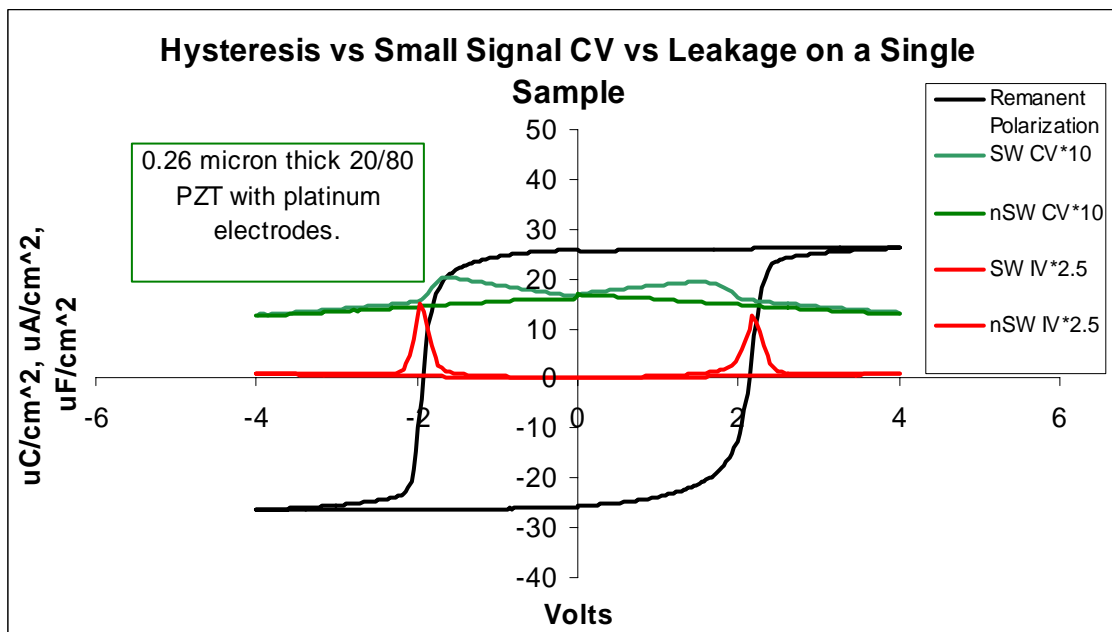


Precision Tester Specifications

3/25/09

Radiant's Precision materials testers are designed unlike any other test instruments in the world. They can characterize the individual material properties of dielectric response, remanent polarization, piezoelectricity, pyroelectricity, and electrical leakage with no configuration change. More important is the fact that they can accurately determine the relationship between these characteristics in an integrated test environment. A virtual tester called Vision operates Radiant's tester hardware. Vision can construct complex programs with any number of tests to characterize all aspects of the sample in one execution while keeping track of the measurement results and the history of the sample being tested. Each Radiant tester is an extension of the Vision virtual tester and can execute any of the measurement tasks in the Vision Library. The type of tester determines the range of voltages, frequencies, and sample sizes that Vision may characterize with that tester. Only with a Radiant Precision tester can the researcher produce the plot below, executed in one hour on a Precision LC. The data shows the relationship in a single sample between the remanent polarization state and the values of its small signal capacitance and leakage.



If the sample had been in an AFM with a heated chuck, the tester could have captured the piezoelectric and pyroelectric responses as well as the ones shown in the figure.

Premier II Specifications:

The Precision Premier II, Radiant's most advanced tester, has the largest envelope in terms of frequency response, voltage range, and accuracy of any ferroelectric tester in the world. It will make the measurements in the figure above with the highest fidelity over the largest frequency range.

