

**NanoScope V**  
**Controller Manual**  
**NanoScope Software v 8**

**004-1030-000**

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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®

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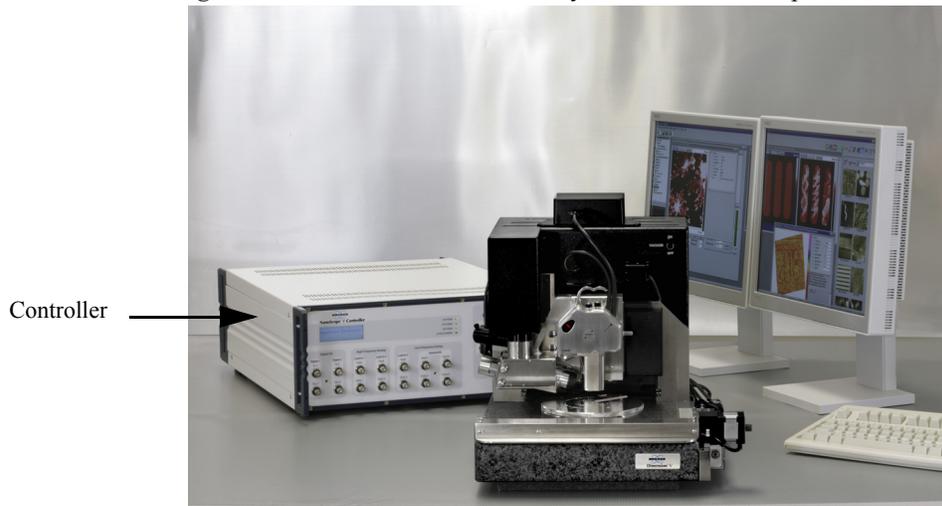
# Chapter 1 Overview

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## 1.1 Introduction

This manual details use of the NanoScope V and NanoScope V-PI Scanning Probe Microscope (SPM) Controllers.

**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 Catalyst, BioScope II, BioScope SZ, Dimension Icon, 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. Some features may not be supported on all microscopes.

## 1.2 NanoScope V vs. NanoScope V-PI Controllers

The differences between the two models, the NanoScope V Controller and the NanoScope V-PI Controller, are listed in [Table 1.2a](#) and [Table 1.2b](#).

**Table 1.2a** NS V vs. NS V-PI hardware differences

	<b>NanoScope V</b>	<b>NanoScope V-PI</b>
<b>DSP</b>	Inside PC	Inside Controller
<b>Communication to PC</b>	LVDS/PCI	USB 2
<b>Display</b>	1 30" monitor	2 19" monitors
<b>CPU</b>	Intel 2.4GHz Quad Core	Intel 2.0 GHz Dual Core
<b>Graphics Card</b>	XFX GeForce 9400GT 512 MB	XFX GeForce 9400GT 512MB
<b>Microscope Support</b>	Dimension Icon, Dimension Icon-PT, BioScope Catalyst	Dimension Icon-PI

**Table 1.2b** NS V vs. NS V-PI feature differences

	<b>NanoScope V</b>	<b>NanoScope V-PI</b>
<b>Max. image size</b>	5,120 x 5,120	1,024 x 1,024
<b>Thermal Tune</b>	1-100 kHz, 5 kHz- 2 MHz	1-100 kHz
<b>Fast Scanning (actuated probes)</b>	included	not available
<b>Q Control</b>	included	optional
<b>High Speed Data Capture</b>	included	not available
<b>Torsional Resonance Mode</b>	included	optional
<b>Piezo response</b>	included	optional
<b>Generic Lock-in</b>	included	not available
<b>vSAM inputs/outputs</b>	included	optional
<b>HarmoniX</b>	included	not available
<b>Pulse Counting</b>	included	not available
<b>Dark Lift</b>	included	not available
<b>NanoScript</b>	optional	optional
<b>LithoScript</b>	optional	optional
<b>NanoMan</b>	optional	optional
<b>Recipes</b>	optional	not available
<b>Nanoindentation</b>	optional	optional
<b>MIRO</b>	optional	not available
<b>Adaptive XY Feedback</b>	optional	not available
<b>Nanoasperity</b>	optional	not available

## 1.3 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 appropriate *NanoScope Software User Guide*. 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 Dimension series microscopes, refer to Support Note 424, *Signal Access Module V*.

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.

## 1.4 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. NSV-PI is used to refer to a NanoScope V-PI.
- For brevity, a Dimension 3000 SPM is referred to as a *D3000*, a Dimension 3100 SPM is referred to as a *D3100*, a Dimension Icon is referred to as an *Icon* 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 Icon, V, 3100, 5000, BioScope SZ, BioScope II and BioScope Catalyst 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.



# Chapter 2 Safety Precautions

This chapter highlights cautions to observe while 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 équipements ou accessoires, et qui, dans les cas extrêmes, peuvent conduire à des dommages corporels.
	Dieses Symbol beschreibt Zustände oder Handlungen die das Gerät oder andere Gegenstände beschädigen können und in Extremfällen zu Verletzungen führen können.
	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 Zustände oder Handlungen die einen elektrischen Schock verursachen können.
	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 autorisierte 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 dangereuses 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.

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## Safety Precautions

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# Chapter 3 Set-Up and Installation

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## 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	15°C (59°F) to 35°C (95°F)
"	Relative Humidity	45% to 80%, non-condensing
Storage	Temperature	10°C (50°F) to 50°C (122°F)
"	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.


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



**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 9.1a](#) in **Maintenance**, [page 107](#)).

**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 (DSI) in the computer or in the controller (NanoScopeV-PI) and a cable to connect the computer and controller. Controllers configured for Dimension and BioScope microscopes include two cables to connect the controller to the microscope. Controllers configured for MultiMode V microscopes include one cable and a 37 pin adapter to connect the controller to the microscope. Also required are one large (30", minimum resolution 2560 × 1600) or two smaller (19", minimum resolution 1280 × 1024) computer monitors which may be purchased with the controller or supplied separately. As the associated computer and Windows XP operating system are custom-fitted with a DSP board and NanoScope software, the computer must be supplied by Bruker. At minimum, an NanoScope V-controlled system includes a

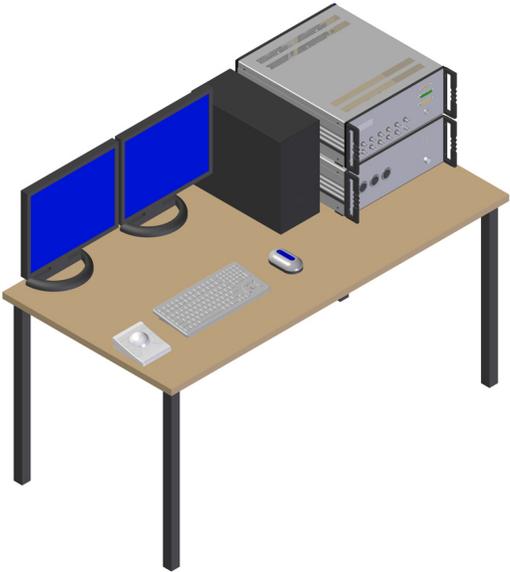
compatible SPM, either supplied with the NanoScope V or an existing SPM capable of being upgraded to NanoScope V operation.

### 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 3.3a](#)).

**Figure 3.3a** Desktop configuration for Dimension Icon-PI

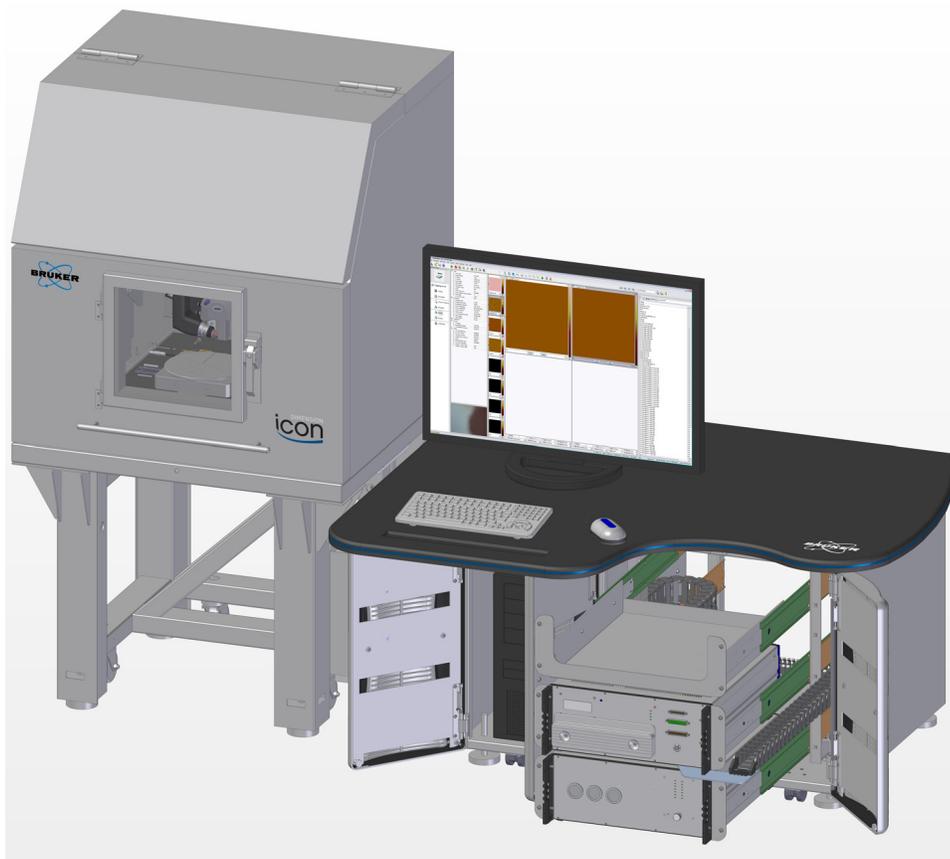


	<b>CAUTION:</b> Do not obstruct either fan on the back of the NanoScope V Controller. A minimum of 3 inches (8cm) of clearance is required.
	<b>CAUTION:</b> Do not obstruct the ventilation slots on the top of the NanoScope V Controller.
	<b>CAUTION:</b> Do not place heavy objects on the aluminum top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

### 3.3.2 Workstation Option

A workstation option, shown in [Figure 3.3b](#), where the NanoScope V Controller and Dimension Stage Controller are incorporated into a workstation, is available with the Dimension Icon microscope.

**Figure 3.3b** Dimension Icon workstation



## 3.4 Important: Powering Sequence

If you do not have a Dimension Icon microscope (i.e. you have access to the power switch at the rear of the NanoScope V Controller), Bruker recommends that you turn on the computer before turning on the NanoScope V Controller.

For non-Icon configurations:

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

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

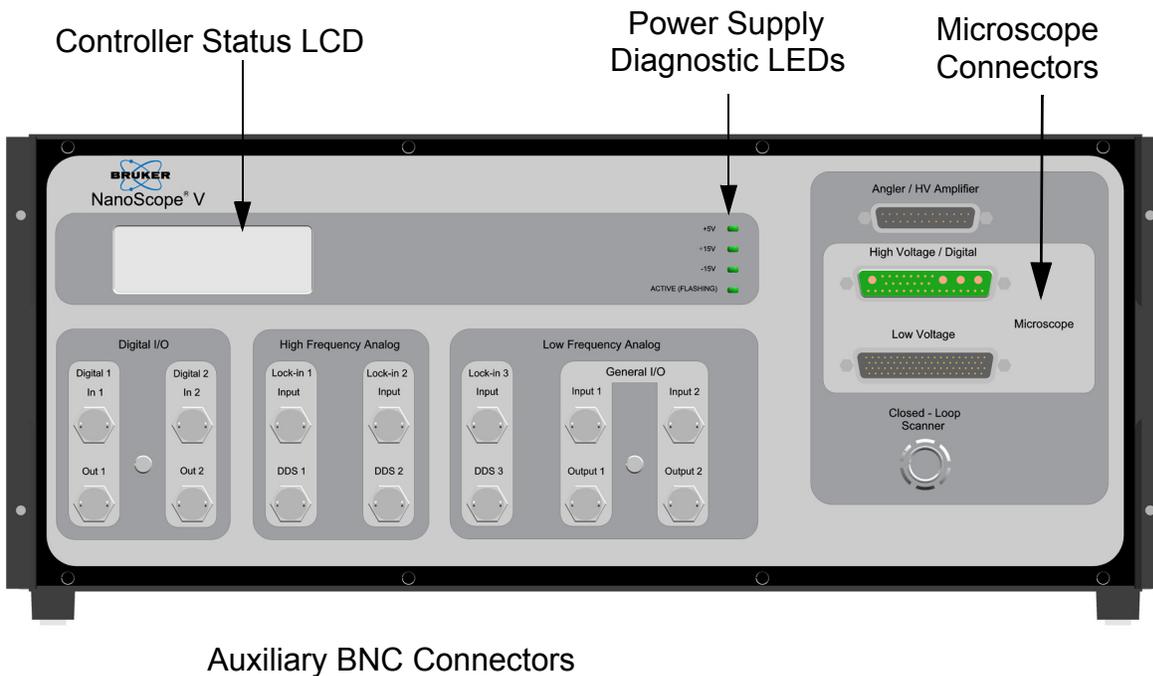
## 3.5 NanoScope V Front Panel

The NanoScope V Controller, 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 30](#).
- Diagnostic LED (“active/flashing”) — indicates the FPGA is loaded.
- Connection to the (optional) PicoAngler.
- Connections for Dimension XY, Dimension Hybrid XYZ or Dimension Icon closed loop heads or the BioScope Catalyst microscope.
- 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).

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 19](#).

### 3.6 NanoScope V Back Panel

The NanoScope V Controller back panel (see [Figure 3.6a](#) and [Figure 3.6b](#)) includes, on the right, the controller power switch and external power source connection with a table of AC power requirements (see [Unpacking, page 11](#)), as well as four fuses and a fuse specification table (see [Fuses, page 107](#)). 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 Controller Back Panel  
 Ventilation Fans, Outflow

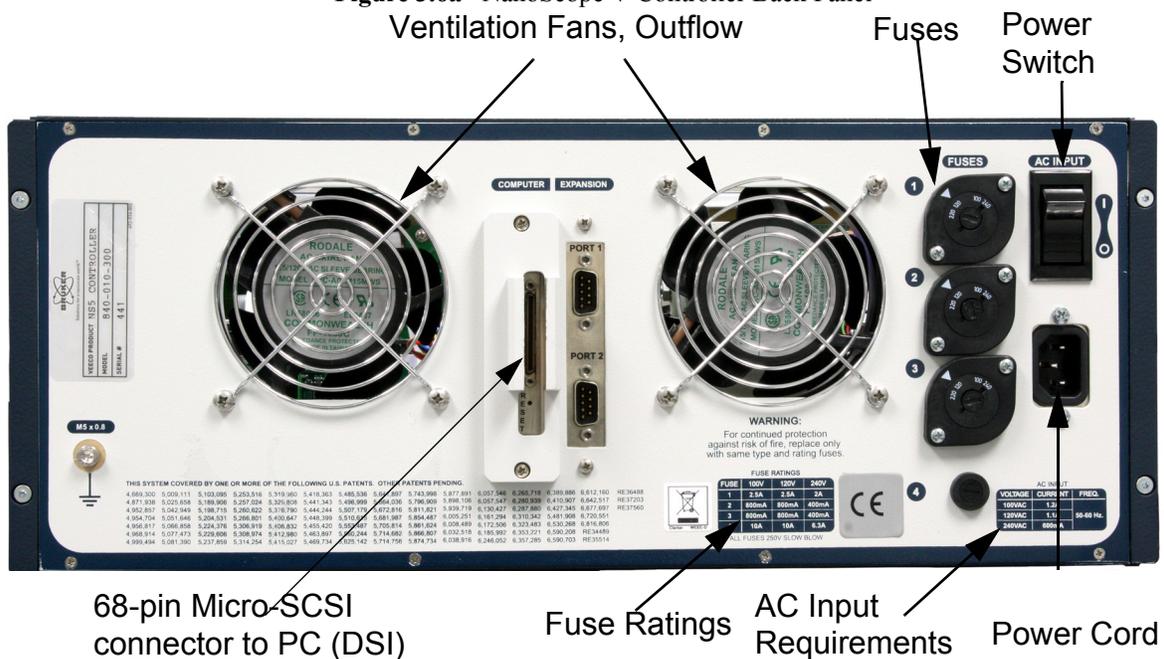
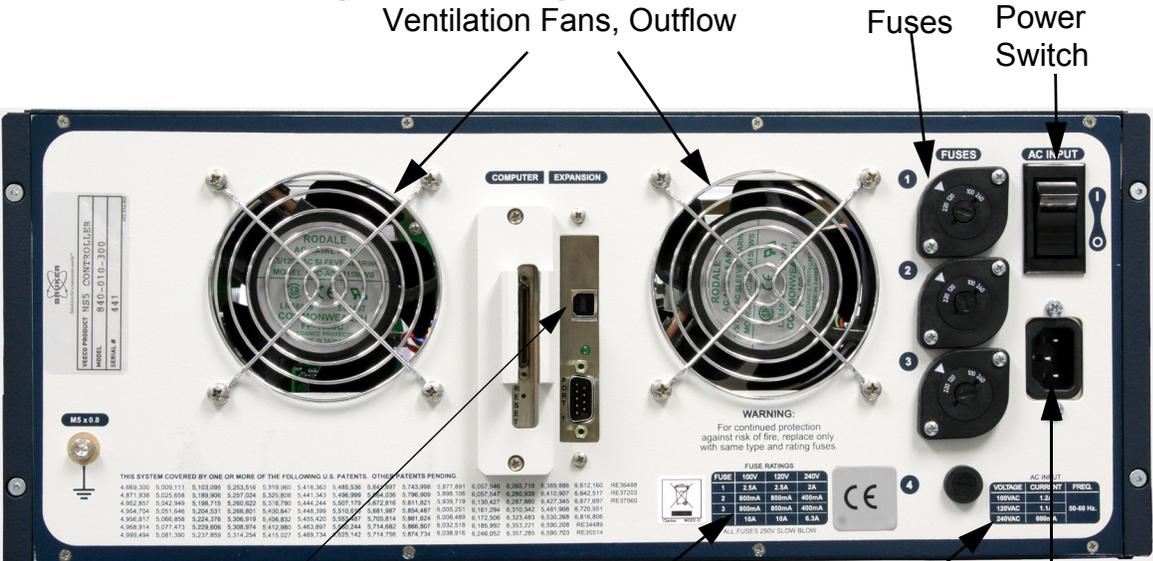


Figure 3.6b NanoScope V-PI Controller Back Panel  
 Ventilation Fans, Outflow



USB connector to PC (DSI)

Fuse Ratings

AC Input Requirements

Power Cord



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# Chapter 4 Configuring a New SPM with a NanoScope V Controller

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This chapter concerns configuring a new SPM purchased with the NanoScope V 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 Icon, Dimension V, updated (to Dimension V) D3100 models, BioScope SZ, D5000, BioScope II and BioScope Catalyst models. NanoScope Software version 8 supports only the Dimension Icon and BioScope Catalyst microscopes.

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. These are presently not supported by NanoScope Software version 8.

