# *DI AFM Nanoscope Dimension 3100:*

# *Atomic Force Microscope*

**(afm2)**

## *1.0 Title, Ownership & Training*

Digital Instruments Nanoscope 3100 atomic force microscope. This tool belongs to the research group of Professor Jeffrey Bokor, and is administered directly by students in his and Prof. V. Subramanian's group. All users must first be cleared by Prof. Bokor, pass a written test, and an oral test that certify not only the knowledge but also the proficiency of the operator. It is obligatory that the potential user undergo a significant amount of hands-on training, and gain a solid understanding of the equipment before taking the qualification tests.

## *2.0 Purpose*

This manual describes basic operation of tapping mode surface contour measurements.

## *3.0 Scope*

### 3.1 Overview / Application

The DI-3100 is an Atomic Force Microscope particularly suited for handling semiconductor wafers and die for device microscopy. It is capable of various Scanning Probe Microscopy techniques including Contact, Tapping, Scanning Tunneling and Lateral Force Modes, although Contact and Tapping Modes are the most prevalently used on the DI-3100. Both Contact and Tapping Mode are well suited for topographical imaging of surfaces, with vertical resolution ranging from one micron down to sub nanometer scales. All of these techniques share a common approach where a motor controlling a mechanical tip is placed in a feedback loop as the tip is scanned across a surface. The mechanism upon which the feedback is based is the predominant difference between the modes. Surface imaging and analytical studies of roughness are common uses for this tool.

### 3.2 Sample Preparation / User Policy

3.2.1 The DI-3100 has a vacuum chuck that can hold 4" and 6" wafers. The switch for the vacuum is on the upper right hand side. The vacuum is weak however and will not hold smaller pieces. For smaller individual samples a magnetic sample holder (located on the AFM bench) is available. The magnetic sample holder adds significant height to the sample with respect to the chuck and added caution is required when translating the stage near the SPM. For non-magnetic samples, double-sided adhesive (also located on the AFM bench) tabs can be used to stick samples to the chuck. Be aware that the adhesive contaminates mounted samples and should only be used for end-of-process samples. Users can also have custom sample holders machined for use with this tool. Minimal force is needed to keep samples in place.

3.2.2 The materials policy for imaging is fairly broad. Most materials related to semiconductor fabrication are allowed in this tool, including gold, photoresist, parylene, copper, etc. If a user feels he/she has a non-standard material, please check with a superuser first.

**3.2.3** Samples to be imaged must be relatively planar to avoid having the scan head crash into features on sample. The scan head nominally focuses approximately one millimeter off of the substrate, with the cantilever tilted slightly down. Hence, vertical features or any tilt on the order of one millimeter needs to be handled with caution. Users may use their own judgment if they believe areas of the sample may be safely imaged without endangering the scanner. However, excessive tall vertical features that cannot be easily navigated around should not be imaged on this device. Once the sample is navigated to a safe area

for engaging (landing) the cantilever however, the topographical features to be imaged must have nominal roughness on the order of one micron or less. ***Although millimeter tilt or features are tolerable on the sample it self, the area to be imaged must not have any topography higher than approximately one micron.*** Rough topography on the order of microns can break the cantilever while scanning, but millimeter scaled features may damage the scan head (which is NOT replaceable). ***Reread this section after studying Section 9.0 of this manual if necessary. The sample requirements here differentiate between topography encountered while translating the stage to an imaging location (before the scanner is engaged), and topography encountered during an actual scan (after the scanner is engaged).***

3.2.4 A default tip is NOT loaded in the scan head. All users must supply their own tips.

3.2.5 All users must use latex gloves while touching any component of the AFM, and must leave the chuck clean. However due to the various materials imaged (e.g. gold, photoresist), wafers imaged by the AFM are no longer VLSI-clean. If there are special needs, please consult staff.

3.2.6 The scan head used can image a maximum field of approximately 100 µm x 100 µm. If a larger lateral displacement is required, use other Microlab tools (e.g. ASIQ, Dektak).

3.2.7 Both tapping mode and contact mode are commonly used. Other modes are possible on the DI-3100, however users are required to discuss these with superusers.

