The Relationship between Hysteresis and PUND Responses

Joe T. Evans, Jr.
Radiant Technologies, Inc.

August 1, 2008

Introduction

- The Hysteresis and pulse polarization tests both measure polarization.
- In short, a pulse test is a *two point* hysteresis test!
- The results of both tests are therefore related intimately to each other.
- This presentation will relate the geometry of the hysteresis loop to the results of the pulse polarization measurement known as the PUND test.

Samples

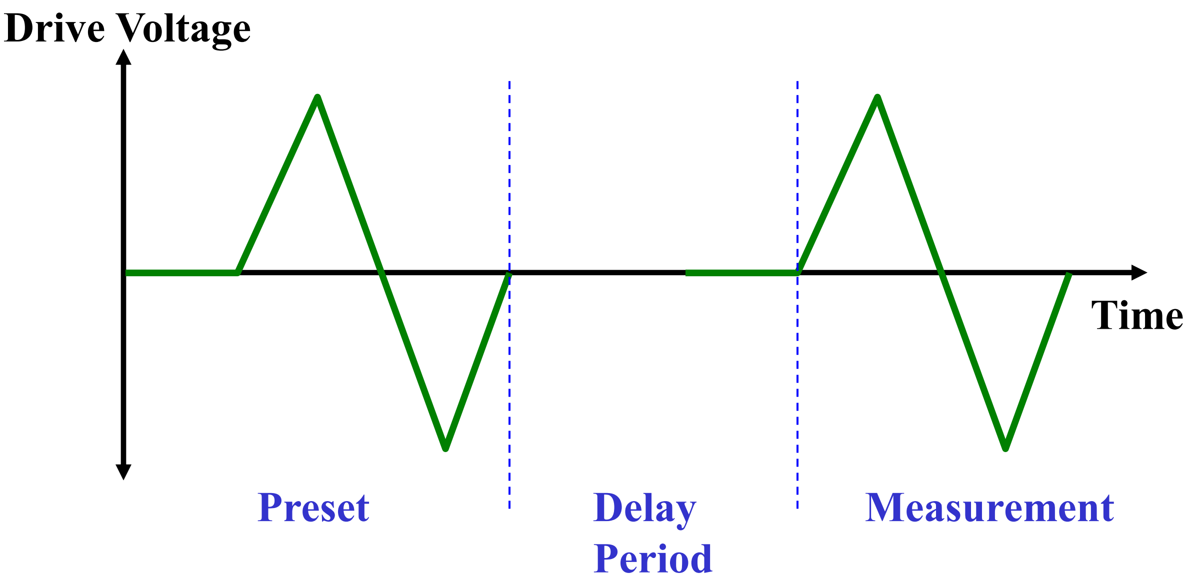
- Unless otherwise stated, all data was measured from a single capacitor on a probe station.
  - 1200Å of 4% Niobium doped 20/80 PZT
  - Bottom electrode = global layers of 1500Å Platinum on 400Å titanium
  - Top electrode = 1500Å Platinum patterned into 110μ x 110μ squares

Summary

- What is a hysteresis test?
- What is a PUND test?
- Can the PUND test be executed using hysteresis loops?
- Correlating the PUND results with the hysteresis loop.
- Conclusion

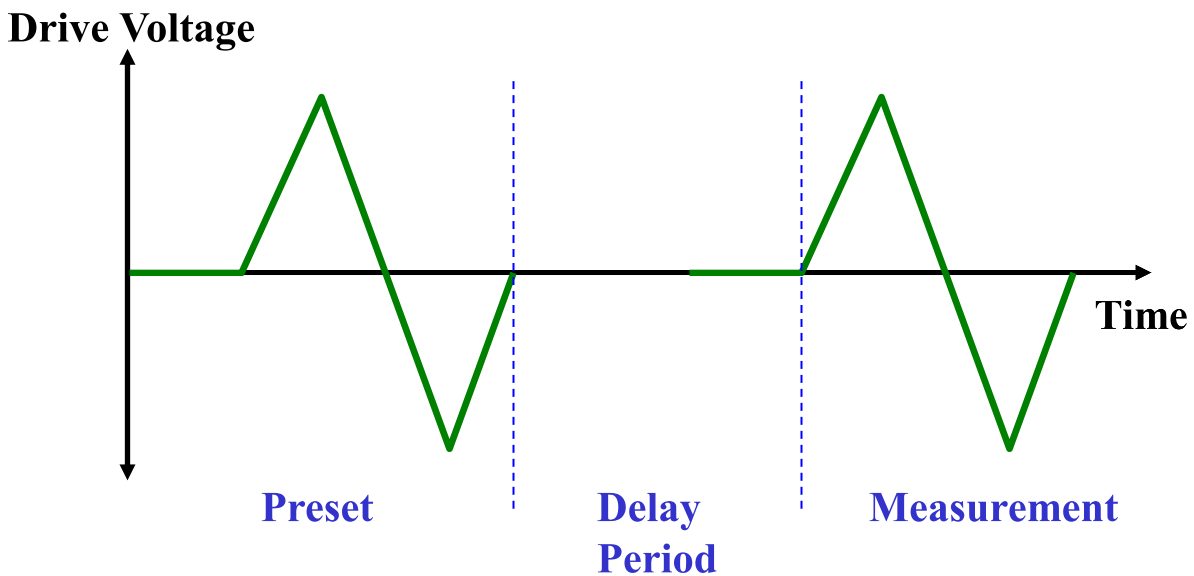
What is the Hysteresis Test?

The Hysteresis Test



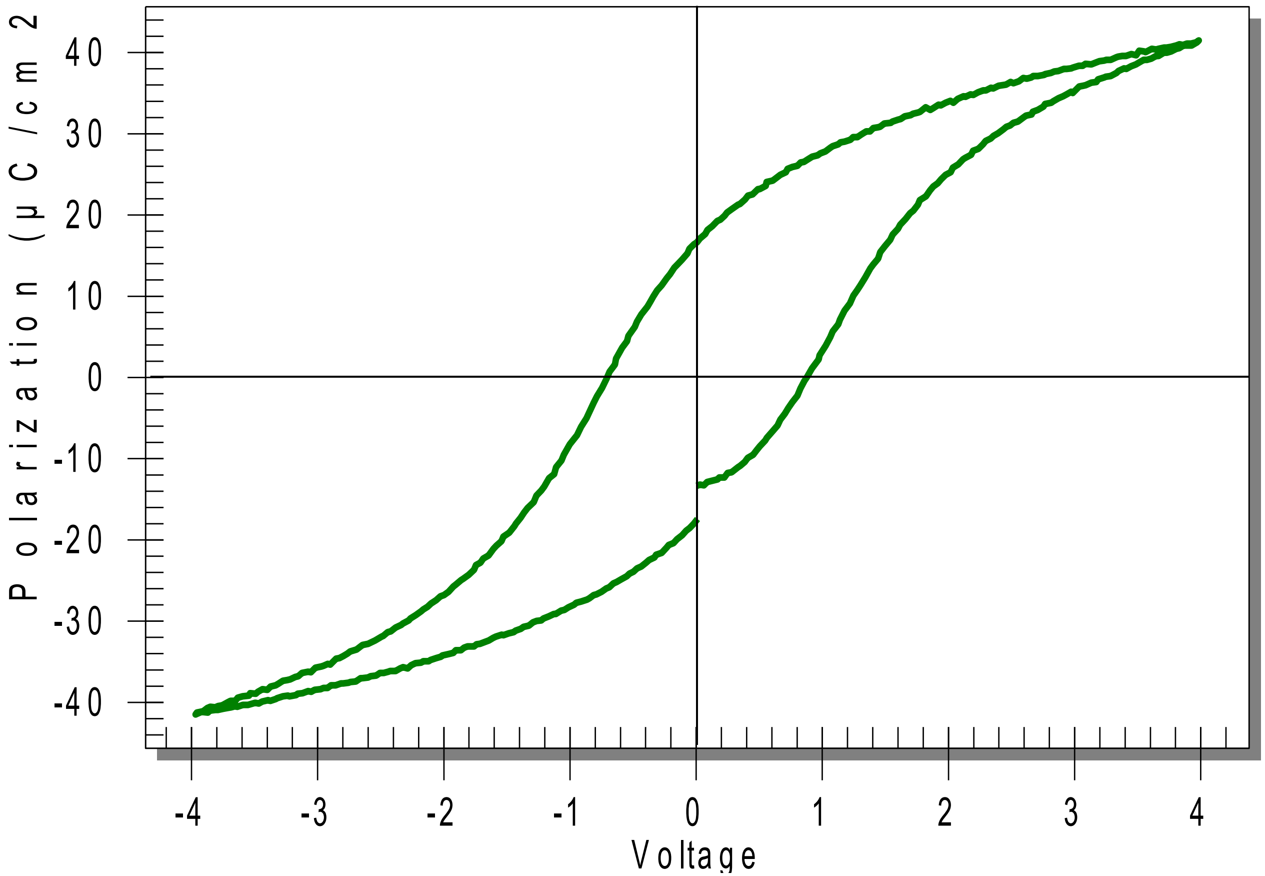
A hysteresis test has a preset loop followed after a delay by the measurement loop. The stimulus Radiant prefers is the triangle wave because, except for the reversal points, the stimulus has a constant [δV/ δt] .