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, BioScope II or BioScope Catalyst 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 (CLH) (XY, Hybrid XYZ, Icon, BioScope II or BioScope Catalyst), connect its preamp or the Dimension Icon E-box to the **Closed Loop Scanner** connector at the right front of the controller (see [Figure 4.2a](#)).

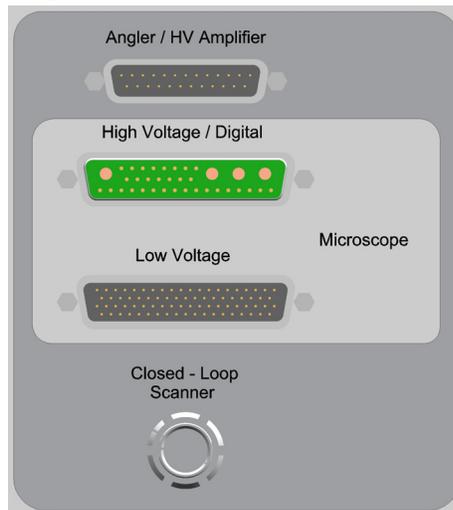
If you have a PicoAngler, connect it to the **Angler** connector at the right front of the controller (see [Figure 4.2a](#)).

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
Computer (back panel)	68-pin micro-SCSI, female	data/control between NanoScope V Controller and computer (DSI)
Expansion (back panel)	USB type B	data/control between NanoScope V-PI Controller and computer (DSI)
Closed Loop Scanner	14-pin Lemo, female	input/output to the XYZ Closed Loop Scanner Head or Closed loop BioScope II/Catalyst 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

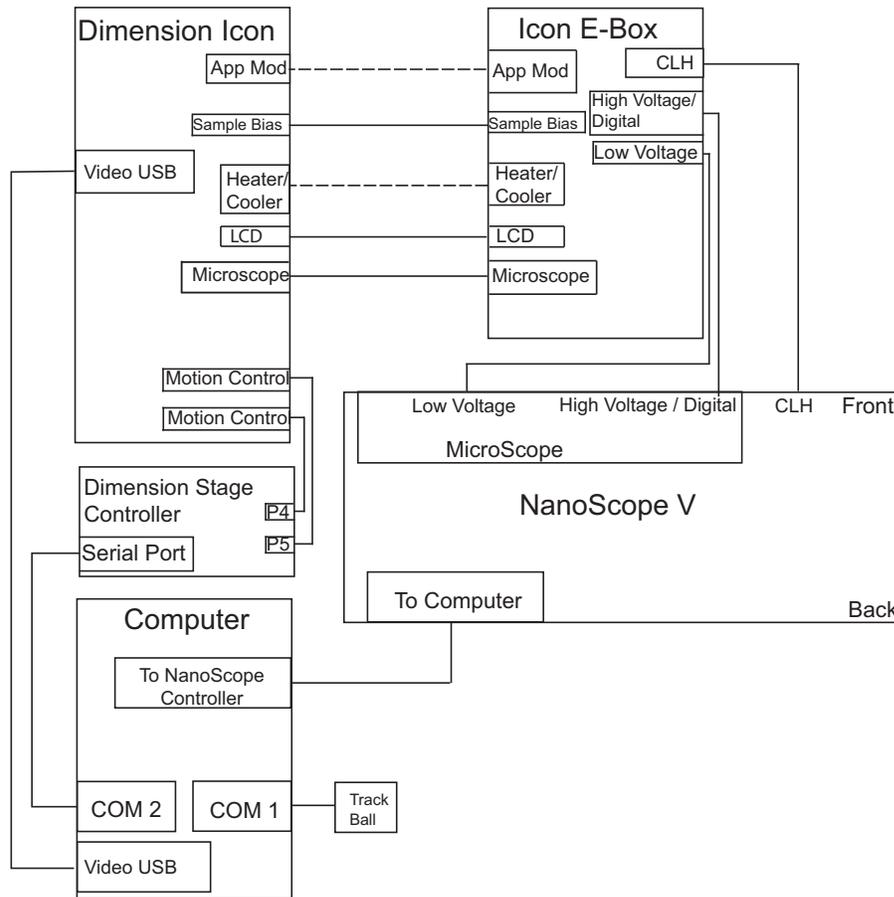


**Table 4.2b** Index to Cabling Diagrams by SPM

<b>SPM</b>	<b>Type</b>	<b>Cabling Diagram</b>
Dimension Icon	Native	<a href="#">Figure 4.2b, page 22</a>
BioScope Catalyst	Native	<a href="#">Figure 4.2c, page 23</a>

## 4.2.1 Dimension Icon: Computer to Controller Cable Connections

Figure 4.2b Cabling Configuration: Dimension Icon

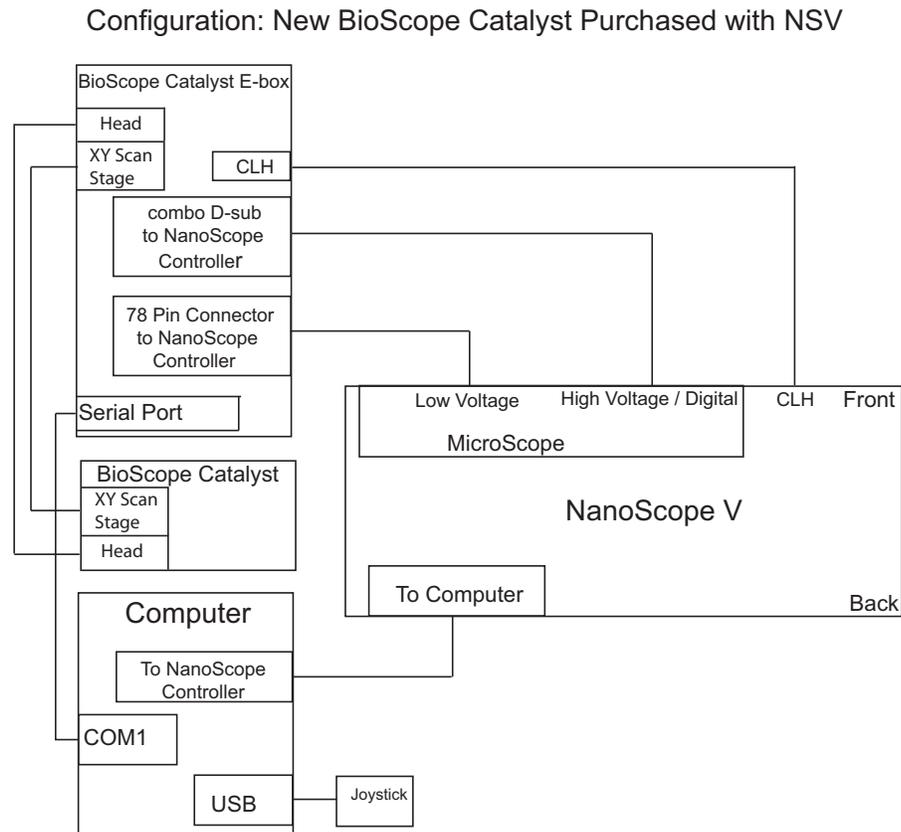


See also the Dimension Icon Instruction Manual for cabling.

- Connect the Low Voltage and High Voltage/Digital cables between the NanoScope V Controller and the rear panel of the Dimension Icon Electronics box (E-box).
- Connect the Closed Loop Scanner cable from the front of the NanoScope V Controller and the rear panel of the Dimension Icon E-box.
- Plug the DSI cable from your computer into the NanoScope V Controller connector labelled **Computer (Expansion)** on the NanoScope V-PI).
- Basic installation for the Native SPM is now complete. Proceed to **Factory Software Configuration of a New SPM**, [page 24](#), then to **Operating Procedures**, [page 29](#).

## 4.2.2 BioScope Catalyst: Computer to Controller Cable Connections

Figure 4.2c Cabling Configuration: New BioScope Catalyst



See also the BioScope Catalyst Instruction Manual for cabling.

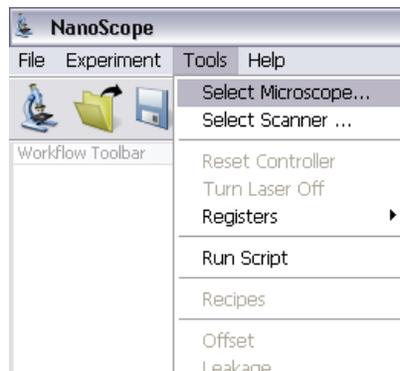
- Connect the Low Voltage and High Voltage/Digital cables between the NanoScope V Controller and the BioScope Catalyst E-box.
- Plug the DSI cable from your computer into the NanoScope V Controller connector labelled **Computer**.
- Connect the serial cable between the computer and the BioScope Catalyst E-box.
- Basic installation is now complete. Proceed to **Factory Software Configuration of a New SPM**, [page 24](#), then to **Operating Procedures**, [page 29](#).

### 4.3 Factory Software Configuration of a New SPM

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

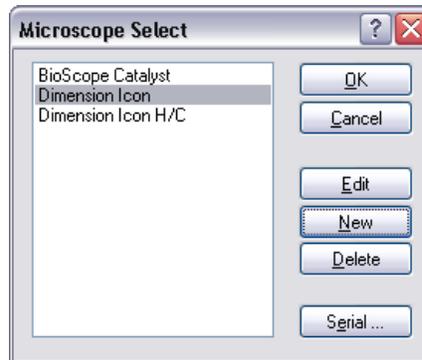
1. Start the NanoScope software.
2. Click the **TOOLS** drop-down menu, then **SELECT MICROSCOPE...**, shown in [Figure 4.3a](#), to specify the SPM.

**Figure 4.3a** Microscope Select



3. This opens the **Microscope Select** window, shown in [Figure 4.3b](#).

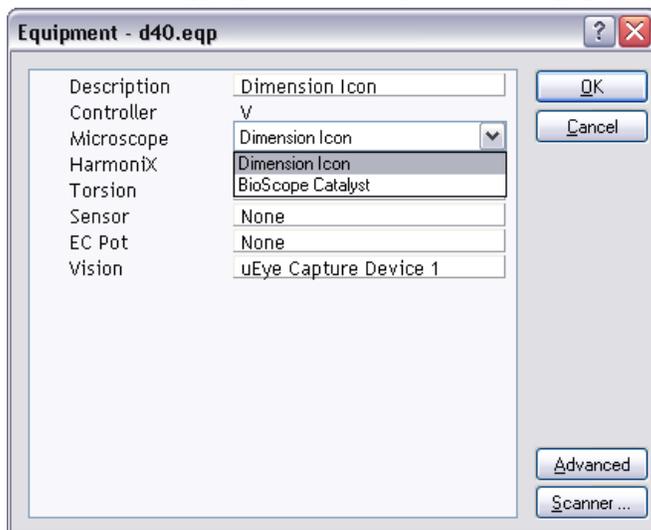
**Figure 4.3b** The Microscope Select window



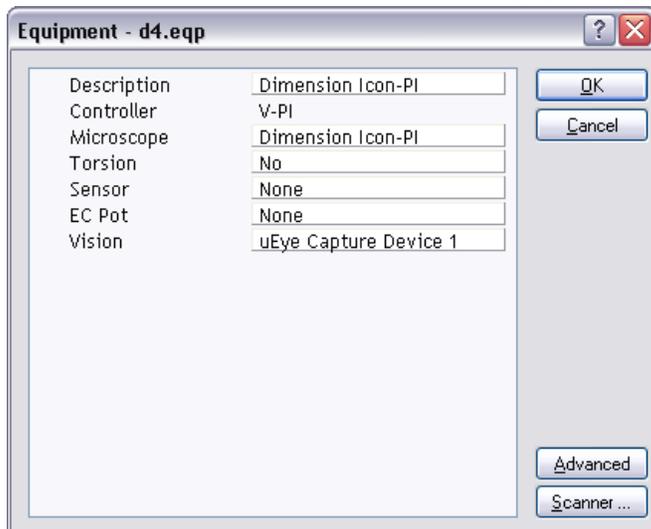
4. Click **NEW** if this is a new microscope, **EDIT** if you wish to modify a configured microscope, **DELETE** to remove a microscope or **CANCEL** to exit.

5. NEW and EDIT open the **Equipment** window, shown in [Figure 4.3c](#) and [Figure 4.3d](#).

**Figure 4.3c** Select the appropriate microscope from the **Equipment** window



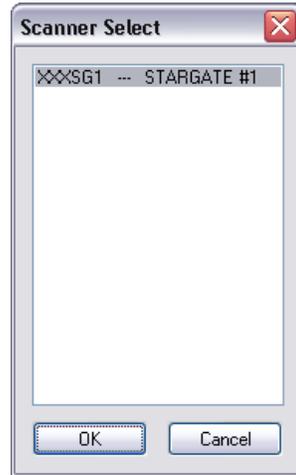
**Figure 4.3d** Select Dimension Icon-PI from the **Equipment** window



6. 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.
7. Verify **V** (NSV) or **V-PI** (NS V-PI) is selected in the **CONTROLLER** drop-down menu of the **Equipment** panel.
8. Verify the configured SPM is selected from the **Microscope** drop-down menu of the **Equipment** panel. See [Figure 4.3c](#) and [Figure 4.3d](#).

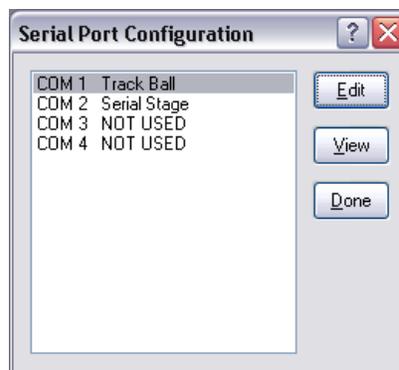
9. Click the **SCANNER...** button of the Equipment panel to open the **Scanner Select** panel, shown in [Figure 4.3e](#) and select the appropriate scanner.

**Figure 4.3e** Scanner Select



10. Click **OK** to close the **Scanner Select** panel.
11. 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**, **TUNA2**, **C-AFM** and **SSRM**.
12. If your SPM includes Torsion hardware, select **YES** in the **Torsion** panel<sup>1</sup>.
13. Click **OK** to close the **Equipment** window. This returns you to the **Microscope Select** window, shown in [Figure 4.3b](#).
14. Click the **SERIAL** button of the **Microscope Select** panel to open the **Serial Port Configuration** window, shown in [Figure 4.3f](#). Verify the COM port assignments.

**Figure 4.3f** Serial Port Configuration, Typical of Dimension SPMs

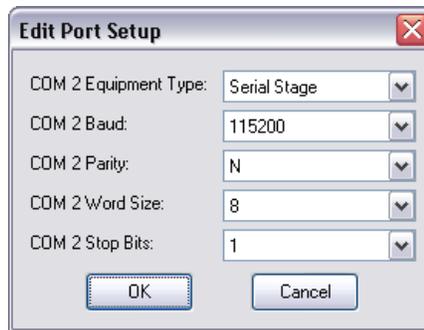


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<sup>1</sup>.Torsion is an optional feature on the NannoScope V-PI and requires a software key.

15. 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 4.3g](#). For instance, in the drop-down menu for COM 1 (for a BioScope Catalyst SPM) verify that **Equipment Type** is **SERIAL STAGE**. Appropriate default settings appear for the other parameters in the panel.

**Figure 4.3g Edit Port Setup Panel**



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, therefore are not discussed here. 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 [Chapter 5](#).



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# Chapter 5 Operating Procedures

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## 5.1 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.<sup>1</sup>

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<sup>1</sup>.

FastScan<sup>1,2</sup> 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<sup>3</sup>.

HarmoniX, an optional NanoScope V feature, allows you to perform quantitative material property measurements with high spatial resolution<sup>1</sup>. See the *HarmoniX User Guide*, Bruker p/n 004-1024-000 for more information.

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1. This feature is not available on the NanoScope V-PI.

2. FastScan is not available on BioScope II or BioScope Catalyst SPMs.

3. This feature is optional on the NanoScope V-PI.

## 5.2 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.

If your NanoScope V Controller is part of a Dimension Icon system, you may power up the system using the system power switch in the workstation cabinet. See the *Dimension Icon Instruction Manual*, Bruker p/n 004-1023-00 for details.



**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 5.2a](#)). The fourth LED blinks at 1 Hz when the FPGA inside the controller is loaded.

**Figure 5.2a** Power Supply LEDs on the Front of the NanoScope V Controller

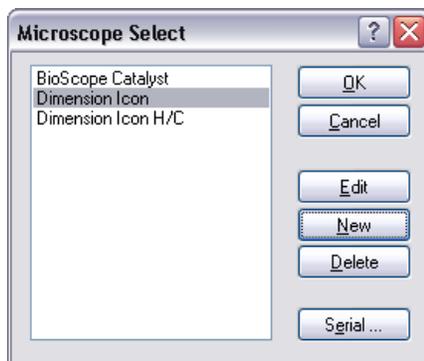


Double-click the **Nanoscope** icon on the desktop to commence software control over the SPM.

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 5.2b](#), to specify the SPM.

Figure 5.2b SPM Designation



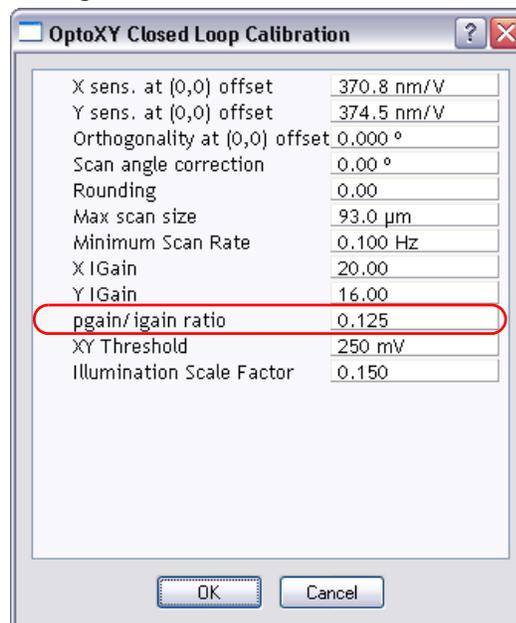
2. Choose the desired SPM configured by clicking its name in the **Microscope Select** list (see [Figure 5.2b](#)). The software has been factory pre-configured for any SPMs purchased with your NanoScope V Controller.

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

- For Dimension systems, **INTEGRAL** and **PROPORTIONAL GAINS** 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  $\pm(\text{DEFLECTION LIMIT}/2)$ . **DEFLECTION SETPOINT + DEFLECTION ERROR** must lie in the range between  $\pm(\text{DEFLECTION LIMIT}/2)$ .
  - **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  $-\text{AMPLITUDE SETPOINT}$  to  $[(\text{AMPLITUDE RANGE})/2 - \text{AMPLITUDE SETPOINT}]$ . The range of **AMPLITUDE** is 0 to  $(\text{AMPLITUDE RANGE})/2$ .

- 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 **CALIBRATE > SCANNER > X-Y** to open the **OptoXY Closed Loop Calibration** window, shown in [Figure 5.3a](#). Set **PGAIN/IGAIN RATIO** TO 0.125.

Figure 5.3a PGAIN/IGAIN RATIO



## 5.4 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** and **Generic Lock-In** settings of the microscope.

**AMPLITUDE** is 0 to peak.

**IN-PHASE** is proportional to  $\text{Amplitude} \cdot \cos(\text{phase})$  and **QUADRATURE** is proportional to  $\text{Amplitude} \cdot \sin(\text{phase})$ .

