Radiant Technologies, Inc.
2835D Pan American Freeway NE
Albuquerque, NM 87107
Tel: 505-842-8007
Fax: 505-842-0366
e-mail: radiant@ferrodevices.com
www.ferrodevices.com

# Large Signal Displacement Measurement with an MTI Photonic Sensor

**Rev B**

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**Author**: Joe Evans

## Introduction:

I used an MTI 2100 Photonic Sensor (http://www.mtiinstruments.com/products/MTI 2100fotonic.aspx) to measure the displacement of a piezoelectric device constructed with Radiant's integrated ferroelectric film capacitor process. The report below describes the characteristics of the MTI sensor and presents the results of the measurements. The measurements were taken using the Precision Displacement Test Stand in conjunction with the Advanced Piezo Task in the Vision Library.

### Test Setup:

The MTI 2100 sensor consists of a mainframe with a backplane for inserting measurement units. The mainframe will hold one or two measurement units. In this case, I used the 2032RX measurement probe which has a stated resolution close to 0.5nm (5Å). The sensor is a fiber optic bundle that projects a cone of white incoherent light onto the sample surface with a known conic angle. Light reflected from the sample surface is captured by the fiber optic bundle and returns to the measurement unit. Because of the increasing diameter of the light beam with distance, the further the sample surface from the exit port of the fiber optic bundle, the lower the amplitude of the captured light in relation to the emitted light. The measurement unit uses the ratio of the emitted and captured light to calculate the distance from the tip of the fiber optic bundle to the sample surface. The tip diameter of the photonic probe of the 2032RX measurement unit is 300μ, making it suitable to study the displacements of MEMs type devices. Because of the geometry of the 2032RX sensor tip, the scale setting entered into Vision this displacement meter should be negative.

Since the sensing medium is photonic, the sensor response is very fast. The frequency specification for the 2032RX is 100 kHz. Selectable high and low pass filters are available on the front panel of the 2032RX. Due to the geometry of the sensing light beam, the tip of the fiber optic bundle must be within 1 millimeter of the sample surface. The sample surface must be at least partially reflective. If the sample surface is not sufficiently reflective, adhesive reflectors are available from MTI. The MTI 2100 generates absolute distance information, not differential information. Consequently, there is no need to connect the SYNC signal from the Precision tester to the MTI unit. Only the output of the measurement unit needs to be connected to the SENSOR input of the Precision tester using a coax cable. For my tests, I used a Precision Premier II Non-linear Materials Tester.

This 2032RX measurement probe has two displacement sensitivity settings: 1) -580nm/V or 2) -5800Å/V. The higher sensitivity is roughly half the resolution of the SIOS laser vibrometer profiled in the application note "Piezo Jena Vibrometer …". Although it has a lower resolution than the SIOS laser vibrometer described in that application note as well as a significantly lower resolution than the Polytec laser vibrometer, the MTI 2100/2032RX system is much less expensive than either of those units, making it a viable alternative in university material research programs for measuring piezoelectric MEMs. The Premier II SENSOR input has a resolution of 76μV/bit and a single pass noise floor of 1mV. Having a 1mV noise floor on a single pass, the Premier II SENSOR input combined with the 2032RX unit generates a noise limited displacement resolution of approximately 5.5Å.

The resolution limit calculated in the previous paragraph assumes no noise contribution by the 2032RX unit. The sensor adds its own noise to the measurement. I set the Low Pass Filter of the 2032RX to 100 Hz and set the High Pass Filter of the 2032RX to DC while running 1 Hz or 0.1Hz loops for the measurements. With this arrangement, the noise level for a single pass was approximately 30Å, or 3nm, a relatively clean signal.

