PACIFIC NANOTECHNOLOGY

Nano-R™ AFM User's Manual

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Before You Start...........

The Nano-R™ AFM can be operated with little or no understanding of the components in an AFM. However, Pacific Nanotechnology recommends that if you are not familiar with the parts in an AFM, you take the time to read the AFM Tutorial in section 1.0. Getting optimal result from the Nano-R™ is greatly facilitated by having some understanding of the theory of an AFM system.

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3. Products not properly placed and installed per our installation instructions.
4. Products not operated within the acceptable parameters noted per our installation instructions.
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6. Products that have had their serial number removed, altered or otherwise defaced.
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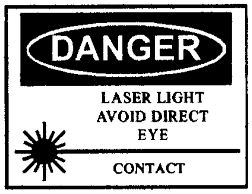
Safety Statement

LASER OPERATION ---- AFM SCANNING HEAD LASER



<u>WARNING:</u> NEVER LOOK DIRECTLY INTO THE LASER BEAM

IN ORDER TO AVOID THE POSSIBILITY OF THE USER INADVERTENTLY LOOKING INTO THE LASER, ALWAYS USE THE SOFTWARE OR HARDWARE TO SWITCH THE LASER OFF BEFORE RAISING THE HEAD TO EYE LEVEL.

The diode laser in the Nano-R™ scanning head complies with US 21 CFR 1040.10 and is certified as a Class IIIa laser. The laser wavelength is 670nm and the maximum power is 3 mW.

In addition to the above, please follow laser safety control measures in American National Standards Institute Z136.1-1986.

HIGH VOLTAGE

Wherever high voltage is present on the system, extreme care should always be taken to avoid direct contact while the instrument hardware is powered on. Always power off the equipment before attempting to remove any panels or PC boards and before touching any connectors by hand or with electrically conductive tools.

Chapter 1

Introduction to AFM

1.1 History of AFM

Introduction

Typically, when we think of microscopes, we think of optical or electron microscopes. Such microscopes create a magnified image of an object by focusing electromagnetic radiation, such as photons or electrons, on its surface. Optical and electron microscopes can easily generate two-dimensional magnified images of an object's surface, with a magnification as great as 1000X for an optical microscope, and as large as 100,000X for an electron microscope. Although these are powerful tools, the images obtained are typically in the plane horizontal to the surface of the object. Such microscopes do not readily supply the vertical dimensions of an object's surface, the height and depth of the surface features.

The atomic force microscope (AFM), developed in the mid 1980's, uses a sharp probe to magnify surface features. With the AFM, it is possible to image an object's surface topography with extremely high magnifications, up to 1,000,000X. Further, the magnification of an AFM is made in three dimensions, the horizontal X-Y plane and the vertical Z dimension. As acknowledged by Bennig and Roher[1], the inventors of the tunneling microscope, such a powerful technique has its origins in the stylus profiler.

Stylus Profilers

Magnification of the vertical surface features of an object, those features leaving the horizontal plane and extending in the vertical direction, have historically been measured by a stylus profiler. An example of an early profiler is shown in Figure 1.1. This profiler, invented by Schmalz[2] in 1929, utilized an optical lever arm to monitor the motion of a sharp probe mounted at the end of a cantilever. A magnified profile of the surface was generated by recording the motion of the stylus on photographic paper. This type of "microscope" generated profile "images" with a magnification of greater than 1000X.

A common problem with stylus profilers was the possible bending of the probe from collisions with surface features. Such "probe bending" was a result of horizontal forces on the probe caused when the probe encountered large features on the surface. This problem was first addressed by Becker[3] in 1950 and later by Lee[4]. Both Becker and Lee suggested oscillating the probe from a null position above the surface to contact with the surface. Becker remarked that when using this vibrating profile method for measuring images, the detail of the images would depend on the sharpness of the probe.

In 1971 Russell Young[5] demonstrated a non-contact type of stylus profiler. In his profiler, called the Topographiner, Young used the fact that the electron field emission current between a sharp metal probe and a surface is very dependent on the probe sample distance for electrically conductive samples. In the Topographiner, the probe was mounted directly on a piezoelectric ceramic used to move the probe in a vertical direction above the surface. An electronic feedback circuit monitoring the electron emission was then used to drive the piezoceramic and thus keep the probe sample spacing fixed. Then, with piezoelectric ceramics, the probe was used to scan the surface in the horizontal (X-Y) dimensions. By monitoring the X-Y and Z position of the probe, a 3-D image of the surface was constructed. The resolution of Young's instrument was controlled by the instrument's vibrations.

Scanning Tunneling Microscopes and Atomic Force Microscopes

In 1981 researchers at IBM were able to utilize the methods first demonstrated by Young to create the scanning tunneling microscope[6] (STM). Bennig and Rohrer demonstrated that by controlling the vibrations of an instrument very similar to Young's Topographiner, it was possible to monitor the electron tunneling current between a sharp probe and a sample. Since electron tunneling is much more sensitive than field emissions, the probe could be used to scan very close to the surface. The results were astounding; Bennig and Rohrer were able to see individual silicon atoms on a surface. Although the STM was considered a fundamental advancement for scientific research, it had limited applications, because it worked only on electrically conductive samples.

A major advancement in profilers occurred in 1996 when Bennig and Quate[7] demonstrated the Atomic Force Microscope. Using an ultra-small probe tip at the end of a cantilever, the atomic force microscope could achieve extremely high resolutions. Initially, the motion of the cantilever was monitored with an STM tip. However, it was soon realized that a light-lever, similar to the technique first used by Schmalz, could be used for measuring the motion of the cantilever. In their paper, Bennig and Quate proposed that the AFM could be improved by vibrating the cantilever above the surface.

The first practical demonstration of the vibrating cantilever technique in an atomic force microscope was made by Wickramsinghe[8] in 1987 with an optical interferometer to measure the amplitude of a cantilever's vibration.

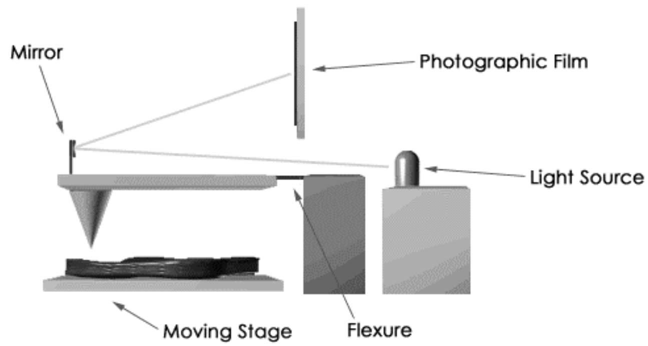


Figure 1.1. : An example of a surface profiler made in 1929.

Using this optical technique, oscillation amplitudes of between .3 nm and 100 nm were achieved. Because the probe comes into close contact with the surface upon each oscillation, Wickramsinghe was able to sense the materials on a surface. The differences between photo-resist and silicon were readily observed.

1 G. Bennig and H. Rohrer, Scanning Tunneling Microscopy—From Birth to Adolescence, Rev. of Mod. Phys, Vol 59, No. 3, 1987, P 615

2 Uber Glatte und Ebenheit als physikalisches und physiologishes Problem, Gustev Shmalz, Zeitchrift des Vereimes deutscher Ingenieurte, Oct 12, 1929, pp. 1461-1467

3 U.S. Patent 2,7288,222

4 UK Patent 2,009,409

5 R. Young, J. Ward, F. Scire, The Topografiner: An Instrument for Measuring Surface Microtopography, Rev. Sci. Inst., Vol 43, No 7, p 999

6 G. Bennig, H. Rohrer, Ch. Gerber, E. Weibel, Surface Studies by Scanning Tunneling Microscopy, Vol. 49, No 1, 1982, p 57

7 G. Bennig, C.F. Quate, Ch. Geber, Atomic Force Microscope, Phys. Rev. Letters, Vol. 56, No 9, p 930

8 Y. Martin, C.C. Williams, H.K. Wickramasinghe, Atomic Force Microscope-Force Mapping and Profiling on a sub 100-Å scale. J. Appl. Phys. Vol 61, No 9, 1987, p 4723

1.2. AFM Tutorial

This tutorial serves as a basic introduction to the design and operation of an atomic force microscope.

Background

The following four sections cover the basic concepts and technologies that help understand the construction and operation of an atomic force microscope. It is essential to understand the contents of these sections for a complete understanding of how an atomic force microscope works.

Dimensions and Magnification

An atomic force microscope is optimized for measuring surface features that are extremely small, thus it is important to be familiar with the dimensions of the features being measured. An atomic force microscope is capable of imaging features as small as a carbon atom and as large as the cross section of a human hair. A carbon atom is approximately .25 nanometers (nm) in diameter and the diameter of a human hair is approximately 80 microns (µm) in diameter.

The common unit of dimension used for making measurements in an atomic force microscope is the nanometer. A nanometer is one billionth of a meter:

1 METER =1,000,000,000 NANOMETERS

1 MICRON =1,000 NANOMETERS

Another common unit of measure is the Angstrom. There are ten angstroms (Å) in one nanometer:

1 NANOMETER =10 ANGSTROMS

Magnification in an atomic force microscope is the ratio of the actual size of a feature to the size of the feature when viewed on a computer screen. Thus when an entire cross section of a human hair is viewed on a 500 MM computer monitor (20 inch monitor) the magnification is:

MAGNIFICATION = 500 MM/.08 MM = 6,250 X

In the case of extremely high resolution imaging, the entire field of view of the image may be 100 nanometers. In this case the magnification on a 500 mm computer screen is:

MAGNIFICATION =500 MM/(100 NM*1 MM/1,000,000 NM)= 5,000,000 X

Piezoelectric Ceramic Transducer

Mechanical motion is created from electrical energy with an electromechanical transducer. Electrical motors such as are used in washing machines are the most common type of electromechanical transducer. The electromechanical transducer most commonly used in an atomic force microscope is the piezoelectric ceramic.

A piezoelectric material undergoes a change in geometry when it is placed in an electric field. The amount of motion and direction of motion depends on the type of piezoelectric material, the shape of the material, and the field strength. Figure 1.2.a. shows the motion of a piezoelectric disk when exposed to an electric potential:

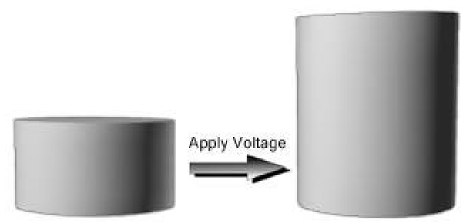


Figure 1.2.a.: When a voltage is applied to the top and bottom surface of the piezoelectric disc, the disc will expand.

A typical piezoelectric material will expand by about 1 nm per applied volt. Thus, to get larger motions it is common to make piezoelectric transducers with hundreds of layers of piezoelectric materials, illustrated in Figure 1.2.b.

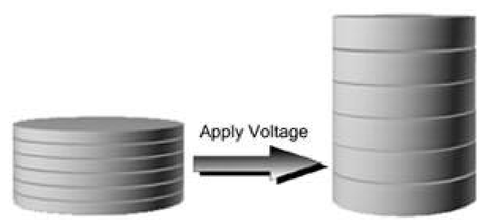


Figure 1.2.b. : Applying a voltage to the top and bottom surface of this stack of piezoelectric disks causes the entire stack to expand. The amount of expansion depends on the applied voltage, piezo-material, and number of disks

By using one thousand layers of piezoelectric material it is possible to get motions as large as 1000 nm per volt. Thus with 100 volts it is possible to get 0.1 mm of motion with a multiple layer piezoelectric transducer.

Force Sensors

The construction of an atomic force microscope requires a force sensor to measure the forces between a small probe and the surface being imaged. A common type of force sensor utilizes the relationship between the motion of a cantilever and the applied force. The relationship, given by Hook's law is:

$$F = - K * D$$

K is a constant and depends on the material and dimensions of the cantilever.

D is the motion of the cantilever. For a cantilever made of silicon that has dimensions of:

L = 100 MICRONS

W= 20 MICRONS

T = 1 MICRON

The force constant, K, is approximately 1 newton/meter. Thus if the cantilever is moved by 1 nm, a force of 1 nanonewton is required.

Measuring the motion of the cantilever is possible with the "light lever" method. In the light lever method, light is reflected from the back side of the cantilever into a photo-detector. See figure 1.2.c..

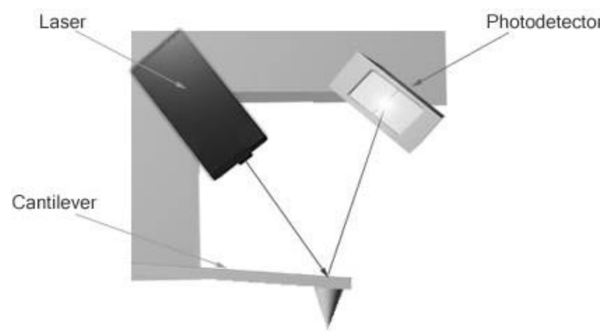


Figure 1.2.c. : The light lever sensor uses a laser beam to monitor the deflection of the cantilever. When the cantilever moves up and down, the light beam moves across the surface of the photo-detector.

The motion of the cantilever is then directly proportional to the output of the photo-detector. Motions as small as 1 nm are routinely measured with the "light lever" method in atomic force microscopes.

Feedback Control

Feedback control is used commonly for keeping the motion of an object in a fixed relationship to another object. A simple example of feedback control occurs when you walk down a sidewalk. As you walk down a sidewalk you constantly control your motion by viewing the edge of the sidewalk. If you begin to walk off the sidewalk you correct your motion so that you stay on the sidewalk. Feedback control is used routinely for many common applications such as the automatic control airplanes and controlling the temperature in buildings. In the AFM, feedback control is used to keep the probe in a "fixed" relationship with the surface while a scan is measured.

Atomic Force Microscope

The theory and operation of an atomic force microscope is similar to a stylus profiler. The primary difference is that in the atomic force microscope, the probe forces on the surface are much smaller than those in a stylus profiler. Because the forces in an AFM are much smaller, smaller probes can be used, and the resolution is much higher than can be achieved with a stylus profiler.

AFM Theory

In an AFM a constant force is maintained between the probe and sample while the probe is raster scanned across the surface. By monitoring the motion of the probe as it is scanned across the surface, a three dimensional image of the surface is constructed. The constant force is maintained by measuring the force with the "light lever" sensor and using a feedback control electronic circuit to control the position of the Z piezoelectric ceramic. See Figure 1.2.d..

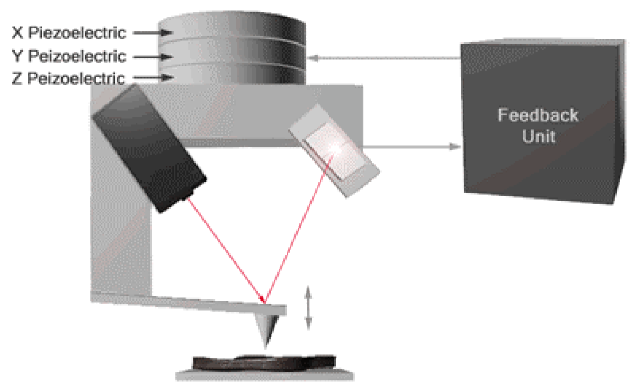


Figure 1.2.d. : This figure illustrates the primary components of the light lever atomic force microscope. The X and Y piezoceramics are used to scan the probe over the surface.

The motion of the probe over the surface is generated by piezoelectric ceramics that move the probe and force sensor across the surface in the X and Y directions.

AFM Instrumentation

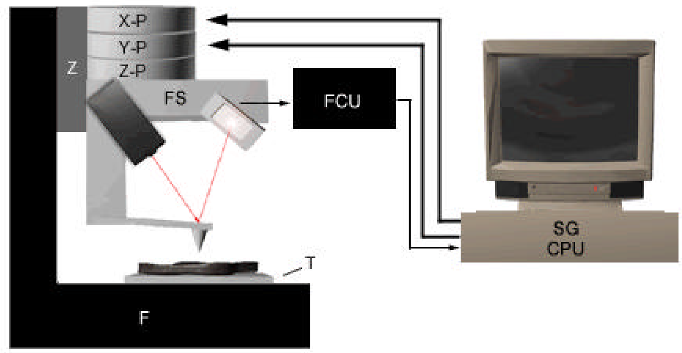


Figure 1.2.e. : Shows all of the components and subsystems of an atomic force microscope system.

