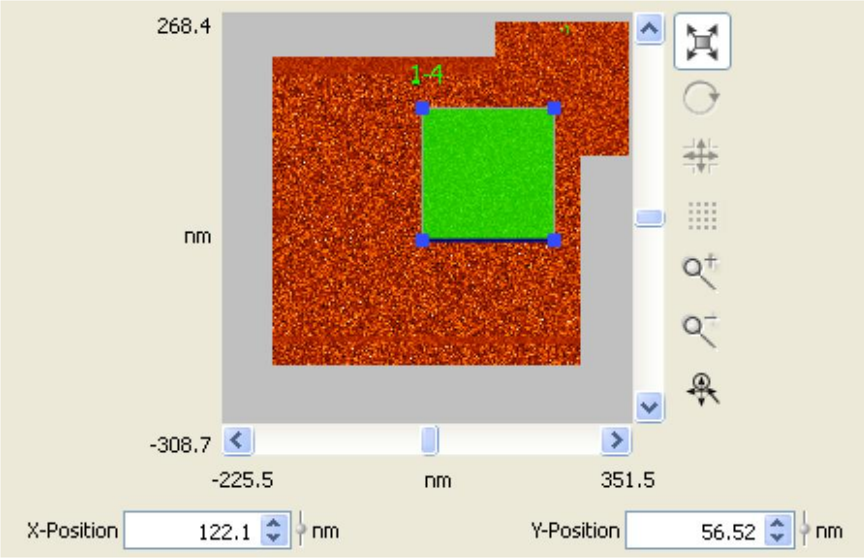


Figure 52. Scan area control showing display contents.

To remove a transferred images place the mouse cursor on the image to be removed, press the right mouse button and select *Remove Image* from the context menu.

Drift Compensation

Mouse controlled drift compensation can be applied if succeeding frames show the same surface feature in different locations, thus indicating thermal drift. Drift compensation can be achieved in two ways, either by direct input in the drift compensation panel or using the controller provided in the channel display.

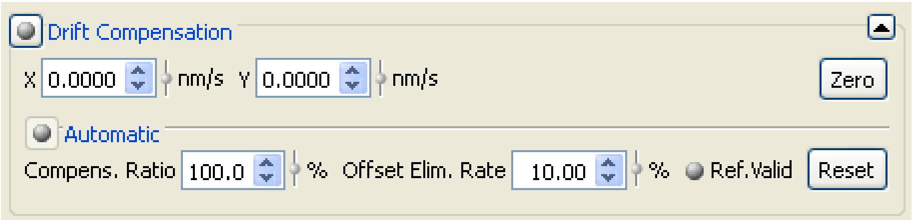


Figure 53. Drift compensation panel in the *XY Scanner* window.

Normally you will probably use the drift compensation controller in the channel display to set a drift compensation vector. However, you may also want to directly enter drift compensation values.

- Activate the drift compensation function using the *On* button in the drift compensation panel.
- Activate the drift compensation controller by selecting the respective mouse tool (shortcut D).
- Mark a feature by a clicking it with the left mouse button.
- Wait until you recognise the same feature in the following frame (or any later frame), then click on the apparently moved feature with the left mouse button.

- The computer now calculates the drift from the apparent shift and the time interval between the acquisition of the corresponding data points (not the time of clicking it) and initiates a compensating offset shift.

If subsequent frames still show a small shift of the marked feature, you can reapply the left mouse button (once in each frame), to compensate for the remaining drift.

Attention

It does not make sense to click twice in the same scan cycle since the same feature cannot possibly appear in two different locations in the same image. The drift compensation function however assumes that the feature has indeed moved from A to B in a few milliseconds and sets the drift compensation accordingly – with probably disastrous results.

Notice

If you decide to focus your attention on a different feature, switch the controller off and on again using the drop-down menu in the channel display. Then mark the new feature and proceed as above.

Note that the previously applied drift compensation will not be deleted if you switch off the mouse tool or the drift compensation function.

- If you switch off the controller only, the drift compensation will continue to be applied but the mouse action is inactive.
- If you switch off the drift compensation function the drift vectors will be set to zero. Note that the offset accumulated at the time of switching off will not be reversed.
- In order to completely clear any previously applied drift settings click the *Zero* button.

Notice

In UP-DOWN scan mode the **offset** between UP-scans and DOWN-scans is a hysteresis effect due to piezo creep and **not a drift effect.**

When using mouse controlled drift correction in UP-DOWN scan mode always click in the frame where the reference point has been set (either UP **or** DOWN.)

Automatic Drift Compensation

The Automatic Drift Compensation option will monitor the data acquired through one of the data channels. When enabling the Automatic Drift Determination option, MATRIX will select a default display as source for the drift determination process. Normally this will be the *Z topography* channel for the forward part of a scan line sweep. The image generated during the first scan cycle (up or up/down sweep) will be marked as "reference image" and images generated during subsequent scan cycles will be automatically compared to the reference image in order to determine the actual drift and a suitable compensation vector. This compensation vector is reflected by the parameters X and Y of the drift compensation configuration panel.

Notice

You may choose a different display by enabling the *Automatic drift compensator* data processor associated with the respective display. This data processor is available for all topography channels and for data channels associated with the feedback signal. MATRIX will store the data processor configurations of all displays when saving the session state. As a result, the data display to be used for the automatic drift determination process will also be remembered across MATRIX sessions.

A dedicated indicator (*Ref. Valid*) reflects whether a valid reference image is available or not. Note that you can manually invalidate a reference image by clicking the *Reset* button on the automatic drift compensation configuration panel. In this case the Z image resulting from the next scan cycle will be used as the new reference image. Any reference image will be automatically invalidated if you modify the scan area dimensions, offset, or rotation angle.

The drift compensation algorithm can be fine-tuned by two dedicated parameters:

- *Compens. Ratio* specifies to which degree the detected drift shall be compensated. The value is specified as a percentage; a value of 100% directs the scanner to compensate the entire drift. In practise, values slightly less than 100% have proven most useful. (The default value of 90% can be considered a useful standard.)

- *Offset Elim. Rate* specifies the time frame during which the scanner attempts to fully compensate the detected drift. The value is specified as a percentage, a value of 100% directs the element to compensate the drift during a single scan cycle. The value for this parameter should usually be set to less than 50%, a value of 20% has proven useful in many scenarios.

The Automatic Drift Compensation option can be enabled or disabled separately from the drift compensation facility by means of a dedicated control button on the automatic drift compensation configuration panel.

Notice

The automatic drift compensation processor is capable of distributing drift information to multiple scanners when required. If an experiment supports multiple scanners, each *Auto drift compensator* processor is able to broadcast its drift velocity computation results to all scanners it has been associated with. When enabling the Broadcast option in one of the processors, each scanner with the automatic drift compensation option enabled will receive its compensation information from the same processor on the basis of the image data this processor uses. As a result, all scanners will attempt to compensate exactly the same drift.

Visualisation of Drift Compensation

MATRIX is capable of visualising the offset changes caused by the drift compensation facility continuously; the software will use both numerical and graphical displays for this purpose:

- The numerical value entry fields for the scanner parameters *X-offset* and *Y-offset* will reflect the current scan area offset at any time. As a result, with drift compensation enabled, you will see continuous value updates. Note however, that setting the input cursor to the entry field for *X-offset* or *Y-offset* will stop the update function temporarily to allow modification of the displayed value. (This is a visual effect only; the drift compensation facility will continue to modify the scan area offset in the background.)

- The scan area visualisation will also be modified continuously, i.e. the graphics representing the actual scan area dimensions gets shifted around as the drift compensation facility changes the offset parameters. This process is temporarily interrupted while you are moving the scan area by mouse, but the drift compensation facility itself is not thereby disabled.

Scan Restart Mechanism

You may restart a progressing scan operation without stopping an experiment first: When clicking the *Restart* button in the *XY Scanner* window

- The scan process will be halted.
- The probe will return to the scan origin (lower left corner of the configured scan area).
- If storing data has been enabled the samples acquired so far will be saved.
- Afterwards, the scan operation will resume automatically.

Regulation

The *Regulation* GUI contains a display and controls for the feedback loop, loop gain control and the feedback setpoint (e.g. tunnelling current).

Attention

Be careful with the ***Feedback Loop*** button: thermal drift and piezo creep may drive the tip into the surface if the loop is switched off.

Z-Metre

A vertical display indicates the tip position relative to the piezo range. This display is called the *Z-metre*.

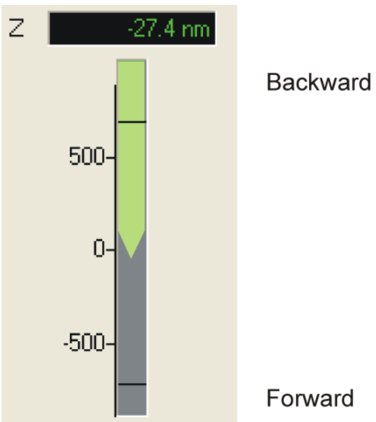


Figure 54. Regulator: Z-metre display.

- A tip shape indicates the regulators Z output or Z-position of the piezo. If the tip shape is green, the position is acceptable for scanning.

- If the tip moves to the top of the metre (red) the regulator has drawn the tip as far back as possible. This is always the case if the remote box tip switch is in position BACKWARD.

- If the remote box tip switch is set to FORWARD the tip shape moves down indicating that the regulator moves the tip towards the sample until tunnelling current (AFM: force) is detected. If the tip shape reaches the bottom of the metre (yellow) no current has been detected within the regulator range and coarse steps or Auto Approach are necessary.

- Otherwise the tip shape stops at the position where stable feedback conditions are met.

- If the tip shape goes into the red warning area during normal scanning this indicates **danger of tip crash** while the yellow area indicates danger of losing contact.

Attention

If the tip shape is within the yellow or red warning region, overflow of the piezo driver output amplifier may lead to unpredictable results.

The Z-meter works at a fix sampling rate of some few values per second. (During Auto Approach this may look strange.)

Feedback Controls

- The feedback loop can be switched on/off using the *Feedback Loop* button.

- The *Loop Gain* can be varied between 0 and 1000%. Low loop gain values result in a slow feedback loop while high loop gain values result in a quickly responding feedback loop and may lead to tip oscillations. Connecting an oscilloscope is generally recommended during AFM or STM operation, see page 135. Alternate setpoints, if activated, are applied for the backward scan direction.

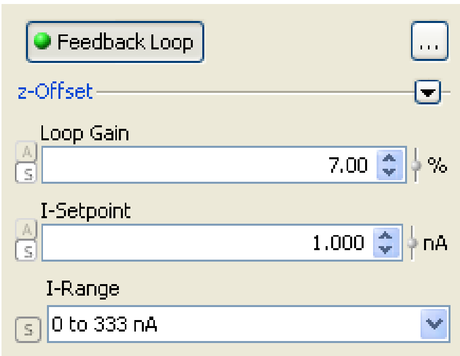


Figure 55. STM Regulation feedback controls.

- The feedback loop gain consists of an integral part (I-part) and a proportional part (P-part). Both can be set separately but, since the influence of the P-part is negligible in most applications, only the Needle Sensor experiment has panel for doing so.

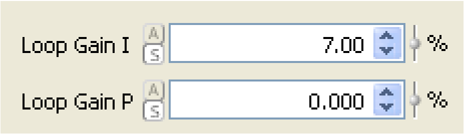


Figure 56. Panel *FeedbackLoopParameterLGP* available in Needle Sensor experiments.

- In all other experiments you can modify the P-part of the loop gain either using a MATE script or by substituting the panel *FeedbackLoopParameter* of the Experiment Element *Regulator* by the panel *FeedbackLoopParameterLGP* shown above in all desired experiment descriptions. For details please refer to the Appendix, page 153.

- Feedback *Setpoint* allows the definition of a setpoint for the feedback loop. Alternate setpoints, if activated, are applied for the backward scan direction.

- Setpoint range: for the SPM PRE4 switch between 0 to 3.3 nA and 0 to 333 nA to control the available ADC resolution. In position low range only 1 percent of the setpoint range are available at full ADC resolution (16-bit).

Characteristics

The MATRIX system supports the explicit configuration of certain aspects of the Z-regulation algorithm characteristics. In particular, you may determine whether the feedback loop input processing has *linear* or *logarithmic* characteristics. By default, the logarithmic characteristics are used by STM experiments while linear characteristics are applied in AFM experiments; however, you may configure logarithmic characteristics also for AFM non-contact mode experiments (note that you must select the Δ*f* sign to be positive in order to use logarithmic characteristics), and linear characteristics for STM experiments.

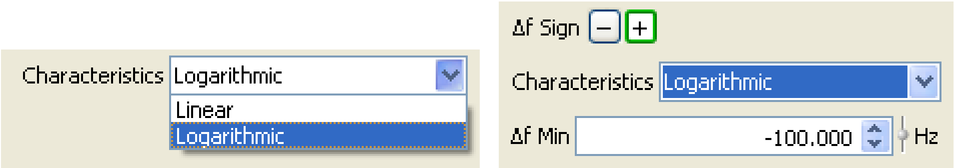


Figure 57. Characteristics settings in the *Regulator* window. Left: STM experiment; right AFM noncontact experiment.

If you decide to use logarithmic characteristics for the feedback loop input processing in an AFM non-contact experiment, you must determine a minimum value for the Δ*f* signal also. (The respective parameter entry field Δ*f Min* is located below the Characteristics control.) The minimum Δ*f* value is important because due to the logarithmic processing characteristics, a feedback loop branch will not contribute to the output signal if the actual Δ*f* value drops below the specified minimum value and thus would be useless.

Twin Regulators

The MATRIX digital regulator component allows an additional feedback loop. This option is called "twin regulator option"; it can significantly simplify your workflow, in particular when running AFM non-contact-mode experiments. Omicron therefore supplies all AFM non-contact experiments (for cantilever/beam deflection sensors, and for the QPlus sensor) using the feedback loops for processing the Δf and tunnelling current signals simultaneously.

- The two feedback loops operate independently on different input signals.

- The characteristics of the loops (setpoint, loop gain) can be configured separately and both feedback loops will compute the Z-axis displacement based on their own loop settings.

- The contribution of each feedback loop branch to the actual output signal can be configured dynamically using the *Weighting* slider.

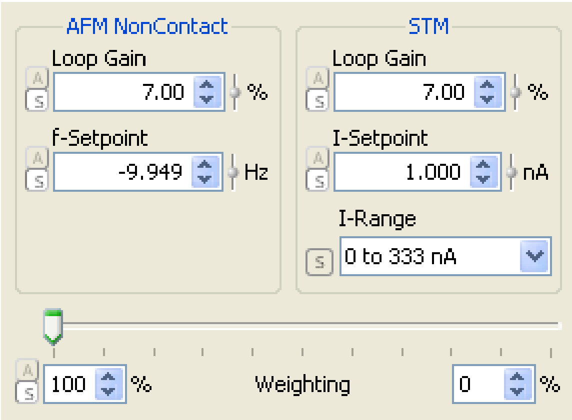


Figure 58. Dual feedback loop option in *Regulator* window.

Attention

Auto Approach operations cannot be run with two active feedback loop branches!

However, you can select which branch (and hence which Auto Approach strategy) shall be used in the *Regulator Options* window. Once an Auto Approach operation has completed, the MATRIX software will enable the second feedback loop automatically.

Using Unspecific Signals as Feedback Loop Input

MATRIX also supports using arbitrary ADCs as input devices for the Z-control process via voltage-calibrated setpoints. This means that any unspecific ADC on a MATRIX board can be used as signal source for the regulator feedback loop. This option is particularly useful in conjunction with the dual ("twin") feedback loop branch Z-control facility detailed above. One could, for example, feed the (voltage-calibrated) Damping signal of an AFM non-contact experiment into the second feedback loop as a supplement to the standard Δf signal.

Notice

A feedback loop that uses an unspecific ADC as signal source cannot be used for running Auto Approach operations.

Notice

The Omicron MATRIX website provides a number of dedicated AFM non-contact experiments (both for MATRIX systems equipped with an AFM-CU II or the new AFM-SPU hardware) utilising the Damping signal as secondary feedback loop input. These can be downloaded at http://www.omicron.de/en/software-downloads/.

If you want to use the unspecific signals option in other experiments, please contact the Omicron Service department for assistance.

Z-Offset

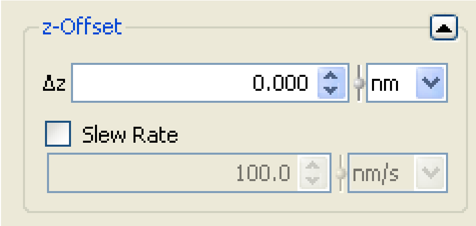


Figure 59. The Z-Offset panel in the *Regulator* window.

- Enter a Z-displacement to be added to the tip-sample distance. This is normally used to achieve a larger gap without touching the bias voltage when the feedback loop is switched off.

- Enter a Z-offset *Slew Rate*. The Z displacement will be approached in steps with the specified slew rate, approximating a linear ramp.

Z-Plane

The *Z-Plane* panel provides options for correcting sample tilts during spatial scan, probe relocation, and atom manipulation operations. These options allow moving the probe across a surface at a configurable height with the feedback loop disabled after having evaluated the surface slope. This feature is useful for scanning modes such as Magnetic Force Microscopy (MFM) and other operations where the probe/sample distance is too large for deriving a feedback loop signal.

> **Attention**
>
> Moving the probe without the feedback loop enabled requires profound knowledge of the sample corrugation and a stable system with little or no drift effects.

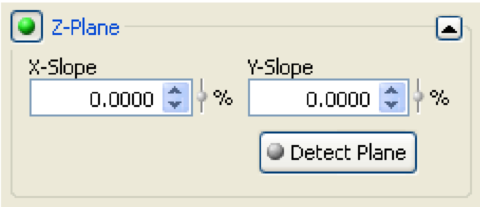


Figure 60. Z-Plane control panel.

- Clicking the button *Detect Plane* will initiate a dedicated scan operation in both X– and Y-direction that is used for evaluating the sample slope. You can use this button at any time (and in any experiment state) for finding (or correcting) the X-axis and Y-axis slopes.

- The numerical value entry fields *X-Slope* and *Y-Slope* will be filled with the values found for the X-axis and Y-axis slopes when a *Detect Plane* operation has been completed. You may modify the detected values also manually. However, be aware that doing so might provoke a tip crash.

- Once the surface slope has been evaluated, you may enable (or disable) the sample tilt correction by means of the control button in the upper left corner of the Z-Plane panel. Note, however, that enabling the sample tilt correction will only cause an effect if you disable the feedback loop by clicking the appropriate button in the *Z Regulation* window. Please note also that the Z-offset to be used for the probe must be specified by means of the numerical entry field ΔZ on the *Z-Offset* panel.

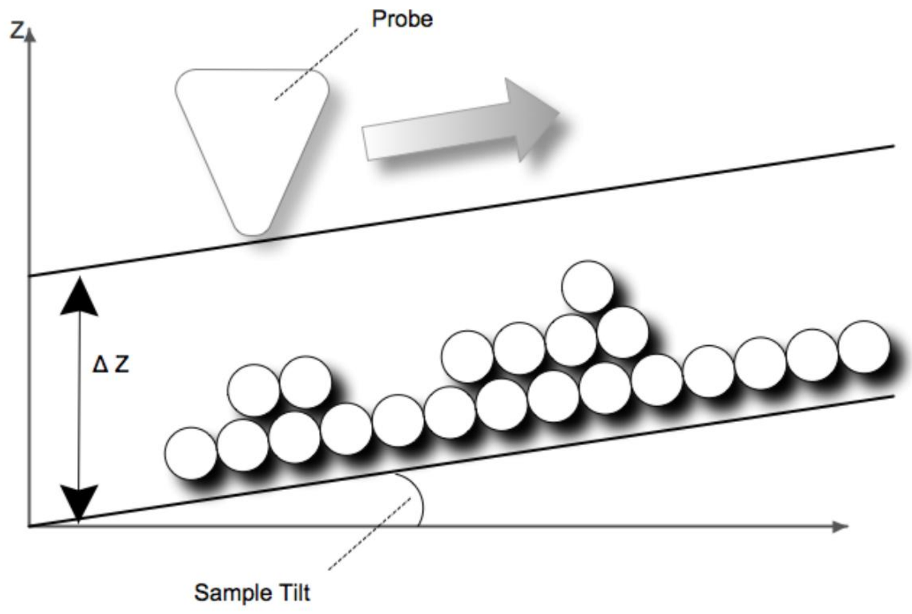


Figure 61. Moving the probe with *Sample Tilt Correction* enabled, schematic diagram.

When enabled, the sample tilt correction mechanisms will be applied to **all** operations involving probe movements, including certain tip conditioning operations, single point spectroscopy experiments, and similar.

You may change the Z-offset of the probe at any time by modifying the parameter ΔZ on the *Z-Offset* panel. The scan area characteristics (dimension, angle and position) can also be changed while the sample tilt correction facility is active. In this case the parameter values of *X-Slope* and *Y-Slope* will be extrapolated with respect to the new scan area configuration. Note, however, that for preventing tip crashes it is generally more secure to trigger an automatic slope detection operation by clicking the button *Detect Plane* after reconfiguring any scan area-related parameter.

Enabling the sample tilt correction facility will automatically disable the Z-profiling option; see page 82 for additional information on Z-profiling in conjunction with atom manipulation operations.

Notice
MATRIX will not record any signal while a sample slope evaluation operation is active; thus you cannot monitor the data acquired during that operation.

MFM Experiment Support

Besides scanning a sample with the feedback loop disabled after evaluating the sample slope, MATRIX also supports a dedicated two-pass scan technique referred to as Z-profiling. Both options are particularly useful for MFM experiments scanning at a given Z-offset to measure magnetic force interactions only.

The two-pass scan technique can be applied to "correct" for topography influences in each scan line. It records the sample profile during the first scan sweep and allows running the scanner in a second scan pass using the recorded profile with a selectable offset without regulation, that means with a defined height at each scan point.

Notice

You may want to apply an adequate T-Fwd Line Delay (see figure 67 on page 75) to ensure the scanner has enough time to reach its new position before the second scan sweep starts. Otherwise you may see transient effects at the beginning/end of your scan lines.

Notice

Note that enabling the Z-profiling option for spatial scan operations will automatically disable the sample tilt correction facility.

The Z-profiling option is capable of acquiring data during both scan passes and supports feeding such data to different displays. As a result, dedicated experiment descriptions (defining and configuring separate displays for data from the two passes) are required for using the option. The standard MATRIX experiments which support the Z-profiling option are listed the table below.

Experiment Name	Experiment Type
AFM_NonContact	Cantilever/beam deflection AFM non-contact for AFM-SPU
AFM_NonContact_AM_KelvinProbe	Amplitude modulation Kelvin Probe experiment for AFM-SPU
AFM_NonContact_FM_KelvinProbe	Frequency modulation Kelvin Probe experiment for AFM-SPU
AFM_NonContact_QPlus	QPlus sensor AFM non-contact for AFM-SPU
AFMHybrid_NonContact	Cantilever/beam deflection AFM non-contact for AFM-CU II
AFMHybrid_NonContact_KelvinProbe	Kelvin Probe experiment for AFM-CU II
AFMHybrid_NonContact_QPlus	QPlus sensor AFM non-contact for AFM-CU II
SFM_NonContact	Cantilever/beam deflection AFM non-contact for AFM-SPU and Cryogenic SFM microscope

Table 2. Experiments which support Z-profiling.

Notice

If you require the Z-profiling option in other experiments also, please contact the Omicron service department for assistance.

For spatial scan operations, the Z-profiling option can be enabled or disabled by means of the Z-Profiling checkbox on the scan parameters panel; this checkbox will only be available if the respective experiment description supports the Z-profiling option.

Please refer to page 82 for more information on the Z-profiling option in conjunction with atom manipulation operations.

Regulator Options

The *Regulator Options* window is available from the […] button in figure 55 on page 66.

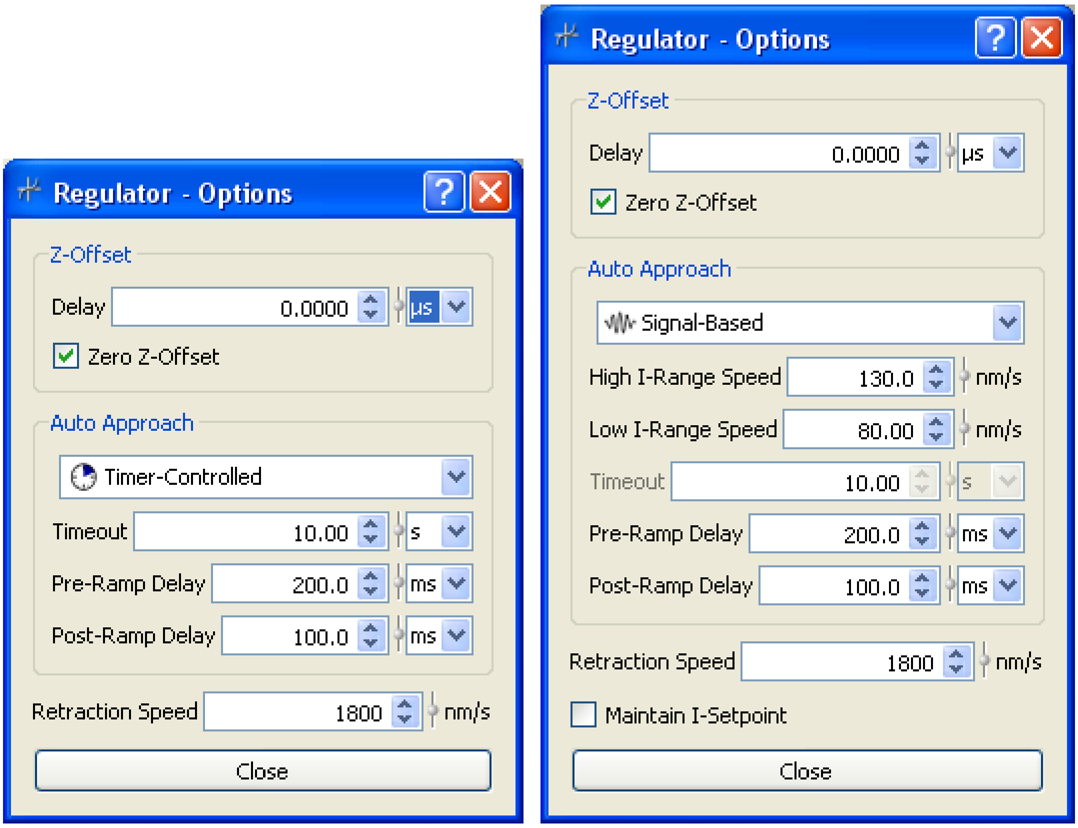


Figure 62. *Regulator Options* window.

Z-Offset

In this window specify the slew rate and delay time for effectuating a Z-Offset initiated manually in the *Regulator* window.

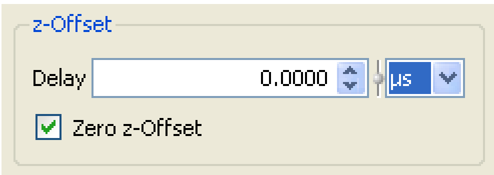


Figure 63. Z-Offset control panel.

- Enter a *Delay* time, i.e. a waiting time, before Z-displacement will be started. Since the actual Z value slightly varies due to the regulation process, this time span is used for a sampling and averaging process in order to calculate a reliable Z value from which to start the displacement. Note that with the feedback loop switched off this parameter is insignificant.

- *Zero Z-Offset*: If ticked the Z-offset will be zeroed when the feedback loop is switched on. Otherwise the Z-offset entered in the entry field will be kept stable regardless of the feedback loop stetting. This allows re-applying a previously used offset at the cost of a potential tip crash.

Auto Approach

- Select *Auto Approach Mode*, see page 37. For details on the speed settings please refer to page 39.
- *Pre-Ramp Delay*: waiting time after a coarse step and before starting a fine-piezo ramp.
- *Post-Ramp Delay*: waiting time after a fine-piezo ramp and before effectuating the next coarse step.

Notice

For further details on the Auto Approach procedure please refer to page 37.

Other

The *Regulator Options* window offers two more parameters.

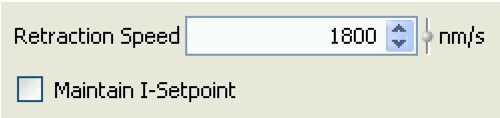


Figure 64. Other regulator options.

- *Retraction Speed* for remote box initiated z displacement, i.e. coarse steps outside the Auto Approach procedure.
- *Maintain I-Setpoint*: If checked the current setpoint is kept when changing I-Range. If that is not possible (e.g. when switching to the 3.33 nA range with a setpoint of 5 nA) the new setpoint will be set to max (or min in case of negative values).

Regulator Low Pass Filter

The *Regulator* low pass filter can be used for filtering noise pickup from the environment on the feedback signal, e.g. across the grounding connection. In case of STM this low pass filter acts on the tunnelling current.

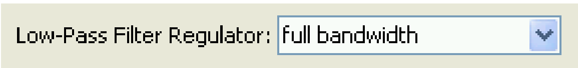


Figure 65. *Regulator* low pass filter.

Notice

Tip. We recommend working at the largest possible bandwidth.

The low pass filter acts on the feedback signal only, the recorded or displayed tunnelling current is not affected.

Attention

Setting the low pass below 30 kHz with the feedback setpoint in the 333 nA range, signal detection is slowed down considerably due to low pass filtering. This may lead to a tip crash during Auto Approach!

In case you still need this low pass filter please reduce the **tip approach speed** accordingly.

Dual Mode

If required, the parameter values for gap voltage, feedback set and loop gain can be set differently, i.e. for the forward and backward directions of the scan line. The *Dual Mode* option can be activated in the context menu of the standard/alternative icon, see figure 66 on page 74. The alternative button is then switched active to allow access to both sets of parameters separately.

Note that the different parameters can be set to *Dual Mode* separately, as required by your experiment. The only exception is the tunnelling current range, because different settings here would require frequent recalibrations of the measurement data range.

Note also that the new parameter setting is always transferred directly to the electronics when activated. This also means that switching to the other mode while the scanner is moving instantly overrides the parameter setting.

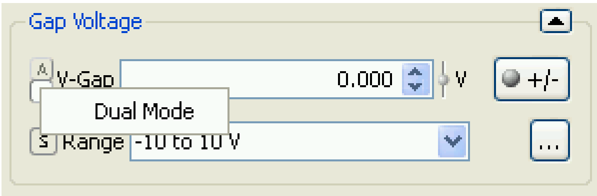


Figure 66. Dual Mode switch in context menu.

Attention

The gap voltage range can also be set differently for both scanning directions. Keep in mind, however, that range switching is done by relays in the preamp box. Different range settings with a fast scan lead to very frequent switching of these relays, which affects the lifetime of the preamplifier electronics.