### 5.4.1 Abbreviations

Some items are abbreviated to fit. These include:

- TM: TappingMode.
- TR: Torsional Resonance mode<sup>1</sup>.
- BW: Bandwidth.
- LP: Low pass.
- DDS: Direct Digital Synthesis.
- SCM: Scanning Capacitance Mode<sup>2</sup>.
- TUNA: Tunneling AFM<sup>2</sup>.
- CAFM: Conductive AFM<sup>2</sup>.
- STM: Scanning Tunneling Microscopy<sup>2</sup>.

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1. Not available on BioScope Catalyst SPMs.

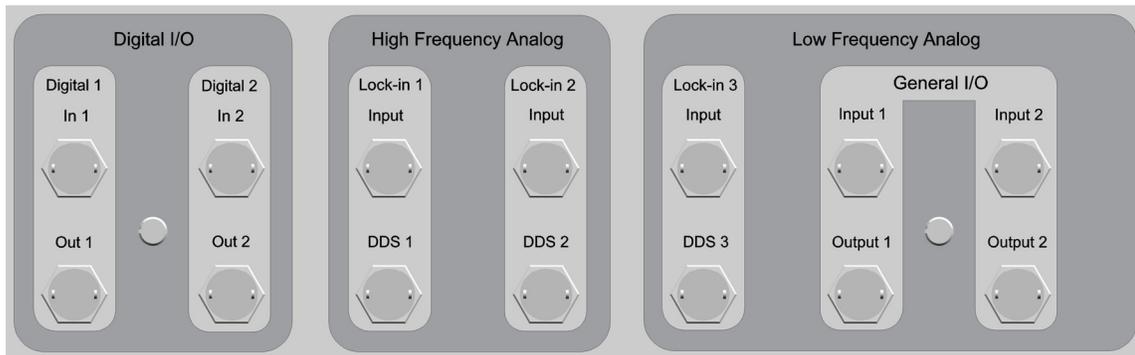
## 5.5 Auxiliary Signal Paths

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 5.5a](#)).

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<sup>1</sup>.
- **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<sup>1</sup>.

**Figure 5.5a** Close-up of Connectors, Front of NanoScope V Controller



- The **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.
- **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.

<sup>1</sup>. This feature is not available on the NanoScope V-PI Controller.

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 sample rate. Outputs allow the user to monitor selectable NanoScope V Controller signals.<sup>1</sup>

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<sup>1</sup>.This feature is optional on the NanoScope V-PI Controller.

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

Connector Label	Connector Type	Purpose
Digital 1 and 2	BNC, ≥1MΩ impedance	Bandwidth 5MHz. See the Generic Lock-In section of the NanoScope Software version 8 Manual
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	Programmable (to 10V) output
General I/O Input 1 and 2	BNC, <1kΩ impedance	inputs for user supplied signals: range: -10V to 10V DC bandwidth: DC to 10kHz
General I/O Output 1 and 2	BNC, ≥1MΩ impedance	analog outputs that can be used to monitor selectable NanoScope V Controller signals. See <b>Signal Access Software: <a href="#">Section 5.8</a></b>

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  $1k\Omega$  and that the voltage does not exceed  $\pm 10VDC$ .
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 **High Resolution Imaging: Page 121**).

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  $1M\Omega$  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.

## 5.6 Piezo Response Force Microscopy<sup>1</sup>

### 5.6.1 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

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<sup>1</sup>. This feature is optional on the Dimension Icon-PI.

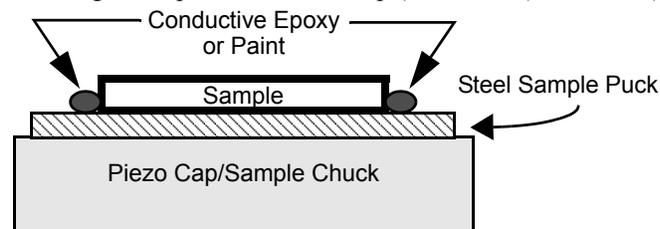
into a lock-in amplifier whose reference signal is the applied AC bias signal, background topography is suppressed from the resulting image which features only the sample surface height changes induced by the applied field.

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,  $F_{Coulomb} = Q_t E_z$ , 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  $2\omega$ , while for electrically polarized samples ( $Q_p \neq 0$ ), the tip oscillation is modulated at  $\omega$ . Therefore by monitoring  $\omega$ , information about charge distribution can be measured. The phase of this signal indicates the sign of the charge. The second harmonic signal at  $2\omega$  can be used to measure the dielectric constant.<sup>1</sup>

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 5.6a).

**Figure 5.6a** 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 probe tip when using the NanoScope V Controller to apply the bias voltage.

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.

- 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.

**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.

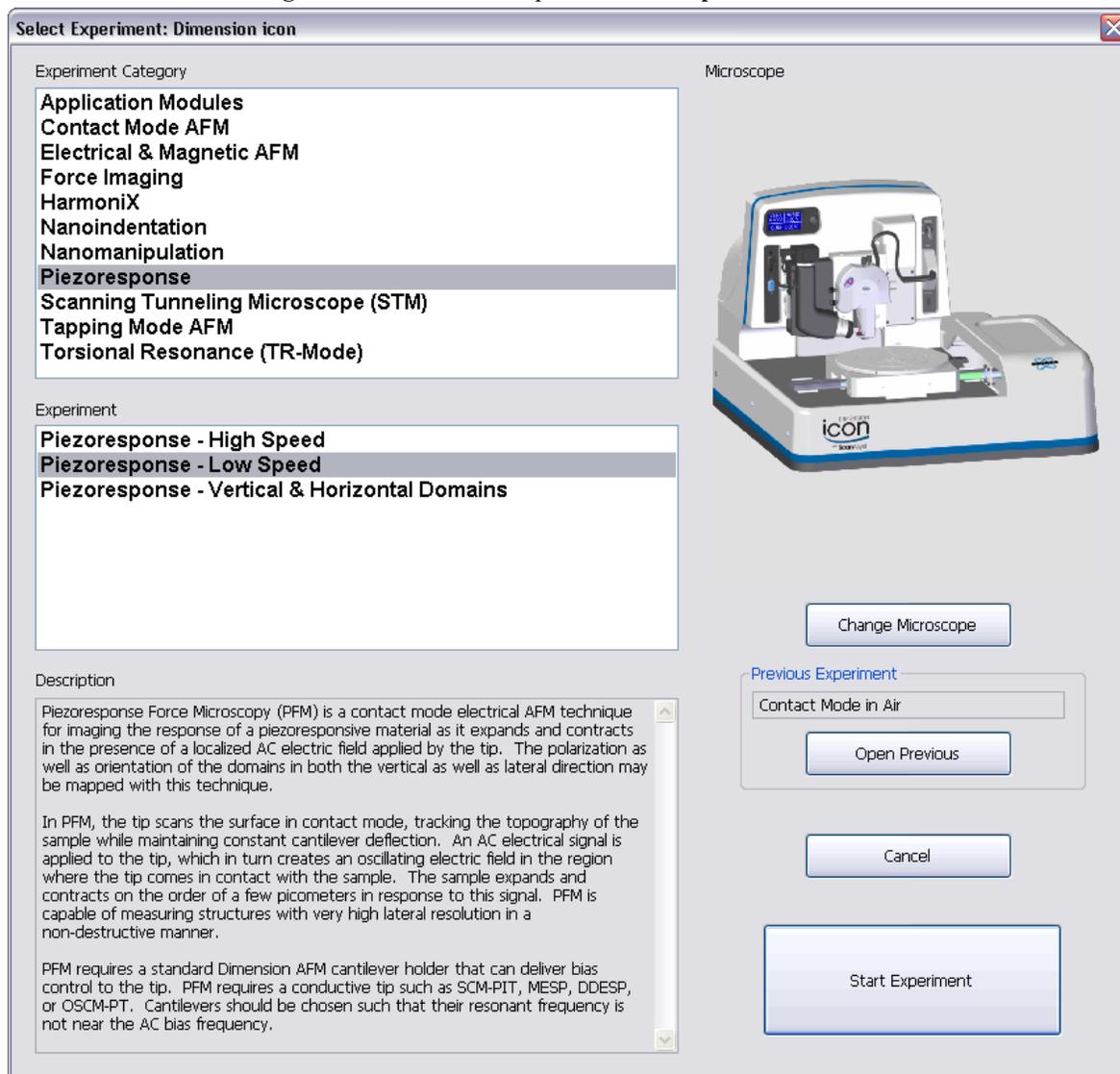
## 5.6.2 Software Selection

Piezoresponse imaging is set up in the following procedure:



1. Click the **SELECT EXPERIMENT** icon. This opens the **Select Experiment** window, shown in [Figure 5.6b](#).

**Figure 5.6b** The Piezoresponse **Select Experiment** window



2. Select **Piezoresponse** in the **Experiment Category** panel.
3. Select the type of piezoresponse measurement that you wish to perform in the **Experiment** panel and click **START EXPERIMENT**.

Table 5.6a summarizes the functions of the parameters in the **Feedback** and **Piezo Response** panels of the **Scan Parameters** window.

**Table 5.6a** Piezo Response Controls Parameters

Parameter	Use with Piezo Response
<b>SPM Feedback</b>	DEFLECTIONIN1B.
<b>Integral Gain</b>	Set the Integral Gain to 2.0 initially.
<b>Proportional Gain</b>	Set the Proportional Gain to 5.0 initially.
<b>Deflection Setpoint</b>	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 value, 0.25V, assumes a stiff cantilever (such as MESP, PIC or PIT).
<b>Sample Bias</b>	DC bias applied to the sample.
<b>Tip Bias</b>	DC bias applied to the tip.
<b>Lock-In Type</b>	Low Speed (15kHz max.) or High Speed (5MHz max.).
<b>AC Bias</b>	To prevent ESD damage, select <b>DISABLED</b> prior to engaging the sample. After engaging, select <b>TIP</b> or <b>SAMPLE</b> . If <b>TIP</b> is selected, the <b>AC BIAS</b> signal is supplied to the <b>TIP</b> and the <b>SAMPLE</b> is grounded. The converse is true if <b>SAMPLE</b> is selected.
<b>Vertical 16x Gain</b>	Increases the vertical gain by 16 times for more sensitivity.
<b>PR Lock-In BW</b>	Reduce for increased signal-to-noise ratio.
<b>PR Drive Amplitude</b>	Amplitude of the AC bias applied to the sample or probe tip. Set <b>PR DRIVE AMPLITUDE</b> to <b>2000mV</b> initially. Adjust this control of AC bias amplitude to optimize contrast in your PR image.
<b>PR Drive Frequency</b>	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 <b>PR DRIVE FREQUENCY</b> 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.
<b>PR Drive Phase</b>	Phase of the lock-in amplifier with respect to the reference bias signal. Set <b>PR DRIVE PHASE</b> to <b>0°</b> initially. This may be adjusted to shift the location of high contrast regions in the piezoresponse image.
<b>Deflection Limit</b>	Decreases the dynamic range and therefore increases sensitivity.

### 5.6.3 Example

#### Image a piezoelectric sample

The default piezoresponse workspace has **Parameter Update Retract** set to **DISABLED** and **XY Closed Loop** set to **ON**.

1. To reduce tip wear and increase resolution, set the **DEFLECTION SETPOINT** (in the **Feedback** panel, [Figure 5.6c](#)) to a low value, **0.25V** initially. Decrease this later while looking at an image to lower the force applied to the sample, or increase it to ensure contact on a rough, but robust sample. This low value, **0.25V**, assumes a stiff cantilever (such as MESP, PIC or PIT).

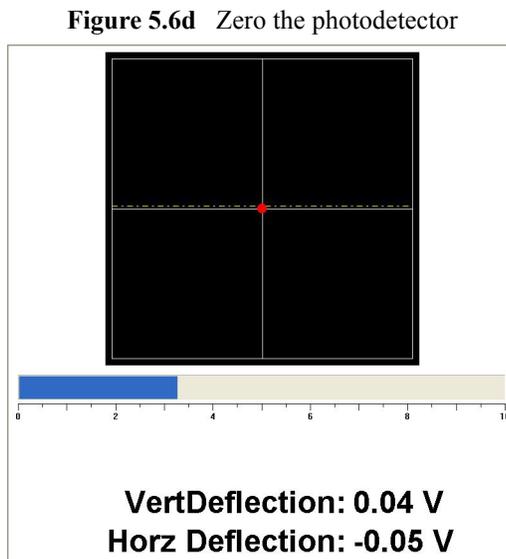
**Note:** For an NPG probe, set **DEFLECTION SETPOINT** to **2.0V** instead.

**Note:** Most Piezo Response control parameters can be found in the **Piezo Response** panel and have PR for Piezo Response in the parameter name. See [Figure 5.6c](#).

Figure 5.6c EXPANDED MODE Scan Parameter List including Piezoresponse variables

[-] 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 Feedback Control	Analog	
[-] Feedback			
	SPM Feedback	DeflectionIn1B	
	Lateral 16x Gain	Disabled	
	Integral Gain	2.000	
	Proportional Gain	5.000	
	Deflection Setpoint	0.2500 V	Step 1
	Sample Bias	0 mV	
	Tip Bias	0 V	
[-] Interleave			
[-] Piezo Response			
	Lock-In Type	Low Speed	Step 6
	AC Bias	Disabled	Step 7
	Vertical 16x Gain	Enabled	Step 4
	LS PR Lock-In BW	0.3000 kHz	Step 6
	LS PR Drive Amplitude	2000 mV	
	LS PR Drive Frequency	15.0000 kHz	
	LS PR Drive Phase	0 °	
[-] Limits			
	Z Limit	9.557 µm	
	Z Range	7.92 µm	
	Amplitude Range	2000 mV	
	Deflection Limit	4.096 V	Step 5
[-] Other			
	LP Deflection	Enabled	
	Units	Metric	
	Minimum Engage Gain	2.00	
	Tip Serial Number		
	Output 1 Data Type	Off	
	Output 2 Data Type	Off	
[-] Channel 1			
[-] Channel 2			
[-] Channel 3			
[-] Channel 4			
	Data Type	LS PR Amplitude	
	Data Scale	4.096 V	
	Data Center	0 V	
	Line Direction	Retrace	
	Scan Line	Main	
	Realtime Plane Fit	Line	
	Offline Plane Fit	None	

2. Click the **Meter** workspace, shown in [Figure 5.6d](#), and zero-out the photodetector. Note the low **DEFLECTION SETPOINT** (dashed line).



3. Set the **Piezo Response LOCK-IN TYPE**. See [Figure 5.6c](#).  
**Note:** This selection is done for you when you select **LOW** or **HIGH SPEED** in the **Experiment** panel of the **Select Experiment** window.
4. To increase vertical sensitivity, set the **Piezo Response VERTICAL 16X GAIN** to **ENABLED** (default for this workspace). See [Figure 5.6c](#).
5. To further increase vertical sensitivity (by 6x), reduce the **DEFLECTION LIMIT** in the **Limits** panel to **4.096V**. See [Figure 5.6c](#).  
**Note:** Reducing the **DEFLECTION LIMIT** only provides additional bit resolution but does not multiply the deflection by a factor as the vertical **16X GAIN** does.
6. Set the **PR DRIVE AMPLITUDE** to **2000mV** and the **PR LOCK-IN BW** to **0.3kHz**. See [Figure 5.6c](#).
7. To prevent ESD, set the **AC Bias** to **DISABLED** before Engaging the sample. See [Figure 5.6c](#).
8. Engage the tip on the sample and optimize scan parameters while watching the displayed image with **Channel 1/Data Type** set to **HEIGHT SENSOR**.



The following steps provide initial settings for the Piezo Response control parameters.

9. Select **SAMPLE** in the **AC Bias** drop-down menu.
10. Adjust the **PR DRIVE AMPLITUDE** to optimize contrast in your PR image.

11. Set the **PR DRIVE FREQUENCY**.



**CAUTION:** AC bias frequency is set to excite piezoresponse in the chosen sample. Typical values are between **2** and **5kHz**, though **60kHz** PR imaging has also been successful. 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. Check TappingMode Cantilever Tune (see **Q Control, Page 95**) to determine the cantilever resonant frequency if there is a possibility it is close to the AC bias frequency desired. PIC cantilevers have resonant frequencies of approximately 10kHz; PIT probes resonate between 60 and 90kHz. 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. A 2nm cantilever deflection amplitude is typical both of a piezoresponsive material and of a cantilever being driven in TappingMode.

12. Set **PR DRIVE PHASE** to **0°** initially. This may be adjusted to shift the location of high contrast regions in the piezoresponse image.

13. Select **PR AMPLITUDE** in **Channel 4** and **PR PHASE** for **Data type** in **Channel 5**.

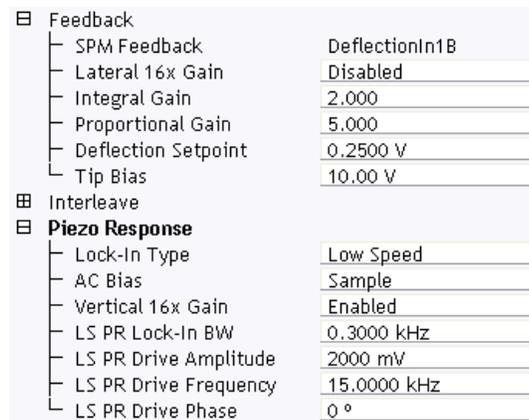
**Note:** These are the Piezoresponse workspace default channels.

### 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 5.6e](#).

**Figure 5.6e** Set the **TIP BIAS** to 10V to write the area.



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  $3\mu\text{m}$ . See [Figure 5.6f](#). Note the written area between  $0.5\mu\text{m}$  and  $2.5\mu\text{m}$ .
  - Increase the **ASPECT RATIO** to 4. The images are shown in [Figure 5.6g](#).

