MATRIX Application Manual

Version 1.3

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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.

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

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

Please note. This documentation is available in English only.

Attention: Please read the safety information on pages 8 and 9 before using the instrument.

Related Manuals
MATRIX Concept Manual
MATRIX EE Catalogue
MATRIX Release Notes
Windows XP Computer Manuals

Table 1: Related manuals.

Copyright

No part of this manual may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying and recording, for any purpose without the express written permission of Omicron NanoTechnology GmbH.

Normal Use

The **Omicron MATRIX system** is an SPM 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).

The Omicron Matrix system consists of the following subunits

1. MATRIX Control Unit (MATRIX CU)
2. Windows XP computer
3. MATRIX SPM control software

optional:

4. AFM CU II
5. Mobile computer desk/rack combination
6. 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.

Please note. 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

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 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: 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 AFM CU, MATRIX CU and computer.

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.

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

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.

> **Please note.** This manual will only cover the predefined Projects as supplied by Omicron.

The Software

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

For information on the special requirements of a specific version of MATRIX please refer to the release notes issued with the program/update.

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.

> **Please note.** When you receive your Windows PC from Omicron, all software is already installed. Additional software installation **is not necessary**.

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.

> **Please note.** Please read the Windows PC Manuals before switching on the computer and installing any software.

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.
- Wait for about one minute for the control units to boot up before starting the MATRIX software. The control unit is ready when the TFTP tool has finished data exchange.

In case of starting MATRIX software before the control units are able to communicate or with the control units switched off, the following error message appears:

```
Communication with the following control units could not be established ...
```

In this case please check the control unit and click Retry.

In case of starting MATRIX after communication channels are established but before control unit boot-up is finished, the following message is displayed on the start-up splash screen:

```
Waiting for Control Units ...
```

There is no need for any user action in this case and MATRIX will come up eventually. This may take up to 60 seconds in rare extreme cases.

In the rare case of switching off the control unit or any other major hardware failure while "Waiting for Control Units” is active, the following error dialogue requests further action:

```
Control unit … did not respond within the timeout period although it was
accessible. Please restart both the control unit and the MATRIX software.
If the problem persists, please contact Omicron service.
```

AFM Control Unit

MATRIX cannot check the boot state of the AFM control unit.

If the AFM CU is not wired correctly or not present at all, the following error message will be displayed when trying to up-load an Experiment to the control unit:

```
The physical device <device name> could not be accessed although defined
for Instrument <instrument name>. Make sure the Instrument description used
is compatible with the affected control unit and all hardware is installed
and connected properly.
```

In case of an AFM control unit present and wired correctly, MATRIX will assume the control unit is switched on and Experiments will be started normally. However, there will be no data output from the AFM CU if not switched on.

3. A Short 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 72 for a short description of special words.

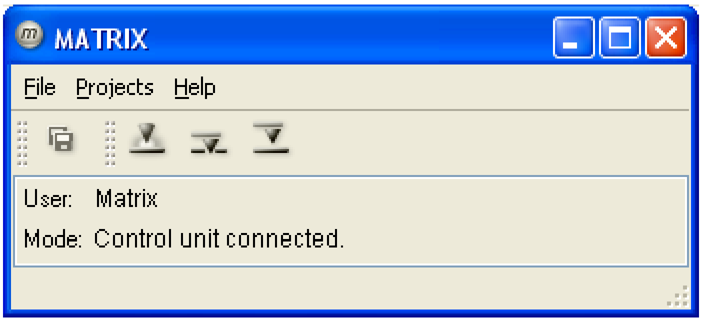


Figure 1. The Matrix main window.

Projects and Experiments

A *Project* is a container for a collection of *Experiments*. It can be use 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 started from the main window, see figure 1 above.

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 10 on page 21.

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.

Data

A novel 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, see below.

Please note. For offline data processing the MATRIX SPM Control System software includes a Scanning Probe Image Processor (SPIP) professional data analysis package from Image Metrology.

The version of SPIP used has been modified for the data formats created by the MATRIX SPM Control System and is also able to handle SCALA file formats. The package offers a variety of data processing functions such as cross-section profile analysis, histogram, calibration, correlation averaging, extended Fourier analysis, roughness analysis, grain analysis, 3D visualisation studio, batch processing, filter modules, force curve analysis, Continuous Imaging Tunnelling Spectroscopy (CITS), I/V data analysis etc.

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 SPIP 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.

Favourites Gallery

The Favourites Gallery allows a direct selection of images to be processed, rather than loading the entire data file into SPIP. 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 SPIP software.

> **Please note.** If the Store measurement box is not ticked, no image data will be stored, irrespective of thumbnails added to the favourites gallery display.

Images can be marked by right-clicking on the channel display showing the image of interest and selecting the menu item "Add to Favourites" from the context menu, see figure 29 on page 36. The Favourites Gallery window can be opened by selecting "Favourites Gallery" from the "View" menu of a Project window or directly from the icon bar.

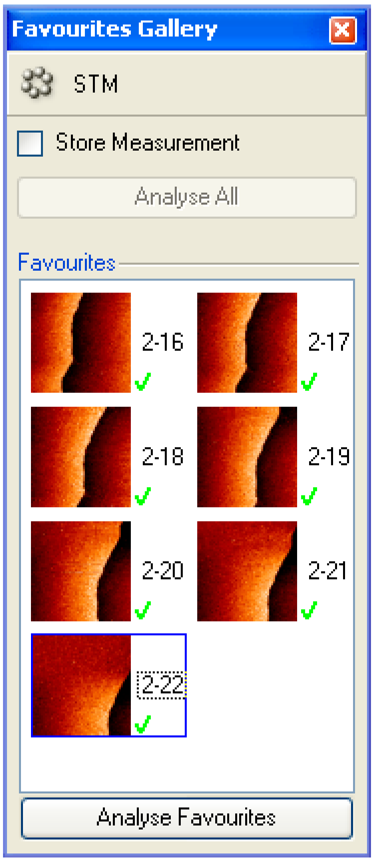


Figure 2. Favourites gallery.

The Favourites Gallery window comprises three sections:

- A checkbox to enable or disable automatic storage of measurement data. In order to save disk space, data recording can be switched off. To do so make sure the Store Measurement box is not ticked. In this case the result file only records log information, parameter changes, etc
- Two buttons for transferring images of the Favourites Gallery (all or selected) and all images produced by an experiment to the SPIP software.

- An area displaying thumbnail representations of the images that have been marked.

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.

Omicron MATRIX data can be analysed using the provided SPIP data analysis package. In order to open the latest recorded image click Analyse in the Experiment Options window, see figure 54 on page 58. For further details on the SPIP data analysis package, please refer to the SPIP manual.

> **Please note.** Every time you click Analyse from the Experiment options window, the result file is closed (and a new one opened) in order to allow SPIP to access the recorded data.

Numerical Value Control

Numerical value controls consist of a name tag or label (e.g. "Height"), a number (e.g. "100") and a unit (e.g. "nm"). There are three methods for data input into a numerical value control:

- Click on the number field to enter numerical values. For direct numerical input always press "Return" to accept the typed value.
- Use the up-down control buttons (step size can be adjusted).
- Hold down the mouse button on the numerical value control field to unfold a smart slider for convenient value adjustment. This works with all numerical value control fields.

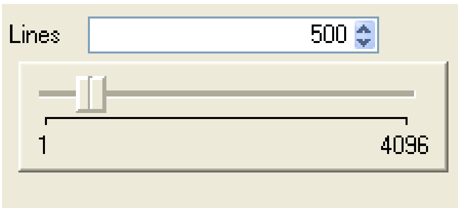


Figure 3. Unfolding slider on numerical value control "$I_{setpoint}$".

Numerical values can be applied instantly, e.g. while moving the slider, or after pressing "Return". In the latter case the numerical value is displayed in blue until it is actually applied. The behaviour of the numerical value control can be configured via the context menu.

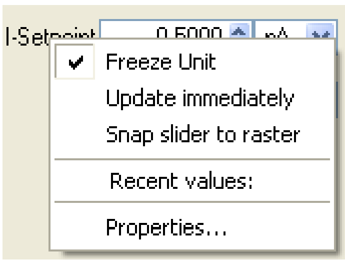


Figure 4. Context menu of numerical control.

In the example (figure 4 on page 15) the following options are available

- Freeze Unit: prevents the adaptation of the unit when entering very large or very small numbers (otherwise 10000 nm will be displayed as "10 µm").

- Update immediately: numerical values are directly uploaded to the hardware when moving the slider or using the up-down control. Note that the function "update immediately" requires extreme care when moving sliders and may cause unexpected effects.

- Snap slider to raster: allows rastered values for slider input (same raster as for up-down control). This can facilitate input if you want rounded values only. The raster size can be configured via Properties in the context menu.

- Recent values: resets the number and unit fields to their previous values (last three valid settings available). This is very useful, e.g. if you have slipped off the slider. Note that the number and unit are treated as a combined entity.

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

Properties

The properties window is available from the context menu e.g. 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.

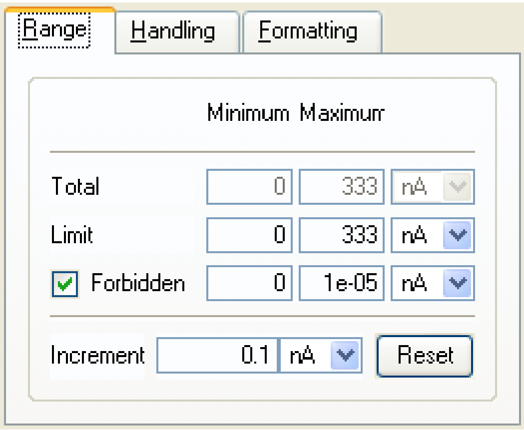
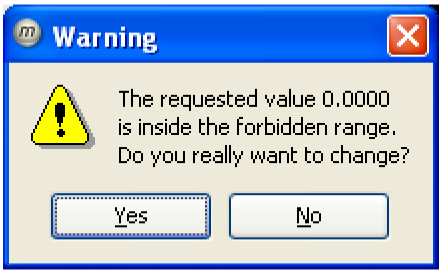


Figure 5. STM Scanner I-Setpoint properties window: Range.

The Range tab in this case shows the total parameter range provided by the software and allows setting the value control limits, a forbidden value range that you want to exclude from the up-down control and slider, e.g. zero, and the increment (step width) for the up-down control (and slider).

Please note. 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".



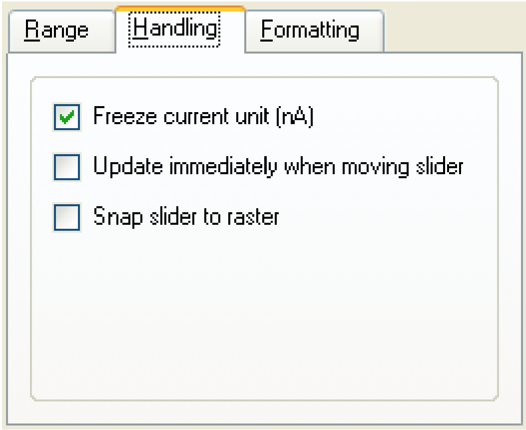


Figure 6. STM Scanner I-Setpoint properties window: Handling.

On the Handling tab you can freeze the current unit (which is "nA"), switch the "update immediately" and "snap slider to raster" features on/off. Note that these settings are also available directly from the context menu.

> **Please note.** The function "snap slider to raster" may lead to problems if the raster is unsuitable for the given situation.
>
> Note that the function "update immediately" requires extreme care when moving sliders and may cause unexpected effects.

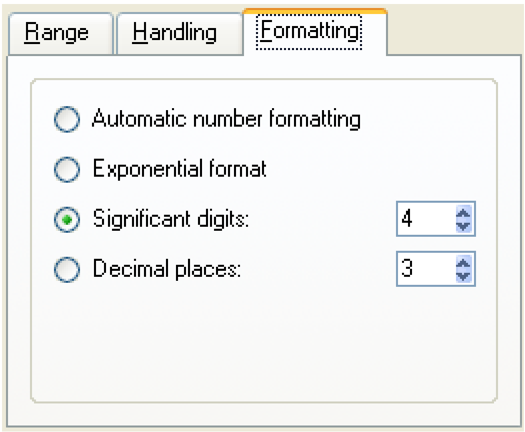


Figure 7. STM Scanner I-Setpoint properties window: Formatting.

On the Formatting tab select a number of options with regard to the formatting of the displayed numbers, e.g. the number of leading and decimal digits.

> **Please note.** Settings in the above windows cannot be saved when leaving the program.