The Hysteresis Test



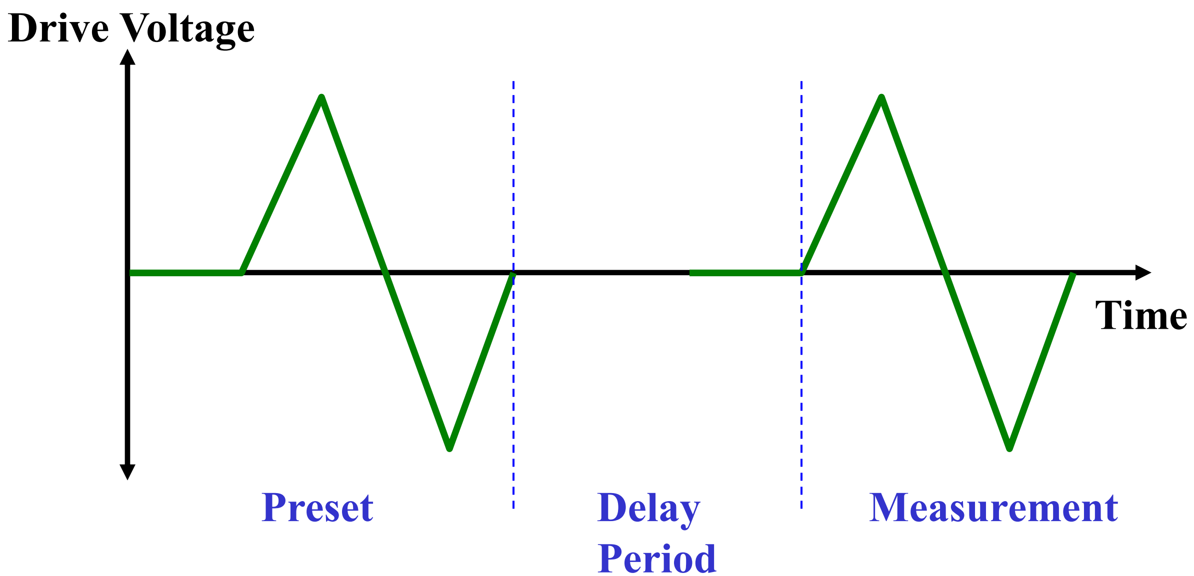
The charge produced by the sample is measured on a continuous basis without interruption during the stimulus period from zero volts to zero volts. Therefore, the measurement gives the total number of electrons that have left or entered the sample at each time point of the stimulus.

The Result



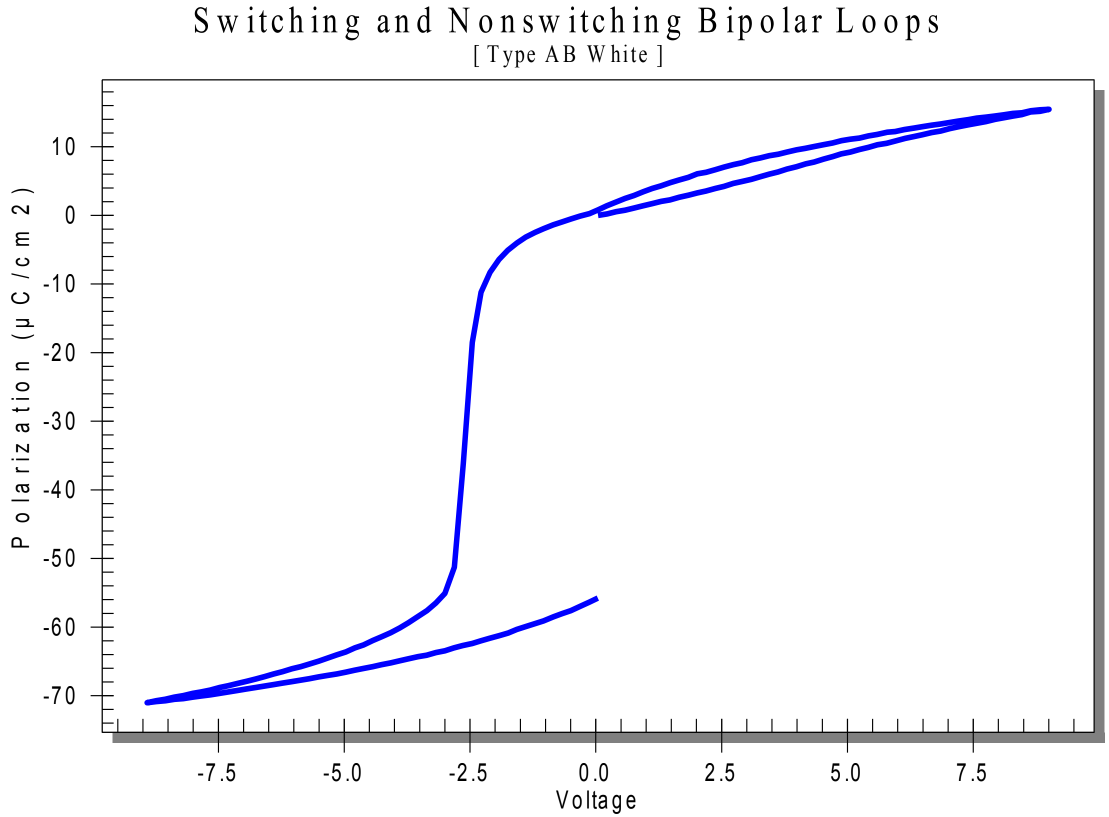
The change in the number of electrons on the plates of the capacitor during the voltage stimulation plotted against the stimulus voltage at which each measurement was made yields the familiar “hysteresis loop”.

The Preset Loop



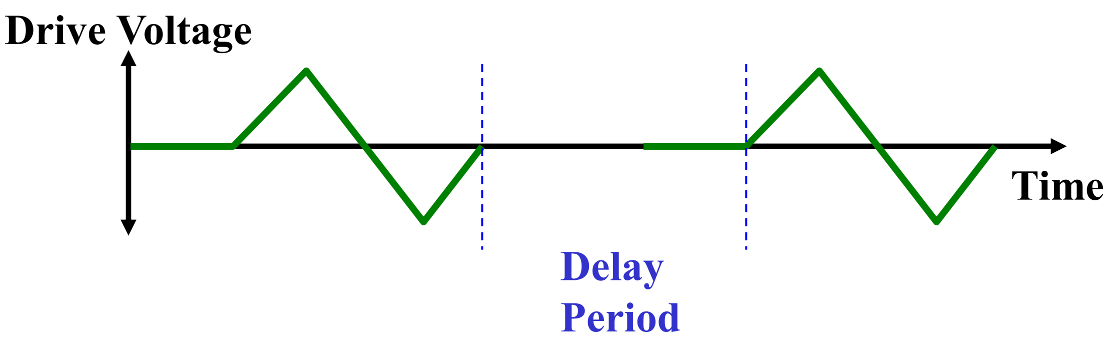
The state of the internal polarization of a ferroelectric capacitor is unknown before the test execution. Therefore, to ensure that we will measure the entire loop, two loops must be done. The data from the first loop is ignored while the data from the second loop is used for the plot. The first loop ***presets*** the internal polarization of the sample capacitor to match the test voltage of the second loop.

No Preset Loop



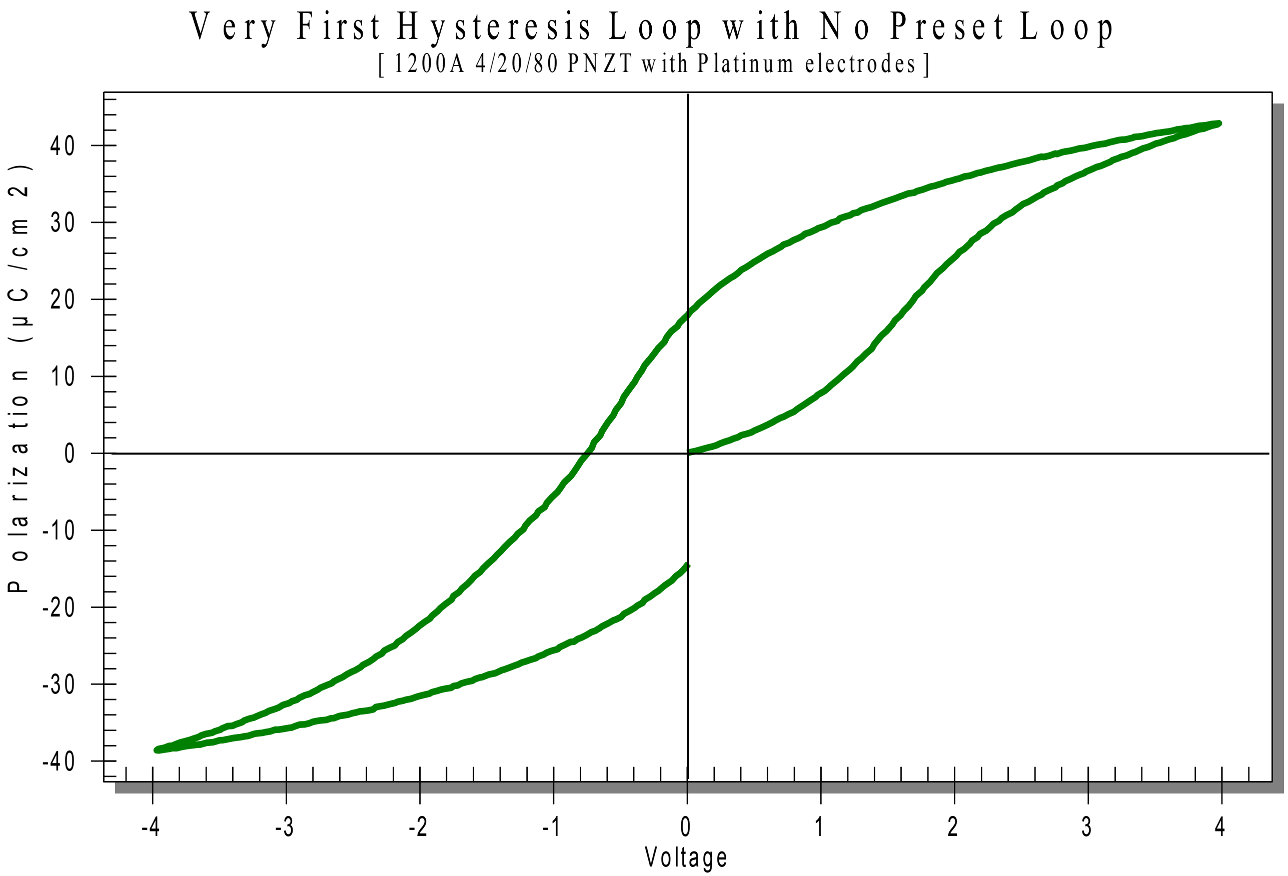
If no preset loop is executed, the polarization could start anywhere. In the plot above of a Type AB capacitor (20/80 PZT), the remanent polarization was already “Up” when a single positive going-triangle wave was executed without a preset. Think about the plot. The capacitor is doing exactly what it should.

