

Experiment F02 Half Loops

Objective:

We conducted all of our previous tests by stimulating the ferroelectric capacitor with a single triangle wave. In this Experiment, we will learn how to use half of a triangle wave to produce a “half-loop”. The half-loop is a very powerful tool that we will use extensively in later experiments.

Method:

We will use the “Monopolar” waveform from the Hysteresis Setup Menu to measure only half of a loop.

Theory:

The complete triangle wave stimulates the sample to the positive and negative voltage you assign in the setup menu.

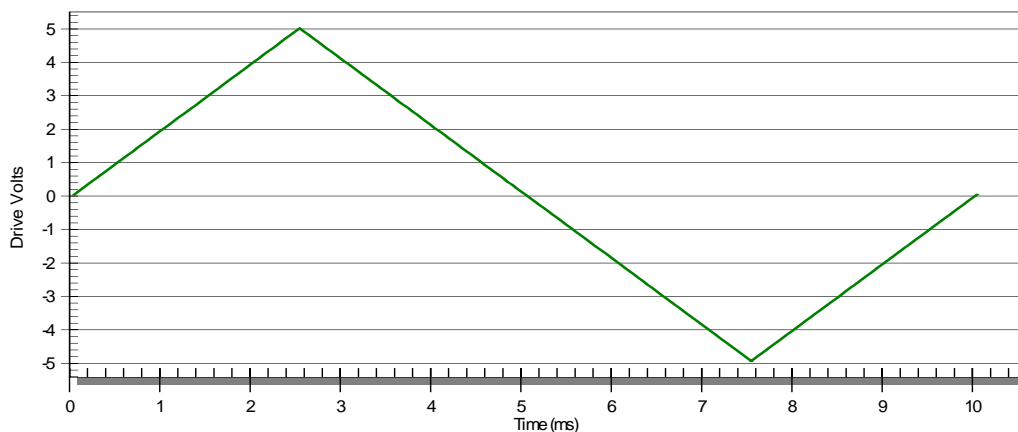


Figure F02.1
The Triangle Stimulus

When a saturation voltage is used (see [Experiment F01 -The Saturated Memory State.doc](#)) the triangle wave forces the ferroelectric capacitor to go all the way around the hysteresis loop and return to its starting position.