- Output Range $\pm 10V$, $\pm 100V$, $\pm 200V$
 - 16-bit Arbitrary Waveform Generator output
 - 100 points in $50\mu s$ single-pass
 - 100 points in $10\mu s$ using interlace feature
 - 1000 points in 30 seconds
 - Pulse Widths down to $1\mu s$ and up to 1s
 - Vision controlled output ramp for maximum accuracy
- Polarization Measurement
 - 18 bit analog to digital converters – $76\mu V$ sensitivity on $10pF$ C_{sense}
 - $0.5\mu s$ capture rate with $0.1\mu s$ interlace facility
 - Polarization, output voltage, and SENSOR inputs captured simultaneously
 - Minimum charge sensitivity -> $0.80fC$
 - Minimum PZT capacitor area -> $0.08u^2$
 - Maximum charge measurement -> $5.26mC$ ($526mC$ w/HVI)
 - Maximum PZT capacitor area -> $52.6cm^2$ ($>100cm^2$ w/HVI)
 - Maximum hysteresis loop frequency -> $100KHz$
 - Minimum hysteresis loop frequency -> $1/30^{th}$ Hz
- 2 COMM channels for controlling high voltage amplifiers.
 - 1 legacy 26-pin COMM channel
 - 1 I^2C COMM channel
- 2 external 18-bit, $\pm 10V$ SENSOR voltage inputs.
- Requires a desktop or laptop computer with USB1.0 Port or better
Can be operated with Windows 2000™, Windows XP™, or Windows Vista™
- Will execute Hysteresis, Remanent Hysteresis, Small signal CV, IV, fatigue, imprint, retention, and piezoelectric displacement from one hardware configuration.

LC Specifications:

The Precision LC is designed to provide excellent performance at a lower cost than does the Premier II. It will measure both thin films and bulk ceramics with high fidelity up to 2KHz. It can measure capacitors from $3\mu^2$ up to square centimeters

- Output Range $\pm 10V$, $\pm 100V$, $\pm 200V$
 - 12-bit Arbitrary Waveform Generator output
 - 100 points in 1ms single-pass
 - 500 points in 10 seconds
 - Pulse Widths down to $50\mu s$ and up to 1s
 - Fixed 125KV/s output ramp.
- Polarization Measurement
 - 16 bit analog to digital converters – $305\mu V$ sensitivity on 100pF Csense
 - $10\mu s$ capture rate
 - Polarization, output voltage, and SENSOR inputs captured simultaneously
 - Minimum charge sensitivity -> $30.5fC$
 - Minimum PZT capacitor area -> $3.05\mu^2$
 - Maximum charge measurement -> $58\mu C$ (5.8mC w/HVI)
 - Maximum PZT capacitor area -> $0.58cm^2$ ($58cm^2$ w/HVI)
 - Maximum hysteresis loop frequency -> 2KHz
 - Minimum hysteresis loop frequency -> $1/10^{th}$ Hz
- 1 COMM channels for controlling high voltage amplifiers.
 - 1 26-pin COMM channel
- 2 external 16-bit, $\pm 10V$ SENSOR voltage inputs.
- Requires a desktop or laptop computer with USB1.0 Port or better
Can be operated with Windows 2000™, Windows XP™, or Windows Vista™
- Will execute Hysteresis, Remanent Hysteresis, Small signal CV, IV, fatigue, imprint, retention, and piezoelectric displacement from one hardware configuration.

RT66B Specifications:

The Precision RT66B is a low cost test instrument for use in the initial process development of ferroelectric materials.

- Output Range $\pm 10V$
 - 12-bit Arbitrary Waveform Generator output
 - 100 points in 5ms single-pass
 - 500 points in 8 seconds
 - Pulse Widths down to 500 μs and up to 100ms
 - Fixed 125KV/s and 1.25KV/s output ramps (selected by the driver).
- Polarization Measurement
 - 14 bit analog to digital converters – 1.22mV sensitivity on 100pF Csense
 - 50 μs capture rate
 - Polarization, output voltage, and SENSOR inputs captured simultaneously
 - Minimum charge sensitivity -> 122fC
 - Minimum PZT capacitor area -> 12.2 μ^2
 - Maximum charge measurement -> 4.8 μC (480 μC w/HVI)
 - Maximum PZT capacitor area -> 4.8mm² (4.8cm² w/HVI)
 - Maximum hysteresis loop frequency -> 200Hz
 - Minimum hysteresis loop frequency -> 1/8th Hz
- 1 COMM channels for controlling high voltage amplifiers.
 - 1 I²C COMM channel
- 1 external 14-bit, $\pm 10V$ SENSOR voltage inputs.
- Requires a desktop or laptop computer with USB1.0 Port or better
Can be operated with Windows 2000™, Windows XP™, or Windows Vista™
- Will execute Hysteresis, Remanent Hysteresis, Small signal CV, IV, fatigue, imprint, retention, and piezoelectric displacement from one hardware configuration.
- HVI requires I²C channel to connect to RT66B