There is Always a Preset Loop!



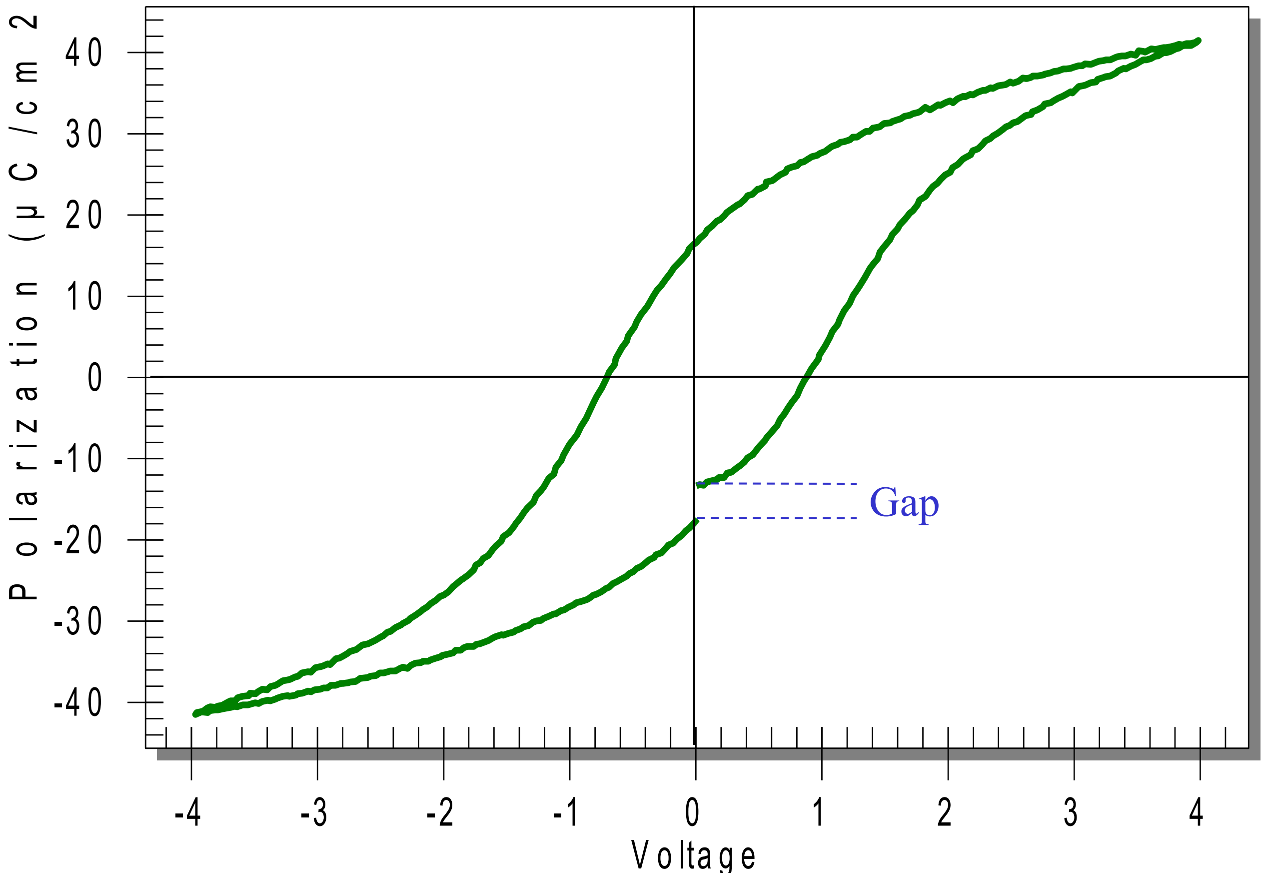
- A single loop measurement like that on the previous page *always* has a preset loop. Ferroelectric materials by definition have memory so the *last stimulus* you applied to the sample is its preset loop *even it was done over a year before!*
- Only one loop does not have a preset loop: *the very first loop after fabrication!*

The First Loop



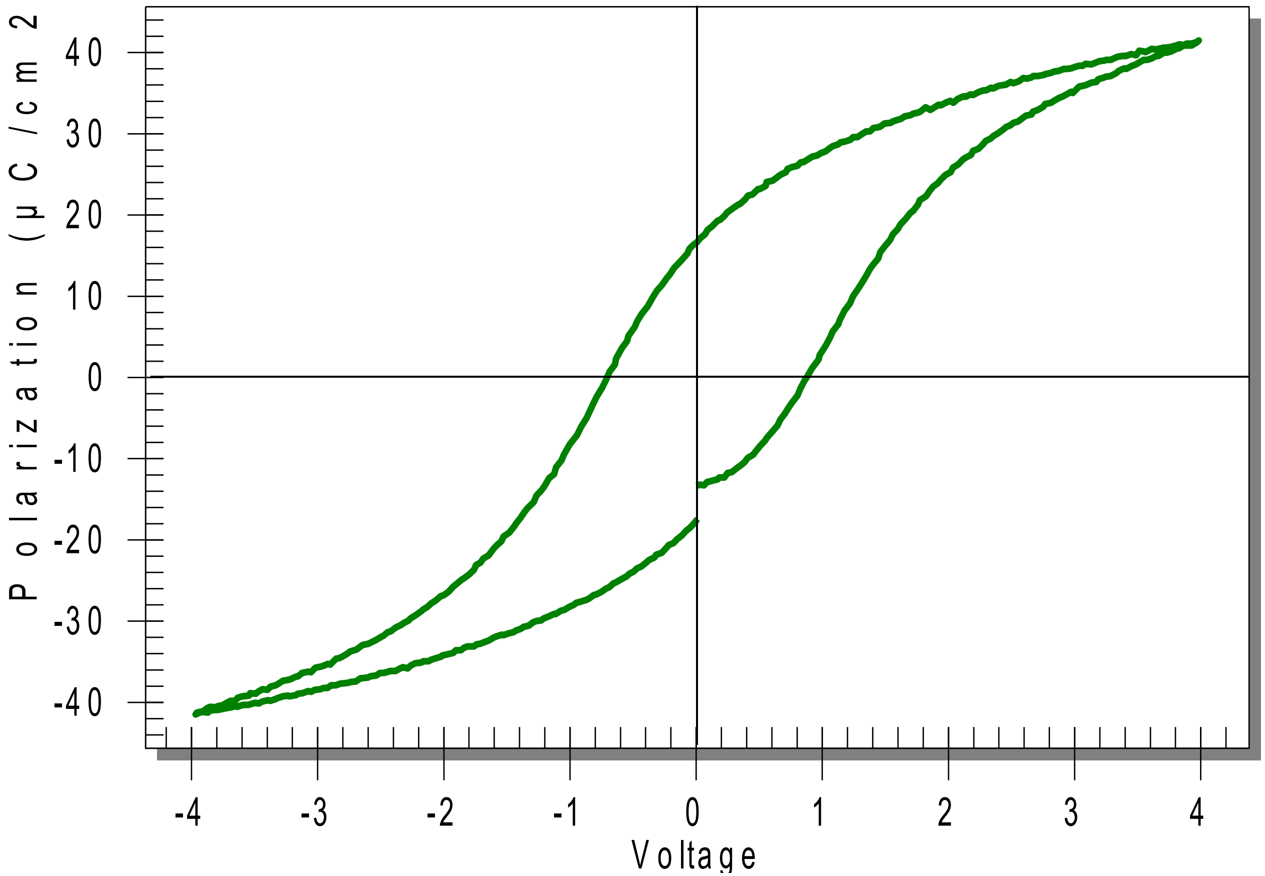
- Ferroelectric films with symmetrical metal electrodes come down from the Curie Temperature with zero remanent polarization.

