Magnetic Force Microscopy (MFM)

Applicable to Dimension™ Series and MultiMode™ Systems

Support Note Table of Contents

This support note describes how to perform magnetic force microscopy (MFM) imaging on either a Dimension-series system or a MultiMode AFM and replaces *Support Note 206, Magnetic & Electric Force (MFM & EFM) Imaging with SPMs—Dimension-series Microscopes* and *Support Note 207, Magnetic & Electric Force (MFM & EFM) Imaging with SPMs—MultiMode Microscopes*. Support Notes 230 and 231 provide information on Electric Force Microscopy (EFM) for Dimension series systems and MultiMode systems, respectively

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Rev. B	25JUN96	addition on pp. 16-17	0120	
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229.1 Magnetic Force Imaging Overview

MFM imaging utilizes the Interleave and LiftMode procedures discussed in Chapter 12 of your product instruction manual; users are advised to read appropriate sections prior to attempting MFM imaging. Best results will be obtained with Digital Instruments' Extender™ Electronics Module. This hardware unit allows phase detection and frequency modulation for optimal MFM imaging. Instructions for software installation of the Extender Electronics Module can be found at the end of this support note; complete instructions for hardware and software installation are found in *Support Note 205A Hardware Installation—Phase Extender Electronics, MultiMode™ AFM* and *Support Note 232A Hardware Installation—Extender Electronics, Dimension™ Series Systems*.

In MFM, a tapping cantilever equipped with a special tip is first scanned over the surface of the sample to obtain topographic information. Using **LiftMode** as shown in Figure 229-1, the tip is then raised just above the sample surface. The surface topography is scanned while being monitored for the influence of magnetic forces. These influences are measured using the principle of *force gradient detection.* In the absence of magnetic forces, the cantilever has a resonant frequency f_0. This frequency is shifted by an amount Δf proportional to vertical gradients in the magnetic forces on the tip. The shifts in resonant frequency tend to be very small, typically in the range 1-50 Hz for cantilevers having a resonant frequency $f_0 \sim 100$ kHz. These frequency shifts can be detected three ways: **phase detection**, which measures the cantilever's phase of oscillation relative to the piezo drive; **amplitude detection**, which tracks variations in oscillation amplitude; and **frequency modulation**, which directly tracks shifts in resonant frequency. **Phase detection** and **frequency modulation** produce results that are generally superior to **amplitude detection**.

1519

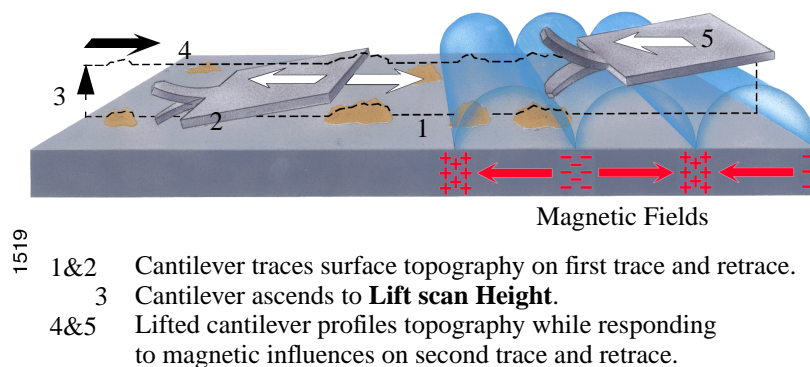| 1&2 | Cantilever traces surface topography on first trace and retrace. |
| 3 | Cantilever ascends to **Lift scan Height**. |
| 4&5 | Lifted cantilever profiles topography while responding to magnetic influences on second trace and retrace. |

Figure 229-1 MFM LiftMode Principles

All standard Dimension-series SPMs and MultiModes are capable of MFM imaging using amplitude detection techniques. By adding an Extender™ electronics module (see Figure 229-2), either system may also be used for frequency modulation or phase detection, giving improved results. Amplitude detection has largely been superceded by frequency modulation and phase detection. A more extensive discussion of force gradient detection and MFM imaging is given in the reprint *Magnetic Force Microscopy: Recent Advances and Applications*. Contact Digital Instruments to obtain a copy.

   NOTE: In the instructions below, steps specific to phase and amplitude imaging are described independently. Use the icons in the margin to locate steps specific to either frequency modulation and phase detection, or amplitude detection.