If no measurement has been started only the forward parameters have effect on the electronics; upon starting a measurement both control fields take effect.

- Use the  buttons to switch between standard  and alternative  parameter settings.

In *Dual Mode* the additional parameters for line delay are useful for controlling the switching process between the two sets of scanning parameters in order to allow the MATRIX software to reconfigure the electronics systems reliably, see figure 67 on page 75. (Failing to set up delay times might result in parameter changes while the scan and data acquisition processes are active, yielding unwanted results.)

Figure 67. Line Delay control panel in *XY Scanner* window.

- The ***T-Fwd*** delay time interval will be applied at the beginning of each **forward** scan line before forward move and data acquisition but after the electronics has been set to the forward parameters in order to give the DACs and the feedback loop time to stabilise.

- The ***T-Bwd*** delay time interval will be applied at the beginning of each **backward** scan line before backward move and data acquisition but after the electronics has been set to the backward parameters in order to give the DACs and the feedback loop time to stabilise.

Notice

Omicron recommends configuring a scan line start delay time of approximately 500 µs to 1 ms.

Gap Control

- The *Gap Voltage* numerical value control sets the voltage bias applied to the tip or surface for STM measurements.

- A *Range* menu allows increasing the voltage resolution by reducing the range. In the –10 V to +10 V range the full gap voltage range is available. In the -1 V to +1 V range the gap voltage range is reduced at full DAC resolution (16-bit). Use the […] button to access the *Options* menu if you want to maintain the gap voltage (if possible) when switching ranges.

- Use the toggle switch to flip the gap voltage sign for an instant "flashing". The reverse gap voltage is applied while the button is pressed and the green light is on.

- *Slew Rate*: Tick the checkbox to define a slew rate to be used for gap voltage changes and enter the respective rate into the associated numerical value entry field. (If the box is unchecked, the gap voltage will be approached as fast as the analogue signal paths allow.) The rate value can range from 10 µV/s. to 10 kV/s.

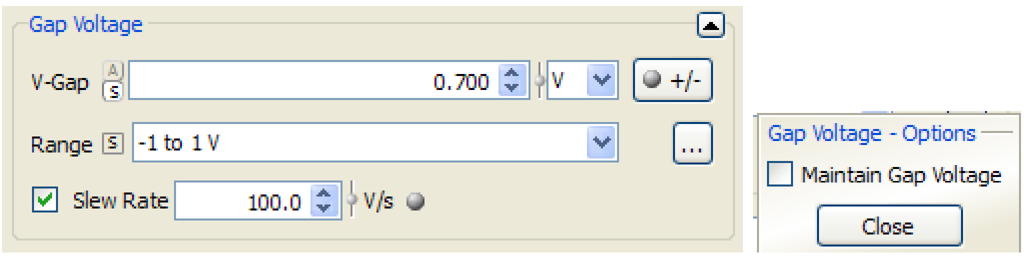


Figure 68. STM Gap control panel and gap voltage options.

Attention

When changing the bias sign (e.g. at a gap voltage of –1 V, the value of the parameter V-Gap gets changed to +1 V), the gap voltage will cross the zero volt level at the specified slew rate. If the Z-control feedback loop uses the tunnelling current as its input signal and the defined slew rate causes slow voltage changes, tip crashes might result!

Notice

While the gap voltage is being changed at the defined rate, an indicator element to the right of the slew rate numerical entry field will flash.

When the gap voltage preamplifier state gets switched any possible change of the actual gap voltage resulting from the state modification will be applied immediately, i.e. the specified voltage slew rate will be ignored in this case.

Gap Voltage Low Pass Filter

A low pass filter allows filtering the gap voltage after summation with an external input (V EXT). This can be useful to eliminate noise pickup from external sources. Note that the additional signal V MOD is added to the gap voltage signal after low pass filtering.

Figure 69. Gap voltage low pass filter.

PFU/SBB

Notice

The PFU/SBB panel is only active for systems with QPlus hardware. For more details please refer to section **QPlus with Additional PDC6DQ Board** on page 119.

Voltage Pulse

STM tip preparation on the sample is a routine procedure which has often to be performed with a new tip. Typical tip preparation methods include point spectroscopy and application of voltage pulses and Z-ramps. A voltage pulse can be applied using either the *Voltage Pulse* panel in the *Tip Conditioning* window or the mouse tool in the channel display.

To apply a pulse via the voltage pulse panel, set the pulse data using the provided numerical input fields for pulse height, voltage range and duration and click *Apply*.

Tick the *Feedback Loop* box to keep the feedback loop enabled during the pulse.

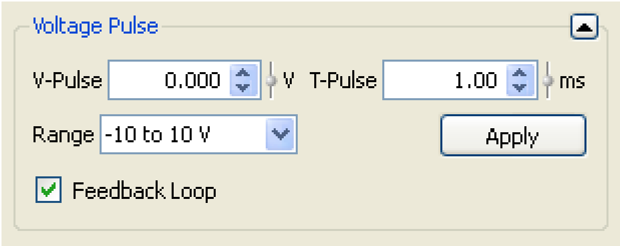


Figure 70. *Voltage Pulse* panel.

Notice

If you set different gap voltage ranges for Z-control and voltage pulse, pulse widths of less than one millisecond will not be supported due to hardware switching times. The MATRIX software will automatically extend the pulse width to one millisecond in this case.

In order to use the mouse tool (shortcut P):

- Select the relevant mouse tool in the channel display window.
- Click into the display area and drag the mouse to adjust the pulse shape.
- Release the mouse button to apply the selected pulse to the tip. The selected values will be transferred to the *Voltage Pulse* panel (see figure 70 on page 77) to allow applying an identical pulse later on.
- To abort pulse application after clicking inside the display area press ESC or release the mouse button outside the display area.

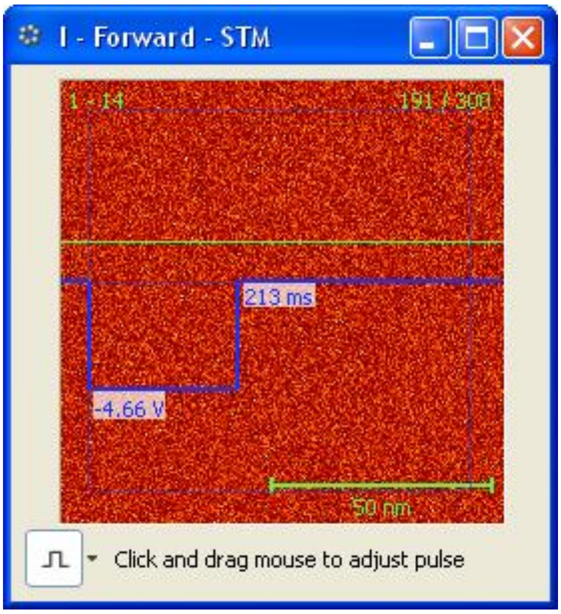


Figure 71. Voltage Pulse mouse tool.

Voltage Pulse Position

To apply a predefined voltage pulse at a specific location on the surface use the *Voltage Pulse Position* mouse tool (shortcut V).

Figure 72. Voltage Pulse Position mouse tool.

- Click in the channel display area to define a position where the pulse is applied immediately upon releasing the mouse button. Pulse settings are as defined in the *Voltage Pulse* panel.

Tip Preparation Z-ramp

A Z-ramp can be applied using the *Tip Preparation Z-Ramp* panel in the *Tip Conditioning* window together with the mouse tool in the channel display. Set the Z-ramp data using the provided numerical input fields.

- *Z-Ramp*: specify the Z-axis offset to be applied during the tip conditioning operation.

- *Slew Rate*: determines whether a dedicated slew rate shall be used for applying the Z-axis offset, as well as the slew rate value.

- *Delay*: specifies an interval for which the Z-axis displacement will be delayed. During this interval MATRIX will continuously sample the Z-axis position and use the average of all samples as the start value for the displacement operation (provided the feedback loop is active). If the feedback loop is disabled or the tip has been retracted the *Delay* parameter will be ignored.

- *Enable Pulse Voltage*: tick this box to apply the gap voltage (V-Pulse) defined in the voltage pulse panel for the duration of the Z-ramp.

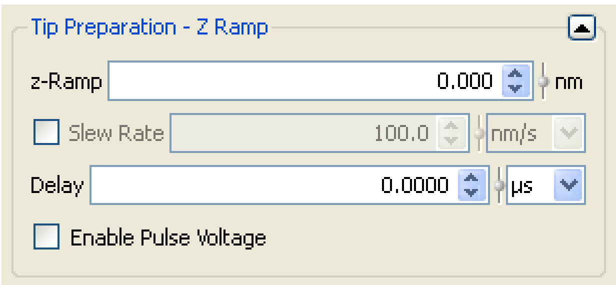


Figure 73. Tip preparation Z-ramp panel.

To apply a predefined Z-ramp at a specific location on the surface use the *Z-Ramp Position* mouse tool (shortcut Z).

Figure 74. Z-ramp Position mouse tool.

- Click in the channel display area to define a position where the Z-ramp is applied immediately upon releasing the mouse button. Ramp settings are as defined in the Tip Preparation Z-ramp panel.

- To abort Z-ramp application after clicking inside the display area press ESC before you release the mouse button.

AtMa - Atom Manipulation

Atom manipulation has long been one of the most ambitious projects in scanning probe microscopy. Manipulation of single atoms with a scanning probe microscope is made possible through the controlled and tuneable interaction between the atoms at the end of the probe tip and the single atom that is being manipulated. In STM the tunnelling junction is used for atom manipulation. Several interactions take place in here that depend on electrical potentials, tunnelling current and tip-adatom proximity effects.

The Atom manipulation process consists of several steps:

1. The scan process (if in progress) is interrupted and the tip moved to a defined start position.
2. The parameters for setpoint and gap voltage are changed as specified.
3. The tip is moved along the specified relocation vector to the defined end position.
4. The parameters for setpoint and gap voltage are changed back to the original values.
5. The tip is returned to where it stopped and the scan process will be resumed.

During steps 3 and 5 MATRIX monitors the feedback signal and displays the resulting data in the *Atom Manipulation* curve display.

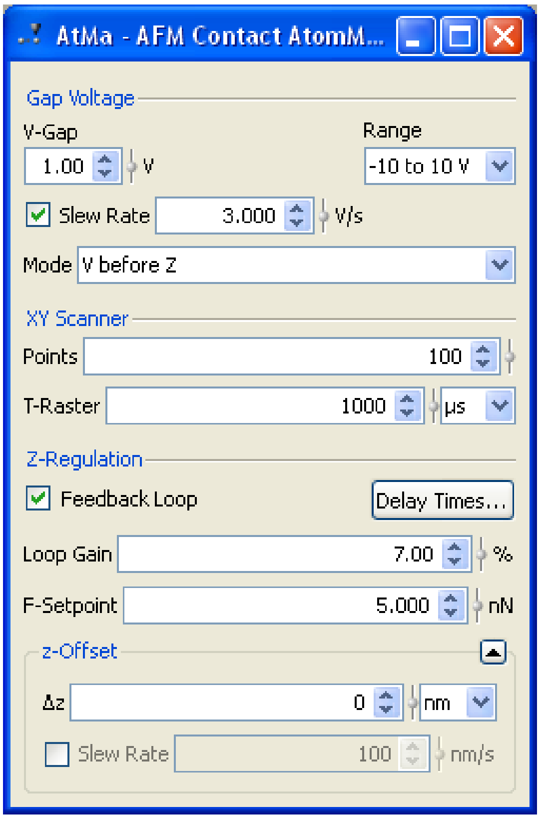


Figure 75. Atom manipulation.

Parameters

The following parameters can be set differently for the duration of the Atom Manipulation procedure:

- The Z-offset of the tip and the related slew rate for approaching the alternative value.

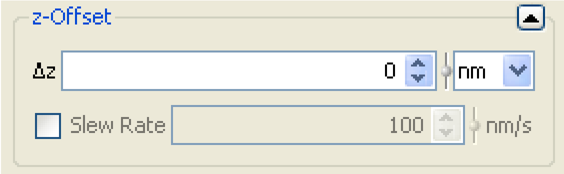


Figure 76. AtMa Z-offset panel.

- The gap voltage along the relocation vector as well as the slew rate for approaching the new gap voltage

Figure 77. AtMa Gap Voltage panel.

- The sequence for changing gap voltage and Z position

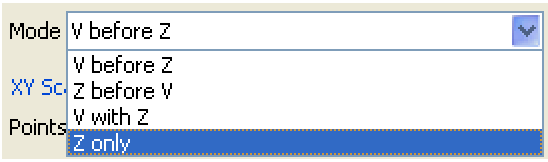


Figure 78. Atom manipulation modes.

- The number of points and the raster time along the relocation vector. Note that the resulting scan speed depends on the length of the relocation vector in the channel display.

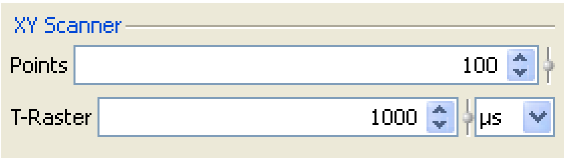


Figure 79. AtMa XY Scanner panel.

- The feedback loop settings along the relocation vector. In STM mode we recommend keeping the feedback loop on. In non-contact mode the tip relocation may significantly upset the feedback system, so you may prefer to switch it off.

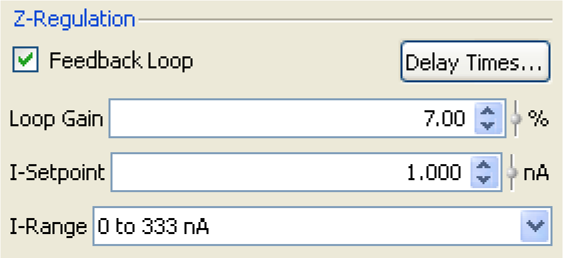


Figure 80. AtMa Z-Regulation panel.

- The *Delay Times* parameters specify waiting times which allow the feedback loop to settle after the feedback loop parameters have been changed in the course of the atom manipulation process. Without this delay time the change of the junction conditions inducing the atom manipulation process cannot be executed entirely at the location of the start marker but would take effect somewhere along the relocation vector.

Atom Manipulation Procedure

- Open the Atom Manipulation experiment and start scanning as usual.

- In the *AtMa* window check or modify the settings as detailed above.

- In one of the channel displays select the atom manipulation icon from the drop-down menu (shortcut M).

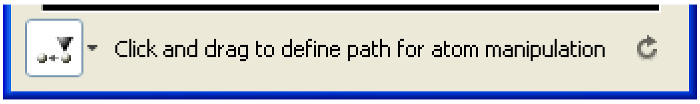


Figure 81. Atom manipulation mouse tool in the channel display.

- You may choose to perform the atom manipulation procedure during scanning or stop the scan manually first.

- With your left mouse button mark a feature, hold the mouse button down and drag the mouse to specify the relocation vector. The manipulation operation is initiated by releasing the mouse button. Click ESC with the mouse button still pressed to abort the process immediately.

- Using the icon at the right hand side of the mouse tool an atom manipulation operation can easily be repeated.

- Note that MATRIX will keep the actual vector plus the latest three previous vectors visible in the channel display for reference.

Atom Manipulation with Z-Profiling

MATRIX also supports a dedicated two-pass scan technique referred to as Z-profiling that can be used with atom manipulation operations and is supported by all experiments providing the atom manipulation facility. When enabled, Z-profiling will alter the sequence of actions during an atom manipulation operation; specifically, the following steps will be performed:

- The probe gets transferred to the marked feature.
- The probe moves along the specified relocation vector with the feedback loop enabled and recording topography information.
- The probe is returned to the marked feature.
- The experiment parameters are changed to the specified values.
- The probe moves along the relocation vector specified with the feedback loop disabled, using the topography information recorded during the first pass.
- At the target location, the experiment parameters will be changed back to their original values.
- The probe gets transferred to its original location.

You may specify whether the Z-profiling option will be used during an atom manipulation operation by simply selecting the appropriate "mouse tool" from the tools menu of an image display, see figure below.

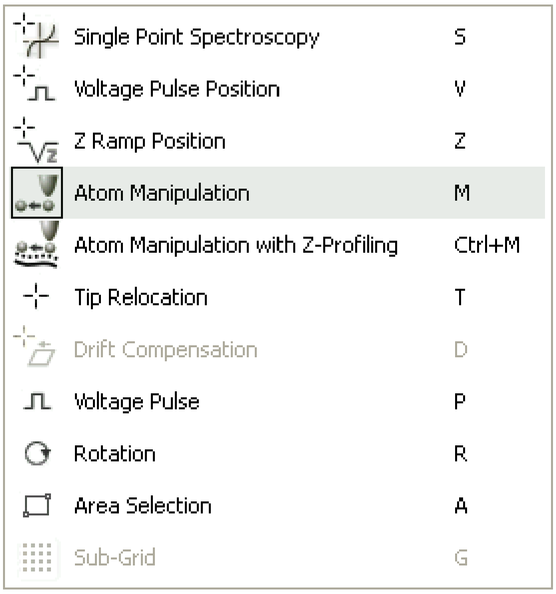


Figure 82. Atom manipulation channel display menu.

Tip Relocation Mouse Tool

To move the tip to a different location within the scan field use the tip relocation mouse tool (shortcut: T). This feature can be used to park the tip at a safe location.

Figure 83. Channel display tip relocation mouse tool.

During scanning

- Click the desired new position and the tip will immediately move there (with the speed defined by the raster time setting in the *XY Scanner* window) and stay at this position (no data acquisition) until recalled or until the scan is stopped.

- Click the *Recall* button to return the tip to its previous position and resume scanning (and data acquisition).

- If you stop the scan with the tip parked, it will move to its default start position, i.e. the beginning of the first scan line. In this case, data acquisition will not resume.

With the scan stopped

- Click the desired new position and the tip will immediately move there (with the speed defined by the raster time setting in the *XY Scanner* window) and stay at this position until recalled.

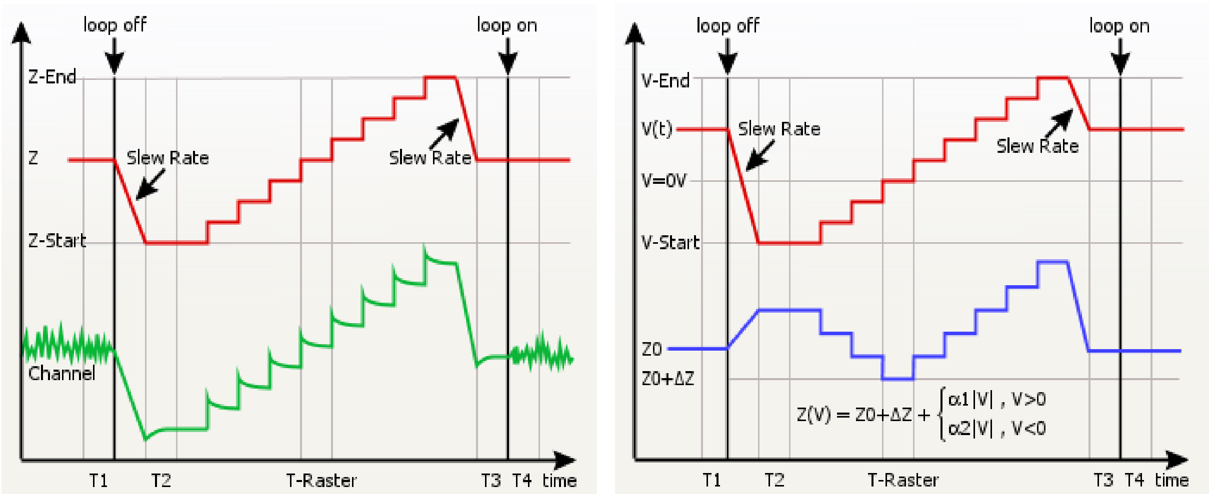
- Click the *Recall* button to return the tip to its previous position, i.e. the beginning of the first scan line. Alternatively click  or  for the same behaviour.

5. A Spectroscopy Experiment

Data acquisition for a spectroscopy curve is very similar to topography data acquisition: an independent **axis** (e.g. voltage V or tip-sample separation Z) is modified while a measurement **channel** takes data at specified "bus stops". In the same way the movement along the axis is specified by parameters, e.g. "points". The following table shows the similarities and differences between the modes.

	Topography	**Spectroscopy**
Axis	X, Y	V, Z
Channel	I, Z, Aux1, Aux2	I, FN, df, Aux1, Aux2
Signal	I(X,Y), Z(X,Y), Aux(X,Y)	I(V), I(Z), df(V), Aux(V)
Points	points, lines	points
Raster time	T-Raster (= initial delay + acquisition time)	T-Raster (= initial delay + acquisition time)
Axis range	width, height	start, end

Table 3. Comparison of parameters spectroscopy versus topography.



V-spectroscopy and Z-spectroscopy   Varied-Z-spectroscopy

Figure 84. Spectroscopy, delay and acquisition times, schematic diagram. Note that for Z-spectroscopy the left diagram has the vertical axis labelled with Z instead of V but is otherwise identical.

Delay times are necessary to achieve stable conditions at the beginning and end of every spectroscopic curve, see figure 84.

Notice

Selecting too many spectroscopic measurements can slow the scan down significantly. Example: taking I(V) curves for every raster point using the default settings in the program a scan may take 4 to 5 minutes (and produce a huge amount of data).

Spectroscopy Modes

The Experiment Element *Spectroscopy* supports the utilisation of two arbitrary ramp devices within a single experiment. The most obvious use of this capability is the combination of V- and Z-spectroscopy operations. The predefined experiment "STM_Spectroscopy" thus configures an instance of the Spectroscopy element in a way you can use these spectroscopy variants from within the same experiment. Key features of the spectroscopy experiment are:

- Single point spectroscopy operations of either type V or type Z can be initiated from within the same experiment. These can also be run as a series of single point spectroscopy operations along a pre-defined vector.
- In raster spectroscopy mode, the type of spectroscopy operations performed during the "forward" direction of a scan line sweep can be different from the spectroscopy type performed during the "backward" sweep.
- As the two ramp devices may also be used simultaneously, combined spectroscopy operations can be performed, such as the V-spectroscopy with synchronously varied tip/sample separation, also called *Varied Z spectroscopy*.

Varied Z Spectroscopy

MATRIX provides support for V-spectroscopy operations with variable gap, also referred to as V-spectroscopy with synchronously varied tip/sample separation or varied-Z-spectroscopy. Using this option can be particularly useful for increasing the sensitivity for very small currents when studying certain materials.

From the MATRIX perspective, this option is a variant of the standard V-spectroscopy mode where the Z-position of the probe is varied synchronously with respect to the V-ramp.

Figure 85 on page 85 depicts the principle of a spectroscopy operation with synchronously varied tip/sample separation.

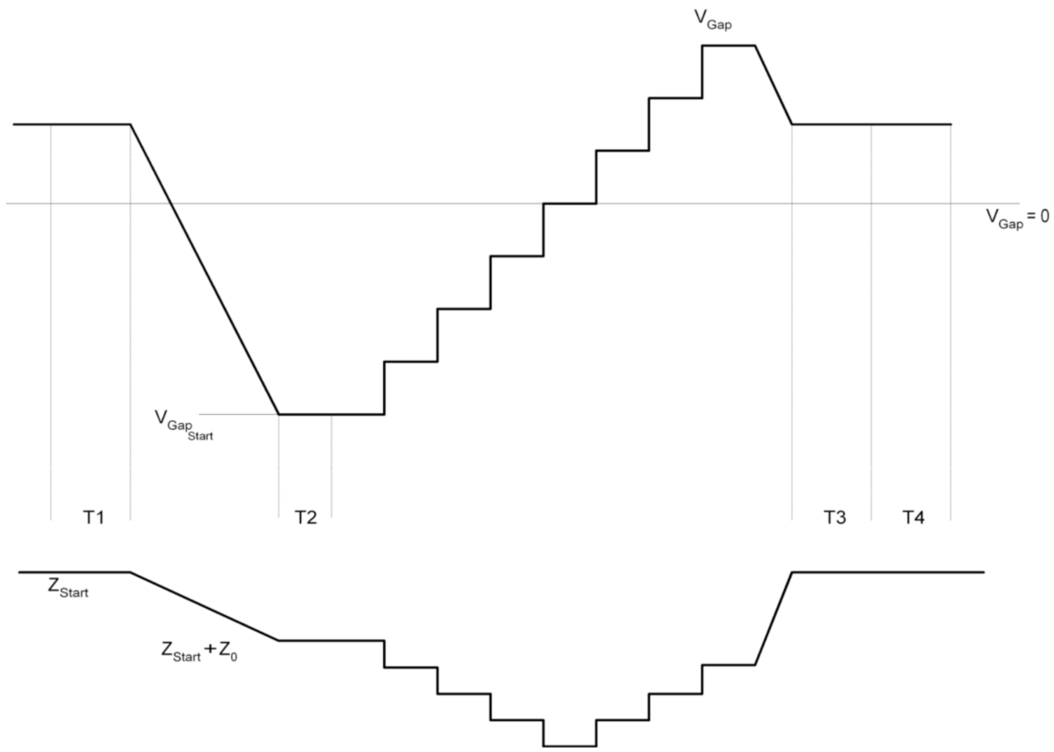


Figure 85. Varied Z spectroscopy principle of operation.

The relation between the gap voltage and the Z-position can be expressed by the following formula:

$$Z(V) = Z_0 + \Delta Z \quad + \begin{cases} \alpha 1 \cdot |V|, V > 0 \\ \alpha 2 \cdot |V|, V < 0 \end{cases}$$

Alternate Spectroscopy Mode

When enabled, a different spectroscopy mode can be selected for the backward sweep. If you want the same mode with different parameters for the backward sweep we recommend that you activate the alternate switches (Dual Mode) on the respective tab and keep this option disabled.

Note that if you activate both, the alternate mode and alternate parameters within the modes, only the standard parameters of the forward mode and the alternate parameters of the backward mode will actually be applied.

Basic Procedure for I(V) Spectroscopy

- The tip moves to the specified sample location for the first I(V) curve. It uses the parameters set for lateral movements in the *XY Scanner* window and has the feedback loop on during this process.
- Having reached the location the tip waits for a specified time **T1** with the feedback loop still on, see figure 84 on page 84. This waiting time takes account of possible piezo creep.
- After T1 the feedback loop is switched off and the parameter for the first spectroscopy measurement is set at the specified **slew rate** in order to avoid overshooting. The feedback loop stays off until after T3.
- Another waiting time **T2** ensures stable conditions before taking the first measurement.
- After T2 the first data point is acquired after a delay time (initial delay) and with the specified oversampling, see figure 86 on page 87. The **initial delay** ensures a stable tunnelling current after the gap voltage change.

Notice

The feedback loop can be set to stay active throughout the spectroscopy procedure, see page 91 for details.

Times **T1 to T4** are applied before and after each I(V) curve while the **initial delay** is applied before every single data point within a curve.

- A data point is taken as a number of different single measurements and averaging over the result. The number of single measurements per data point can be selected using the parameter **oversampling factor** accessible from the channel list, see figure 21 on page 36.

$$\text{data point} = \frac{\sum_{1}^{\text{oversampling factor}} \text{single measurement}}{\text{oversampling factor}}$$

- A single measurement takes a fixed time of 2.5 micro seconds.
- The next data point is taken after one raster time, see also figure 86 on page 87. Consequently, the raster time must be longer than the combination of initial delay and data acquisition time, i.e.

$$\text{raster time} > \frac{\text{oversampling factor}}{400\,\text{kHz}} + \text{initial delay}$$

- In Auto Oversampling mode (default) the software ensures that this requirement is adhered to. We recommend to always set the raster time first. With Auto Oversampling disabled an auto correction function during input makes sure that all times are correctly matched.
- After taking the last data point of the spectroscopy curve the gap voltage is returned to the value specified in the *Gap Voltage Control* window, again with the designated **slew rate**.
- After reaching the gap voltage the software waits for a time T3 before switching the feedback loop back on and a time T4 after that to ensure stable feedback conditions before resuming the normal scan.

Attention
Always check the low pass filter settings before starting a spectroscopy scan.

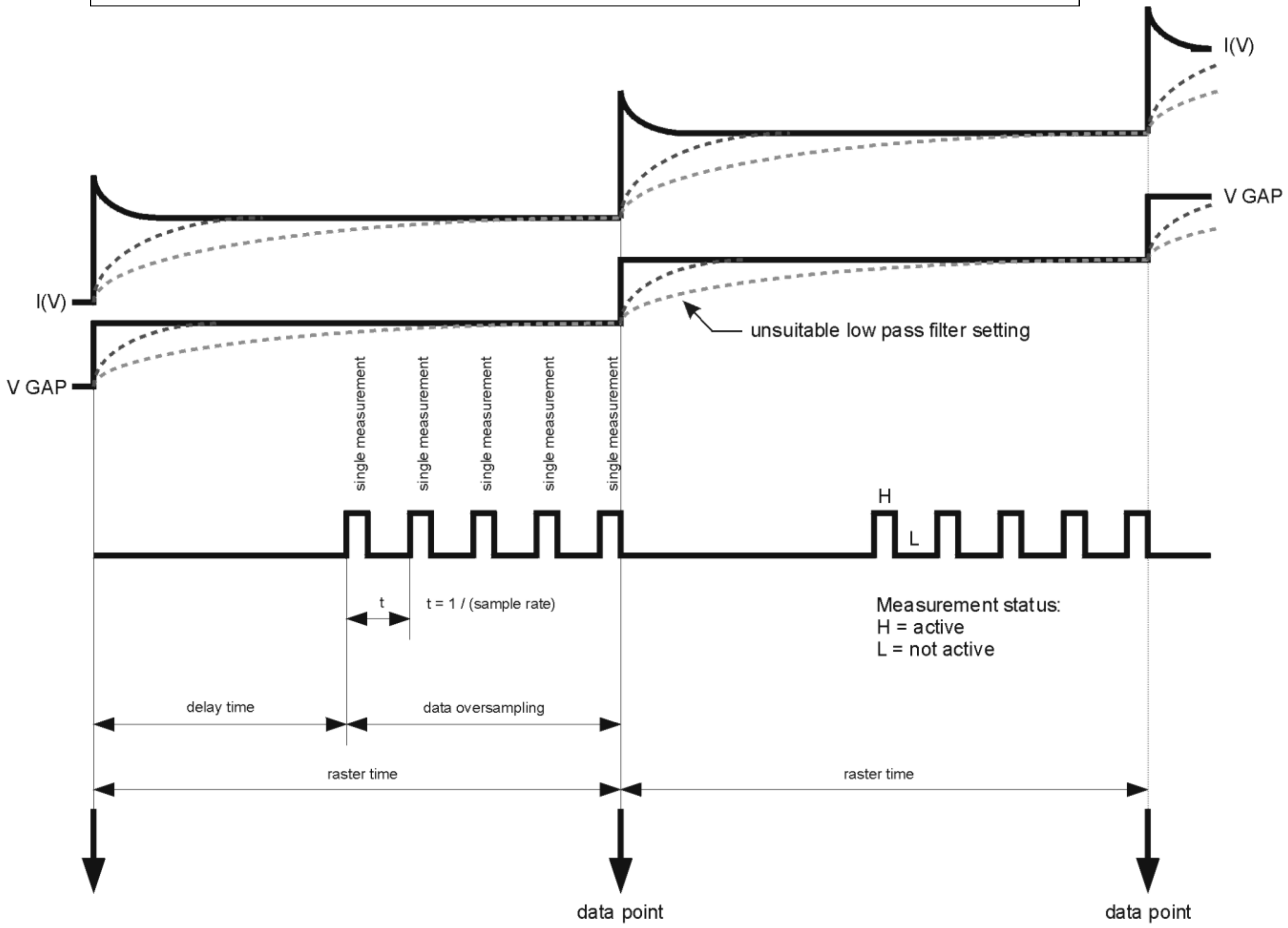


Figure 86. Spectroscopy data acquisition and oversampling.