The Gap



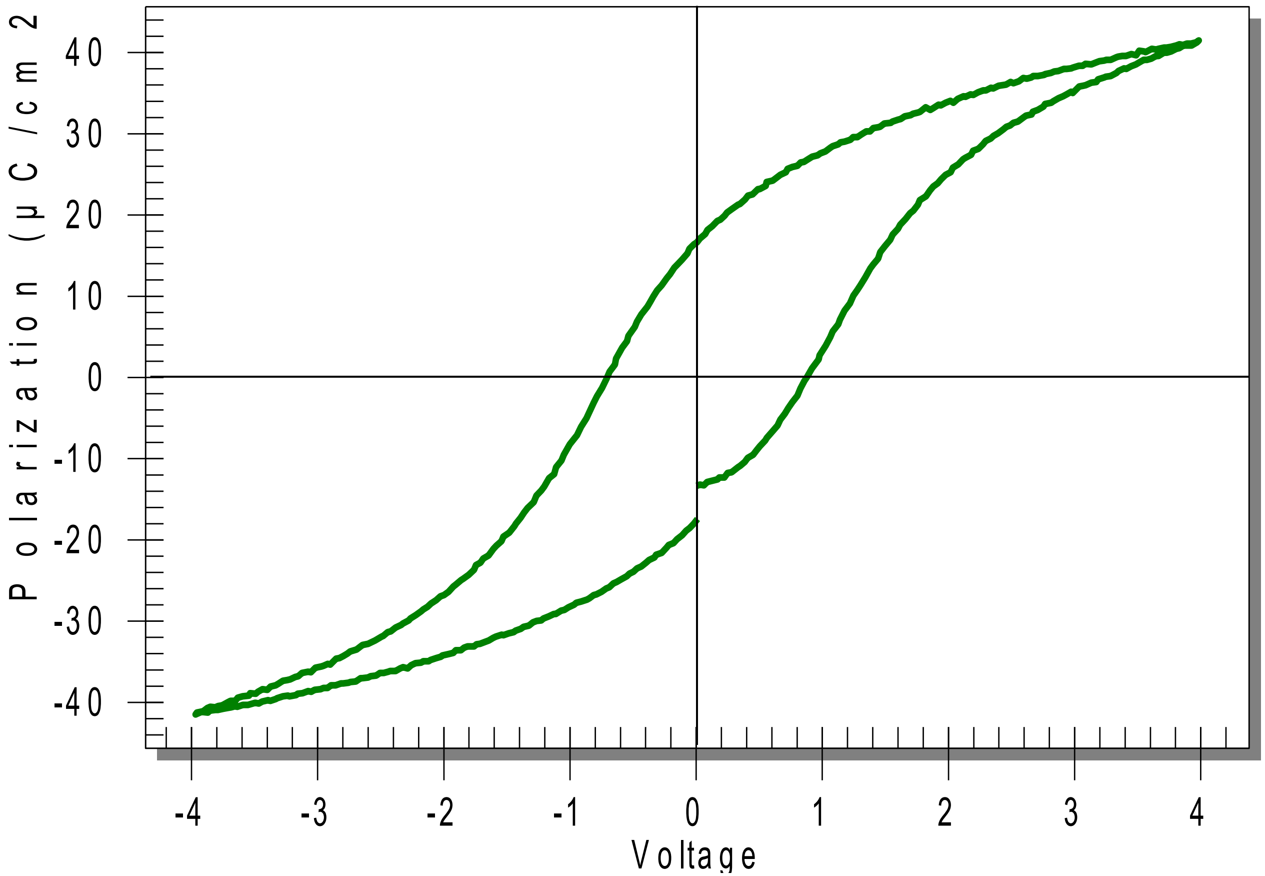
Many times, the hysteresis loop does not close on itself, stopping at a different location than it started from after the preset loop.

The Gap



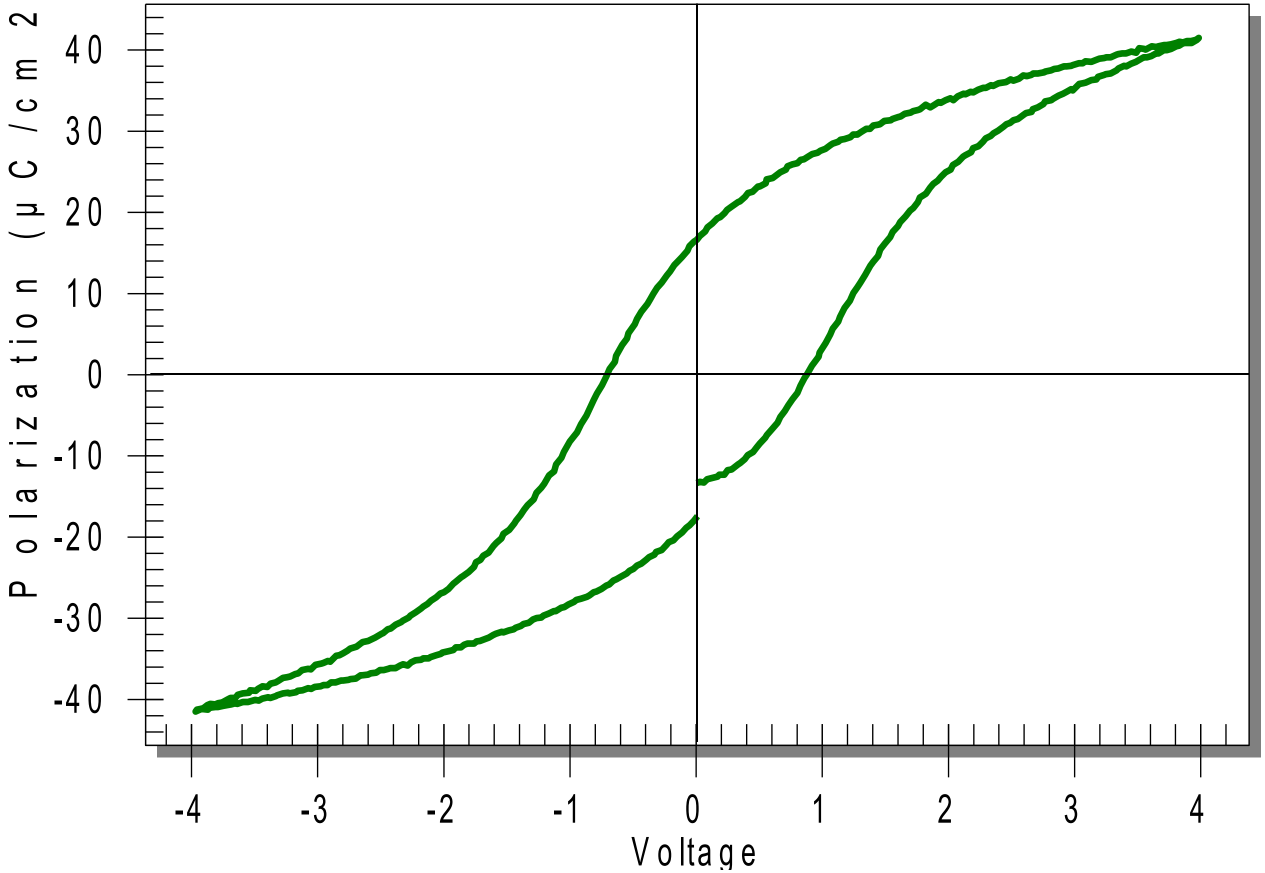
There are several causes for this effect. For a “perfect” capacitor with no leakage or imprint, the gap still occurs. For the remainder of this presentation, I will assume we are dealing with a perfect capacitor.

The Gap



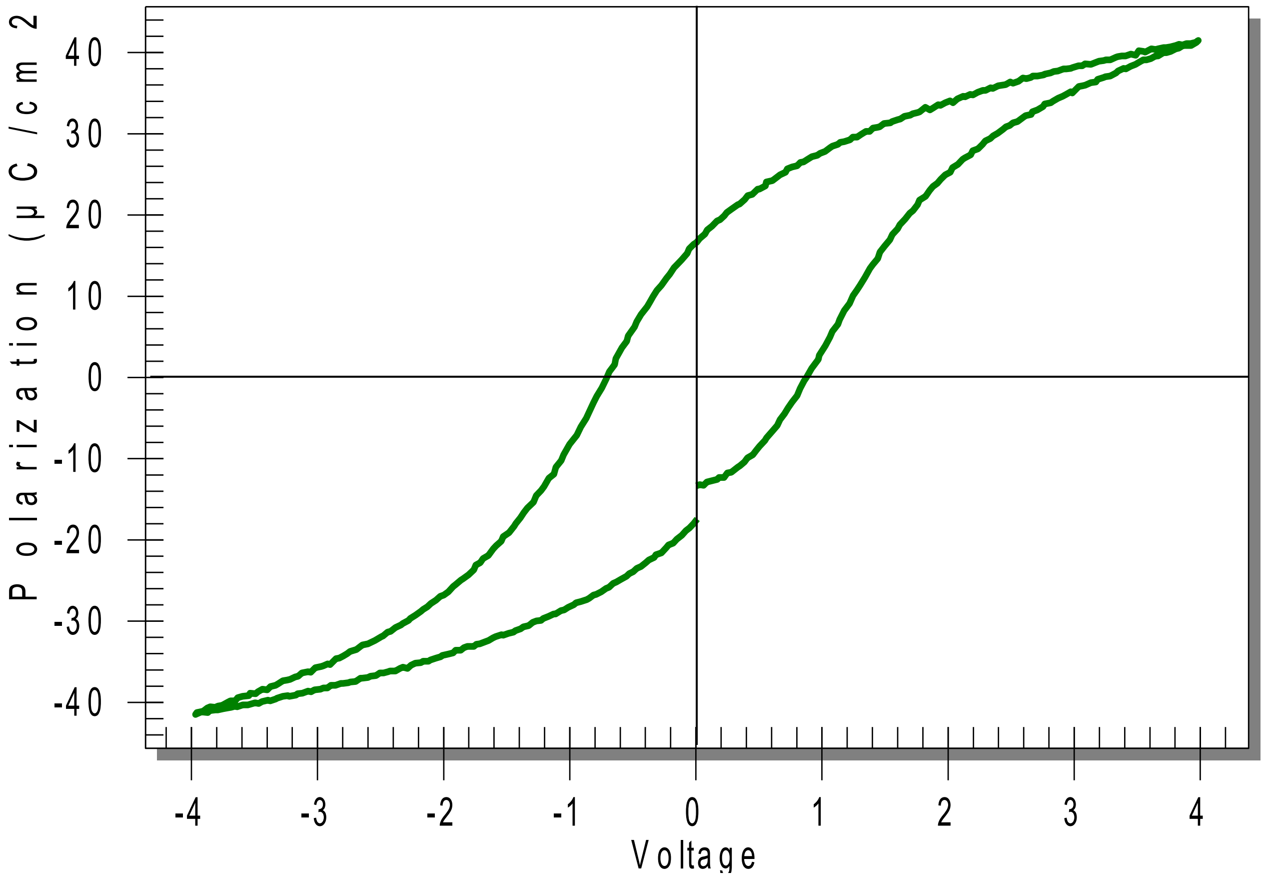
The cause of the gap is unknown but it is real. It is directly related to results measured in the PUND test. *It is the bane of FRAM memory designers who must contend with its presence during read operations.*