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**Figure 229-2 Extender™ Electronics Module (required for MFM phase
detection and frequency modulation)**

229.2 MFM Using Interleave Scanning and LiftMode

This section provides instructions for using the **LiftMode** of Interleave scanning to obtain MFM images. These guidelines will help in obtaining an MFM image of a standard magnetic sample (metal-evaporated video tape). Standard tape samples are provided with purchase of MFM probes, and can be obtained free of charge from Digital Instruments. Other samples can also be used; however, you will not have the benefit of comparing your results with the images shown here. Obtaining a good image of the tape sample will familiarize you with Interleave and MFM techniques and provide a check that the system is correctly tuned to image magnetic samples of interest. Many of the principles discussed here also apply to Electric Force Microscopy (EFM), described elsewhere.

For MFM procedures, NanoProbe™ magnetic coated tips are required. Various kinds of MFM probes are available for specific applications; contact Digital Instruments for more information. The remainder of this chapter assumes that the reader is familiar with the operation of TappingMode to obtain topographical images of a sample surface and has read the description of Interleave scanning in their manual.

LiftMode allows the imaging of relatively weak but long-range magnetic interactions while minimizing the influence of topography (Figure 229-1). Measurements are taken in two passes across each scanline; each pass consists of one trace and one retrace. In the first pass, topographical data is taken in TappingMode on one trace and retrace. The tip is then raised to the lift scan height and a second trace and retrace performed while maintaining a constant separation between the tip and local surface topography. Magnetic interactions are detected during this second pass. Using LiftMode, topographical features are virtually absent from the MFM image (see Figure 229-7).

The procedure below gives suggested parameter values that should work well for most applications. Further adjustment will, in some cases, improve the quality of MFM scans, and some experimentation may be needed to optimize the imaging of specific samples. See the suggestions at the end of this section.

As mentioned above, the NanoScope III uses *force gradient detection* for MFM imaging. Within this general technique, there are three possible schemes, known as *frequency modulation*, *phase detection*, and *amplitude detection*. All three are discussed here. Prior to 1994, amplitude detection had been the standard method for magnetic force imaging on the NanoScope III. However, hardware that allows phase detection and frequency modulation is now available for all TappingMode-capable microscopes in the form of Digital Instruments' Extender™ Electronics Module. (Microscopes without the Extender addition cannot utilize phase detection; for more information, contact Digital Instruments.) Phase detection and frequency modulation detection are superior methods for magnetic force imaging, offering greater ease of use, better signal-to-noise ratios, and reduced artifact content as compared to amplitude detection. If extensive MFM imaging is planned, the Extender Electronics module is strongly recommended.

229.2.1 Procedure

1. Mount a NanoProbe magnetic probe on the scanner or tip holder. The tip should be magnetized with a strong permanent magnet before installing the tip holder on the AFM head. Tips are usually magnetized with the field aligned along the tip axis (perpendicular to the sample surface). The MFM then senses force gradients due to the perpendicular component of the samples's stray field. Tip magnetizers are provided with MFM probes purchased from Digital Instruments.

2. Set up the AFM as usual for TappingMode operation. In all **Channel** panels, the **Highpass** and **Lowpass** filters should be **Off**. Set the **Rounding** parameter in the **Microscope / Calibrate / Scanner** window to zero (**0.00**).

3. The procedure to tune the cantilever drive frequency and amplitude depends on whether you are using phase detection or amplitude detection. Both cases rely on automatic **Cantilever tune** just as when preparing for TappingMode; see Chapter 8 of the product instruction manual. MFM cantilevers have resonant frequencies between 50 and 100 kHz. If using the **AutoTune** feature, these values can be used as bounds for the frequency sweep. With the Extender option, two curves appear in the **Cantilever Tune** box: the *amplitude* curve in white, and the *phase* curve in yellow (Fig. 229-3). Microscopes without the Extender Electronics Module display only the amplitude curve.