Uploading - Controlling Experiment State

Each Experiment has a "master"-window which contains dedicated controls for the state of the Experiment. These consist of a symbol button, a display and three radio buttons, see figure 8 below.

Please note. Check that the TFTP connection has been opened correctly, otherwise select the respective entry from the start menu.

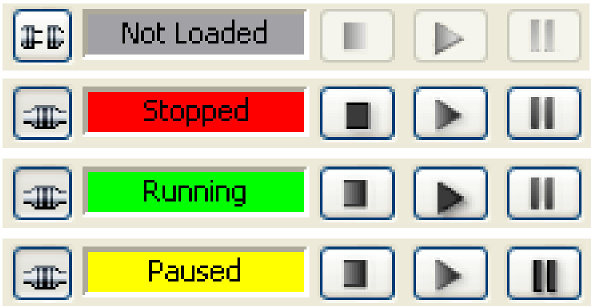


Figure 8. Experiment state control field in different states of operation.

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. Note that uploading may take some time. The display field then indicates the current state. e.g. "Loading".

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.

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 8 above.

After uploading, the symbol in the window title changes from grey (not loaded) to green (running), red (stopped, or not yet running) or yellow (stopped).This can help you to identify loaded and running components even when their windows have been minimised.

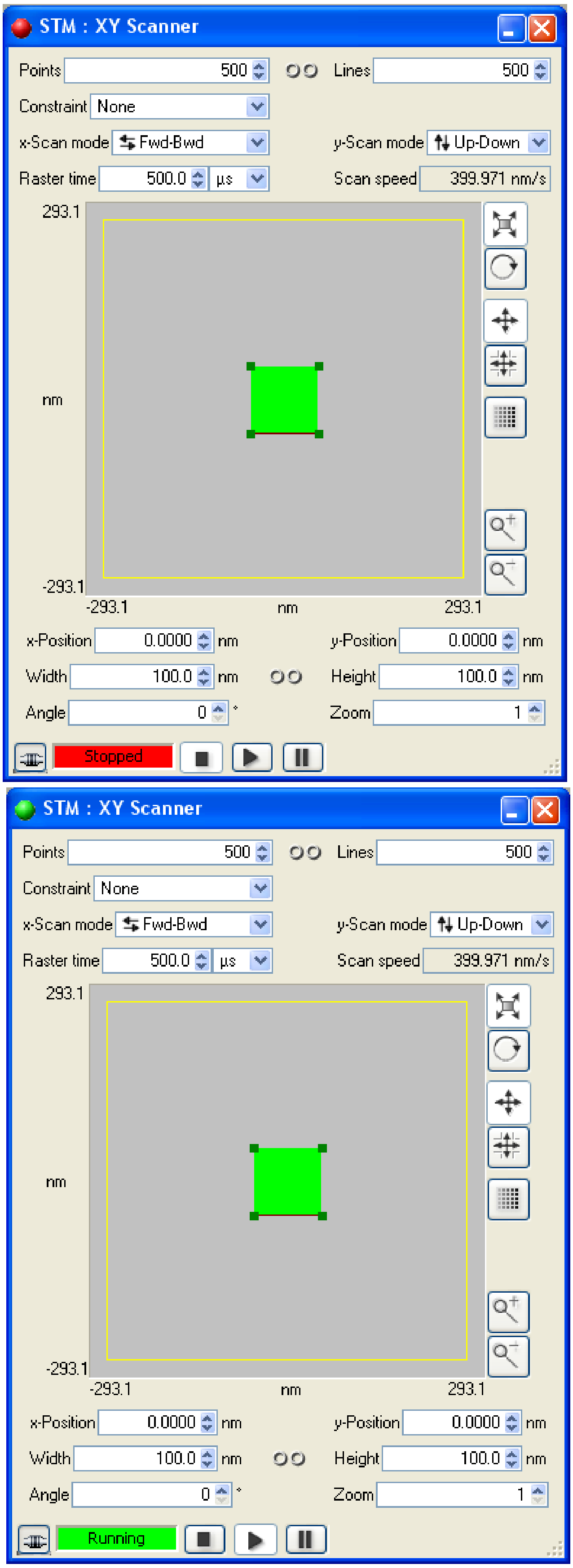


Figure 9. Colour changes from ready to running. Note the matching colours of display field and window title symbol.

4. The STM Project

The STM Project is started from the main window, see figure 1 on page 12, using the  icon.

Figure 10. Matrix – STM project window controls.

The STM Project provides the following Experiments:

	STM topography
	STM V-spectroscopy
	STM Z-spectroscopy

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 and not distract you by repeating known facts.

Scanner

The scanner window (see figure 9 on page 20) 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

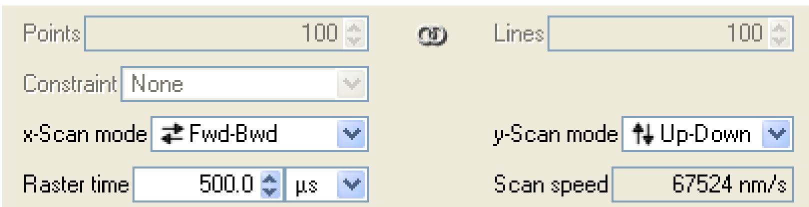
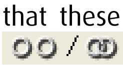


Figure 11. STM Scanner: raster settings.

Scan Resolution

- The scan resolution (raster) can be set with the Points/Lines control fields. Note that these two parameters can be linked for a constant aspect ratio using the  button.

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-Down Mode** stands for scanning a normal frame.

> **Please note.** Some scanning modes may not be available in the present version of MATRIX.

- 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.

> **Please note.** 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

- The raster time (RPT) 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.

- Upper limit: apart from the fact that scanner and electronics system have natural speed limitations the minimum raster time supported is currently 5 µs.

- Lower limit: the maximum raster time (i.e. minimum scan speed) supported is 300 ms.

> **Please note.** The raster time is not identical to the data acquisition time per data point. For a graphical representation please refer to figure 35 on page 43.

> **Please note.** The slider 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 slider limits.

Estimated Scan Speed

The scan 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.

Scan Area

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

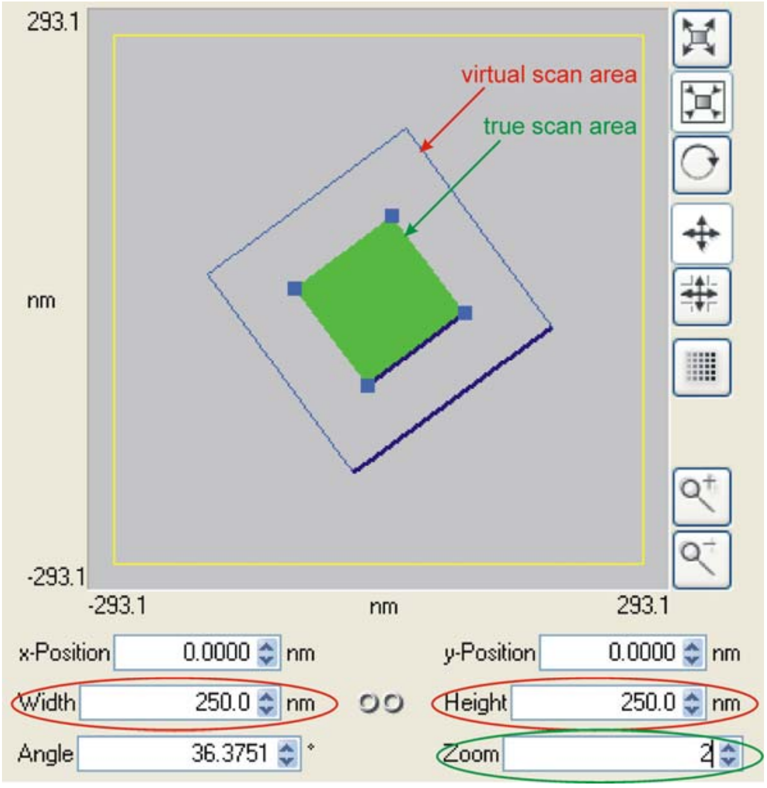
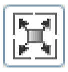
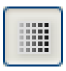


Figure 12. STM Scanner: scan area display.

	Resize scan area while scanning. i.e. by applying hardware zoom factor (integer steps only)
	Resize area at constant aspect ratio (grip corner handles). Note that this function is only available while not scanning.
	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

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.

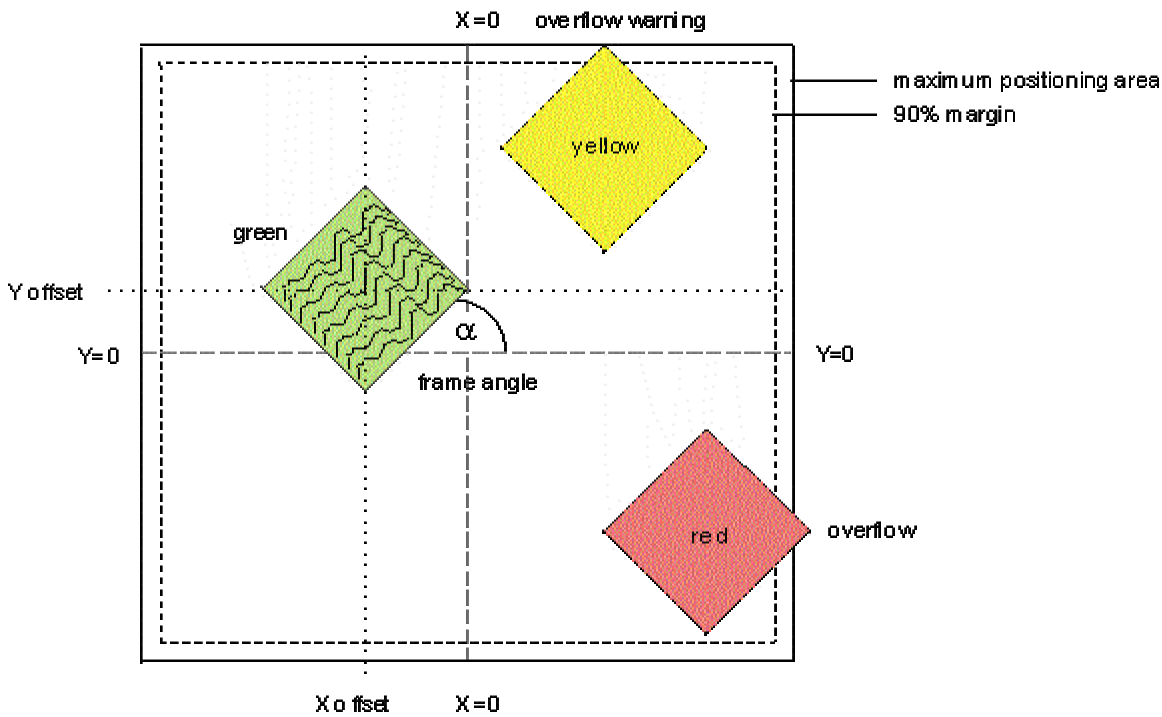


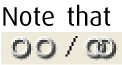
Figure 13. Frame positioning parameters.

- The first scan line is indicated in blue. Note that the default tip position is always at the centre of the scan range.

- 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.

- 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 14. 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.

- A **Zoom** factor allows reducing and resizing the scan area during scanning. Zooming takes place towards the centre and with fixed aspect ratio.

Please note. The following parameters can be changed online, i.e. without stopping the Experiment:

x-Position, y-Position, Zoom, Angle and Raster time.

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 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

There are various possibilities to zoom into the scan area. Do not confuse the optical zoom feature (eyeglass buttons) provided for optical magnification, with the hardware zoom feature that changes the size of the scan area.

While width and height can only be used to define the size of the scan area before starting a scan or with the scan stopped, the Zoom factor allows reducing the scan size (i.e. the travelling distance of the tip, NOT the number of points and lines) while scanning. There are several access points to this feature:

- Zoom button or numerical value control in the scanner window

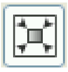
- Mouse function in the channel display window

These have slightly different operation modes that will be explained below. In any case the applied zoom factor can only be an integer number.

Zoom Numerical Value Control

A zoom factor specified using the numerical value control will be applied as specified, i.e. immediately or after pressing return. See on page 15f for details on the numerical value control.

Zoom Button in Scanner Window

	Resize scan area while scanning by applying hardware zoom factor (integer steps only).
	Resize scan area by directly manipulating the width and height parameters (grip corner handles). Note that this function is only available while not scanning.

Zoom Function in Channel display

- 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 to activate the new scan parameters. (Note that for technical reasons the applied zoom factor will be rounded to the nearest integer value.)