Raw vs Centered Data



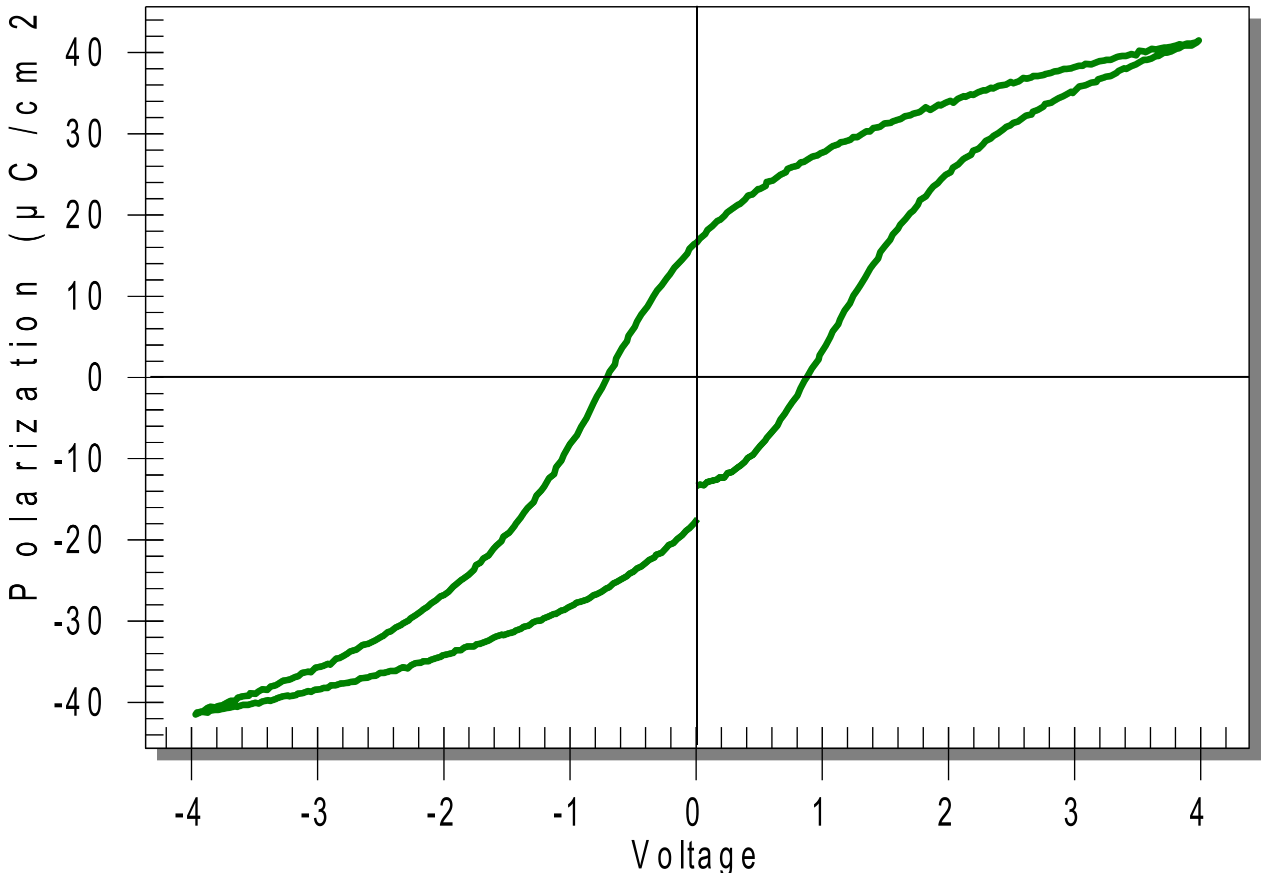
As noted earlier, the polarization state of a device is unknown prior to a test. The test instrument in use knows not what the starting value should be. Therefore, the first point of the raw data ***is always zero***!

Raw Loops



The hysteresis loop in the plot above looks normal but it is offset up because its first point is at the origin of the graph. This is how the tester sees the loop.

Centered Loops



Vision will center a loop if requested by averaging the +Pmax and –Pmax values from the raw loop and subtracting that average from every point. This offset is reported by Vision for all hysteresis loops.

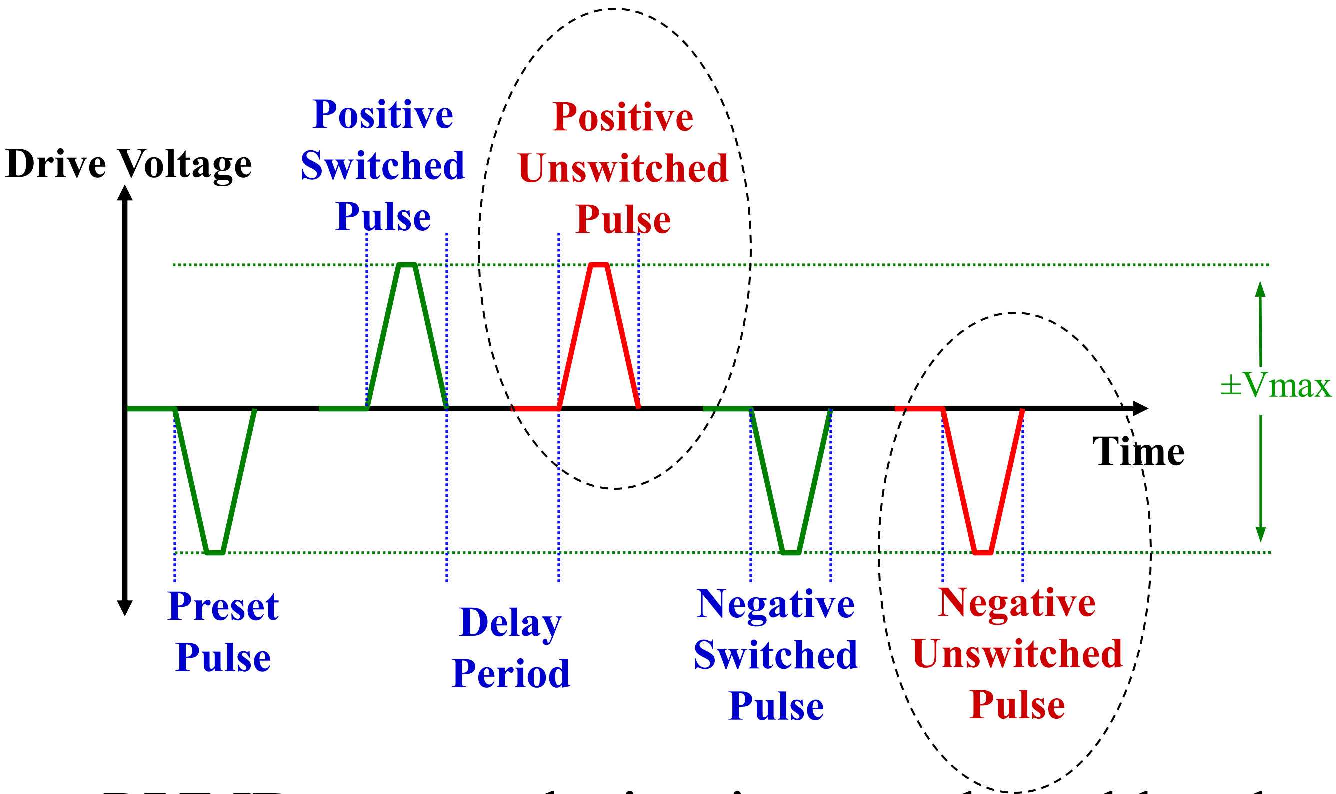
Remanent Hysteresis

Without giving a explanation, I will assert that the offset value calculated by Vision to center the raw hysteresis loop is exactly equal to the remanent polarization of the capacitor. I believe that this assertion can be proven geometrically.

Note: This assertion only applies to capacitors with symmetrical loops having no imprint.

