NanoScope V

Controller Manual

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004-992-100 (cleanroom)

Document Revision History: NanoScope V Manual

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A	05/19/2006	Initial Release.	N/A	Vinson Kelley

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Product Names:
NanoScope®
MultiMode™
Dimension™
BioScope™
Atomic Force Profiler™ (AFP™)
Dektak®

Software Modes:
TappingMode™
Tapping™
TappingMode+™
LiftMode™
AutoTune™
TurboScan™
Fast HSG™
PhaseImaging™
DekMap 2™
HyperScan™
StepFinder™
SoftScan™

Hardware Designs:
TrakScan™
StiffStage™

Hardware Options:
TipX®
Signal Access Module™ and SAM™
Extender™
TipView™
Interleave™
LookAhead™
Quadrex™

Software Options:
NanoScript™
Navigator™
FeatureFind™

Miscellaneous:
NanoProbe®

NanoScope V Controller Manual

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Chapter 1 Overview

1.1 Introduction

This manual details use of the NanoScope V Scanning Probe Microscope (SPM) Controller.

Figure 1.1a A Dimension V SPM System with NanoScope V Controller

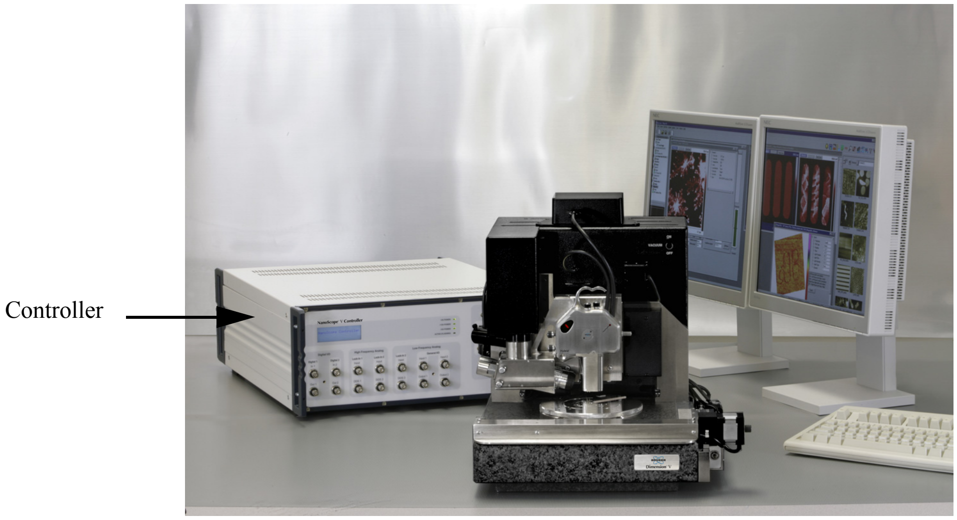

Figure 1.1b A BioScope II SPM System with NanoScope V Controller

The NanoScope V functions with many advanced Bruker SPMs, including the MultiMode, MultiMode V, BioScope II, BioScope SZ, Dimension V, Dimension 5000 and EnviroScope atomic force microscopes (AFMs). The NanoScope V Controller is not compatible with the Dimension Metrology Head.

The NanoScope V Controller retains features of previous NanoScope Controllers and provides new input/output options, increased data resolution (5k x 5k points), new high-speed data capture, up to eight simultaneous data channels and multiple lock-in amplifiers with independent reference frequencies.

Most existing NanoScope SPM systems benefit from existing controller trade-in for a NanoScope V Controller, but may require upgrades to support NanoScope V operation.

1.2 Scope of This Manual

This manual introduces the new features provided by the NanoScope V Controller.

Note: This manual is *not* a comprehensive guide to all operations of all SPM systems.

For specifics of your SPM, refer to its accompanying *Instruction Manual*. For coverage of all software commands and details of the various modes of operation (Real-time, Offline, Image, Scope, Force, etc.), refer to the *Command Reference Manual*. Similarly, add-on modules, sensors, and even areas of investigation (such as electrochemistry) are introduced in Support Notes and Application Notes. The *Scanning Probe Microscopy Training Notebook* is a compact introduction for getting started on MultiMode and Dimension SPMs.

For detail regarding access to intermediate signals from the controller when using MultiMode or EnviroScope microscopes, refer to *Support Note 210C, NanoScope Signal Access Module (SAM)—Description & Use* and *Support Note 332, SAMIII.*

As new SPM hardware capabilities are developed for the NanoScope V Controller and as NanoScope software evolves, this manual will also be updated. Contact Bruker to determine the most recent document revision.

1.3 Conventions and Definitions

- In the interest of clarity, certain nomenclature is preferred. An SPM *probe* is comprised of a *tip* affixed to a *cantilever* mounted on a *substrate*, which is inserted in a *probe holder*.
- Three font styles distinguish among contexts. For example:
  Window or Menu Item / **BUTTON OR PARAMETER NAME** is set to **VALUE**.
- NSIII(a) is used to refer to either a NanoScope III or NanoScope IIIa. NSIV(a) is used to refer to either a NanoScope IV or NanoScope IVa. NSV is used to refer to a NanoScope V.
- For brevity, a Dimension 3000 SPM is referred to as a *D3000,* a Dimension 3100 SPM is referred to as a *D3100* and a Dimension 5000 is referred to as a *D5000*.
- *Native* SPMs are TappingMode-capable, phase-equipped SPMs that can take advantage of the new NanoScope V features. Native SPMs plug into the two connectors labeled **MICROSCOPE** (High Voltage/Digital and Low Voltage Analog) on the front of the controller. Native SPMs are Dimension V, 3100, 5000, BioScope SZ and BioScope II models.
- Adapted SPMs are connected to the controller by one cable through a 37 pin Adapter on the front of the NanoScope V. Adapted SPMs are MultiMode and EnviroScope models.
- An *Application Module-ready SPM* implies that the SPM has all the required modifications to the SPM head and electronics to directly support optional Application Modules except the Generation I and II Scanning Capacitance Microscopy (SCM) Application Modules. An Application Module-ready SPM may also be referred to as *equipped* for Application Modules or *capable of supporting* optional Application Modules. A Generation III SCM Application Module is required for operation with a NanoScope V Controller, whether purchased with the controller or as a later upgrade. See Chapter 5 for additional information.

Chapter 2 Safety Precautions

This chapter highlights cautions to observe using the NanoScope V Controller.

Table 2.0a Safety Symbols Key

Symbol	Definition
	This symbol identifies conditions or practices that could result in damage to the equipment or other property, and in extreme cases, possible personal injury.
	Ce symbole indique des conditions d'emploi ou des actions pouvant endommager les équipments ou accessoires, et qui, dans les cas extrêmes, peuvent conduire à des dommages corporels.
	Dieses Symbol beschreibt Zustaende oder Handlungen die das Geraet oder andere Gegenstaende beschaedigen koennen und in Extremfaellen zu Verletzungen fuehren koennen.
	This symbol identifies conditions or practices that involve potential electric shock hazard.
	Ce symbole indique des conditions d'emploi ou des actions comportant un risque de choc électrique.
	Dieses Symbol beschreibt Zustaende oder Handlungen die einen elekrischen Schock verursachen koennen.
	This symbol identifies a laser hazard. Exposure could result in eye damage.
	Ce symbole indique un risque lié à un laser. Une exposition à ce laser peut entraîner des blessures aux yeux.
	Dieses Symbol bedeutet "Gefährliche Laserstrahlung." Laserstrahlung kann zu Beschädigung der Augen führen.
	This symbol identifies a mechanical crushing hazard. Moving parts can result in serious injury to hands or fingers.
	Ce symbole indique un risque d'écrasement. Déplacer des pièces de l'appareil peut entraîner des blessures sévères des mains ou des doigts.
	Dieses Zeichen bedeutet "Quetschungsgefahr durch mechanisch bewegte Teile." Bewegliche Teile können zu erheblichen Quetschverletzungen von Fingern oder Händen führen.

WARNING: Service and adjustments should be performed only by qualified personnel who are aware of the hazards involved.

AVERTISSEMENT: Tout entretien ou réparation doit être effectué par des personnes qualifiées et conscientes des dangers qui peuvent y être associés.

WARNUNG: Service- und Einstellarbeiten sollten nur von qualifizierten Personen, die sich der auftretenden Gefahren bewußt sind, durchgeführt werden.

WARNING: Follow company and government safety regulations. Keep unauthorized personnel out of the area when working on equipment.

AVERTISSEMENT: Il est impératif de suivre les prérogatives imposées tant au niveau gouvernemental qu’au niveau des entreprises. Les personnes non autorisées ne peuvent rester près du système lorsque celui-ci fonctionne.

WARNUNG: Befolgen Sie die gesetzlichen Sicherheitsbestimmungen Ihres Landes. Halten Sie nicht authorisierte Personen während des Betriebs vom Gerät fern.

DANGER: Voltages supplied to and within certain areas of the system are potentially dangerous and can cause injury to personnel. Power-down all components and unplug from power sources before doing **any** electrical servicing. (Bruker service personnel, *only*).

DANGER: Les tensions utilisées dans le système sont potentiellement dangeureuses et peuvent blesser les utilisateurs. Avant toute intervention électrique, ne pas oublier de débrancher le système. (Réservé au personnel de Bruker, seulement.)

GEFAHR: Die elektrischen Spannungen, die dem System zugeführt werden, sowie Spannungen im System selbst sind potentiell gefährlich und können zu Verletzungen von Personen führen. Bevor elektrische Servicearbeiten irgendwelcher Art durchgeführt werden ist das System auszuschalten und vom Netz zu trennen. (Nur Bruker Personal.)

DANGER: Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous laser light exposure. The use of optical instruments with this product will increase eye hazard.

DANGER: Toute utilisation, ou étalonnage ou essai de modification, autre que ci-dessous décrits, peut entraîner une exposition dangereuse à la lumière du laser. L’utilisation de systèmes optiques avec ce produit peut entraîner un danger pour les yeux.

GEFAHR: Die falsche Verwendung dieses Gerätes mit nicht in diesem Handbuch beschriebenen Vorgehensweisen kann gefährliche Laserstrahlung freisetzen. Optische Instrumente, die zusammen mit diesem Produkt verwendet werden, können evtl. Augenschäden hervorrufen und verstärken.

CAUTION: Cables should not be removed or installed while power is applied to the system.

Connecting cables while power is applied may damage the instrument.

Chapter 3 Set-Up and Installation

3.1 Unpacking

The NanoScope V Controller unit ships in a single crate. Additional computer and SPM system components are crated separately.

CAUTION: Do not store the equipment outside, even in a dry weather location

Provide the proper environmental conditions (see Table 3.1a) for system operation and storage.

Table 3.1a Environmental Requirements

Equipment Use	Condition	Requirement
Operation	Temperature	15ºC (59ºF) to 35ºC (95ºF)
″	Relative Humidity	45% to 80%, non-condensing
Storage	Temperature	10ºC (50ºF) to 50ºC (122ºF)
″	Relative Humidity	35% to 90%, non-condensing

Carefully unpack the controller from its crate.

CAUTION: Handle sensitive electronics with care. Avoid dropping or bumping the controller, especially once outside the shipping crate.

The unit measures 60cm (23.6 inches) long by 45cm (17.7″) wide by 19cm (7.5″) tall, including its four feet.

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CAUTION: The NanoScope V Controller weighs 18kg (40lbs) so requires two people to move safely.

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CAUTION: Each controller is shipped equipped for a customer-specified AC input voltage. Input power requirements are listed as a function of AC input voltage in a table on the back of the controller (and duplicated below in Table 3.1b). Verify appropriate fuses are installed for the power supplied. A fuse rating table appears on the back of the controller and is duplicated later (see Table 11.1a in **Maintenance,** page 141).

Table 3.1b AC Input Power Requirements

AC Input		
Voltage (VAC)	**Current (A)**	**Frequency (Hz)**
100	5.2	50 - 60
120	4.3	
240	2.2	

3.2 NanoScope V Controller Components

A NanoScope V Controller consists of a minimum of three components: the controller box, a computer with Digital Signal Processing/Interface (DSP) in the computer and a cable to connect the computer and controller. Controllers configured for Dimension microscopes include two cables to connect the controller to the microscope. Controllers configured for MultiMode V microscopes include one cable and a 37PA adapter to connect the controller to the microscope. Also required are two computer monitors which may be purchased with the controller or supplied separately (minimum resolution 1024 × 768, 60Hz refresh). As the associated computer and XP operating system are custom-fitted with a DSP board and version 7.00 or later of NanoScope software, the computer must be supplied by Bruker. At minimum, an NanoScope V-controlled system includes a compatible SPM, either supplied with the NanoScope V or an existing SPM capable of being upgraded to NanoScope V operation (see **Configuring an Existing SPM with a NanoScope V Controller,** page 25).

3.3 Assembly

3.3.1 Desktop Option

The NanoScope V Controller requires no mechanical assembly. Place it on a flat horizontal surface providing access to both the front face and back of the instrument (see Figure 1.1a).

CAUTION:	Do not obstruct either fan on the back of the NanoScope V Controller. A minimum of 3 inches (8cm) of clearance is required.
CAUTION:	Do not obstruct the ventilation slots on the top of the NanoScope V Controller.
CAUTION:	Do not place heavy objects on the aluminum top of the NanoScope V Controller.

3.4 Important: Powering Sequence

If the computer is turned off, the NanoScope V controller must also be unpowered.

CAUTION: Never supply power to the NanoScope V Controller unless the computer is already running

Power on sequence: 1) computer
2) NanoScope V Controller

Power off sequence: 1) NanoScope V Controller
2) computer

3.5 NanoScope V Front Panel

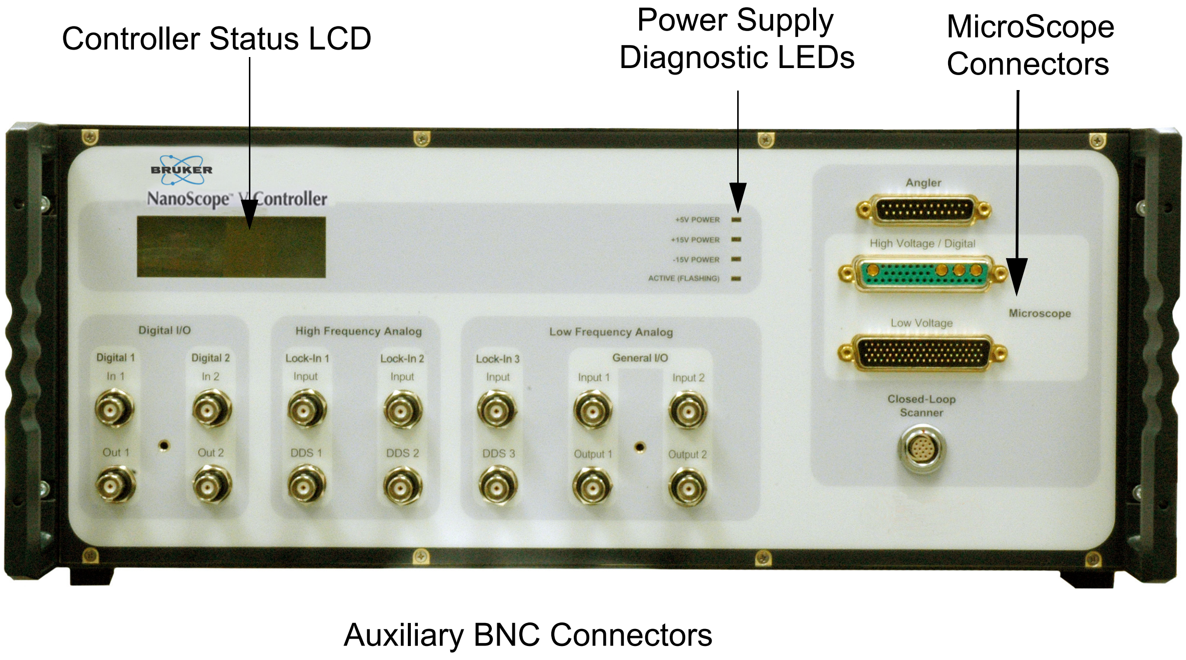
The NanoScope V Controller front panel, shown in Figure 3.5a, has the following items on the front panel:

- Controller status LCD.
- Power Supply LEDs (top 3) — indicates the power supply status. These are discussed in **System Initialization,** page 41.
- Diagnostic LED (“active/flashing”) — indicates the connection status of the LVDS cable between the computer and the NanoScope V Controller.
- Connection to the (optional) PicoAngler.
- Connections for Dimension XY or Dimension Hybrid XYZ Closed Loop heads.
- Digital I/O BNCs:
    - Inputs (In 1/2) — Pulse counter inputs.
    - Output 1 (Out 1) — End of Line: TTL pulse at the end of each scan line.
    - Output 2 (Out 2) — End of Frame: TTL pulse at the end of each scan frame.
- High Frequency Analog:
    - Lock-In 1/2 Inputs — Analog inputs for two high frequency lock-ins accessible via NanoScope software. The sample rate is 50MHz giving an effective bandwidth of 1kHz to 5MHz.
    - DDS 1/2 Outputs — Analog output of the reference signals for two high frequency lock-ins accessible via NanoScope software (1kHz - 5MHz).
- Low Frequency Analog
    - Lock-In 3 Input — Analog input for a low frequency lock-in accessible via NanoScope software. The sample rate is 500kHz giving an effective bandwidth of 5Hz to 50kHz. If this lock-in is not used, the BNC connector is available as a third General I/O Input (see below).
    - DDS 3 Output — Analog output of the reference signal for the low frequency lock-in accessible via NanoScope software.
    - General I/O Inputs 1/2 — Analog inputs that can be read as data channels in the NanoScope software. Continuous data collection is done at a sample rate of 100kHz. “Burst” capture (data collection for a limited duration of time) can be done at a sample rate of 500 kHz via the High Speed Data Capture function in the NanoScope software.

- General I/O Outputs 1/2 — Analog outputs that can be used to monitor various signals within the controller selectable via Nanoscope software. The update rate is 100kHz (40kHz in ramp mode).

Note: An adapter (see Figure 4.3a) is required to connect the NanoScope V controller to MultiMode and EnviroScope SPMs.

Figure 3.5a NanoScope V Front Panel



The MicroScope Connectors on the right of the NanoScope V Controller front panel are detailed in **Connect the NanoScope V Controller to a New Native SPM,** page 15.

CAUTION: Cables should not be removed or installed while power is applied to the system.

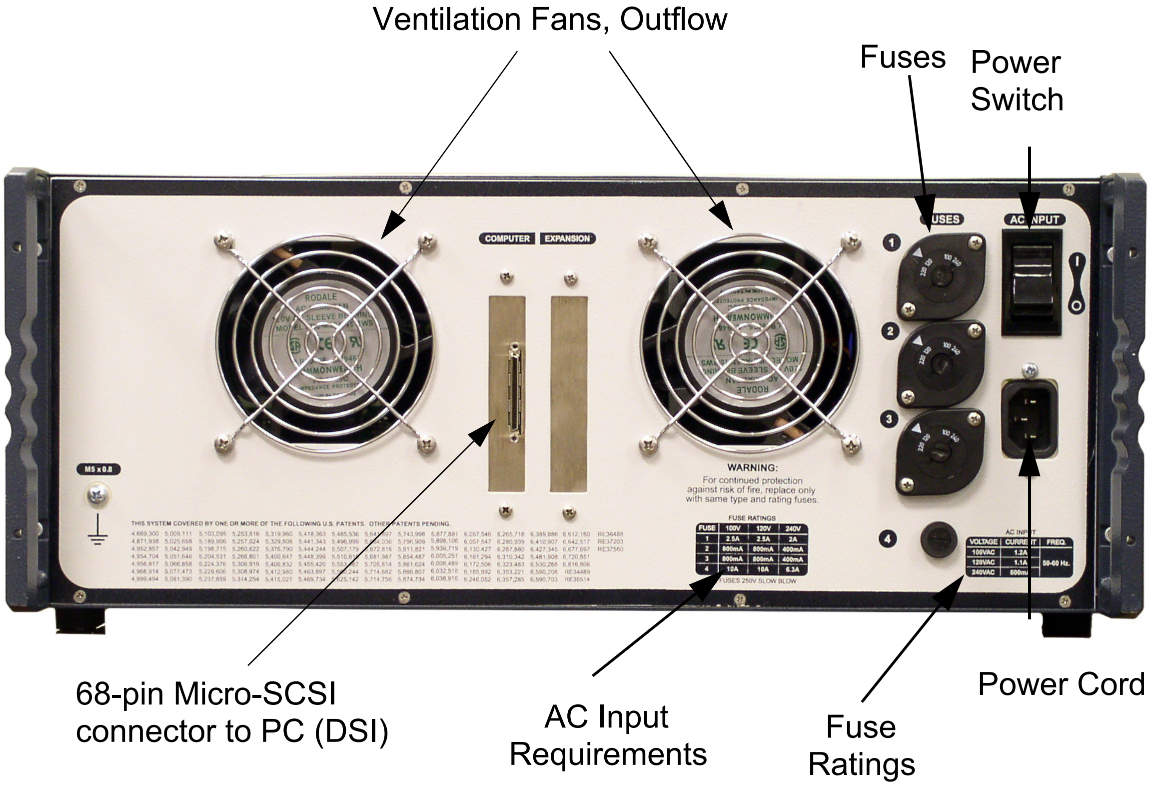
Connecting cables while power is applied may damage the instrument.

3.6 NanoScope V Back Panel

The NanoScope V Controller back panel (see Figure 3.6a) includes, on the right, the controller power switch and external power source connection with a table of AC power requirements (see **Unpacking,** page 9), as well as four fuses and a fuse specification table (see **Fuses,** page 141). In the center of the back panel is a 68-pin Micro-SCSI connector that connects the controller to the computer.

Verify that the power disconnect device is readily accessible.

Figure 3.6a NanoScope V Back Panel



Chapter 4 Configuring a New SPM with a NanoScope V Controller

This chapter concerns configuring a new SPM purchased with the NanoScope V Controller. For a NanoScope V Controller purchased for use with an existing SPM, see **Configuring an Existing SPM with a NanoScope V Controller,** page 25. In either case you must make all system cable connections before powering the controller.

4.1 Definitions: Native and Adapted SPMs

With respect to connecting a NanoScope V Controller, there are *Native* and *Adapted* SPMs.

Native SPMs are two-cable TappingMode-capable, phase-equipped SPMs. Native SPMs plug into the two connectors labeled **MICROSCOPE** (High Voltage/Digital and Low Voltage Analog) on the front of the controller. The Native SPMs are Dimension V, updated (to Dimension V) D3100 models, BioScope SZ, D5000 and BioScope II models.

Adapted SPMs are connected to the controller by one cable through a 37 pin Adapter on the front of the NanoScope V Controller. Adapted SPMs are MultiMode and EnviroScope models.

Older SPMs that can not be phase-equipped, such as AFM, LFM and ECM can not be operated by the NanoScope V Controller.

4.2 Connect the NanoScope V Controller to a New Native SPM

Connections to the microscope are made through connectors on the front of the NanoScope V Controller. See Table 4.2a for descriptions of the main front panel connectors.

Plug the cables from your new Dimension SPM or BioScope II E-box into the NanoScope V Controller through the connectors labelled **MICROSCOPE** (**High Voltage/Digital** and **Low Voltage Analog**) at the right front of the controller (see Figure 4.2a).

If you have a Closed Loop head (XY or XYZ), connect its preamp to the **Closed Loop Scanner** connector at the right front of the controller (see Figure 4.2a).

If you have a PicoAngler, connect it to the **Angler** connector at the right front of the controller (see Figure 4.2a).

Identify your SPM in Table 4.2b then see the associated figure for a cabling overview.

Table 4.2a NanoScope V Controller, Main Connections

Connector Label	Connector Type	Purpose
High Voltage/Digital	36-pin combo D-sub, female	Piezo drive/digital control between controller and SPM
Low Voltage	78-pin DB, male	Differential low voltage analog/digital (LVDS) signals between controller and SPM
Angler	25-pin DB, female	Communicates with PicoAngler
To Computer (back panel)	68-pin micro-SCSI, female	data/control between controller and computer
Closed Loop Scanner	14-pin Lemo, female	input/output to the XYZ Closed Loop Scanner Head or Closed loop BioScope II head and XY scan stage
Digital I/O	BNC, female	TTL compatible synchronization signals (i.e. EOL and EOF)
High Frequency/ Analog	BNC, female	Used as either a lock-in input or for HSDC. Sample rate is 50 MS/s.
Low Frequency Analog	BNC, female	Used for external measurement. Can bring up as a data type in NanoScope software.

Figure 4.2a MicroScope Connectors on the Front of the NanoScope V Controller

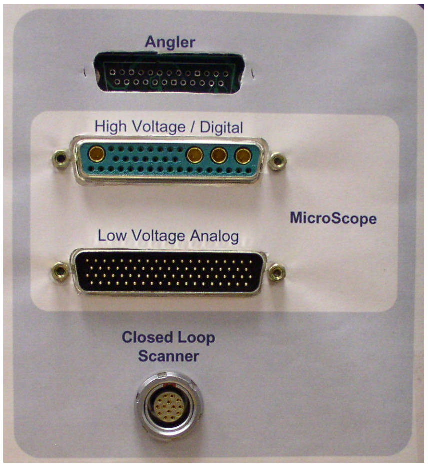
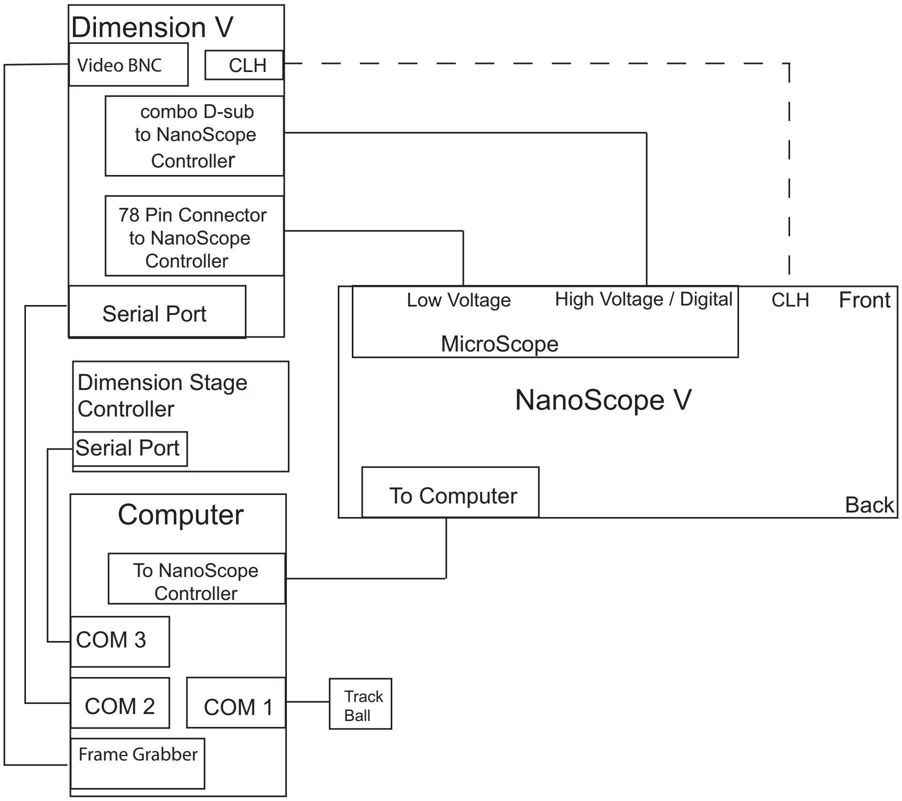


Table 4.2b Index to Cabling Diagrams by SPM

SPM	Type	Cabling Diagram
Dimension V	Native	Figure 4.2b, page 18
MultiMode V	Adapted	Figure 4.3c, page 23
BioScope II	Native	Figure 4.2d, page 20
BioScope SZ	Native	Figure 4.2e, page 21
EnviroScope	Adapted	Figure 4.3d, page 24
Dimension 5000	Adapted	Figure 4.2c, page 19

4.2.1 Dimension V: Computer to Controller Cable Connections

Figure 4.2b Cabling Configuration: **Dimension V**

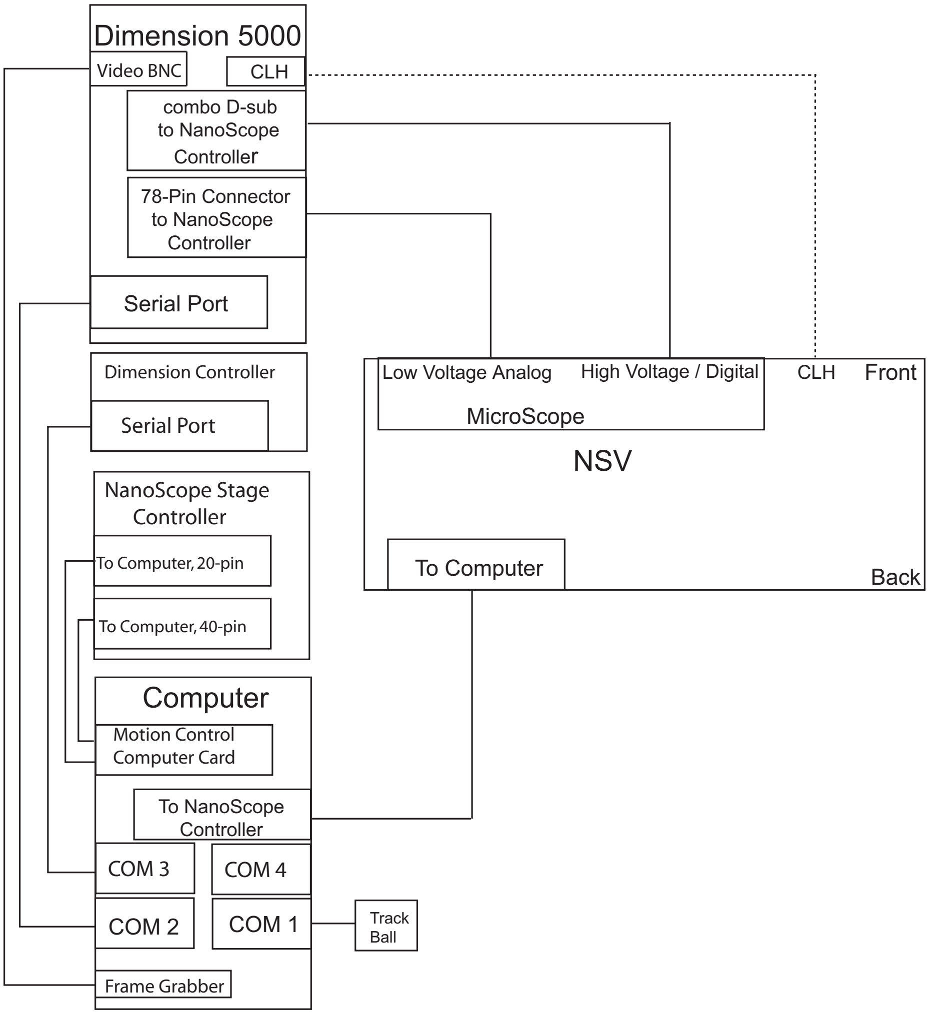


See also the Dimension V Instruction Manual for cabling.

- Connect the Low Voltage and High Voltage/Digital cables between the NanoScope V Controller and the back panel of the Dimension V.
- Plug the DSI cable from your computer into the NanoScope V Controller connector labelled **To Computer**.
- Basic installation for the Native SPM is now complete. Proceed to **Factory Software Configuration of a New SPM,** page 25, then to **Operating Procedures,** page 35.

4.2.2 D5000: Computer to Controller Cable Connections

Figure 4.2c Cabling Configuration: **D5000**



- Connect the Low Voltage and High Voltage/Digital cables between the NanoScope V Controller and the back panel of the Dimension 5000.

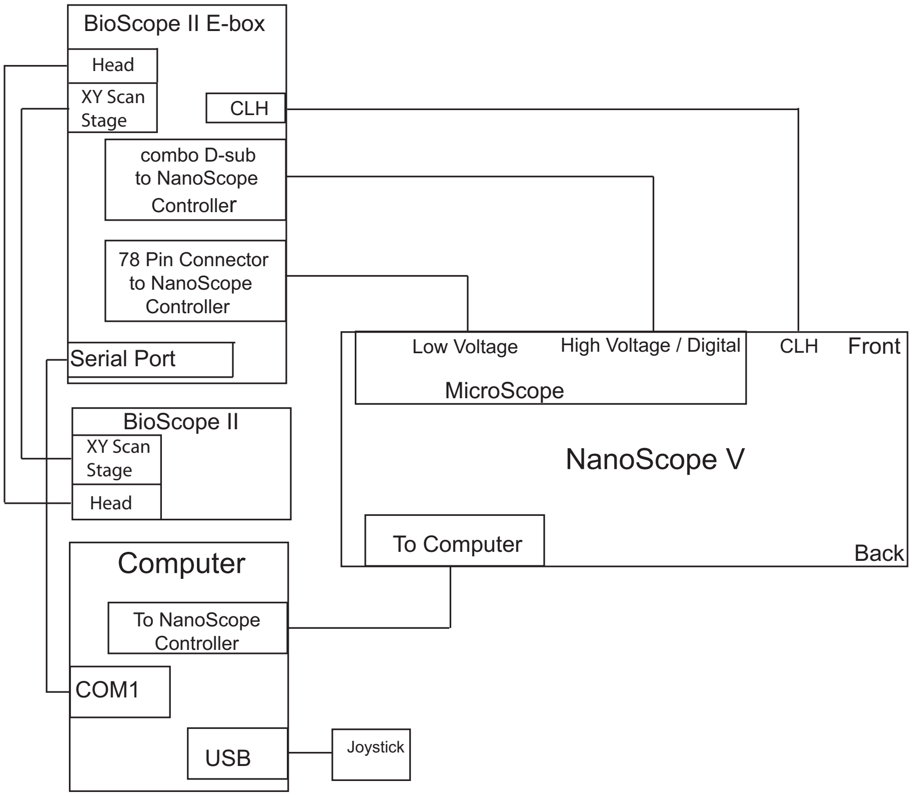
- Connect the output cable from the Closed Loop Head preamplifier and the Closed Loop Scanner input on the front of the NSV.

- Plug the DSI cable from your computer into the NSV Controller connector labelled **To Computer**.

- Basic installation for the D5000 SPM is now complete. Proceed to **Factory Software Configuration of a New SPM,** page 25, then to **Operating Principles,** page 41, **Operating Procedures,** page 35 and **New NanoScope V Parameters,** page 119.

4.2.3 BioScope II: Computer to Controller Cable Connections

Figure 4.2d Cabling Configuration: New **BioScope II**

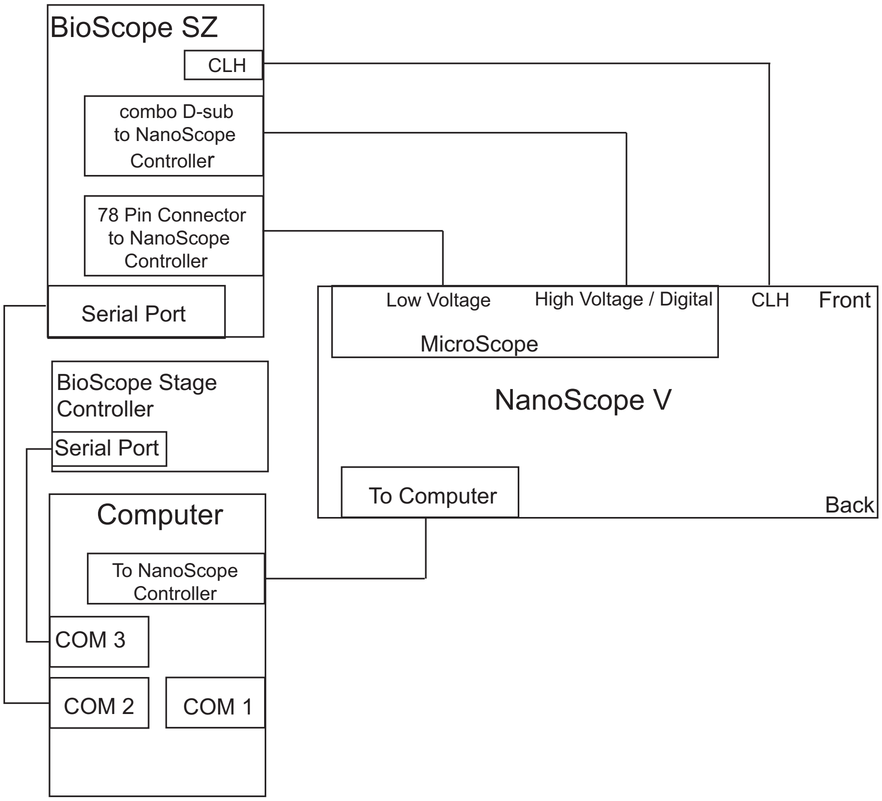


See also the BioScope II Instruction Manual for cabling.

- Connect the Low Voltage and High Voltage/Digital cables between the NanoScope V Controller and the BioScope II E-box.
- Plug the DSI cable from your computer into the BioScope II Controller connector labelled **To Computer**.
- Connect the serial cable between the computer and the BioScope II E-box.
- Basic installation is now complete. Proceed to **Factory Software Configuration of a New SPM,** page 25, then to **Operating Procedures,** page 41.

4.2.4 BioScope SZ: Computer to Controller Cable Connections

Figure 4.2e Cabling Configuration: **BioScope SZ**



See also the BioScope SZ Using a NanoScope V Controller Instruction Manual for cabling.

- Connect the Low Voltage and High Voltage/Digital cables between the NanoScope V Controller and the BioScope Controller.
- Connect the output cable from the Closed Loop Head preamplifier and the Closed Loop Scanner input on the front of the NSV.
- Plug the DSI cable (defined in **NanoScope V Controller Components,** page 10) from your computer into the NSV Controller connector labelled **To Computer**.
- Connect the stage controller to the computer.
- Basic installation for the Adapted SPM is now complete. Proceed to **Factory Software Configuration of a New SPM,** page 25, then to **Operating Principles,** page 41, **Operating Procedures,** page 35 and **New NanoScope V Parameters,** page 119.

4.3 Connect the NanoScope V Controller to a New Adapted SPM

Single-cable (To Controller) SPMs (e.g. MultiMode, EnviroScope) require the use of a 37 pin Adapter (Bruker P/N 37PA), shown in Figure 4.3a, that converts the two connectors on the front of the NanoScope V to one large microscope cable and a smaller sensor cable. Plug the 37 pin adapter into the Low Voltage and High Voltage/Digital connectors on the front of the NanoScope V Controller and tighten the two thumbscrews to secure it. See Figure 4.3b.

Figure 4.3a Two-cable to one-cable 37 pin Adapter

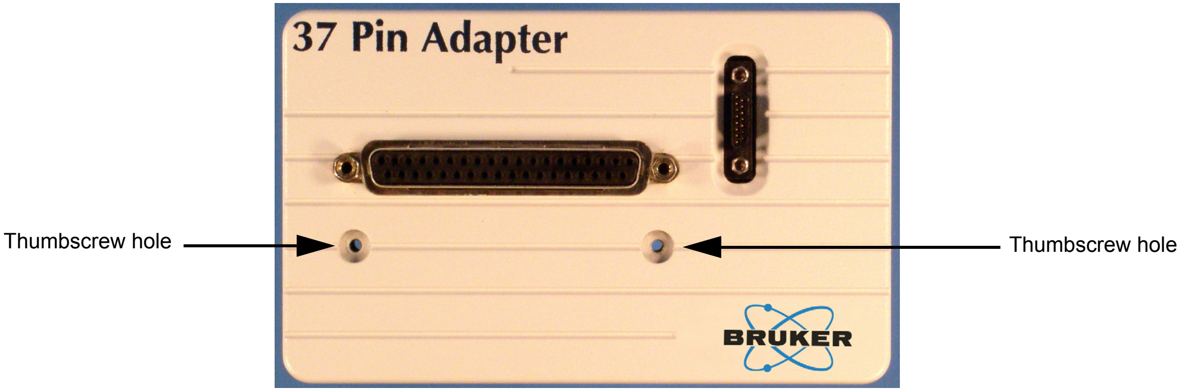
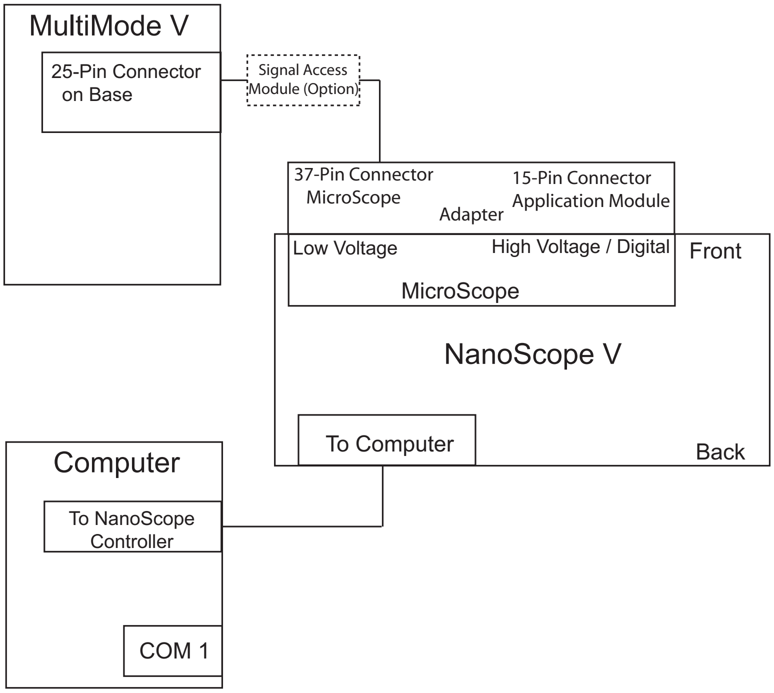


Figure 4.3b 37 Pin Adapter plugged into the NanoScope V Controller

4.3.1 MultiMode V: Computer to Controller Cable Connections

Figure 4.3c Cabling Configuration: **MultiMode** V SPM

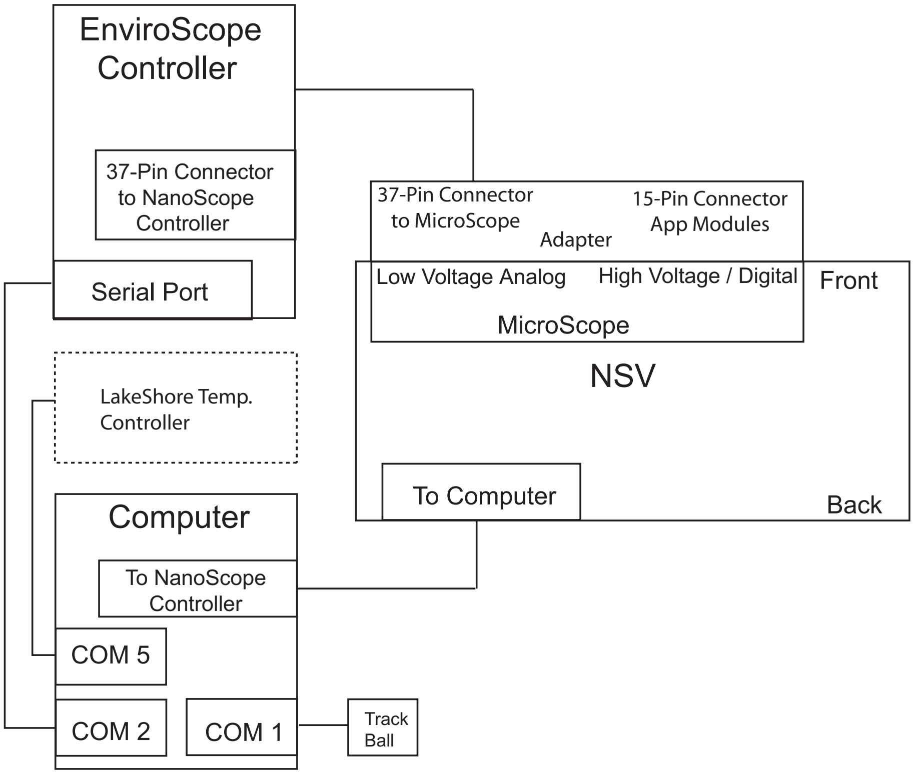


See also the MultiMode Instruction Manual for cabling. This figure is an addendum to that documentation for use with NSV only and only details cabling that differs between NSIV(a) and NSV.

