Discussion

The Piezo Task adds to the standard Hysteresis Task the automatic measurement of the output of a displacement meter that detects motion at the surface of a Piezoelectric sample that is stimulated by the Hysteresis drive profile. The displacement meter output is connected to the "Sensor" input at the rear of the Precision tester. Radiant Technologies, Inc. normally provides an MTI-2000 meter to detect displacement in a bulk sample. However, any meter may be used provided it produces a voltage of not greater than ±10.0 Volts that is linearly related to the displacement:

$$\text{Meter Voltage} = m \times \text{Sample Displacement} + b \quad (1)$$

Where m is a scale factor and b is an offset value. Radiant Technologies has demonstrated that an Atomic Force Microscope (AFM) can be used in conjunction with the Precision test system and Piezo Task to characterize the piezoelectric response of a thin film sample. The figure shows a typical experimental configuration for a bulk sample using the MTI sensor.

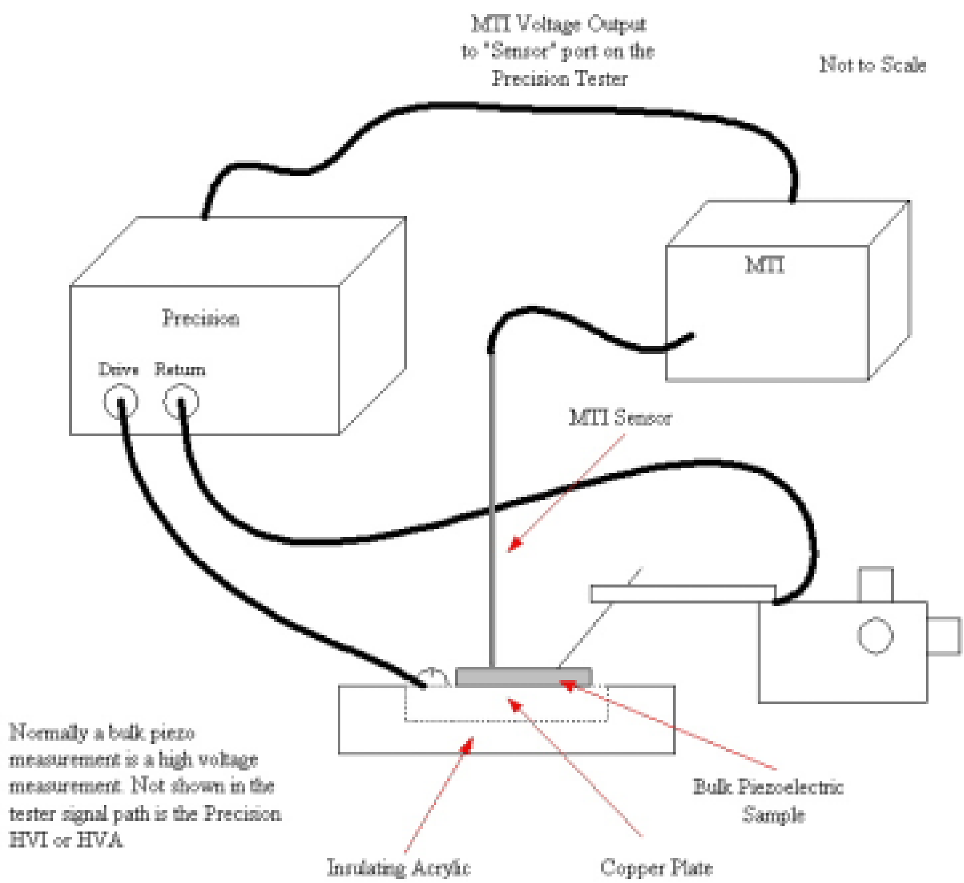
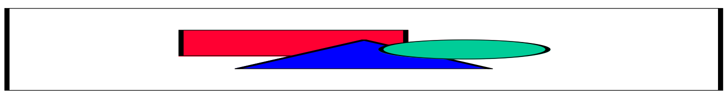


Figure 1 - Typical Piezo Task Experimental Configuration.

Once the displacement is measured over the course of the Piezo Task's Hysteresis loop, the measured voltage is reconverted into displacement by solving for Sample Displacement in (1). The user will provide calibrated *m* and *b* values for the specific detector being used. The Hysteresis measurement provides the user with the most general and common tool for characterizing a ferroelectric sample. In the Piezo Task a voltage waveform is applied to the sample in a series of voltage steps to stimulate both the hysteretic and piezoelectric response. At each voltage step, along with the sensor detection, the current induced in the sample by the voltage step is integrated and the integral value is captured and converted into Polarization ($\mu C/cm^2$) by:



(2)

(2) is scaled by appropriate factors to properly adjust computed values to the standard polarization units of $\mu C/cm^2$.