(Z) Coarse Z motion translator- This translator moves the AFM head towards the surface so that the force sensor can measure the force between the probe and sample. The motion of the translator is usually about 10 mm.

(T) Coarse X-Y translation stage - The XY translation stage is used to place the section of the sample that is being imaged by the AFM directly under the probe.

(X-P) X and Y piezoelectric transducer - With the X and Y piezoelectric transducer the (Y-P) probe is moved over the surface in a raster motion when an AFM image is measured.

(FS) Force Sensor - The force sensor measures the force between the probe and the sample by monitoring the deflection of a cantilever.

(ZP) Z piezoelectric Ceramic - Moves the force sensor in the vertical direction to the surface as the probe is scanned with the X and Y piezoelectric transducers.

(FCU) Feedback control unit - The feedback control unit takes in the signal from the light lever force sensor and outputs the voltage that drives the Z piezoelectric ceramic. This voltage refers to the voltage that is required to maintain a constant deflection of the cantilever while scanning.

(SG) X-Y signal generator - The motion of the probe in the X-Y plane is controlled by the X-Y signal generator. A raster motion is used when an image is measured.

(CPU) Computer - The computer is used for setting the scanning parameters such as scan size, scan speed, feedback control response and visualizing images captured with the microscope.

(F) Frame - A solid frame supports the entire AFM microscope. The frame must be very rigid so that it does not allow vibrations between the tip and the surface.

NOTE - Not shown, is an optical microscope that is essential for locating features on the surface of the sample and for monitoring the probe approach process.

Measuring images with an atomic force microscope

1. Place a probe in the microscope and align the light lever sensing system.
2. With the X-Y sample and the optical microscope place the region of the sample that will be imaged directly under the AFM probe.
3. Engage the Z translation stage to bring the probe to the surface.
4. Start the scanning of the probe over the surface and view the image of the surface on the computer screen.
5. Save the image on a computer disk

Resolution in an atomic force microscope

Traditional microscopes have only one measure of resolution; the resolution in the plane of an image. An atomic force microscope has two measures of resolution; the plane of the measurement and in the direction perpendicular to the surface.

In Plane Resolution: The in-plane resolution depends on the geometry of the probe that is used for scanning. In general, the sharper the probe the higher the resolution of the AFM image. In the figure below is the theoretical line scan of two spheres that are measured with a sharp probe and a dull probe.

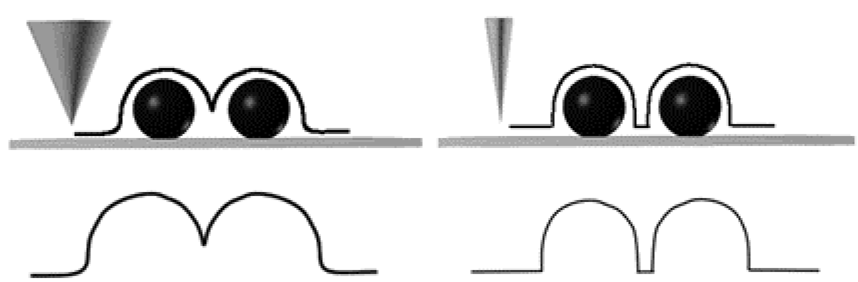


Figure 1.2.f.: The image on the right will have a higher resolution because the probe used for the measurement is much sharper.

Vertical Resolution: The vertical resolution in an AFM is established by relative vibrations of the probe above the surface. Sources for vibrations are acoustic noise, floor vibrations, and thermal vibrations. Getting the maximum vertical resolution requires minimizing the vibrations of the instrument.

Probe Surface Interactions

The strongest forces between the probe and surface are mechanical, which are the forces that occur when the atoms on the probe physically interact with the atoms on a surface. However, other forces between the probe and surface can have an impact on an AFM image. These other forces include surface contamination, electrostatic forces, and surface material properties.

Surface contamination: In ambient air all surfaces are covered with a very thin layer, < 50 nm, of contamination. This contamination can be comprised of water and hydrocarbons and depends on the environment the microscope is located in. When the AFM probe comes into contact with the surface contamination, capillary forces can pull the probe towards the surface.

Electrostatic forces: Insulating surfaces can store charges on their surface. These charges can interact with charges on the AFM probe or cantilever. Such forces can be so strong that they "bend" the cantilever when scanning a surface.

Surface material properties: Heterogeneous surfaces can have regions of different hardness and friction. As the probe is scanned across a surface, the interaction of the probe with the surface can change when moving from one region to another. Such changes in forces can give a "contrast" that is useful for differentiating between materials on a heterogeneous surface.

Topography Modes

When scanning a sample with an AFM a constant force is applied to the surface by the probe at the end of a cantilever. Measuring the force with the cantilever in the AFM is achieved by two methods. In the first method the deflection of the cantilever is directly measured. In the second method, the cantilever is vibrated and changes in the vibration properties are measured.

Deflection Mode

Using the feedback control in the AFM, it is possible to scan a sample with a fixed cantilever deflection. Because the deflection of the cantilever is directly proportional to the force on the surface, a constant force is applied to the surface during a scan. This scanning mode is often called "contact" mode. However, because the forces of the probe on the surface are often less than a nanonewton, the probe is minimally touching the surface.

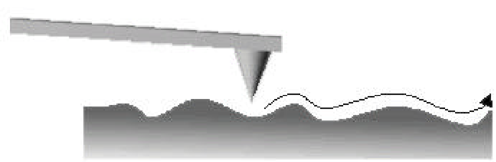


Figure 1.2.g. : In contact mode AFM the probe directly follows the topography of the surface as it is scanned. The force of the probe is kept constant while an image is measured.

Vibrating Mode

The cantilever in an AFM can be vibrated using a piezoelectric ceramic. When the vibrating cantilever comes close to a surface, the amplitude and phase of the vibrating cantilever may change. Changes in the vibration amplitude or phase are easily measured and the changes can be related to the force on the surface. This technique has many names including non-contact mode, and intermittent contact mode. It is important that the tip not "tap" the surface because the probe may be broken or the sample may be damaged.

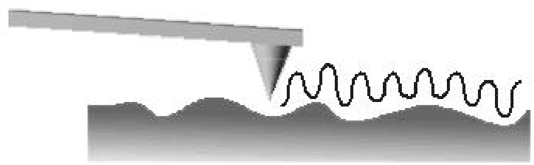


Figure 1.2.h. : In vibrating methods, changes in probes vibrations are monitored to establish the force of the probe onto the surface. The feedback unit is used to keep the vibrating amplitude or phase constant.

Material Sensing Modes

The interaction of the probe with the surface depends on the chemical and physical properties of the surface. It is possible to measure the interactions and thus "sense" the materials at a sample's surface.

Vibrating Material Sensing Mode

The AFM cantilever may be vibrated to measure the force between a probe and surface during an AFM scan. The magnitude of amplitude damping and the amount of phase change of the cantilever depends on the surface chemical composition and the physical properties of the surface. Thus, on an inhomogeneous sample, contrast can be observed between regions of varying mechanical or chemical composition. Typically, in the vibrating material sensing mode, if the amplitude is fixed by the feedback unit, then the contrast of the material is observed by measuring phase changes. This technique has many names including phase mode, phase detection and force modulated microscopy.

Torsion Modes

In contact mode AFM it is possible to monitor the torsion motions of the cantilever as it is scanned across a surface.

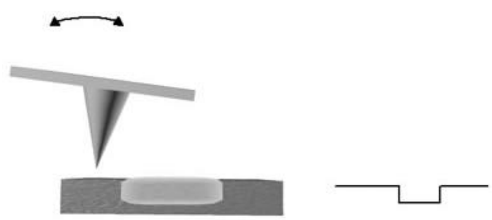


Figure 1.2.i. : Torsions of the cantilever are measured in the AFM. Changes in the torsion of the cantilever are an indication of changes in the surface chemical composition.

The amount of torsion of the cantilever is controlled by changes in topography as well as changes in surface chemical properties. If a surface is perfectly flat but has an interface between two different materials, it is often possible to image the change in material properties on a surface. This technique is similar to lateral force microscopy (LFM).

Chapter
2

Getting Started

2.1 Description of the Nano-R™ AFM

The Nano-R™ AFM is a high performance tabletop microscope system that is intended for research, development and process control applications. Figure 2.1. is a block diagram of the Nano-R™ AFM showing the main components.

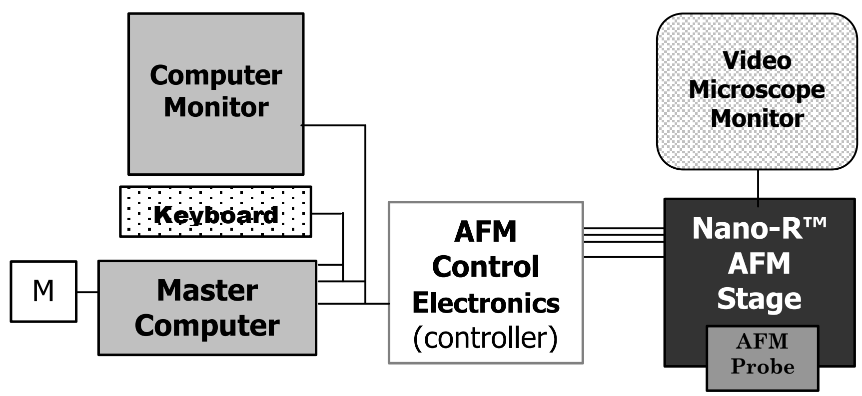


Figure 2.1.

Master Computer/ Monitor – The IBM PC type computer is the virtual interface to the Nano-R™ AFM stage. Software programs resident on the computers hard disk drive are used for measuring AFM images as well as the visualization and analysis of AFM images.

Video Monitor – A video monitor displays the optical microscope image of the probe and of the sample. In some cases the computer monitor may be used as the video monitor.

Controller – The controller has most of the electronics that are required for operating the Nano-R™ AFM stage. It is connected to the Master Computer with a standard Ethernet cable. 5 Cables are used for the connection between the controller and Nano-R™ stage.

Stage Track Ball – A track ball is available for activating many of the Nano-R™ stage features. These features include the video Microscope Zoom/Focus as well is the automated X-Y positioning stage.

Nano-R™ Stage – The Nano-R™ stage includes the sample stage, video optical microscope, and the AFM Scanner. Also included in the stage are the modules for the AFM Scanner calibration sensors.

2.1.1. NANO-R™ STAGE

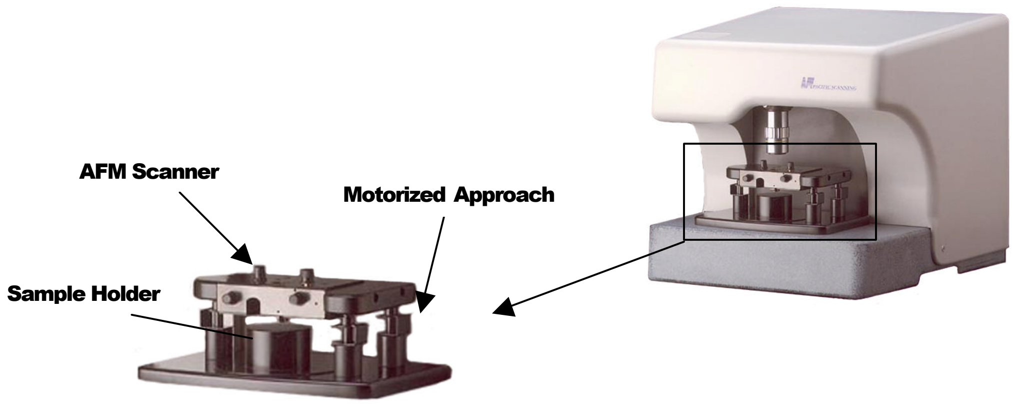


Figure 2.1.a

The Nano-R™ AFM stage includes a motorized zoom/focus video microscope, an AFM scanner, three motors for moving the probe towards the sample, a sample puck and a motorized X-Y positioning stage. At the rear of the Nano-R™ stage there are five cables that are connected to the stage controller. The sample puck (holder) is easily removed from the stage. Sample holders for specialized applications can be easily designed.

2.1.2. NANO-R™ AFM SCANNER

The Nano-R™ AFM scanner uses a light lever design. A red laser is focused on the back of a cantilever and is then projected onto a four section photodiode. There are two adjustment knobs to position the laser light on the backside of the cantilever, and there are two knobs for moving the photodetector into the light path.

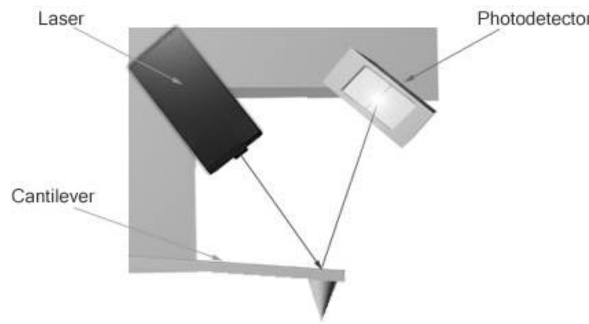


Figure 2.1.b

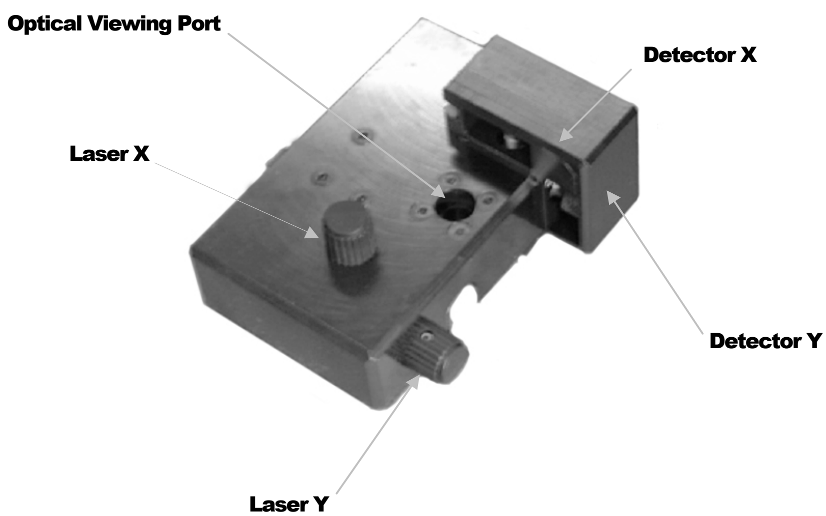


Figure 2.1.c

2.1.3 NANO- R AFM PROBES

There are two basic types of probes for the Nano-R™ AFM; contact mode probes and close contact mode probes.

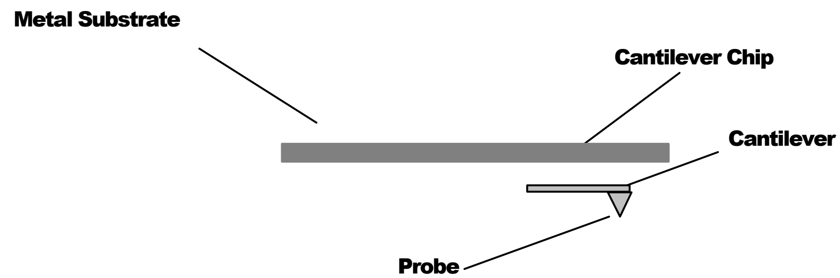


Figure 2.1.d.

The cantilever is held in the AFM scanner with a metal substrate that is magnetically coupled to the bottom of the scanner.

2.1.4. NANO- R SOFTWARE

There are several software modules available for acquiring AFM images and for the display and the analysis of AFM images. Figure 2.1.c. shows a top level block diagram of the Nano-R™ AFM software.

