Version: 3.5
Modified: July 20
Products: ASC500

User Manual

ASC500
SPM Controller & Software

attocube systems AG, Eglfinger Weg 2, D – 85540 Haar bei München, Germany
Phone: +49 89 420 797 0 Fax: +49 89 4207 9720 190
E-Mail: info@attocube.com www.attocube.com

For technical queries, contact:
support@attocube.com

attocube systems office Munich:
Phone +49 89 420 797 0
Fax +49 89 420 797 201 90

Table of Contents

1 Introduction

1.1 System Overview

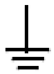
The SPM Scan Controller ASC500 is a complete scan control unit providing the suitable signals for the use with the attoCFM Confocal Microscope, the attoAFM Atomic Force Microscope and the attoSNOM Near-Field Optical Microscope as well as any other homebuilt or commercial scanning probe microscope.

The modular and flexible digital SPM controller, ASC500, combines state of the art hardware with innovative software concepts and offers an unmatched variety of controlling possibilities, enabling the customer to perform many different scanning probe microscopy applications. All desirable functions and high-end specifications are available to control the experiment of your choice. The flexible, FPGA-based architecture allows the on demand implementation of your particular requirements.

1.2 Safety Information

For the continuing safety of the operators of this equipment, and the protection of the equipment itself, the operator should take note of the **Warnings, Cautions,** and **Notes** throughout this handbook and, where visible, on the product itself.

The following safety symbols may be used on the equipment:

	**Warning**, risk of danger. Refer to the handbook for details on this hazard.
	**Warning**, risk of electric shock. High voltages present.
	**Warning**, laser radiation. Do not stare into beam. Class 1M Laser product.
	Functional (EMC) earth/ground terminal.

The following safety symbols may be used throughout the handbook:

	Warning. An instruction which draws attention to the risk of injury or death.
	Caution. An instruction which draws attention to the risks of damage to the product, process or surroundings.
	Note. Clarification of an instruction or additional information.

1.2.1 Warnings

The unit may only be connected to an earthed and fused supply of 110 to 230 V.

	The equipment, as described herein, is designed for use by personnel properly trained in the use and handling of mains powered electrical equipment. Only personnel trained in the servicing and maintenance of this equipment should remove its covers or attempt any repairs or adjustments. If malfunction is suspected, immediately return the part to attocube systems for repair or replacement. There are no user-serviceable parts inside the electronics. Modified or opened electronics cannot be covered by the attocube warranty anymore. Take special care if connecting products from other manufacturers. Follow the General Accident Prevention Rules.
	If this equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired. Do not operate the instrument outside its rated supply voltages or environmental range. In particular, excessive moisture may impair safety.
	Never connect any cabling to the electronics when contacts are exposed! Never connect any cabling to the electronics when the electronics is not in GND mode! Avoid shorts. Be careful not to cause a short circuiting between the contacts in the BNC or any other connector.
	For laboratory use only. This unit is intended for operation from a normal, single phase supply in the temperature range 5° to 40°C, 20% to 80% RH.

1.3 Declarations of Conformity

For Customers in Europe

This equipment has been tested and found to comply with the EC Directives 89/336/EEC ‘EMC Directive’ and 73/23/EEC ‘Low Voltage Directive’ as amended by 93/68/EEC.

Compliance was demonstrated by conformance to the following specifications which have been listed in the Official Journal of the European Communities:

Safety EN61010: 2001

EMC EN61326: 1997

1.4 Waste Electrical and Electronic Equipment (WEEE) Directive

DE16963721

Compliance

As required by the Waste Electrical and Electronic Equipment (WEEE) Directive of the European Community and the corresponding national laws, attocube systems offers all end users in the EC the possibility to return "end of life" units without incurring disposal charges.
This offer is valid for attocube systems electrical and electronic equipment:

- sold after August 13th 2005,
- marked correspondingly with the crossed out "wheelie bin" logo (see logo to the left),
- sold to a company or institute within the EC,
- currently owned by a company or institute within the EC,
- still complete, not disassembled, and not contaminated.

As the WEEE directive applies to self-contained operational electrical and electronic products, this "end of life" take back service does not refer to other attocube products, such as

- pure OEM products, that means assemblies to be built into a unit by the user (e. g. OEM electronic drivers),
- components,
- mechanics and optics,
- left over parts of units disassembled by the user (PCB's, housings etc.).

If you wish to return an attocube unit for waste recovery, please contact attocube systems or your nearest dealer for further information.

Waste treatment on your own responsibility

If you do not return an "end of life" unit to attocube systems, you must hand it to a company specialized in waste recovery. Do not dispose of the unit in a litter bin or at a public waste disposal site.

Ecological background

It is well known that WEEE pollutes the environment by releasing toxic products during decomposition. The aim of the European RoHS directive is to reduce the content of toxic substances in electronic products in the future.
The intent of the WEEE directive is to enforce the recycling of WEEE. A controlled recycling of end of live products will thereby avoid negative impacts on the environment.

2 Hardware Description

2.1 Mechanical Installation

Siting

Unpack all components and retain all packing material and shipping containers for your future shipping needs. When placing the controller, do not obstruct the ventilation slots in any way. Make also sure that the controller is not placed close to any liquids or moisture source.

Carefully unpack and visually inspect the controller for any damage. Place all components on a flat and clean surface.

Caution. When siting the unit, it should be positioned so as not to impede the operation of the rear panel power supply plug and switch. Ensure that proper airflow is maintained to the unit. Do not obscure the ventilation holes

Warning. Operation outside the following environmental limits may adversely affect operator safety:

Indoor use only

Maximum altitude 2000 m

Temperature range 5°C to 40°C

Maximum humidity less than 80% RH (non-condensing) at 31°C

To ensure reliable operation the unit should not be exposed to corrosive agents, excessive moisture, heat or dust. If the unit has been stored at a low temperature or in an environment of high humidity, it must be allowed to reach ambient conditions before being powered up.

Note. In applications requiring the highest level of accuracy and reproducibility, it is recommended that the controller unit is powered up approximately 30 minutes before use, in order to allow the internal temperature to stabilize.

Caution. Do not connect cabling longer than 3m. Longer cabling may increase the sensitivity of the device to external influences.

2.2 Electrical Installation

2.2.1 Connecting to the Voltage Supply

Warnings. The unit must be connected only to an earthed and fused supply of 110 to 230V.

Use only power supply cables supplied by attocube systems, other cables may not be rated to the same current. The unit is shipped with appropriate power cables for use in the UK, Europe, and the USA. When shipped to other territories the appropriate power plug must be fitted by the user.

2.2.2 Fuses

Two T 4 A/250 V fuses are located on the back panel for the mains voltage.

Note. When replacing fuses:

Switch off the power and disconnect the power cord before removing the fuse cover.

Always replace broken fuses with a fuse of the same rating and type.

2.3 Front and Rear Panel Connections

2.3.1 Front Panel ASC500 v1

Software development for v1 ASC500 was ceased around 2010.

Figure 1: *Front panel of the ASC500.*

On the front panel of the ASC500 v1, there is only the green "ON"-LED indicating the power status of the unit. If the unit is on, the LED is lit.

2.3.2 Rear Panel ASC500 v1

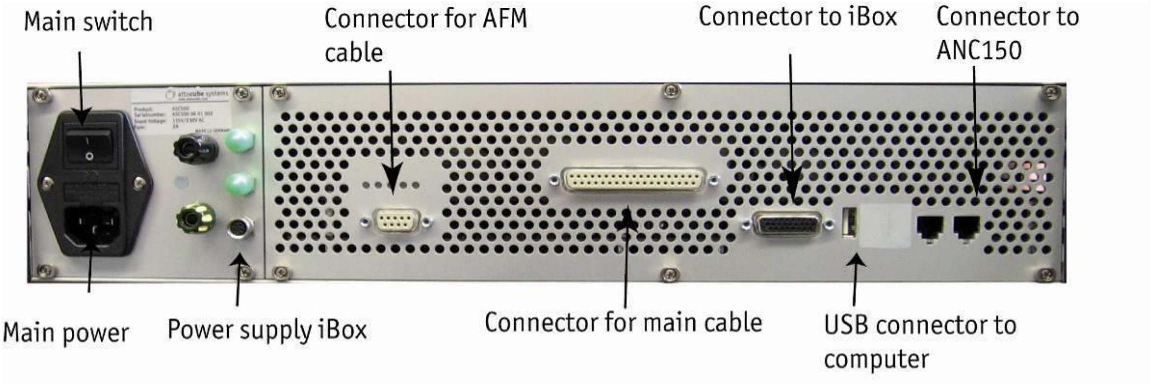


Figure 2: *Back panel of the ASC500 v1 scan controller.*

On the back panel, there are:

- the main power switch,
- the fuse holder (see fuse description above),
- the main power supply connector,
  (110/220 V, 50 – 60 Hz, max. 20 VA),
- an earth terminal for additional connection of the unit to earth,
- the functional ground for connecting a setup to the electronics ground,
- 3 power connectors for supplying additional hardware
- the AFM connector (high speed input and output),
- the main SPM outputs,
- the connector for the iBox (discontinued),
- the USB connector for connection to a PC,
- the serial connector to connect to the ANC150.

2.3.3 Cable description ASC500 v1

Power supply:
Use the power cable to connect the ASC500 to the 100, 115 or 220 V jack.

USB cable from computer to ASC500:
Use the USB connector to connect to your computer.

ASC500-iBox:
Connect the cable attached to the ASC500-iBox to the respective connector of the ASC500 and the round pin connector for the power supply.

Main cable - Signal In- and Outputs:
Use the main cable and connect it to the respective connector. The BNC connectors are connected to the setup as follows:

ADC 1:	sensor signal
ADC 2:	optional input
ADC 3:	optional input
DAC 1:	optional output
DAC 2:	optional output
x-Out:	connects to the voltage amplifier for x-axis (e.g. ANC200)
y-Out:	connects to the voltage amplifier for y-axis (e.g. ANC200)
z-Out:	connects to the voltage amplifier for z-axis (e.g. ANC200)

AFM cable – High Speed Signal In- and Output:
Use the AFM cable and connect it to the respective connector. The BNC connectors are connected to the AFM setup as follows:

Fosc:	high frequency sensor signal (e.g. AFM tapping mode) as feedback input
Fexc:	high frequency excitation signal

Warning. Do not, under any circumstances attempt to connect the digital I/O to any external equipment that is not galvanically isolated from the mains or is connected to a voltage higher than the limits specified. In addition to the damage that may occur to the controller there is a risk of serious injury and fire hazard.

2.3.4 Front Panel ASC500 v2

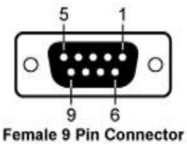
Since end of 2008, v2 hardware of the ASC500 controller is available. The latest supported software version is V26. Implementation of new features was ceased 2016, bugs are continuously being fixed.

Figure 3: *Front panel of the ASC500 v2. The break-out cable of v1 was replaced by easily accessible BNC connectors at the front panel. Please note that both input and output ranges and sampling rate of all converters are indicated directly below the connector plugs.*

With the new hardware versions, most connections to and from the controller are available on the front panel. Different sections in the front panel combine the plugs for certain functionalities like inputs, outputs, trigger ports, etc. The different sections are (from left to right):

iBox connection: The iBox (discontinued) connector is to be plugged into this socket.

External: There are two 8 bit LVTTL (low voltage TTL, 3.3 V) connectors, one for input and one for output triggering. Connectors are 9-pin D-sub (Pin 9 is GND).



On the left, the pin numbering for the sub-D connector of the *External* lines is shown. The upper **input** connector (labeled ‘1’ or ‘IN’) is used for TTL inputs:

Input pin	Usage
1	Counter input
2	Reserved
3	External Handshake SYNC
4-8	Reserved
9	GND

The **output** connector (labeled ‘2’ or ‘OUT’) is used as follows:

Output pin	Usage
1	Pixelclock output (see section 6.2.1 for details6.2)
2	Lineclock output
3	Frameclock output
4	External Handshake SYNC OUT
5	Shutter (used by lithography, see section 6.2.3)
6-8	Reserved
9	GND

ADC section: There are six ADC inputs available, labeled 1 through 6, with 18 bit 400 kS/s each.

DAC section: There are four DAC outputs available (+/-10 V, 16 bit, 200 kS/s). Two additional modulation ports, labeled MOD1 and MOD2 can be used to add any analog voltage to the outputs of DAC1 and DAC2, respectively.

SCAN section: The SCAN section provides the outputs of the scan engine: Xout, Yout and Zout. In addition, there is a modulation input for the Zout that gives you the possibility to externally modulate the voltage output to the z scanner.

HF section: This section provides the high frequency inputs and outputs (50 MS/s) of the controller. There are two independent groups of in- and outputs. Each group features 16 bit, 50 MS/s ADCs and DACs, as well as SYNC out (same output frequency than OUT with +/- 5V amplitude) and MON out (pre-amplified IN signal). Only one of the two HF channels can work at a time.

AUX power: This connector provides stable +/- 15 V and +/- 5 V for external devices. Maximum current is 200 mA at 5 V and 100 mA at 15 V. The connector is a 5pin Binder series 440.

2.3.5 Back Panel ASC500 v2

The back panel of the ASC500 generation v2, features two new possibilities to connect the controller to other devices. There is a digital serial interface (called NSL A and NSL B) and a LAN connector.

Figure 4: *Back panel of the ASC500 v2. Please note the new digital interface (NSL) and the LAN connection.*

The connectors from left to right are the following:

Power connection: Connection to mains. The ASC500 features auto range for 110 - 115 V and 230 V, 50..60 Hz.

Ground: 4 mm plug for connecting to earth and housing GND.

Voltage indicators: Shows correct availability of internal DC voltages.

NSL A/B: Digital serial interface to connect to attocube ANC350 Step/Scan-Controller. 9 pin D-sub connector.

USB: USB 2.0 interface to connect to the PC.

Serial: Serial interface to connect to attocube ANC150 /ANC300 Step-Controller. RJ45 connector.

LAN: LAN 100 Mbit connection to the PC.

2.3.6 Front Panel ASC500 v3

In 2013 attocube released its new, version 3 controller. The design was kept similar to V2 though two ports were added to the back panel to enable connectivity to attocube's FPS3010 displacement sensor.

ASC500 v3 currently runs with V27 software where the last release can be requested from attocube support support@attocube.com.

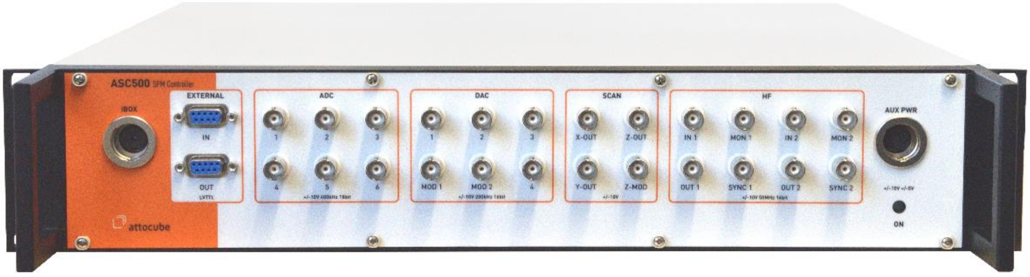


Figure 5: *Front panel of the ASC500 v3. It is identical to the v2.*

The connectors on the front plate of v2 and v3 are identical. For more information see 2.3.4

2.3.7 Back Panel ASC500 v3

The back panel of the ASC500 generation 3 features SENSOR X and SENSOR Y connectors to establish a link to the FPS3010. This enables optical readout of the sample position to eliminate the non-linearity of the scanner piezos (Closed Loop Scanning functionality). The rest is similar to the v2 back panel.

Figure 6: *Back panel of the ASC500 v3. Compared to v2 two HDMI ports have been added (SENSOR X/Y).*

The connectors will be described in more detail from left to right:

Power connection: Connection to mains. The ASC500 features auto range for 110 - 115 V and 230 V, 50..60 Hz.

Ground: 4 mm plug for connecting to earth and housing GND.

Voltage indicators: Shows correct availability of internal DC voltages.

Sensor X/Y: These ports can be used to connect to the FPS3010. HDMI ports.

NSL A/B: Digital serial interface to connect to attocube ANC350 Step/Scan-Controller. 9 pin D-sub connector.

USB: USB 2.0 interface to connect to the PC.

Serial: Serial interface to connect to attocube ANC150 /ANC300 Step-Controller. RJ45 connector.

LAN: LAN 100 Mbit connection to the PC.

3 Description of the Controller

3.1 Key Features and Benefits

AFM/SNOM Control

- 18 bit 400 kS/s ADC input-channel for AFM contact mode signal
- digital measurement of frequency and phase for AFM non-contact mode with feedback
- DDS for oscillation excitation / frequency range 1 kHz to 400kHz
- 14 bit 40 MS/s ADC input-channel for measurement of the amplitude dampening (new v2 version: 16 bit 50 MS/s)
- digital PI feedback loop for z controller

CFM Control

- 18 bit 400 kS/s ADC input-channel for CFM signal
- counter input for connection to single photon counter

STM Control

- 18 bit 400 kS/s ADC input-channel for measurement of tunneling current
- 16 bit 200 kS/s DAC output-channel for gap voltage
- modulation input for gap voltage
- digital PI feedback loop for z controller

Scan Generation

- 2D xy-scan generator with 4 MHz pixel frequency
- 16 bit resolution, effective resolution of 20bit in full range mode
- hardware crosstalk compensation
- hardware slope compensation
- slew rate controlled movement
- direct vectorized positioning

Other

- counter input: i.e. 24 bit 10 MHz min. pulse width 50 ns
- online data processing: digital filter, low-pass, averaging, offset correction, calibration, FFT

3.2 Hardware Specifications

Inputs (ADC1-6)

Voltage range:	+/- 10 V
Max. allowed voltage:	+/- 15 V
Converter resolution:	18 bit
Voltage resolution:	76 µV
Update rate:	400 kHz
Input resistance:	10 kOhm
INL	+/- 2.5 LSB
DNL	+ 1.75/-1 LSB
Offsets:	+/- 60 mV

Outputs (X-, Y-, Z-Out)

The Z-Out output to the z scanner features an 18 bit resolution with possible 14 bit attenuation. The scan outputs are designed in a way that you will never reach the digital bit resolution limit!

	Voltage range:	+/- 10 V (uni- or bipolar)
	Max. output current:	+/- 20 mA
	Converter resolution:	16 bit (18 bit for Z-Out)
	Programmable attenuation:	14 bit
	Programmable offset:	+/- 10 V
	Offset resolution:	16 bit
	Max. resolution in small range mode:	16 bit over 1.2 mV
	Update rate:	4 MHz
Outputs (DAC1-4)	Voltage range:	+/- 10 V
	Max. output current:	+/- 20 mA
	Converter resolution:	16 bit
	Voltage resolution:	305 µV
	Update rate:	200 kHz
	INL:	+/- 1 LSB
	DNL:	+/- 1 LSB
External	External 1:	8 LVTTL inputs (Pin 1-8)
	External 2:	8 LVTTL outputs (Pin 1-8)
	GND Pin:	Pin 9
	Pulse Level:	3.3 V

3.3 General Functionality

Scanning probe microscopy works by scanning a probe across a sample or the sample under the probe and thereby recording certain physical variables. The ASC500 controller and software controls the scan position and movement, acquires several signals simultaneously during the scan and saves the acquired images. Furthermore, it offers a feedback option for AFM measurements in feedback mode.

In order to perform the scan, the software calculates voltage ramps depending on the scan amplitude, the scan speed and the number of pixels of the image. The voltage ramps will be amplified by one of attocube's high voltage amplifiers (ANC200, ANC250, ANC300, and ANC350) and applied to the piezos moving the sample in X-, Y- and Z-direction. The imaging process is done in a line-by-line scanning manner. During the displacement in X-direction, called the fast axis, the Y-position remains constant. The X-direction will be scanned in both forward and backward direction, leading to two images: the forward and backward image. All signals are acquired during both forward and backward motion.

In case of scanning in feedback mode, the feedback loop will keep the sensor value as close as possible to the value called *Setpoint* by controlling the output on the z-piezo.

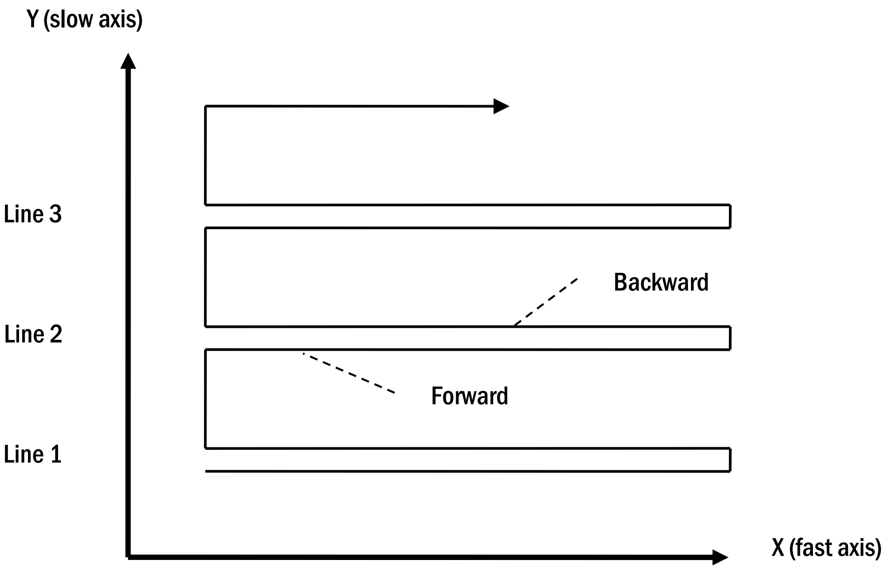


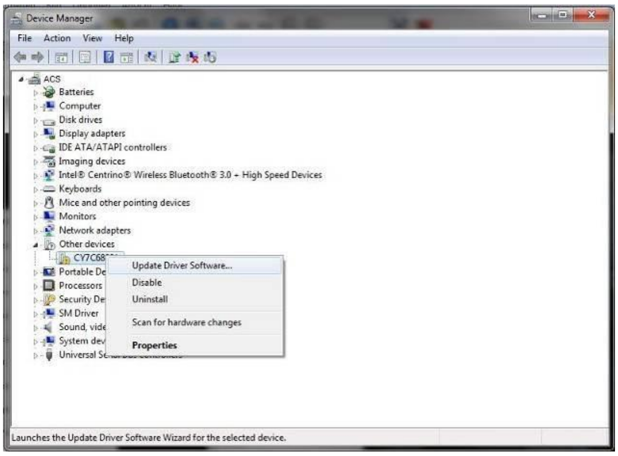
Figure 7: *Movement of the tip during the scan. The scanners therefore move the exact opposite way.*

3.4 Hardware Requirements and Operating Systems

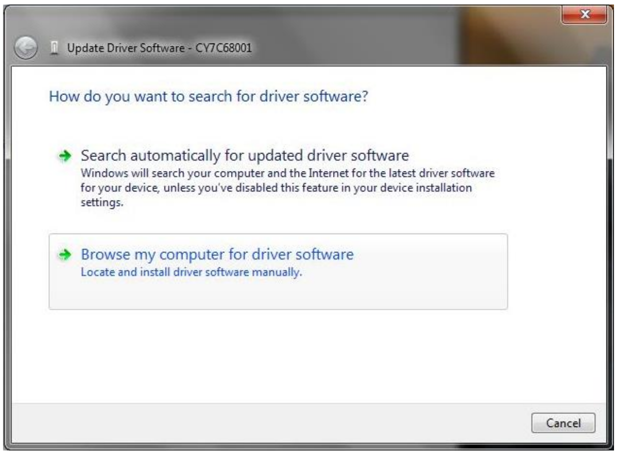
The minimum system requirements are the following: a recent multicore processor, 1 GB RAM, 100 GB hard disk, and an HD monitor. The current version of the software is available for Windows 7, the appropriate drivers for the software are delivered with the system.

3.5 Hardware Driver Installation

The controller is connected to the computer via USB. Software and drivers are either installed on the computer delivered with the system or included on a CD. In the latter case, please copy the software (folder 'ASC500_Software') and the drivers (folder 'ASC500_Driver') from the CD onto your computer.
When the ASC500 is connected to the computer and switched on for the first time, the computer should recognize the new hardware. Please follow the steps below to install the driver.
Since October 2014 the Software is shipped with an installer executable file. Installing this will automatically install all required drivers.



Go to *Control Panel -> Device Manager*, and search for the new device. Right click to select *Update Driver Software*.

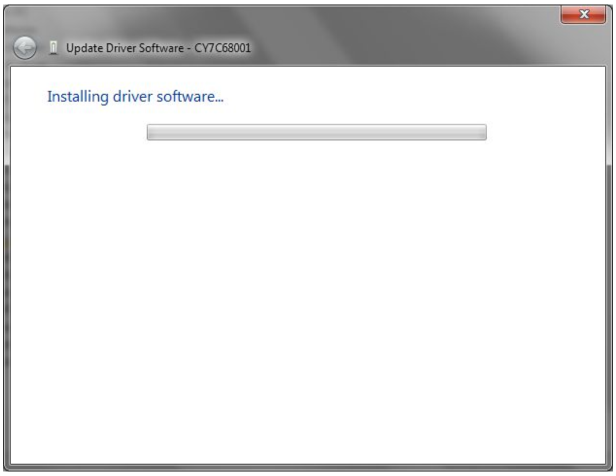


Select *Browse my computer for driver software*.

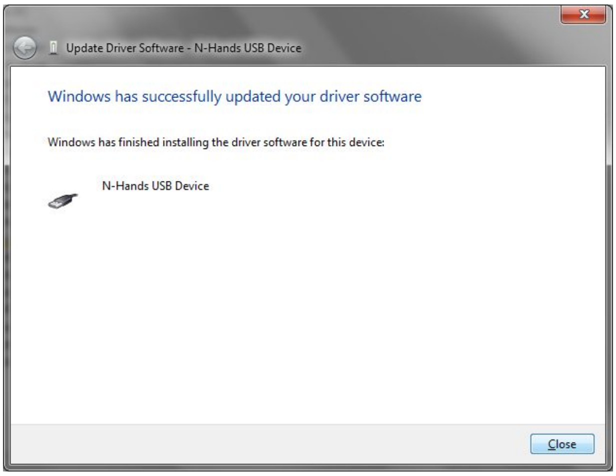
Browse to select the directory where you have stored the ASC500 driver(s) and click *Next*.

(Note that there are separate driver files for Windows Vista / Windows 7 32 bit and 64 bit versions.)

Click on *Install…*



...to start the driver installation.



Click *Close* to finish the installation procedure.

4 Data handling

Any successful experiment relies on a safe and reliable storage of its outcome. Moreover, the quality of a measurement may not be immediately apparent so the data has to be analyzed in a second step. The format of the stored data has to be compatible to all tools the user might want to employ. In this sense, the act of saving the experimental outcome is a task of major importance in the course of the experiment. In the design of the ASC500 and its software, this importance was especially emphasized.

The software allows for fast and flexible procedures of data storage:

- data can be saved on a time base from microseconds to hours
- data can be saved in a multiple of 1D, 2D and 3D file formats
- user defined data groups can be saved by one single mouse click
- automatic snapshots and text files containing parameters are generated
- all file formats are compatible to all major analyzing software (SPIP, MountainsMap, Gwyddion, Wsxm, ...) or can be directly viewed in the Windows Explorer

The following chapter will explain in detail the data storage capabilities of the ASC500 controller.

4.1 Quick guide for data saving

The next section will give a short overview and provide a quick entry on how to use the controller's data storage capabilities. The following sections will give all necessary details for getting the maximum flexibility and time efficiency out of the product.

4.1.1 The Data Channel Configuration dialogue

The central point for all data related processes in the ASC500 is the *Data Channel Configuration* dialogue (DCC). It is used to define what signals are accessible in the various modules of the controller and how these signals are saved. The DCC is accessible from various points of the graphical user interface (GUI) via the icon that is shown to the left.

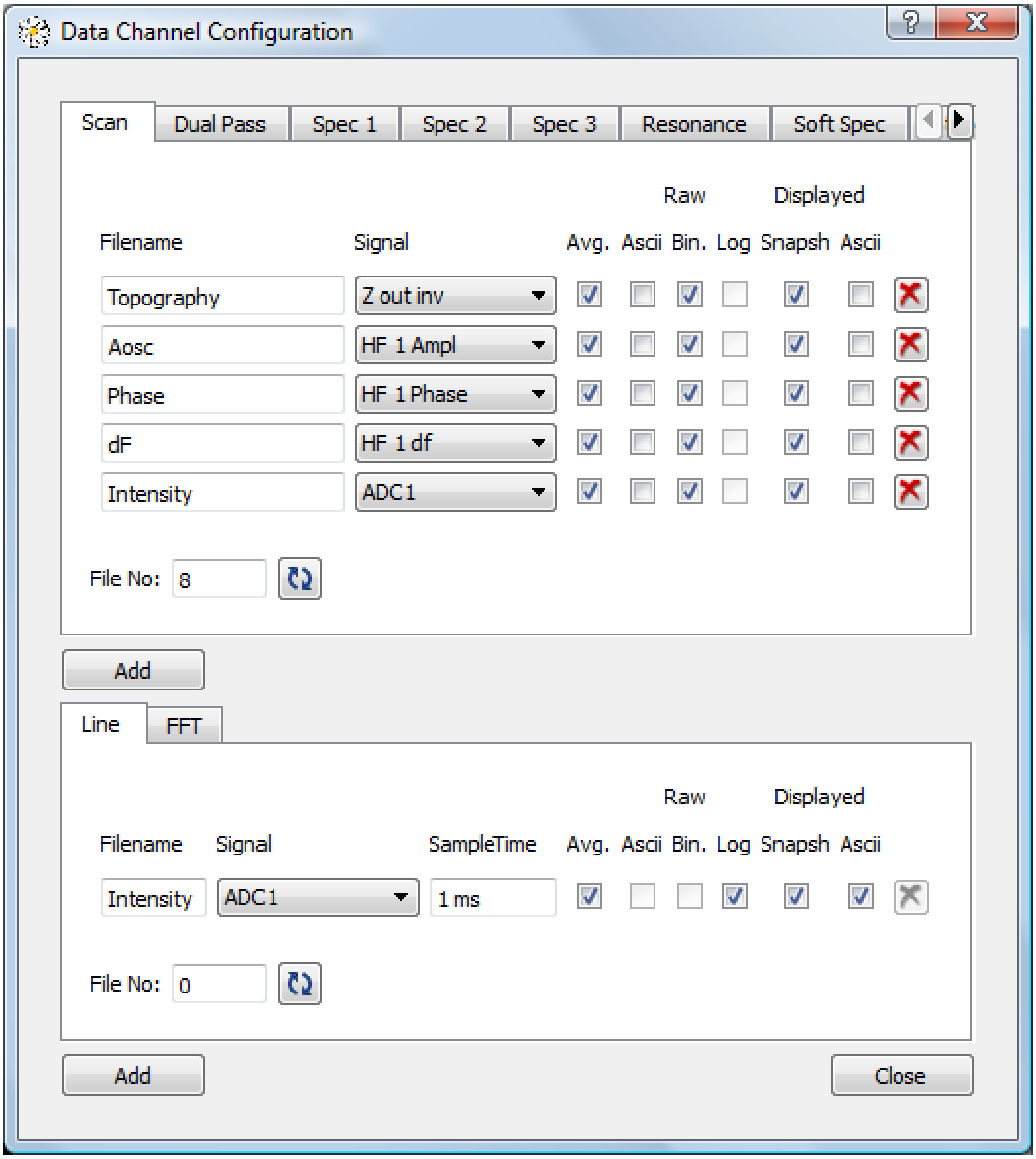


Figure 8: *The Data Channel Configuration dialogue.*

Figure 8 shows the DCC in a typical SPM configuration. In the bottom half of the window the *Line* and *FFT* tab can be found, in which one can set the saving configurations for the *Line View* and *Frequency analyzis* tab in the *Main Control*. The *Filename* textbox defines the name of the saved file and must not be empty. Via the *Signal* drop-down list the channel to be saved can be chosen. To record multiple channels, one can add additional channels via the *Add* button underneath the *Line* and *FFT* tab. The *SampleTime* textbox sets the time interval between to samples. It is unit sensitive and will automatically add the last correct unit if the input is just a number. It recognizes the units ms (millisecond) and µs (microsecond) which can also be written as us. The AVG checkbox defines, whether the saved value corresponds to a specific readout at the moment of sampling (unchecked) or if it is averaged over one *SampleTime* (checked). For optimal results, we recommend to keep this box checked. As the Raw and Displayed data for the *Line* and *FFT* tab are identical, the *Ascii* and *Bin.* checkboxes will always be disabled. If the *Log* checkbox is active, the raw data is stored continuously in ASCII formt. The Snapsh and ASCII checkboxes enable the storage of the data in PNG and/or CSV format if one of the SNAPSHOT icons (shown to the left) is pressed.