## *4.0 Applicable Documents*

Revision History

4.1 After becoming familiar with the aspects covered in this overview of the AFM, it is recommended that users look over the **Scanning Probe Microscopy Training Notebook** provided by Digital Instruments. This provides some additional information on some of the data analysis and modification tools described above as well as tips on imaging techniques and artifacts. The section on **Imaging Artifacts** at the end is particularly recommended. A copy of this training manual is located next to the AFM.

4.2 Advance users of the DI-3100 are also encouraged to utilize the **Command Reference Manual** provided by Digital Instruments. This manual is available upon request.

## *5.0 Definitions & Process Terminology*

### 5.1 TAPPING MODE

Tapping Mode is the most common imaging technique used with the DI-3100. This mode operates by scanning a tip attached to the end of an oscillating cantilever across the sample surface. The amplitude of oscillation ranges from 20 nm to 100 nm, with the frequency near the resonant peak of the cantilever. The tip lightly 'taps' the surface, altering the oscillatory motion as the scanner moves across the surface. By adjusting the vertical position of the scanner to maintain a constant RMS signal of oscillation, a surface is imaged. The oscillation is measured by a laser positioned by the user to reflect signal into a photodiode detector)

Advantages

5.1.1 Higher lateral resolution on most samples (1 nm to 5 nm)

5.1.2 Lower forces and less damage to soft samples imaged in air

5.1.3 Lateral forces are virtually eliminated, so there is no scraping

Disadvantages

5.1.4 Slightly lower scan speed than contact mode AFM

5.1.5 For tapping mode, use an etched single crystal silicon probe tip (TESP/RTESP). This probe is a silverish color and is available in the Microlab for check out. *(See Section 9.0*

*for probe tip policies).* Standard TESP/RTESP tips have a resonant frequency ~300 kHz and have cantilevers 125 µm long.

## *6.0 Safety*

Large voltages (upwards of +/- 220V) are applied in order to actuate the piezo. While these voltages nodes are shielded from human contact, care must be exercised, especially if they are accessed through the break-out box.

## *7.0 Statistical/Process Data*

## *8.0 Available Process, Gases, Process Notes*

## *9.0 Operating Procedure*

### 9.1 Tip Mounting

If you need to load a new tip:

9.1.1 Open the hood to the AFM and *tighten* (turn clockwise) the knob attached to the dovetail. This lifts the SPM slightly so that it can be removed. Unplug the cord and gently slide the SPM out of the dovetail and place it on the workbench.

9.1.2 Remove the Cantilever Holder from the SPM and place it onto the cylindrical tip mounter.

9.1.3 Pull the metal spring back, load tip using the etched guides and replace spring. Check that tip is mounted firmly and is secure. Use sharp tweezers when handling the tip, and *only* touch the probe by the side edges.

9.1.4 Replace the Cantilever Holder. DO NOT APPLY TWISTING MOTIONS when placing the cantilever holder onto the head. Doing so will DAMAGE THE PIEZO SCANNER. The piezo scanner is made of a half-cylinder of piezo crystal, which is extremely fragile and expensive to replace or repair. Place the SPM into dovetail. Gently *loosen* knob to allow the SPM to fall into place. Reconnect the cord.

### 9.2 System Startup

9.2.1 You must follow the following procedures exactly. Without starting the nanoscope software first, random voltages (which maybe very large) will be applied to the piezo scanner, causing possible damage.

9.2.2 Enable the DI-3100 on the wand.

9.2.3 Start Nanoscope software (icon on desktop).

9.2.4 Turn on the microscope controller and facilities.

9.2.5 Under the **DI** menu, select **Microscope Select** and choose **Quadrexed3100**. (A DI Multimode AFM shares this controller and software and may have been setup prior).

9.2.6 Verify at the bottom Status Bar that **TappingAFM** Mode is displayed.

### 9.3 Align the Laser to the Tip

9.3.1 While looking at the trace of the laser beam, turn the upper knob at the top of the SPM clockwise until the intensity of the trace just becomes very dim (start with the laser trace towards the left). This means the laser has just hit the substrate off of which the 125 µm cantilever is mounted. Turn the upper knob <1/4 turn counter-clockwise to bring the laser just off the substrate.

9.3.2 By turning the lower knob in either direction (the laser trace should move towards and away from you), find the point at which the laser is just shadowed by the cantilever. It should only require less than 1/8 turn to move on and off the cantilever; if it requires more than this, the laser is most likely hitting the substrate and you need to back off slightly.