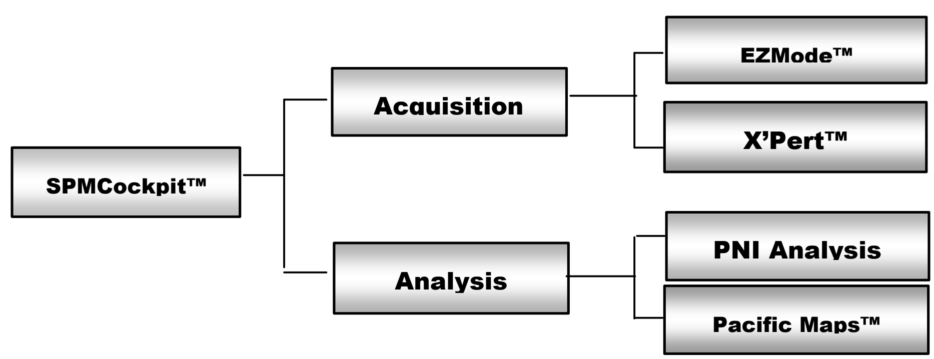


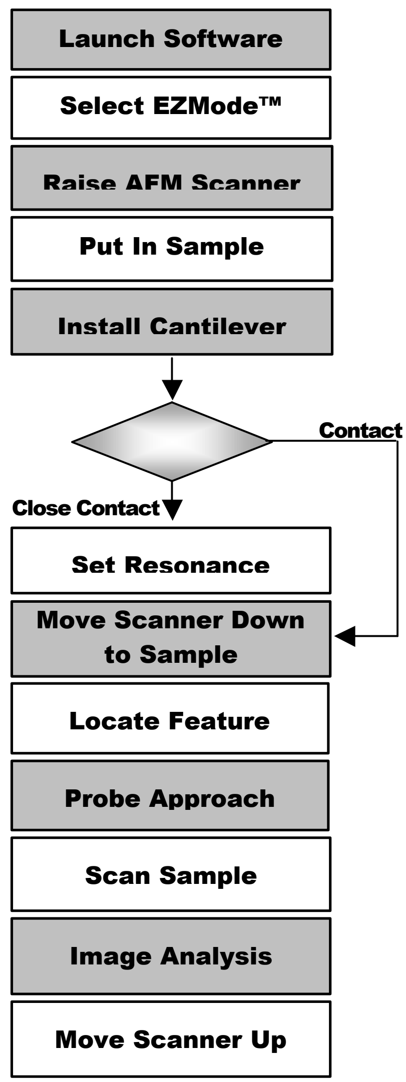
Figure 2.1.e

The two acquisition modules are EZMode™ and X'Pert™ software. EZMode™ is useful for people that use the AFM only occasionally and the X'Pert™ software is used by advanced users with substantial experience with an AFM.

Image Analysis software modules are the PNI software and the Pacific Map™ software. The PNI software is included with all Nano-R™ AFM systems and Pacific Map™ software is offered as an option for the Nano-R™ AFM.

2.2. Measuring an Image in 12 Steps or Less

Measuring AFM images with the Nano-R™ is greatly facilitated with the EZMode™ software. EZMode™ software is ideal for learning the basic operation of the Nano-R™ AFM. The following flow chart gives the step required for measuring and analyzing an AFM image of a silicon test pattern.



Measuring an Image in 12 Steps	
Step 1:	Launch SPM Cockpit Software
Step 2:	Click Mode then EZMode™
Step 3:	Raise the AFM Head
Step 4:	Put in Sample
Step 5:	Install Align Cantilever
Step 6:	Set Resonance (only for Close Contact)
Step 7:	Move Probe to Sample
Step 8:	Locate feature for imaging
Step 9:	Probe Approach
Step 10:	Scan
Step 11:	Analysis of Image
Step 12:	Move Probe away from Sample

Chapter
3

Software Manual

3.1. Acquisition Software

There are four main screens in the Nano-R™ software package. They are:

- Acquisition – EZMode™
- Acquisition – X'Pert™ Software
- Analysis – PNI
- Analysis – Pacific Map™

To Access the Acquisition Software:

Click on the Pacific Map™ Software - *A description is found in Appendix C*

3.1.1. ACQUISITION EZMODE™

EZMode™ software is ideal for beginners that want to learn to use the Nano-R™ AFM and for those that use the AFM system on an occasional basis.

To Access:

- Click on SPMCockpit™ Icon on Windows Desktop
- Click on modes
- Click on EZMode™

Measuring an image with EZMode™ software is achieved by following the steps on the shortcut bar from left to right. The shortcut icons can be opened in sequence or out of sequence.

Figure 3.1.: Screen shot of the EZMode™ Software Interface

Shortcut Icons for EZMode™

At the top of the EZMode™ Screen is a series of actions in the order that is required for measuring and image with the Nano-R™ AFM. Each of the buttons at the top of the page can be activated in any sequence. For example, if during image acquisition it becomes necessary to check the laser alignment, it is possible to click on the align laser button. A description of each option in the EZMode™ Icon Bar software follows.

The "linearize/calibrate" window is used for testing the system to see if it is calibrated in the X-Y axis.

An imaging mode is selected in this window. The two primary modes are contact and close contact mode. Other modes such as lateral force may be selected here.

The align laser window is used for assuring that the laser light is projected from the back of the cantilever onto the photodetector.

If close contact mode is selected, this window shows the resonance peak of the cantilever. Also, the feedback setpoint is selected here.

After the probe is in the AFM head and is aligned the "tip approach" button is used for moving the probe to the sample.

This window displays the image as it is measured and allows changes to the feedback parameters, scan rates, and scan range.

Images can be displayed and analyzed by selecting this button.

3.1.2. ACQUISITION X'PERT™ SOFTWARE

To Access:

- Launch SPMCockpit™ Software
- Click on mode in the toolbar
- Click on X'Pert™ mode

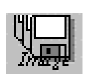
Figure 3.1.a.: Screen shot of the X'Pert™ Mode Software Interface

Shortcut Icons for X'Pert™™ Mode Software

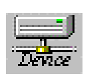
After the Nano-R™ AFM system is started, fifteen short-cut icons appear under the top pull-down menu. Most of the icons are used frequently during imaging. The following definitions and functions are explained below.

Open Configuration File – Will open a configuration file in the "Program Files\MISeries2000\ConfigFiles" directory. A configuration file contains appropriate parameters, including the scanner's calibration and initial operation parameters, in Settings.

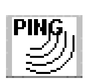
Save Configuration File (File -> Save Configuration As) – To save new parameters or settings.



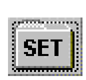
Save Image (File -> Save Image(s) -> Save Image(s) in digital Surf format) – To save image(s) in digital surf file format.



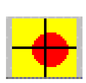
Device Directory (Device -> Directory Setup) – To select the device directory (e.g. C:\Pscan2) created in Section 3.3.



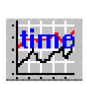
Ping (Device -> Ping) – To test whether a controller is on network or not.



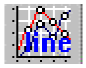
Settings (Settings) – To activate the Settings folders. Items in Settings will be briefly explained in the next subsection.



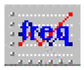
Red Dot (Tools -> Red Dot Alignment) – To show the position of the laser spot on the detector.



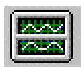
Time Mode (Oscilloscope, time) – To display a selected input signal as a function of time. Up to four windows can be displayed simultaneously.



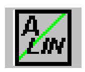
Line Mode (Tools -> Oscilloscope, line mode) – To display a selected input signal for a scan line. Up to four windows can be displayed simultaneously.



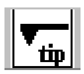
Frequency Sweep (Tools -> Oscilloscope, frequency sweep) – For oscillating mode only. To find the resonance frequency of a cantilever, and to select the right driving frequency and amplitude.



Dual-Trace Scope (Tools -> Dual-trace Storage Scope) – Similar to Time Mode. It displays two input signals at the same time.



Auto Linearization (Tools -> Automatic Linearizer Range) – To map the maximum scan area to a linear range of the X and Y sensors.



Tip Approach (Tools -> Tip Approach / Retract) – Engage or withdraw the tip. The parameters in Tip Approach / Retract window should not be changed by new users.

Scan Control (Tools -> Scan Control Panel) – Start or stop scans.

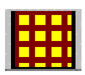


Image Display (Tools -> Display Scanned Image) – To display a selected input image signal.

Settings

Laser/Motors – Stepper functions for the motor and ON/OFF switch for the laser. Fwd: moving the tip towards the sample. Stepper motor is used quite often to bring the tip really engaged right after the stepper motor stops by automatic approach.

Scan Image Setup – To set up common scan controls, such as pixel resolution, scan rate, number of input channels to be displayed, rotation angle, and image acquisition direction. Overscan is the number of pixels scanned before acquisition starts for each line. Prescan is the number of lines scanned before acquisition starts for each image. Skew (pre-set at factory) corrects non-orthogonal angle of the X and Y scanners.

Input Selects to ADC – To specify the type of input signals to be displayed. Z Sensor's Gain and Offset are pre-set at factory.

Frequency Synthesis – Showing the driving frequency and amplitude in oscillating mode.

X-Y Control – Showing the X/Y offset and zoom size. Proportional and Integral gains in X Feedback and Y Feedback are pre-set at factory. These are for the X and Y sensors in the closed X-Y loop.

XYZ Scales – X, Y, and Z calibration factors, pre-set at factory.

Z feedback – To adjust gains and set-point while scanning to improve the image. Initial gains are provided in the configuration files. Input Polarity and Set-point Polarity are positive for contact mode and negative for oscillating mode. Demodulator Mode is at BYPASS for contact mode and DEMOD for oscillating mode. These settings are all in the configuration files.

Nonlinearity, XY – Mainly used to correct the second order nonlinearity of the X and Y sensors. Only "On-line correction (Acquire image)" is used. The numbers are pre-set at factory.

3.2. Analysis Software

3.2.1. PNI IMAGE ANALYSIS SOFTWARE

There are several "shortcut" icons at the top of the SPMCockpit™ image analysis software the icons as well as a description of the icon functions are listed below.

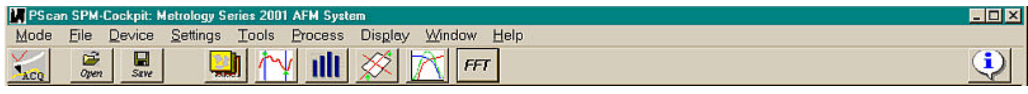
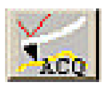


Figure 3.2.: SPMCockpit™ image analysis software interface.

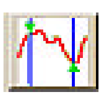


The acquisition icon is used for changing to the image acquisition window in the SPM cockpit software. After choosing the acquisition icon either EZMode™ or X'Pert™ software may be selected.

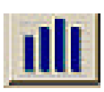
With the "open" icon an image is loaded from a source such as a floppy disk or a hard disk. Images must be stored in the SPMCockpit™ format to be opened with this icon.

Images are saved with the "save" icon. Saved images may be retrieved at a later time with the "open" icon.

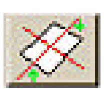
Using the "select image" icon retrieved an image from the most recently stored source; either a hard disk drive or an image in the image buffer used for image acquisition.



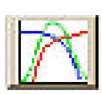
The line profile icon enables a window that facilitates the measurement of distances and surface roughness on many types of line profiles. The line profiles may be horizontal, vertical, random or circular. Surface roughness parameters include the standard values of Ra and Rs.



Adjusting the range of colors in an image is enabled with the histogram adjustment option. Also, the histogram adjustment option may be used for measuring step heights in images



Plane Correction



Several type of filtering may be applied to images with the image filter window. After filtering the images may be saved with the "save" icon that is located on the toolbar.

Fast Fourier filter of images is possible with the "FFT" option.

3-Dimensional isometric images may be displayed with this option. After displaying this option images may be displayed with light shading from may angles. Also, the color palette of the image may be changed.

Editing and printing images from the PNI analysis software: Images may be captured from the PNI analysis software by using the print screen function on your computer. Once the print screen function is selected, the image window may be pasted into any Microsoft windows compatible program such as Word, or Powerpoint.

3.2.2. PACIFIC MAP™ SOFTWARE

Pacific Map™ software is selected from the X'Pert™ mode software and facilitates complete analysis and display of images.

Chapter 4

Technical Guide

4.1. Nano-R™ Specifications

1.0 Nano-R™ Stage Specifications

1.1 AFM Scanner Head Modes

	DC	Contact Mode Lateral Force Mode
	Vibrating	Close-Contact Mode Non-Contact Mode Material Sensing Mode
	Other	Force/Distance Pulsed Force (optional)
Scanning Method	Tip (cantilever moves over stationery sample)	
X-Y Scan	Range	>80 Microns
	Resolution	<2nm with scan correction
	Linearity	<1% non-rotated <2% rotated
	Zoom	TBD
	Orthogonality	TBD
Z Scan	Range	8 Microns
	Sensor Noise	<0.13 nm with external sensor
	Instrument Noise	<0.05 nm
	Sensor Linearity	<
	Z-XY Orthogonality	<100nm for 80 Micron Scan (<2%)
Probe handling	Cantilevers pre-mounted on steel crescents	
Size, scanner module	1" H, 4" W, 2.5" D (25 mm, 102 mm, 64 mm), with 0.2" (5 mm) extension of scanning probe below	
Optical viewing ports	Top View, 31 mm, from top to tip 45 degree from vertical, 50 degree from face –onto-cantilever	

1.2 X-Y Stage Specifications

Automated X-Y Stage	Range	25.4 x 25.4 mm
	Step Size	<3 microns
	Slew Rate (maximum)	2.5 mm/sec
Sample Holder (Std.)	Sample Size	TBD
	Sample Height	< 1 inch
	Sample Holder	magnetic
Sample Holder (opt.)	Sample Size	

1.3 Color Video Microscope		
Magnification	Standard (5X)	330X
	Optional (10X)	660X
Field of View	Standard	410 X 540 Microns
	Optional	203 X 270 Microns
Resolution	Standard	4 Micron
	Optional	1.5 Micron
Motorized Control	Focus	DC Motor
	Zoom	DC Motor
Manual Control	X-Y Lens Position	1 mm
1.4 Physical Specifications		
Dimensions	Width	14 Inch
	Length	14 Inch
	Height	12 Inch
	Weight	55 Lbs.
2.0 Software Specifications		
2.1 Expert Mode	Pixels	64x64, 128x128, 256x256, 512x512, 1024x1024
	Image Rotation	0, 90, 180, 270, and any arbitrary angle
	Acq. Direction	Forward, Reverse, Forward & Reverse
	Channels	1 to 4 Channels (Selected from Z Sensor, Lateral Force, Z Voltage....)
2.2 Typical Mode		
2.3 Standard Analysis	3D Display	
	Line Analysis	
	Light Shade	
	Top View	
	Filter	
2.4 Software Platforms	Master Computer	Visual Basic, operating under Windows 95/98/NT/XP
		C++ based, operating under MS-DOS
		Linked to Master by DCEx Protocol via Ethernet
3.0 Master Computer Specifications		
3.1 Processing		Pentium III
		800 Mhrz
		40 Gbits Hard Drive
3.2 Connectivity		USB
		Ethernet
		Serial
		Parallel
4.0 Control Electronic Specifications		
4.1 Basic A/D Conversion	Conversion range	10 V to + 10 V, or 0 to + 10 V
	Resolution:	16 bits
	Number of Input Channels	1 to 4
	Sampling rate:	- g.t. 20 kHz @ 1, 2, or 3 channel acquisition - g.t. 16 kHz @ 4 channel acquisition
	Freq. Response before Demod:	DC to 500 kHz, nominal
	Freq. Response, Z-PID loop:	DC to 20 kHz

4.2 Z-feedback Loop

Digitally controlled analog

Internal:

- 4 Inputs for 4-sector Photodetector
- Tuning-fork Sensor

External:

- For other AFM sensors and STM sensing
- Range: -10 V to +10 V
- Differential, buffered input

Z-height sensor:

- Provision for a sensor, absolute Z-piezo motion (e.g. strain gauge) to be incorporated - into a z feedback loop for absolute Z positioning
- Differential, buffered input
- Range: 0 to 10 V

4.3 Demodulator:

Type	Balanced Demodulator
Frequency range:	50 kHz – 500kHz
Demodulated bandwidth:	DC – 20 kHz
Input gain range:	1x, 2x, 3x, or 4x

4.4 Modulator:

Output Waveform	Sinusoidal, digitally synthesized
Frequency Range:	50 to 500 kHz
Frequency Resolution:	<0.01 Hz
Output Voltage Range:	0 to +/- 10 V, peak to peak
Output Voltage Resolution	10-bits (10mV)
Output Connections:	Two options, capacitive coupled to: 1) Z-piezo driver via ext resistor 2) to an independent piezo driver

4.5 Output Amplifiers:

Z Driver (output from PID loop):

- Driver output voltage range: 0 to +140 V
- Frequency range: DC to 20 kHz
- Noise:@ Ground: 3 mV, rms, nominal
  @ External + 5 VDC 3 mV, rms, nominal
- Instantaneous max. output current: 500 mA , min.
- Average continuous output current: 50 mA (power supply limited)
- Power Rating of output amplifier: 85 Watts

X & Y Scan Drivers:

- Driver output voltage range: 0 V to +140 V
- Frequency range: DC to 20 Hz min.
- Noise:@ Ground: 3 mV, rms, nominal
  @ External + 5 VDC: 3 mV, rms, nominal
- Instantaneous max. output current: 500 mA , min., per axis
- Average continuous output current: 50 mA per axis (power supply limited)
- Power Rating of output amplifier: 85 Watts

4.6 Accessory Functions:

Auxiliary Analog I/O	**Input**	**Output**
Number:	2, differential, buffered	2
Signal range:	-10V to + 10V	0 to +10 or 0 to –10 V
Resolution:	1.2 mV	2.4 mV
Update rate:	16 kHz min.	10 kHz min.