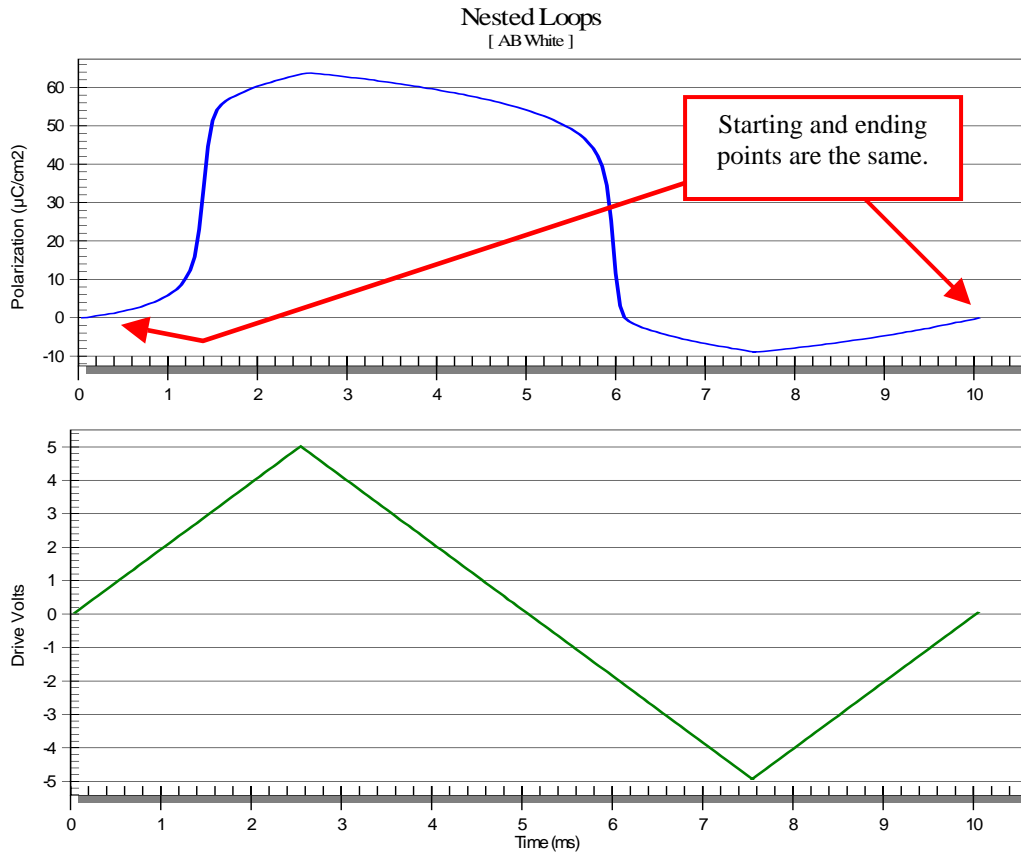


Figure F02.2
The Complete Hysteresis Loop Caused by the Triangle Wave

The triangle wave stimulus actually consists of two half-hysteresis loops in sequential order, one up and one down. Examine Figure F02.3 below. Notice how the polarization response of the ferroelectric capacitor in the second half of the test is the same as the first half only flipped upside down. Symmetry at work!

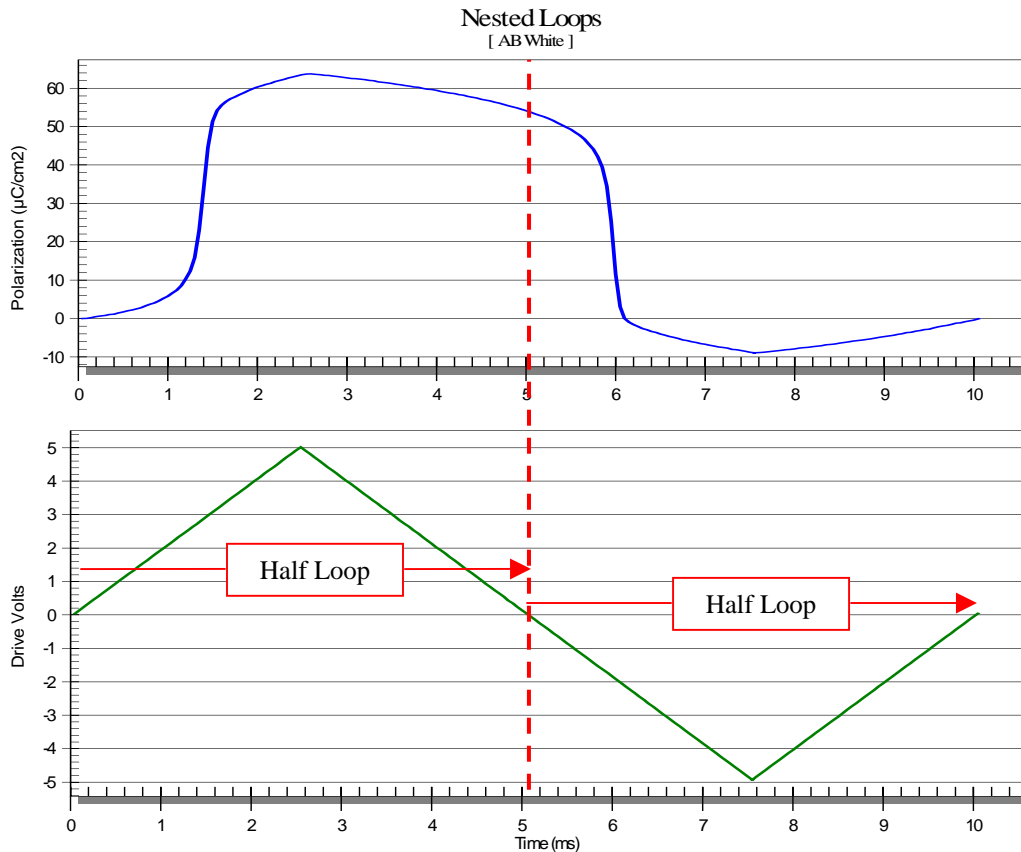


Figure F02.3
The Triangle Wave is Two Half Hysteresis Loops

We will setup the hysteresis measurement on the EDU to use a “monopolar” loop and generate “half-loops” for the polarization.