- **Setting a Drive Frequency for Phase Detection**
  The **Drive frequency** should be set to the center of the cantilever resonance, as shown in Figure 229-3. This will be done automatically if using **AutoTune.**
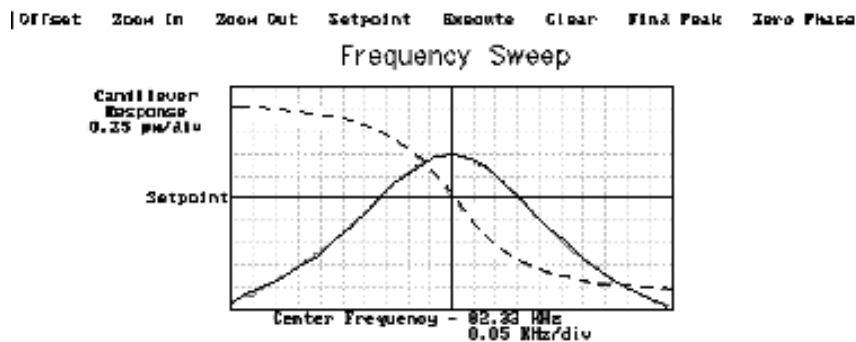
Phase
Detection

MFM / EFM

Figure 229-3 Cantilever Tune for Phase Detection and Frequency Modulation

To correctly track the cantilever phase, the **Phase offset** parameter must be adjusted. This is automatically done in **AutoTune**; alternatively, **Zero Phase** can be selected from the menu bar above the **Cantilever Tune** frequency sweep window. The phase curve should appear as in Figure 229-3, decreasing with increasing frequency, and crossing the center line (corresponding to a 90° phase lag) at the peak frequency. The phase curve then measures the phase lag between the drive voltage and the cantilever response. Again, vertical gradients in the magnetic force cause a shift Δf_0 in the resonance frequency. In this case, resonance shifts give rise to phase

shifts $\Delta\phi$ which then give an image of the magnetic force gradients; see Figure 229-4.

Technical Note:

The Extender electronics give a measure of the phase lag of the cantilever oscillation relative to the piezo drive. This measurement is monotonic versus frequency as is the true phase lag in degrees. The Extender measurement; however, has slightly different nonlinear characteristics *vs.* frequency. The measurement technique allows optimal signal-to-noise ratios; however, absolute values of phase data should be taken as approximate. Users requiring quantitative measures of force gradient are advised to use frequency modulation (See Section 229.2.2).
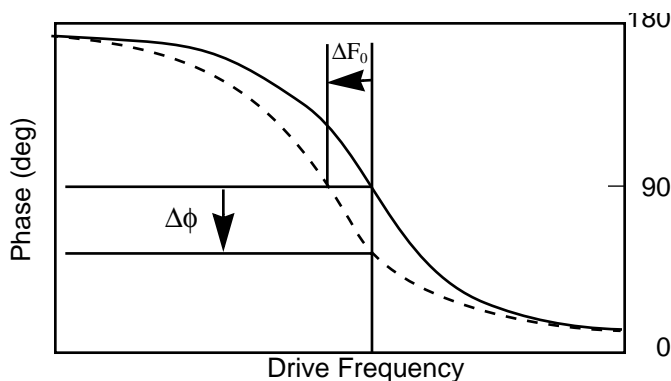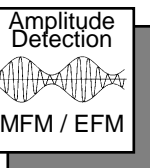
Proceed to Step #4 below.

Figure 229-4 Shift In Phase at Fixed Drive Frequency

Setting a Drive Frequency for Amplitude Detection

Set the **Drive frequency** to the left side of the cantilever resonance curve, as shown in Figure 229-5. This can be done by using the **AutoTune** feature to first find the resonance peak, then using **Offset** under the **Cantilever Tune** menu bar to manually move the drive frequency to the side of the resonance. For maximum sensitivity, set the **Drive frequency** to the steepest part of the resonance curve. As the tip oscillates above the sample, a gradient in the magnetic force will shift the resonance frequency f_0; (see Figure 229-6). Tracking the variations in oscillation amplitude while in LiftMode yields an image of the magnetic force gradients.
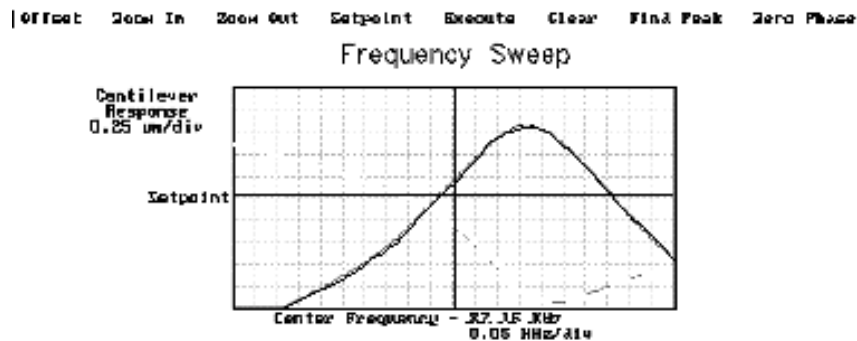
Proceed to Step #4 below.

