Comparison of the Remanent Polarization, IV, and Small Signal CV for a PZT Capacitor

Radiant Technologies, Inc.

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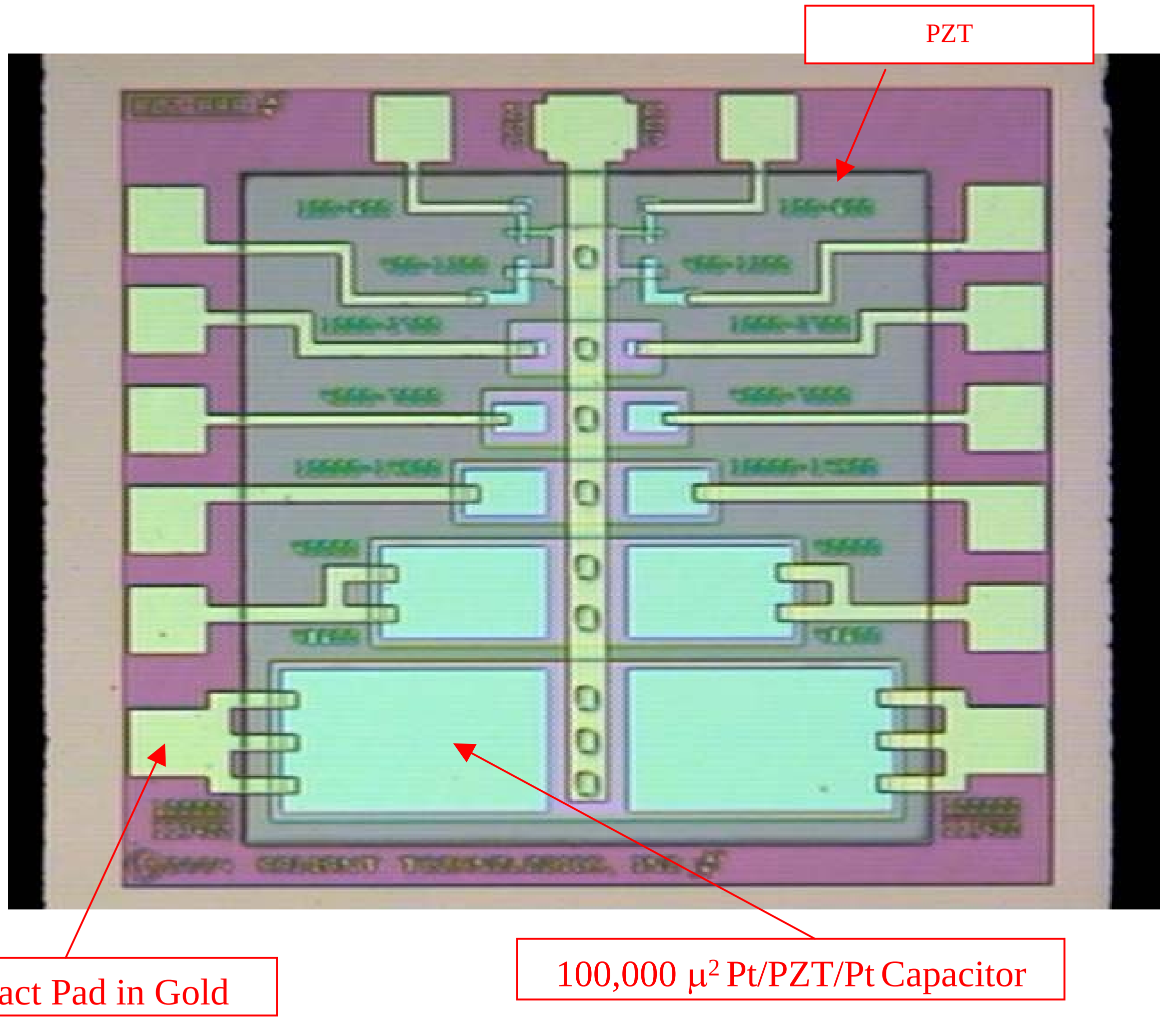
ISAF-ECAPD '10

Summary

- It is possible to measure the remanent polarization curve, the IV, and the small signal CV of a capacitor in addition to its normal polarization hysteresis.
  - Small signal and large signal piezoelectric displacement are next.
- The IV response and small signal CV response of a ferroelectric capacitor seem to be modulated by the remanent polarization state of the capacitor.
- Comparison of the remanent polarization, the IV, and the small signal CV of a single PZT capacitor with platinum electrodes indicates that that leakage is a direct function of remanent polarization but the small signal CV has a more complex relationship to the remanent polarization.

Capacitor under Test

- 0.26µ 20/80 PZT
- Platinum electrodes
- TiOx/SiOx ILD
- Chrome/Gold metallization
- 3.0V saturation
- Can withstand long exposures to 9V.



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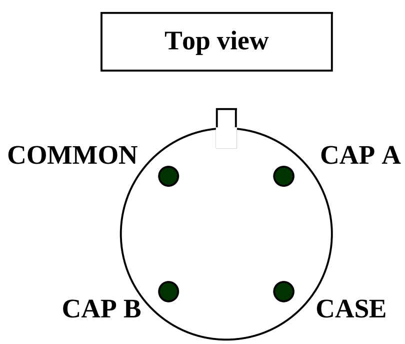
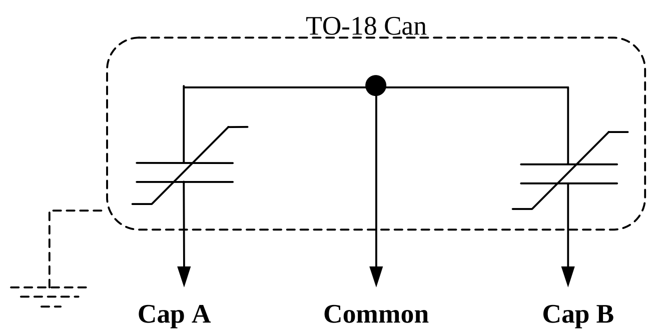
Packaging

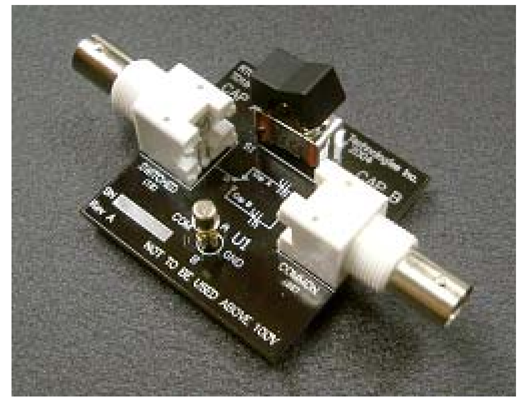
- Two capacitors to each package
- A shared common plus an independent connection for the other side of each capacitor.
- The package header and lid are connected together electrically and then to the system ground at the socket to provide a shielded enclosure for the devices when inserted into a tester or TO-18 socket board.
- TO-18 headers exhibit <0.5pF parasitic capacitance.

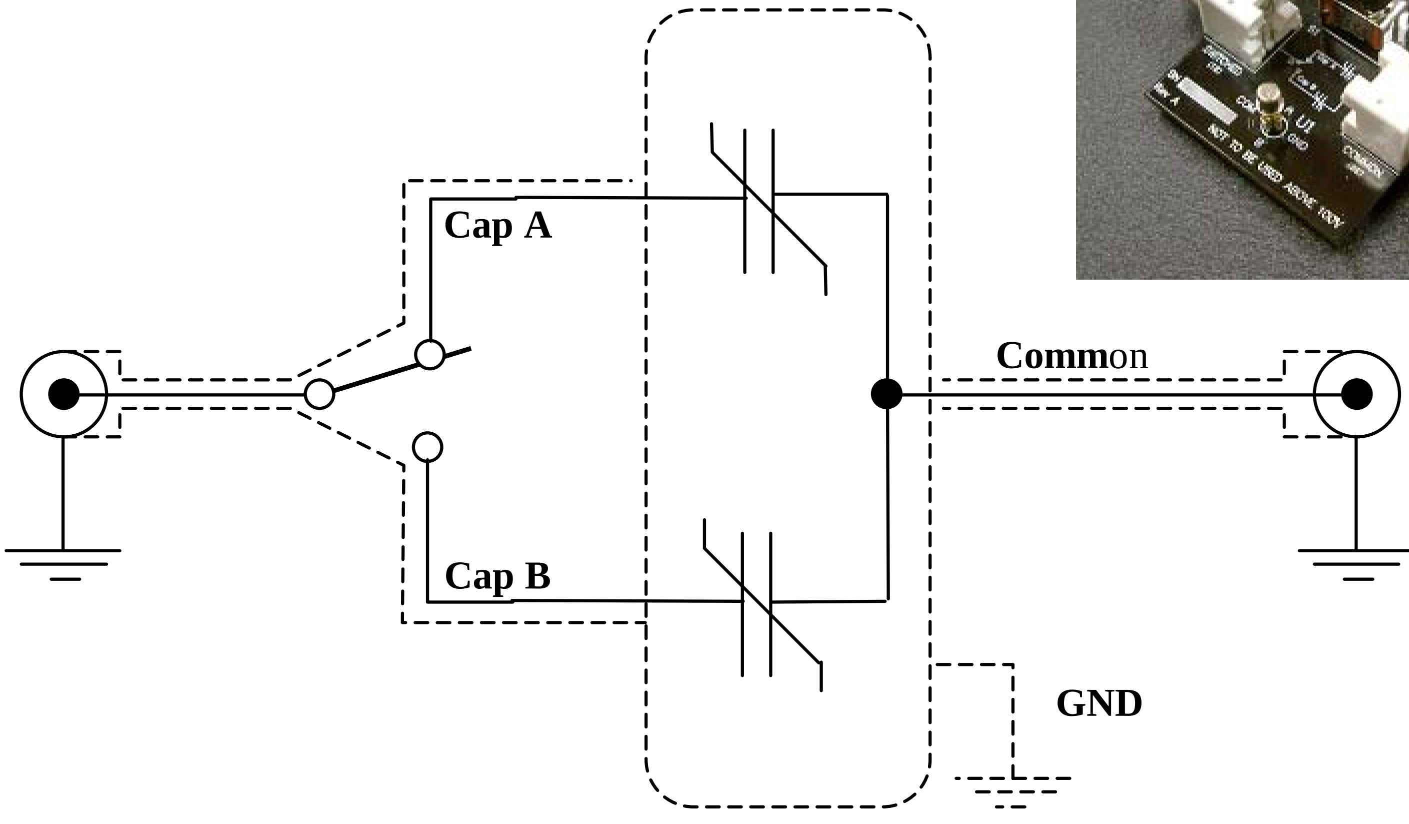




Test Fixture

- The test data were collected from a single “AB” capacitor mounted on the TO-18 Socket Board shown below.