Procedure:

We will recover our test capacitor to make sure it is symmetrical. We will then select the “monopolar” test option and make half-loop measurements.

- 1) Execute a *recovery* procedure on a type AB White capacitor.

- 2) Configure the test for
 - a) -9.0V Vmax
 - b) 10ms Hysteresis Period
 - c) 0.0V Hysteresis Offset
 - d) 0.0001 Sample Area (Use the correct number if you are using a different area.)
 - e) Cap A Capacitor to Measure
 - f) 0.95 Amplification Level (Adjust this value if you are using a smaller capacitor.)

NEW:

- g) Select “Standard Monopolar” in the “Drive Profile Type” window on the left-hand side of the Hysteresis Setup menu.

NOTE: The Vmax is set to “-9V”. This means that the monopolar stimulus will go to negative 9V and then back to 0V. It will not go to positive 9V until we change the Vmax to “+9V”.

- 3) Execute a single hysteresis loop. This is the *Preset Loop*. Then, press the CLEAR DATA button on the EDU Control Panel to erase the measurement from the plot.

Now, we are ready to conduct our experiment.

- 4) Create a new folder on your disk named “Experiment F02 Data”.
- 5) Press the CONFIGURE TEST button on the EDU Control panel. Go to the second page “Plot Setup”.
 - a) Type in “+9V Half Loop” into the Data Label window.
 - b) Make the Plot Title “Saturated Monopolar Loops”
 - c) Make the Plot Subtitle “ [Type AB White] ”.
 - d) Leave the Plot Filter selected to <<None>>
 - e) Press OK.

NOTE: Again notice that documentation comes first!

- 6) Go to the first page of the CONFIGURE TEST menu. Change the Vmax to “9V”.
- 7) Execute the test. The hysteresis should look like Figure F02.4 below. Save this data in the folder with the name “Positive 9V Half Loop”.

Standard Monopolar Loops

[Type AB White]