- Plug the 37 pin Adapter into the Low Voltage and High Voltage/Digital connectors on the front panel of the NanoScope V controller.
- Connect the 37 pin connector of the microscope cable to the 37 pin Adapter and the 25-pin connector to the base of the MultiMode.
- Plug the DSI cable (defined in **NanoScope V Controller Components,** page 10) from your computer into the NanoScope V Controller connector labelled **To Computer**.
- Basic installation for the Adapted SPM is now complete. Proceed to **Factory Software Configuration of a New SPM,** page 25, then to **Operating Procedures,** page 35.

4.3.2 EnviroScope

Figure 4.3d Cabling Configuration: **EnviroScope**



See also the EnviroScope Instruction Manual for cabling.

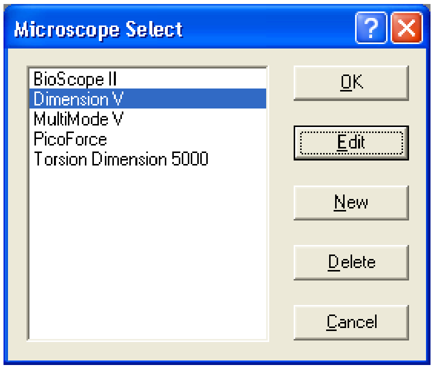
- Plug the 37-pin Adapter into the Low Voltage Analog and High Voltage/Digital connectors on the front panel of the NSV controller.
- Connect the 37-pin “Monster Cable” between the 37-pin Adapter and the EnviroScope Controller.
- Plug the DSI cable (defined in **NanoScope V Controller Components,** page 10) from your computer into the NSV Controller connector labelled **To Computer**.
- Basic installation for the Adapted SPM is now complete. Proceed to **Factory Software Configuration of a New SPM,** page 25, then to **Operating Principles,** page 41, **Operating Procedures,** page 35 and **New NanoScope V Parameters,** page 119.

4.4 Factory Software Configuration of a New SPM

All SPMs purchased with a NanoScope V Controller are shipped with software setup at the factory. To verify your NanoScope V controller system software:

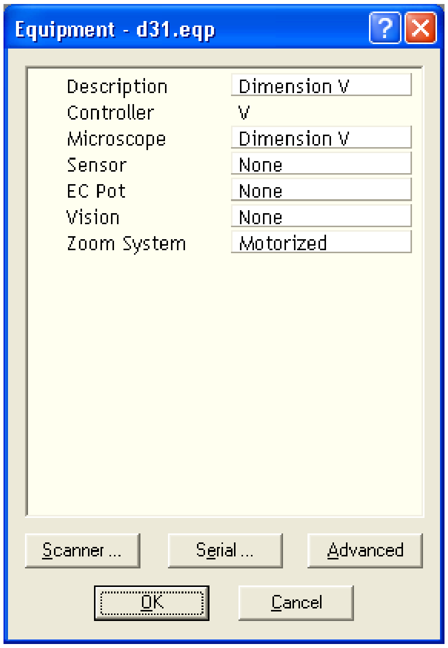
1. Click the **TOOLS** drop-down menu, then **SELECT MICROSCOPE...**, shown in Figure 4.4a, to specify the SPM.

Figure 4.4a Microscope Select



2. Click **EDIT** in the **Microscope Select** panel to open the **Equipment** panel, shown in Figure 4.4b.

Figure 4.4b System Component Designation



Description	Dimension V
Controller	V
Microscope	Dimension V
Sensor	None
EC Pot	None
Vision	None
Zoom System	Motorized

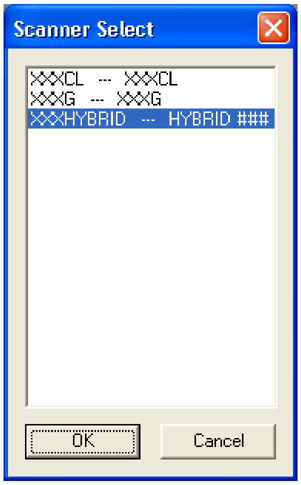
3. If you enter a distinguishing name for your SPM system under **DESCRIPTION**, the name will be added to the **Microscope Select** list when the **Equipment** panel is closed.

4. Verify **V** (NSV) is selected in the **CONTROLLER** drop-down menu of the **Equipment** panel.

5. Verify the configured SPM is selected from the **Microscope** drop-down menu of the **Equipment** panel (e.g., **V** in Figure 4.4b).

6. Click the **SCANNER...** button of the Equipment panel to open the **Scanner Select** panel, shown in Figure 4.4c and select the appropriate scanner.

Figure 4.4c Scanner Select

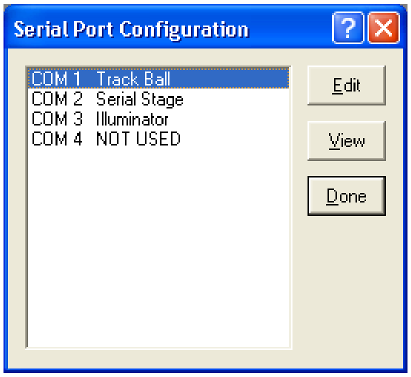


XXXCL --- XXXCL
XXXG --- XXXG
XXXHYBRID --- HYBRID ###

7. Click **OK** to close the **Scanner Select** panel.

8. Click the **SERIAL...** button of the Equipment panel to open the **Serial Port Configuration** panel, shown in Figure 4.4d. Verify the COM port assignments.

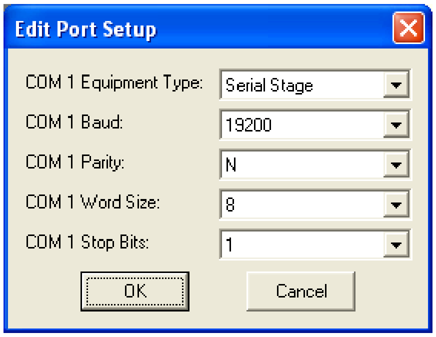
Figure 4.4d Serial Port Configuration, Typical of Dimension SPMs



COM 1 Track Ball
COM 2 Serial Stage
COM 3 Illuminator
COM 4 NOT USED

9. Highlight a COM port in the **Serial Port Configuration** panel and click the **EDIT** button to open the **EDIT PORT SETUP** panel, shown in Figure 4.4e. For instance, in the drop-down menu for COM 1 (for a BioScope II SPM) verify that **EQUIPMENT TYPE** is `SERIAL STAGE`. Appropriate default settings appear for the other parameters in the panel.

Figure 4.4e Edit Port Setup Panel



COM 1 Equipment Type: Serial Stage
COM 1 Baud: 19200
COM 1 Parity: N
COM 1 Word Size: 8
COM 1 Stop Bits: 1

10. Click **OK** to close the **Edit Port Setup** panel. Click **DONE** to close the **Serial Port Configuration** panel.

11. The remaining Equipment panel options are SPM-dependent so are not discussed here. Click **OK** to close the **Equipment** panel. Click **OK** to close the **Microscope Select** panel.

12. If your SPM is equipped with a sensor, select a sensor module entry from the **SENSOR** drop-down menu. Your options may include: **NONE**, **SCM**, **TUNA**, **C-AFM**, **SSRM**, and **TORSION**.

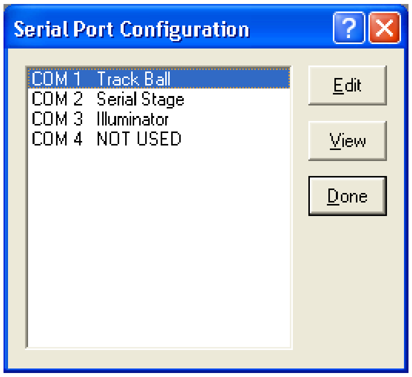
13. **VINTAGE SCM** refers to the original SCM sensor. **SCM** refers to an Application Module, either Generation I (not operable with the NanoScope V Controller) or Generation II (either Dimension or MultiMode, for use with the NanoScope V Controller). All SCM sensors supplied with the NanoScope V Controller must be operated using selection **SCM**. TUNA, SSRM and C-AFM refer to Generation I or Generation II Application Modules, all operable by the NanoScope V Controller.

    Note: Select **TUNA**, **SSRM**, **C-AFM**, respectively, for either generation Application Module.

14. Click the **SERIAL...** button of the **Equipment** panel to open the **Serial Port Configuration** panel (see Figure 4.4f). Verify the **COM** port assignments.

    Note: The assignment of your computer COM ports for different SPMs is diagrammed in **Configuring a New SPM with a NanoScope V Controller,** page 15 and illustrated (for a Dimension SPM) in Figure 4.4f.

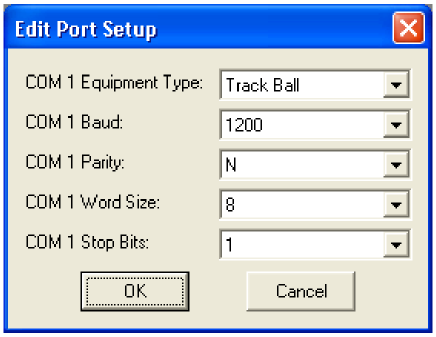
Figure 4.4f Serial Port Configuration, Typical of Dimension SPMs


Serial Port Configuration

COM 1 Track Ball
COM 2 Serial Stage
COM 3 Illuminator
COM 4 NOT USED

15. Highlight a **COM** port in the **Serial Port Configuration** panel and click the **EDIT** button to open the **Edit Port Setup** panel (see Figure 4.4g). Appropriate default settings appear for the other parameters in the panel.

Figure 4.4g Edit Port Setup Panel


Edit Port Setup

COM 1 Equipment Type: Track Ball
COM 1 Baud: 1200
COM 1 Parity: N
COM 1 Word Size: 8
COM 1 Stop Bits: 1

16. Click **OK** to close the **Edit Port Setup** panel. Click **DONE** to close the **Serial Port Configuration** panel.

17. The remaining **Equipment** panel options are SPM-dependent. Refer to the *Instruction Manual* for your SPM for details on these options. Click **OK** to close the **Equipment** panel. Click **OK** to close the **Microscope Select** panel.

Proceed to **Operating Procedures,** page 41.

Chapter 5 Configuring an Existing SPM with a NanoScope V Controller

5.1 About Using an Existing SPM with a NanoScope V Controller

Many purchasers of a new NanoScope V Controller have existing SPM instrumentation from Bruker and are interested in the possibility of operating existing SPMs from the NanoScope V Controller. Bruker emphasizes compatibility with existing products in new developments wherever this can be done without limiting the introduction of advanced designs and features.

While the advanced capabilities of the NanoScope V Controller are best utilized on the latest generation of MultiMode or Dimension SPMs, the NanoScope V Controller generally operates many compatible earlier Bruker SPMs, once they are modified for use with the NanoScope V Controller, providing many of the NanoScope V Controller benefits. This is detailed in the current chapter.

Note: All phase imaging capabilities of the NSIII(a) Controller with the Extender Electronics Module are surpassed by the hardware incorporated in the NanoScope V Controller. **All SPMs operated with the NanoScope V Controller must be phase-equipped for full NanoScope V Controller features.**

Neither Vintage SCM, nor existing (Generation I) SCM Application Modules supplied for NSIII(a) operation, function with an NanoScope V Controller. Contact Bruker for your upgrade or trade-in options.

5.2 About NanoScope V Controllers Purchased Without an SPM

Bruker consults with all customers who wish to purchase an NanoScope V Controller without an SPM for use with an existing SPM, in order to reduce equipment conflicts with NanoScope V Controller upgrades.

All Bruker required and recommended upgrades to the existing SPM must be installed prior to operation with the NanoScope V Controller.

Bruker may recommend or require pre-sale equipment inspection, and/or on-site installation for a NanoScope V Controller upgrade. If all Bruker recommendations and requirements have been followed, the NanoScope V Controller purchased for use with an existing SPM will have the standard warranty. The warranty of the existing SPM will be based on the original purchase date of the SPM, without regard to the NanoScope V Controller purchase date or warranty. Contact your Bruker salesperson if you have any related questions.

5.3 Requirements: NanoScope V Controller with an Existing SPM

Because existing SPM equipment originally sold for use with an NSIII(a) or NSIV(a) is beyond the control of Bruker, this compatibility information is provided solely to provide guidelines for user consideration, and does not constitute a warranty for NanoScope V Controller compatibility with any SPM. Special modifications previously supplied by Bruker at the expressed request of a customer may also prevent NanoScope V Controller compatibility. While it is expected the information provided here is accurate, Bruker cannot be responsible for the failure of any existing system to operate with the NanoScope V, even if listed as compatible with NanoScope V Controllers in this and any other documentation. Bruker cannot be responsible for any required service or repairs due to user attempts to install the NanoScope V Controller on existing SPMs. Contact your local Bruker sales or service person for assistance in understanding this policy and your options.

The following factors summarize compatibility issues with existing SPMs:

A. With all existing SPMs the NanoScope V Controller must be operated by the computer supplied for use with the NanoScope V Controller.

B. Some upgrades are required for all SPMs to support NanoScope V Controller features. Briefly, the required upgrades include at least the following:

- Non TappingMode SPMs are not supported by the NanoScope V Controller.
- Non Phase SPMs that can support Phase need a Phase Upgrade.
- An AFM Head Upgrade (HU) is recommended for some MultiMode SPMs.
- An AFM Head Upgrade is recommended for D3100 SPMs; an Electronics Upgrade is required. Do not attempt to operate a D3100 with the NanoScope V Controller without first completing the Electronics Upgrade.

Note: Head Upgrades are always recommended for the best Q Control.

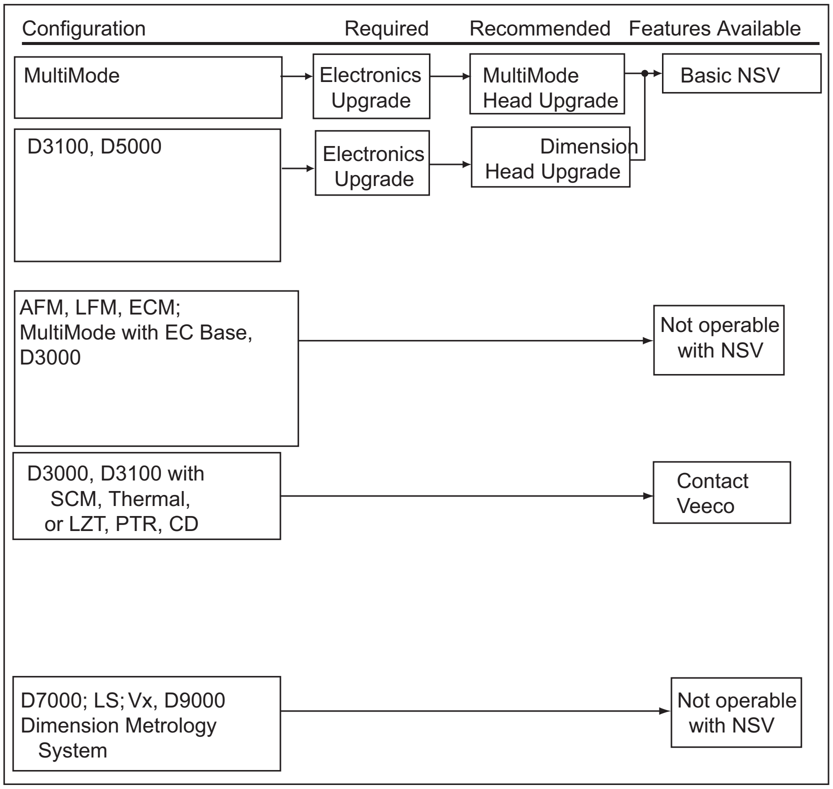
C. Industrial semi-automated, D3100 SPMs, particularly in IS3K enclosures, with dedicated application equipment (e.g., LZT, PTR, DVD/CD, etc.) may not be operable with the NanoScope V Controller. Contact your local Bruker sales representative for more information.

D. D3100 SPMs equipped with custom sensors, Thermal or Application Modules such as SCM, SSRM, Conductive AFM, or TUNA, all require Bruker guidance and significant modification for NanoScope V Controller operation. Thermal, original SCM and Generation I and II SCM Modules supplied for NSIII(a) operation do not function with the NanoScope V Controller.

While many existing D5000 systems are expected to be operable by the NSV if reconfigured by a trained service person, Bruker strongly advises that this should not be attempted by users. This is due to the many possible D5000 options that complicate the computer configuration and software setup. To determine whether your existing D5000 can be operated from an NSV, contact your local Bruker sales or service representative for assistance. Bruker cannot be responsible for any required service or repairs due to user attempts to convert any D5000 to NSV operation.

CAUTION: Never connect an SPM through an Extender Electronics box to the NanoScope V Controller via the 37 pin adapter.

Figure 5.3a Visual Guide to NanoScope V Controller Compatibility with Existing SPMs



5.4 NanoScope V Controller with Existing SPMs: Installing Required Upgrades

Refer to the instructions supplied with the specific NanoScope V SPM upgrade.

The remainder of this manual assumes that all required and recommended NanoScope V upgrades for an existing SPM have been installed.

In most cases, a microscope electronics upgrade is required and we recommend purchase of other optional upgrades to provide best NanoScope V Controller operation on existing SPMs. SPM system conversion to NanoScope V Controller operation is best performed by a trained service person. Contact Bruker for assistance in understanding the benefits and requirements of upgrading your existing compatible SPM to take best advantage of the NanoScope V Controller.

Table 5.4a locates more detail for each configuration of an existing SPM with a NanoScope V Controller.

Table 5.4a Index to Configuration Detail by Existing SPM

#	Existing SPM	Configuration Detail
1a	AFM	Not Allowed
1b	Lateral Force Microscope (LFM)	
1c	ECM (EC-STM)	
2a,b	MultiMode with Base equipped with Extender Electronics	Table 5.4b, page 33
2c, d	MultiMode without Base equipped with Extender Electronics or MultiMode with Electrochemistry Option in Base	
3a	BioScope/ BioScope SZ	Not Allowed
3a	BioScope/ BioScope SZ	Table 5.4c, page 34
6a, b	Dimension 3100 equipped with Extender Electronics	Table 5.4d, page 35
6c, d	Dimension 3100 not equipped with Extender Electronics	
7a, b	Dimension 3100 equipped for SSRM, TUNA or CAFM Application Modules	Table 5.4e, page 36
7c	Dimension 3100 equipped for any SCM	
7d	Dimension 3100 equipped for original style Thermal (not Applications Module)	

Table 5.4b Configurations: Existing **MultiMode** SPMs with a New NanoScope V Controller

Configuration (#)	**Existing MultiMode SPM(*)**	**SPM to NanoScope V Controller Cabling and Software Configuration**	**Associated Features**
2a	MultiMode with Base equipped for Extender Electronics	**Required** Connection of MultiMode to NanoScope V is by 37 pin connector on the Adapter, **without using the Extender Electronics box**. See Figure 4.3c. *Configure Software as:* Controller: V Microscope: MultiMode	***Basic NanoScope V*** features available. Optional MultiMode head upgrade to low noise laser.
2b	MultiMode without Base equipped for Extender Electronics	**Required** Upgrade base equipped for phase operation. Operation follows Configuration 2a above.	If Extender Electronics are purchased for base in case of MultiMode without Phase, or if a second base is purchased equipped with Phase, then the SPM will function with the ***Basic NanoScope V*** *Feature Set*. Optional MultiMode head upgrade to low noise laser.
2c	MultiMode with Electrochemistry option in base	**Required** Purchase base equipped for Extender electronics and electrochemistry potentiostat. Connection of the MultiMode to the NanoScope V Controller is by Microscope connector on the 37 pin adapter with the EC potentiostat located in-line between the controller and microscope, without using the Extender electronics box.	

Note referenced in Table 5.4b:

* See **Requirements: NanoScope V Controller with an Existing SPM,** page 30.

Table 5.4c Configurations: Existing **BioScope/BioScope SZ** SPM with a New NSV Controller

Config-uration (#)	**Existing BioScope SPM(*)**	**SPM to NSV Cabling and Software Configuration**	**Associated Features**
3a	BioScope equipped with Extender Electronics	**Required** Contact Bruker to purchase an upgrade kit (new back pannel and cables). Connection of BioScope to NanoScope V Controller is by the Low Voltage and High Voltage/Digital MicroScope connectors on the front of the NanoScope V Controller. See Figure 4.2e. *Configure Software as:* Controller: V Microscope: BioScope SZ	***Basic NSV*** features are available. Optional Dimension head upgrade to special laser may provide improved Q control.

Note referenced in Table 5.4c:

* See **Requirements: NanoScope V Controller with an Existing SPM,** page 30.

Table 5.4d Configurations: Existing **D3100** SPMs with a New NanoScope V Controller

Config-uration (#)	**Existing Dimension 3100 SPM(*)**	**SPM to NanoScope V Controller Cabling and Software Configuration**	**Associated Features**
6a	Dimension 3100 equipped for Extender Electronics	**Required** Purchase a D3100-NS5U upgrade kit (new back-panel and cables). Connection of D3100 to NanoScope V Controller is by the Low Voltage and High Voltage/Digital MicroScope connectors on the front of the NanoScope V Controller. See Figure 4.2b. *<u>Configure Software as:</u>* Controller: V Microscope: Dimension V	***Basic NanoScope V Controller*** features are available. Optional Dimension Head upgrade to special laser may provide improved Q control.
6b	Dimension 3100 not equipped for Extender Electronics	**Required** Purchase a D3100-NS5U upgrade kit (new back-panel and cables). Connection of D3100 to NanoScope V Controller is by the Low Voltage and High Voltage/Digital MicroScope connectors on the front of the NanoScope V Controller. See Figure 4.2b. *<u>Configure Software as:</u>* Controller: V Microscope: Dimension V	***Basic NanoScope V Controller*** features are available. Optional Dimension Head upgrade to special laser may provide improved Q control.

Note referenced in Table 5.4d:

* See **Requirements: NanoScope V Controller with an Existing SPM,** page 30.

Table 5.4e Configurations: Existing **D3100** SPMs **with** a New NanoScope V Controller and **Sensors or Application Modules**

Configuration (#)	**Existing Dimension 3100 SPM with Sensors or Application Modules**(1)	**SPM to NanoScope V Controller Cabling and Software Configuration**	**Associated Features**
7a	Dimension 3100 equipped for SSRM, TUNA or CAFM Application Modules	**Required** Purchase a D3100-NS5U upgrade kit (new backpanel and cables). Connection of D3100 to NanoScope V Controller is by the Low Voltage and High Voltage/Digital MicroScope connectors on the front of the NanoScope V Controller. See Figure 4.2b. *Configure Software as:* Controller: V Microscope: Dimension 3100 Sensor: SCM, TUNA, C-AFM, SSRM, Torsion.	***Basic NanoScope V*** Controller features are available. Optional Dimension Head upgrade to special laser may provide improved Q control.
7b	Dimension 3100 equipped with gen. 3 SCM(2)	**Required** Purchase a D3100-NS5U upgrade kit (new backpanel and cables). Connection of D3100 to NanoScope V Controller is by the Low Voltage and High Voltage/Digital MicroScope connectors on the front of the NanoScope V Controller. See Figure 4.2b. *Configure Software as:* Controller: V Microscope: Dimension 3100 Sensor: SCM, TUNA, C-AFM, SSRM, Torsion.	***Basic NanoScope V*** Controller features are available. Optional Dimension Head upgrade to special laser may provide improved Q control.
7c	Dimension 3100 equipped with gen. 1 or gen. 2 SCM(2)	**Not Allowed**	
7d	Dimension 3100 equipped original style Thermal (not Application Module)	**Not Allowed**	

Notes referenced in Table 5.4e:

1. See **Requirements: NanoScope V Controller with an Existing SPM,** page 30.

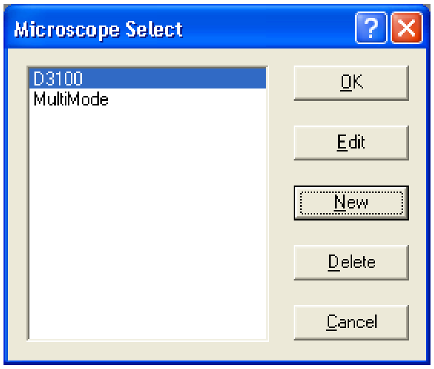
2. Gen. 3 SCM refers to an SCM module that is currently being run on a Quadrex box (NSIII(a) Controller) or a NSIV(a) Controller. If the SCM module is not being run with a Quadrex box or from a controller other than a NSIV(a), it is a gen. 1, sometimes referred to as a “vintage,” or a gen. 2 SCM.

5.5 Software Configuration with an Existing SPM

To specify your NanoScope V-controlled system software:

1. Click the **TOOLS** drop-down menu, then **SELECT MICROSCOPE...**, shown in Figure 5.5a, to specify the SPM.

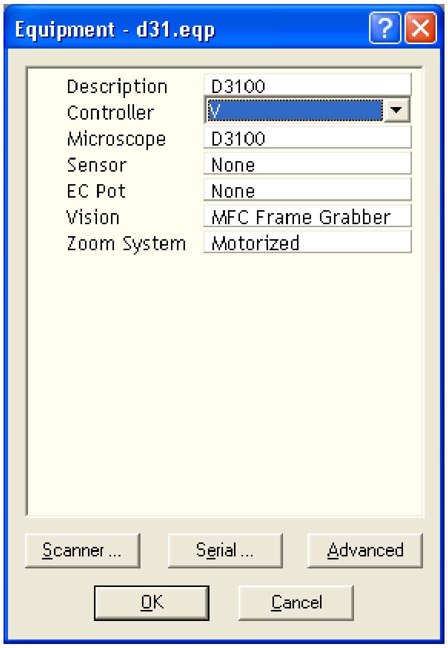
Figure 5.5a Microscope Select



D3100
MultiMode

2. Click **EDIT** in the **Microscope Select** panel to open the **Equipment** panel, shown in Figure 5.5b.

Figure 5.5b System Component Designation



Description D3100
Controller V
Microscope D3100
Sensor None
EC Pot None
Vision MFC Frame Grabber
Zoom System Motorized

3. If you enter a distinguishing name for your SPM system under **DESCRIPTION**, the name will be added to the **MICROSCOPE SELECT** list when the **Equipment** panel is closed.

4. Verify **`V`** (NSV) is selected in the **Controller** drop-down menu of the **Equipment** panel.

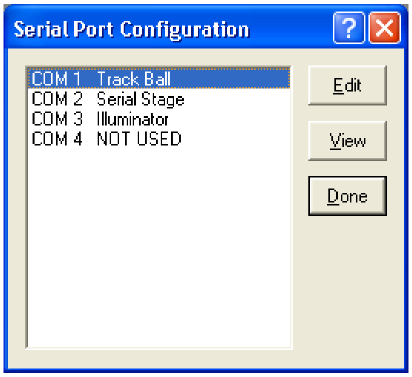
5. Verify the configured SPM is selected from the **Microscope** drop-down menu of the **Equipment** panel (e.g., **`D3100`** in Figure 5.5b).

6. If your SPM is equipped with a sensor, select a sensor module entry from the **Sensor** drop-down menu. Your options may include: **`None`**, **`SCM`**, **`TUNA`**, **`C-AFM`**, **`SSRM`**, and **`Torsion`**.

7. **`Vintage SCM`** refers to the original SCM sensor. **`SCM`** refers to an Application Module, either Generation I (not operable with the NanoScope V Controller) or Generation II (either Dimension or MultiMode, for use with the NanoScope V Controller). All SCM sensors supplied with the NanoScope V Controller must be operated using selection **`SCM`**. TUNA, SSRM and C-AFM refer to Generation I or Generation II Application Modules, all operable by the NanoScope V Controller. Select **`TUNA`**, **`SSRM`**, **`C-AFM`**, respectively, for either generation Application Module.Click the **Serial...** button of the **Equipment** panel to open the **Serial Port Configuration** panel (see Figure 5.5c). Verify the **COM** port assignments. Click **Done** to close the **Serial Port Configuration** panel.

Note: The assignment of your computer COM ports for different SPMs is diagrammed in **Configuring a New SPM with a NanoScope V Controller,** page 15 and illustrated (for a Dimension SPM) in Figure 5.5c.

Figure 5.5c Serial Port Configuration, Typical of Dimension SPMs



COM 1 Track Ball
COM 2 Serial Stage
COM 3 Illuminator
COM 4 NOT USED

Table 5.5a shows the COM port assignments used for Dimension V, BioScope II and Multimode V SPMS.

Table 5.5a COM Port Assignments

Port	Dimension V	BioScope II	MultiMode V
COM 1	Track Ball	Not Used	Not Used
COM 2	Serial Stage	Not Used	Not Used
COM 3	Illuminator	Not Used	Not Used
COM 4	Not Used	Not Used	Not Used

8. The remaining **Equipment** panel options are either SPM-dependent or are not new to the NanoScope V Controller so are not discussed here. Click **OK** to close the **Equipment** panel. Click **OK** to close the **Microscope Select** panel.

Now your existing SPM is configured for use with a NanoScope V Controller. Operation of new NanoScope V Controller features is presented in is presented in **Operating Procedures,** page 41. Software changes with the introduction of the NanoScope V Controller are itemized in **New NanoScope V Features,** page 117.

Chapter 6 Operating Procedures

6.1 NanoScope V Controller Capabilities

The NanoScope V Controller features many enhancements over its predecessors. The NanoScope V Controller provides new features for customization, including several synchronization outputs, reference signal outputs for all three lock-ins, and five analog inputs which can be sampled with Analog-to-Digital Converters (ADCs).

Data can now be captured at effective bandwidths of up to 25MHz.

The resolution of the NanoScope V Controller has been increased to 5k x 5k points from 4k by 1k points on the NSIV(a) and 512 x 512 points on the NSIII(a) controllers.

FastScan[1] enables both an approximately 10× scan speed increase and reduced tip damage through micro-actuation of the cantilevered probe. In TappingMode, FastScan is also known as TappingMode+, but the capability benefits Contact Mode microscopy too.

Another feature, Q Control, improves sensitivity by either enhancing or suppressing a selectable narrow band within the tuning spectrum. Sharpening a resonance peak particularly improves phase contrast, as may be desirable for MFM imaging. Q Control is also useful for damping an unwanted resonance in a multi-peaked spectrum.

6.2 System Initialization

With all hardware connected, turn on power to the computer, then to the controller (back of NanoScope V Controller, upper right, shown in Figure 3.6a) and then to the other components of the SPM system.

CAUTION: Do not connect or disconnect any component of the SPM configuration without first turning **OFF** power to all components.

---

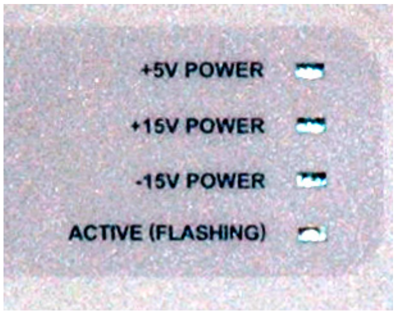
[1] FastScan is not available on BioScope II SPMs.

.

CAUTION: Leaving the NanoScope V Controller **On** for extended periods with the computer **Off** may damage the scanner.

Verify the three power supply Light-Emitting Diodes (LEDs) on the front face of the NanoScope V Controller are lit (see Figure 6.2a). The fourth LED has three powered states: on when the NanoScope V Controller is powered but the NanoScope software is not running, blinking at 1Hz when most new features (e.g. FastScan, Q Control, etc.) are active, and blinking at 5Hz during software downloads from the computer to other SPM system components.

Figure 6.2a Power Supply LEDs on the Front of the NanoScope V Controller

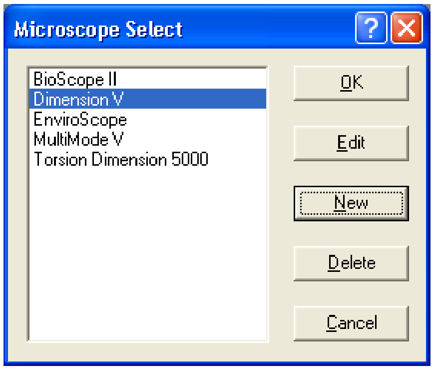


Double-click the **Nanoscope** icon on the desktop to commence software control over the SPM.

Confirm that the software and hardware match or enter details of any new SPM configuration before proceeding to Real-time Mode:

1. Click the **Tools** drop-down menu, then **Select Microscope...**, shown in Figure 6.2b, to specify the SPM.

Figure 6.2b SPM Designation



BioScope II
Dimension V
EnviroScope
MultiMode V
Torsion Dimension 5000

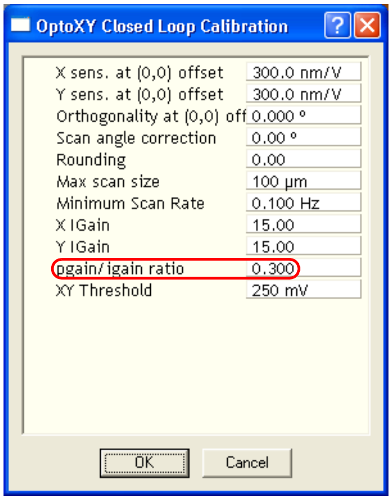
2. Choose the desired SPM configured by clicking its name in the **Microscope Select** list (see Figure 6.2b). The software has been factory pre-configured for any SPMs purchased with your NanoScope V Controller.

6.3 Scale Differences between the NS III(a), IV(a) and the NS V Controller

- **INTEGRAL** and **PROPORTIONAL GAIN**s should be 5-10 times those used with a NS III(a) or NS IV(a) controller with the same type of scanner.
- Signals:
  - The names of the SPM feedback **DATA TYPES** have changed for the NS V controller. **DEFLECTION** on the NS IV(a) is now called **DEFLECTION ERROR** and **AMPLITUDE** on the NS IV(a) is now called **AMPLITUDE ERROR**.
  - **DEFLECTION ERROR** for the NS V controller is approximately equal to that of the **DEFLECTION** on a NS IV(a) controller.
    - Like the NS IV(a), the NS V Controller **DEFLECTION ERROR** uses analog setpoint subtraction. The range of **DEFLECTION ERROR** is ±(**DEFLECTION LIMIT/2**). **DEFLECTION SETPOINT** + **DEFLECTION ERROR** must lie in the range between ±(**DEFLECTION LIMIT**/2).
  - **AMPLITUDE ERROR** for NS V controllers is approximately 0.28 of the **AMPLITUDE** on a NS IV(a) controller. When auto tuning, set your **TARGET AMPLITUDE** and **SETPOINT** to be approximately 28% of the values used with a NS III(a) or NS IV(a) controller.
    - **AMPLITUDE ERROR** is defined as **AMPLITUDE** - **AMPLITUDE SETPOINT**. The range of **AMPLITUDE ERROR** is -**AMPLITUDE SETPOINT** to [(**AMPLITUDE RANGE**)/2 - **AMPLITUDE SETPOINT**]. The range of **AMPLITUDE** is 0 to (**AMPLITUDE RANGE**)/2.
- NS V controller **DRIVE AMPLITUDE** is one half [NS IV(a) **DRIVE AMPLITUDE**].
- In **TAPPINGMODE**, **LOCK-IN BW** (bandwidth) should be set to be approximately one third of the [**DRIVE FREQUENCY**] for maximum feedback response.
- When collecting an image, the **AMPLITUDE** and **AMPLITUDE ERROR** channels display larger amplitudes as brighter areas. This is opposite to the behavior of the NS IV(a) where darker areas in the image correspond to larger amplitudes. This will affect force modulation and **TAPPING** mode constant height images. They will be negatives of the images from the NS IV(a).
- Change the **PGAIN/IGAIN RATIO** for Dimension closed loop heads from 0.50 for NS IVa controllers to 0.30 for NS V controllers:

- Set **XY CLOSED LOOP** to ON. Select **TOOLS** > **CALIBRATE X-Y...** to open the **OptoXY Closed Loop Calibration** window, shown in Figure 6.3a. Set **PGAIN/IGAIN RATIO TO** `0.3`.

Figure 6.3a **PGAIN/IGAIN RATIO**



X sens. at (0,0) offset	300.0 nm/V
Y sens. at (0,0) offset	300.0 nm/V
Orthogonality at (0,0) off	0.000 °
Scan angle correction	0.00 °
Rounding	0.00
Max scan size	100 µm
Minimum Scan Rate	0.100 Hz
X IGain	15.00
Y IGain	15.00
pgain/igain ratio	0.300
XY Threshold	250 mV

6.4 Signal Naming Conventions

If the channel is setpoint subtracted, “Error” is added to the end of the name (e.g. **AMPLITUDE** becomes **AMPLITUDE ERROR**).

Signal names depend on the **MODE** of the microscope (see Table 6.4a).

Table 6.4a Signal Names

Contact	Tapping
Amplitude1	Amplitude
Amplitude2	Amplitude2
Amplitude3	Amplitude3
Phase1	Phase
Phase2	Phase2
Phase3	Phase3
Deflection	TM Deflection

AMPLITUDE is 0 to peak.

IN-PHASE is proportional to Amplitude*cos(phase) and **QUADRATURE** is proportional to Amplitude*sin(phase).

6.4.1 Abbreviations

Some items are abbreviated to fit. These include:

- TM: TappingMode.
- TR: Torsional Resonance mode[1].
- BW: Bandwidth.
- LP: Low pass.
- DDS: Direct Digital Synthesis.
- SCM: Scanning Capacitance Mode[1].
- TUNA: Tunneling AFM[1].
- CAFM: Conductive AFM[1].
- STM: Scanning Tunneling Microscrospy[1].

6.5 Auxiliary Signal Paths

The NanoScope V Controller facilitates integration of SPM imaging with other laboratory equipment by providing the experimenter with numerous auxiliary input and output signal path options. Access to these features is clustered in the lower left of the front panel of the NanoScope V Controller (see Figure 6.5a).

The auxiliary signal path options are:

- **DIGITAL 1 IN 1** and **DIGITAL 2 IN 2** are BNC digital inputs used to count pulses. **DIGITAL 1 IN 1** and **DIGITAL 2 IN 2** are assigned to **DATA TYPES** `COUNTER 1` and `COUNTER 2` or `FREQ. 1` and `FREQ. 2` respectively.
- **HIGH FREQUENCY ANALOG INPUTS** are BNC connectors labeled Lock-In 1 and Lock-In 2. The sample rate is 50MHz giving an effective bandwidth of 500Hz to 5MHz. External signals are introduced to be viewed alongside SPM parameters, each being assigned to a channel via the **DATA TYPE** parameter in a **Channel** panel. These auxiliary signals can also be captured for analysis in Offline Mode. The two signal paths are identical and independent.

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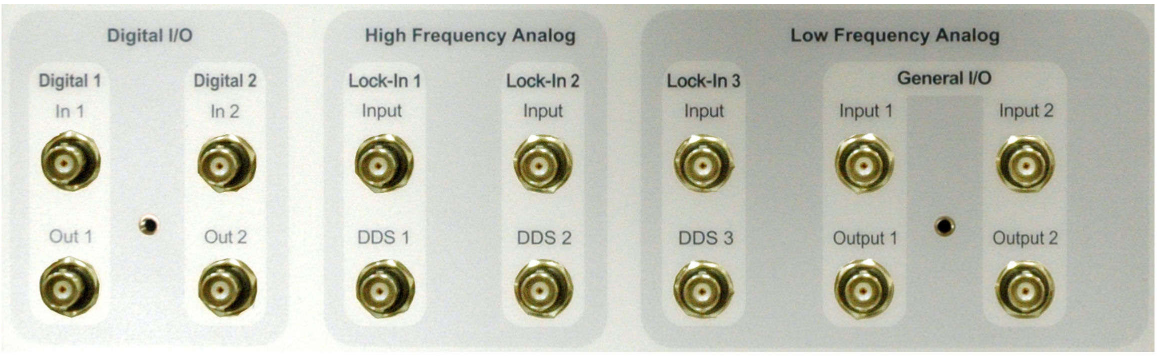
[1] Not available on BioScope II SPMs.

Figure 6.5a Close-up of Connectors, Front of NanoScope V Controller



- **LOW FREQUENCY ANALOG INPUT** is a BNC connector labeled Lock-In 3. The sample rate is 500kHz giving an effective bandwidth of 5Hz to 50kHz. External signals are introduced to be viewed alongside SPM parameters, each being assigned to a channel via the **DATA TYPE** parameter in a **Channel** panel. These auxiliary signals can also be captured for analysis in Offline Mode. The two signal paths are identical and independent.

- **LOCK-IN REFERENCE OUTPUTS** are BNC connectors labeled DDS 1, DDS 2 and DDS 3.

