

Chamber/Pyroelectric Task

The Chamber Task measures the Pulse Polarization response and Small Signal Capacitance of a Pyroelectric material that is being heated and/or cooled within a thermal chamber, on a hot chuck or in a furnace. From these measurements the Spontaneous Polarization $P_r(\theta)$ and the Dielectric Constant $\epsilon_r(\theta)$ are computed. These are then combined to determine the Electrical Displacement $D(\theta)$ as a function of the temperature θ . This is known as the *Pyroelectric Coefficient* and is given by:

$$D(\theta) = \epsilon_0 \epsilon_r(\theta) * \vec{E} + PR(\theta) \quad (A.1)$$

Where

- ϵ_0 = Free Space Permittivity = 8.85×10^{-12} .
- \vec{E} = DC Bias Field = Bias Volts/Sample Thickness

The Dielectric Constant, the Spontaneous Polarization, the Displacement, the small signal capacitance and all pulse polarization measurements may be plotted in any combination. These may be plotted as a functions of the temperature θ or the change in temperature from sample point to sample point. The derivatives of $P_r(\theta)$ and $\epsilon_r(\theta)$ may also be plotted with respect to the change in temperature. All data may be printed or exported to a Text or Excel file.

For a detailed listing of Thermal Controllers Registered in Vision, please see link below.

<http://www.ferrodevices.com/1/297/files/ThermalControllersRegisteredinVision.pdf>

Please note that additional items may be needed to interface Thermal Controllers to Vision. Direct GPIB (requires a National Instruments GPIB Interface - NI GPIB-USB-HS+ recommended); Direct Serial (very few controllers. Normally requires an inexpensive USB<->Serial cable); GPIB/Serial (requires the NI GPIB interface and a GPIB<->serial converter - NI recommended.)

Custom versions can also be produced provided the customer provide a complete manual

for the desired thermal chamber. This must include the GPIB command set. The user must also provide the temperature tolerant chuck that will hold the sample under test and cabling between the Precision tester and the chuck. The GPIB cable is provided with the Precision unit.

NOTE - Several late changes have been made to accompany the release of Version 4.0.0 of the Chamber Task. These are not completely documented in these pages although they are summarized here and in the discussions of the appropriate configuration tabs.

- **The Vision Data File selection flag is now passed from the Sample Configuration dialog tab to all other configuration tabs (Temperature, Measurement, GPIB and Plot). If the Task is configured to read information from a Vision Data File, all controls and all labels are disabled in these tabs. This is because the values that are configured in them are to be input from the file. When the Task has executed and is recalled from the DataSet Archive, the labels and text controls will be enabled to show the configuration values read from the file. Text controls will be set to read-only.**
- **The Internal/High-Voltage Amplifier selection is now passed from the Sample Configuration dialog tab to the Measurement configuration tab. The PUND/SSAC selection buttons in the Measurement configuration tab have been replaced by a *Measurement Type* list box control. This control lists "PUND" only in high-voltage mode. In low-voltage mode, the control lists "PUND", "SSAC" or "Both". Both measurements may be made in a single execution of the Task in low-voltage mode. In High-Voltage mode, all SSAC and Sensor configuration controls and labels are disabled.**
- **The selected Measurement Type is passed from the Measurement Configuration dialog to the Plot Configuration dialog. The values listed in the Y Values list box will depend on the measurement type selected. Only PUND values are selectable if the type is "PUND". Only Small Signal values are available if the type is "SSAC". All values are available if the type is "Both".**
- **An error condition exists if the user takes the following steps:**
 - **Select High-Voltage in the Sample Configuration tab.**
 - **Set a PUND voltage of absolute value greater than 100.0 Volts in the Measurement Configuration tab.**
 - **Select Low-Voltage in the Sample Configuration tab.**
- **An internal reference ferroelectric sample has been added to the Precision Premier II tester and is planned in the Precision LC II tester. The ferroelectric test element includes two switchable capacitors in a single package inserted into a user-accessible connector. A variety of capacitors are available from Radiant Technologies, Inc. and this test element may be easily changed to adjust the type or to replace fatigued samples. Just as with the internal reference capacitor and resistor, the ferroelectric test sample may be**



switched into the test signal path in parallel with any externally-connected test sample and/or the internal reference capacitor and/or resistor. More information is available in the Version 4.0.0 What's New document, section E.1.8.

In this case, the high-voltage *PUND (Start Volts)* value will be reset to the default value of 5.0 Volts.