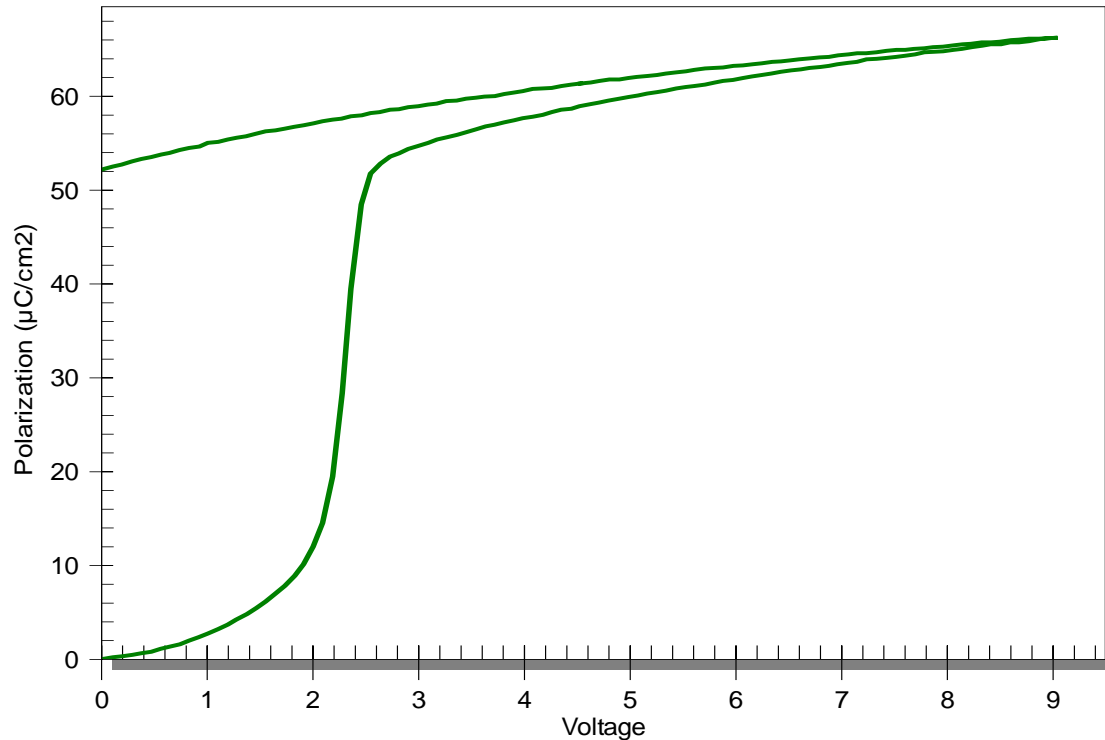


Figure F02.4

The +9V Half Loop Starting at Negative Saturation.

- 8) We will now capture the “-9V” half-loop. Again, notice that the first loop we executed in Step (7) is the *preset loop* for the next loop we are about to do.
 - a) Press the CONFIGURE TEST button on the EDU control Panel.
 - b) Change Vmax to -9.0 Volts.
 - c) Go to the Plot Setup page and change the Data Label to “-9V Half Loop”.
 - d) Execute the test.
 - e) Save the data to the file “Negative 9V Half Loop”.

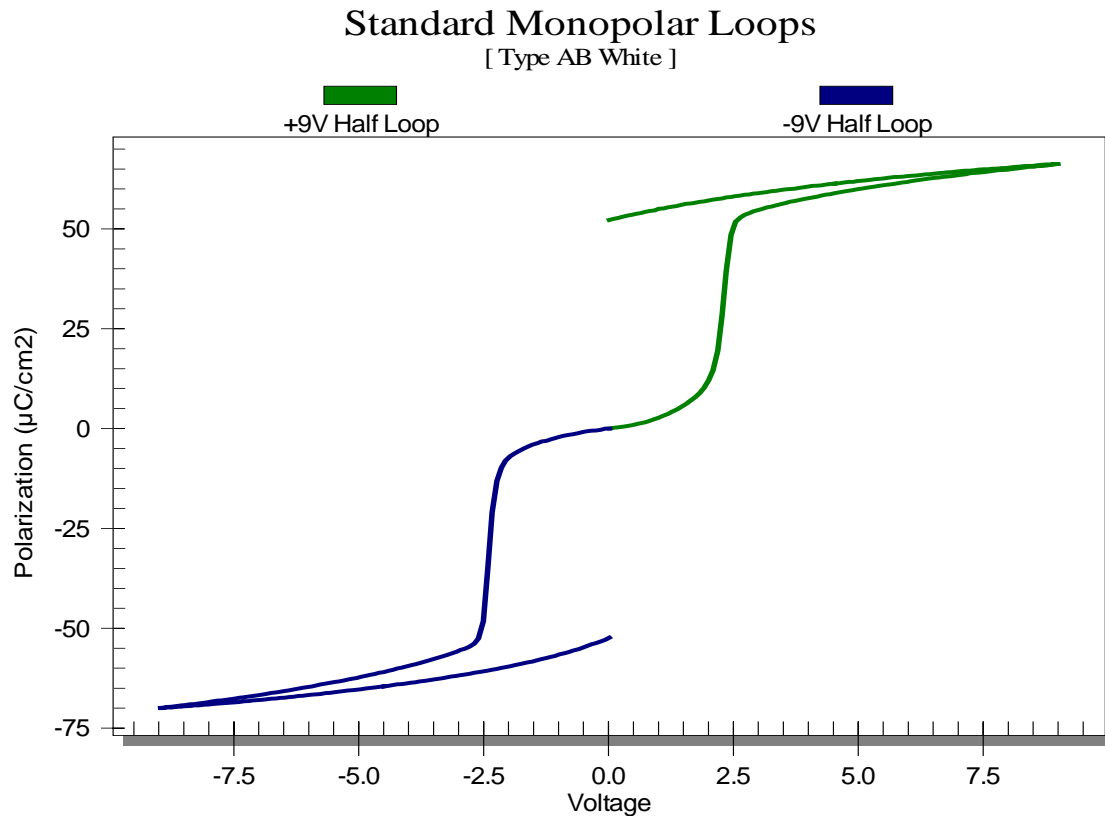


Figure F02.5
The -9V Half Loop Starting at Negative Saturation.