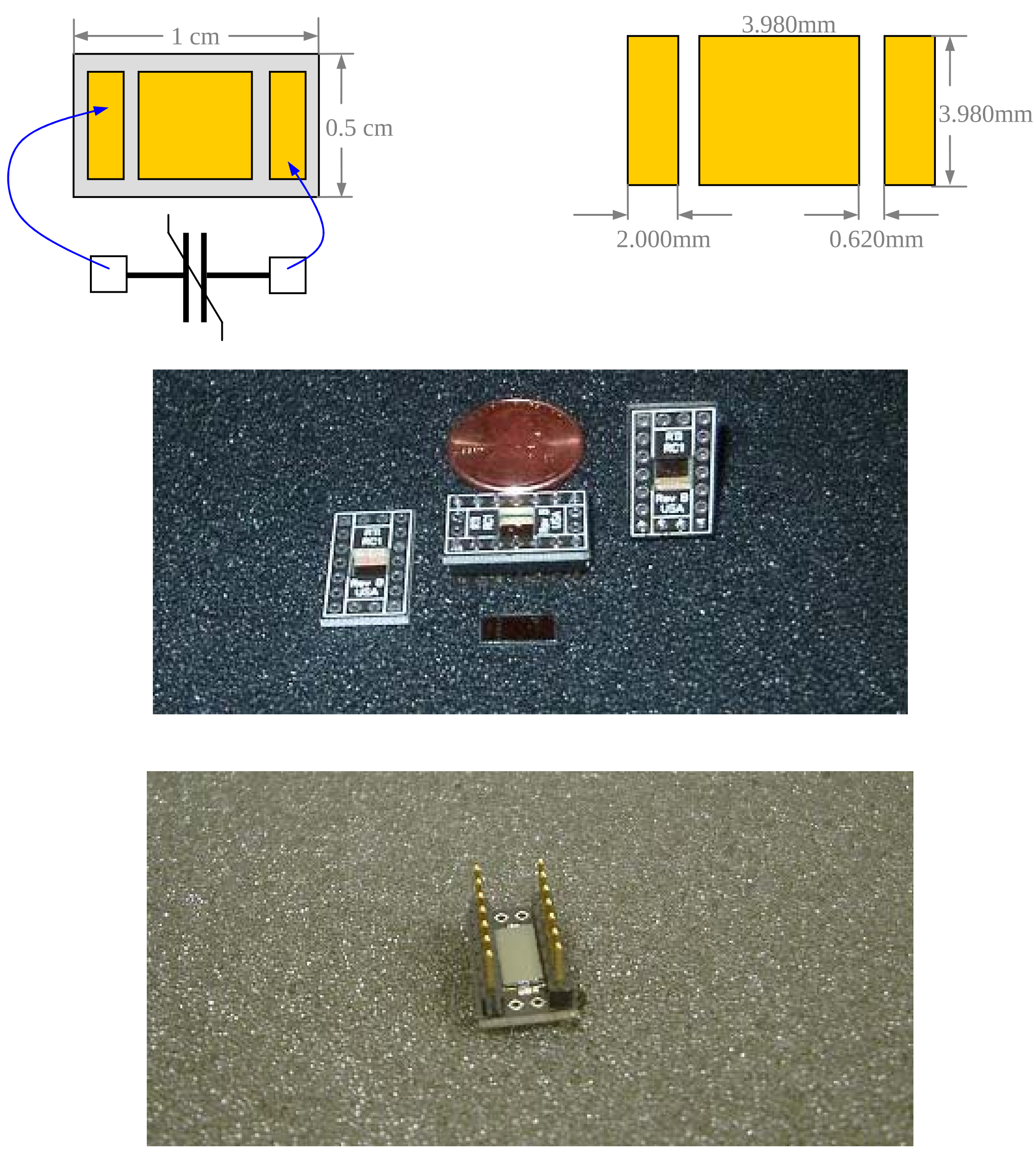
> NOTE: It is extremely important to set the High Pass Filter control of the 2032RX to DC. Otherwise, the filter will block the hysteresis loop itself!

The sample was mounted on the Brick in the Precision Displacement Test Stand shown in Figure 1 below. The PDTS was situated on the granite table of an old Ultratech printer. There was no active vibration control for this arrangement.