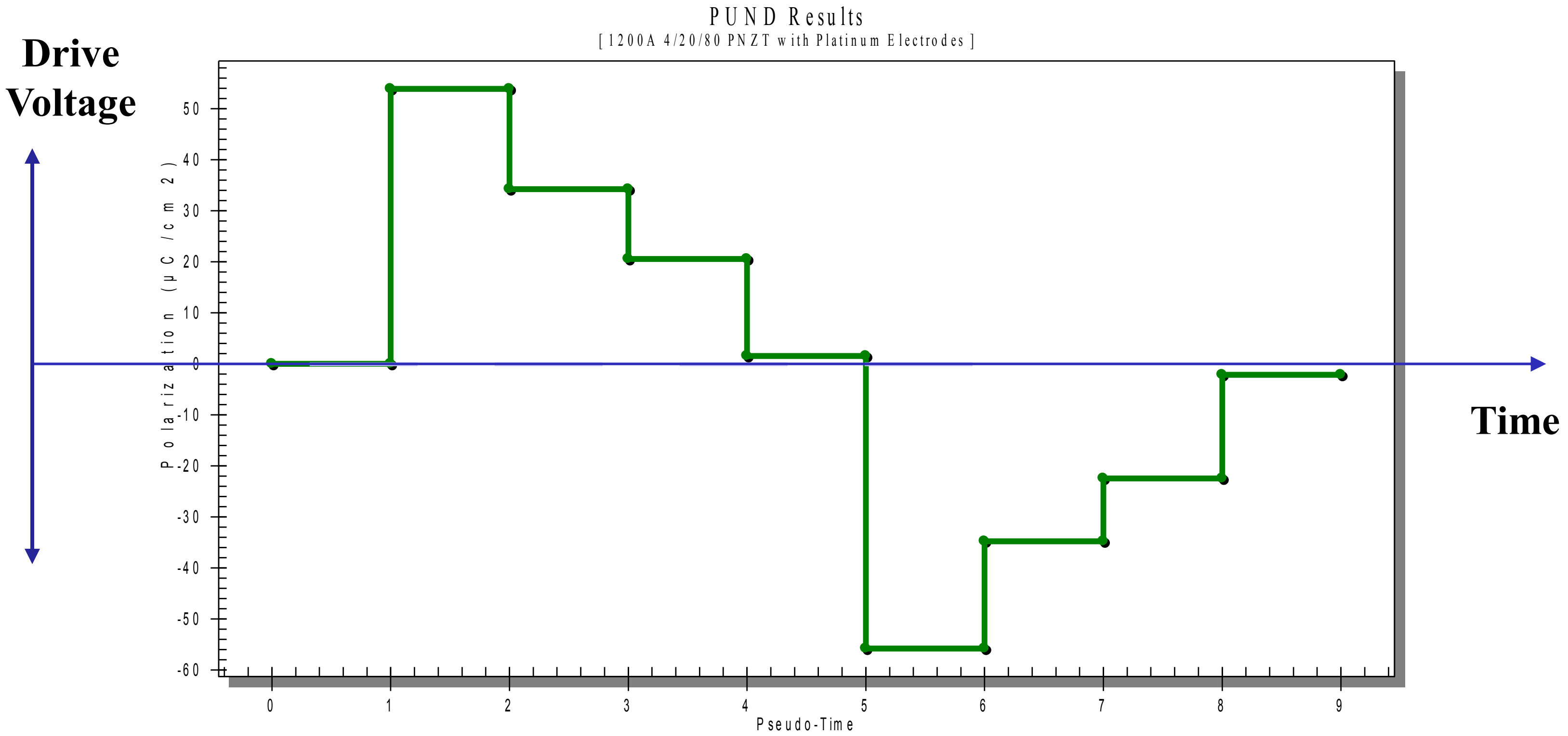
What is the PUND Test?

"PUND"



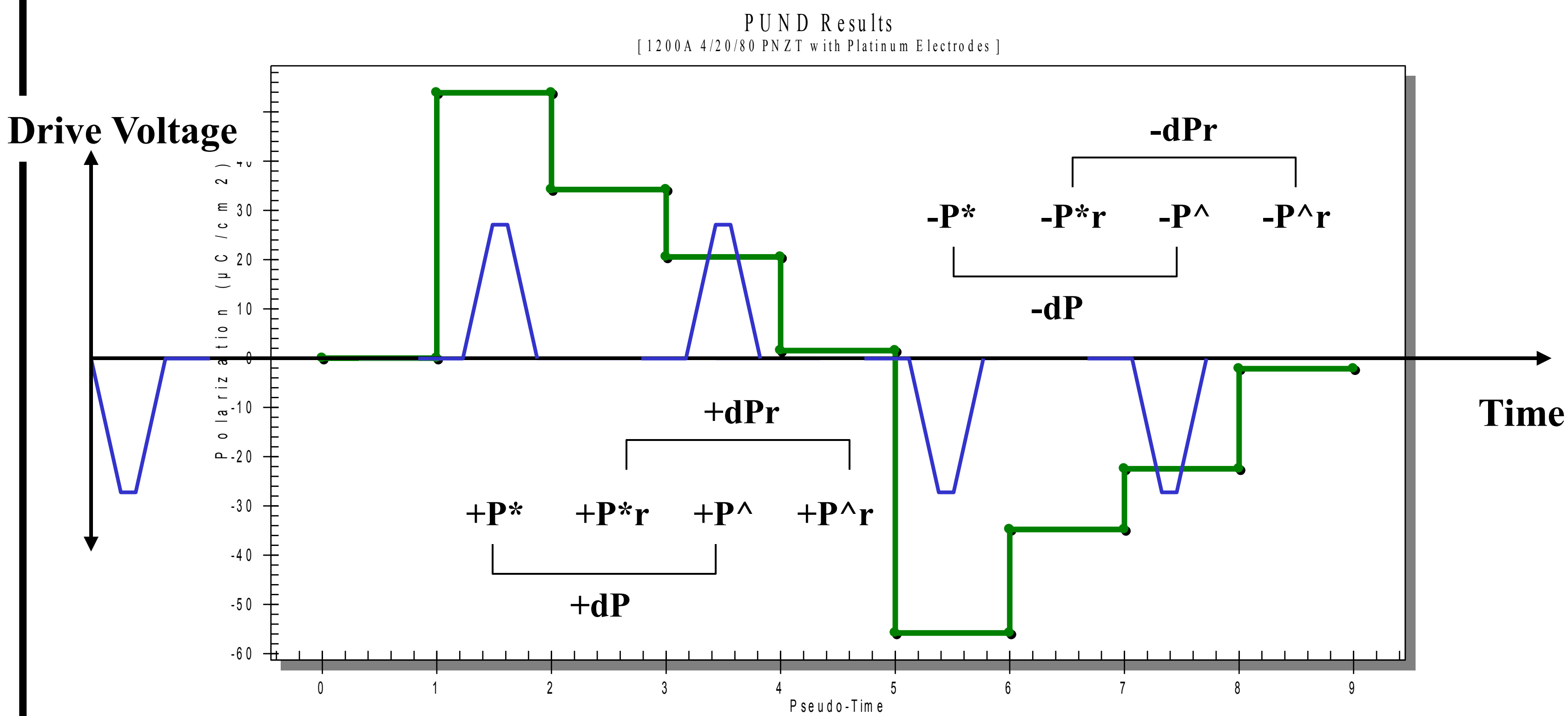
In a PUND test, polarization produced by the non-switching pulses does not go back to zero! These values are labeled ±**P^r** on Radiant Technologies' testers.

"PUND" Results



***This data taken from a separate 4/20/80 PNZT capacitor than the remainder of the data.**

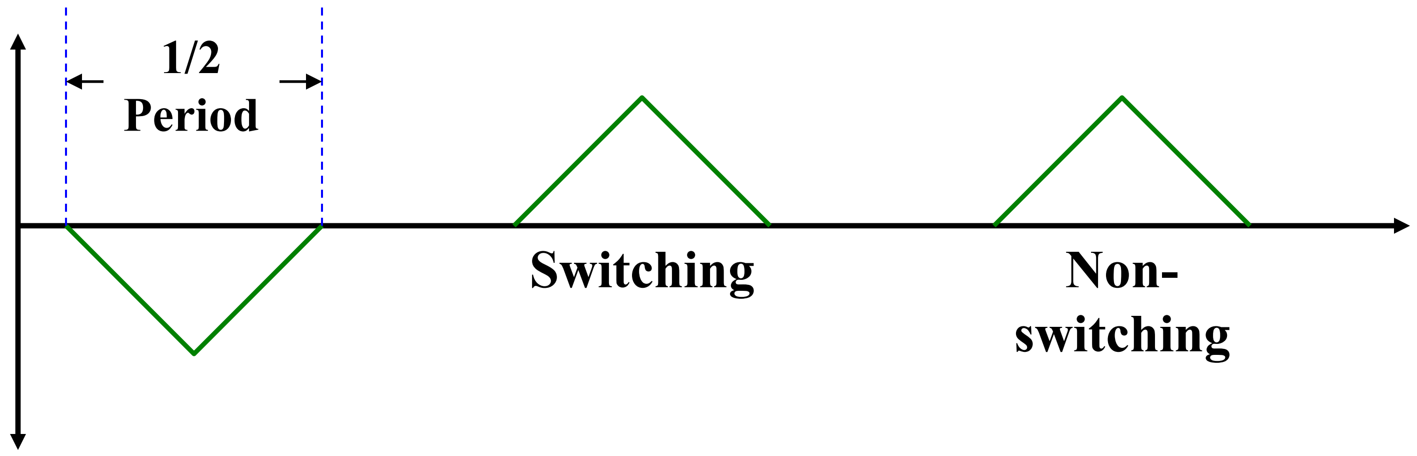
"PUND" Results



*This data taken from a separate 4/20/80 PNZT capacitor than the remainder of the data.