**Figure 5.6f** Written strip

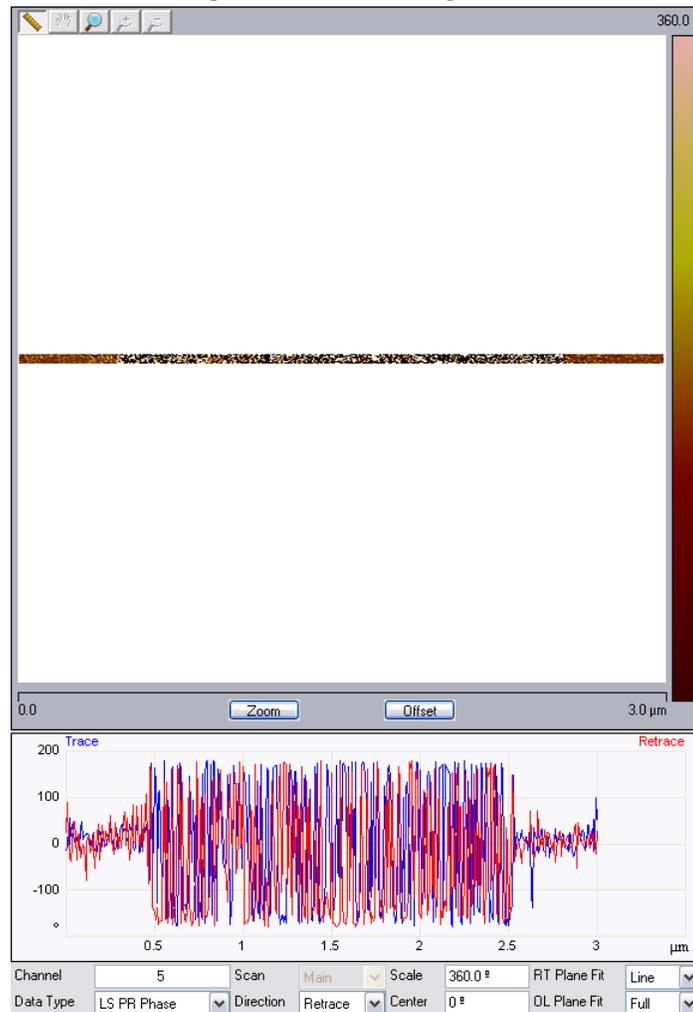
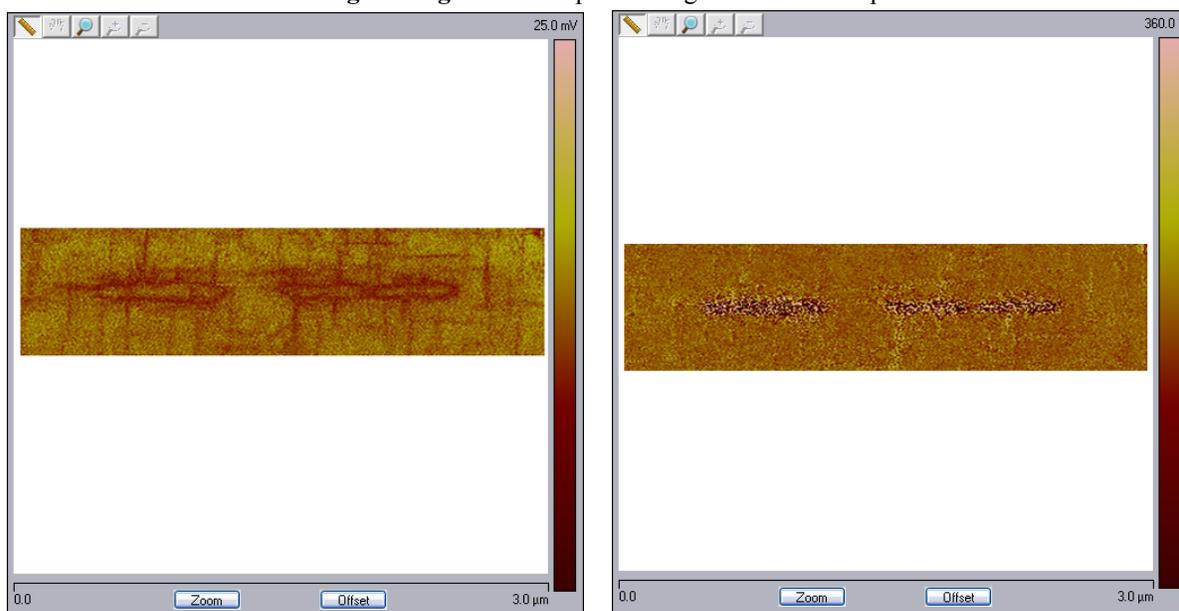


Figure 5.6g Piezo Response images of written strip



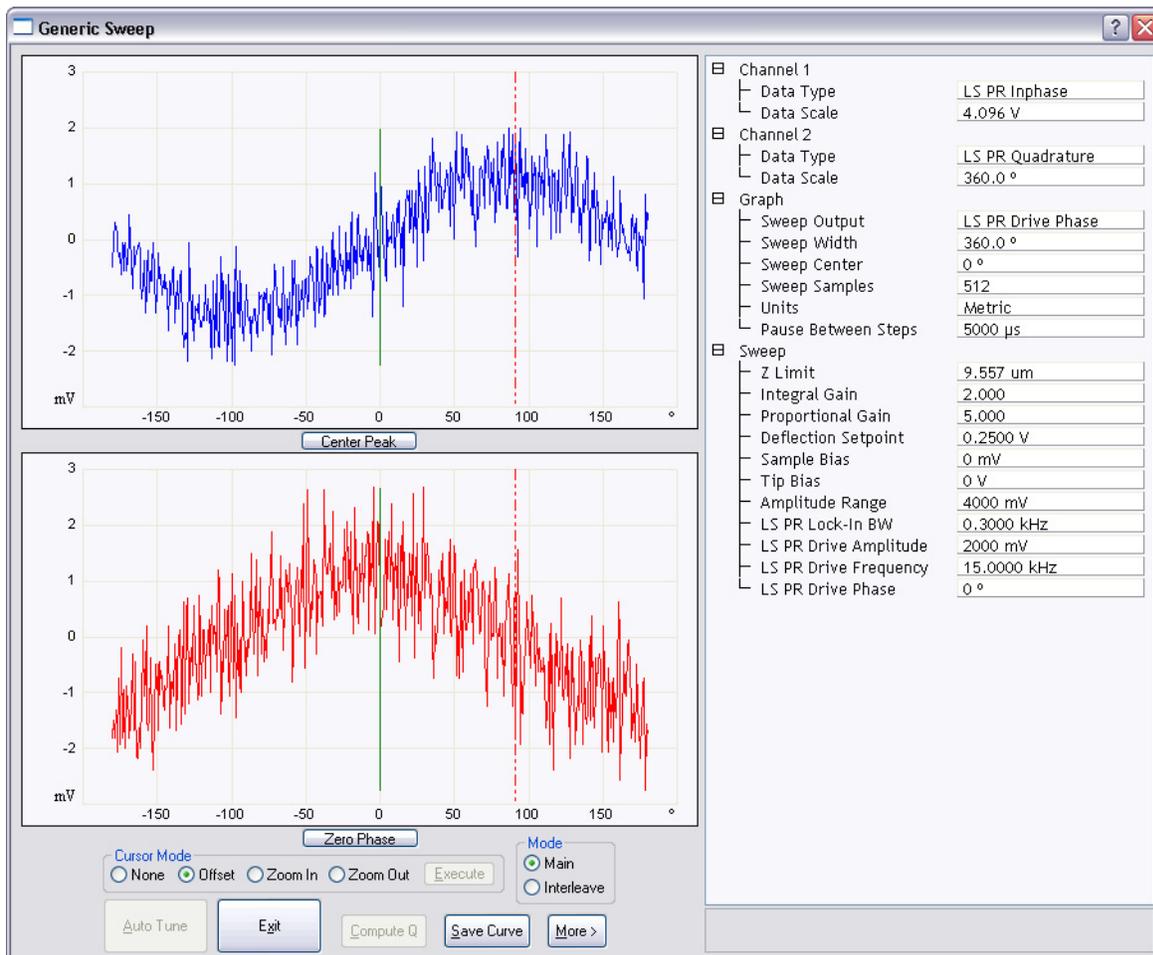
### Optimize the image

Piezo response image contrast may 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 the **SWEEP** icon in the **Workflow Toolbar** to open the Generic Sweep window, shown in [Figure 5.6h](#).

**Figure 5.6h** Generic Sweep Window

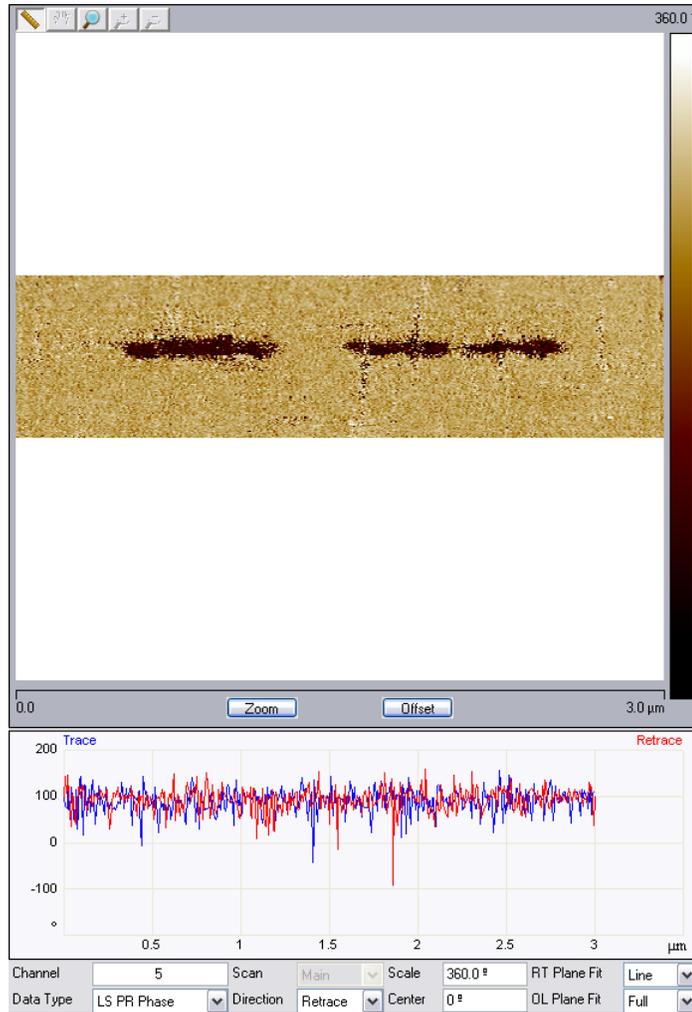


2. Set the **CHANNEL 1 DATA TYPE** to LS PR INPHASE and the **CHANNEL 2 DATA TYPE** to LS PR QUADRATURE.
3. Set the **SWEEP OUTPUT** to PR DRIVE PHASE.
4. Click the **OFFSET Cursor Mode** radio button.
5. Drag the dashed red cursor to the point of maximum response and click **EXECUTE** to set the **PR DRIVE PHASE**.

6. 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 5.6i](#).

**Figure 5.6i** LS PR In Phase optimized



7. 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 Mode** to **INTERLEAVE**. See [Figure 5.6j](#).

**Figure 5.6j** Interleave

Interleave	
SPM Feedback	DeflectionIn1B
Lateral 16x Gain	Disabled
Integral Gain	2.000
Proportional Gain	5.000
Deflection Setpoint	0.2500 V
Sample Bias	0 mV
Tip Bias	0 V
Interleave Mode	Interleave
Lift Start Height	0 nm
Lift Scan Height	130.5 nm
Dark Lift	Disabled
Dark Lift Delay	300 ms

2. Set the **Piezo Response (Interleave) Lock-In Type** to **HIGH SPEED**. See [Figure 5.6k](#).

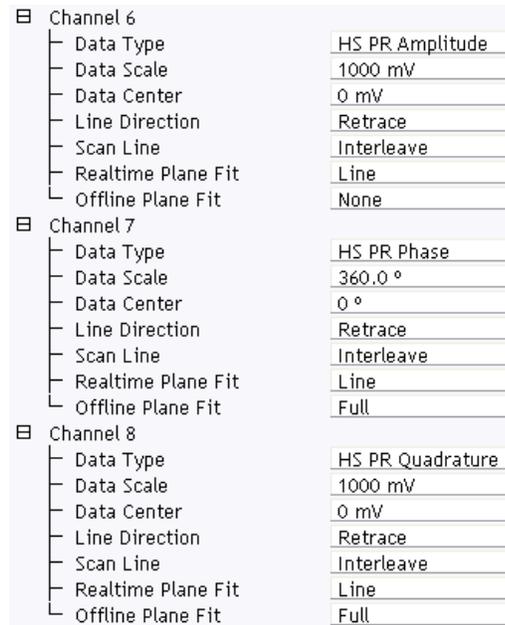
**Figure 5.6k** Set the **Piezo Response (Interleave) Lock-In Type** to **HIGH SPEED**.

Piezo Response (Interleave)	
Lock-In Type	High Speed
AC Bias	Disabled
Vertical 16x Gain	Enabled
HS PR Lock-In BW	0.7500 kHz
HS PR Drive Amplitude	2000 mV
HS PR Drive Frequency	60.0000 kHz
HS PR Drive Phase	0 °

3. Set the other **Interleave Piezo Response** parameters as shown in [Figure 5.6k](#).

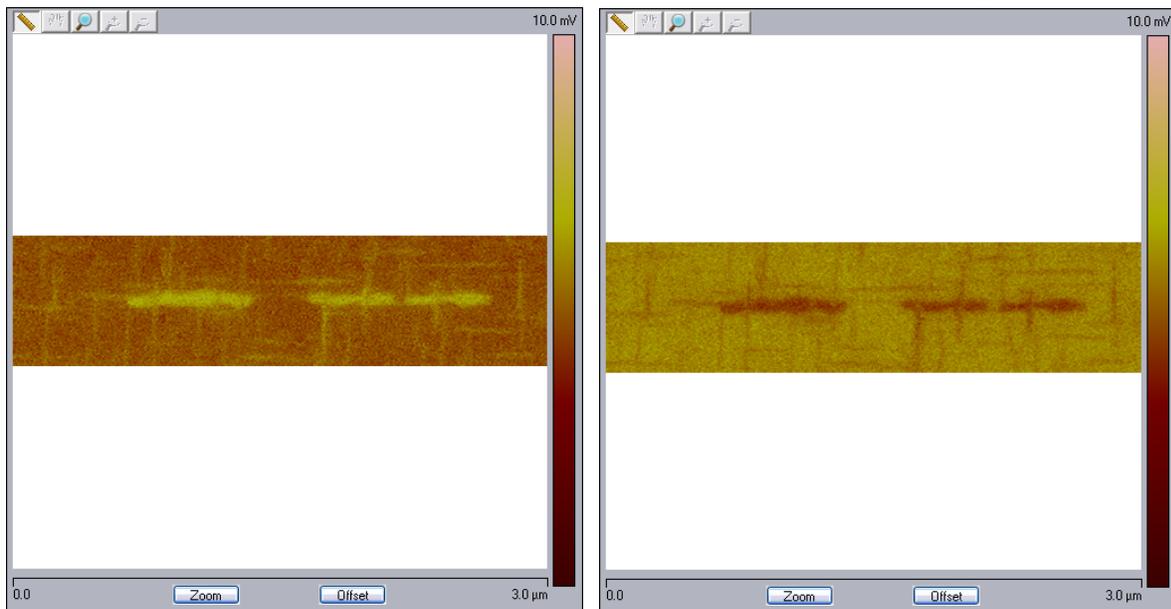
4. Set the **Scan Line** for Channel 6, Channel 7 and Channel 8 to **INTERLEAVE**. See [Figure 5.6l](#).

**Figure 5.6l** Set the **Scan Line** to **INTERLEAVE**.



5. Assign the following **DATA TYPES** to channels:
  - **Channel 1: HEIGHT SENSOR**
  - **Channel 2: DEFLECTIONIN1B**
  - **Channel 3: LS PR DATA**
  - **Channel 4: LS (LOW SPEED) PR (PIEZO RESPONSE) AMPLITUDE**
  - **Channel 5: LS PR PHASE**
  - **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 5.6h](#)) and optimize the **LS PR INPHASE** signal using the procedure **Optimize the image**, [page 49](#).
7. Select the **INTERLEAVE** radio button (see [Figure 5.6h](#)) and optimize the **HS PR QUADRATURE** signal using the procedure **Optimize the image**, [page 49](#).
8. Re-scan the sample. The optimized images are shown in [Figure 5.6m](#).

**Figure 5.6m** Simultaneously Optimized IN PHASE and QUADRATURE Images



Additional information about the piezoresponse mode can be found in *Piezoresponse Atomic Force Microscopy Using a NanoScope V Controller*, Bruker p/n 013-444-000.

## 5.7 High Resolution Imaging

Your NanoScope V Controller can collect data at a maximum resolution of 5120 x 5120 points per image for 8 simultaneous channels. This increase makes reimaging at higher resolution unnecessary in many situations<sup>1</sup>.

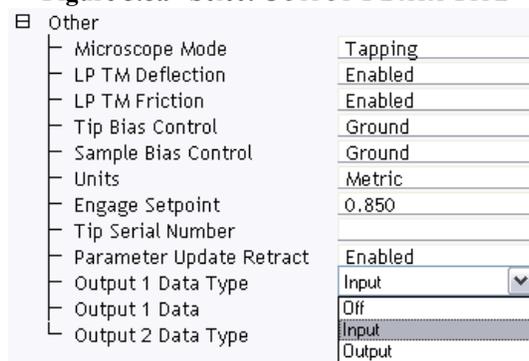
<sup>1</sup>. This feature is not available on the NanoScope V-PI.

## 5.8 Signal Access Software

Signal Access Software<sup>1</sup> 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** in the **Other** panel while in **EXPANDED MODE**. See [Figure 5.8a](#). **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.

**Figure 5.8a** Select **OUTPUT 1 DATA TYPE**

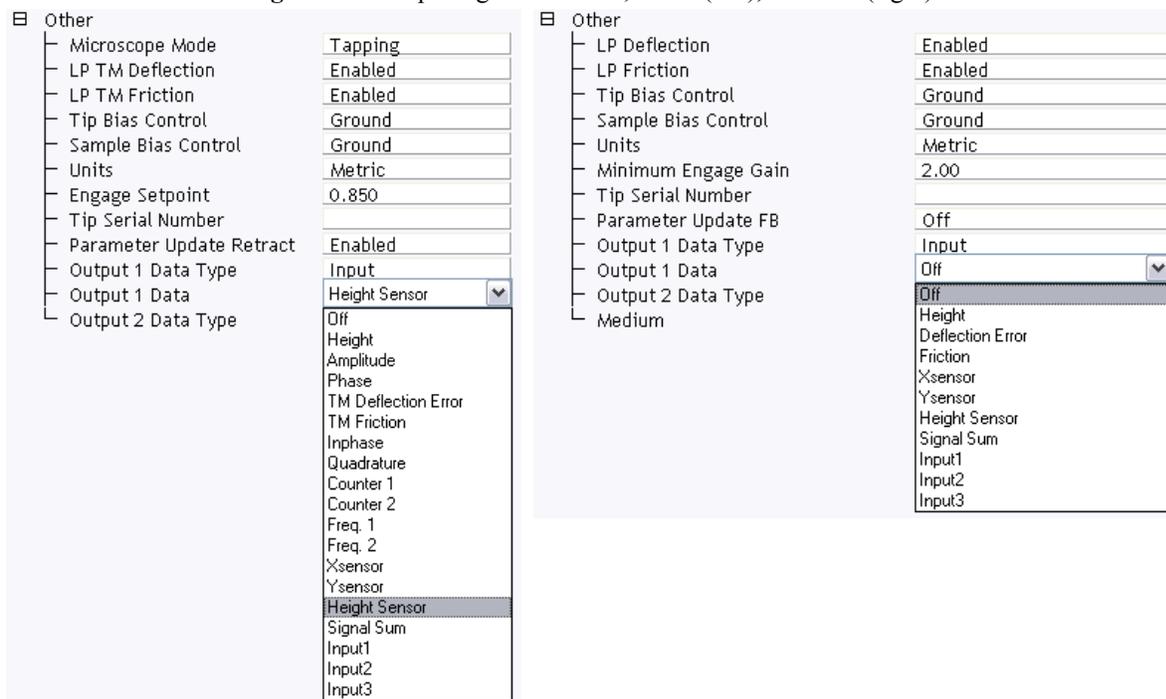


<sup>1</sup>. This feature is optional on the NanoScope V-PI.