	Click the Apply button to activate the new scan parameters

Pan

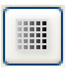
There are several possibilities to move the image or the scan area. You can either use the buttons in the channel display to manipulate the obtained image or use the buttons in the Scanner window to manipulate the scan area.

Pan and Rotation Numerical Value Controls

An offset set using the numerical value control will be applied as specified, i.e. immediately or after pressing return. See on page 15f for details on the numerical value control.

Pan Button in Scanner Window

Use the pan and rotation buttons in the 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 to activate the new scan parameters.

	Click the Apply button to activate the new scan parameters

Rotation

There are several possibilities to rotate the image or the scan area. You can either use the button in the channel display to manipulate the obtained image or use the button in the Scanner window to manipulate the scan area.

Rotation Numerical Value Controls

A rotation angle set using the numerical value control will be applied as specified, i.e. immediately or after pressing return. See on page 15 for details on the numerical value control.

Rotation Button in Scanner Window

Use the rotation buttons in the 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 Button 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.

- Click the Rotation button to activate the rotation function. 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.

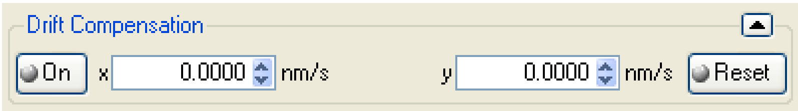
	Rotate obtained image freely (click image with the left mouse button and rotate)

Please note. 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 scanner window if the image had been rotated before.

Drift Compensation

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

Drift compensation **panel** in scanner window:



Drift compensation **button** in channel display: 

Figure 15. Drift compensation panel and button.

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. In any case the drift compensation function has to be switched on in the drift compensation panel before you can activate the drift compensation button in the channel display.

- Activate the drift compensation function using the On button in the drift compensation **panel**.
- Activate the drift compensation controller by clicking the drift compensation **button**.
- 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 electronic drift.

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.

Please note. If you decide to focus your attention to a different feature, switch the controller off and on again using the button 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 controller 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 please use the Reset button in the drift compensation panel. Note that the Reset button is inactive when a scan is in progress.

Please note. 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.)

Regulator

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

Please note. 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-Meter

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

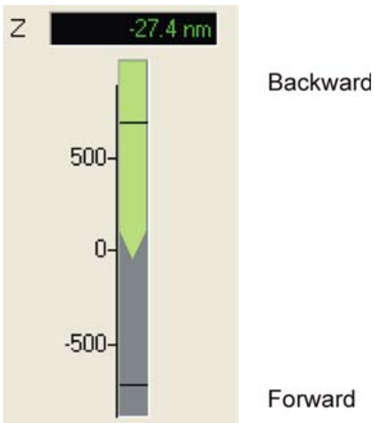


Figure 16. STM regulator: Z-meter display.

- 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 meter (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 meter (yellow) no current has been detected within the regulator range and coarse steps or AUTOAPPROACH 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.

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

- When no measurement has been started the Z-meter works at a sampling rate of some few values per second. (During AUTOAPPROACH this may look strange.)

- When Z-data is available from a measurement in progress the Z-meter takes information directly from there.

Feedback Controls

- The feedback loop can be switched on/off using the "Loop" tick box.

- The Loop Gain can be varied between 0 and 100%. 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 60.

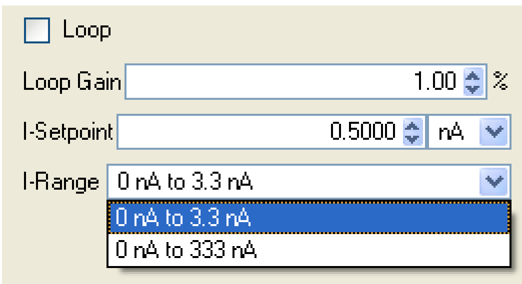


Figure 17. STM Regulator: feedback controls.

- In case of a Needle Sensor (regulation for constant phase shift, special electronics required) the label Loop Gain is replaced by Loop Gain (I), indicating the integrating part of the feedback, and a second loop gain control Loop Gain (P) appears. The linear Loop Gain (P) slider allows adding a proportional component (p) to the feedback signal.

- Feedback Setpoint allows the definition of a setpoint for the feedback loop. The feedback sources are

Mode	Feedback Signal	Signal Name	Range
STM mode	tunnelling current	I	0 to 3.3 nA or 0 to 333 nA
AFM contact mode	normal force	FN	±100 nN
AFM non-contact mode	frequency shift	df	±1500 Hz

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. In case of AFM this low pass filter acts on Delta FN or df (contact mode or noncontact mode, respectively).

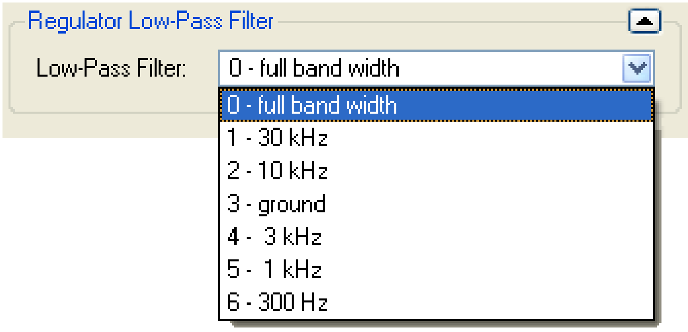


Figure 18. Regulator low pass filter.

Tip. We recommend working at the largest possible bandwidth.

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

Figure 19. Regulator tip approach speed.

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 AUTOAPPROACH!

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, e.g. 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 20 on page 32. 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.

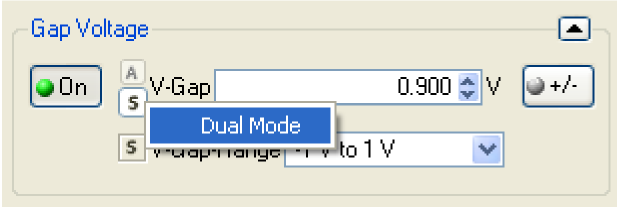


Figure 20. Dual Mode switch in context menu.

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 you might want to avoid.

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 A S buttons to switch between standard S and alternative A 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, see figure 21 below.

Figure 21. Line Delay control panel in 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.

Gap Control

- The gap voltage can be switched on or off, default setting is "On". If "Off", V-Gap is set to 0 V.

- 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 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.

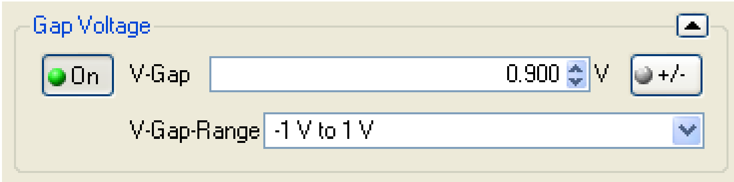


Figure 22. STM Gap control panel.

Gap Voltage Low Pass Filter

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

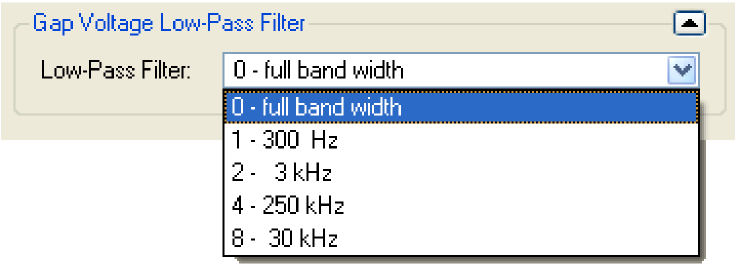


Figure 23. Gap voltage low pass filter.

Z-Control

Note that the Z-Control field is only active with the Feedback Loop switched off.

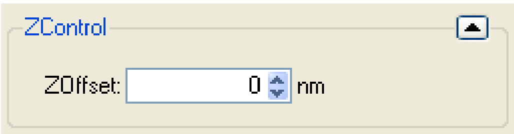


Figure 24. Z-Control panel.

- Enter a Z offset value (numerical value control field) to initiate a Z displacement of the tip (positive Z values increase, negative Z values decrease gap width). The Z displacement will be approached in steps, approximating a linear ramp.

Channel

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 (e.g. "STM – Z Channel – Backward"). The window display can be adjusted using the controls from the context menu.

The following channels are available for the different operation modes:

channel	recorded signal	applicable
Z	tip Z position	all modes
I	current	all modes
FN	normal force (full range)	all modes, if AFM available
FL	lateral force (friction)	all modes, if AFM available
df	force gradient (frequency shift)	AFM non-contact mode only
D	damping signal	AFM non-contact mode only
Ext 1	external channel	STM
Ext 2	external channel	STM, AFM if available

Table 2. Measurement channels and corresponding signals.

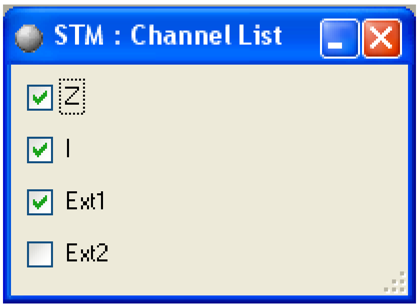


Figure 25. Channel list window, example shown.

- A window with tickboxes allows deselecting the respective channel: a channel that is not ticked will have no display and the data of this channel is not saved to file.

Image Mode Controls

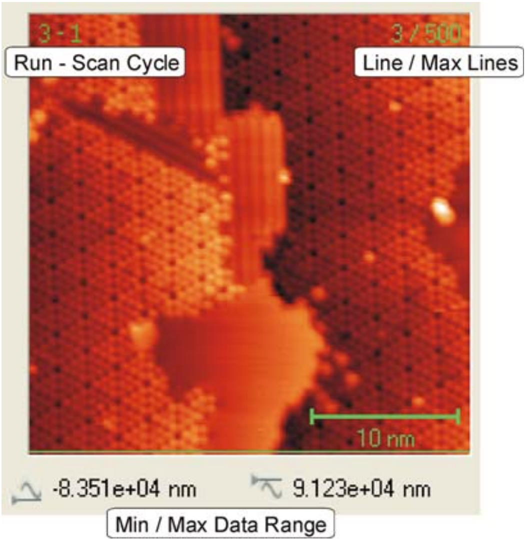


Figure 26. Channel display in image mode.

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 Z-values as different colours.
- At the top of the image four numbers inform about experiment progress and help locating a special image for data analysis, see page 37.
- A scale gives an idea of the size of the scanned surface. Available scale modes are bar, axes and none.
- 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 has been performed.

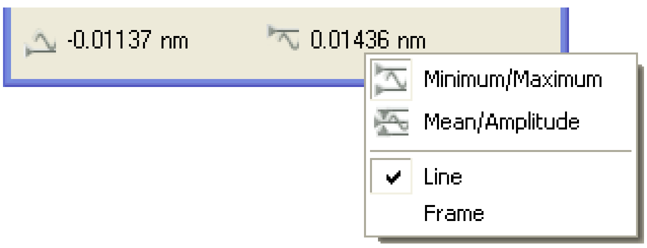


Figure 27. Data range context menu.

- 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 30 on page 37. In this case the colour table can be adapted manually by pressing "Reset".

Lines Mode Controls

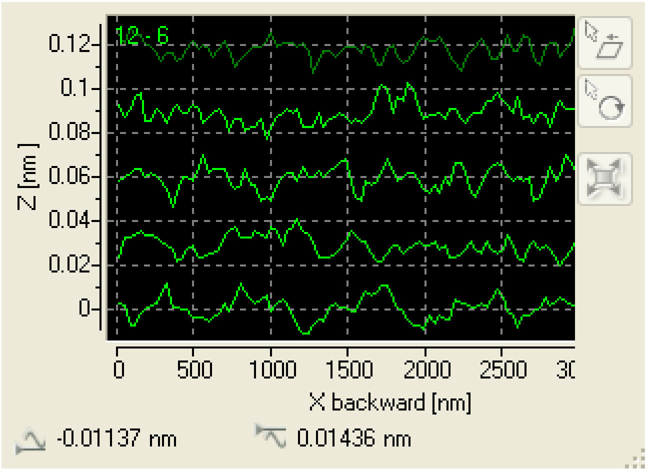


Figure 28. Channel display in lines mode.

If a channel display window is switched from image mode to line 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.

Customising the Channel Display

The layout of a channel display window depends on the type of channel which is displayed (topography or spectroscopy) and on the display mode actually selected.