Spectroscopy Controls

The *Spectroscopy Settings* window offers a number of control options for your spectroscopy experiment.

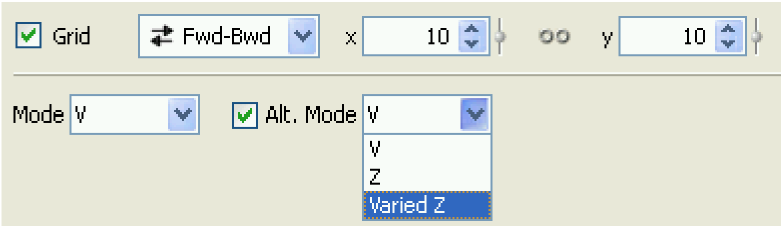


Figure 87. Spectroscopy mode control.

Grid

Ticking the checkbox *Grid* will cause an experiment to execute spectroscopy operations at each point on a specific sub-grid of the scan raster. Note that this checkbox is only accessible with the scan process stopped. When the checkbox has been cleared, the mouse tools for initiating single point spectroscopy operations will become selectable, and raster spectroscopy operations are disabled.

Next to checkbox *Grid* additional controls can be found. Use the two numerical value entry fields labelled x and y to configure the sub-grid for raster spectroscopy operations; the lowest value supported by both fields is 1.

- Grid spectroscopy will be performed at a regular subset of the raster points.
- x: N specifies that a spectroscopy measurement will be done at every N-th point of a line.
- y: M specifies that a spectroscopy measurement will be done in every M-th line. The first spectroscopy location is always the first data point of the frame.
- Setting both fields to 1 will cause a spectroscopy operation at every raster point on the scan grid.

In addition, the direction control element determines during which part of a scan sweep the configured sub-grid will be applied. Depending on the selected option the system will execute raster spectroscopy operations:

- During the forward part of a scan sweep only.
- During the backward part of a scan sweep only.
- During either part of a scan sweep.

Single Point Spectroscopy

The Single Point Spectroscopy option is always available when the raster spectroscopy mode has been disabled; you can select the type of spectroscopy (V, Z, or Varied-Z) in any experiment state then.

Figure 88. Channel display Single Point Spectroscopy mouse tool.

During the scan first select the single point activation mouse tool (shortcut S) and then click a location in any of the topographic channel displays to start the following procedure:

- Stopping the scan (if in progress) and memorising the current position.
- Moving the tip to the selected spectroscopy location.
- Performing the spectroscopy measurement as specified in the Spectroscopy *Settings* window and displaying the result in the corresponding channel display(s).
- Returning the tip to the memorised position and resume scanning (if applicable).

Notice

Single point spectroscopy operations are Dual Mode-aware, i.e. the spectroscopy parameters that will be utilised actually depend on the direction of the scanner movement at the time the operation was initiated or "re-applied".

Line Spectroscopy

The single point spectroscopy can also be run a series of single point spectroscopy operations along a pre-defined line. This might be useful when you plan to align the spectroscopy measurement locations e.g. to periodic features in the image. Use the image display mouse tool *Spectroscopy at Line* (shortcut Ctrl + L) to activate a numerical value entry field at the bottom of the respective image display. Here you can specify the number of spectroscopy operations per vector, allowed values range from 2 through 1000.

Notice

This mouse tool is only available when the raster spectroscopy mode is disabled. The details of the spectroscopy measurement itself like e.g. parameters of the voltage ramp, are defined in the *Spectroscopy* window.

By clicking and dragging the mouse over the display region you can now specify a vector. The vector can be relocated by dragging the start or end point of the vector with the left mouse button pressed.

Notice

Pressing the Esc key while dragging the vector will cancel the definition process.

Once you finished the position alignment and settings you can trigger the spectroscopy process by clicking the start button in the lower right corner of the window. The scanner will then move to the starting point of the vector and a spectroscopy measurement is applied. After that the other positions are sequentially approached. The progressing line spectroscopy operation is visualised by highlighting the points green that have already been processed.

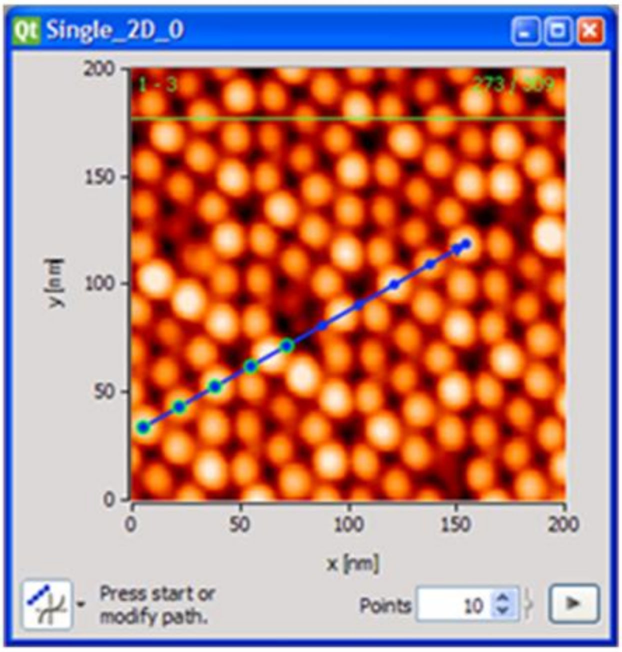
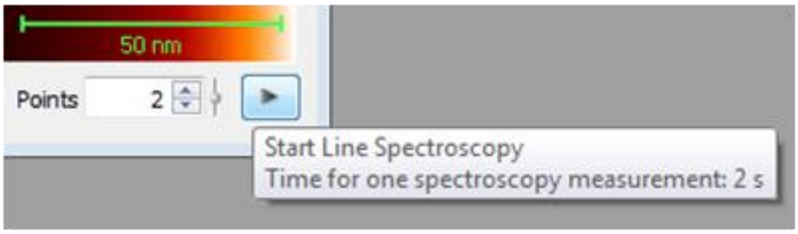


Figure 89. Channel display Spectroscopy at Line mouse tool.

After finishing the last spectroscopy operation at the end point of the vector, the scanner moves back to its initial position or it continues the raster scan operation if it was started before.

Notice

- To specify the scanner velocity when approaching the first spectroscopy location and between the spectroscopy locations along the vector refer to the Move Speed control in the *Scanner* window.
- When hovering the start button a tool tip shows the estimated time for one single spectroscopy measurement.



Spectroscopy Modes

The various controls on the tabs can be used for configuring spectroscopy operations, but the type of spectroscopy operation that will actually be executed in raster mode or single point mode is determined by the Mode selector.

To change the type of spectroscopy operation with respect to the scan direction, you can enable the Dual Mode for spectroscopy operations by checking the *Alt. Mode* checkbox. MATRIX will then run the type of spectroscopy operation determined by the Mode selector during the forward part of a scan sweep, and the type of operation determined by the *Alt. Mode* selector during the backward part of a scan sweep.

Spectroscopy Options

Click the ellipsis-labelled button [...] to the right of the mode selector controls to open the *Spectroscopy Options* window.

Feedback Loop

During the acquisition of a spectroscopy curve the feedback loop is normally switched off. With the feedback loop box empty the software will take care of this. If you want the feedback loop to stay active during spectroscopy, tick this box.

Since the feedback loop is normally switched off when taking a spectroscopy curve, drift may become a severe problem. It may therefore be desirable to take the tip a short distance away from the surface using Z-offset in the *Z-Regulation* window before starting spectroscopy.

Notice

The feedback loop state option affects V-spectroscopy operations only. For Z– or "varied Z"-spectroscopy operations, the feedback loop will always be disabled, regardless of the state of the feedback loop checkbox.

If Z– or "varied Z"-spectroscopy operations are applied as part of a Dual Mode experiment, the feedback loop will also be disabled, even if the standard or alternate mode has been set to V-type spectroscopy.

Intermediate Feedback Loop

If *Repetitions* in figure 93 on page 95 has been set to a number greater than one you can decide whether the feedback loop should be on or off between repetitions. Switching the intermediate feedback loop on can help to stabilise the tip position.

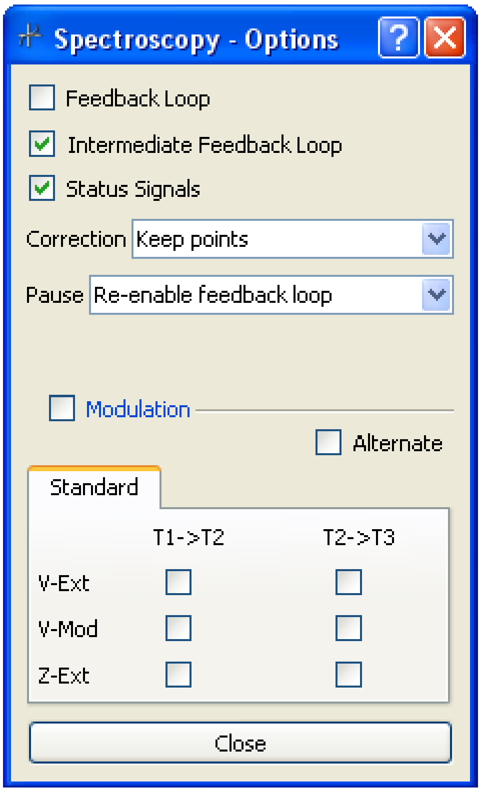


Figure 90. *Spectroscopy Options* window.

Status Signals

Status signals are dedicated digital TTL signal outputs (at the trigger port of a CRTC board) during the various phases of a spectroscopy operation. Users may choose to enable or disable the generation of TTL signals during spectroscopy operations. Disabling signal output is useful if no external electronics needs to be triggered, as switching the signals will cause additional (although short) latency times. The default setting is signal generation enabled

Table 4 below summarises the TTL signals generated during a spectroscopy operation.

Signal #	Pin #	Description
0	24	HIGH during delay period T1, LOW otherwise
1	8	HIGH during delay period T2, LOW otherwise
2	25	HIGH while spectroscopy ramp is driven, LOW otherwise
3	9	HIGH during delay period T3, LOW otherwise
4	26	HIGH during delay period T4, LOW otherwise

Table 4. TTL signals generated during a spectroscopy operation

Correction Strategy

MATRIX will adapt either the number of points or the start and end values if the desired number of points cannot be distributed evenly within the specified limits of the spectroscopy curve.

- Enabling the option *Keep points* will cause the MATRIX software to adapt the start or end value chosen for the spectroscopy ramp in case the number of ramp points configured cannot be distributed equidistantly between the start and end value. For most experiments, this strategy is the option of choice. It does not require any additional input.

- The option *Maximise points* prevents the software from modifying the start or end value of the spectroscopy ramp but causes an automatic adjustment of the ramp points instead: The number of points will be set to the maximum number that still can be distributed equidistantly across the ramp. The upper limit for this operation can be set with Max.Points on the respective spectroscopy tab.

Notice

As altering the number of ramp points is not supported during a progressing spectroscopy experiment (or as a result of a Dual Mode operation), the MATRIX software will implicitly utilise the Keep Points option while an experiment is in state Running or Paused, or when the spectroscopy ramp is subject to Dual Mode operations.

Tip

To change the value of Max. Points select Correction = Maximise Points in the *Spectroscopy Options* window.

Behaviour Upon Pause

The Pause mode selector determines the system behaviour in case an experiment is paused while a spectroscopy operation is in progress. In this case, the software will either finish the ongoing spectroscopy operation before actually pausing the experiment, or interrupt the operation immediately (which might cause the experiment to halt with the feedback loop disabled). Alternatively, users may choose to direct the system to interrupt a progressing spectroscopy operation but automatically re-enable the feedback loop afterwards.

Note that the default spectroscopy experiment set-up will utilise option "Re-enable feedback loop".

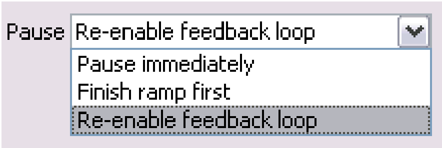


Figure 91. Pause conductance drop-down field.

- **Re-enable feedback loop** — When stopping an experiment while a spectroscopy operation is in progress, the MATRIX software will terminate the operation immediately and return the gap voltage (or Z-axis position, respectively) to the initial value – i.e. the value that was effective before the spectroscopy operation started –, taking the configured slew rate into account. Afterwards, the feedback loop (if disabled) will be re-enabled.

- **Pause immediately** — The spectroscopy operation is halted immediately and will continue when the experiment execution is resumed. As the feedback loop might have been disabled, this option should be used only in situations where thermal drift effects can be neglected, otherwise a tip crash might be the result.

- **Finish ramp first** — An ongoing spectroscopy operation will be finished before the experiment actually enters the state "Paused". This option ensures that the feedback loop is enabled while the experiment pauses; on the other hand it will silently delay the requested state transition by the time the system requires to finish the spectroscopy operation.

Attention

Opting to finish an ongoing spectroscopy operation before actually pausing is not recommended when using large spectroscopy raster times, as it is difficult to recognise when the progressing operation has finished in fact.

Although the user interface will indicate a paused experiment immediately, the current spectroscopy operation might still be progressing "in the background". Make sure that the operation has actually been completed before changing spectroscopy parameters or resuming the experiment.

Omicron discourages to continue a spectroscopy experiment that has been requested to pause but has not reached this state due to a progressing spectroscopy operation.

Modulation

The lower part of the *Spectroscopy Options* window contains controls for manipulating certain modulation input signals. Dedicated checkboxes allow enabling or disabling the signals V MOD, V EXT, and Z EXT during the initial relaxation phase and during the acquisition phase of a spectroscopy operation. In addition, the Alternate checkbox and tab allow specifying the status of these signals during Dual Mode operations.

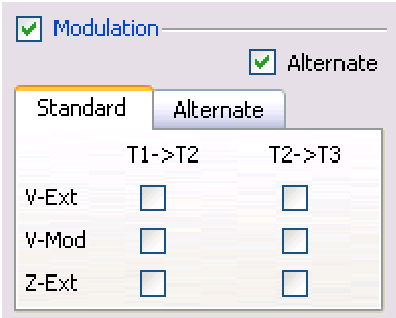


Figure 92. Modulation controls for input signals.

T1->T2 Enable or disable the external signal in the time interval between the beginning of interval T1 and the beginning of interval T2, see figure 84 on page 84.

T2->T3 Enable or disable the external channel in the time interval between the beginning of interval T2 and the beginning of interval T3 (i.e. including slew rate relaxation), see figure 84 on page 84.

Note that no tick in one of these boxes means that the respective input signal is explicitly switched off for this interval, even if the signal is generally switched on. For further details on external inputs please refer to page 32.

> **Notice**
>
> **Z EXT Low-Pass Filter Caveat**
>
> Be aware that changing the cut-off frequency of the Z EXT input signal low-pass filter causes significant peaks in the output signal Z OUT controlling the Z-axis position. As a result, when using n-type scanner equipment, the probe/sample distance will spontaneously decrease significantly, probably causing a tip crash.
>
> To prevent potential tip crashes, the Z EXT input signal state should not be changed when the probe is in close proximity to the sample; in this case neither change the cut-off frequency of the associated low-pass filter, nor enable or disable the signal manually or by means of the signal modulation support for spectroscopy operations.

Spectroscopy Curve Options

For the axis specify the following parameters :

- The **variation limits**, i.e. the first and last value of the independent parameter.
- **Range (V-spectroscopy only)**: A drop-down menu allows increasing the voltage resolution by reducing the range. In the -10 V to +10 V range the full gap voltage range is available. In the -1 V to +1 V range the gap voltage range is reduced at full DAC resolution (16-bit). Note that the preamplifier voltage range setting can be different during spatial scanning and spectroscopy sequences; in addition, the range setting can be manipulated when in Dual Mode.
- The **number of data points** of a spectroscopy curve, for possible values see table 5 on page 96 (watch memory usage).
- The **T-Raster** is the time distance between two adjacent data points within a spectroscopy curve, for possible values see table 5 on page 96.

- **Repetitions:** enter the number of repetitions for every spectroscopy execution (single point spectroscopy only). Repeated curves will be saved separately. The maximum number of repetitions is 2 billion.

- **Ramp reversal:** if checked the configured ramp will be driven again with reversed parameters after the original ramp is finished.

- **Slew rate**: ramp speed for changing the independent parameter (e.g. V-Gap) from its default value to the first spectroscopy value and after the last spectroscopy value back to its default value.

- **Step slew rate**: the ramp speed for individual voltage steps. When the ramp step slew rate results in a longer duration than the configured raster time MATRIX will issue a parameter inconsistency warning.

- **Max points**: Specify the maximum number of points that MATRIX tries to approach if the correction strategy in the *Spectroscopy Options* window has been set to Maximise Points, see page 92. Note, that a large number of data points may drastically increase result file sizes and memory usage.

- **Delay**: delay time for stabilisation/averaging of the Z-value before starting a spectroscopy curve (in addition to T1).

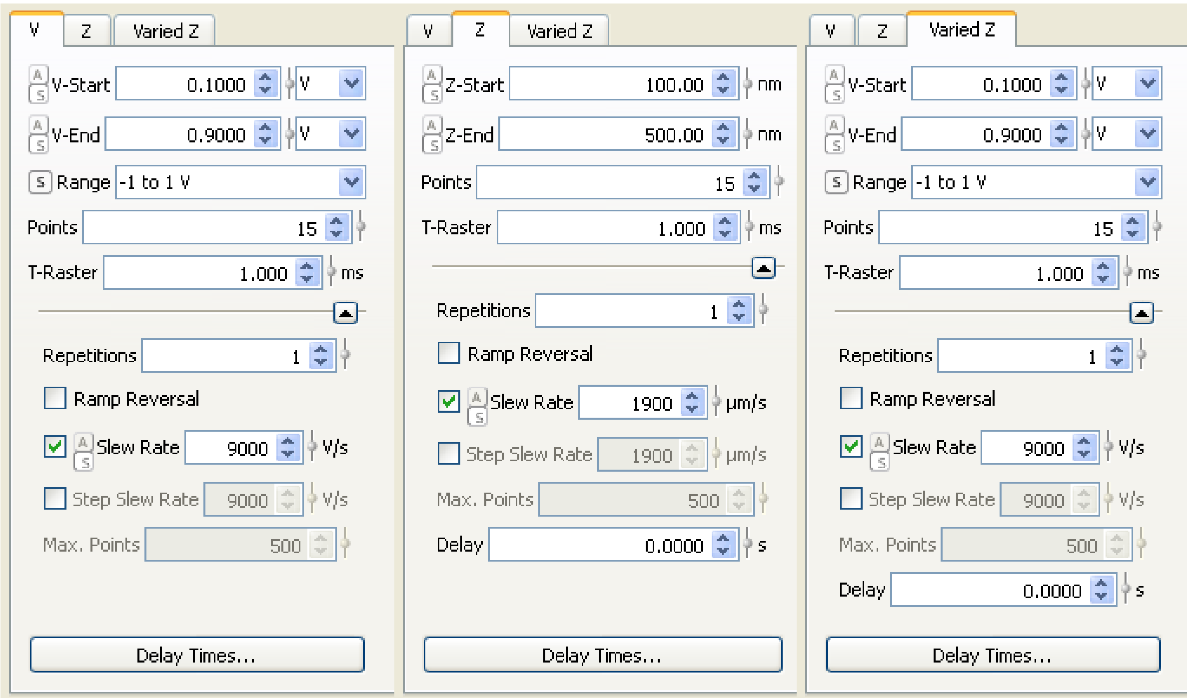


Figure 93. Spectroscopy curve control.

The feedback loop will automatically be switched off and on as indicated in figure 84 on page 84.

	Min	Max
Initial delay	0	1 s
Sample Count	0/s	7.6 Mio/s *
T-Raster	20 µs V/Z, 75 µs Varied Z	19 s
T1 to T4	0	10 s
Slew rate	0	10 000 V/s (20 000 µm/s)
Number of points	2	4096 (grid), 1048576 single point
Voltage range	-1 V or –10 V	+1 V or +10 V

Table 5. Spectroscopy settings min/max values. *) Note that the sample count maximum depends on the settings of initial delay and raster time.

Varied Z Parameters

- **Δz:** enter a Z-Offset value to define a Z displacement start value corresponding to V-Start value of the ramp, see figure 84 on page 84. (Positive Z values increase, negative Z values decrease gap width.) The Z displacement will be approached with the specified slew rate.

- Factors **a1 and a2** in the *Varied Z* window are the conversion factors between V and Z (These parameters are the factors $\alpha 1$ and $\alpha 2$ in the conversion formula as seen in the visualisation and on page 86.)

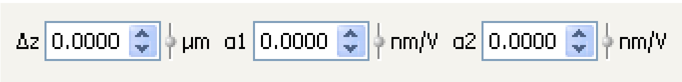


Figure 94. Special parameters for Varied Z mode.

Delay Times

The button *Delay Times* gives access to a number of additional parameters for the spectroscopy process. All parameters are indicated in the graphical representation, see also figure 84 on page 84.

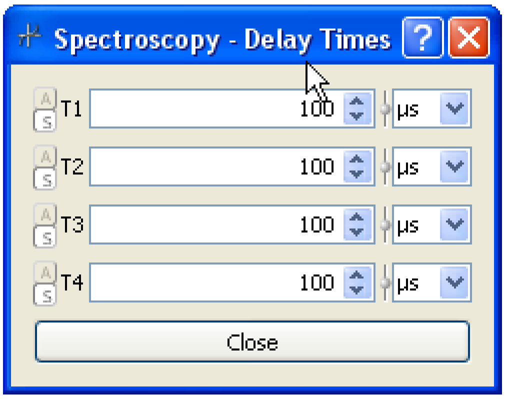


Figure 95. Spectroscopy curve delay times.

- **T1**: additional delay that will be applied before each spectrum, before the feedback loop is switched off and the initial parameter step is done.

- **T2**: additional delay that will be applied after the initial parameter step before the spectrum is taken.
- **T3**: additional delay that will be applied after the final step before the feedback loop is switched on again.
- **T4**: additional delay that will be performed after the feedback loop has been switched on after the spectrum and before the tip continues to move.

Gap Preset Options

Every STM spectroscopy data acquisition operation can optionally be preceded by a phase during which certain parameters determining the characteristics of the tunnelling gap can be set to dedicated values for the subsequent spectroscopy operation. This functionality is referred to as **Gap Preset** and can be switched on or off at the bottom of the *Spectroscopy* window, see figure 97 on page 98.

During the Gap Preset phase the following parameters can be modified:

- Gap voltage, gap voltage pre-amplifier range state and gap voltage value approach slew rate.
- Feedback loop characteristics, including tunnelling current setpoint, feedback loop gain and tunnelling current pre-amplifier range setting.

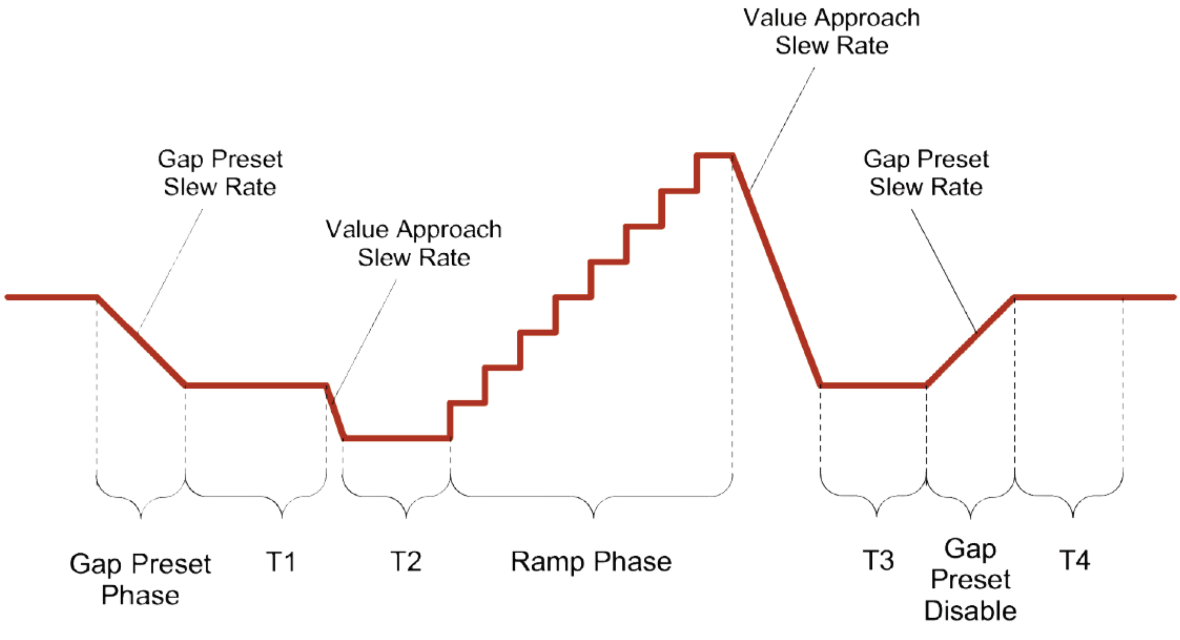


Figure 96. Spectroscopy time scale including gap preset.

As shown in figure 96, these parameters will be modified before the spectroscopy delay period **T1**, and reverted to their original settings before the spectroscopy delay period **T4**.

To configure the Gap Preset phase select a modification strategy from the drop-down list and set the respective parameters in the pop-up menus.

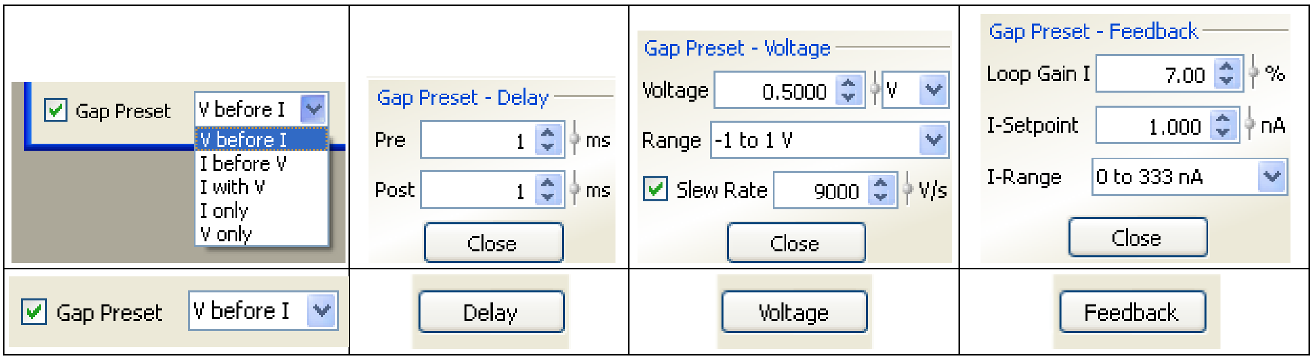


Figure 97. Gap preset options in spectroscopy experiments.

The following modification strategies are available

- **V before I** — modify both, gap voltage-related and feedback loop-related parameters; change the gap voltage-related parameters *before* modifying the feedback loop characteristics.
- **I before V** — modify both, gap voltage-related and feedback loop-related parameters; change the gap voltage-related parameters *after* modifying the feedback loop characteristics.
- **I with V** — modify both, gap voltage-related and feedback loop-related parameters, simultaneously.
- **I only** — modify the feedback loop-related parameters only.
- **V only** — modify the gap voltage-related parameters only.

The *Delay* button allows two dedicated delay times for the Gap Preset option to be set:

- The **Pre** delay time defines how long the start of the regular spectroscopy operation will be deferred after the feedback loop-related parameters have been changed, allowing the Z-control to settle.
- The **Post** delay time defines how long the system shall pause after re-establishing the original feedback loop configuration at the end of a spectroscopy operation.

Please note that the Pre and Post delay parameters will only be applied if the feedback loop characteristics modification is actually part of the Gap Preset operation, i.e. any other option than V only has been selected.

The *Voltage* button gives access to the following voltage preset options:

- Gap voltage and gap voltage range. (For more information on gap preset options please refer to page 75.
- Slew rate, i.e. the "speed" of the voltage change.

The *Feedback* button gives access to the following feedback loop options:

- Loop gain, setpoint and range. For more details on feedback controls please refer to page 66.

6. The AFM Contact Project

Notice

From MATRIX version 3.0 we support two different types of AFM hardware:

- AFM CU II
- AFM-SPU

Although the two variants work very differently "under the bonnet", from the GUI point of view all contact mode procedures are the same.

The AFM Contact Project is opened from the main window, see figure 4 on page 18, using the  icon. It provides a complete set of GUI controls for AFM contact mode measurements and does not require the STM Project to be open or even present.

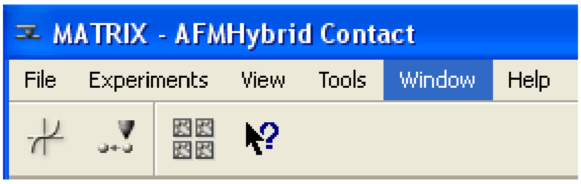


Figure 98. MATRIX – AFM Contact project window controls.

The AFM Contact Project provides the following Experiment:

 AFM Spectroscopy

 AFM Atom Manipulation

Note however, that many components are very similar or identical to those of the STM Project, e.g. Regulator, Scanner and Channel displays. In this chapter we will therefore only describe the AFM contact specific GUI panels.

AFM Sensor Alignment

The *AFM Sensor Alignment* window provides controls for the light source and offset adjustment.