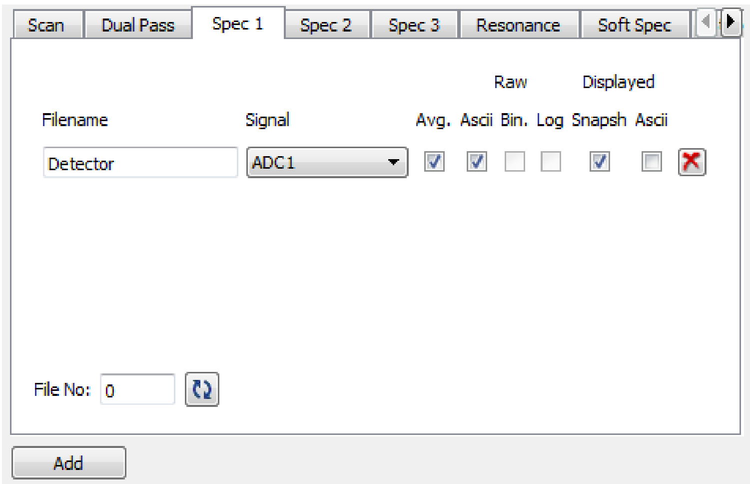
The SCAN data group on the top of the DCC is responsible for all data collected during an xy raster scan and is thus of major importance. Normally, at least two channels will be defined here:

- One will be the topography signal, defined as the output of the z controller. The corresponding signal is called *Z out inv* as shown in the example above.
- The other could be the error signal of the z controller. For contact mode AFM, this would be the deflection signal usually connected to ADC1. For non-contact AFM, it would be the output of the lock-in called *HF 1 Ampl*. For STM, it would be the tunneling current, again usually connected to ADC1.

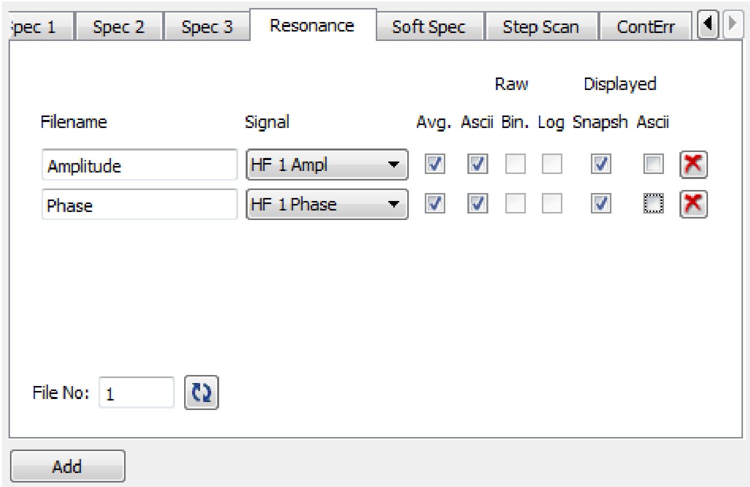
The AVG, RAW BIN, RAW ASCII and DISPLAYED SNAPSH checkboxes should all be checked to save the SCAN data in a binary data format, a text type data format and as a snapshot image. The Checkboxes under Raw and Displayed differentiate between the unchanged recorded data and the data displayed as an image in the main control that might be different depending on the Underground Filter settings. Any number of additional data channels can be added by clicking the ADD button. As the SCAN data is resolved in a special manner, a continuous storage is not possible, thus the Log checkbox will always be disabled.

For most experiments, one or more spectroscopy and/or resonance features will be necessary. The data channels needed for these operations can be created in one of the Spec tabs and the Resonance tab.

DCC Spectroscopy Tab



DCC Resonance Tab



With the settings shown above, all of the basic experiments in scanning probe microscopy can be done. Scan data will be recorded on several channels simultaneously, spectroscopy and resonance experiments can be done and any given signal can be examined in a line and FFT display. The recorded data can be stored to the hard disk by clicking on one of the snapshot icons in a display. The snapshot trigger in a SCAN display will save the data of all SCAN data channels simultaneously. The data will be stored in a multitude of formats: For example, the SCAN data of Figure 8 will be saved in averaged binary type format and in addition as a picture file. There will be separate files for both forward and backward scan direction. There will also be a snapshot of the SCAN line view and an extra text file with all the relevant scan parameters. All of this will be saved by a single mouse click and all files will automatically be numbered and grouped.

The time of the data saving will depend on the type of snapshot icon that is used for triggering the data storage.

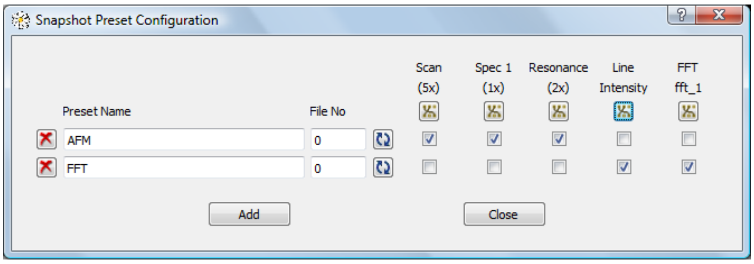
The Snapshot Immediate will save all data in its current state: It may be a half-filled SCAN image or any arbitrary fraction of a LINE display.

Snapshot Delayed will save the data at the next completion of the underlying operation. A SCAN will be saved when the scan area has been completed, a spectroscopy will be saved once the sweep range has been swept through.

Snapshot Repeat will turn the Snapshot Delayed function on an endless cycle. The cycle can be stopped with a following click on the Snapshot Repeat button.

4.1.2 The Snapshot Preset Configuration

A click on the snapshot icons within a display will trigger the data storage of the complete data group that corresponds to the display. I.e. a snapshot trigger in a SCAN display will save all data channels belonging to SCAN. To save a multiple of data groups simultaneously, the SNAPSHOT PRESET functionality can be used:



For each preset, any combination of data groups can be chosen. Only data groups with at least one data channel are allowed in the preset configuration dialogue. Any number of presets can be added with the *Add* button.

To trigger the data storage of a preset, the preset icons shown to the left can be used. The icons can be found in the main status line of the Daisy program. To reach the Snapshot Preset Configuration dialogue, the leftmost icon has to be clicked. The drop-down list is used to choose the preset for the next saving process. The preset snapshot icons work similar to their local display counterparts described in the section above.

After this short overview, the next section will give details and background on the data handling and saving capabilities of the ASC500 SPM controller.

4.2 Data handling details

4.2.1 Signals, data channels and data groups

A signal is a stream of data that can have two origins:

1. The signal is directly sampled through one of the input connectors. This would be called an external signal. There are 8 external signals that are named after its input connector (ADC1, ..., HF1 IN, ..., Counter)

2. The signal is generated within the ASC500 (internal signal). Internal signals could be the output of a PI controller (*Z_out*) or a lock-in (*HF 1 Ampl, HF 1 Phase*).

Signals are routed into data channels. A data channel combines the measurement data with some secondary data that carries additional information like the position within an image or a time stamp.

It is common that several different signals are measured in the same context and need the same secondary data. One typical example would be a scan where multiple signals should be recorded parallel and hence combined with the same location information. Therefore data channels are divided into different groups depending on the context of the data.

Furthermore the same signal is often needed in different context and hence data channels at the same time. For example, the deflection read-out of an AFM (connected to the ADC1 input) could be used for recording the topography and feeding the FFT module at the same time. The ADC1 signal would then be used in two data channels, one belonging to the data group SCAN and one belonging to the data group FFT.

Up to 14 data channels can be used at the same time.

4.2.2 Internal Signal Flow

The ASC500 SPM controller features a very flexible architecture. There are many different ways to route the signals between the internal controller modules to gain maximum functionality. *Figure 9* gives an overview of this internal signal flow. The most important controller functions are illustrated by boxes. Each controller function is connected to other functions via data lines. Data lines attached to the left of a controller module show all possible input signals for the respective controller function. Data lines starting from the right side or from the bottom of a controller module show the possible output signals generated or altered by the module.

For example, in a standard non-contact mode AFM measurement, the intensity signal would be attached to the HF IN connector on the front panel. The signal that is carrying the lever information is *HF 1* which is automatically routed into the high frequency *HF Lock-In*. The lock-in demodulates the *HF 1* and generates the *HF 1 Ampl* signal which can then be used both as an input value for the *Z Controller* and also to feed a two-dimensional display during the scan in the *Data Collection* module.

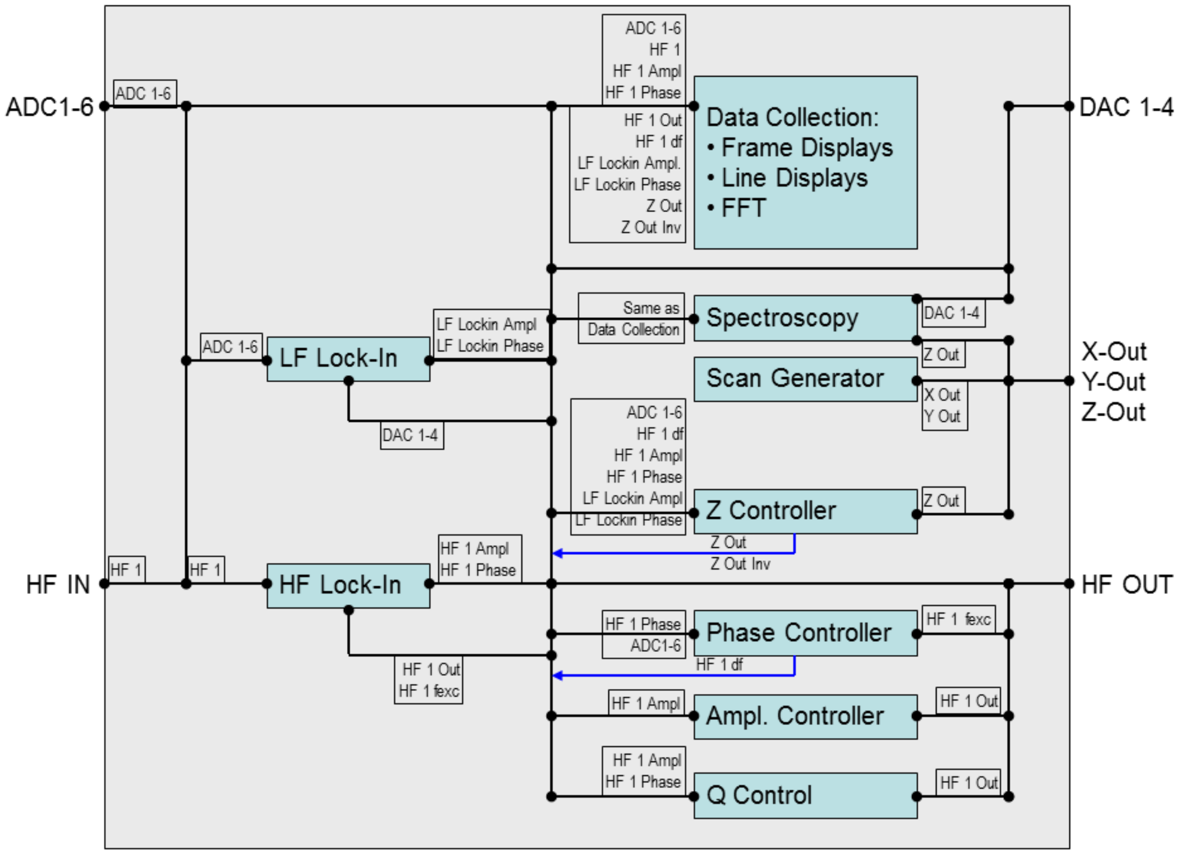


Figure 9*: Internal Signal Flow Diagram. This diagram gives an overview on the relation between input and output connectors, the names of the signals and the most important controller functions. Data flow direction is from left to right (otherwise indicated). Each controller function is depicted by a box, all possible input signal are shown on the input side of the box, the output signal are shown to the right of the box.*

The controller modules shown in *Figure 9* are explained in more detail in section Operating the Controller of this manual.

4.2.3 Data processing chain

The diagram of the data processing chain is shown in *Figure 10*. All signals are either captured or generated within the physical unit of the ASC500 controller. The data is subsequently averaged according to the user’s settings (defined in the DCC, see 4.2.5). After transmission to the PC via USB, the data is stored in a buffer. The content of the buffer can be saved directly to hard disk, choosing from various types of file formats. In addition, it can be routed to a display (optionally via one or more filtering stages). The content of the display can then again be saved either in a Windows picture format (for fast overview via Windows explorer) or in a data format that now includes the filter stages (pre-processed or as-displayed data).

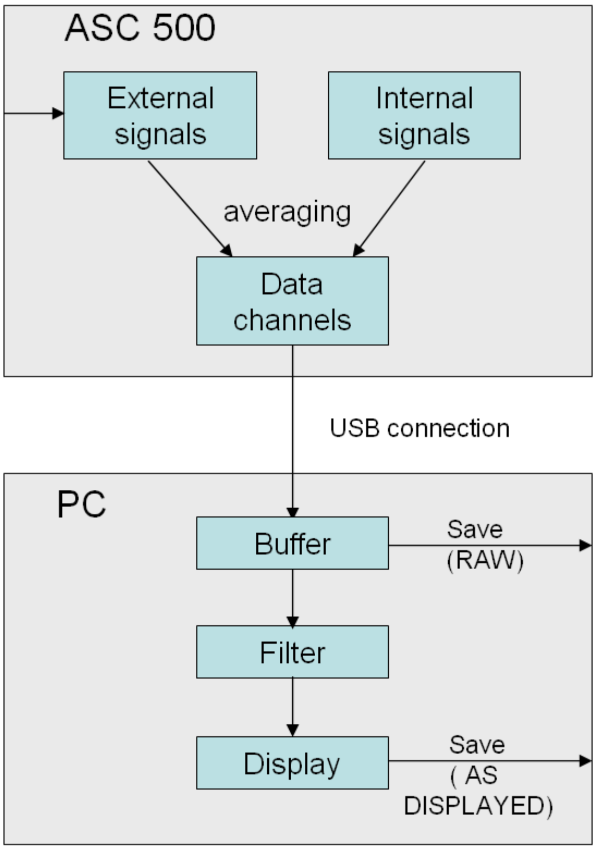


***Figure 10:** The data flow chain of the ASC500*

4.2.4 Sample Time and Average

All internal and external signals use an internal general time base of 2.5 µs. This time corresponds to the 400 kHz sampling frequency of the general ADC inputs. In some cases, data is needed only in a slower repetition rate. In the Daisy GUI, the repetition time for signals is called *Sample Time*. If *the Sample Time* is set to a value larger than the time base of 2.5 µs, data has to be reduced. The user can choose from two options on how to reduce the data:

1. Averaging ON: All values recorded within a *Sample Time* are averaged.

2. Averaging OFF: The first value of the *Sample Time* sets the signal value and during the rest of the sample time, all other incoming data is ignored.

The data reduction is done in the ASC500 controller in order to reduce the traffic on the USB connection between ASC500 and PC as much as possible.

The *Sample Time* of all channels within one data group will be equal. However, there are two exceptions: The LINE and FFT groups leave it to the user to define a separate sample time for each channel. For all groups, the *Sample Time* is defined in the respective parts of the GUI corresponding to the data group. For example, the *Sample Time* for the SCAN group is set via choosing the scan speed. The *Average* option can be set in the DCC. It is set to *Average* ON for all channels per default.

4.2.5 Data Channel Configuration (DCC) in detail

A central point for the configuration of the data processing chain is the Data Channel Configuration dialogue (DCC). It can be accessed from various points in the graphical user interface by clicking on the DCC button shown to the left. In the DCC, data channels are created and signals are assigned to the data channels.

The DCC is also the place to select file format for the data saving. It is important to .

The data channels are sorted in the following groups:

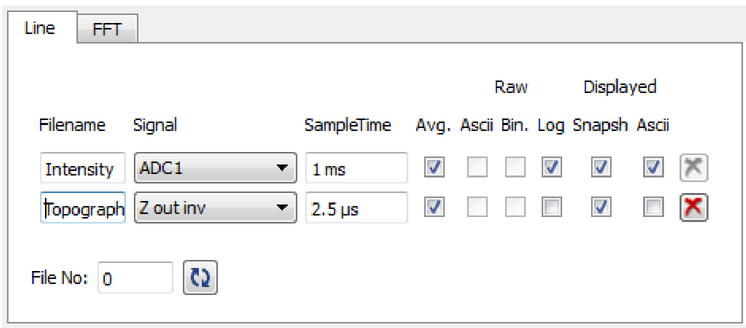
SCAN data associated with the scan motion. Each data point is referenced within a 2-dimensional frame and has been recorded in either forward or backward direction. Data from the SCAN group can be represented in either a two dimensional display (called a *frame view*) or as a one dimensional display showing single or multiple lines of the scan.

DUAL PASS data associated with the *Dual Pass Mode* (see 6.5.7 Dual Pass on page 92. If he dual pass mode is set to ON, the data group 2nd PASS represents the data collected during each second line. Since the origin of the data is very similar to the data of the SCAN group, it can be viewed with the same display types.

SPEC1, SPEC2, SPEC3
data associated with the *Spectroscopy* feature. It will be displayed in a 1D type display.

RESONANCE data associated with the *Resonance* feature. Representation: Two 1D type displays, usually showing the amplitude and phase of a lever against frequency.

SOFT SPEC data associated with the *Soft Spectroscopy* feature. Representation: 1D display.



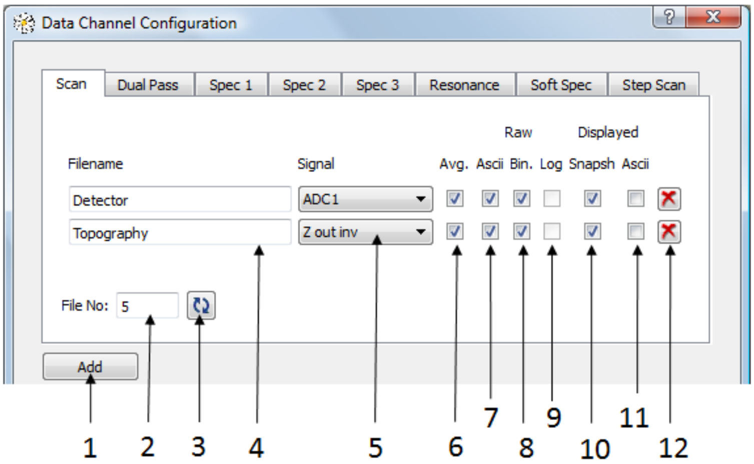
The above image shows the lower part of the DCC with both LINE and FFT data groups.

LINE — no data association. Any signal can be shown against time. Representation: 1D line, multiple 1D line.

FFT — no data association. Any signal can be shown in frequency space: Representation: 1D line.

4.2.6 DCC usage

Before the experiment is started, the data channel configuration has to be defined in the DCC. After the definition, the data channel configuration can be saved by saving the GUI profile under *File – Save Profile* or *Save As*. The different sections of the DCC are described in more detail below.



1 – Using the *Add* button, a new data channel can be created in the current data group. Up to 14 data channels can be distributed at the same time between the data groups. Please note that it is not possible to add data channels during operation. For Examples, during a scan no channel can be added.

2 – The current filename index number is shown here. It will be automatically increased with each saving process. This number cannot be edited.

3 – Reset the *File No* to 0.

4 – *Filename* used for storing the data of the data channel.

5 – The *Signal* that will be routed into the data channel.

6 – *Average* button. The signal will be averaged over its sample time. See 4.2.4 for more details.

7, 8, 9, 10, 11 – Here, the file and data format for the disk storage of the data can be defined. There are in general five possible formats.

Not every data group has all five formats available. A more detailed description of the formats is given in section 4.2.7.

12 – The *Remove* button will remove the corresponding data channel from the data group. Please note that the first data channel of both LINE and FFT data group cannot be removed.

4.2.7 Saving the data

Available options

There are several options for the storage of each data channel. In general, the data can be saved in either RAW or as DISPLAYED (see *Figure 10* for clarity). RAW means that the data is taken from the buffer, i.e. before any filtering. For example, SCAN data will be saved without the underground filter if the RAW option is chosen. The DISPLAYED option will save the data as it is shown in the corresponding display, i.e. after the filter stages. NOTE: the frequency spectrum of the FFT display is achieved through an “FFT filter.” To save the spectrum you must select one of the DISPLAYED formats.

RAW ASCII: The data of the channel will be saved in an ASCII type format. The data will be stored as recorded. For SCAN and similar data groups, there will be one file for forward and one for the backward direction. This format is available for SCAN, 2nd PASS, SPEC1-3, CALIB and SOFT SPEC data groups.

RAW BIN: The data of the channel will be saved in a binary format. The data will be stored as recorded. For SCAN and similar data, there will be one file for forward and one for backward direction. This format is available for SCAN, 2nd PASS and STEP SCAN data groups.

LOG: The LOG option is only accessible for LINE data. This option will write the data to a file as a stream of points, one point with each *Sample Time*. The resulting file will be of ASCII (text) type. Please note that LOG files can get very large, so it is advisable to use the log function only with large *Sample Times*. The logging is started and stopped by using the *Snapshot Repeat* button in the respective LINE display.

DISPLAYED SNAPSHOT: If checked, the data will be saved as a screen snapshot of the current display. It will be saved in a PNG file format by default, but the format can be changed using the *Settings – Preferences – File Output – Snapshot Format*. This feature is especially useful to provide an overview on the stored data. Later it can be quickly browsed using the Windows Explorer. NOTE: As with all DISPLAYED save options, data will only be saved if the channel is shown in a DAISY display. For SCAN channels, both forward and backward scan snapshots will be saved, even if only one direction is shown on the screen.

DISPLAYED ASCII: The content of the display that shows the data channel will be stored in a text type format. In contrast to the RAW ASCII option, the file will contain all data changes resulting from the filters the data might have passed. Again, the data will only be saved if the data is shown in a display at the time of the saving trigger.

Triggering data storage

Each display in the Daisy GUI contains three buttons for issuing a saving trigger (shown to the left). These buttons will be used to trigger the process of data storage

The *Save Immediate* button will save the data in its current state, i.e. a scan frame that is half filled or a fraction of a LINE VIEW line.

The *Save Delayed* button will store the data when the corresponding data unit is completed for the next time. This means that a scan will be saved once the frame is finished and a spectroscopy will be saved as soon as it is completed. A save icon will appear above the top right corner of the corresponding display to note that a data storage process is pending.

A third option is the SAVE REPEAT button. With this button pressed, the data will be repeatedly saved in a manner that is equal to the SAVE DELAYED option. For example, a scan will be repeatedly saved every time the complete scan area has been imaged. The procedure can be stopped by a second click on the SAVE REPEAT button. For LINE data, the SAVE REPEAT button can have two meanings: 1. If the LOG option in the DCC is chosen, the data will be saved as a continuous data stream in one file, one data point for each sample time. 2. If the LOG option in the DCC is not chosen, the SAVE REPEAT for LINE data will work similar to all other data groups: data will be saved at the moment the display is full.

Triggering the data storage will always save all channels of the data group. For example, a click on a SAVE button in a frame display will write all data belonging to the SCAN data group to the hard disk. This will be both the 2D image, but also the 1D data of the corresponding scan line view (meaning the line view that shows the scan data line per line). There are, however, two exceptions for this rule: The LINE and FFT data group behave differently: Here, a SAVE trigger will only store the data channel shown in the display where the SAVE is triggered. If there are several displays with LINE information and all of them need to be stored to hard disk, the user needs to click on all corresponding SAVE buttons. Another possibility is to use the *Snapshot Preset* option of the DAISY GUI to combine any combination of data channels to be saved with one mouse click (see next section 4.2.9). The reason for the different behaviour of LINE and FFT data compared to all other data groups is that the time scales of various LINE or FFT displays may be very different. One LINE view could show a signal on a microsecond time scale, while another LINE display could very slowly log data from for example a temperature controller. The splitting of both LINE's saving process allows for a separate data storage for either long term or short term data. The differences between LINE/FFT compared to other data groups is also highlighted in the splitting of the DCC, where LINE and FFT are shown in the extra lower part of the DCC window.

Filename Convention

The filename will be composed from several parts. The name starts with a prefix referencing the data group followed by an index number. The index number will automatically increment after each saving cycle. The next part of the filename is the data channel name as entered by the user in the DCC. This is followed by an extension providing some closer description of the file. For SCAN data, this could be 'fwd' or 'bwd', denoting the scan direction. It could also be the name of the display in case the data is saved AS DISPLAYED. Finally, the Windows filename extension shows the file format. A large number of files can be created by one save trigger. These files' filenames will all start with the same prefix, so it will be immediately clear that they are all based on the same data.

Here are several examples:

SC002-Topography-bwd.asc

This filename is composed as follows:

SC	SCAN data group
002	index
TOPOGRAPHY	name taken from DCC
BWD	backward scan
.ASC	2D ASCII type format

S1002-Tunnel Current-Spectroscopy 1.png

S1	data group SPEC1
002	index number
TUNNEL CURRENT	Name from DCC
SPECTROSCOPY 1	Name of the display that was the origin of the snapshot. The existence of the display name within the filename is a sign that the data was saved as DISPLAYED.
.PNG	picture file format

The name of the display can be changed by clicking *Rename* in the right-click context menu of the respective display (section5.4.2).

If a filename is already used in the target directory, DAISY will automatically add a '[number]' part to the filename to avoid conflicts and to guarantee a successful storage of the data.

Target directory

All files will be stored in the same directory. This directory can be changed at any time under *Settings – Preferences – File Output - Target Directory*.

File formats

All data saved by Daisy will contain a file header that is readable with any standard text editor. A typical file header looks as follows:

```
# Daisy line view snapshot
# 2011-02-01T07:26:35
# display:  FFT Display
# x-pixels: 813
# x-unit:   Hz
# y-unit:   V
X ; Y
```

In this case, an FFT display was saved with a content of 813 pairs of voltage versus frequency data points, in the unit of Hz.

After the header, the file contains the measurement data in either ASCII or binary format (depending on the file format type). In case of an ASCII file format, the data is written in a form similar to the last line of the header: Two columns separated by a semicolon.

The following table provides an overview on the available file format types:

	ASC	BCRF	PNG	CSV
SCAN	+	+	+	-
SCAN LINE	-	-	+	+
DUALPASS	+	+	+	-
SPEC 1-3	-	-	+	+
CALIB	-	-	+	+
SOFT SPEC	-	-	+	+
STEP SCAN	+	+	+	-
LINE	-	-	+	+
FFT	-	-	+	+

Note: SCAN LINE data is not a separate data group but belongs to the SCAN data group and is saved by the same trigger. SCAN LINE data is only available AS DISPLAYED and will thus be saved automatically if one of the DISPLAYED checkboxes in the SCAN section of the DCC is marked.

ASC Format

The ASC format is used for 2D data (SCAN, DUAL PASS). The data will be written to a file as ASCII text. The resulting files can be opened in a text editor or any standard image analysing software. Due to the nature of text files, the file size will be 2-5 times larger than its binary counterpart BCRF. There are two slightly different versions of the ASC file format:

- The data points are separated by a line feed.
- Data within one scan line are separated by a TAB and the end of a scan line is marked by a line feed (line oriented).

To choose between these two options, a checkbox under *Settings – Preferences – File Output – ASC Format* can be used.

BCRF Format

The BCRF is the binary counterpart of the ASC format and can be used for the same data (2D data). After the ASCII header, the data points are saved in a binary format which leads to a file size reduction of up to 5.

PNG Format

This format is a picture type format for screen snapshots. It is available for all data and display types. The content of the display is saved to hard disk as it is shown on the screen. For SCAN and DUAL PASS, the forward and backward scan direction is always saved into a separate file (even if only one direction is shown in the display).

Post processing of the data is not possible with this format. Still, saving screenshots provides an easy overview over collected data. The format can be switched between JPEG, BMP and others under *Settings – Preferences – Snapshot Format*.

CSV Format

The CSV (comma separated values) format is an ASCII/text type file format for 1D data (LINE, SPEC1-3, FFT). CSV can be imported to every program that is capable of analysing data sorted in columns and rows (Excel, Origin, Sigmaplot, SciLab, …)

The CSV files generated by daisy comprises of a header of several lines masked by #. Different datapoints are separated by CR LF; different fields by SP;SP. The first line after the header is not a data point but the title of the columns.

```
# Daisy frameless snapshot
# 2017-06-20T14:36:37
# display:  channel resonance_ampl
# x-pixels: 8
# x-unit:   Hz
# y-unit:   V
X ; Y
25000.076 ; 0.0594836835
25009.019 ; 0.0600328565
25017.962 ; 0.0594307108
25026.9049 ; 0.0590073759
25035.8479 ; 0.0590793473
25044.7909 ; 0.0586746387
25053.7339 ; 0.0588722247
25062.6769 ; 0.0590837431
```

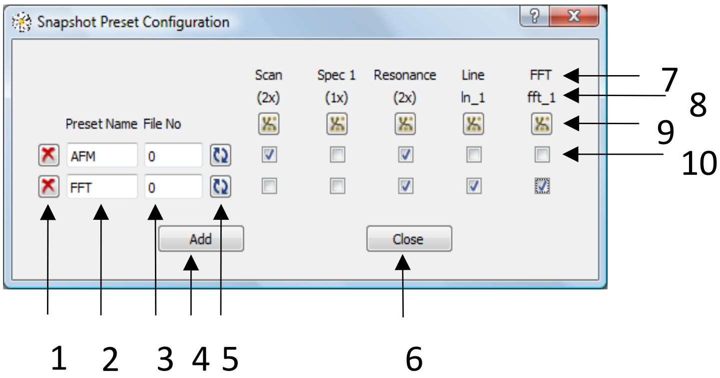
4.2.8 Parameter File

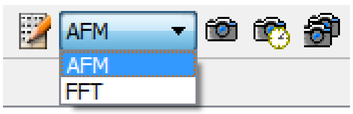
For each data storage cycle the software can create an additional text file, the *Parameter File*. The *Parameter File* will contain the most important parameters that were set in the Daisy GUI at the time of the saving process. The filename is parameter.txt with a prefix equal to the prefixes of the corresponding data files. The file is readable with any text editor. The user can add an arbitrary text to the *Parameter File* via *Displays – Snashot Comments*. The creation of *Parameter File* can be omitted under *Settings – Preferences – File Output – Parameter file*.

4.2.9 Snapshot Presets

Often during an experiment, several data groups need to be saved at the same time. For example, FFT and LINE data are a common couple because they represent complementary information of the same physical origin. Also, SCAN and LINE data might be interesting to save together, if for example the LINE data represents an additional parameter of the measurement. The DAISY GUI is equipped with functionality to combine several data groups in presets and save all data with one mouse click. Moreover, different presets can be defined and activated via a simple drop down list. Thus a very flexible and powerful tool for data saving is at hand of the user.

To enter the *Snapshot Presets Configuration* dialogue, the user has to click on the button, shown on the left, in the status line of the DAISY. In the following menu, the data groups can be assigned to certain presets. Each preset will be represented by one line in the dialogue.





1 – The *Remove* button is used to remove a preset from the list.

2 – Name of the preset. This is used to identify the preset in the trigger dropdown list (shown on the left).

3 – Index number of next data filename.

4 – Reset index number to zero.

5 – The *Add* button is used to add another preset to the list. There is no limit to the number of presets.

6 – The *Close* button closes the dialogue.

7 – *Data Groups*: all data groups with active data channels are visible. For LINE and FFT data, each separate channel is shown separately because these channels could potentially be stored separately. For all other data groups, all data channels of the group is stored simultaneously.

8 – This line shows either the number of active data channels in the group or the name of the data channels for LINE or FFT group.

9 – DCC shortcut. To change the data channel configuration, a click on this icon leads to the DCC.

10 – These checkboxes are used to add the corresponding data group to the preset.

Snapshot Preset Filename Convention

The filenames created by the snapshot presets are composed similarly to the filenames from data group storage. The difference is the prefix numbers. All filenames saved by a snapshot preset begin with the preset name.

1) Prefix: Preset name+ 3-digit number. P0 corresponds to the first preset, P1 to the second and so on
2) Data channel name
3) Name of the source display
4) For SCAN data: denotation of scan directions; *fwd* or *bwd*
5) Filename extension

Example:

P0001-In_1-Line View.csv

This filename is composed as follows:

P0	preset name
001	index number
In_1	data channel name taken from the DCC
Line View	name of the display (marks the data that was saved AS DISPLAYED)
.csv	text type data format ('comma separated values')

How to trigger a snapshot preset

The data storage of a *Snapshot Preset* is done via one of the three snapshot buttons shown to the left. These buttons can be found in the main status line of the Daisy program. The usage of these buttons is very similar to the snapshot icons from the data group storage (see page 34).

5 Operating the Controller: General Usage and Overview

This chapter gives a general overview on the *Daisy* software and its functionalities.

5.1 Software Installation and Getting Started

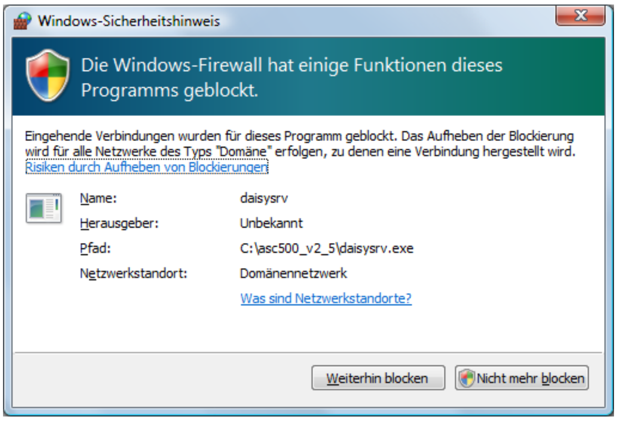
Make sure your controller is switched off.