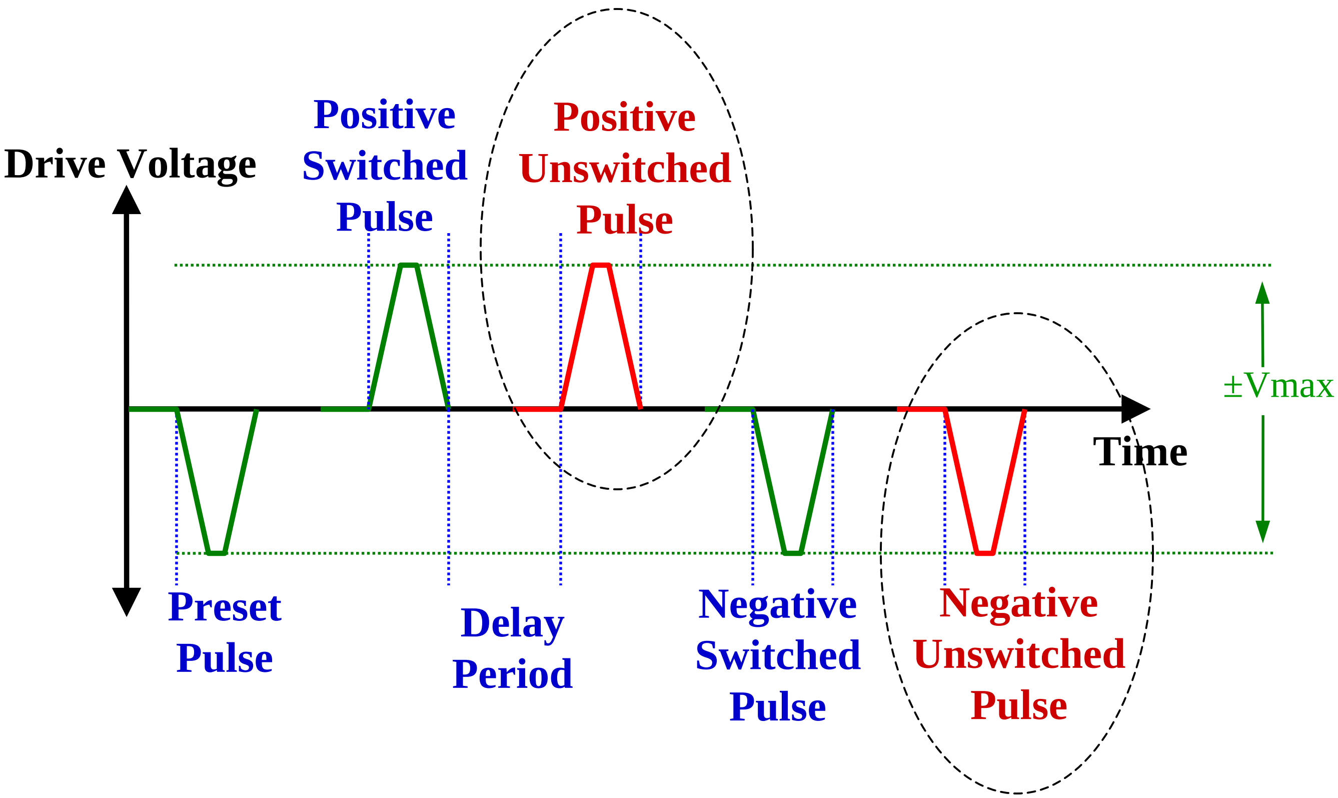


Test Procedure

- The test procedure consisted of the following tests in order:
  - Three polarization vs voltage measurements:
    - → +4V 1 second hysteresis loop
    - → -4V 1 second hysteresis loop
    - → ±4V 1 second remanent hysteresis loop
  - Two small signal capacitance vs voltage tests to ±4V using 1 kHz signal:
    - → Switching
    - → Nonswitching
  - Two current vs voltage tests to ±4V using 1 second integration:
    - → Switching
    - → Nonswitching

Remanent Hysteresis

- The PUND test is a familiar measurement:



- Any matched pair of switched and non-switched pulses may be subtracted from each other to get the remanent polarization.

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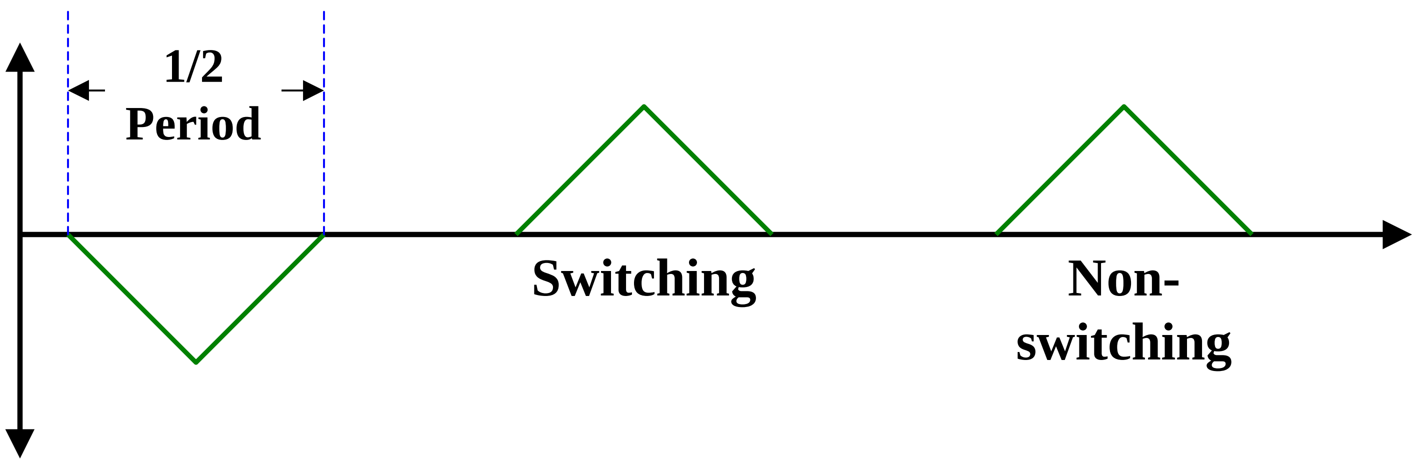
Remanent Hysteresis

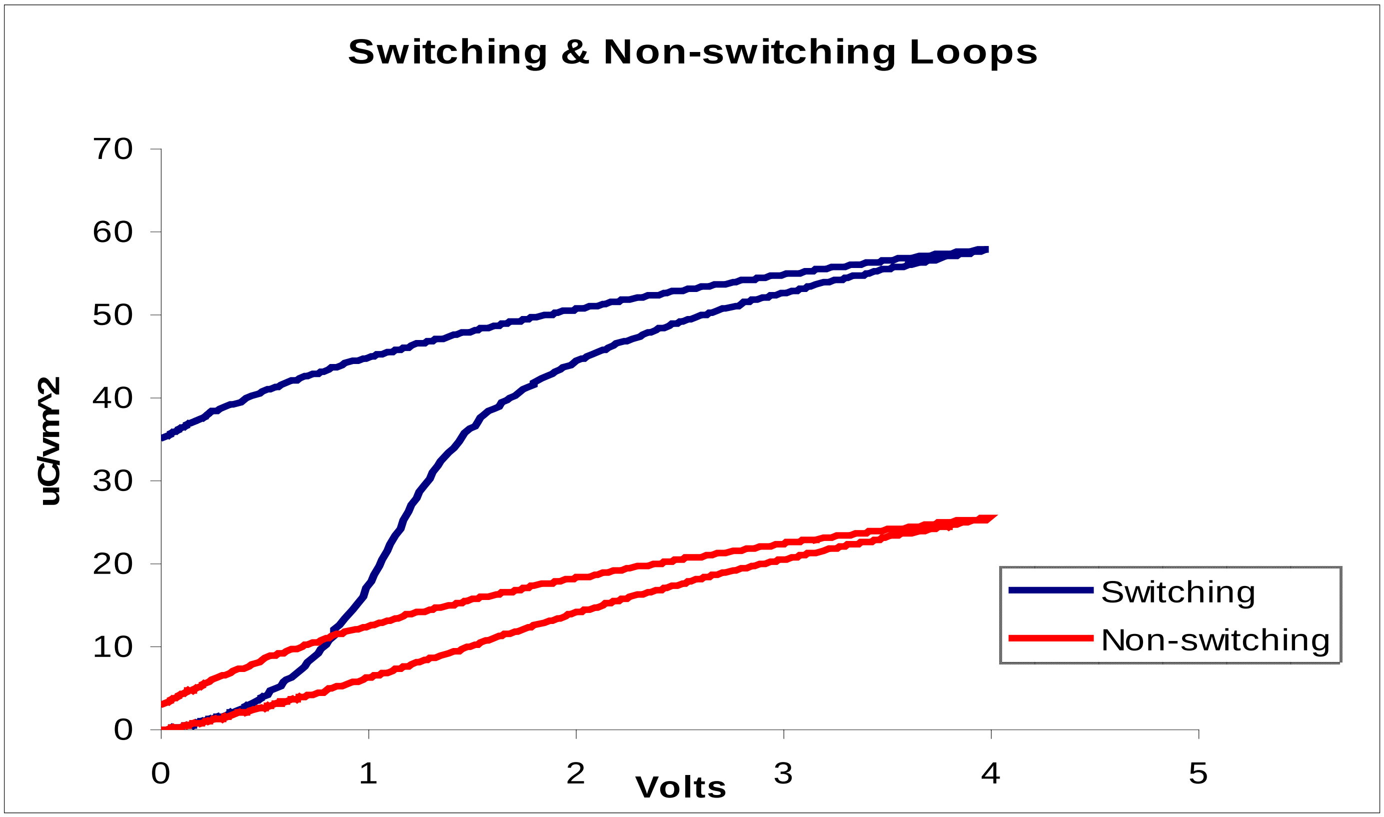
- The same measurement may be made using half-hysteresis loops instead of pulses:



- The difference between the switching and non-switching measurements will give the Remanent Polarization vs Voltage function.

Remanent Hysteresis

Switching and Non-switching half loops:



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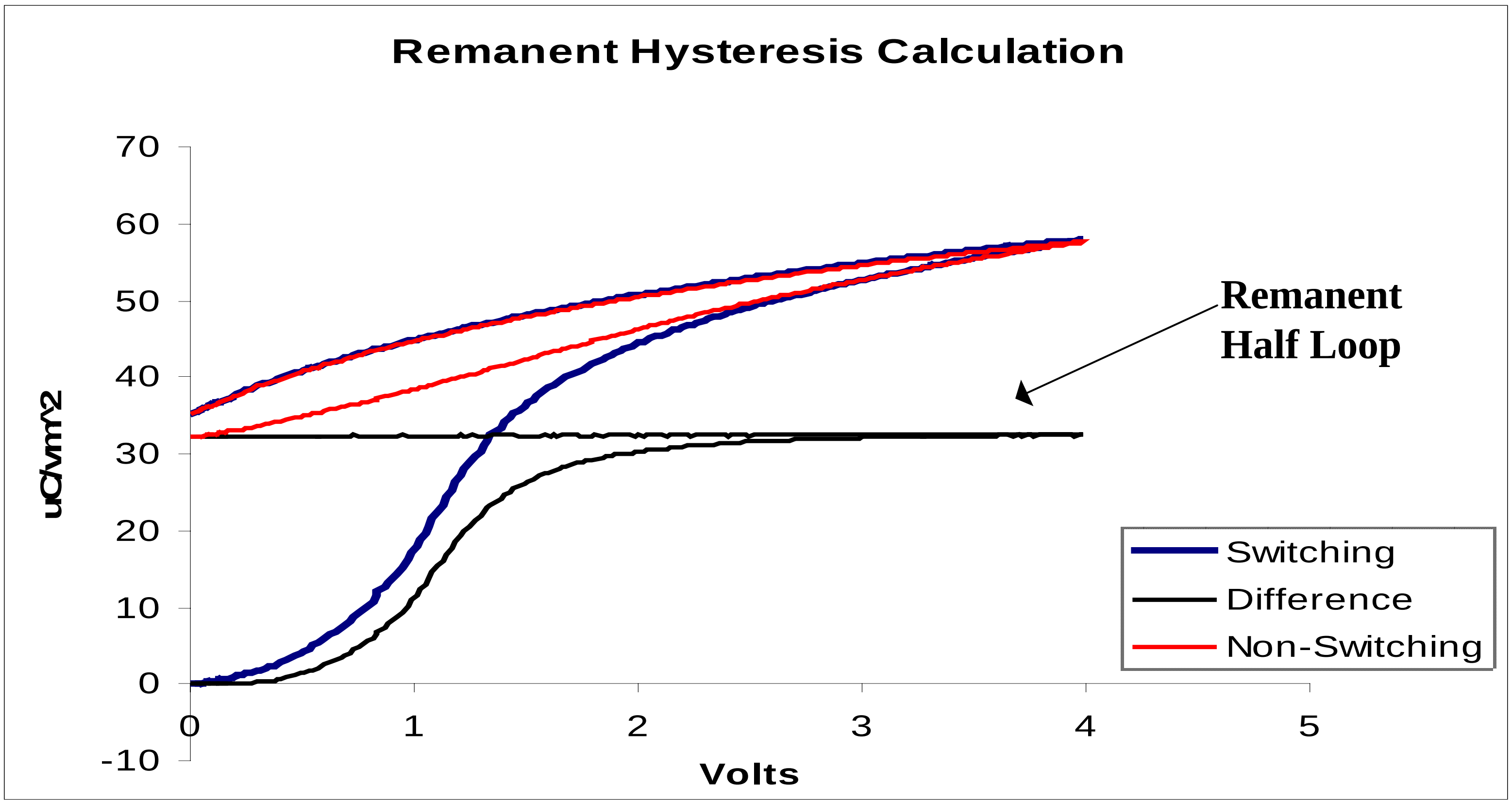
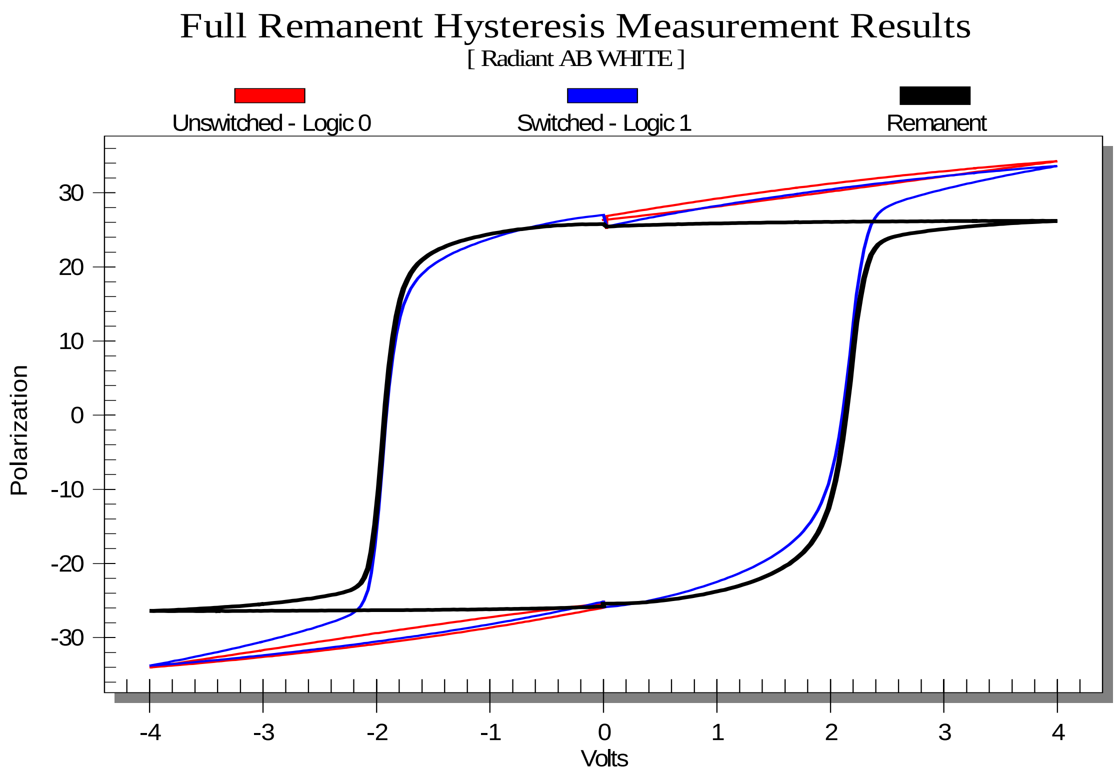
Remanent Hysteresis

- PUND: P*r - P^r = dP = Qswitched
- Hysteresis: Switching - Non-switching = Remanence:



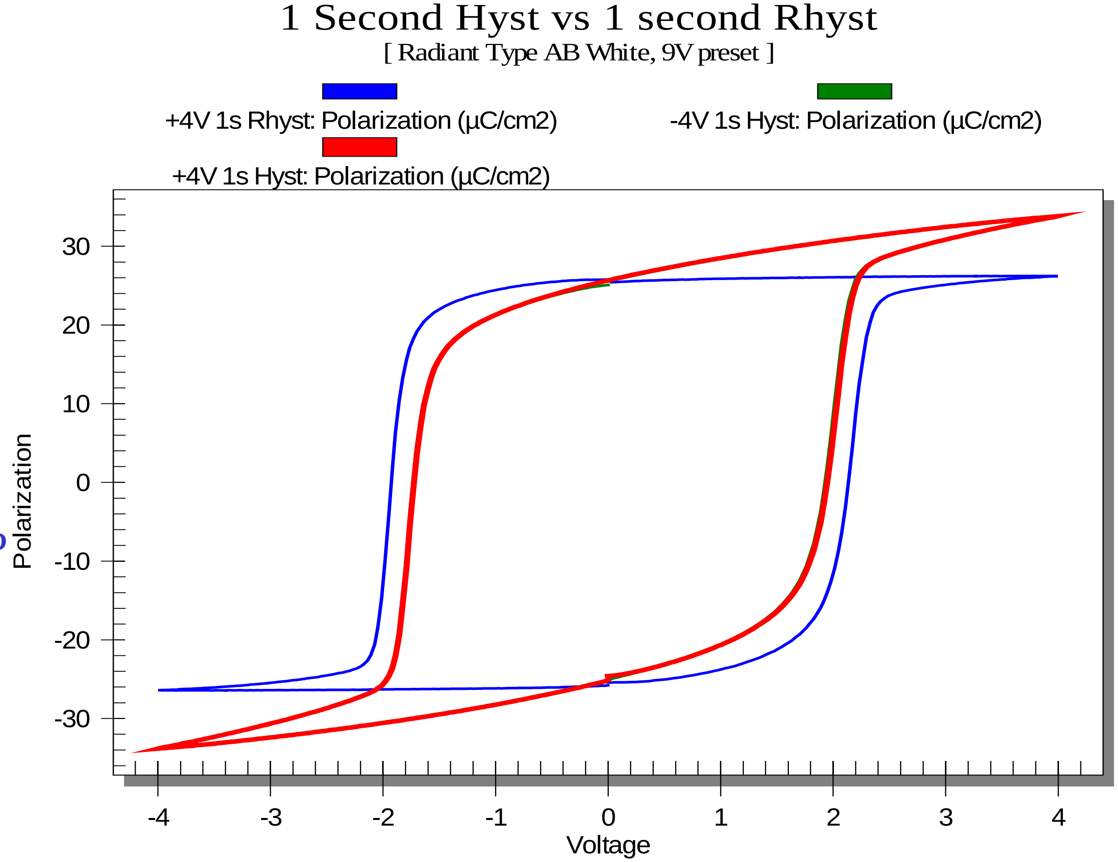
Remanent Hysteresis

- The test may be executed in both voltage directions and the two halves joined to show the switching of the remanent polarization that takes place *inside* the full loop.



Remanent vs Normal Hysteresis

- The first stage of the experiment consisted of measuring two 4V hysteresis loops going in opposite directions (including their gaps) and a 4V remanent polarization loop.
  - The remanent hysteresis is in blue.
  - The full loops in opposite directions overlay exactly.
  - The Vc of the remanent loop lies outside that of the normal loops. Why? (Hint: the reason is purely mathematical.)
  - The Vc of the remanent loop is the true Vc.



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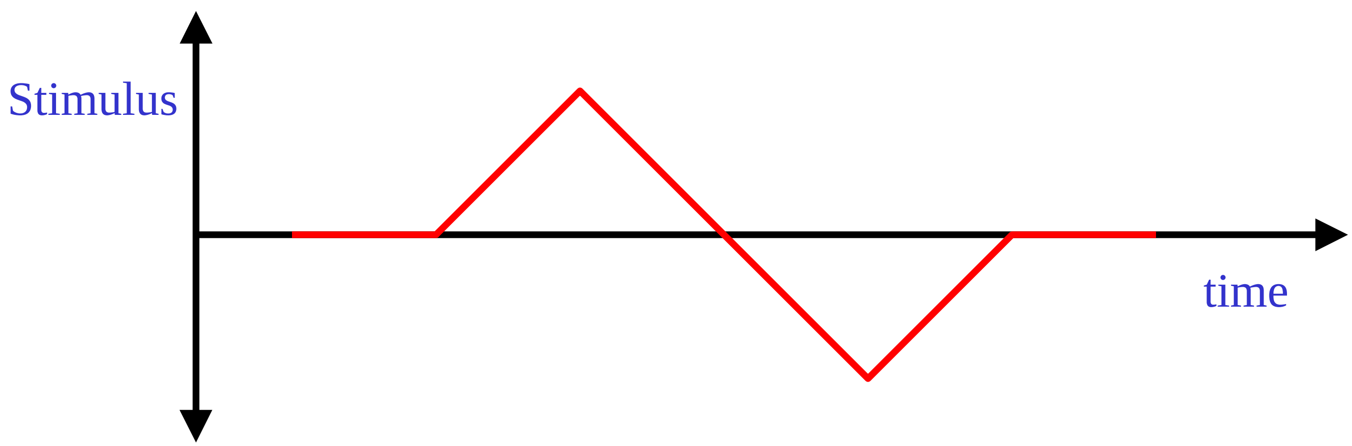
DC Bias Tests

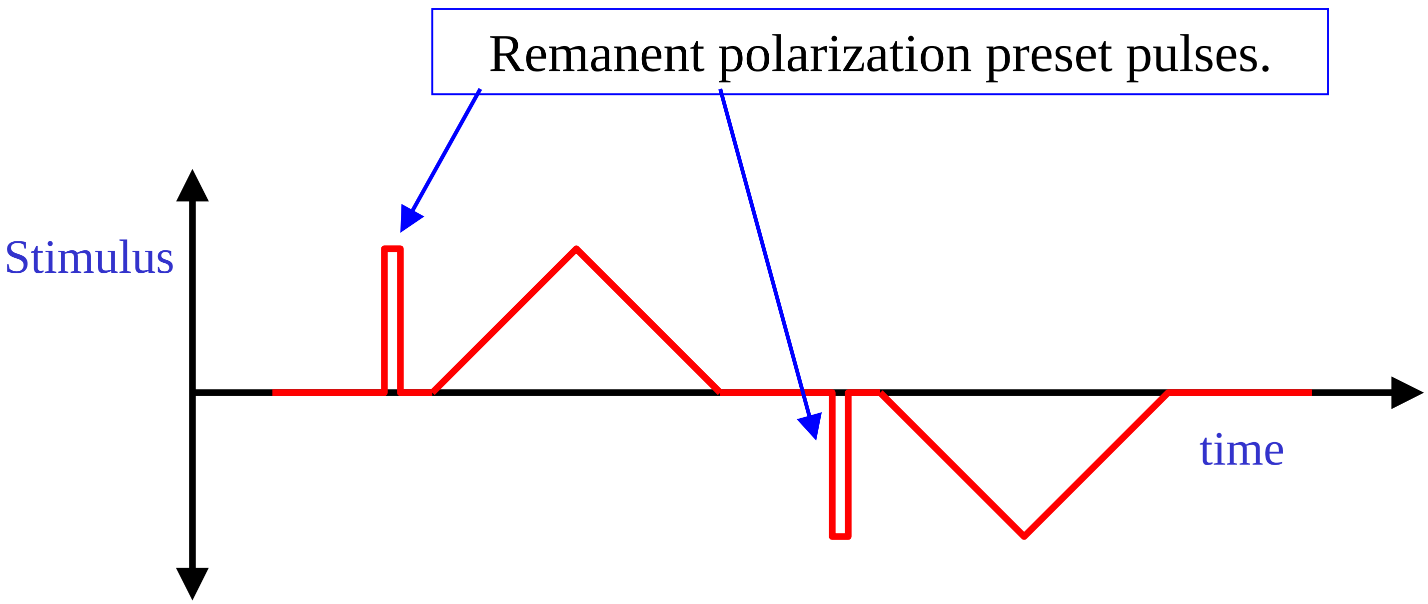
- There are two tests in Vision that take data over a range of DC bias values:
  - Small Signal Capacitance (the Advanced CV task)
  - IV

- Normally, a DC bias profile for these tests should look like the figure below:



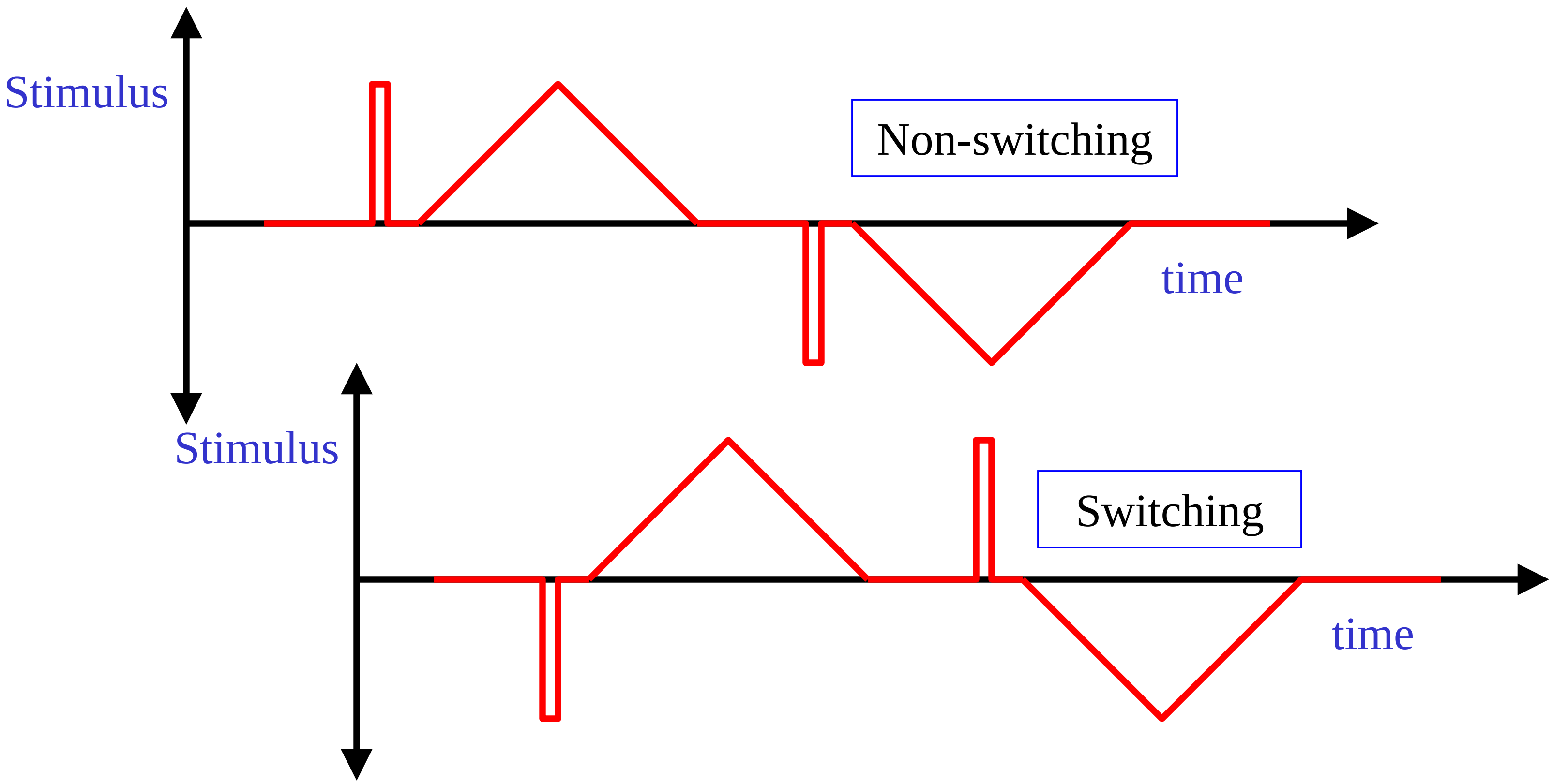
DC Bias Tests

- Since there is the possibility that remanent polarization might affect the outcome of these tests, both of these tasks provide a method by which the state of the remanent polarization may be set prior to the beginning of ***both halves*** of the DC bias profile.



DC Bias Tests

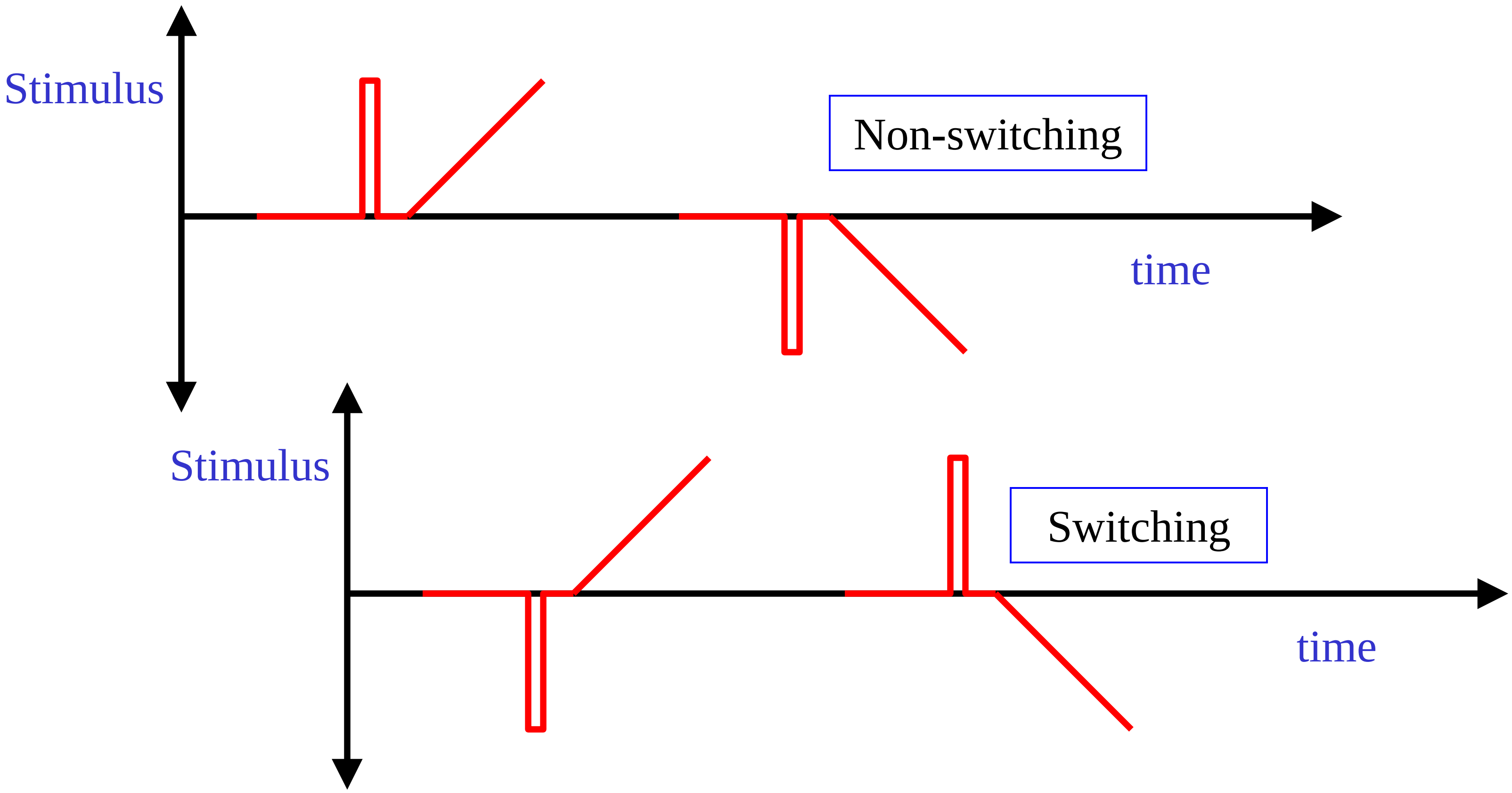
- Using saturated polarization conditions, there are two possibilities!



- The trajectory of the tests shown above will check for "hysteresis" in the IV and small signal CV measurements.

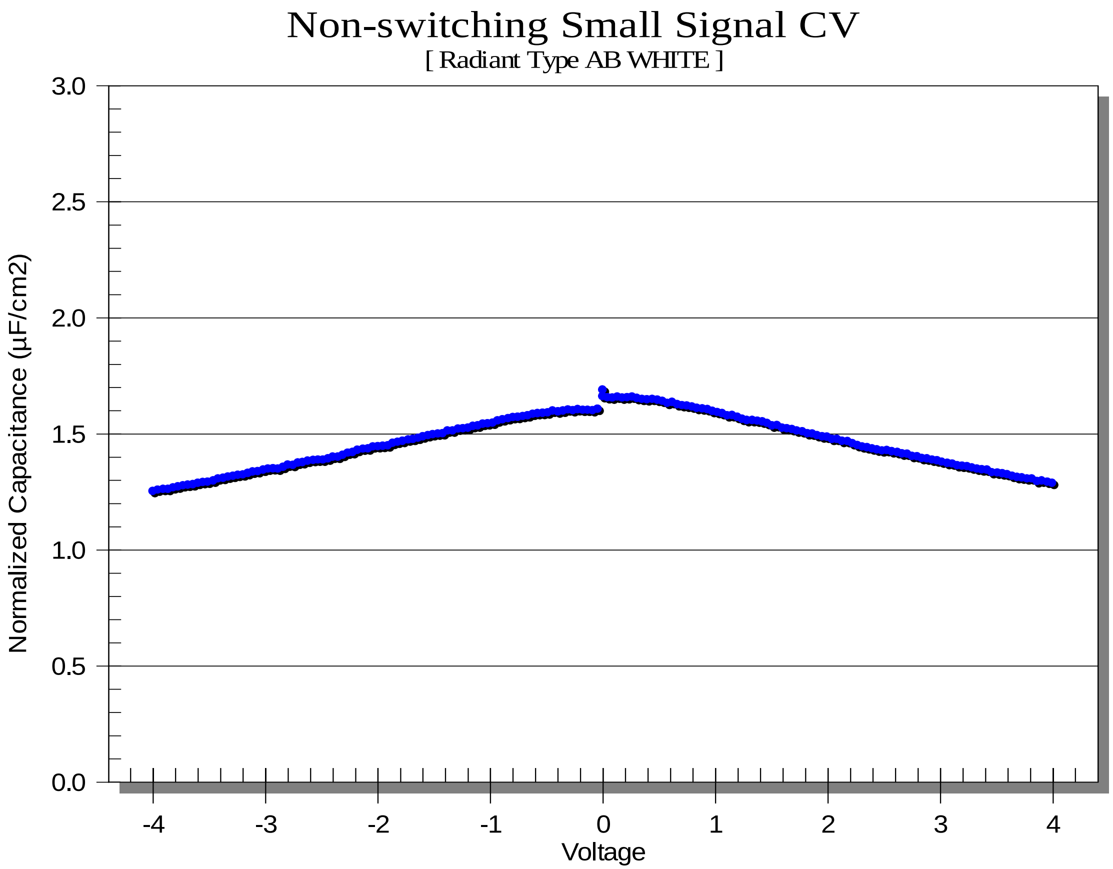
DC Bias Tests

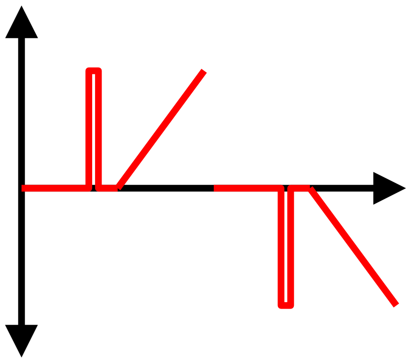
- The test profiles below eliminate the hysteresis measurement and check the measured properties only with increasing bias.