Tester Parameter	Premier II	LC	RT66B
Voltage Range (no external amp)	±200V	±200V	±10V
Voltage Range (external amp)	±10KV	±10KV	±10KV
Number of ADC Bits	18	16	14
Minimum Charge Resolution	0.80fC	30.5fC	122fC
Minimum Area Resolution* (assuming 1 ADC bit = 1μC/cm ²)	0.080μ ²	3.05μ ²	12.2μ ²
Maximum Charge Resolution	5.26mC	58μC	4.8μC
Maximum Area Resolution (assuming saturation polarization = 100μC/cm ²)	52.6cm ²	0.58cm ²	4.8mm ²
Max Charge Resolution w/HVI	526mC	5.8mC	480μC
Maximum Area Resolution (assuming saturation polarization = 100μC/cm ²)	>100cm ²	58cm ²	4.8cm ²
Max Hysteresis Frequency	100kHz**	2kHz	0.2kHz
Min Hysteresis Frequency	0.03Hz	0.1Hz	0.125Hz
Min Pulse Width	0.5μs	50μs	500μs
Minimum Pulse Rise Time (5V)	400ns	40μs	500μs
Max Pulse Width	1s	1s	100ms
Max Delay between Pulses	40ks	40ks	40ks
Internal Clock	25ns	1μs	50μs
Minimum Leakage Current (assuming maximum current integration period = 20 seconds)	2pA	1pA	10pA
Maximum Small Signal Cap Freq.	1MHz	20kHz	2kHz
Minimum Small Signal Cap Freq.	1Hz	1Hz	10Hz
Output Rise Time Control	10 ⁵ scaling	125KV/s fixed	2 settings
Input Capacitance	~60fF	1pF	1pF
Electrometer Input	Yes	Yes	Yes

* The minimum area resolution under actual test conditions depends upon the internal noise environment of the tester, the external noise environment, and the test jig parasitic capacitance.

** The maximum hysteresis or fatigue frequency is 5KHz with the 200V internal amplifier and 10KHz with the 100V internal amplifier. The 100V amplifier may be adjusted to 50KHz. Call Radiant.

*** Tester specifications are subject to change without notice.

Precision Tester Architecture:

The Premier II is controlled internally by an embedded 8051 microprocessor. The microcontroller receives the test parameters and voltage profiles from the host, loads the voltages into memory, sets the clocks, and starts the acquisition. The actual data acquisition is executed under crystal clock control. Once the test is completed, the microcontroller then uploads the measured data to the host computer by USB.

All Precision testers have an external fatigue input so researchers may bypass the internal fatigue waveform generation by the tester in favor of an external function generator.

Operating Systems:

The Premier II, LC and RT66B are controlled by Vision running on a separate computer using USB communications. The USB communications bus is the most popular high-speed serial communications standard today and it will remain embedded in personal computers for a long time to come. The operation of the USB communications standard is independent of the operating system running the computer. Its interface to the Microsoft Windows™ operating system should remain constant even as Windows evolves in the future. The Precision testers will operate on Windows 2000™, Windows XP™, and Windows Vista™ and will continue to operate with future versions of Windows.

(Windows 2000, Windows XP, and Windows Vista are trademarks of Microsoft Corporation.)

All three of the testers will run all of the measurement tasks now available in Vision including small signal CV, IV, leakage, remanent hysteresis, fatigue, imprint, retention, voltage breakdown, piezoelectric displacement, and others. The primary differences between the systems will be the minimum and maximum frequency limits, the number of points captured during a test, the voltage range of the test, and minimum or maximum sample areas.

Enclosures:

The Precision testers are enclosed in steel housings with powder coating for environmental and scratch protection.