B - Hardware Configuration

The simplest hardware setup for using the Chamber Task is shown in **Figure B.1**. The figure shows the Precision tester, the Thermal Chamber and a Chamber Controller. Although the Chamber Controller is shown separately, normally it is an integral part of the chamber. The controller is used to set and maintain specific temperatures within the chamber. Also shown is an LN₂ tank. Liquid nitrogen is used to provide cooling between a higher set point and a lower point. With the liquid nitrogen, temperatures of -200 °C may be obtained. Without LN₂, the experimental thermal profile must be continually increasing or delays between test points using only ambient cooling will be prohibitive.

The connections shown in **Figure B.1** include the Precision Drive and Return Signals attached to opposite sample electrodes. The sample itself is shown placed in the chamber. These signal cables are connected to the front or rear of the Precision tester using BNC connectors. Attachment to the sample is at the user's discretion. Any high-temperature cabling, sample test chucks, etc. are to be provided by the user. The GPIB cable shown is connected from the rear of the Precision tester to the Chamber Controller. (In the case of the Precision Premier and Workstation testers, the GPIB communication cable connects directly to the tester. For the Precision LC family, the host computer must be equipped with a National Instruments GPIB board for communications with the thermal device to occur.) This connection is used to allow the software to automatically control the temperature of the sample during Task execution. This is an optional connection. Chamber may be run in either Manual or Automatic Mode. In Automatic Mode, the software will control the entire experiment including the sequencing through the Thermal Profile. In Manual Mode, a dialog will appear and the program will pause each time the temperature is to be changed. An operator must first set the temperature manually, then acknowledge the dialog. Clearly the need for human attention makes this a less efficient option.



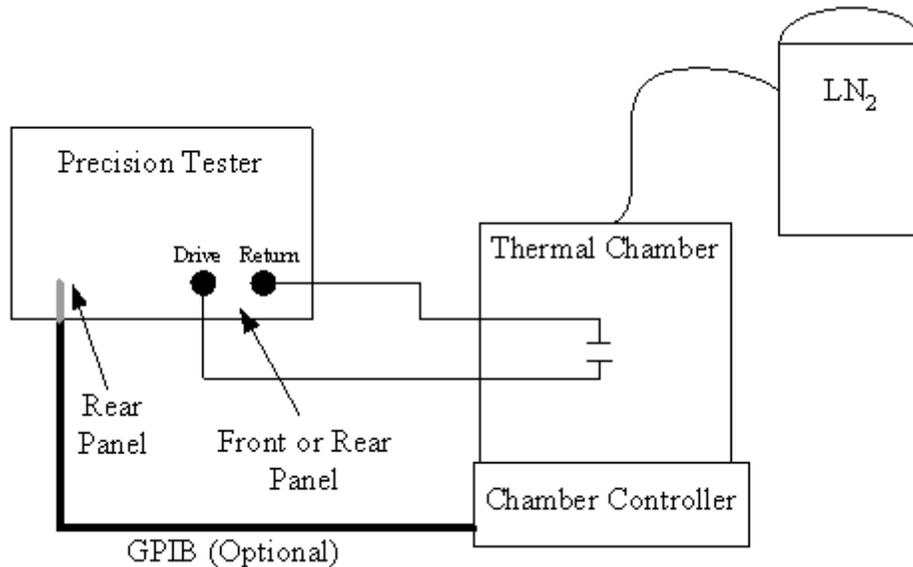
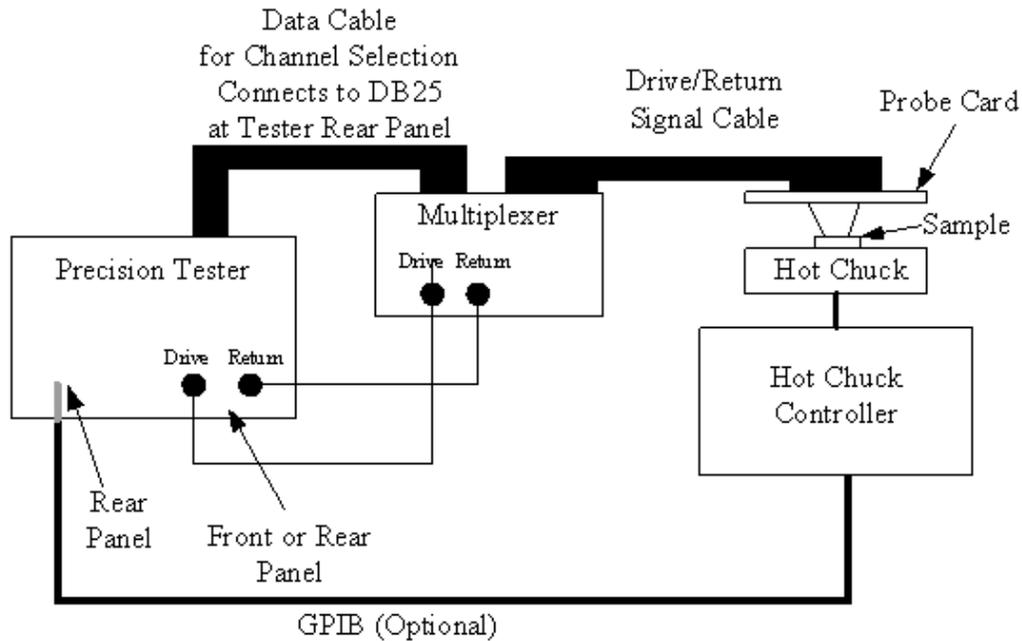