Non-switching CV Result

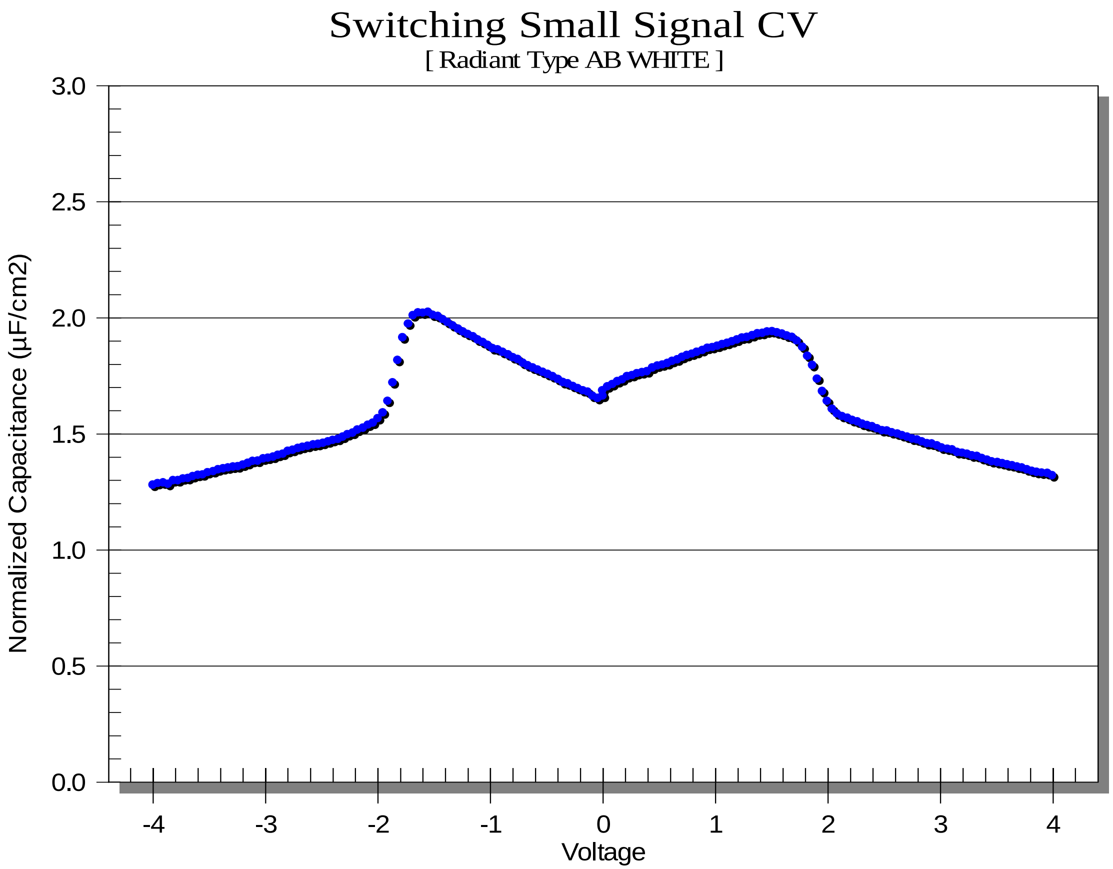
- 1 kHz 0.2V test with 182 points

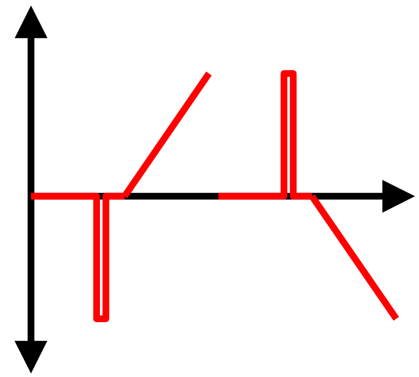




Switching CV Result

- 1 kHz 0.2V test with 182 points





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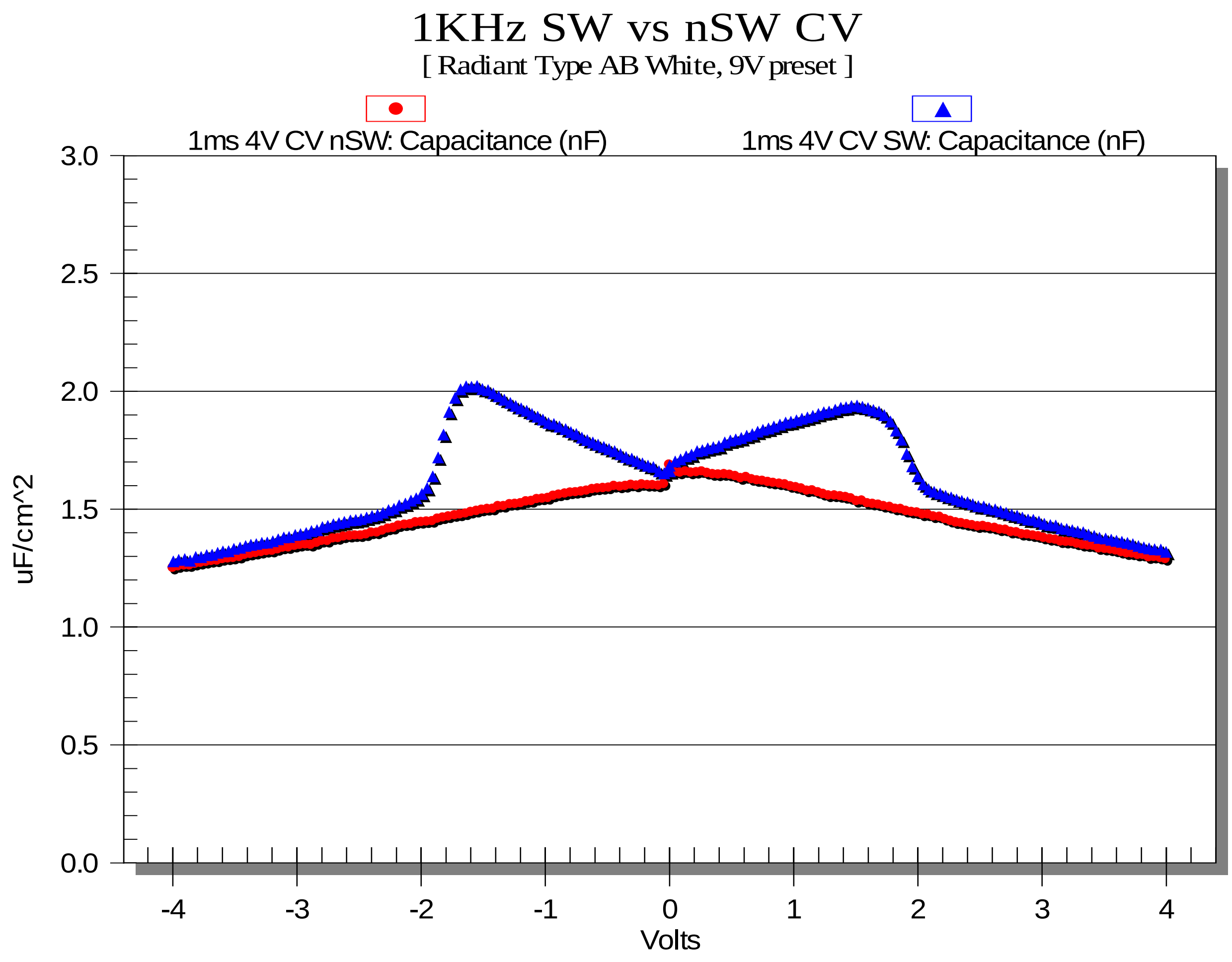
Non-switching vs Switching CV