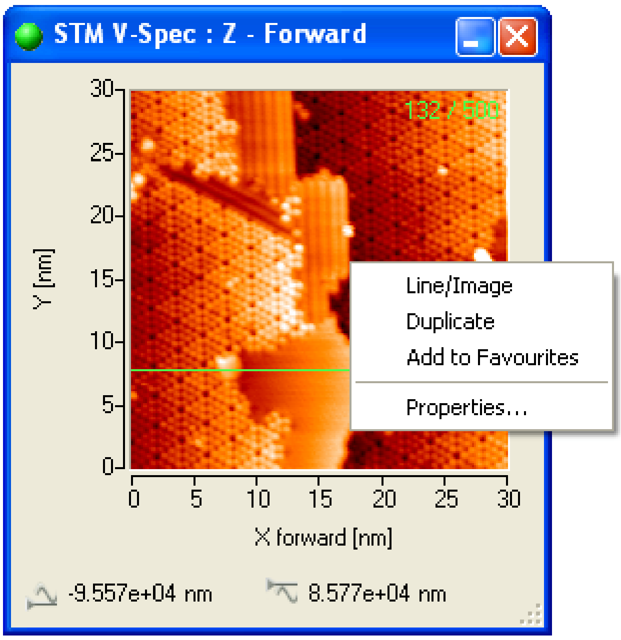


Figure 29. The channel display context menu.

The context menu allows

- Switching between image and line mode
- Duplicating the channel display (e.g. for viewing the same channel in different modes at the same time)
- Adding the current image to the favourites list, see figure 2 on page 14.
- 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.

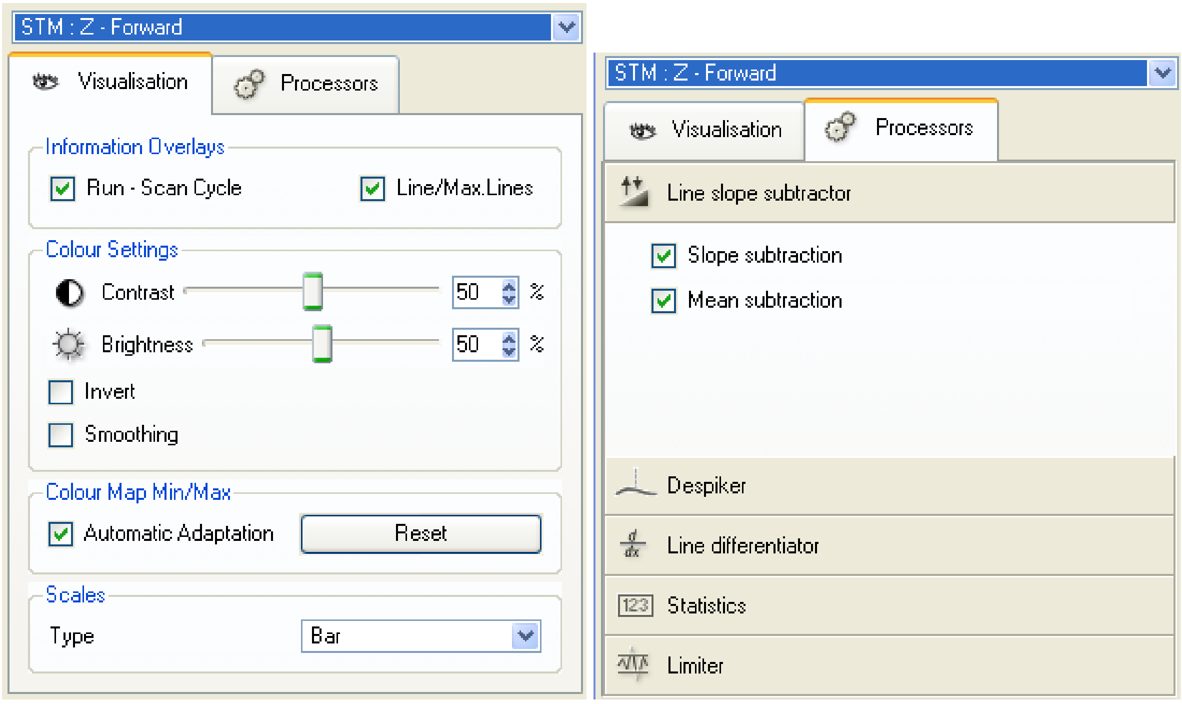


Figure 30. Display Properties windows, examples shown.

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

Information Overlays

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

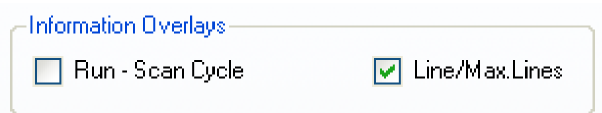


Figure 31. Information overlays panel of the display properties window.

Run	the number of times this experiment has been started using the experiment controls. Every Run command initiates a new data bricklet (new data file).
Scan Cycle	the number of times a full scan cycle (e.g. one up and one down) has been finished.
Line	the current scan line within the cycle
Max. Lines	the maximum number of scan lines within a cycle

Visualisation Colour/Curve

The Visualisation tab has different appearances depending on the selected display mode of the related channel display, see figure 32 below.

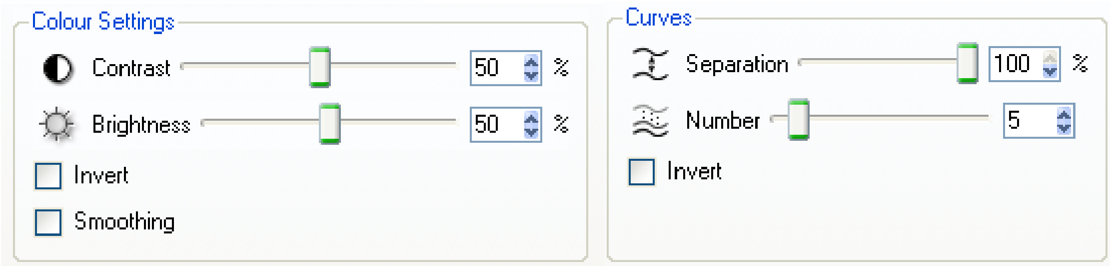


Image mode Line mode

Figure 32. 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 check box 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.

Colour Map

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

- Click "Automatic Adaptation" to automatically adapt the colour table for every displayed frame. Note that the colour table adaptation is reset when a new frame 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

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.

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. As a result, the images visible in the channel display windows cannot be saved as such. In special cases you may want to take a screen shot (e.g. using Alt+Print) for reference purposes.

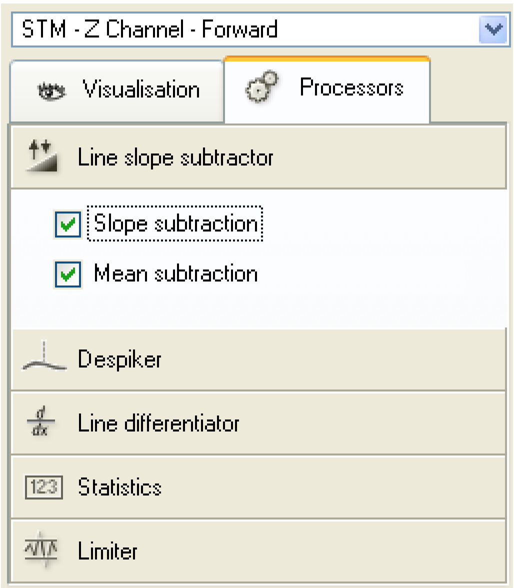


Figure 33. Processors visualisation tab, example shown.

The provided display processors are applied to the incoming data in the order of appearance on the tab. Although some thought has been put into selecting a useful order of processing steps, you can change the order of steps by editing the related XML file. To modify the order of processors edit the *.vied file of your Experiment and change the order in which the processors are listed in this file. File and path example:

```
C:\documents and settings\<user name>\application data\Omicron
 NanoTechnology\MATRIX\default\Experiments\STM_Basic.vied
```

Attention. Before editing any Omicron supplied MATRIX source file please copy the original to a safe location in case you run into problems later on.

Line slope subtractor

The Line Slope Subtractor fits a straight line through the data values of a scan line. Two subtraction modes are available: slope subtraction and mean subtraction. Slope subtraction eliminates slopes along the scan lines, e.g. due to a sample tilt. Mean 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 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.

5. A Spectroscopy Experiment

Data acquisition for a spectroscopy curve is very similar to topography data acquisition: an independent **axis** (e.g. voltage V) 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, Ext1, Ext2	I, FN, df, Ext
Signal	I(X,Y), Z(X,Y), EXT(X,Y)	I(V), I(Z), df(V), Ext(V)
Points	points, lines	points
Raster time	raster time	T-Raster (= delay time + acquisition time)
Axis range	width, height	start, end

Table 3. Comparison of parameters spectroscopy versus topography.

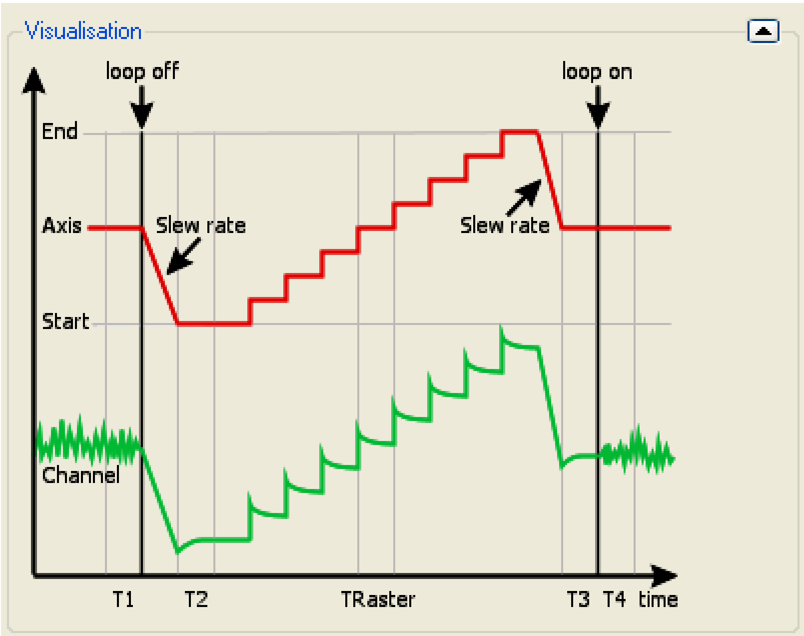


Figure 34. Spectroscopy, delay and acquisition times. schematic diagram.

These delays are necessary to achieve stable conditions at the beginning and end of every spectroscopic curve, see figure 34.

Please note. 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.

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 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 34 on page 41. 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 and with the specified oversampling, see figure 35 on page 43. The **delay time** ensures a stable tunnelling current after the gap voltage change.

> **Please note.** Times **T1 to T4** are applied before and after each I(V) curve while the **delay time** 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 **sample count**.

$$\text{data point} = \frac{\sum_{1}^{\text{sample\_count}} \text{single measurement}}{\text{sample count}}$$

- A single measurement takes a fixed time of a few micro seconds. The time between single measurements hence results from the sample rate setting.

- The next data point is taken after one raster time, see also figure 35 on page 43. Consequently, the raster time must be longer than the combination of delay time and data acquisition time, i.e.

$$\text{raster time} > \frac{\text{sample count}}{\text{sample rate}} + \text{delay time}$$

- In automatic mode (default) the software ensures that this requirement is adhered to. We recommend to always set the raster time first. In manual mode the user has to make 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 **slew rate** from the Extra Settings.

- 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.