Even though the plot in Figure F02.5 has both the +9V and -9V plots on them, only the last plot was saved in Step 8(e) above.

Notice how both of the half-loops start at zero polarization with one going up and the other down. This caused both the X and Y scales of the plot to change from that in Figure F02.4. We saw this up/down characteristic earlier in Figure F01.11 of [Experiment F01 -The Saturated Memory State.doc](#). Why does this occur? We are using the <<NONE>> plotting format which plots the raw data where the first point is always zero. The vertical direction indicates which way the polarization is switching, up or down. What happens if we try to center the loops about each other using the “Centering” filter format?

- 9) Press the PLOT DATA button. Select “Centering” from the “Plot Filter” window in the lower right hand corner of the menu. Press OK. What happens?

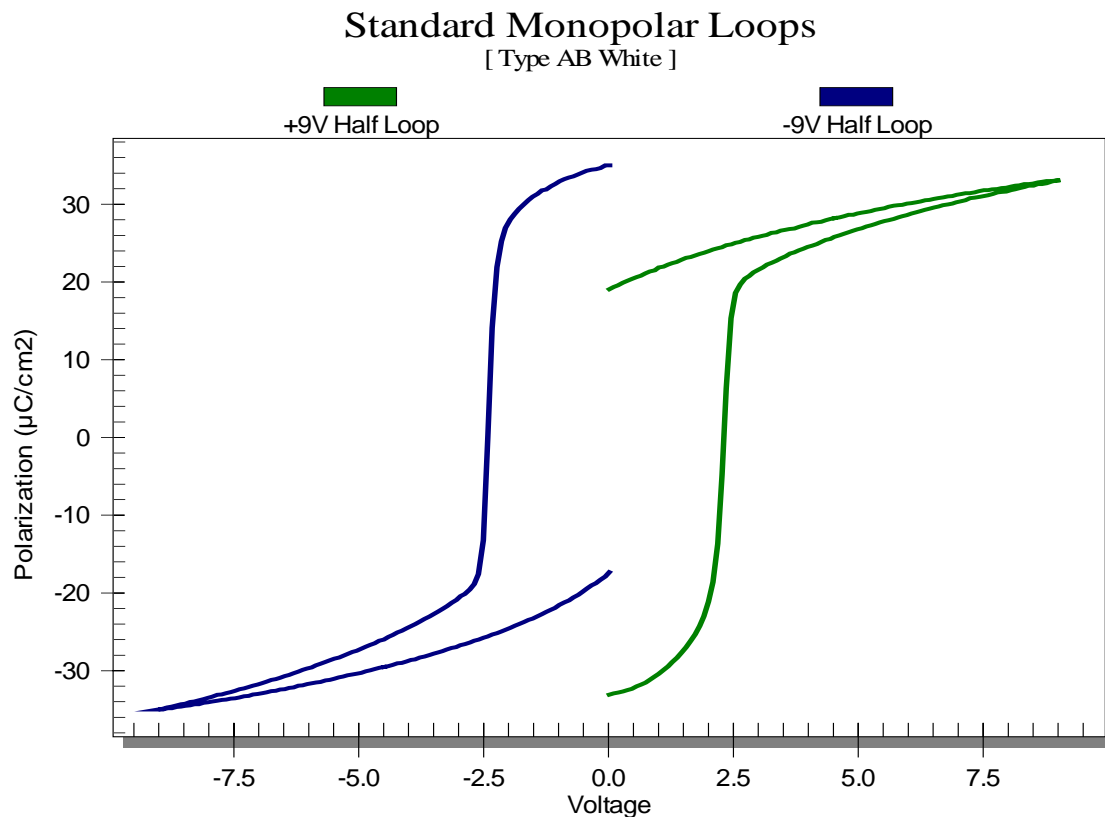


Figure F02.6
“Centered” Half Loops

The loops do not line up in a recognizable manner. This is because the “Centering” filter expects to plot bipolar measurements and will not correctly position half-loops. Do not use the “Centering” plot filter on half-loops. Also, notice that the scales changed again, changing the perspective of the plots.