DC Motor Driver

Use:	Operate probe approach motor	
	Output voltage range:	-5 to + 5 VDC, 8 bit resolution
	Output current:	150 mA max.

Stepping Motor Drivers

Use:	Operate for probe approach, and coarse X, Y, & Z motions	
	Number on controller	6 each
	Operating voltage:	12 VDC, maximum
	Current rating:	0.50 A, maximum
	Software functions:	enable reduced current, set direction step
	Options:	Chip-bypass for larger external stepper drivers 6-bit port for additional steppers or other use

Other features:

Digital Flags:	Output:	- FLGSS	- Start Scan indicator
	Output:	- PIXCLK	- X & Y increment indicator
	Output:	- FLGPT	- Set/clear bit to flag a data point
	Input:	- EXTSS	- External start scan

16-bit Digital I/O bus @ 10 KHz min. update

4.7 Signal Access Console Option:

External flat cable & BNC-type connector box to monitor more than 25 incoming, outgoing and internal signals and connections for Digital Flags.

4.8 Physical Specifications

Size	15" H, 13" W, 17" D (38.1 cm, 33.0 cm, 43.2 cm)
Weight:	35 lbs (16 kg)

4.9 Operating Specifications

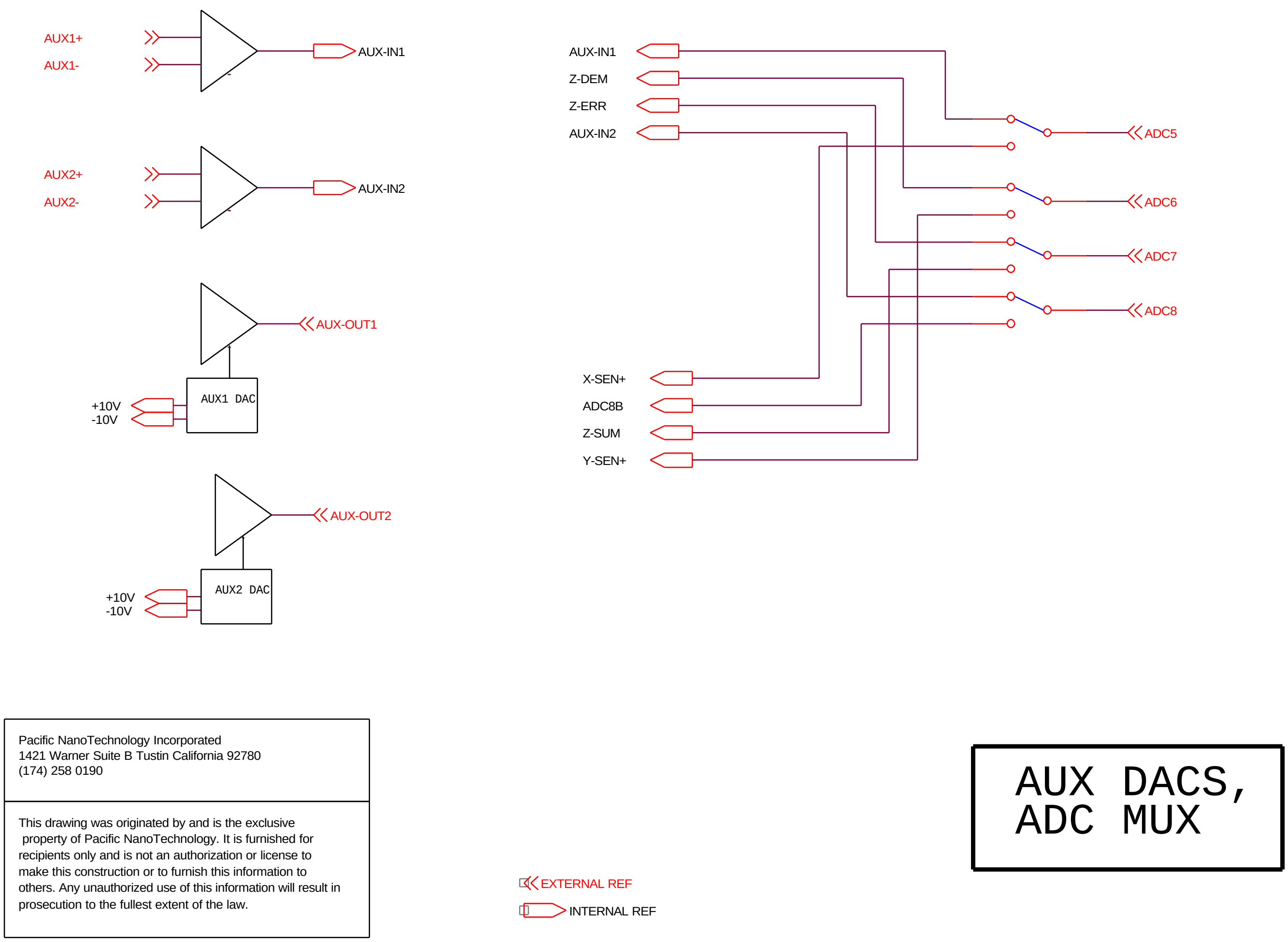
Voltage	115/230 VAC, 50/60 Hz
Current:	0.95/0.45 Amp
Temperature:	50 – 95 deg. F (10 – 35 C)
Humidity:	5 – 60% RH

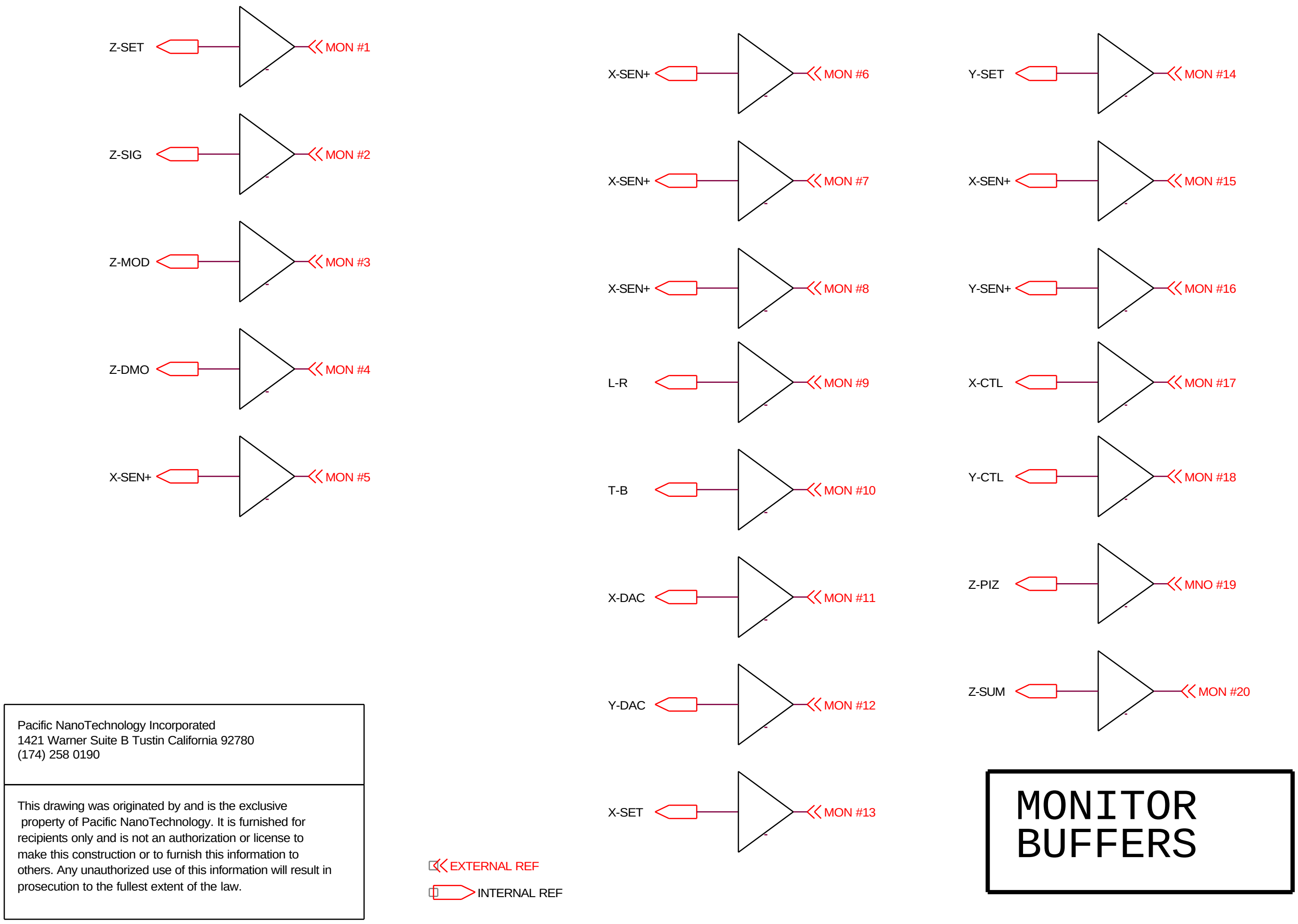
4.10 Safety Europe CE Certification

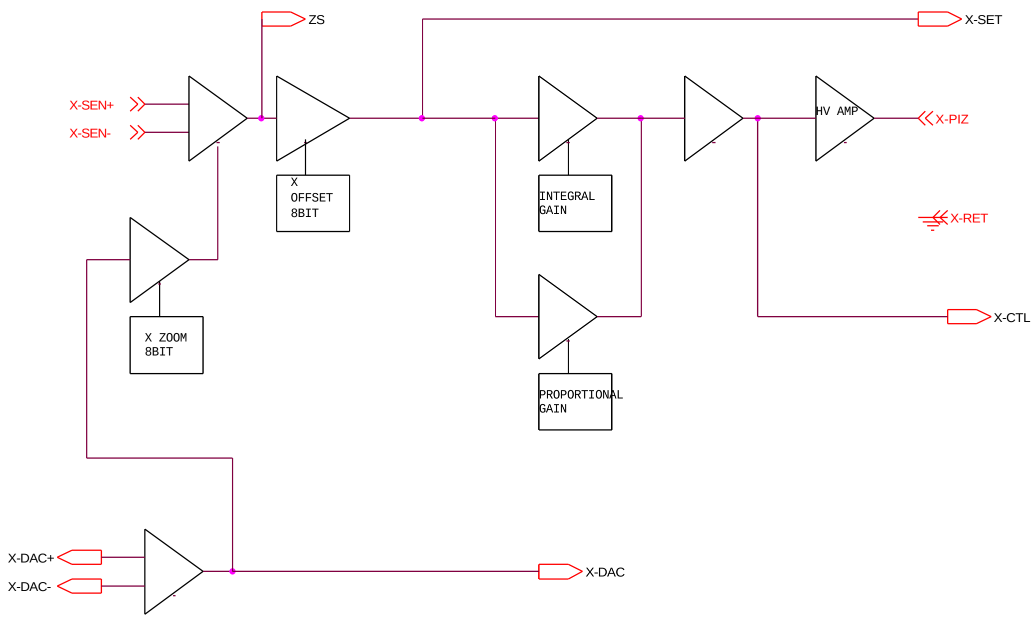
4.11 Control Computer Specifications

Processing:	PC-based, 266 MHz or greater 32 Mbyte RAM 3.2 Gbyte Hard Disk Drive 1.44 Mbyte Floppy Drive SVGA video card (for diagnostics)
Connecting:	AC Power Ethernet (10/100 Mbit/sec) Scanner/Stage, Input/Output lines Linearizer Inputs (X, Y, & Z) Stepper Motor Port Signal Access Port

4.2. Data Station Block Diagrams




Z-SET
MON #1
Z-SIG
MON #2
Z-MOD
MON #3
Z-DMO
MON #4
X-SEN+
MON #5
X-SEN+
MON #6
X-SEN+
MON #7
X-SEN+
MON #8
L-R
MON #9
T-B
MON #10
X-DAC
MON #11
Y-DAC
MON #12
X-SET
MON #13
Y-SET
MON #14
X-SEN+
MON #15
Y-SEN+
MON #16
X-CTL
MON #17
Y-CTL
MON #18
Z-PIZ
MNO #19
Z-SUM
MON #20
Pacific NanoTechnology Incorporated
1421 Warner Suite B Tustin California 92780
(174) 258 0190
This drawing was originated by and is the exclusive property of Pacific NanoTechnology. It is furnished for recipients only and is not an authorization or license to make this construction or to furnish this information to others. Any unauthorized use of this information will result in prosecution to the fullest extent of the law.
EXTERNAL REF
INTERNAL REF
MONITOR
BUFFERS



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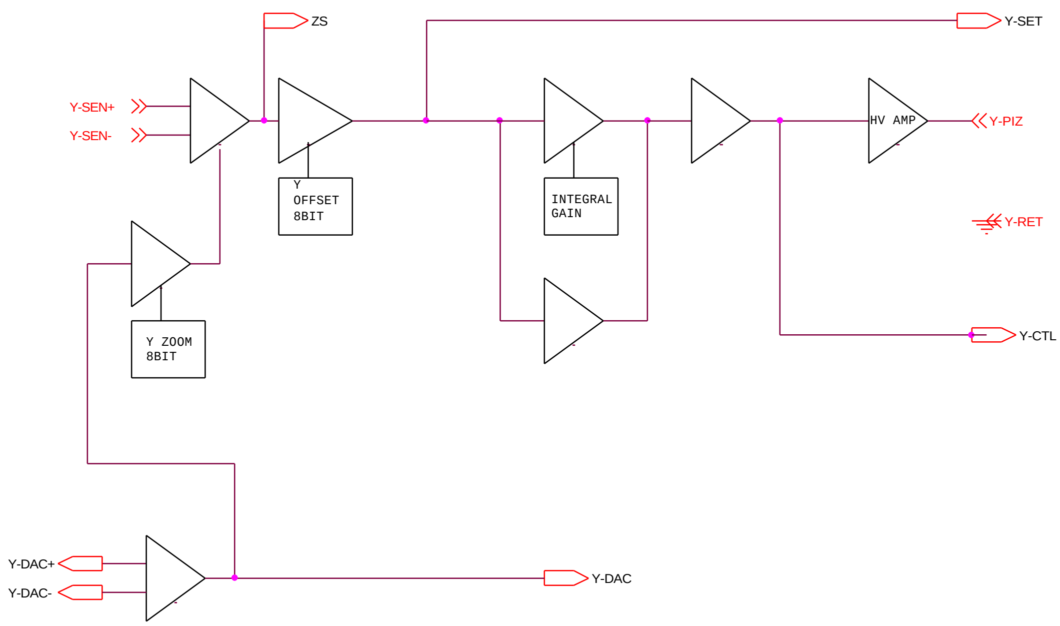
EXTERNAL REF
INTERNAL REF