Offset   Zoom In   Zoom Out   Setpoint   Execute   Clear   Find Peak   Zero Phase

Frequency Sweep

Cantilever
Response
0.25 um/div

Setpoint

Center Frequency - 37.15 KHz
0.05 MHz/div

Figure 229-5 Cantilever Tune for Amplitude Detection

ΔF_0

Amplitude

Drive Frequency

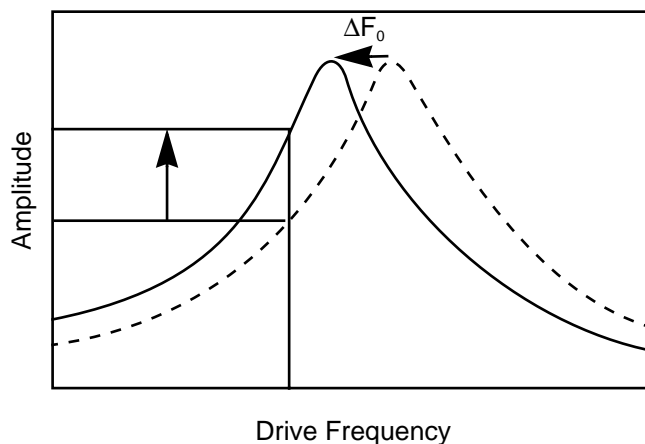**Figure 229-6 Shift In Amplitude at Fixed Drive Frequency**

4. Adjust the **Drive Amplitude** so that the RMS voltage response of the photodetec-
tor is approximately 2 volts. (Somewhat larger values may be beneficial if using
amplitude detection.) This can be done with **Auto Tun**e by selecting an appropriate
Target Amplitude (in this case, 2V) before tuning, or by exiting **Cantilever Tune**
and manually adjusting the **Drive Amplitude** parameter under **Feedback Controls**.

 Quit Cantilever Tune and return to **Image Mode**. Under **Interleave Controls** set
the **Lift start height** to **0 nm**, and **Lift scan height** to **100 nm**. (The lift height can
be optimized later.) Set the remaining Interleave parameters (**Setpoint**, **Drive
Amplitude, Drive frequency**, and gains) to the **Main Controls** values. This can be

done by setting the flags left of the **Interleave Control** column to "off" (grayed bullets).

5. Under **Scan Controls**, set the **Scan size** to **5 µm** and **Scan rate** to **1–2 Hz**. For the left image, set the **Z range** to **75 nm** and the **Line direction** to **Retrace**. Engage the AFM and make the necessary adjustments to obtain a good topographical image while displaying height data. Use the maximum possible **Setpoint** to ensure that the tip is contacting the surface only lightly. The image should be similar to the topographic image shown on the left of Figure 229-7. The surface is fairly flat with lubrication nodules of various sizes. A good image of the nodules provides a check that the tip is sharp.
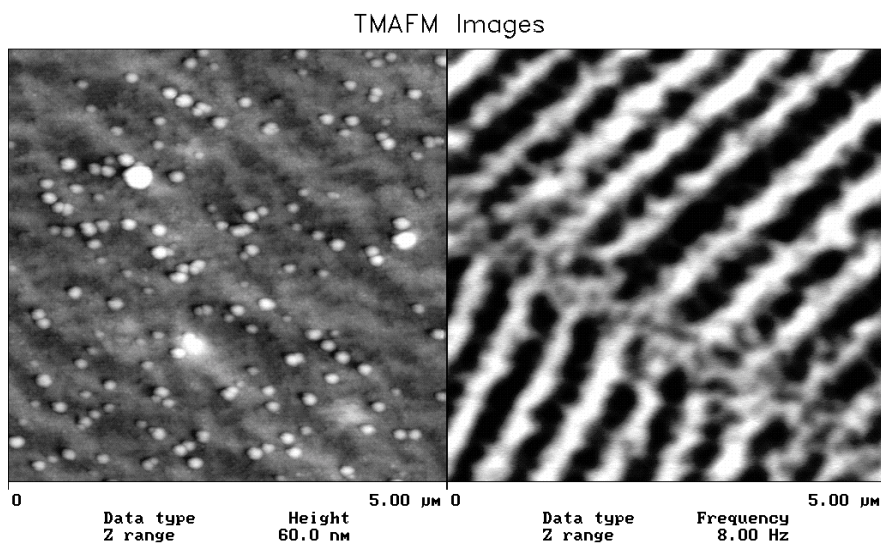
TMAFM Images

| 0 | | 5.00 µm 0 | | 5.00 µm |

| Data type | Height | Data type | Frequency |
| Z range | 60.0 nm | Z range | 8.00 Hz |