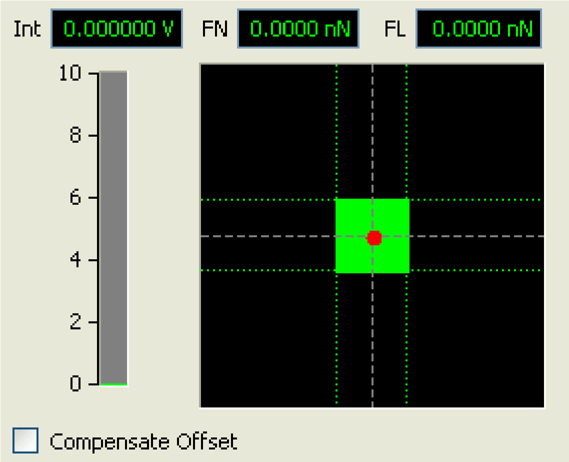


Figure 99. The AFM Sensor Alignment GUI, contact mode variant.

Force Display

The Force Display illustrates the normal and lateral force (F_N and F_L) values and serves for mirror adjustment. The adjustment is correct when the red spot is near the centre (centre box turns green). For further information on the beam deflection method please consult your SPM head user's guide.

Numerical Values

Three numerical values are presented above the display field. They show calibrated values for normal force "FN", lateral force "FL" and total intensity "I total" (the sum over all sectors of the position sensitive detector). I total is additionally displayed in a bar graph.

Offset Compensation

Offset compensation may be switched on or off.

- When you switch offset compensation ON the actual F_N and F_L values are stored and used as a reference. This means that a force setpoint of 0 V really corresponds to a force load of zero, even if the mirrors are not perfectly adjusted.
- When offset compensation is switched OFF, F_N and F_L will not be corrected for adjustment mismatch.

Notice

To update offset values switch **Comp. Offset** OFF and back ON.

Light Source

The AFM light source (for optical beam deflection) may be switched on or off (e.g. during longer breaks and overnight in order to save lifetime).

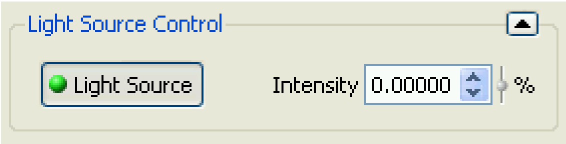


Figure 100. *AFM Light Source* work-window.

Notice

Allow 30 minutes warming-up time for stable intensity.
Retract cantilever from surface before switching the light source off.

Force Curve

In AFM the force-distance curve shows the behaviour of the interaction force between the tip and the surface with varying distance. To be able to judge the behaviour of the actual cantilever it is sensible to measure a force-distance curve before starting a measurement. This also shows the region of reliable force setpoint values. For further information on force curves and force calibration see your SPM head User's Guide.

The *Force Curve* window allows taking force-distance curves automatically. The following parameters can be set:

- Specify the number of points for the force-distance curve.
- Specify the raster time i.e. the averaging time per point for the force curve measurement. (The total averaging time for the whole curve should be at least 1 second.)
- Specify the number of repetitions to be performed when starting a force curve measurement.
- *Delay*: The delay time is used to average the Z-position before the force curve acquisition starts. The averaged z value is used as reference position for the force curve operation.
- Specify the slew rate for setting up Z-Start and for returning to the initial offset after the force curve operation.
- Bring the cantilever into contact with the surface using the Auto Approach or the manual approach procedure, see your SPM head User's Guide.
- Use small coarse steps to adjust the cantilever vertical position such that the tip shape in the Z-metre is in the middle.

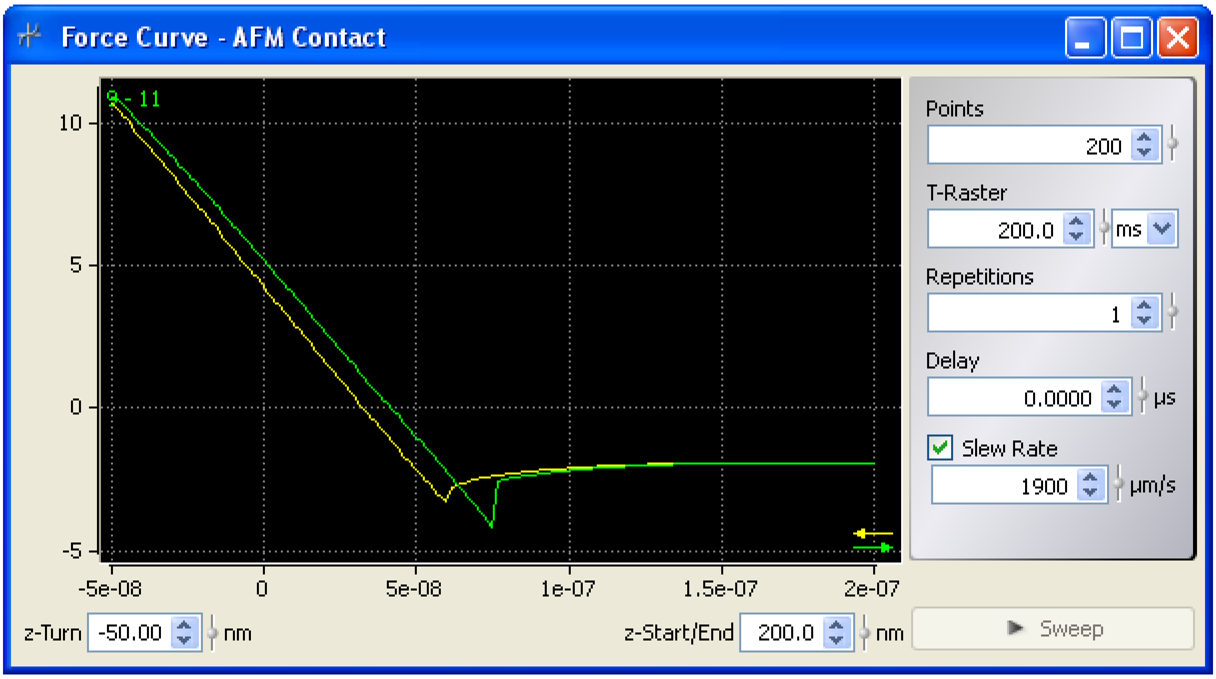


Figure 101. *Force Curve* window.

- Specify the distance limits for the Z-movement relative to the actual position or use the default values.
- Specify the number of points and averaging time per point for the force curve measurement or use the default values. (The total averaging time for the whole curve should be at least 1 s)
- Click *Sweep*.

Notice
The oversampling conditions can be defined in the *Channel List* window. For details please refer to page 35. Force curve measurements can be aborted using the *Sweep/Abort* toggle button.

Force Curve Position Mouse Tool

A force curve with the same settings can also be initiated using the respective mouse tool in the channel display (shortcut F).

- In the *Force Curve* window check the settings for the force-distance curve.
- In one of the channel displays select the Force Curve Position mouse tool.
- Click a position in the channel display to start measuring a force curve (including repetitions as specified in the *Force Curve* window).

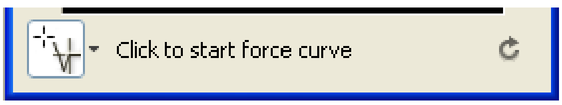


Figure 102. Channel Display Force Curve Position mouse tool.

7. AFM Noncontact Mode and QPlus with AFM-SPU

Notice

From MATRIX version 3.0 we support two different types of AFM hardware:

- AFM CU II
- AFM-SPU

If you use this software with AFM CU II hardware, please refer to chapter **AFM Non-Contact Mode and QPlus with AFM CU II** on page 121

Notice

The AFM-SPU solution supports a digitally phase-locked loop (PLL) that can be run in constant amplitude and constant excitation mode.

PLL supports extremely small amplitudes at a detection bandwidth between 4 KHz to 3 MHz. At input signal-to-noise ratios of 1:10 or worse atomic resolution is still possible.

The AFM-SPU supports a flexible demodulation bandwidth resulting in "adjustable" output signal frequency noise. For example, at a signal-to-noise ratio of 25 and a demodulation bandwidth of 2 KHz (the value applied by the AFM CU II hardware when used with a cantilever/beam deflection-based system), the resulting frequency noise is 6 Hz_{pp} while at 400 Hz (the value used by the AFM CU II hardware for QPlus sensor-based systems) the output signal noise is 2 Hz_{pp}. When reducing the demodulation bandwidth down to 1 Hz, the achievable frequency noise at a S/N ratio of 25 will be even better (0.03 Hz_{pp}).

The AFM-SPU provides excellent frequency stability with respect to temperature changes over time and an average drift of just 10 µHz/K.

Kelvin Probe Force Microscopy (KPFM) experiments are supported intrinsically, but external lock-in hardware is still required.

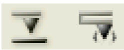
The AFM Noncontact and QPlus Projects are opened from the main window via the  icons, see figure 4 on page 18. They provide a number of Experiments, each with a complete set of GUI controls for AFM noncontact mode measurements.

Figure 103. MATRIX - AFM NonContact project window controls.

Notice

Note that the **QPlus method** works very similar to the noncontact method. From the software point of view there are two differences:

- The QPlus method does not use a deflected laser beam for detection, so the laser beam related window has been removed from the QPlus experiments.
- The df range is different: it is ±2 kHz in beam deflection noncontact mode and ±500 Hz in QPlus mode.

The AFM Noncontact Project provides the following Experiments:

	AFM NonContact & Spectroscopy
	AFM Atom Manipulation
	FM Kelvin Probe AFM (not for QPlus)
	AM Kelvin Probe AFM (not for QPlus)

Notice

For Kelvin Probe applications two special Experiments are available from the NonContact menu. For a description of controls please see below.

PLL Control

The *PLL* window provides all controls for adjusting your AFM or SFM Non-Contact experiment.

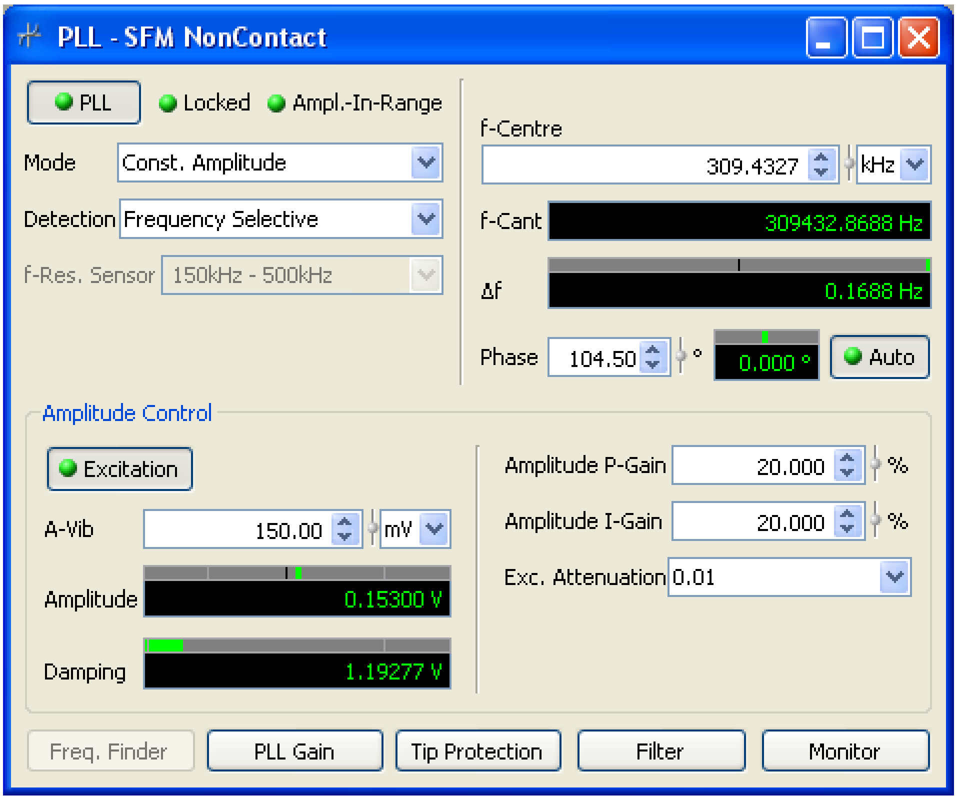


Figure 104. PLL control window for noncontact AFM/SFM applications.

Mode Select Panel

At the top left the window provides some general controls and indicators together with the mode select panel. The *PLL* button activates and deactivates the phase locked loop. This feedback method actively keeps the phase of the internal PLL reference signal locked to the phase of the cantilever signal by adjusting the reference frequency. This allows detecting the shift of the cantilever resonance frequency. *Ampl.-In-Range* indicates if the measured amplitude at FN matches the amplitude setpoint (including tolerance set in tip protection dialogue).

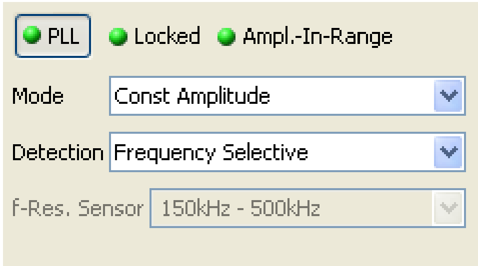


Figure 105. PLL mode select panel.

With the Mode drop-down menu select between *Self Excitation*, *Constant Amplitude* and *Constant Excitation*.

- In **Self Excitation** mode the PLL is kept inactive and the frequency shift is detected via a mixed demodulator. This mode is also used for the frequency finder. The excitation is achieved by coupling the phase-shifted FN IN input to the excitation piezo. The vibration amplitude is kept constant by gain-controlling the excitation.

  In Self Excitation mode select the **f-Res. Sensor** range where you suspect the resonance frequency of the sensor. The manufacturer's documentation should give you a sufficiently accurate hint even for unfamiliar cantilevers.

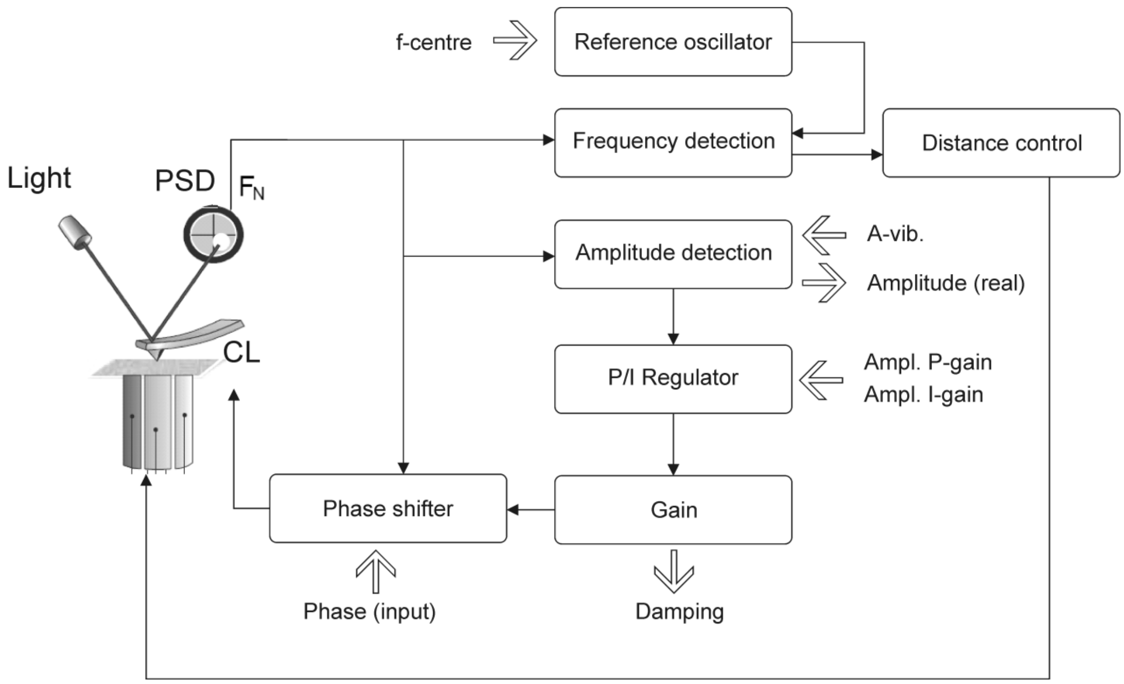


Figure 106. Self excitation mode, schematic diagram.

- In **Constant Amplitude** mode the PLL is active. The frequency shift is detected via the PLL. The vibration amplitude is kept at a user defined setpoint by the amplitude regulator. The excitation source is the internal reference oscillator.

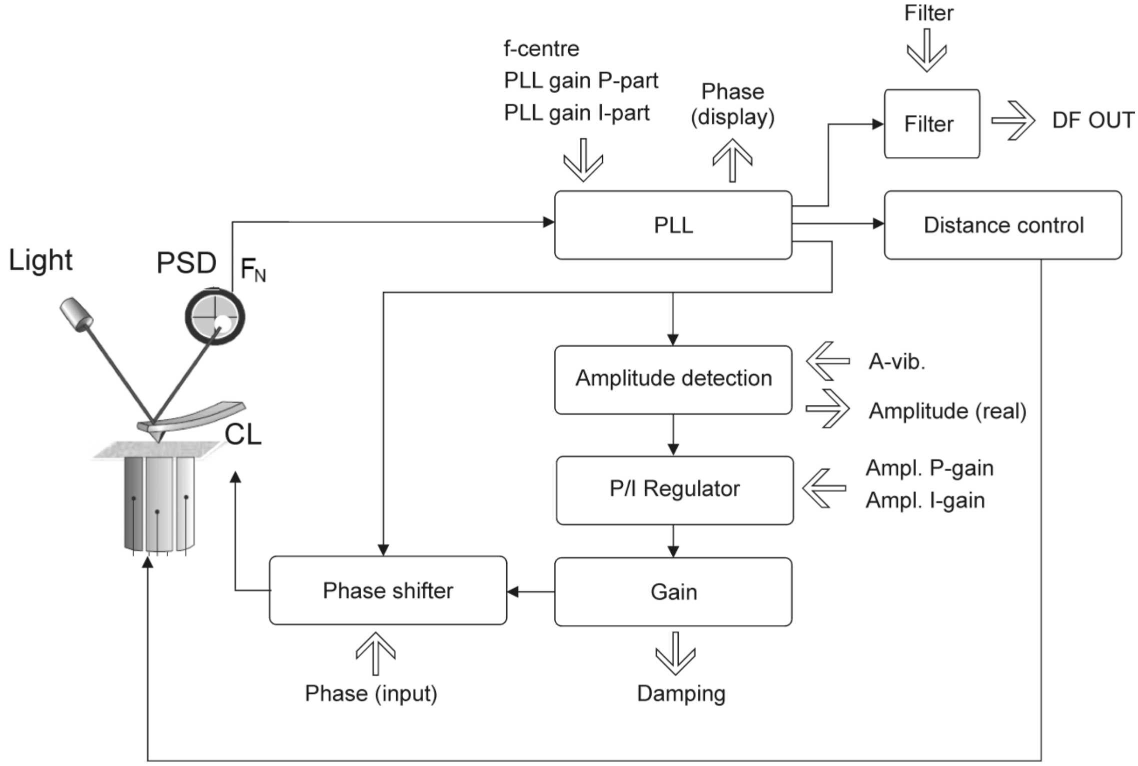


Figure 107. Constant amplitude mode, schematic diagram.

- In **Constant Excitation** mode the PLL is active. The frequency shift is detected via the PLL. The excitation signal amplitude is predefined by the user and fed to the gain control as a fix parameter. In this case no damping signal is available. The excitation source is the internal reference oscillator.

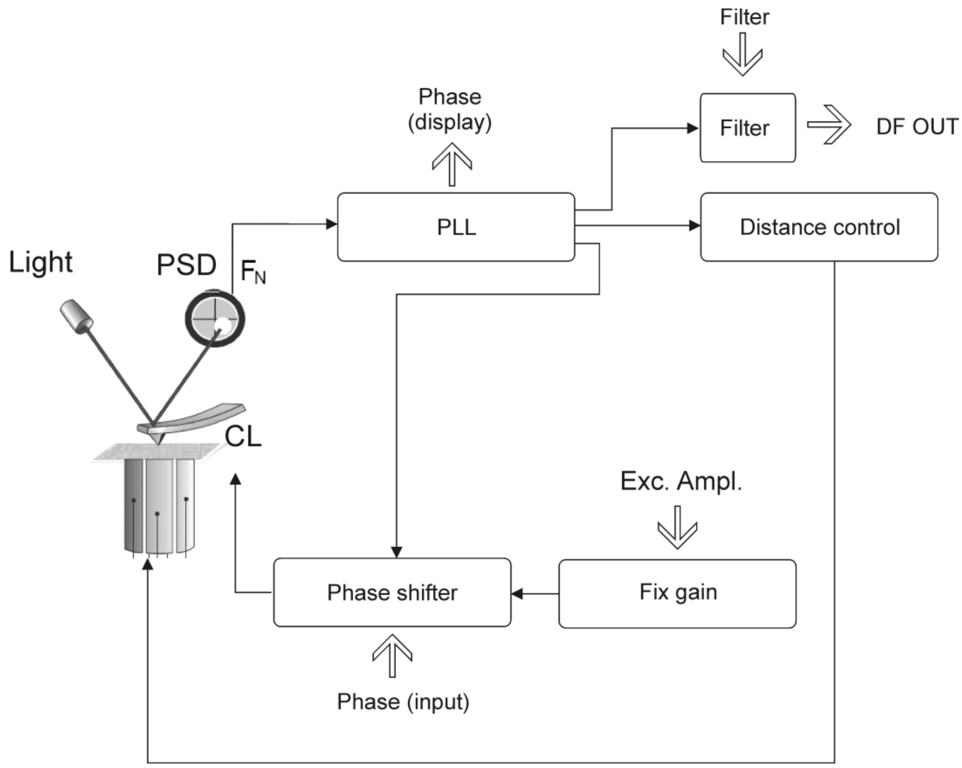


Figure 108. Constant excitation mode, schematic diagram.

With the *Detection* drop-down menu select between *Frequency Selective* and *Broad Band*.

- **Broad Band:** The signal amplitude is derived from the gain controller signal on the signal input which does not require a correct PLL centre frequency. However, with bad signal-to-noise ratios the value will be too high because the noise is also taken for signal amplitude.

- **Frequency Selective:** In this mode the lock-in derived amplitude is additionally taken into account. This works well even with bad signal-to-noise ratios but only close to the PLL centre frequency (typically ±10 kHz).

Amplitude Control Panel

The *Excitation* button connects or disconnects the vibration excitation piezo. It must be ON for the cantilever to oscillate.

The **Amplitude** control field A-Vib allows numerical or slider controlled input for the vibration amplitude setpoint. The related *Amplitude* display indicates the measured vibration amplitude. The displayed voltage value is the peak-to-peak amplitude of the AC signal at FN IN. This may be converted into a mechanical vibration amplitude which depends on sensor type, cantilever geometry and light beam adjustment.

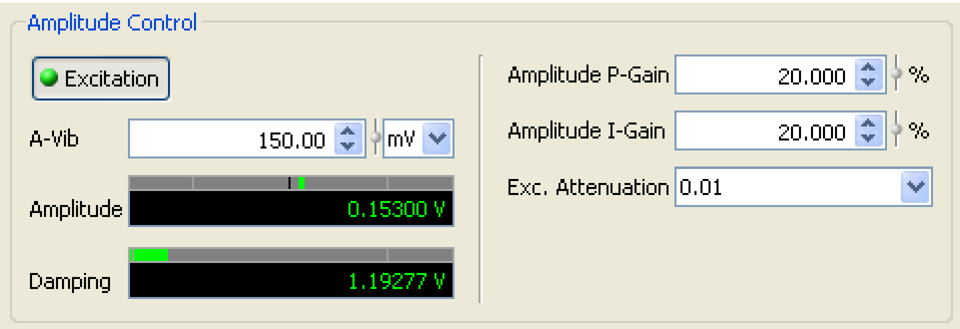


Figure 109. PLL Amplitude Control panel.

The ***Damping*** indicator shows the gain of the amplitude regulation. This value is directly related to the cantilever damping dissipation if all other parameters are left untouched. For stable feedback loop conditions select the ***Exc. Attenuation*** parameter such that *Damping* is between 0.1 V and 1 V.

Frequency Panel

The centre frequency of the PLL, f-Centre, must be set to the resonance frequency of the free/non-interacting cantilever. It is important to know this frequency as exactly as possible, otherwise the PLL cannot lock on the vibration sensor. As even the resonance frequency of a free cantilever depends on a number of parameters, e. g. temperature, it is necessary to measure this frequency at the beginning of an experiment and to check the value from time to time. This can be done using the *Frequency Finder* button at the bottom of the window (set *Mode* to *Self Excitation* and *Detection* to *Broadband*). Note that the centre frequency can also be entered and adjusted manually using a standard numerical value control.

Notice

The frequency finder only works for resonance frequencies up to 500 kHz. If you employ MHz cantilevers, please use the phase/amplitude curve for resonance curves.

The actual **cantilever vibration frequency** (f-Cant) is shown below the centre frequency. For a free cantilever away from the surface this should be the same as the centre frequency. Δf is the difference between f-Cant and f-Centre.

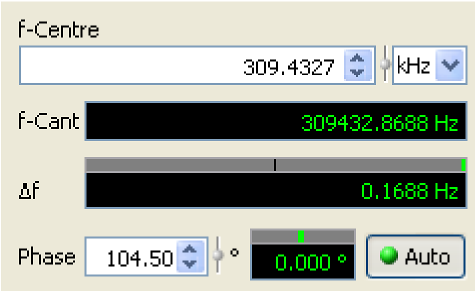


Figure 110. PLL frequency panel.

With the *PPL* button set to OFF (i.e. the PLL regulation loop open) and the *Excitation* set to ON use the phase input field to correct any systematic phase offset for the PLL and the free cantilever until the measured phase shift between cantilever signal (FN IN) and the internal oscillator of the PLL is as close to zero as possible. Note that you need to evaluate and set the correct resonance frequency first.

Alternatively switch the *Auto* button ON to automatically adjust the phase shift applied to the excitation signal so that one of the following conditions holds:

- In Constant Amplitude mode the excitation signal phase shift will be adjusted such that the phase shift of the complex PLL signal becomes zero.

Notice

The digital PLL of the AFM-SPU can only lock in if the initial phase shift is in the range ±80˚. We therefore recommend using the automatic phase adjustment option before enabling the PLL.

- In Self Excitation mode the excitation signal phase shift will be adjusted such that the gain value of the amplitude regulation (which is directly related to the damping signal) gets minimised.

Frequency Finder

Use the frequency finder to determine the resonance frequency of the free sensor.

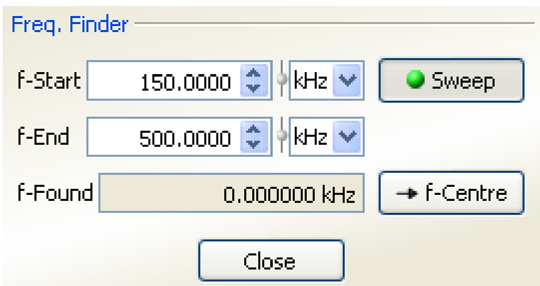


Figure 111. PLL Frequency Finder.

- In the Mode Select panel choose Self Excitation and pick an f-Res. Sensor range.
- Select a vibration amplitude:

0.5 V is a good initial value for cantilevers,

0.02 V is a good initial value for QPlus sensors.

- Set Amplitude P Gain and Amplitude I Gain. The I Gain should be smaller or equal the P Gain; 5% is a good initial value for both.

- In the Amplitude control panel click the Excitation button to switch the excitation on.

- Adjust Phase to get stable oscillation and minimize Damping (choose appropriate Exc.-Attenuation for Damping between 0.1 and 1 V).

- In the Frequency Finder panel select start and end values inside the selected range.

- Now click Sweep in the frequency finder panel. After a successful sweep use the "-> f-Centre" button to set the PLL centre frequency to the found value with a click.

PLL Gain

Use the PLL Gain panel to adjust the behaviour of the PLL regulator and balance between frequency noise (which results in noise in your measured images) and PLL demodulation bandwidth (which restricts the maximum scan speed). Check the amount of noise you have by switching one data display to line mode while scanning.

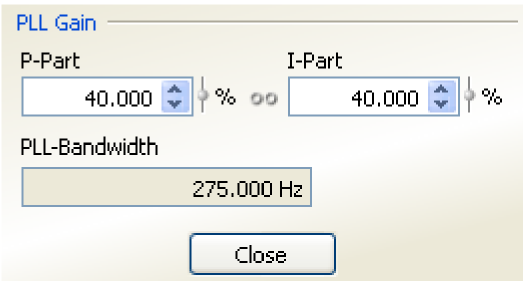


Figure 112. PLL Gain.

Ideally, the I-part and the P-part should be about equal. To force the P-Part and I-Part gain to equal values use the "wedding rings" icon. Larger gain values result in a wider bandwidth and a faster maximum scan speed. Unfortunately, they also result in increased frequency noise. The resulting PLL bandwidth is shown below the gain values. The optimum PLL bandwidth depends on surface corrugation, scan speed, loop gain of the z-regulator and many more.

Tip Protection

When a brief variation of the amplitude or frequency shift is strong the PLL runs the risk of losing hold and crashing the tip. In the tip protection panel you can set an allowed amplitude threshold as well as the related time spans which define the conditions prior to a protective tip reaction.

- If the amplitude variation is more than <Threshold> (percentage of A-Vib) for a duration of <Attack> the tip will be automatically pulled back from the surface with <Retraction Speed>.

- If the amplitude variation is less than <Threshold> for a duration of <Release> after the retract event the tip will automatically return to the surface with <Approach Speed>.

For details on approach speed and retraction speed please refer to pages 72 and 73.

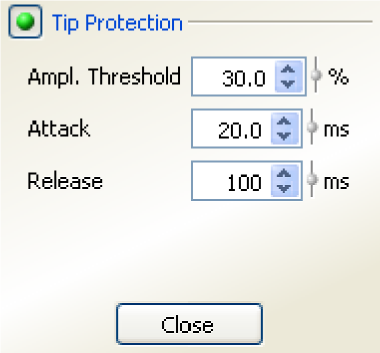


Figure 113. PLL Tip Protection.

Notice
The tip protection function is not supported in Constant Excitation mode.

Filter

Use the *Filter* panel to choose low pass filters to minimise noise for the DF OUT channel selected on the Monitor panel (i.e. the signal on the monitor socket DF-OUT of the AFM-SPU board) and the corresponding measurement channel.

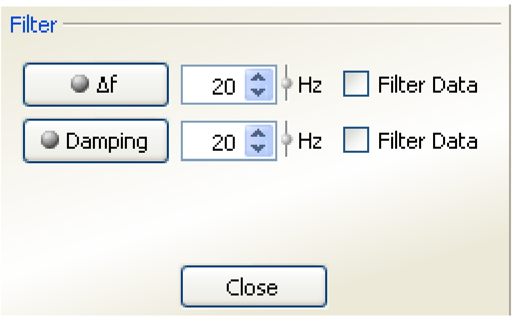


Figure 114. PLL Filter.

Monitor

The *Monitor* panel allows selecting the signal which is routed to the monitor socket DF OUT on the AFM-SPU board.