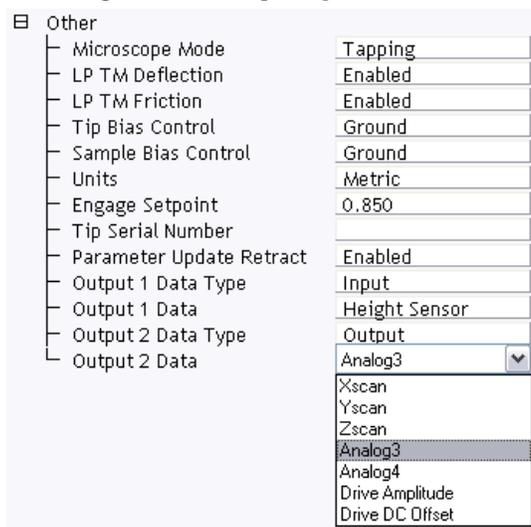
2. Select, using the **Output 1/2 Data** field, the signal that you wish to be copied. See [Figure 5.8b](#) and [Figure 5.8c](#).

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

**Figure 5.8b** Input signal selection; NS V (left), NS V-PI (right)



**Figure 5.8c** Output signal selection.



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

## 5.9 PicoAngler

The PicoAngler, shown in [Figure 5.9a](#), 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  $\pm 20\mu\text{m}$ , 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.

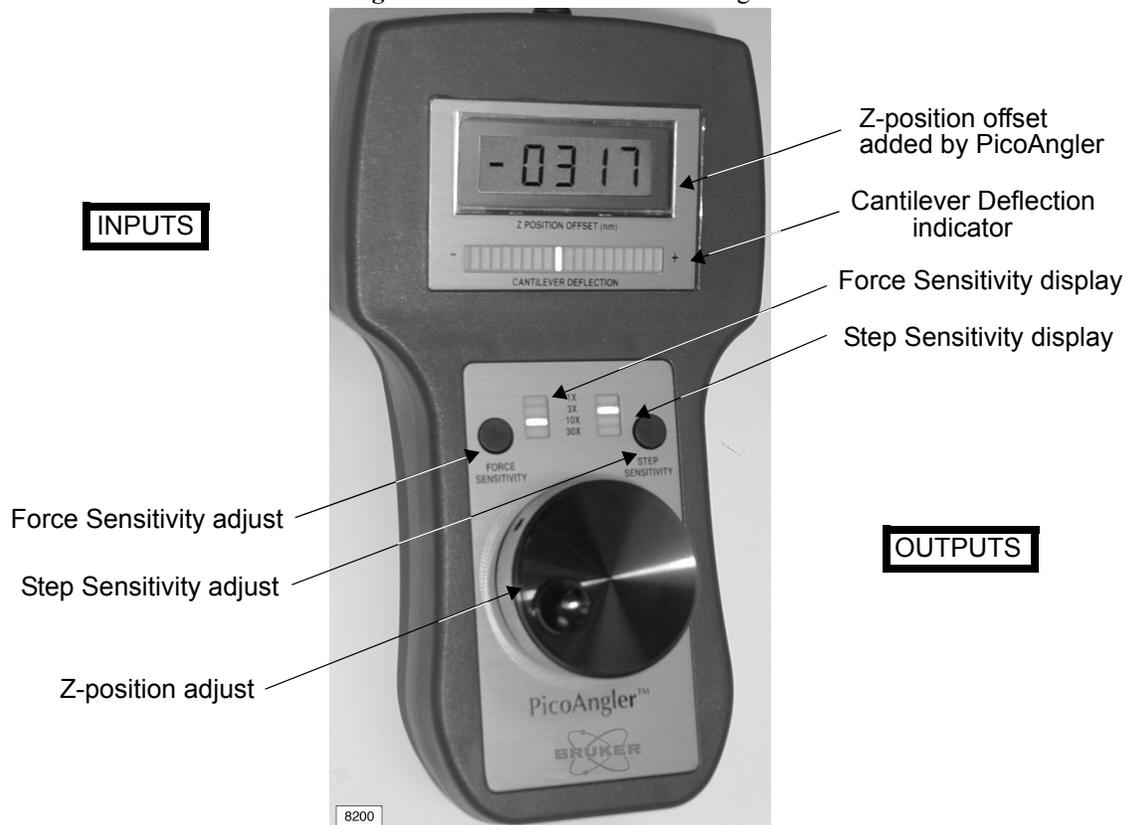
**Note:** The PicoAngler adds a voltage to the low voltage Z signal coming from the NanoScope V Controller before it is amplified in the closed loop Z-axis circuitry of the PicoForce Control Module. The low voltage Z signal from the NanoScope V controller can vary over  $\pm 10\text{V}$ , which corresponds 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  $-10\text{V}$  (fully retracted), the PicoAngler can add  $20,000\text{nm}$  ( $\sim 20\text{V}$ ) to that value in order to fully extend the Z-piezo. So while the PicoAngler is capable of adding  $\pm 20,000\text{nm}$ , you will only use the maximum PicoForce offset if the NanoScope V 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 ( $\sim 0\text{V}$ ), the useful range of the PicoAngler will be about  $\pm 10,000\text{nm}$ , corresponding to the  $\sim 20\mu\text{m}$  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,  $1\times$ ,  $3\times$ ,  $10\times$ , or  $30\times$ , 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,  $1\times$ ,  $3\times$ ,  $10\times$ , or  $30\times$ , 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 5.9a** The PicoForce PicoAngler



### 5.9.1 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, Strip Chart Mode data collection is used, as described in the previous section.

1. Click **Force Controls** > **ANGLER ENABLE** to activate PicoAngler (see [Figure 5.9b](#)).



**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 5.9a](#)) **should be near zero when first engaging the microscope**. This is most easily accomplished in **Force Mode View** by clicking PicoForce Controls > **ANGLER ZERO** to zero the Z-position offset (see [Figure 5.9b](#)) 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 5.9b](#)).
  - 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 5.9a](#)) 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.

## 5.9.2 Using the PicoAngler in Conjunction with Basic Force Plots

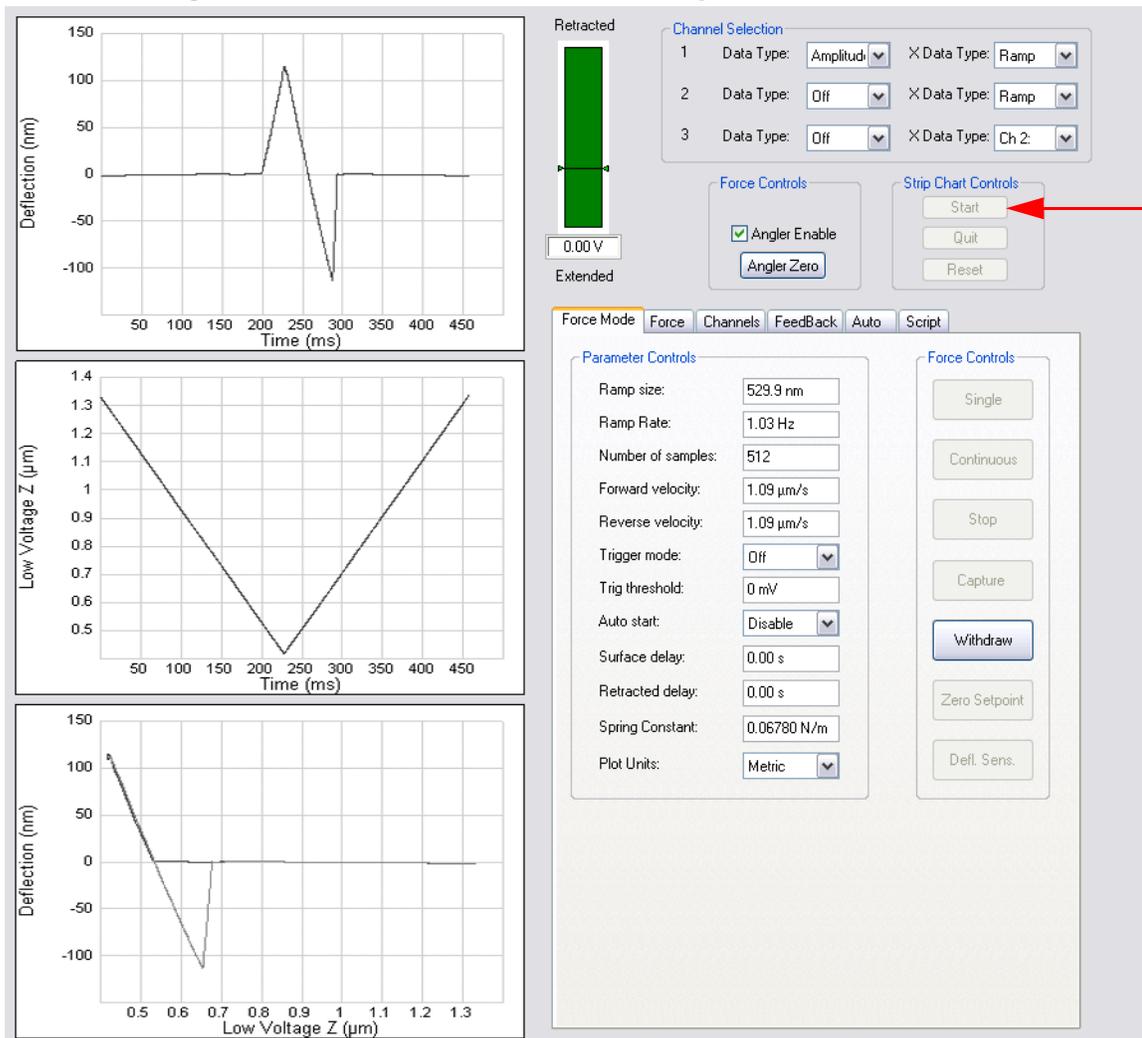
Besides being used as a tool for fully manual force curves, the PicoAngler is also very useful during basic force curves. In basic force curves, if no trigger is set and the continuous ramp button is clicked, the piezo begins to ramp up and down around the defined **Z START** position. This may not result 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 5.9b Force Mode: Channels Tab Featuring Inverted Channel 2 Z-Axis



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# Chapter 6 Fast Scan

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## 6.1 Active Tip Probes

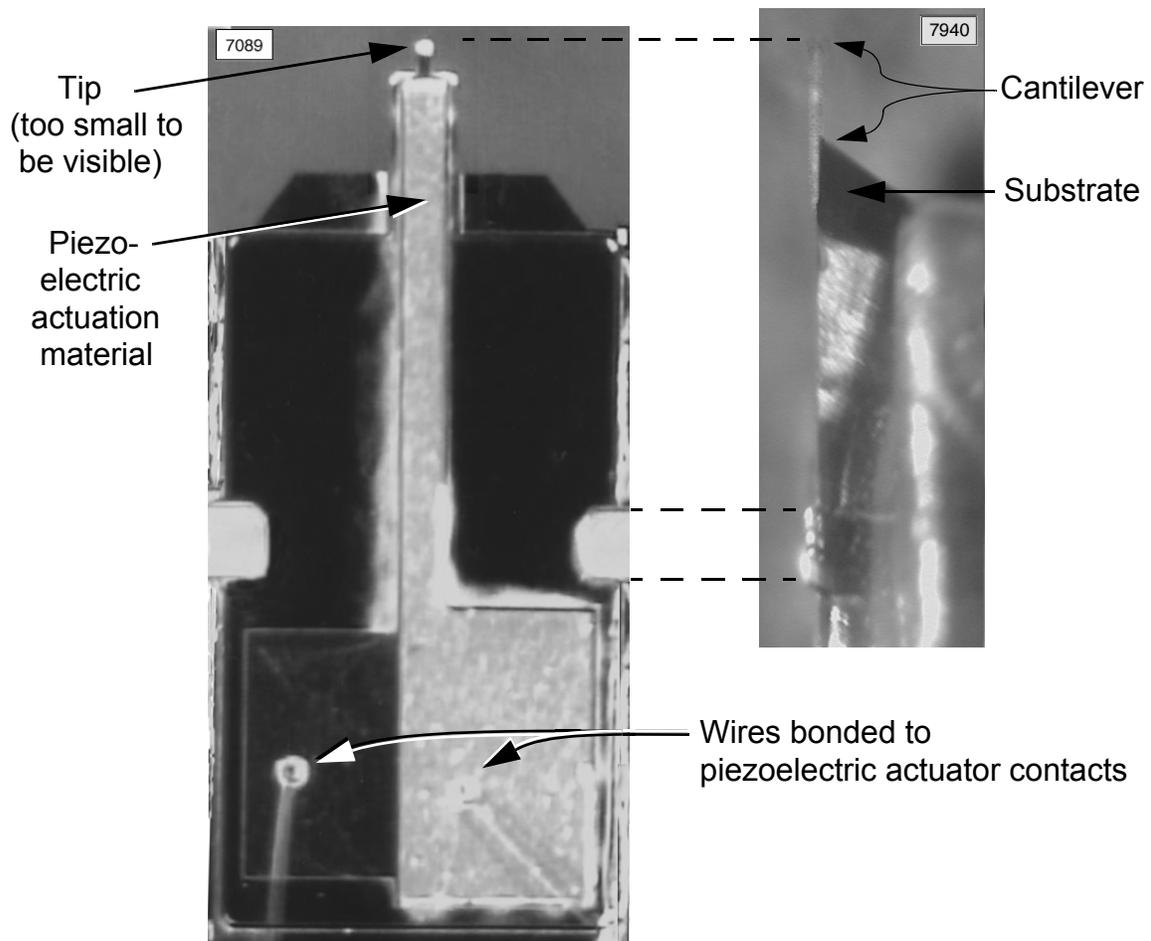
The FastScan capability of the NanoScope V Controller<sup>1</sup> is based on an Active Tip probe, which merges in a single component the essential microscope/sample interface element—the probetip—with the vertical position control mechanism, a piezoelectric actuator (see [Figure 6.1a](#)). A voltage 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).

**Note:** FastScan/Active Tip probes are not available on BioScope microscopes.

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<sup>1</sup>The FastScan feature is not available on the NanoScope V-PI.

Figure 6.1a Active Tip Probe: Looking at Tip (Left), Side View (Right)



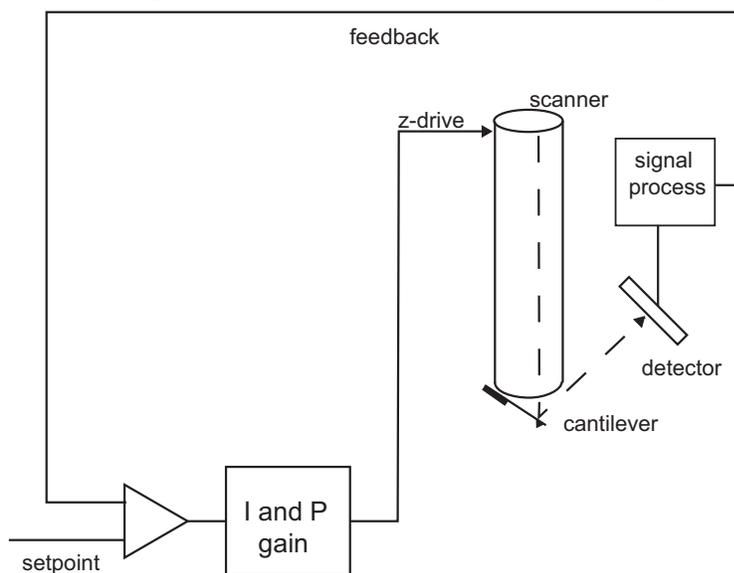
## 6.2 Dual Actuator FastScan

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.

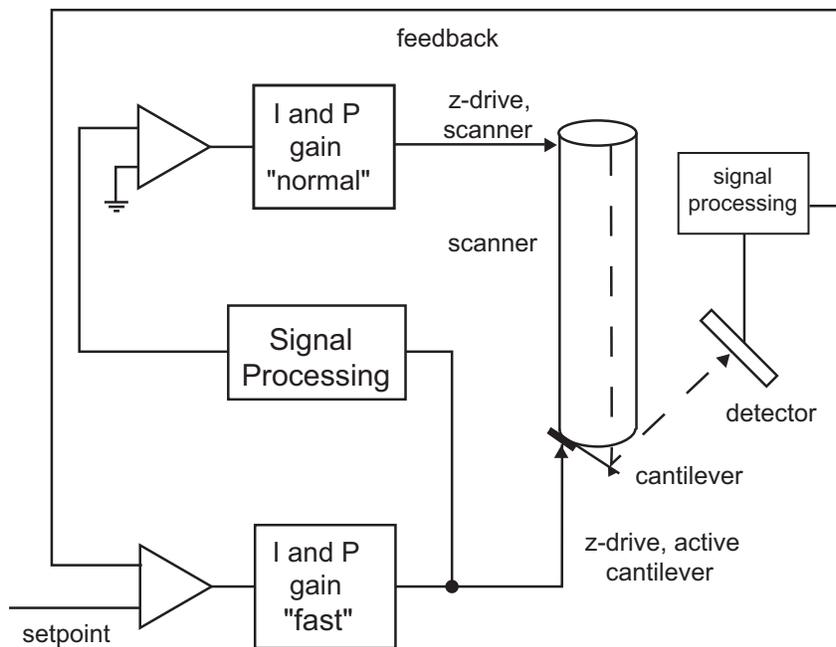
**Figure 6.2a** The Traditional SPM Feedback Loop



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 6.2a).

**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 ( $205\text{nm/V} \times 440\text{V} = 90\mu\text{m}$  for typical Dimension Icon, 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 6.2b). Together, the two actuators provide both range of motion and response speed.

**Figure 6.2b** 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:

$$(1/\text{second}) \times (\text{meter}) = (\text{meter}/\text{second}).$$

## 6.2.1 FastScan in Contact Mode

In the traditional SPM feedback loop (see [Figure 6.2a](#)) 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 6.2c](#)).

The **Fast Scan Engage/Determine Contact Gain** parameter is enabled (see [Figure 6.3g](#)) 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).