The attocube ASC500 software *Daisy* is distributed in two different formats: an installer executable and a zip folder.

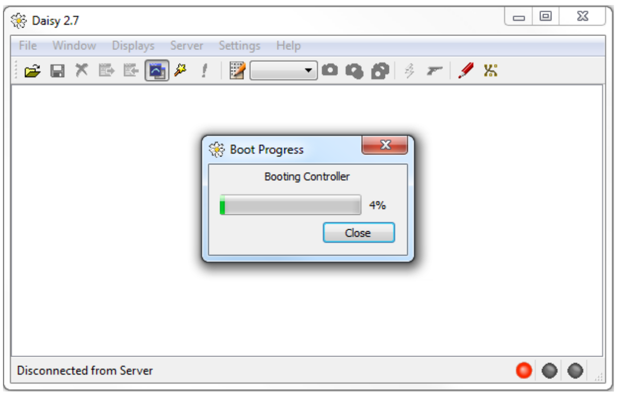
Double clicking the executable will start an installation routine that will install the drivers, copy all necessary files to the hard drive and create a desktop shortcut.

If the drivers are already installed it is also possible to simply unpack the content of the zip folder to your hard drive and run the file 'daisy.exe'.

Switch on the controller.



Open the 'daisy.exe' file. If your firewall is activated, the following error message appears. Choose "Unblock" to go on.

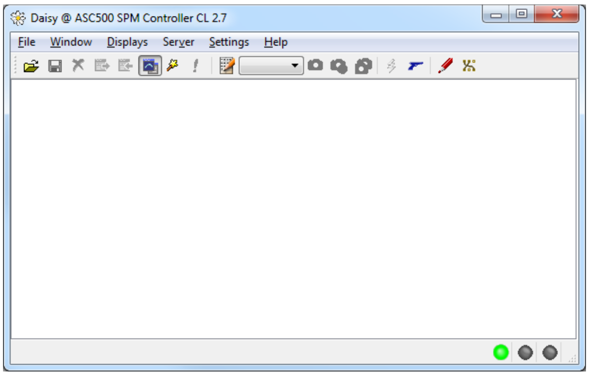


Now, the ASC500 hardware is automatically booted and the window as shown to the left appears.

Remark: by booting the hardware, all FPGA and DSP code is transferred from the computer to the controller, thus defining its functionalities. Please note that upgrading to a new software version requires starting the new version of the Daisy program and rebooting the controller. All changes will be automatically programmed into the hardware.

5.2 Description of Main Daisy Program

After booting, the main program is running (see image below). It enables the connection to the hardware and handles data inputs and outputs. Also, it can reboot the controller and send new boot code. Yet, for controlling parameters and outputs of the ASC500, a *profile* has to be loaded that defines the graphical user interface (GUI). A *profile* (*.ngp) consists of saved settings and a *panel* (*.ngc). Hence, user settings can be saved with the profile.



On the lower right there are three status LEDs (from left to right):

- the server is connected to the hardware (green LED),
- the server is receiving data (green),
- an overload error occurred (red).

5.2.1 The main toolbar

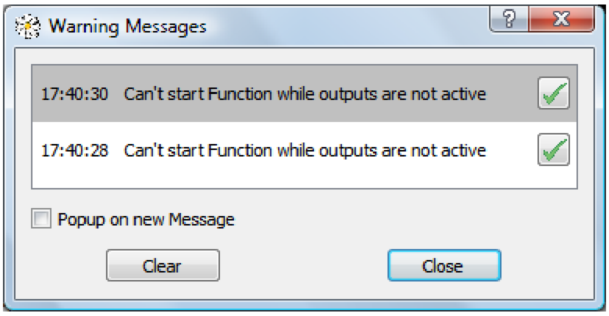
Load/ Save Profile. Profiles and panels can also be loaded and saved with the *File* menu.

Close/ Detach/ Collect Panel. If you have loaded one or several panels, it is possible to detach them from the server application or re-collect them also by using the *Window* menu.

Always on top. If this button is checked, *Daisy* windows will always stay on top of other windows running on the computer.

Display wizard. You can open additional data windows using the display wizard. Please see section 5.4.4 on page 53 for further information.

Warning messages. Press this button to show the warning messages window. This window can also be configured to pop up on every new message by clicking the checkbox *Popup on new Message*. From the window you can clear the whole list, or check single messages to delete them.

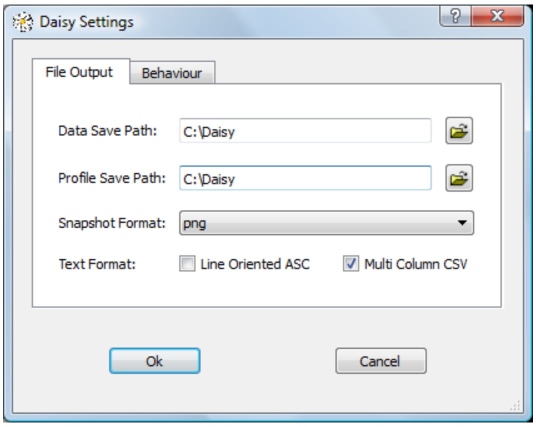


Snapshot Presets: Data of different context can be saved within one mouse click. The *Snapshot Preset* icons shown to the left are used for this functionality. Further details on data handling and saving are given in section 4.

Start/ Shutdown Server. The server application on the PC as well as the hardware can be booted or shut down using the *Server menu*. The boot messages from the server program can also be opened here. In case of problems, the *Server Output* can help to trace a problem.

Daisy settings. Open the preferences dialog to change certain global settings.

The *File Output* tab features the following settings:



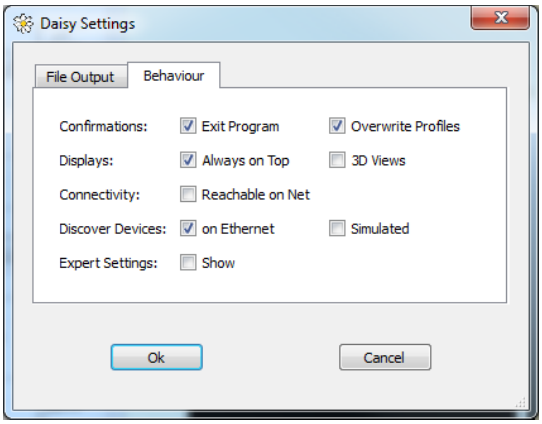
Data Save Path: Set the target directory in which all data / snapshots will be saved by selecting a path with the *Open* icon to the right.

Profile Save Path: Set the target directory in which the profiles will be saved.

Snapshot Format: You can choose between bmp, png, ppm, xbm & xpm file formats for the snapshots.

Text Format: For 2D data, choose between *Line Oriented ASC* and one data point per line. For multiple curves, use multiple columns in .csv files or alternatively, write multiple curves one after another.

The *Behavior* tab features the following settings:



Confirmations: Check the corresponding boxes if you want to be notified before exiting the program, and before overwriting panels respectively.

Displays: Check the corresponding boxes to activate *Always on Top* for the displays, and for enabling 3 dimensional data displays (available upon right-clicking in a frame view). Since this functionality is not supported by all PC hardware configuration, the 3D views option is set to OFF by default.

Connectivity: Allows connection to the ASC 500 server remotely. Use with care as the network often is not reliable enough.

Simulated Device: *On Ethernet* can be used to connect to a Daisy that is connected to the same network as the computer running the daisy software. Check *Simulated* to start the Daisy in simulation mode (without actually connecting to the ASC500 hardware).

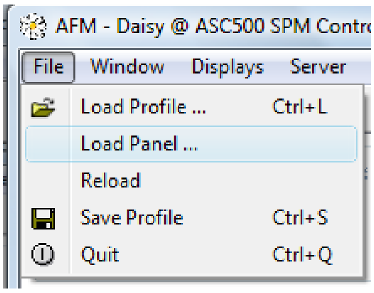
Export settings: Check this box to show the *Expert Settings.*

For any of the changes to take place you have to restart *Daisy.*

5.2.2 The menu bar

In addition to the standard menu entries as already described above, there are the following options available in the main menu bar:

The *File* menu contains the following entries:



Load Profile: Click here to load a profile (.ngp).

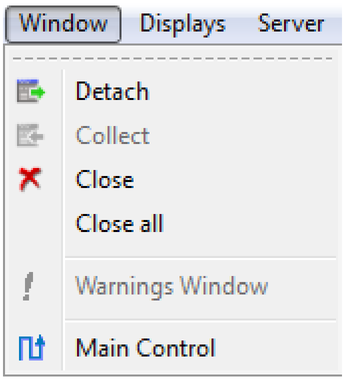
Load Panel: In addition to profiles (.ngp), there is also a number of preconfigured panels (.ngc) available.

Reload: Use this option to reload the current profile. This option is helpful if e.g. settings have been changed which will only come into effect after reloading the profile.

Save Profile: Use this option to save you profile.

Quit: Exit the program.

The *Window* menu contains the following entries:



Detach: Use this option to detach the current display from the main Daisy window. This option is particularly useful when using more than one screen or very large screens.

Collect: Use this option to re-attach detached displays to the main GUI window.

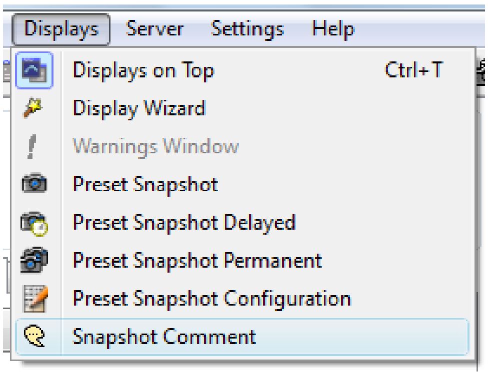
Close: Use this option to close the current display.

Close all: Use this option to close all displays at once.

Warnings Window: Shows the warnings message window

The last entry consists of all currently active / open displays; use this to switch between the different windows.

The *Displays* menu contains the following entries:

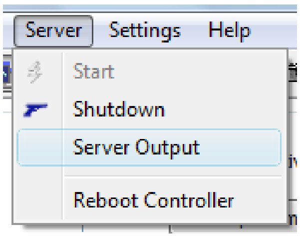


Display Wizard: See the corresponding section above (section 5.4.4).

Preset Snapshot: These entries can be used to configure and trigger the preset snapshots (section 4.1.2).

Snapshot Comment: Here you can enter comments which will be saved in the parameter file.

The *Server* menu contains the following entries:

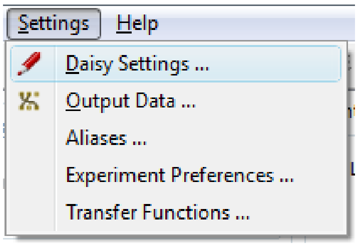


Start & Shutdown: See the corresponding button descriptions above (section 5.2.1)

Server Output: This opens a window which lists the communication between the Daisy server and the hardware.

Reboot Controller: Use this option to reboot the controller.

The *Settings* menu contains the following entries:



Daisy Settings: See the corresponding button description above (section 5.2.1).

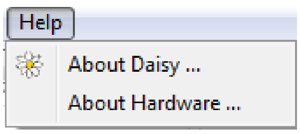
Output Data: This opens the DCC window, see description in section 4.1.1.

Aliases: This opens a window to adjust the names of different data channels and windows. It is described in detail below (section 5.3.2).

Experiment Preferences: This opens a window with several tabs for certain settings associated with program behaviors during experiments (in contrast to the *Daisy Settings* menu), which are described below (section 5.2.2.1)

Transfer Functions: This opens a window allowing to set transfer functions. The details are described below (section 5.2.2.2).

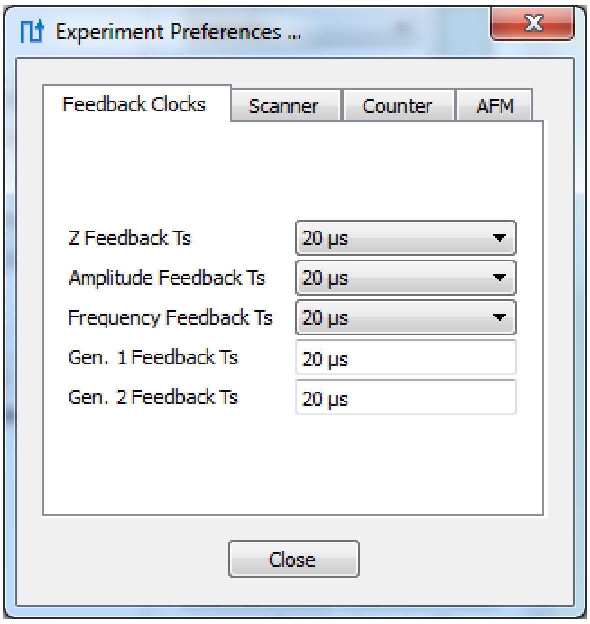
The *Help* menu contains the following entries:



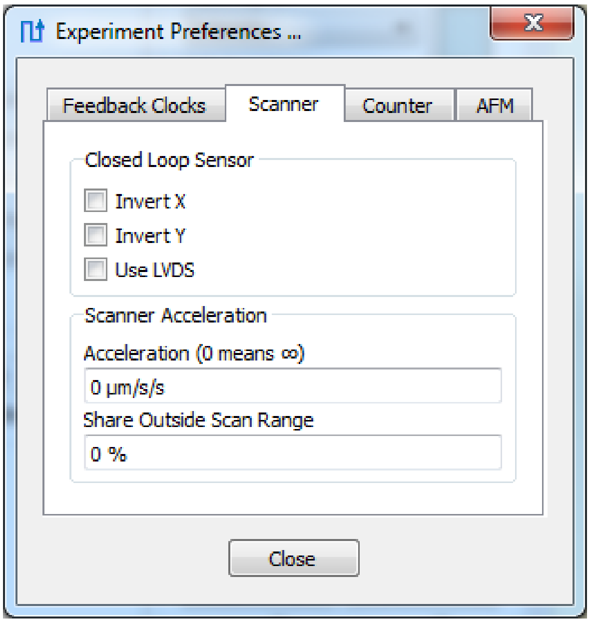
About Daisy: Here you can find information about the Daisy software version as well as licensing issues.

About Hardware: Here you can find information about your current ASC500 hardware.

5.2.2.1 Experiment Preferences Window

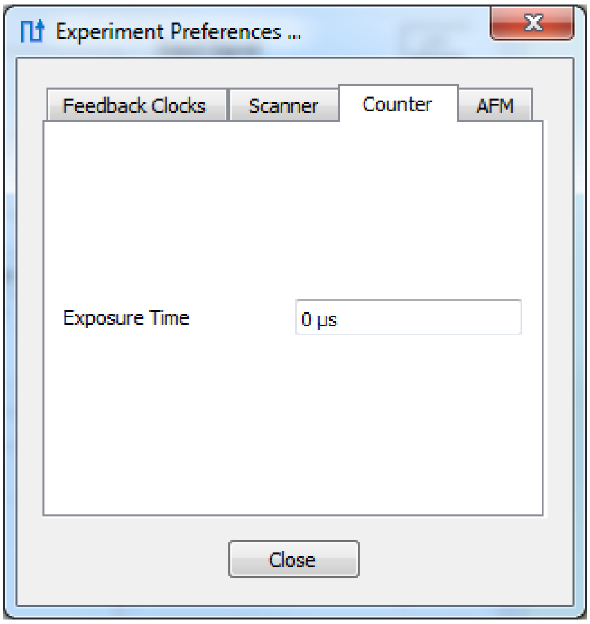


In this tab, you can change the different *Feedback Clocks*, which correspond to the sampling time of the different Feedback loops.



Closed Loop Sensor: Inverts the axes if the positive direction of the scanner matches the negative direction of the sensor readout. This item is only visible if the CL scanning upgrade is unlocked in the ASC500.

Scanner Acceleration: This can be used to prevent quick change of direction at the end of a scanline to reduce shaking.

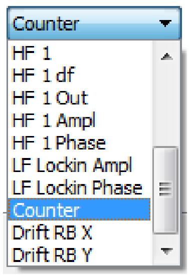


The ASC500 has a dedicated input port for low-voltage TTL pulses. Within the software, a counting procedure keeps track on the number of received TTL pulses. It can be used to display the number of counts in any line or frame view. To use the counter, please connect the source of the pulses to pin 1 of the *External In* connector (see *Figure 3* in section 2.3.4).

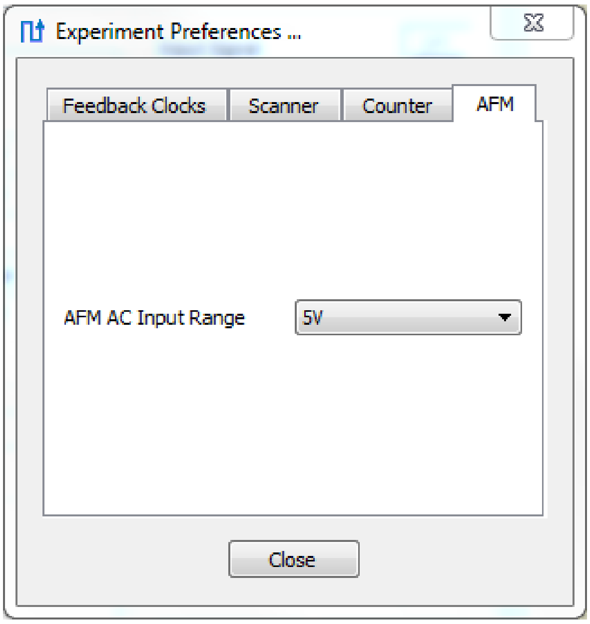
Please note that the ASC500 accepts only low-voltage TTL pulses, i.e. pulses with an amplitude of 3.3 V. The maximum repetition rate is 20 MHz.

To activate the *Counter* in the software, go to *Experiment Preferences* tab and enter an *Exposure Time* for the counter. The exposure time is the time interval in which the incoming pulses are accumulated. The exposure time can range between 2.5 µs and 163 ms in 2.5 µs steps.

Signal

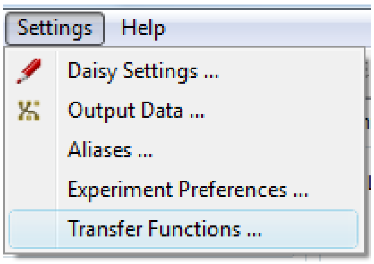


The counter signal can be chosen in all line and frame displays. If the sample time of the display is larger than the exposure time, a number of exposures can be averaged. In case the exposure time is larger than the display's sample time, a number of samples will be equal.



This feature is not used anymore.

5.2.2.2 Transfer Functions Window

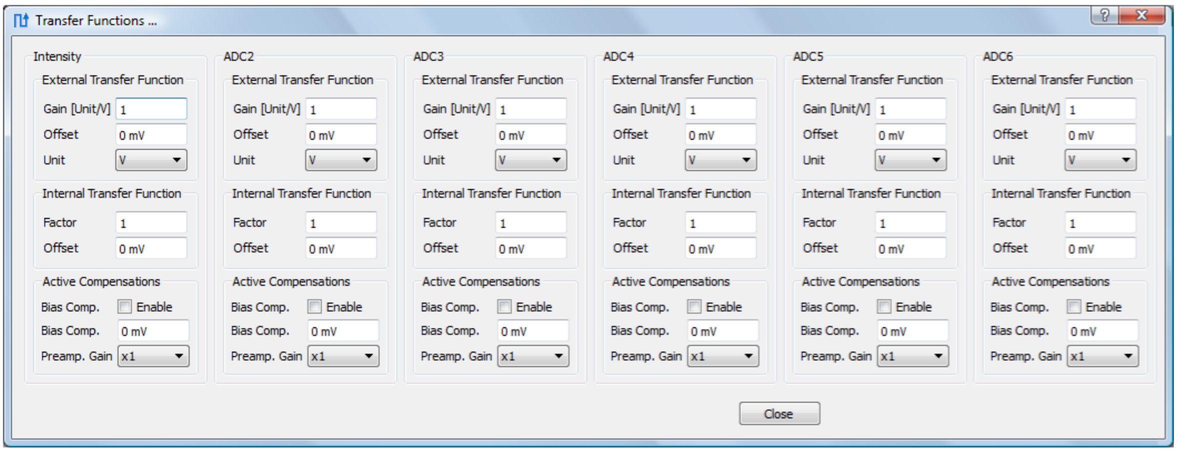


The *Transfer Functions* offers the following functionalities:

1. Conversion of the voltage values read by ADC inputs towards physically meaningful units. For example, if a photo-detector is used to collect your data, *Daisy* can display it in *Watts*. Use *External Transfer Function* for the conversion.

2. Calibration of the ADC inputs. ADC voltage inputs usually show small voltage offsets in the milli-Volt range. You can compensate for this offset with the *Internal Transfer Function*.

3. Setting of a working point and an additional preamp gain. If you have e.g. a small signal on a constant DC voltage, you can compensate for this DC part and increase the gain for this channel.



External Transfer Function

Gain: Enter the conversion factor in *Unit/V*. For example, if a photo-detector with an amplification of 5e6 V/W is used (corresponding to 0.2 µW/V), you can enter either *Gain* = 0.2 and *Unit* = *uW* or *Gain* = 200 and *Unit* = *nW*. Please note that *Daisy* automatically displays the appropriate unit prefix (nano- or micro-Watt) independent of the *Unit* setting.

Offset: Adds an offset to the signal.

Internal Transfer Function

Factor: Use this factor to correct for an ADC gain different to 1. Please note that the actual signal will be divided by this factor.

Offset: Offset value to be added on the respective ADC.

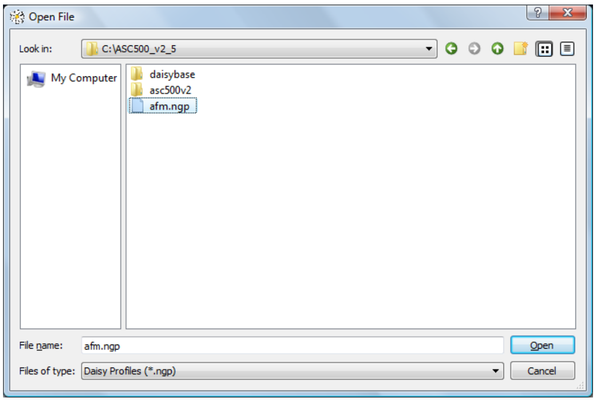
Active Compensations

Bias Comp. Enable: Enable the active bias compensation.

Bias Comp.: Enter the DC offset on the input signal that is to be subtracted.

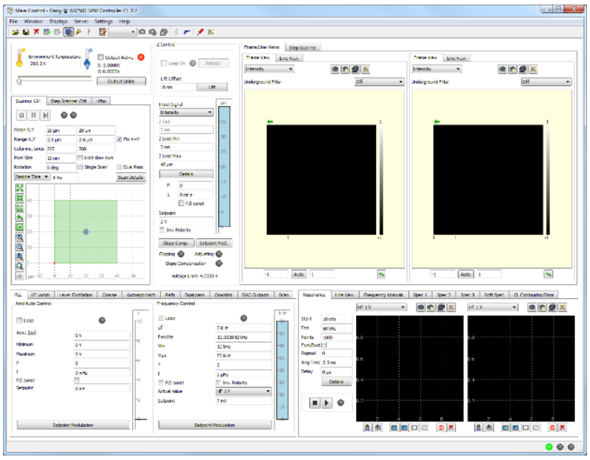
5.2.3 Loading a profile

In order to perform a Scanning Probe Microscopy (SPM) measurement, a profile needs to loaded, which defines the graphical user interface (GUI):



Open a profile of your choice, e.g. “afm.ngp” for atomic force microscopy.

After opening the GUI, the main panel appears (see below). In the main panel, all functions of the AFM can be controlled.



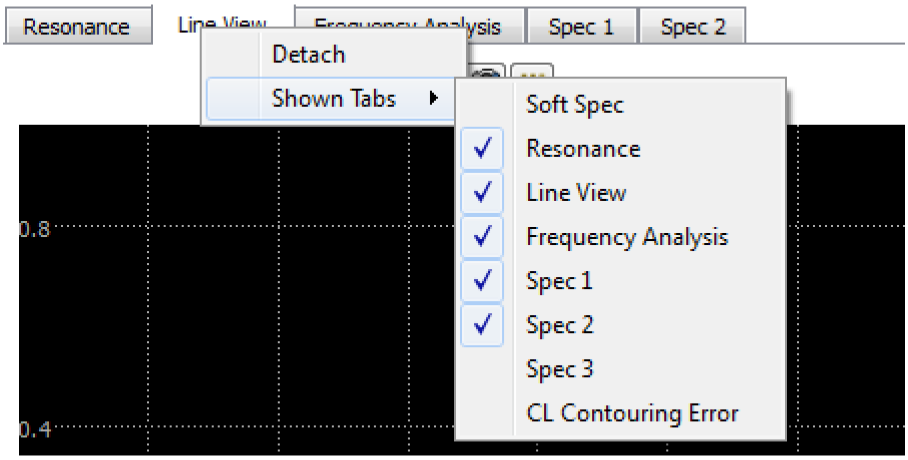
Special GUIs are available for all attocube systems microscopes. These have been developed to adapt for the use of the specific instrument and hide some of the controls to facilitate the usage. The according profile files are shipped with the system.

5.3 Profile configuration

While preconfigured profiles (.ngp) are available for the most common scanning probe methods, the new Daisy release v2.7 allows the user to customize certain parts of the GUI. This will be described in the following section. Besides, parameters (like output limits, scan ranges, slew rates etc.) are also stored in the profile, this allows every user of the instrument to create his/her own profile.

5.3.1 User-configurable GUI appearance

By right-clicking on *any* of the tabs in the main GUI, the user can decide whether to show, hide or detach it:

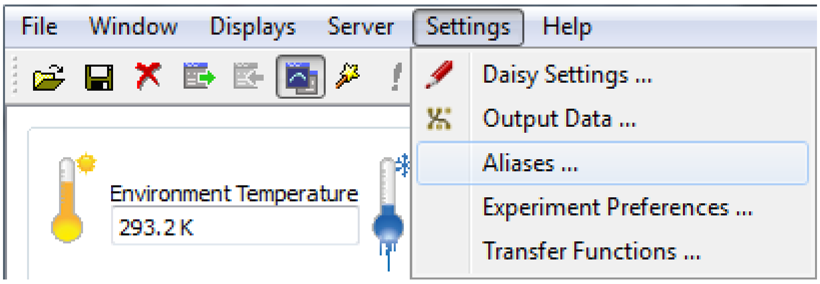


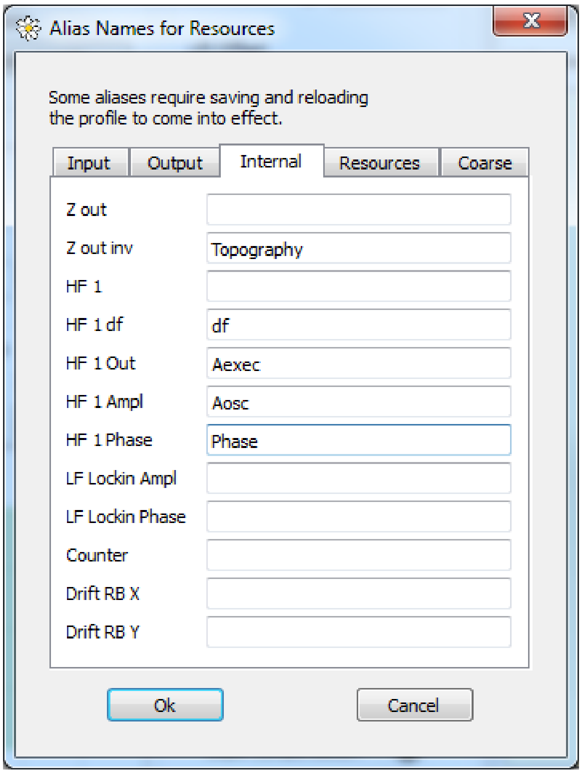
The order of the tabs can also be changed by dragging and dropping any of the tabs to a new position within the tab bar.

The configuration of each tab section can be stored by creating a customized profile.

5.3.2 Aliases menu

Since both the ASC500 hardware as well as the Daisy software serve the purpose of a powerful generic, multipurpose SPM controller, many of the signals, parameters and tab names within the software have been kept generic. However, most users will only perform one or two specific SPM methods and use a well-defined sets of parameters for their experiments. To make life easier, the software offers the possibility to rename most of the generic resources in the *Aliases*:





In the corresponding tabs one can set new *Aliases* for *Input, Output* or *Internal* signal names, change the label of spectroscopies or coarse axes.

Note: In certain version of the Daisy software the new *Aliases* for the resources will not come into effect until the current profile is saved and reloaded.

5.3.3 New signal and parameter names in v2.5 and later

Starting from v2.5, several signals, parameters and tabs in the GUI have been renamed compared to previous versions of the Daisy software (or have been equipped with the opportunity of aliases). The following table lists the changes in order to help existing users with an updated Daisy software to get an overview of the mapping between old and new names:

Signals

Previous name	New name in v2.5
SPM Z out	Z out
SPM Z out inv	Z out inv
AFM signal	HF 1
AFM df	HF 1 df
AFM Aexc	HF 1 OUT
AFM Aosc	HF 1 Ampl
AFM Phase	HF 1 Phase
LockIn Ampl	LF Lockin Ampl
LockIn Phase	LF Lockin Phase

Tabs

Previous name	New name in v2.5
Calibration	Resonance
LockIn	2 separate tabs: - LF LockIn - Lever excitation (=HF 1)
2nd Pass	Dual Pass
Pref	tab removed! see: - Output Limits (section 6.1), - Experiment settings (section 5.2.2), and - Transfer Functions (section 5.2.2)
Transfer	moved to Settings menu → Transfer functions (section 5.2.2): all 6 transfer functions are now combined

5.4 General Usage and Description of Common GUI Controls

5.4.1 Text Edit Boxes

Most parameters of the experiment are controlled by entering numbers into text edit boxes. The *Daisy* software provides a simple and intuitive way of entering numbers.

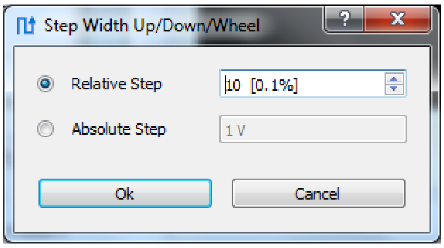
Most numbers are accompanied by a physical unit. When entering or changing a number, the units do not have to be entered. Just type the number and press return; *Daisy* will automatically add the appropriate unit. Most of the time, a unit such as 'meter' will come with a convenient SI prefix like 'nano' and the edit box will show 'nm'. There are two ways of changing the prefix:

1. Enter a value greater than 1000 or less than 1. If you enter for example 1200 and the old unit is 'nm', *Daisy* will change to microns and show '1.2 µm'.
2. Type the new prefix behind the number. Entering '1.2u' will result in '1.2 µm', regardless what the old prefix was. Use 'p' for pico-, 'n' for nano-, 'u' for micro-, 'm' for milli- and 'k' for kilo.

If you do not enter a prefix, *Daisy* will keep the last prefix. The only time you'll have to enter the unit itself is when you want to change to a number without prefix, like '5 Hz'. Please note that in this case it is usually sufficient to enter the first letter of the unit, so '5h' will result in '5 Hz'. There are a few parameters without units. In these cases the way to go back to a number without prefix is to either type 0.1 k or 1000 m.

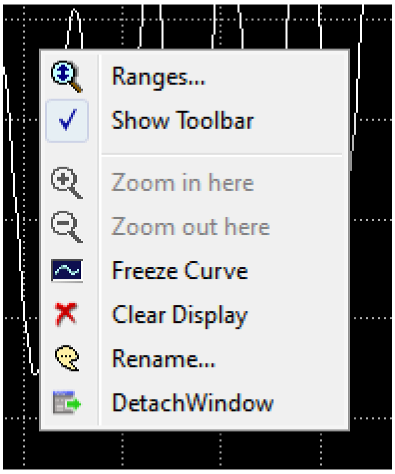
Using the mouse wheel

The mouse wheel can be used to conveniently edit the value of any text edit box containing a number throughout the Daisy program. If the cursor is positioned on a text field, the field's value can be increased by turning the mouse wheel upward and decreased by turning the mouse wheel downward.



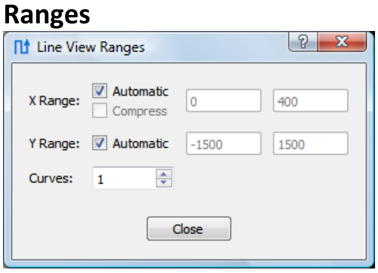
The sensitivity of the mouse wheel increment can be set for each text edit box separately by using the *Step Width* function in the field's context menu. It can be chosen between relative (default) or absolute steps. Even without using the context menu, the sensitivity of the mouse wheel can be increased by pressing the SHIFT and/or STRG key during turning of the mouse wheel.

5.4.2 Context Menu



By right-clicking on any graph window, one can open the corresponding context menu. The functions that are available to the graphs are the same throughout the program. The context menu is shown on the left.

Ranges



The *X Range* and *Y Range* of the graph can be explicitly set. Deactivate the *Automatic* check-boxes to enter the range values manually. Please note that it is not recommended to use the manual *X Range* functionality. In the FFT graph, please use the *Fmin/Fmax* parameters instead.

The *Curves* value allows for displaying several adjacent traces within the same graph. The traces will be displayed in different colors for clarity.