**Precision Displacement Test Stand**
**Figure 1**

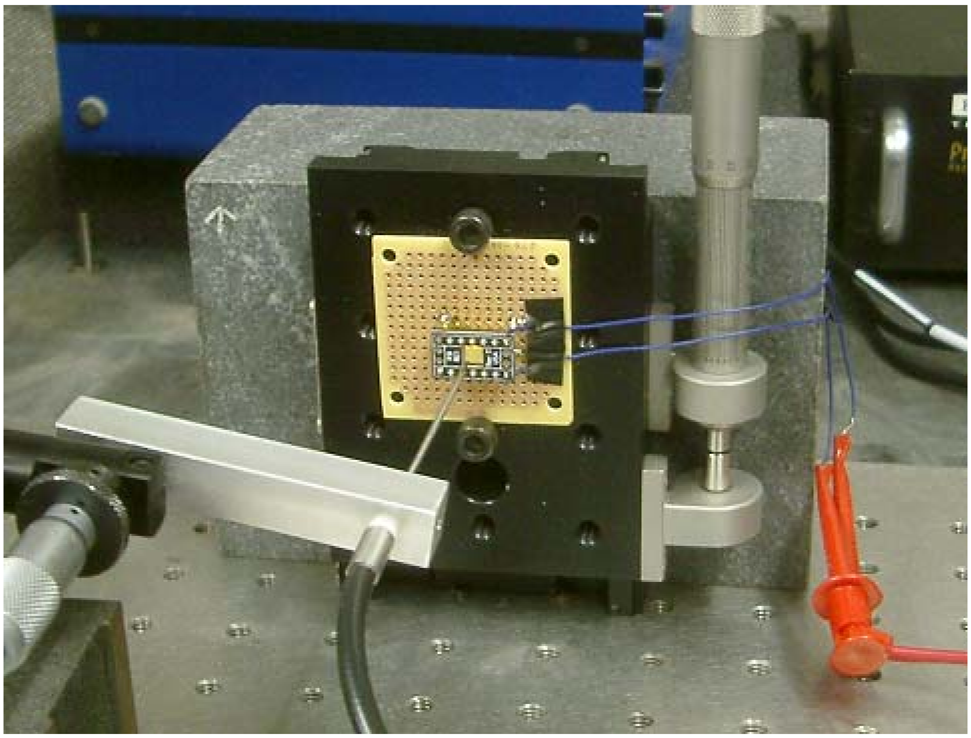
The PDTS is designed to minimize vibration of the sample and the sensor fixture as well as screen out turbulent currents in the atmosphere between the sample and the sensor. The MTI2100 may be seen in the background for the photograph in Figure 1 but it was moved off the table prior to the measurements to prevent its cooling fan from inducing vibration in the test fixtures.

**Sample Description:**
The RC1-166A Sensor Die (www.ferrodevices.com/components2.html), with its large 4mm x 4mm PNZT capacitor, is designed to be used as a passive force or temperature sensor. However, it also makes a nifty cantilever. Mounted on its printed circuit board (PCB) carrier, both ends are pinned by the solder connections so it arches when voltage is applied to the capacitor. The physical layout of the Sensor Die is shown in Figure 2 below.




**The Sensor Die on its PCB Carrier**
**Figure 2**

I soldered the PCB flush in the holes of a Radio Shack project board and mounted the board to the Brick in the PDTS. I soldered wires to the PCB and connected them to the cable harness using minigrippers.



**Cantilever-in-a-Can on the Test Fixture**
**Figure 3**

**Advanced Piezo:**
The Advanced Piezo Task greatly simplifies the work required to acquire high quality butterfly loops for samples that generate small displacements where averaging is essential. Thermal atmospheric currents and test fixture vibration are eliminated by the Precision Displacement Test Stand but test fixture creep still occurs. Advanced Piezo will de-trend the mechanical creep from each measurement and align each measurement to a common reference point prior to executing an averaging routine on the measurements. The task then runs a smoothing filter over the averaged results. The user may disable one or all of the correction functions as desired.

**Calibrating the MTI Photonic Sensor:**
The calibration procedures for the MTI 2032RX are described in the documentation provided by MTI. It consists of two stages: 1) calibrate Range 1 of the 2032RX using the standard procedures and 2) switch to Range 2 to adjust the DC bias.

To calibrate Range 1,

1) Position the sensor probe very close to the sample surface and align it as close as possible to be perpendicular to the sample surface.