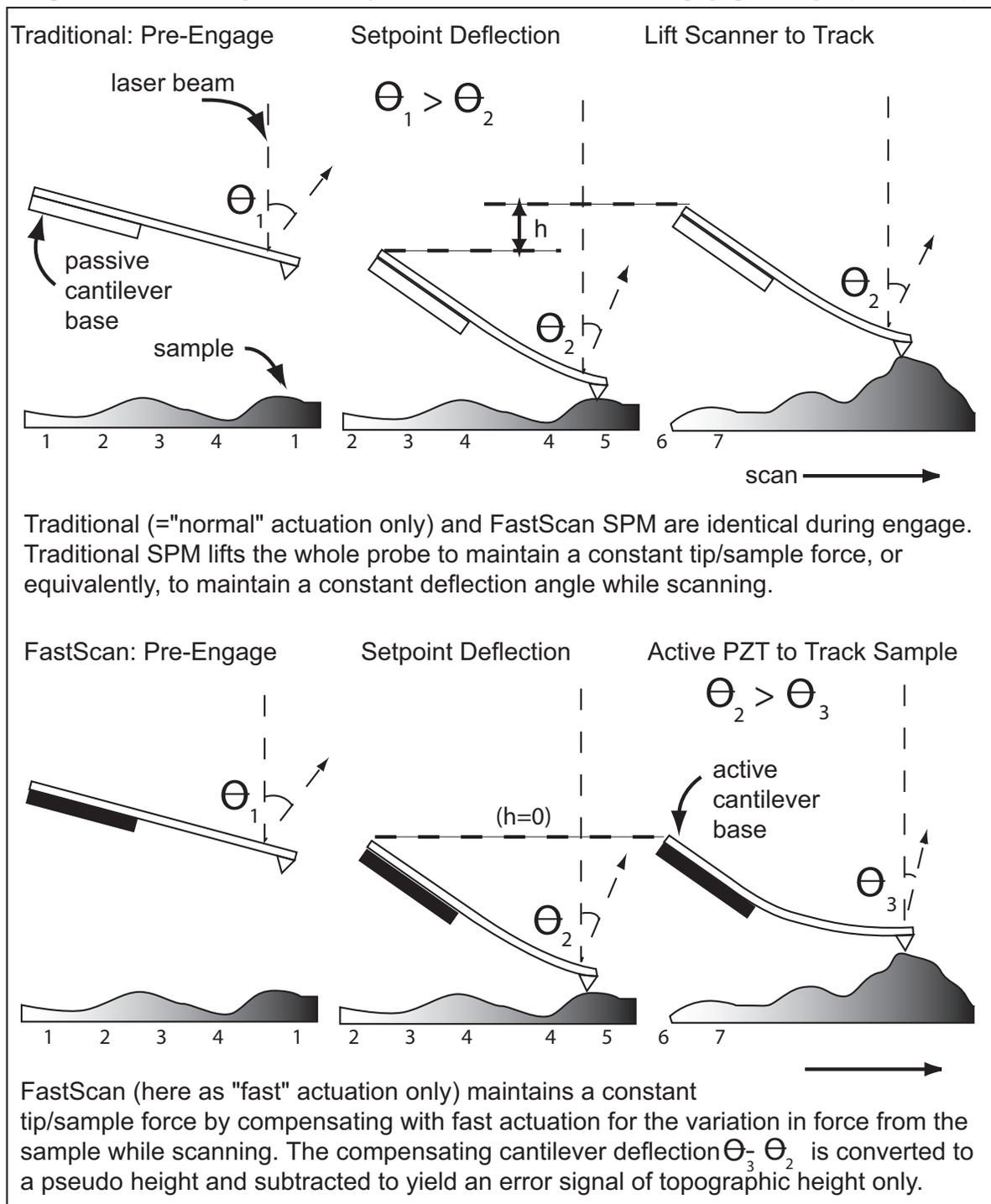
$$V_{\text{topographic component}} = V_{\text{cantilever deflection}} - [(Fast Z)(Contact Gain)/4096]$$

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 6.2c** Translating Deflection by Cantilever PZT Actuation into Topographic Height (Not to Scale)

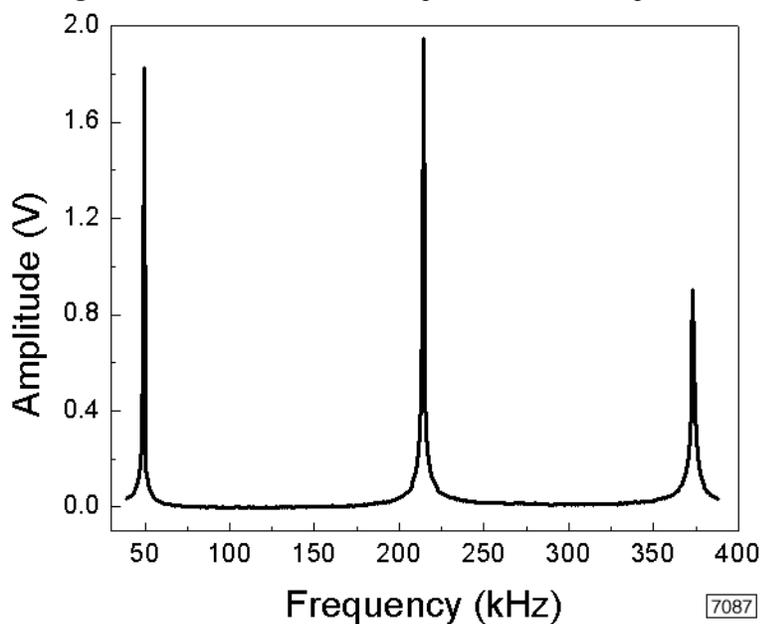


## 6.2.2 FastScan in TappingMode



Active Tip probes exhibit three resonances: at approximately 50 kHz, 200 kHz and above 300 kHz (see [Figure 6.2d](#), 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 68](#) for explanation).

**Figure 6.2d** Dimension Active Tip Cantilever Tune Spectrum



## 6.3 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:

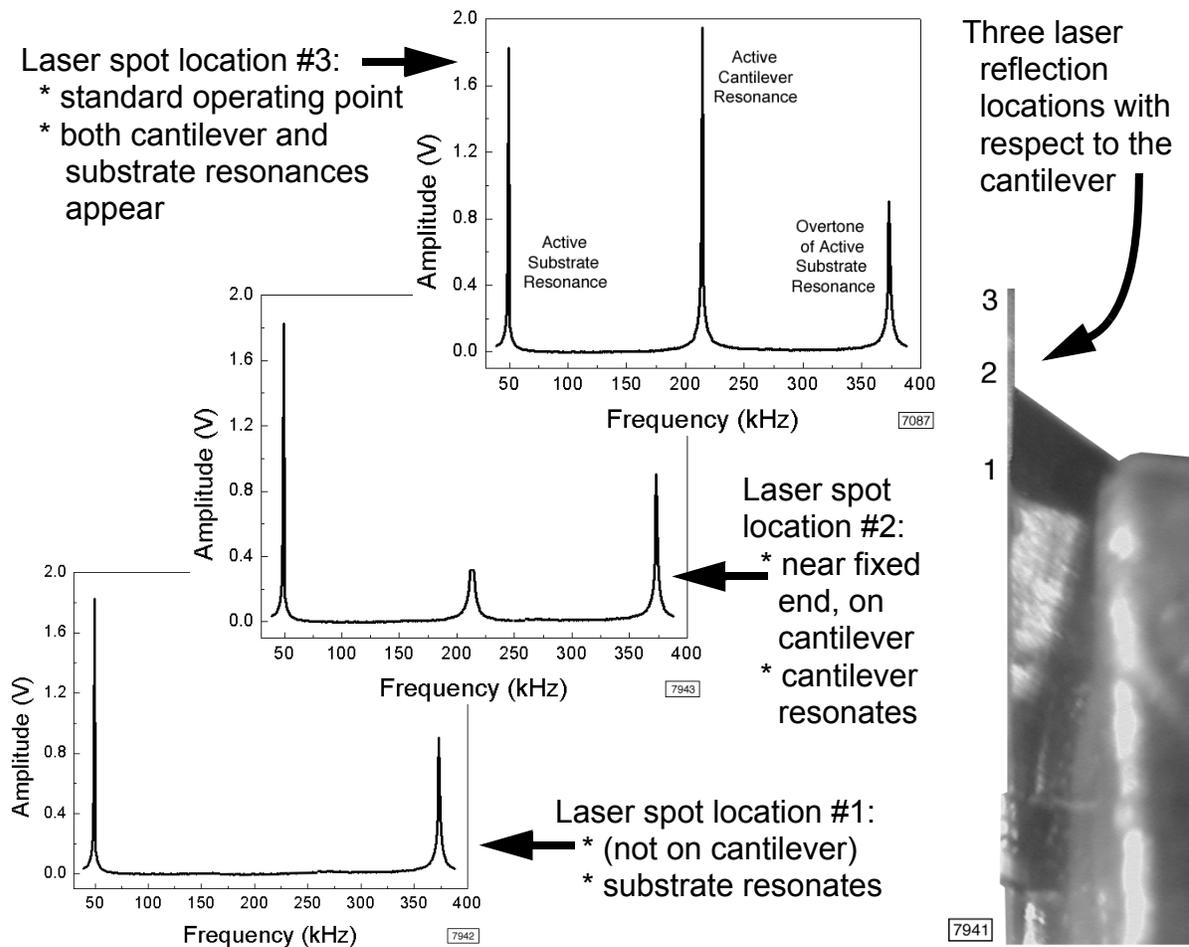


**CAUTION:** The present Active Tip probes risk a short circuit or degradation of the piezoelectric actuator if immersed in a conductive fluid, so this is not recommended.

### 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 6.3a) 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 6.3a).

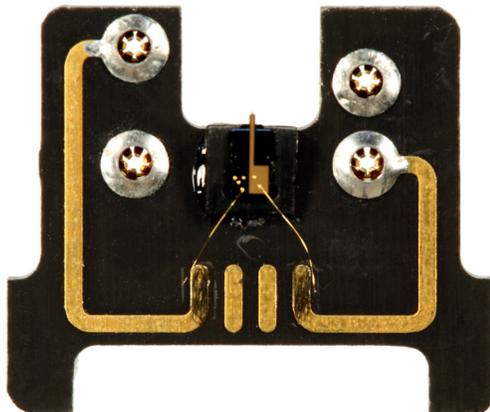
**Figure 6.3a** Demonstration of the Origin of the Dimension Active Tip Cantilever Tune Spectrum



### FastScan Probe Installation and Laser Alignment: Dimension SPMs

1. An Active Tip probe and its electrical contacts (see [Figure 6.3b](#)) 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.

**Figure 6.3b** Active Tip Probe: Tip Side (Left), Other Side (Right)



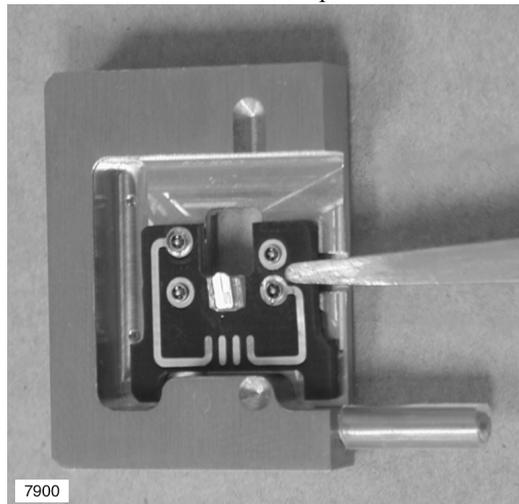
2. Use optics, laser light and positioners to align the SPM laser on the Active Tip cantilever toward its tip end (e.g., by selecting the **ALIGN/LOCATE TIP** icon (shown)) and to set tip/sample separation without permitting their contact (e.g., by selecting the **NAVIGATE/FOCUS SURFACE** icon (shown)).



### FastScan Probe Installation and Laser Alignment: MultiMode SPMs

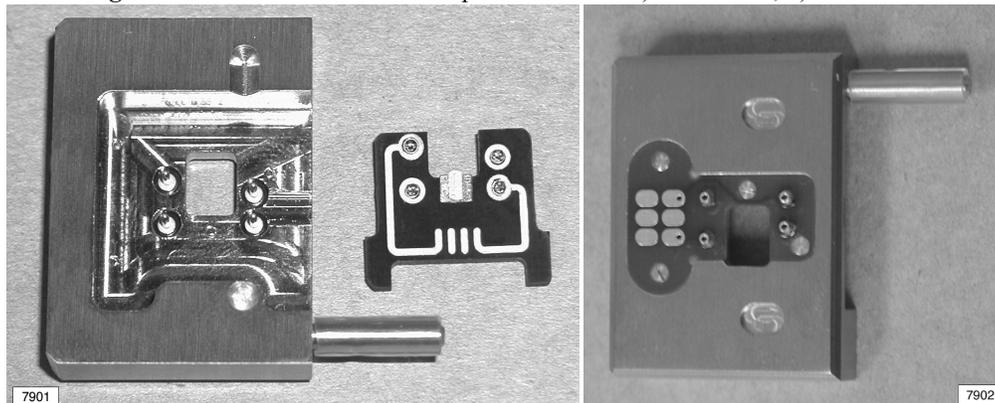
1. Without contacting the probe cantilever or tip against anything:
  - a. Grasp the Active Tip probe with tweezers (without touching the metallic conductors, as in [Figure 6.3c](#)) and press the probe into the MultiMode probe holder (see [Figure 6.3d](#)).
  - b. Grasping the probe holder by its extended handle, insert the probe assembly into the MultiMode optical head (see [Figure 6.3e](#)).
  - c. Lock it into position by turning the knob in the center of the back of the optical head.

**Figure 6.3c** MultiMode Active Tip Probe Holder and Probe

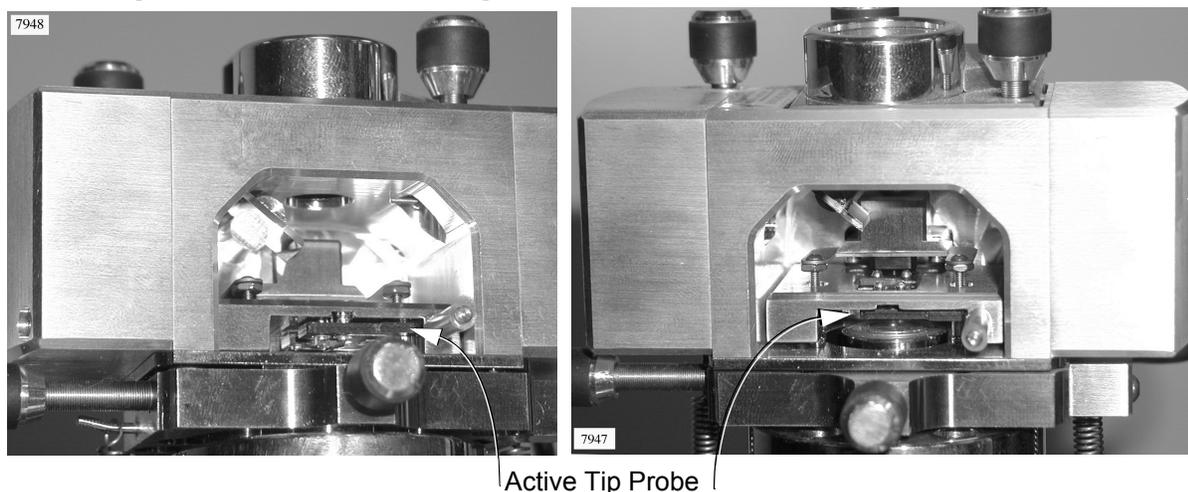


2. Arrange the optical detection path:
  - a. Use optics, laser light and a piece of paper (or alternative, if not using the “paper method”) to align the SPM laser on the Active Tip cantilever toward its tip end.
  - b. Adjust the tilt mirror to maximize the SUM signal, centering the reflected laser beam on the photodetector.

**Figure 6.3d** MultiMode Active Tip Probe Holder a) Probe Side, b) Other Side



**Figure 6.3e** 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 6.3f](#)) in the **Scan Parameters List** if you have not done so already.

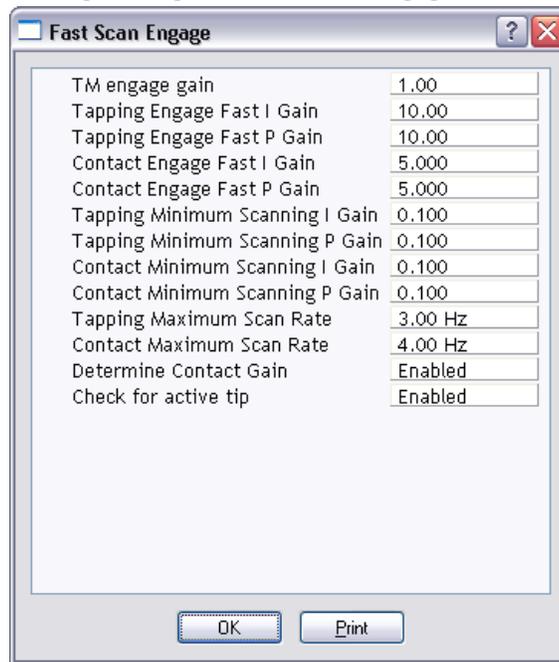
**Note:** The default settings of parameters in the **Fast Scan Engage** panel, shown in [Figure 6.3g](#), are designed to be effective in many circumstances. You may click the **ENGAGE** icon and only refer to the **Fast Scan Engage** panel if engagement fails. If so, skip to [Step 7](#); engage occurs in [Step 10](#).

**Figure 6.3f** Other panel - FAST SCAN ENABLED

Other	
LP TM Deflection	Enabled
LP TM Friction	Enabled
Sample Bias Control	Ground
Fast Z Scan	Enabled
Fast Z Feedback	Digital
Units	Metric
Engage Setpoint	0.850
Tip Serial Number	
Output 1 Data Type	Off
Output 2 Data Type	Off

4. Select **MICROSCOPE > ENGAGE SETTINGS > FAST SCAN** to open the panel shown in [Figure 6.3g](#). 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.)

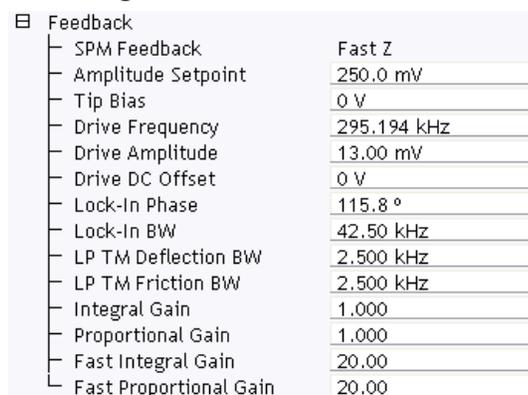
Figure 6.3g The Fast Scan Engage Panel



- 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.
- 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 6.3h](#)):

**INTEGRAL GAIN = 1.0**      **FAST INTEGRAL GAIN = 20**  
**PROPORTIONAL GAIN = 1.0**      **FAST PROPORTIONAL GAIN = 20.**

Figure 6.3h The Feedback Panel





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.

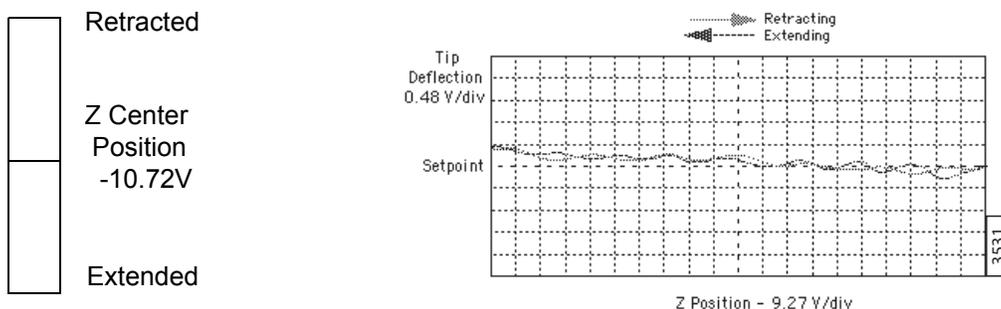
8. In the **Scan** panel begin with a small, slow scan by setting **SCAN SIZE** to 1-2 $\mu$ m and **SCAN RATE** to 1Hz.