X DAC & AMP



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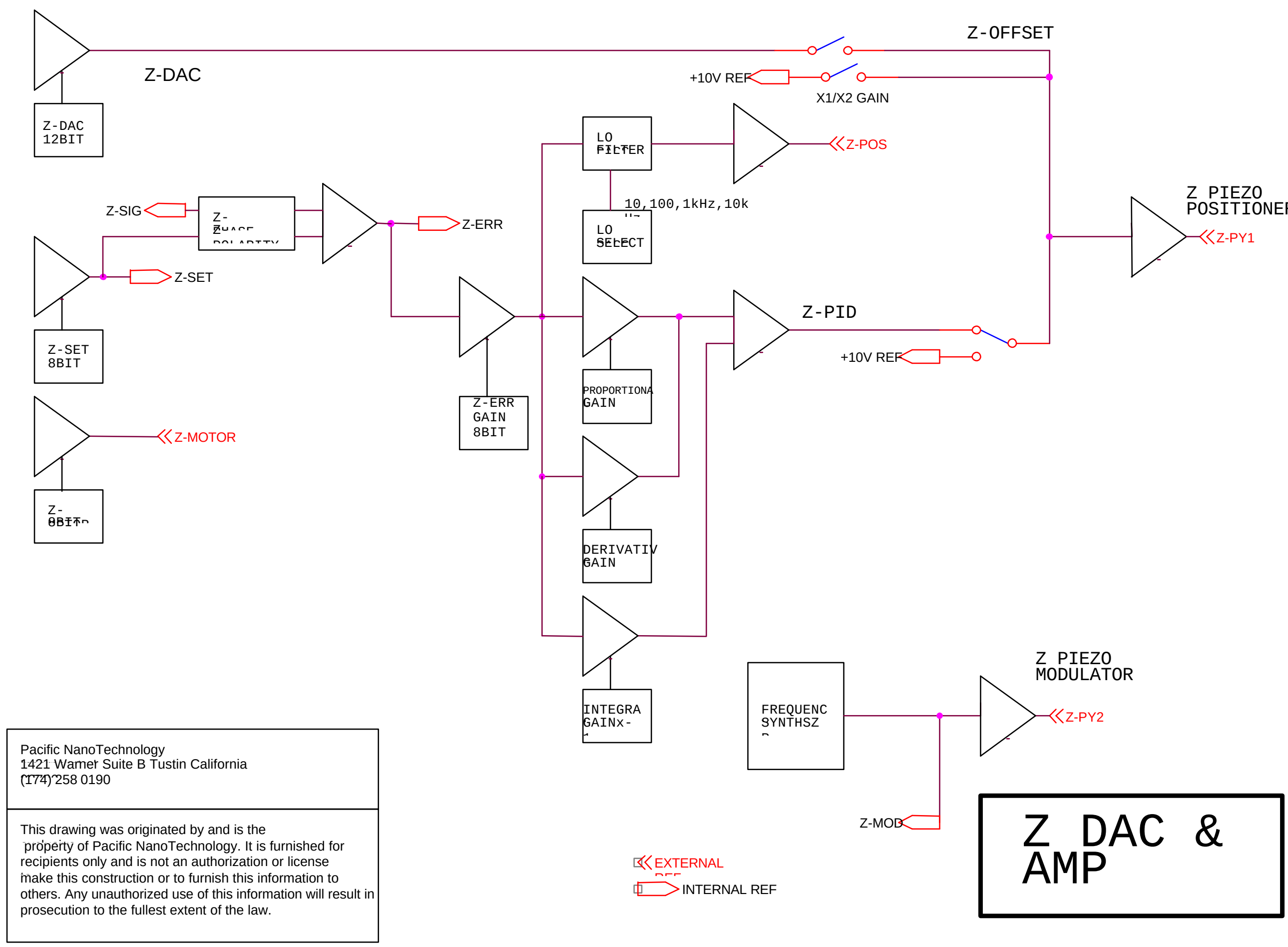
1421 Warner Suite B Tustin California 92780
(174) 258 0190

EXTERNAL REF
INTERNAL REF

Y DAC & AMP


Z-DAC
Z-DAC 12BIT
Z-OFFSET
+10V REF
X1/X2 GAIN
LO FILTER
Z-POS
10,100,1kHz,10k
LO SELECT
Z-SIG
Z-ERR
Z-SET
Z-SET 8BIT
Z-MOTOR
Z-ERR GAIN 8BIT
PROPORTIONA GAIN
DERIVATIV GAIN
INTEGRA GAINx-
Z-PID
+10V REF
Z PIEZO POSITIONER
Z-PY1
Z PIEZO MODULATOR
Z-PY2
FREQUENC SYNTHSZ
Z-MOD
EXTERNAL
INTERNAL REF
Z DAC & AMP
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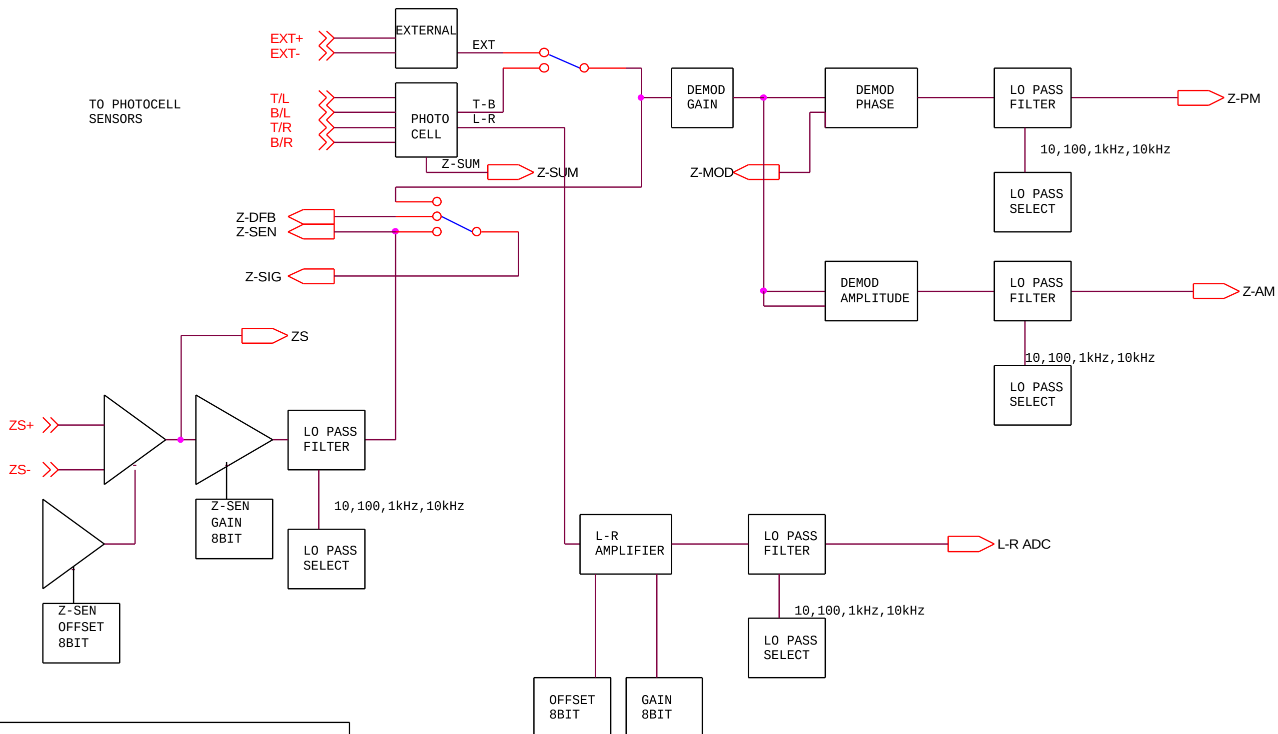

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EXTERNAL REF
INTERNAL REF

Z SIGNAL PROCESSING

4.3. Windows XP Network Setup

SETTING UP PNT PSCAN2001 COCKPIT FOR WINDOWS XP

Introduction: This procedure will set up your system and install Cockpit.

These are the steps to preparing the computer, setting up XP for networking, and installing and configuring Cockpit.

i. Setting up User

A. A special user account needs to be set up on the computer. Click on the Start menu, click on Control Panel, click on User Accounts, click on Create a New Account.

B. Enter "PSCAN2" in capital letters, as the name for the account. Click Next. Select Computer administrator as the account type. Click Create Account.

C. You will now see the new account in the User Accounts menu. Click on the account. You will see a different menu with choices for this account. Click on Select Password.

D. Type in a password for the account. Note that you must use this same password later in the Cockpit software configuration, so make a note of it. Click the create password button. You should now see the PSCAN2 user icon, with Computer administrator and Password protected beside it.

ii. Setting up networking

A. Insert a Windows XP disk or a Windows XP Recovery disk. XP will open a window asking what to do when you insert CD's, select Open Files with Windows Explorer.

B. You should see folders, select VALUEADD, then MSFT, then NET, then NETBEUI. You should see three files, NBF.SYS, NETNBF.INF, NETBEUI.TXT. Copy NBF.SYS and NETNBF.INF to the C:\WINDOWS\SYSTEM32\DRIVERS.

C. This next step is required to see a hidden directory, C:\WINDOWS\INF. While still in Windows Explorer, click on Tools, click on Folder Options, click on View, and locate Hidden Files and Folders. Click on Show Hidden Files and Folders. Click OK. Now, copy NETNBF.INF to C:\WINDOWS\INF. Exit Windows Explorer.

D. Click on Start, click on Control Panel, click on Network and Internet Connections, click on Network Connections, double click on Local Area Connection, click on Properties. Looking at the General menu, click on Install, select Protocol and click on Add to see list of protocols. Select NETBEUI protocol and click OK. Restart computer at the request.

E. After restarting, go back to the Properties menu to verify you now see NetBEUI protocol in the list for the network card.

iii. Installing the software (updated for 1-30-02 version)

A. Insert CD, open setupCD dir, locate and run Setup.

B. Accept default choice for Program Group.

B. After the install finishes, close file folder, click on Start menu, click on All Programs, you should see an directory for Pscan SPM-Cockpit 2001 AFM System, click on it, then click on the icon for Cockpit, to start program.

C. Open the Device menu, select Create Device Directory. You should see a default of C:\Pscan\PScan2001\DemoDevice. Change to C:\Pscan\PScan2001\PScan238.

D. A box asking you to share the directory before use appears, click yes. There will be a response that sharing is successful, clear the box. <note: due to a bug, it will NOT have shared the directory at this point, despite the statement, and will need the following steps > Go to Start menu and right click on it to open the smaller menu, click on Explore, find the C:\Pscan\PScan2001\PScan238 directory you created and right click on it, click on Sharing and Security. You should be in a properties menu with a couple of choices, in Network Sharing and Security, you will see the Share this Folder on the Network and the Allow Network Users to Change my Files boxes checked. Uncheck Share this Folder on the Network, click Apply, recheck the box, and click Apply again. Click OK to exit, your directory is now shared.

E. A box asking to switch to the directory now appears, click yes. The software will detect a missing file in your newly created directory, (slave.ini) click yes and select slave.ini, to put a copy into it.

F. Click on the Device menu, click on Directory Setup, you should see your C:\Pscan\PScan2001\PScan238 directory selected as the default, click OK.

G. Return again to the Device menu, click on Create Configuration Diskette, verify that the computer name and the device directory share name, are correct, then enter the same password from the

PSCAN2 user account that you created earlier. These two passwords MUST be the same.

H. At the prompt, insert an empty 3.5" floppy disk into the computer's floppy drive. Click OK. A small setup file is written on the floppy.

I. At the prompt, remove the floppy, insert it into the Controller's floppy drive, disconnect the Ethernet cable from the Controller, and reboot (power off and on) the Controller. Removing the Ethernet cable causes the Controller to read the floppy rather than trying to make a connection to the Cockpit PC.

J. The Controller will reboot, and if it successfully reads the floppy, there will be four beeps. Now, remove the floppy, turn off the Controller, reconnect the Ethernet cable, and turn on the Controller.

K. A dual tone indicates a successful configuration, (a single tone indicates an unsuccessful one.) You should see Device Initialized in the bottom bar of the Cockpit window, and the "traffic signal" indicator should have turned from red to green.

Chapter 5

How To Guide

5.1. Exchange Probes

Probes in the Nano-R™ are mounted on a metal substrate that is magnetically mounted to the bottom of the AFM scanner. The probe and metal substrate are removed with tweezers.

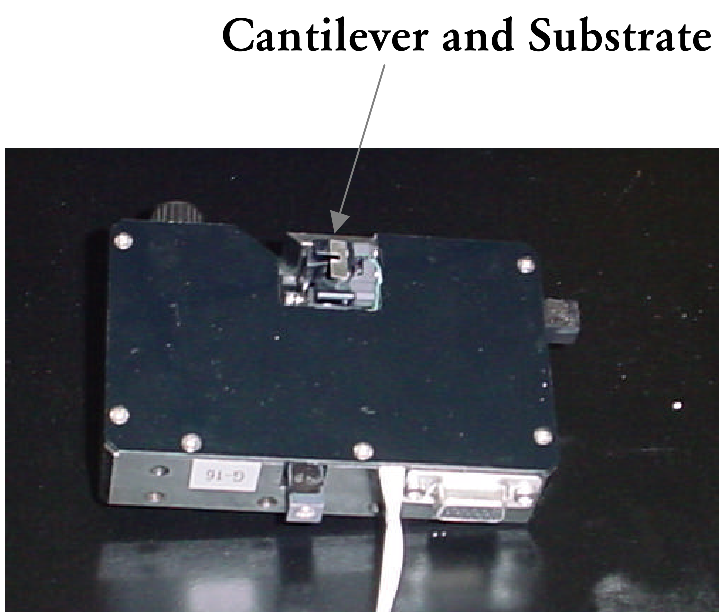


Figure 5.1.

5.2. Operating the Track Ball

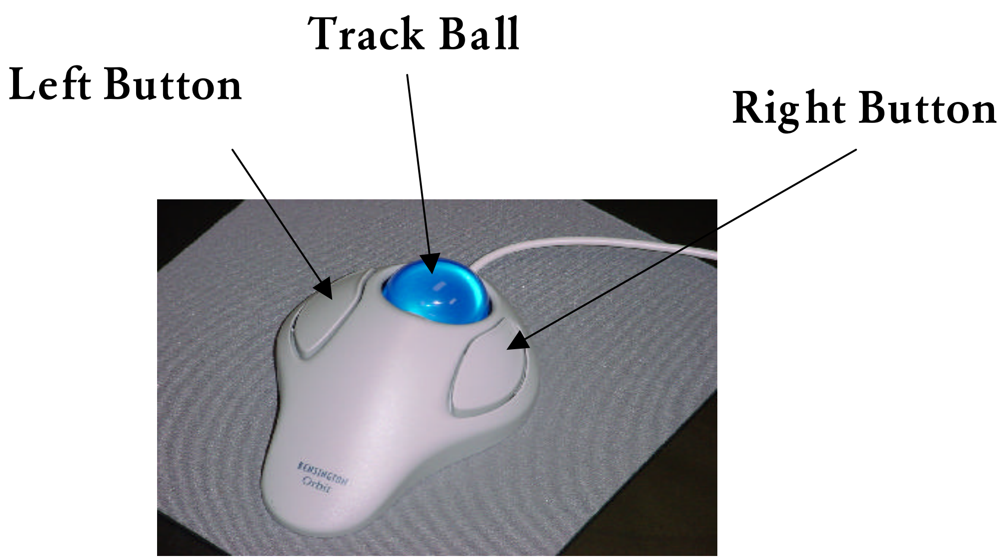


Figure 5.2.