- **DIGITAL OUTPUTS EOF** (**OUT 1**, End-Of-Frame) and **EOL** (**OUT 2**, End-Of-Line) are BNC connectors providing transistor-transistor logic (TTL) synchronization pulses from both upwards and downwards going frames and from both trace and retrace lines. For example, a scan rate of 1Hz generates 2 line-sync pulses per second, one for trace and one for retrace.

- **GENERAL I/O** are BNC connectors labeled Input 1, Input 2, Output 1 and Output 2. Inputs are DC to 100kHz bandwidth. Outputs allow the user to monitor selectable NanoScope V Controller signals.

See the table below for more detail concerning the auxiliary connectors.

Connector Label	Connector Type	Purpose
Lock-In 1 and 2	BNC, ≥1MΩ impedance	inputs for user-supplied digital TTL-compatible signals. bandwidth: 25.6MHz max minimum pulsewidth: 20ns
Lock-In 1 and 2	BNC, <1kΩ impedance	inputs for user-supplied signals: range: -10V to 10V DC bandwidth: 500Hz to 5MHz
Lock-In 3	BNC, <1kΩ impedance	inputs for user-supplied signals: range: -10V to 10V DC bandwidth: 5Hz to 50kHz
Out 1 (EOF output)	BNC, ≥1MΩ impedance	TTL reference signal for image end-of-frame: negative-going pulse, +5V to 0V after every frame, up and down
Out 2 (EOL output)	BNC, ≥1MΩ impedance	TTL reference signal for image end-of-line: negative-going pulse, +5V to 0V after every trace and retrace
DDS 1, 2 and 3 (Lockin Ref. output)	BNC, ≥1MΩ impedance	reference signal: a 5V peak-to-peak sine wave synchronized to the analog frequency source used by the lock-in amplifiers
General I/O Input 1 and 2	BNC, <1kΩ impedance	inputs for user supplied signals: range: -10V to 10V DC bandwidth: DC to 100kHz
General I/O Output 1 and 2	BNC, ≥1MΩ impedance	analog outputs that can be used to monitor selectable NanoScope V Controller signals

To image an external analog signal:

1. Before connecting external lines to the analog input connectors, verify that the impedance of the external device is less than 1kΩ and that the voltage does not exceed ±10VDC.
2. Connect the external signal line to **Analog Input 1**, **2** or **3** on the front panel of the NanoScope V Controller.
3. In one of the three **Channel** panels, select for **Data Type**: **Input 1**, **2** or **3** (see **Eight Channels:** Page 134).

To obtain synchronization signals:

1. Before connecting any external equipment to any synchronization connector (**DDS 1, 2 or 3**), verify that each external device (e.g., oscilloscope) has an impedance of 1MΩ or larger.
2. Connect the device to the desired sync output connector on the front panel of the NanoScope V Controller.

CAUTION: Never connect two outputs together.

6.6 Piezo Response Force Microscopy

6.6.1 Introduction

The lock-in amplifiers used in the NSV Controller also enable Piezoresponse (PR) imaging. Piezo response force microscopy is a Contact Mode technique to measure sample displacement out of the sample plane in response to an applied AC bias. The method is most directly applicable to piezoelectric samples such as lead zirconia titanate, but can also work for electrostrictive samples such as lead magnesium niobate, and has been used on ferroelectric materials such as barium titanate.

Piezo response force microscopy's ability to induce and detect switching in small areas provides insight into domain transformation processes within individual grains and can help to explore the correlation between macroscopic switching characteristics and elementary switching mechanisms of ferroelectric materials.

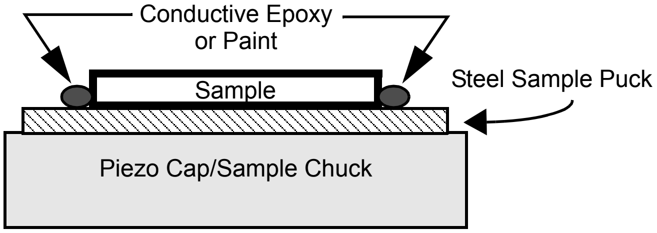
With the SPM in Piezo response Mode, the tip is engaged with the sample and an AC voltage is applied between tip and sample during scanning. A responsive sample expands and contracts in synchronization with the applied voltage. By feeding the photodetected cantilever deflection signal into a lock-in amplifier whose reference signal is the applied AC bias signal, background topography is suppressed from the resulting image which features only the sample surface height changes induced by the applied field.

An AC bias voltage, $V_{ac} = V_0\sin(\omega t)$, applied between the bottom electrode and the probe tip induces an oscillating charge, $Q_e = CV_{ac}$, where C is the tip to bottom electrode capacitance, on the electrode which produces an equal image charge of the opposite sign on the probe tip. The total charge on the tip is $Q_t = -(Q_e + Q_p)$ where Q_p is the static charge from the polarization. The resulting electrostatic force on the tip consists of two terms: a capacitive term due to the applied voltage, $F = \frac{1}{2}V_{ac}^2\left(\frac{\partial C}{\partial z}\right)$, where z is the tip-sample distance and a term due to tip-sample Coulomb interaction, $F_{Coulomb} = Q_tE_z$, where E_z is the stray electric field produced by polarization charges of the ferroelectric sample. It has been shown that in the absence of net polarization ($Q_p = 0$ and $E_z = 0$), the force gradient varies as $V_{ac}{}^2$ and the tip oscillation is modulated at 2ω, while for electrically polarized samples ($Q_p \neq 0$), the tip oscillation is modulated at ω. Therefore by monitoring ω, information about charge distribution can be measured. The phase of this signal indicates the sign of the charge. The second harmonic signal at 2ω can be used to measure the dielectric constant.[1]

Piezo response imaging does not require additional dedicated hardware and works with both fixed tip/rastered sample (MultiMode) and fixed sample/rastered tip (Dimension, BioScope) SPMs. There are several consequences of the need to form a circuit to bias the sample:

- The sample must be electrically connected to the sample platform (e.g., with silver paint; see Figure 6.6a).

Figure 6.6a Electrically Connecting a Sample to the Piezo Cap (MultiMode) or Chuck (Dimension)



- Though a light imaging force best preserves samples, the tip must stay in contact with the sample to maintain the applied tip/sample voltage. A particularly rough sample may require a higher load force, higher gains or slower scan speeds to ensure a continuous electrical connection.

  Note: Internal current limiting protects the NSV Controller and the probetip when using the NanoScope V Controller to apply the bias voltage.

- A conductive cantilever (such as MESP [Magnetic, Etched Silicon Probe], NPG [silicon Nitride Probe, Gold-coated], PIC [Platinum Iridium, Contact], or PIT [Platinum Iridium, Tapping]) is required.

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[1] A. Gruverman et. al., “Imaging and control of domain structures in ferroelectric thin films via scanning force microscopy,” *Annu. Rev. Mater. Sci.*, 1998. 28:101-23.

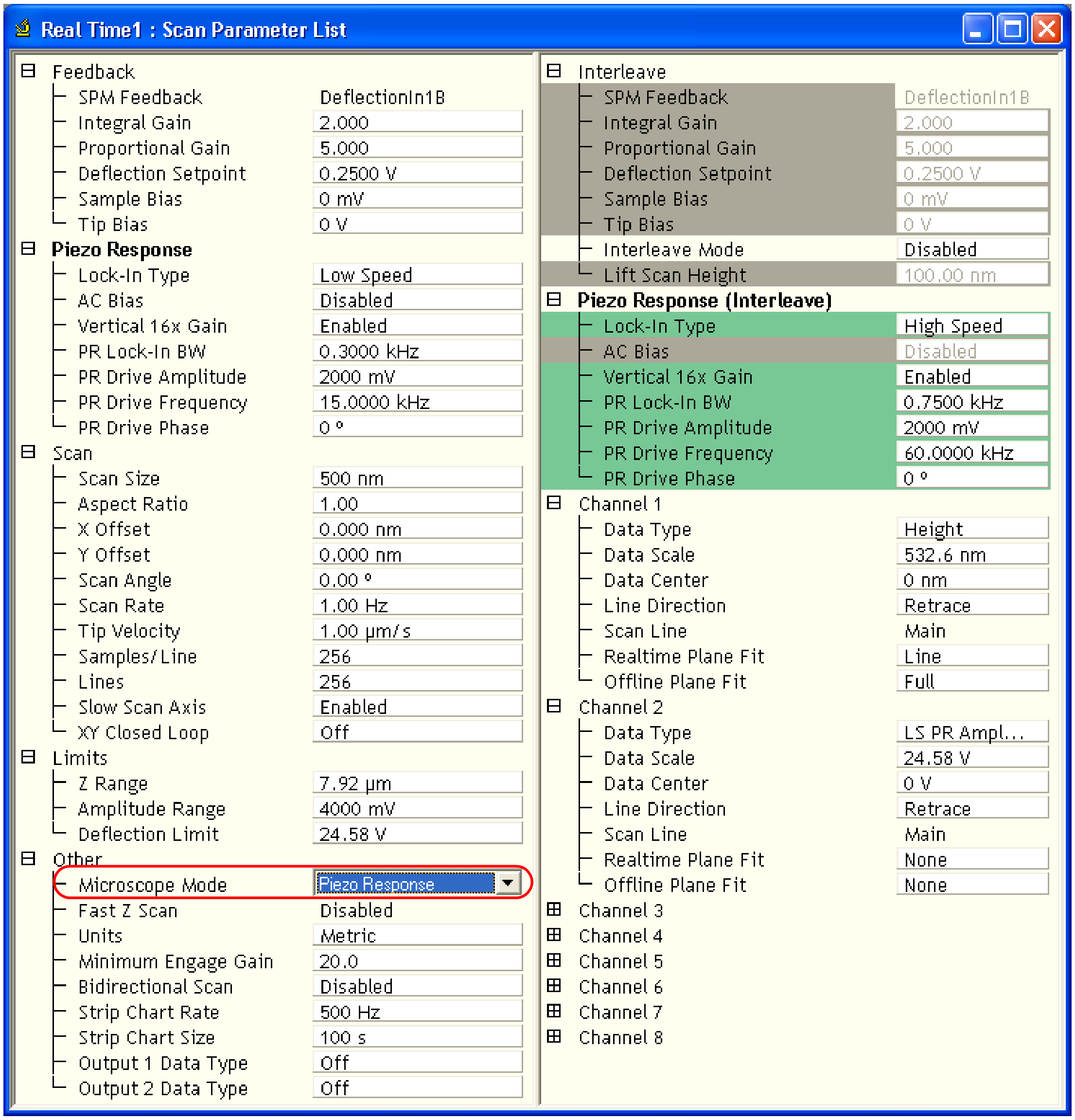
Note: Active tip cantilevers are not conductive, so PR is not operable with FastScan or dual scan, but only by normal scan using the tube scanner exclusively.

- Piezo response imaging may be performed in a nonconducting fluid. In a conductive fluid, a conductive cantilever must be insulated from the fluid, except at the tip; this is difficult to accomplish.

6.6.2 Software Selection

1. If you are not already operating in Realtime Mode, click the **REAL TIME** icon.
2. In the **Other** panel of the **Scan Parameters List**, select **Piezo Response** as the **Microscope mode**. The **Feedback** and **Piezo Response** panels display all Piezo Response control parameters (see Figure 6.6b).

Figure 6.6b Piezo Response: Scan Parameter List



Real Time1 : Scan Parameter List

Feedback	
SPM Feedback	DeflectionIn1B
Integral Gain	2.000
Proportional Gain	5.000
Deflection Setpoint	0.2500 V
Sample Bias	0 mV
Tip Bias	0 V
Piezo Response	
Lock-In Type	Low Speed
AC Bias	Disabled
Vertical 16x Gain	Enabled
PR Lock-In BW	0.3000 kHz
PR Drive Amplitude	2000 mV
PR Drive Frequency	15.0000 kHz
PR Drive Phase	0 °
Scan	
Scan Size	500 nm
Aspect Ratio	1.00
X Offset	0.000 nm
Y Offset	0.000 nm
Scan Angle	0.00 °
Scan Rate	1.00 Hz
Tip Velocity	1.00 µm/s
Samples/Line	256
Lines	256
Slow Scan Axis	Enabled
XY Closed Loop	Off
Limits	
Z Range	7.92 µm
Amplitude Range	4000 mV
Deflection Limit	24.58 V
Other	
Microscope Mode	Piezo Response
Fast Z Scan	Disabled
Units	Metric
Minimum Engage Gain	20.0
Bidirectional Scan	Disabled
Strip Chart Rate	500 Hz
Strip Chart Size	100 s
Output 1 Data Type	Off
Output 2 Data Type	Off

Interleave	
SPM Feedback	DeflectionIn1B
Integral Gain	2.000
Proportional Gain	5.000
Deflection Setpoint	0.2500 V
Sample Bias	0 mV
Tip Bias	0 V
Interleave Mode	Disabled
Lift Scan Height	100.00 nm
Piezo Response (Interleave)	
Lock-In Type	High Speed
AC Bias	Disabled
Vertical 16x Gain	Enabled
PR Lock-In BW	0.7500 kHz
PR Drive Amplitude	2000 mV
PR Drive Frequency	60.0000 kHz
PR Drive Phase	0 °
Channel 1	
Data Type	Height
Data Scale	532.6 nm
Data Center	0 nm
Line Direction	Retrace
Scan Line	Main
Realtime Plane Fit	Line
Offline Plane Fit	Full
Channel 2	
Data Type	LS PR Ampl...
Data Scale	24.58 V
Data Center	0 V
Line Direction	Retrace
Scan Line	Main
Realtime Plane Fit	None
Offline Plane Fit	None
Channel 3	
Channel 4	
Channel 5	
Channel 6	
Channel 7	
Channel 8	

Table 6.6a summarizes the functions of the parameters in the **Feedback** and **Piezo Response** panels of the **Scan Parameters** window.

Table 6.6a Piezo Response Controls Parameters

Parameter	Use with Piezo Response
SPM Feedback	DEFLECTIONIN1B.
Integral Gain	Set the Integral Gain to 2.0 initially.
Proportional Gain	Set the Proportional Gain to 5.0 initially.
Deflection Setpoint	Set to 0.25V initially. Decrease this later while observing an image to lower the force applied to the sample, or increase it to ensure contact on a rough, but robust, sample. This low vale, 0.25V, assumes a stiff cantilever (such as MESP, PIC or PIT).
Sample Bias	DC bias applied to the sample.
Tip Bias	DC bias applied to the tip.
Lock-In Type	Low Speed (15kHz max.) or High Speed (5MHz max.).
AC Bias	To prevent ESD damage, select DISABLED prior to engaging the sample. After engaging, select TIP or SAMPLE. If TIP is selected, the **AC BIAS** signal is supplied to the TIP and the SAMPLE is grounded. The converse is true if SAMPLE is selected.
Vertical 16x Gain	Increases the vertical gain by 16 times for more sensitivity.
PR Lock-In BW	Reduce for increased signal-to-noise ratio.
PR Drive Amplitude	Amplitude of the AC bias applied to the sample or probe tip. Set **PR DRIVE AMPLITUDE** to **2000MV** initially. Adjust this control of AC bias amplitude to optimize contrast in your PR image.
PR Drive Frequency	Frequency of the AC bias applied to the sample or probe tip. The bias frequency should be well above the scan rate so at least one full bias cycle is performed at each pixel in a piezoresponse image. Do not set **PR DRIVE FREQUENCY** near the cantilever resonant frequency because the probe could begin mechanically oscillating, compromise tip/sample contact and confound cantilever deflection due to energy absorbed at resonance from the desired deflection due only to piezoresponse of the sample.
PR Drive Phase	Phase of the lock-in amplifier with respect to the reference bias signal. Set **PR DRIVE PHASE** to **0°** initially. This may be adjusted to shift the location of high contrast regions in the piezoresponse image.
Deflection Limit	Decreases the dynamic range and therefore increases sensitivity.

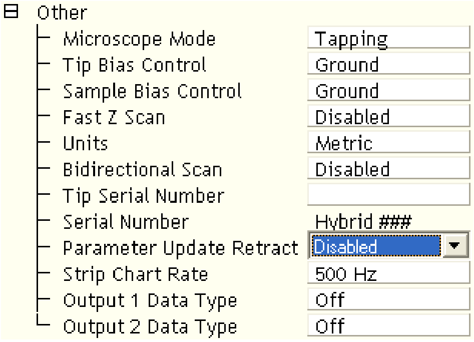
Select a piezo response **DATA TYPE**: Low Speed (**LS**) or High Speed (**HS**) **PR DATA**, **AMPLITUDE**, **PHASE**, **INPHASE** or **QUADRATURE** to image.

6.6.3 Example

Image a piezoelectric sample

1. DISABLE **PARAMETER UPDATE RETRACT**, shown in Figure 6.6c, in the **Other** panel of the **Scan Parameters List** window.

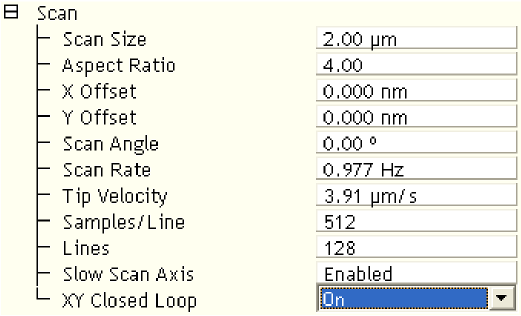
Figure 6.6c Disable **PARAMETER UPDATE RETRACT**



⊟ Other
- Microscope Mode: Tapping
- Tip Bias Control: Ground
- Sample Bias Control: Ground
- Fast Z Scan: Disabled
- Units: Metric
- Bidirectional Scan: Disabled
- Tip Serial Number:
- Serial Number: Hybrid ###
- Parameter Update Retract: Disabled
- Strip Chart Rate: 500 Hz
- Output 1 Data Type: Off
- Output 2 Data Type: Off

2. Turn **XY CLOSED LOOP**, shown in Figure 6.6d, in the **Scan** panel ON.

Figure 6.6d Turn **XY CLOSED LOOP** ON

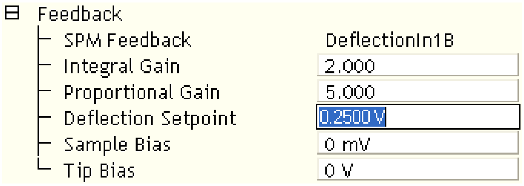


⊟ Scan
- Scan Size: 2.00 µm
- Aspect Ratio: 4.00
- X Offset: 0.000 nm
- Y Offset: 0.000 nm
- Scan Angle: 0.00 º
- Scan Rate: 0.977 Hz
- Tip Velocity: 3.91 µm/s
- Samples/Line: 512
- Lines: 128
- Slow Scan Axis: Enabled
- XY Closed Loop: On

3. In the **Other** panel of the **Scan Parameters List**, select **Piezo Response** as the **Microscope mode** (see Figure 6.6b).

4. To reduce tip wear and increase resolution, set the **Deflection Setpoint** (in the Feedback panel, Figure 6.6e) to a low value, `0.25V`.

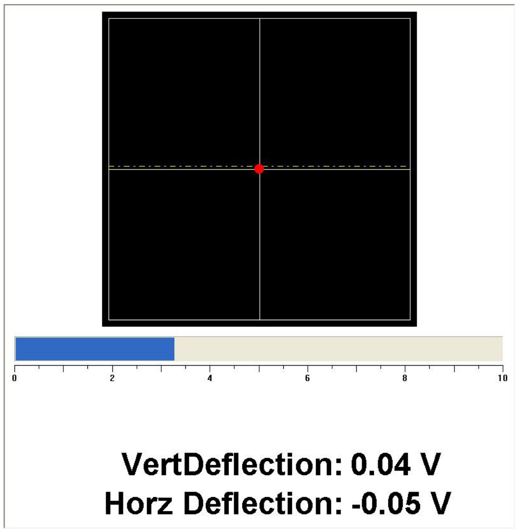
Figure 6.6e Set the **Deflection Setpoint** to `0.25V`



Feedback	
SPM Feedback	DeflectionIn1B
Integral Gain	2.000
Proportional Gain	5.000
Deflection Setpoint	0.2500 V
Sample Bias	0 mV
Tip Bias	0 V

5. Click the **Meter** workspace, shown in Figure 6.6f, and zero-out the photodetector. Note the low **Deflection Setpoint** (dashed line).

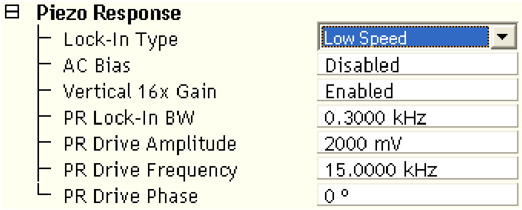
Figure 6.6f Zero the photodetector



VertDeflection: 0.04 V
Horz Deflection: -0.05 V

6. Set the **Piezo Response Lock-In Type** to `Low Speed`. See Figure 6.6g.

Figure 6.6g Set the **Piezo Response Lock-In Type** to `Low Speed`



Piezo Response	
Lock-In Type	Low Speed
AC Bias	Disabled
Vertical 16x Gain	Enabled
PR Lock-In BW	0.3000 kHz
PR Drive Amplitude	2000 mV
PR Drive Frequency	15.0000 kHz
PR Drive Phase	0 °

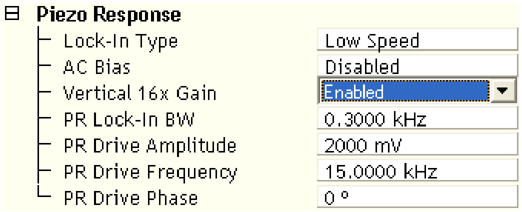
7. Assign the following Data Types to channels:

    - **Channel 1**: `Height`
    - **Channel 2**: `DeflectionIn1B`

- **Channel 3**: LS (LOW SPEED) PR (PIEZO RESPONSE) AMPLITUDE
- **Channel 4**: LS PR PHASE
- **Channel 5**: LS PR DATA
- **Channel 6**: LS PR INPHASE
- **Channel 7**: LS PR QUADRATURE

8. To increase vertical sensitivity, set the **Piezo Response VERTICAL 16X GAIN** to ENABLED. See Figure 6.6h.

Figure 6.6h Set the **Piezo Response VERTICAL 16X GAIN** to ENABLED



Piezo Response

Lock-In Type	Low Speed
AC Bias	Disabled
Vertical 16x Gain	Enabled
PR Lock-In BW	0.3000 kHz
PR Drive Amplitude	2000 mV
PR Drive Frequency	15.0000 kHz
PR Drive Phase	0 °

9. To further increase vertical sensitivity (by 6x), reduce the **DEFLECTION LIMIT** in the **Limits** panel to 4.096V. See Figure 6.6i.

Figure 6.6i Set the **Limits** > **DEFLECTION LIMIT** to 4.096V

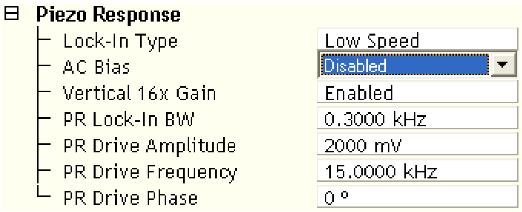
Limits

Z Range	7.92 µm
Amplitude Range	4000 mV
Deflection Limit	4.096 V

10. Set the **PR DRIVE AMPLITUDE** to 2000MV and the **PR LOCK-IN BW** to 0.3KHZ. See Figure 6.6h.

11. To prevent ESD, set the **AC Bias** to DISABLED before Engaging the sample. See Figure 6.6j.

Figure 6.6j Set the **AC Bias** to DISABLED before Engaging the sample



Piezo Response

Lock-In Type	Low Speed
AC Bias	Disabled
Vertical 16x Gain	Enabled
PR Lock-In BW	0.3000 kHz
PR Drive Amplitude	2000 mV
PR Drive Frequency	15.0000 kHz
PR Drive Phase	0 °

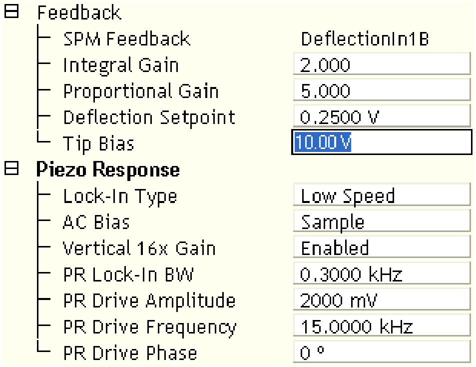
12. Set the remaining Scan parameters shown in Figure 6.6d:
    - **SCAN SIZE**: `2` µm
    - **ASPECT RATIO**: `4` (to speed imaging)
    - **SCAN RATE**: `1Hz`
    - **SAMPLES/LINE**: `512`
13. Engage the tip with the sample: click **RealTime** > **ENGAGE** or the **Engage** icon (shown).
14. Set the **AC Bias** to `SAMPLE`.

Write an area in the piezoelectric sample

Using the ferroelectric properties of piezoelectric materials, we will now write an area.

1. Change the **ASPECT RATIO** to `64` to write a small strip.
2. View the **LS PR Phase** channel.
3. Set the **REALTME PLANE FIT** to `NONE`.
4. Set the **TIP BIAS** to `10V` to write the area. See Figure 6.6k.

Figure 6.6k Set the **TIP BIAS** to 10V to write the area.



Feedback
SPM Feedback: DeflectionIn1B
Integral Gain: 2.000
Proportional Gain: 5.000
Deflection Setpoint: 0.2500 V
Tip Bias: 10.00 V
Piezo Response
Lock-In Type: Low Speed
AC Bias: Sample
Vertical 16x Gain: Enabled
PR Lock-In BW: 0.3000 kHz
PR Drive Amplitude: 2000 mV
PR Drive Frequency: 15.0000 kHz
PR Drive Phase: 0 º

5. After writing the area, turn off the **TIP BIAS** by setting it to `0V`.

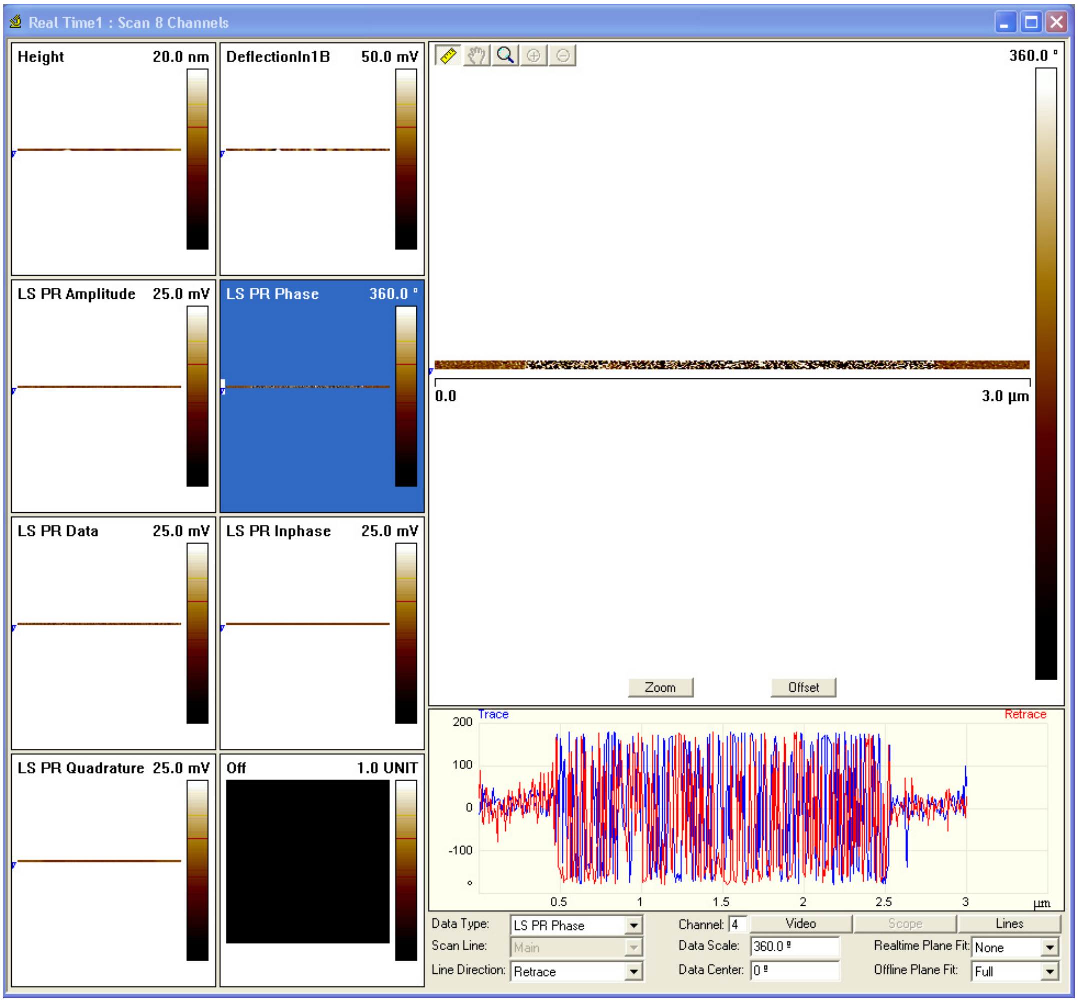
Image the written area

1. Increase the scan size to see the area that was written:

   - Increase the Scan Size to `3`µm. See Figure 6.6l. Note the written area between 0.5µm and 2.5µm.

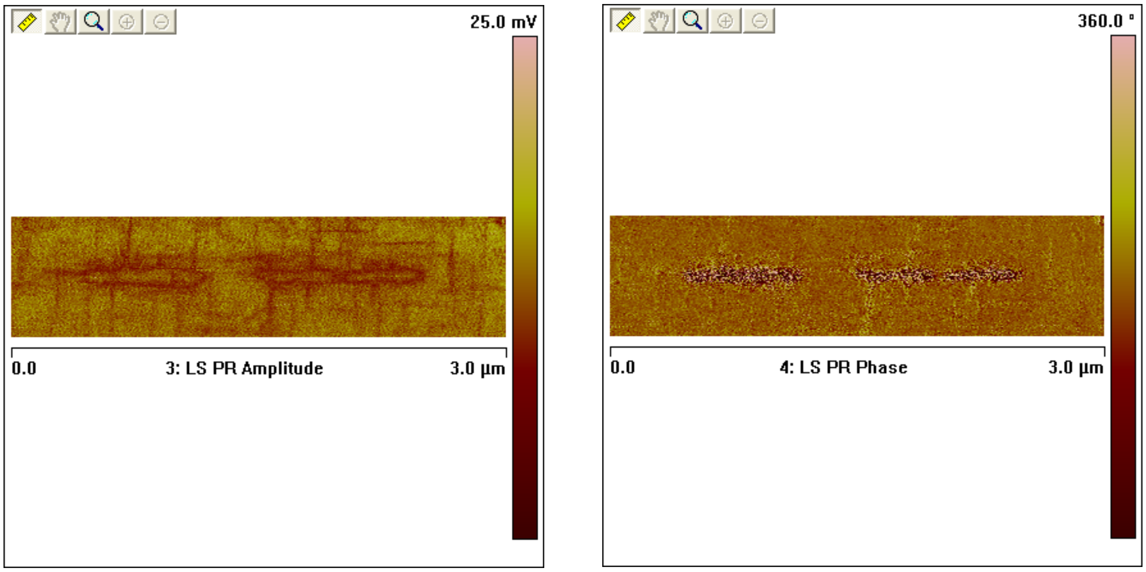
   - Increase the **Aspect Ratio** to `4`. The images are shown in Figure 6.6m.

Figure 6.6l Written strip



Data Type: LS PR Phase
Scan Line: Main
Line Direction: Retrace
Channel: 4
Data Scale: 360.0 º
Data Center: 0 º
Realtime Plane Fit: None
Offline Plane Fit: Full

Figure 6.6m Piezo Response images of written strip



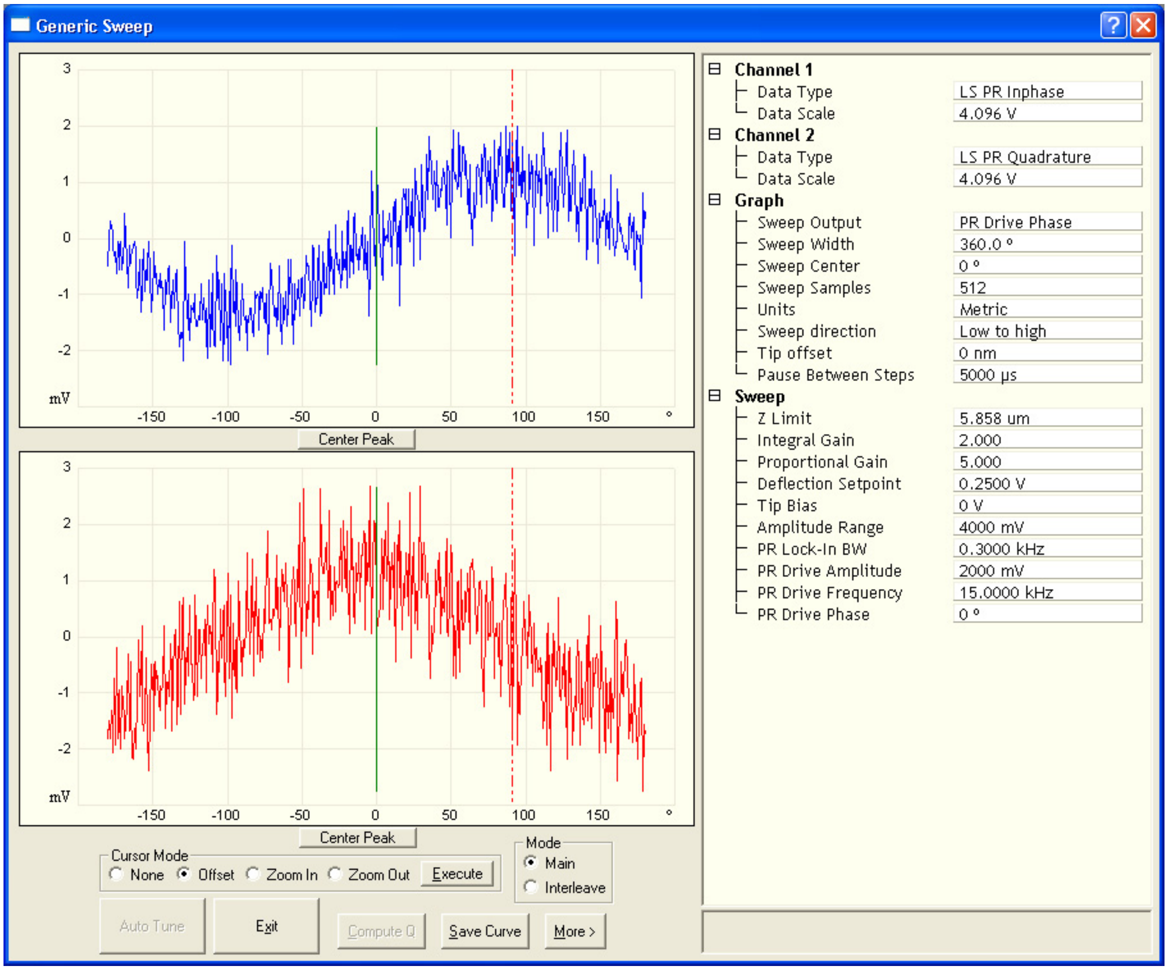
Optimize the image

Piezo response image contrast my be improved by using the **Generic Sweep** feature of the NanoScope V Controller to optimize the drive frequency or phase.

1. Start the **Generic Sweep** by clicking **RealTime** > **Generic Sweep**.

2. Set the tip offset to `0` in the **Start Sweep On Surface** window and click **OK** to open the Generic Sweep window, shown in Figure 6.6n.

Figure 6.6n Generic Sweep Window



Channel 1
- Data Type: LS PR Inphase
- Data Scale: 4.096 V

Channel 2
- Data Type: LS PR Quadrature
- Data Scale: 4.096 V

Graph
- Sweep Output: PR Drive Phase
- Sweep Width: 360.0 °
- Sweep Center: 0 °
- Sweep Samples: 512
- Units: Metric
- Sweep direction: Low to high
- Tip offset: 0 nm
- Pause Between Steps: 5000 µs

Sweep
- Z Limit: 5.858 um
- Integral Gain: 2.000
- Proportional Gain: 5.000
- Deflection Setpoint: 0.2500 V
- Tip Bias: 0 V
- Amplitude Range: 4000 mV
- PR Lock-In BW: 0.3000 kHz
- PR Drive Amplitude: 2000 mV
- PR Drive Frequency: 15.0000 kHz
- PR Drive Phase: 0 °

3. Set the **Channel 1 Data Type** to `LS PR Inphase` and the **Channel 2 Data Type** to `LS PR Quadrature`.

4. Set the **Sweep Output** to `PR Drive Phase`.

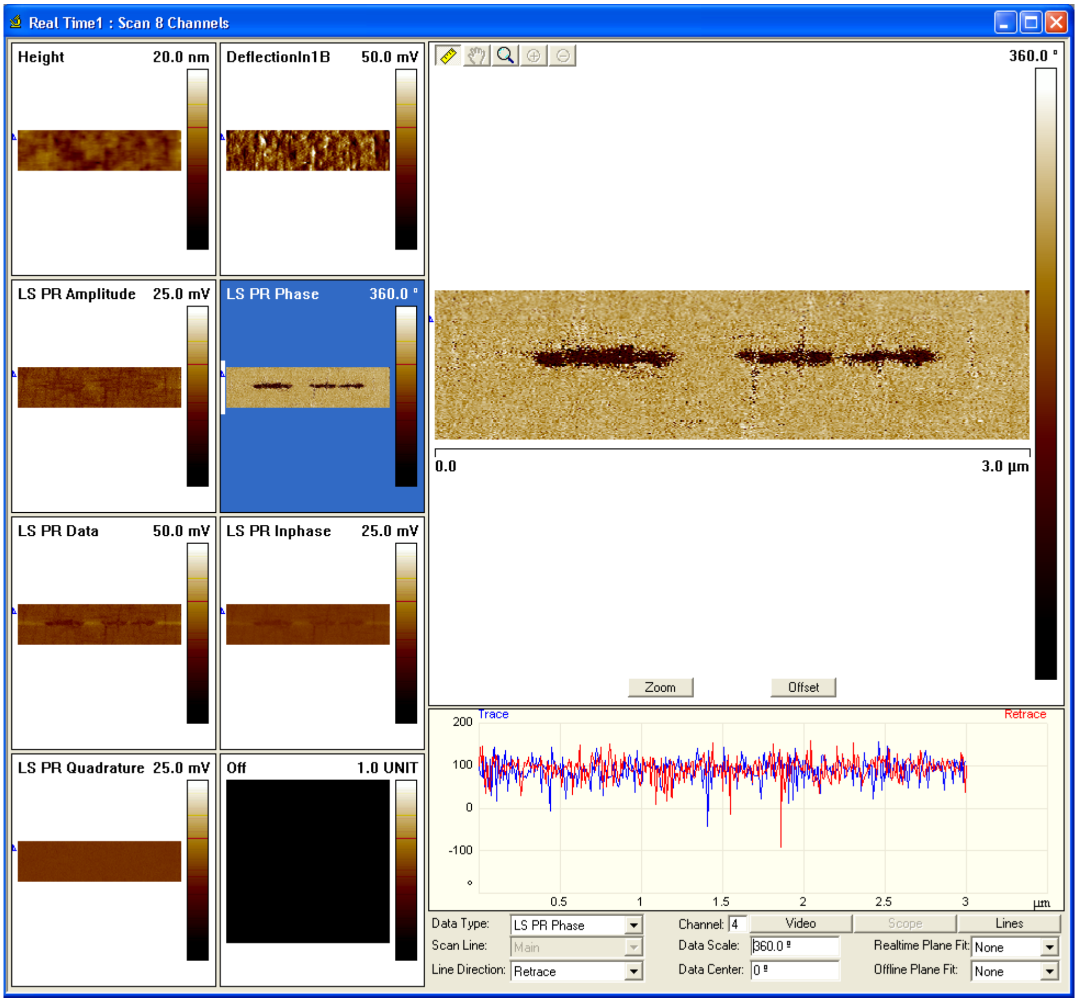
5. Click the **Offset Cursor Mode** radio button.

6. Drag the dashed red cursor to the point of maximum response and click **Execute** to set the **PR Drive Phase**.

7. Click **Exit** to exit the **Generic Sweep** function.

This will change the **PR Drive Phase** to maximize the PR In Phase signal and minimize the PR Quadrature signal. See Figure 6.6o.

Figure 6.6o LS PR In Phase optimized



Data Type: LS PR Phase
Scan Line: Main
Line Direction: Retrace
Channel: 4
Data Scale: 360.0 º
Data Center: 0 º
Realtime Plane Fit: None
Offline Plane Fit: None

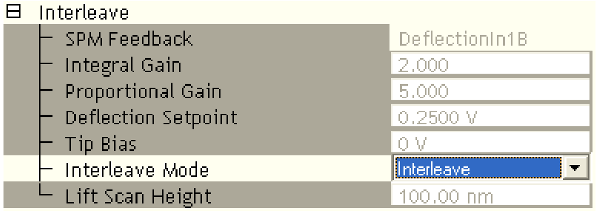
8. Similarly, one may also optimize LS PR Quadrature.

Simultaneous Multiple Optimizations

It is possible to simultaneously optimize two PR parameters using both the Low Speed (LS) and High Speed (HS) Lock Ins by using one on the **MAIN SCAN LINE** and the other on the **INTERLEAVE SCAN LINE**.

1. Set **INTERLEAVE** to `INTERLEAVE`. See Figure 6.6p.

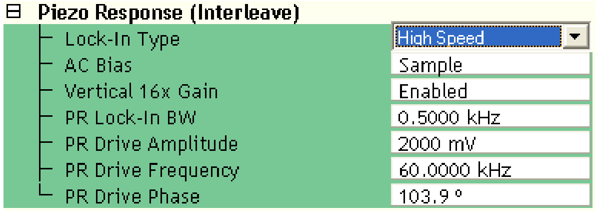
Figure 6.6p Interleave



Interleave	
SPM Feedback	DeflectionIn1B
Integral Gain	2.000
Proportional Gain	5.000
Deflection Setpoint	0.2500 V
Tip Bias	0 V
Interleave Mode	Interleave
Lift Scan Height	100.00 nm

2. Set the **Piezo Response (Interleave) LOCK-IN TYPE** to HIGH SPEED. See Figure 6.6q.

Figure 6.6q Set the **Piezo Response (Interleave) LOCK-IN TYPE** to HIGH SPEED.