2) Set the MTI 2100 to the calibration mode on the front panel.

3) Adjust the micrometer that positions the probe tip above the sample surface to maximize the signal strength displayed on the front panel of the MTI 2100.

4) Once the maximum signal is reached, press the "Cal Start" button on the front panel. The unit will then self-calibrate, determining a reference ratio of the transmitted signal to the reflected signal for the maximum distance. When calibrated, the display will show 10 Volts, the saturation level.

5) Once the self-calibration is completed, take the unit out of calibration mode and put it into the displacement mode.

6) Adjust the micrometer to move the probe tip closer to the surface and reduce the value displayed on the front panel of the MTI. I generally set the display to output the sensor voltage and move the probe tip to reduce the sensor voltage to about 5V.

Using Range 2:

1) Press the selection button on the front panel of the 2032RX to change from Range 1, which you just calibrated, to Range 2.

2) It may be necessary to move the probe slightly to bring the displacement value on the front panel out of saturation. The micrometer will be extremely sensitive at this point.

    a. If the "Over" LED is on, turn the micrometer clockwise to move the sensor tip more towards the sample.
    b. If the "Under" LED is on, turn the micrometer counterclockwise to move the sensor tip away from the sample.

3) When neither LED is on, adjust the DC Bias knob on the front panel to set the desired starting value for the test.

**Results:**
The data was acquired with single run of Advanced Piezo Task taking five measurements. The task was set to

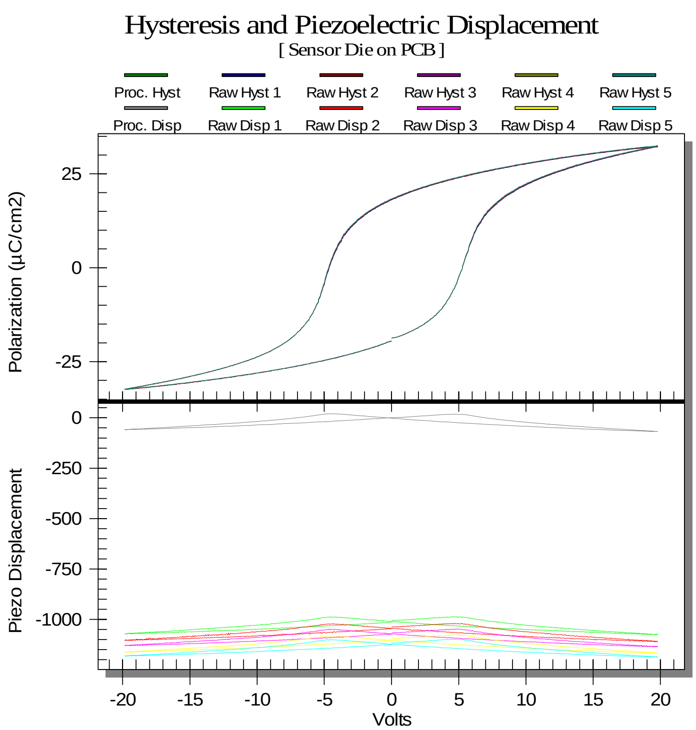
1) Remove the drift,

2) Zero all of the loops to the origin,

3) Average the five loops, and

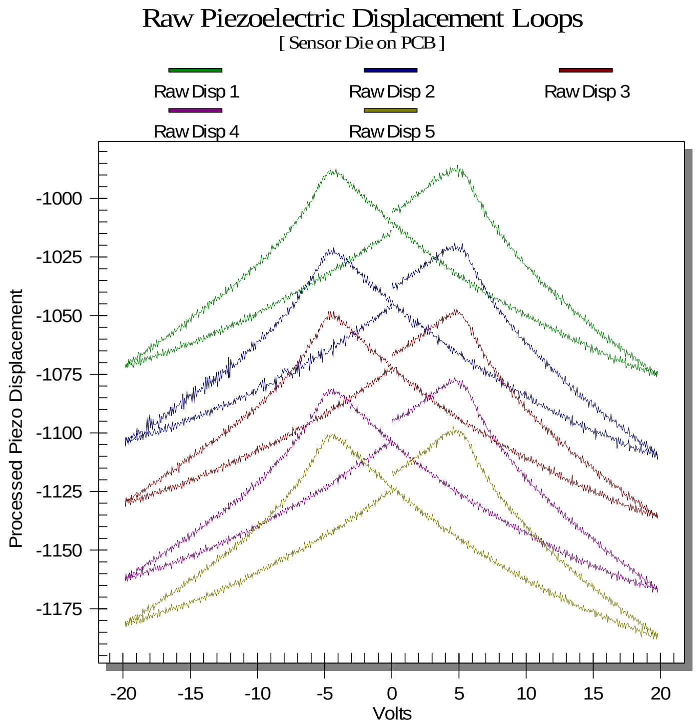
4) Smooth the averaged measurement.