The RT66B has a small outline, $7^{11/16}$ " x $4^{11/16}$ " x $1^{14/16}$ " (19.6cm x 12cm x 4/7cm). It has an external power pack that connects to either 110V or 220V power. The RT66B 4KV HVI uses the same enclosure as the RT66B. The RT66B communicates with the RT66B HVI and the associated ID Module by I2C.

The Premier II and LC have dimensions of 17 " x $13^{2/16}$ " x $3^{8/16}$ " (44.6cm x 33.5cm x 9cm). These enclosures are suitable for a 19" rack. They have internal, auto-selecting power supplies.

Premier II Performance Summary:

The Precision Premier II tester is capable of executing a single-pass hysteresis loop in 50 μ s with no interlacing of the data acquisition. The Premier II uses a 40MHz clock through a downcounter resulting in an effective maximum clock rate of 10MHz. The capture rate for the 18bit ADCs in the system is 2MHz. The driver for the Premier II will be able to interlace multiple loops to generate an effective capture rate of 10MHz on hysteresis and a total loop period of 10 μ s. This hysteresis measurement will be compatible with the loops measured by all of the Precision testers made by Radiant. The tester executes the delay period between each of the interlaced loops, preserving the gap in the loop. The Premier II can execute hysteresis loops lasting up to 30 seconds. The Premier II will execute a PUND pulse measurement with pulse widths ranging from 1 μ s up to 1s on capacitors with areas ranging from 0.5 μ^2 up to multiple square centimeters. The minimum leakage resolution for the Premier II is 2pA. The Premier II has approximately 60fF of parasitic capacitance between the DRIVE and RETURN.

LC Performance Summary:

The Precision LC tester is capable of executing a single-pass hysteresis loop in 500 μ s direct acquisition. The LC uses a 1MHz clock. The capture rate for the 16bit ADCs in the system is 100KHz, giving a point density of 100points/millisecond. The LC can execute hysteresis loops lasting up to 10 seconds. The LC will execute a PUND pulse measurement with pulse widths ranging from 50 μ s up to 1s on capacitors with areas ranging from 3 μ^2 up to 0.58cm² or 58cm² with an HVI attached. The minimum leakage resolution for the LC is ~200fA. The Precision LC has ~1pF of parasitic capacitance between the DRIVE and RETURN.

RT66B Performance Summary:

The Precision RT66B tester is capable of executing a single-pass hysteresis loop in 5ms with no interlacing of the data acquisition. The RT66B uses a 20KHz clock. The capture rate for the 14bit ADCs in the system is 175KHz. The maximum point density for the RT66B is 100 points in 5ms. The maximum loop period is 8 seconds. The RT66B will execute a PUND pulse measurement with pulse widths ranging from 500 μ s up to 0.1s on capacitors with areas ranging from 12 μ^2 up to 4.8mm² or 4.8cm² with an HVI attached. The minimum leakage resolution for the RT66B is 10pA. The RT66B has approximately 1pF of parasitic capacitance between the DRIVE and RETURN.

Data Management Software:

Radiant Technologies actually offers only one tester: the Vision data management software. The Graphical Users Interface for Vision is the same for all testers, including the Premier II, and all of Radiant's Precision testers run under Vision. Any Precision tester from Radiant can be connected to the USB port of a host computer containing Vision. Vision will then recognize the tester and execute measurements with that tester. Vision contains all data acquisition and data analysis tasks in an attached library. Vision offers an editor where the user can combine individual tasks to create complex custom test programs. Vision stores all of the test info and test results as records in database files set up and managed by Vision. The Vision data management system is network compliant, allowing users to communicate results over a LAN or over the Internet. Using the programmability of Vision, the researcher or production test engineer may create a program to execute a complex test on a large number of samples and then let Vision execute the test unattended for 12 to 24 hours or longer.

Radiant provides a universal license for its Vision software so every researcher in the institution can load Vision on his or her laptop. They can program their tests off-line and then connect to the Precision testers to execute the measurements.

Under Vision V4.0 or higher, the user may connect more than one tester to the host computer simultaneously.