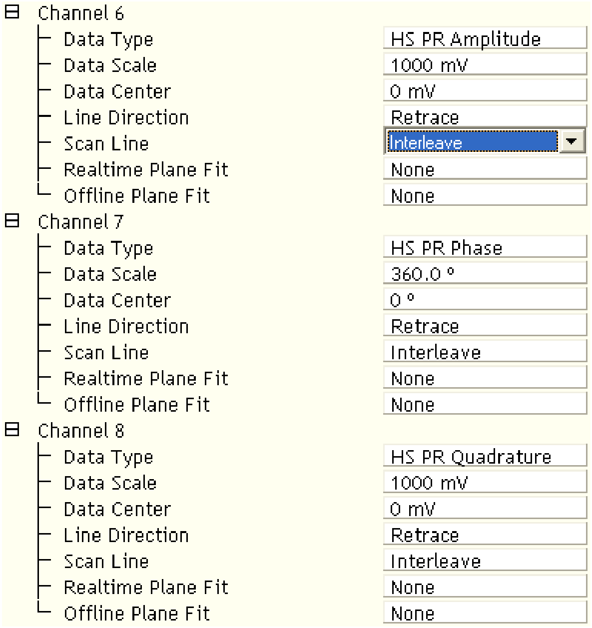


Piezo Response (Interleave)	
Lock-In Type	High Speed
AC Bias	Sample
Vertical 16x Gain	Enabled
PR Lock-In BW	0.5000 kHz
PR Drive Amplitude	2000 mV
PR Drive Frequency	60.0000 kHz
PR Drive Phase	103.9 °

3. Set the other **Interleave Piezo Response** parameters as shown in Figure 6.6q.

4. Set the **SCAN LINE** for Channel 6, Channel 7 and Channel 8 to INTERLEAVE. See Figure 6.6r.

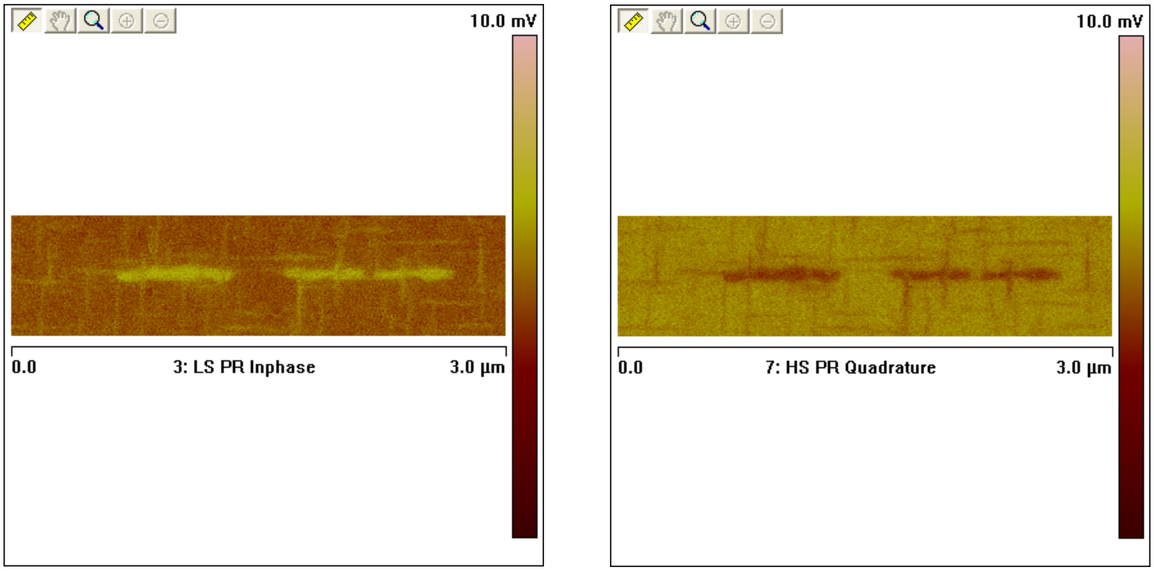
Figure 6.6r Set the **SCAN LINE** to INTERLEAVE.



Channel 6	
Data Type	HS PR Amplitude
Data Scale	1000 mV
Data Center	0 mV
Line Direction	Retrace
Scan Line	Interleave
Realtime Plane Fit	None
Offline Plane Fit	None
Channel 7	
Data Type	HS PR Phase
Data Scale	360.0 °
Data Center	0 °
Line Direction	Retrace
Scan Line	Interleave
Realtime Plane Fit	None
Offline Plane Fit	None
Channel 8	
Data Type	HS PR Quadrature
Data Scale	1000 mV
Data Center	0 mV
Line Direction	Retrace
Scan Line	Interleave
Realtime Plane Fit	None
Offline Plane Fit	None

5. Assign the following **Data Types** to channels:
    - **Channel 1**: Height
    - **Channel 2**: DeflectionIn1B
    - **Channel 3**: LS (Low Speed) PR (Piezo Response) Amplitude
    - **Channel 4**: LS PR Phase
    - **Channel 5**: LS PR Data
    - **Channel 6**: HS PR Amplitude
    - **Channel 7**: HS PR Phase
    - **Channel 8**: HS PR Quadrature
6. Start the **Generic Sweep** function, select the **Main** radio button (see Figure 6.6n) and optimize the LS PR Inphase signal using the procedure **Optimize the image,** page 58.
7. Select the **Interleave** radio button (see Figure 6.6n) and optimize the HS PR Quadrature signal using the procedure **Optimize the image,** page 58.
8. Re-scan the sample. The optimized images are shown in Figure 6.6s.

Figure 6.6s Simultaneously Optimized **In Phase** and **Quadrature** Images



6.7 High Resolution Imaging

Your NanoScope V Controller can collect data at a maximum rate of 5120 x 5120 points per image for 3 simultaneous channels. The maximum data rate is reduced to 1024 x 1024 for eight simultaneous channels. This increase makes reimaging at higher resolution unnecessary in many situations.

6.8 PicoAngler

The PicoAngler, shown in Figure 6.8a, provides a novel interface, modeled on the experience of fishing, for “catching” a molecule, pulling on it and feeling its resistance to unfolding from its resting position on the sample platform. The handheld PicoAngler displays numerically the Z-position offset added by the PicoAngler and, in digital light bars, cantilever deflection, force sensitivity and step sensitivity. The controls that the PicoAngler provides are: **Z-POSITION** (with simultaneous force feedback), **FORCE SENSITIVITY** and **STEP SENSITIVITY**. Each of these is described below.

- Z-position digital readout—displays in nanometers over a range of ±20µm, from fully extended (positive) to fully retracted (negative), the current Z-offset which the PicoAngler is adding to the Z-signal coming from the NanoScope V Controller.

  Note: The PicoAngler adds a voltage to the low voltage Z signal coming from the NanoScope V Controller before it is amplified in the closed loop Z-axis circuitry of the PicoForce Control Module. The low voltage Z signal from the Nanoscope controller can vary over ±10V, which corresponds to the full range of the PicoForce Scanner Z-range. The PicoAngler can add an offset to this voltage sufficient to move the Z-position anywhere in its range, regardless of the current value coming from the controller. For example, if the controller voltage is at -10V (fully retracted), the PicoAngler can add 20,000nm (~20V) to that value in order to fully extend the Z-piezo. So while the PicoAngler is capable of adding ±20,000nm, you will only use the maximum PicoForce offset if the Nanoscope Controller is fully extended or retracted. During normal operation when the controller is directing the Z-piezo to be near the middle of its range (~0 V), the useful range of the PicoAngler will be about ±10,000nm, corresponding to the ~20um range of the PicoForce Z-stage. Continuing to turn the knob when the stage has already reached its limit will not damage the unit in any way, but the position offset indicated by the LCD display on the PicoAngler will be inaccurate.

- Relative deflection display—is indicated by the horizontal light bar. A tip deflected downwards by attraction to the sample moves the light to the left of center (blue). A tip deflected away from the sample by contact with it moves the light to the right of center (red).

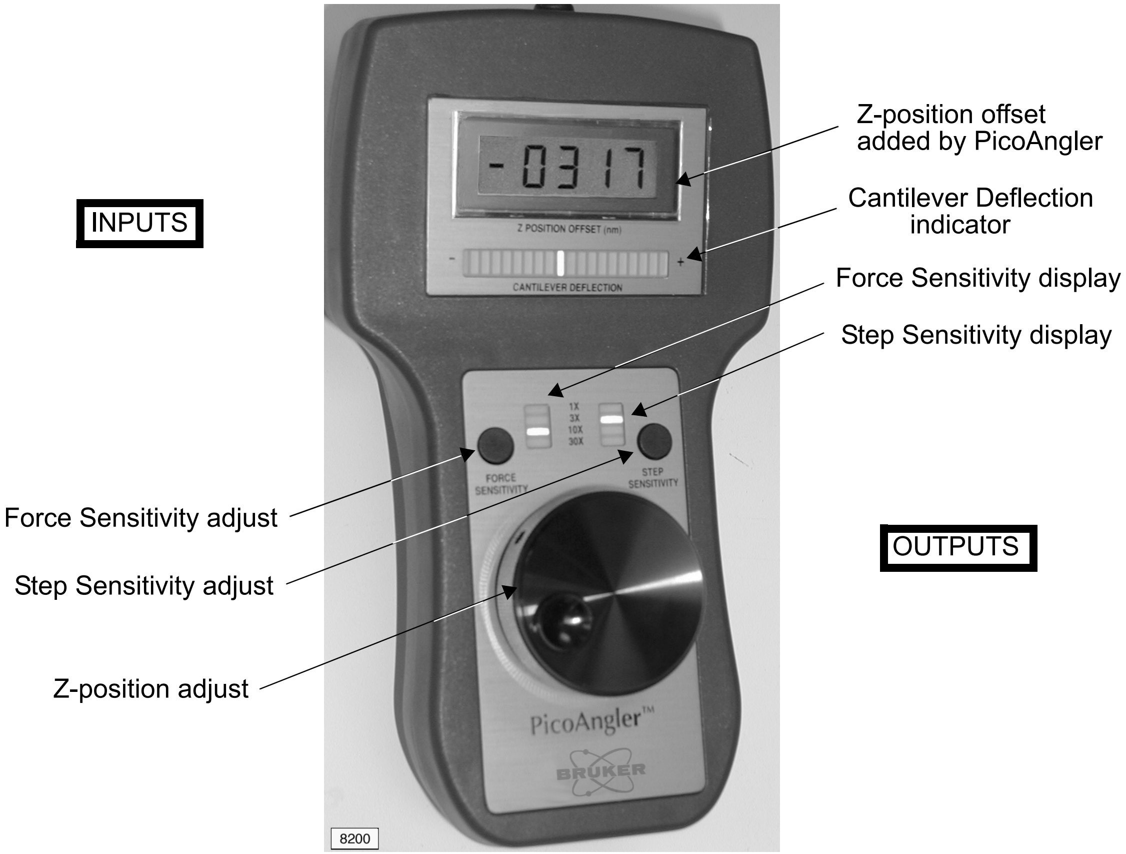
- **FORCE SENSITIVITY** knob—adjusts the strength of force feedback felt while turning the Z-position knob. The selection, 1×, 3×, 10×, or 30×, is indicated on the associated vertical 4-position light bar.

- STEP SENSITIVITY knob—adjusts the range of Z-motion in one full revolution of the Z-position knob. The selection, 1×, 3×, 10×, or 30×, is indicated on the associated vertical 4-position light bar.

- Z-position knob—adjusts the sample platform proximity to the probe in realtime while resisting adjustment in proportion to the induced deflection of the cantilever.

Note: Manual control is ideal for exploratory force plots. Use the PicoAngler to bring the sample platform toward the tip arbitrarily slowly, then feel the cantilever deflect decidedly when the tip and sample begin to interact. Once the tip is pressed into the sample and deflecting as the sample is raised toward the tip, the decision to begin to retract is informed by tactile feedback, the Z-position readout on the PicoAngler and displayed Realtime force plot. For multiple force plots, triggered basic or scripted force plots may produce more repeatable results than the PicoAngler simply because the sample platform movement is pre-defined, so identical with each repetition.

Figure 6.8a The PicoForce PicoAngler



6.8.1 Directing a Force Plot Under Full Manual Control with the PicoAngler

Using the procedure below, you can make and record manual force curves by using the PicoAngler to control the tip-sample separation. When using the PicoAngler in this way, the Strip Chart Mode data collection is used, as described in the previous section.

1. Click PicoForce Controls > **ANGLER ENABLE** to activate PicoAngler (see Figure 6.8b).

   Note: Verify switch on PicoForce Control Module is set to **ANGLER INPUT**.

CAUTION: The PicoAngler adds a voltage to the Z-piezo drive signal otherwise set through the NanoScope software. The PicoAngler contribution, as displayed in nanometers by the Z-position digital readout (see Figure 6.8a) **should be near zero when first engaging the microscope**. This is most easily accomplished in **Force Mode View** by clicking PicoForce Controls > **ANGLER RESET** to zero the Z-position offset (see Figure 6.8b) or by manually turning the knob.

2. Click the **ZERO SETPOINT** button to set the noncontact force.

3. Click Strip Chart Controls > **START** (see Figure 6.8b**)**.

   Note: Click Strip Chart Controls > **RESET** if the top or middle graph windows display anything from prior strip chart recording.

   Note: You may set the **SAMPLE RATE** and **DISPLAY SIZE** in the force menu.

4. Turn the Z-position adjust knob (see Figure 6.8a) clockwise to move the sample platform toward the tip.

   Note: Positive deflection is signaled by red lights to the right on the Cantilever Deflection indicator. Negative deflection is signaled by blue lights to the left on the same indicator.

5. Feel the force feedback through the Z-position adjust knob as the tip and sample interact. The top **Force Mode View** graph displays cantilever deflection as a function of time; the middle graph displays sample platform Z-position as a function of time.

   Note: The PicoAngler Z-position readout also displays sample platform Z-position in nanometers according to the same conventions:

   a. A negative Z-axis motion separates tip and sample. A positive Z-axis motion brings tip and sample closer together.

   b. The middle Force Mode graph plots absolute Z-position, where Z=0 roughly is the middle of the range of Z-axis travel. The PicoAngler Z-position readout displays relative Z-position, where Z=0 at the sample platform position when Picoforce Controls > **ANGLER RESET** was last clicked.

6. Continue to press tip and sample together to as high a cantilever deflection as desired (keeping in mind sample fragility, laser alignment and cantilever fragility).

7. Turn the Z-position adjust knob counterclockwise to retract the sample from the tip. Continue until you no longer feel or observe tip/sample interaction.

8. Click **STRIP CHART CONTROLS** > **PAUSE** to terminate (Z-position, deflection) data collection and freeze the three graphs.

9. The bottom graph displays a force plot by pairing data points determined at the same time on the top and middle graphs. The entire time interval is used in the force plot.

10. To zoom in on the force plot, position the cursor over either the left or right edge of either the top or middle graph, then drag a line marker into the graph. Repeat the action to provide a second marker line. Position the marker lines to bracket the time interval of interest in both the top and middle graphs simultaneously. The (bottom) force plot is redrawn, restricted to the subinterval of time defined by the markers.

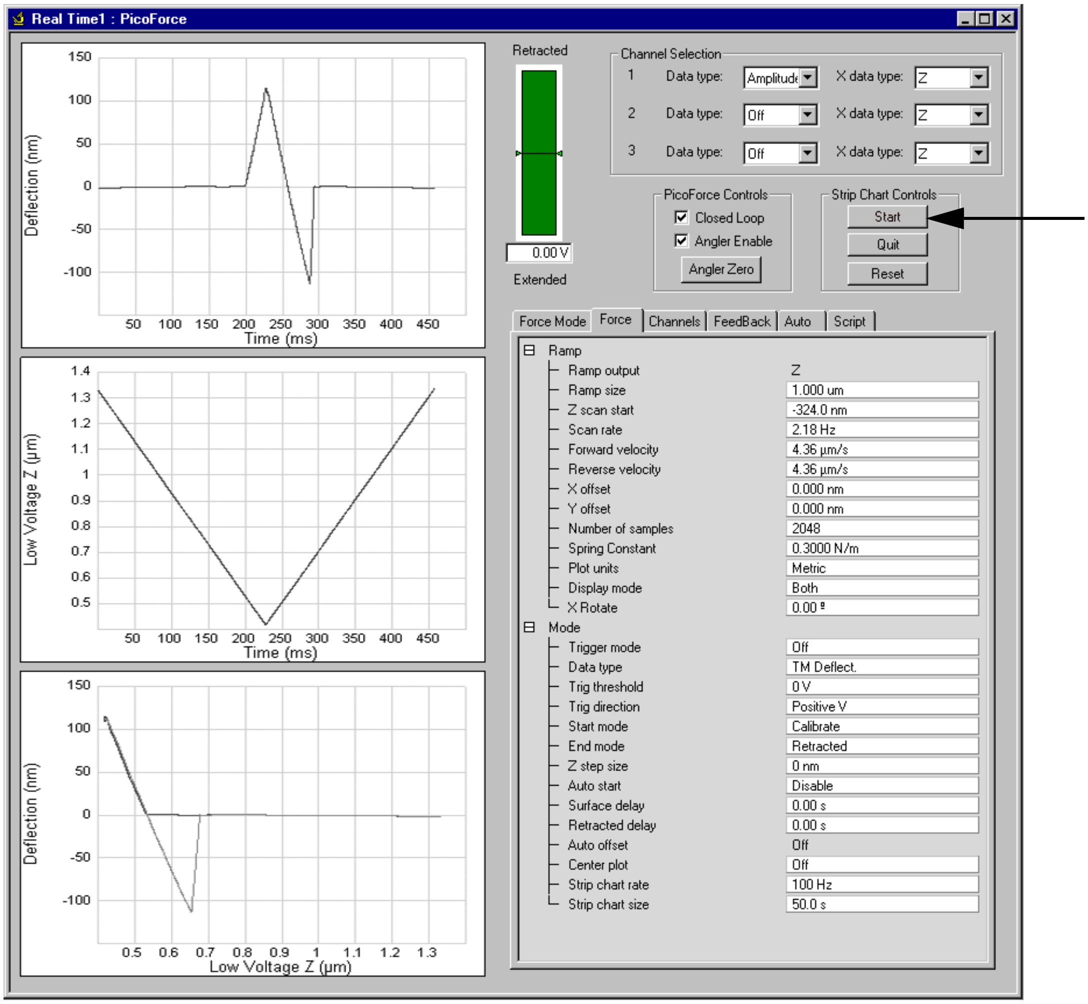
Note: To zoom into the top or middle graphs to better view detail, press **CONTROL** on your keyboard and use the mouse to drag a box around the area you want to zoom. To zoom out: double click inside the graph.

6.8.2 Using the PicoAngler in Conjunction with Basic Force Plots

Besides being used as a tool for fully manual force curves, the PicoAngler is also very useful during basic force curves. In basic force curves, if no trigger is set and the continuous ramp button is clicked, the piezo begins to ramp up and down around the defined **Z START** position. This may not result in a force plot if the automated ramping is not bringing the tip close enough to the sample. Before PicoForce, the only way to guarantee force plot generation was to manually adjust the **Z START** position parameter in software or else define a trigger and turn on the “auto-offset” feature to find the surface. With the PicoAngler, however, you can conveniently and quickly find the surface by enabling the PicoAngler, beginning continuous force ramps in Basic Force Mode, and then using the PicoAngler to reduce the ramping tip-sample separation. This is functionally equivalent to moving down the **Z START** position, but it is more convenient since you only have to turn the knob instead of manually adjusting a numerical parameter. The force-feedback feature of the PicoAngler knob also makes it clear when you have found the surface. There, use the PicoAngler to fine-tune the offset of the force plot (how much of it occurs on the surface and how much is the retraction). You may find this a convenient alternative to using triggers in some applications.

CAUTION: While the PicoAngler is helpful in tip/sample engagement in Basic Force Mode, once on the surface, if not using the PicoAngler for a while, you may want to disengage to avoid the possibility of accidentally bumping the Z-position adjustment knob when tip/sample separation is being controlled independently.

Figure 6.8b Force Mode: Channels Tab Featuring Inverted Channel 2 Z-Axis



Channel Selection

	Data type:	X data type:
1	Amplitude	Z
2	Off	Z
3	Off	Z

☑ Closed Loop
☑ Angler Enable

⊟ Ramp

Ramp output	Z
Ramp size	1.000 um
Z scan start	-324.0 nm
Scan rate	2.18 Hz
Forward velocity	4.36 µm/s
Reverse velocity	4.36 µm/s
X offset	0.000 nm
Y offset	0.000 nm
Number of samples	2048
Spring Constant	0.3000 N/m
Plot units	Metric
Display mode	Both
X Rotate	0.00 º

⊟ Mode

Trigger mode	Off
Data type	TM Deflect.
Trig threshold	0 V
Trig direction	Positive V
Start mode	Calibrate
End mode	Retracted
Z step size	0 nm
Auto start	Disable
Surface delay	0.00 s
Retracted delay	0.00 s
Auto offset	Off
Center plot	Off
Strip chart rate	100 Hz
Strip chart size	50.0 s

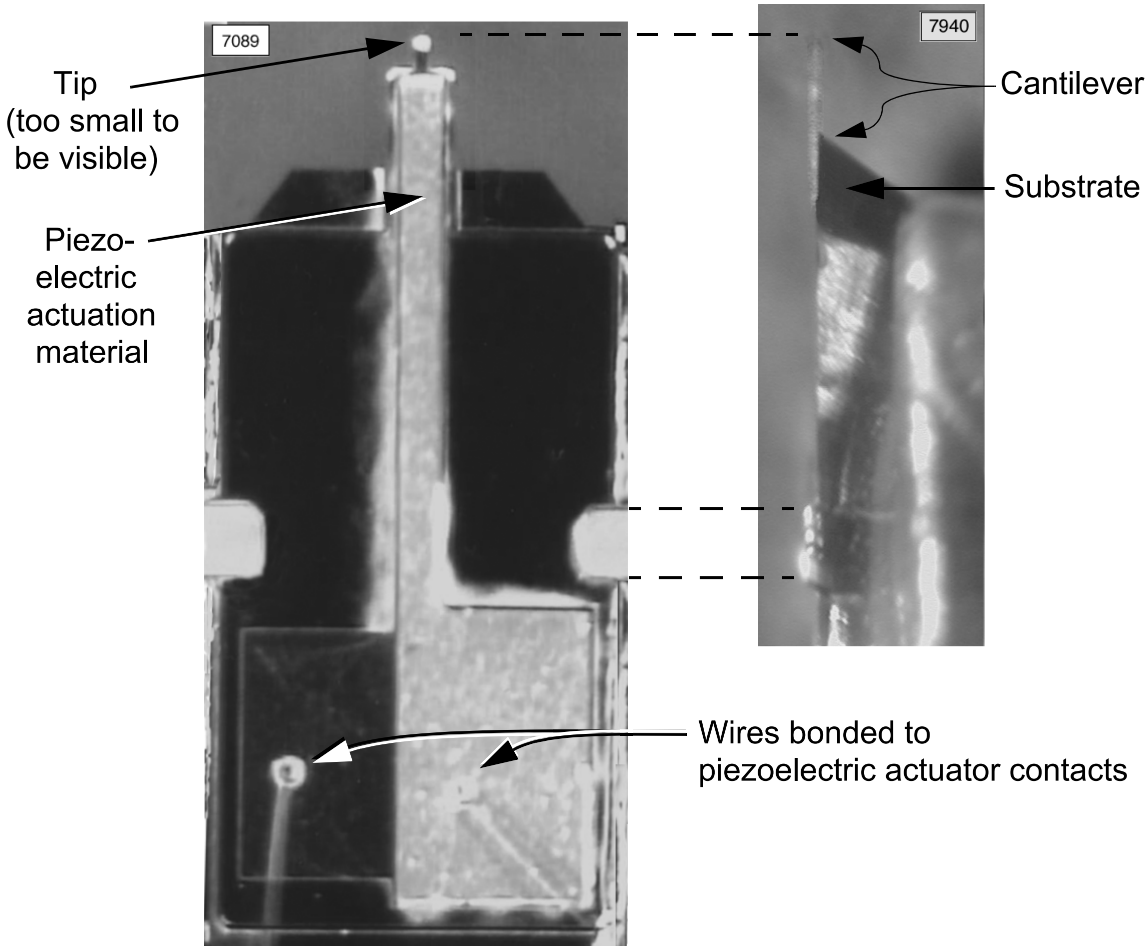
Chapter 7 Fast Scan

7.1 Active Tip Probes

The FastScan capability of the NanoScope V Controller is based on an Active Tip probe, which merges in a single component the essential microscope/sample interface element—the probetip—with the vertical position control mechanism, a piezoelectric actuator (see Figure 7.1a). A voltage applied across the Active Tip probe bond pads induces expansion (or contraction) of the piezoelectric material. Where the actuator material overlays the cantilever beyond the edge of the substrate, the cantilever is free to respond by lifting the tip away from the sample (or lowering it toward the sample).

FastScan/Active Tipe probes are not available on the BioScope II.

Figure 7.1a Active Tip Probe: Looking at Tip (Left), Side View (Right)



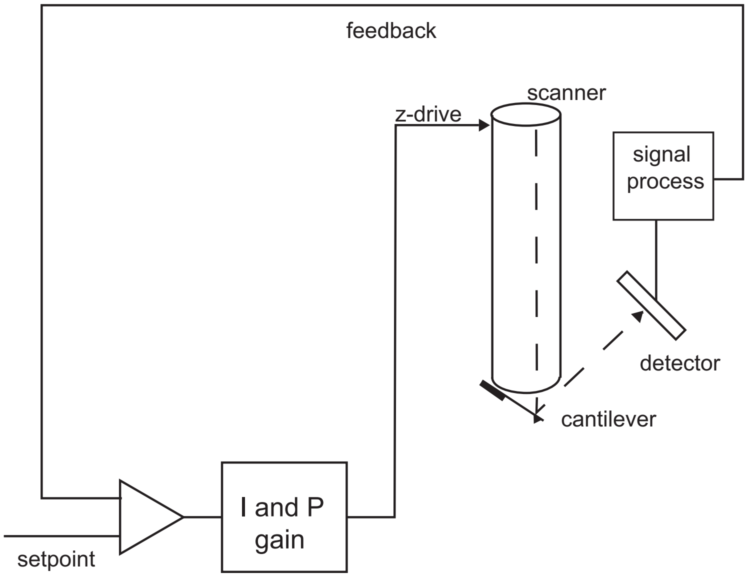
7.2 Dual Actuator FastScan

The FastScan capability of the NanoScope V Controller offers three specific benefits.

- First, **for samples with less than 700nm topographic range, the cantilever-mounted fast actuator may be used alone for the highest scan speed and least tip damage**.
- Second, for samples with more than 700nm topographic range, the traditional piezoelectric scanner and the cantilever-mounted piezoelectric element are combined in **dual actuation**, **providing either faster scanning with the same rate of tip wear** as compared to traditional scanner-only imaging…
- …**or reduced tip wear at the same scan rate** (benefit three).

The heart of most SPMs is a feedback loop controlling tip/sample interaction. Many of the wide range of nanoscale measurements made possible by SPM technology are based on reading the feedback signal that is recorded while comparing from position to position along a scan line the effort necessary to restore a standard interaction of the desired parameter. For instance, the original target parameter—surface height—is derived from the displacement of the scanner required to maintain a fixed tip/sample separation. An AFM in TappingMode deduces the same target parameter values by controlling tip/sample separation through monitoring the amplitude of the oscillations of the cantilever.

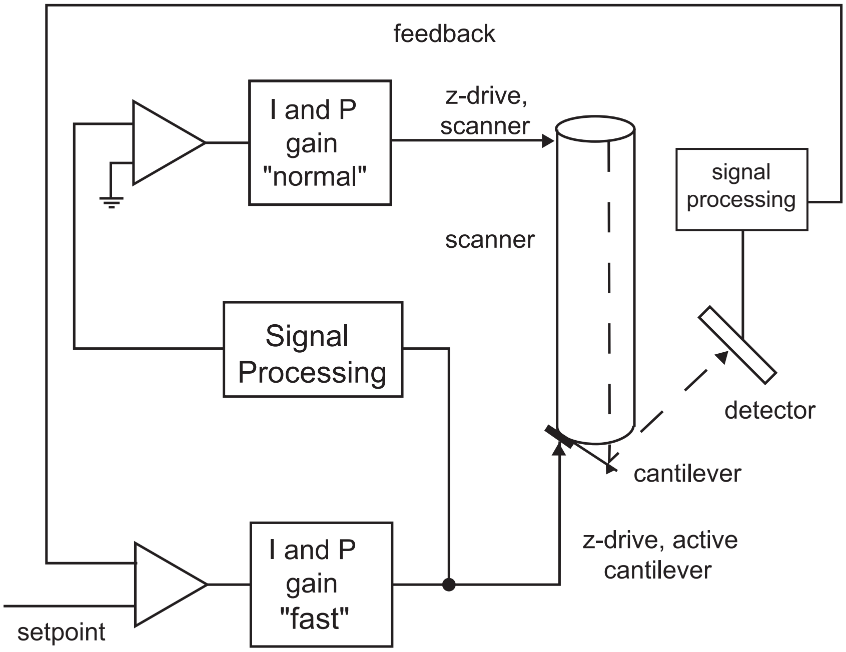
Figure 7.2a The Traditional SPM Feedback Loop



The image acquisition sampling rate is therefore constrained by the frequency response of the components of the feedback loop—in particular, the most bandwidth-limited element. The natural resonances of the largest mechanical component, normally the scanner tube, that displaces the probe as a whole in the Z-direction, acts as the limiting factor on the bandwidth of the feedback signal in traditional SPM controllers (see Figure 7.2a).

Two-stage actuation is the strategy taken to increase scan rate without reducing the height (and thereby the inertia, but also the Z-range) of the entire piezoelectrically-driven scanner. The NanoScope V Controller in FastScan Mode also employs a second, smaller, faster piezoelectric actuator at the base of the cantilever as part of an Active Tip probe. Both positioners operate within a single nested feedback loop. The normal loop tracks the surface over a large Z-range (205nm/V × 440V = 90µm for typical Dimension Hybrid XYZ, and “G” and “J” MultiMode scanners, which have the largest Z-range), but with a relatively long response time to abrupt topography changes. The Active Tip fast actuator (both for Dimension and MultiMode SPMs) is limited to a total Z-range of approximately 700nm, but responds quickly to sample surface steps (see Figure 7.2b). Together, the two actuators provide both range of motion and response speed.

Figure 7.2b The NanoScope V Controller Microactuated SPM Dual Feedback Loop



Note: Speed of image acquisition is limited first by the height of steep features in the sample. If a feature is taller than approximately 700nm, the normal Z-scanner (with its slower response time) must be active in addition to the fast actuator to avoid crashing the tip into the feature. Otherwise, the tip scanning velocity and feature slope determine whether either the Z-scanner or fast actuator response time is insufficient to track the surface under controlled, constant tip/sample force. The tip scanning velocity is twice the product of scan rate (in hertz) and scan size. In units:

(1/second) × (meter) = (meter/second).

7.2.1 FastScan in Contact Mode

In the traditional SPM feedback loop (see Figure 7.2a) in Contact Mode all Z-direction probe travel is due to activation of the “normal” scanner piezoelectric actuator. The probe is raised or lowered while contacting the sample to restore the cantilever deflection angle and, therefore, a constant tip/sample force. Any cantilever deflection can be converted directly into a height measurement equal to the vertical displacement of the scanner made in response to sample topography.

The NanoScope V Controller offers a spectrum of probe control options ranging from traditional normal actuation only, to fast actuation only, as well as any combination in between. Feedback processing differs between the fast and normal actuators. In the case of fast-only actuation, in response to a change in sample height as detected by a change of cantilever angle while scanning, the probe may only be raised or lowered by activating the Active Tip (fast) actuator. Just like in normal actuation, this displaces the probetip in the Z-direction as needed, but unlike normal actuation, it also alters the cantilever deflection angle in a way that may not converge on the cantilever angle specified as the deflection setpoint. In other words, fast actuation while the tip is scanning the surface results in a cantilever deflection signal consisting of two components: one due to topography and the other due to fast actuation. Physically, during scanning, fast actuation is applied to maintain a constant tip/sample force, so always acts in opposition to the topographically-induced force on the tip. Thus, unlike normal actuation, fast actuation does not maintain a constant cantilever deflection angle to maintain a constant tip/sample force. Because cantilever deflection angle is used as a control signal in both normal and fast actuation, the fast actuator control loop must subtract the component due to fast actuation alone, so as to isolate and control only the component due to topography (see
Figure 7.2c).

The **Fast Scan Engage**/**DETERMINE CONTACT GAIN** parameter is enabled (see Figure 7.3i) to perform the subtraction of the fast actuation component from the cantilever deflection signal. Because the desired error signal from either control loop is a topographic height, the fast actuation-induced component is translated into a pseudo-height which is subtracted from the cantilever deflection signal to produce an accurate height representation (see equation below).

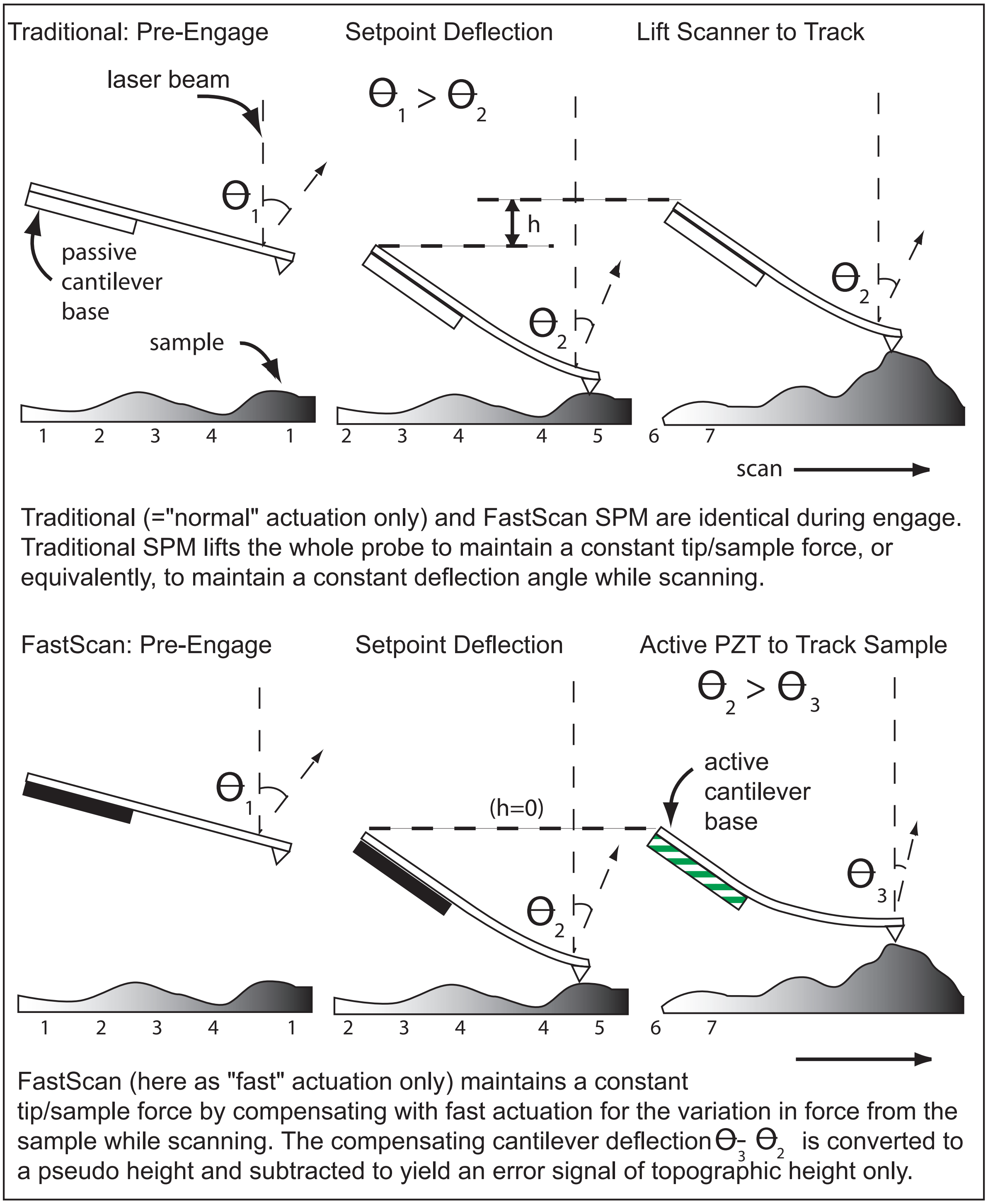
$$V_{\text{topographic component}} = V_{\text{cantilever deflection}} - [(\text{Fast Z})(\text{Contact Gain})/4096]$$

To calibrate **CONTACT GAIN**, measure cantilever deflection as a function of fast actuation with the probe in air, not contacting a sample. This eliminates the topographic component of cantilever deflection. With **CONTACT GAIN** set properly, the corrected cantilever deflection signal remains unchanged as the fast actuator is activated in air.

Typically, both actuators are activated to provide the full range of motion of the normal scanner along with the quick response of the fast actuator.

For further discussion of active tip compensation (though employed for a single actuator control system), refer to *High-Speed Atomic Force Microscopy Using an Integrated Actuator and Optical Lever Detection*, by S. R. Manalis, et. al., Review of Scientific Instruments 67 (9), September 1996.

Figure 7.2c Translating Deflection by Cantilever PZT Actuation into Topographic Height (Not to Scale)



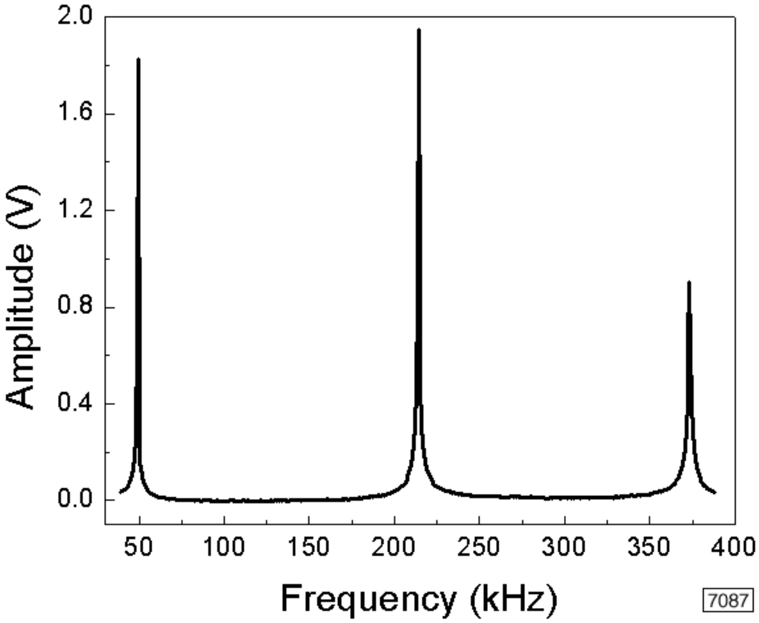
Traditional (="normal" actuation only) and FastScan SPM are identical during engage. Traditional SPM lifts the whole probe to maintain a constant tip/sample force, or equivalently, to maintain a constant deflection angle while scanning.

FastScan (here as "fast" actuation only) maintains a constant tip/sample force by compensating with fast actuation for the variation in force from the sample while scanning. The compensating cantilever deflection $\theta_3 - \theta_2$ is converted to a pseudo height and subtracted to yield an error signal of topographic height only.

7.2.2 FastScan in TappingMode

Active Tip probes exhibit three resonances: at approximately 50 kHz, 200 kHz and above 300 kHz (see Figure 7.2d, the result of measuring response amplitude while sweeping drive frequency in Cantilever Tune, icon shown). The Active Tip probe substrate resonates at the lowest of the three frequencies and has an overtone at the highest of the three frequencies. The Active Tip cantilever, which forms the optical lever used for photodetection of probe deflection, is designed to resonate at a frequency between the lower and higher peaks. The middle resonance is intended for use in TappingMode imaging (see **Laser Alignment and the Cantilever Tune Spectrum,** page 76 for explanation).

Figure 7.2d Dimension Active Tip Cantilever Tune Spectrum



7.3 FastScan Imaging

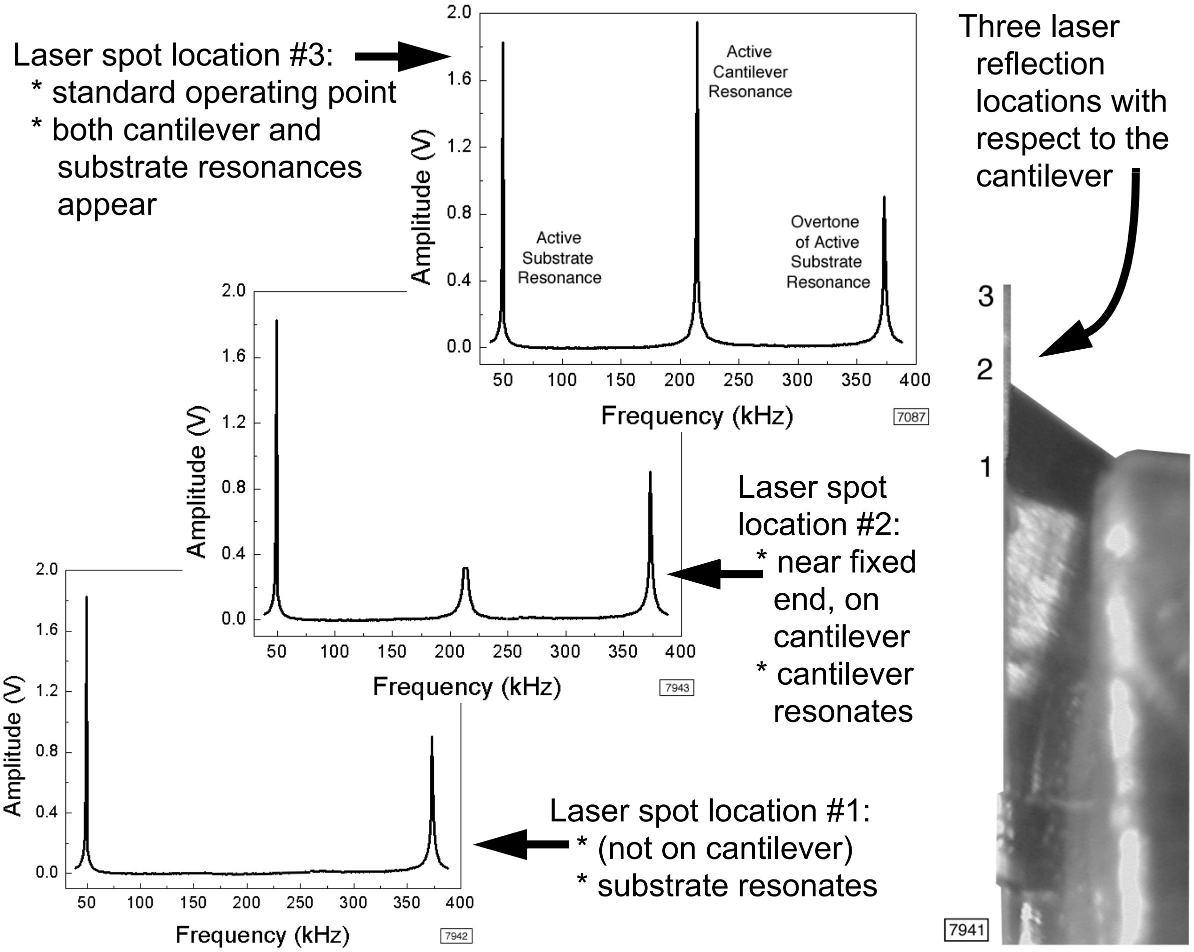
1. The following generic procedure describes FastScan TappingMode+ imaging. Active Tip probes can be used for Contact Mode imaging as well, but current probes are designed for TappingMode and have spring constants which may be too high for Contact Mode. Consult your SPM-specific manuals for coverage of standard scanning for hardware-specific details that apply equally to FastScan imaging. FastScan imaging is currently not supported in fluid operation:

CAUTION: The present Active Tip probes risk a short circuit or degradation of the piezoelectric actuator if immersed in a conductive fluid, so this is not recommended.