	Left Button	Right Button	Track Ball
Move X-Y Stage	off	off	Active
Move Z Stage	off	on	Active
Focus	on	on	Active
Zoom	on	on	Active

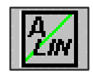
The "Track Ball" active icon must be activated in the Nano-R™ stage window to use the track ball for moving the stage.

5.3. Measuring an image with X'Pert™ Software

5.3.1. CONTACT MODE

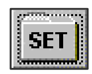
1. Click on Open Configuration File icon. 

    ➔ Select the contact mode configuration file, for example, g5-229-CON-991110. This the basic settings for operating a particular scanner and scanning mode.

2. Open "XY Offset and Zoom" window. 

Press A/LIN icon and then, Yes to run auto linearization.

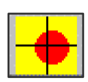
    ➔ The autoline function should be repeated two to three times in order to obtain consistent offset and zoom setting

3. Check a few initial parameters in Settings: 

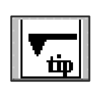
    ➔ In "Scan Image Setup" folder, set Resolution to 256, Scan Rate to 1, Channels to 4.

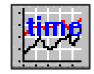
    ➔ In "X-Y Control", set Zoom to 12 (this gives about a 10 μm^2 image).

    ➔ In "Input Selects to ADC", select Channel 1: Z (HGT) (topography), Channel 2: Z(ERR) (deflection), Channel 3: Z (L-R) (friction), and Channel 4: Z (SEN) (height measured by Z sensor) for a 3-axis system with a Z sensor.

4. Press Red Dot icon  and make sure the spot is in the green area, below the horizontal axis.

NOTE: the Z-Set-point value is zero, so that when the cantilever tip contacts the surface, the approach motor will stop when the Z(ERR) is zero (red dot in center).

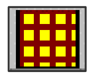
5. Press Tip Approach icon, and engage the tip. 

6. After the stepper motor stops, press Time Mode icon, 

and select Z (HGT) as input.

   ➔ Click on Full to make Y-axis to the full scale (-10 to 10 V). Typically, Z(Hgt) will be at to 10 V after the motor stops, indicating that the tip is in contact and the Z actuator is at or near full extension.

   ➔ Select Laser/Motors in Settings. Stepping down ("Fwd") 30 – 60 pulses should bring Z(HGT) into the center of the Z-actuator range (0 V).

7. Press Image Display icon  twice and select Z (HGT), and Z (ERR) as the inputs for the Display Scanned Image windows. Also, the Scan Line Cuts (click on the Line Mode Icon twice) can be displayed for each input.

8. Press Start on the Scan Control Panel window. This action will provide your first topography, deflection, friction, and Z sensor (3-axis only) images in the contact mode.

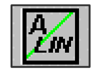
   ➔ The GPID settings may be adjusted to optimize the quality of the topographical image.

9. Press Image Display icon four times, select Z (HGT), Z (ERR), Z (L-R), and Z (SEN) (for 3-axis system) as the inputs of the four Display Scanned Image windows. Press Start on the Scan Control Panel window, and image acquisition will commence, providing topography, deflection, friction, and Z sensor (3-axis only) images in the contact mode.

5.3.2. OSCILLATING MODE

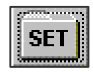
1. Click on Open Configuration File icon. 

Select the configuration file for oscillating mode, for example, g5-229-OSC-991110.

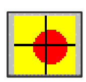
2. Open "XY Offset and Zoom" window. Press A/LIN icon 

and then *Yes* to run auto linearization.

   - ➔ This must be run 2 to 3 times before consistent offset and zoom values are obtained. (This has to be repeated both to warm up the piezo's and because their behavior is somewhat history dependent. Repeat until the X & Y offsets differ by less than 100 mV between successive scans.)

3. Check a few initial parameters in Settings. 

   - ➔ In "Scan Image Setup" folder, set Resolution to 256, Scan Rate to 1, Channels to 4.
   - ➔ In "X-Y Control", set Zoom to 15.
   - ➔ In "Input Selects to ADC", select Channel 1: Z (HGT) (topography), Channel 2: Z(ERR) (amplitude), Channel 3: Z (DEM) (phase), and Channel 4: Z (SEN) for a 3-axis system.
   - ➔ In "Z feedback", set set-point to 0.

4. Press Red Dot icon  and make sure the spot is at the center of the cross. It is more important to have it centered up and down than it is right to left.

5. Press Frequency Sweep icon. 

Make sure Z (ERR) is selected. Type in 250,000 for 'Start', and 350,000 for 'End'. Click on 'Auto' to set the voltage range (Y-axis). For convenience, have the set-point for the initial sweeps is set at 0.

   - ➔ Press Start Sweep. A sharp inverted peak should appear.
   - ➔ To reduce the sweep range, left click on the left side of the peak and drag the mouse to the right side. Release the left mouse and right click on the shadow area. Press 'Yes', and start sweep again.
   - ➔ To select the modulation frequency, double click at a point somewhat to the left of the resonant peak. When queried if these are the values you

want click Yes. [In the "Typical" operating mode, the Autoset button will pick a frequency just to the left of the peak where the amplitude is ~90% of the resonant peak height.

- Adjust the modulation amplitude so that the demodulated signal level (the height of the peak) is about –1100 mV (when the demodulation gain setting, in the Demod selects folder in Settings, is 1x). [The peak height referred to here is also known as the Error Signal amplitude, Z (ERR). This value depends on the size of the oscillation amplitude desired. For example, the Nanosensors cantilevers (100 micron length, 300kHz) have an amplitude sensitivity of 0.12 nm/mV of drive amplitude. At the modulation frequency, the observed amplitude, Z (ERR), is about 1100 mV for a drive amplitude of 1000mV. The oscillation amplitude of the cantilever is about 120 nm.]

- Check the height of the peak. The peak height is adjusted by changing the Z-feedback set-point. Decreasing the set-point lowers the feedback amplitude and increases the amount of intermittent force of the tip contacting the surface.

- Set the set-point Value in "Z feedback" folder to 2/3 of the amplitude at the modulated frequency.

- Between 0.5x and 0.7x of the Error Signal amplitude is considered hard intermittent contact and 0.8x to 0.9x is considered light intermittent contact. **The set-point value is what determines the instantaneous force applied during imaging, and, therefore, greatly affects the quality of the image.** (Also, blunter tips will require more force.)

- Do a '**Z>**' sweep. This varies the force (actually the applied voltage from 0 to 10 V to 0 again) at constant voltage to determine the amplitude of motion. This sweep is performed at the selected modulation frequency (fixed frequency, variable voltage, before it was fixed voltage, variable frequency).

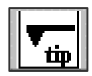
- The height and shape of the peak can be modified somewhat by changing the laser alignment. Also adding a very small amount of glycerol (glycerin) can ensure a good mechanical coupling, which in turn will improve the Z-sweep results.

- The effect of the Z-piezo position on the amplitude can be checked by clicking on the "**Z>**" icon within the frequency sweep window. This function moves the Z-piezo actuator from an extended to retracted and back to extended position. The change in amplitude should be less than

15 %, and at no time should it exceed the zero-crossing of the error signal.

➔ If the Z-sweep variation is too high, it can be improved by adjusting the alignment. The alignment can be further optimized by doing a frequency sweep and selecting a modulation frequency. Then look at the line oscilloscope and adjust the photodiode knobs to minimize the voltage reading. This in turn is maximizing the response amplitude on the frequency sweep and minimizes Z-sweep.

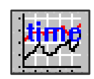
NOTE: also, that the quality and cleanliness of the cantilever's reflective surface greatly affects the Z-sweep variation. Possible problems include the presence of interference fringes of the reflected beam due to a poor reflective coating , and adsorbed chemicals on the surface (often removed by a water rinse and a blow dry with dry nitrogen or a pressurized "air" can).

6. Click on the Tip Approach/Retract icon 

and then engage tip.

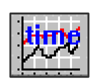
   ➔ Z (ERR) should be chosen in the 'select channel' box.

   ➔ If the error signal crosses the set-point value before the surface is not contacted, the Z-actuator will retract and a high frequency oscillating sound occurs. Click on "tip retract", which will lift the cantilever/tip from the surface and disengage the PID loop. Recheck the alignment and the frequency sweep.

7. After the stepper motor stops, press Time Mode icon, 

and select Z (HGT) as input.

   ➔ Click on 'Full' to make Y-axis to the full scale (-10 to 10 V). Mostly, Z(HGT) is at 10V right after the motor stops, indicating the tip is not really engaged.

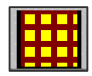
   ➔ Click on the Time Mode Icon 

again and select Z(ERR) as input. Which will

   ➔ Click on Full to make Y-axis to the full scale (-10 to 10 V). Typically, Z(Hgt) will be at 9 to 10 V after the motor stops, indicating that the tip is in contact and the Z actuator is at or near full extension.

   ➔ Select Laser/Motors in Settings. Stepping down ("Fwd") 30 – 60 pulses (30 pulses = 2 microns) should bring Z(HGT) into the center of the Z-actuator range (0 V).

   ➔ By activating the "Incremental" approach, and addition routine is initiated during tip approach, one which will reduce the chances of tip damage. The tip is retracted before the stepper motor is incremented by a small amount (about 3 –5 microns). Then the Z-actuator is incremented, checking several times after each increment for zero-crossing. The stepper/actuator sequence is repeated until the zero-crossing is reached. Then, the GPID feedback loop is turned on. With proper adjustment of the "Advanced" settings, the Z-actuator will be positioned at approximately mid-range, ready for scanning.

8. Press Image Display icon  two times: selecting Z (HGT) and Z (ERR) as the inputs of the four Display Scanned Image windows.

   ➔ Also a Scan Line Cut (hit the Line Mode Icon twice) can be displayed. Set the size of the area to be imaged and pick the image location on the sample. Click on the Display Scanned Image window twice. The new window is titled "X-Y offset and zoom." This window will allow the image size to be changed (via the zoom setting).

9. Press 'Start' on the Scan Control Panel window. Now you are getting your first topography, amplitude, phase, and Z sensor (3-axis only) images in the oscillating mode.

   ➔ Incrementally, increase the GPID settings to improve the quality of the image

   ➔ Save images in digital surf format. The data may be saved with line-by-line leveling, as needed.

   ➔ To change the image size or location: double click on the display scanned image window. The new window is titled 'X-Y offset and zoom.' This window will allow the image size to be changed (via the zoom setting).

   ➔ Before changing the location of the image use the Laser/Motors tabsheet in the Settings window to lift (motor in reverse direction) the tip. Note that you will probably have to change the set-point as in step 7.

   ➔ In the 'X-Y offset and zoom window' the displayed image area may now be moved to the desired location on the sample. Changing the zoom, changes the spatial field-of-view (FOV). As the resolution (in number of pixels) is fixed the spatial resolution is degraded as the FOV is increased.

Appendix A – Installation Procedures

To install the Nano-R™ scanning probe microscope, please follow the procedures listed to establish the site for your instrument before it arrives. It is your responsibility to ensure that the site specifications conform to the guidelines and specifications delineated before the installation.

Site Specifications

Installation Requirements

Needed:

- Fork Lift – to move the shipment from the truck to your loading dock.
- 3 Shelf Utility Carts – to move the shipment from the dock to its destination. (capable of supporting 100 lbs)
- Pallet Truck – (if a vibration table is included)

Location

The scanning probe microscope is designed for use in a standard laboratory environment. Temperature changes can cause the metal parts in the microscope stage to expand and contract and images to drift. The microscope should not be placed near any heat or cold sources or windows that could contribute to temperature changes. Humidity must also be considered as failure is possible if the piezoelectric ceramics are operated while wet or if the humidity is in excess of 60%.

Vibration

The most important consideration in the placement of the instrument is vibration as image noise can cause a substantial decrease in resolution due to disproportionate motion between the probe tip and the sample. The best images are obtained by minimizing vibration. The manufacturer suggests a ground floor laboratory and a vibration free table.

Testing for Vibration

A rudimentary test for vibrations can be obtained by placing a glass of water on a surface where the microscope will be used. The ripples on the surface of the water indicate that vibrations may cause difficulty in imaging. A lack of ripples doesn't necessarily mean that vibrations aren't present.

The major sources of vibration noise are as follows:

1. Structure – Vibrations coming through the floor of your building such as those from elevators, air conditioners, transformers, and other machinery can be a problem. Try to place the microscope near a load-bearing wall avoiding hallways and heavy doors that are used often.

2. Sound – Minimize acoustic waves as they can cause vibration induced noise in the cantilever.

3. Support – The microscope should be separated from the other components to minimize vibration as even the use of the mouse can generate vibration. Mechanical devices such as fans can also cause excessive vibrations.

Air Table

The air table (optional vibration isolation platform) will require an air line that supplies 100-120 psi of regulated dry-filtered air.

Acceptable Parameters for the placement of the Nano-R™

- **Room Location**
  The location should be free of chemical, dust and other contaminants.
- **Telephone Accessibility**
  A phone nearby the operator is recommended for reaching Customer Support while using the system.
- **Operating Temperature Range**
  15°- 25°C (59° - 77° F)

  Note: The maximum allowable gradient is ±°C/h (±4°F/h)
- **Storage Temperature Range**
  0°C - 40°(+32°F - 104°F)
- **Operating Humidity Range**
  30 – 60% (non-condensing)
- **Storage Humidity Range**
  10 – 100%

❖ Maximum Acceptable Vibration Parameters

<u>Vertical</u>

Acceleration: <50µG, ? f: 0-300 Hz, 1G = 9.81 m/s^2.

The RMS value of the tip-sample motion must not exceed 0.01 nm when integrated over ? f.

<u>Horizontal</u>

Horizontal values are generally smaller than vertical values and have less effect on tip vertical motion.

Acceleration: smaller than vertical acceleration values

❖ Operating Electrical Power Tolerances

110/220 – 240 VAC (±50 – 60 Hz, 1 Phase

AC Voltage Stability = +/- 1.5%, +/-1 Hz

❖ Maximum Acceptable Sound Pressure

< 5 mPa @	10 – 90 Hz
<15 mPa @	90 – 210 Hz
<75 mPa @	210 - 500 Hz

The noise level inside the enclosure must not exceed 75dBc (=~0.112Pa integrated from 10 to 10,000 Hz).

❖ Compressed Air (for air table option only)

6.8 – 8.1 bar (100 – 120 PSI)

The compressed air must be dry, regulated, filtered and oil free. The regulator must be accessible at the installation site. A .25-inch female NPT connector or .25-inch quick connect connector is required.

Appendix B

Description of SPMCockpit™ Software

User

Typical Mode

This mode is intended for the occasional user. It provides access to a limited number of functions on the PScan2™ Controller. These functions are arranged as a sequential menu and offer a step-wise method for initializing the scanner, setting scanning mode, beam alignment, tip engagement and retract, selected scanning options, image display and direct access to an image analysis program (optional program). This mode will over-ride certain parameters in the configuration file, using instead "typical-mode default"-parameters which minimize the possibility of a improper cantilever/tip engagement.

Expert Mode

This mode provides access to all the functions currently available on the PScan2™ Controller.

File

Open Configuration File

The configuration file contains the operating parameters, which have been previously set and saved. Any directory can be accessed; the default directory can be set under "Preferences". The SPM Cockpit™ program opens with the setup and scanning parameters from the previous session.

Save Configuration File as…

This function will save the setup and scanning parameters in the current session at any time.

Edit Configuration File

Under some conditions it may be useful to manually change a particular parameter in the Configuration File. A text editor is opened to allow changes. The file must be saved when exiting the editor in order for the changes to take place.

Save Images

An image is acquired for each of the selected channels (see "Scan Image Setup"), 1 through 4. They may be saved in one or any of three formats: TopoMetrix™ (ThermoMicroscopes), Nanoscope 3™ (Digital Instruments, Veeco) and Digital Surf, that can be accessed by the corresponding image analysis software. A list of extensions for each type of image acquired is provided in the appendix of the User's Manual. Please note that in the "Typical Mode" only one image, the "clicked-on" highlighted image, can be saved in the image bank under "scanner controls". However, all the images can still be saved under the "file" menu selection, as in the "X'pert™ Mode".