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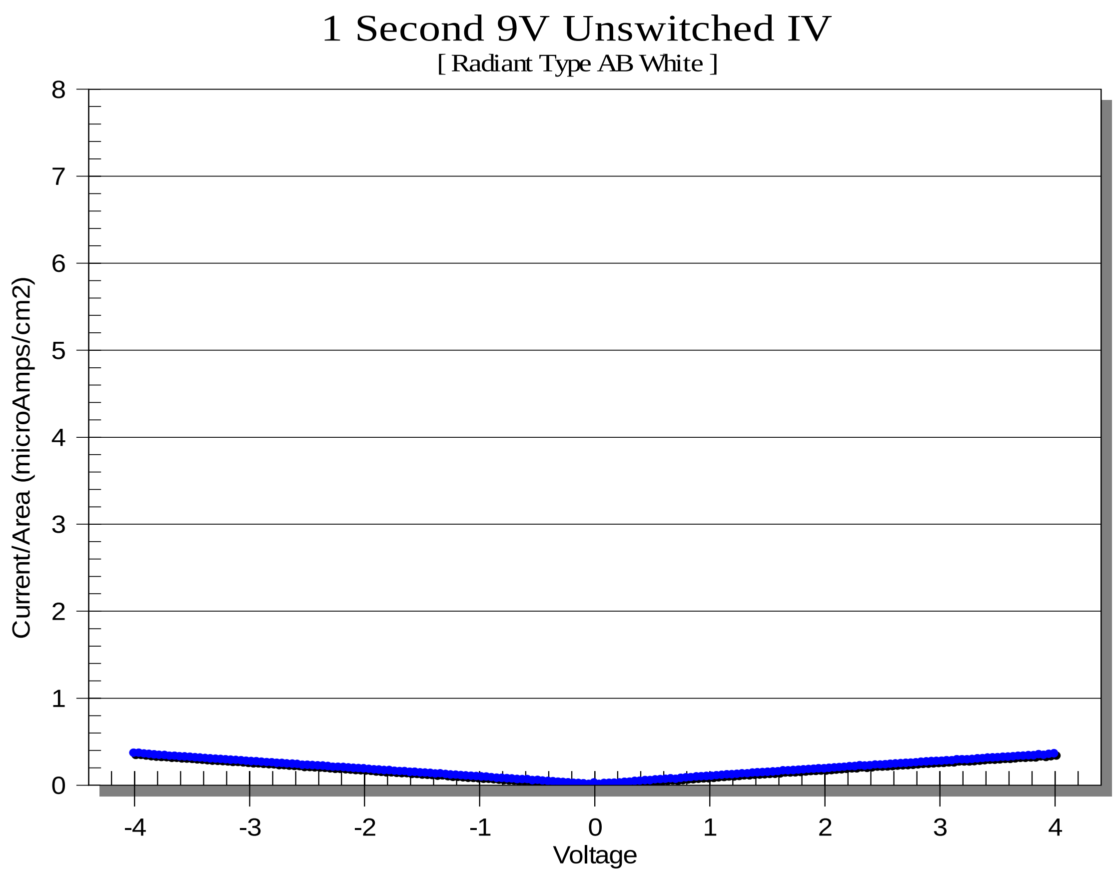
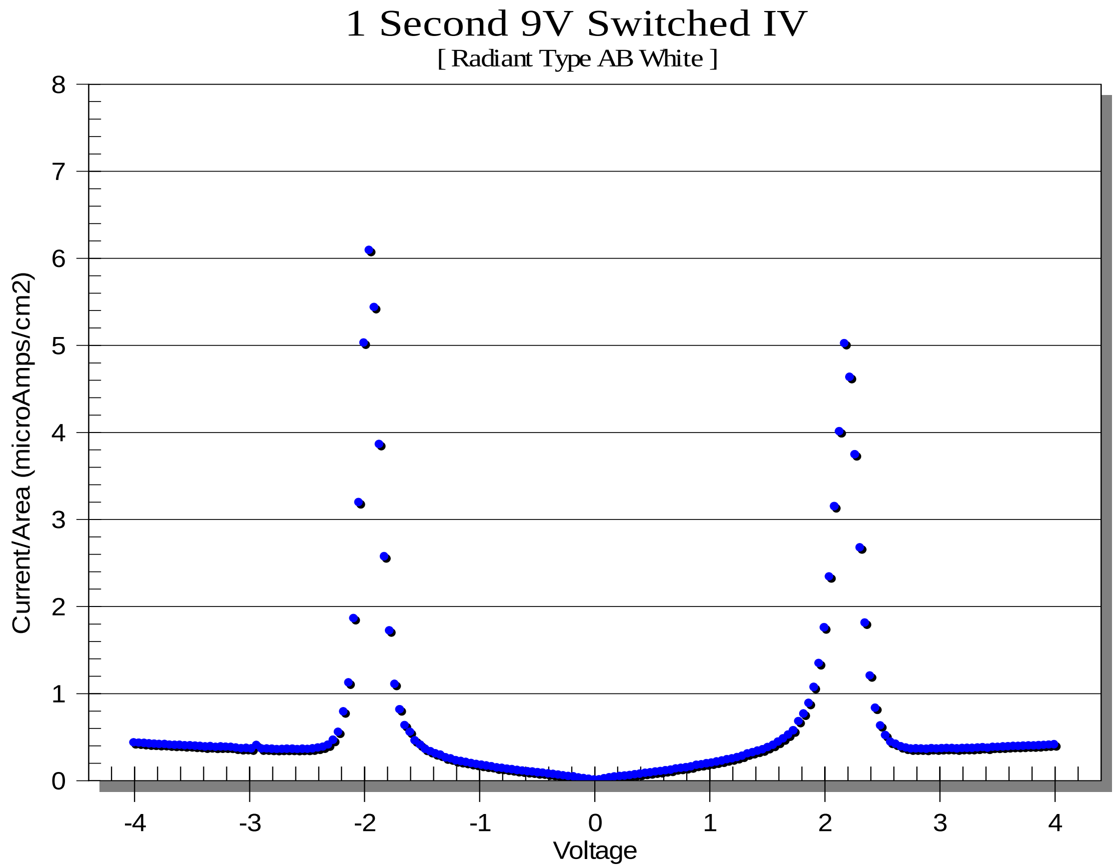
Non-switching IV for the Sample under Test