Laser Alignment and the Cantilever Tune Spectrum

The separate origin of the central peak compared to the surrounding peaks of the Cantilever Tune spectrum (see Figure 6.2d) is demonstrated by comparing spectra as a function of where the laser is reflecting from the probe. For maximum sensitivity of the optical lever (and, therefore, in standard usage), the laser spot is located near the free end of the cantilever. When the laser spot is re-positioned to near the fixed end of the cantilever, the central resonance peak is suppressed. With the laser reflecting off a point on the probe no longer on the cantilever at all, the cantilever resonance is absent from the spectrum, but the two substrate peaks remain (see Figure 7.3a).

Figure 7.3a Demonstration of the Origin of the Dimension Active Tip Cantilever Tune Spectrum

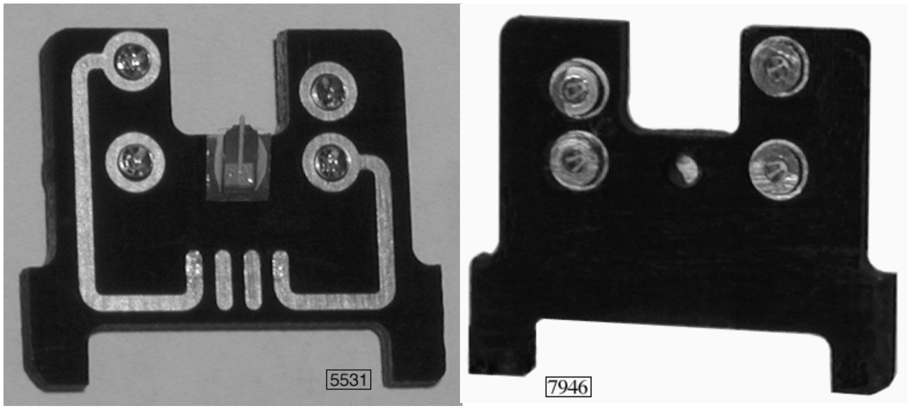


FastScan Probe Installation and Laser Alignment: BioScope II and Dimension SPMs

1. An Active Tip probe and its electrical contacts (see Figure 7.3b) constitute an integrated assembly. Press the probe into position at the base of the scanner tube. The probe only fits in

one orientation and completes the electrical circuit through the cantilever piezoelectric actuator (see Figure 7.3c).

Figure 7.3b Active Tip Probe: Tip Side (Left), Other Side (Right)



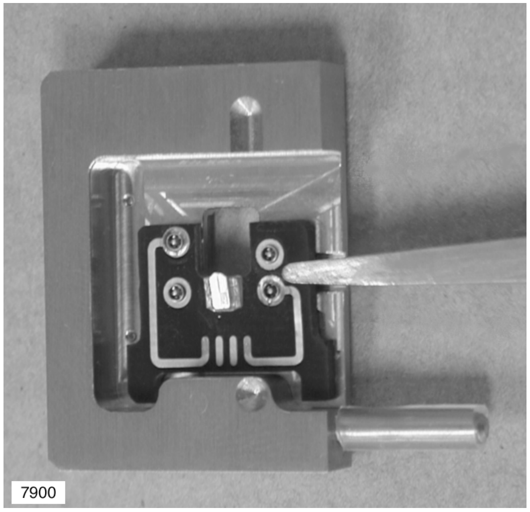
2. Use optics, laser light and positioners to align the SPM laser on the Active Tip cantilever toward its tip end (e.g., by selecting the **STAGE/LOCATE TIP** icon (shown)) and to set tip/ sample separation without permitting their contact (e.g., by selecting the **STAGE/FOCUS SURFACE** icon (shown)).

Figure 7.3c Six Views of an Active Tip Probe Mounted on a Dimension Scanner

FastScan Probe Installation and Laser Alignment: MultiMode SPMs

1. Without contacting the probe cantilever or tip against anything:
    a. Grasp the Active Tip probe with tweezers (without touching the metallic conductors, as in Figure 7.3d) and press the probe into the MultiMode probe holder (see Figure 7.3e).
    b. Grasping the probe holder by its extended handle, insert the probe assembly into the MultiMode optical head (see Figure 7.3f).
    c. Lock it into position by turning the knob in the center of the back of the optical head.

Figure 7.3d MultiMode Active Tip Probe Holder and Probe



2. Arrange the optical detection path:

   a. Use optics, laser light and a piece of paper (or alternative, if not using the “paper method”) to align the SPM laser on the Active Tip cantilever toward its tip end.

   b. Adjust the tilt mirror to maximize the **SUM** signal, centering the reflected laser beam on the photodetector.

Figure 7.3e MultiMode Active Tip Probe Holder a) Probe Side, b) Other Side

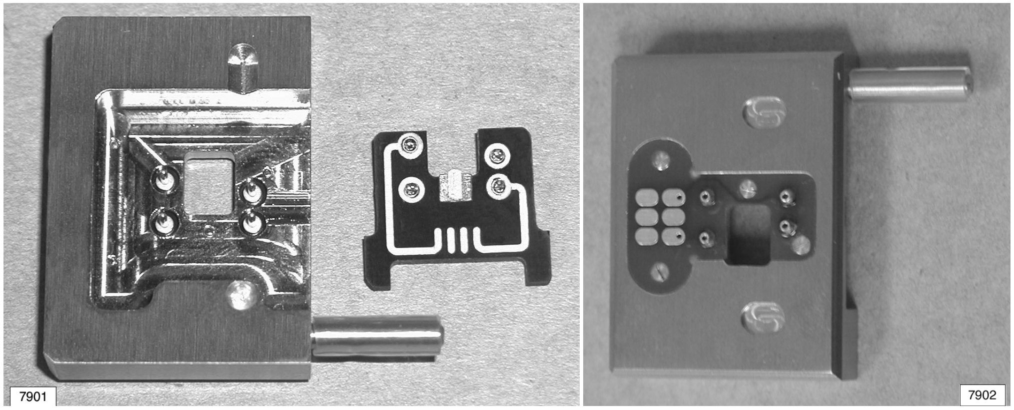
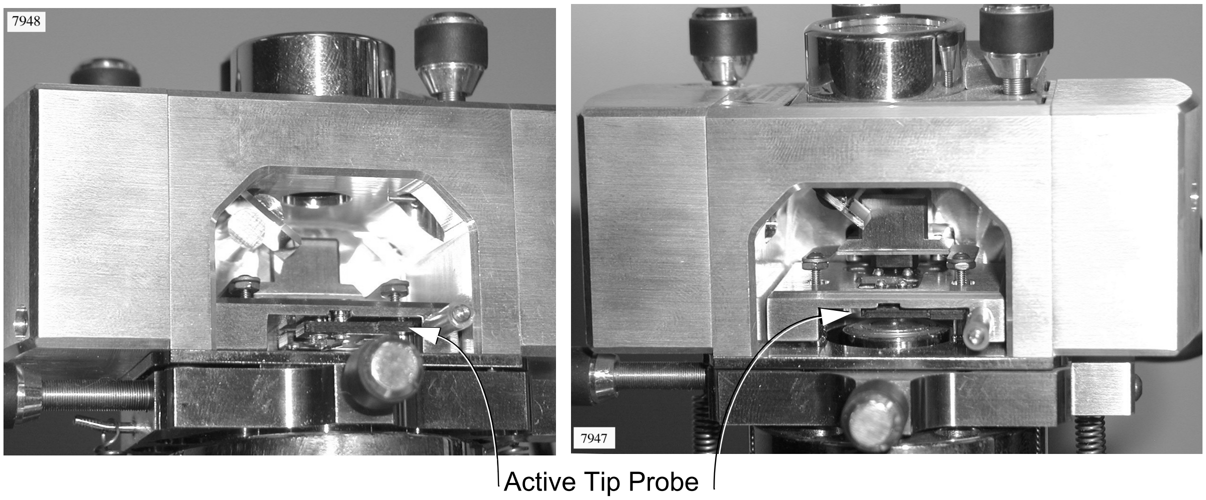


Figure 7.3f MultiMode Active Tip Probe Holder Mounted in MultiMode Head, Two Views

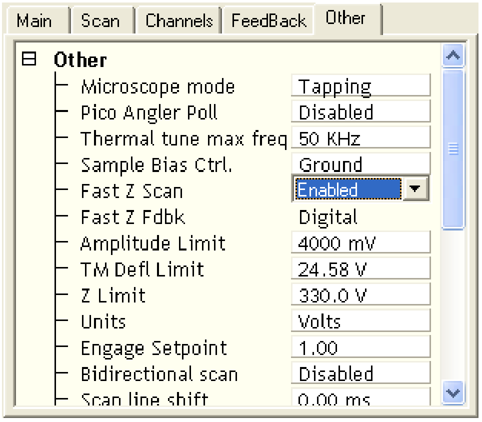


FastScan Setup and Engage for TappingMode

3. Enable **Fast Scan** in either the **Other** panel (see Figure 7.3g) or the **Scan Parameters List** (see Figure 7.3h) if you have not done so already.

> **Note:** The default settings of parameters in the **Fast Scan Engage** panel, shown in Figure 7.3i, are designed to be effective in many circumstances. You may click the **Engage** icon and only refer to the **Fast Scan Engage** panel if engagement fails. If so, skip to Step 7; engage occurs in Step 10.

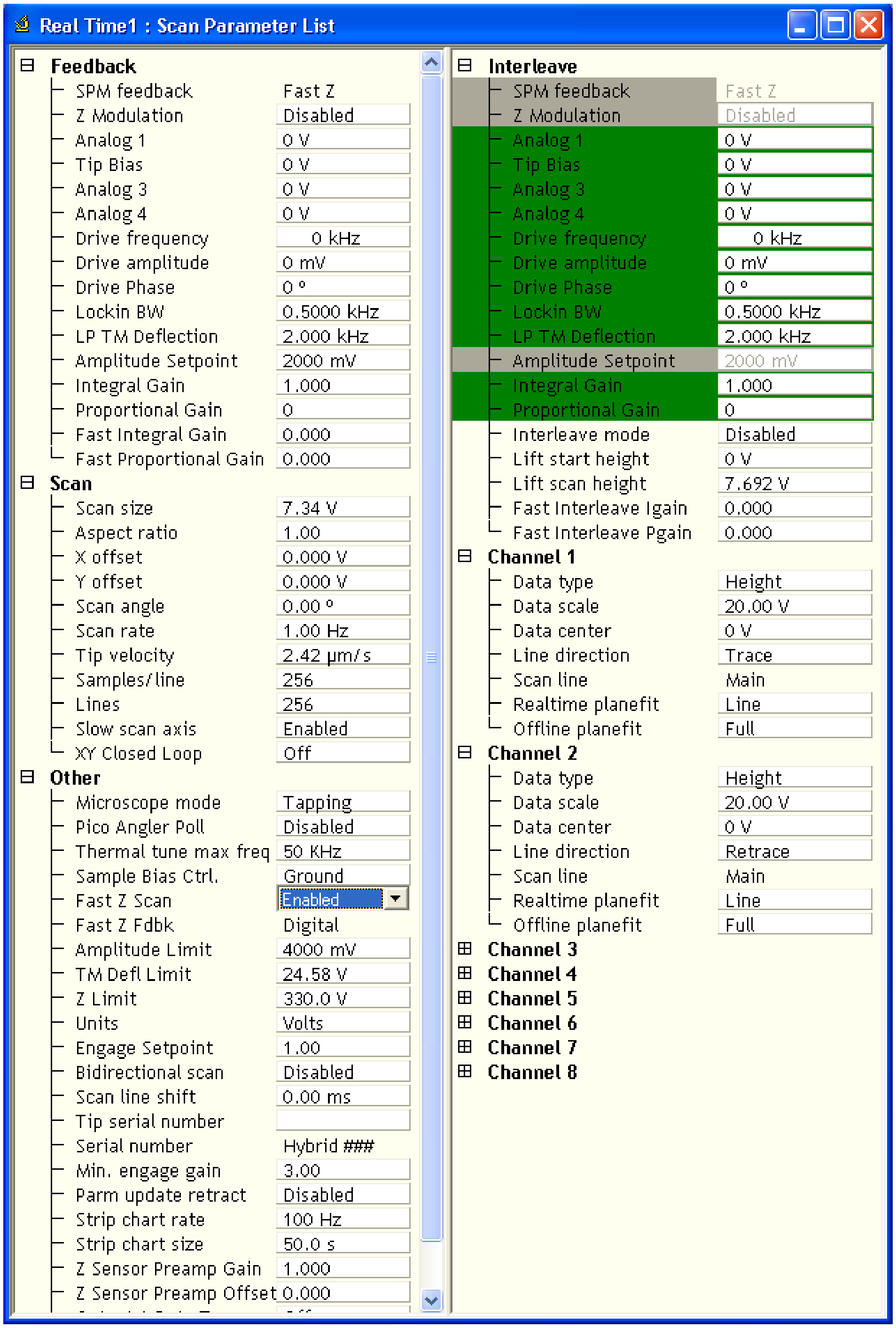
Figure 7.3g Other panel - Fast Scan Enabled



Other

Microscope mode	Tapping
Pico Angler Poll	Disabled
Thermal tune max freq	50 KHz
Sample Bias Ctrl.	Ground
Fast Z Scan	Enabled
Fast Z Fdbk	Digital
Amplitude Limit	4000 mV
TM Defl Limit	24.58 V
Z Limit	330.0 V
Units	Volts
Engage Setpoint	1.00
Bidirectional scan	Disabled
Scan line shift	0.00 ms

Figure 7.3h Scan Parameter List - FAST SCAN ENABLED



⊟ Feedback	
SPM feedback	Fast Z
Z Modulation	Disabled
Analog 1	0 V
Tip Bias	0 V
Analog 3	0 V
Analog 4	0 V
Drive frequency	0 kHz
Drive amplitude	0 mV
Drive Phase	0 °
Lockin BW	0.5000 kHz
LP TM Deflection	2.000 kHz
Amplitude Setpoint	2000 mV
Integral Gain	1.000
Proportional Gain	0
Fast Integral Gain	0.000
Fast Proportional Gain	0.000

⊟ Scan	
Scan size	7.34 V
Aspect ratio	1.00
X offset	0.000 V
Y offset	0.000 V
Scan angle	0.00 °
Scan rate	1.00 Hz
Tip velocity	2.42 µm/s
Samples/line	256
Lines	256
Slow scan axis	Enabled
XY Closed Loop	Off

⊟ Other	
Microscope mode	Tapping
Pico Angler Poll	Disabled
Thermal tune max freq	50 KHz
Sample Bias Ctrl.	Ground
Fast Z Scan	Enabled
Fast Z Fdbk	Digital
Amplitude Limit	4000 mV
TM Defl Limit	24.58 V
Z Limit	330.0 V
Units	Volts
Engage Setpoint	1.00
Bidirectional scan	Disabled
Scan line shift	0.00 ms
Tip serial number	
Serial number	Hybrid ###
Min. engage gain	3.00
Parm update retract	Disabled
Strip chart rate	100 Hz
Strip chart size	50.0 s
Z Sensor Preamp Gain	1.000
Z Sensor Preamp Offset	0.000

⊟ Interleave	
SPM feedback	Fast Z
Z Modulation	Disabled
Analog 1	0 V
Tip Bias	0 V
Analog 3	0 V
Analog 4	0 V
Drive frequency	0 kHz
Drive amplitude	0 mV
Drive Phase	0 °
Lockin BW	0.5000 kHz
LP TM Deflection	2.000 kHz
Amplitude Setpoint	2000 mV
Integral Gain	1.000
Proportional Gain	0
Interleave mode	Disabled
Lift start height	0 V
Lift scan height	7.692 V
Fast Interleave Igain	0.000
Fast Interleave Pgain	0.000

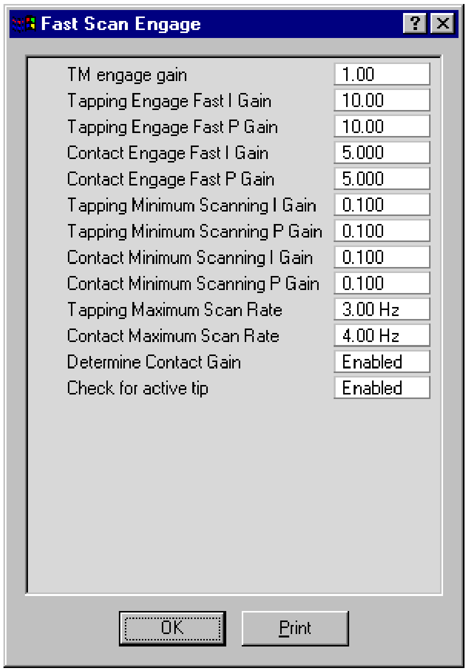
⊟ Channel 1	
Data type	Height
Data scale	20.00 V
Data center	0 V
Line direction	Trace
Scan line	Main
Realtime planefit	Line
Offline planefit	Full

⊟ Channel 2	
Data type	Height
Data scale	20.00 V
Data center	0 V
Line direction	Retrace
Scan line	Main
Realtime planefit	Line
Offline planefit	Full

⊞ Channel 3
⊞ Channel 4
⊞ Channel 5
⊞ Channel 6
⊞ Channel 7
⊞ Channel 8

4. Select **TOOLS** > **ENGAGE SETTINGS** > **FAST SCAN...** to open the panel shown in Figure 7.3i. All of its parameters are new except the first, **TM ENGAGE GAIN** (which accepts values between `0.1` and `10` and appears in the **Tapping Engage** panel as well. Refer to the *Command Reference Manual* for more detail.)

Figure 7.3i The Fast Scan Engage Panel



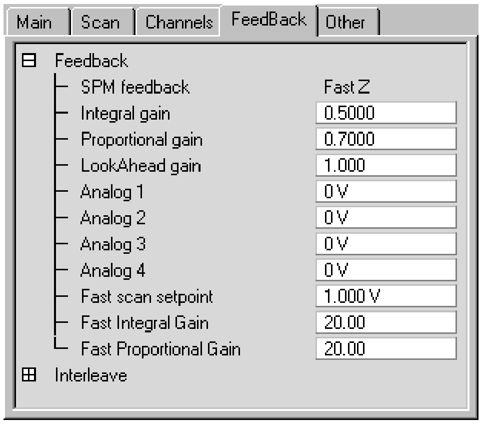
TM engage gain	1.00
Tapping Engage Fast I Gain	10.00
Tapping Engage Fast P Gain	10.00
Contact Engage Fast I Gain	5.000
Contact Engage Fast P Gain	5.000
Tapping Minimum Scanning I Gain	0.100
Tapping Minimum Scanning P Gain	0.100
Contact Minimum Scanning I Gain	0.100
Contact Minimum Scanning P Gain	0.100
Tapping Maximum Scan Rate	3.00 Hz
Contact Maximum Scan Rate	4.00 Hz
Determine Contact Gain	Enabled
Check for active tip	Enabled

5. Set **Fast Scan Engage** > **Tapping Engage Fast** integral (**I**) and proportional (**P**) **Gains** between `5` and `10`. These relatively low values are used during engage because that is the only time when these two parameters are active.

6. Higher fast actuator gain values apply after the tip is engaged. Set up the nested feedback loops by setting four gain parameters in the **Feedback Controls** panel (see Figure 7.3j):

Integral Gain = 0.5 **Fast Integral Gain** = 20
Proportional Gain = 0.7 **Fast Proportional Gain** = 20.

Figure 7.3j The Feedback Panel



Feedback	
SPM feedback	Fast Z
Integral gain	0.5000
Proportional gain	0.7000
LookAhead gain	1.000
Analog 1	0 V
Analog 2	0 V
Analog 3	0 V
Analog 4	0 V
Fast scan setpoint	1.000 V
Fast Integral Gain	20.00
Fast Proportional Gain	20.00

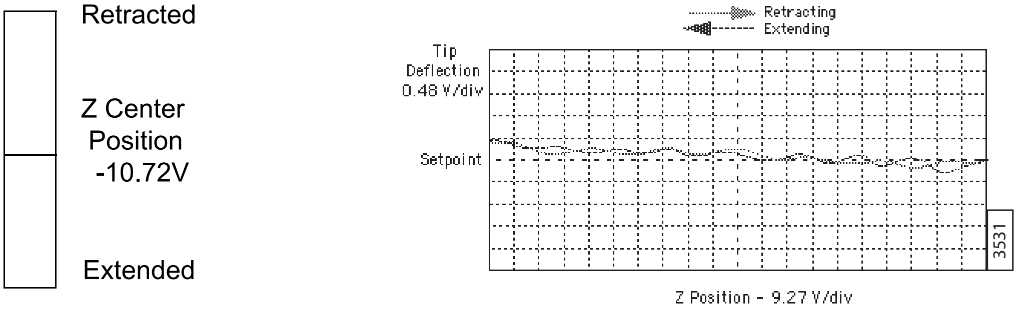
7. TappingMode only: Click **RealTime** > **Cantilever Tune...** or the **Cantilever tune** icon (shown). Set **Start frequency** to **100kHz**, **End frequency** to **250kHz** and **Target amplitude** to between **280** and **600 milli-volts** root-mean-square (RMS). Close the **Cantilever Tune Control** panel when tuning completes.

8. In the **Scan** panel begin with a small, slow scan by setting **Scan Size** to **1-2mm** and **Scan Rate** to **1Hz**.

9. Engage the tip with the sample: click on **RealTime** > **Engage** or the **Engage** icon (shown).

   Note: False engagement can occur in TappingMode; probe oscillation is damped within ten microns of a sample due to a layer of trapped air between the cantilever and the sample surface. This effect is called *squeeze-in layer damping*. This amplitude decrease can be mistaken for direct interaction with the surface below. Reduce the **Tapping Engage Fast Gains** (Step 5) and try again. It is also possible that something beside air is interfering: a high point in the sample touching the cantilever before the tip reaches the sample.
   In Contact Mode, false engagement may result from a particle becoming attached to the cantilever, blocking the probe from reaching the sample, or from poor laser alignment on the cantilever combined with unintended laser reflections from the sample surface into the photodetector. If the beam straddles the edge of the cantilever, optical interference of laser light between the cantilever and sample can produce false detector readings (see Figure 7.3k, right). Static electricity on the tip may also induce the false engage condition, particularly in Contact Mode. The **Z Center Position** changes by 10 to 20V with a 1V **Setpoint** change when the tip is falsely engaged, but only by approximately 1V during a successful engage. However, a Z-position approximately midway between retracted and extended, though necessary, is not sufficient to ensure proper engagement. Also, **Vertical Deflection** jumps from a negative value to the **Setpoint** with a successful engage, rather than drifting slowly.

Figure 7.3k Display Monitor: Z Position (Left), Optical Interference in False Engage Scope Trace (Right)



10. Select the **Scope** button in **Scan View** to open the **Scope Trace** window. Set **Channel 1 Data type** to **Fast Z.** Similarly, display **Fast RMS** on channel 2 (see **Channel Panel Parameters: New Values,** Page 129).

11. To enhance the performance of the control loop, shift the ratio of integral and proportional gains away from the normal scanner piezoelectric driver to the fast cantilever piezoelectric driver (see Figure 6.2b). Initially reduce the normal scanner gains to near zero (e.g. **Integral gain** = 0.0001 and **Proportional gain** = 0), then increase the fast scanner gains. Monitor the **Fast Z** (channel #1) *trace-minus-retrace* (TMR) signal to minimize it.

    Note: To compare TMR signals before and after parameter adjustment, *capture* the scope traces. First, select **RealTime > Capture Filename** and enter a filename in the **Capture Filename** panel. With the TMR scope trace on the Display Monitor, either click **Capture**, then **OK** in the **Capture Filename** panel, or click **OK** to exit the panel and select either the **Capture** icon (shown) or **Real-time** > **Capture** to initiate image acquisition and storage.
    To display a captured image, click the file icon in the Image Browse area and open the named file.

    The force between tip and sample may also be minimized, preserving the sample and the tip, by *increasing* the control loop target cantilever oscillation amplitude: click **Fast scan setpoint** and increase (versus decrease) it with the right (versus left) arrow key. **Fast scan setpoint** is the parameter that controls TappingMode tip/sample interactions. A lower setpoint can improve tracking of the surface, but also increases the force between the tip and sample. If the gains are set too high the TMR value can increase, or its constituent traces can oscillate, indicating loss of control.

    Observe, in the **Scope Trace** window, the effect of parameter adjustments to trace and retrace scan line profiles individually.

12. Once the fast scan loop is optimized, boost the normal scan loop gain parameters. Typical suitable gain values are:

    Integral Gain = `4-8` **Fast Integral Gain** = `30`
    Proportional Gain = `15-20` **Fast Pro. Gain** = `20`.

    Note: In traditional imaging without the additional microactuating feedback loop, the **Integral** and **Proportional Gain** settings are typically smaller by a factor of ten.

13. Set **Scan Controls** panel parameters such as **Scan Size**, **Aspect Ratio**, **X** and **Y Offset**s, **Scan Angle** and **Samples/line** for the image desired. Set **Slow Scan Axis** to **Enabled**.

14. Increase **Scan rate** until the TMR signal begins to degrade or edges lose resolution in the image on the display monitor; reduce the **Scan rate** slightly to restore image quality. Typical FastScan **Scan rate** values are between **8** and **12Hz** for a scan size <20µm, though **Scan rate** is highly sample-dependent.

    Note: If operating FastScan in Interleave Mode**,** the integral and proportional gain settings for interleave traces are also employed. Enter parameter values for these in the **Interleave Controls** panel under **Fast Interleave igain** and **Fast Interleave pgain**, respectively.

FastScan Setup and Engage for Contact Mode

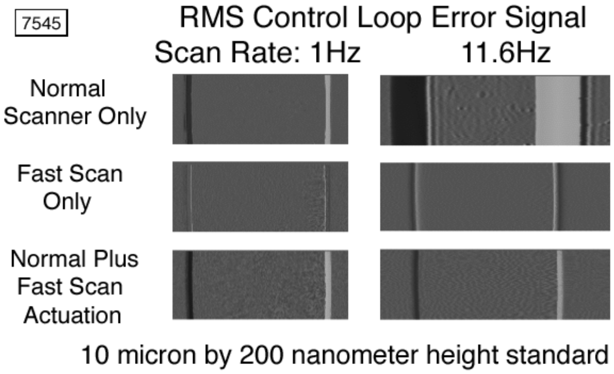
Fast Contact Mode imaging follows a similar procedure to that just outlined for TappingMode+. The Contact Mode feedback loop controls cantilever deflection.

Note: Whereas an undeflected standard silicon nitride Contact Mode probe typically is set to -2 to -1V deflection signal, an undeflected Active Tip probe signal level is set to -0.1 to -0.2V, both with a setpoint equal to 0V. Present Active Tip probe cantilevers have a higher spring constant than the standard contact probe cantilever.

Enhancing FastScan Image Quality

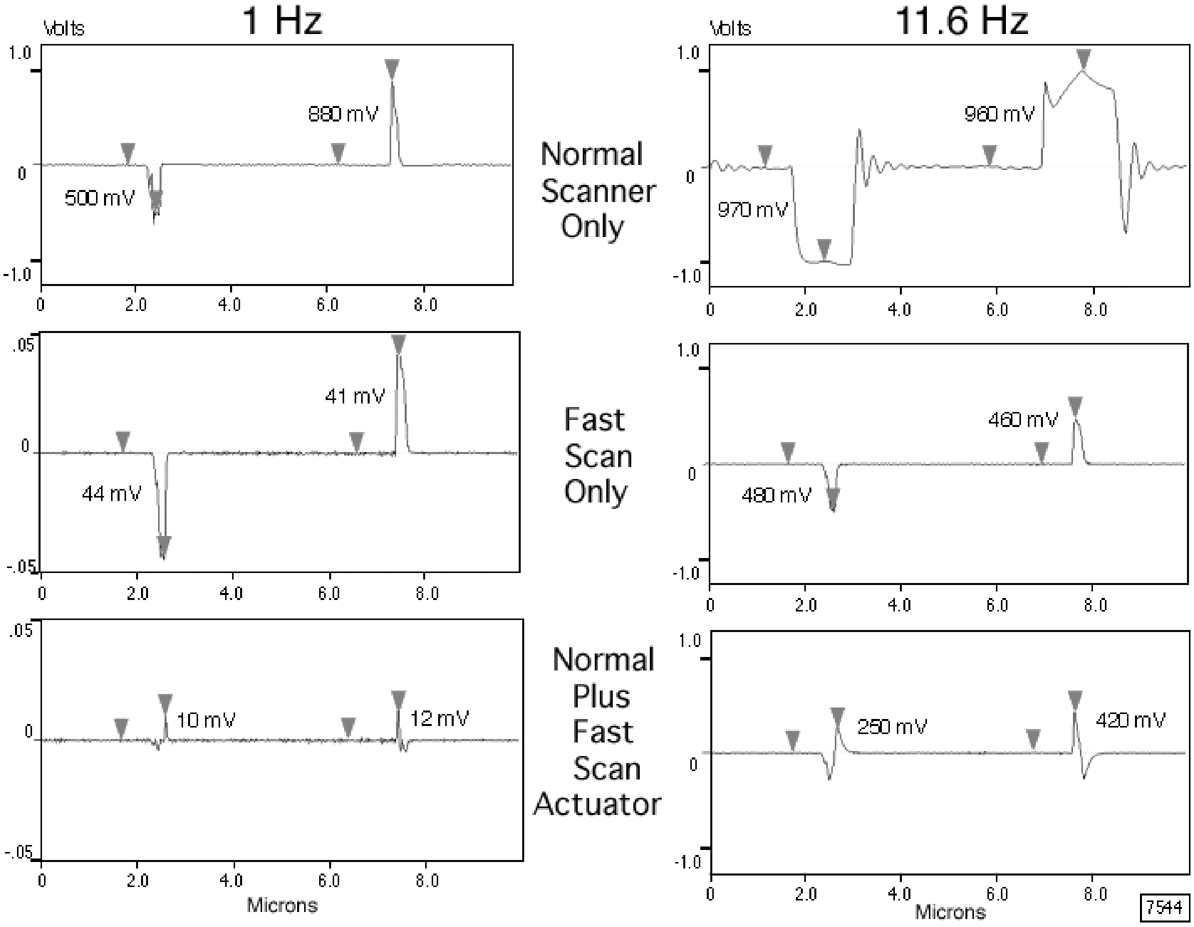
A typical first sample is a height standard. Traversing a 200nm high, 10µm feature, the example shown in Figure 7.3l illustrates the three methods of actuation available with the NanoScope V Controller: 1) the normal scanner only, 2) FastScan only and 3) dual actuation with both the traditional tube scanner and an Active Tip probe tracking the steps of the calibration reference together. The error signal fed back to the controlling actuator(s) is imaged in each case, at 1Hz scan rate on the left and 11.6Hz on the right. Specifically, the error signal is the **AMPLITUDE** signal in the case of normal, scanner actuation only, and the error signal is **FASTRMS** in the cases of fast actuation and dual actuation. In Figure 7.3m, representative single trace cross-sections are plotted from the images in Figure 7.3l.

Figure 7.3l Height Image Comparison: Three Control Methods and Two Scan Rates



The faster response of the Active Tip results in an 11× lower error signal stepping up compared to the normal scanner at 1Hz. The improvement is 21× stepping down under the same conditions. At 11.6Hz scan rate, the normal scanner never “catches up” with the slope of the steps (i.e., the error signal remains large—10 to 95 percent larger than at 1Hz—during at least a micron of lateral movement. With fast actuation alone at 11.6Hz scan rate, the peak error is only reduced by 1/2 compared to normal actuation alone, but recovery is quick.

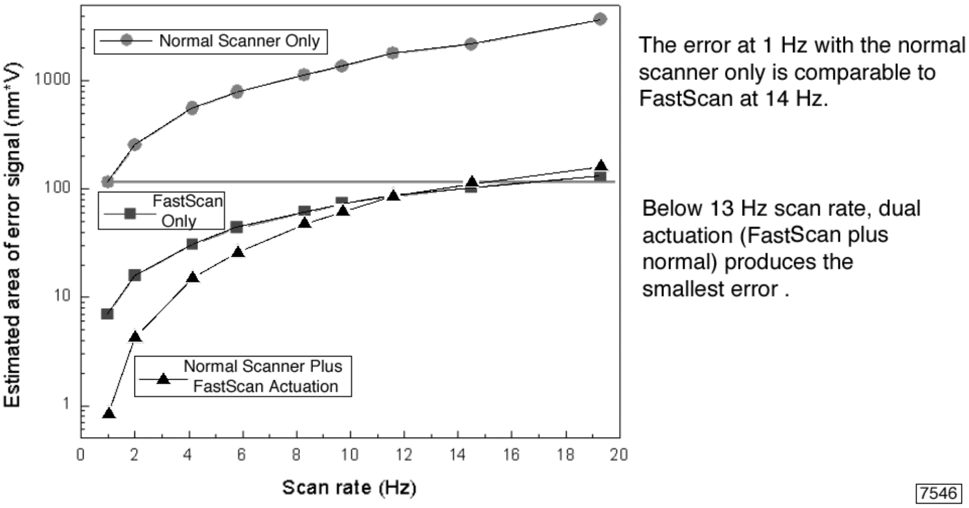
Figure 7.3m Height Profile Error Signal Comparison: Three Control Methods and Two Scan Rates



Dual actuation at 1Hz further reduces peak error signals to approximately 25 percent of their values with fast actuation alone. With such a small error signal, tip/sample interaction forces are minimized, reducing tip wear and possible sample damage. At 11.6Hz scan rate, dual actuated peak error is less than half of that for the normal scanner alone at 1Hz, illustrating the other benefit of dual actuation: increased speed for comparable (or reduced) tip wear.

By repeating the height standard imaging of Figure 7.3l in increments of scan rate, and integrating the absolute value of error signal profiles such as Figure 7.3m, Figure 7.3n demonstrates the equivalence in overall error between normal actuation alone at 1Hz and fast actuation alone at 14Hz. Furthermore, below 13Hz scan rate, dual actuation reduces the integrated error below what is achievable with fast actuation alone.

Figure 7.3n Step Traversal Integrated Error Versus Actuation Method and Scan Rate



The error at 1 Hz with the normal scanner only is comparable to FastScan at 14 Hz.

Below 13 Hz scan rate, dual actuation (FastScan plus normal) produces the smallest error .

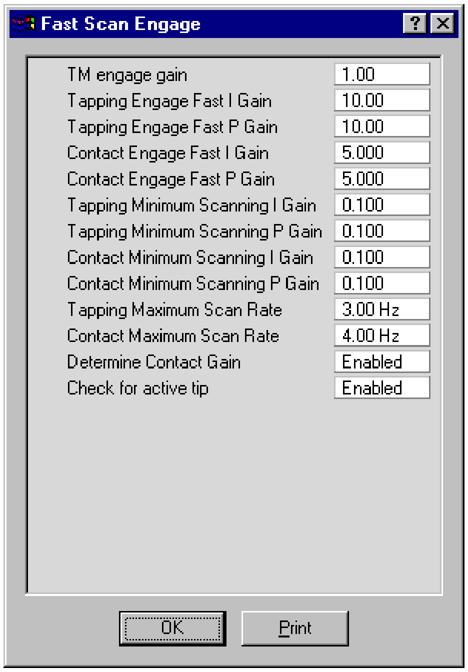
To calibrate the cantilever piezoelectric actuator so that **FAST Z** is an accurate height indicator, minimize the normal control loop integral and proportional gains so that only the fast loop is active and the scanner stays stationary: **INTEGRAL GAIN** = `0.0001`, **PROPORTIONAL GAIN** = `0`, **FAST INTEGRAL GAIN** = `18`, **FAST PRO. GAIN** = `30`. Generate a **FAST Z** (height) image traversing a known step standard. Note the step height recorded in units of volts. Select **TOOLS > Calibrate** > **DETECTOR** to open the **Detector Calibration** panel. Enter the calibration factor you determine in units of nanometers/volt as the value of parameter **FAST Z SENSITIVITY**. Channel panel height values are then automatically converted from voltages to distances, until exiting the NanoScope software.

Note: A handy "trick" is to enter an approximate value for **FAST Z SENSITIVITY** at the start of an imaging session so natural readings in nanometers appear. Later, these can be corrected with a recalibration.

High FastScan scan rates may introduce ringing artifacts at the end of scan lines. Scanner calibration, performed at 2.44 Hz, may not adequately compensate for these distortions at higher scan rates. To eliminate them from displayed and captured images, select **TOOLS > CALIBRATE > XY...** to open the **Scanner Calibration** panel. Set **ROUNDING** to a value between `0` and `0.5`. This entry specifies the percentage of the scan line at its ends that is cropped from display and capture. Typical **ROUNDING** values for high scan rates are between `0.05` and `0.1` percent. Slightly higher scan rates are sustainable in Contact Mode compared to TappingMode.

7.4 Fast Scan Engage Panel

Figure 7.4a The Fast Scan Engage Panel



TM engage gain	1.00
Tapping Engage Fast I Gain	10.00
Tapping Engage Fast P Gain	10.00
Contact Engage Fast I Gain	5.000
Contact Engage Fast P Gain	5.000
Tapping Minimum Scanning I Gain	0.100
Tapping Minimum Scanning P Gain	0.100
Contact Minimum Scanning I Gain	0.100
Contact Minimum Scanning P Gain	0.100
Tapping Maximum Scan Rate	3.00 Hz
Contact Maximum Scan Rate	4.00 Hz
Determine Contact Gain	Enabled
Check for active tip	Enabled

The **Fast Scan Engage** panel serves the same purpose in the dual control loop FastScan Mode as the **Tapping Engage** panel does for traditional control loop TappingMode in earlier NanoScope software. That is, each contain parameters that control the tip/sample engage process.

Note: Default settings of the engage parameters are usually suitable for satisfactory engagement on most samples. These settings appear when either engage panel opens. Typically, it is only if engagement fails that engage parameters are adjusted.

To open the **Fast Scan Engage** panel (see Figure 7.4a), select **TOOLS** > **ENGAGE SETTINGS** > **FAST SCAN...**

Parameters in the Fast Engage Panel

TM ENGAGE GAIN

The normal (scanner) piezoelectric actuator integral gain value used during Fast Scan (and TappingMode) engage. Once the surface is engaged, the value reverts to that of **Feedback** > **TM ENGAGE GAIN**.

Range and Settings: `0.01` – `10.0`. Typical values: `0.2 – 3.0`.

Hints for Optimizing TM Engage Gain

- As **TM ENGAGE GAIN** is increased, the tip's vertical downward velocity increases. **TM ENGAGE GAIN** is used to speed the engagement process; however, if set too high, the tip and/or sample may be damaged.
- During engagement, gain values (**INTEGRAL** and **PROPORTIONAL**) displayed on the **Feedback** panel are *not* used. Instead, **TM ENGAGE GAIN** is used for engage; the integral gain and proportional gain parameters are not involved in engage.
- With normal (non-fluid) samples, higher values of **TM ENGAGE GAIN** accelerate engagement speed at the cost of endangering tips and samples. A higher gain is recommended for TappingMode scanning of hard samples in fluid; increase gain cautiously.

TAPPING ENGAGE FAST I GAIN

The fast (cantilever) piezoelectric actuator integral gain value used during Fast Scan engage in TappingMode. Once the surface is engaged, the value reverts to that of **Feedback** > **FAST INTEGRAL GAIN**.

Range and Settings: `0` – `128.` Typical values: `10 — 20`.

TAPPING ENGAGE FAST P GAIN

The fast (cantilever) piezoelectric actuator proportional gain value used during Fast Scan engage in TappingMode. Once the surface is engaged, the value reverts to that of **Feedback** > **FAST PROPORTIONAL GAIN**.

Range and Settings: `0` – `128`. Typical values: `10 — 20`.

CONTACT ENGAGE FAST I GAIN

The fast (cantilever) piezoelectric actuator integral gain value used during Fast Scan engage in Contact Mode. Once the surface is engaged, the value reverts to that of **Feedback** > **FAST INTEGRAL GAIN**.

Range and Settings: `0` – `128`. Typical values: `5 — 10`.

CONTACT ENGAGE FAST P GAIN

The fast (cantilever) piezoelectric actuator proportional gain value used during Fast Scan engage in Contact Mode. Once the surface is engaged, the value reverts to that of **Feedback** > **FAST PROPORTIONAL GAIN**.

Range and Settings: `0` – `128`. Typical values: `5 — 10`.

CAUTION: If the probe is allowed to engage by actuation of the (fast) cantilever piezo alone, with the scanner tube gains set to zero, the probe tip may be driven into the sample when the scanner tube gains are raised to nonzero values. The **MINIMUM SCANNING GAIN** parameters protect against this.

TAPPING MINIMUM SCANNING I GAIN

The minimum integral gain value the normal Z-actuator may have during TappingMode engage. This value overrides any lower setting of **Feedback** > **INTEGRAL GAIN**, including remaining in effect after engage.