Open Images

Images of any of the three above mentioned formats may be opened for viewing. The image can then be saved in another format or exported (discussed below).

Save Raw Scan Data

The primary scan data may be saved in a "Pacific Scanning" format.

Open Raw Scan Data

This function opens a "Raw Scan Data" file for viewing. The image may then be saved in another format or saved in a standard format for exporting into other word processing and spreadsheet program files.

Export Displayed Images

Images may be saved for export as Bitmap (*.bmp), GIF (*.gif), JPEG (*.jpg), or TIF (*.tif) files.

Preferences

Configuration

The user may select a default directory for storing and retrieving Configuration (*.cfg) files.

Raw Data

The user may select a default directory for storing and retrieving "Raw Data" files.

Export Image

The user may select a default directory for storing and retrieving "Image" files (.bmp, .gif, .jpg, .tif formats) for exporting into other programs.

Image Files

The user may select a default directory for storing and retrieving "Image" files in TopoMetrix™, Nanoscope™, and Digital Surf™ formats.

Auto-linearizer

The user may select the size of the lower and upper "buffer" regions for use by the "auto-linearizer" routine. The size of the buffers for the X- and Y-axis may be set separately. The lower buffer is set as a voltage that is typically 200 to 700 mV. The smaller the value, the smaller the buffer region. If the setting is too small, then the lower voltage side of the scanned image (depending on rotation angle) will appear distorted along that axis. The upper buffer is set as a percentage, and is typically 90 to 96%. If this value is set too high, then the higher voltage side of the scanned image will be distorted for that axis. Smaller mV and higher percent value will increase the scan range. However, thermal effects and piezo performance may cause small changes in the operating range of the actuators, requiring more frequent use of the auto-linearizer function.

Miscellaneous

The user may select several among display and activity options for operating convenience.

Typical Mode

The user may select certain properties as to how the Typical Mode is displayed and as to which image analysis program is activated.

Calculate Non-linearity

This function is reserved for qualified technical persons.

Exit

This function closes the image acquisition program.

Device

Directory Setup

The Input/output (I/O) directory for a particular PScan2™ Controller may be selected from this menu item. Be sure to "double-click" on the directory of choice in order- to bring the directory name into the lower window before clicking "OK".

Create Device Directory

When first installing a new PScan2™ Controller to the Master Computer, a new directory must be created. Usually, the name of the directory is the same as serial number of the Controller. For example, the directory can be named "PscanXXX", where "XXX" is the last three digits of the serial number of the Controller.

Create Configuration Diskette

Before the PScan2™ Controller can recognize the existence of the Master Computer on the Ethernet, a Configuration Diskette must be generated by the Master Computer and installed on the Slave. Using an empty diskette, follow the instructions displayed in the window. Remember to disconnect the Ethernet cable to the Controller before rebooting the Controller in order for the Controller to accept and read the diskette generated from the Master Computer. This operation takes only a few minutes. A series of four medium-length beeps indicates that the diskette was read and information transferred. Also, remember to reconnect the Ethernet cable when the configuration file installation is complete and the Controller is rebooted. A "hi-lo-hi" series of three beeps indicates that the Controller has been successfully connected to the Ethernet. This may be confirmed by using the "Ping" function.

Ping

This function provides a quick means for confirming that the PScan2™ Controller is connected to the Master Computer and is operating properly. If network and controller are working, there is an almost immediate response indicating that the system is operational. A time-out error message is displayed after a few seconds if the system is not working.

Multiple Unit Setup

Two or more controller/scanners can be operated from one master workstation. This function allows the user to set-up one program to operate two controllers independently by setting a "multiple device capability". During operation each controller/scanner can be operated by simply selecting the "device menu".

Park Idle Piezos

The performance characteristics of the piezo actuators may deteriorate if substantial voltage is applied to the actuators over an extended period. This function provides a "time-out" capability when the controller is in Idle Mode; that is, when there is no active data acquisition (such as oscilloscope or image acquisition modes). The piezo voltages are brought to zero volts after a specified time period. If the tip is in feedback, a "tip retract" operation will be performed. Any movement of the mouse will reactivate the actuator voltage setting, but the tip engagement routine will not be performed. The minimum time-out range is 1 minute; the maximum is 1000 minutes.

Diagnostics

This function is reserved for qualified technical persons.

Settings

Input Selects to ADC

Channel Selects

Up to four channels of twelve possible signals may be monitored using the various oscilloscope functions and scan image functions (see the User's Manual for a list and description of these signals).

Normally, Z(HGT), Z(ERR), ZDEM), and Z(SEN) (if the Z-axis sensor option is active) are used for oscillating mode, and Z(HGT), Z(ERR), Z(L-R), and Z(SEN) for contact mode.

Certain channels, ones in which simultaneous monitoring is not typically needed, cannot be acquired at the same time. If a conflict during selection occurs, an error message will be displayed. One or more channels are only available for oscilloscope line display and image acquisition if the appropriate channel number is selected in the "Scan Image Setup" section. All four channels are available in the oscilloscope time mode.

Lateral Force

Normally, a gain of "one" and offset of "255" is sufficient for most lateral force imaging situations. If a higher gain is needed, the "Red Dot" should be set to the left of the vertical mid-line, near the left border of the green zone. The gain and offset can then be adjusted while scanning for optimal image acquisition. An optimal filter setting (full range, 1000 Hz, 100 Hz and 10 Hz) can also be established.

Z Sensor, Z(Sen)

These parameters are only active for 3-axis sensor scanners. The Z sensor gain and offset are factory calibrated to approximately overlap the Z(Hgt) span in microns (7-10 microns). For correct ranging, the gain is typically set at "6" or "7", and the offset is adjusted so that the center of the Z(Hgt) range (zero volts) and the center of the Z(Sen) range are approximately the same. If the decade filter is engaged, the noise will be lower, allowing for more precise height measurements, although at lower scan rate.

Error Signal Z(Pos) Filter

The Z(Pos) signal is the inverted Z(Err) with the addition of decade filters (full range, 1000 Hz, 100 Hz, and 10 Hz). When monitoring the error signal, the Z(Pos) signal is useful for reducing noise and noise spikes in either contact mode or oscillating mode.

Z(Hgt) Gain

The Z (Hgt) bit resolution can be doubled, particularly for enhancing the image quality of features of small height. The Z range is also reduced a factor of two, with the upper half of the range being active (0 to 10 V of the -10 to +10 V). (The extended portion of the Z-piezo is active.)

Z Piezo

With the PID setting "off" and the "Fast Retract" set to "Z DAC applied", the Z piezo voltage may be set directly with this function. The voltage range of the piezo is the inverse of the set voltage, i.e. set-voltage is 10,000 to 0 mV for 0 to 130 V output to the Z piezo (140V in newer units). For normal scanning, the set-voltage is zero volts. The "fully retracted" setting of the "fast retract" function is intended for a specialized application; the normal setting is "Z DAC applied".

PID On/Off

The PID loop may be turned on or off manually at any time. In any event, during tip approach the PID is turned on before the approach motor is activated. During tip retract, the PID is turned off after the motor pulls back.

Scan Image Setup

Resolution

Over all scan ranges the images may be acquired at resolutions from 16 x 16 to 1024 x 1024 pixels. Initially, 256 x 256 resolution is used.

Overscan

Under some conditions, it may be useful to reduce artifacts associated with reversing tip scan direction. When scanning in the forward direction, up to 127 pixels may be "removed" at the beginning of the line. Depending on the resolution, the range will be reduced proportionally. However, the resulting image is still at the specified scanning resolution.

Prescan

As above, under some conditions it is useful to scan a few lines at the beginning before an image is acquires. Up to 127 lines may be eliminated from the acquired image. Again, the resulting image is still at the specified scanning resolution.

Scan Rate

The scan rate may be varied from a few thousandths of a line per second up to about 15 lines per second for four channel acquisition. Above 0.2 lps, user interrupts are only allowed at the end of a scanned line; interrupts are allowed after each point below 0.2 lps.

Channels

One to four channels may be acquired simultaneously and stored.

Skew

The extent of skew between the X- & Y-axis is corrected during image acquisition. It is typically less than one degree.

Rotation

The angle for the fast-scan axis can be set manually or by clicking on one of the primary axis setting. The slight distortion effect of the skew correction setting in the first few scanned lines along the X-axis may be removed by setting the rotation angle the same as the skew angle; thereby, the "zero" angle for scanning becomes the skew angle.

Scan Data Transfer

Image data can be transferred form the Controller to the Master Computer on a line-by-line basis (usually selected) or after the whole image is acquired.

Scan Image Direction

The image may be acquired in the Forward, Reverse or both directions along the fast axis.

X-Y Control

The **X-Offset**, **Y-offset** and **Zoom** set the effective scan range and start-of-scan position, which is also dependent on the rotation angle. The initial offsets and maximum zoom are set by the configuration file or by running the Auto-linearizer routine (see below). These values can be adjust for smaller scan range and location by using the two zoom features: "box-click" mouse on the image for zoom-in, or "box-click" mouse adjacent to the image for zoom-out; or "double-click" adjacent to the image to open a separate window for zoom-in or zoom-out. Alternatively, the user may adjust these boxed values to select a particular value.

In addition to the zoom features above, an **Extra Zoom** with **Offsets** can be selected for higher resolution or positioning capability. By "double-clicking" within an image, a new "extra Zoom" window is opened. The user may select a zoom value of 2X or 4X and locate scanning region.

The **X & Y Feedback** parameters are also set within this section. The respective feedback loops may be manually turned on or off for test purposes.

Z-feedback

PID Channel

One of three inputs may be selected for the Z-Feedback Loop: (1) T-B Photodiode from the AFM scanner, (2) External and (3) Z-Sensor (if option is installed).

Input Polarity

The PScan2™ Controller is capable of engaging in feedback for both positive-going and negative-going error signals. Typically SPM users are more familiar the former, i.e., with the error signal response from a lower (more negative) signal to a more positive signal. For contact mode, the Input Polarity is set for "Positive" and for the oscillating mode, it is set for "Negative".

Set-point Polarity

For contact mode, the set-point is typically set to "zero" and the set-point Polarity setting is not important. If a positive set-point value is required, the setting is "Positive", and visa versa if a negative set-point value is needed. For oscillating modes, the Error Signal is always negative (see above); the set-point Polarity is "Negative".

Set-point Value

The set-point value controls the relative force that the tip interacts on the surface. The set-point range is from 0 to 10 volts; the sign depends on the Set-point Polarity. For contact mode the set-point, typically set for "zero" volts initially, may be increased or decreased to change the force on the cantilever.

For the oscillating modes involving a resonance of the cantilever (a "negative" error signal, see above), the set-point is usually "negative". As an example, the setting ranges from 0.5x to 0.7x of the Error Signal out-of-feedback for "hard" intermittent contact mode to 0.8x to 0.9x for "light" intermittent contact mode. The actual preferred setting depends on the cantilever/tip characteristics as well as the particular experiment at hand.

Demodulation

"Bypass" is selected for contact mode; "Demod" activates the demodulator circuits and is selected for any oscillating mode.

Error Signal Gain

The Error Signal Gain compensates for variations in cantilever reflection intensity. For contact mode, if Z(Sum) is at or near "max" (about 40% of full scale), the Error Signal Gain is typically "1", increasing to a value of "10 - 15" for Z(Sum) at its minimal value. The Error Signal Gain ranges from 1 to 255.

GPID Values

G (overall feedback Gain), P (Proportional), I (Integral) and D (Derivative) setting may range from 1 to 255. The higher the value, the greater the influence of the parameter. A suggested initial GPID setting for contact or intermittent contact modes is 1,8,20,1.

Frequency Synthesizer

Frequency

The frequency of the driving oscillator for the oscillating modes may be set from a few Hertz to several MHz. The typical range for this system is from 50 kHz to 500 kHz.

Amplitude

The peak-to-peak amplitude may be set from a few millivolts to 10 volts in approximately 20 mV increments.

Phase

For Phase Detection, the contrast of the acquired image may be enhanced by changing the phase of the detected signal relative to the reference signal. The range is 0 to 360 degrees.

AUX 1 & 2 Outputs

The Auxiliary outputs, AUX1 and AUX2, provide the user with 0 - 10 V DC, 10 mA outputs with 12 bit resolution.

Demod Selects

Demod Gain

Four settings are available: 1x, 2x, 3x, and 4x. The higher gains are used to assure a satisfactory signal level for the demodulator section.

Demod Filter

High frequency effects can be reduced after demodulation by the use of decade filters: 10 Hz, 100 Hz, 1000 Hz, and full range.

Demod Type

This switch selects the type of detection in the demodulator: Amplitude Detection (typical for oscillating mode) and Phase Detection (used to control the PID loop by sensing small changes in the phase of the oscillating cantilever/tip).

Laser/Motors

Laser

The Laser is ON under typical program initialization. It can be turned off at any time.

Stepper Motors

Motor Select

Any of six micro-stepper motors (rated at 12 V, 0.5 A per phase) can be selected. Just to the right of the select window is a window that indicates the motor location on a relative scale. The primary approach motor for AFM is motor #1.

Control

An individual stepper may be moved in the **Forward** or **Reverse** direction and **Stopped** at any time. (In a typical set-up, **Forward moves the tip towards the sample. Reverse lifts it up.**) Any number of Pulses may be sent to the motor; the controller sends pulses to the stepper motor as a "packet", the size of which is determined by the **Packet** number (usually 10-20). This packet method for pulse transfer allows the controller to check for a user interrupt between packets, such as "STOP". The **Step** size may be Full or Half Step.

DC Motor

Some scanners incorporate a +/- 5 V DC motor for controlling the tip/cantilever approach and withdrawal. The **Forward** (e.g., -2000 mV) and **Reverse** voltages (e.g., 5000 mV) are controlled separately for a given **Duration** (e.g., 200 ms). The **Stop** button sets the voltage to zero.

X Y Z Scales

X & Y Full Scale

The X- & Y-axis scales may be set independently and can be expressed in Angstroms (A), nanometers (nm) or microns (um). If the two axis are not in feedback, the numbers entered represent the actual "full scale" of the scanned image. For systems with X & Y feedback and linearization, the situation is more complicated, resulting in the need to enter larger numbers than the actual scan range. (For the PTrak3™ Scanner, for example, the scaling numbers are ranged from 190 to 220.)

Z Full Scale

The **Z(Hgt)** represents the voltage applied to the actuator in the Z PID loop in order to maintain feedback. **Z(Sen)** is the output of the optional independent sensor. The scales for both signals may be presented in the three units mentioned above. All **other ADC** voltages are given the same full-scale factor and units. (For direct reading in volts, Aux-in1=20000 mV, Aux-in2=20000 mV, other ADC=20000mV.)

Non-linearity X Y

To correct for non-linearity of the X & Y actuators or linearization sensors, several options are available for up to third-order correction.

Scale Correction

With the **Image Correction** turned off, and the **Correct** box checked, the image scale is corrected to positional non-linearity for any zoomed region within the full scan area.

Image Correction

<u>Off-line</u>

A correction is applied to an uncorrected scanned image. The data is then re-sampled when stored in the Digital Surf format. The Correct box of the Scale Correction may be either on (conveniently displaying the proper range when scanning) or off.

<u>On-line</u>

A correction is applied during scanning, eliminating the need for off-line correction. The actual correction parameters for all options are factory-set.

Tools

Red Dot Display

This display provides a convenient means for aligning the laser beam onto the detector. For contact-mode AFM, the red dot is located below the horizontal median line within the green region. The set-point is typically set at zero volts, so that the red dot crosses the median line in an upward direction as the cantilever/tip contacts the surface. The more negative (lower) the red dot, the higher the contact force.

If Lateral Force images are to be acquired, which may require increased gain settings for Lateral Force (see **Settings**), then the red dot should be set slightly to the left of the vertical median line and below the horizontal median line.

The bar meter to the right of the red dot region shows the total light intensity on the detector, **Z(Sum)**. For more precise beam positioning at low light levels, a 1x to 4x **Scale** switch is provided. This scale setting does not affect the Z-PID loop. **For convenience, the Laser may be turned on and off from this window.**

Oscilloscope, time mode

The time dependence of up to 4 signals may be presented in graphical form. The time-base ranges from 10 to 1000 ms. The update interval depends on the time-base setting and the performance of the master computer, but is typically several times a second.