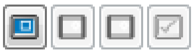
Click on *Close* to close the window.

Show Toolbar

If the *Show Toolbar* button is activated, several toolbar icons will be shown below the graph:

Rescale X range manually. This changes the status of the *Automatic* checkbox in the *Line View Ranges* tab. Moving the mouse wheel while hovering above the graph will change the shown range. Exact values can be entered in the *Line View Ranges* tab.

Rescale Y range manually.



These buttons represent the *Frame Tools*. When active, certain operations to modify the data range can be performed. See the description of the *Frame Tools* in the *Data Display* section 6.4.

Clear the display. The current data will be deleted and the graph will start over. Useful if you have chosen a slow display.

Stop the display from being updated. The graph will stay until cleared or *Stop* is pressed again.

Freeze Curve

This function freezes the currently displayed curve to be used as a reference. The frozen curve can be erased using the *Clear Display* function.

Clear Display

Use this option to clear the current display.

Rename

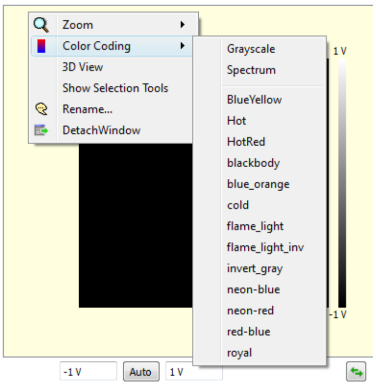
Here you can rename the snapshot data of the current display.

Detach Window

Use this function to detach the graph from the *Daisy* window into an independent window. You can then resize this window and move it wherever it suits you best. This is especially useful when you use a system with two monitors. This function can also be accessed by double-clicking on the graph.

You can reattach the window either by using the context menu of the new stand-alone graph (*Attach window*), by right clicking on the empty space in the *Daisy* window and selecting *Attach Window,* or by simply closing the window.

5.4.3 Frame View context menu



The Frame view context menu mainly offers the same options as described above, but in addition, one can also activate a 3 dimensional data view (*3D view*), and/or change the *Color Coding*. One can choose the colors which provide best contrast for the data.

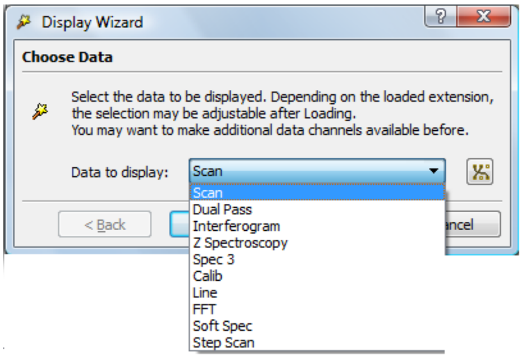
5.4.4 Display wizard

The *Display Wizard* is a powerful tool to personalize the GUI and to open access to more data windows. It is possible to create line and frame views (and combinations thereof) and to apply filters. The data in these windows can be integrated into the automatic global snapshot routine, giving you the possibility to save all interesting data with one mouse click.

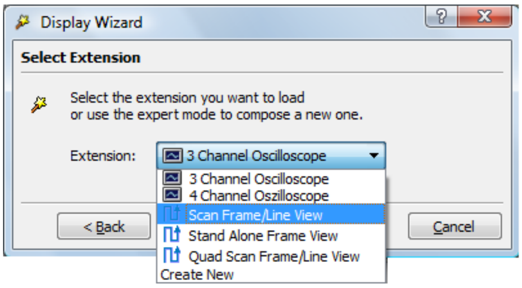
One example of use would be the Lift Mode, where one requires an additional data display for the second pass data.

One can open a new display as described below:

First, click on the *Display Wizard* button.

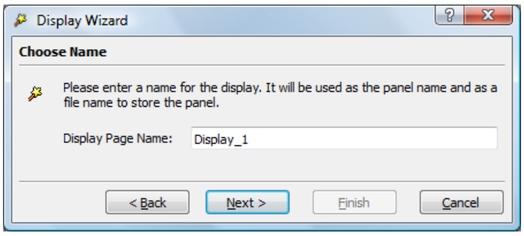


The first wizard window appears, where you can use the pull-down menu to choose the data group for the new display that you are about to create. The channels for the data group can be modified in the now familiar DCC. For more information see section 4.2.5.

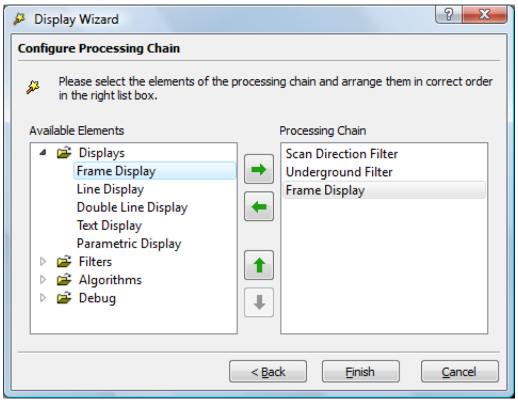


For most of the data categories, there are preconfigured *Extensions* available, but you can also select *Create New* to manually choose the details of your new display.

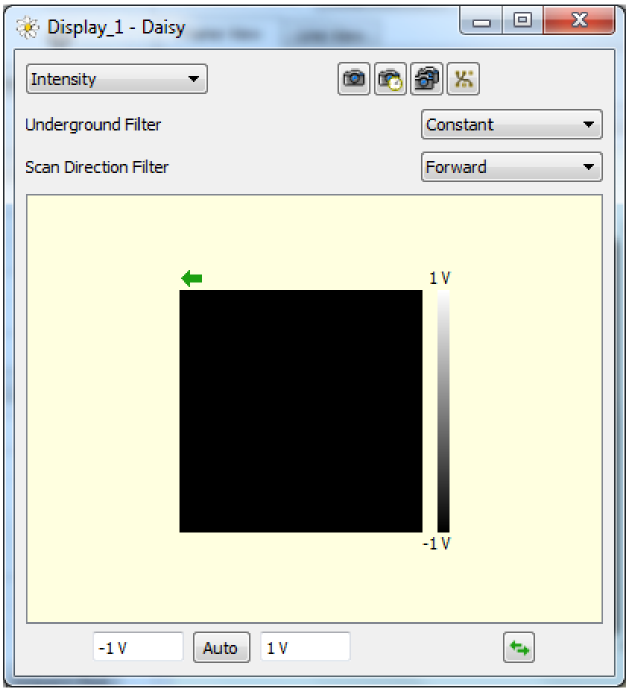
If you select one of the preconfigured *Extensions*, simply click *Finish* to start using the new display.



In case you choose a data display that either lacks a pre-configuration, or that you would like to set up manually, you are first asked to assign a name to the new display. Click *Next*.

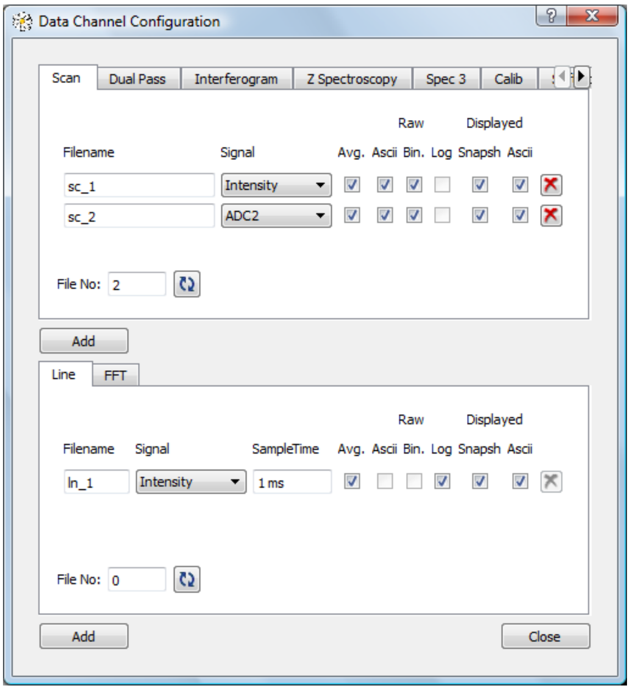


Now, configure the processing chain. Select the actions and elements you want to use for the new display. In this example, a frame display together with a scan direction filter and an underground filter is selected. Highlight the elements on the list to the left, then press the right arrow button to add the element to the processing chain. The processing chain will be executed from top to bottom, so it is important to place the filter before the display. To do this, highlight the filters in the processing chain list and then press the up arrow button. Press *Finish*.



The new window will appear. Detach it from the *Daisy* window, or keep it as another tab within your main window. The signal can be chosen via the drop down list in the upper left of the window. Set the *Scan Direction Filter* according to your needs (forward or backward; *Off* means forward and backward, watch out for the arrow symbol in the upper left corner of the image as it marks the displayed scan direction).Now the new display is configured for the measurement and ready to use.

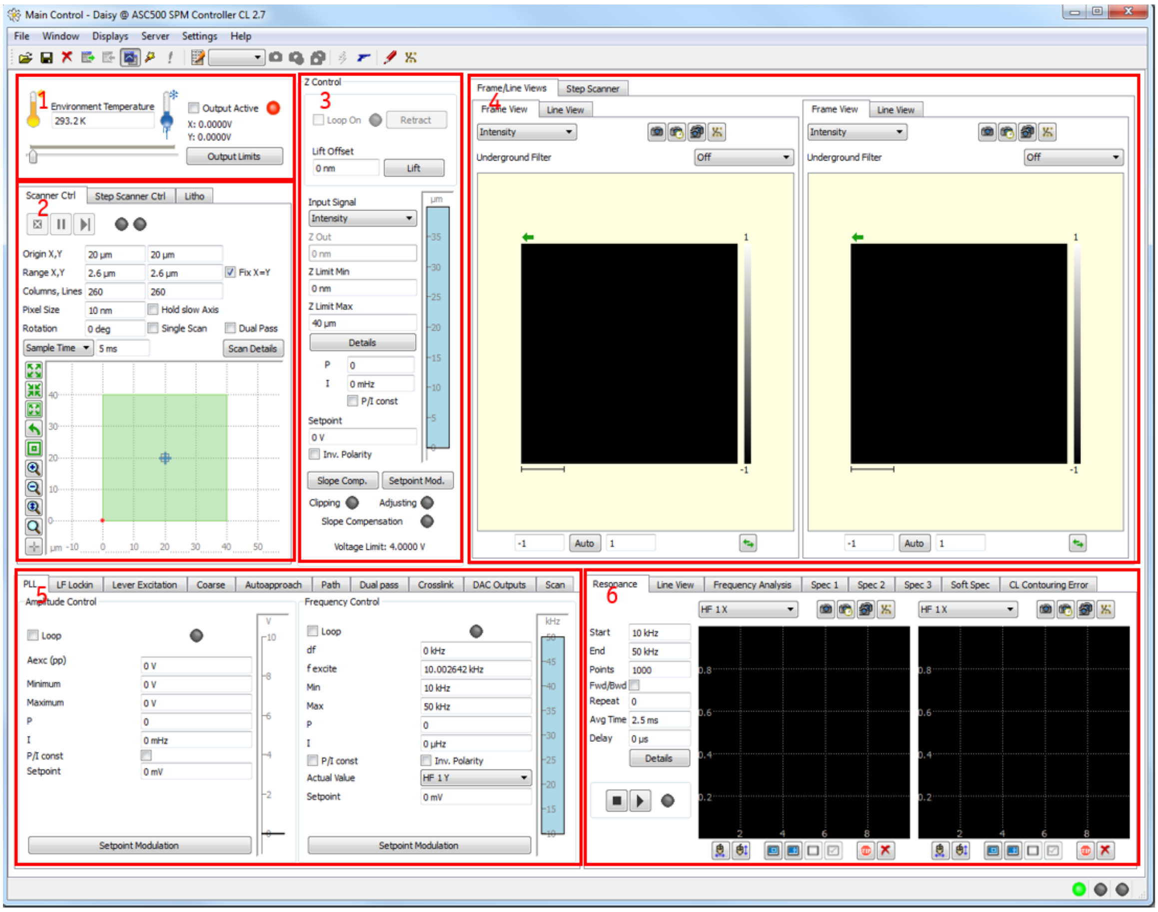
Note: Not every combination of *Trigger*, *Filter* and type will result in a reasonable display. For example, an underground filter is only valuable in a SCAN type context.



If you have not done so already, please check that your desired signal(s) are available as data channels in the *DCC* (see section 4.1 for details.)

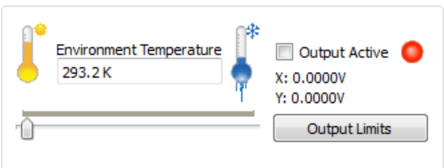
6 Description of the default AFM layout

This layout can be loaded by loading the afm.ngp file. It is often already preset in the shortcut on the desktop.



The GUI is organized in 6 main sections: in the upper half of the screen, the *Output Limits* (1), *Scan Control* (2), *Z Control* (3) and the *Scan Data Displays* (4) are located, whereas the lower half contains tab section on the left for the main parameter functions (5) and a right tab section for the spectroscopies (6), a frequency analysis and the time-based line view.

6.1 The Output Limits

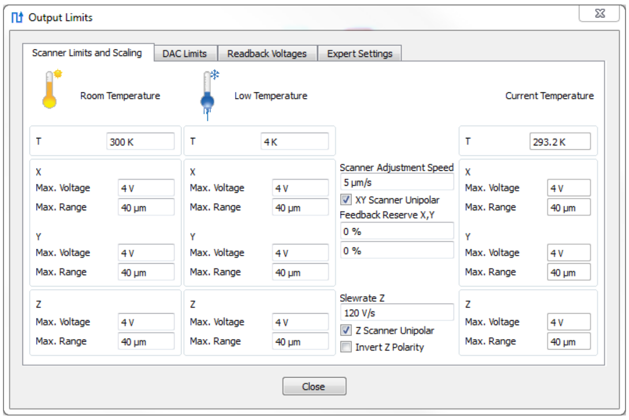


The upper left corner of the GUI hosts the control section for the activation of all controller outputs as well as the settings for their corresponding limits.

Without the *Output Active* option activated no voltages will be applied to any of the analog outputs of the controller. Some digital functions (Coarse positioning) will work without the outputs being activated.

The controller is designed to operate variable temperature SPM devices. The piezoelectric scanners in these microscopes have strongly temperature dependent behavior. The maximum applicable voltage and the maximum extension changes with temperature. To accommodate this the controller offers temperature dependent limits and scaling factors.

These can be defined in the *Output Limits* window under the similarly named button.



The first tab contains the *Scanner limits and scaling* details for RT and LT respectively. If a temperature between RT and LT is chosen in the main window the software uses an interpolation formula to calculate the actual limits and scaling factors. There can be seen in the *Current Temperature* table. For the max Voltage a linear interpolation is used, whereas the Max range is interpolated with a second order curve.

You can also find switches to toggle between uni- and bipolar settings for all scanner outputs: using the latter will also switch between max. voltage ranges of either *0..max* (unipolar) or *-max..+max* (bipolar).

Furthermore, the presets for *Scanner Adjustment Speed* (which controls the rate at which the tip position is moved upon changing the position of the scan field), the slew rate of the Z output and its polarity can be adjusted.

Feedback reserve defines an extra scan range margin around the actual scan range which can be helpful in CL scanning mode (check CL addendum).

Slewrate Z determines the maximum speed Zout can be changed with.

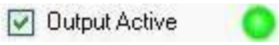
Important Note: Choose all of these settings very carefully, since wrong voltage ranges (also wrong polarity settings) may damage the piezos of your scanners.

Typical values are stored in the respective profiles provided by attocube and/or can be found in the respective manual of your attocube microscope. If in doubt, please contact attocube’s technical support.

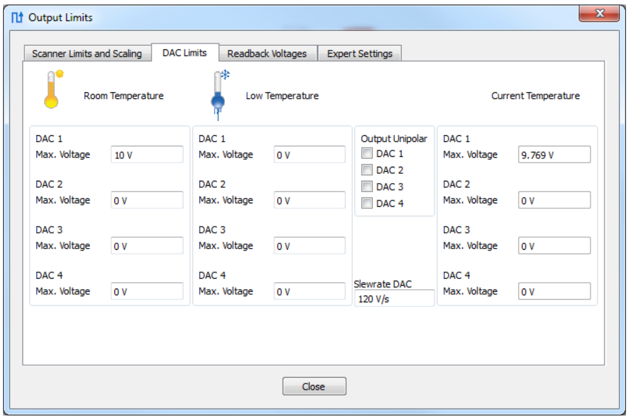
Caution. The output limit is the voltage supplied by the ASC500 controller. This voltage is then typically fed into a voltage amplifier (e.g. the ANC300) which amplifies this voltage by some factor before it is applied to the piezos. The amplification factor for different attocube systems' voltage amplifiers are:

ANC250	factor 20
ANC300	factor 15
ANC350 (7 axis)	factor 14

Always take the amplification factor provided by your voltage amplifier into account. Do not exceed the maximum allowed voltage.



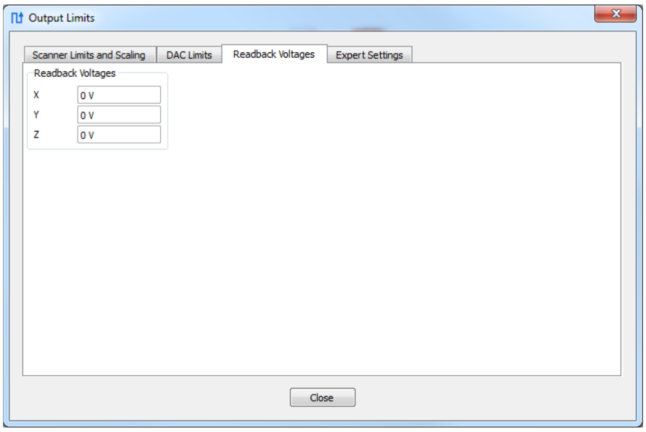
Output Active: With the Output Active button all electrical outputs of the ASC500 controller can be enabled or deactivated. If disabled, all electrical outputs are set to zero. The voltages are ramped to 0 with the slew rates/Scanner adjustment speed defined in the Output limit window. Therefore the switching procedure may take some seconds. The LED to the right of Output Active indicates whether the outputs are active (green) or not (red).



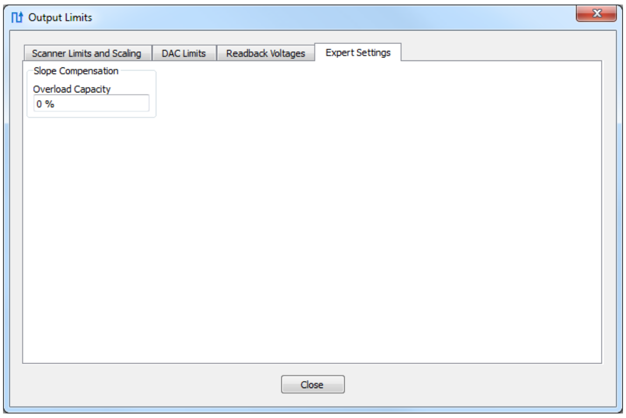
The second tab *DAC Limits* contains the min. and max. voltages for all DAC outputs at RT and LT respectively. Besides, the slew rate can be adjusted.

As an additional safety feature, the user needs to allow bipolar outputs for each DAC separately by checking the corresponding box.

Note: Please be aware that also wrong DAC limits may damage your hardware. For example in case of the cantilever based AFM/MFM the dither piezo, which is usually connected to DAC1, has a similar temperature dependence than the scanners.

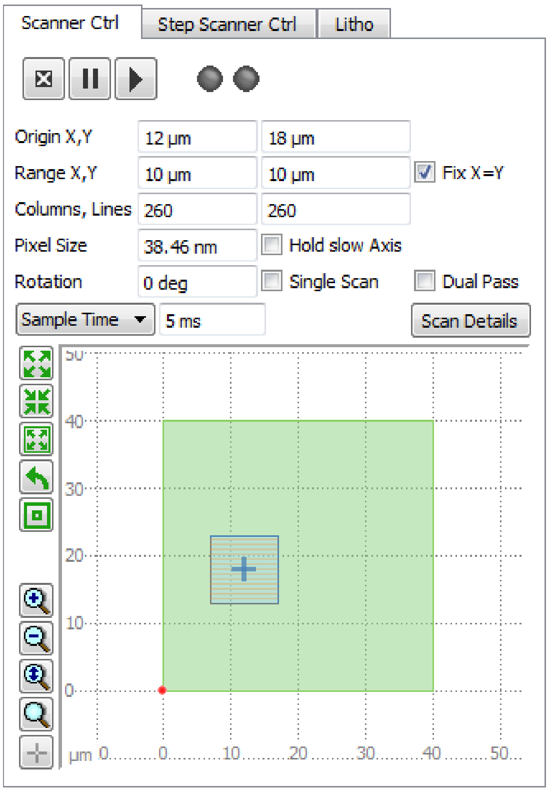


The third tab *Readback Voltages* contains displays for the actual voltages of x, y and z (read back from the controller).



Setting the overload capacity in the fourth tab *Expert Settings* has an influence on the behavior of the Slope Compensation feature (section 6.3.2)

6.2 The Scan Control



The *Scanner Ctrl* is the control center of the scan generation. All important scan parameters, such as the number of *Scan Lines* and *Scan Columns*, *Pixel Size*, and *Sample Time* can be entered here. Furthermore, an offset for the scan area can be set (*Origin X* and *Origin Y*).

The scan area can also be rotated by entering the desired *Rotation* angle.

The green square displays the available *Scan Range*, the blue rectangle the set *Active Scan Area* and the red dot the actual position of the scanner. The grid in the background depicts the global coordinates of the system (if the CL scan engine is active).

The position of the red dot is calculated based on the voltages. The software uses linear interpolation for the actuator scaling. The position is calculated according to the following formula:

$$p^{(x/y)} = \frac{p_{max}^{(x/y)}}{V_{max}^{(x/y)}} V^{(x/y)}$$

Where p and V are the position and the voltage and the upper index denotes the axis (x or y). The max signifies maximum value set in the *Output limits* window.

Note: Rotation is done by hardware mixing of the x- and y-channels. This has the great advantage of a smooth and step-free rotation as compared to digital rotation.

Due to this analog mixing procedure, there is a small error to the angle. A slight angle error of about +/-150mdeg may be visible in certain check measurements.

Start/Stop, Scan Status LEDs

These buttons are the main *Scanner Ctrl*. Their effect depends on the state of the system.

The LEDs display the respective state of the system

Scanner Ready LED:

Grey: output inactive

Yellow: Not available without CL scan engine running. *If CL ON: The scanner does not hold a steady position on the sample grid. The position is shown nevertheless by the sample grid moving in respect to the green square and red dot. This mode has to be used when moving the coarse positioners.*

Green: The scanner is active. *If CL ON: The regulation keeps the red dot stable in respect to the sample grid.*

Scanner Running LED:

Grey: The scanner is neither moving to the start point of the blue scan area.

Green: The scanner is moving.

Depending on the state of the scan engine the three buttons have different effects. This is also indicated by switching icons. All states are depicted below:

Stop Scanner: no effect

Pause Scanner: no effect

Start Scanner: switch to CL regulation active

Stop Scanner: switch to CL regulation inactive

Pause Scanner: no effect

Start Scanner: go to start of scan area

Stop Scanner: switch to CL regulation inactive

Pause Scanner: no effect

Start Scanner: start scan

Stop Scanner: stop scan and move back to start point

Pause Scanner: pause scan (press pause again to resume, press start to start a new scan from this point)

Start Scanner: start a new scan from this point

If the *Single Scan* button is active, the scanner will be stopped and repositioned to the origin after one complete scan. If *Single Scan* is not active, the scanner will run until you press either *Stop* or *Pause Scan*.

Origin X/Origin Y [pm/nm/µm]: Offset of the center of the active scan area.

Range X/Range Y [pm/nm/µm]: Size of the scan area.

Scan Lines/Scan Columns: The number of pixels in x (columns) and y (lines) direction that will be collected. The scan range will be *Pixel Size* times the number of pixels in each direction. If the *Fix X=Y* button is active, only square scan areas are allowed and each change in *Scan Lines* or *Scan Columns* will immediately affect the complementary parameter.

Pixel Size [nm]: The pixel size in nanometers. The pixels are squares by definition.

Sample Time [µs]: Time for the collection of one image data point. Please note that the *Sample Time* is usually much higher than the time needed to acquire one data point (2.5 µs). If the *Average* button in the *Data Display* window is not activated, *Daisy* will acquire one data point and saves it to the image, then skips all data points for the rest of one *Sample Time*. If *Average* is activated, then all data points within one *Sample Time* will be acquired and averaged to give one image data

point.
For a smooth scanning movement, the scanner is not stopped during the *Sample Time*, but moves steadily to the next pixel.

Instead of the Sample Time, the user can choose to set and maintain the following derived parameters:

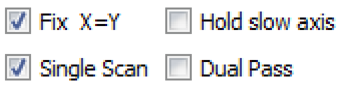
Line Frequency: = 1/(*Sample Time* * *Scan Columns* *2). The factor two is given for forward and backward measurement.

Scan Speed: = *Pixel Size / Sample Time*

Time per Frame: = *Sample Time* * *Scan Columns* * *Scan Lines* * 2

Dependent on which parameter is chosen, *Daisy* will try to keep this parameter constant if other parameters are changed. For example, if *Time per Frame* is selected and *Scan Columns* and *Lines* are decreased (*Fix x=y* enabled), the *Sample Time* is increased accordingly. If the *Pixel Size* is increased, the *Scan Speed* will increase accordingly to meet the same *Time per Frame*.

Rotation [deg]: Enter a value between 0 and 360 degree. The *Active Scan Area* will be rotated around the *Origin*.



Fix X=Y: Toggle between fixing the scan range to be equal in both directions and allowing different ranges for X and Y.

Hold slow axis: Activate this option to always scan the same line.

Single Scan: Activate this option to automatically stop the scan upon completion of the frame. If not on, the system will start a new scan starting from the finishing point of the last scan.

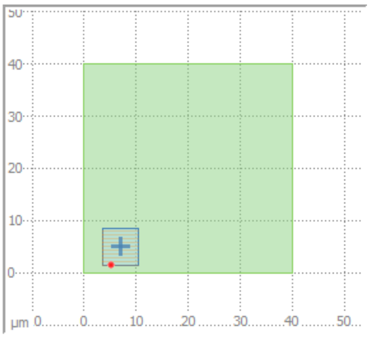
Dual Pass: Use this option for the Dual Pass mode, see also section see 6.5.7 Dual Pass on page 92. In this mode, every line is scanned twice (fwd-bkwd, fwd-bkwd, next line).

The Scan Display

The *Scan Display* gives an overview over the *Sample Grid*, *Scan Range* and *Active Scan Area*. The *Active scan Area* is marked by the blue rectangle and can be arbitrarily chosen within the total *scan range* which is displayed as a green rectangle. A red dot marks the current position of the scanner. The blue cross marks the center of rotation.

If the CL scan engine is active, movement of the positioners will be visualized by a movement of the S*can range* over the sample grid.

To change the active scan area, one can either enter the desired parameters manually or adjust the *Active Scan Area* using the mouse. There are three different possibilities to change the active scan area with the mouse:



Move: Position the mouse on the blue cross in the middle of the Active Scan Area. The mouse pointer will change to a cross. Drag with the left mouse button to reposition the scan area.

Resize: Position the mouse on the border of the *Active Scan Area*. The mouse pointer will change to a rectangle. Drag the border with the left mouse button until the desired size is reached. This will change the *Pixel Size*, whereas the *Scan Lines/Columns* remain unchanged.

Rotate: Position the mouse somewhere between the border and the middle of the *Active Scan Area*. The mouse pointer will change to a circle. Drag to rotate.

Active Scan Area Manipulation Tools

One can use the *Size Tools* to change the *Active Scan Area*.

Enlarge: Enlarges the Active Scan Area by 19%.

Shrink: Shrinks the Active Scan Area by 19%.

Maximize: Sets the Active Scan Area to fill the total available scan range. *Rotation* is set to zero. If *Fix X=Y* is active and the maximum scan ranges are not equal, both Range X and Range Y are set to max. Range X.

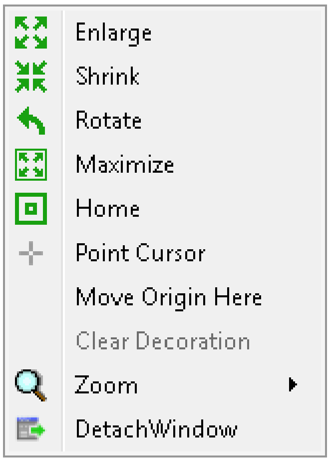
Rotate: Rotates the Active Scan Area by 90 degrees. This feature is helpful if you want to quickly exchange the fast and slow scanning axis.

Home: This sets the origin to the middle of the scan range.

Point Cursor: Changes the curser to the point curser. Moving this into the scan area causes a popup with the coordinate position of the cursor.

Decoration

It is possible to drag and drop an image from the *Frame View* display to the Scan Area. It will be depicted at the coordinates it was recorded. This can be especially helpful in closed loop scan mode to find a certain area of the sample again after moving around.



Right clicking on the scan area will open up a menu that allows to use the active scan area manipulation tools. You can also move the origin of the background coordinate system to the current position of the cursor.

To remove all decorations from the scan area click the *Clear Decoration* button.

Active Scan Area Zoom Tools

Use these icons to zoom in and out of the *Scan Display*. These tools do not change the *Active Scan Area*.

The mouse wheel can also be used to zoom in the scan display.

Zoom in

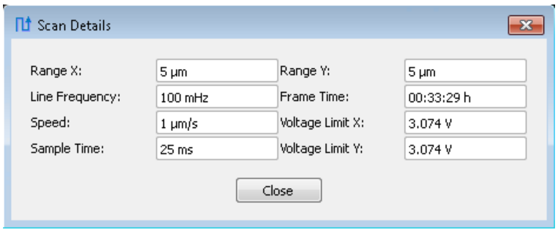
Zoom out

Zoom all: Shows the total available scan area.

Zoom Adjust: Shows the *Active Scan Area*.

Scan Details

Click on *Scan Details* to display important additional scan parameters which follow directly from the defined scan parameters.



Range X/Y: Size of the *Active Scan Area*.

Line Frequency: Line Frequency in Hertz. Please note that *Line Frequency* is based on the time for forward *and* backward scan of one line.

Frame Time: Time needed for the completion of one up scan **or** one down scan.

Speed: Scan speed in micrometers per second.

Voltage Limit X/Y: The current voltage output limit as defined in the *Preferences Tab.*

6.2.1 Scan, line and pixel trigger

To synchronize an external detector to the scanner motion one option is to use the pixel-, line- and frame trigger accessible via the sub-D 9 pin connector on the front panel (see 2.3.4).

Trigger pulse shape: LVTTL pulses (high active, 3.3 V) with 1µs pulse length. The feature is automatically used when scanning and has no corresponding settings in the ASC500 daisy software.

Pin 1, pixel trigger: During the continuous fast axis scan the data is binned according to the sample time. At the start of each of these bins the pixel trigger is sent.

Pin 2, line trigger: At the beginning of a slow axis movement (typically y) a line trigger pulse is sent. Switching from forward to backward direction is implemented as a step in y direction with 0 distance and micro second duration, also sending a line trigger.

Pin 3, frame trigger: A frame trigger pulse is sent at the beginning of a new frame, synchronized with the first line trigger.

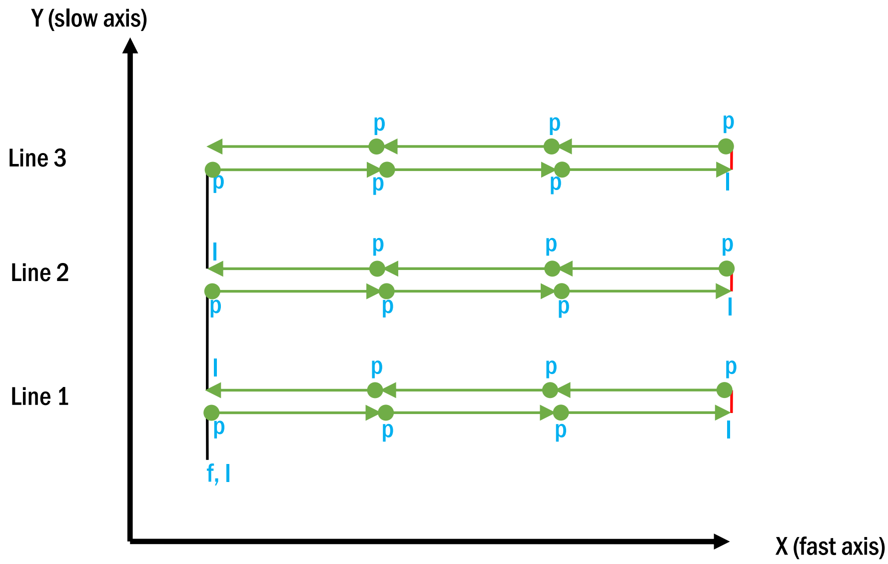
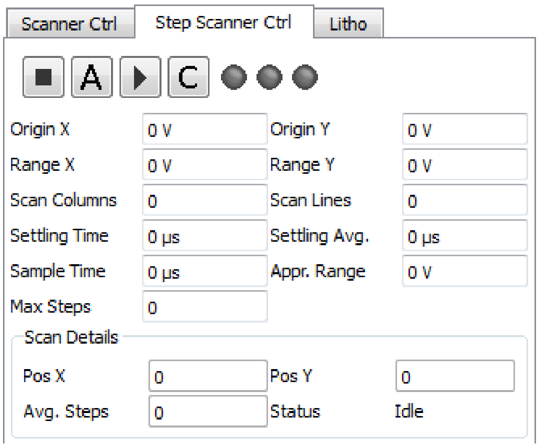


Figure 11: Visualisation of a 3x3 scan and the respective frame (f), line (l) and pixel (p) triggers. After the pixel trigger is generated, the data is recorded during movement along the fast axis for the given sample time. The 'zero length movements' are highlighted red, and the binning is visualized with green arrows.