Figure 229-7 Topographic (left) and Magnetic Force Gradient Image (right) of Metal Evaporated Tape at 100 nm Lift Height

6. The MFM data can be shown on Channel 2; however, the parameter settings are different depending on whether Phase Detection or Amplitude Detection is being used

Phase
Detection

MFM / EFM

•   **Phase Detection**
    Set the Channel 2 image **Data type** to **Phase**, **Z range** to **3 degrees**, and **Line direction** to **Retrace**.
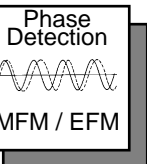
NOTE: It is important that the **Scan direction** be set to **Retrace** for both the main and interleave scans. If instead it is set instead to **Trace**, a band may appear along the left side of the images due to the time taken for the tip to move between the surface and the lift scan height.

Amplitude
Detection

MFM / EFM
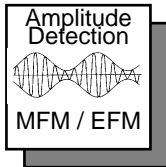
- **Amplitude Detection**
  Set the Channel 2 image **Data type** to **Amplitude**, **Z range** to **1 nm**, and **Line direction** to **Retrace**.

7. Change **Interleave mode** to **Enable** to invoke **LiftMode**. Set the Channel 2 **Scan line** to **Interleave** to display the interleaved data. (This can only be done after **Interleave mode** is **Enabled**.) A magnetic force gradient image similar to that shown on the right of Figure 229-7 should appear as the Channel 2 image. The alternating dark and light stripes represent the recorded magnetic information, and signify a varying resonant frequency and hence magnetic force gradient on the tip. As usual, keep the **Setpoint** as large as possible while consistent with a good image. Wider scans (> 25 μm) will reveal separate tracks in which the magnetic stripes are at different angles.

229.2.2 Frequency Modulation

Phase
Detection

MFM / EFM

With the Extender Electronics Module, it may be desirable to use frequency modulation. This activates a feedback loop which modulates the **Drive Frequency** to keep the cantilever's phase lag at 90 degrees relative to the drive, corresponding to resonance. The frequency **Data Type** displays the resulting shift in **Drive Frequency** in *Hz*, and gives the most direct, quantitative image of force gradients.

To enable frequency modulation, follow the procedure above for obtaining an MFM image with phase detection, but switch the Channel 2 image **Data type** to **Frequency**. Try a **Z range** (frequency shift) of approximately **10 Hz**. Select **Other Controls**, then adjust the frequency modulation gains. Setting both frequency modulation **Integral gain** and **Proportional gain** to **100** is a good starting point. As with the topography gains, the scan can be optimized by increasing the gains to maximize feedback response, but not so high that oscillation sets in. With 225-micron MFM cantilevers, gains are usually in the range of **100–250**.
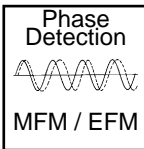
229.3 Troubleshooting Suggestions

229.3.1 MFM Image Verification

The procedure described above should produce a good magnetic force gradient image of the videotape sample. If there is a problem, check that the **Interleave Mode** is set to **Lift**, that **Interleave** is **Enabled** and that the **Scan Line** is set to **Interleave**. Check also that the **Interleave** values of **Drive Amplitude** and **Drive Frequency** are initially set equal to the main **Scan Controls** values.

229.3.2 Saturation in Amplitude Detection

If using amplitude detection, the magnetic force image can saturate (appear completely featureless) if the **Interleave Drive Amplitude** is significantly different than the **Drive Amplitude** in the main scan. Adjust the **Interleave Setpoint** to restore the image. (Note that the **Interleave Setpoint** has no physical effect in **Lift-Mode** since there is no surface feedback during the lift pass.