Figure 4 shows the hysteresis loop, the five raw butterfly loops, and the averaged butterfly loop together in one plot. The units of displacement on all plots below are **nanometers**.



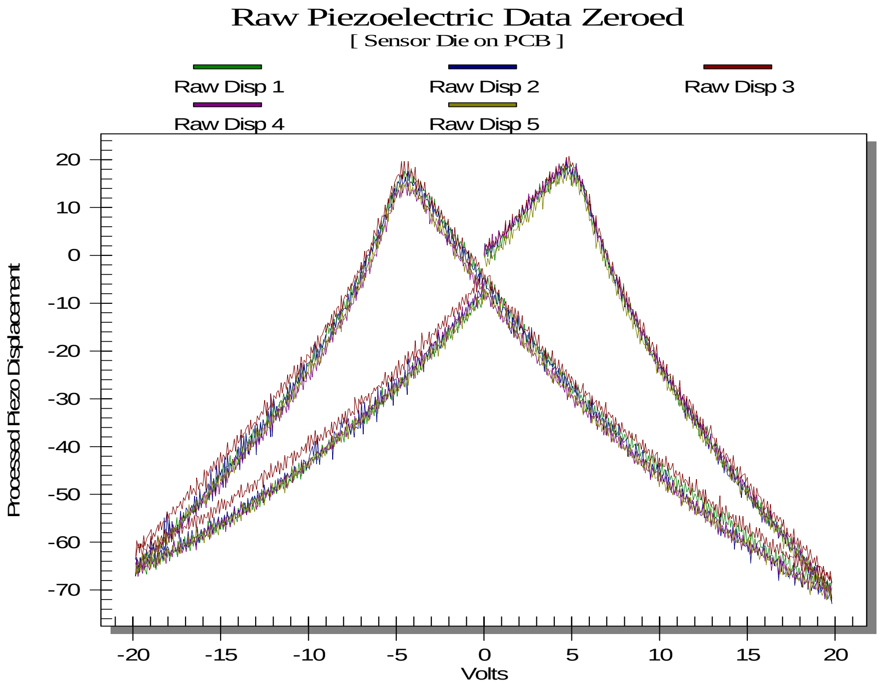

**Five Butterfly Loops from the Cantilever-in-a-Can**
**Figure 4**

The five polarization hysteresis loops measured concurrently with the displacement loops all overlay each other. The five displacement loops do not. They have starting values below <1000> nanometers because of the DC Bias I arbitrarily set on the MTI2100 display when calibrating the 2032RX sensor. (See above). Additionally, the five loops all have a different starting point because of mechanical creep in the fixture holding the sensor wand. A closer look at the displacement loops is in Figure 5.