6.2.2 Step Scanner Control (discontinued)



Step Scanning is discontinued in Daisy v2.7. This tab is a leftover and can only be accessed in simulation mode.

6.2.3 Lithography

The Daisy Lithography module can be used for defining geometrical shapes that will be retraced by the sensor head. It allows the definition of arbitrary convex polygons and single points. Moreover, a shutter can be controlled via TTL pulses to allow for exposition control.

It has to be activated in the ASC500 hardware before the tab shows up in the software.

Lithography can be operated in both closed loop and open loop mode.

Shape definition

The shape definition of the lithography pattern is done via a text file. There are two basic shapes to define the lithography pattern:

Polygons and Points. Each of these basic shape definitions can be combined with a command to control an optional shutter. An example for a shape file is shown in *Figure 12*.

```
<ShapeFile Version="2">

  <Polygon Spacing="200" Speed="200" PosSpeed="1000">
    <Vertex X="-2000"   Y="3000"/>
    <Vertex X="2000"   Y="3000"/>
    <Vertex X="0"   Y="1100"/>
  </Polygon>

  <!-- Comment   -->

  <Polygon Spacing="75" Speed="400">
    <Vertex X="2000"  Y="3200"/>
    <Vertex X="2000"  Y="6500"/>
    <Vertex X="-2000"  Y="6500"/>
    <Vertex X="-2000"  Y="3200"/>
  </Polygon>

  <Point X="-700" Y="700" PosSpeed="10000" Beam="1" Wait="150" />
  <Point X="-1000" Y="0" PosSpeed="10000" Beam="1" Wait="150" />
  <Point X="-700" Y="-700" PosSpeed="10000" Beam="1" Wait="150" />
  <Point X="0" Y="-1000" PosSpeed="10000" Beam="1" Wait="150" />
  <Point X="700" Y="-700" PosSpeed="10000" Beam="1" Wait="150" />
  <Point X="1000" Y="0" PosSpeed="10000" Beam="1" Wait="150" />
  <Point X="700" Y="700" PosSpeed="10000" Beam="1" Wait="150" />
  <Point X="0" Y="1000" PosSpeed="10000" Beam="1" Wait="150" />

</ShapeFile>
```

Figure 12: Example of a shape definition file.

The shape file must be an ASCII file with an *nls* extension. It must start with a <ShapeFile Version”2”> command and end with a </ShapeFile> command. In between, there can be any number of *Polygon* and *Point* commands. Comments can be inserted enclosed in a <!-- and --> respectively. All coordinates given in a shape definition file are interpreted in nm and are relative to the center of the current scan range.

The two basic definitions can be done via:

1. Polygon command:
   <Polygon Attributes>
     <Vertex X Y/>
     <Vertex X Y/>
     <Vertex X Y/>
   </Polygon>

The *Attributes* can be:

a. Spacing : the spacing of the filling pattern in nm (default: 1). The polygon will be written by meandering lines with a line spacing given the *Spacing* attribute.

b. Speed: the scan speed during the writing of the polygon in nm/s (default: 10000).

c. PosSpeed: the scan speed during the approach of the polygon in nm/s (default: 10000).

d. Beam: controls a shutter via a TTL output. Beam on (1) leads to high voltage on the TTL output, Beam off (2) leads to GND voltage on the output connector. The output connector for this functionality is pin number 5 of the *External OUT* connector (see section 2.3.4 on page 14).

e. Handshake: Stop for handshake with external device before scanning (Default: 0).

All attributes can be omitted. The default values will be used for omitted attributes.

The polygon itself is defined via a sequence of vertices. Each vertex has to be specified with a <Vertex/> command. It is important to note that only convex polygon will result in a well-defined output.

2. Point command
<Point X Y/>

a. X and Y: mandatory attributes in nm.

b. PosSpeed: the scan speed during the approach of the point in nm/s (default 10000).

c. Wait: Wait time in ms after reaching the point (default: 0).

d. Beam: Beam on (1) or off (0) during wait time (default: 1).

To check the shape, the text file can be loaded into the Daisy software where the shape will be displayed in the *Lithography* section of the Scan Control widget. How this is done will be explained in the next section.

Operation of lithography

The lithography control is placed in the *Litho* tab of the Scan Control widget. The tab is shown in *Figure 13*. The lithography tab is similar to the scanner control tab. Some settings can be changed in both tabs and the changes in one tab will immediately affect the other.

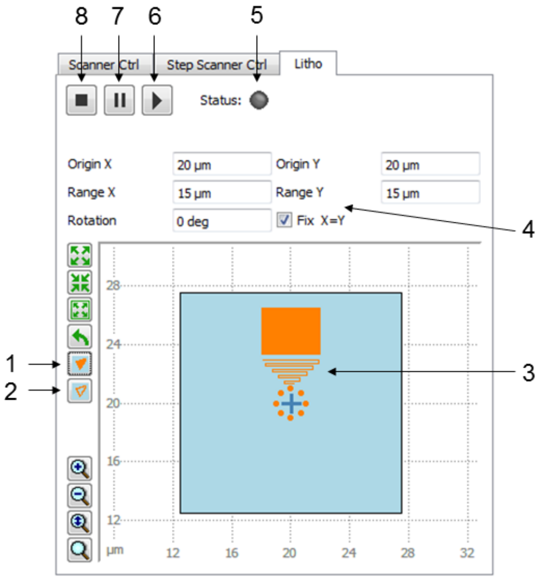


Figure 13: Lithography widget with shape definition. The shape that is shown was produced by the shape definition file of Figure 12.

1 – load lithography definition file: upon a click on this button, a Windows dialogue will appear to specify the lithography shape definition file. After loading, the lithography shape will be shown in the display.

2 – clear shape: with this button, any shape that is displayed will be erased.

3 – the loaded shape is drawn into the actual scan range. It is worth noting that the meandering lines of the lithography are only resolved in the lower triangle of the shape. Here, a line spacing of 200 nm was used. The single lines of the rectangle (spaced 75 nm apart) can only be displayed using the zoom buttons in the lower left of the panel.

4 – here, the basic definition of the actual scan range can be set. Changes will immediately affect the *Scanner Ctrl* Tab.

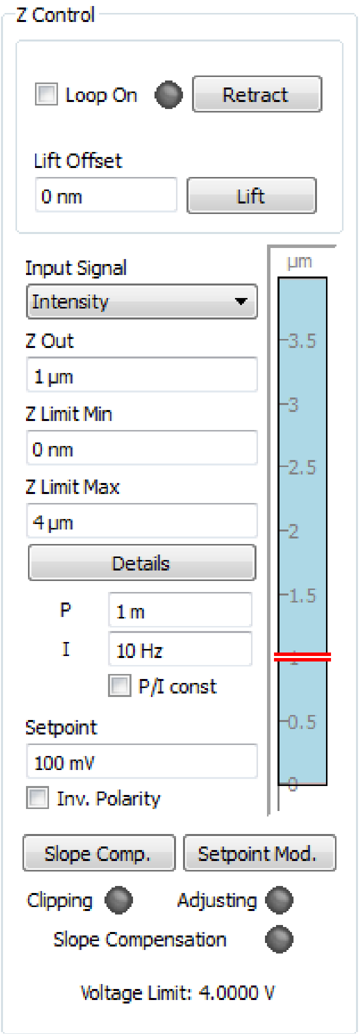
5 – Status LED: green is lithography is running.

6 – Start button: starts the lithography .

7 – Pause button: pauses the lithography. During pause, the shutter will be closed and reopen upon ending of the pause in case its status was open before the pause.

8 – Stop button: Stops the lithography. The shutter is closed and the scanner moves to the origin.

6.3 The Z Control



The *Z control* feedback loop controls the z-position of a sample with respect to a probe. There are several *Input Signals* to choose from, whereas the output of the loop is strictly connected to *Z OUT*. The loop output is limited to a voltage ranging from *0* to *Z Range.* The output can be additionally limited using the *Z Limit min* and *Z limit max* settings.

The feedback loop always tries to modify z-out so that the input signal, *actual value,* gets closer to the *setpoint.* Whether the loop needs to be in negative or positive feedback, can be chosen with *Inv. Polarity*. The proportional gain *P* is sensitive to sudden jumps in the signal, whereas the integral gain *I* is sensitive to the integral of the signal.

The main loop-controls are: The *Loop On* checkbox, the *Retract* Button at the top as well as the indicator LEDs at the bottom. The following states are possible:

Loop on: Enable the check box to switch on the loop. The LED will turn green.

Loop off: If the box is unchecked, the feedback loop will hold the position of z-out and will not react on changes of the input signal.

Retract: If *Retract* has been pressed, the loop is switched off and the voltage is taken down to 0 (i.e. the tip is retracted from the sample).

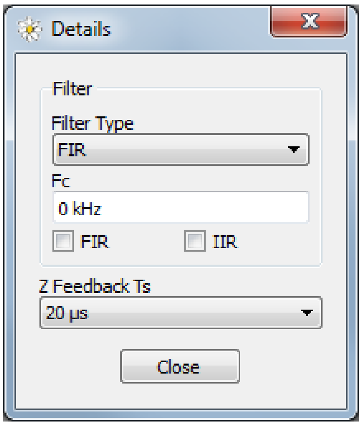
Clipping: The Clipping LED is enabled, if the active loop reaches one of the limits, i.e. either the lower limit, or the upper limit.

Adjusting: This LED indicates that the red bar is not yet synchronized with the real z-out value (due to lower update rate).

Slope Compensation: This LED indicates that the Slope Compensation is enabled.

Inv. Polarity: For experiments, in which the sensor signal increases with decreasing sensor sample distance (e.g. in STM, the tip gets closer with higher z-out voltage), leave this box unchecked. For experiments, where the sensor signal decreases with decreasing sensor sample distance (e.g. oscillation amplitude of a vibrating tip), do check the box.

6.3.1 Details



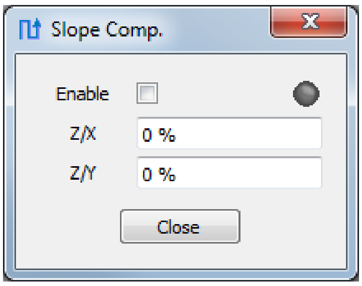
The details dialog allows to set some of the details of the *Z Control* behavior. Different filters can be used on the Input signal before it is fed into the PI loop. The easiest method to apply a low pass filter is to increase *Z Feedback Ts* which controls the underlying time base of the discrete PI controller. Increasing this value decreases the sensitivity to high frequency noise on the input signal.

A more sophisticated way is to use a FIR (finite impulse response filter) or IIR (infinite impulse response filter) to achieve a similar effect.

6.3.2 Slope Compensation

The *Slope Compensation* is an important feature to compensate for a tilt of the sample with respect to the horizontal plane. Quite often in SPM experiments, the height of the investigated feature is much smaller than its lateral dimension so the scan range will be large in x and y and small in z. In this configuration even a small tilt of the sample does disturb the image and masks smallest topographic variations. To compensate for these sample tilts, the ASC500 features a powerful *Slope Compensation* that enables scanning of a tilted plane without any influence on the z controller. Once the *Slope Compensation* is set and activated, the sample will be scanned as if it was lying perfectly in the x-y plane.

This feature is also very handy when it comes to scans in “constant height mode”, leaving the sensor sample distance constant even without employing a z feedback.



The *Slope Compensation* settings can be reached through the *Slope Comp*. button in the z controller widget. A window as shown to the left will appear. The compensation values for both X and Y axis can be entered separately in the *Z/X* and *Z/Y* box, respectively. The Slope Compensation can be activated and deactivated using the *Enable* checkbox.

A negative slope (of the forward scan) will be compensated by a positive value and vice versa.

The slope compensation is realized by mixing of up to 20% of the x or y scanner voltage respectively to the z scanner voltage. Z/X is the percentage of the X extension that is mixed to the Z extension. The maximum value is limited by the hardware to $Z/X = 20\% \cdot V_{max,\,x}/V_{max,\,z} \cdot Z_{max}/X_{max}$.

To set the correct values the compensates the sample tilt, it is best to do the following:

1. Set the scan rotation to 0 degrees.

2. Scan a line and change the *Z/X* factor of the *Slope Compensation* until a flat line appears horizontal.
3. Set the scan rotation to 90 degrees and repeat the previous step for the *Z/Y* factor.

Figure 14 shows typical line scans with and without *Slope Compensation* for an AFM scan of the 25 nm high grating with a 4 µm pitch. As can be seen in the image, the *Slope Compensation* acts on the total scan range of the scanner; the two line scans displayed here would meet at an x position of 0 µm, the offset between the white and the red scan line is thus the result of the *Slope Compensation* together with a scan field that does not include the x origin position.

Figure 14: A typical line scan before (red) and after (white) the sample tilt is compensated by the Slope Compensation *feature.*

Since the slope compensation will change the Z OUT voltage abruptly (with the Z slew rate set in the Output limit dialog), it is not recommended to turn it on while the loop is ON. The sudden change in the sample lift can easily damage an AFM tip.

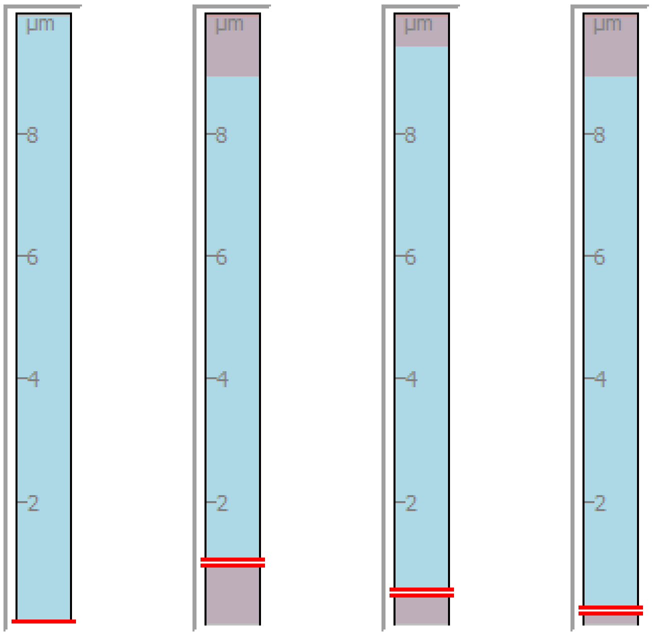
Slope Compensation Details

The *Slope Compensation* is realized internally by the analog addition/subtraction of some part of the *X OUT* and *Y OUT* voltages to the *Z OUT* voltage. A positive *Slope Compensation* of 20 % for both X and Y axes will thus lead to a large additional voltage (called *Slope Compensation Voltage SCV*) in the Z OUT voltage output if the scanner moves to the upper right corner of the total scan range. If for example the maximum allowed voltage for the x and y scanner is 4 V, the SCV can vary between -1.6 V and 1.6 V (These voltages will typically be amplified by a factor of 15 before applied to the scanner). If the SCV would simply be added or subtracted to the *Z OUT* voltage, the resulting voltage could possibly be either large enough to damage the scanner piezo or negative enough to lead to some depolarization of the scan piezo.

To prevent this from happening, a safety margin for the Z OUT voltage is employed in the following way: for the actual settings of Z/X and

Z/Y, the maximum positive and negative SCV will be calculated ('maximum' meaning the value of the SCV for a scanner position in the upper right corner of the total scan range). If the *Slope Compensation* is activated, the *Z OUT* voltage range will automatically be reduced by the exact values of the SCV. This way, the sum of the *Z OUT* voltage (as set by the z controller) and the SCV will never exceed the maximum allowed voltage and no harm will be done to the scanner.

The reduction of the z scan range is visualized in the z controller's display. The safety margin due to the slope compensation will be shown purple in this display. Below, are several examples.



1 2 3 4

(1) The display shows a z scan range of 10 µm that is not restricted because the *Slope Compensation* factors are both set to zero. The full range of the scanner is accessible for scanning.

(2) The display shows a z scan range with a restriction due to the *Slope Compensation* by Z/X = 2.5% and Z/Y = -2.5%. In this case[1], 2.5 % of X OUT means 1 µm safety margin in Z OUT. The positive factor for Z/X leads to a reduction of 1 µm at the upper limit of the z scan range. The negative Z/Y factor of -2.5% leads to a reduction of the z scan range of 1 µm at the lower limit of the z scan range. It is important to note that this reduction automatically leads to an elevation of the z scanner's retract position.

[1] X, Y scan range 40µm, Z scan range 10µm: 2.5% · 10µm = 1µm

At the moment the *Slope Compensation* is activated, the scanner will move the tip closer to the sample! However, this will not harm the tip if the *Slope Compensation* is set correctly. Basically, the tip will be driven closer to the sample only in those lateral positions, where the sample is 'far away' from the tip due to its tilt.

Overload Capacity

(3) As in (2), the display again shows a z scan range with a restriction due to the *Slope Compensation* by Z/X = 2.5% and Z/Y = - 2.5%. The fact that the restrictions are smaller is due to another margin that has not been discussed so far. The hardware parameter, *Slope Compensation Overload Capacity*, will increase the accessible z scan range. This parameter is related to the fact that piezos in general have some tolerance in their voltage ratings. A piezo rated for 0 V to 60 V can safely be driven by a voltage of – 3 V to 63 V. This *Overload Capacity* can be used to regain some or all of the z scan range that is 'lost' to the *Slope Compensation*. In the example shown above in (3), an *Overload Capacity* of 5% has been employed to reduce the restrictions to 0.5µm on each end of the z scan range. The *Overload Capacity* can be set in the *Output Limits – Expert Settings – Overload Capacity* section. **It is strongly recommended not to change the *Overload Capacity* and leave the value that is set in this field by the manufacturer. False settings of the *Overload Capacity* may damage the piezo and will lead to a loss of warranty.**

(4) The display shows a 10 µm z scan range with the following settings: Z/X = -3.75%, Z/Y = 1.75 %, *Overload Capacity* = 5 %. The negative *Slope Compensation* factor of 3.75 % together with the *Overload Capacity* leads to restriction of 1 µm at the upper limit of the z scan range. At the lower side, the positive *Slope Compensation* factor of -1.75% will be diminished by the 5% *Overload Capacity*, leaving a restriction of 200 nm at the lower end of the z scan range. The retract position is elevated to this value.

Notes

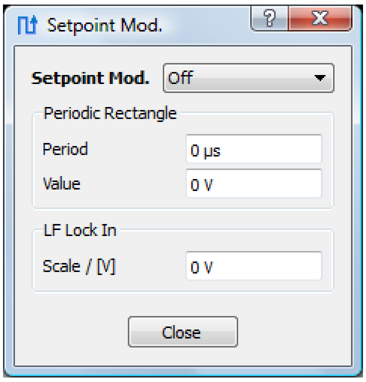
a. The SCV will not be part of the internal signals Z OUT and Z OUT INV. However, it will of course be a part of the Z OUT voltage.

b. The *Slope Compensation* can be set at any time during a scan. A change in the *Slope Compensation* will immediately lead to a change in the Z OUT voltage. The speed of this change is governed by the *Z Slewrate* that can be set under *Output Limits – Sanner Limits and Scaling – Slewrate Z*. If the *Z Slewrate* is faster than the speed of the z control loop, a change in the *Slope Compensation* can potentially lead to a tip degrading.

c. The limits of +/- 20% voltage of the Slope Compensation are set by hardware limits that where built into the ASC500. These limits were designed to avoid an exceeding crosstalk of noise from the X OUT and Y OUT voltage on the Z OUT voltage.

6.3.3 Setpoint Modulation

This feature is useful to optimize the *P-I* parameters with a tip in contact.



You can choose between Setpoint Mod. *Off*, *Periodic Rectangle* and *LF Lock In*.

If you enable *Periodic Rectangle*, the setpoint of the feedback loop will be switched with the given period between the value entered in the feedback loop control and the value given in this dialog. Hence, the setpoint modulation simulates an ultimately sharp feature. This facilitates the tuning of the feedback loop accordingly.

The *Periodic Rectangle* function alters the setpoint between the actual setpoint of the loop and *Value* with a switching time of *Period*.

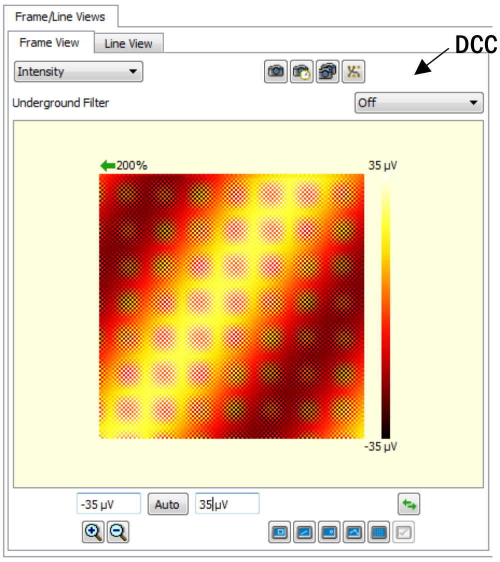
If selecting *LF LockIn* one can use the signal of the LF LockIn to modulate the setpoint to achieve a similar effect to above except of it not being rectangular.

Caution: The Setpoint Modulation has an immediate effect on setpoint of the feedback loop. It is recommended to enter meaningful values **before enabling this feature**. Also, sensitive tips may be damaged if the values for the feedback loop and the two setpoints are not correctly chosen.

The physical unit of the P and I parameters of the feedback loop are dependent on the input signal of the loop. The units are:

Input Signal	**P unit**	**I unit**
ADC 1..6	µm/V	µm/V/s
HF 1 df	µm/Hz	µm/Hz/s
HF 1 Ampl	µm/V	µm/V/s
HF 1 Phase	µm/deg	µm/deg/s
LF Lockin Ampl	µm/V	µm/V/s
LF Lockin Phase	µm/deg	µm/deg/s

6.4 The Scan Data Displays



In the main screen there are two display windows (left and right display) showing the scanning results. In these windows either images (*Frame View*) or line scans (*Line View*) can be displayed. Furthermore, data can be saved and the scan area can be modified.

The drop down menu at the top left of each window allows for selecting the respective signal to be displayed. By activating the *Average* button in the *DCC* all incoming data within one sample time (as specified in the *Scanner Ctrl*) is averaged before it is displayed on the screen. If *Average* is deactivated, Daisy displays the first incoming data point at a new scan position and then discards all further data within this sample time.

In the *Frame View* the acquired data is shown in a xy-plot, with the intensity color-coded as specified (see section 5.4.3 for a description of the context menu). In *Line View* the data is shown as curves.

If the cursor is paused for a second over one of the displays a pop-up window will display the physical coordinates of the chosen point.

Also, you can double-click on the window to detach it from the main window at any time, allowing for any user-defined resizing or repositioning of the window on the screen.

6.4.1 Frame View

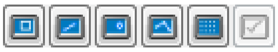
The drop down menu at the top of each window allows for selecting the respective signal to be displayed. The available signals can be defined in the DCC (see 4.1.1). To the right, the snapshot icons allows for saving of the SCAN data as described in section 4.2.7. Below that is the pull-down menu to select an Underground filter: this filter can be used to subtract a function of 0[th] (*Constant*) or 1[st] order (*Linear*) from each line to remove scan artefacts.

Range Tools: Below each frame display area the *Range Tools* are shown. By pressing the *Auto* button, the range limits will be calculated from the currently displayed values, i.e. the currently chosen color scale will be spread to match the data which is displayed at the moment of pressing the button. To further enhance the contrast or highlight certain parts of the image, one can choose the range limits manually by entering values to the left (*Range Minimum*) and to the right (*Range Maximum*). It is also very convenient to use the mouse wheel to change the Range settings. For this, just move the mouse pointer on the respective input field and then use the mouse wheel to continually change the setting. Use STRG or SHIFT key together with the mouse wheel to change the sensitivity of the wheel (see also section 5.4.1).

Scan Direction Switch: This button allows you to switch between displaying either the *Forward* (data acquired in a left-to-right scan) or *Backward* (right-to-left) data.

Please note that the following *Selection tools* are only shown when activated by right-clicking on the frame view, see section 5.4.3.

Frame Zoom Tools: The *Frame Zoom Tools* allow for zooming in or out. Please note that only integer zoom factors (or 1/integer factors) are allowed to avoid aliasing effects. If the image size in any zoom setting is larger than the available size in the *Frame View* window, scroll bars appear.



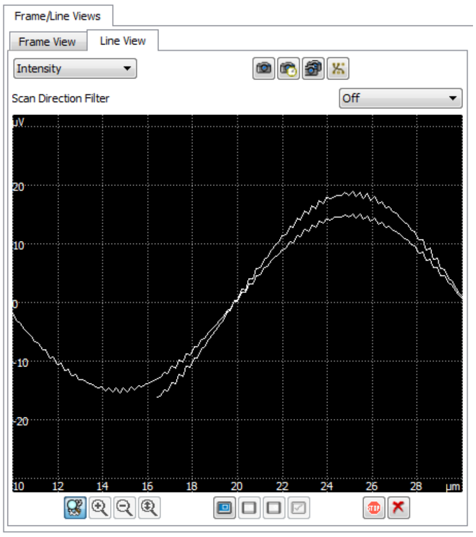
Frame Tools: The *Frame Tools* are shown to the lower right of the *Frame View*. The *Frame Tools* can be used to alter the current scan area. The *Frame Tools* are advantageous when one wants to reposition the scan area based on information that is currently shown in the *Frame View*. It is possible to (from left to right):

- select a rectangle as new scan range,
- rotate the scan direction or measure distance of two points,
- move the scan area by selecting a new center,
- select a new center of the scan area, or
- select a path for the *Pathmode* or
- create a grid for the *Pathmode*.

The rightmost button is used to accept the selections made. Please note that you cannot use that *Frame Tools* until a scan image has been taken.

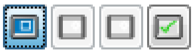
6.4.2 Scan Data Display: Line View Tab

In the *Line View* Tab, single or multiple lines of the scan image can be displayed during scanning. The *Line View* is constantly updated during scanning and shows the current values of the chosen *Signal* versus slow axis position. Please note that a comment window appears if you stop the cursor over the line view graph, displaying the actual position.



You can use the *Scan Direction Filter* to either display the *Forward* or the *Backward* scan. If the *Scan Direction Filter* is turned off, then both forward and backward scans will be displayed. You can increase the number of simultaneously displayed lines using the *Curves* function in the *Line View Ranges* context menu. Multiple lines are displayed in different colors for better clarity.

Use the *Zoom Tools* to adjust the display range. You can also use the *Stop*  and *Clear*  buttons and the right-click menu as described in section 5.4.2.

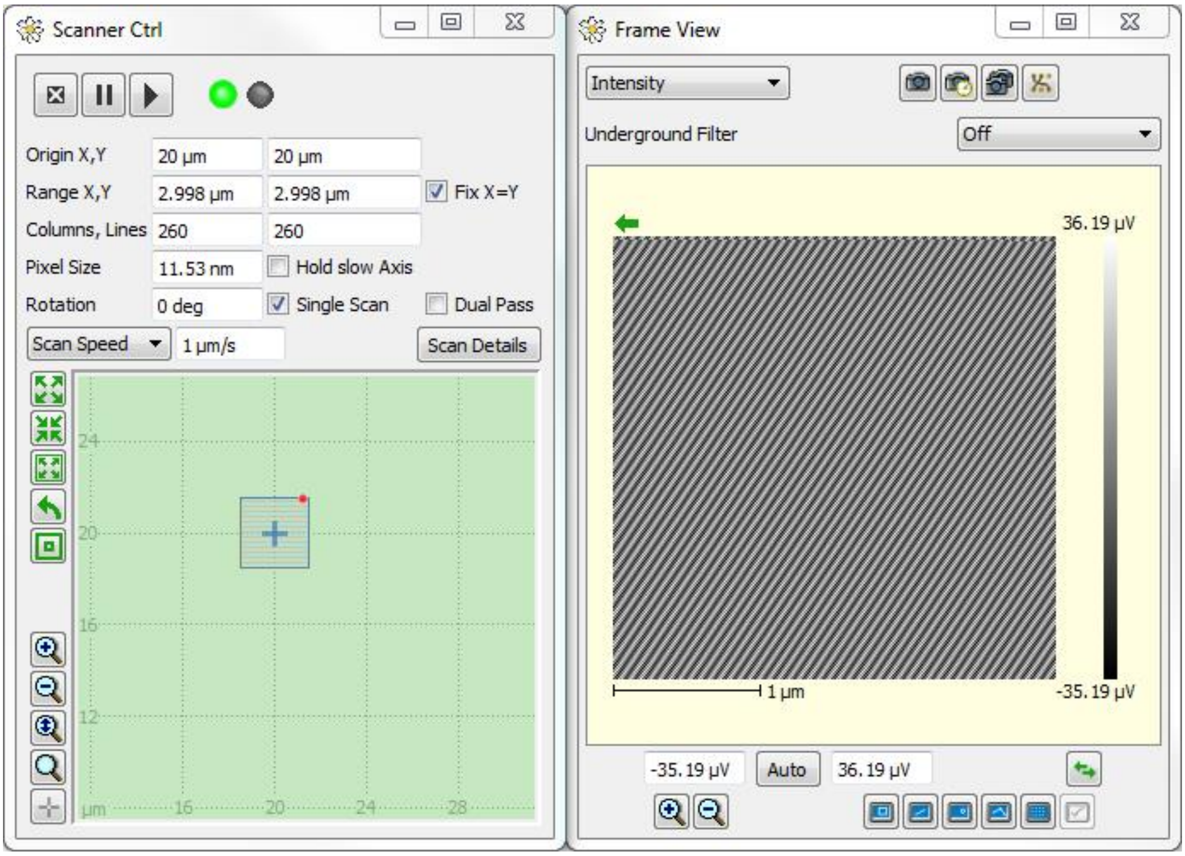


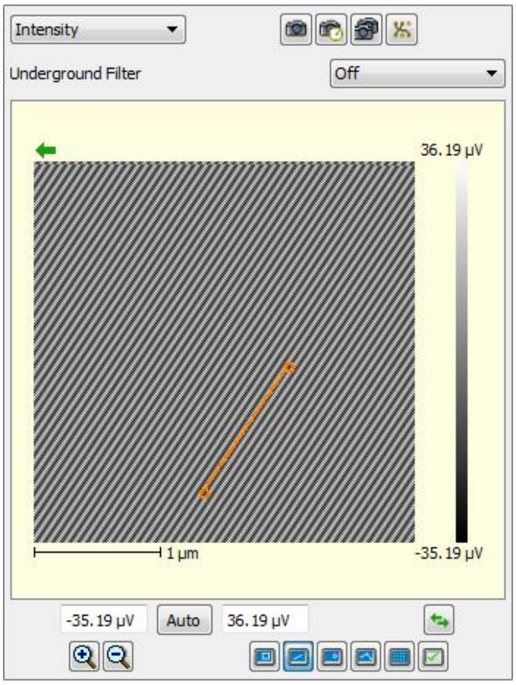
Frame Tools: These buttons allow to set a new scan range directly from the *Line View* graph of the Display. Choose the *Select New X Range* button and then drag the two vertical lines to enclose the desired new x-range (as shown in the graph).

Click on the *Accept* button and note how the active scan area changes in the *Scanner Ctrl*. If the *Fix X=Y* button is activated, the y scan range will be changed, too.