9.3.3 Check the viewport on the side of the SPM to confirm the laser is approximately aligned to the cantilever with the red dot centered.

9.3.4 Move the laser with the upper knob until the laser is approximately at the end of the cantilever. Adjust either knob in small increments to maximize the **Laser Sum Signal**, as displayed on the right monitor.

### 9.4 Adjust the Photodetector

9.4.1 Use the two knobs located at the left of the SPM to adjust the photodetector.

9.4.2 Look at the laser signal on the right monitor and try to center the red dot at the center of the cross.

9.4.3 Try to get ~0V vertical deflection.

9.4.4 Sum should be ~2 (or slightly less).

### 9.5 Align the Microscope to the Tip

9.5.1 Select **Stage** → **Locate Tip** from the top menu. You should do locate tip before focus surface. Doing it the other way risks crashing the tip.

9.5.2 The tip will move up and down before stopping to help you find it. Zoom out if necessary. There needs to be reflective light to adequately see the tip: Use the chuck if necessary. To move chuck, use the **Focus Surface** instructions that follow.

9.5.3 Use the two knobs at the left of the optical objective on the camera to center the cantilever under the cross hairs.

9.5.4 Use the trackball to focus on the tip as best as possible (requires holding down the left **Focus** button on trackball).

9.5.5 If you cannot find the tip when zoomed in, it may be too far from the surface to reflect light. Use “focus surface” to lower the head slightly and try again.

### 9.6 Focus on the surface of the sample

9.6.1 Load your sample. Use the chuck and vacuum, magnetic sample holder studs, or provided double sided adhesive to fix your sample onto the chuck. (Note: The travel on the chuck is limited so keep your sample on the upper half of the chuck if possible. The chuck can also be manually rotated if necessary.)

9.6.2 Select **Stage** → **Focus Surface** from the top menu.

9.6.3 Check visually to ensure that there is enough clearance such that the sample can move under the SPM with adequate clearance. ***There is no interlock or detection mechanism preventing users from crashing their samples into the SPM,*** so make conservative estimates. If there is not enough clearance, hold down on the **Focus** button on the trackball, and push the ball upwards; this lifts the SPM.

9.6.4 Use the trackball to move the wafer under the SPM (note the top of the trackball orients towards the back of the DI-3100).

9.6.5 Follow instructions on screen to focus on the surface of your sample. ***Watch both the monitor and the SPM itself when focusing; it is possible to crash the head into the sample when trying to focus and this will damage the tip AND SPM. The SPM should be at least 2 mm above the surface (although you will need to be closer than 5 mm) to focus.***

9.6.6 **Tips**

9.6.6.1 Use the **Lock** button in any mode to lock in your fastest movement on the trackball.

9.6.6.2 Always **Zoom Out** before trying rough focusing.

9.6.6.3 It is typically easiest to focus on the edge of a wafer (especially if the features on your wafer are small) as this provides a guaranteed 500 µm of relief that is relatively easy to find.

9.6.6.4 Focus Surface is one of the few modes that allow you to move the chuck. You can do this step before **Locate Tip**, as that typically also requires the chuck to be under the SPM.

9.6.6.5 Instructions for available functions of the trackball are displayed in the **Focus Surface** window. This is also true for other modes such as **Locate Tip**.

9.6.7 After rough focus, find the features to be imaged, zoom in and refocus. Center desired feature in view.

***Note: Users must always both Locate Tip AND Focus Surface (zoomed fully in) for every new sample that is loaded. Whenever moving to new sections of a sample, the user must also repeat Focus Surface, even if there is no specific topography to be imaged. The DI-3100 calculates the difference in working distance between the tip and the surface in order to estimate how far it must lower the SPM head.***

## 9.7 Tuning the Cantilever

9.7.1 Select **View** → **Cantilever Tune** from the top menu (or click the tuning fork icon).

9.7.2 Check that **Auto Tune Controls** has a frequency sweep from 100 kHz to 500 kHz, with a Target Amplitude of 2 - 3 V. Rough surfaces may do better with a Target Amplitude set at 0.5 - 1 V.

9.7.3 Click on the **Auto Tune** button.

9.7.4 A classic resonant peak curve should appear with a resonant frequency around 300 kHz. (A frequency outside of 220 - 320 kHz warrants a tip change.) Note the software picks a frequency slightly below the resonant peak to account for damping that occurs when the tip approaches a surface.