9. Engage the tip with the sample: click **MICROSCOPE > 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 6.3i, 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 6.3i** Display Monitor: Z Position (Left), Optical Interference in False Engage Scope Trace (Right)



10. Set **Channel 4 Data Type** to **FAST Z** and view the traces in the **scope window**.

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 #4) *trace-minus-retrace* (TMR) signal to minimize it.

**Note:** To compare TMR signals before and after parameter adjustment, *capture* the scope traces. First, select **CAPTURE > CAPTURE FILENAME** and enter a filename in the **Capture File** panel. With the TMR scope trace visible, either click **CAPTURE**, then **OK** in the **Capture File** panel, or click **OK** exit the panel and select either the **CAPTURE** icon (shown) or **CAPTURE > 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 **Amplitude setpoint** and increase (versus decrease) it with the right (versus left) arrow key. **Amplitude 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** 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** panel parameters such as **Scan Size**, **Aspect Ratio**, **X and Y Offsets**, **Scan Angle** and **Samples/Line** for the image desired. Set **Slow Scan Axis** to **ENABLED**.
14. Increase the **Scan Rate** until the TMR signal begins to degrade or edges lose resolution in the image; 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** panel under **Fast Interleave Igain** and **Fast Interleave Pgain**, respectively.

## FastScan Setup and Engage for Contact Mode

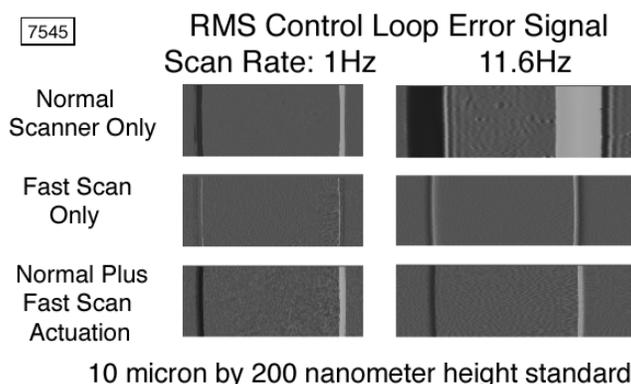
Fast Contact Mode imaging follows a similar procedure to that just outlined for TappingMode. The Contact Mode feedback loop controls cantilever deflection.

**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

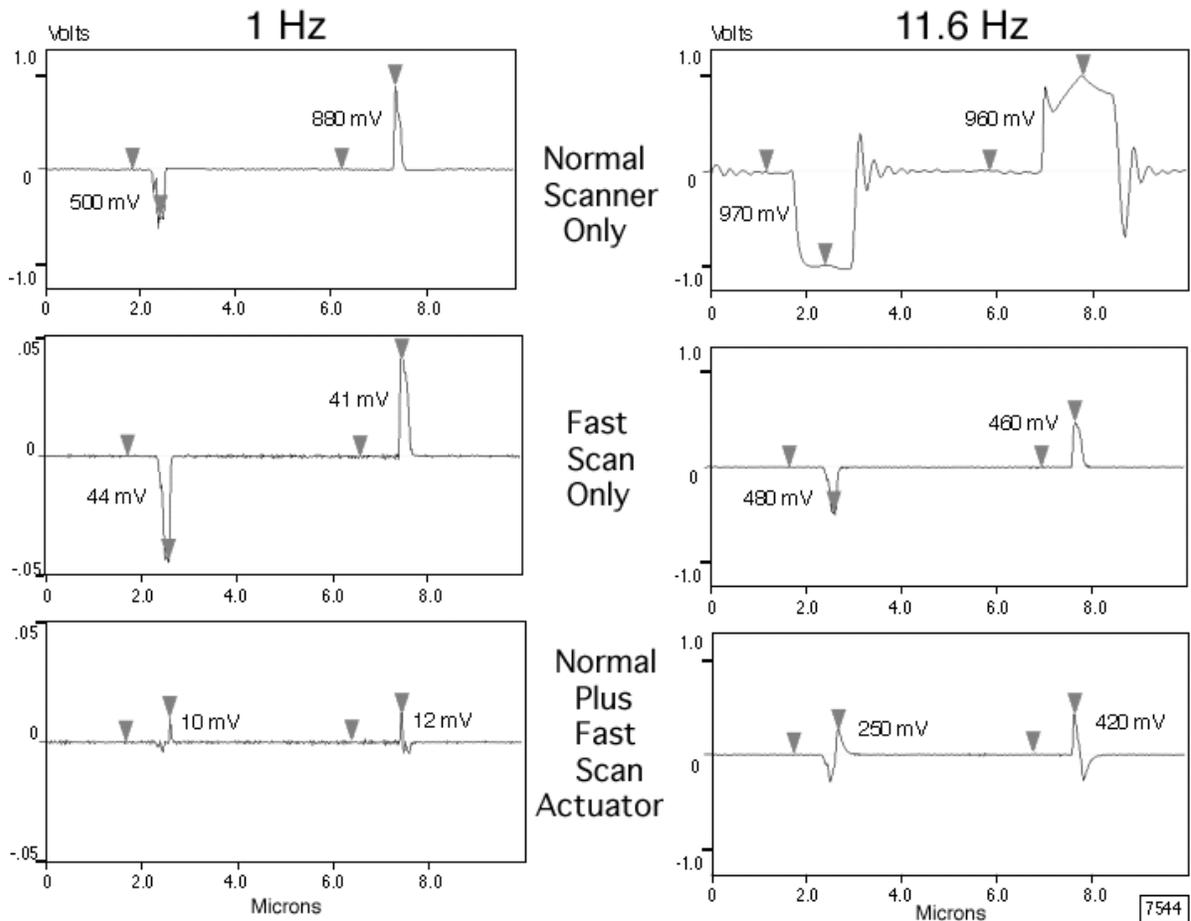
A typical first sample is a height standard. Traversing a 200nm high, 10 $\mu$ m feature, the example shown in [Figure 6.3j](#) illustrates the three methods of actuation available with the NanoScope V Controller: 1) the normal scanner only, 2) FastScan only and 3) dual actuation with both the traditional 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 **FASTZ** in the cases of fast actuation and dual actuation. In [Figure 6.3k](#), representative single trace cross-sections are plotted from the images in [Figure 6.3j](#).

**Figure 6.3j** Height Image Comparison: Three Control Methods and Two Scan Rates



The faster response of the Active Tip results in an 11 $\times$  lower error signal stepping up compared to the normal scanner at 1Hz. The improvement is 21 $\times$  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.

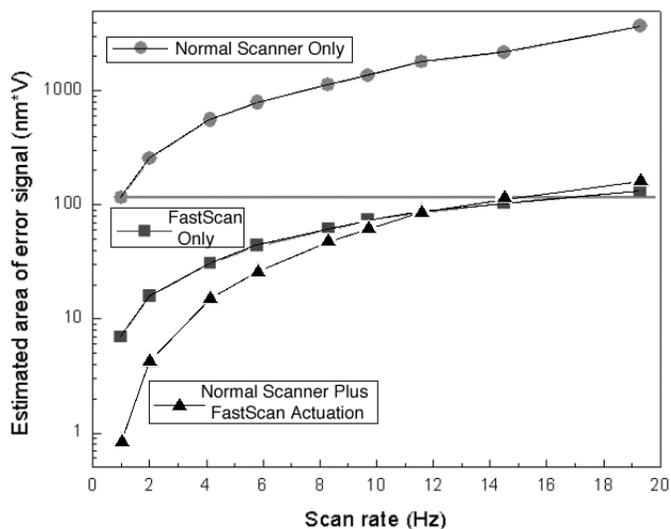
**Figure 6.3k** Height Profile Error Signal Comparison: Three Control Methods and Two Scan Rates



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 6.3j](#) in increments of scan rate, and integrating the absolute value of error signal profiles such as [Figure 6.3k](#), [Figure 6.3l](#) 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 6.31 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.

7546

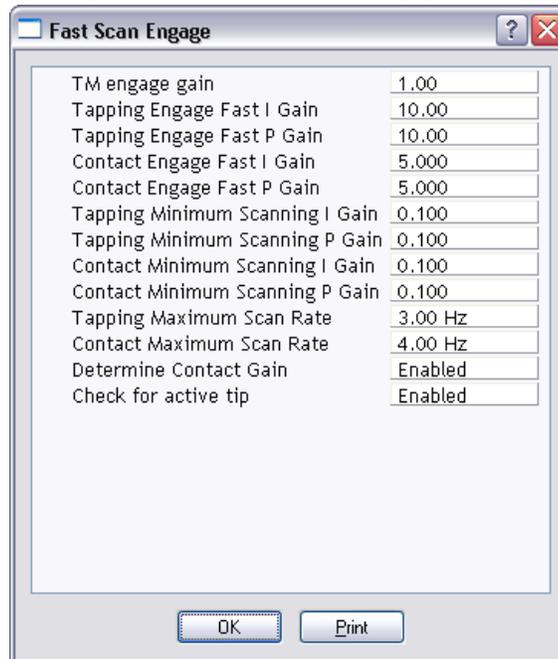
To calibrate the cantilever piezoelectric actuator so that **FAST Z** is an accurate height indicator, minimize the normal control loop integral and proportional gains so that only the fast loop is active and the scanner stays stationary: **INTEGRAL GAIN = 0.0001**, **PROPORTIONAL GAIN = 0**, **FAST 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 **CALIBRATE > DETECTOR** to open the **Detector Calibration** window. 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 **CALIBRATE > SCANNER > 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.

## 6.4 Fast Scan Engage Panel

Figure 6.4a The Fast Scan Engage Panel



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 6.4a](#)), select **MICROSCOPE > 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  $\pm 10V$  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**.

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Fast Scan  
**Fast Scan Engage Panel**

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# Chapter 7 ThermalTune

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## 7.1 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 V Controller automates the thermal tune method.

### 7.1.1 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<sup>3</sup>/meter, and the spring constant for a cantilever in the family is derived from the measured resonant frequency,  $f$  in seconds<sup>-1</sup>, 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 7.1a](#).

**Table 7.1a** Typical Tip Factor Values

Cantilever Class	Representative Cantilever Families	Tip Factor
V-shaped, Contact Mode	NP, DNP, OTR, ORC	$7 \times 10^{-15}$ Newton-seconds <sup>3</sup> /meter
Single beam, TappingMode	ESP, FESP, LTESPW, MESP, RTESPA, TESP, FIBLADE, FISPIKE, IBMSC	$4 \times 10^{-15}$ Newton-seconds <sup>3</sup> /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](#).

## 7.1.2 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,  $m = \rho wL$ ,  $\rho$  = 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 instrumentation, 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.

### 7.1.3 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 =  $1.3805 \times 10^{-23}$  joules/kelvin. In particular, for the potential energy,

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

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 V 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 7.1a](#): 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.

### 7.1.4 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 85](#)),  $\rho_f$  = density of the fluid (e.g., 1.18kg/m<sup>3</sup> for air),  
 $Q_f$  = the cantilever resonance quality factor in fluid,  
 $\omega_f$  = cantilever resonant frequency in the fluid,  
 $\Gamma_i$ , 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,

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

and

$$\Omega_i(\omega) = \frac{-0.024134 - 0.029256\tau + 0.016294\tau^2 - 0.00010961\tau^3 + 0.6458 \times 10^{-4}\tau^4 - 0.00004451\tau^5}{1 - 0.59702\tau + 0.55182\tau^2 - 0.18357\tau^3 + 0.079156\tau^4 - 0.014369\tau^5 + 0.0028361\tau^6}$$

where  $\tau = \log_{10}(\text{Re})$ , and the Reynolds number,  $\text{Re} = \rho_f \omega w^2 / (4\eta)$  for fluid viscosity  $\eta$ .  $K_0$  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  $L/w > 5$
- $Q_f \gg 1$ ; 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.

## 7.2 Calibrating a Cantilever

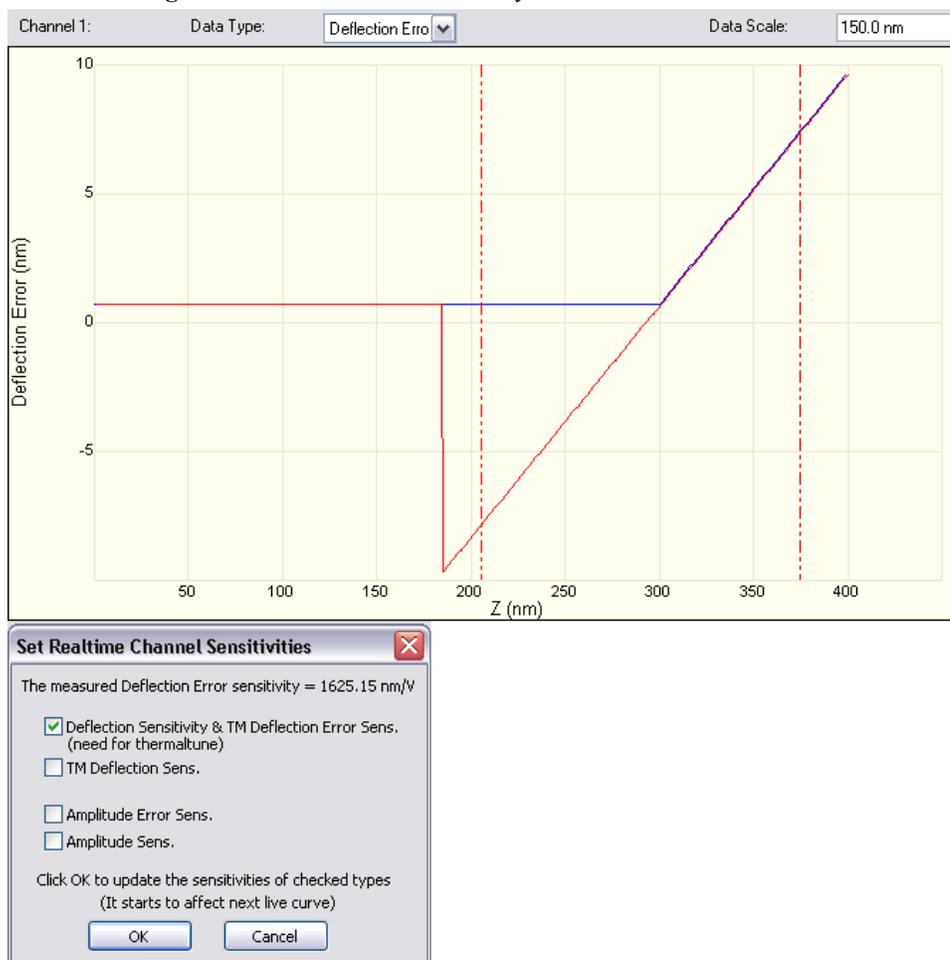
### 7.2.1 Determine Deflection Sensitivity in Force Mode

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 ERROR** 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 7.2a](#). Click **RAMP > UPDATE SENSITIVITY**.

You are asked whether you accept the calculated value (see [Figure 7.2a](#)).

Figure 7.2a Deflection Sensitivity Determination in Force Mode



**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.

### 7.3 Determine Cantilever Spring Constant by Thermal Tune

The Thermal Tune method (see [Measuring Thermal Noise](#), page 86) provides an automated and quick determination of cantilever spring constant.

		<b>CAUTION:</b> 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.
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Determine the cantilever spring constant by the thermal tune method according to the following procedure:

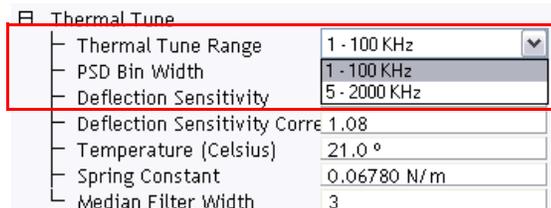
1. Determine cantilever deflection sensitivity if you have not done so already (see [Determine Deflection Sensitivity in Force Mode](#): Page 88).

**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 7.3b](#)) (**DEFL. SENS. CORRECTION**).



2. Click **WITHDRAW**.
3. Click **CALIBRATE > THERMAL TUNE** or the Thermal Tune icon in the NanoScope tool bar (shown).
4. Select a frequency range over which you will tune (see [Figure 7.3a](#))<sup>1</sup>.

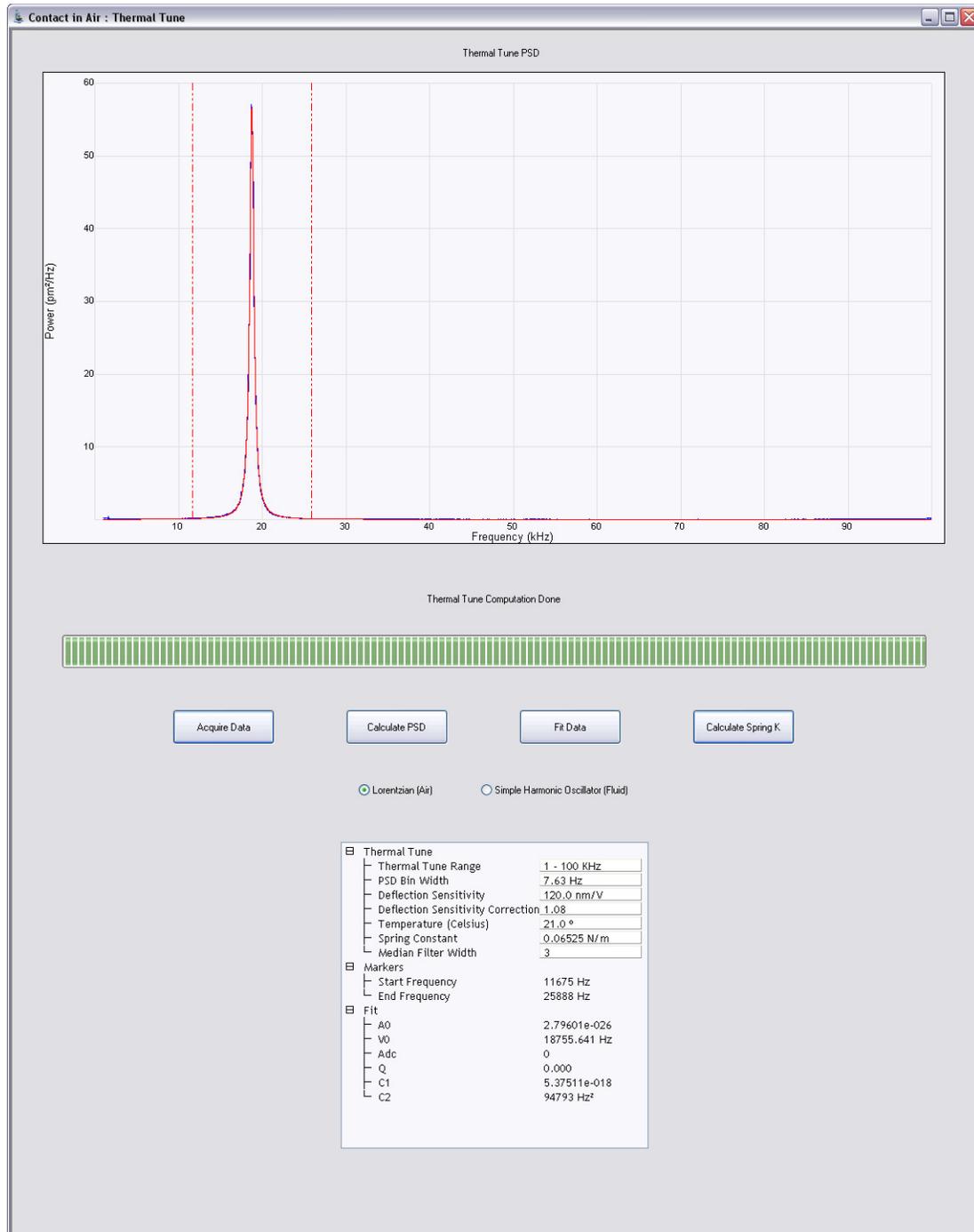
**Figure 7.3a** Select Thermal Tune Frequency Range



1. The 5 - 2000 kHz range is not available on the NanoScope V-PI.

5. Click **ACQUIRE DATA** in the **Thermal Tune** panel (see [Figure 7.3b](#)).
6. The microscope will acquire data for about 30 seconds.