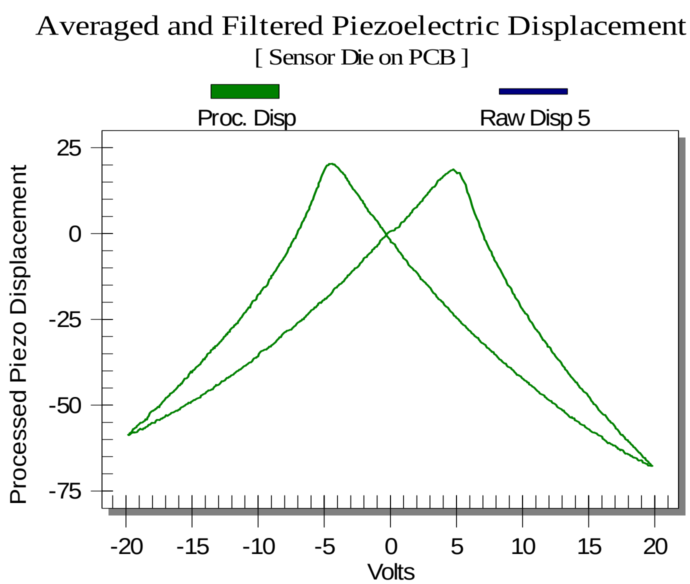

**The Five Raw Data Displacement Loops as Measured by Advanced Piezo**
**Figure 5**

Not only does each butterfly loop have a different starting point because of creep, each loop is distorted by the creep so that the ending point does not line up with the starting point. Advanced Piezo will remove both types of creep. Figure 6 shows the five raw loops after zeroing. They have not been de-trended yet in Figure 6.



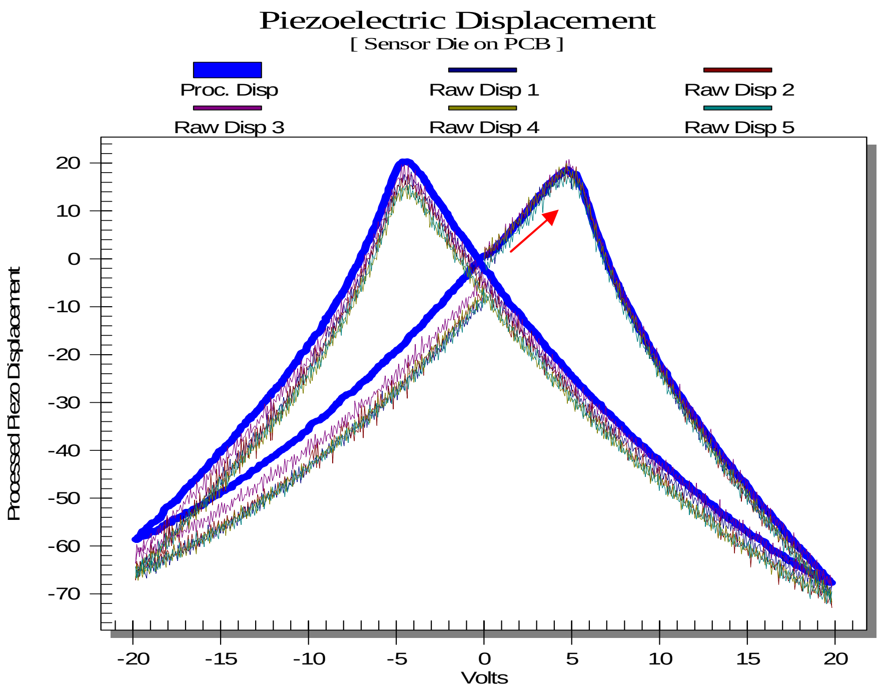

**The Five Raw Data Displacement Loops before Averaging**
**Figure 6**

Averaging and application of the smoothing filter completes the plot generation by Advanced Piezo.




**The Butterfly Loop of the Sensor Die on its PCB Carrier**
**Figure 7**

Note that the amplitude of this measurement is approximately 80 nanometers, or 800Å. The quality of the final loop generated by Advanced Piezo may be examined by plotting the final plot over the zeroed raw data in Figure 8.




**The Corrected Loop vs the Raw Loops**
**Figure 8**

The corrected loop is in thick dark blue. The red arrow highlights where the test starts and in what direction it progresses. The droop in the raw data due to mechanical creep becomes progressively worse as the 10 second stimulus is executed. It is most pronounced on the left-hand side, reaching a maximum of 50Å.

## Conclusion

The MTI 2100 Photonic Sensor is an excellent sensor for measuring piezoelectric MEMs displacements. The system balances performance and price. The MTI photonic sensor is capable of achieving a noise level of better than 10Å in a laboratory environment when combined with the Precision Displacement Test Stand and Advanced Piezo.