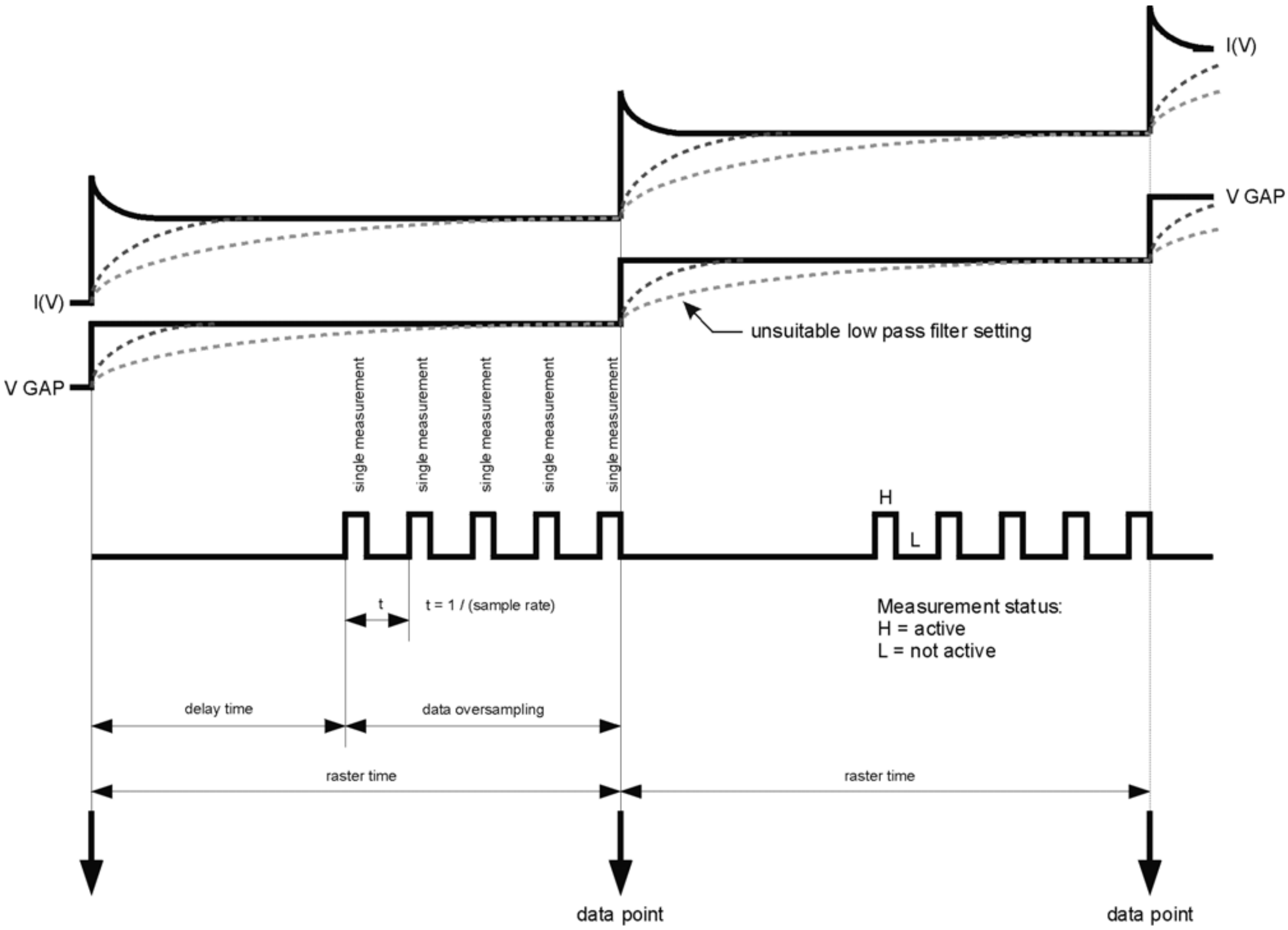


Figure 35. Spectroscopy data acquisition and oversampling.

Spectroscopy Controls

The spectroscopy settings window offers a number of control options for your spectroscopy experiment.

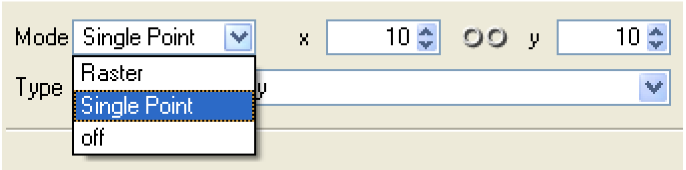


Figure 36. Spectroscopy mode control.

Raster

To execute raster spectroscopy the corresponding option must be selected in the Spectroscopy Settings window with the experiment stopped.

- Raster 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 N-th point of the M-th line counted from lower left corner of the frame.

Single Point Spectroscopy

To execute single point spectroscopy the corresponding option must be selected in the Spectroscopy Settings window with the experiment stopped.

During the scan you have to first click the single point activation button  and may then click a location in any of the topographic channel displays to start the following procedure:

- Stopping the scan 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.
- Returning the tip to the memorised position and resume scanning.

Spectroscopy Curve Options

For the axis specify the following parameters :

- The **variation limits**, i.e. the first and last value of the independent parameter.
- The **number of data points** in a spectroscopy curve, for possible values see table 4 below (watch memory usage).
- The **T-Raster** is the time distance between two data points within a spectroscopy curve, for possible values see table 4 below.

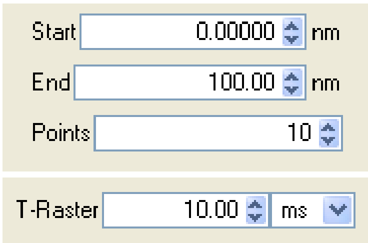


Figure 37. Spectroscopy curve control.

The feedback loop will automatically be switched off and on as indicated in figure 34 on page 41.

	Min	**Max**
Sample rate	1000 Hz	200 kHz
Delay time	10 µs	1.8 s
Sample Count	0/s	400 000/s [*]
T-Raster	20 µs	19 s
T1 to T4	71 µs	1 s
Slew rate	0	100 V/s
Number of points	2	2048
Voltage range [**]	-1 V or –10 V	+1 V or +10 V

Table 4. Spectroscopy settings min/max values. [*]) Note that the sample count maximum depends on the settings of sample rate, delay time and raster time. [**]) Range depends on V-Gap-Range setting.

Extra Settings

The button **Extra Settings** gives access to a number of additional parameters for the spectroscopy process. All parameters are indicated in the graphical representation, see also figure 34 on page 41.

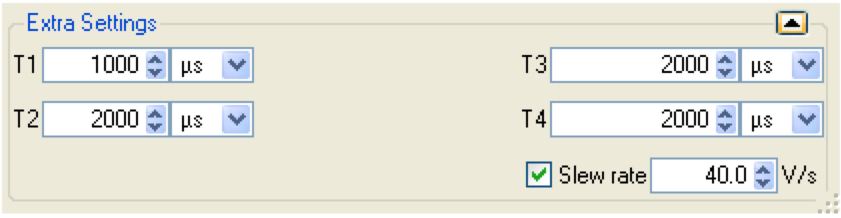


Figure 38. Spectroscopy curve extra settings.

- **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.

- **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.

Sensor Control

The sensor control settings are available in the channel display windows of the spectroscopy channels.

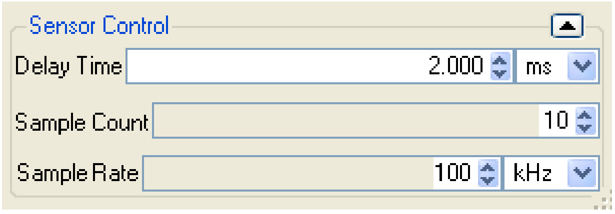


Figure 39. Spectroscopy sensor control.

Delay Time

Delay between voltage step and first single measurement

After every voltage step the delay time ensures stable conditions before the first spectroscopy single measurement takes place. Note that the spectroscopy raster time must be longer than (sample count / sample rate) + delay time. Always set the raster time value in the Spectroscopy window first.

Sample Count

Number of single measurements for every data point (oversampling)

For every data point in the I(V) curve several single measurements can be taken and averaged over. This process is called oversampling and is used to eliminate statistical spikes. Note that the spectroscopy raster time must be longer than (sample count / sample rate) + delay time. Always set the raster time value in the Spectroscopy window first.

Sample Rate

Frequency at which single measurements are repeated

The sample rate defines how closely single measurements for a data point follow each other. Note that the spectroscopy raster time must be longer than (sample count / sample rate) + delay time. Always set the raster time value in the Spectroscopy window first.

6. The AFM Contact Project

The AFM Contact Project is started from the main window, see figure 1 on page 12, 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 40. Matrix – AFM Contact project window controls.

The AFM Contact Project provides the following Experiments:

	AFM Contact topography
	AFM Contact Z-spectroscopy

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 and not distract you by repeating known facts.

AFM Sensor Alignment

The AFM sensor alignment window provides calibration fields and controls for the light source and offset adjustment.

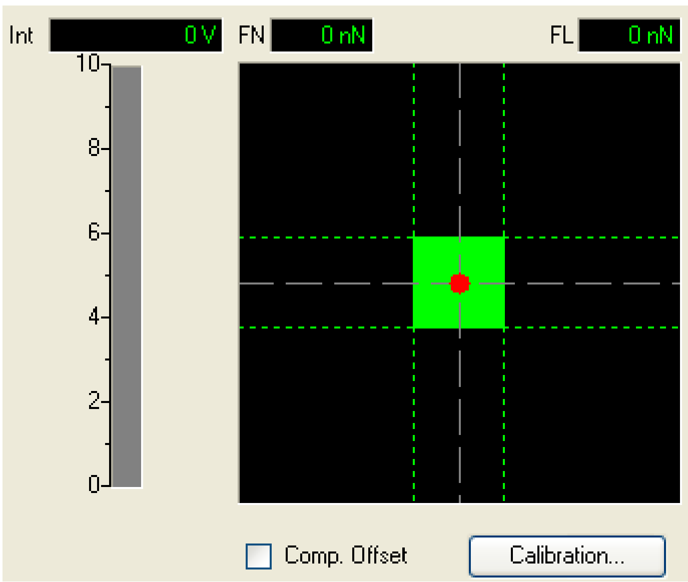


Figure 41. The AFM Sensor Alignment GUI, contact mode variant.

Force Display

The force display illustrates the normal and lateral force (F_N and F_L) values and serves for the adjustment of mirror 2. Mirror 2 is adjusted correctly when the red spot is near the centre (centre box turns green).

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.

Force Calibration

A force calibration is required if you want to measure absolute force values. This is necessary for every new cantilever and after adjusting the mirrors.

When you press the Calibration button the actual F_N and F_L values are stored and used as a reference. This means that a force setpoint of 0V really corresponds to a force load of zero, even if the mirrors are not perfectly adjusted.

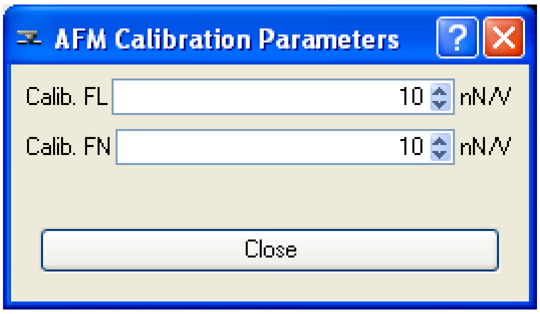


Figure 42. AFM calibration parameters window.

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). The **ON/OFF** button is a two or three status button, depending on the selected instrument/scanner class.

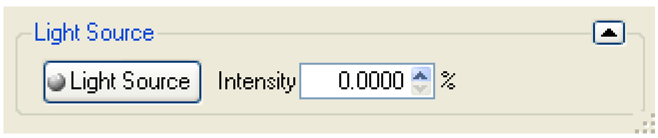


Figure 43. AFM Light Source work-window.

> **Please note.**
>
> 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 "The UHV AFM/STM User's Guide".

The Force Distance Curve window allows taking force distance curves automatically and selecting a setpoint.

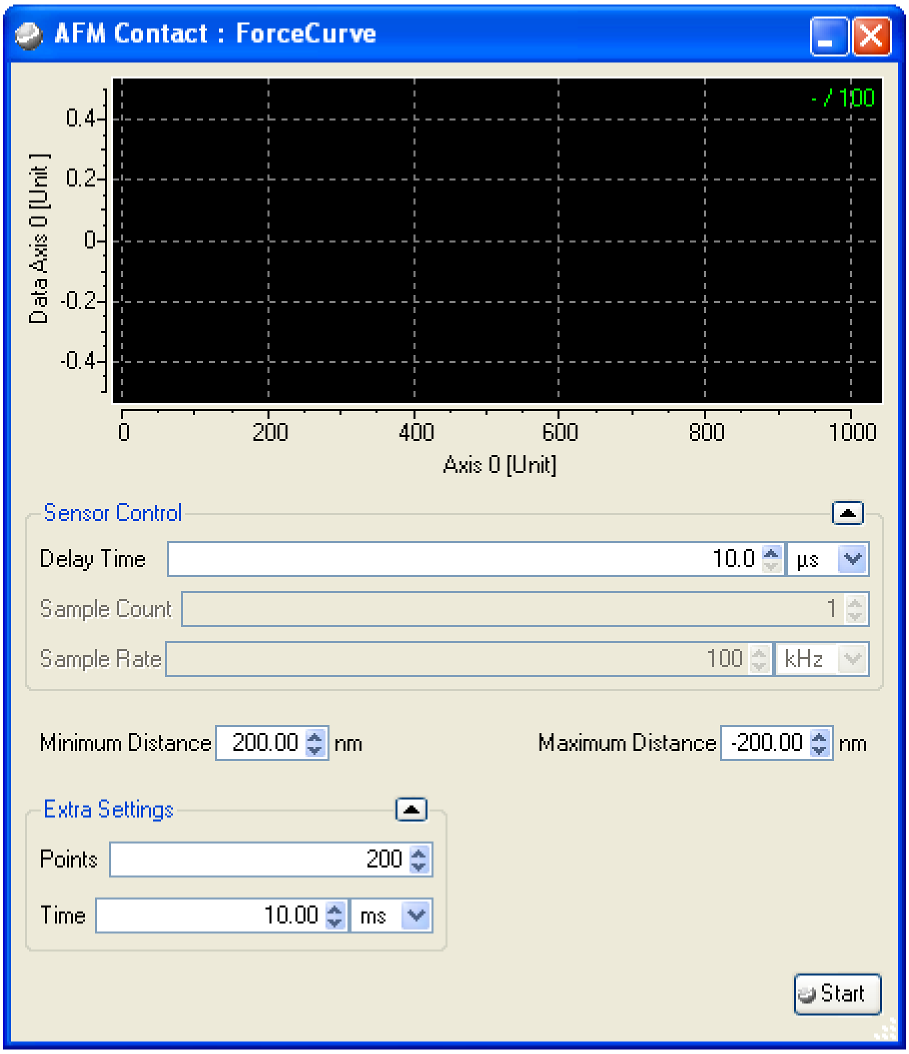


Figure 44. Force Curve window.