Range and Settings: `0` – `1024`. Typical values: `0.1 — 0.5`.

TAPPING MINIMUM SCANNING P GAIN

The minimum proportional gain value the normal Z-actuator may have during TappingMode engage. This value overrides any lower setting of **Feedback** > **PROPORTIONAL GAIN**, including remaining in effect after engage.

Range and Settings: `0` – `1024`. Typical values: `0.1 — 0.5`.

CONTACT MINIMUM SCANNING I GAIN

The minimum integral gain value the normal Z-actuator may have during Contact Mode engage. This value overrides any lower setting of **Feedback** > **INTEGRAL GAIN**, including remaining in effect after engage.

Range and Settings: `0` – `1024`. Typical values: `0.1 — 0.5`.

CONTACT MINIMUM SCANNING P GAIN

The minimum proportional gain value the normal Z-actuator may have during Contact Mode engage. This value overrides any lower setting of **Feedback** > **PROPORTIONAL GAIN**, including remaining in effect after engage.

Range and Settings: `0` – `1024`. Typical values: `0.1 — 0.5`.

TAPPING MAXIMUM SCAN RATE

The maximum scan rate value allowed before TappingMode engage completes. This value overrides any higher setting of **Scan Controls/SCAN RATE** made before engage completes. If an override occurs, the maximum remains in effect after engage until changed in **Scan Controls**/**SCAN RATE**.

Range and Settings: `0` – `10,000Hz`. Typical values: `2.00 — 4.00Hz`.

CONTACT MAXIMUM SCAN RATE

The maximum scan rate value allowed before Contact Mode engage completes. This value overrides any higher setting of **Scan** > **SCAN RATE** made before engage completes. If an override occurs, the maximum remains in effect after engage until changed in **Scan** > **SCAN RATE**.

Range and Settings: `0` – `10,000Hz`. Typical values: `3.00 — 5.00Hz`.

DETERMINE CONTACT GAIN

Set to **ENABLED** to obtain accurate height data with both slow and fast control loops active. After **DETERMINE CONTACT GAIN** has been enabled, prior to engage, the cantilever piezoelectric actuator is ramped over ±10V drive amplitude while monitoring deflection. This contact gain calibration records the resultant deflection per applied drive signal for future use.

Range and Settings: **ENABLED** or **DISABLED**. Typical value: **ENABLED**.

CHECK FOR ACTIVE TIP

Automatically verifies a functioning Active Tip probe before each engage operation.

Range and Settings: **ENABLED** or **DISABLED.** Typical value: **ENABLED**.

Chapter 8 ThermalTune

8.1 Spring Constant Calibration

While a cantilever moves in response to forces on it, the measurement made by an *optical lever*—by bouncing a laser off the top of the cantilever and into a photodetector—is of the cantilever free end position as a function of time. When cantilever deflection is sufficiently small, as is the case in most Contact Mode and TappingMode applications, the relation of the force on the tip to the cantilever free end position is elastic, that is, linear, given by Hooke's Law applied to a spring:

$$F = -k \times h$$

where F = the force on the tip in Newtons,
h = vertical displacement of the free end of the cantilever toward or away from the sample in meters, and
k = the proportionality constant, known as the *spring constant*, in Newtons/meter (or equivalently, and more typically in nanoscale work, in picoNewtons/picometer).

Given the spring constant of a cantilever, measured cantilever deflections are converted into inferred tip/sample forces. Therefore, the first step in making accurate force measurements is the determination of the spring constant of the cantilever to be used.

Note: The spring constant is a property of the cantilever. For instance, if determined in air, the spring constant applies to the same cantilever in water or vacuum.

Four methods to deduce a cantilever spring constant are described:

1. estimation from representative geometry
2. comparison with and without added mass
3. thermal tuning
4. by hydrodynamic model

Other methods, notably the added mass method, can be more accurate if done with great care. However, the thermal tune method is very simple as automated here and offers accuracy comparable to that normally obtained by other methods. The NanoScope 5 Controller automates the thermal tune method.

8.1.1 Estimation from Cantilever Geometry

This first method is quick, but suffers from uncertainty because typically the specific cantilever geometry is not measured and may vary in production. Instead, a representative of the appropriate family of cantilevers is used. Each cantilever family is distinguished by a *tip factor*, b in Newton-seconds^3/meter, and the spring constant for a cantilever in the family is derived from the measured resonant frequency, f in seconds^{-1}, of the free cantilever in air by:

$$k = b \times f^3$$

The assumptions that go into this relation are that cantilevers within a family agree in material properties and in geometry, with the exception of cantilever thickness, which varies from wafer to wafer. Typical average tip factor values by cantilever class are provided in Table 8.1a.

Table 8.1a Typical Tip Factor Values

Cantilever Class	Representative Cantilever Families	Tip Factor
V-shaped, Contact Mode	NP, DNP, OTR, ORC	7×10^{-15} Newton-seconds^3/meter
Single beam, TappingMode	ESP, FESP, LTESPW, MESP, RTESPA, TESP, FIBLADE, FISPIKE, IBMSC	4×10^{-15} Newton-seconds^3/meter

Identify your probe cantilever type, measure its resonant frequency (click the **CANTILEVER TUNE** icon (shown)), and calculate its spring constant using the above formula. See the Bruker website, **http://www.bruker.com**, for more information about available probes.

Note: For an explicit expression for the spring constant of a single beam cantilever with rectangular cross section in terms of its geometry (other than cantilever thickness), material properties and resonant frequency (cubed, as noted above) see the end of **Adding Mass to the Cantilever,** next.

8.1.2 Adding Mass to the Cantilever

The second method of spring constant determination contrasts with the first in requiring careful work that is rewarded with a more accurate value. Measure the resonant frequency before and after adding a known mass to the cantilever and the resonant frequency shift specifies the cantilever spring constant.

The method is derived here for a model appropriate to TappingMode probes, a single beam cantilever of rectangular cross-section, whose spring constant is given by.

$$k = \frac{Et^3w}{4L^3}$$

where E = the elastic modulus (Young's Modulus),
t = the cantilever thickness
w = the cantilever width,
L = the cantilever length.

The resonant frequency of such a beam is:

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{M + m^*}}$$

where m^* = the effective mass ($\approx$ 0.24m, for beam mass, m = ρtwL, ρ = the cantilever density),
M = the known mass added to the cantilever free end.

Re-arranging the last equation, added mass, M, varies linearly with $(2\pi f)^{-2}$: $M = k(2\pi f)^{-2} - m^*$. As a linear relation, comparing the resonant frequency with one added mass to that without any is sufficient to solve for both the spring constant and the effective mass of the cantilever:

$$k = (2\pi)^2\frac{M}{(1/f_1^2) - (1/f_0^2)} \qquad m^* = M\frac{f_1^2}{f_0^2 - f_1^2}$$

The first solution of the simultaneous equations provides the spring constant, given the added mass and the two resonant frequencies, with added mass, f_1 and without, f_0. The accuracy of the spring constant determination depends primarily on the uncertainty in the added mass as the resonant frequencies typically may be measured to higher precision.

Various methods have been used to affix particles to cantilevers. Three such procedures, developed by researchers using Bruker NanoScopes, are detailed in *Support Note 226B, Attaching Particles to AFM Cantilevers*. By using a cantilever before calibrating it, one can avoid the step of removing the added mass to perform an experiment with a calibrated cantilever.

Substituting the first equation of this section, the expression for spring constant in terms of cantilever geometry and material properties, k(E, t, w, L), into the second equation of this section, the expression for cantilever resonant frequency in terms of spring constant and mass components, $f(k, M, m^*)$, results in an equation, $f(E, t, w, L, M, m^*)$, which expresses cantilever resonant frequency in terms of geometric characteristics. Rearranging the new equation as an expression of cantilever thickness in terms of the other variables, now including resonant frequency, that is, as t(E, w, L, M, m^*, f), then substituting this rearranged equation for thickness back into the first equation demonstrates that spring constant is proportional to resonant frequency cubed, independent of cantilever thickness:

$$k = 2\pi^3 L^3 w f_0^3 \sqrt{\rho^3 / E}$$

For further discussion of this derivation, refer to *A Nondestructive Method for Determining the Spring Constant of Cantilevers for Scanning Force Microscopy*, by J. P. Cleveland, et. al., in Review of Scientific Instruments, 64 (2), February 1993, page 403.

8.1.3 Measuring Thermal Noise

The third method of spring constant calibration is often preferred because it is neither as demanding and time-consuming as attaching a particle (method two) nor has as large an associated uncertainty as relying on a representative model (method one). The measurement data consists of a time interval of the deflection signal in Contact Mode (i.e., with no driving oscillation applied electronically) at thermal equilibrium, while the cantilever is suspended, away from any solid surface. Brownian motion of surrounding molecules (e.g., air) impart random impulses to the cantilever during the sampling. The resulting function of time is Fourier transformed to obtain its Power Spectral Density (PSD) in the frequency domain. Integrating the area under the resonant peak in the spectrum yields the power associated with the resonance.

Expressing the dynamics of the cantilever as a harmonic oscillator by the total system energy (the Hamiltonian), the average value of the kinetic and potential energy terms are both

$$\frac{1}{2}k_B T$$

according to the Equipartition Theorem, where T is the temperature in kelvins and k_B is Boltzmann’s constant = 1.3805×10^{-23}joules/kelvin. In particular, for the potential energy,

$$\left\langle \frac{1}{2} m \omega_0^2 z^2 \right\rangle = \frac{1}{2} k_B T$$

where $\omega_0 = \sqrt{}(k/m)$ is the resonant angular frequency, m is the effective mass, z is the displacement of the free end of the cantilever and the “angle” brackets indicate average value over time. Simplifying, the temperature and average displacement determine the cantilever spring constant.

$$k = (k_B T) / \langle z^2 \rangle = (k_B T) / P$$

The original displacement time-series is Fourier transformed to segregate other, broadband, noise contributions from the narrowband thermal noise around resonance. By integrating the area under the resonance in the PSD, while excluding both the noise floor and the “shoulders” to either side of the resonance peak, only the power, P, of the thermal cantilever fluctuations is included. The latter is equal to the mean square of the time-series data. For further discussion of this derivation, refer to *Calibration of Atomic-Force Microscope Tips*, by Jeffrey L. Hutter and John Bechhoefer, in Review of Scientific Instruments, 64(7), July 1993, page 1868.

The NanoScope V Controller automates the thermal tune calculations. Ten seconds of sampling is sufficient to define the PSD with 25Hz frequency resolution.

The accuracy of the thermal method of cantilever spring constant determination depends not only on the effective isolation of nonthermal noise contributions to the PSD, but also on the accuracy of the PSD and on its magnitude. The Nyquist Sampling Theorem guarantees Fourier Transform accuracy for frequencies up to one half the sampling rate. **The standard NanoScope Controller samples the deflection signal every 16.5μs, corresponding to a 64kHz sampling rate. Therefore, cantilever resonances with contributions from frequencies above 32kHz can produce distorted PSDs. This particularly constrains using the method for small cantilevers in air.** The Thermal Tune technique is mainly applicable to soft cantilevers, particularly in fluids where cantilever resonant frequencies are considerably lower than in air.

Because the magnitude of the PSD is proportional to the average cantilever displacement, higher spring constant (stiffer) cantilevers produce a smaller signal to analyze. For instance, a spring constant of 0.05N/m produces cantilever displacements of approximately 0.3nm at room temperature. This is representative of the probes with the smallest spring constants in Table 8.1a: SiN, NP, NP-STT, DNP, DNP-S (0.01-0.6N/m), and OTR4 (0.02-0.08N/m) among V-shaped cantilevers, and ESP (0.02-0.1N/m) among single-beam cantilevers.

8.1.4 Rectangular Cantilever, Hydrodynamic Model

By comparing resonance in vacuum to resonance in fluid for a rectangular cantilever and introducing the hydrodynamic function, $\Gamma(\omega)$, which depends on the fluid Reynolds number, the cantilever spring constant is computed from easily obtained resonance characteristics and the less variable of probe dimensions:

$$k = 0.1906\rho_f w^2 L Q_f \Gamma_i(\omega_f)\omega_f^2$$

where w and L are defined as before (see page 95), ρ_f = density of the fluid (e.g., 1.18kg/m^3 for air),

Q_f = the cantilever resonance quality factor in fluid,
ω_f = cantilever resonant frequency in the fluid,
Γ_i, the imaginary component of the hydrodynamic function, $\Gamma(\omega)$, where

$$\Gamma(\omega) = \Omega(\omega)\left[1 + \frac{4iK_1((-i)\sqrt{iRe})}{\sqrt{iRe}K_0((-i)\sqrt{iRe})}\right]$$

and $\Omega(\omega) = \Omega_r(\omega) + i\Omega_i(\omega)$, where,

$$\Omega_r(\omega) = \frac{0.91324 - 0.48274\tau + 0.46842\tau^2 - 0.12886\tau^3 + 0.044055\tau^4 - 0.0035117\tau^5 - 0.00069085\tau^6}{1 - 0.56964\tau + 0.4869\tau^2 - 0.13444t^3 + 0.045155\tau^4 - 0.0035862\tau^5 + 0.00069085\tau^6}$$

and

$$\Omega_i(\omega) = \frac{-0.024134 - 0.029256\tau + 0.016294\tau^2 - 0.00010961\tau^3 + 0.6458\times10^{-4}\tau^4 - 0.00004451\tau^5}{1 - 0.59702\tau + 0.55182\tau^2 - 0.18357\tau^3 + 0.079156\tau^4 - 0.014369\tau^5 + 0.0028361\tau^6}$$

where $\tau = \log_{10}(\mathrm{Re})$, and the Reynolds number, $\mathrm{Re} = \rho_f \omega w^2/(4\eta)$ for fluid viscosity η. K_0 and K_1 are modified Bessel functions of the third degree (refer to a source for mathematical functions).

The simplicity of data acquisition and computation (once the equations are set up!) are balanced by a few limitations to the method:

- the leading numerical term (0.1906) assumes a high aspect ratio rectangular cantilever with $L/w > 5$
- $Q_f >> 1$; a high quality resonance is required: air is a suitable fluid, water is not.

For a derivation of this method, refer to *Calibration of Rectangular Atomic Force Microscope Cantilevers*, John E. Sader, James W. M. Chon and Paul Mulvaney, Review of Scientific Instruments, Vol. 70 (10), October 1999.

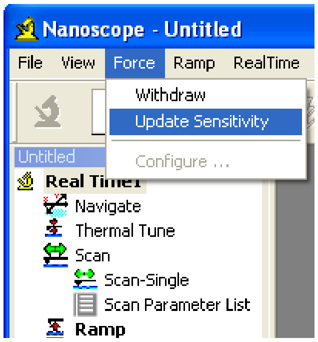
8.2 Calibrating a Cantilever

8.2.1 Determine Deflection Sensitivity in Force Mode

Deflection sensitivity should be recalculated whenever the laser beam path changes due to laser alignment, probe change or re-seating or photodetector adjustment.

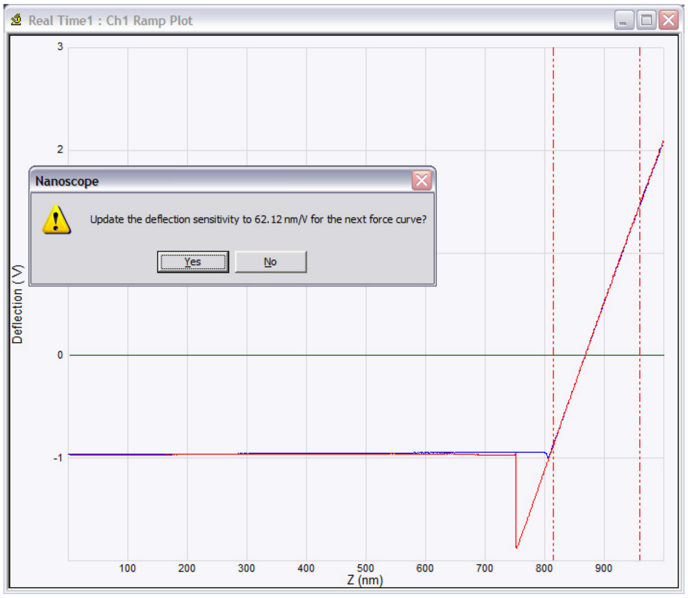
ENGAGE on a hard surface such as glass or silicon and switch to Ramp Mode. Collect a force plot which demonstrates interaction with the surface (a contact region). With the force plot displayed (deflection vs. Z sensor) in Ramp Mode or Force Mode, drag two markers in from the left and/or right edges and position them as far apart as possible while both still within the contact region of the force plot, shown in Figure 8.2b. Select **UPDATE SENSITIVITY** from the Force menu (see Figure 8.2a).

Figure 8.2a Deflection Sensitivity



You are asked whether you accept the calculated value (see Figure 8.2b).

Figure 8.2b Deflection Sensitivity Determination in Force Mode



Update the deflection sensitivity to 62.12 nm/V for the next force curve?

Note: The deflection sensitivity is calculated based on the assumption that the tip and sample do not deform. The deflection sensitivity calibration must, therefore, be done on a hard, stiff surface.

8.3 Determine Cantilever Spring Constant by Thermal Tune

The Thermal Tune method (see **Measuring Thermal Noise**, page 96) provides an automated and quick determination of cantilever spring constant.

CAUTION: Make sure the probe is withdrawn adequately from the sample before activating Thermal Tune. The probe should not interact with the sample during its self-excitation under ambient conditions.

Determine the cantilever spring constant by the thermal tune method according to the following procedure:

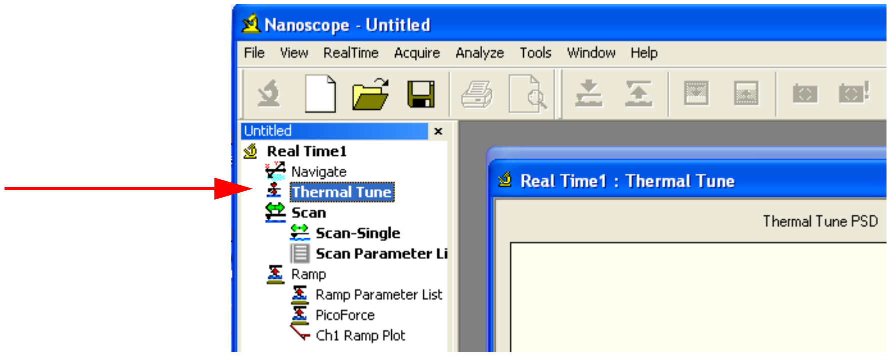
1. Determine cantilever deflection sensitivity if you have not done so already (see **Determine Deflection Sensitivity in Force Mode**: Page 98).

   Note: A correction factor should be applied to this calibration. When we determine the deflection sensitivity, we exert a static load at the end of the cantilever, but when we measure the thermal energy the cantilever is oscillating at resonance and is constrained at only one end rather than two. The cantilever bends differently in the two situations and thus reflects the laser beam of the optical lever differently. See D. Sarid, “Scanning Force Microscopy With Applications to Electric, Magnetic and Atomic Forces,” 2nd Edition, Oxford University Press, New York 1994, pp 5-6 and pp 10-11.When you calibrate the deflection sensitivity using a static force, you underestimate the amplitude of dynamic motion by approximately 8% (for a simple beam). This correction factor is applied in the thermal tune panel (Figure 8.3c) (**DEFL. SENS. CORRECTION**).

2. Click **WITHDRAW**.

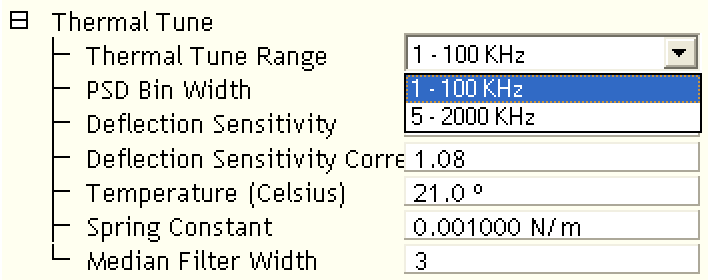
3. Click **THERMAL TUNE** in the Workspace View or **ACQUIRE** menu (see Figure 8.3a).

Figure 8.3a Thermal Tune



4. Select a frequency range over which you will tune (see Figure 8.3b).

Figure 8.3b Select Thermal Tune Frequency Range

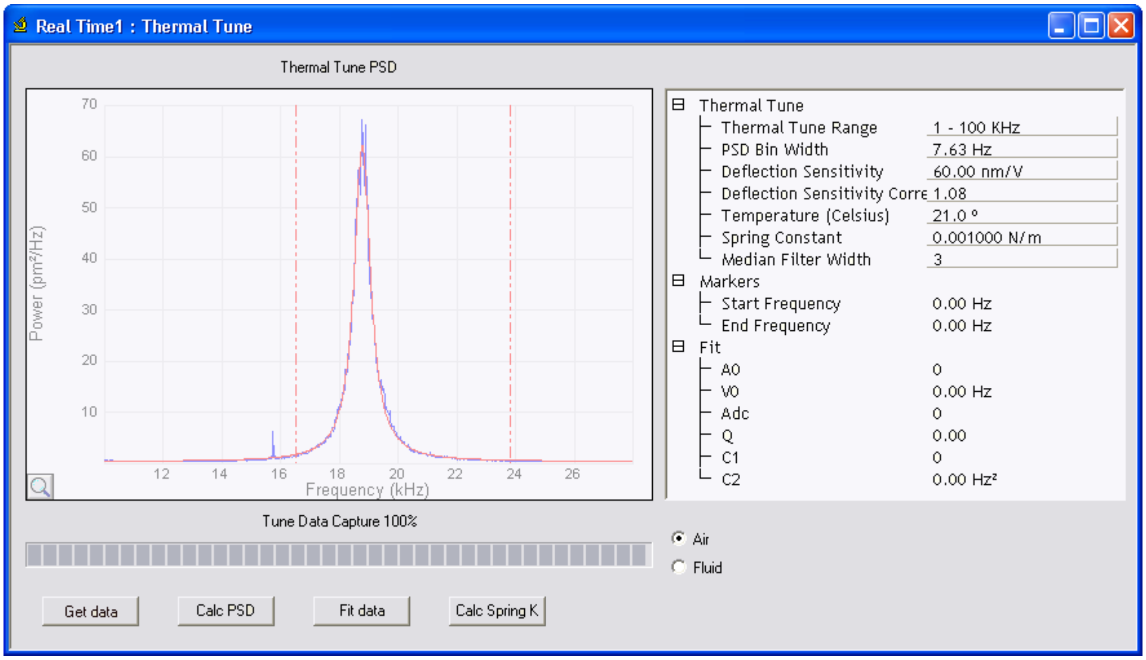


Thermal Tune
- Thermal Tune Range: 1 - 100 KHz (1 - 100 KHz, 5 - 2000 KHz)
- PSD Bin Width
- Deflection Sensitivity
- Deflection Sensitivity Corre: 1.08
- Temperature (Celsius): 21.0 °
- Spring Constant: 0.001000 N/m
- Median Filter Width: 3

5. Click **GET DATA** in the **Thermal Tune** panel (see Figure 8.3c).

6. The microscope will acquire data for about 30 seconds.

Figure 8.3c The Thermal Tune Panel



Thermal Tune
- Thermal Tune Range: 1 - 100 KHz
- PSD Bin Width: 7.63 Hz
- Deflection Sensitivity: 60.00 nm/V
- Deflection Sensitivity Corre: 1.08
- Temperature (Celsius): 21.0 °
- Spring Constant: 0.001000 N/m
- Median Filter Width: 3

Markers
- Start Frequency: 0.00 Hz
- End Frequency: 0.00 Hz

Fit
- A0: 0
- V0: 0.00 Hz
- Adc: 0
- Q: 0.00
- C1: 0
- C2: 0.00 Hz²

● Air
○ Fluid

7. A power spectral density (PSD) plot of the cantilever response to ambient conditions is displayed. Click either **AIR** or **FLUID** to select a Lorentzian or a simple harmonic oscillator model, respectively, of the PSD to be least squares fit to the data.

Note: The equations used to fit the filtered data are:

Simple Harmonic Oscillator, for use in fluid

$$A(\nu) = A_0 + A_{DC} \cdot \frac{\nu_0^2}{\sqrt{(\nu_0^2 - \nu^2)^2 + \frac{\nu_0^2 \nu^2}{Q^2}}}$$

where: A(ν) is the amplitude as a function of frequency, ν
A_0 is the baseline amplitude
A_{DC} is the amplitude at DC (zero frequency)
ν_0 is the center frequency of the resonant peak
Q is the quality factor

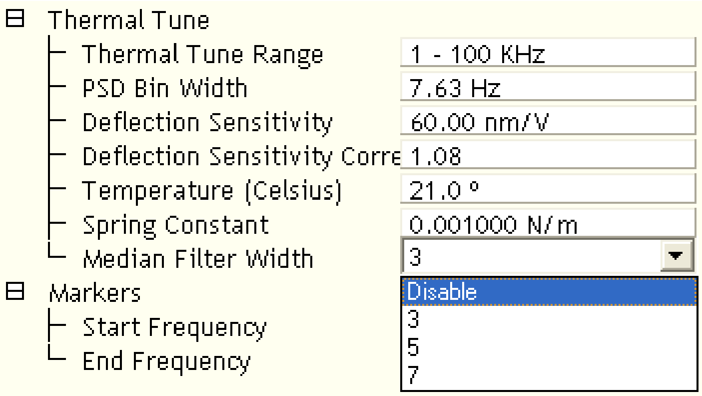
Lorentzian, for use in air

$$A(\nu) = A_0 + \frac{C_1}{(\nu - \nu_0)^2 + C_2}$$

where: A(ν) is the amplitude as a function of frequency, ν
A_0 is the baseline amplitude
ν_0 is the center frequency of the resonant peak
C_1 is a Lorentzian fit parameter
C_2 is a Lorentzian fit parameter

8. Adjust the **MEDIAN FILTER WIDTH**, shown in Figure 8.3d, to remove individual (narrow) spikes. This replaces a data point with the median of the surrounding n (n =3, 5, 7) data points.

Figure 8.3d **MEDIAN FILTER WIDTh**



⊟ Thermal Tune

Thermal Tune Range	1 - 100 KHz
PSD Bin Width	7.63 Hz
Deflection Sensitivity	60.00 nm/V
Deflection Sensitivity Corre	1.08
Temperature (Celsius)	21.0 °
Spring Constant	0.001000 N/m
Median Filter Width	3

⊟ Markers

Start Frequency
End Frequency

9. Adjust the **PSD BIN WIDTH** to reduce noise by increasing the averaging.

10. Drag markers in from the left and/or right plot edges to bracket the bandwidth over which the fit is to be performed.

Note: Typically the markers are located roughly where the spectrum rises from the noise floor. Precise placement is unnecessary; the fit is insensitive to the minimal power contributed from these frequencies far from the natural resonance (see right "shoulder" of waveform, Figure 8.3c). You may exclude a larger portion of a shoulder of the waveform from the fit bandwidth to ignore a noise spike (see left shoulder, Figure 8.3c). Experiment with repeated fits of the same acquired thermal tune data to become familiar with its sensitivity to bandwidth and choice of model.

11. Click **FIT DATA**. The curve fit, in red, is displayed along with the acquired data. If necessary, adjust the marker positions and fit the data again to obtain the best fit at the thermal peak.

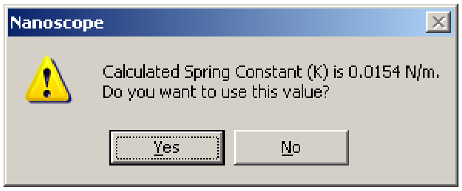
12. Adjust the markers for the bandwidth of the fit PSD to include in the spring constant calculation.

Note: While the goal of setting the bandwidth for the curve fit was to achieve the highest signal-to-noise ratio by excluding noise, in setting the bandwidth for spring constant calculation from the (noise-free) fit curve the objective is to include all frequencies that contribute power to the spectrum. For instance, if you left out part of a shoulder in performing the curve fit, include it in determining the spring constant (see Figure 8.3c).

13. Enter the cantilever **TEMPERATURE**.

14. Click **CALC. SPRING K**. You will be asked whether you want to accept the calculated value of the spring constant, k (see Figure 8.3e). Clicking **OK** copies the calculated spring constant in the "Ramp" list in the PicoForce view.

Figure 8.3e Spring Constant Calculation Result



Calculated Spring Constant (K) is 0.0154 N/m.
Do you want to use this value?

Note: See **Problems with Thermal Tune**, page 103 for troubleshooting tips.

8.3.1 Problems with Thermal Tune

Baseline Not Flat

If the baseline is not flat, adjust the photodetector until the vertical deflection is approximately 0 V.

Sharp Noise Spike near 20kHz

If there is a sharp noise spike near 20 kHZ, adjust the photodetector until the vertical deflection is approximately 0 V.

Other Sharp Noise Spikes

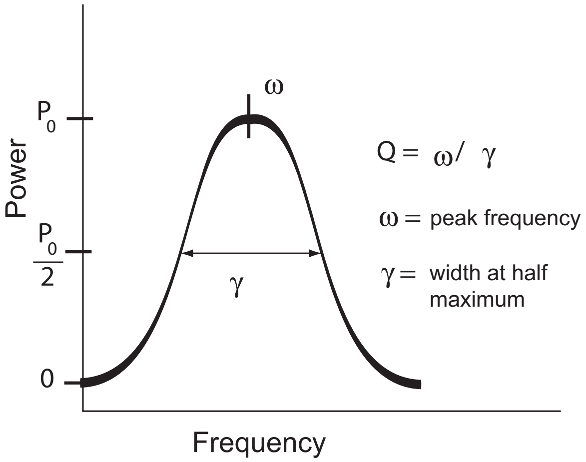
Try to eliminate electronic and acoustic noise from external sources. Some monitors can be a problem — try turning them off.

Chapter 9 Q Control

9.1 Introduction

Q Control refers to the use of a frequency-dependent drive amplitude in TappingMode. “Q” is a measure of the sharpness of the resonant peak and is calculated by dividing the resonant frequency by the width of the resonant peak at half the maximum power (see Figure 9.1a). Power is proportional to amplitude squared, so the frequency interval, γ, between half-peak-power points, equals the interval between $A_0/\sqrt{2}$ points, where A_0 is the peak amplitude.

Figure 9.1a The Q of a Resonance



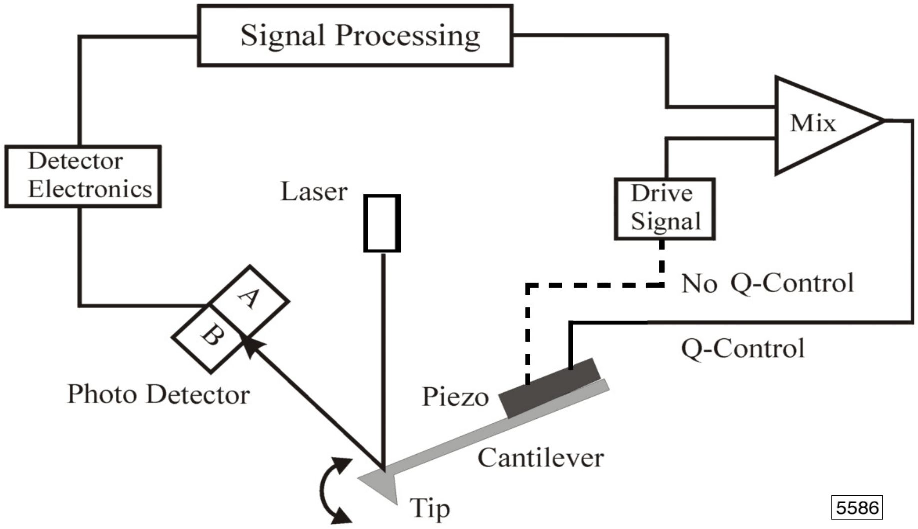
Q control enables either enhancement or damping of a resonance. That is, Q may be increased or decreased with respect to the natural value that is observed in Cantilever Tune when sweeping over a range of frequencies while holding drive amplitude constant. One application of Q reduction is to damp the lower frequency Active Tip cantilever resonance (i.e., ~50 kHz) while driving probe oscillation at the resonance located at approximately 200 kHz. A typical application of Q enhancement is to increase phase contrast by applying Q control to the cantilever resonant frequency.

As demonstrated in the first example, Q Control need not be applied at the resonant frequency chosen for tapping. However, Q Control may only be applied to a single frequency at a time, so both enhancement and damping cannot be employed simultaneously.

CAUTION: Q control enhancement is desirable to counteract damping and favor a particular peak in a typically multi-peaked Cantilever Tune spectrum in fluid. Active Tip probe electrical conductors are not adequately insulated for operation in fluid. Use an alternative probe style to take advantage of Q control with samples in fluid. Contact Bruker or reference the Internet website, www.bruker.com, for an illustrated survey of probe options.

The implementation of Q control is diagrammed in Figure 9.1b. Q Control is a feedback loop. The proprietary signal processing block features programmable control of phase shifting and amplification gain of the cantilever deflection signal. The result of signal processing is mixed with the independently-generated cantilever drive signal to produce a Q controlled cantilever drive. For a mathematical derivation of Q control properties from signal processed feedback, see **A Q Control Model,** Page 114.

Figure 9.1b Q Control Block Diagram



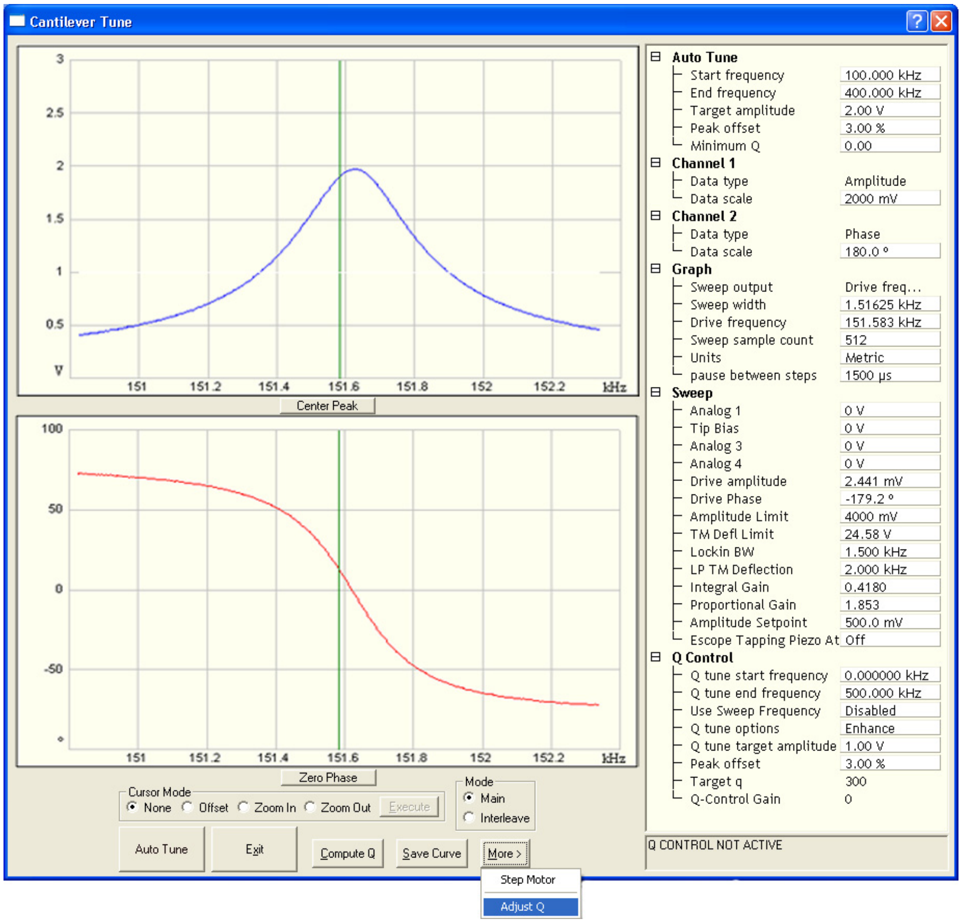
Summarizing, the cantilever piezoelectric actuator (“Piezo” in Figure 9.1b) is driven from two electrical contacts that may be influenced by three sources.

When Q control is active (TappingMode only), an adjustment is mixed into the AC piezo drive signal to achieve the target Q.

9.2 Q Control Setup

1. Access the **Cantilever Tune** dialog box by selecting the **Tune** icon (shown) or by selecting **Tune...** from the **RealTime** menu. The **Sweep**, **Q Control**, **Auto Tune** and selected **Channel** parameter lists open (see Figure 9.2a).

Figure 9.2a Cantilever Tune Dialog Box



Auto Tune	
Start frequency	100.000 kHz
End frequency	400.000 kHz
Target amplitude	2.00 V
Peak offset	3.00 %
Minimum Q	0.00
Channel 1	
Data type	Amplitude
Data scale	2000 mV
Channel 2	
Data type	Phase
Data scale	180.0 °
Graph	
Sweep output	Drive freq...
Sweep width	1.51625 kHz
Drive frequency	151.583 kHz
Sweep sample count	512
Units	Metric
pause between steps	1500 µs
Sweep	
Analog 1	0 V
Tip Bias	0 V
Analog 3	0 V
Analog 4	0 V
Drive amplitude	2.441 mV
Drive Phase	-179.2 °
Amplitude Limit	4000 mV
TM Defl Limit	24.58 V
Lockin BW	1.500 kHz
LP TM Deflection	2.000 kHz
Integral Gain	0.4180
Proportional Gain	1.853
Amplitude Setpoint	500.0 mV
Escope Tapping Piezo At	Off
Q Control	
Q tune start frequency	0.000000 kHz
Q tune end frequency	500.000 kHz
Use Sweep Frequency	Disabled
Q tune options	Enhance
Q tune target amplitude	1.00 V
Peak offset	3.00 %
Target q	300
Q-Control Gain	0

Q CONTROL NOT ACTIVE

2. In the **Q Control** parameter list, if **Use Sweep Frequency** is **Disabled**, then enter a **Q tune start frequency** and a **Q tune end frequency** to bracket the cantilever resonance peak of interest and exclude other peaks. Select **Enhance** or **Damp** for **Q Control/Q tune options** to optimally boost or reduce Q by a factor of approximately 10, respectively.

   In the **Q Control** parameter list, if **Use Sweep Frequency** is **Enabled**, then **Q tune start frequency** and **Q tune end frequency** are grayed out and, instead, Q control seeks a peak over the frequency range **Sweep Controls/Drive Frequency** ± 10kHz. Select **Enhance** or **Damp** just as for **Use Sweep Frequency Disabled**.

   For more specific Q control, select **Seek Q** for **Q Control/Q tune options**. Enter a value for **TARGET Q**. You are selecting enhancement/damping if the target Q value is greater than/less than the natural Q.

Note: With **Q TUNE OPTIONS** of **ENHANCE** or **DAMP**, Q Control attempts to achieve, to within 10 percent, the factor of 10 increase or decrease, respectively, in Q, subject to the constraint that **DRIVE AMPLITUDE** is kept within the range of 10mV to 9V. If this is not possible, Q Control finds the largest factor less than 10 that meets the constraint on **DRIVE AMPLITUDE**.

With **Q TUNE OPTIONS** of **SEEK Q**, Q Control simply fails if it is unable to achieve the **TARGET Q** within 10 percent while constraining **DRIVE AMPLITUDE** to the range [.01, 9] volts.

With Q Control active, you may enter a **Q TUNE TARGET AMPLITUDE**, a **PEAK OFFSET** and you may alter the **Q CONTROL GAIN** (i.e., variable G in the equation of motion on page 114) in the **Q Control** panel. Generally, Q increases with increasing G.

3. Click **MORE** > **ADJUST Q** in the **Cantilever Tune** dialog box to initiate Q Control. Automatic optimization is initiated to achieve the enhancement, damping or specified target Q. The calculation may take tens of seconds.

Note: An asymmetric tune spectrum with ringing (transient oscillation) to the right (at higher frequencies) than the peak indicates frequency was swept too quickly; increase the value of **Sweep Control** (Graph Controls)/**PAUSE BETWEEN STEPS** until the ringing is negligible.

4. To re-establish Q control at a different **TARGET Q** and/or **Q TUNE TARGET AMPLITUDE**, enter the new value(s) in the **Q Control** parameter list and click the **ADJUST Q** button.

Note: **ADJUST Q** performs the minimum adjustment necessary to achieve Q control. If Q Control is not already active, **ADJUST Q** initiates the complete Q Control algorithm. However, if Q Control is active, several parameters do not need redetermination, so **ADJUST Q** does only what is necessary. If the algorithm fails, input parameters and their outcome are restored to their values following the most recent successful Q determination and displayed in the **Q Control** panel. While Q Control is active, parameters **DRIVE PHASE** and **DRIVE AMPLITUDE** in the **Feedback** panel are preceded by “QC” as a reminder. Click **TURN Q CONTROL OFF** to deactivate Q control.

Note: An **Auto Tune** of the cantilever is performed at the start of Q Control so does not need to be performed separately. However, when **USE SWEEP FREQUENCY** is **ENABLED**, you may want to check the cantilever resonance before proceeding. At any time you may click **COMPUTE Q** (see Figure 9.2a). The **Q** panel opens and displays the current measured value of cantilever Q.

Q Control Example: Enhancing a Force Field Measurement

An example of the use of Q Control illustrates interactions it has with the engage process and with drive amplitude. These interactions were taken into account to generate the images shown in Figure

9.2b and Figure 9.2c. In each of the two figures a topographic image appears on the right and a Magnetic Field Microscopy (MFM) image on the left. Nonuniformity of recorded magnetic transition widths is apparent in the high contrast MFM image (Figure 9.2c) taken with an enhanced Q of 1500. This feature of the recording is less discernible in the low Q MFM image (Figure 9.2b). Specifics of the set-up follow.

CAUTION: To take advantage of the improved phase contrast available with enhanced cantilever Q, the direct approach is to adjust Q to a target higher than the Q initially calculated, then engage the probe with the sample. However, the heightened Q can result in false engagement, thereby preventing real engagement. If you turn on Q control only after engaging the surface, then Q control must be established while the tip is engaged with the surface, which can be hazardous to the probe tip and is not recommended. The "middle road" is to activate Q control before engaging, but *reduce* Q to damp cantilever oscillation during engagement. Once engaged, Q is increased.