6.4.3 Example for Shifting, Moving and Zooming the Scan Area

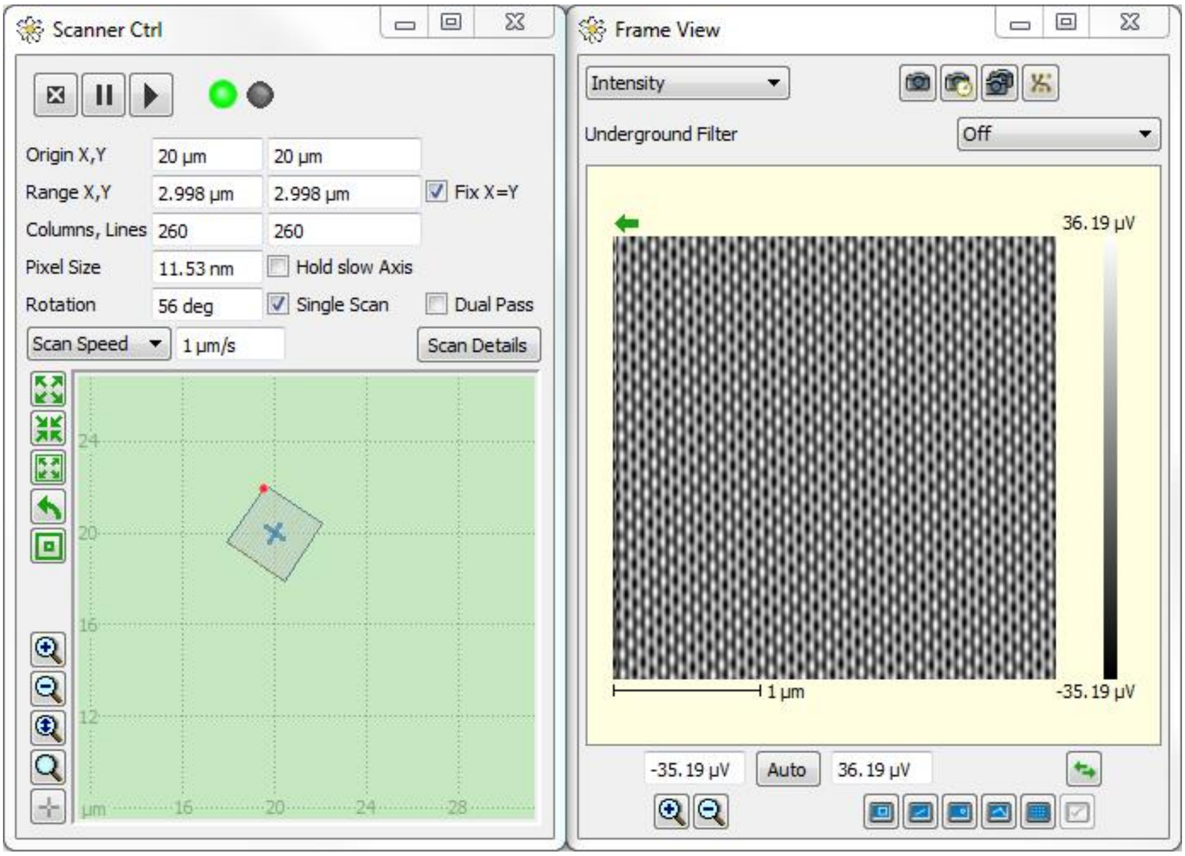
As an example, an image in the simulation mode of the software was acquired. As can be seen below, the full scan range of the xy scanner was 40 x 40 µm, and a 3x 3µm image (blue square) was taken in the middle of the full range. Also, the frame axes of the image are parallel to the x- and y-direction of the scanner.

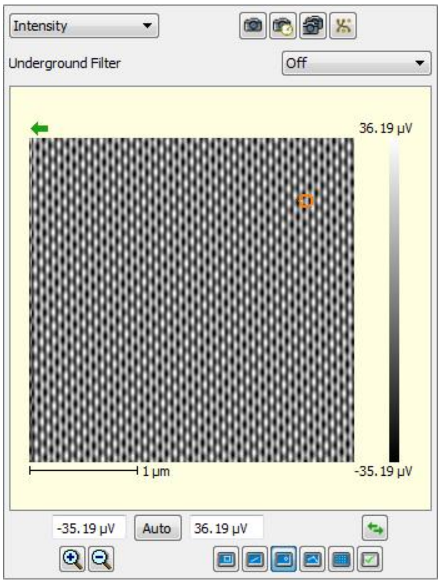




To rotate the scan direction so that the artificial dot array has a certain orientation to the frame axes, one has to activate the button, then draw a line in the *Frame View* window, as can be seen in the picture aside. Click on the button to accept the choice. The next scan will be carried out with the x-axis along the line.

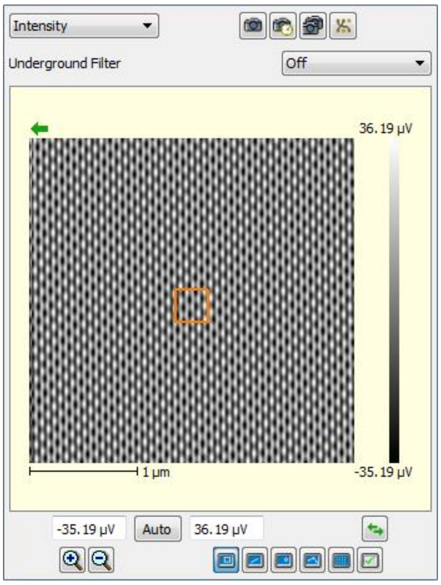
All parameters in the *Scanner Ctrl* are automatically adjusted and the blue square is rotated to show the new scan area (see below).





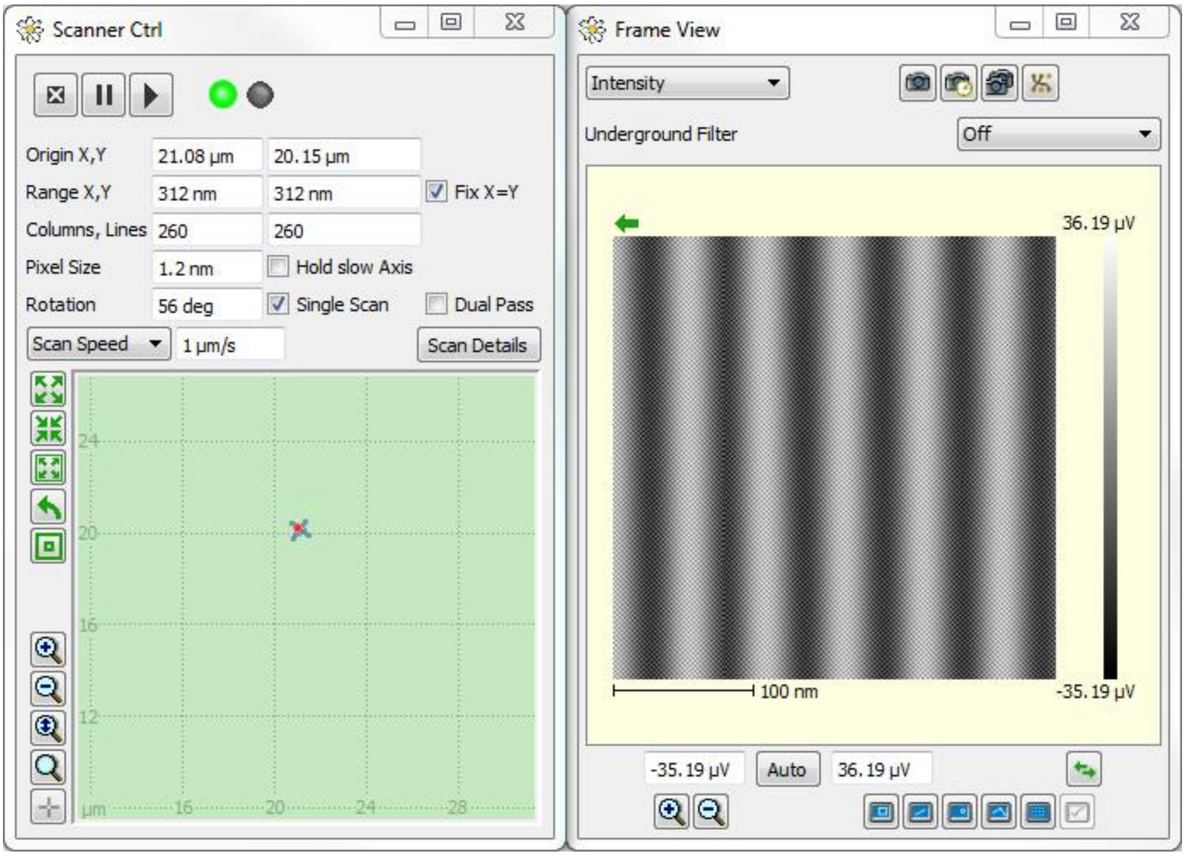
To choose a new center of scan, use the button. Click on the new center in the *Frame View* and accept the selection with .

The *Scanner Ctrl* will automatically adjust the scan area to be centered on the new spot as close as possible within the allowed maximum scan range of the scanner.



Finally, to zoom in on details of the image, use the button and drag a rectangle around the area of interest. Please note that the chosen rectangle is transformed to a square if the *Fix X=Y* button in the *Scanner Ctrl* is activated.

Again, after accepting with the button, a new scan area will be defined. The screen shot below shows the result of these actions.



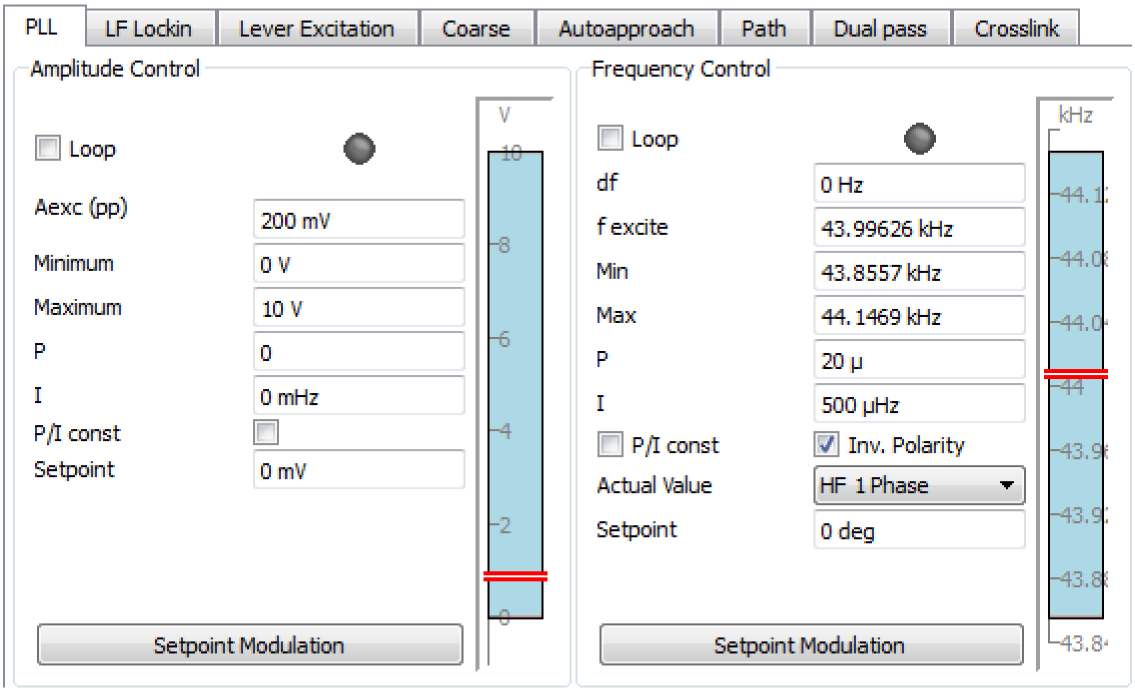
It is possible to drag and drop the scan from the frame view window to the Scan Area of the Scanner Ctrl window. It will then be shown as a decoration in the scan area (c.f. 6.2).

6.5 The main functions tab section

All main functions such as the PLL, Coarse Motion Control, Pathmode, Lock-In(s) & Q Control, Dual Pass and DAC Outputs are located in the tab section on the lower left part of the GUI. The user can conveniently adjust the order of the tabs as well as choose which tabs to show and which to hide, as described in section 5.3.1.

6.5.1 Phase Locked Loop (PLL tab)

A completely digital Phase Locked Loop (PLL) is integrated in the ASC500. The PLL Tab contains the functionality needed to control any type of oscillating appliance. It comprises two PI loops for automated excitation frequency and amplitude control. Note that the amplitude and frequency value can also be addressed in the Lever Excitation tab (section 6.5.3).



The configuration of the PLL loops is similar to the z controller (see section 6.3). They can act in a certain range between *Min* and *Max*. *P* and *I* parameters need to be chosen accordingly. The *Inv. Polarity* checkbox inverts the logic of the loop. The green LED indicates an active loop.

The two loops are internally bound to certain input and output signals, which cannot be changed (see section 4.2.2). For the Amplitude loop, the input signal is *HF 1 Ampl.* and the output signal is the excitation amplitude *Aexc*. For the phase control loop, the input signal may be chosen via a drop-down list: it could be either one of the *ADCs* or one of the *HF* and *LF Lockin* signals. This leaves the user the choice to use an external lock-in (connected to one of the ADCs) to drive the PLL.

In both loops one can use the *Setpoint Modulation* in order to find reasonable P and I parameters.

For a working example on how to set up a measurement with the PLL please see section 6.7.1.

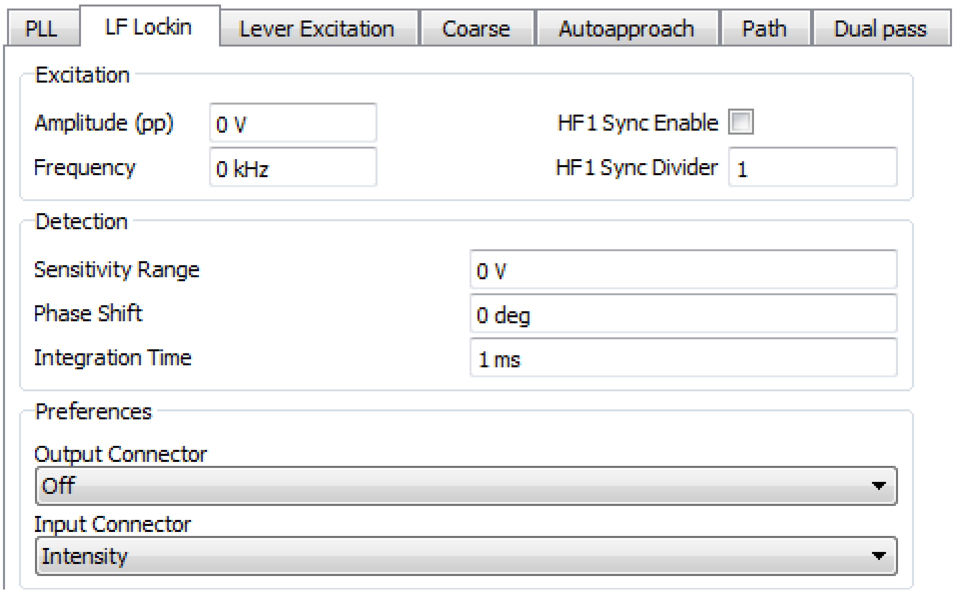
6.5.2 LF Lockin

The low frequency Lock-In produces a reference signal with a certain *Amplitude* and *Frequency* which is passed to the respective *Output Connector* (DAC1 or/and DAC2).

The input signal (*Input Connector*) is then analyzed using the demodulation values (*Sensitivity Range*, *Phase Shift*, and *Integration Time*). The output channels of the LF Lockin are *LF Lockin Ampl* and *LF Lockin Phase*. These can be selected as source for most displays.

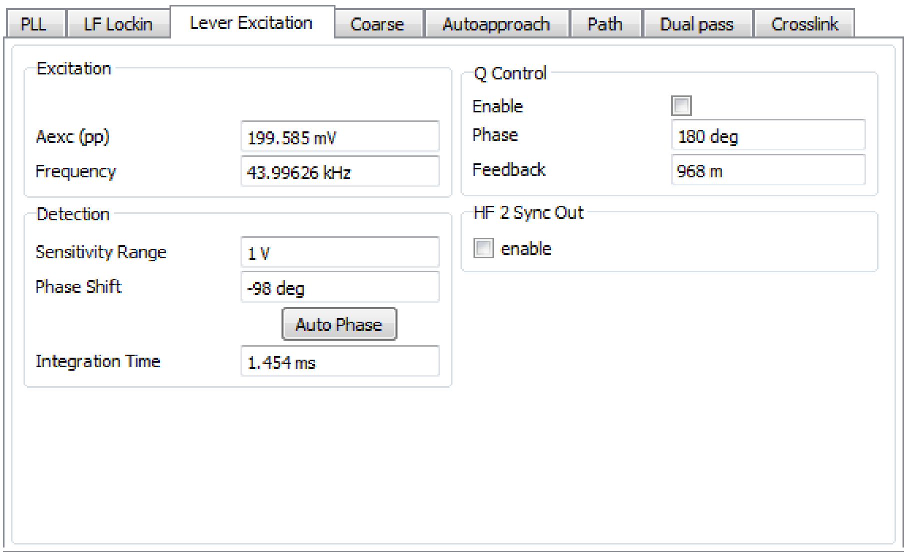
Other than that, the LF Lockin settings work in complete analogy to the ones for the HF Lockin (located in Lever excitation tab, see section

6.5.3 Lever Excitation on page 83). *HF 1 Sync Enable* can be used to lock the LF Lockin to the HF Lockin.



6.5.3 Lever Excitation

Some of the most common scanning probe techniques like AFM or MFM use a mechanical oscillator given by a cantilever or tuning fork to detect changes in the interaction strength between the probe (e.g. AFM tip) and the sample surface. In this AC mode (tapping mode) the cantilever is excited (usually) at its resonance frequency, and the resulting oscillation signal is recorded with a HF Lock-In amplifier. In the ASC500, this functionality is covered by the HF section, which is controlled via the *Lever Excitation* tab:

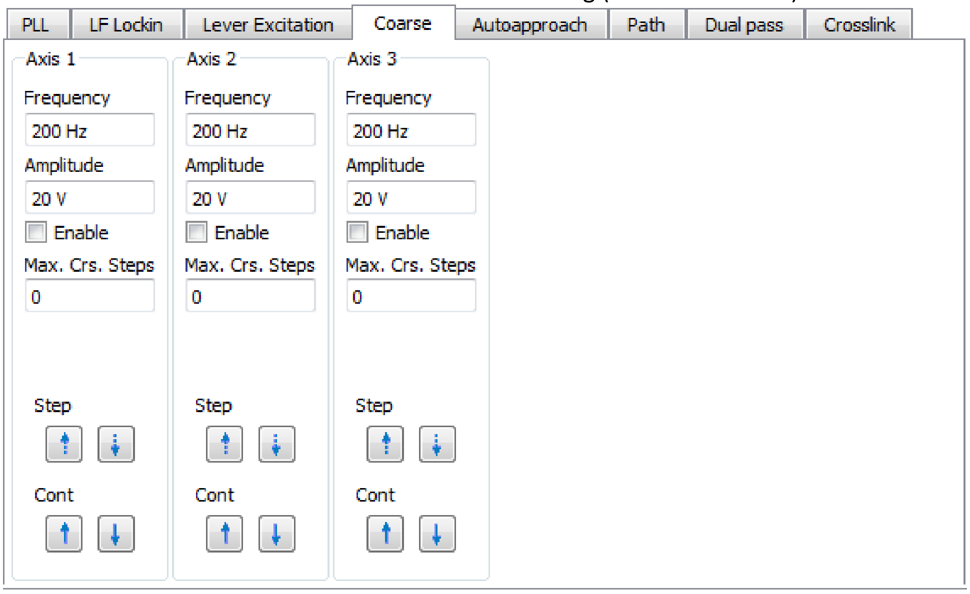


	The input signal for this HF Lock-In is *HF IN 1*, the output is both *HF 1 Ampl* and *HF 1 Phase.* Refer to section 4.2.2 for the connection schematics. The lock-in is configured with the following values:
Excitation	The excitation signal is applied to *HF 1 Out*. **Amplitude:** Amplitude of the output reference (peak to peak). To change the range of this output use the *Minimum* and *Maximum* values in the *PLL Amplitude Control* tab. This can become necessary to increase the resolution when outputting small amplitudes. **Frequency:** Frequency of the reference output. Note that these two values can also be addressed in the *PLL* tab (see section 6.5.1). The resolution is also affected by the *Min* and *Max* values in that tab.
Detection	**Sensitivity Range:** Sensitivity of the Lock-In. If the signal exceeds the Sensitivity Range, overflow may occur and wrong values may be displayed. The maximum sensitivity is 5 V. Decreasing the *Sensitivity* increases the lock-in resolution. To achieve maximum effect of the Q control decrease the sensitivity range if possible. **Phase Shift:** Can correct for constant phase shifts of the Signal with respect to the reference. Note that this governs only the output of *HF 1 Phase*. *HF 1 Ampl* measures the full amplitude of the signal. **Auto Phase:** Measures the phase difference at the selected excitation frequency and sets it as the *Phase Shift*. If the phase shift jumps to +-180° reset it to 0° and *Auto Phase* again. • **Integration Time:** Integration Time of the Lock-In. With longer integration time the *HF1 Ampl* and *Phase* reacts slower, though with having less noise.
Q Control	The Q control can be used to reduce or increase the Q factor of a resonator which corresponds to its sensitivity and reaction speed. How to set up the Q control is discussed in a working example in section 6.7.2. **Phase:** This sets the phase parameter for the Q Control functionality. **Feedback:** This determines the feedback parameter of the loop.
HF 2 Sync Out	Use this checkbox to sync HF1 Out and HF2 Out.

6.5.4 Coarse

If the ASC500 Controller is used in combination with attocube's ANC300 positioner controller, the Daisy software can be used to operate coarse positioner movement. To use the coarse movement features, please make sure that the

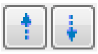
ASC500 is connected to the controller using the respective cabling (see section 2.3.5).



Each *Axis* section can operate one axis of the coarse positioners. Basic parameters of the coarse movement are set in the *Frequency* and *Amplitude* fields. For further details on these parameters, please see the respective manuals of coarse positioners and coarse positioning controllers. The *Enable* button will enable the coarse steps using the arrow buttons in the lower part of the axis sections.

Be aware that the communication is unidirectional. Changes in the ANC300 will not be taken over in the Daisy software.

The software will display one section for each active ANM module in the ANC300, but it can only control the settings of the ANM100 and ANM300 stepping modules.



The *Step* buttons initiate a single step movement.

The *Cont* buttons can be used for continuous movement. The movement will start when the mouse button is pressed and will stop when the button is released. If the text edit field *Max. Crs. Steps* is set to a value > 0, the *Cont*. coarse movement can be used to execute a well-defined number of coarse steps. If, for example, the *Max. Crs. Steps* is set to 100 and the *Cont*. button is pressed for a sufficiently long time, the movement will stop after exactly 100 steps. For safety reasons, the movement will stop sooner if the button is released before the total of 100 steps is completed. In case the *Max. Crs. Steps* is set to zero, the movement will only be stopped by the release of the mouse button.

Note. The *Frequency* and *Amplitude* values are programmed to the coarse controller only if the value is changed and confirmed. These edit boxes are in no way an indicator for the values that are currently set in the coarse control device.

6.5.5 Autoapproach

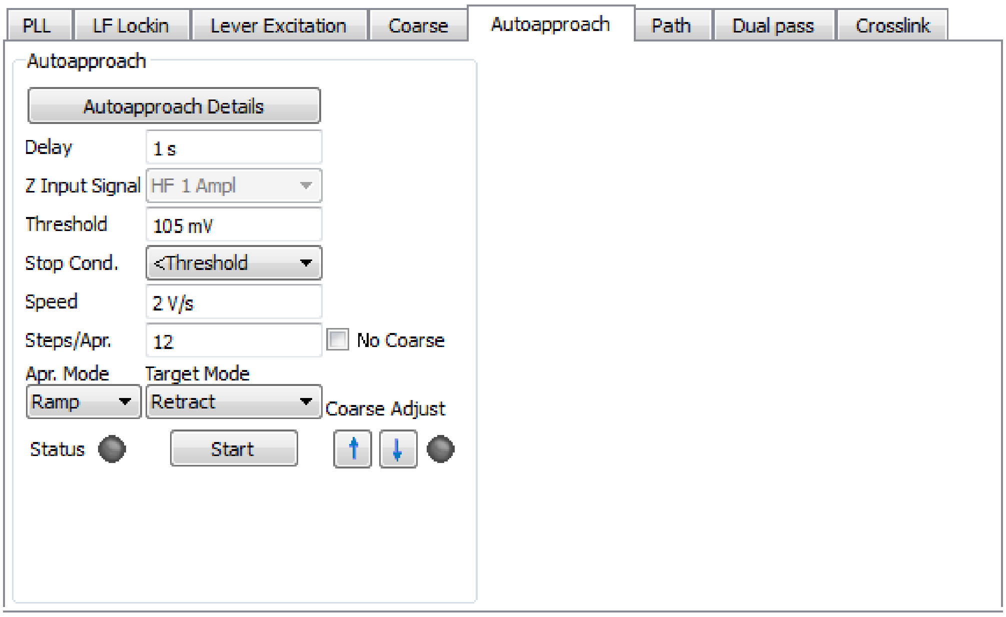
The *Autoapproach* is used to bring the tip into close proximity of the sample surface. The procedure that is employed for this task works as follows: the z scanner is continuously expanded while the sensor signal is being traced. When the stop condition is met, i.e. when the tip is close to the sample, the system will immediately finish the *Autoapproach* and enter the *Target Mode*. The *Target Mode* can be defined to be either an activated z feedback loop or it could also be a tip retract. If the stop condition is not met till the maximum stroke of the z scanner, the z scanner will be retracted and a number of coarse steps will be issued. After this the procedure will be restarted.

There are two different ramp modes for the *Autoapproach*: In the *Ramp* mode the z scanner expansion is done in a constant speed. This speed must be chosen small enough so that the tip is not damaged before the stop condition is met. The alternative is to use the *Loop* mode, where the speed of the z scanner expansion is defined through the z controller’s I and setpoint parameters (the P parameter does not contribute due to the definition of a proportional feedback gain). As in normal feedback operation, the expansion speed will be depending on the difference between the actual sensor signal and the setpoint. This means that the *Loop* mode will react on slow changes in the sensor signal (for example due to long range forces) with an adaption of the approach speed.

It is important to note that the parameters used to define the *Autoapproach* behavior are partly set in the z controller section of the Daisy GUI (section 6.3). Most importantly, the sensor signal that is being traced for the stop condition is defined through the *Input Signal* of the z feedback loop. In case the *Loop* mode is used, of course all parameters of the z feedback loop are taken as entered in the respective fields of the z controller.

In *Loop* mode, the approach can come to a halt if the sensor signal equals the setpoint before the threshold condition is met. The system will be in a stable condition, but the *Autoapproach* will still be active in the background. If this behavior is to be avoided, the setpoint of the z controller and the threshold value of the *Autoapproach* should be set to equal values.

The *Autoapproach* can be manually stopped either by clicking the *Start* button of the *Autoapproach* section while the *Autoapproach* is running or by clicking on the *Retract* button of the z controller. In the first case, the z scanner will keep its current position; in the latter case, the z scanner will be driven to zero (i.e. maximum distance between tip and sample).



Delay: Delay after coarse stepping. Stepping may induce some noise or ringing in the experiment. The settling time between the coarse step and the start of the z scanner expansion can be defined here. During this time, the sensor signal will not be traced for the threshold condition.

Z Input signal: This display shows the input signal used for the Autoapproach procedure. The Z Input signal can be changed in the *Z Control* section (see section 6.3).

Threshold: Value for the stop condition.

Stop Cond.: Defines if the threshold represents a lower or upper boundary of the sensor signal range. In STM type experiments, the *Stop Condition* will always be a “>” while in non-contact AFM type experiments, the condition will be set to “<”.

Speed: Approach speed for *Ramp Mode.*

Steps/Apr.: Defines the number of coarse steps that will be executed after each scanner ramp. Usually, this value will be defined depending on the stroke of the z scanner in relation to the step width of the coarse device.
Apr. Mode: Approach mode; defines whether *Loop* or *Ramp* mode is used. Details are given in the text above.

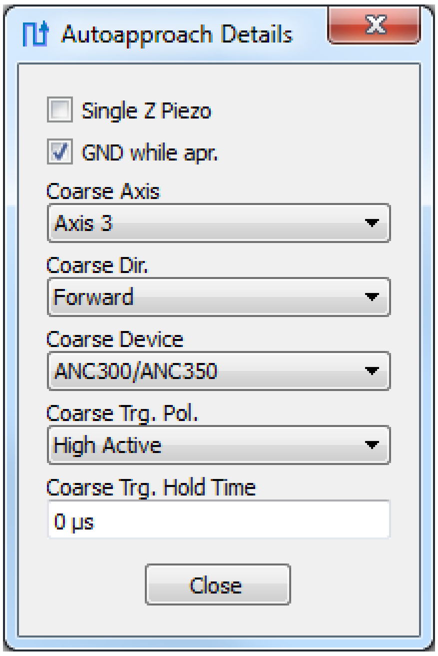
Target Mode: Defines the mode that is activated after the stop condition was reached. It is possible to switch on the feedback loop (*Loop On*), or to retract the tip (*Retract*).
Status LED: The status LED indicates whether the Autoapproach is active or not.

Start: Press Start to start the Autoapproach.

Coarse Adjust: Additional to the axis' coarse control, one can issue single steps with the Autoapproach coarse axis. The coarse adjust button is meant to set the contact range of the tip within the z scanner stroke. Normally, after finishing the Autoapproach the tip is in the upper part of the z scanner range. Using the Coarse Adjust buttons, one can move the contact point of the tip to a more convenient position in the middle of the z scanner range (with better scanner linearity). For that the Coarse Adjust button will deactivate the feedback loop, trigger one coarse step and then restart the feedback. This functionality can be used with the feedback turned ON without any risk of damaging the tip.

Note: if the feedback was not active upon the triggering of the *Coarse Adjust*, it will not be activated after the execution of the coarse step.

No coarse: If this option is chosen, the coarse movement of the Autoapproach will be deactivated.



The *Autoapproach Details* section includes all approach parameters that will have to be set only once to configure a certain hardware configuration.

Single Z-Piezo: Enable, if the z positioner piezo and the z scan piezo are the same physical device. In this case, the ANC300 will be switched to EXT mode during the approach.

GND while apr.: When enabled, the coarse control device will be switched to GND mode during z scanner expansion. For lowest noise, this option should always be activated.

Coarse Axis: Defines the axis number of the z coarse positioner. The attocube standard is to use Axis 7 as the z-axis.

Coarse Dir.: Defines the coarse approach direction. Standard is *forward*.

Coarse Device: Defines the coarse control device. The possibilities to choose from are

1. *ANC300/ANC350* for operation with an attocube ANC300 or attocube ANC350. The connection to the ANC300/ANC350 has to be done with a serial cable.
2. *TTL via DAC2*: Can be used to control any coarse controller that can be triggered by a TTL pulse (5V pulse amplitude). The connection has to be made via the standard DAC2 output.
3. *LVTTL via DAC2*: Can be used to control any coarse controller that can be triggered by a low voltage TTL

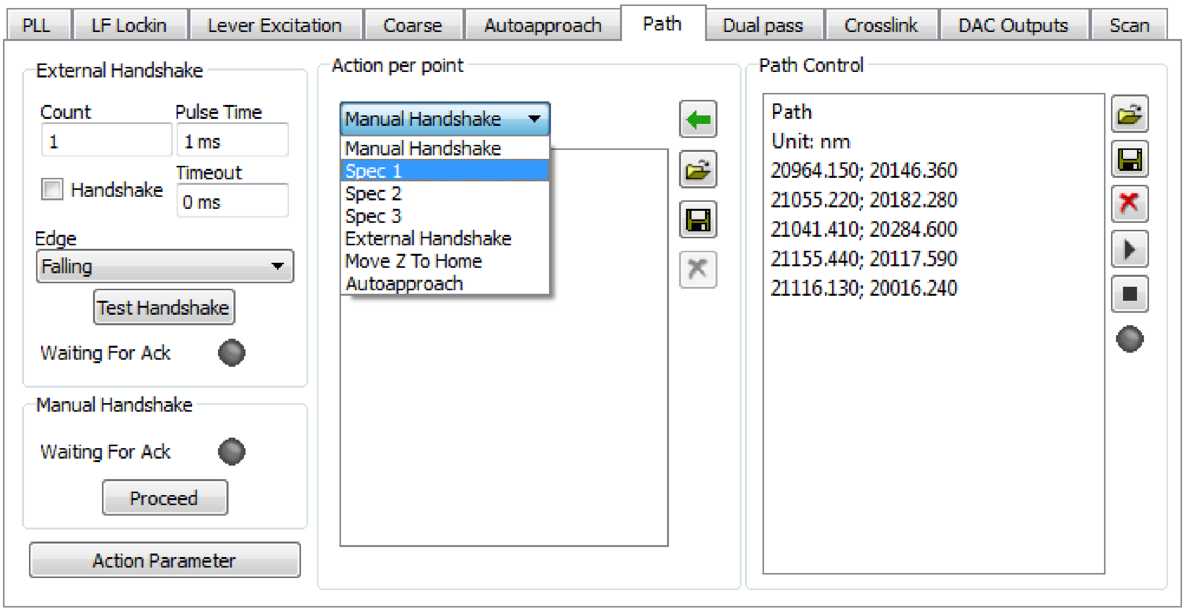
pulse (2.2V pulse amplitude). The connection has to be made via the standard DAC2 output.

4. *ANC350 via NSL A/B*: For operation with an attocube ANC350. The connection is done via a special NSL cable. For further information on this connection, please contact attocube. When using two ANC350 modules you can switch between the two NSL channels.

6.5.6 Path

The Pathmode is used for experiments that are defined on a grid of points or on a number of randomly selected points of the scan field. On each point, a number of actions can be defined and grouped into *action lists*. Predefined actions include any of the internal spectroscopies as well as handshake actions (either manually or with external instruments). The flexibility and diversity of this function makes it a very powerful tool for the experimentalist.

The Pathmode is enabled using the *Frame Tools* of either frame view (see section 6.4). To select a path, first click on the button, then select points of interest in the data display. These positions will be shown as small circles in the display, with a line connecting the different points indicating the path. After selecting the path, a click on the accept button will initialize the *Pathmode*. Paths and grids can be saved, edited and reloaded using the respective buttons in the *Path Control* section of the *Path* tab.