- Bring the cantilever into contact with the surface using the AUTOAPPROACH or the manual approach procedure, see "The UHV AFM/STM User's Guide".
- Use small coarse steps to adjust the cantilever vertical position such that the tip shape in the Z-meter is in the middle.
- 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 **Start**.

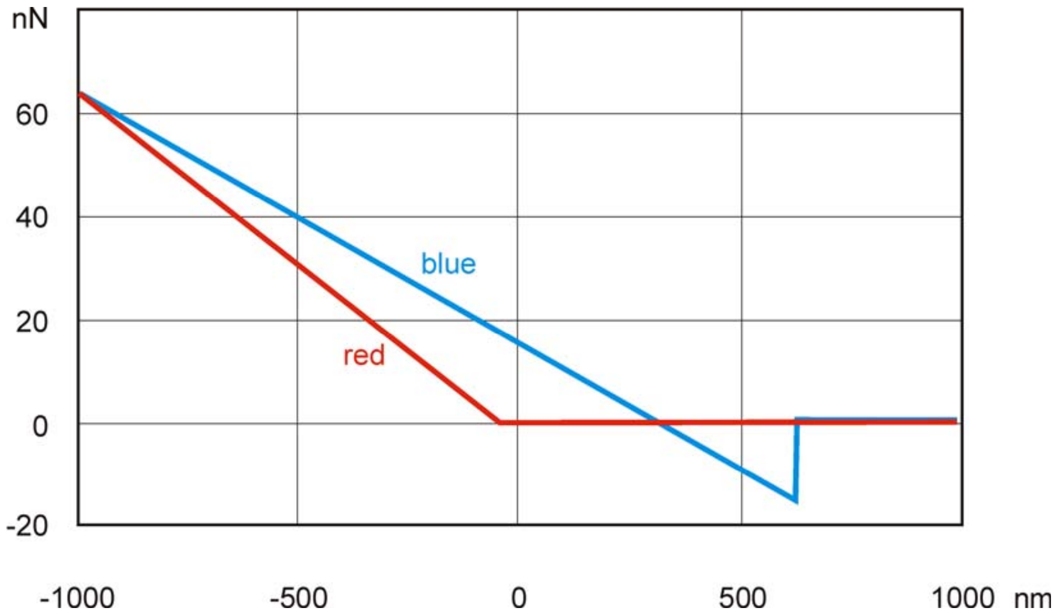


Figure 45. The Force Distance Curve schematic diagram. Red curve: towards the sample, blue curve: away from the sample.

7. The AFM Noncontact Project

The AFM Noncontact Project is started from the main window, see figure 1 on page 12, using the  icon. It provides a number of Experiments, each with a complete set of GUI controls for AFM noncontact mode measurements.

Figure 46. Matrix - AFM NonContact project window controls.

The AFM Noncontact Project provides the following Experiments:

	AFM NonContact topography
	AFM NonContact V-spectroscopy
	Kelvin Probe AFM
	Needle Sensor AFM

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 and not distract you by repeating known facts.

Please note. 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.

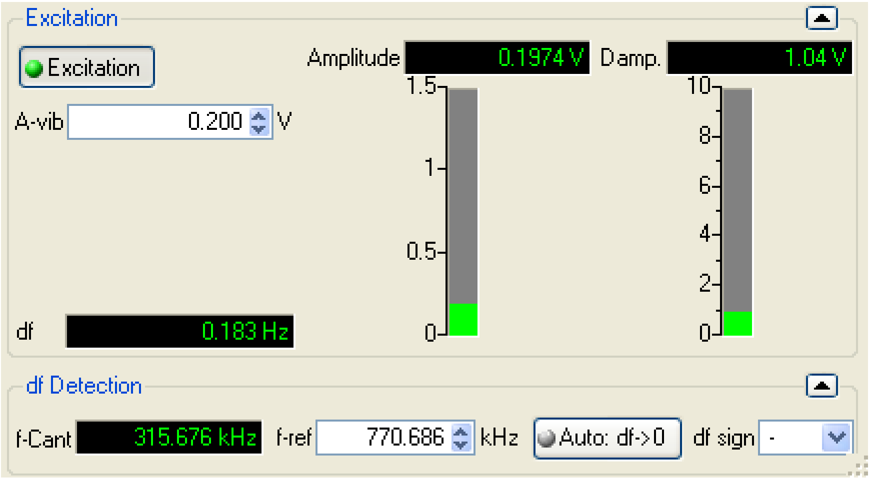


Figure 47. The AFM NonContact Excitation panel.

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.

df 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.

df Detection 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.

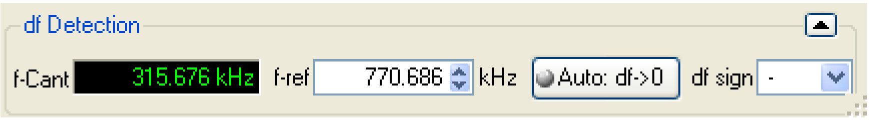


Figure 48. The AFM NonContact df Detection panel.

If your hardware equipment includes a software controllable Oscillator/Counter board (OCB) the AFM Noncontact window 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 **df** = zero. This is achieved with

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

where $f_{intermediate} \approx 455$ kHz. Alternatively Click **Auto df -> 0** to do this process automatically. The **Auto df -> 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.

The **df sign** box allows selecting the correct polarity for attractive or repulsive interaction.
....

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

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

AFM Needle 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 49. Needle sensor excitation controls.

- **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.

- **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.

- A button additionally provides the option to switch the range between 6.55 V and 0.65 V. This is particularly useful for very small excitation amplitudes (<0.5 mV) in order to increase the signal-to-noise ratio.

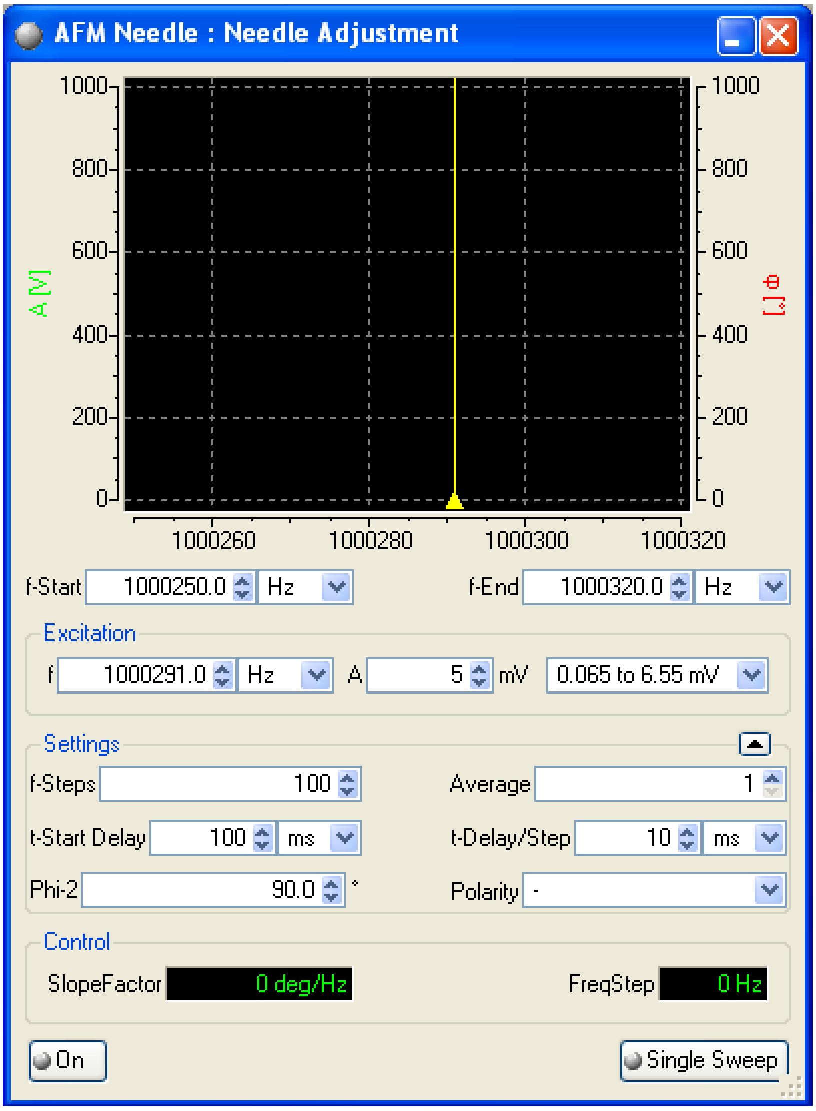


Figure 50. The AFM Needle Adjustment window.

Settings

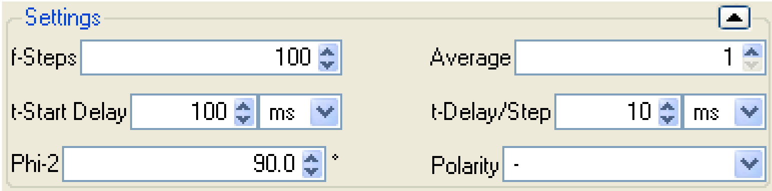


Figure 51. Needle sensor special settings.

- **Frequency steps** defines the number of data points in a single adjustment sweep.
- **Average**: The sampling rate for amplitude and phase values is 100 kHz. Every displayed data point is averaged by a factor which can be set here.
- The **t-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.
- The **delay time per step** likewise is the time between moving to the next step and actually taking data. Default is 10 ms, which should be fine for most applications.
- **Phi 2** is the start value for the reference phase oscillator. It is set in such a way as to give zero output at the phase detector (comparator). For the VT STM this value is about 90°, it is, however, dynamically adjusted after each characterisation measurement and depends on the actual needle sensor used.
- **Polarity** changes the phase of the excitation signal by 180°.
- The vibration amplitude of the needle sensor at a given excitation voltage depends on the vibrational Q of the needle sensor.

Control

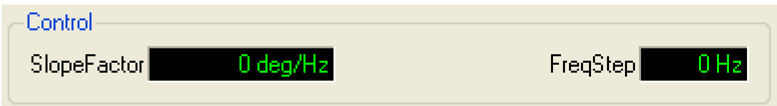


Figure 52. Needle sensor sweep controls.

- **Slope Factor.** 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.
- **Frequency Step:** the increment used for frequency sweeps depends on the settings for start, end and number of steps, see figure 51 above.

Single Sweep

Upon clicking **Single Sweep** the selected frequency window is scanned once, 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.

- **Single Sweep** is suitable for quartz resonators with roughly known resonance characteristics.

- For a measurement over a large frequency interval Single Sweep should be used repeatedly with decreasing interval width around the resulting resonance peak.

- For a good resonance frequency result in the last step the interval should not be larger than a few hundred Hertz.

The Resonance Curve Display

After a characterisation sweep the upper 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 typical measurement is shown in figure 53 below.

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

- The red 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.