9.7.5 Return to Image mode.

## 9.8 Set Initial Scan Parameters

9.8.1 In the Scan Controls panel, set the initial scan parameters to a conservative setting. A good start is a Scan Size of 1 µm, X and Y Offsets of 0, a Scan Angle of 0, and a Scan Rate of 2 Hz.

9.8.2 In the Feedback Controls panel, set Integral Gain to 0.5, and Proportional Gain to 0.7.

9.8.3 Channel 1 is typically set to collect Height data, while Channel 2 collects Phase data. Line Direction should be set to Trace, Real Time Plane Fit should be Line, and Offline Plane Fit to None. Both High and Low Pass Filters should be Off. Other types of data collection can be selected if desired for either channel, although only two channels can be saved at once.

## 9.9 Engaging the Surface

9.9.1 Select **Motor** → **Engage** from the top menu (or click on the green down arrow **Engage** icon) to engage the tip (the motor value located at the bottom of the monitor displays the number of microns the motor has moved down from its original position).

9.9.2 Wait until the tip engages the surface.

9.9.3 Once contact with the wafer surface occurs, go to **View** → **Scope Mode** (Or click the **Scope Mode** icon. This will show the Scope Trace on the right monitor allowing you to view the trace and retrace of the sample.

**<u>If it fails to engage because the tip is too far from the wafer</u>**

9.9.3.1 Go to **Motor/Withdraw** then go to **Stage/Focus Surface**.

9.9.3.2 Using the roller, manually move the SPM 50-100 µm more negative.

9.9.3.3 Repeat "**Engage**" until motor no longer fails.

**If it fails to engage because the tip is too close to the wafer**

9.9.3.4 Go to Motor/Withdraw 2 - 3 times.

9.9.3.5 Using the roller, manually move the SPM 50 - 100 µm more positive.

9.9.3.6 Repeat "**Engage**" until motor no longer fails.

## 9.10 Z-Offset

9.10.1 In the "scope mode", the right-hand side of the screen shows the "Z-Offset Voltage". This is voltage applied to the piezo to maintain constant oscillation amplitude. If it is substantially different from zero, go to **Motor** → **Step Motor** and click on "tip up" or "tip down" to bring the Z-Offset to about zero. Doing so will avoid applying a large, sustained voltage to the piezo. Large applied voltages tend to depole the piezoelectric material and cause it to lose its sensitivity permanently.

## 9.11 Scanning Technique

9.11.1 Go to **View** → **Scope Mode** (or click on the Scope Mode icon).

9.11.2 Check to see if Trace and Retrace are tracking each other well (i.e. look similar). If they are tracking, the lines should look the same, but they will not necessarily overlap each other, either horizontally or vertically. It may help here to disable the Slow Scan Axis, forcing the SPM to image the same line over and over.

9.11.3 **If tracking well (tip is scanning on the sample surface)**

9.11.3.1 Click on Setpoint and use right arrow key to gradually increase the Setpoint value, until the tip lifts off the surface (at this point the Trace and Retrace will no longer track each other).

9.11.3.2 Next, decrease the Setpoint with the left arrow key until the Trace and Retrace follow each other again.

9.11.3.3 Decrease the Setpoint 1 - 2 arrow clicks more to ensure that the tip will continue to track the surface. Occasionally the tip will lift off of the surface during a scan and the setpoint will need to be re-lowered.

9.11.3.4 If necessary, increase the Integral Gain until the tracking between Trace and Retrace lines is optimal. Over increasing the Integral Gain will result in noise showing up on top of the signal. Proportional Gain should also be adjusted in the same direction as Integral Gain, remaining 30 - 100% higher in value. Integral Gain is a high frequency parameter, while Proportional Gain is a low frequency parameter. Both modulate the response time of the applied feedback.

9.11.3.5 Go to View → Image Mode (or click on the Image Mode icon) to view the image.

9.11.4 **If not tracking well**

9.11.4.1 Adjust the Scan Rate, Gains, and/or Setpoint to improve the tracking. Using the arrow keys (left/right) increments each parameter by a recommended amount. Wait 1 - 3 scanlines after each adjustment to allow the SPM to settle.