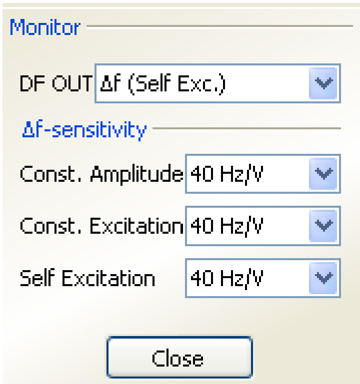


Figure 115. PLL Monitor.

Use Δf-Sensitivity to select the DAC range for the monitor output DF-OUT so that ±10 V monitor output represent the corresponding frequency range.

Measurements in Non-Contact Mode

- Make sure the tip is in "backward" position
- Set f-Centre to the resonance frequency of the free cantilever, see section **Frequency Finder** on page 108.
- Set the PLL mode to *Constant Amplitude* and the Amplitude Mode to *Frequency Selective*.
- Select a vibration amplitude (0.5 V is a good initial value for cantilevers, 0.02 V for QPlus sensors).
- Set *Amplitude P Gain* and *Amplitude I Gain*; 5% is a good initial value for both.
- In the *Amplitude Control* panel click the *Excitation* button to switch the excitation on.
- Select *Exc. Attenuation* to have the smallest possible *Damping* above 0.05 V.
- Check that the true cantilever amplitude is about the same as the amplitude setpoint A-Vib, see figure 109 on page 107. This indicates that the amplitude control works properly.
- Adjust *f-Centre* until *Damping* is at its minimum value.
- Adjust the parameter *Phase* until the measured phase is as close to zero as possible.
- Choose the proper frequency detection bandwidth by setting the PLL gain values.
- Set the tip protection conditions. This mode is activated by default but can be switched off, if required.

- Switch PLL on: the *Locked* indicator should now be green and Δf and phase should be about zero.
- In the *Regulation* window enter an appropriate Δf-Setpoint for Auto Approach, e.g. -5 Hz for cantilevers or -1 Hz for QPlus sensors.
- Set an appropriate loop gain for Auto Approach, e. g. 30% for cantilevers or 100% for QPlus sensors.
- Now start your Auto Approach.

Phase/Amplitude Curve (AFM-SPU)

All native AFM non-contact experiments support the acquisition and processing of sensor resonance curves. For obtaining a resonance curve specify

- The excitation frequency range (either numerically, or by via the dedicated frequency selection mouse tool in the phase/amplitude curve display),
- The number of data points to be acquired per curve,
- The raster time to be used, and a dedicated settling time.

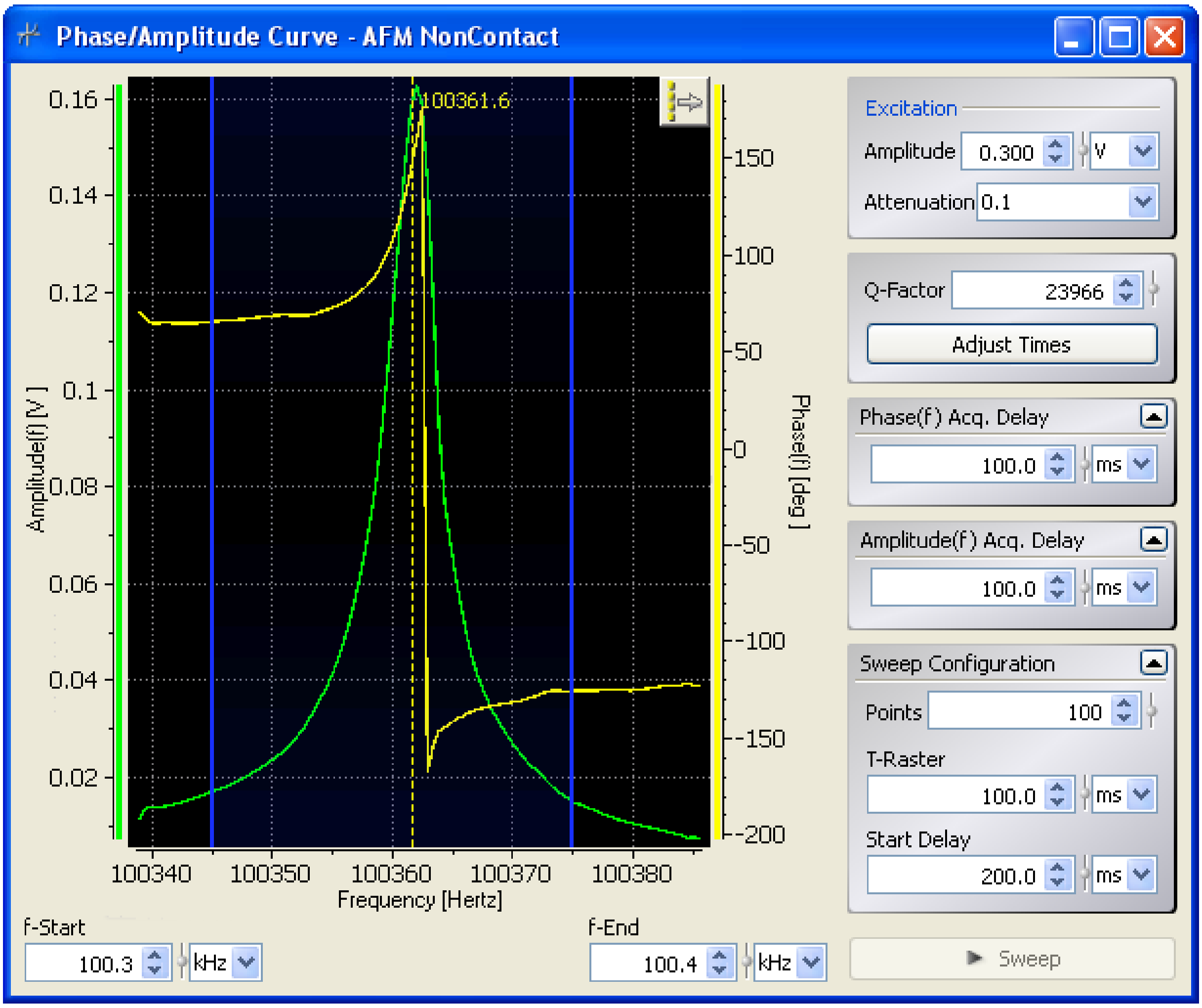


Figure 116. *Phase/Amplitude Curve* acquisition window.

Besides displaying the phase and amplitude data acquired during each excitation frequency step, the resonance curve facility is capable of computing the sensor quality factor (*Q*-factor) after the curve acquisition process has been completed. In addition, the phase/amplitude curve display supports a dedicated mouse tool for directly manipulating the PLL centre frequency.

Notice

Please note that the phase and amplitude parts of a resonance curve will be stored separately, i.e. in two result data files; the respective channels are referred to as *Phase(f)* and *Amplitude(f)*.

Excitation

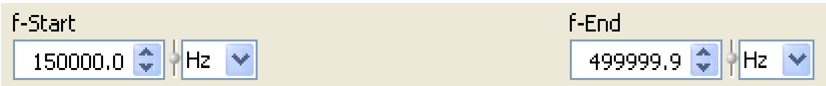


Figure 117. Phase/Amplitude curve frequency settings.

- **Start** and **End Frequency.** Insert the start and end values of a frequency region where you suspect the needle sensor resonance by direct numerical input.

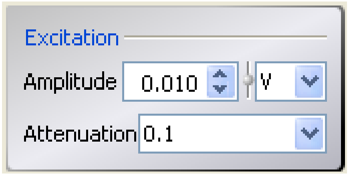


Figure 118. Phase/Amplitude curve excitation panel.

The values for *Amplitude* and *Attenuation* in the excitation panel are used for the frequency sweep only and are returned to the respective settings of the PLL window afterwards.

- **Excitation Amplitude.** With the excitation amplitude numerical input field select a value close to the amplitude you want to use for experiments later-on. The selected value will be displayed in the window.

  The vibration amplitude of the sensor at a given excitation voltage depends on the vibrational Q of the needle sensor.

  For a small Q and a small excitation voltage the resulting resonance amplitude is only very small, leading to a rather uncertain resonance estimate due to noise.

  For a large Q and a high excitation voltage the resulting resonance amplitude may be very large, i.e. giving a constant maximum value over a broad range (overflow) due to the limited dynamics of the electronics system.

- **Excitation Attenuation.** Select an attenuation factor for the excitation amplitude amplifier.

Further Settings

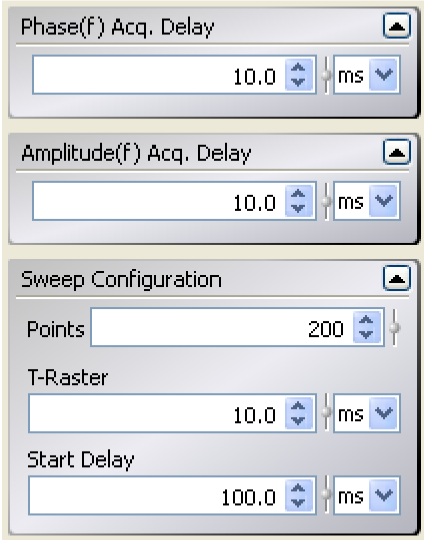


Figure 119. Phase/Amplitude curve special settings.

- The **Acquisition Delay** is the time between moving to the next step and actually taking data; 10 ms should be fine for most applications. This parameter can be set separately for the **Phase(f)** channel and the **Amplitude(f)** channel.
- **Points** defines the number of data points in a single evaluation sweep.
- **T-Raster.** Specify the averaging time per point for the phase/amplitude curve measurement or use the default values.
- The **Start Delay** is the time between setting a new frequency interval and starting a characterisation. This time is needed for the quartz to adapt to the new excitation frequency. Normally you will be happy with the set default value of 100 ms.

Sweep

Upon clicking *Sweep* the selected frequency window is scanned, measuring and displaying the amplitude and phase characteristics. The program fits a curve to the measured amplitude-frequency data, evaluates a maximum and adjusts the frequency accordingly. The accuracy of the amplitude evaluation strongly depends on the measurement parameters, such as the frequency region and number of steps.

The phase and amplitude parts of a resonance curve will be stored separately, i.e. in two result data files; the respective channels are referred to as *Phase(f)* and *Amplitude(f)*.

Q-Factor

The *Q-factor* of the sensor will be computed automatically after a resonance curve has been acquired. Use the *Adjust Times* button to optimise the frequency sweep raster time and the minimum relaxation periods for the resonance curve acquisition process with respect to sensor quality.

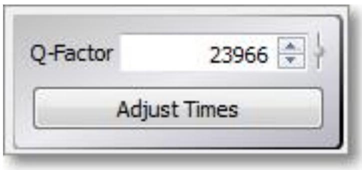


Figure 120. Q-factor settings window.

- **Adjust Times.** Adjust the frequency sweep raster time according to the configured sensor quality factor. In addition, the element will compute a suitable minimum relaxation time (initial delay time) that is required after a change of the excitation frequency during sweep operations.

The Resonance Curve Display

After a characterisation sweep the display part of the *Phase/Amplitude* window shows two curves, both of which have the excitation frequency as their common abscissa. The green amplitude curve has its related ordinate on the left, the yellow phase curve has its ordinate on the right hand side of the display.

- Use the blue vertical lines to define start and end frequencies for a subsequent sweep.

- The yellow vertical line is automatically set to the amplitude maximum. The related frequency can be taken over for the PLL as centre frequency using the takeover button at the top right of the display: . Alternatively you may also move the line (right mouse button pressed) to a different frequency before takeover.

Kelvin Probe Modes

AFM FM Mode

The response of the AC voltage is detected via the modulation of the force gradient, i.e. Δf. The modulation frequency should be set between 1-3 kHz to avoid a crosstalk to the topography but still remain within the bandwidth of the FM demodulator.

The AUTO APPROACH is performed in the standard non-contact way with the Kelvin regulator switched off. Perform the following steps:

- Monitor signal CP (connector CP/AUX1 OUT at AFM-SPU) using an oscilloscope.

- Position the z-scanner to the centre of its range as usual.

- Go to Δf feedback, adjust imaging parameters to obtain reasonable topography contrast

- Take a Δf(V) curve to determine the local contact potential difference (CPD, maximum of the Δf(V) parabola)

- On the SPM remote box switch to Backward.

- Set the oscillator to 1-1.5 kHz, 2 Vpp.

- Set the PLL bandwidth to 1-1.5 kHz (P,I = 90-125%)

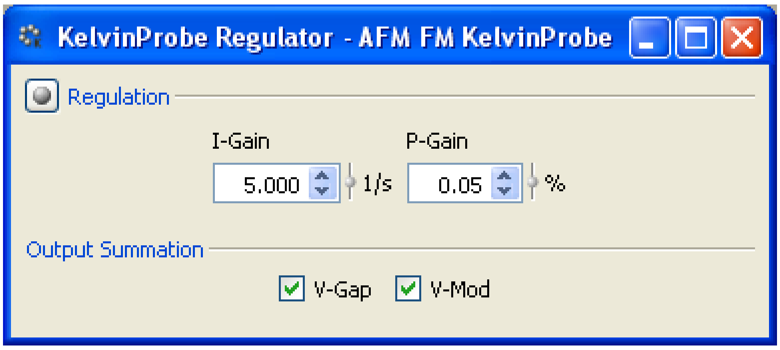


Figure 121. KelvinProbe Regulator panel, FM mode.

- On the KelvinProbe Regulator panel switch V-Gap and V-Mod on, Regulation off.
- Apply a ΔV = +1 V more positive gap voltage than the previously determined CPD.
- On the SPM remote box switch to forward to re-engage the z feedback loop.
- Monitor "R" (magnitude) at the Lock-In amplifier: typical amplitude should be 10-100 mV.
- On the Lock-In use "Auto Phase" or adjust phase manually to maximise the X signal. Hint: temporarily use large time constants (e. g. 100 ms) to improve accuracy of the Auto Phase
- On the SPM remote box switch to Backward.
- On the Gap Voltage panel set gap voltage to zero.
- On the KelvinProbe Regulator panel switch Regulation on. Start with I-Gain 1/s and P-Gain <0.1% for input sensitivity 20 mV.
- On the SPM remote box switch to Forward.

Attention

If CP jumps to 10 V switch to Backward, “Regulation” off, turn Lock-In phase by 180° and repeat

- The Kelvin regulator should now regulate X (Lock-In) to zero while Y is also zero.
- Start a line scan with line speed ¼ Hz.
- Optimise topography regulation as usual. Hint: due to the additional AC component in the frequency shift, topography contrast is typically found at a larger (negative) frequency shift than without modulation.
- Optimise Kelvin regulation with I-Gain (small P-Gains can be used to fine-tune the regulation behaviour):

  - Minimum contrast for the error signal "LOCK IN"

  - No oscillations and maximum contrast for the contact potential "KELVIN".

Hint: Alternatively also voltage jumps created with the V-Gap control can be used to optimise the Kelvin regulation. However, be careful and do not work too close to the surface to avoid tip crashes.

- Now you can start your measurement.

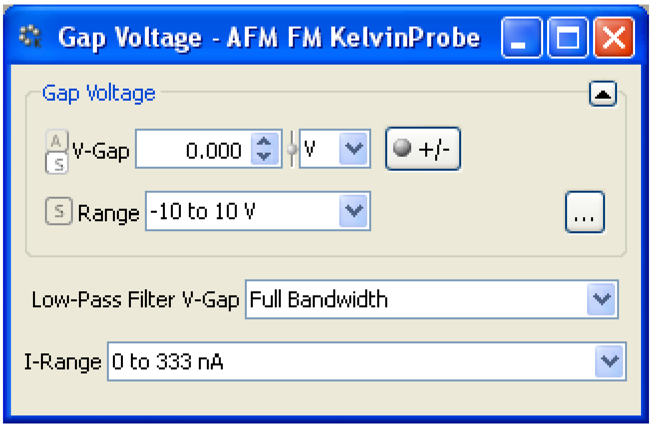


Figure 122. Gap Voltage panel for Kelvin Probe experiments.

AFM AM Mode

The detection of the Kelvin signal is performed in resonance with the 2nd flexural mode (f_2) of the cantilever on the normal force signal F_N. f_2 is theoretically found at $6.31 \cdot f_1$ and should be chosen within the available bandwidth of the Omicron AFM preamplifier.

Before setting up the cantilever oscillation switch the HP Filter f-high to a frequency range with $f_{cutoff} < 6f_1$ and Input Filter f-low to $f_{cutoff} > f_1$ (for a typical 70 kHz cantilever this would be 300kHz for the HP Filter f-high and 3 kHz – 148 kHz for the Input Filter f-low). Then set up the cantilever oscillation as usual. The Auto Approach is performed in the standard non-contact way with the Kelvin regulator switched off.

- Monitor signal CP (connector CP/AUX1 OUT at AFM-SPU) using an oscilloscope.
- Position the z-scanner to the centre of its range as usual.
- Go to Δf feedback, adjust imaging parameters to obtain reasonable topography contrast.
- Take a Δf(V) curve to determine the local contact potential difference (CPD, maximum of the Δf(V) parabola).
- On the SPM remote box switch to Backward.
- Set the oscillator to about 6 x f_1, $0.2V_{pp}$.

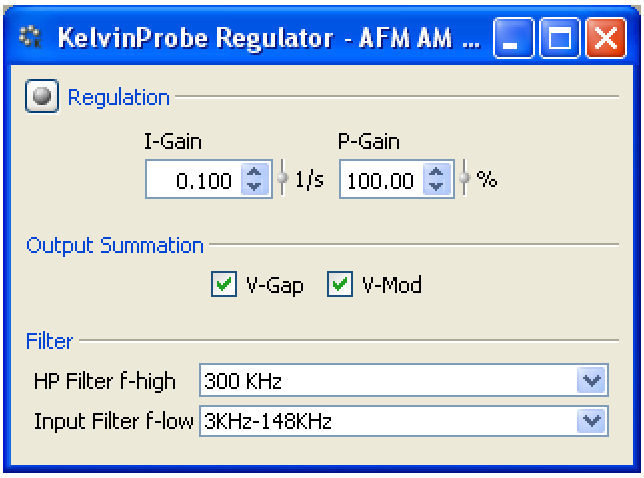


Figure 123. KelvinProbe Regulator panel, AM mode.

- On the KelvinProbe Regulator panel switch V-Gap on, Regulation off .
- Apply a $\Delta V = +1$ V more negative gap voltage than the previously determined CPD.
- On the SPM remote box switch to forward.
- Monitor R at the Lock-In amplifier.
- Increase the reference frequency in 100 Hz steps to find a signal, then use 1 Hz steps.
- Find f_2 at maximum of R (accuracy 1 Hz), typical R-amplitude 10 mV_{pp}.
- On the Lock-In use "Auto Phase" or adjust phase manually to maximise the X signal. Hint: temporarily use large time constants (e.g. 100 ms) to improve accuracy of the Auto Phase. On the SPM remote box switch to Backward.
- On Gap Voltage panel set gap voltage to zero.
- On the KelvinProbe Regulator panel switch Regulation on. Start with I-Gain 1/s and P-Gain <0.1% for input sensitivity 20 mV.
- On the SPM remote box switch to Forward.

Attention

If CP jumps to 15 V switch to Backward, Bypass on, turn Lock-In phase by 180° and repeat.

- The Kelvin regulator should now regulate X (Lock-In) to zero while Y is also zero.
- Start line scan with line speed ¼ Hz
- Optimise topography regulation as usual.

- Optimise Kelvin regulation with I-Gain (small P-Gains can be used to fine-tune the regulation behaviour):

  - Minimum contrast for the error signal "LOCK IN"

  - No oscillations and maximum contrast for the contact potential "KELVIN" .

  Hint: Alternatively also voltage jumps created with the V-Gap control can be used to optimise the Kelvin regulation. However, be careful and do not work too close to the surface to avoid tip crashes.

- Now you can start your measurement.

QPlus with Additional PDC6DQ Board

The **QPlus option** needs a special piezo driver board PDC6D**Q**. This board has a reduced bandwidth compared to the regular PDC6D in order to provide an enhanced signal-to-noise ratio. In principle you can also use the PDC6DQ for STM scanning but **not** the other way round. Note that **fast scanning is not possible** with the PDC6DQ.

Attention
Connecting to the wrong Piezo Driver board may destroy your scanner!!

For a scanning probe microscope with QPlus option ordered the MATRIX CU contains both PDC6 boards. These are connected to the Piezo Filter Unit (PFU) which provides some filtering and the means to switch between the two PDC6 boards – either manually or via software. The signal for PDC6-switching is generated on the CRTC and transferred to the PFU boards via the SBB, see figure 125 on page 120. The signal for Z-gain switching is also generated on the CRTC and transferred to the PDC6 boards via the SBB and BUS.

The *Regulator* window provides a panel for switching the PFU on/off and selecting the related Z-gain:

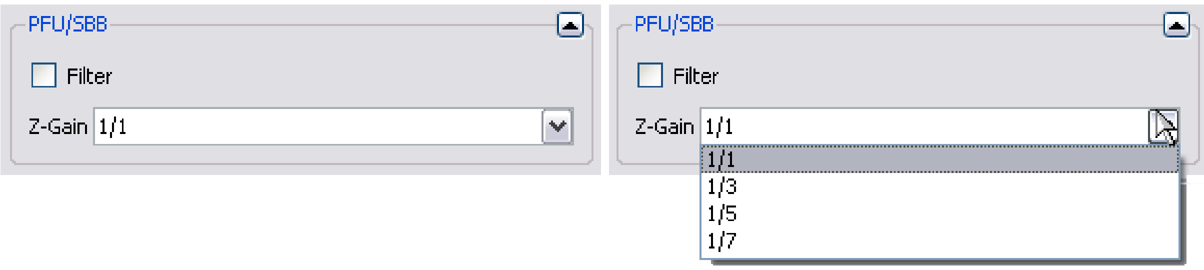


Figure 124. PFU/SBB panel in *Regulator* window.

The Z-gain of the PDC6 boards can be set to 4 different values:

1 x 10.8	1/3 x 10.8	1/5 x 10.8	1/7 x 10.8

The Z-gain reduction leads to an increase in bit-resolution (Z-resolution) by reducing the minimum Z-step width of the scanner. Note that this also requires a reduction of the coarse step width during AUTO APPROACH. Example: Reducing the Z-gain to 1/5th reduces the entire scanner Z-range to 1/5th. In this case the coarse step width (SPEED dial on remote box) must also be reduced to 1/5th so that the scanner range is still larger than the coarse step width. Otherwise a tip crash during AUTO APPROACH might be the result.

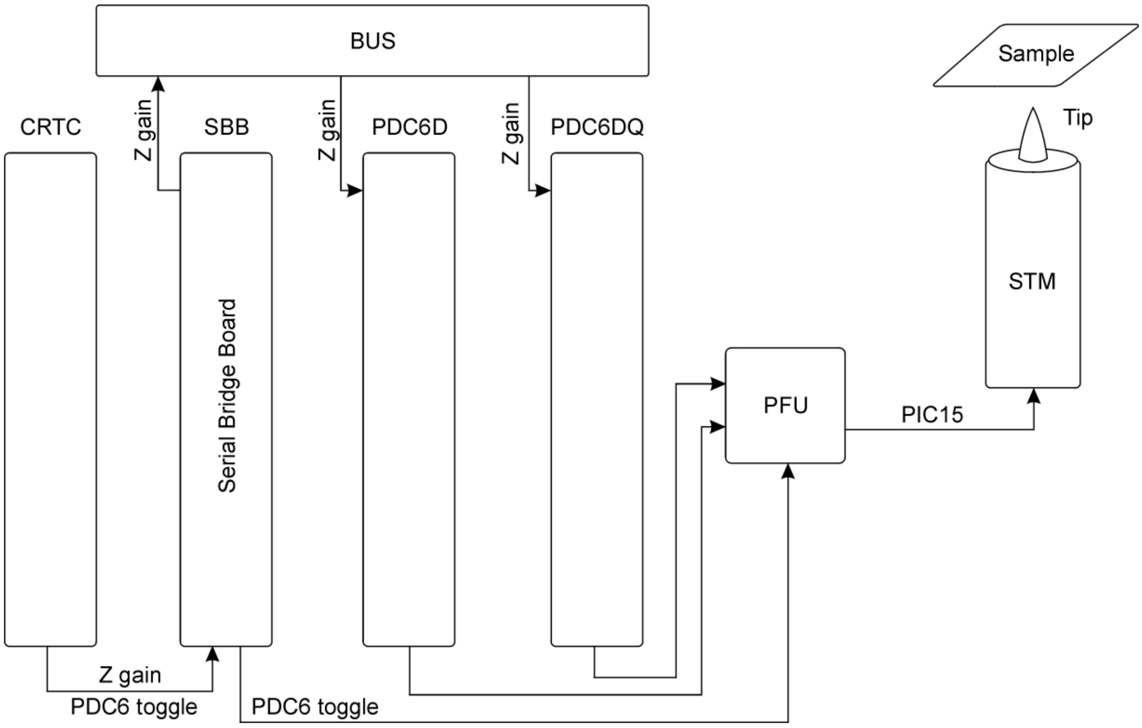


Figure 125. QPlus signal diagram for PDC6D and PDC6DQ.

7. AFM Non-Contact Mode and QPlus with AFM CU II

> **Notice**
>
> From MATRIX version 3.0 we support two different types of AFM hardware:
>
> - AFM CU II
> - AFM-SPU
>
> If you use this software with AFM-SPU hardware, please refer to chapter **AFM Noncontact Mode and QPlus with AFM-SPU** on page 103.

The AFM Noncontact and QPlus Projects are opened from the main window via the  icons, see figure 4 on page 18. They provide a number of Experiments, each with a complete set of GUI controls for AFM noncontact mode measurements.

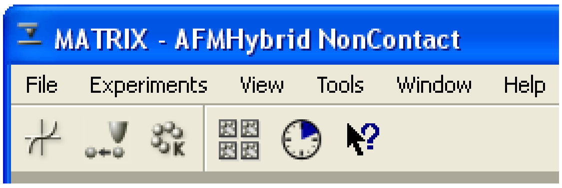


Figure 126. MATRIX - AFM NonContact project window controls.

> **Notice**
>
> Note that the **QPlus method** works very similar to the noncontact method. From the software point of view there are two differences:
>
> - The QPlus method does not use a deflected laser beam for detection, so the laser beam related window has been removed from the QPlus project.
> - The df range is different: it is ±2 kHz in beam deflection noncontact mode and ±500 Hz in QPlus mode.

The AFM Noncontact Project provides the following Experiments:

	AFM NonContact & spectroscopy
	AFM Atom Manipulation
	Kelvin Probe AFM (not for QPlus)

Note that the AFM Noncontact Experiment does NOT require the AFM Contact Project or the STM Project to be open or even present. Note however, that many components are very similar or identical to those of the STM Experiment and AFM Experiment, e.g. Regulator, Scanner, Sensor Alignment, Light Source and Channel displays. In this chapter we will therefore only describe the AFM noncontact specific GUI panels.

Notice

For Kelvin Probe applications a special Experiment is available from the NonContact menu. For a description of controls please see below.

NonContact Adjust

Excitation Panel

The **Excitation** button connects or disconnects the vibration excitation piezo. It must be ON for the cantilever to oscillate.

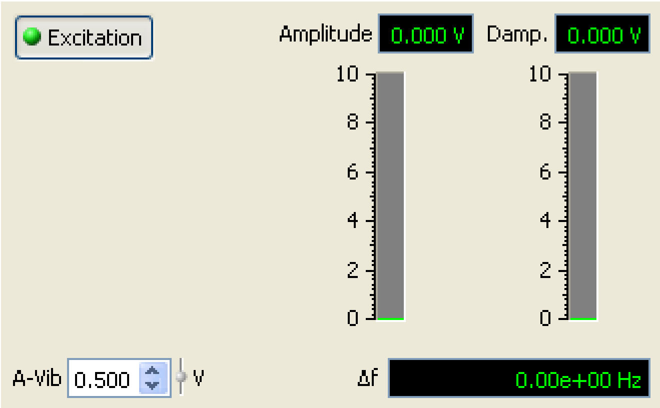


Figure 127. The AFM NonContact Excitation panel.

The **Amplitude** control field A_{vib} allows numerical or slider controlled input for the vibration amplitude setpoint. The analogue meter indicates the vibration amplitude.

The displayed voltage value is the AC signal at FN IN. This may be converted into a mechanical vibration amplitude which depends on cantilever geometry and light beam adjustment.

The **Damping** indicator shows the gain value of the amplitude regulation. This value is directly related to the cantilever damping signal if all other parameters are left untouched. Adjust the output gain (AFM remote box) to achieve a Damping of about +1 V. For negative damping values, i.e. the amplitude regulation detects too large an amplitude, the indication bar turns red. In this situation stable cantilever vibration is not possible. For further information please refer to your SPM head User's Guide.

Δf shows the following signal in kHz:

$$\Delta f = f_{cantilever} - f_{reference} + f_{intermediate}$$

where $f_{intermediate} \approx 455$ kHz and $f_{cantilever.}$ = f-Cant. This display is only activated with stable vibration amplitudes.

Δf Adjustment Panel

The **cantilever vibration frequency** (f-Cant) is shown in the df detection panel. The direction of gap regulation can be selected with a toggle switch.

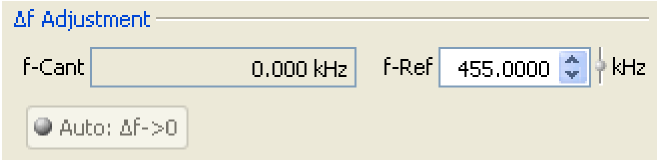


Figure 128. The AFM NonContact df Detection panel.

The AFM Noncontact window also has a second control field providing information on the internal frequency generator (OCB). Here, the **reference frequency** given by the OCB can be adjusted using a standard numerical value control. Before starting a measurement adjust **f-Ref** to yield **Δf** = zero. This is achieved with

$$f_{reference} = f_{cantilever} + f_{intermediate}$$

where $f_{intermediate} \approx 455$ kHz. Alternatively Click **Auto: Δf -> 0** to do this process automatically. The **Auto: Δf -> 0** function switches back Off after successful adjustment to allow for non-zero frequency shift setpoints. If necessary fine-adjust f-ref manually until df is exactly zero.

Notice

The **Δf sign** buttons **in the Z-Regulation window** allow selecting the correct polarity for attractive or repulsive interaction.

Δf sign "-" : attractive interaction: frequency decreases with decreasing gap width (normal case).

Δf sign "+" : repulsive interaction: frequency increases with decreasing gap width.

QPlus with Additional PDC6DQ Board

The QPlus option needs a special piezo driver board PDC6D**Q**. This board has a reduced bandwidth compared to the regular PDC6D in order to provide an enhanced signal-to-noise ratio. In principle you can also use the PDC6DQ for STM scanning but NOT the other way round. Note that fast scanning is not possible with the PDC6DQ.