Manual Handshake

Manual Handshake: If this option is enabled, the user has to confirm each step with the *Proceed* button (in the *Manual Handshake* section). The scanner position on each point can be manually altered using the *Manual Positioning* option in the *Scan* tab described in section 6.5.10.

External Handshake

The External Handshake is used to integrate external devices into the control capabilities of the ASC500. The interaction between the ASC500 and the external device is done by means of TTL pulses. For the definition of the SNYC connector pins, see 2.3 Front and Rear Panel Connections on page 12. The idea of the procedure is the following:

1. The ASC500 drives the tip to a certain spot of interest (defined by the path mode).
2. A SNYC OUT TTL pulse is issued once the tip has reached the target position to trigger the external device.
3. The external device (for example a spectrometer) executes a certain measurement task.
4. After the measurement is finished, the external device issues another TTL pulse which triggers the ASC500.
5. Upon receiving a SNYC IN TTL pulse, the ASC500 drives the tip to the next point (or repeat the measurement circle).

To use this capability, the following conditions have to be fulfilled:

a) The SYNC OUT line of the ASC500 must be connected to the external device

b) The SYNC IN line of the ASC500 has to be connected to the external device

c) The external device must be capable of being triggered by a TTL pulse.

d) The external device must be capable of sending a TTL pulse after the fulfillment of its measurement task. If this is not possible, the ASC500 can also wait a predefined amount of time at each spot before moving to the next spot. The waiting time at each point must be adjusted to make sure the external device has finished its measurement task.

NOTE on TTL pulses:

The ASC500 TTL input and output lines are using low-voltage TTL (LVTTL) pulses, i.e. pulses with a high level of 3.3 V. However, the use of 5 V TTL pulses (also commonly used) will not damage the input stage of the ASC500. Also, since the threshold voltage for all TTL high levels is defined as 2.5 V, communication with a 5 V-TTL device is guaranteed without problems.

To setup the handshake procedure with the external device, the *External Handshake* section of the *Path* tab is used. The parameters will be explained in the following:

Count: Number of handshake cycles to be executed per point.

Pulse Time: Defines the length of the SYNC OUT pulse.

Handshake: If activated, the controller waits for a return SYNC IN pulse (or until timeout). If deactivated, the tip will smoothly move from point to point sending a SYNC OUT whenever a new point is reached.

Timeout: Defines the maximum period of time the controller is waiting for a SYNC IN pulse. After *Timeout* time has elapsed, the controller will either proceed with the next SYNC OUT pulse (if *Count* > 1) or the tip will move to the next point. The *Timeout* can be deactivated by setting it to 0. In this case, the tip will not move to the next pixel until a SYNC input is sensed. *Timeout* can be used to control external devices that do not have the capability to return a SYNC IN TTL pulse.

Edge: Defines if the SYNC input TTL pulse will be triggered on either *Falling* or *Raising* edge.

Test Handshake: Runs one cycle of the *Handshake* procedure. A first click on this button will issue a SYNC OUT TTL pulse. A second click will simulate the SNYC input pulse, i.e. the tip will move to the next point (or repeat the cycle if *Count* > 1). Note that a *Timeout* can occur before the second click is done in which case the second click will not end the cycle but instead start a new cycle.

Wait for Ack: This green LED is ON as long as the controller is waiting for a SYNC IN pulse.

Action per point

This section can be used to define the actions that have to be performed at every point of the path.

You can chose an action with the dropdown menu and use  to add it to the sequence.

The buttons to the right can be used to load and save a series of actions.

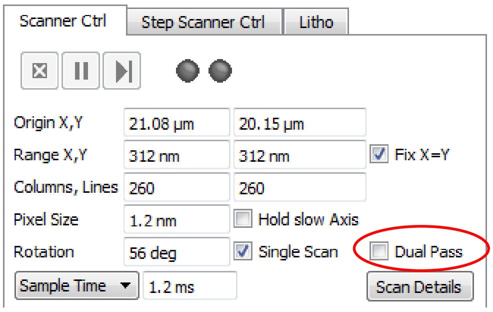
The available actions are:

- Manual Handshake, see description above
- Spec 1-3, the systems runs one of the spectroscopies using all its parameters. For more information on the Spectroscopy tool see Section 6.6.4
- External handshake see description above
- Move Z to home, this is identical to the retract action of the z-loop. (Section 6.3)
- Autoapproach, performs the Autoapproach as described in Section 6.5.5

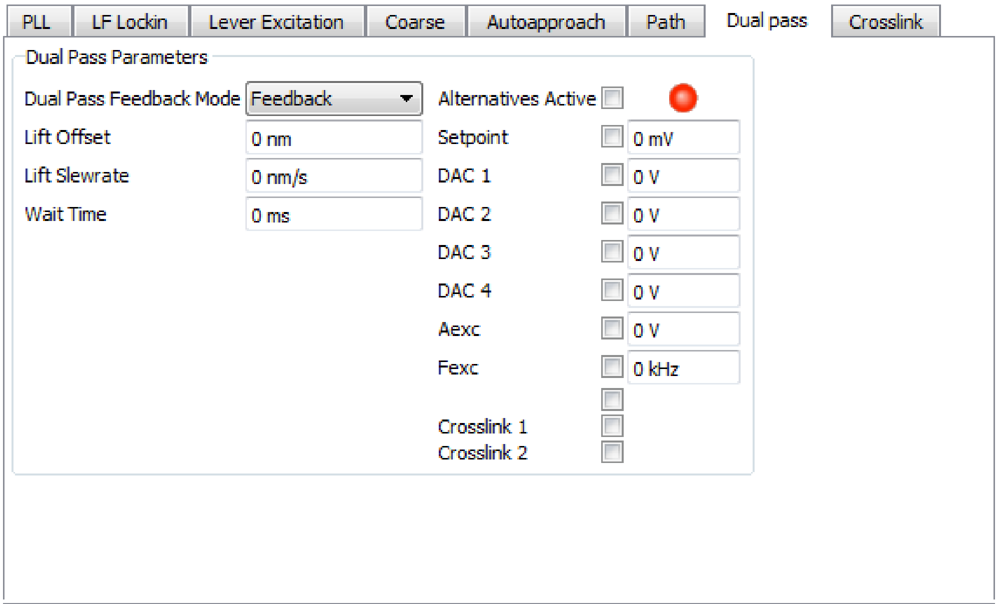
Path Control

The *Path Control* section can be used to load and save paths and to start and stop the execution. On how to create a new path please see section 6.4.1. The LED indicates whether a path is executed at the moment.

6.5.7 Dual Pass



The *Dual Pass Mode* changes the scan movement so that each line is scanned twice (forward – backward – forward – backward) before proceeding to the next scan line. Various parameters can be altered during the second line pass, including a constant height offset between first and the second pass, sometimes referred to as *Lift Mode*. The *Dual Pass Mode* is activated within the *Scanner Ctrl*; the parameters used for the second line pass can be set in the *Dual pass* Tab. The data from the second pass belongs to a separate Data group called dual pass. To visualize the data, please employ the *Display Wizard* to open new frame or line views.



Dual Pass Feedback Mode: The Dual Pass Mode allows for two different modes of operation:

1. *Feedback:* All the Alternative parameters, explained in this section, will be applied during the second pass. This way one can apply for example different force during the second pass of an AFM scan by adjusting the cavity tuning.

2. *First Line Profile:* This option records the sample topography during the first pass. In the second pass, the feedback is turned off and the tip is scanned along the recorded topography plus the *Lift Offset.* If made correctly the distance between tip and sample is kept constant this way. This mode is especially useful to image long range forces (i.e. electrostatic or magnetic) without topographic side effects.

To display, record, and save the data from the second pass, one employs the Display Wizard as described in section 5.4.4 on page 53.

Below is a detailed description of the behavior with the *First Line Profile* Option enabled*:*

The topography (i.e. Z out) information during the first line pass (forward and backward) is recorded.

Before starting the second pass, the z feedback is stopped and the tip is retracted to a certain height specified under *Lift Offset*. The speed of this retraction movement is governed by the *Lift Slewrate*. The scanner pauses for the *Wait Time* in order to give the system the chance to settle.

The topography of the first line pass is repeated in the defined offset height. At each point, the tip is at the well-defined distance over the sample surface. Data recording on each of the 'normal' frame views (i.e. those frame views triggered by *Scanner*) is stopped. The second pass data is recorded in data windows triggered by *Second Line*.

After completing the second pass (forward and backward) the z feedback is turned on again and the scan is paused for another *Wait Time* to let the system settle. The scanner is moved to the next line and the first pass of the new line started.

Lift Offset: Specify the distance between tip and surface during the second pass. Please note that a positive value will cause the tip to be lifted by this height. Negative values are forbidden.

Wait Time: Defines the time the scanner is paused at the beginning and the end of the second pass. Please note that the *Lift Slewrate* may automatically be adapted to ensure that the scanner has reached the defined lift height before the wait time has ended (before the second pass). After finishing the second pass, the z feedback will be turned on. Please make sure that the *Wait Time* is long enough to give the feedback the possibility to reach the first pass setpoint.

Lift Slewrate: Defines the voltage rate of change that is applied to the z scanner to reach the lift height at the beginning of the second pass.

Alternatives Active: This checkbox enables the alternative values set for the second pass. This is useful to test the settings of the second pass

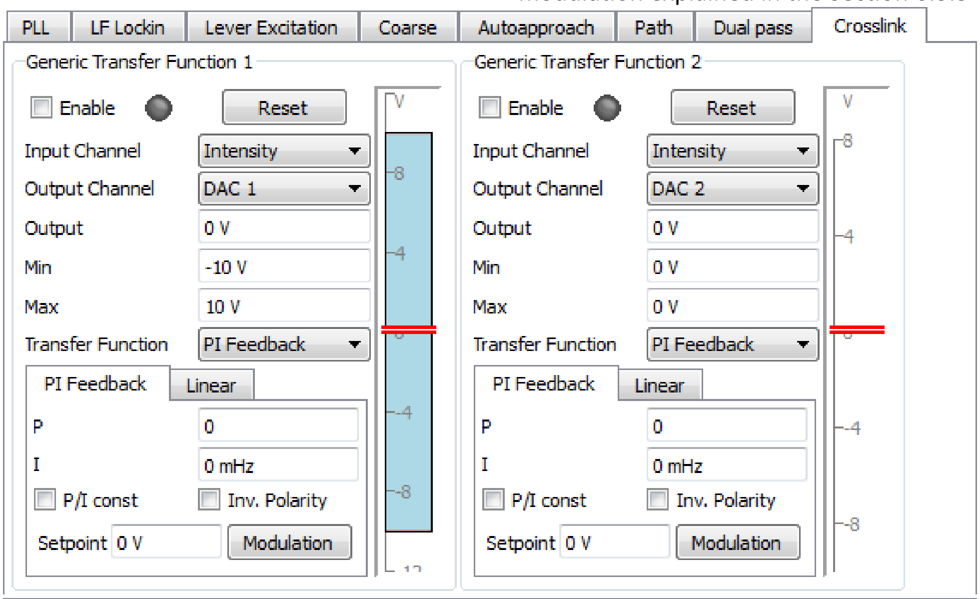
Setpoint, DAC1…: Each line allows to set an alternative value for these setting. When the checkbox is set, these alternative parameter will be applied during the second pass.

Crosslink1, Crosslink2: These two allows the user to selectively turn on the Crosslinks during the second pass. Only the OFF-> ON direction is possible. A crosslink cannot be turned off during the second pass.

Please note that some of these parameters only have an effect if *Feedback* is selected under *Second Pass Feedback Mode*.

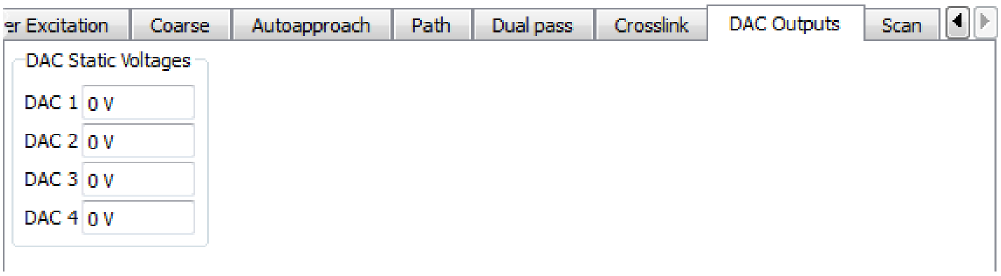
6.5.8 Crosslink

The crosslink feature offers the option to link any input to one of the DAC outputs. This can e.g. be used to stabilize the working point of an AFM (crosslink Intensity to the Dither (DAC1)).
To set up one of the two identical *Generic Transfer Functions* you can select Input and Output channel, a starting value and limits to the output channel and choose the Transfer Function. This decides the kind of link between the two channels. *PI Feedback* allows a PI control similar to e.g. the Z-Control. *Linear* enables a direct coupling of input to the output channel.
To find PI values for a specific application you can use the *Modulation* functionality. This works similar to the setpoint modulation explained in the Section 6.3.3



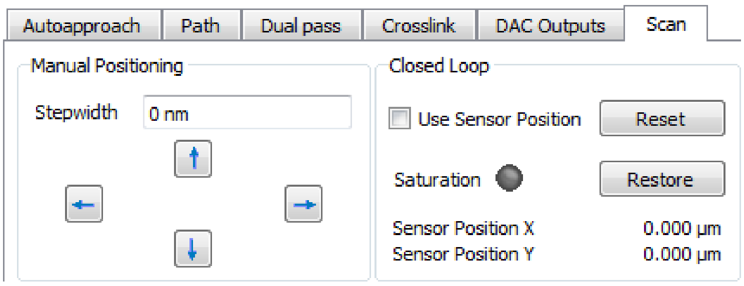
6.5.9 DAC Outputs

The ASC500 comprises four DAC outputs. They can be used to output voltages from -10 to 10V. Notice that the voltages can't be set when *Output Active* is not ticked. The possible output range can be limited in the *Output Limits* window.



6.5.10 Scan

The scan window tab can be used for *Manual Positioning*, moving in a certain direction by a certain *Stepwidth* with the Scanners. The On/Off button (*Use Sensor Position*) for the *Closed Loop* Scanning feature is also located here. For detailed setup of the Closed Loop Scanning feature with FPS and optical readout please see the corresponding addendum to the ASC500 manual.

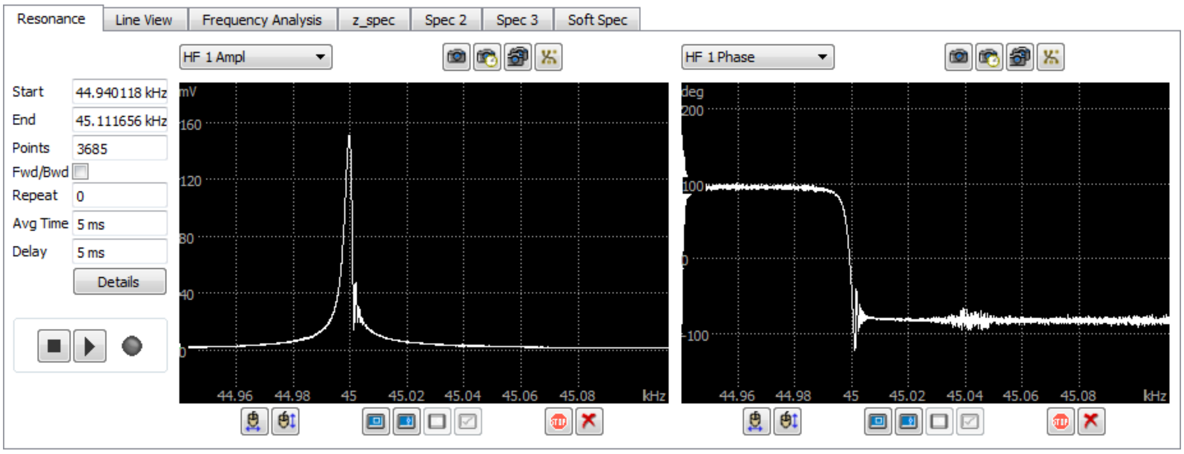


6.6 1-dimensional data displays

6.6.1 Resonance View

Use the *Resonance View* to find and characterize an oscillation with frequency and phase response. By pressing the *Start* button, the given frequency window will be scanned, while the response from the HF Lock-in is imaged in the amplitude (left) and in the phase window (right). Of course any data channels can be plotted here after adding them in the DCC (check section 4.2.5 Data Channel Configuration (DCC) in detail). See section 4.2.2 for details on the internal signal flow.

Be aware that the PLL is connected after the frequency sweeper. Therefore an activated PLL will effectively compensate for the frequency sweep. Always turn off the PLL before running a frequency sweep.



Start: The start frequency for the frequency sweep.

End: The stop frequency for the frequency sweep.

Points: The number of data points to be recorded and displayed in the images to the right. With fewer points the calibration run will be faster of course.

Fwd/Bwd: If enabled, after sweeping the frequency from *Start* to *End,* the controller also collects the data from *End* to *Start and* displays it in the same window.

Repeat: The frequency sweep will be repeated several times, this can be done by entering a respective number in this field. Please note that zero corresponds to no repetition.

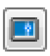
Avg. Time: Specify here the measurement time per pixel. All collected data during this measurement time will be averaged.

Delay: Enter a delay for each point after the new frequency value has been set, before the data is taken. This can help to avoid ringing after the excitation frequency has been changed.

Status LED: Indicates whether the frequency sweep is running.

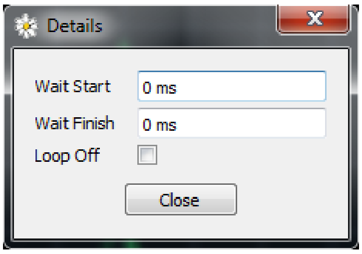
Start: Starts the frequency sweep.

Select new window: Use this Frame Tool to select a new frequency window from the amplitude or phase display. Accepting this range will enter the new start and end values in the *Start, End* field. This will also adjust the *Min* and *Max* of the PLL. Keep in mind that a selection during the frequency sweep running will not work.



Select frequency: If you select a point in the amplitude or phase window, the respective value will be entered as the new frequency.

Details: This opens up the Details window.



Details:

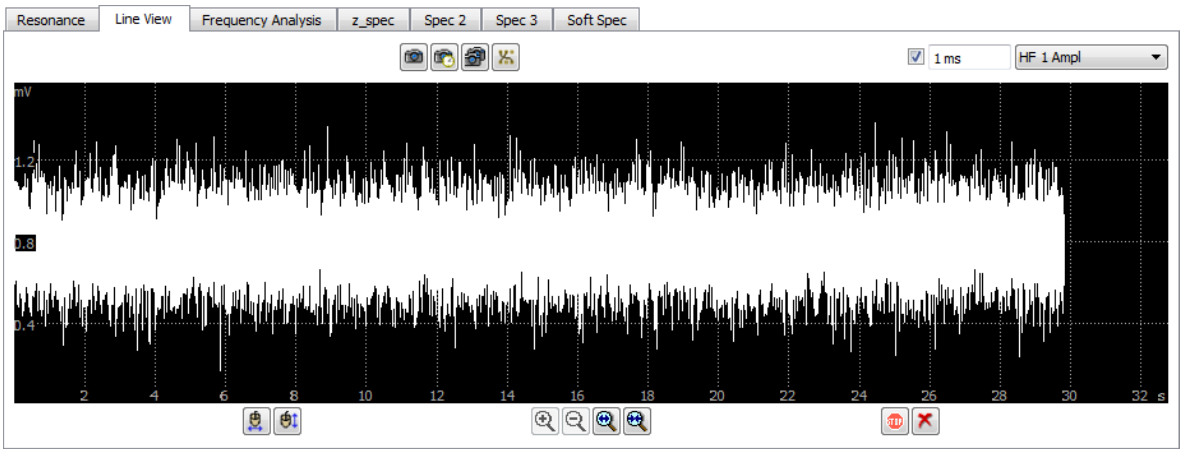
Wait Start: This is a delay time before the calibration run is started.

Wait Finish: This is a delay time after the calibration run is stopped and the system returns to the main frequency as given in the *Lock-In Tab* or *Dual Pass Tab*.

Loop Off: When this is checked the Loop is automatically turned off before doing a Scan.

6.6.2 Line View

The *Line View* is the most elementary form of displaying data. The data is displayed against time. Although it is a very basic tool, the line view can be highly useful because of its simplicity and versatility. It is capable of displaying data in the time range from milliseconds to kiloseconds.



In the top right corner of the Line View tab, the input signal can be chosen. You can display any signal of the ASC500 here. Below the graph are the common tools to change the display and save the displayed data (described in detail in chapter 5.4.2).

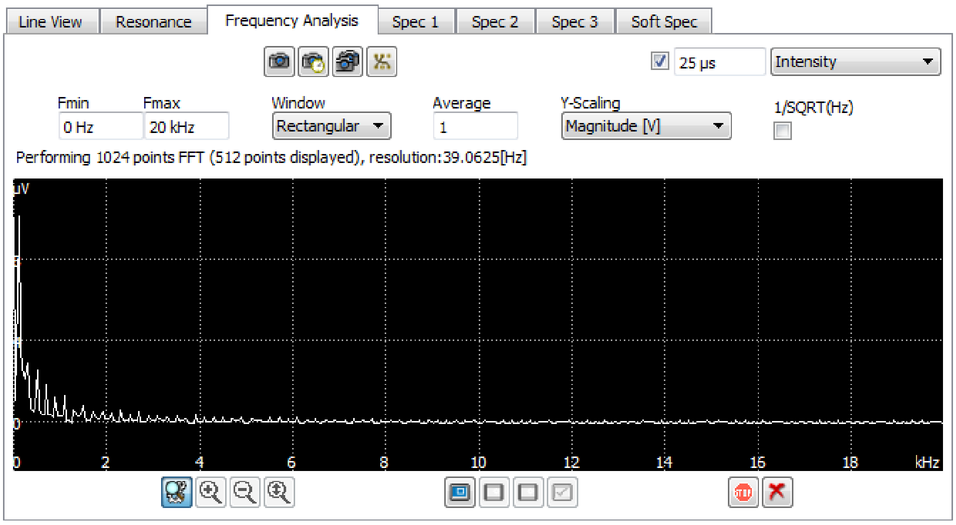
Signal: Choose the input signal to be displayed in the line view.

Sample Time: The time which corresponds to one data point. Since the sampling speed of the ASC500 inputs is 400 kHz, the smallest value to be entered here is 2.5 µs.

Average: With this check box you can activate data averaging. This means that all incoming data (frequency 400 kHz) within one *Sample Time* is averaged before it is displayed in *line view*. If this is unchecked only the first incoming data points is taken in each *Sample Time* window.

6.6.3 Frequency Analysis View

The *Frequency Analysis* allows for examination of signals in a frequency domain representation. The ASC500 offers an extremely powerful Frequency Analysis tool to help optimizing the signal, analyzing mechanical or electrical noise and to better understand properties of oscillating systems like cantilevers or tuning forks. Signals can be analyzed in a frequency range from DC to 200 kHz, with possible a frequency resolution well below 1 Hz (depending on the range). Different window functions can be used to reduce leakage and a number of representations can be chosen to meet your application.



The image above shows the *Frequency Analysis* window. In the top right corner of the tab, the input signal and the sample time can be chosen. Above the graph, the FFT parameters can be set. The graph itself is displayed in a frequency vs. amplitude style. Please note that the unit of the amplitude axis is automatically adjusted to the unit of the input signal as specified in the *Transfer Functions* Panel.

Time Domain Parameters

Signal: Specification of the input signal. One can choose between any ADC or AFM input, lock-in data, or Z-Out.

Sample Time: One can choose the sample time for the FFT input signal. The sample time determines the maximum frequency which can be displayed in the spectrum. Enter 2.5 µs to access the full sampling speed of the ADC converters (400 kHz), which will allow a FFT from DC to 200 kHz. Increase the sample time in case the full frequency range is not needed and also to gain higher frequency resolution. Also, higher sample times reduce the CPU load.

Average: This button activates time domain averaging, i.e. all incoming data within one *Sample Time* is averaged before it is processed by the FFT. One can use this averaging to reduce aliasing artifacts in low frequency FFT data.

FFT Parameters

Fmin/Fmax: Enter the frequency range you want to analyze here. Fmax must be smaller or equal to 1/(2**Sample Time*). The status line below the input fields immediately shows the frequency resolution corresponding to the chosen settings.

Window: Setting of the window function used for FFT calculation. Choose from *Rectangular*, *Hamming*, *Blackman,* and *Flat Top* to meet your requirements in either amplitude or frequency resolution and leakage.

Average: Allows for applying a linear averaging to the FFT data. In contrast to the time domain averaging, FFT averaging calculates the mean value of several FFT traces, not input values. Please note that high *Average* values may lead to long update intervals of the FFT graph.

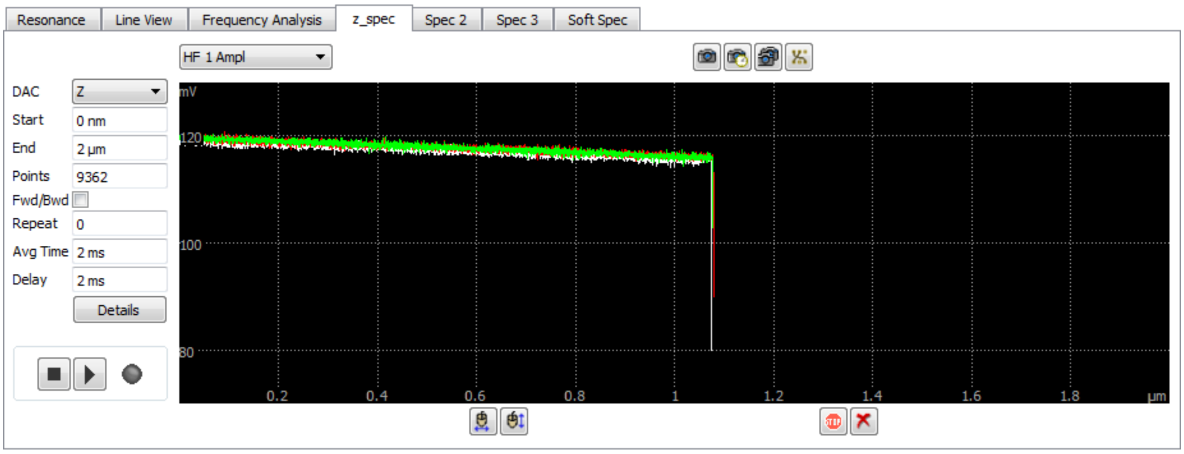
Y-Scaling: Choose between *Magnitude[V]*, logarithmic *Magnitude [dBV]*, *Power Density [dBm]* and *Power Spectrum [dBm]*.

1/SQRT(Hz): Use this button to display the magnitudes normalized by a $1/\sqrt{Hz}$ factor.

6.6.4 Spectroscopy Tab(s)

With the spectroscopy tabs (Spec 1-3), one or more signals can be recorded while changing certain system parameters. For example, you can sweep the gate voltage of a quantum dot and record the response of the dot's photoluminescence as a function of the gate voltage.

Note that you can change the name of these three tabs in the *Aliases* menu, see section 5.3.2 for details. In the supplied images *Spec 1* was renamed to *z_spec.*



There are three basic types of spectroscopies:

1. *DAC Spectroscopy:* Any of the four standard DAC outputs can be used for spectroscopy purposes.

2. *Z Spectroscopy:* this type of spectroscopy will sweep the Z Out voltage while recording any kind of internal or external signal.

3. *Low Freq:* low frequency spectroscopy changes the frequency of the low frequency lock-in.

The type of spectroscopy is defined in the DAC drop-down list of either of the three Spec tabs. All types of spectroscopies are operated in the same way. For simplicity, we refer in the following only to a *Z-Spectroscopy*.

The voltage is swept in a step-like way: the sweep range is divided into a number of steps (*Data Points*). The first voltage step is generated and is kept constant during the measurement of the response signal. Only after the measurement of the first data point is finished, the output voltage changes to the next point.

The settings for this calibration are similar to those in the *Resonance* tab.

Start: Specify the start position within the allowed z-range .

End: Specify the end position within the allowed z-range . If *End* is smaller the *Start*, the output will be swept backwards.

Points: Specify the number of data points between *Start* and *End*. Please note that this number is slightly altered once you start the sweep. This is because of the quantized nature of the digital output; the minimum step size of the 16 bit DAC output is for example 300 µV.

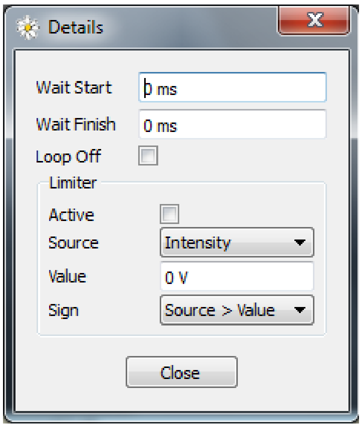
Fwd/Bwd: If activated, the voltage is swept from *Start* to *End* and then back to *Start*. If the end is not reached (for example due to Limiter) the backward scan is omitted.

Repeat: If the measurement should be repeated automatically, increase the *Repeat* value. Please note that by default, the graph will only show one measurement trace. To display more than one trace in the spectroscopy view, open the *Ranges* dialog of the *Spectroscopy View* (see section 0 for details).

Avg Time: Specify here the measurement time per pixel. All collected data during this measurement time will be averaged.

Delay: Enter a delay for each point after the new value has been set, before the data is taken.

Details: Opens the Details dialog window:



Wait Start: Delay time before the spectroscopy is started.

Wait Finish: Delay time after the spectroscopy is finished.

Loop Off: Switches the feedback loop off during the measurement. Especially with the *Z-Spectroscopy*, it is important to switch the loop off; otherwise the loop override the spectroscopy. When the spectroscopy measurement is finished, the loop is automatically switched on again.

Limiter Active: Activates the Limiter. When a certain condition is met the Spectroscopy will be stopped.

Limiter Source: Signal to trace during the measurement.

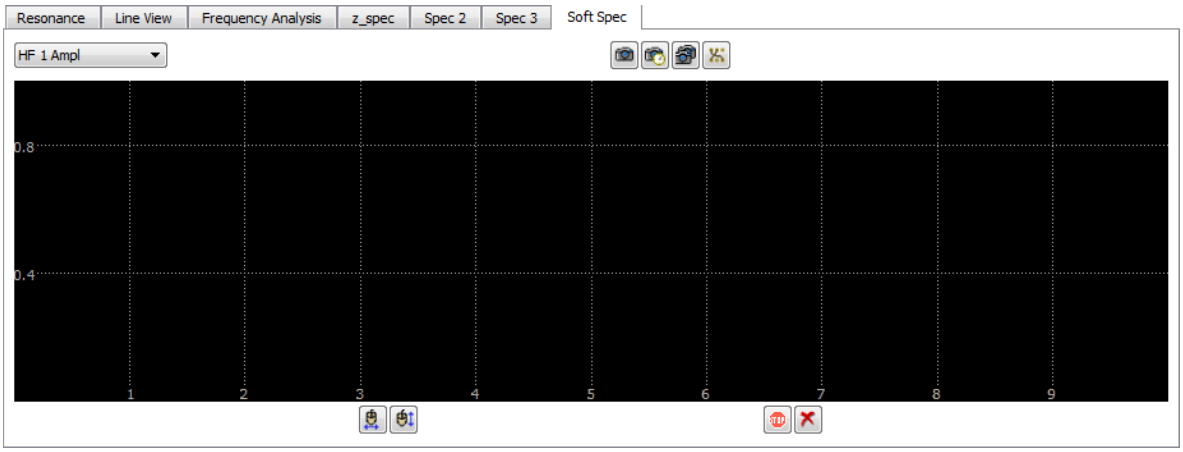
Limiter Value: Exact value for the limit criteria.

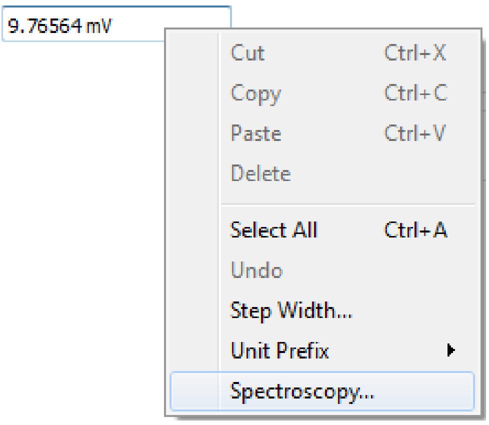
Limiter Sign: Stop when *Value* is exceeded or when the signal falls below *Value*.

The end of the sweep range is the trigger for both Save delayed at the end of the frame and backward sweep. Therefore when a limiter is used it is possible that the data won't be saved automatically, and the backward scan won't happen.

The graph generated can be manipulated and saved using general graph tools described in detail in section 5.4.2.

6.6.5 Soft Spec

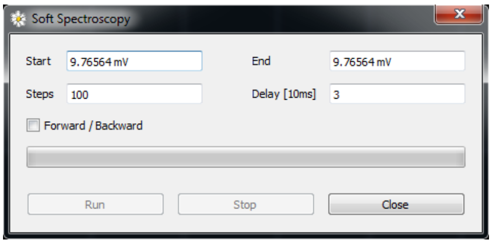




The Soft Spec can be used similarly to Spec 1-3. The displayed value can be selected in the top left corner of the tab.