The voltage waveform is normally a standard bipolar triangular waveform that can be simply defined by providing the maximum voltage and the entire duration of the waveform in milliseconds. The sign of the voltage indicates the direction of the first leg of the waveform. The number of points is controlled primarily by the duration of the waveform, though it may also be adjusted by the voltage. The software automatically computes the number of points and provides the maximum number possible for the conditions specified. The waveform begins at 0.0 volts and steps to a maximum value of the assigned voltage. It then proceeds to step to the negative of the assigned maximum. Finally it steps back to zero volts. A DC bias level may be assigned that will allow the entire waveform to be shifted from the zero-volt symmetry without losing the waveform symmtery. *Note that care must be taken that at no time does the combination of the DC Bias level and the step voltage exceeds the capabilities of the Precision hardware configuration.* The entire Standard Bipolar waveform structure is shown in **Figure 2**.

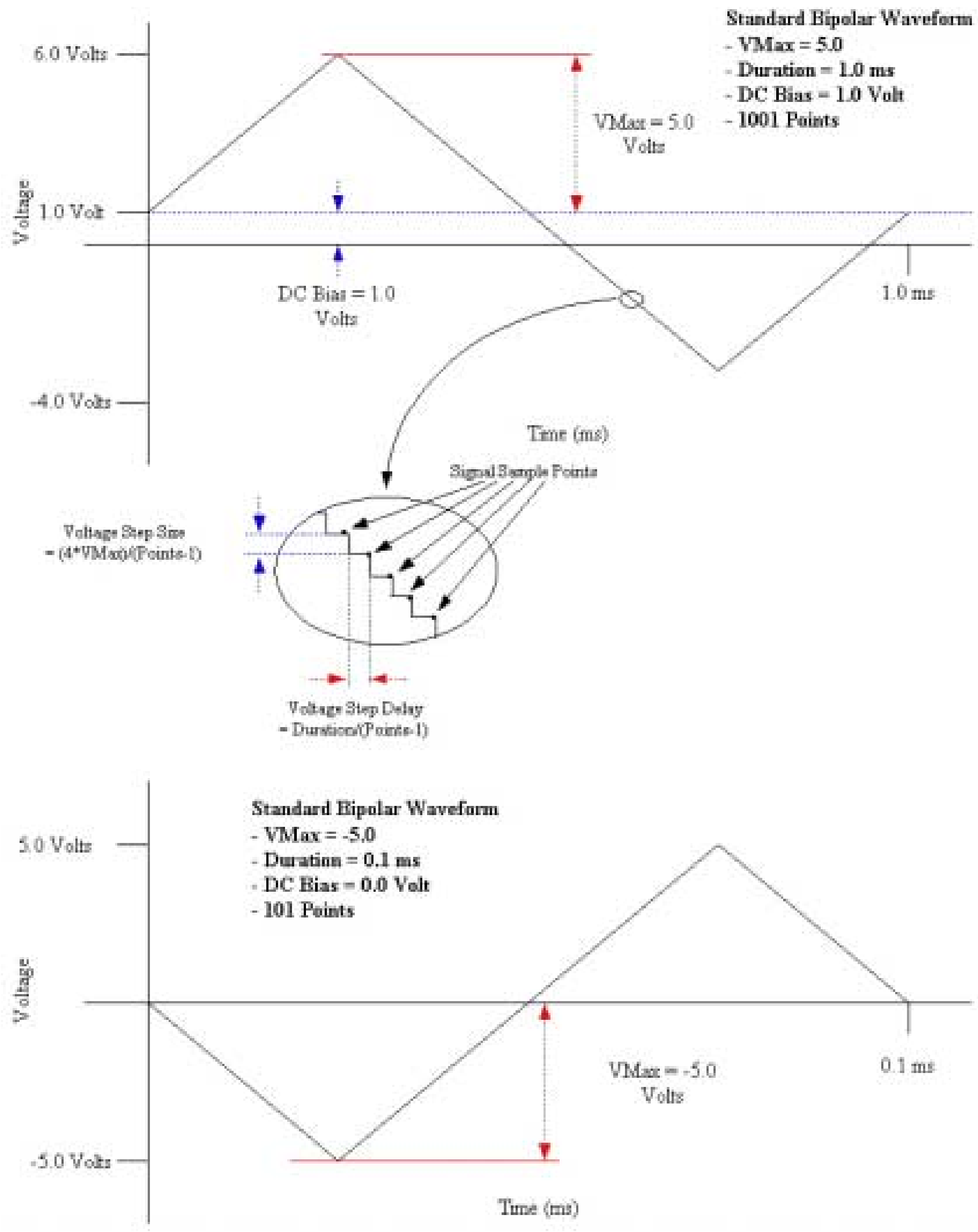


Figure 2 - Standard Bipolar Waveform Characterization.