229.3.3 Optical Interference

When using **Amplitude Detection**, optical interference may sometimes appear in the Lift (magnetic force gradient) image when imaging highly reflective samples. Optical interference appears as evenly spaced, sometimes wavy lines with ~1–2 μm spacing superimposed on the lift image. This occurs when ambient laser light (i.e., light passing around or through the cantilever, then reflecting off the sample) interferes with laser light reflecting from the cantilever. Interference can be alleviated by moving the beam spot up the cantilever away from the tip; about one-third of the cantilever length works well. The adjustment can be refined by carefully moving the beam spot laterally a small distance on the cantilever while scanning until interference fringes are minimized. Be careful not to move the beam off the cantilever or feedback may be lost.

NOTE: Optical interference is essentially eliminated by using <u>phase detection</u> or <u>frequency modulation</u>.)
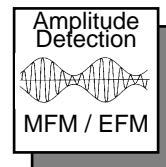
229.4 Advanced Topics

229.4.1 Lift Scan Height and Magnetic Imaging Resolution

The most important parameter affecting imaging resolution is the **Lift scan height**. The range of 10–200 nm is most useful. In general, MFM resolution is roughly equal to the lift height: smaller **Lift Scan heights** give better resolution; conversely, magnetic features smaller than the **Lift Scan height** may not be resolved. The tip also experiences stronger fields close to the surface, giving improved signal-to-noise ratios.

For example, the image of metal-evaporated tape in Figure 229-7 has a resolution limited by the 100 nm **Lift Scan height**. To improve the resolution, try reducing the **Lift scan height** to ~ **25 nm**. Ensure that the tip does not strike the surface on the low point of its swing in the Lift image. Tip strikes appear as black or white spots, or even noisy, high-contrast streaks crossing the image. If the tip begins to strike the surface, reduce the **Interleave Drive Amplitude**. (In general, MFM tips are not damaged by intermittent tip strikes, except in extreme cases of very large amplitude and small lift heights.) An example of an image of the metal-evaporated tape taken with a **Lift scan height** of **30 nm** is shown in Figure 229-8. Note the fine magnetic structure that is not visible in Figure 229-7. When imaging a sample for the first time, begin with moderate **Lift scan heights** (**50 nm or greater**), then adjust downward. On relatively smooth samples (e.g., hard disks), lift heights down to 0 nm can be used, as long as the drive amplitude is adjusted accordingly. (Lift scan heights of 0 nm still correspond to a non-zero mean tip-sample distance. See the section on **Setpoint** below.) It is usually not beneficial to use **Lift scan heights** much smaller than the surface roughness. Users are encouraged to experiment for the best images on their samples.

The ultimate resolution of MFM with the NanoScope III is near 20 nm. Resolution is affected by properties of the tip, including mechanical sharpness and magnetic structure. When in good condition, NanoProbe magnetically coated tips routinely give 50 nm resolution, and many achieve 30 nm or better.
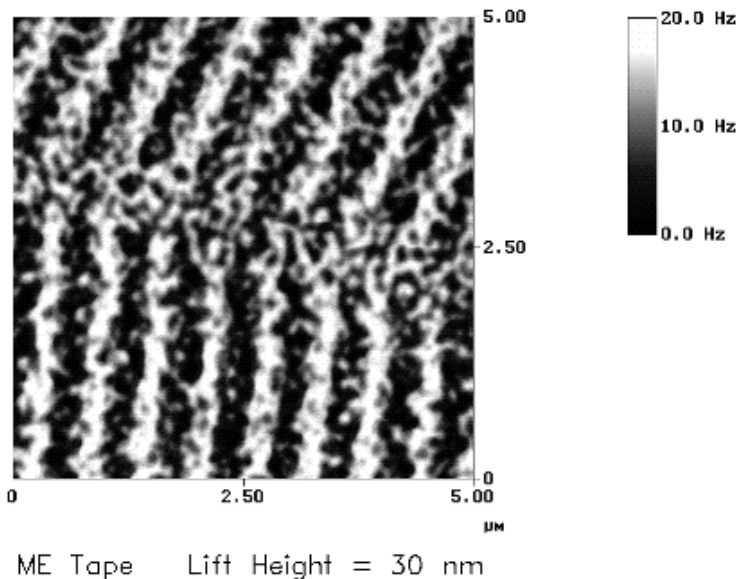
ME Tape   Lift Height = 30 nm

**Figure 229-8 High-resolution Magnetic Force Gradient Image of
Metal Evaporated Tape at 30 nm Lift Height**

229.4.2 Fine Tuning Interleave Controls

Certain scanning parameters found under **Interleave Controls** can be set to values
in the Interleave (Lift) scan that differ from the values in the main scan. These
parameters are enabled by clicking on the circular flag to the immediate left of the
desired Interleave control, toggling its state from "off" (gray bullet) to "on" (green
bullet). When the flag is set to "off", the main scan control parameter setting takes
precedence. When the flag is set to "on," the displayed Interleave scan value is
active, overriding the main scan value.