Figure B.1 - Simple Hardware Configuration for the Chamber Task.

A more elaborate hardware configuration includes the connection of an accessory 48-Channel Multiplexer provided by Radiant Technologies, Inc. As shown in **Figure B.2**, this accessory allows the Tester to be connected to multiple samples simultaneously, normally by connecting the Multiplexer to a probe card. The probe card is normally connected to the sample at a probe station. In this case, Chamber would normally use the probe station's hot chuck to control the experimental temperature. During any given execution of the Chamber Task only a single sample can be addressed through the Multiplexer. However, the Chamber Task can be repeatedly executed in a Branch Loop and programmed to automatically sequence through up to fifteen Multiplexer channels, one per Branch Loop iteration.



**Figure B.2 - Hardware Configuration for the Chamber Task
Using the 48-Channel Accessory Multiplexer.**

A third configuration is used for bulk samples that require high voltages. Internal voltages of up to ± 100 Volts (± 10.0 Volts in some models) can be generated by the Precision tester. For higher voltages an external High Voltage Amplifier (HVA) must be connected to the Precision Tester through a High Voltage Interface (HVI). Both the HVI and the HVA are provided as accessories by Radiant Technologies, Inc. Amplifiers are available at up to $\pm 10,000$ Volts. With the release of Vision Version 3.1.0 any amplifier may be connected so that the experiment may use an existing amplifier. In this case, Radiant Technologies must be informed of the amplifier specifications so that a logic unit for the amplifier can be provided. A logic unit (ID Module) will allow the HVI to recognize the amplifier. A high-voltage configuration is shown in **Figure B.3**. A five-channel High Voltage Multiplexer is also available that combines the High Voltage feature with the advantages of multi-sample testing.

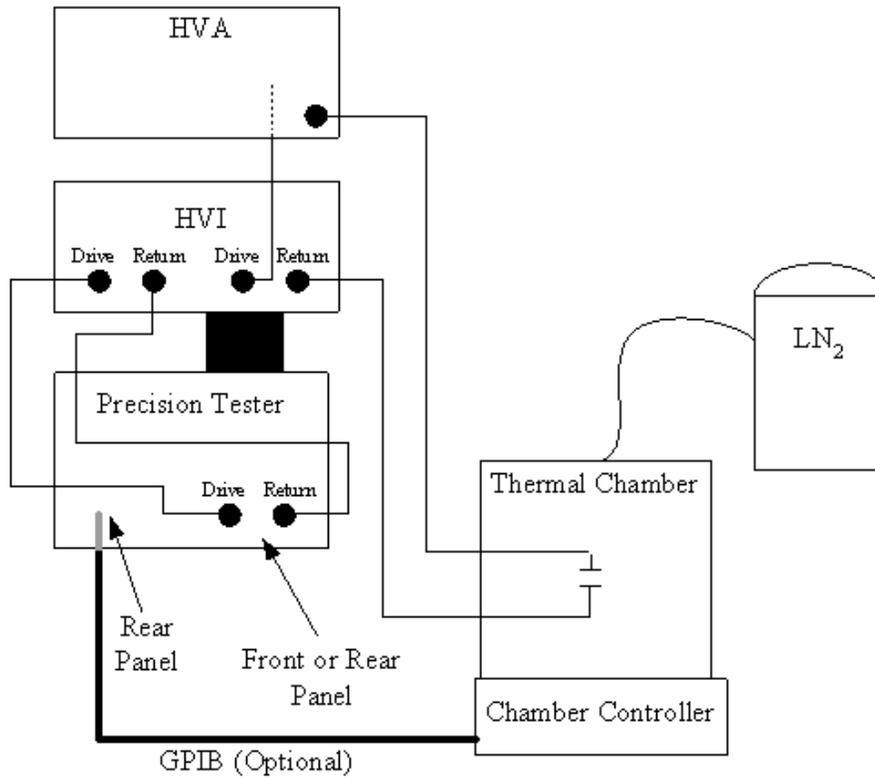


Figure B.3 - High Voltage Hardware Configuration for the Chamber Task.