In these examples, the number of points is first set to the maximum of 1001. Then, if the duration is too short, the number is reduced to the point where the minimum step delay times the number of points is near the duration. A low voltage may also influence the number of points downward as the minimum voltage step must be observed. Finally, the duration itself will be adjusted so that it can accomodate an exact integer number of minimum step delays. The step delay is consistent between points and is the duration of the waveform divided over the number of steps (Points - 1). The voltage step is equal to four times the maximum voltage divided over the number of steps. The integrated value is sampled at the end of the step delay, just before the next voltage step is taken.

The standard bipolar waveform produces five derived parameters of interest. These are:

PMax The polarization at the maximum applied voltage. Note that this will be the polarization at +5.0 Volts in both the examples.
+Pr The polarization at zero volts when voltage is moving from positive to negative. If VMax is negative, this will be the polarization at the final sample point.
-Pr The polarization at zero volts when voltage is moving from negative to positive. If VMax is positive, this will be the polarization at the final sample points.
+Vc The voltage at which polarization is zero when switching from negative to positive.
-Vc The voltage at which polarization is zero when switching from positive to negative.

Note that these parameters are computed based on "Centered" data. In raw data, the first measurement point is assumed to be 0.0 µC/cm^2, with all other points valued relative to that point. The result is that for positive VMax, the Hysteresis loop is shifted upward and is asymmetric relative to the zero polarization axis. To provide a symmetric representation that is more conventional, the average of the polarization values at the maximum and minimum (maximum negative voltages), known as the *offset*, is subtracted from every point. Centered or uncentered data can be plotted, but only centered data are used to compute these values.

An option exists to preset the sample by applying the waveform without measuring. The advantage to this is that the sample is set into a known polarization state. For the Standard Bipolar waveform, the presetting ensures that both legs of the waveform will switch the sample. The user may program the delay between the presetting and measuring Hysteresis loops. While this is the normal default operation, a disadvantage of this option is that signals are applied to the sample that are not measured. Frequently in ferroelectric research it is important to capture the sample response to all applied voltages. In that case, this option should be disabled.

A similar difficulty arises in amplifying (or deamplifying) the return signal into a range that can be properly measured. This process is normally done automatically by repeatedly measuring the sample and adjusting the amplification level. Again this stimulates the sample with multiple, unmeasured signals. To eliminate this problem, the amplification level may be set manually. In this case a sacrificial sample is usually stimulated repeatedly to determine the appropriate amplification level.
The Standard Bipolar waveform is the most common and default sample stimulus. However, other options do exist. A Standard Monopolar waveform can also be applied. The same defining properties apply to the waveform. However, the voltage will only step

from DC Bias to DC Bias + VMax and back to DC Bias, resulting in half of the Standard Bipolar measurement. There are a number of consequences of using this profile in making a measurement.

- PMax, ±Pr and ±Vc, though computed, may not represent meaningful measurement parameters.
- Centering the data will not position the data as it would if they were part of a full loop.
- Enabling a preset loop will switch the sample into a polarization state that ensures that the sample will not switch during the measurement loop.
- The Voltage Step size is given by twice VMax divided by the number of steps (Points - 1).

Using a Custom File Drive Profile

As an alternative to the standard triangular bipolar or monopolar Hysteresis waveforms automatically generated by the Task, the user can construct a custom waveform of any shape. This is discussed in detail in the Main Configuration page.

Drift Correction

Displacement of a piezoelectric sample that is unrelated to the application of the measurement voltage has been demonstrated during the period of measurement. This is particularly evident in measurements on thin film samples made using Atomic Force Microscopes (AFM). This drift in displacement constitutes error in the measurement and makes both direct comparison of multiple measurements and the application of certain filters difficult and impractical. If the drift can be linearly characterized and expressed as motion over time, it can be entered into the Piezo Task and used to correct the error. The *Displacement Drift* control has been placed into the Sensor configuration block of the main and QuikLook setup dialogs. Here, the drift can be entered in units of µm/ms. This value can be used to correct the error by...

$$\text{corrected displacement}_i = \text{displacement}_i - \text{drift } (\mu\text{m/ms}) \times \text{period (ms)/points} \times \text{measurement point}_I$$

This equation gives a correction in µm-per-point and scales it by the point count at the current point. This correction is subtracted from the original measured displacement.

Data Zeroing

Error in measuring displacment, including the drift discussed above, can result in a displacement measurement that begins away from the expected reference value of 0.0 µm. This is true of any measurement system and is not specifically related to AFM measurements. The result of these "Displaced" displacement data are errors in comparing multiple measurements and incorrect mathmatical derivations when filters are applied. In particular, the L/V filter, that provides the piezoelectric constant, from point-to-point, cannot be used when the data do not start at 0.0 µm. On the plotting dialog that appears both as a tab under the QuikLook dialog and during an Archive Regraph operation an option is provided to zero the data. This option simply instructs the Task to subtract the first measured displacement data value from all measured points in the displacement loop. When displacement data are selected for plotting and the "L/V" filter is specified, this control is checked and then disabled, forcing the zeroing option.

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Updated 2/19/02