Drive Amplitude

For MFM, of particular use is the Interleave **Drive Amplitude**. This parameter can
affect a magnetic force image in a variety of ways.

- Increasing the **Drive Amplitude** can improve the signal-to-noise ratio when
  using phase detection or frequency modulation. This is because intrinsic, low-
  level noise interferes less when measuring the phase of a larger cantilever oscil-
  lation amplitude and hence stronger photodetector output. As an illustration, try
  setting the Interleave **Drive Amplitude** to **0**; the resulting phase image will be
  pure noise because measuring the phase of a non-oscillating cantilever is mean-
  ingless.

In **LiftMode**, the Interleave **Drive Amplitude** can often be set to a value larger than in the main scan, thus giving optimal signal-to-noise. In some cases this is beneficial as long as the **Drive Amplitude** is not increased to the extent that the tip strikes the surface on the low point of its swing. The signatures of tip-sample contact are white and black spots in the image, or, in extreme cases, noisy, high-contrast streaks across the whole image. It is usually safe to increase the **Drive Amplitude** until the first signs of tip strike are noticed, then reduce the amplitude slightly.

CAUTION: Before enabling the Interleave **Drive Amplitude**, check that its value is not much larger than the main **Drive Amplitude** value. This will prevent the cantilever oscillation from jumping to a very large amplitude when the parameter is enabled, possibly damaging the tip. The **Drive Amplitude** can be adjusted even when the parameter is disabled (i.e., when the flag is set to "off" (gray bullet)).

Amplitude
Detection

MFM / EFM
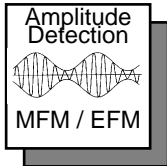
- When using amplitude detection, variations in **Drive Amplitude** affect sensitivity and image contrast as well as signal-to-noise ratio. This is because changes in the oscillation amplitude change the slope of the amplitude *vs.* frequency curve, and hence the effective sensitivity; see Figure 229-6. With phase detection and frequency modulation, changes in amplitude produce no change in contrast, and results are thus more reproducible than with amplitude detection.

NOTE: On some microscope models, there is a lowpass filter in the scanning electronics that prevents fast switching of the **Drive Amplitude** between main and Interleave scanning. This can interfere with very fast rates (> a few Hz).

Setpoint

For the most reproducible results, it is best to use a consistent setpoint. In **Lift-Mode**, the total tip-sample distance h_{tot} is the sum of the average tip-sample distance in TappingMode h_T, and the lift scan height h_{lift} (see Figure 229-9). In **TappingMode**, the average tip-sample distance h_T is equal to the oscillation amplitude, which is determined by the setpoint. Large variations in setpoint can thus change the total tip-sample distance in **Liftmode**, sometimes with visible results in the magnetic image. For this reason, reproducible results are most easily obtained by using consistent setpoints. Note that a lift scan height of 0 nm still gives a mean tip-sample distance of h_T in **LiftMode**.
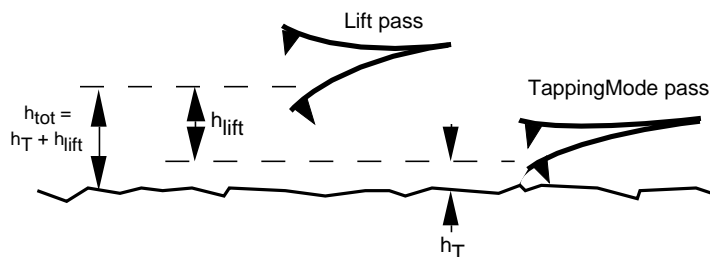
Figure 229-9 Tip Heights and Oscillation Amplitudes in TappingMode and LiftMode

The relationship between setpoint voltage and oscillation amplitude is known as the *sensitivity*. Its value can be determined with **Force Calibration**; see Chapter 11 in the product instruction manual. For 225 μm MFM cantilevers, the sensitivity is typically in the range 15-20 nm/V. (The exact value depends on the position of the laser spot on the cantilever, the cantilever geometry, and the particular instrument.) A 1V **Setpoint** typically corresponds to h_T ~15-20 nm.