C - Measurements

The Chamber Task performs one of two basic measurements – the standard PUND Pulse Measurement and the Small Signal Capacitance measurement. Significant measured parameters are further derived using both the values obtained by these measurements and certain key measurement and sample configuration parameters. Both measurements and all measured and computed parameters are presented in detail in this chapter.

Note that the user must choose the measurement to be made. For full characterization, Chamber should be executed twice to allow both measurements to be made and then combined. The reason that the measurements are separated is that the Task is often applied to high-voltage samples. PUND measurements are acceptable at high voltage, but (as described below) the small signal measurement relies on small perturbations. Furthermore, at higher temperatures samples become more conductive. The rapid application of the small signal perturbation at high voltage and high temperature can lead to sample breakdown. To correct for this problem, the measurements are made separately and the Small Signal Capacitance measurement should be made a low voltage.

C.1 PUND Measurement

The PUND (Positive Up Negative Down) measurement is a standard ferroelectric measurement well known to users of the Radiant Technologies, Inc. Charge program. The test consists of five pulses as shown in **Figure C.1.1**. The first pulse presets the sample to a known Polarization state, but makes no measurement. Each of the next four pulses is used to measure two PUND parameters, one at the maximum applied voltage and one at zero volts after the pulse. These pulses alternately switch the sample (P^* measurements), then repeat without switching (P^\wedge measurements). The two final pulses are of opposite signs to fully characterize the sample in both polarization states. The profile can be easily constructed out of three configuration parameters...

1. **Test Voltage** - This defines the absolute value of the maximum voltage of each pulse. The non-zero polarization measurement is made at this voltage. The sign of this value determines the polarity of the preset pulse and the pulse sequence. A negative test voltage will invert the profile of **Figure C.1.1**.
2. **Pulse Delay** – This is the delay time between each pulse. In RT6000 and RT66A test systems this time was fixed at 1 second. In Vision it is programmable in milliseconds. The extended time is important to let any Non-Remanent Polarization settle out before beginning the next measurement.
3. **Pulse Width** – The time between the start of the rise of the pulse and the measurement. It is also the time at which the pulse begins to fall back to zero volts. In



RT6000 and RT66A systems this period could be switched from "Fast" to "Standard" to "Slow". In the Precision system this is continuously variable in milliseconds.

Table C.1.1 shows the relationship between the pulse, its voltage and the parameters measured. **Figure C.1.2** shows a detailed close up of the first measurement pulse (test voltage positive).