9.11.4.2 Scan Rates and Setpoints depend significantly upon the type of sample being imaged. Recommended scan rates are 2 Hz for scan sizes 1 - 3 µm, 1 Hz for 5 - 10 µm, and 1.0 - 0.1 Hz for larger scans. Samples with larger steps typically need slower scan speeds. Decreasing the Setpoint increases the amplitude of oscillation of the cantilever, although too high a value may lead to distorted

images and damage of soft films. Increasing the Integral and Proportional Gain can also improve tracking by decrease the response time of the feedback loop.

9.11.4.3 If there is noise riding on top of image signal (i.e. signal oscillation *not* the same in the trace and retrace directions), decreasing the Gain may help.

9.11.5 **Tips**

9.11.5.1 Scan Size, Scan Angle, and other parameters can be modified after features are located.

9.11.5.2 Decreasing Samples per Line and the Resolution of the scan can speed up rough scans to allow the user to locate small features by producing a quick rough image.

9.11.5.3 In Image Mode, **Offset** and **Zoom In/Out** can be used to reposition the cantilever within the current scan window without manually typing in x/y offsets (click on execute after placing a cursor or box). Such repositioning however is only accurate within microns of displacement and may not work well with small scans.

9.11.5.4 After a large displacement by the scanner (including forcing the SPM to the top or bottom of a scan), there may be significant 'creep' distortion observed in the scanned image. This should fade with time, and image capture can begin after the creep has settled. For large displacements, it may take more than 1 scan for the creep to completely settle out.

9.11.5.5 Remember that the scan rate needs to be adjusted when scan sizes are enlarged.

9.11.5.6 Typical tapping mode tips are anisotropic in shape and can give higher resolution imaging depending on scan angle. Consult either the DI website or user manuals for more information (this typically only an issue for very thin imaging).

9.11.5.7 Further advice and more advance image adjustment techniques are available in DI-3100 manuals that are available upon request from the superuser (Section 5.0).

**Note:** ***The piezo crystal that is utilized by the SPM is subject to stress and wear, especially with the application of large DC offsets. After the SPM head is engaged, it relies upon the piezo crystal for lateral displacement (i.e. X Offset and Y Offset); hence large (> ~20 µm) displacements in the scanning field tend to stress the crystal more than average and are to be avoided if possible. Large scans have the same effect, and since large scans often required a slow Scan Rate (and hence long scan time), they tend to particularly stress the piezo. If step heights are the main function for such sweeps, use of either of the Microlab profilometers (asiq/Dektak) is recommended instead.***

## 9.12 Image Capture

9.12.1 In **Image Mode**, image captures consist of raw data from the AFM, yielding all possible information. In **Scope Mode** the image capture grabs a screen shot of the scope output and is not as useful. ***Remember to be in Image Mode when capturing images.***

9.12.2 Select **Capture** → **Capture Filename** to set the file name. (Use the extension .**001** for the first file of a series. The software will then increment each subsequent capture to **002**, **003** and so on.

9.12.3 Make sure the hood is closed while capturing the image to prevent optical noise from disturbing the photodetector.

9.12.4 Select **Capture** → **Capture** (or click on the **Eye Icon**) to begin capture. At the bottom of the screen, the Capture bar should say either **Capture: On** or **Capture:Next**. **Capture:On** means the capture has begun and will end when the scan reaches the opposite end of the

screen. *Changing any essential control parameters will halt the scan and require you to start the scan over.* **Capture:Next** means the image capture will begin after the scanner reaches the top or bottom of the screen. You can force the scanner to go to the top or bottom by using the respective icon. When the capture is done, **Capture:Done** will appear in the Capture bar.

9.12.5 Typically data is saved **Offline** with no plane fitting. This allows you to save data directly from the AFM, and perform analysis and corrections (leveling, flattening, etc.) offline. If desired, **Offline Planefit** can be set to **Full** under the Channel 1/2 Control Panel.

9.12.6 Clicking on Capture twice in a row enters **Capture:Forced** mode, where you can force a capture to begin mid-screen.

9.12.7 By default, captured images go into the **!:/** directory and can be viewed and analyzed in **Offline Mode**. ***All users are responsible for saving their data to disk immediately after use.*** There is a Zip™ and floppy Drive on the computer that can be used to retrieve files. The computer may be formatted at any time as files build.