Charge Measurement Algorithm:

All of Radiant's testers starting with the RT66A in 1988 use a Virtual Ground input for the charge measurement. Radiant uses a hardware integrator behind the virtual ground to collect the charge generated by the test waveform. A hardware integrator essentially counts electrons and outputs a voltage proportional to the count. The Precision testers plot hysteresis data taken directly from the integrator output scaled only by the sense capacitor size to convert the measurements from volts to charge. The test frequency limits specified for each tester maintains a constant signal to noise ratio and a constant distortion envelope for the hardware integrator on samples over each test system's measurement envelope.

Summary:

Radiant Technologies has striven to create a test environment that is universal across all of its testers and that has minimal distortion of the measurements across each tester's performance envelope.

Precision Tester Design Criteria:

In order to operate with Vision, the tester must have a very specific architecture that makes it an extension of the Vision virtual tester. To execute any test that Vision specifies the output of the tester must be able to produce arbitrary waveforms. To prevent distortion, the charge measurement circuitry must be able to follow whatever waveform generated by the Arbitrary Waveform Generator output (AWFG). Below are the critical design parameters that Radiant uses to create its integrated test environment along with a table comparing the different Radiant testers.

Voltage Output Stage:

The output of the test system must be an arbitrary waveform generator so it can generate any waveform for any test requested by Vision. This allows the tester to execute hysteresis, leakage, and CV without a configuration change. The parameters for an AWFG are its bit resolution, its conversion frequency, its voltage limits, and its current limits.

	Premier II	LC	RT66B
Resolution (bits)	16	12	12
Conversion Frequency	30MHz	250KHz	40KHz
Voltage Limits	±200V	±200V	±10V
Current Limits	12.5mA	12.5mA	12.5mA
Rise Time Control	Yes	Yes	Yes

*The 12.5mA current limit on the AWFG voltage output occurs during testing to prevent saturation of the measurement capacity of input electrometer. This increases the accuracy of the measurement.

Charge Input Stage:

The charge measurement circuits of the test system must hold the RETURN input at zero volts during the entire test and measure the total charge entering and leaving the sample. The critical features of the charge measurement are its frequency response, whether it is a charge amplifier or an electrometer, and the intrinsic distortion of the measurements

	Premier II	LC	RT66B
Resolution (bits)	18	16	14
Sampling Frequency	2MHz	100KHz	20KHz
Circuit Frequency Response	85MHz	4MHz	4MHz
Distortion Ratio*	850	2,000	8,000
Electrometer	Yes	Yes	Yes
Current Cancellation	50mA	50mA	50mA

*The higher the ratio of the test speed to the amplifier frequency response, the less distortion in the measurement. A ratio greater than ~700 gives less than 0.1% distortion.

**All Radiant testers have a built-in electrometer. The output voltage of the electrometer at any instance is the value of the total charge exchanged with the sample during the test. The frequency response of the amplifiers noted above is the frequency response of the electrometer.

AWFG/Current Input Interaction:

The most critical factor controlling accuracy is the match between the AWFG output and the current measurement input of the tester. If the AWFG has too high of a rise time, the measurement input cannot follow the signal, resulting in polarization lost from the measurement. If the current output of the AWFG is too high, the input stage will saturate, again resulting in lost polarization. Frequency response is also a factor. It is better to have the input faster than the output or to match the output so the input can capture whatever the sample does in response to the output. Finally, no filtering or data post-processing can be used as they add phase delay to the results and distort the shape of the measured hysteresis relative the actual hysteresis.

	Premier II	LC	RT66B
Controlled Rise Time	Adjustable	Fixed	Fixed
Current Limit during Test	Yes	Yes	Yes
AWFG Frequency Capability	30MHz	4MHz	4MHz
Measurement Frequency Response	85MHz	4MHz	4MHz
Hardware Filtering	No	No	No
Simultaneous AWFG and Measurements*	Yes	Yes	Yes

*In all Radiant testers, the response of the sample to the last AWFG change is allowed to settle before it is captured. The output voltage is not allowed to change during the individual charge measurements. The next AWFG change occurs almost immediately after the digital sample of the sample's last charge state.