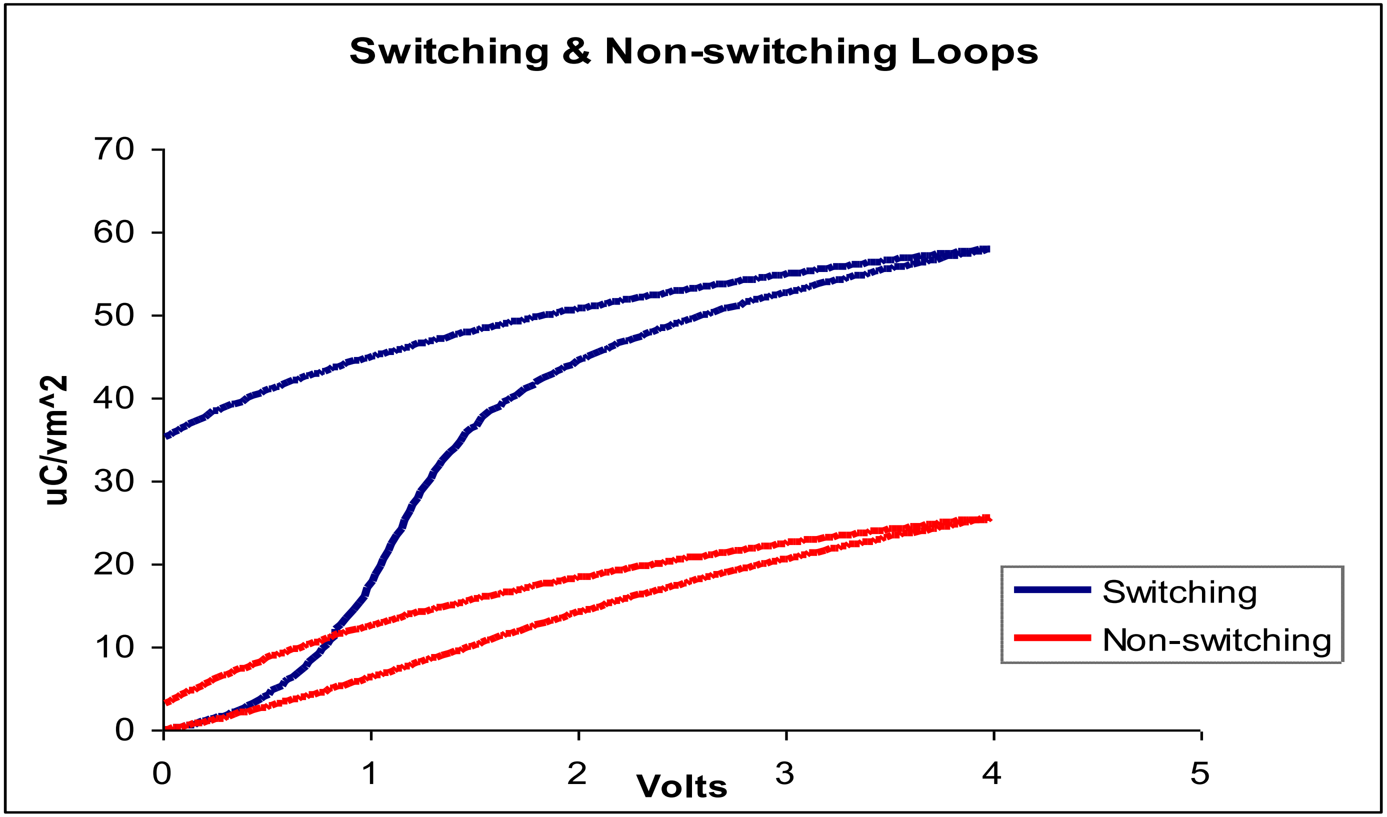
Can We do the PUND test with Hysteresis Loops?

Use half loops:



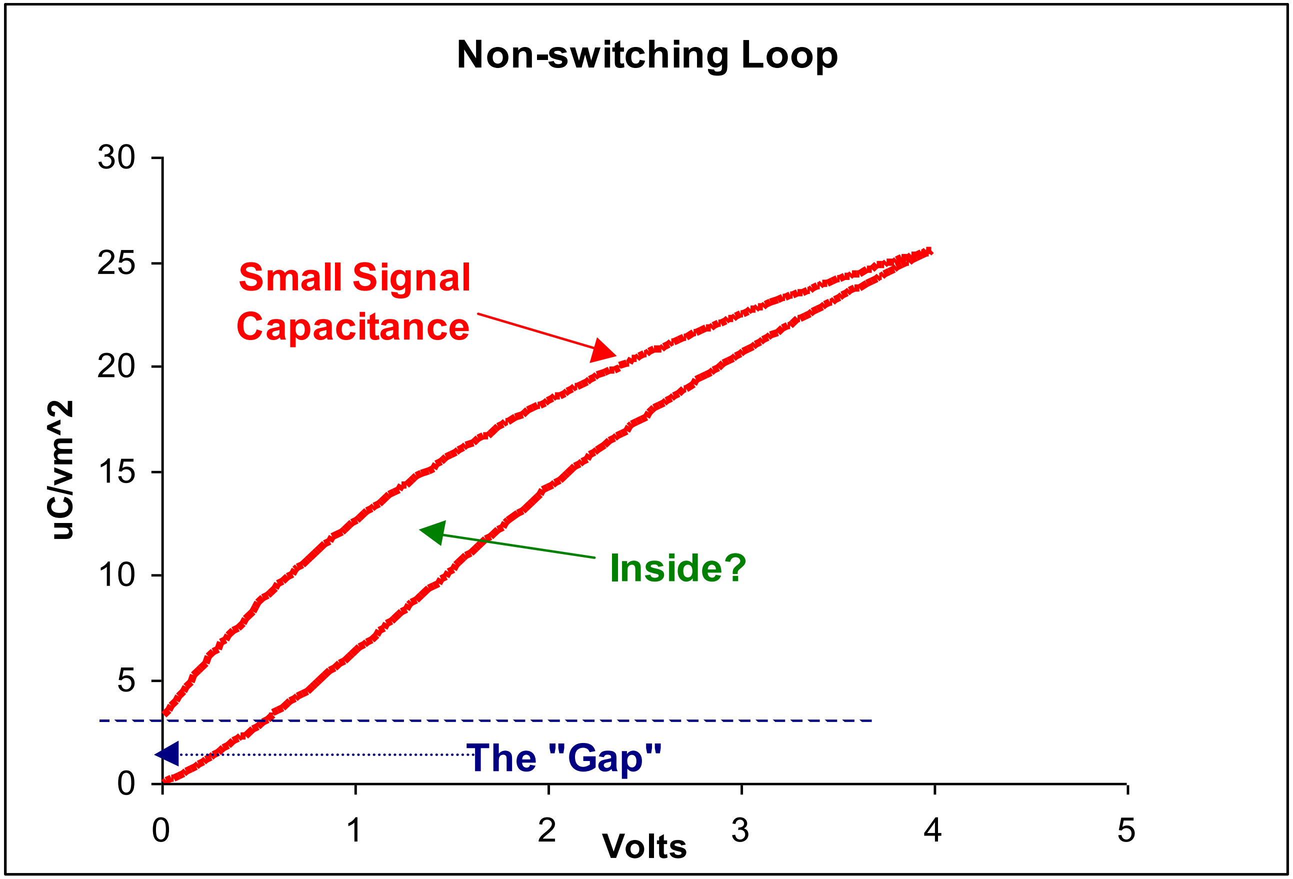
The Parts of the Hysteresis

Switching and Non-switching half loops:



“Gap” in the Half Loop

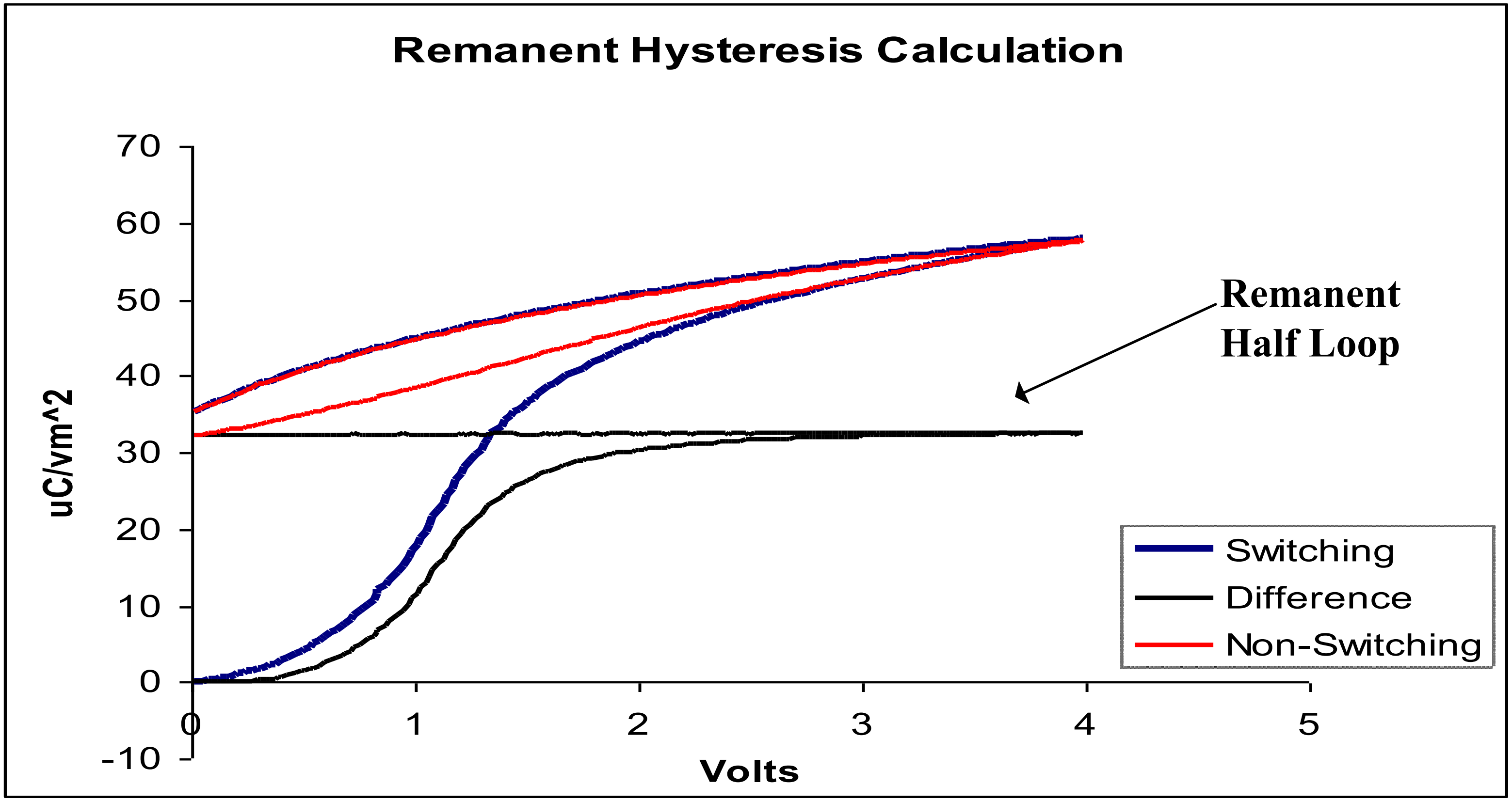
The Non-switching half loop does not go back to zero!