- 10) Go back to the PLOT DATA menu. This time select the “Normalized Capacitance vs Voltage” plot filter. (nCV)

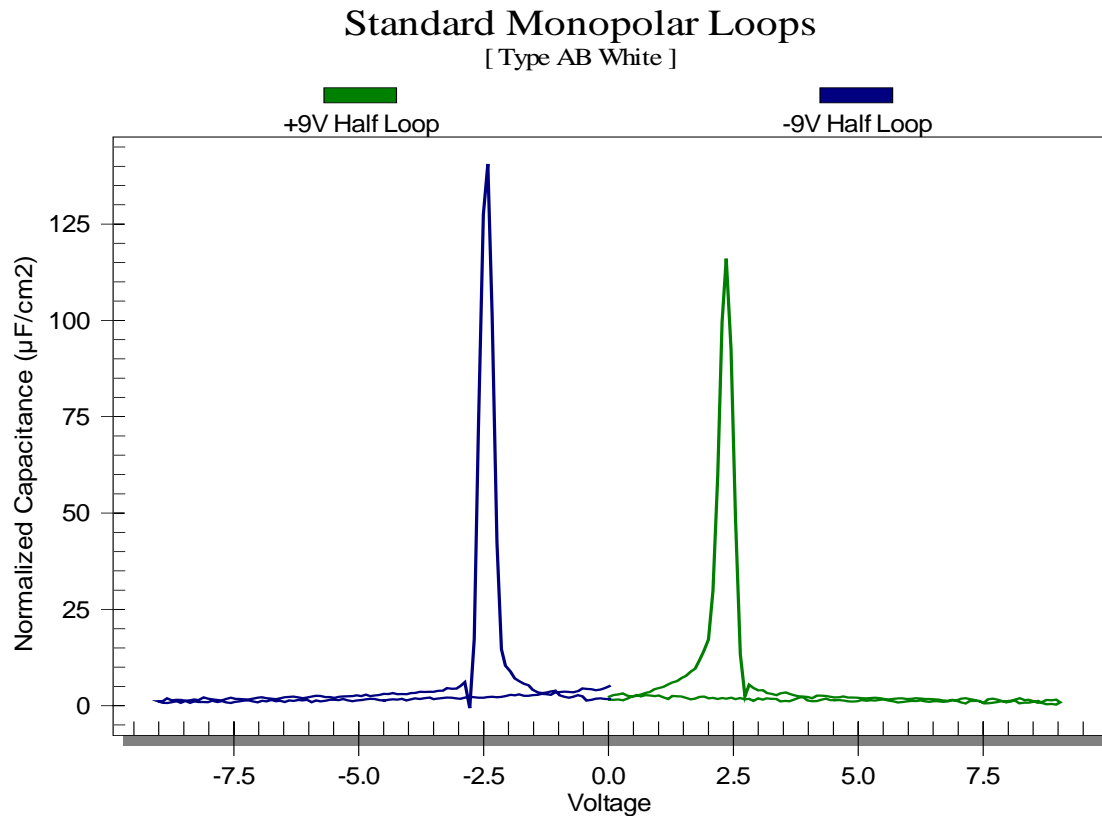


Figure F02.7
Normalized CV plot of Positive and Negative Saturated Half Loops

The plots in Figure F02.7 look like the plots we took in Figure I05.5 of [..Introduction Experiments\Experiment I05 - Data Analysis.doc](#). A little thought about what we have learned about hysteresis loops indicates that this is as it should be. We are seeing the derivative of the two halves of the hysteresis loop. It does not matter much if the two halves were taken together with a triangle wave or separately with two monopolar tests.

One point of interest: notice that the two halves of the half-loops plotted in F02.7 line up vertically when they did not do so for the “Centering” plot filter. Why? The vertical position on the Y-axis for the hysteresis loop is a constant added to every point of the loop. For those of you familiar with calculus, the derivative of a constant is zero! The nCV function automatically takes out the vertical offsets of both loops and lines them up.