**Figure 7.3b** The Thermal Tune Panel



7. A power spectral density (PSD) plot of the cantilever response to ambient conditions is displayed. Click either **LORENTZIAN (AIR)** or **SIMPLE HARMONIC OSCILLATOR (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:  $A(\nu)$  is the amplitude as a function of frequency,  $\nu$   
 $A_0$  is the baseline amplitude  
 $A_{DC}$  is the amplitude at DC (zero frequency)  
 $\nu_0$  is the center frequency of the resonant peak  
 $Q$  is the quality factor

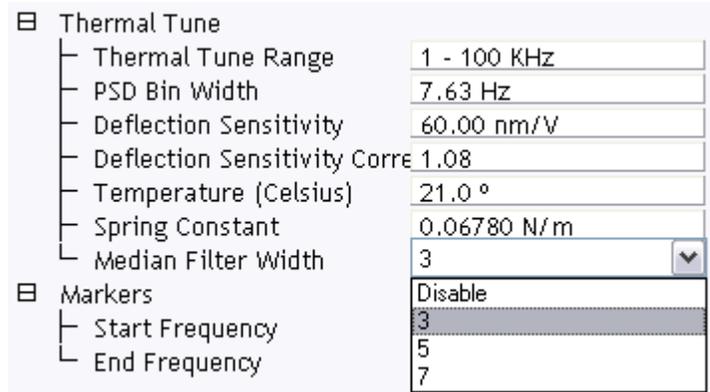
Lorentzian, for use in air

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

where:  $A(\nu)$  is the amplitude as a function of frequency,  $\nu$   
 $A_0$  is the baseline amplitude  
 $\nu_0$  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 7.3c](#), to remove individual (narrow) spikes. This replaces a data point with the median of the surrounding n (n =3, 5, 7) data points.

**Figure 7.3c MEDIAN FILTER WIDTH**



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 7.3b](#)). 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 7.3b](#)). Experiment with repeated fits of the same acquired thermal tune data to become familiar with its sensitivity to bandwidth and choice of model.

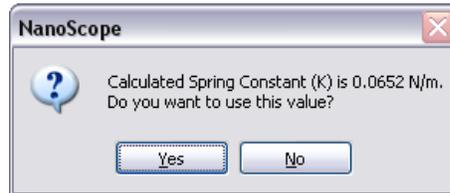
11. Click **Fit Data**. The curve fit, in red, is displayed along with the acquired data. If necessary, adjust the marker positions and fit the data again to obtain the best fit at the thermal peak.
12. Adjust the markers for the bandwidth of the fit PSD to include in the spring constant calculation.

**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 7.3b](#)).

13. Enter the cantilever **Temperature**.

14. Click **Calculate Spring K**. You will be asked whether you want to accept the calculated value of the spring constant,  $k$  (see [Figure 7.3d](#)). Clicking **OK** copies the calculated spring constant in the “Ramp” list in the PicoForce view.

**Figure 7.3d** Spring Constant Calculation Result



**Note:** See [Problems with Thermal Tune, page 94](#) for troubleshooting tips.

### 7.3.1 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.

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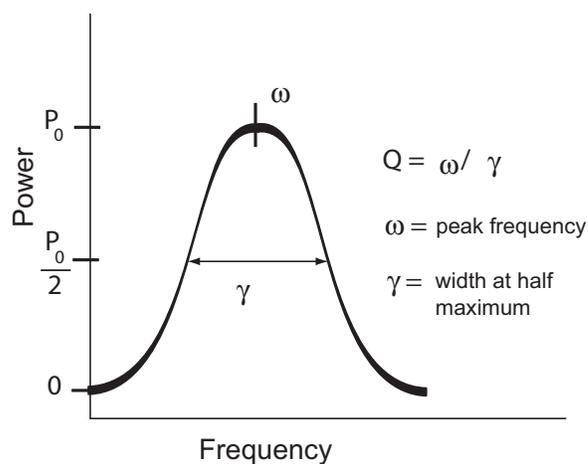
# Chapter 8 Q Control

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## 8.1 Introduction

*Q Control*<sup>1</sup> 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 8.1a). Power is proportional to amplitude squared, so the frequency interval,  $\gamma$ , between half-peak-power points, equals the interval between  $A_0/\sqrt{2}$  points, where  $A_0$  is the peak amplitude.

**Figure 8.1a** 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.

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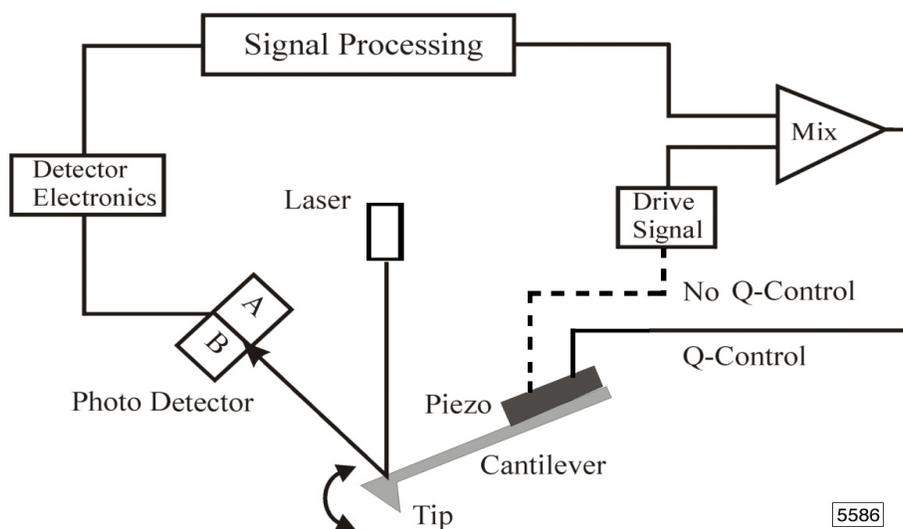
1. The Q Control feature is optional on the NanoScope V-PI.

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](http://www.bruker.com), for an illustrated survey of probe options.

The implementation of Q control is diagrammed in [Figure 8.1b](#). 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 105](#).

**Figure 8.1b** Q Control Block Diagram



Summarizing, the cantilever piezoelectric actuator (“Piezo” in [Figure 8.1b](#)) is driven from two electrical contacts that may be influenced by three sources.

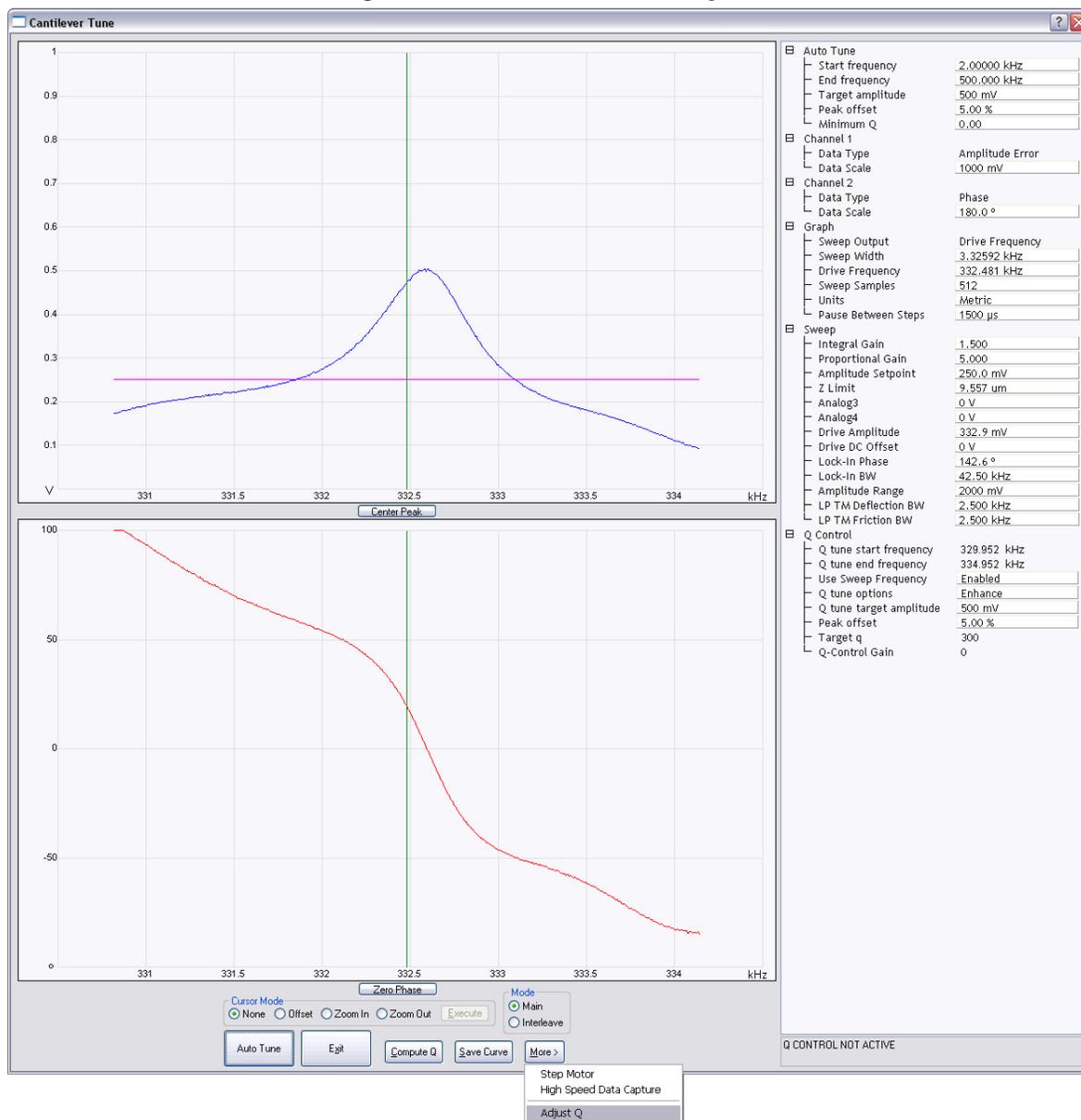
When Q control is active (TappingMode only), an adjustment is mixed into the AC piezo drive signal to achieve the target Q.

## 8.2 Q Control Setup



1. Access the **Cantilever Tune** dialog box by clicking the **TUNE** icon (shown) or by selecting **CANTILEVER TUNE** from the **MICROSCOPE** menu. The **Auto Tune**, **Channel 1**, **Channel 2** and **Sweep** parameter lists open (see Figure 8.2a). The **Q Control** panel will open in the **EXPANDED** mode.

Figure 8.2a Cantilever Tune Dialog Box



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 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/Drive Frequency**  $\pm$  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 105](#)) 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/Graph/Pause Between Steps** until the ringing is negligible.

- 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. Click **TURN OFF Q CTRL** 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 8.2a](#)). The **Q** panel opens and displays the current measured value of cantilever Q.

### Q Control Example: Enhancing a Force Field Measurement

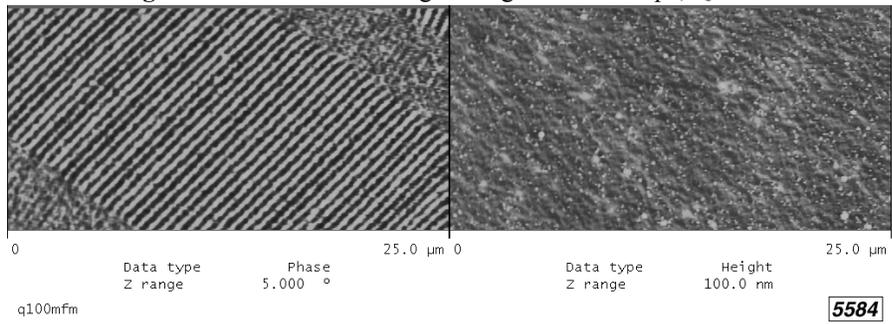
An example of the use of Q Control illustrates interactions it has with the engage process and with drive amplitude. These interactions were taken into account to generate the images shown in [Figure 8.2b](#) and [Figure 8.2c](#). In each of the two figures a topographic image appears on the right and a Magnetic Field Microscopy (MFM) image on the left. Nonuniformity of recorded magnetic transition widths is apparent in the high contrast MFM image ([Figure 8.2c](#)) taken with an enhanced Q of 1500. This feature of the recording is less discernible in the low Q MFM image ([Figure 8.2b](#)). Specifics of the set-up follow.



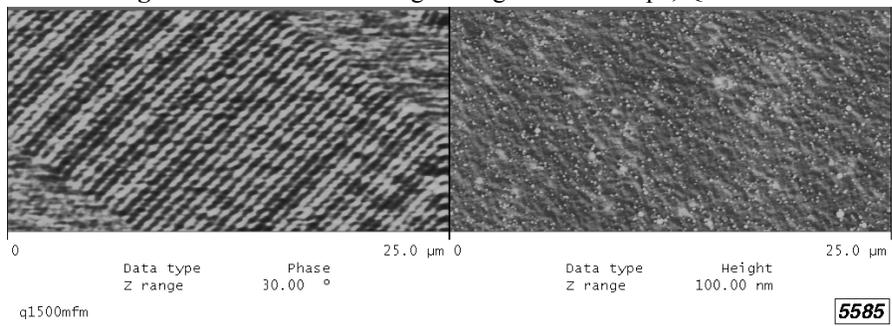
**CAUTION:**

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 8.2b** MFM and Height Images of Videotape, Q = 100

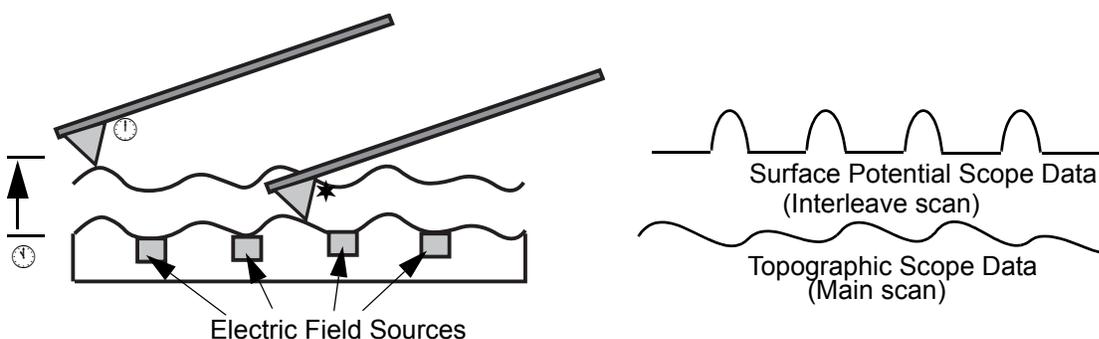


**Figure 8.2c** MFM and Height Images of Videotape, Q = 1500



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 8.2d](#)).

**Figure 8.2d** 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/Lift start height**. In the **Interleave** panel, click on the parameter name, **Drive Amplitude**. The parameter turns green to indicate the value appearing for the same parameter in the **Sweep** panel is used on-surface, while the **Interleave** value is used off-surface.

## 8.3 Cantilever Tune Window



The **Q Control** parameter list (see [Figure 8.3a](#)) opens, along with **Sweep**, **Auto Tune**, **Graph** and at least one **Channel** parameter list upon clicking the **CANTILEVER TUNE** icon (shown) or selecting **CANTILEVER TUNE** from the **MICROSCOPE** menu. At any time, **Cantilever Tune/COMPUTE Q** can be selected to monitor cantilever Q, either visually or numerically. The **Q Control** panel will open in the **EXPANDED** mode.

**Figure 8.3a** The Q Control Parameter List

☰ Q Control	
├ Q tune start frequency	93.9520 kHz
├ Q tune end frequency	500.000 kHz
├ Use Sweep Frequency	Disabled
├ Q tune options	Seek Q
├ Q tune target amplitude	500 mV
├ Peak offset	5.00 %
├ Target q	300
└ Q-Control Gain	4095

### 8.3.1 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  $\pm 10$ kHz 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 105](#).

*Range and Settings:* Typical value: application-dependent.

## 8.3.2 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 OFF Q CTRL**

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

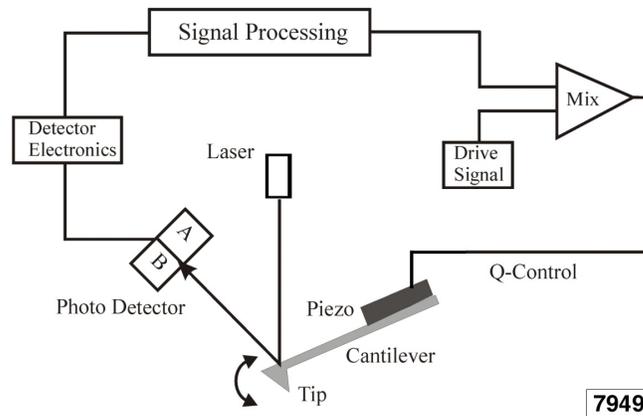
**Cantilever Tune/COMPUTE Q**

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

## 8.4 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 8.4a** 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,
  - $\alpha$  = 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
  - $\omega$  = the cantilever drive frequency, (typically, near the cantilever resonance frequency)
  - $\phi$  = the phase shift applied to the feedback signal,
  - $e = 2.71828\dots$ , 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  
 $\psi$  = 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,  $\alpha$ , is replaced by a new one,  $\alpha' = \alpha - (G/\omega)$ .

Given that the width of the resonance at half-maximum,  $\gamma$ , equals the damping constant,  $\alpha'$ , 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

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# Chapter 9 Maintenance

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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.

## 9.1 Troubleshooting



### 9.1.1 Fuses

If any of the three power **Diagnostics** LEDs (i.e., +5V, +15V, -15V) on the front panel (see [Figure 9.1a](#)) fails to illuminate when the system is turned **ON**, a fuse may be blown.

**Figure 9.1a** Power Supply LEDs on the Front of the NanoScope V Controller



Figure 9.1b 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 9.1b) and reproduced in Table 9.1a. 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 9.1a 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.

### 9.1.2 Fast Feedback Failure

If a warning message questions whether the probe is an Active Tip, inspect it to be sure (see [Figure 6.3b](#) and [Figure](#) for Dimension, and [Figure 6.3c](#) and [Figure 6.3d](#) 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 6.3b](#)). 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 6.3c](#)).
3. If the resistance reading is less than  $1\text{ M}\Omega$ , the microactuated piezoelectric element has failed and must be replaced with a fresh Active Tip probe.

## 9.2 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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