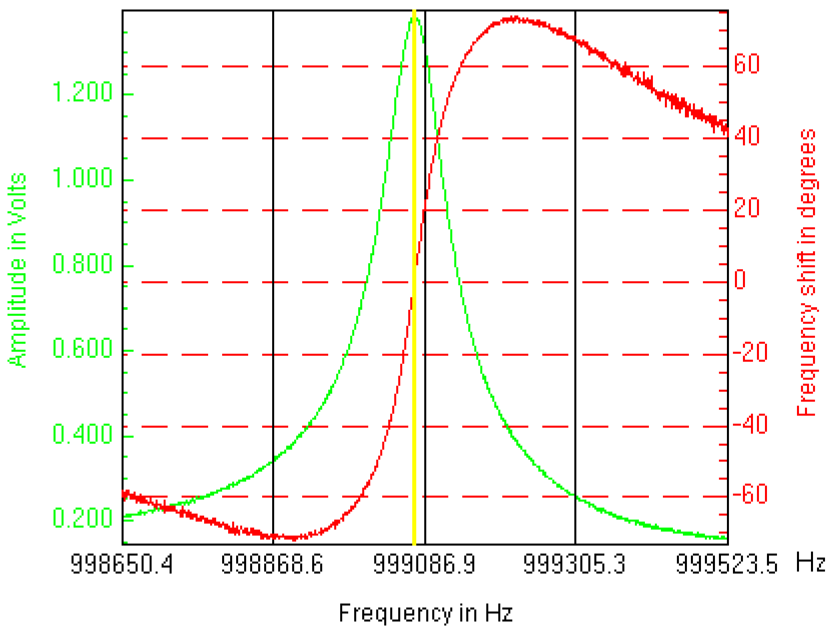


Figure 53. Typical needle sensor curve for an Omicron VT STM.

8. Experiment Options

From the Project window main toolbar select  to open the Experiment Options window. Alternatively select Experiment Options from the View menu.

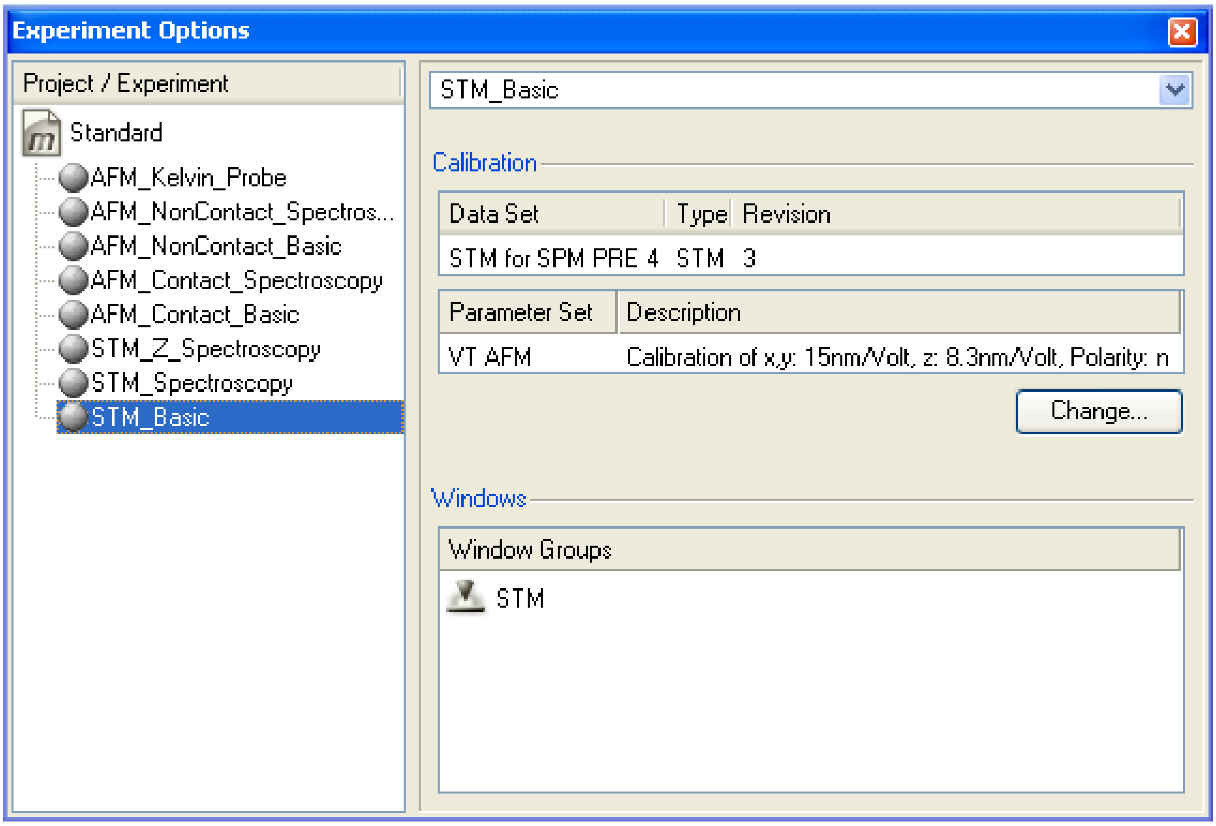


Figure 54. The Experiment Options window.

Project / Experiment

MATRIX comes with at least one preconfigured Project to suit the needs of your specific Omicron SPM. The standard file tree provided by the installation contains a number of files reflecting the Project structure. Figure 54 above shows a MATRIX installation with one Project. The name of the Project is "Standard". This Project comprises 3 Experiments called AFM_non_contact_Basic, AFM_contact_Basic and STM_Basic.

Calibration

For each of the Experiments a parameter set is loaded. Some Omicron SPMs need more than one parameter set, e.g. for different temperature regions. In this case other parameter sets can be loaded using the change button.

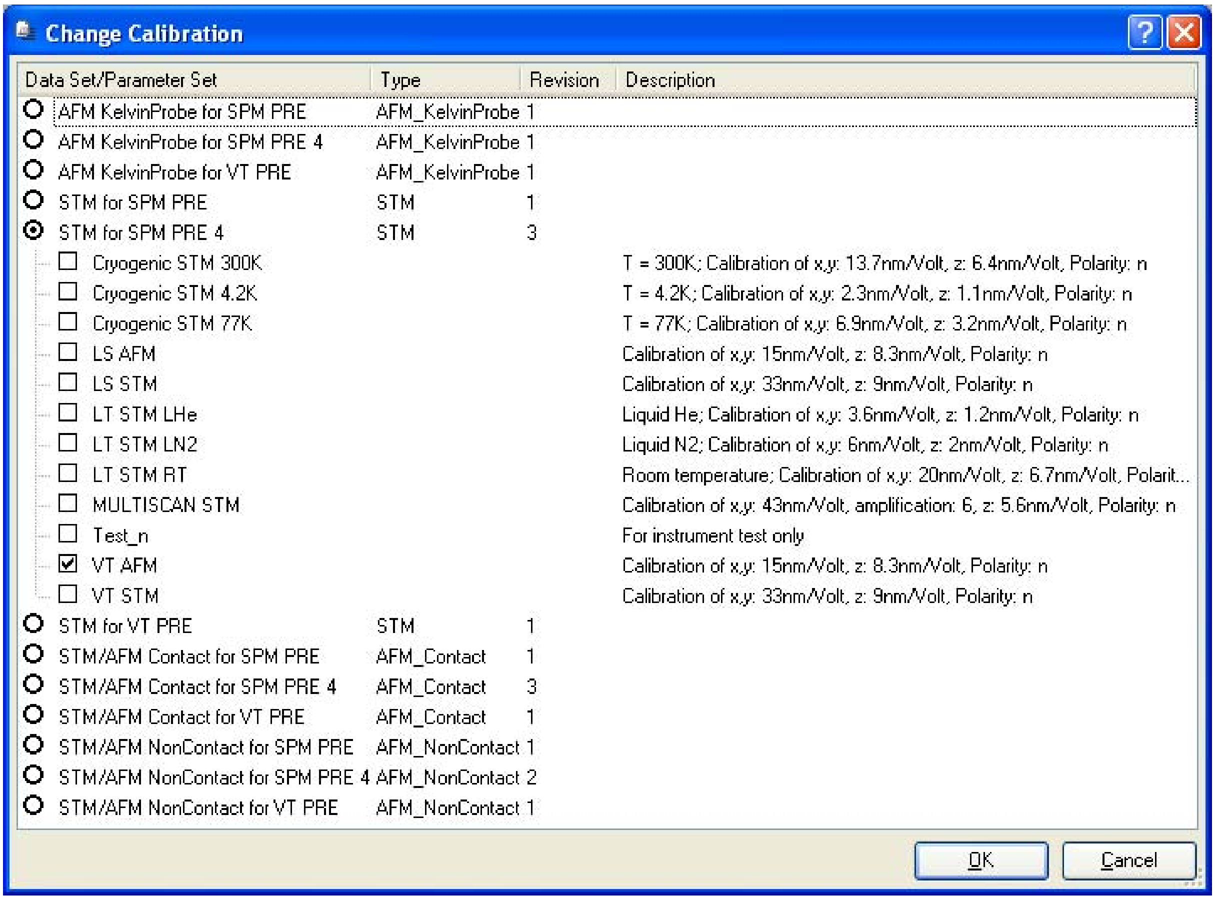


Figure 55. Change calibration window accessible from Experiment options.

Windows

The Windows field lists the window groups related to the selected Experiment.

9. 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 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.

Please note. 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)
AFM during adjustment	FN IN (DC, x-y mode)	FL IN (DC, x-y mode)
AFM contact mode	FN IN (DC mode)	Z MON (AC-mode)
AFM non-contact mode	FN IN (AC mode)	FN OUT (DC mode)

Table 5. Oscilloscope cabling.

Attention. Always use the Z MON socket on the DRB 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 AFM CU and oscilloscope if used.
- Switch on the computer.
- Start 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 STM coarse approach procedure suggested in your SPM head manual.
- In the Gap Voltage Control GUI choose a gap voltage and feedback setting appropriate for your sample.
- Click  in the Experiment state control field.
- Now try playing around with the parameters accessible from the Scanner Window and watch the Channel displays.
- Once you are happy with the appearance of the scan click "Store Measurement" in the Favourites Gallery window.

Please note. One data point takes 4 bytes of storage space on your harddisk. This means that a 1000 x 1000 pixel topographic scan occupies 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!

Caution: 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 56. 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 the resulting help-pointer on the parameter of interest.

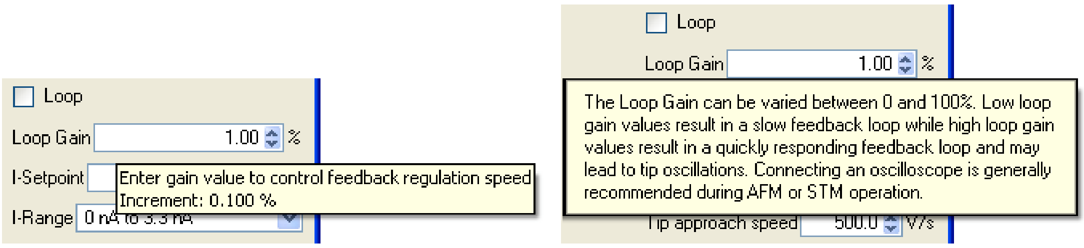


Figure 57. ToolTip and Context sensitive help or What’s This help for the feedback setpoint parameter in the regulator window.

10. 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 two different types are currently used; these types are described in table 6 on page 64. (Details regarding the Transfer Function parameters are discussed below.)

Type	Description	Mathematical Representation
TFF_Linear1D	Linear Transfer Function, one Raw Device	$r = f \cdot p + n$
TFF_MultiplierLinear1D	Linear Transfer Function, two Raw Devices	$r = ((f_n \cdot f_p) / (r_0 - n_p)) \cdot p + n$

Table 6. 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. (The default Instrument Description suitable for Omicron equipment can be found in the file “Core.inst” of a Matrix installation.)

An Instrument Description file consists of two sections:

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 “Core.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 LHe” found in “Core.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_1"/>
</PhysicalDevice>
<PhysicalDevice name="Y" unit="m" valueType="double">
  <Device name="Y_1"/>
</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). Their is one Raw Device associated with each Physical Device; these are called *X_1* and *Y_1*.