NOTE: For those of you not familiar with calculus, take a course in it if you have the opportunity. Calculus changed the world after Sir Isaac Newton and Gottfried

Wilhelm Leibniz created the mathematical discipline. Be sure to take the course from a good teacher who will excite your interest in and fascination with mathematics.

- 11) As a final note, you can export the values of the plot in Figure F02.6 above to a spreadsheet and then “center” the loops yourself. To export the numerical values of this plot, follow the instructions in Step 15 of [..\Introduction Experiments\Experiment I04 - Plotting Tools.doc](#). Paste the data into the spreadsheet. Next, find the average of the first and last points of each measurement and subtract that average from every point in that plot. Finally, re-plot the data. The results look amazingly like a full hysteresis loop! We will use this technique in the next experiment to great effect.

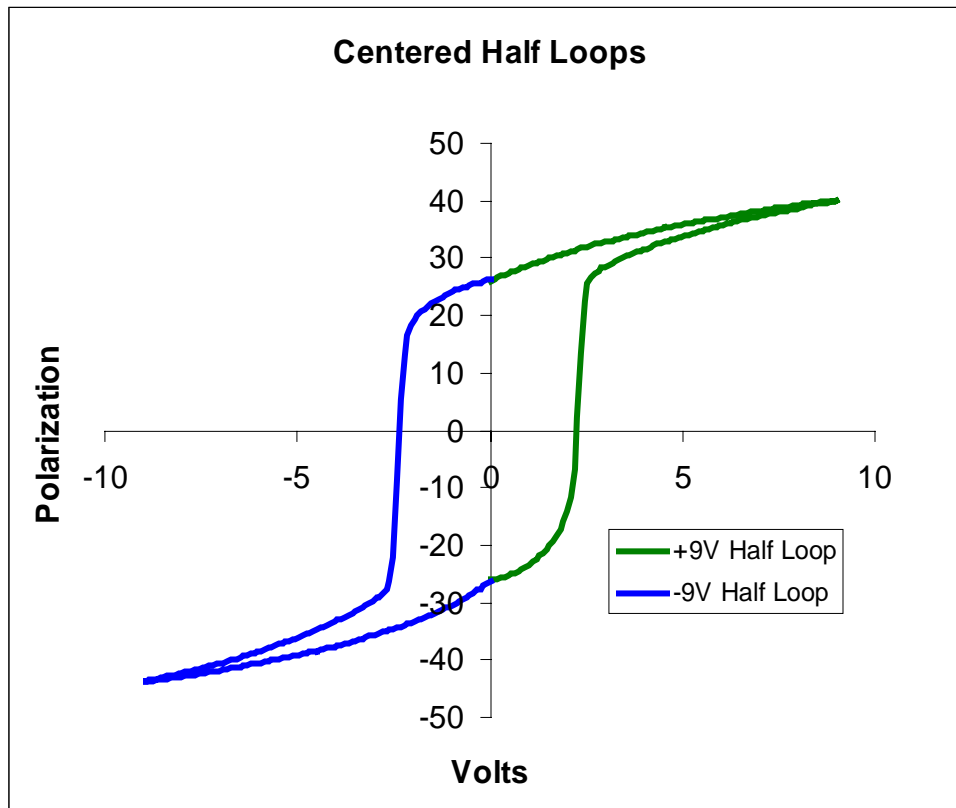


Figure F02.8
Centered Half Loops Look Like Full Hysteresis

Conclusion to Experiment F02

Experiment F02 was relatively simple. We learned how to set up and execute half-loops of hysteresis. We found that the ferroelectric capacitor actually produces the results that we talked about theoretically in [..\Introduction and Theory\Chapter 5 - Theory of Ferroelectric Switching.doc](#). In the next experiment, we will use the half-loop test as our microscope to look inside the ferroelectric capacitor and measure the actual remanent polarization inside the hysteresis loop!

Recommended Exercise:

As a preview for the next experiment for measuring remanent polarization, execute different combinations of +9V and -9V half-loops in different orders. How are the results of these measurements affected by the order of the tests? How are these outcomes related to the property of ferroelectric capacitors that they *remember* their *history*?