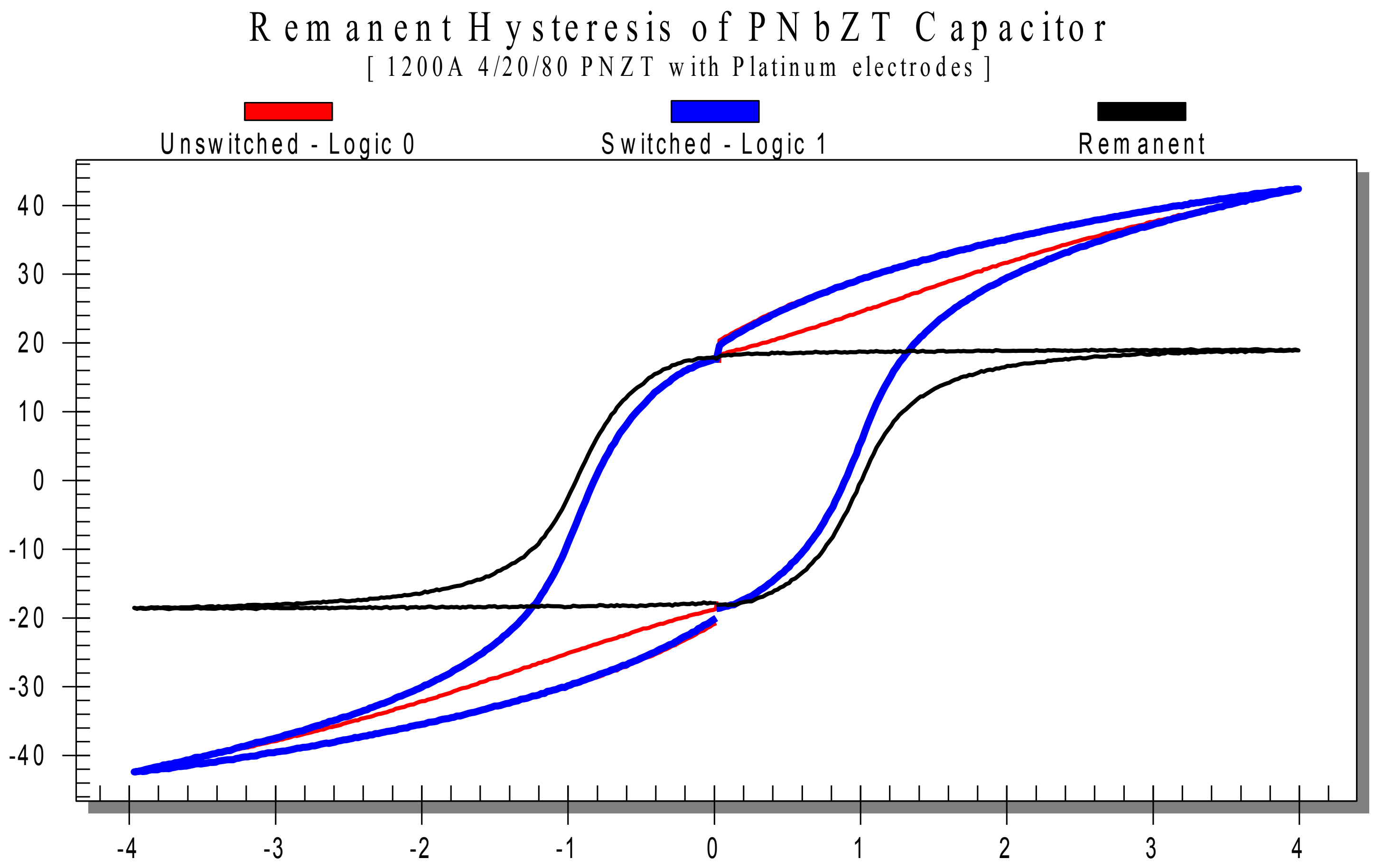
Remanent Hysteresis

PUND: P*r - P^r = dP = Qswitched

Hysteresis: Switching - Non-switching = Remanence:

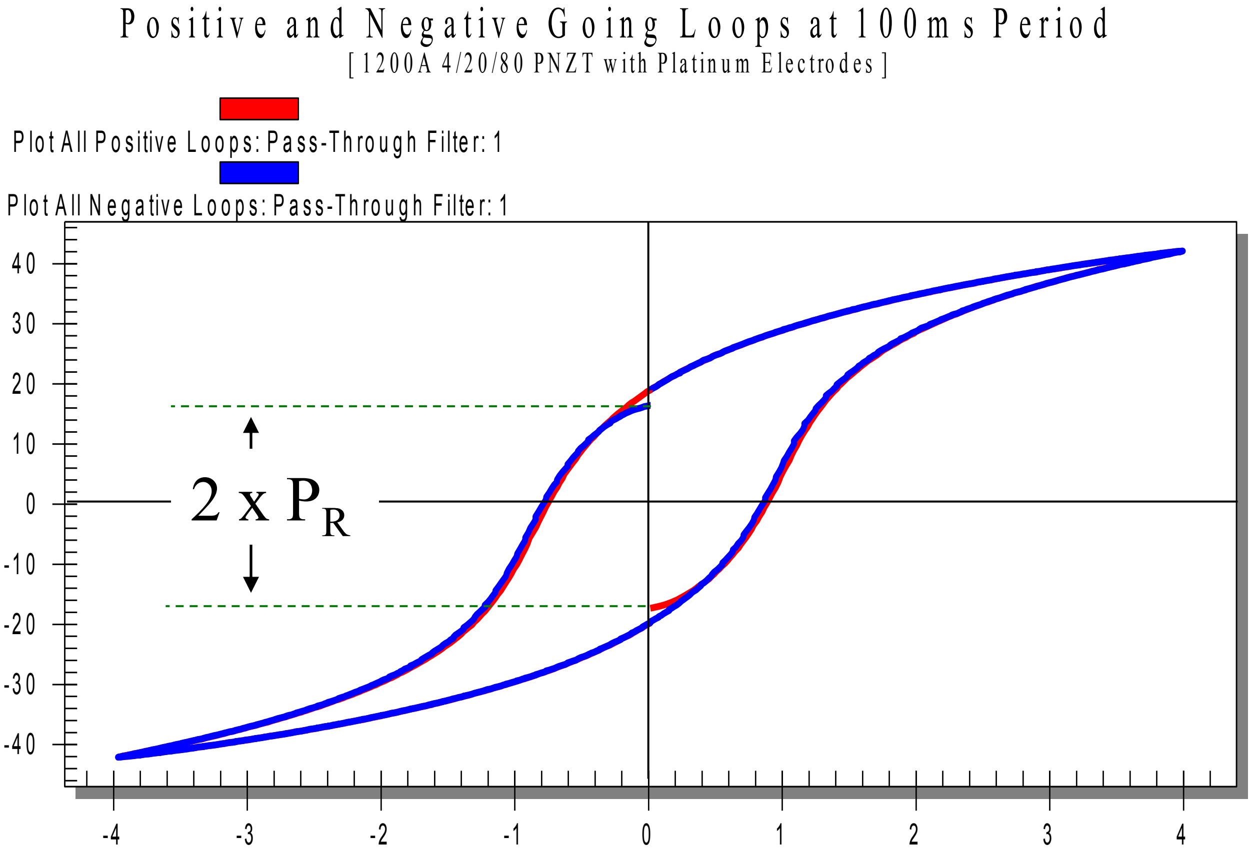


The Full Remanent Loop



Radiant Technologies, Inc.

Remanent Polarization in the Hysteresis Loop



The distance between the gaps is the remanent polarization.

Conclusion

- The gaps in the hysteresis loop are equal to ±P^r.
- 2Pr from the hysteresis loop *almost never* equals the remanent polarization.
- deltaP from the PUND test is equal to the value of 2Pr from the hysteresis loop minus the magnitudes of the top and bottom gaps.

Conclusion

- deltaP is equal to two times remanent polarization.
- The "offset" value reported for a hysteresis loop by Vision is equal to the remanent polarization for a symmetrical loop.
- The PUND test can be executed using half-triangle waves instead of pulses. The results are the same.