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 LN2" description="Liquid N2">
  <DeviceParameters device="X_1">
    <TransferFunction name="TFF_Linear1D"/>
      <Parameter name="Factor" type="double" value="2.95198e+011"
       minimum="0" maximum="0" unit="m"/>
      <Parameter name="Offset" type="double" value="0" minimum="0" maximum="0"
       unit="none"/>
  </DeviceParameters>
  <DeviceParameters device="Y_1">
    <TransferFunction name="TFF_Linear1D"/>
      <Parameter name="Factor" type="double" value="2.95198e+011"
       minimum="0" maximum="0" unit="m"/>
      <Parameter name="Offset" type="double" value="0" minimum="0" maximum="0"
       unit="none"/>
  </DeviceParameters>
          .
          .
          .
</ParameterSet>
```

For both Raw Devices, a linear transfer function (identified by the type code *TFF_Linear1D*, see table 6 on page 64) will be used for value conversion. This function can be expressed by the below formula:

$$r = f \cdot p + n$$

with *r* being the "raw value" and *p* being the physical value. 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:

$$X\_1 = 2.95198 \cdot 10^{11} \cdot X + 0$$

$$Y\_1 = 2.95198 \cdot 10^{11} \cdot Y + 0$$

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 14.8
- The Raw Devices *X_1* and *Y_1* both support a value range from $-2^{19} - 16$ to $+2^{19} - 16$, 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:

$$f = r_{max} / p_{max}$$

$$f = (2^{19} - 16) / (2 \cdot 10\ [\text{Volt}] \cdot 14.8 \cdot 6\ [\text{nm/Volt}]) = 295.198\ \ [1/\text{nm}] = \underline{2.95198 \cdot 10^{11}\ \ [1/\text{nm}]}$$

Note: The "offset" parameter can be assumed to be zero, as permanent offsets are rarely found currently.

For an arbitrary Raw Device that maps a signed 16 Bit integer value (i.e. a value ranging between -2^{15} and $+2^{15} - 1$) to a voltage range of −10 to +10 Volts in a linear fashion, the gradient can be computed as follows:

$$f = r_{max} / p_{max} = (2^{15} - 1) / 10\ [\text{Volt}] = \underline{3276.7\ [1/\text{Volt}]}$$

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_1* and *ClassicPreampl_1*. The first Raw Device supports signed 16 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_1*. 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:

$$r = ((f_n \cdot f_p) / (r_0 - n_p)) \cdot p + n$$

With:

- r — "Raw value" obtained from "main" Raw Device (i.e. *IT_Image_1* in case of the tunnelling current example)
- r_0 — "Raw value" obtained from "dependent" Raw Device (i.e. *ClassicPreampl_1* in case of the tunnelling current example)
- p — Physical value
- f_0 — Pre-factor
- f_n — Neutral factor
- n_0 — Pre-offset
- n — Offset

The parameters "Pre-factor", "Neutral factor", and "Pre-offset" 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:

1. Determining the neutral factor is equivalent to determining the gradient of the function. For the tunnelling current Physical Device we can thus write:

$$f_n = r_{max} / p_{max}$$

$$f_n = (2^{15} - 1) / (10\ [\text{Volt}] \cdot 33.3\ [\text{nA/Volt}]) = 98.399\ \ [1/\text{nA}] = \underline{9.8399 \cdot 10^{10}\ \ [1/\text{A}]}$$

   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 $2^{15} - 1$, as the Raw Device *IT_Image_1* uses 16 Bit signed integer values.

2. The pre-factor and pre-offset 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 pre-factor to 1.01, and the pre-offset to –0.01. For example, we would yield:

$$r = ((f_n \cdot f_p) / (r_0 - n_p)) \cdot p + n$$

$$r = (9.8399 \cdot 10^{10}\ \ [1/\text{A}]) \cdot (1.01) / (0 + 0.01) \cdot (1 \cdot 10^{-9}\ \ [\text{A}]) \approx \underline{9840}$$

$$r = (9.8399 \cdot 10^{10}\ \ [1/\text{A}]) \cdot (1.01) / (1 + 0.01) \cdot (100 \cdot 10^{-9}\ \ [\text{A}]) \approx \underline{9840}$$

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 7 below.

Name	Description
X_1	20 Bit signed integer device controlling the scanner actuator for the X-axis
Y_1	20 Bit signed integer device controlling the scanner actuator for the Y-axis
Z_In_1	16 Bit signed integer device controlling the scanner actuator for the Z-axis
Z_Axis_1	Similar to *Z_In_1* but used for different purposes internally. The gradient factor for this device must be set to half the value used for *Z_In_1*
IT_Image_1	16 Bit signed integer device for obtaining the tunnelling current. Must be used in conjunction with *ClassicPreampI_1*
VirtualIset_1	16 Bit signed integer device for controlling the tunnelling current regulator setpoint. Must be used in conjunction with *ClassicPreampI_1*
VGap_Out_1	16 Bit signed integer device for controlling the gap voltage. Must be used in conjunction with *ClassicPreampV_1*
USCBAux1_In_1	16 Bit signed integer device for accessing sensor data in AFM mode, such as F_n or F_l
USCBAux2_In_1	16 Bit signed integer device for accessing sensor data in AFM mode, such as F_n or F_l
Aux3_In_1	16 Bit signed integer device for accessing sensor data in AFM mode, such as damping or ΔF
Aux4_In_1	16 Bit signed integer device for accessing sensor data in AFM mode, such as damping or ΔF

Table 7. Important Raw Devices

Literature

Please note. 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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[6] Hamann C, Hietschold M (1991). Raster-Tunnel-Mikroskopie (in German). Akademieverlag 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 under

http://www.omicron.de/om-adr.html

or via e-mail reply service under

contact.info@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:

> **Please note:** 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 license 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

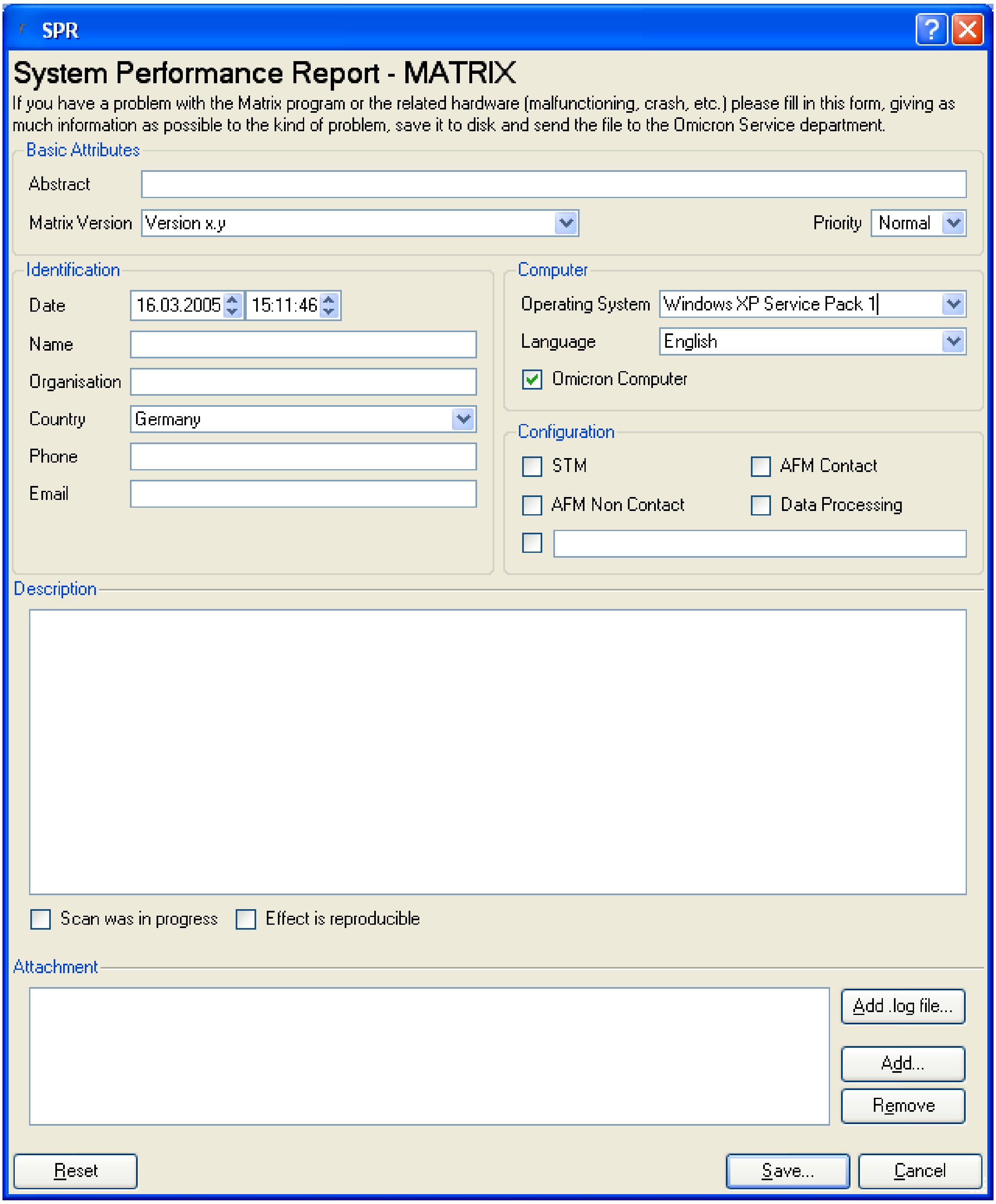
We are sorry that you have encountered a problem with MATRIX or the related hardware. In order to help us solve your problem as quickly as possible we kindly ask you to fill in the following **System Performance Report**, giving as much detail as possible. Screen shot files and the software performance report can be sent via e-mail.

Thank you for helping us to help you.

> **Please note.** 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.
- From the start menu open the clipboard (Start-Programs-Accessories-Clipboard).
- For printing the screen shot copy it from the clipboard into WordPad (Start-Programs-Accessories-WordPad).
- Alternatively select "Save as" from the file menu and save the image as *.clp file. Please choose self-explanatory file names since the files will be handled by different people.


SPR
System Performance Report - MATRIX
If you have a problem with the Matrix program or the related hardware (malfunctioning, crash, etc.) please fill in this form, giving as much information as possible to the kind of problem, save it to disk and send the file to the Omicron Service department.
Basic Attributes
Abstract
Matrix Version
Version x.y
Priority
Normal
Identification
Date
16.03.2005
15:11:46
Name
Organisation
Country
Germany
Phone
Email
Computer
Operating System
Windows XP Service Pack 1
Language
English
Omicron Computer
Configuration
STM
AFM Contact
AFM Non Contact
Data Processing
Description
Scan was in progress
Effect is reproducible
Attachment
Add .log file...
Add...
Remove
Reset
Save...
Cancel

Glossary of Terms

Channel display
Display window showing **incoming data of a specific measurement channel** in either image mode or line 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 Parameter**s.

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 **View**s, **Experiment** Structure, **Parameter**s, the graphical **User** interface (**GUI**) and, possibly, **Script**s.

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 Component** 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 button**s.

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**.

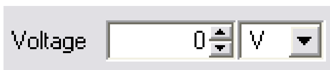
Image
A pictorial representation of a frame belonging to some data set.

Instrument
Collection of information on the microscopy hardware (SPM including electronics components) to be used for **Experiment**s

Master component
Every **Experiment** has a single "**Master Component**" which contains the start/stop controls for the entire **Experiment**.

MATRIX system
The **MATRIX System** consists of a MATRIX control unit and a MATRIX software package (including SPIP).

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 control**s, etc. that have been carefully arranged by the designer of an **Experiment** Element.

Parameter
MATRIX knows three types of **Parameter**s: **Deployment Parameter**s, optional **Parameter**s and expert **Parameter**s. 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**: **Tooltip**s 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 **Experiment**s. It can be used much like a sub-folder in a file system.

Radio button — **Radio button**s are the start-stop-pause control buttons on the tagged **Master Component** of an **Experiment**. They are part of the **Experiment state control** field in the bottom left hand corner.

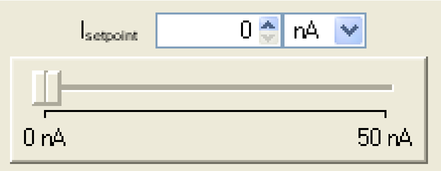
Raster — Digital size of a scan in terms of number of lines and points per line.

Scan area — Physical area to be scanned in terms of length units, rotation angle etc.

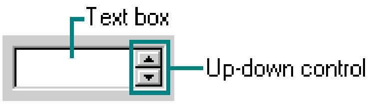
Script — Using the provided command language **Script**s can be created to relate or manipulate **Parameter**s and/or components, etc.

Session — A **Session** is the combination of **User** profile, **Project**s and **Instrument** data. The **Session** file is **Session**.sess in your "documents and settings" path. During a **Session** all loaded **Project**s may be accessed.

Smart slider — Hold down the mouse button on a **Numerical value control** field to unfold a **Smart slider** for convenient value adjustment. This works with all **Numerical value control** fields.



Spin box — A **Spin box** allows input by typing into the text box or by using the up-down control buttons. For the up-down control a step width can be set in the properties window.



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 Component** 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 button**s.

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**: **Tooltip**s and **Context sensitive help**. **Tooltip**s 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.

UCB — Universal Counter Board

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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