229.5 Installation of Extender Electronics Module

In the Spring of 1994, Digital Instruments began making available its Extender Electronics Module (sometimes referred to as "phase box" or "phase extender") for customers wanting phase detection and frequency modulation MFM. Hardware changes, different for each system type, are required to retrofit Dimension Series systems or MultiMode systems originally shipped without the Extender Electronics module.

For Dimension systems, the Extender is installed using 37-to-37 pin ribbon cables between: 1) the NanoScope III or IIIA SPM controller and the Extender Electronics Module; as well as 2) from the Extender to the microscope. The hardware change consists of replacing the main electronics backplane board at the rear of the microscope (this may be done by either the customer or a factory representative). Detailed installation instructions are provided with the new hardware when shipped. For more information, contact Digital Instruments.

For MultiMode systems, the Extender is installed using a 37-to-37 pin ribbon cable between the NanoScope III or IIIA SPM controller and the Extender Electronics

Module, and a 37-to-25 pin ribbon cable from the Extender to the microscope. The hardware change consists of replacing a circuit board in the base of the microscope (this may be done by either the customer or a factory representative). Detailed installation instructions are provided with the new hardware when shipped. For more information, contact Digital Instruments.

229.5.1 Setting the Extender Electronics for Dimension or MultiMode

The Extender Electronics box is equipped with a slider switch for switching internal electronics between Dimension-series and MultiMode SPM signals. This switch may be accessed through a hole on the underside of the box. In the drawing below, the switch is set to "**Dimension**".

Dimension
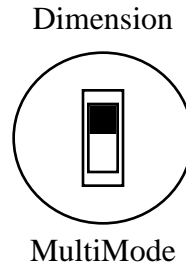
MultiMode

For Dimension-series SPMs, the switch should always be set to "**Dimension**", and for MultiMode SPMs, it should be set to "MultiMode". Use a pencil to access the switch through the hole. **CAUTION!** Do not insert a conducting object (e.g., screwdriver) into the Extender box.

229.5.2 Microscope Parameter Files

There are two parameter (par) file contexts that are used with the Extender Box: Extended AFM and Extended STM. The former of these two contexts is used for the following operational modes: contact AFM, TappingMode AFM, LFM, MFM, force modulation, electric field measurement and others. The latter context is for use only with STM.

For each scanner intended to be used with the Extender, there must be a PAR file for the context required. For example, if there are three scanners, all intended for both STM and AFM use, a total of six PAR files are required.

(**NOTE:** Due to the many Digital Instruments' microscope systems available, the variety of scanners, when the system was purchased, and the system's history of software updates, not all systems will have PAR files with the same name or naming scheme. You can determine the exact name of the PAR file to be modified by using the `DOS EDIT` file editor to list the contents of the file `/SPM/SYS-TEM.PAR`. The name of the most recent PAR file in use will be on the line that starts with the words `\Microscope file:`. **Caution:** When closing the `System.par` file after viewing it, if you are asked to SAVE the file or to SAVE CHANGES, be sure to say **No**.)

To modify the PAR files on a MultiMode or Dimension system, locate the proper PAR file in the `/SPM/EQUIP` directory on your computer. Use a text editor to modify the file. The text must be saved as plain ASCII (standard DOS text). DI recommends using the DOS EDIT file editor. (Microsoft Word® or other similar desktop-editors normally save files with embedded formatting commands causing the par files to be unreadable by the NanoScope software.) Using the EDIT program, modify the file to include a new line at the bottom of the file. For example:

If the line

`\Is FM: No`

 is present in the file, then change the line to read:

`\Is FM: Yes`

If the line

`\Is FM: No`

 is not present, add the line:

`\Is FM: Yes`

Then locate the line:

`\In Polarity: Reverse`

and change it to read:

`\In Polarity: Forward`

Then locate the line:

```
\In Polarity: AUX D: Reverse
```

Change it to read:

```
\In Polarity AUX D: Forward
```

Repeat the above procedure for each scanner (i.e. PAR file) in use. After the cables are connected, power up the NanoScope controller and start the microscope control program.

229.5.3 . Important Points

1. Extender-compatible microscope electronics are required to permit operation of the phase detection extender option. Standard electronics on these microscopes require hardware upgrades. Consult your Digital Instruments sales representative for details.

2. Turn off the power to the NanoScope controller whenever connecting or disconnecting the Extender.

3. In **LiftMode**, the best performance is obtained if the RMS amplitude is kept below 7.0 volts, the limit of the RMS output's linear operation.