As with all oscilloscope modes, the voltage range is +/- 10 volts. The scaling may be set at **Full scale**, one-time **Auto-scale** or continuous auto-scale (with box checked). With the Auto box unchecked, the **Half Range** and **Offset** settings can be independently controlled.

Oscilloscope, line mode

This mode is similar to the time mode, except that the abscissa becomes the voltage ramp of a line scan. The repetition rate is set under the **Scan Image Setup** (scan rate) as is the resolution (pixels).

If the Z(Hgt) or Z(Sen) signals are selected, an **Auto-leveling** box is available for observing the line scan corrected for background slope.

Oscilloscope, frequency sweep mode

This mode is for determining the characteristics of a demodulated signal as a function of driving frequency and amplitude. It provides a convenient means for frequency scanning (nominally 50 kHz - 500kHz), determining the resonance frequency, setting the driving frequency and amplitude, and measuring the signal amplitude as a function of applied Z-piezo voltage. The scaling boxes are similar to the modes above.

To the lower left of the graph is the selected **Signal**. The **Sweep Rate** is typically set to 5 - 10 ms. The **Start** and **End** frequencies are typically set around the anticipated resonance frequency, or they may be set to scan the full range. The **Start** and **Stop Sweep** initiate and terminate the frequency sweep. The driving amplitude and phase (for phase-detection mode) may be set at anytime. Two successive sweeps are displayed: the current sweep is green; the previous sweep is red.

For convenience, the left mouse key may be pressed while the cursor is within the graph screen in order to sweep a particular range. The range is fixed and the graph screen reset to the new sweep ranges by a right mouse click. Positioning the cursor on the desired frequency and double-clicking the left mouse button sets the indicated frequency, amplitude and phase into the **Settings** windows when the user is ready for tip/cantilever approach.

The **"Z>"** button is used to ascertain whether the cantilever and mount are in satisfactory mechanical contact as a function of the applied Z-piezo voltage. Once the desired frequency is selected, pressing the **"Z>"** button will ramp the output voltage to the Z actuator from high-to-low-to-high voltage and return to the initial state. The resulting plot of the amplitude at the selected resonance frequency should be relatively flat (less than 10% variation). This assures that the amplitude is substantially constant over the Z actuator range.

When operating in the Typical Mode, two additional functions are presented: **Full Range** sets the sweep range from 50kHz to 400kHz. **Auto set** sets the frequency at 90% of the maximum value to the left of the peak and sets the set-point so that error signal (Z(Err)) is zero at two-thirds of maximum amplitude.

Detector Sensitivity: The amplitude of the cantilever oscillation, under typical conditions for cantilevers in the 250 - 350 kHz resonance frequency range, is approximately 0.12 nm/mV drive amplitude for Nanosensor cantilevers and approximately 0.31 nm/mV drive amplitude for K-Tek cantilevers.

Dual-trace Storage Scope Mode

This mode is similar to the time mode, except that the full-scale time ranges from 2000 to 10000 ms. Although only two signals may be displayed at any time, the two signals are synchronized to within 15 to 45 microseconds, depending on which channels are selected. This mode is useful for observing long term drift effects.

Automatic Linearizer

This function automatically maps the X and Y actuator movements onto a selected region within the sensors' full scale range. From the **Preferences** window, the lower limit (selected as a millivolt offset) and the upper limit (selected as a percentage of the maximum available range) for each axis provide a buffer zone, below the lower limit and above the upper limit, respectively. This assures that the signal in the feedback loop will not exceed the actuator's mechanical range. A succession of eight windows are displayed in order to provide a visual sense as to how well each axis is operating.

Tip Approach / Retract

The primary control of engaging and retracting cantilever/tip relative to the scanning surface are three icon buttons. Stop is in the center of the window, Retract is just above, and Approach is just below the Stop icon. The motor for Z motion is selected in the box just to the right of the Stop icon. If a stepper motor is selected, then the relative position of the tip/cantilever is shown in the box just below the motor selection box..

Approach

For systems using **DC motor**, the rate of approach is set by the **Voltage** box. The voltage may be positive or negative. For systems using **Steppers**, the **Step Size** and **Direction** may be selected. The approach rate is fixed, but may be changed if needed (See User's Manual, DCEx, initialization file structure).

Select Channel

Any signal sensing the Z cantilever/tip interacting with the surface, i.e., the feedback error signal, may be selected. Typically, it is Z(Err) for contact mode and Z(Dem) for oscillating modes.

"Surface" Value & Deviation

In order to provide for both positive-going and negative-going feedback error signals as the tip/cantilever approaches the surface, the motor can be stopped within any range of positive or negative signal voltage. The Surface Value is the center of the required voltage range, and Deviation is the voltage above and below the center voltage. For example, for most AFM systems, the feedback error signal is negative-going-positive, with zero volts as the cross-over, i.e., the voltage above which will stop the approach motor. A Surface Value and Deviation setting of 5000 mV and 5000 mV, respectively, will stop the motor if the feedback error signal is between zero and +10 V.

Incremental Approach

This function activates a Z-voltage ramp between step increments. This provides a gentler interaction of the tip with the surface during tip engagement. Prior to each downward motion of the stepper motor (a few microns), the Z-piezo is ramped at a set rate with the PID feedback loop off. The process is stopped when the Z(Err) becomes positive and PID loop is activated. If the recommended parameters (displayed when the **Advanced** window is opened), the tip will be positioned approximately mid-scale for Z(Hgt). The parameter settings are listed from top to bottom: Fast Approach- 500,50,20,20,1; Medium - 500,200,20,20,1; and Slow - 500,500,20,20,1. The approximate approach rates for each speed (overall rate followed by actual ramp rate in microns per second): Fast - 2.0/ 0.9; Medium - 0.9/ 1.5; Slow - 0.5/ 0.6

Monitored Value

As the tip/cantilever approaches the surface, the feedback error signal is periodically updated in this box.

Retract

For DC motors, the extent to which the cantilever/tip is retracted from the surface is set by a combination of the applied **Voltage** and the **Duration** in ms of the voltage pulse.

For steppers, the **Step Size**, **Direction**, and **Number** of steps are set. The rate is preset at the maximum rate for reliable operation. The **Distance** movement of the cantilever/tip is indicated in the box adjacent to the step number.

Scan Control Panel

Scanning and image acquisition is controlled from this window with the **Start** and **Stop** buttons. If the **Repeat Scan** box is checked, the scan routine will restart a few seconds after completion. The **Elapsed Time** and **Lines Remaining** for the scan are updated during scanning.

Display Scanned Image

By successively clicking on the "grid" icon, up to four different signals can be imaged during scanning. (See the **Settings** section for selecting available signals). Any of the displayed images may be expanded to full screen.

The color bar on the left of the image represents the range of signals for the data acquired. Checking the **Histogram Correction** box allows the user to define the Z scale of interest, with the upper and lower limits set as a percent of full scale. For some viewing situations, the quality of the image may be enhanced by 1) checking the **Shading box** and 2) selecting the apparent direction of the light source (**N, S, E,** & **W**).

The image can be leveled on a line-by-line basis by checking the **Auto-leveling** box. The color bar and scaling are corrected automatically.

Zoom

An area to be zoomed may be defined by pressing the left mouse button on the upper left region to be outlined and drawing the cursor across the scanned image. The zoomed area is locked-in by releasing the left mouse button and clicking on the right button. To zoom out to a previously zoomed region, a small box is formed just outside the scanned image, but within the window. This procedure may be performed successively, expanding the zoomed area until the maximum scanned area is accessed.

An alternative means for zooming is accomplished by double clicking the left mouse button when the cursor is outside of the scanned image. A new window is opened which defines the entire area accessible by the X Y sensors. The maximum scanned area is defined by white dotted lines; this represents the region in which the linearizing routine has selected. By pointing the cursor within the outlined green region, the scan area may be positioned anywhere within the range of the sensor. However, if the green outline is outside of the white dotted line, the scanned area is not linear and will cause a distorted image. For convenience, the Start and Stop points are indicated. When scanning at angles other than 0, 90, 180, and 270 degrees, the actual scan area is marked by the red outline.

Extra Zoom

By double-clicking the left mouse button when the cursor is within the scanned image, a new window is opened. The grid region represents the current zoomed area. The user may zoom 2x or 4x anywhere within the area by clicking on a zoom button at the bottom of the window and moving the outlined area by pointing the cursor within the area and dragging the outline while pressing the left mouse button. Clicking the Apply button locks in the new scan region.

Force Distance Curve

This function allows the user to measure a force-distance curve at any arbitrary location within a scan area. Typically, the F-D curve refers to measuring the Error signal Z(Err), which is the cantilever deflection, as a function of the Z actuator position. It represents how the cantilever bends as the tip approaches the surface until contact, and the degree of adhesion of the tip onto the surface on retraction. There may or may not be deformation of the surface, depending on the hardness of the surface relative to the stiffness of the cantilever.

The F-D location is selected by pressing the control key and clicking the left mouse key when the cursor is pointing at the location within the scanned image display. A black dot appears on the scanned image. By selecting "Force-Distance Curve" under the pull-down Tools menu, a new window appears for selecting the F-D parameters, activating the F-D routine, and displaying the approach (Curve #1, green line) and retract curves (Curve #2, red line), provided the cantilever is sufficiently stiff. The F-D curve may be obtained when the Z PID loop is in feedback and the Z actuator (Z(Hgt) is in mid-scale.

The range of the Z actuator is approximately 10 microns. The Z-DAC voltage is the inverse of the extension: The actuator is fully retracted at 10000 mV and fully extended at 0 mV. The Start position should be a higher value (less extended) than the Stop position. If Z(Hgt) is about mid-scale (5000 mV), then a typical Start position might be 8000 mV and Stop position at initially 3-4000 mV. The degree of deflection of the cantilever relative to the Z actuator position is dependent on a number of factors. The user should refer to the large body of F-D literature for further understanding of the nature and implications of the measurement.

In addition to the usual scaling parameters for the display, the user may select the resolution (Pixels, usually 256) and the rate of data acquisition. When the data rate is set to 0 ms/pixel, the data acquisition rate is set for maximum, about 15 to 25 microseconds, depending on the controller processor speed.

Display

Color palette

This feature opens a directory that contains the available color palettes that can be selected for displaying images.

Window

The contents listed are the windows that have been opened in the Main Window.

Help

- Additional information on the various functions listed above.
- Information on the version of image acquisition software that is currently in operation.

Appendix C

Nano-R™ Configuration File

The following is a list of the items in the configuration file that is loaded into the Nano-R™ AFM controller. These settings are typically set by Pacific Nanotechnology at the factory.

[INPUT SELECTS]
CH1=1
CH2=8
CH3=5
CH4=7
ZSEN_G=43
ZSEN_O=137
ZSEN_F=2
ZPOS_F=0
ZADC_G=0
LR_G=255
LR_OFS=255
LAT_F=0
LR_F=0
ZHGT_G=0

[Z FEEDBACK]
PID_CH=0
PID_DEM=1
PID_POL=1
PID_SET=1
ZERR_G=13
PID_P=8
PID_I=10
PID_D=100
Z_SET=1013.18

[DEMOD SELECTS]

DEM_G=0
DEM_F=1
DEMOD=1

[PID ON/OFF]
PID_ON=1

[Z PIEZO]
Z_OUT=2048
Z_OFS=0
X5=0

[XY CONTROL]
X_OFS=73
Y_OFS=67
ZOOM=8
XFBK_P=51
XFBK_I=50
YFBK_P=255
YFBK_I=40
EXTRA_ZOOM=1
XPI_ON=1
YPI_ON=1
EXTRA_XOFS=0
EXTRA_YOFS=0

[FREQUENCY SYNTH]
F_AMP=15
FREQ=59801795
PHASE=0
OSC_AMPL=1500

[AUX 1&2]
AUX1=0
AUX2=0

[STEPPERS]
MOTOR=264

STEP_DIR=0
STEP=1
PULSES=5
PACKET=100
SYNC_FOCUS=1
LOG_PACKET=1

[LASER]
LASER=1

[DC MOTOR]
DCMTR_FWD=-127
DCMTR_REV=127
DCMTR_TIME=20000

[SCAN IMAGE]
POINTS=256
LINES=256
SCAN_RATE=0.3
ROTATE=0
XYMODE=0
DIR=2
CH=4
DATA=0
SKEW=0.7
OVERSCAN=0
PRESCAN=0
LINE_CUT=0
ZXY_CROSS=1
ZXY_STORE=1

[TIP APPROACH]
ZMTR_TIP=1
CH_TIP=8
SRF_TIP=16384
ZADC_TIP=0
DCREV_TIP=127
DCTIME_TIP=2000

ZHGT_TIP=0
DIRUP_TIP=1
STEPUP_TIP=0
PULSES_TIP=120
DCFWD_TIP=0
DIRDWN_TIP=0
STEPDWN_TIP=1
CYCLES_TIP=50
PACKET_TIP=500
DEV_TIP=16384
TIP_INC=1
RUN_INC=40
RAMP_INC=4
DELAY_INC=1
CHK_ZSUM=0
FAST_INC=1
FAST_PRCNT=4.00
SLOPE_INC=0
SLOPE_PRCNT=0.01
SLOPE_RATIO=1.00
SAFE_PRCNT=30.00
AUTO_SET=0
SET_PRCNT=70.00
FAST_RUN=4
SLOPE_RUN=1
RUN_SLW=4
RAMP_SLW=4
DELAY_SLW=1
TEST_DSETP=100.00
TEST_ZHGT=1638
SETP0_PRCNT=10.00
SETP1_PRCNT=25.00
INC_DSETP=600.00
SETP_AUTO=1
ZERR_G=128
PID_P=10
PID_I=10
PID_D=1

```
[FREQ SWEEP]
FREQ_S=57756573
FREQ_E=62051540
F_AMP=20
F_PHASE=0
SWEEP_RATE=5

[OSC TIME]
TIME_BASE=300

[OSC STORAGE]
TIME_BASE=3000
DUTY_TIME=1200

[XYZ SCALE]
X_SCALE=312
X_UNIT=0
Y_SCALE=312
Y_UNIT=0
Z_SCALE=4000
Z_UNIT=1
ZS_SCALE=12000
ZS_UNIT=1
ADC_SCALE=20000
ADC_UNIT=4
AUX1_SCALE=20000
AUX1_UNIT=4
AUX2_SCALE=20000
AUX2_UNIT=4
ZSEN_G0=43

[ZOOM_OUT]
ZOOM=45

[TIP XY]
X_POS=2048
Y_POS=2048
```

PID_ON=0
SETP_UP=0

[NON LINEAR]
SCL_CORR=0
SX1=1
SX2=0.0054
SX3=0.00095
SY1=1
SY2=0.0054
SY3=0.00085
IMG_CORR=1
A1=1
A2=-0.00025
A3=0
B1=1
B2=-0.00048
B3=0
X_OFS0=0
Y_OFS0=0
ZOOM0=0
PIX0=256

[IDLE PARK]
ENABLE=1
TIME=30

[AUTO LINEARIZER]
XOFS_ADJUST=400
YOFS_ADJUST=400
XPIX_ZOOM=0.93
YPIX_ZOOM=0.93

[FORCE DIST]
F_SCALE=0
F_UNIT=NN
SPRING_K=1
ZDAC_S=0

ZDAC_E=4095
CH=8
PIX=128
FORCE_RATE=2
DEF_LIMIT=6553
NUMBER=1
CONTINUE=0

[STAGE]
ZOOM_DIR=0
DCMTR_FWD=-127
DCMTR_TIME=10000
F_STEP_DIR=0
F_PULSES=50
XY_TBALL=0
DCMTR_REV=127
F_STEP=0
DELAY_US=1000
X_STEP_DIR=0
X_STEP=0
X_PULSES=33
Y_PULSES=0
Y_STEP_DIR=-1
LIGHT_ON=1
LIGHT_DAC=200
XY_MGAIN=1