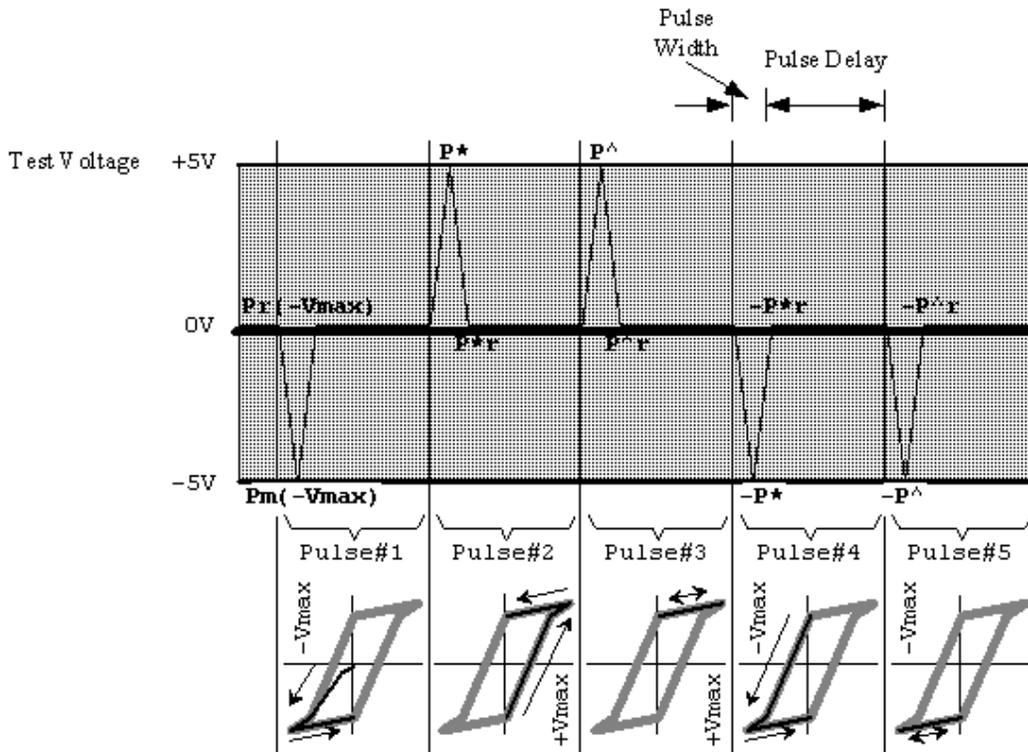


Figure C.1.1 - PUND Pulse Voltage Profile.

Pulse #	Voltage Applied	Parameter Measured
1	-Vmax	-
1	0	-
2	Vmax	P*
2	0	P*_r
3	Vmax	P^
3	0	P^_r
4	-Vmax	-P*
4	0	-P*_r
5	-Vmax	-P^
5	0	-P^_r

Table C.1.1 - PUND Pulse Voltages and Parameters.

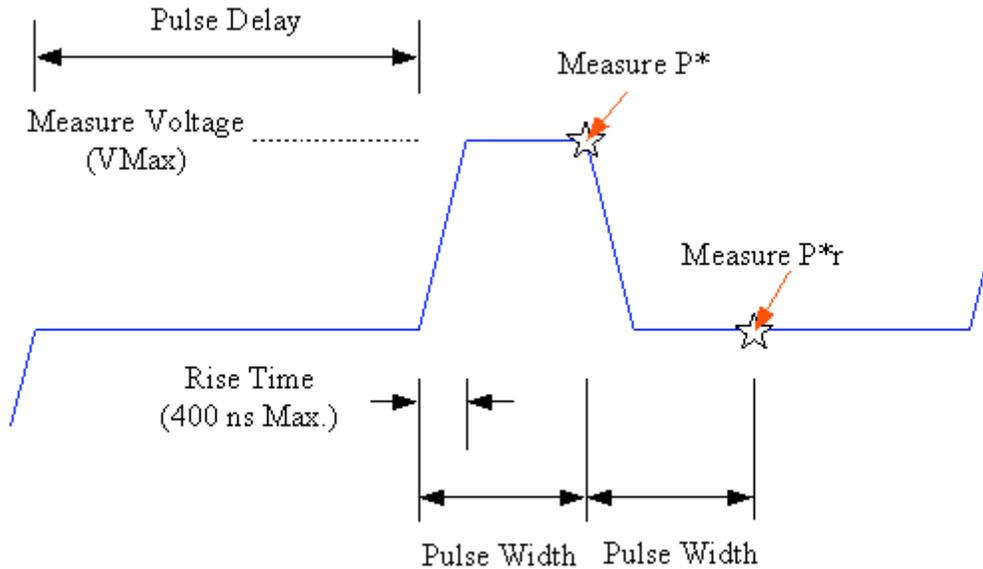


Figure C.1.2 - PUND Single Pulse Detail.

Definitions:

- $P_r(X)$ = Remanent Polarization state at zero volts after the application of X volts.
- $P_m(X)$ = the polarization state at X volts.

In the PUND measurement, the switching (P^*) measurements contain both Remanent and Non-Remanent polarization values. The non-switching (P^\wedge) measurements contain only Non-Remanent polarization. The desired remanent property can therefore be derived by subtracting the non-switching values from the switching. In an ideal ferroelectric sample, identical non-remanent values should be calculated regardless of the parameters used to derive them, so that:

$$abs(P^* - P^\wedge) = abs(P^*_r - P^\wedge_r) = abs(-P^* - (-P^\wedge)) = abs(-P^* - (-P^\wedge_r)) \quad (C.1.1)$$

Each of these terms are computed and recorded in Chamber...