Attention

Connecting to the wrong Piezo Driver board may destroy your scanner!!

For a scanning probe microscope with QPlus option ordered the MATRIX CU contains both PDC6 boards. These are connected to the Piezo Filter Unit (PFU) which provides some filtering and the means to switch between the two PDC6 boards – either manually or via software. The signal for PDC6-switching is generated on the CRTC and transferred to the PFU boards via the SBB, see figure 125 on page 120. The signal for Z-gain switching is also generated on the CRTC and transferred to the PDC6 boards via the SBB and BUS.

The Regulator window provides a panel for switching the PFU on/off and selecting the related Z-gain:

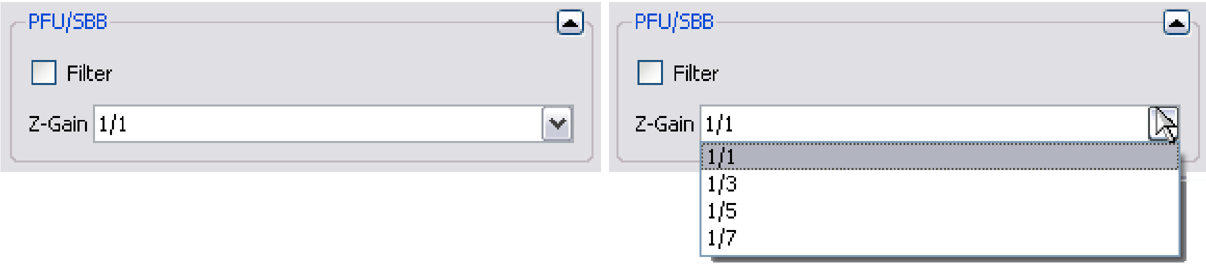


Figure 129. PFU/SBB panel in regulator window.

The Z-gain of the PDC6 boards can be set to 4 different values:

1 x 10.8	1/3 x 10.8	1/5 x 10.8	1/7 x 10.8

The Z-gain reduction leads to an increase in bit-resolution (Z-resolution) by reducing the minimum Z-step width of the scanner. Note that this also requires a reduction of the coarse step width during AUTO APPROACH. Example: Reducing the Z-gain to 1/5th reduces the entire scanner Z-range to 1/5th. In this case the coarse step width (SPEED dial on remote box) must also be reduced to 1/5th so that the scanner range is still larger than the coarse step width. Otherwise a tip crash during AUTO APPROACH might be the result.

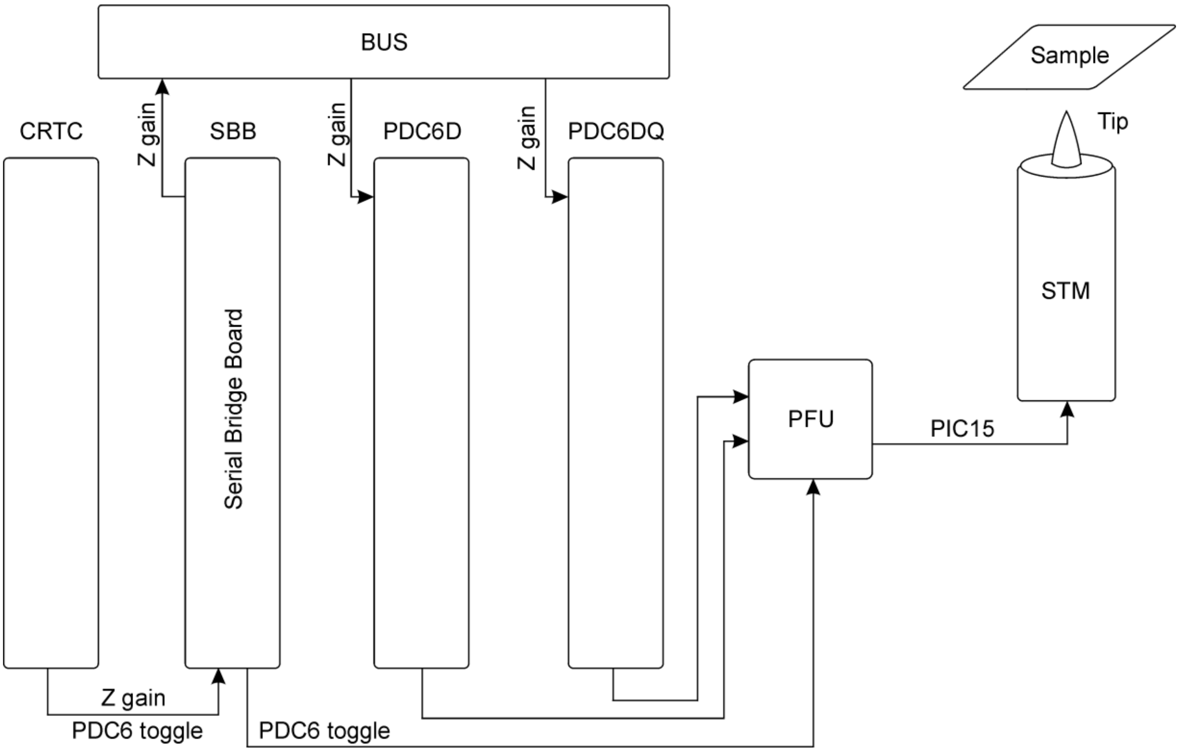


Figure 130. QPlus signal diagram for PDC6D and PDC6DQ.

8. AFM with Cryogenic SFM

SFM Sensor Alignment

The Omicron Cryogenic SFM uses an interferometric detection method for the cantilever position and therefore needs a different alignment procedure. The related window is shown below.

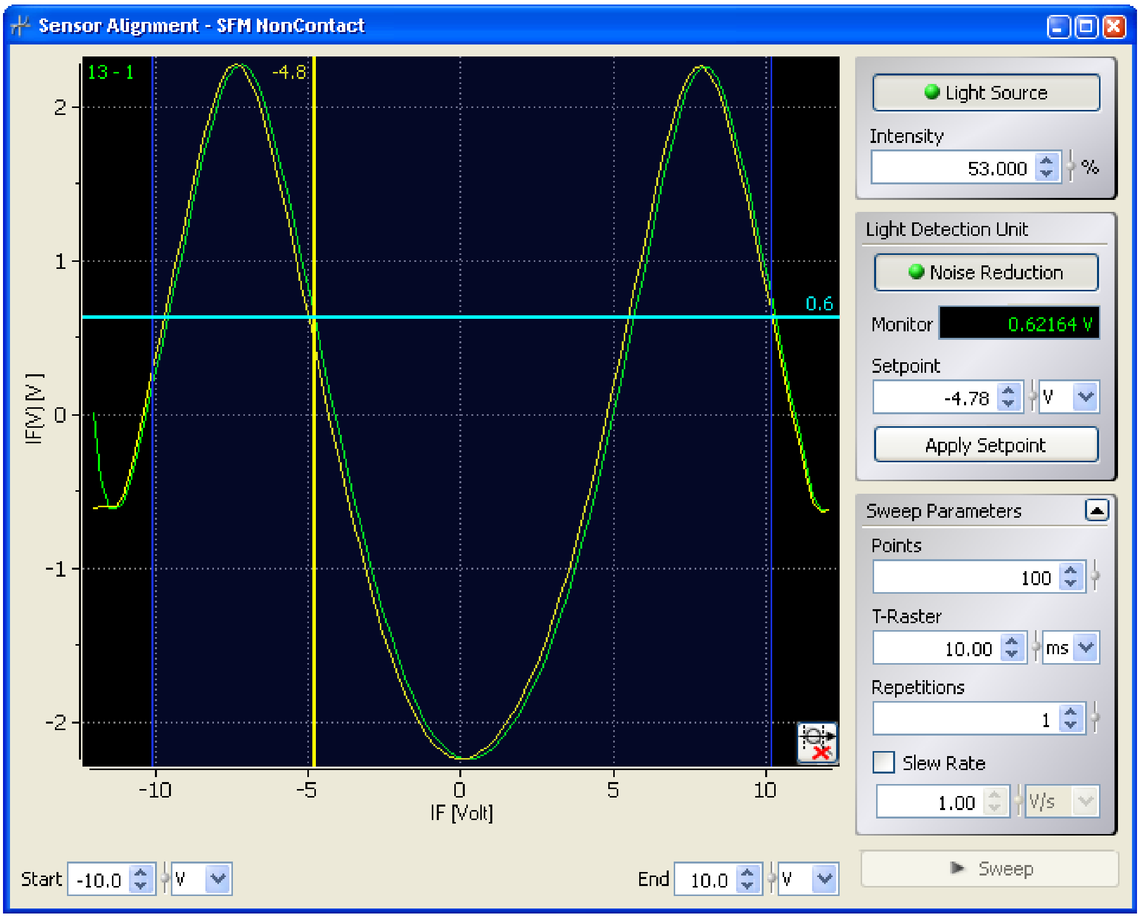


Figure 131. *SFM Sensor Alignment* window.

As with the other curve controllers you can define start and end values, the number of points and repetitions as well as the raster time. The slew rate controls the velocity with which the cantilever approaches the start point and is returned to its previous position after completing the curve.

- Set the parameters as desired. We recommend that you keep *Noise Reduction* switched on.
- Click *Sweep* to measure an interferometer curve.
- Move the vertical yellow line in the display to select your setpoint on the yellow curve.
- Click *Apply Setpoint* to activate this setting.

For details on the interferometer method please refer to chapters **Setpoint Interaction and Recommendations** and **Adjusting the Interferometer Setpoint** in your Cryogenic SFM Manual.

9. AFM Non-Contact Mode with Needle Sensors

Matrix comprises a dedicated Project named *AFM_Needle* for supporting Needle sensor microscopes in AFM-mode; this Project contains a single experiment also called *AFM_Needle*. The experiment supports all typical SPM features such as various spectroscopy modes, tunnelling current and auxiliary data channels, options for acquiring continuous signals, etc. The Needle Sensor experiment also provides dedicated sensor characterisation and adjustment features. (For example, you can use the experiment facilities to determine the *Q*-factor of the current sensor.)

Notice

The Needle Sensor experiment requires an AFM-SPU board. It cannot be used with an AFM CU II.

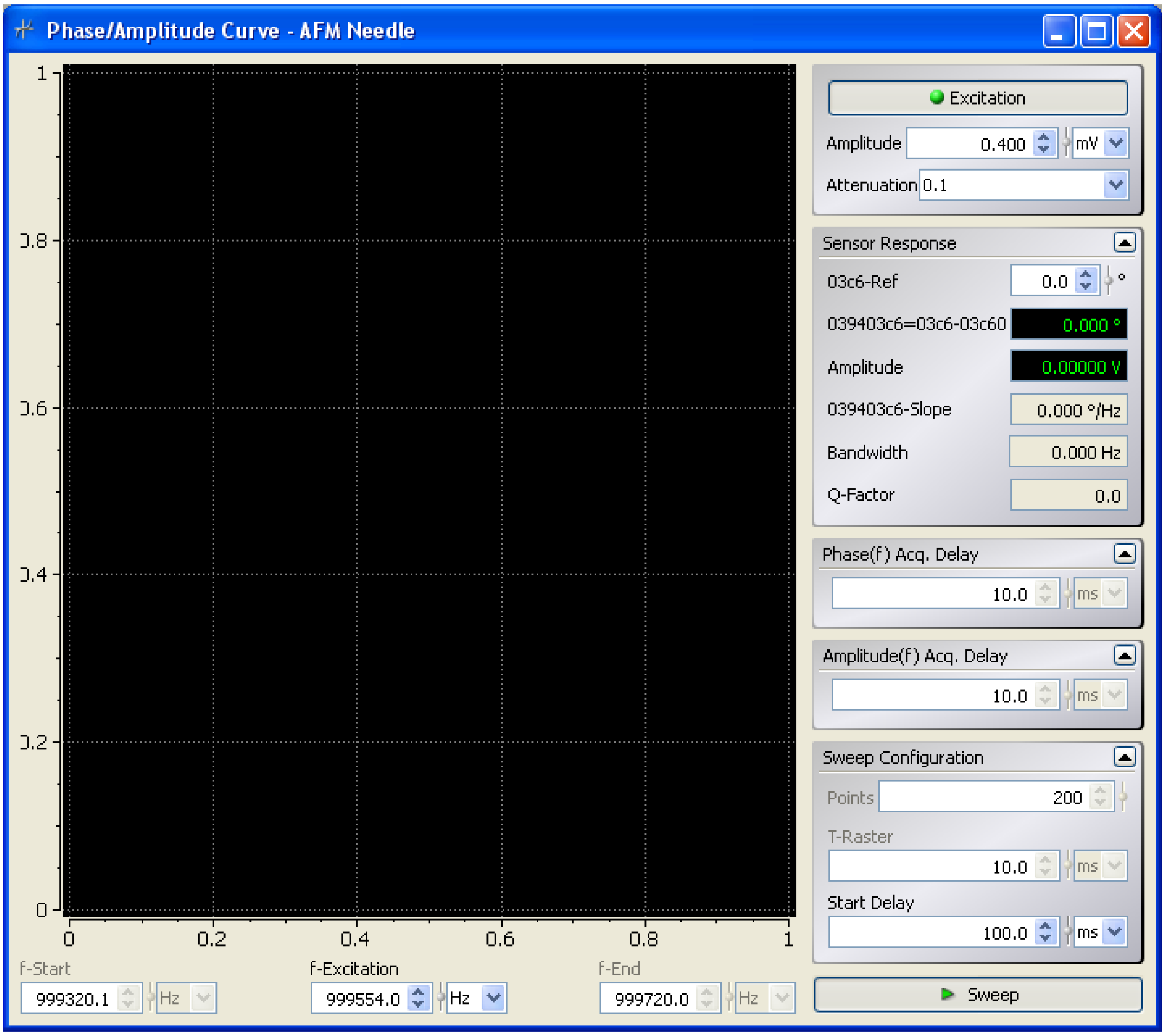


Figure 132. *Phase/Amplitude Curve* window for Needle sensors.

Needle Sensor Adjustment

The *AFM Needle Adjustment* window characterises the resonance performance of the employed needle sensor and sets the excitation parameters during measurement.

Since the needle sensor is normally driven close to its resonance frequency, a new, unused needle sensor poses the problem of initial characterisation, i.e. evaluation of the resonance frequency. For this procedure the following parameters can be set.

Excitation

Figure 133. Needle sensor frequency settings.

- **Start** and **End Frequency.** Insert the start and end values of a frequency region where you suspect the needle sensor resonance by direct numerical input.

- Excitation **Frequency.** The program can evaluate the resonance frequency of the employed needle sensor, see below, and set the excitation frequency accordingly. You may, however, manually specify the excitation frequency by direct numerical input, using the increment buttons or by clicking and moving the yellow line. Note that a new sweep will automatically set the excitation frequency to the new maximum.

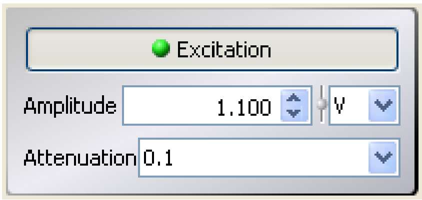


Figure 134. Needle sensor excitation panel.

- **Excitation Amplitude.** With the excitation *Amplitude* numerical input field select a value close to the amplitude you want to use for experiments later-on. The selected value will be displayed in the window.

  The vibration amplitude of the sensor at a given excitation voltage depends on the vibrational Q of the needle sensor.

  For a small Q and a small excitation voltage the resulting resonance amplitude is only very small, leading to a rather uncertain resonance estimate due to noise.

  For a large Q and a high excitation voltage the resulting resonance amplitude may be very large, i.e. giving a constant maximum value over a broad range (overflow) due to the limited dynamics of the electronics system.

- **Excitation Attenuation.** Select an attenuation factor for the excitation amplitude amplifier.

Notice

For further details on Delay and Sweep Configuration settings please refer to section **Phase/Amplitude Curve** on page 112ff.

Sensor Response

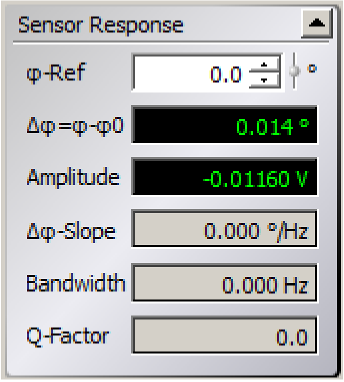


Figure 135. Needle sensor response panel.

- ***Phi-Ref.*** Phase difference between the vibrating needle sensor and the reference oscillator at the resonance frequency. Ideally this value should be 90°. In reality this value varies due to non-ideal quartzes, phase detection and wiring effects, etc. The expected true phase shift is about 90° +/- 40°. Extreme deviations from the ideal 90° value, however, indicate a major fault, e.g. incorrect wiring, short, defective needle sensor.

- ***Delta Phi.*** Phase shift between the vibration and the excitation. After a resonance evaluation cycle the resonance frequency is selected at the amplitude maximum, while Phi-Ref is set in such a way as to give zero at Delta-Phi (phase detector output = 0V).

- ***Amplitude.*** The vibration amplitude of the needle sensor at a given excitation voltage depends on the vibrational Q of the needle sensor.

  For a small Q and a small excitation voltage the resulting resonance amplitude is only very small, leading to a rather uncertain resonance estimate due to noise. Therefore a minimum excitation voltage can be set for characterisation. If, at the beginning of a characterisation, the actual excitation voltage is smaller than the preset **minimum excitation** voltage, the true excitation voltage is automatically raised to the preset minimum value.

  For a large Q and a high excitation voltage the resulting resonance amplitude may be very large, i.e. giving a constant maximum value over a broad range (overflow) due to the limited dynamics of the electronics system. As a result the resonance estimate is again rather uncertain. Therefore a maximum excitation voltage can be set. If, at the beginning of a characterisation measurement, the actual excitation voltage is higher than the preset **maximum excitation** voltage, the true excitation voltage is automatically decreased to the preset maximum value in order to avoid a detector overload.

- ***Delta Phi Slope.*** This is the slope of the phase-vs.-frequency curve in linear approximation. It determines the phase variation per 1 Hz frequency variation, typical values are around 1°/Hz to 2°/Hz. Much smaller values indicate a low Q-value for the quartz, i.e. a low needle sensor sensitivity.

- ***Bandwidth.*** After a resonance curve has been acquired, this parameter will reflect the width of the interval between two frequencies that mark a 3 dB change of the sensor vibration amplitude.

- ***Q-Factor.*** The *Q*-factor of the sensor will be computed automatically after a resonance curve has been acquired. The *Q*-factor can be used to optimise the frequency sweep raster time and the minimum relaxation periods for the resonance curve acquisition process.

Sweep

Upon clicking *Sweep* the selected frequency window is scanned, measuring and displaying the amplitude and phase characteristics. The program fits a curve to the measured amplitude-frequency data, evaluates a maximum and adjusts the frequency accordingly. The accuracy of the amplitude evaluation strongly depends on the measurement parameters, such as the frequency region and number of steps.

The phase and amplitude parts of a resonance curve will be stored separately, i.e. in two result data files; the respective channels are referred to as *Phase(f)* and *Amplitude(f)*.

The Resonance Curve Display

After a characterisation sweep the display part of the *AFM Needle Adjustment* window shows two curves, both of which have the excitation frequency as their common abscissa. An example curve of a measurement is shown in figure 136 below.

- The green curve is a graphical representation of the voltage equivalent to the mechanical vibration amplitude of the quartz.

- The yellow curve represents the phase shift between the vibration and the excitation.

The characteristic features are the expected amplitude increase at the resonance frequency (left ordinate) and the resulting strong phase shift (right ordinate).

The excitation frequency is normally set to the reversal point of the red curve and the phase shift is adjusted to zero accordingly.

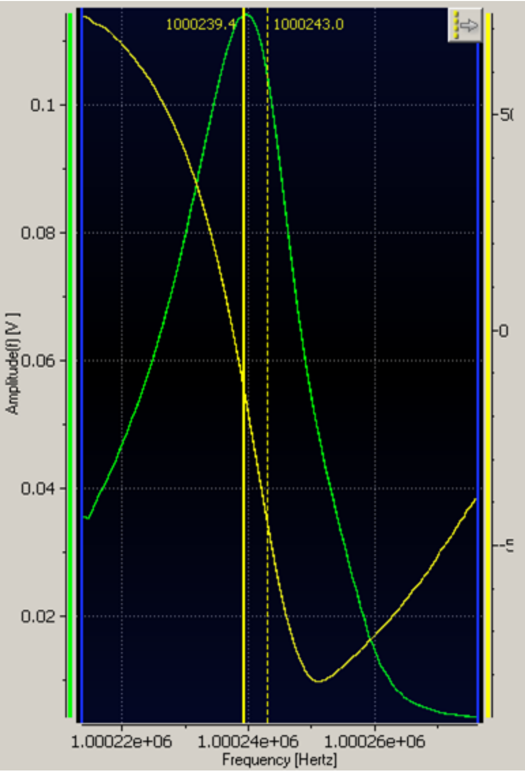


Figure 136. Needle sensor curve example.

10. Tools Menu

Calibration Options

From the Project window menu select *Tools* → *Calibration Selection* to open the *Calibration Options* window. Select your preamplifier type and related calibration set as well as the parameter set for your specific instrument. Some Omicron SPMs need more than one parameter set, e.g. for different temperature regions. In this case select the variant from the drop-down menu.

Attention

The MATRIX system does not prevent you from selecting new calibration parameters while certain operations are progressing although changing the calibration data is only supported in idle experiments. In order to avoid experiment malfunction, abrupt software terminations and other problems, Omicron strongly recommends selecting the menu item *Tools* ⇨ *Calibration Selection* **only if no experiment operations are active.**

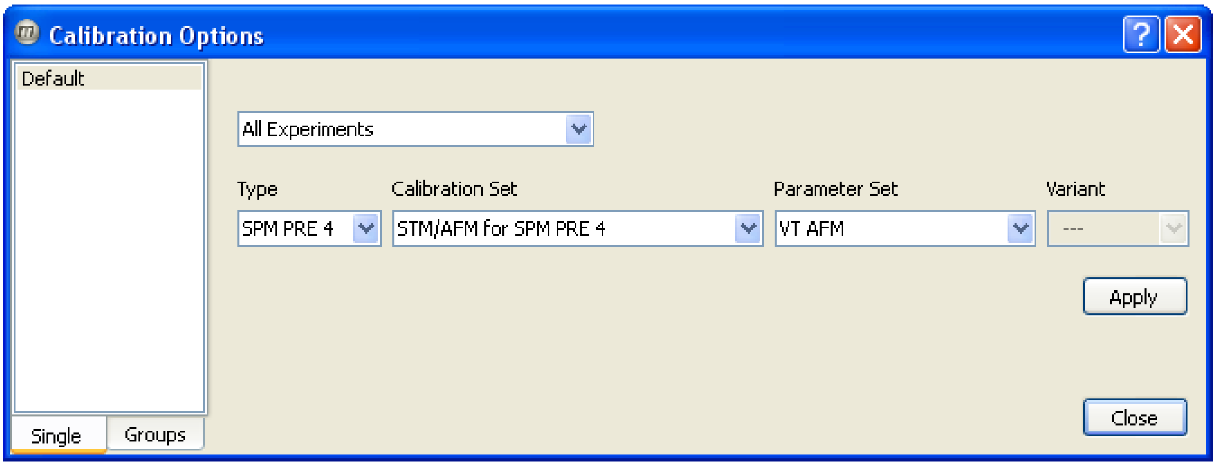


Figure 137. *Calibration Options* window.

The interface allows configuring several instruments individually, or by instrument type group.

- The tab ***Single*** of the list view of the calibration selection dialogue window contains the names of all available instruments. For configuring each instrument individually, select the name of the respective instrument first and configure the type, calibration set, parameter set and parameter set variant to be used afterwards. This procedure allows you to set up one or more instruments. Clicking the *Apply* button will apply all changes you made to the instrument calibration instantly.

- For configuring all instruments of a certain type—e.g. all Matrix Control Units (MCUs)—, click on the ***Groups*** tab of the list view of the calibration selection dialogue window, select the type code of the instrument group, and select the calibration data as usual. Clicking the *Apply* button will apply the calibration changes to all instruments of the respective group.

Notice

Please note that clicking the button *Close* without clicking *Apply* first will **discard** all configuration changes not yet applied.

Result File Preferences

From the Project window menu select *Tools* → *Result File Preferences* to open the respective window, see figure 138 on page 131. Note, that this is only possible while the experiment is not uploaded to the MATRIX CU. Set the available options to suit your needs.

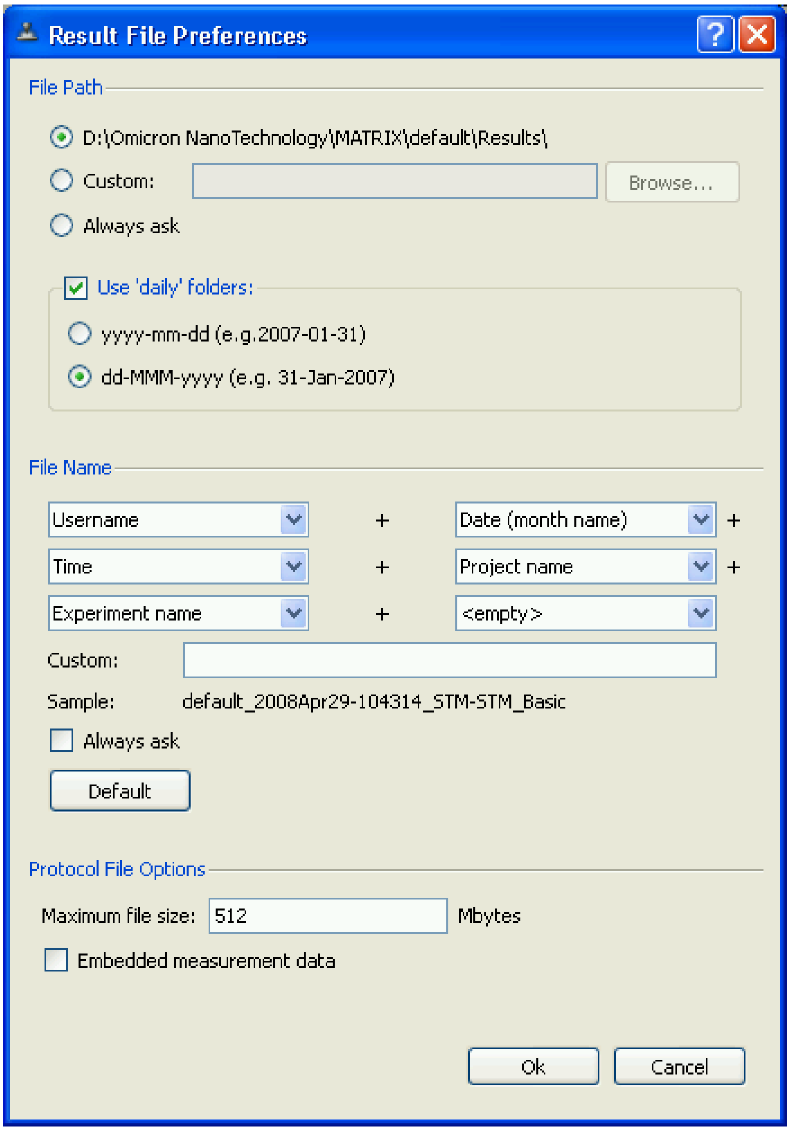


Figure 138. The *Result File Preferences* window.

File Path

The target folder for storing result files can be selected. You may choose to:

- Use the system default (which is determined by the Microsoft Windows environment variable MATRIX_RESULT_PATH).

- Specify an arbitrary folder to be used for storing result files. (Browse the file system in order to determine the target folder.)

- Direct the software to prompt you for target folder paths each time a new result file is about to be created.

The "daily result folders" introduced in earlier versions are optional now; in addition, the date format for naming the folders can be configured. (Available options are dd-MMM-yyyy e.g. 04-Feb-2007, or the alternative scheme yyyy-mm-dd, e.g. 2007-02-04.)

File Name

You can determine up to six components of which a file name consists of as well as the placement of each of these components within a particular file name. Available components are:

- MATRIX username (usually "default")

- Experiment launch date information. The date representation can take two different forms:

  The variant month name will add a prefix of the form yyyyMMMdd (e.g. "2006Nov13" for 13-Nov-2006)

  The variant month as number will add a prefix of the form yyyymmdd (e.g. "20061113" for 13-Nov-2006)

- Experiment launch time (of the form hhmmss, e.g. "113342" for 11:33:42)

- Name of the Project the respective experiment is associated with (e.g. "STM")

- Name of the respective experiment (e.g. "STM_Basic")

- Custom file name specification

Notice

To add a custom string to the file name you need to add text to the Custom field and select *Custom* in one of the drop-down fields.

The above components can be determined by selecting the appropriate item from six distinct drop-down menus. An additional option (*Always ask*) will cause the MATRIX software to construct a file name proposal from the components selected, however, you will be prompted for the actual file name to be used each time an experiment gets uploaded to a MATRIX CU. The *Default* button will reset the file name settings to Omicron default.

Notice

Changes in the result file preferences only take effect upon experiment upload.

Protocol File Options

- Normally, acquired data will be stored in separate files by default. For specific purposes, however, you may want to revert to the behaviour of older versions of the MATRIX software, which have embedded the acquired data in the files of a result file chain (NOT recommended).

- Finally, you may now determine the maximum size of a single result file (not a result data file, however). If this size is exceeded, the MATRIX software will automatically add a new result file to the existing result file chain. The minimum result file size supported is 10 Mbytes.

Notice

Note that each time the MATRIX software is about to create a new result file (i.e. after the user has clicked the "initialise" button on the experiment state control panel), it will search the selected target directory for all files with a name similar to the configured result file name. If such files exist, the MATRIX software will issue a warning message and offer to either reselect the result file name and location, or to continue at the risk of overwriting older files.

Manage Scripts

Use this menu item to open the *Script Manager*. For more information on the MATRIX scripting model and its associated scripting language MATE please refer to the dedicated MATE manual.

Settings

Data Storing

In the Project *Settings* window tick the respective boxes if you want to automatically save the unfinished frame upon pressing the restart button or if you want to switch prophylactic data storing on. For more details on prophylactic data storing please refer to page 20.

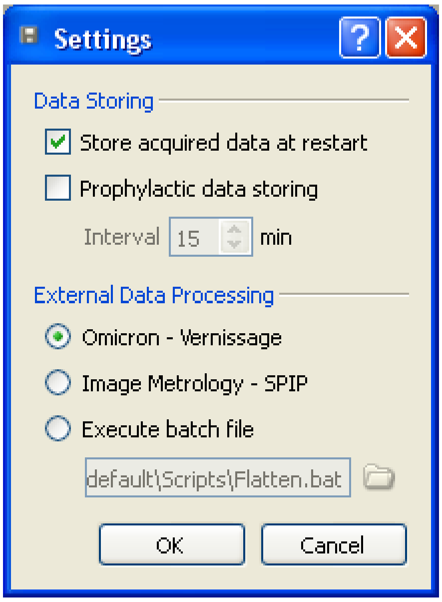


Figure 139. Project *Settings* window.