- 1 second integration time test with 182 points

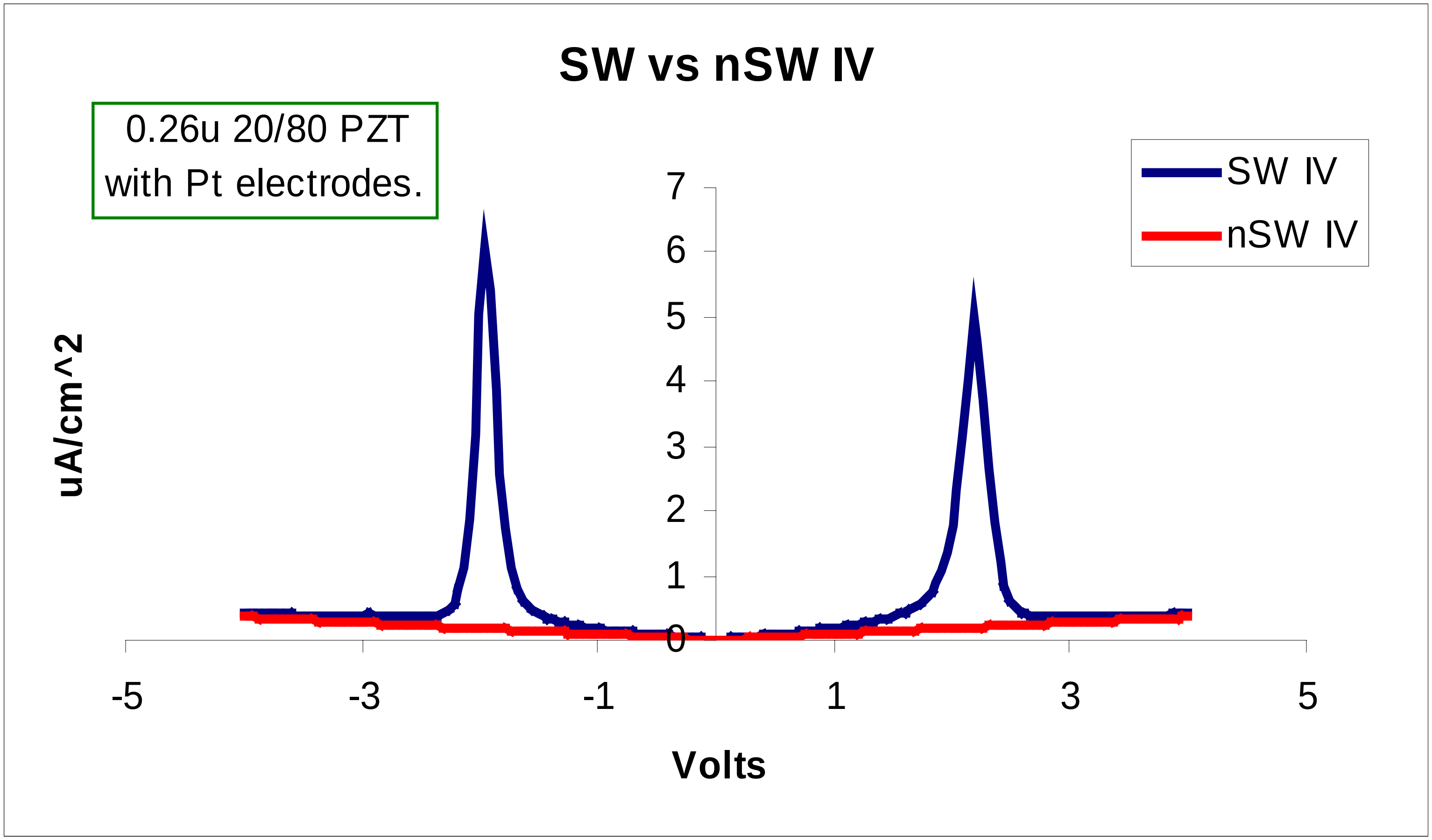


Switching IV for the Sample under Test

- 1 second integration time test with 182 points

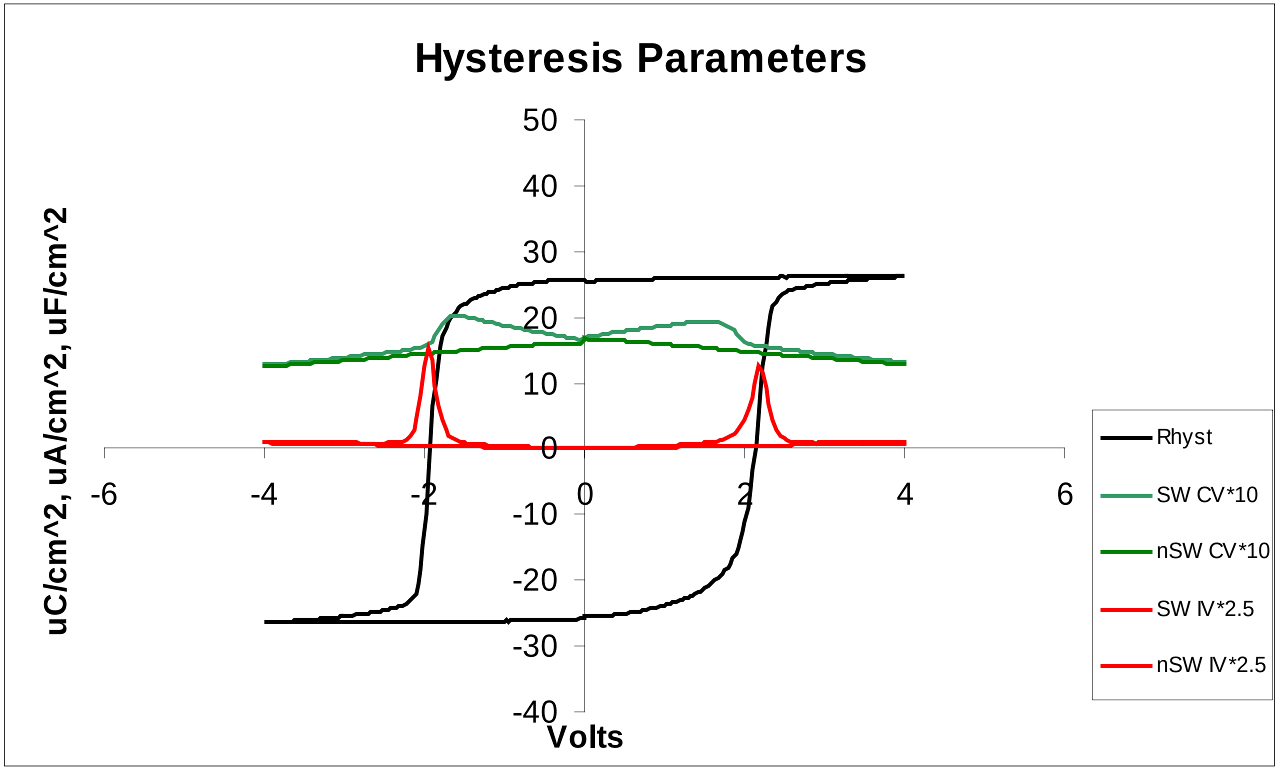


Non-switching vs Switching IV



Compare PV, CV, & IV

- The IV values (μA/cm[2]) are multiplied by x2.5 to make them more visible.
- The CV values (μF/cm[2]) are multiplied by x10 to make them more visible.



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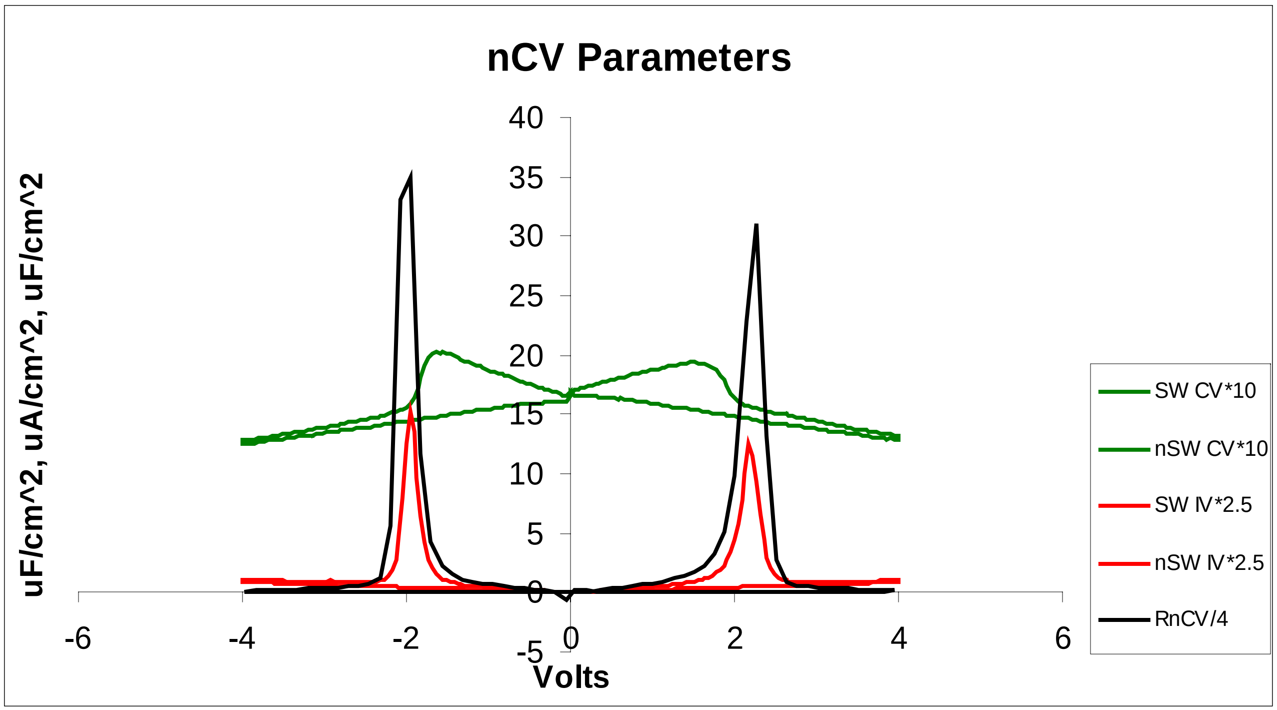
Compare nCV, CV, & IV

- The IV values (µA/cm²) are multiplied by x2.5 to make them more visible.
- The CV values (µF/cm²) are multiplied by x10 to make them more visible.



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Analysis

- The small signal leakage of the capacitor is a direct function of the remanent polarization with the highest leakage occurring at the coercive voltage for the remanent polarization switching.

- The small signal CV function is not linearly related to the remanent polarization switching function.

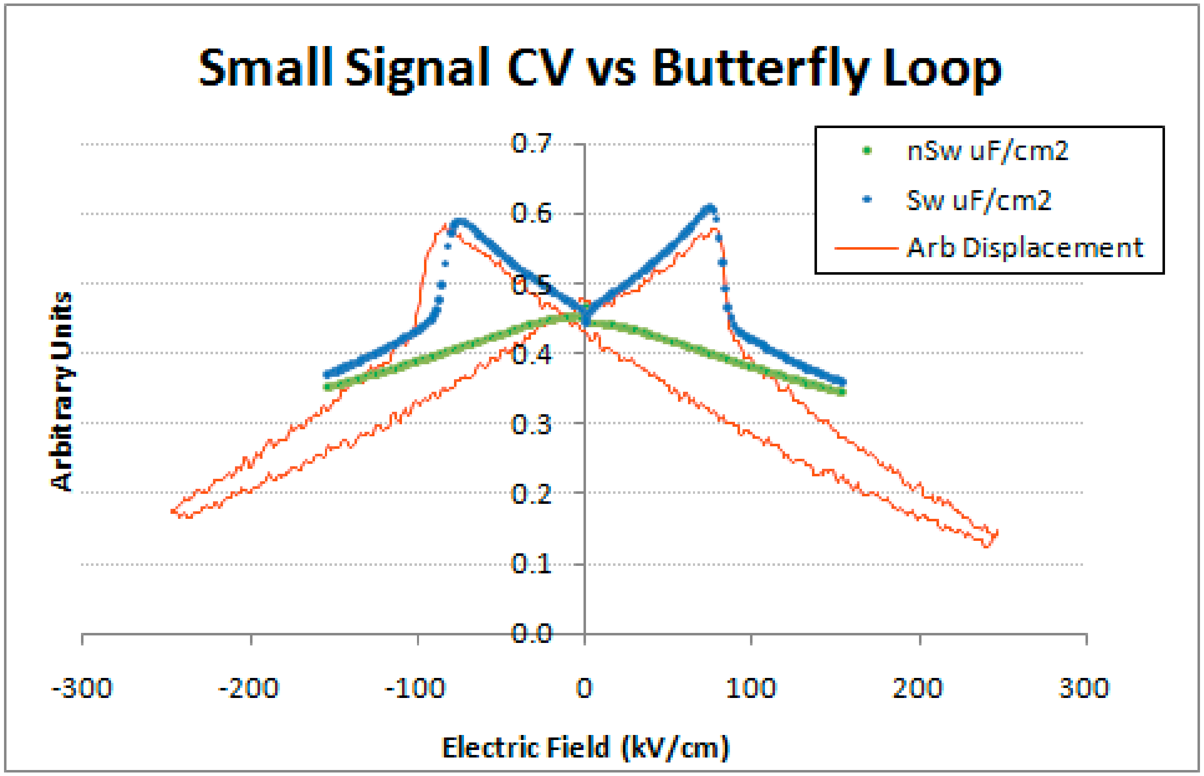
- The small signal CV function is completed in its “switching” before the coercive voltage of the remanent polarization switching.

- The small signal CV function appears to be an inverted “butterfly loop” typical of displacement measurement of a ferroelectric piezoelectric material.
  - An AFM measurement of the film displacement could be executed to compare the small signal capacitance with piezoelectric displacement.

Compare ssCV to Displacement

- The displacement curve was measured on a 0.8µ thick 4/20/80 PNZT film with platinum electrodes. The capacitor was 25µx40µ and was measured with a Polytec Laser Vibrometer.
- The small signal CV measurement came from the 0.26µ thick 20/80 PZT film used in this presentation.

- **The displacement measurement was divided by an arbitrary factor and inverted to scale it with the small signal capacitance measurement.**



Conclusion

- The small signal capacitance versus voltage, current versus voltage characteristics, and remanent polarization versus voltage share an intriguing relationship *when measured on the same capacitor*.

- No model or theory explaining the relationship is provided by the author. Only the physical relationship of the properties is presented.

- The most interesting comparison will be of the following measurements all made from the same location on the same capacitor:
  - Small signal capacitance versus voltage
  - Current versus voltage
  - Remanent polarization versus voltage
  - Large signal piston displacement of the capacitor surface (butterfly loop)
  - Small signal piston displacement of the capacitor surface.
  - Dynamic PFM movie of domain switching at the location of the measurements.
  - Static PFM small signal piezoelectric constant.