$$\begin{aligned}
dP &= P^* - P^\wedge \\
dP_r &= P^*_r - P^\wedge_r \\
-dP &= -P^* - (-P^\wedge) \\
-dP_r &= -P^*_r - (-P^\wedge_r) \quad (C.1.2)
\end{aligned}$$

Combining these comparisons and scaling by 1/2 to account for full switching of states from negative to positive, gives the averaged equation:

$$\begin{aligned}
PR(\theta) &= \frac{abs(P^* - P^\wedge) + abs(P^*_r - P^\wedge_r) + abs(-P^* - (-P^\wedge)) + abs(-P^*_r - (-P^\wedge_r))}{8} \\
&= \frac{abs(dP) + abs(dP_r) + abs(-dP) + abs(-dP_r)}{8} \quad (C.1.3)
\end{aligned}$$

Table C.1.2 summarizes all PUND measured parameters. All parameters are given in $\mu\text{C}/\text{cm}^2$.

P*	$P_m(V_{max}) - P_r(-V_{max})$: The polarization transferred out of the capacitor traversing from zero to V_{max} volts when the capacitor starts at $P_r(-V_{max})$.
P*_r	$P_r(V_{max}) - P_r(-V_{max})$: The polarization remaining out of the sample capacitor after going to zero volts from P*.
P^	$P_m(V_{max}) - P_r(V_{max})$: The polarization transferred out of the capacitor traversing from zero to V_{max} volts when the capacitor starts at $P_r(V_{max})$.
P^_r	$P_r(V_{max}) - P_r(-V_{max})$: The polarization remaining out of the sample capacitor after going to zero volts from P^.
-P*, -P*_r, -P^, -P^_r	These are the negative equivalent of the previous four measurements but tested with negative instead of positive pulses, i.e. zero to $-V_{max}$ instead of zero to $+V_{max}$.
dP, dP_r, -dP, -dP_r	Various representations of the derived Remanent Polarization.
PR(θ)	Spontaneous Polarization computed from $\pm P^*$, $\pm P^\wedge$, $\pm P^*_r$ and $\pm P^\wedge_r$.

Table C.1.2 - PUND Measured Parameters.

C.2 Small Signal Capacitance Measurement

A small signal capacitance measurement is used to determine the sample capacitance from which the dielectric constant is calculated. The measurement is made by holding the sample at a constant DC voltage. (This voltage is used to calculate the bias field \vec{E} in the defining equation for $D(\theta)$). The bias voltage is then perturbed by a very small ‘tickle’ voltage. The resultant current is integrated to give the accumulated charge, $q(\theta)$. The charge can then be divided by the tickle voltage to produce the capacitance through the relationship:



$$C(\theta) = \frac{q(\theta)}{V} \quad (\text{C.2.1})$$

Since the very small voltages and currents involved in the analysis can result in significant noise measurement, the process is repeated 30 times per measurement, and the noise is averaged out. The result is a measurement of fairly long duration. The capacitance $C(\theta)$ is then used to compute the dielectric constant $\epsilon(\theta)$ using the relationship:

$$\epsilon_r(\theta) = \frac{C(\theta) * d}{A * \epsilon_0} \quad (\text{C.2.2})$$

With d being the sample thickness in μm , A the area in cm^2 and ϵ_0 the permittivity constant of free space.

$PR(\theta)$ (C.1.3) can then be combined with $\epsilon_r(\theta)$ to produce the overall Pyroelectric effect, displacement, given as $D(\theta)$ through the relationship (repeated here):

$$D(\theta) = \epsilon_0 \epsilon_r(\theta) * \vec{E} + PR(\theta) \quad (\text{C.2.3})$$

Figure C.2.1 shows a single instance of the small signal capacitance measurement, including all configuration parameters. The bias voltage applied during the measurement is \vec{E} in (1.1). Clearly, if this value is held at 0.0 Volts, the dielectric constant term falls out of (1.1) and...

$$D(\theta) = PR(\theta), \vec{E} = 0.0 \quad (\text{C.2.4})$$

The Pre-Measure Bias Soak parameter is a delay period, for each iteration of the Small Signal Capacitance measurement, during which the sample is simply held at the bias voltage before the tickle voltage is applied and the capacitance is read. The main purpose of this delay is to allow any current that results from switching the sample from zero to \vec{E} volts to settle so that only current induced by the application of the Tickle Voltage will be integrated into the measurement. It is important that this delay be large enough to account for the fact that the voltage switches from zero to the bias value each iteration of the measurement. The Tickle Delay is the duration, in milliseconds of the application of the Tickle voltage at each iteration.