External Data Processing

MATRIX allows configuring the actions to be taken when using the *Favourites Gallery* functions *Analyse* or *Analyse all*. Select the appropriate option in the *External Data Processor* section of the *Settings* window. Note that you can also specify the batch script file to be run when selecting the *Execute Batch File* option.

Notice

A sample batch file "Flatten.bat" is part of the MATRIX kit, see the "Scripts" folder of the MATRIX user data directory (<InstallDir>). For details on file path settings please refer to page 138. This file runs the Vernissage software in batch mode to convert the contents of the Favourites Gallery into the Omicron Flat File Format.

The external data processor option will be saved as part of the preferences data when storing the session state by e. g. choosing *Save All* from the *File* menu of the MATRIX main window.

11. Running MATRIX

Connecting an Oscilloscope

For monitoring purposes an oscilloscope is strongly recommended (interacting time scale typically around 1 ms/div). The oscilloscope is the best instrument to see most of the problems in AFM/STM work after you have gained some experience in interpreting its lines. Try switching the scan on and off with the *Stop* and *Start* buttons in the *XY Scanner* window. Without scanning you should see a relatively stable DC-signal with only a little noise.

Connect the oscilloscope cables to the MATRIX rack from the back using one of the provided openings. Thread the cables through on the provided guide rails and connect to the connector terminal on the front. You can now easily access all signals of interest.

Notice

Initially only a few signals are connected to the terminal on the front. Please feel free to connect other signals of interest as described above.

Function generator, lock-in amplifier or similar devices can be connected in the same way as the oscilloscope.

To connect an oscilloscope to your system please follow the table below.

mode	channel 1	channel 2
STM measurement	IT MON (DC mode)	Z MON (AC mode)

Table 6. Oscilloscope cabling.

Caution

Always use the Z MON socket on the DRB/SCAR board for connecting the oscilloscope. Do not use the Z MON signal from the PDC board as this is intended for fault finding measurements only.

Getting Started

- Check the cabling, see respective hardware manual.
- Switch on the MATRIX CU.
- Switch on the oscilloscope if used.
- Switch on the computer.
- Start the MATRIX software.

Running an Experiment

- Select a Project from the main window toolbar .
- Select an Experiment from the Project window toolbar .
- Upload the Experiment to the MATRIX CU → .
- Start the coarse approach procedure suggested in your SPM head manual.
- Choose a feedback and loop gain setting appropriate for your experiment and sample.
- Click in the Experiment state control field.
- Now try playing around with the parameters accessible from the *XY Scanner* window and watch the Channel displays.

Once you are happy with the appearance of the scan

- Select the channels to be saved in the *Channel List*.
- Tick the save data box in the *XY Scanner* window.

Notice

One data point takes 4 bytes of storage space on your harddisk. This means that a 1000 x 1000 pixel topographic scan occupies about 4 Megabytes. A spectroscopic channel may, however, be much larger! Measuring 250 spectroscopic data points for every pixel position in the above raster and storing both directions requires 2 gigabyte of harddisk space!

Attention

Always take the tip away from the surface (+Z) before closing MATRIX.

Help System

In addition to printed manuals MATRIX offers two types of pop-up help: ToolTips and context sensitive help. ToolTips appear when you move the mouse pointer over an input box or a button. A ToolTip gives a very short explanation of the item in question.

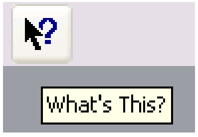


Figure 140. Context sensitive help button and corresponding ToolTip.

For more information click the "What's this" help icon  or press Shift+F1 on your keyboard and click on the item of interest. Note that the mouse pointer changes into a special symbol with a question mark attached.

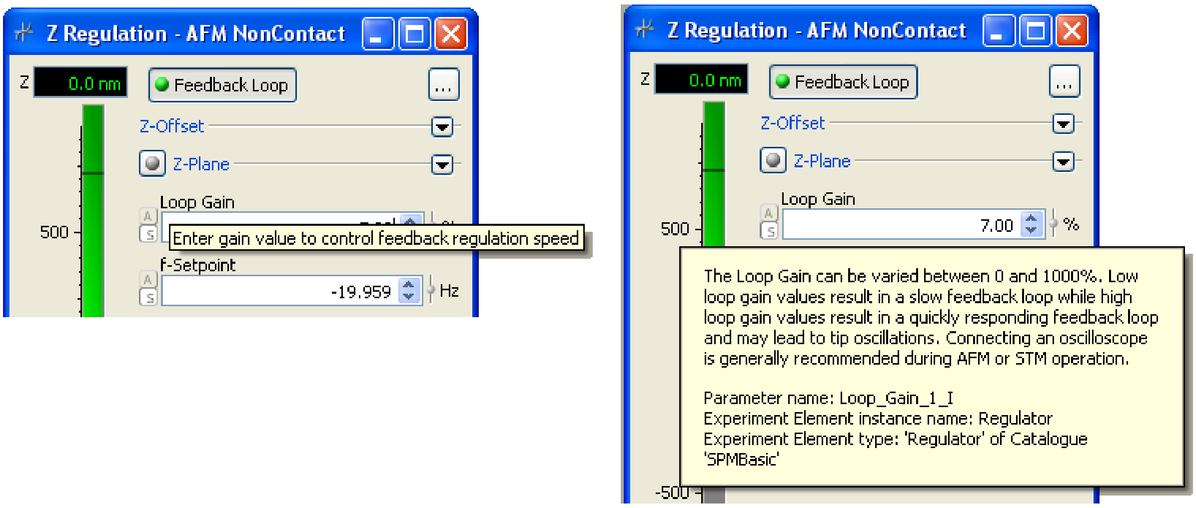


Figure 141. ToolTip and Context sensitive help or What's This help for the Loop Gain parameter in the *Regulator* window.

12. Appendix

MATRIX File Path Systematic

The entire matter of paths is complicated business, even more so as it depends on the operating system and the language of the operating system. MATRIX has three important paths that are relevant when manually handling data files:

- The **installation directory**, denoted as **<InstallDir>**, where the executable file resides and where the licence files go.
- The **temporary directory**, denoted as **<TempDir>**, where the log files are saved.
- The **persistence root directory**, denoted as **<RootDir>**, where instrument descriptions and data files go.

MATRIX uses the system defined environment variables %TMP%, %APPDATA%, %PROGRAMFILES% and %PROGRAMFILES(X86)% to generate the above paths. The schema works as follows:

Installation Directory

Windows XP: %PROGRAMFILES%\<Company Name>\<Application Name>\<Software Version>\
Windows 7 (32 bit): %PROGRAMFILES(X86)%\<Company Name>\<Application Name>\<Software Version>\

Temporary Directory

Windows XP & Windows 7: %TMP%\Temporary <Application Name> Files\ <Software Version>\

Persistence Root Directory

Windows XP & Windows 7: %APPDATA%\<Company Name>\<Application Name>\default\

Place Holders

<Company Name> = "Omicron NanoScience" (used to be "Omicron NanoTechnology" in V3.1 and earlier)
<Application Name> = "MATRIX" (or "Vernissage")
<Software Version>: = "V3.2" (used to be "V3.1" or lower)
<Account Name>: = "Omicron" (default super user), "Matrix" (default user) or your personal user name

Environment Variables

The environment variables can be accessed by typing their name, including both % signs, in the address line of the Windows Explorer. Their contents depends on the operating system, its language and the account user name under which you work.

Examples

The following table gives examples for the different paths for the two common operating systems (old and new) as installed by Omicron.

Windows XP (English)	
<InstallDir>	C:\Program Files\Omicron NanoScience\MATRIX\V3.2\
%TMP% <TempDir>	C:\temp\ C:\temp\Temporary MATRIX Files\V3.2
%APPDATA% <RootDir>	C:\Documents and Settings\<Account Name>\Application Data\ C:\Documents and Settings\<Account Name>\Application Data\Omicron NanoScience\MATRIX\default\
Windows 7 (32 bit, English)	
<InstallDir>	C:\Program Files (x86)\Omicron NanoScience\MATRIX\V3.2\
%TMP% <TempDir>	C:\Users\<Account Name>\AppData\Local\Temp\ C:\Users\<Account Name>\AppData\Local\Temp\Temporary MATRIX Files\V3.2
%APPDATA% <RootDir>	C:\Users\<Account Name>\AppData\Roaming\ C:\Users\<Account Name>\AppData\Roaming\Omicron NanoScience\MATRIX\default

Table 7. Important paths used by MATRIX.

Changing Calibration Data

Although each MATRIX kit contains carefully assembled calibration data for Omicron equipment, it might become necessary to either adjust the predefined data shipped with the kit, or to even introduce new calibration data sets. Thus, understanding and using the calibration mechanisms of the MATRIX system can be important under certain circumstances.

To understand the calibration concepts, you need to be familiar with the following entities:

- Devices
- Transfer functions
- Instruments
- Calibration data sets
- Parameter sets

The subsequent sections detail these entities and the underlying concepts.

Devices and Transfer Functions

The MATRIX system uses *Devices* to represent hardware resources. A Device is a virtual entity that is associated with a particular resource or functionality, such as an Analogue-to-Digital converter (ADC), a Digital-to-Analogue converter (DAC), a switch (e.g. a preamplifier range selector, a filter selector, etc.) or similar. Some Devices can be written to (for example, if the respective resource can be written to, such as a DAC), others are read-only (this is true for Devices associated with an ADC); there are also Devices that both accept a value but can be read also. When writing to a Device, the status of the associated hardware resource is changed according to the value written. Reading from a Device will obtain the status of the associated resource, e.g. the current value of an ADC.

Two different types of Devices can be distinguished: a *Raw Device* represents a resource from the hardware perspective. When read, a Raw Device will deliver a value "as is", i.e. as maintained by the respective resource. In most cases, such a value is meaningless for a MATRIX user, as it is just a number without an obvious relationship to some physical value. For example, a Raw Device associated with an ADC could represent a voltage of 5 V by the value "16535". Vice versa, when writing to a Raw Device, one has to supply a value that will be accepted by the associated hardware resource.

Physical Devices represent physical values such as 5 volts, 100 hertz, $4 \cdot 10^{-9}$ amperes, 5 seconds, etc. Each Physical Device is always associated with one or more Raw Devices; thus, a Physical Device can be viewed as a "wrapper" for its associated Raw Device(s). When writing to a Physical Device, the value provided will be first converted to a value suitable for the associated Raw Device, and afterwards been written to that Raw Device. Reading from a Physical Device will first cause the associated Raw Device to be queried, the value obtained will then be converted to a physical value.

The process described above utilises a *Transfer Function* for converting physical values to values accepted by a Raw Device and vice versa. A Transfer Function thus determines how a physical value is turned into a "raw value". By reversing the Transfer Function, a "raw value" can be converted to a physical value.

The MATRIX system supports arbitrary types of Transfer Functions, however, only three different types are currently used; these types are described in table 8 on page 140. (Details regarding the Transfer Function parameters are discussed below.)

Type	Description	Mathematical Representation
TFF_Linear1D	Linear Transfer Function, one Raw Device	$r = f \cdot p \cdot f_{post} + n$
TFF_MultiLinear1D	Linear Transfer Function, two Raw Devices	$r = ((f_n \cdot f_{pre}) / (r_0 - n_{pre})) \cdot p \cdot f_{post} + n$
TFF_Identity	Identity transfer function	$r = \varphi$

Table 8. Transfer Function Types.

The calibration process for some resource simply requires to determine the type and parameters of a Transfer Function that relates the Raw Device representing the resource in a suitable manner to its Physical Device. This process is detailed below.

Instruments and the Instrument Description

The term *Instrument* refers to a combination of microscopy equipment and MATRIX CU electronics resources. From the software perspective, an Instrument is just a collection of Devices that represent the capabilities of both the microscope and its control unit.

The characteristics of an Instrument are specified by an *Instrument Description*. Each Instrument Description provides information about the Physical Devices supported, the Raw Devices associated with these Physical Devices, and the Transfer Functions that relate raw values to physical values. Instrument Descriptions take the form of XML-encoded files that typically use the file extension ".inst" and that are located in the "Instruments" folder of a MATRIX user's directory hierarchy

<RootDir>\Instruments

The default Instrument Description template suitable for Omicron equipment can be found in the file "SPM.inst" of a MATRIX installation

<InstallDir>\Templates\Common\Instruments\Core.

For details on file path settings please refer to page 138f. An Instrument Description file consists of several sections but only the following two are relevant for calibration purposes:

1. A *Device Map*, i.e. a list of Physical Devices and their attributes (name, unit of physical values, and type of values). For each Physical Device, the Device Map also specifies the associated Raw Device(s). Note: The number and characteristics of Raw Devices is not declared in an Instrument Description but automatically determined by the MATRIX system; each MATRIX CU reports the Raw Devices it supports during the start-up process.

2. A list of *Calibration Data Sections* and *Parameter Sets*. Calibration Data Sections as well as Parameter Sets contain calibration information: For each Raw Device referenced by some Physical Device, the Transfer Function type and the function parameters are determined. The difference between Calibration Data Sections and Parameter Sets is thus just an organisational one, as Parameter Sets are always part of a Calibration Data Section. (The interpretation and use of Calibration Data Sections and Parameter Sets is beyond the scope of this document. However, it is worth mentioning that Omicron mostly uses Calibration Data Sections as containers for a specific methodology/preamplifier combination such as "STM for SPM PRE 4", while Parameter Sets represent a particular microscopy equipment, e.g. a VT AFM instrument.)

Regarding the instrument descriptions collection shipped as part of each MATRIX kit (i.e. the contents of the "SPM.inst" file), calibration information for a particular microscope can be changed by modifying the respective Parameter Set. More precisely, the Transfer Function parameters of a specific Physical Device are adapted; the respective parameters are part of a specific Parameter Set representing some microscope.

For example, the Parameter Set "LT STM" (variant "LHe") found in "SPM.inst" describes the Transfer Function parameters for the Raw Devices associated with Physical Devices representing X, Y, X/Y, and Z actuators of an LT STM microscopy operated at the temperature of liquid Helium (LHe).

Determining Transfer Function Characteristics

Calibrating the MATRIX system means determining the characteristics of the Transfer Functions utilised to "bridge" Raw Devices and Physical Devices. The type of Transfer Function required for converting "raw values" into physical values and vice versa is usually fixed (i.e. determined by the characteristics of the hardware resource associated with a particular Raw Device) and thus does not have to be changed, however, the Transfer Function parameters may vary with respect to customer installations.

For example, the X- and Y-axis calibration of a given scanner might need adoption, because the original calibration does not match an actual installation for some reason. The Physical Devices controlling the respective piezo actuator hardware are called X and Y and can be found in the Device Map section of an Instrument description:

```
<PhysicalDevice name="X" unit="m" valueType="double">
  <Device name="X_Axis"/>
</PhysicalDevice>
<PhysicalDevice name="Y" unit="m" valueType="double">
  <Device name="Y_Axis"/>
</PhysicalDevice>
```

Both Physical Devices use values of type "double" (actually double-precision floating point figures compliant with the IEEE standard) and their unit is "m" (metre). There is one Raw Device associated with each Physical Device; these are called X_*Axis* and Y_*Axis*.

Depending on the microscopy equipment used, different Transfer Function parameters are required for the above Raw Devices. For example, for an Omicron LT STM microscope operated at the temperature of liquid nitrogen an extract of the respective Parameter Set would look similar to the code below.

```
<ParameterSet name="LT STM" variant "LN2" description="Liquid N2">
  <DeviceParameters device="X_Axis">
    <TransferFunction name="TFF_Linear1D"/>
      <Parameter name="Factor" type="double" value="1.193e+15"
       unit="m"/>
      <Parameter name="Offset" type="double" value="0" minimum="0" maximum="0"
       unit="none"/>
      <Parameter name="PostFactor" type="double" value="1" unit="none"/>
  </DeviceParameters>
  <DeviceParameters device="Y_Axis">
    <TransferFunction name="TFF_Linear1D"/>
```

```
        <Parameter name="Factor" type="double" value="1.193e+15"
         unit="m"/>
        <Parameter name="Offset" type="double" value="0"
         unit="none"/>
        <Parameter name="PostFactor" type="double" value="1" unit="none"/>
    </DeviceParameters>
                .
                .
                .
  </ParameterSet>
```

For both Raw Devices, a linear transfer function (identified by the type code *TFF_Linear1D*, see table 8 on page 140) will be used for value conversion. This function can be expressed by the below formula:

$$r = f \cdot p \cdot f_{post} + n$$

with r being the "raw value", p being the physical value and f_{post} being the PostFactor. The parameters f and n represent the gradient factor and the offset of the linear function and are called "Factor" and "Offset" in an XML Instrument Description file. Thus, the above Parameter Set describes the below equations:

$$X\_Axis = 1.193 \cdot 10^{15} \cdot X \cdot 1 + 0$$

$$Y\_Axis = 1.193 \cdot 10^{15} \cdot Y \cdot 1 + 0$$

To change the calibration, a different gradient and/or offset must be specified.

In order to determine the function parameters, some details regarding the system behaviour must be known. In case of the X/Y piezo actuators, the following information is required:

- The scanner has bipolar characteristics
- The X/Y sensitivity of the scanner is 6 nm/Volt
- The gain factor for the X/Y direction applied by the piezo driver hardware is 15
- The Raw Devices X_*Axis* and Y_*Axis* both support a value range from -2^{31} to $+2^{31}$, which is equivalent to –10 to +10 Volts at the respective DAC output.

Using this information, we can compute the gradient factor by dividing the maximum "raw value" of the Raw Device by the maximum scanner deflexion, and set up the equation below:

$$f = r_{max} / p_{max}$$

$$f = (2^{31} \cdot 2) / (2^{\dagger} \cdot 2 \cdot 10 \text{ [Volt]} \cdot 15 \cdot 6 \text{ [nm/Volt]})$$

$$f = 2^{31} / (2 \cdot \pm 10 \text{ [Volt]} \cdot 15 \cdot 6 \text{ [nm/Volt]}) = 1\,193\,046 \text{ [1/nm]} = \underline{1.193 \cdot 10^{15} \text{ [1/m]}}$$

Note: The "offset" parameter can be assumed to be zero, as permanent offsets are rarely found currently.

For calibrating the Z-axis sensor of a scanner (sensitivity 8.3 nm/V, Z gain factor 10.8, Raw Device value range -2^{31} to $+2^{31}$) we'll thus yield:

$$f = 2^{31} / (\pm 10 \text{ [Volt]} \cdot 10.8 \cdot 8.3 \text{ [nm/Volt]}) = 2\,395\,675 \text{ [1/nm]} = \underline{2.396 \cdot 10^{15} \text{ [1/m]}}$$

For an arbitrary Raw Device that maps a signed 32 Bit integer value (i.e. a value ranging between -2^{31} and $+2^{31} - 1$) to a voltage range of –10 to +10 Volts in a linear fashion, the gradient can be computed as follows:

$$f = r_{max} / p_{max} = (2^{31} - 1) / 10 \text{ [Volt]} = \underline{2.148 \cdot 10^{8} \text{ [1/Volt]}}$$

[†] Due to bipolar characteristics.

A more complex situation involves Physical Devices that are associated with two Raw Devices. The most prominent example for such a Physical Device is *IT_Image*, a device for inquiring the tunnelling current for imaging purposes that is used as a sensor device by many experiments. The device *IT_Image* is associated with two Raw Devices, *IT_Image* and *IT_Preamp_Range*. The first Raw Device supports signed 32 Bit integer values for representing the tunnelling current, the latter Raw Device represents a switch and accepts the values "1" and "0" only. As this switch controls the range selector of the tunnelling current preamplifier (e.g. "1" = selector set to range 0 ... 3 nA, "0" = selector set to range 0 ... 333 nA) its setting impacts on the interpretation of the value of device *IT_Image*. As a result, the physical value must be computed by taking the current value of both Raw Devices into account.

The Transfer Function supporting such scenarios is referred to as "Multiplier Linear Transfer Function" and takes the following form:

$$r = ((f_n \cdot f_{pre}) / (r_0 - n_{pre})) \cdot p \cdot f_{post} + n$$

With:

- r — "Raw value" obtained from "main" Raw Device (i.e. *IT_Image* in case of the tunnelling current example)
- r_0 — "Raw value" obtained from "dependent" Raw Device (i.e. *IT_Preamp_Range* in case of the tunnelling current example)
- p — Physical value
- f_{pre} — PreFactor
- f_n — NeutralFactor
- n_{pre} — PreOffset
- n — Offset
- f_{post} — PostFactor (optional)

The parameters "PreFactor", "NeutralFactor", and "PreOffset" must be determined so that the correct "main raw value" is obtained for a given physical value, and the current state of the dependent Raw Device. For the *IT_Image* Physical Device, this involves the steps outlined subsequently:

Determining the neutral factor is equivalent to determining the gradient of the function. For the tunnelling current Physical Device we can thus write:

$$f_n = r_{max} / p_{max}$$

$$f_n = (2^{31} - 1) / (10\ [\text{Volt}] \cdot 33.3\ [\text{nA/Volt}]) = 6\,448\,899\ \ [1/\text{nA}] = \underline{6.449 \cdot 10^{15}\ \ [1/\text{A}]}$$

In the above expression, we have assumed that the preamplifier represents the maximum current by an output voltage of 10 V, and that a change of 1 Volt actually represents a tunnelling current change of 33.3 nA in the "high range" preamplifier mode. Note that the maximum "raw value" is $2^{31} - 1$, as the Raw Device *IT_Image* uses 32 Bit signed integer values.

The PreFactor and PreOffset parameters have to be set so that a physical value of i.e. 100 nA is mapped to the same "raw value" as a value of 1 nA if the value of the dependent Raw Device is "0" for 100 nA, and "1" for 1 nA. This can be easily achieved by setting the PreFactor to 1.01, and the PreOffset to –0.01. For example, we would yield:

$$r = ((f_n \cdot f_{PRE}) / (r_0 - n_{PRE})) \cdot p + n$$

$$r = (\underline{6.449 \cdot 10^{15}}\ [1/\text{A}]) \cdot (1.01) / (0 + 0.01) \cdot (1 \cdot 10^{-9}\ \ [\text{A}]) \approx \underline{6.5 \cdot 10^{8}}$$

$$r = (\underline{6.449 \cdot 10^{15}}\ [1/\text{A}]) \cdot (1.01) / (1 + 0.01) \cdot (100 \cdot 10^{-9}\ \ [\text{A}]) \approx \underline{6.5 \cdot 10^{8}}$$

Note that with the exception of the tunnelling current sensor device, the gap voltage DAC device, and the tunnelling current setpoint device, all Physical Devices currently used by the MATRIX system use the plain linear Transfer Function.

In practice, the scanner devices are the most likely candidates for re-calibration. However, when using special preamplification equipment the sensor devices might be subject for re-calibration also. The respective Raw Devices are listed in table 9 on page 144.

Name	Description
X_Axis*	32 Bit signed integer device controlling the scanner actuator for the X-axis; PostFactor = 1
X-Crosstalk*	32 Bit signed integer device controlling the scanner actuator for the X-axis; PostFactor = 1 • e^{-20}
Y_Axis*	32 Bit signed integer device controlling the scanner actuator for the Y-axis; PostFactor = 1
Y-Crosstalk*	32 Bit signed integer device controlling the scanner actuator for the Y-axis; PostFactor = 1 • e^{-20}
Z_Out*	32 Bit signed integer device controlling the scanner actuator for the Z-axis; PostFactor = 1
Z_In	32 Bit signed integer device representing the Z-axis sensor signal
IT_Image	32 Bit signed integer device for obtaining the tunnelling current. Must be used in conjunction with *IT_Preamp_Range*
Setpoint_I	32 Bit signed integer device for controlling the tunnelling current regulator setpoint. Must be used in conjunction with *IT_Preamp_Range*
VGap_Out	32 Bit signed integer device for controlling the gap voltage. Must be used in conjunction with *VGap_Preamp_Range*
ADC1_In	32 Bit signed integer device for accessing sensor data in AFM mode, such as F_n or F_l
ADC2_In	32 Bit signed integer device for accessing sensor data in AFM mode, such as F_n or F_l
ADC3_In	32 Bit signed integer device for accessing sensor data in AFM mode, such as damping or ΔF
ADC4_In	32 Bit signed integer device for accessing sensor data in AFM mode, such as damping or ΔF
$F_n - F_n0$*	32 Bit signed integer device for accessing "Force Normal" data in AFM mode; PostFactor = 1
Fl – Fl0*	32 Bit signed integer device for accessing "Force Lateral" data in AFM mode; PostFactor = 1

Table 9. Important Raw Devices
*) The asterisk marks the devices that use the optional PostFactor.

Crosstalk Compensation

Scan stages based on piezo actuators can experience crosstalk effects: When deflecting the probe in X-direction, the Y-axis position may also change to a certain degree, and vice versa. This behaviour, although unwanted, can most often be ignored, as it does not impose significant scan errors.

When utilising certain scan stages, however, provisions should be taken for compensating crosstalk effects. MATRIX from version V2.1 supports a dedicated scanner crosstalk compensation facility by providing two devices called X_Crosstalk and Y_Crosstalk. By choosing an appropriate value for the parameter factor of the transfer function associated with these devices, crosstalk effects between the X– and Y-axis of a scan stage can be eliminated.

For a crosstalk compensation procedure you'll need a well-known sample surface, e.g. a standard checkerboard sample, figure 142 A shows a graphical representation. In case of a crosstalk problem the recorded image will show a deformed pattern, see figure 142 B. Since crosstalk normally works in both directions, we recommend splitting the measured distortion and correcting both axes, see figure 142 C.

The correction factor can be calculated from the distortion angle via the tangent function:

$$\tan(11.4°) = 0.20 \text{ (i.e. the crosstalk is 20\%)}$$

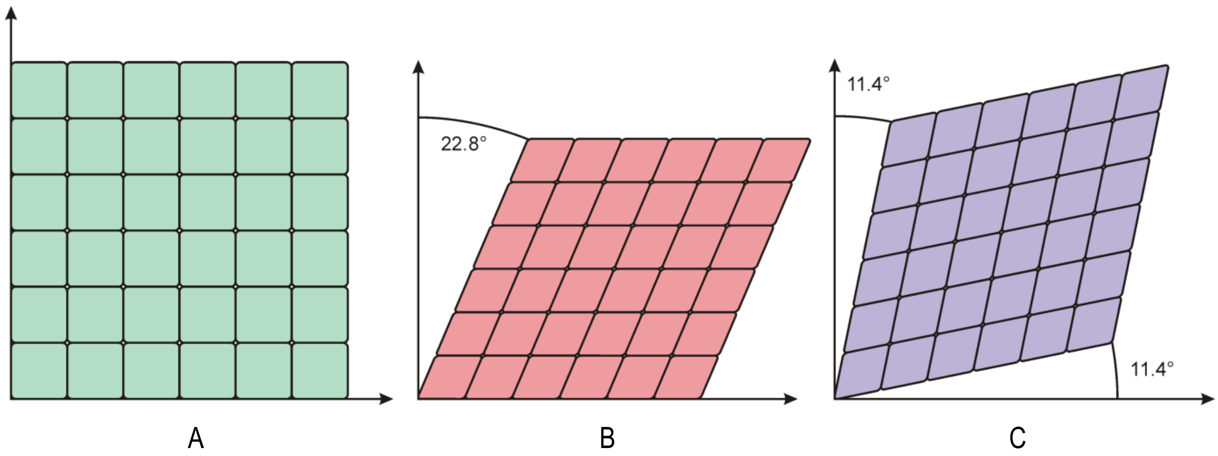


Figure 142. Crosstalk effects on a checkerboard sample, schematic diagram.

To set up the transfer function parameter factor of the devices X_Crosstalk and Y_Crosstalk, follow the procedure below:

- Determine the crosstalk of X– and/or Y-axis by analysing a topography image of a known sample. The MATRIX software expects the crosstalk to be expressed as a factor describing the actual scan axis deflection, e.g. 0.2 would mean a crosstalk of 20% from one axis to the other.

- Multiply the value of the scanner's X_Axis device transfer function parameter factor by the crosstalk value caused by the X-axis (e.g. $4.772214 \cdot 10^{14} \cdot \mathbf{0.2} \cdot 1.0 \cdot e^{-20}$). Use the result as value for the device transfer function parameter factor of the device X_Crosstalk.

- Likewise, multiply the value of the scanner’s Y_Axis device transfer function parameter factor by the crosstalk value caused by the Y-axis. Use the result as value for the device transfer function parameter factor of the device Y_Crosstalk.

Sampler

MATRIX provides an additional Experiment Element that is not accessible from the standard GUI because its panel is not part of any window of the standard MATRIX experiments. The so-called *Sampler* can be used to sample any MATRIX CU data source such as an analogue-to-digital converter (ADC) component. In contrast to the Experiment Element *Channel* the *Sampler* is not able to acquire data at high sample rates and neither supports storing acquired data as part of a result file, nor does it allow online data processing. The main purpose of the *Sampler* is to support access to acquired data from within MATE scripts. However, the element can also be used to provide a continuous live value display for monitoring purposes, e.g. for sample temperatures.

Adding *Sampler* Instances

To add one or more instances to any experiment you have to edit the experiment structure description file (e.g. "STM_Spectroscopy.exps") and insert a declaration similar to the one shown below:

```
<ExperimentElementInstance name="Aux" elementType="Sampler"
                           catalogue="SPMBasic">
  <DeploymentParameter name="Device" value="Default:ADC4_In"/>
  <DeploymentParameter name="Label" value="ADC 4"/>
</ExperimentElementInstance>
```

The above ExML fragment declares an instance of *Sampler* called "Aux". The new instance will acquire data via the physical device "ADC4_In" of the instrument "Default", which is actually associated with the ADC #4 of a MATRIX CU board of type U-SCB (or SASS).

For visualisation purposes the Experiment Element also supports the specification of an identification label; in the above example, this label is "ADC 4".

The following code example demonstrates how to declare two instances of the Experiment Element *Sampler* that will acquire data from the two auxiliary ADC components of the MATRIX CU DRB (or SCAR) hardware:

```
<ExperimentElementInstance name="Aux1" elementType="Sampler"
                           catalogue="SPMBasic">
  <DeploymentParameter name="Device" value="Default:Aux1_In"/>
  <DeploymentParameter name="Label" value="Aux 1"/>
</ExperimentElementInstance>
<ExperimentElementInstance name="Aux2" elementType="Sampler"
                           catalogue="SPMBasic">
  <DeploymentParameter name="Device" value="Default:Aux2_In"/>
  <DeploymentParameter name="Label" value="Aux 2"/>
</ExperimentElementInstance>
```

Adding Panels

The only panel supported by the Experiment Element is also called "Sampler" and consist of a single value display (with the text label mentioned above) and a context menu. The context menu allows you to enable or disable the data acquisition process and provides access to the additional Experiment Element parameters.