Figure 9.2b MFM and Height Images of Videotape, Q = 100

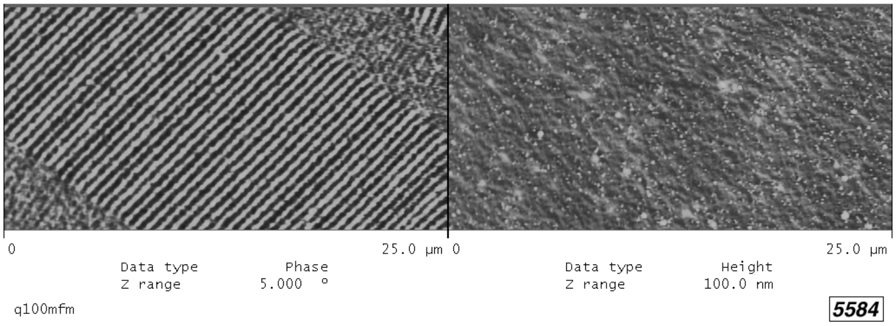
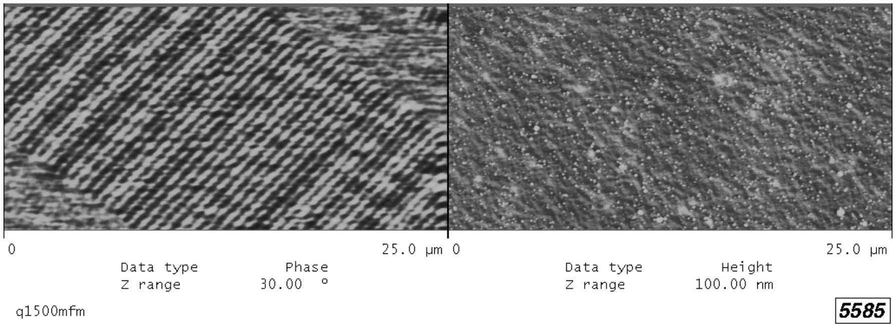
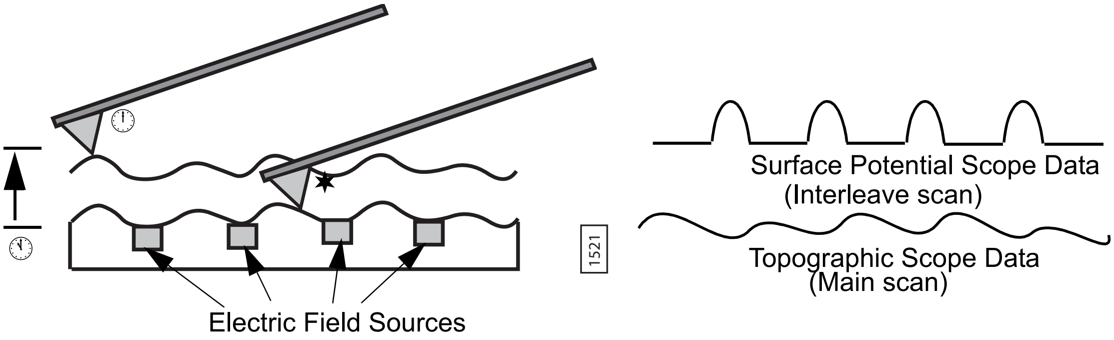


Figure 9.2c MFM and Height Images of Videotape, Q = 1500



Magnetic force microscopy benefits from greater cantilever phase contrast, and so benefits from high Q. MFM image acquisition is a two-stage process: the probe tip traverses the sample surface to record topography and then returns for a second pass measuring the magnetic field perpendicular to the surface and offset above it. In this procedure, called *LiftMode*, the fixed vertical displacement is maintained along the entire scan line by replaying the recorded topography-capturing feedback control signal while adding a constant offset to it (see Figure 9.2d).

Figure 9.2d LiftMode Principles Used in Surface Potential Detection



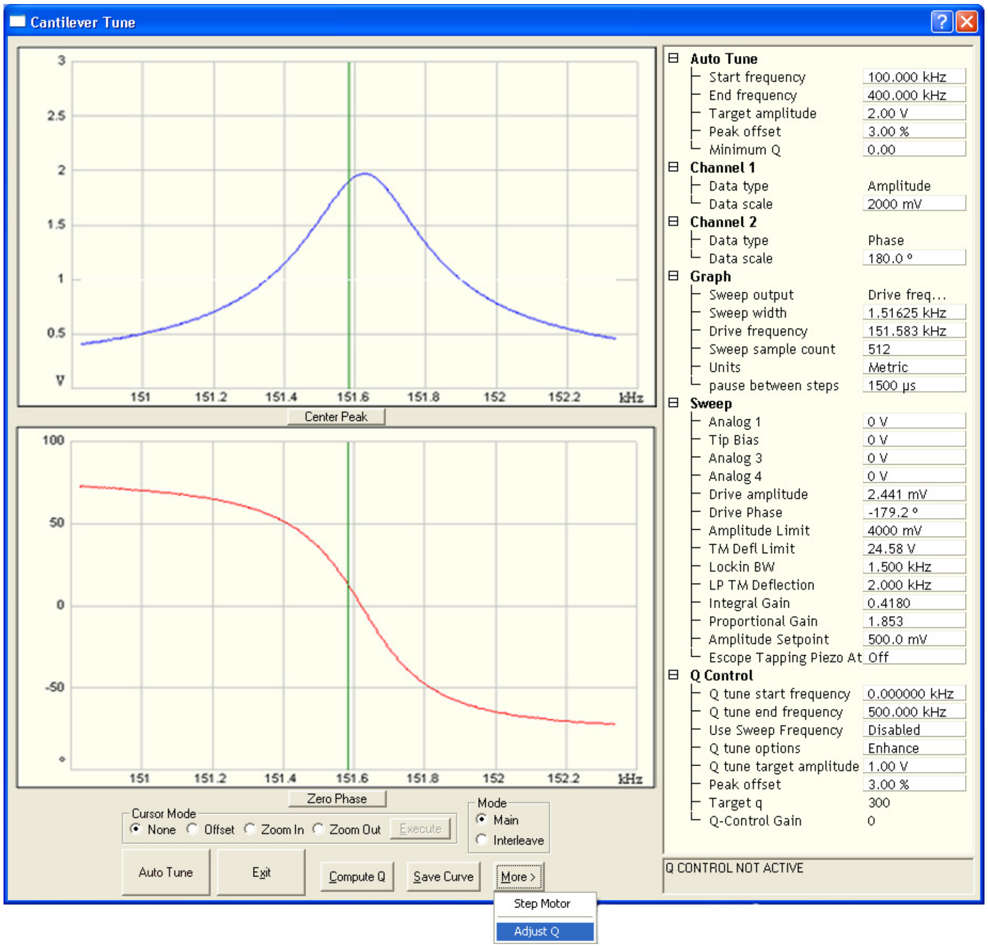
1. Cantilever measures surface topography on the first (main) scan.
2. Cantilever ascends to lift scan height.
3. Cantilever follows stored surface topography at the lift height above sample while responding to electric field influences on the second (interleave) scan.

You can set scan parameters independently for the interleaved surface and elevated scans. On the sample, a **DRIVE AMPLITUDE** of `300mV` works well to track the surface (and not lift off). However, `40mV` is sufficient **DRIVE AMPLITUDE** off-surface at, for instance, `100nm` tip/sample separation for the value of **Interleave Controls**/**LIFT START HEIGHT**. In the **Interleave Controls** panel, click on the circle between the parameter name, **DRIVE AMPLITUDE**, and its value. The circle turns green to indicate the value appearing for the same parameter in the **Sweep Controls** panel is used on-surface, while the **Interleave Controls** value is used off-surface.

9.3 Cantilever Tune Window

The **Q Control** parameter list (see Figure 9.3a) opens, along with **Sweep**, **Auto Tune**, and at least one **Channel** parameter list upon clicking the **CANTILEVER TUNE** icon (shown) or selecting **Tune...** from the **RealTime** menu. At any time, **Auto Tune Controls**/**AUTO TUNE** and/or **Cantilever Tune**/**UTILITIES**/**COMPUTE Q** are selected to monitor cantilever Q, either visually or numerically, respectively.

Figure 9.3a The Q Control Parameter List



Auto Tune

Start frequency	100.000 kHz
End frequency	400.000 kHz
Target amplitude	2.00 V
Peak offset	3.00 %
Minimum Q	0.00

Channel 1

Data type	Amplitude
Data scale	2000 mV

Channel 2

Data type	Phase
Data scale	180.0 °

Graph

Sweep output	Drive freq...
Sweep width	1.51625 kHz
Drive frequency	151.583 kHz
Sweep sample count	512
Units	Metric
pause between steps	1500 µs

Sweep

Analog 1	0 V
Tip Bias	0 V
Analog 3	0 V
Analog 4	0 V
Drive amplitude	2.441 mV
Drive Phase	-179.2 °
Amplitude Limit	4000 mV
TM Defl Limit	24.58 V
Lockin BW	1.500 kHz
LP TM Deflection	2.000 kHz
Integral Gain	0.4180
Proportional Gain	1.853
Amplitude Setpoint	500.0 mV
Escope Tapping Piezo At	Off

Q Control

Q tune start frequency	0.000000 kHz
Q tune end frequency	500.000 kHz
Use Sweep Frequency	Disabled
Q tune options	Enhance
Q tune target amplitude	1.00 V
Peak offset	3.00 %
Target q	300
Q-Control Gain	0

Q CONTROL NOT ACTIVE

Parameters in the Cantilever Tune Window

Q TUNE START FREQUENCY

The minimum frequency of a Q Control frequency sweep.

Range and Settings: **0 — 250KHZ**. Typical values: halfway between the target resonance and the next lower frequency peak in the Cantilever Tune spectrum.

Q TUNE END FREQUENCY

The maximum frequency of a Q Control frequency sweep.

Range and Settings: **250KHZ — 5MHZ**. Typical values: halfway between the target resonance and the next higher frequency peak in the Cantilever Tune spectrum.

USE SWEEP FREQUENCY

When **ENABLED**, the Q Control frequency sweep specification is provided by **Sweep/ DRIVE FREQUENCY** and a sweep width of ±10kHz instead of the previous two parameters in the Q Control panel. The sweep is centered on the drive frequency.

Range and Settings: `ENABLED` or `DISABLED`. Typical value: `DISABLED`.

Q TUNE OPTIONS

Q Control may be given either a general or a specific target Q-value. `ENHANCE` increases Q above its natural value. `DAMP` decreases Q below its natural value. In both cases the target Q-value change is by a factor of 10: `X10` for `ENHANCE`, and `X0.1` for `DAMP`. The closest achievable factor less than 10 is used when a factor of 10 cannot be attained while keeping **DRIVE AMPLITUDE** within the range of 10mV to 9V. If `SEEK Q` is selected for **Q TUNE OPTIONS**, then a specific Q-value is entered for **TARGET Q**. The [0.01, 9] voltage range of **DRIVE AMPLITUDE** is also a constraint when `SEEK Q` is selected.

Range and Settings: `ENHANCE`, `DAMP` or `SEEK Q`. Typical value: `ENHANCE`.

Q TUNE TARGET AMPLITUDE

The intended output signal amplitude *at the photodetector* (not to be confused with the drive amplitude applied to the cantilever).

Range and Settings: `0 — 5.00V`. Typical values: `2.00V` *(Dimension),* `3.00V` *(MultiMode).*

PEAK OFFSET

Percentage displacement from cantilever's free-air resonance to offset the drive frequency. The compensation anticipates the change in resonant frequency resulting from tip/sample interaction once engaged.

Range and Settings: `-50% — +50%`. Typical values: `1% — 2%`.

TARGET Q

The intended Q-value when **Q TUNE OPTIONS** is set to `SEEK Q`. The closest achievable Q-value less than the target is used in enhancement and the closest achievable Q-value greater than the target is used in damping when the target Q cannot be attained.

Range and Settings: `5 — 10,000`. Typical value: application-dependent.

Q-CONTROL GAIN

Direct numerical control of the Q control feedback loop amplification, and thus of cantilever damping is available when Q Control is active. The **Q -CONTROL GAIN** parameter is the damping control variable "G" in **A Q Control Model,** Page 114.

Range and Settings: Typical value: application-dependent.

Buttons on the Q Control Panel

ADJUST Q

Initiates Q control using the parameter settings displayed in the **Q Control** panel and minimizes recalculation when the parameter settings are near those last used in successful Q control.

Note: Click **ADJUST Q** when first using Q Control in an SPM session. There is no speed advantage the first time **ADJUST Q** is clicked in an SPM session.

RESTORE Q CONTROL

Restores Q Control parameter settings to their values following the last successful Q Control use. Then Q Control is re-established.

TURN Q CONTROL OFF

When Q Control is active, the **TURN Q CONTROL OFF** button replaces the **RESTORE Q CONTROL** button so Q control can be stopped.

Cantilever Tune/COMPUTE Q

Perform a frequency sweep (not displayed) and measure the quality factor, Q, of the cantilever resonance. The calue of Q is displayed.

Cantilever Tune/SAVE CURVE

Stores the most recent phase- and amplitude-as-a-function-of-frequency data in a user-named file.

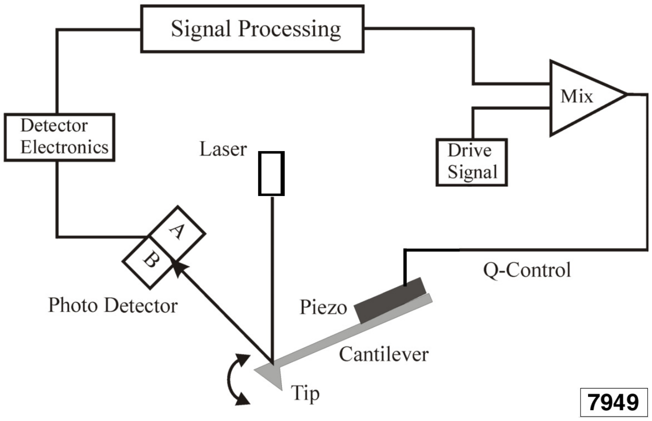
Cantilever Tune/More >/RESET Q CONTROL PROCESS

An intermediate alternative between the **ADJUST Q** and the **RESTORE Q CONTROL** buttons, **RESET Q CONTROL PROCESS** is used to re-establish Q Control with new parameter settings in the **Q Control** panel if the settings represent a significant change from those previously used. For instance, changes to **Q TUNE START FREQUENCY** and **Q TUNE END FREQUENCY** are sufficient to click **RESET Q CONTROL PROCESS** rather than **ADJUST Q**.

9.4 A Q Control Model

The following is a mathematical model for control of the Q of a resonating cantilever by feedback of its detected oscillation.

Figure 9.4a Q Control Block Diagram



The equation of motion of the tip of a driven cantilever with feedback is given by a balance of forces [1]:

$$m\frac{d^2}{dt^2}z(t) + \alpha\frac{d}{dt}z(t) + kz(t) = E + Fe^{i\omega t} + Ge^{i\phi}z(t)$$

expressed in terms of the unknown, variable over time, t: position of the tip, z(t), as well as tip velocity, $\frac{d}{dt}z(t)$, and acceleration, $\frac{d^2}{dt^2}z(t)$, first and second derivatives of position, respectively,

and m = the effective mass of the cantilever and tip,
α = the damping constant of the cantilever,
k = the spring constant of the cantilever,
E = the tip/sample interaction force,
F = the cantilever drive amplitude, as converted to a force through piezo actuation
G = the gain of the amplified feedback signal, as converted to a force via piezo actuation
ω = the cantilever drive frequency, (typically, near the cantilever resonance frequency)
ϕ = the phase shift applied to the feedback signal,
e = 2.71828..., the base of natural logarithms
i = $\sqrt{}$(-1). (Electrical engineers usually use “j” for the same quantity.)

Assuming a solution where the cantilever begins at position z(0) = 0, oscillates at the drive frequency, and has no components at higher frequencies, then

$$z(t) = Ae^{i(\omega t - \psi)} \quad \text{and} \quad \frac{d}{dt}z(t) = i\omega(A \cdot e^{i(\omega t - \psi)}) = i\omega z(t)$$

where A = the cantilever oscillation amplitude, and
ψ = the phase shift of the tip position relative to the drive phase.

The sinusoidal probe tip motion is described as a *phasor* in *exponential form*: a counterclockwise rotating line segment in the complex number plane (i.e., a real number horizontal axis and an imaginary number vertical axis) such that the segment length corresponds to the oscillation amplitude, its rotation rate corresponds to the oscillation frequency and its angle corresponds to the phase of the oscillation

Consider the case of a 90 degree phase shift applied in the feedback loop, that is: $\phi = \pi/2$. The third term on the right-hand side of the equation of motion becomes:

$$Ge^{i\phi}z(t) = Ge^{i(\pi/2)}z(t) = G\left(\cos\left(\frac{\pi}{2}\right) + i\sin\left(\frac{\pi}{2}\right)\right)\left(\frac{1}{(i\omega)}\right)\left(\frac{d}{dt}z(t)\right) = \left(\frac{G}{\omega}\right)\left(\frac{d}{dt}z(t)\right)$$

which can be subtracted from both sides of the equation of motion to yield:

$$m\frac{d^2}{dt^2}z(t) + \left(\alpha - \left(\frac{G}{\omega}\right)\right)\frac{d}{dt}z(t) + kz(t) = E + Fe^{i\omega t}$$

A new cantilever equation of motion results. In the new equation of motion, there is no feedback term while the tip/sample interaction and drive forces are the same as in the original equation of motion. Significantly, the original damping constant, α, is replaced by a new one, $\alpha' = \alpha - (G/\omega)$.

Given that the width of the resonance at half-maximum, γ, equals the damping constant, α', divided by the effective mass of the system, m, the Q of the resonance is given by:

$$Q = \frac{\omega}{\gamma} = \left(\frac{m}{\alpha - (G/\omega)}\right)\omega$$

The result shows that any solution of the chosen form also solves a feedback-free equation of motion with a different damping constant. For a properly chosen Q control feedback phase shift (i.e., $\phi = \pi/2$), the Q control feedback amplifier gain, G, determines the damping, and therefore the Q of the cantilever oscillation.

Reference

[1] *Piconewton Regime Dynamic Force Microscopy in Liquid*, Javier Tamayo, Andrew D. L. Humphris, Mervyn J. Miles, Applied Physics Letters, Vol. 77, No. 4, p. 582, July 24, 2000

Chapter 10 New NanoScope V Features

The NanoScope V Controller enables new NanoScope software enhancements. New hardware features also require introducing corresponding new software features. This chapter highlights software changes introduced with the NanoScope V Controller.

10.1 Ease of Use Interface

The ease of use interface (EOU/Easy AFM) is a LabVIEW executable that is able to control BioScope II, Dimension and MultiMode microscopes through a COM interface. The EOU interface is designed with the infrequent or novice user in mind. It is not intended to replace either the user manual or training by a suitably qualified person on the basic operating principles of the system. It does however, provide a single interface that presents the user with all of the inputs required to obtain high quality TappingMode images from the majority of samples in air. The interface is arranged as a series of pages with a row of tabs along the top for navigation.These tabs are arranged in the order that they should be used. The purpose of each tab is outlined briefly below and is discussed in detail later in this manual.

- **Setup:** This is the default tab when starting the EOU software. Animated guides are included on the setup tab to assist users who are unfamiliar with the basic operation of the microscope.

- **Photodetector Alignment:** The photodetector alignment tab presents the user with an easy to understand interface to assist in the alignment of the reflected laser spot on to the photodetector.

- **Scan:** All of the user inputs required for imaging are entered in the scan tab. Inputs are kept to a minimum and are restricted to items such as the scan size and image quality. The optimization of scan parameters for the final image is done by the EOU software and requires no user input.

- **What's New:** Dynamic content served from the Bruker web server and has information about offers, conferences and product releases.

New or infrequent users should attempt to follow the steps outlined by these tabs, especially the setup tab. More confident users may proceed directly to the scan tab if desired.

While the guides themselves may be skipped by more experienced users, the steps outlined by these guides must be completed prior to engaging the microscope. Failure to ensure the completion of these steps may result in the systems inability to correctly engage on the sample and damage to the tip and or sample may occur. With the exception of the focus tip/sample step for the Dimension, all of these steps are completed using the hardware and cannot be achieved with software.

1. **Replace the cantilever:** The cantilever need not be changed with each new sample. However, if you do not know the history of the probe, i.e. it was already installed when you arrived at the microscope, you should change it. Cantilevers should be regarded as a consumable and changed whenever appropriate. The only part of the microscope that interacts directly with the sample is the probe at the end of the cantilever. If this probe is bad, the resultant images will be of poorer quality and may contain significant tip-induced artefacts.

2. **Laser alignment:** In order for the feedback system to function correctly, the laser must be aligned to the end of the cantilever. The easiest method of completing this task is outlined in the guide. There are, however, several other methods — experienced users should use the method they are comfortable with.

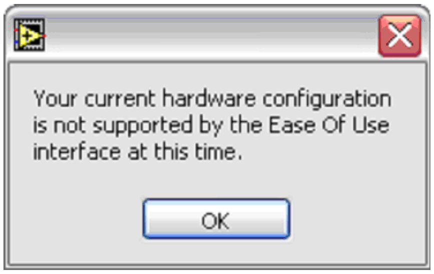
3. **Photodetector alignment:** Once the laser is aligned onto the back of the cantilever, it is necessary to adjust the reflected light path so that it falls onto the center of the photodetector.

4. **Focus tip/sample:** For Dimension series microscopes this operation is vital for the system to correctly engage onto the sample surface. This is achieved through software and is the final step before moving on to the scan tab.

10.1.1 Starting the EOU Interface

Start the EOU interface by clicking Start/Programs/NanoScope/EOU. The interface currently supports the NanoScope V Controller with the Dimension V, and MultiMode microscopes. Any other hardware configuration will cause EOU to display the message shown in Figure 10.1a and terminate. If the EOU interface terminates, check the current microscope configuration from NanoScope and change it if necessary.

Figure 10.1a Incompatible hardware message



Your current hardware configuration is not supported by the Ease Of Use interface at this time.

CAUTION: Damage may occur if the user attempts to run the system by selecting incorrect hardware in the **Microscope Select** panel.

10.1.2 Setup Tab

The setup tab, shown in Figure 10.1b, is the default tab selected at startup and provides the user with a collection of guides appropriate for the microscope being used. The EOU interface currently supports the BioScope II, Dimension and MultiMode series of microscopes with relevant guides loaded based on the configuration of your system. There are four guides available and it is anticipated that new users will work through these in the order presented. Users who are more familiar with the microscope may choose to skip any or all of these guides and go directly to the scanning tab and setup the hardware un-aided. A brief description of the guides is given below:

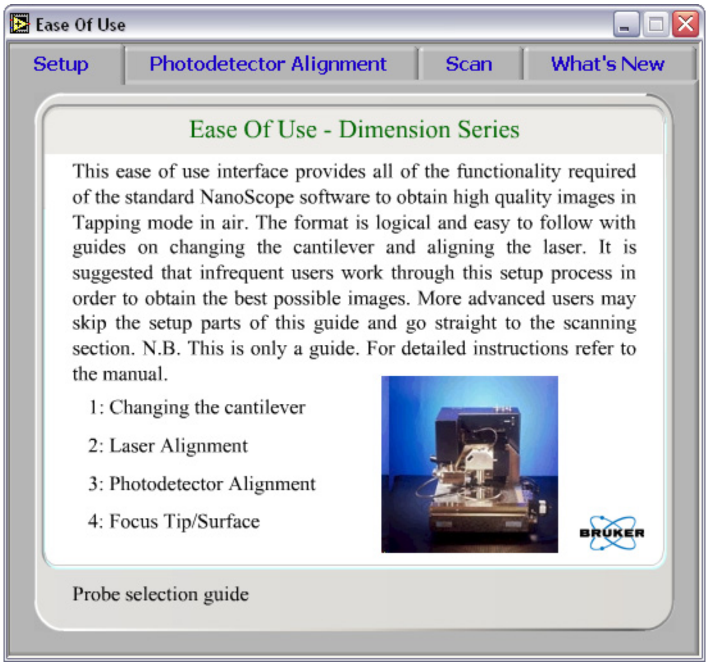
1. **Changing the cantilever:** Demonstrates the correct method for safely replacing the cantilever on the BioScope II, Dimension or MultiMode microscope.

2. **Laser alignment:** Deals with what most novice users find the hardest concept to understand. A simple and reliable method of aligning the laser onto the back of the cantilever is presented with animations where appropriate.

3. **Photodetector alignment:** Describes the actions required to align the photodetector although it is expected that the actual alignment will be carried out using the photodetector alignment tab (Dimension users). The photodetector tab is not available for MultiMode users who should refer to the manual for detailed instructions.

4. **Focus tip/surface:** This guide, while not interfacing directly with the hardware, explains both the theory and steps required to safely complete this process. MultiMode users should simply ensure that the tip/sample separation is minimized prior to engaging to reduce the engage time.

Figure 10.1b The setup interface for Dimension series microscopes. Links to available guides are numbered 1 through 4.



Ease Of Use - Dimension Series

This ease of use interface provides all of the functionality required of the standard NanoScope software to obtain high quality images in Tapping mode in air. The format is logical and easy to follow with guides on changing the cantilever and aligning the laser. It is suggested that infrequent users work through this setup process in order to obtain the best possible images. More advanced users may skip the setup parts of this guide and go straight to the scanning section. N.B. This is only a guide. For detailed instructions refer to the manual.

1: Changing the cantilever
2: Laser Alignment
3: Photodetector Alignment
4: Focus Tip/Surface

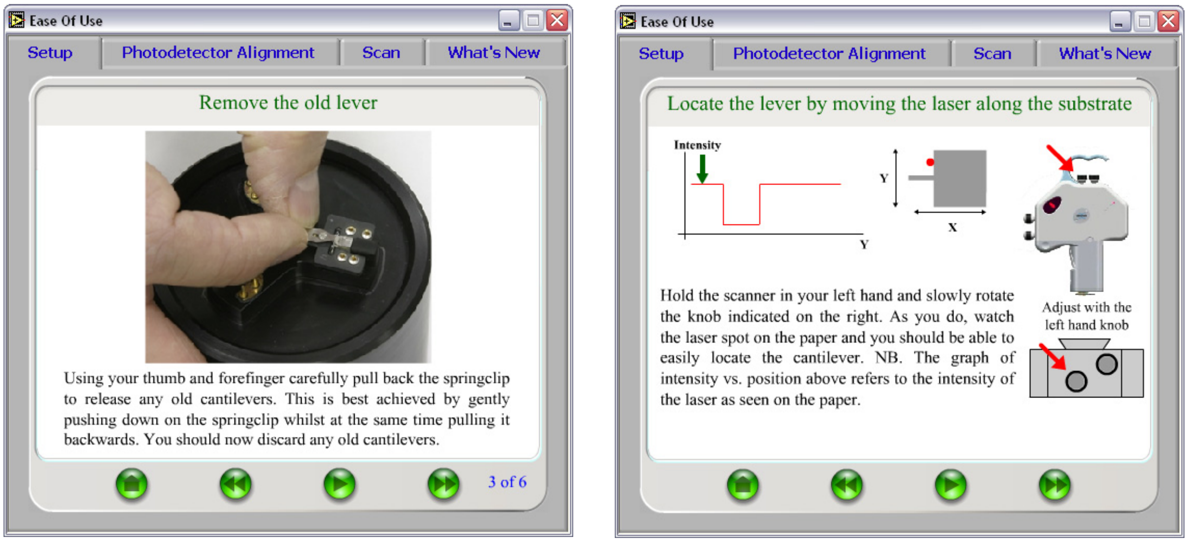
Probe selection guide

The guides are selected by clicking one of the links at the bottom left of the setup panel. The user will be presented with an embedded document that describes in detail the process required to complete the selected operation. Navigation through the guides is done via the four green buttons along the bottom of the panel, shown in Figure 10.1c. The functionality of the buttons is common throughout all of the guides available and is also described in Figure 10.1c.

Figure 10.1c Navigation controls within the user guides use common buttons.

⌂	**Home:** Back to the first page with links to the available guides
⏪	**Back:** Rewind to the previous section
▶	**Play:** Forward to the next section including any available animations
⏩	**Forward:** Moves to the next section skipping animations

Figure 10.1d Guides are available to help the user set up the system including changing the cantilever and aligning the laser.



Remove the old lever

Using your thumb and forefinger carefully pull back the springclip to release any old cantilevers. This is best achieved by gently pushing down on the springclip whilst at the same time pulling it backwards. You should now discard any old cantilevers.

3 of 6

Locate the lever by moving the laser along the substrate

Hold the scanner in your left hand and slowly rotate the knob indicated on the right. As you do, watch the laser spot on the paper and you should be able to easily locate the cantilever. NB. The graph of intensity vs. position above refers to the intensity of the laser as seen on the paper.

Adjust with the left hand knob

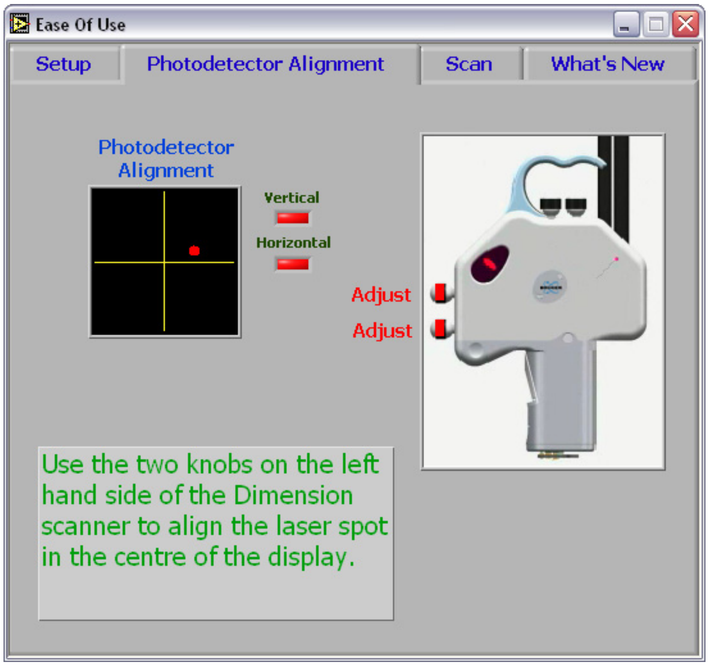
10.1.3 Photodetector Alignment Tab (Dimension only)

The **Photodector Alignment** tab assists with the alignment of the laser onto the center of the photodetector.

Note: This tab is only available for the Dimension series of microscopes due to hardware limitations within the current MultiMode architecture. Users of the MultiMode should follow the directions outlined in the photodetector alignment guide under the setup tab or refer to the *MultiMode SPM Instruction Manual*.

Figure 10.1e shows a typical **Photodetector Alignment** tab following the replacement of the cantilever. The indicator shows that the photodetector needs to be aligned both vertically and horizontally. This is indicated by the fact that the representation of the laser spot is red and off center. If the spot appears grey instead of red, the laser is far from the center of the photodetector and coarse adjustment is needed. The knob that needs adjusting is indicated in red. The photodetector should be adjusted until the laser spot on the physical head is approximately in the center of the window, shown in Figure 10.1f.

Figure 10.1e Alignment of the photodetector is accomplished with this interface. The diagram below indicates that both the horizontal and vertical axis need to be adjusted.

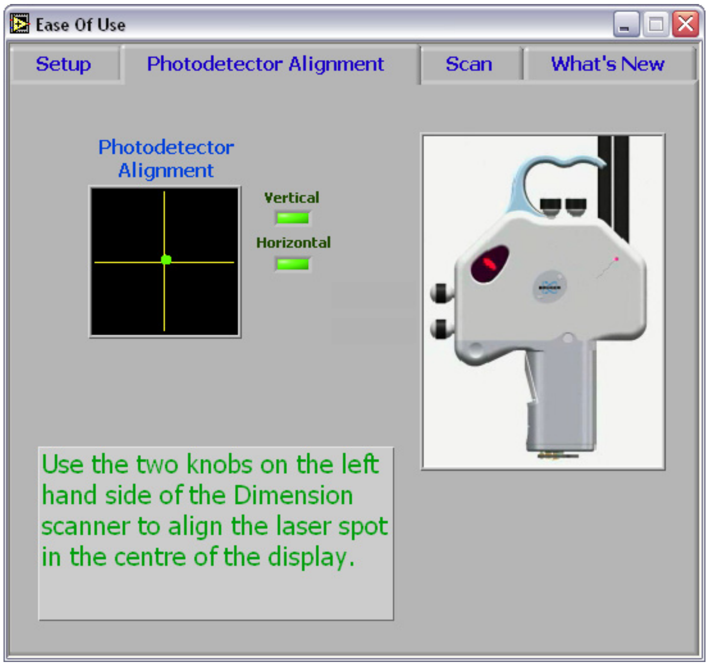


Use the two knobs on the left hand side of the Dimension scanner to align the laser spot in the centre of the display.

Figure 10.1f Coarse alignment should leave the laser spot in the center of the indicator.

Following coarse adjustment, the spot should be red and fine adjustment may be attempted. As the spot crosses the center of the meter screen (zero volts), either horizontally or vertically, there will be a beep from the computer to alert the user. This makes photodetector alignment easier when the user cannot clearly see the computer screen. No sound will be heard if the photodetector alignment tab is not active within the EOU interface. When the photodetector is aligned in both axes, the two indicators and the spot will turn from red to green. The range for acceptable alignment is ±0.2 volts in both horizontal and vertical axes. A system that is correctly aligned is shown below in Figure 10.1g.

Figure 10.1g The photodetector is now correctly aligned both horizontally and vertically.

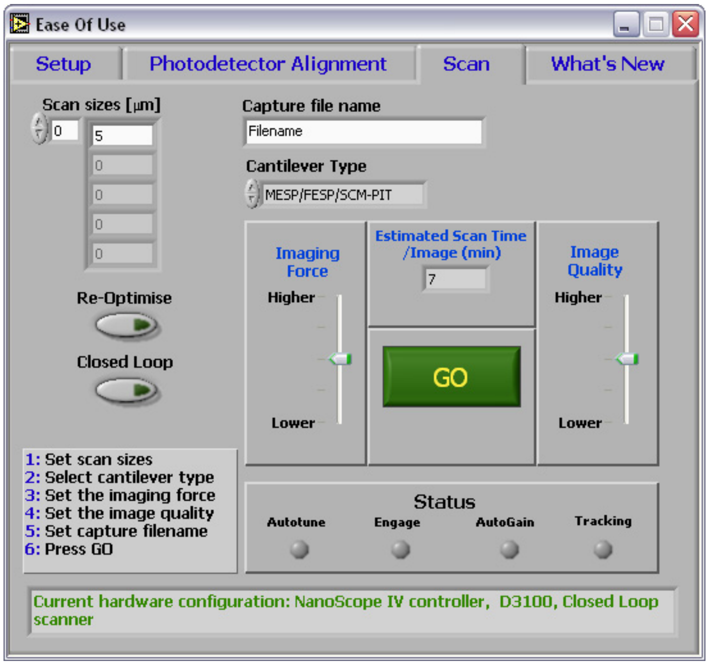


Use the two knobs on the left hand side of the Dimension scanner to align the laser spot in the centre of the display.

10.1.4 Scan Tab

The scan tab contains all of the user inputs required to obtain high quality images in TappingMode. These parameters are described in detail below with reference to Figure 10.1h.

Figure 10.1h The Scan tab. Scanning is initiated by pressing the “GO” button.



Scan sizes [µm]: 0; 5, 0, 0, 0, 0

Capture file name: Filename

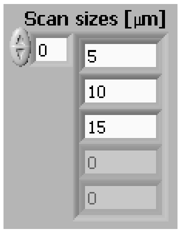
Cantilever Type: MESP/FESP/SCM-PIT

Estimated Scan Time /Image (min): 7

1: Set scan sizes
2: Select cantilever type
3: Set the imaging force
4: Set the image quality
5: Set capture filename
6: Press GO

Current hardware configuration: NanoScope IV controller, D3100, Closed Loop scanner

Scan Sizes: Input the required scan sizes in microns. The counter to the left of the array field allows the user to scroll the scan sizes and input more than the five shown. The user is prohibited from collecting images with a zero scan size. If this is required, a scan size of 1nm (0.001 µm) is suggested.



Scan sizes [µm]

0

5
10
15
0
0

Cantilever Type: Select the cantilever type according to the cantilever currently being used. This defines the frequency range for the autotune algorithm. Selecting an incorrect frequency type will cause the autotune algorithm to fail.

Cantilever Type: MESP/FESP/SCM-PIT

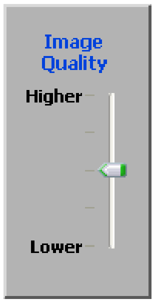
Capture File Name: The filename used for the captured image file. If multiple scans are being done, the files are saved as Filename.000 through Filename.xxx.

Capture file name: Filename

Imaging Force: The amount of force exerted by the cantilever on the sample during imaging. Higher forces are typically used with hard samples with the imaging force being reduced for softer samples. The default setting will give good images for most samples. See the note below for a more detailed explanation.

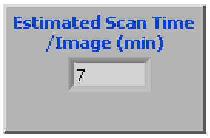
Re-optimise: Clicking this button restarts the tracking optimization process.

Image Quality: Sets the number of pixels in the final captured image. The range is 128 x 128 up to 1024 x 1024 pixels with the default setting being 256x256. All captured images have an aspect ratio of 1:1 yielding square pixels that are needed for offline statistical analysis. The higher the image quality setting, the longer the scan time required to complete the capture.

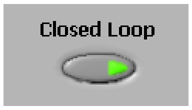


Go: When the above parameters have been set and you are ready to image the sample, simply press the GO button.

Estimated Scan Time/Image: Provides an indication of the estimated time per image based on the image quality setting. Because the final scan rate is calculated from the sample topography, this is only an estimate until the scan parameters are optimized, at which point the remaining scan time is calculated and displayed.


Estimated Scan Time /Image (min)
7

Closed Loop: Switches the XY closed loop on for closed loop enabled scanners. This button does not appear if the currently selected scanner is an open loop scanner or you have the MultiMode microscope selected.



Note: **Imaging Force:** The imaging force slider sets both the autotune amplitude and the setpoint change by which the setpoint is reduced (setpoint delta) following a successful engage. The parameters used for this are given in Table 10.1a.

Table 10.1a Tuning Amplitude and Setpoint Delta are controlled by the **IMAGING FORCE** slider in the EOU.

	Tuning Amplitude (mV)	**Setpoint Delta**
Higher Force	570	70%
	510	75%
	420	80%
	280	85%
Lower Force	200	90%

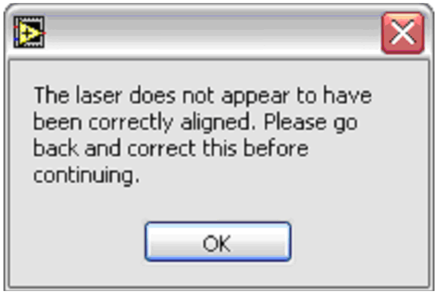
Parameter Check

Prior to engaging, the system will check, independently of any engage checks performed by NanoScope, the imaging parameters set by the user. The basic checks carried out are:

Laser alignment check (Dimension only)

In order to correctly perform the autotune, it is important that the laser has been correctly aligned. If this step has not been carried out, the user will be directed back to the photodetector alignment tab to correct this situation (see Figure 10.1i). You will not be able to continue without correctly aligning the laser.

Figure 10.1i Laser alignment check

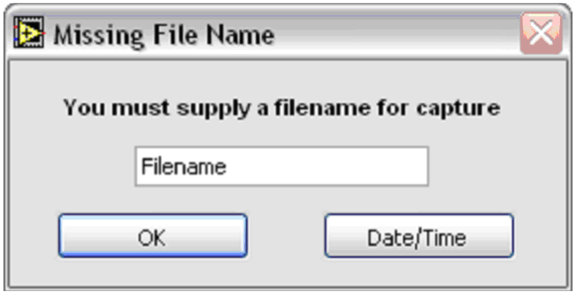


The laser does not appear to have been correctly aligned. Please go back and correct this before continuing.

Valid file name

A valid file name is required for the NanoScope software to capture images. If the field is left blank, an error box, shown in Figure 10.1j, will be displayed. At this point, you have the option of inserting a filename or selecting DATE/TIME. Click **OK** when finished. On saving, spaces will be replaced with underscores (_).

Figure 10.1j Valid file name needed



Missing File Name

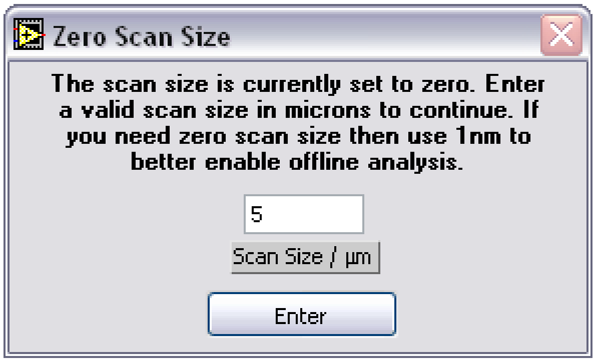
You must supply a filename for capture

Filename

Scan size

The scan sizes entered into the scan size array must be non-zero. A scan size of zero is used to halt the program. If you need to scan to zero, try a scan size of 1nm (0.001µm). See Figure 10.1k.

Figure 10.1k Check for a zero scan size



Zero Scan Size

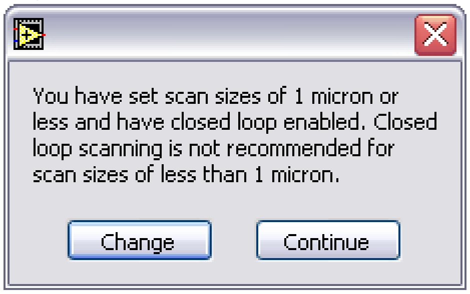
The scan size is currently set to zero. Enter a valid scan size in microns to continue. If you need zero scan size then use 1nm to better enable offline analysis.