Unlike for the other Spectroscopies you can use most any of the input fields as the sweep variable.

To set up the sweep, right klick on the desired input field (e.g. *Amplitude* in the *Excitation* tab) and choose Spectroscopy.



The *Soft Spectroscopy* setup window opens up. Here you can set the *Start* and *End* values of the sweep. Also you can choose a number of *Steps* and the *Delay* between each points.

Run starts the measurement and outputs the data in the *Soft Spec* tab.

6.7 Working Examples

6.7.1 Setting up the PLL

A completely digital Phase Locked Loop (PLL) is integrated in the ASC500. With the PLL, an advanced operation mode is provided to control high Q oscillators (like tuning forks at low temperatures). The PLL mode is an alternative to standard non-contact mode operation. During the standard operation the oscillator (tuning fork or cantilever) is driven at a fixed frequency and the change in oscillation amplitude is used to drive the z controller and to gain topographic information. This mode will be called amplitude modulation mode in the following sections, in contrast to frequency modulation or PLL mode.

In a typical non-contact AFM measurement, the oscillating tip is brought into the force field of the sample surface. Figure 15 shows the response of the oscillation properties of the tip on the force gradient originating from the sample. PLL and amplitude modulation mode differ in the way the controller reacts to such changes in oscillation properties. In amplitude modulation mode, the tip is constantly excited with the frequency f0, i.e. the resonance frequency of the freely oscillating lever.

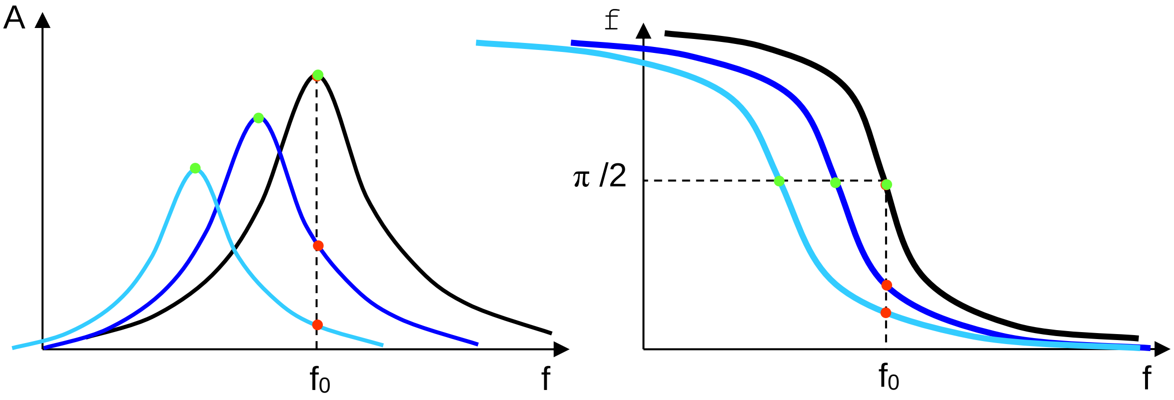


***Figure 15:** Amplitude and phase response of a driven oscillator in presence of a force gradient (black curve shows response at no gradient, dark blue and light blue curves at increasing force gradient). f_0 denotes the resonance frequency of the oscillator without an applied force gradient. With increasing force, the amplitude maximum is damped and shifts to lower frequencies. The phase response also shifts to lower frequencies and the maximum slope of the curve decreases. The working points in amplitude modulation mode (red dots) and in PLL mode (green dots) are displayed in the curves. The PLL mode traces the resonance frequency of the oscillating lever.*

Figure 15 demonstrates the different behavior of both modes. The measured oscillation amplitude follows the red dots. The measurement does not reflect the real amplitude damping due to sample forces; the amplitude drops due to the shape of the amplitude response curve. In PLL mode, the excitation always follows the amplitude maximum (i.e. the resonance frequency shown by the green dots), giving more valuable physical information. The question is how it can be achieved that the excitation always follows the resonance?

At the resonance frequency, the phase shift between input and output signal is always $\pi/2$. This fact is used in PLL mode to control the excitation frequency. An extra proportional integral control loop is operated to keep the excitation on resonance. The input value for this loop is the phase between excitation and oscillation signal as it is calculated by the internal lock-in amplifier, the output value is the excitation frequency or simpler the shift in excitation frequency Δf. This control loop is called phase loop. The frequency shift Δf is directly proportional to the force gradient that affects the lever oscillation. *Figure 16* shows a schematic of the frequency-modulated AFM operation mode that relies on the PLL. The output of the phase loop is used as an input for the z controller, keeping the frequency shift and thus the force on the tip constant.

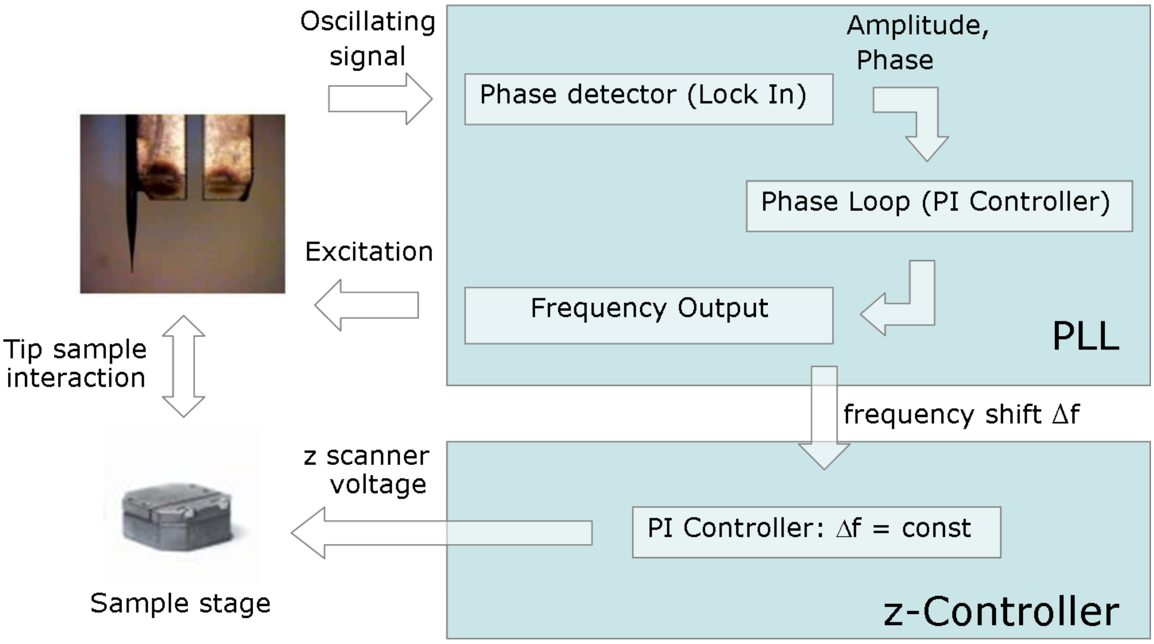


Figure 16: *Schematic of the PLL operation mode.*

The PLL mode is an advanced mode to operate, in the sense that two PI loops have to be operated at the same time. Potential instabilities in one loop will directly affect the other loop. The advantages are twofold:

1. The measured signal Δf will give a direct measure on the force gradient acting on the tip.
2. The PLL allows higher scan speeds for high Q levers.

PLL controller P and I units

The physical units of the P and I parameters of the feedback controllers can be found here:

Amplitdue Control

Input signal	**P unit**	**I unit**
HF 1 Ampl	V/V	V/V/s

Frequency Control

Input Signal	**P unit**	**I Unit**
HF 1 Phase	kHz/deg	kHz/deg/s
ADC1 .. 6	kHz/V	kHz/V/s

Operation of the PLL

Preparations

Before employing the PLL, all relevant connections have to be made. In particular, the signal from the oscillating lever has to be connected to the HF IN 1 input and the dither signal has to be connected to HF OUT 1. With these connections, the lever signal will be addressed via *HF 1* within the Daisy software, and the demodulated lock-in signal will be *HF 1 Ampl* and *HF 1 Phase*.

While the PLL is running, a number of signals are interesting to observe:

- *HF 1 Phase*: the phase between lever excitation and lever oscillation. This is the input signal for the phase loop.
- *HF 1 Ampl*: the amplitude of the lever oscillation. In PLL mode this is a measure of the oscillation damping due to sample forces.
- *df*: the frequency shift relative to the free resonance frequency of the lever. This is the output signal of the phase loop and at the same time the input value of the Z Controller
- *Z out inv*: this is the output value of the Z Controller that gives the topographic information.

Find the resonance of the cantilever using the *Resonance* feature (section Resonance View6.6.1) of the ASC500. Choose an appropriate excitation amplitude in the *Lock In* tab and set the *Integration Time* of the lock in to a reasonable value (500 µs .. 2 ms). After starting the *Resonance*, set the excitation frequency to match the resonance frequency and set the offset phase (under *Lock In, High Frequency, Demodulation, Phase Shift*) so that the *HF LI 1 Phase* at the resonance frequency is 0. The result should look similar to *Figure 17*.

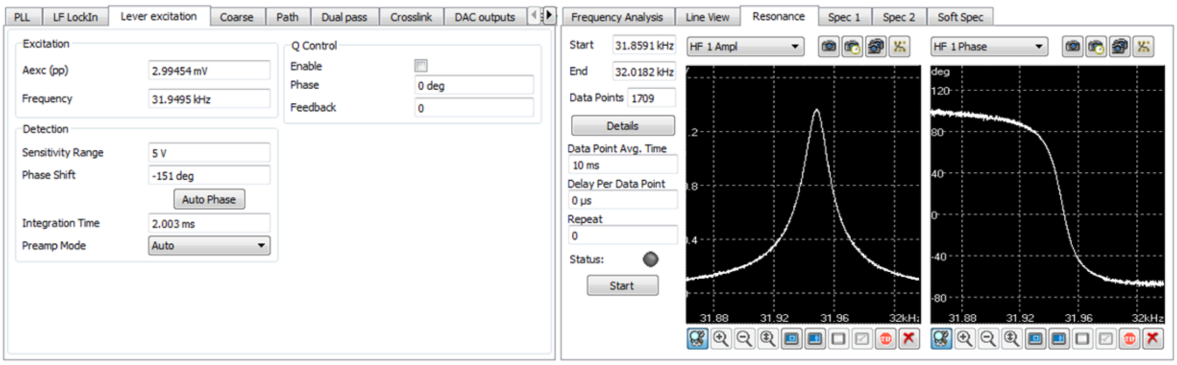


Figure 17: *Recording amplitude and phase response of the lever using the Resonance tool. This picture is from v26 daisy software.*

Phase Loop settings

The phase loop settings can be found in the *PLL* tab under *Frequency Control*. Before you turn on the loop, the following settings have to be made:

- Limit the range of the output frequency to gain higher frequency resolution. A range of 1 to 2 kHz around the resonance is recommended. Insert the appropriate values to the *Min* and *Max* fields.

- Choose the proportional and integral parameters for the loop. Start with small values (P = 10 µ and I = 1 mHz). The *P/I const* button always keeps the ratio of P and I constant when one parameter is changed.
- The input signal for the phase loop can be selected in the *Actual Value* list. Mostly, this will be set to *HF 1 Phase*, so that the internal lock in is delivering the phase signal. In case an external lock in amplifier is used for the phase detection, connect it to one of the ADC inputs and choose the respective ADC in the *Actual Value* list.
- If the phase offset was correctly compensated (see Preparations), the *Setpoint* value is 0 deg. Check the *Inv. Polarity* button as the phase response has a negative slope.

The phase loop can now be started by checking the *Loop* button. The green LED will be turned on and the value in the *df* field will by constantly updated to show the current value of the frequency shift. The *Frequency Control* unit should look similar to *Figure 18*.

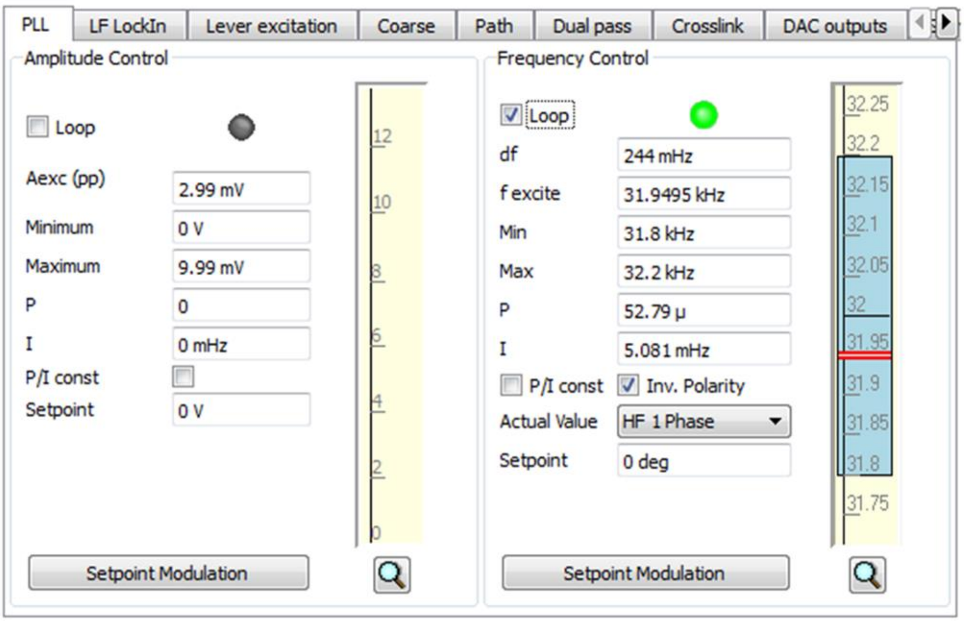
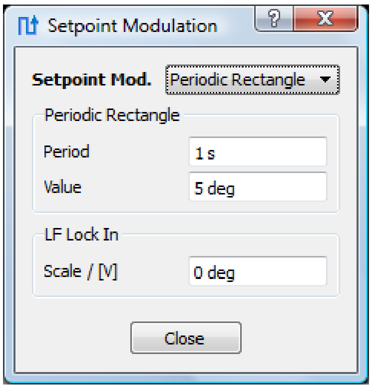


***Figure 18**: Phase loop settings.*



Before the z controller is started, it is important to improve the P and I settings of the phase loop. Open the *Setpoint Modulation* window and choose *HF 1 Phase* and *df* to be shown in the two *Line Views*. The Setpoint modulation will periodically change the phase loop setpoint between two values, simulating the loop response to a step function input. Choose a *Period* of 1 s and an alternate setpoint *Value* of 5 deg. Start the setpoint modulation by checking the button. Change the phase loop P and I parameters until the *df* line view shows a stable step function with only a light overshoot as shown in *Figure 19*. Now that the phase loop is stable and optimized, the setpoint modulation has to be stopped.

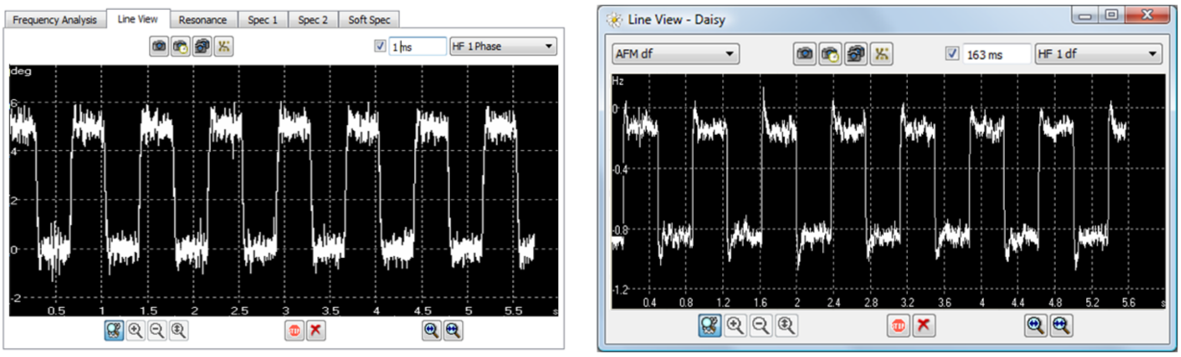


Figure 19: *Using the Setpoint Modulation to optimize the phase loop parameters.*

Z controller settings

Now the z controller can be employed. Choose *df* as the *Actual Value* for the z controller. The polarity of the z controller depends on the application: for application with increasing frequency shift with increasing force on the tip (mostly tuning forks) the z controller setpoint should be positive and the *Inv. Polarity* button in the z controller should be left unchecked. If the frequency shift decreases with increasing force on the tip, the setpoint should be chosen negative and the *Inv. Polarity* has to be checked. If the tip is within z scanner reach of the sample, turn on the z feedback using slow P and I parameters (if the tip is further away, employ the Autoapproach). Start the scan with a low scan speed (≤ 1 µm/s) and tune the z controller P and I parameter until a stable and fast feedback is reached.

Figure 20 shows a measurement in PLL mode of a Si test grating done in Daisy V2 (outdated version).

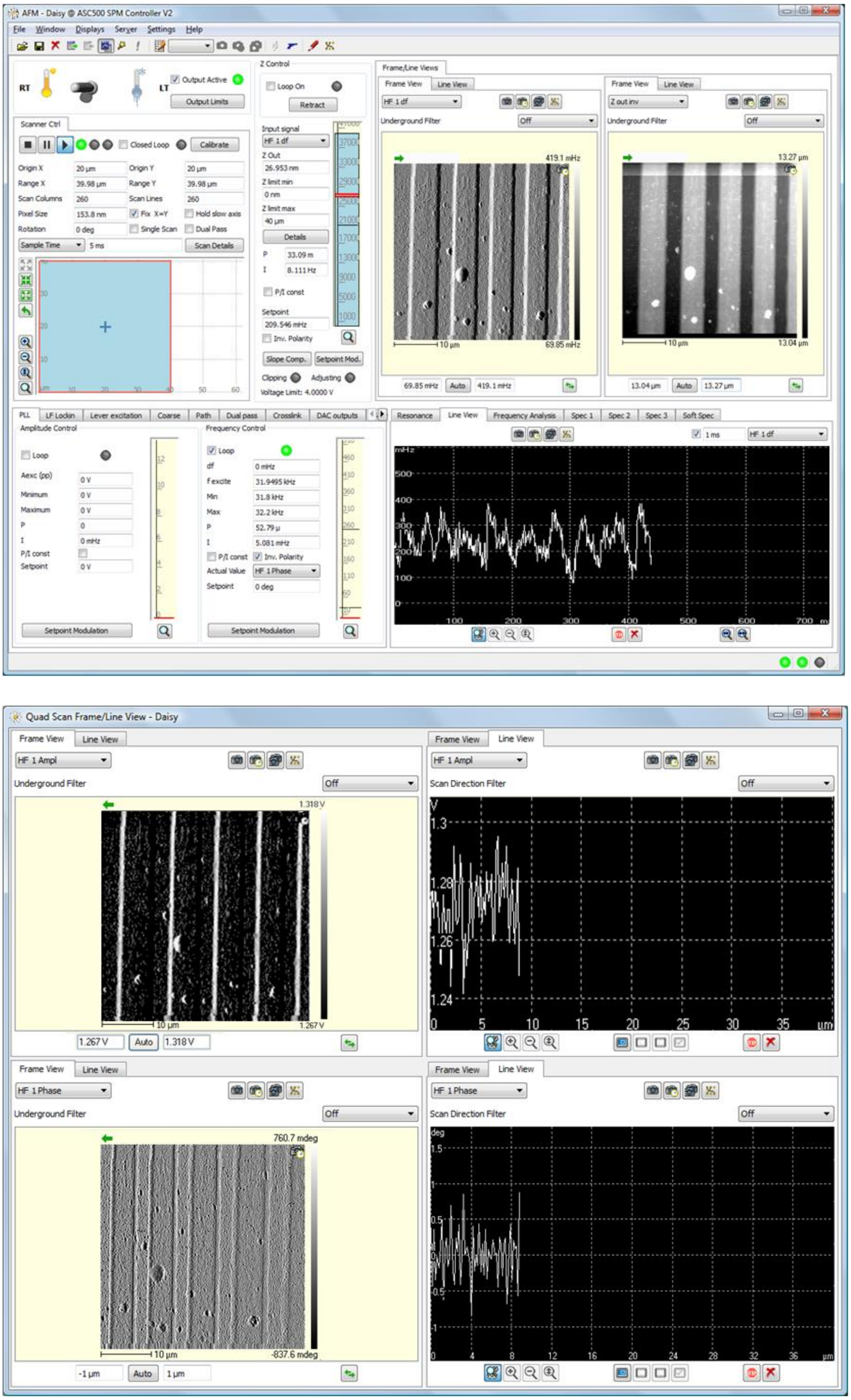


Figure 20: *Screenshot of PLL operation. The measurement was taken with an outdated daisy version.*

6.7.2 Using the Q-control feature

Any oscillating system showing resonance behavior can be described by a Q factor. The Q factor is a measure of the dissipative forces acting on the oscillating system.

In non-contact mode AFM, the Q factor is a function of the internal damping of the lever (cantilever or tuning fork) and the lever environment (fluid, ambient, high vacuum, and UHV). The Q factor is a very important parameter for non-contact AFM, because it determines or constrains important measurement parameters such as sensitivity and scan speed.

Given a certain measurement environment and a certain lever, the Q factor can be easily measured but it cannot be altered in standard SPM applications. The ASC500 Q Control feature enables changing the Q factor and thus gives access to the control of important measurement parameters.

The Q control can be especially helpful in two situations:

1. Non-contact measurements in a low temperature and/or UHV environment. Q factors in these environments can get very high (up to 10^5-10^6), resulting in very small damping of the oscillation amplitude and thus to very large time constants for changes in the oscillation amplitude (order of tens of seconds). In amplitude modulation mode, the z feedback control will work directly on this very slowly changing oscillation signal, thus reducing the scan speed significantly. Q reduction is a very effective way to overcome these speed limits.
2. Measurements in a liquid environment typically show very low Q factors (< 100). Increasing the Q factor may give reasonable sensitivity for these measurements.

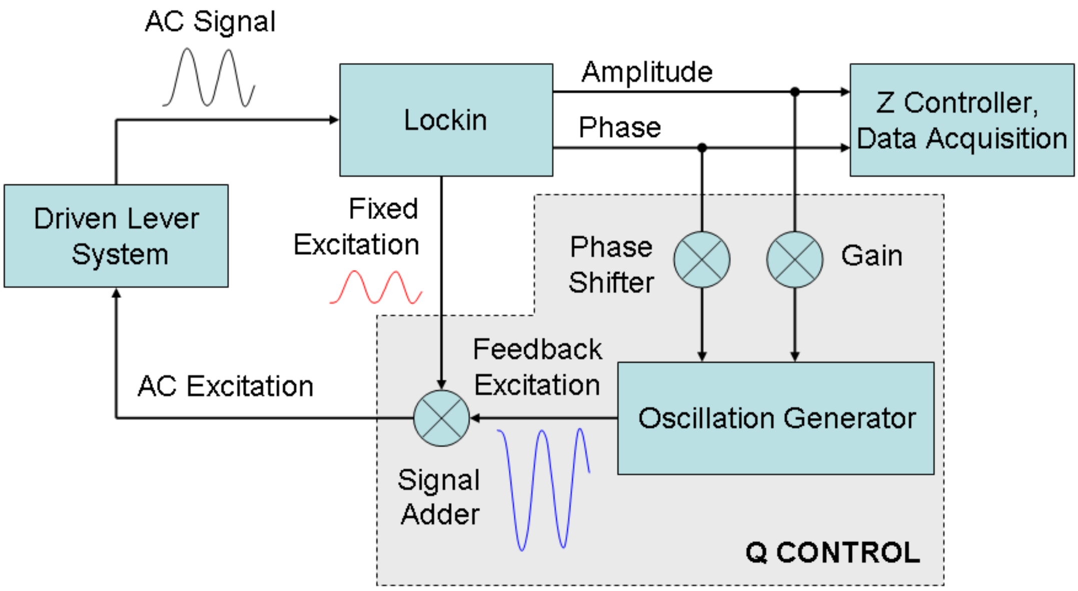
6.7.2.1 Schematics

To gain access of the control over the Q factor, a sophisticated oscillation scheme is necessary. The excitation signal for the lever is composed in the *Signal Adder* from two parts:

The first part is the fixed AC signal at the resonance frequency of the lever, coming from the Lock-In amplifier.

The second part is the signal that is deduced from the oscillation signal of the lever: The output of the lever is demodulated by the internal Lock-In detector to obtain its amplitude and phase (relative to the fixed excitation signal). These signals are routed into a phase shifter and an amplitude gain and a new oscillating signal is synthesized in the *Oscillation Generator*, called *Feedback Excitation*.

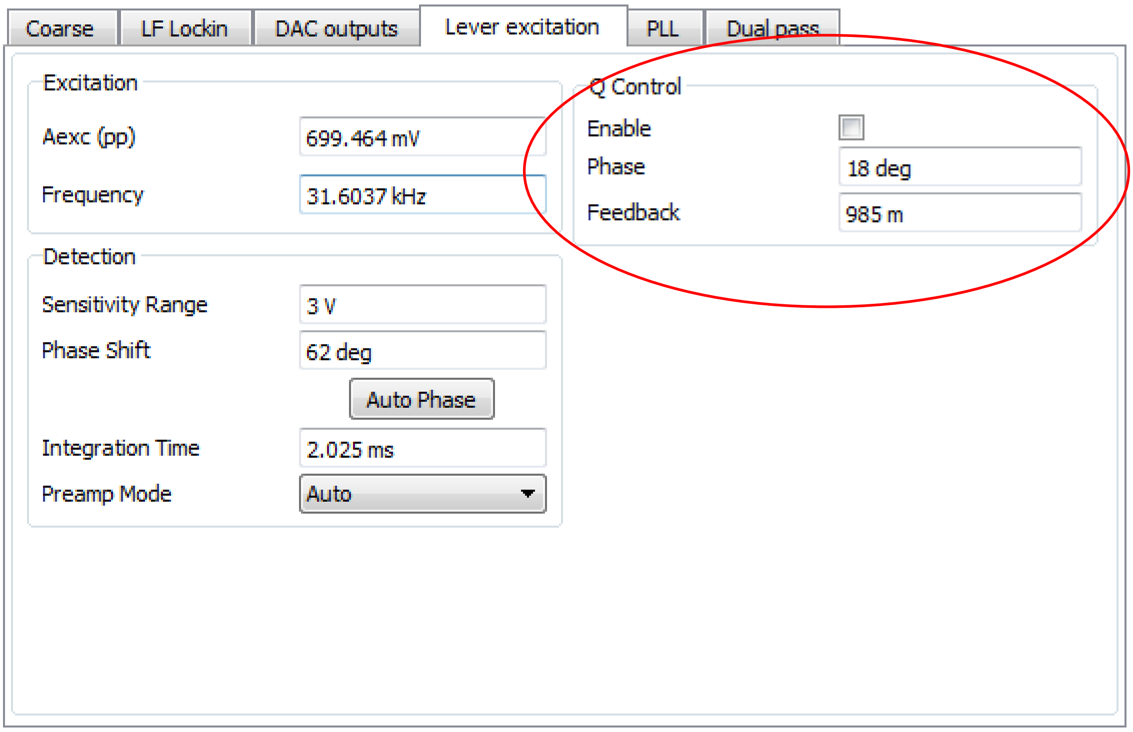
One can show mathematically that feedback signals with a phase shift of +/- π/2 enhance or reduce the effective damping in the system. The lever will behave exactly as if it was built in a different way or if the environment has changed. Below, one can see the schematics of the Q control excitation.



The Q factor can be measured with the *Resonance* feature (see section 6.6.1 on page 95). Find the FWHM (full width half maximum) Δf from the amplitude vs. frequency plot to the left. The Q factor is then calculated using the relationship:

$$Q = f_{res}/\Delta f$$

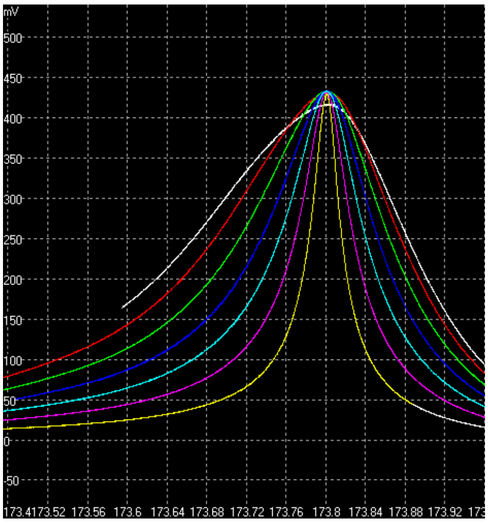
The *Q Control* controls can be found in the *Lock In* tab. There are only two parameters and one *Enable* button. You can set the phase shift between the cantilever oscillation and the feedback excitation signal and the gain of the feedback signal.

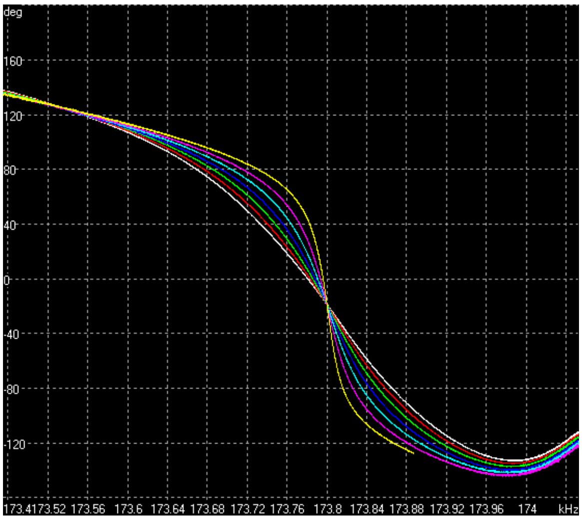


Enable: Turns the Q control on or off. Please note that turning the Q control on or off may change the oscillation amplitude of the lever significantly. Although this will not damage the tip, you may want to use the excitation amplitude field *Aexc (pp)* to reduce the excitation before checking or unchecking the *Enable* button.

Phase: Sets the phase shift between the lever oscillation and the feedback excitation signal. Although in theory this should be either +90 deg or -90 deg, there are always additional phase shifts due to electronic components in the signal path and due to the (short but non-zero) time it takes for the ASC500 to demodulate the signal. The best way to find the right value is to change the *Phase* systematically while repeatedly doing the *Resonance* (set the *Curves* value of both Resonance views to 10 or larger to have several frequency sweeps displayed in one graph). For values differing from +/-90 deg phase, the resonance frequency is shifted in frequency. By going stepwise through the -180 deg .. +180 deg Phase range, one should see the maximum of the amplitude resonance curve moving around in a circle. Note the values for minimum resonance peak if you want to reduce the Q factor or either note the *Phase* value of the maximum if you want to enhance the Q factor. If you don't see any changes, increase the *Feedback* value.

Feedback: This sets the gain of the feedback excitation signal. The range of this value is 0 to 1. Please note that for values above 0.5, the effective value of the fixed excitation is reduced to strengthen the feedback excitation part. One can easily increase the fixed excitation if only loosing signal amplitude and not seeing any impact on the Q control. For most applications, a value of larger than 0.85 will be necessary to effectively alter the Q factor.





The above examples show the Q reduction of a cantilever based AFM at 4 K. The Q factor could be reduced by approximately one order of magnitude (note that the original amplitude response is not shown).
Please note that due to the self-excitation nature of the Q control, the oscillating system can show rather strange behavior far off the resonance frequency of the lever. This does not have any consequences on the reproducible and stable behavior of the Q control near the resonance frequency.

7 Firmware Upgrade

At some point a new version of the “daisy.exe” might be available for the ASC500. As there is no permanent firmware inside the ASC500, all one has to do is to boot the controller with the new software. This uploads the new hardware program onto the controller.
So, all that needs to be done is to install the software as written in section 5.1.

8 Preventive Maintenance

Warning. The equipment contains no user serviceable parts. There is a risk of severe electrical shock if the equipment is operated with the covers removed. Only personnel authorized by attocube systems and trained in the maintenance of this equipment should remove its covers or attempt any repairs or adjustments. Maintenance is limited to safety testing and cleaning as described in the following sections.

8.1 Safety Testing

Safety testing in accordance with local regulations, should be performed on a regular basis, (typically annually for an instrument in daily use).

Caution. The instrument contains a power supply filter. Insulation testing of the power supply connector should be performed using a DC voltage.

8.2 Fuses

Two T 4 A/250 V fuses are located on the back panel.

Note. When replacing fuses:

Switch off the power and disconnect the power cord before removing the fuse cover.

Always replace broken fuses with a fuse of the same rating and type.

8.3 Cleaning

Warnings:

Disconnect the power supply before cleaning the unit.

Never allow water to get inside the case.

Do not use any type of abrasive pad, scouring powder, or solvent, e.g. alcohol or benzene.

The front panel may be cleaned with a soft cloth, lightly dampened with water or a mild detergent.

Note. Any time you call for technical support, the software version and the serial number are essential to trouble-shoot a problem. The serial number is shown on the backside of the ASC500. the software version can be queried in the “Help -> About” menu.

attocube systems AG
Eglfinger Weg 2
D-85540 Haar
Germany

Phone +49 89 420 797 0
Fax +49 89 420 797 201 90

E-Mail: info@attocube.com
www.attocube.com