### 9.13 Liftoff / Shutdown Procedure

9.13.1 When done imaging, lift the SPM by selecting → **Withdraw** (or clicking the red up arrow icon).

9.13.2 If a subsequent scan is desired, select **Stage** → **Focus Surface** and move the sample to the new area. ***Always be aware of any topography on samples that may be high enough to crash into the head when translating the stage.***

9.13.3 If ready for unload, check to see if there is enough clearance to withdraw the head. If not, select **Stage** → **Focus Surface** and defocus such that the head rises sufficiently.

9.13.4 Select **Stage** → **Load New Sample**. This should further raise the SPM and pull the chuck out to the unload position.

9.13.5 Turn off the vacuum and unload your sample.

9.13.6 If double-sided adhesive was used, use methanol or ethanol and Kim-wipes to clean the chuck of all adhesive (to prevent damaging chuck vacuum tubing, do not use acetone).

9.13.7 Exit software and ***then*** turn off controllers.

9.13.8 Disable the AFM on the wand and close the hood.

9.13.9 **Note:** ***Exiting the software and then turning off the controllers avoids stressing the Scan Head. However, leaving the controllers ON while turning the computer OFF results in floating voltages driving the piezo in the SPM. This situation is highly stressful for the piezo crystal and will result in rapid deterioration of the Scan Head.***

### 9.14 Data Retrieval / Image Analysis

9.14.1 Captured Data can be analyzed by selecting **Offline Mode** (or clicking on the Offline Mode icon in the upper right hand corner of the left monitor. By default the file browser opens to the Capture Directory, labeled **!:**.

9.14.2 Image analysis can only be performed on one channel of data at a time. **Select Image** → **Select Left <Right> Image** to perform analysis on the left <right> image. When an image is selected, typically the left monitor is used to adjust parameters, while the right monitor allows for selection of partial areas, drawing of scales/lines, and execution of desired functions.

9.14.3 Typically, while in Microscope mode, a Real-time Linefit is used to display collect image data. For most scans, a linefit is required to visually interpret the data. Offline however, it is recommended that the data be captured in its raw form. Hence when first viewing captured

data offline, the image will often appear either warped or non-existent. While it is desirable to modify the raw image data as little as possible, often some type of fit or flattening is required. In many cases this fitting process is iterative, with better planefits/flattening possible as the image becomes clearer. The functions used to fit/flatten/filter data are located under the Modify menu. Commonly used functions include:

9.14.3.1 Planefit Auto/Manual - Planefits are commonly used to remove bow or tilt from images. Planefit calculates a single polynomial fit for the entire image (or selected areas) and then subtracts the polynomial fit from the image. Manual mode allows for the planefit to be calculated from a manually positioned line.

9.14.3.2 Erase Scan Lines - Removes scan lines from image due to skips, noise, etc. The selected line is replaced by the average of the two adjacent lines.

9.14.3.3 Flatten - Flatten may be used to remove image artifacts due to vertical (Z) scanner drift, image bow, skips, etc. It modifies the image on a line-by-line basis, removing the vertical offset between scan lines in the fast scan direction by calculating a least squares fit polynomial for a scan line, and subtracting it from the polynomial fit from the original line. This makes the average Z value of each scan line equal to 0V. ***The result is that information in the Y direction is removed.*** Hence when there are regular feature heights, it is best to scan *across* these features in the fast scan direction (i.e. the tip is scanned directly over the step instead of along the step). On smooth surfaces, Flatten has negligible effect on roughness measurements.

9.14.4 There are many Image Analysis tools available under the **Analyze** menu. Commonly used tools include:

9.14.4.1 Section - Depth, height, width and angular measurements can be easily made on cross-sections with Section.

9.14.4.2 Roughness - Roughness measurements over both an entire image or a selected area, can be calculated. Different parameters can be chosen using the **Screen Layout** button.

9.14.5 Different views are also selectable including 3-D isometric views, lit from any angle.

9.14.6 When modification and analysis is complete, data can be exported to a variety of formats including TIFF and JPEG. The raw data can also be saved allowing for custom data manipulation and analysis. Remember to save any desired data onto a Zip™ or floppy disk. It is advisable to always backup raw captured data onto disk along with any processed data. Raw data can always be re-examined on the Nanoscope software without turning on the controllers if the user directly selects Offline mode.

## *10.0 Troubleshooting Guidelines*

## *11.0 Figures & Schematics*

## *12.0 Appendix*