Scan Size / µm: 5

Closed loop (Dimension only)

If **CLOSED LOOP** is enabled with either a CL or Hybrid head and any of the scan sizes entered into the scan size array is below 1µm, a warning, shown in Figure 10.1l, will be generated. For scan sizes of 1µm or less Bruker recommends that you scan in open loop mode. At this point you have the choice of ignoring the warning by clicking **CONTINUE**, or going back and changing the scan size/closed loop parameters by clicking **CHANGE**. For more information regarding closed loop heads refer to *Support Note 394, Dimension Hybrid XYZ Scanning Probe Microscope Head* or *Support Note 360, Closed Loop XY Dimension Head.*

Figure 10.1l Closed loop scan size check

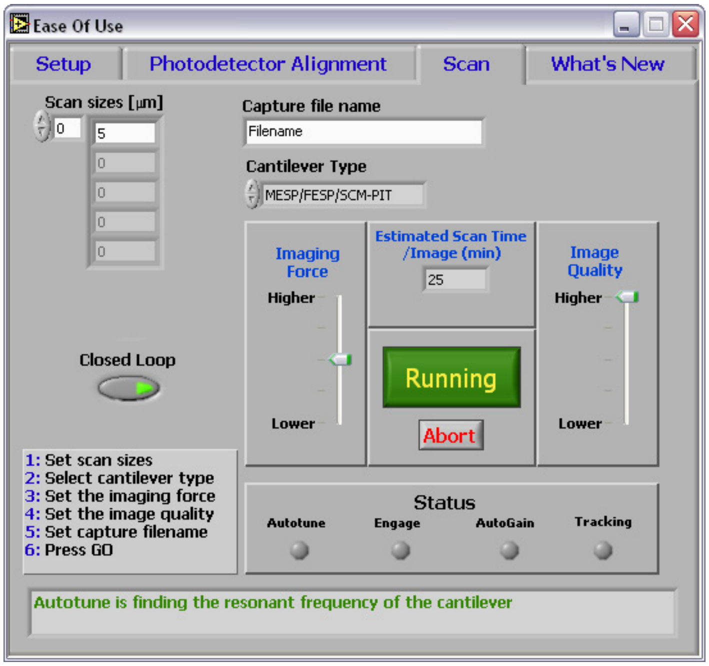


You have set scan sizes of 1 micron or less and have closed loop enabled. Closed loop scanning is not recommended for scan sizes of less than 1 micron.

Tracking

Once the required image parameters have been set, the user can initiate the engage and scanning process by pressing the **GO** button. Once the engage process has been initiated, the **GO** button will change to **RUNNING** to indicate the EOU interface is controlling NanoScope, shown in Figure 10.1m. From this point on, no further user intervention is required and the interface ignores further user input.

Figure 10.1m When the system is running, the **GO** button changes to **RUNNING** and no further user input is allowed.



Scan sizes [µm]: 0 | 5, 0, 0, 0, 0

Capture file name: Filename

Cantilever Type: MESP/FESP/SCM-PIT

Estimated Scan Time /Image (min): 25

1: Set scan sizes
2: Select cantilever type
3: Set the imaging force
4: Set the image quality
5: Set capture filename
6: Press GO

Autotune is finding the resonant frequency of the cantilever

While the system is running the current status is displayed in the message box at the bottom of the interface panel, shown in Figure 10.1n to Figure 10.1q. Key events are indicated by four indicators along the bottom of the scan panel, which turn green after successful completion of the event. These key events are:

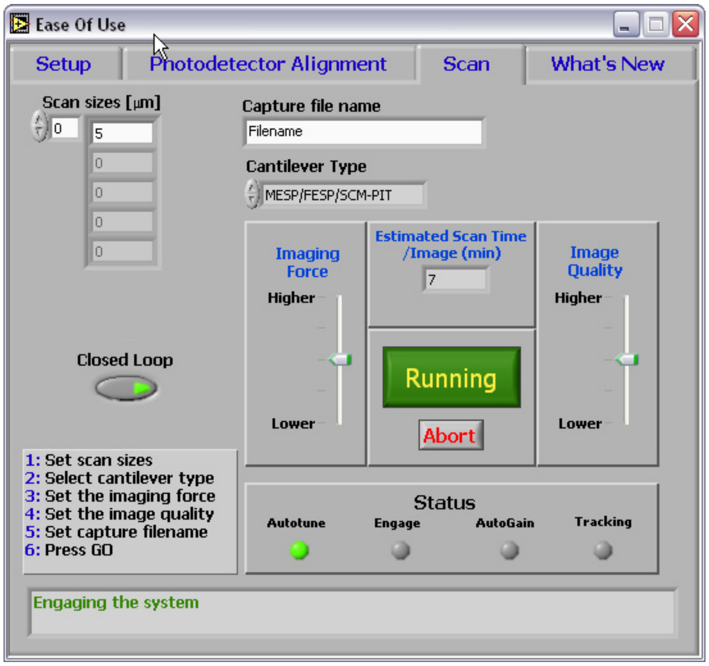
1. **Autotune:** Illuminated if the system correctly finds the resonant frequency of the cantilever. The system uses a minimum Q value to determine whether or not the correct peak has been identified. The system will not continue if autotune fails to locate the resonant peak of the lever. See Figure 10.1n.

2. **Engage:** Once the microscope has acquired the surface, the engage indicator will be illuminated. A check is performed to verify that the Z Center voltage is within limits (+/-200 Volts) before continuing in order to protect the piezo. If outside this range, the microscope will withdraw and you should retry. Once this indicator is illuminated the system is ready to begin optimization of the scan parameters based on the measured sample topography. See Figure 10.1o.

3. **Completion of the initial gain adjustments:** After engaging, the integral and proportional gains are adjusted. When done, the **AUTOGAIN** indicator will be illuminated and the system will proceed to optimize scan rate, feedback gain and imaging force to give the best image possible. See Figure 10.1p.

4. **Tracking:** With a good set of scan parameters, the system will look at the data to determine whether or not the tip is correctly tracking the surface. Good tracking is indicated by the illumination of the fourth indicator, shown in Figure 10.1q. If good tracking has not been achieved, a **RE-OPTIMISE** button will appear.

Figure 10.1n Autotune has identified the resonant peak of the selected cantilever.



Scan sizes [µm]: 0; 5, 0, 0, 0, 0

Capture file name: Filename

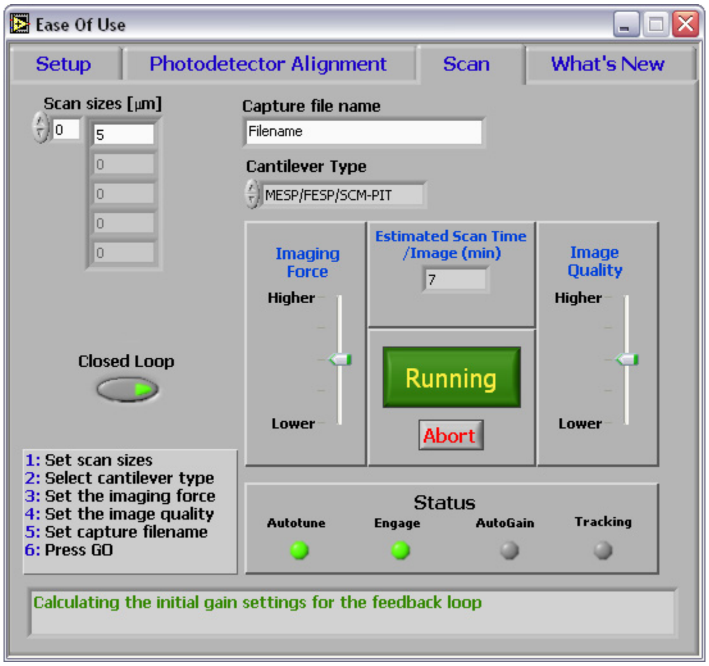
Cantilever Type: MESP/FESP/SCM-PIT

Estimated Scan Time /Image (min): 7

1: Set scan sizes
2: Select cantilever type
3: Set the imaging force
4: Set the image quality
5: Set capture filename
6: Press GO

Engaging the system

Figure 10.1o The microscope has successfully engaged.



Scan sizes [µm]: 0; 5, 0, 0, 0, 0

Capture file name: Filename

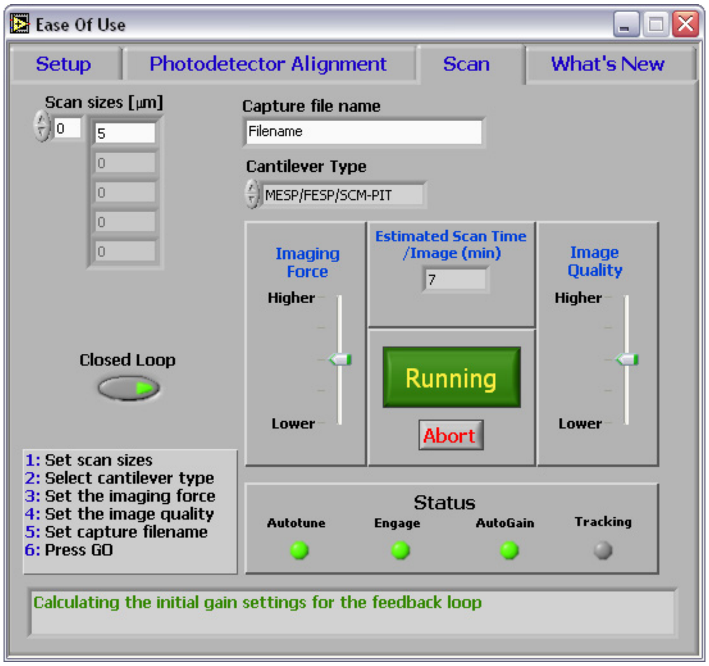
Cantilever Type: MESP/FESP/SCM-PIT

Estimated Scan Time /Image (min): 7

1: Set scan sizes
2: Select cantilever type
3: Set the imaging force
4: Set the image quality
5: Set capture filename
6: Press GO

Calculating the initial gain settings for the feedback loop

Figure 10.1p AutoGain has correctly set the gains for initial scanning.



Scan sizes [μm]: 0 | 5, 0, 0, 0, 0

Capture file name: Filename

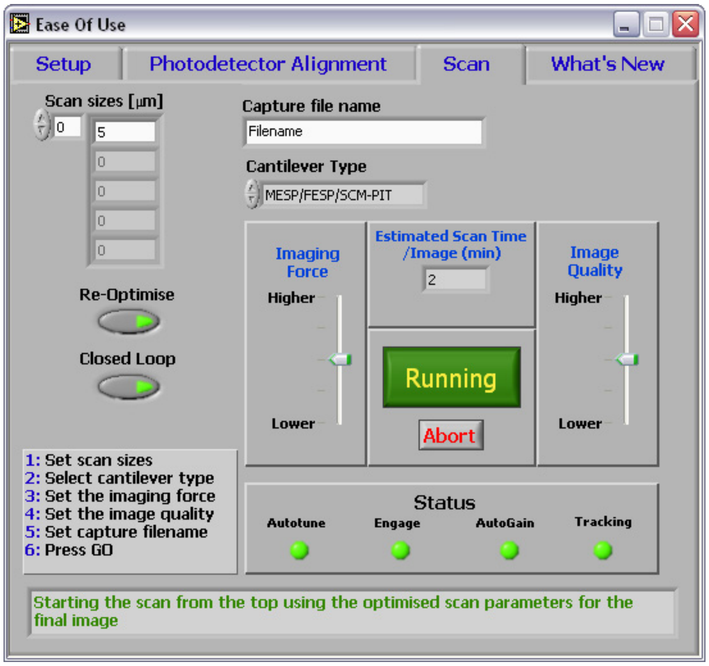
Cantilever Type: MESP/FESP/SCM-PIT

Estimated Scan Time /Image (min): 7

1: Set scan sizes
2: Select cantilever type
3: Set the imaging force
4: Set the image quality
5: Set capture filename
6: Press GO

Calculating the initial gain settings for the feedback loop

Figure 10.1q Tracking is good and the image will now be captured at the required scan resolution



Scan sizes [μm]: 0 | 5, 0, 0, 0, 0

Capture file name: Filename

Cantilever Type: MESP/FESP/SCM-PIT

Estimated Scan Time /Image (min): 2

1: Set scan sizes
2: Select cantilever type
3: Set the imaging force
4: Set the image quality
5: Set capture filename
6: Press GO

Starting the scan from the top using the optimised scan parameters for the final image

Once engaged on the surface with the initial integral and proportional gains set, the system will proceed to set scan parameters appropriate to the topography of the sample being measured. This is done in several stages.

First the software will obtain a low-resolution topography image at the requested scan size to determine the height variations within the scan area. This is calculated from the rms amplitude within the image and is then used to determine initial scan parameters. The scan parameters are based on the scan size selected, the sample roughness and the imaging force selected by the user. The variables are set using the following arguments:

Scan rate (Hz)

The scan rate is initially set based on the sample roughness with an additional factor to account for scan size and imaging force. The scan rate is given by:

$$\mathrm{ScanRate} = 2.65e^{-6x10^{-4}(\mathrm{RmsAmplitude})} \bullet \left[\frac{4}{\sqrt{\mathrm{ScanSize}(\mu\mathrm{m})}}\right]$$

The scan size correction factor reduces the scan rate as the scan size increases to maintain tip velocity relative to the sample. This ensures that the tip will track surface topography regardless of scan size. The correction factor is only applied for scan sizes above 1μm. For scan sizes of 1μm or less, the correction factor is set to 1.0 and hence, as the sample roughness tends to zero the maximum scan rate tends to 2.65Hz.

Setpoint reduction

The amplitude setpoint is reduced resulting in a higher tip/sample force and enables the feedback loop to better track the sample topography. The setpoint reduction factor is further modified by the setpoint delta discussed earlier. This ensures that when running samples with lighter imaging forces, as defined by the user with the imaging force setting, the setpoint reduction is scaled accordingly. The setpoint reduction factor is calculated by:

$$\mathrm{ReductionFactor} = \frac{1}{e^{-6x10^{-5}\langle \mathrm{RmsAmplitude}\rangle} \bullet \left[\frac{1}{\mathrm{SetpointData}}\right]}$$

If the current setpoint is lower than 0.3 volts, the setpoint reduction step is not executed.

Gain factor

The integral and proportional gains that were set to capture the initial low-resolution scan must now be modified based on the measured roughness of the sample. Samples with little topography require lower gains for the feedback loop to track the surface, while samples with rougher surfaces need higher feedback gain at the same scan rate. Multiplying by a gain factor varies the initial gains — this factor is given by:

$$\mathrm{GainFactor} = [0.35 \bullet \ln\langle \mathrm{RmsAmplitude}\rangle] - 1$$

The gain factor will, in most cases, reduce the initial gains from those used for the low-resolution capture. This is partially due to the fact that the survey image is captured at a higher scan rate of 4Hz and hence higher gains are required to track the surface. Because high-resolution images will be captured at slower scan rates, they do not require such high gain settings. For samples with large variations in surface topography, however, it is possible for the gain settings to be increased.

The corrections given by these equations allow the feedback loop to better follow the surface topography for a sample with a given roughness. Finally, the Z-limit is reduced to a value appropriate for the measured roughness.

Once the scan parameters for the final high-resolution image have been set, the system will attempt to optimize them to ensure the highest image quality. Optimization of the scan parameters for the final image are measured by the ability of the tip to correctly track the surface topography using both trace and retrace data. Variation in measured trace vs. retrace topography will cause the system to take the following actions in the order shown:

1. **Increase tapping force:** The amplitude setpoint is reduced by a factor of 0.9 resulting in an increase in the tip/sample interaction force.

2. **Increase feedback gains:** The integral and proportional gains are increased by a factor of 1.2 and 1.4 respectively.

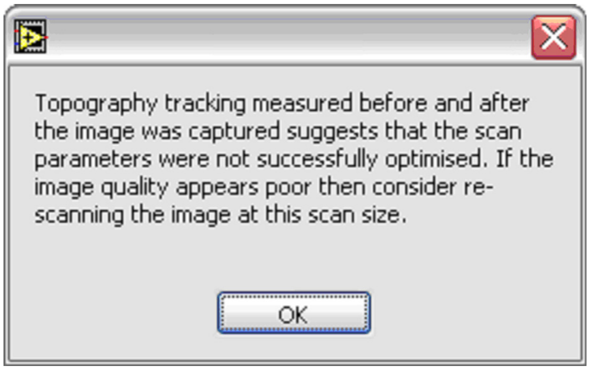
3. **Reduce scan rate:** The scan rate is reduced by a factor of 0.9 enabling the system to better track the topography with the current tapping force and gain settings.

4. **Increase drive amplitude:** The drive amplitude is increased by a factor of 1.15. This has the effect of increasing the tapping force while preventing the setpoint becoming too low when imaging with light tapping forces and low drive amplitudes.

Between each of the four adjustments outlined above, tracking is re-measured, so that only those actions necessary for good image quality are carried out. Once the scanning parameters are finalized the scan is started from the top of the image and the system set to capture the resultant data.

Following the capture of the image, the “Tracking Factor” is measured and compared to that recorded before the image was acquired. The first value is taken at the top of the image while the second is measured at the bottom. Significant variations in the observed topography between these two regions may affect the calculated value used to validate the overall tracking. If tracking in both of these regions is not optimum, the warning shown in Figure 10.1r is displayed.

Figure 10.1r A message is displayed to the user indicating that the topography-tracking algorithm was not optimized



Topography tracking measured before and after the image was captured suggests that the scan parameters were not successfully optimised. If the image quality appears poor then consider re-scanning the image at this scan size.

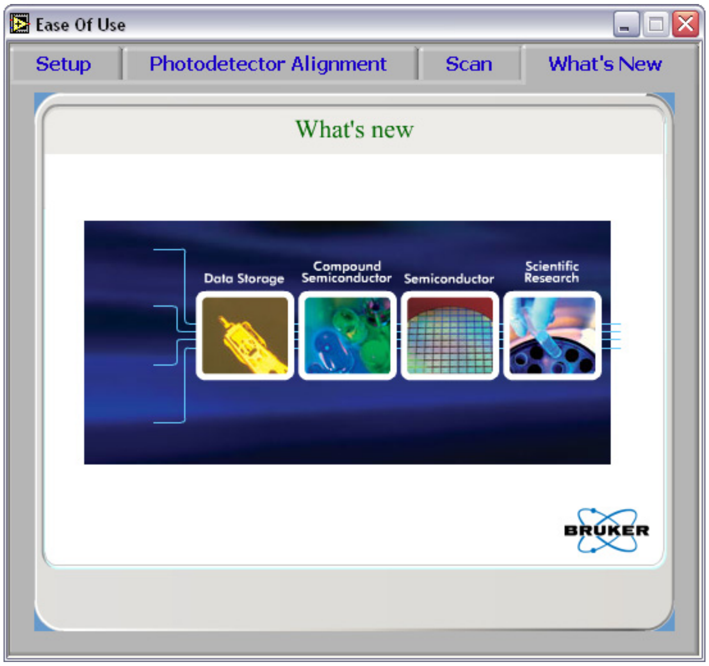
This should not be treated as an error but simply an indication that the tracking was not optimized. Bruker suggests that you inspect the image and decide whether or not to rescan. If a rescan is performed, Bruker recommends that the imaging force be increased slightly to allow for better tracking within the boundaries of the optimization algorithms.

Scan parameter optimization may have been performed at a location with sufficiently different topography than other regions on your sample resulting in poor tracking in those regions. Click **RE-OPTIMISE** to optimize scan parameters in the vicinity of the tip.

10.1.5 What’s New Tab

The **What’s New** tab is an active flash movie that is streamed to the EOU interface from the Bruker web server. It is proposed that information on the latest offers for tips, upcoming conferences and software releases will be announced here. The flash movie will only be running when the what’s new tab is active and will not run in the background so as not to use system resources. The panel will look similar to that shown in Figure 10.1s although the content is dynamic. Anytime the Bruker logo appears it is a link to the Bruker website, http://www.bruker.com.

Figure 10.1s The **What's New** panel displays the latest information from the Bruker website.

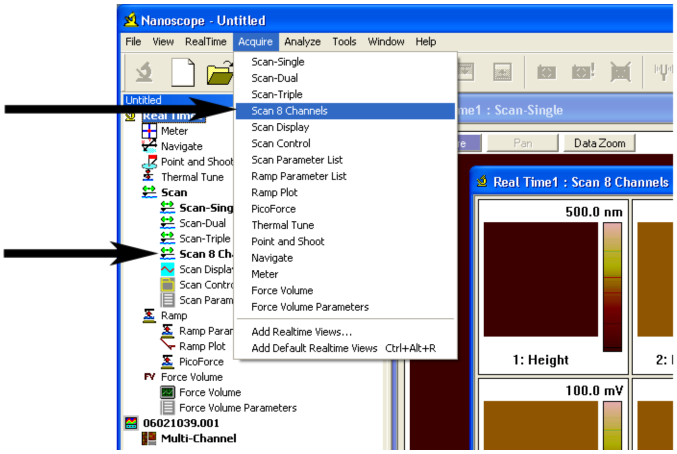


10.2 Eight Channels

10.2.1 RealTime View

NanoScope Version 7.00 software supports data capture in eight simultaneous channels. Start this by clicking ACQUIRE > SCAN 8 CHANNELS from the Menu Bar. You may also start this by clicking the SCAN 8 CHANNELS workspace node shown in Figure 10.2a. This opens the **Scan 8 Channels** window, shown in Figure 10.2b.

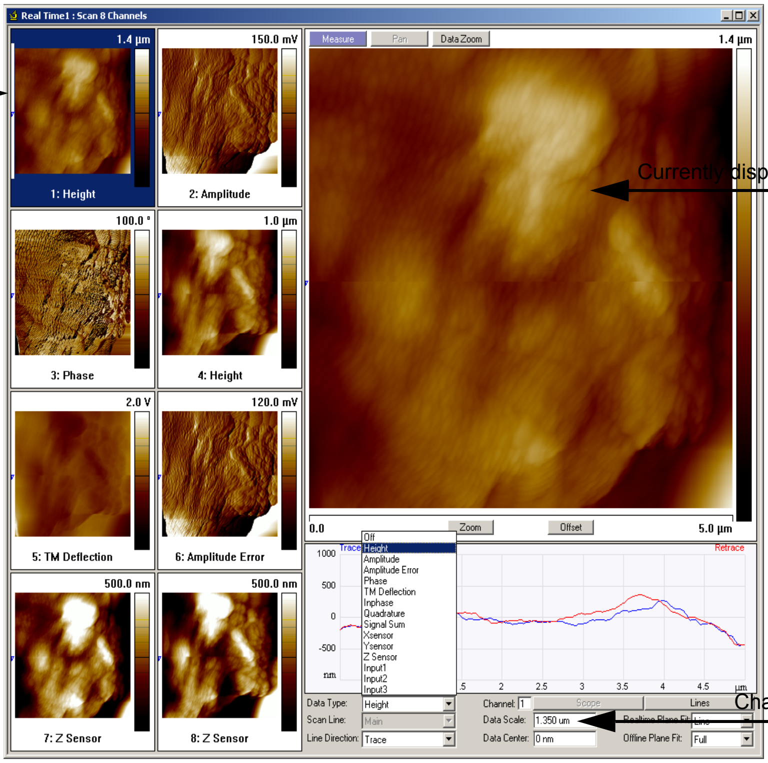
Figure 10.2a Select SCAN 8 CHANNELS in **RealTime** view



Thumbnail panel

All active channels have an associated thumbnail down the left-hand side of the **Scan 8 Channels** window, shown in Figure 10.2b. The currently displayed channel is highlighted. The image parameters may be set independently for all eight channels including data type and scale, plane fitting and color table. See Channel Settings in Figure 10.2b. Settings common to all channels can be set through the **Scan Parameter List**.

Figure 10.2b Scan 8 Channels RealTime view



Data Type: Height
Scan Line: Main
Line Direction: Trace
Channel: 1
Data Scale: 1.350 um
Data Center: 0 nm
Realtime Plane Fit: Line
Offline Plane Fit: Full

Currently displayed channel

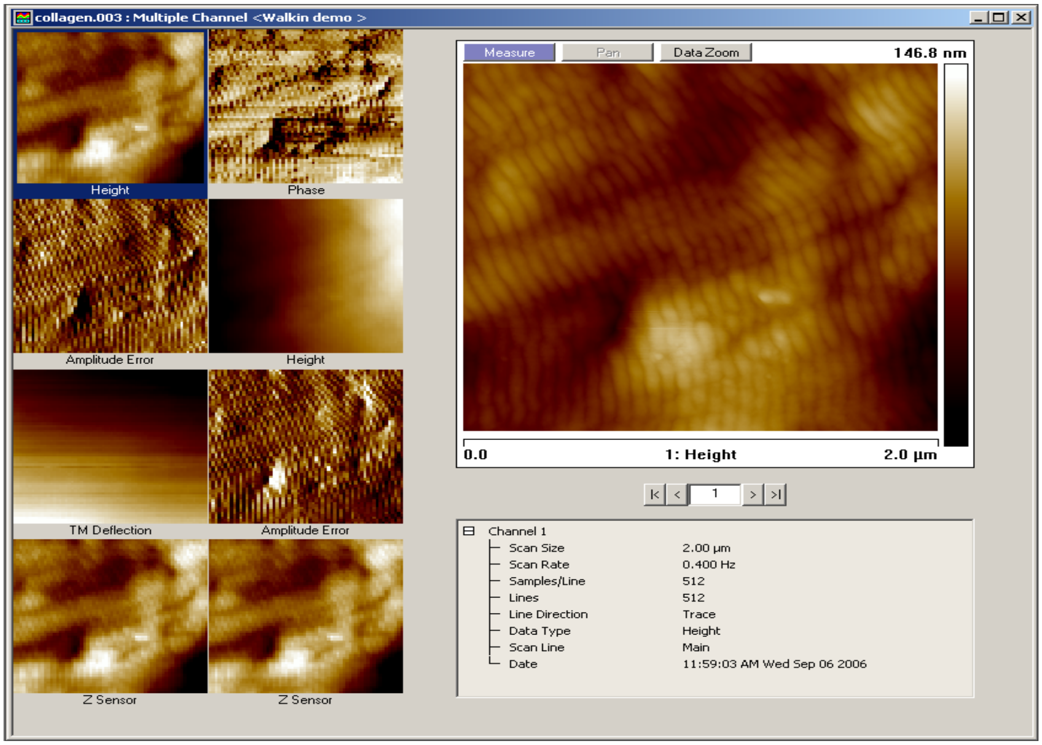
Currently displayed channel

Channel settings

10.2.2 Offline View

Open the Multi-Channel offline view by double-clicking an image file containing more than three channels in the image browse window. See Figure 10.2c. Change the displayed channel by clicking either a thumbnail on the left or the previous/next buttons below the image window.

Figure 10.2c Multi-Channel offline view



Channel 1

Scan Size	2.00 µm
Scan Rate	0.400 Hz
Samples/Line	512
Lines	512
Line Direction	Trace
Data Type	Height
Scan Line	Main
Date	11:59:03 AM Wed Sep 06 2006

10.3 High Resolution Imaging

Your NanoScope V Controller can collect data at a maximum rate of 5120 x 5120 points per image for 3 simultaneous channels. This increase makes re-imaging at higher resolution unnecessary in most situations.

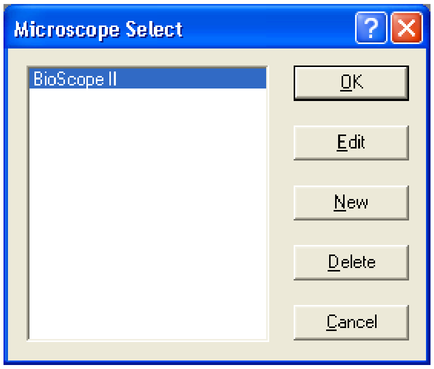
The maximum image size is reduced to 1024 x 1024 for more than three simultaneous channels.

The maximum number of scan lines is reduced to 2560 when the **INTERLEAVE MODE** is set to INTERLEAVE or LIFT.

Note: Images with more than 1 million data points require that the **SCAN DATA LIMITS** parameter in the **Equipment** panel be set to **SYSTEM MAXIMUMS**.

1. Click the **TOOLS** drop-down menu, then **SELECT MICROSCOPE...**, shown in Figure 10.3a, to specify your SPM.

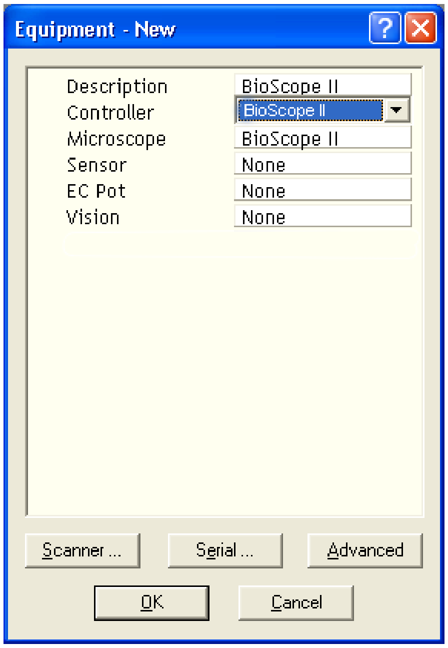
Figure 10.3a Microscope Select



BioScope II

2. Click **EDIT** in the **Microscope Select** panel to open the **Equipment** panel, shown in Figure 10.3b.

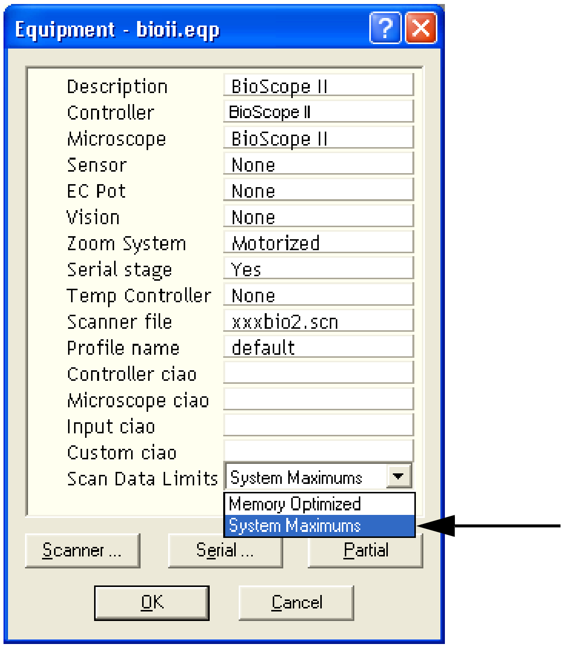
Figure 10.3b System Component Designation



Description BioScope II
Controller BioScope II
Microscope BioScope II
Sensor None
EC Pot None
Vision None

3. Click **ADVANCED** and set the **SCAN DATA LIMITS** parameter to **SYSTEM MAXIMUMS**. See Figure 10.3c.

Figure 10.3c Set the **Scan Data Limits** to **System Maximums** for images with more than 1 M data points.



Equipment - bioii.eqp

Description	BioScope II
Controller	BioScope II
Microscope	BioScope II
Sensor	None
EC Pot	None
Vision	None
Zoom System	Motorized
Serial stage	Yes
Temp Controller	None
Scanner file	xxxbio2.scn
Profile name	default
Controller ciao	
Microscope ciao	
Input ciao	
Custom ciao	
Scan Data Limits	System Maximums

4. Click **OK** to close the **Equipment** panel. Click **OK** to close the **Microscope Select** panel. The NanoScope software will close all open RealTime and Offline panels before re-entering RealTime.

10.4 Signal Access Software

Signal Access Software allows selected signals to be copied, at 10 micro-second intervals, to the Output 1/2 connectors on the front of the NanoScope V Controller. To use this feature:

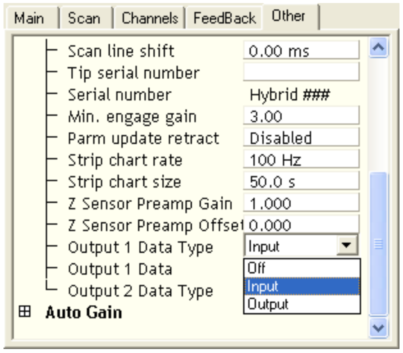
1. Select the **Output 1** and/or **Output 2 Data Type**. See Figure 10.4a. **Input** allows selected input signals to be copied to the Output 1/2 connectors. **Output** allows selected output signals to be copied to the Output 1/2 connectors.

2. Select, using the **Output 1/2 Data** field, the signal that you wish to be copied. See Figure 10.4b and Figure 10.4c.

    a. These menu options are also available in the **Scan Parameter Lis**t.

    Note: For purposes of this section, **Input** is defined as input to the DSP.

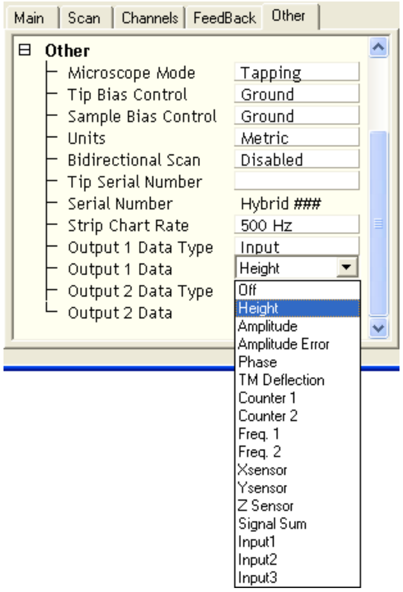
Figure 10.4a Select OUTPUT 1 DATA TYPE



Scan line shift	0.00 ms
Tip serial number	
Serial number	Hybrid ###
Min. engage gain	3.00
Parm update retract	Disabled
Strip chart rate	100 Hz
Strip chart size	50.0 s
Z Sensor Preamp Gain	1.000
Z Sensor Preamp Offset	0.000
Output 1 Data Type	Input
Output 1 Data	
Output 2 Data Type	

Auto Gain

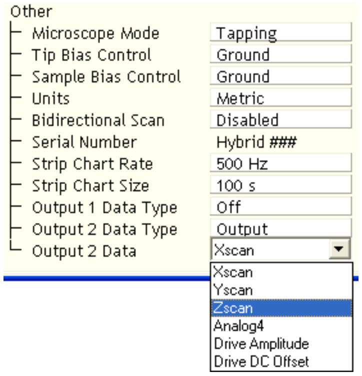
Figure 10.4b Input signal selection.



Other

Microscope Mode	Tapping
Tip Bias Control	Ground
Sample Bias Control	Ground
Units	Metric
Bidirectional Scan	Disabled
Tip Serial Number	
Serial Number	Hybrid ###
Strip Chart Rate	500 Hz
Output 1 Data Type	Input
Output 1 Data	Height
Output 2 Data Type	
Output 2 Data	

Figure 10.4c Output signal selection.



Other

Microscope Mode	Tapping
Tip Bias Control	Ground
Sample Bias Control	Ground
Units	Metric
Bidirectional Scan	Disabled
Serial Number	Hybrid ###
Strip Chart Rate	500 Hz
Strip Chart Size	100 s
Output 1 Data Type	Off
Output 2 Data Type	Output
Output 2 Data	Xscan

The Output/Utility DACs have a range of ±10V. Low voltage signals, ≤ ±15V, are copied, at 1:1 scale, but are clipped when between -15V to -10V and +10V to +15V. High voltage signals including Xscan, Yscan and Zscan are scaled by (20V/440V).

Chapter 11 Maintenance

The NanoScope V Controller does not require periodic servicing if always operated at a room temperature comfortable to the operator.

CAUTION: Do not allow the fans on the back or the ventilation slots on the top of the NanoScope V Controller to become obstructed and compromise the internal temperature of the NanoScope V Controller.

11.1 Troubleshooting

11.1.1 Fuses

If any of the three power **Diagnostics** LEDs (i.e., +5V, +15V, -15V) on the front panel (see Figure 11.1a) fails to illuminate when the system is turned **ON**, a fuse may be blown.

Figure 11.1a Power Supply LEDs on the Front of the NanoScope V Controller

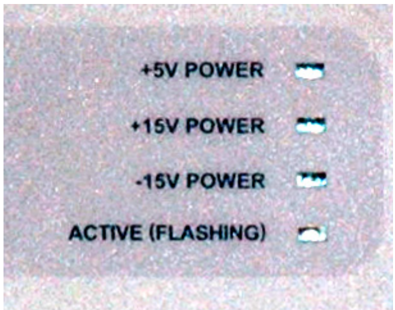
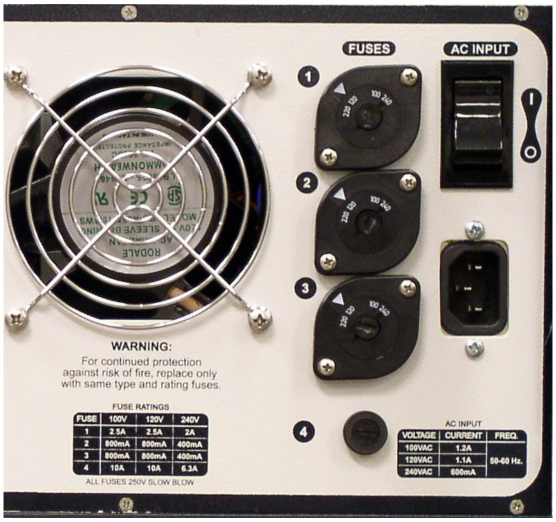


Figure 11.1b Fuse Holders on the Back of the NanoScope V Controller



To replace the fuse, complete the following:

1. Toggle the **Power** switch to **OFF**, and unplug the system power.
2. Replace the fuse with the proper fuse indicated in the table on the back of the NanoScope V Controller (see Figure 11.1b) and reproduced in Table 11.1a. The fuses are located in black oval housings mounted diagonally and placed in a column to the right of the power cord and the **ON**/**OFF** switch and to the left of the fuse rating table.

Table 11.1a Fuse Ratings

Fuse	100V	120V	240V
1	2.5A	2.5A	2.0A
2	800mA	800mA	400mA
3	800mA	800mA	400mA
4	10A	10A	6.3A
ALL FUSES: 250V SLOW BLOW			

3. Connect the system power and toggle the **Power** switch to **ON**.

Note: If the problem persists, contact Bruker to determine which system components to return for repair.

11.1.2 Fast Feedback Failure

If a warning message questions whether the probe is an Active Tip, inspect it to be sure (see Figure 7.3b and Figure 7.3c for Dimension, and Figure 7.3d and Figure 7.3e for MultiMode SPMs). If an Active Tip probe seems unresponsive, its piezoelectric element may have developed an electrical short circuit.

1. Remove the Active Tip probe from the scanner.

2. (Dimension SPM) With the probe still installed in the holder, observe on the reverse side of the holder the four electrical contact pads matched to the scanner pins (see Figure 7.3b). With the gap in the U-shaped holder oriented upwards, measure electrical resistance between the upper left and lower right contacts.
   (MultiMode SPM) Measure the electrical resistance between the two metallic contact pads (see Figure 7.3d).

3. If the resistance reading is less than 1 MΩ, the microactuated piezoelectric element has failed and must be replaced with a fresh Active Tip probe.

11.2 Warranty

This product is covered by the terms of the Bruker standard warranty as in effect on the date of shipment and as reflected on Bruker's Order Acknowledgement and Quote. While a summary of the warranty statement is provided below, please refer to the Order Acknowledgement or Quote for a complete statement of the applicable warranty provisions. In addition, a copy of these warranty terms may be obtained by contacting Bruker.

WARRANTY. Seller warrants to the original Buyer that new equipment will be free of defects in material and workmanship for a period of one year commencing (x) on final acceptance or (y) 90 days from shipping, whichever occurs first. This warranty covers the cost of parts and labor (including, where applicable, field service labor and travel required to restore the equipment to normal operation).

Seller warrants to the original Buyer that replacement parts will be new or of equal functional quality and warranted for the remaining portion of the original warranty or 90 days, whichever is longer.

Seller warrants to the original Buyer that software will perform in substantial compliance with the written materials accompanying the software. Seller does not warrant uninterrupted or error-free operation.

Seller’s obligation under these warranties is limited to repairing or replacing at Seller’s option defective non-expendable parts or software. These services will be performed, at Seller’s option, at either Seller’s facility or Buyer’s business location. For repairs performed at Seller’s facility, Buyer must contact Seller in advance for authorization to return equipment and must follow Seller’s shipping instructions. Freight charges and shipments to Seller are Buyer’s responsibility. Seller will return the equipment to Buyer at Seller’s expense. All parts used in making warranty repairs will be new or of equal functional quality.

The warranty obligation of Seller shall not extend to defects that do not impair service or to provide warranty service beyond normal business hours, Monday through Friday (excluding Seller holidays). No claim will be allowed for any defect unless Seller shall have received notice of the defect within thirty days following its discovery by Buyer. Also, no claim will be allowed for equipment damaged in shipment sold under standard terms of F.O.B. factory. Within thirty days of Buyer’s receipt of equipment, Seller must receive notice of any defect which Buyer could have discovered by prompt inspection. Products shall be considered accepted 30 days following (a) installation, if Seller performs installation, or (b) shipment; unless written notice of rejection is provided to Seller within such 30-day period.

Expendable items, including, but not limited to, lamps, pilot lights, filaments, fuses, mechanical pump belts, V-belts, wafer transport belts, pump fluids, O-rings and seals ARE SPECIFICALLY EXCLUDED FROM THE FOREGOING WARRANTIES AND ARE NOT WARRANTED. All used equipment is sold ‘AS IS, WHERE IS,’ WITHOUT ANY WARRANTY, EXPRESS OR IMPLIED.

Seller assumes no liability under the above warranties for equipment or system failures resulting from (1) abuse, misuse, modification or mishandling; (2) damage due to forces external to the machine including, but not limited to, acts of God, flooding, power surges, power failures, defective electrical work, transportation, foreign equipment/attachments or Buyer-supplied replacement parts or utilities or services such as gas; (3) improper operation or maintenance or (4) failure to perform preventive maintenance in accordance with Seller’s recommendations (including keeping an accurate log of preventive maintenance). In addition, this warranty does not apply if any equipment or part has been modified without the written permission of Seller or if any Seller serial number has been removed or defaced.

No one is authorized to extend or alter these warranties on Seller’s behalf without the written authorization of Seller.

> THE ABOVE WARRANTIES ARE EXPRESSLY IN LIEU OF ANY OTHER EXPRESS OR IMPLIED WARRANTIES (INCLUDING THE WARRANTY OF MERCHANTABILITY), AND OF ANY OTHER OBLIGATION ON THE PART OF SELLER. SELLER DOES NOT WARRANT THAT ANY EQUIPMENT OR SYSTEM CAN BE USED FOR ANY PARTICULAR PURPOSE OR WITH ANY PARTICULAR PROCESS OTHER THAN THAT COVERED BY THE APPLICABLE PUBLISHED SPECIFICATIONS.

NO CONSEQUENTIAL DAMAGES. LIMITATION OF LIABILITY. Seller shall not be liable for consequential damages, for anticipated or lost profits, incidental, indirect, special or punitive damages, loss of time, loss of use, or other losses, even if advised of the possibility of such damages, incurred by Buyer or any third party in connection with the equipment or services provided by Seller. In no event will Seller’s liability in connection with the equipment or services provided by Seller exceed the amounts paid to Seller by Buyer hereunder.

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