To show a *Sampler* display on the graphical user interface, add the panel to an existing window by editing the experiment description file of the respective experiment, e.g. "STM_Spectroscopy.expd". (As the panel is actually quite small, using a separate window is not recommended unless you place several *Sampler* panels in the same window.)

The following ExML code fragment shows an example for declaring the *Sampler* panel if the Experiment Element instance has been named "Aux":

```
<Panel name="Aux" experimentElementInstanceName="Aux"
                  panelType="Sampler">
</Panel>
```

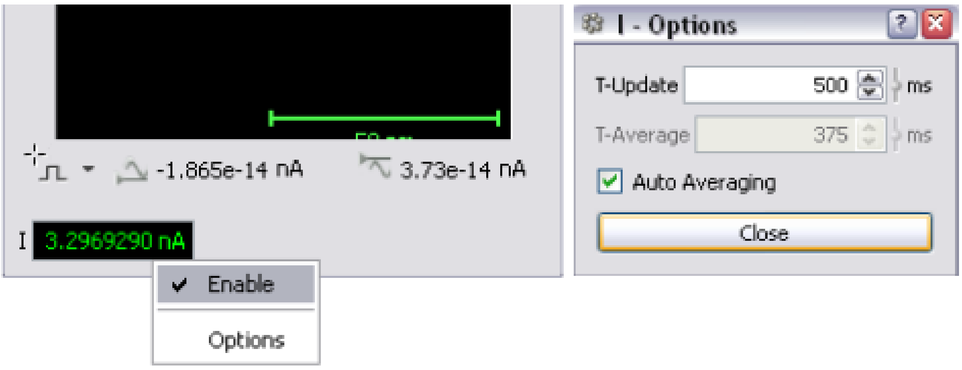


Figure 143. A *Sampler* element with label "I" has been defined and added to a channel display. The *Options* window is accessible via the context menu.

Parameters

The Experiment Element *Sampler* supports the following parameters:

- `Enable` *(Boolean)* — Controls the state of the Experiment Element. If set to *true* the element will enable the periodic sampling of data. If set to *false* the sample process will be disabled.

- `Sample_Period` *(Double-precision floating point)* — Determines the sampling frequency (maximum is 100 samples per second, i.e. 100 Hz).

- `Averaging_Period` *(Double-precision floating point)* — Specifies the period during which the Experiment Element will continuously sample and average the associated device. The averaging period must be shorter than the sample period specified by means of the parameter `Sample_Period`.

- `Auto_Averaging` *(Boolean)* — If set to *true* the Experiment Element automatically determines the sample-and-average period to be used. If set to *false* the Experiment Element uses the period specified via the parameter `Averaging_Period` described above.

Query parameter value:

```
function readSample ()
{
  return Aux.Sample;
}
```

Using an entity observer:

```
function Aux.Sample (val)
{
  // The new sample is available
  // in variable 'val'
  …
```

In a MATE script, you may either obtain the most recent sample by inquiring the current value of parameter `Sample`, or use an entity observer function that gets triggered each time a new sample becomes available. The MATE script code fragments above demonstrate both options.

Supplemental Instrument Descriptions

Instrument descriptions can be distributed across different files. While the Omicron microscopy hardware support is still provided by so-called *core* instrument descriptions, *supplemental* instrument descriptions allow extending any of the core instrument descriptions by additional calibration data sets and calibration parameter sets without modification of the core instrument description files. This policy is also reflected by a dedicated directory structure for storing instrument descriptions. For details on file path settings please refer to page 138f.

The core and supplemental instrument descriptions are stored separately in dedicated directories; provided that the default installation path was not changed by the user, the respective paths are:

```
<InstallDir>\Templates\Common\Instruments\Core
<InstallDir>\Templates\Common\Instruments\Supplemental
```

Attention

Do not delete/damage the files in the "`Templates\Common\Instruments\Core`" folder!

While the sub-directory "Core" contains the instrument description collection for instrument "Default" (*SPM.inst*), the sub-directory "Supplemental" is initially empty.

Note that MATRIX generates an SPM.inst file in your user directory tree when you select "Save project data" from the *File* menu or click Ok in the respective message box that pops up when you close MATRIX down. For a standard installation your "user directory tree" will be:

```
<RootDir>\Instruments
```

The load procedure for instrument descriptions works as follows:

- If MATRIX upon startup finds an *SPM.inst* file in the MATRIX user directory tree, see above, it will load this file. If you have created new supplemental instrument descriptions after generating the *SPM.inst* file, these will not be included. To get the new supplemental instrument descriptions loaded you have to delete your old *SPM.inst* file in you user directory tree before startup.

- If MATRIX finds no instrument descriptions (i.e. no *SPM.inst* file in you user directory tree), the software will generate a new user-specific *SPM.inst* file by collecting the core and supplemental instrument descriptions from the *Templates* section of the MATRIX software installation directory tree. The resulting instrument description set will be used for the session and can be stored as *SPM.inst* in the MATRIX user directory tree by saving the session (select *Save all* from the *File* menu of the MATRIX main window).

The main advantage of this approach to instrument management is that support for customised or customer-supplied instruments can be easily integrated into an existing MATRIX installation. By placing the respective instrument description files in the "Supplemental" sub-directory, users can extend the range of supported calibration data sets without modifying the Omicron-supplied instrument descriptions.

Add Supplemental Instrument Descriptions

If you have created or received additional calibration data sets and/or calibration parameter sets from Omicron, please follow the steps below:

1. Copy the descriptions files to the following directory in your installation tree:

<InstallDir>\Templates\Common\Instruments\Supplemental

2. Delete the old *SPM.inst* file in you user directory tree

<RootDir>\Instruments

3. Start MATRIX.

Note that this operation is required only once: since the MATRIX software upgrade processes do not modify the contents of the supplemental instrument descriptions directory, all additional descriptions you provide will be kept, even after future software upgrades.

Extending Calibration Data Sets

Users may directly modify the calibration of the *X*–, *Y*– and *Z*-axis of a scan stage without editing the underlying instrument descriptions manually. Calibration data modification is based on user-supplied correction factors, which will be stored permanently when saving the MATRIX session state.

The stage calibration panel offers a number of numerical value entry fields for specifying various correction factors. Select *Stage Calibration* from the *Window* menu of a Project window in order to access the stage calibration panel.

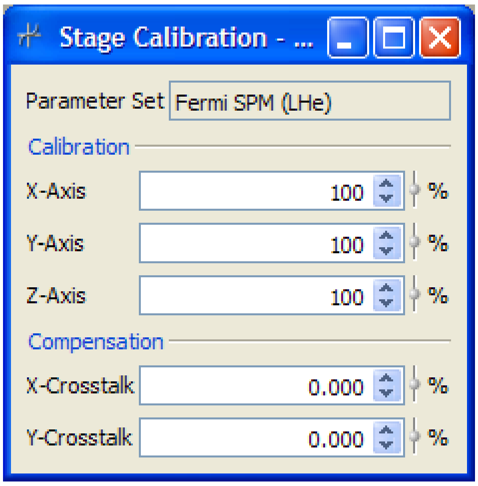


Figure 144. *Stage Calibration* window, example shown.

From the *Stage Calibration* window, the following operations can be initiated:

- Reduce or increase the calibrated scanner deflection in *X*– and *Y*-direction.
- Change the standard calibration of the *Z*-axis.
- Define crosstalk compensation factors for the *X*– and *Y*-directions.

To change the calibration of the *X*–, *Y*– and *Z*-axis, enter a percentage (ranging from 0.001% to 1000%) specifying to which degree the original deflection calibration shall be applied; the default value is 100%.

The crosstalk compensation factors are also specified as percentages; they, however, determine the degree of crosstalk that must be compensated. For example, specifying the value 20% for both factors will cause the MATRIX system to compensate a piezo crosstalk of 20%. (Please refer to page 145 for more information on how to determine the actual crosstalk of a particular scan stage.) The supported value range for the crosstalk compensation factors is –100% to +100%.

> **Notice**
>
> The MATRIX software will store modified calibration data as user-specific instrument description files each time you will store the session state e.g. by choosing “Save All” from the *File* menu of the MATRIX main window. These files are located in the “Instruments” sub-folder of the respective user account’s MATRIX file tree (*<RootDir>\Instruments*).

Supplemental Instrument Descriptions

The supplemental instrument descriptions also support the dynamic extension of existing calibration data sets. As a result, supplemental instrument descriptions can be used for integrating new calibration parameter sets (e.g. variants of existing scan stage calibration information) into the standard calibration data sets. This can be useful, for example, for the task of providing support for additional boards (such as multiple U-SCB).

> **Notice**
>
> If you have created new supplemental instrument descriptions after generating your *SPM.inst* file, these will not be included.
>
> To get the new supplemental instrument descriptions loaded you have to delete (or rename) your old *SPM.inst* file in you user directory tree before startup, see above.

A new file in the supplemental folder needs a specific structure.

- A **header** that identifies the file *.inst as an instrument description. Remember that the XML file needs to be terminated ("</Instrument>").

- A **parameter set** with modified scanner calibration values. For a calibrated scanner you should use a new name, e.g. " VT AFM calibrated"

- A **calibration data set** (defines the preamplifier used). In the calibration data set, it is necessary to reference the new scanner calibration.

Example for a Scanner Calibration

File myscanner.inst

```
<?xml version="1.0" encoding="UTF-8"?>
<Instrument xmlns="http://www.omicron.de/schema"
            xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"

            name="Default" type="MCU" version="v091301"
            manufacturer="Omicron NanoTechnology GmbH"
            description="Omicron SPM instruments">

  <ParameterSet name="VT AFM calibrated"
  description="Calibration of x,y: 15nm/Volt, z: 8.3nm/Volt, Polarity
n">

    <DeviceParameters device="X_Axis">
      <TransferFunction name="TFF_Linear1D"/>
      <Parameter name="Factor" type="double" value="4.7722e+14" unit="m"/>
      <Parameter name="Offset" type="double" value="0" unit="none"/>
      <Parameter name="PostFactor" type="double" value="1" unit="none"/>
    </DeviceParameters>

    <DeviceParameters device="Y_Axis">
```

```
      <TransferFunction name="TFF_Linear1D"/>
      <Parameter name="Factor" type="double" value="4.7722e+14" unit="m"/>
      <Parameter name="Offset" type="double" value="0" unit="none"/>
      <Parameter name="PostFactor" type="double" value="1" unit="none"/>
    </DeviceParameters>

    <DeviceParameters device="X_Crosstalk">
      <TransferFunction name="TFF_Linear1D"/>
      <Parameter name="Factor" type="double" value="1.0" unit="m"/>
      <Parameter name="Offset" type="double" value="0" unit="none"/>
      <Parameter name="PostFactor" type="double" value="1.0e-20" unit="none"/>
    </DeviceParameters>

    <DeviceParameters device="Y_Crosstalk">
      <TransferFunction name="TFF_Linear1D"/>
      <Parameter name="Factor" type="double" value="1.0" unit="m"/>
      <Parameter name="Offset" type="double" value="0" unit="none"/>
      <Parameter name="PostFactor" type="double" value="1.0e-20" unit="none"/>
    </DeviceParameters>

    <DeviceParameters device="Z_In">
      <TransferFunction name="TFF_Linear1D"/>
      <Parameter name="Factor" type="double" value="2.3957e+15" unit="m"/>
      <Parameter name="Offset" type="double" value="0" unit="none"/>
    </DeviceParameters>

    <DeviceParameters device="Z_Out">
      <TransferFunction name="TFF_Linear1D"/>
      <Parameter name="Factor" type="double" value="2.3957e+15" unit="m"/>
      <Parameter name="Offset" type="double" value="0" unit="none"/>
      <Parameter name="PostFactor" type="double" value="1" unit="none"/>
    </DeviceParameters>

    <DeviceParameters device="Z_Inverter">
      <TransferFunction name="TFF_Linear1D"/>
      <Parameter name="Factor" type="double" value="1" unit="none"/>
      <Parameter name="Offset" type="double" value="-1" unit="none"/>
    </DeviceParameters>

  </ParameterSet>

  <CalibrationData name="STM/AFM for SPM PRE 4" type="SPM PRE 4">
      .
      .
      .
      .
    <ParameterSetRef name="VT AFM calibrated"/>

  </CalibrationData>

</Instrument>
```

Example for a Scanner Calibration with Temperature Variants

```
<?xml version="1.0" encoding="UTF-8"?>
<Instrument xmlns="http://www.omicron.de/schema"
            xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"

            name="Default" type="MCU" version="v091301"
            manufacturer="Omicron NanoTechnology GmbH"
            description="Omicron SPM instruments">
```

```
  <ParameterSet name="LT STM calibrated" variant="LN2"
  description="Liquid N2; x,y: 6nm/Volt, z: 2nm/Volt, Polarity n">
      .
      .
      .
  </ParameterSet>

<ParameterSet name="LT STM calibrated" variant="LHe"
  description="Liquid He; x,y: 3.6nm/Volt, z: 1.2nm/Volt, Polarity n ">
      .
      .
      .
   </ParameterSet>

  <ParameterSet name="LT STM calibrated" variant="RT"
  description="Room temp; x,y: 20nm/Volt, z: 6.7nm/Volt, Polarity n ">
      .
      .
      .
  </ParameterSet>

  <ParameterSet name="LT STM calibrated" variant="mytemp"
  description="My Temperature; x,y: 6nm/Volt, z: 2nm/Volt, Polarity: n">
      .
      .
      .
  </ParameterSet>

  <CalibrationData name="STM/AFM for SPM PRE 4" type="SPM PRE 4">
      .
      .
      .
    <ParameterSetRef name="LT STM calibrated" variant="LN2"/>
    <ParameterSetRef name="LT STM calibrated" variant="LHe"/>
    <ParameterSetRef name="LT STM calibrated" variant="RT"/>
    <ParameterSetRef name="LT STM calibrated" variant="mytemp"/>

  </CalibrationData>

</Instrument>
```

Once you have successfully integrated your supplemental instrument descriptions you can access them in the *Calibration Options* window.

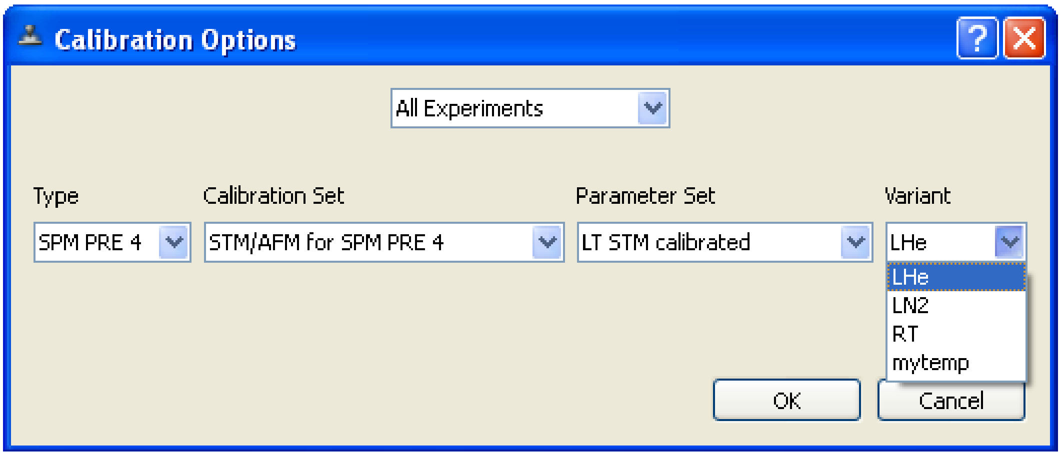


Figure 145. Calibration options with integrated supplemental calibrations.

Configuring the Proportional Part of the Feedback Loop Gain

The proportional part (*P*-part) of the feedback loop gain can be explicitly modified. However, with the exception of the Needle sensor AFM experiment, none of the standard experiments provides a user interface control for modifying the *P*-part of the feedback loop. You may use either of the below options if you require access to the proportional part of the loop gain.

MATE Access

MATE scripts (and MATE remote access client software) may use the following new parameters of the Experiment Element type *Regulator*:

- `Loop_Gain_1_P` — proportional part of loop gain of feedback loop branch #1
- `Loop_Gain_2_P` — proportional part of loop gain of feedback loop branch #2
- `Alternate_Loop_Gain_1_P` — proportional part of loop gain of feedback loop branch #1, Dual Mode option
- `Alternate_Loop_Gain_2_P` — proportional part of loop gain of feedback loop branch #2, Dual Mode option
- `Special_Loop_Gain_1_P` — proportional part of loop gain of feedback loop branch #1, special parameter set for atom manipulation and other operations
- `Special_Loop_Gain_2_P` — proportional part of loop gain of feedback loop branch #2, special parameter set for atom manipulation and other operations
- `Enable_Alternate_Loop_Gain_1_P` — Enable/disable Dual Mode for proportional part of loop gain of feedback loop branch #1
- `Enable_Alternate_Loop_Gain_2_P` — Enable/disable Dual Mode for proportional part of loop gain of feedback loop branch #2

Please refer to the MATE onscreen documentation for more information on the above parameters.

Invoking the Panel

The panel *FeedbackLoopParameterLGP* of the Experiment Element *Regulator* provides a graphical user interface control for modifying the feedback loop parameters including the proportional part of the gain. You may substitute this panel for the standard panel *FeedbackLoopParameter* used by all standard experiment descriptions.

For example, the experiment description of the simple STM experiment STM Basic (found in the description file "STM_Basic.expd") contains the following declaration:

```
<Window name="STMB_ZControl" caption="Z Regulation">
  <GuiContainer name="STMB_ZControl_Regulator_Row">
    <Layout border="noFrame" spacing="7">
      <BoxSpecification alignment="auto" direction="horizontal"/>
    </Layout>
    <Panel name="STMB_Regulator_ZMeter"
           experimentElementInstanceName="Regulator"
           panelType="ZMeter"/>
    <GuiContainer name="STMB_ZControl_Regulator_Column">
      <Layout border="noFrame" spacing="7">
        <BoxSpecification alignment="auto" direction="vertical"/>
      </Layout>
      <Panel name="STMB_FeedbackLoopBasic"
             experimentElementInstanceName="Regulator"
             panelType="FeedbackLoopBasic"/>
      <Panel name="STMB_FeedbackLoopZOffset"
             experimentElementInstanceName="Regulator"
             panelType="FeedbackLoopZOffset"/>
```

```
        <Panel name="STMB_FeedbackLoopParameter"
               experimentElementInstanceName="Regulator"
               panelType="FeedbackLoopParameter"/>
        <Stretch value="10"/>
      </GuiContainer>
    </GuiContainer>
    <Panel name="STMB_IRegulatorFilter"
           experimentElementInstanceName="STMSCBService"
           panelType="IRegulatorFilter"/>
    <Panel name="STMB_PfuControl"
           experimentElementInstanceName="CRTCService"
           panelType="PFUControl"/>
  </Window>
```

After substituting the highlighted panel type name *FeedbackLoopParameter* by *FeedbackLoopParameterLGP* and restarting the MATRIX software, the window *Z Regulation* of the respective experiment will also offer a control element pertaining to the *P*-part of the feedback loop gain, as depicted below.

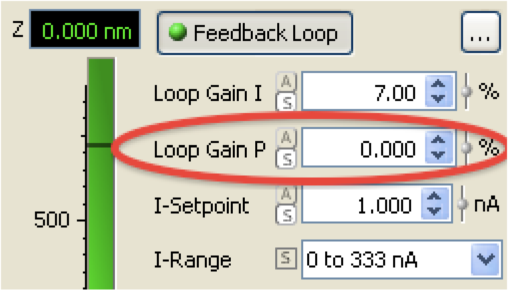


Figure 146. Value Control of Feedback Loop Gain Proportional Part.

As its counterpart, the *P*-part of the feedback loop gain is specified as a percentage; the value range supported is also 0% through 1000%.

Please note also that the following custom experiments available on the Omicron MATRIX website support the explicit configuration of the proportional part of the feedback loop gain:

- AFM_NonContact_AtomManipulation_Twin (AFM-SPU hardware required)
- AFM_NonContact_QPlus_AtomManipulation_Twin (AFM-SPU hardware required)
- AFMHybrid_NonContact_AtomManipulation_Twin (AFM-CU II hardware required)
- AFMHybrid_NonContact_QPlus_AtomManipulation_Twin (AFM-CU II hardware required)

Literature

Notice

This is **not** a complete list. Suggestions for further references are welcome.

SPM Review Publications and Books

[1] Wickramasinghe H K (1989). Scanned Probe Microscopes. *Scientific American*, October issue.

[2] Binnig G and Rohrer H (1987). Scanning Tunneling Microscopy-From Birth to Adolescence. *Rev. Mod.Phys.* **59**, No.3, Part I, page 615.

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[4] Binnig G and Rohrer H (1985). The Scanning Tunneling Microscope. *Scientific American*, August issue.

[5] Behm R J, Garcia N, Rohrer H (1990). Scanning Tunneling Microscopy and Related Methods. *NATO ASI Series E* **184**, Kluwer Academic Publishers Dordrecht, The Netherlands

[6] Hamann C, Hietschold M (1991). Raster-Tunnel-Mikroskopie (in German). Akademieverlag Berlin, Germany.

[7] Güntherodt H-J, Wiesendanger R (1992). Scanning Tunneling Microscopy I. Springer Series in Surface Science, Vol. 20. Springer Verlag Berlin, Germany.

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[9] Bonnell D A (1993). Scanning Tunneling Microscopy and Spectroscopy. VCH New York, USA.

[10] Wiesendanger R (1994). Scanning Probe Microscopy and Spectroscopy. Cambridge University Press, UK.

[11] Sarid D (1994). Scanning Force Microscopy: With Applications to Electric, Magnetic and Atomic Forces. Oxford Series in Optical and Imaging Sciences. Oxford University Press New York, USA.

[12] Bai C (1995). Scanning Tunneling Microscopy and its Application. Springer Series in Surface Science, Vol. 32. Springer Verlag, Berlin, Germany.

[13] Magonov S N, Whangbo M-H (1996). Surface Analysis with STM and AFM. VCH Weinheim, Germany

Further References

[14] Press W H, Flannery B P, Teukolsky S A, and Vetterling W T (1986). The Art of Scientific Computing. Cambridge University Press, U.K.

[15] Franke R (1982). Smooth interpolation of scattered data by local thin plate splines. Computer Mathematics with Applications **8**, 273-281

Service at Omicron

Should your equipment **require service**

- Please **contact OMICRON** headquarters or your local OMICRON representative to discuss the problem. An up-to-date address list is available on our website

  http://www.omicron.de/

- Make sure all necessary information is supplied. Always **note the serial number(s)** of your instrument and related equipment (e.g. head, electronics, preamp…) of your instrument or have it at hand when calling.

If you have to **send any equipment back to OMICRON**

- Please contact **OMICRON headquarters** before shipping any equipment.

- Place the instrument it in a polythene bag and **use the original packaging and transport locks.**

- Take out a **transport insurance policy.**

For computer equipment only:

Notice
OMICRON reserves the right to restore the computer to its original state of delivery.

- OMICRON does not accept any liability for the conservation or recovery of any data present on the computer, hard disk or any supplied data storage devices (e.g. measured data or licence information, etc.). We expect our customers to perform data backup procedures regularly. **In addition**, please carry out the following steps before shipping any computer equipment:

- If at all possible make a complete backup of all data present on your hard disk before shipping. If you need to supply a storage device (tape, disk, etc.) send a copy and keep the original.

- Make sure the computer can be run up in a stand-alone mode. This may mean that you uninstall/deactivate network configurations or external devices.

- Make sure the original passwords are re-installed or supply the current passwords by fax or e-mail.

Reporting a Problem

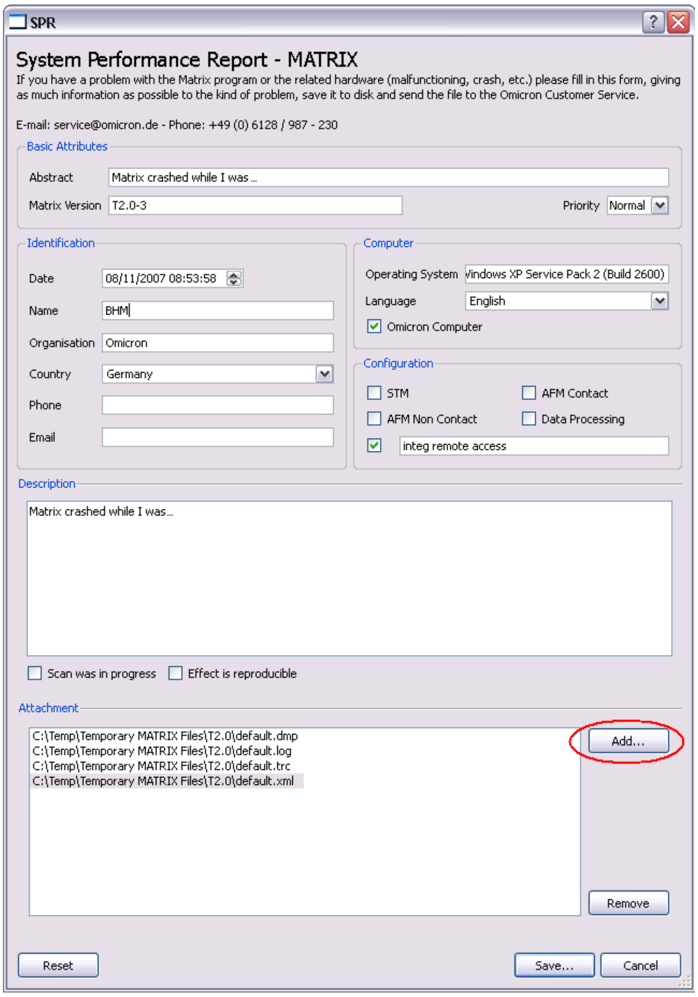
We are sorry that you have encountered a problem with MATRIX or the related hardware. In order to help us solve your problem as quickly as possible we kindly ask you to fill in the following **System Performance Report**, giving as much detail as possible. Screen shot files and the software performance report can be sent via e-mail.

Thank you for helping us to help you.

> **Notice**
>
> An interactive software performance report form for filling in on-screen is available from the *Help* menu.

Obtaining Screen Shots

- Make sure the window you want to record is active.
- On your keyboard press Alt + Print: this copies the active window to the clipboard.
- Copy it from the clipboard into WordPad (Start-Programs-Accessories-WordPad).
- Save as *.rtf file and add the file to the report using the *Add…* button. Please choose self-explanatory file names since the files will be handled by different people.



Glossary of Terms

Channel display
Display window showing incoming data of a specific measurement channel in either image mode or curves mode.

Context sensitive help
MATRIX offers two types of Pop-up help: ToolTips and Context sensitive help. To access Context sensitive help click the "What's this" help icon (↖?) or press Shift+F1 on your keyboard and click the resulting help-pointer on the Parameter of interest.

Deployment parameter
Compulsory Parameter of an Experiment Element. Every Experiment must contain a full set of Deployment Parameters.

Display
A Display is the graphical representation of data on a computer screen. Technically it is the front end of a View.

Experiment
An Experiment is an executable Element of a Project, similar to a computer program. It includes Views, Experiment Structure, Parameters, the graphical User interface (GUI) and, possibly, Scripts.

Experiment Element
Experiment Elements act as building blocks of the functionalities of an Experiment. Each Experiment Element provides some logic (e.g. a scanner provides the logic to generate a scan movement) and one or more Panel(s).

Experiment state control
The tagged Master window of an Experiment has an Experiment state control field in the bottom left hand corner. This consists of a symbol button, a Status Display and three Radio buttons.

GUI
Graphical User Interface. A GUI is that part of the program that interacts with the person on the other side of the screen/keyboard, i.e. the User.

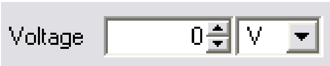
Image
A pictorial representation of a frame belonging to some data set.

Instrument
Collection of information on the microscopy hardware (SPM including electronics components) to be used for Experiments.

Master component
Every Experiment has a single "Master Component" which represents the state of the entire Experiment.

MATRIX system
The MATRIX system consists of a MATRIX control unit and a MATRIX software package.

Numerical value control
A numerical value control consists of a name tag (label), a numerical input field (spin box) and a unit field.



label spin box unit

Panel
A Panel is a fixed set of GUI controls such as buttons, sliders, Numerical value controls, etc. that have been carefully arranged by the designer of an Experiment Element.

Parameter
MATRIX knows three types of Parameters: Deployment Parameters, optional Parameters and expert Parameters. Some of these can be changed in the GUI. For each Experiment a Parameter set is loaded upon start-up.

Pop-up help
MATRIX offers two types of Pop-up help: ToolTips and Context sensitive help.

Processor
Processors provide online image processing options in order to improve the scan image appearance on the fly, i.e. while scanning. Please note that these image manipulations are for display purposes only and do not manipulate the recorded raw data.

Project
A Project is a container for a collection of Experiments. It can be used much like a sub-folder in a file system.

Radio button
A radio button is a type of graphical user interface widget that allows the user to choose one of a predefined set of options. Example: the start-stop-pause control buttons on the tagged Master Component of an Experiment are radio buttons.

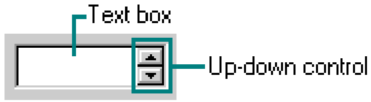
Raster
Digital size of a scan in terms of number of lines and points per line.

Scan area
Physical area to be scanned in terms of length units, rotation angle etc.

Script
Using the provided command language Scripts can be created to relate or manipulate Parameters and/or Experiment Elements, etc.

Session
A Session begins with starting the application and ends when closing it down. During a Session all loaded Projects may be accessed.

Spin box
A Spin box allows input by typing into the text box or by using the up-down control buttons.



A spin box

State of operation
The Status Display indicates the current state of the Experiment: Not Loaded, (Loading,) Stopped, Running, (Stopping,) Paused...

Status display
The tagged Master window of an Experiment has an Experiment state control field in the bottom left hand corner. This consists of a symbol button, a Status Display and three Radio buttons.

Status line
The Status line at the bottom of the window produces additional information, e.g. on the operation status of the Experiment.

ToolTip
MATRIX offers two types of Pop-up help: ToolTips and Context sensitive help. ToolTips appear when you move the mouse pointer over an input box or a button. A ToolTip gives a very short explanation of the item in question.

User
1. The person on the other side of the screen/keyboard
2. An account in MATRIX

View
A View is an operator which maps the result data in such a way that they can be visualised in a 2D Display element, e.g. by defining a 2D cut through 3D data. A View also controls the Display processors and their succession. The front end of a View is the Display.

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