

AN 16—Using the CureView LT-4203 Option

Summary

CureView Version 1.73 released July 1, 2011 has implemented an option to facilitate ASTM D150 standard measurements with the LT-4203 Parallel Plate Test Fixture. This option allows the user to do the following:

- Calibrate the LT-4203 for accurate measurements.
- Make multiple measurements with calculation of average and standard deviation.
- Automatically calculate dielectric constant and dissipation for the contacting electrode method of measurement.

Good parallel plate measurements of dielectric constant ϵ' (also known as the real component of complex permittivity or, simply, relative permittivity) and dissipation use an excitation and a sense electrode. A guard electrode eliminates fringing electric fields around the sense electrode. This guarded electrode configuration allows accurate calculation of test cell capacitance. Consequently, ASTM D150-98 states that “the guarded electrode (three terminal method) is to be used as the referee method unless otherwise agreed upon.”

Good measurements require careful attention to measurement technique, which includes well prepared samples and a calibrated instrument. An ideal sample has the following characteristics:

- An area large enough to completely cover the sense electrode
- Smooth, flat surfaces for the sides contacting the electrodes
- Parallel surfaces for the sides contacting the electrodes

The LT-4203 option in CureView guides the user through the steps of calibrating the LT-451 Dielectric Cure Monitor, and then makes multiple measurements which are averaged together for increased accuracy. The LT-4203 option performs calculations for the contacting electrode method and presents the results for dielectric constant and dissipation.

USING THE LT-4203 OPTION

To access the LT-4203 option, click on the **Parallel Plate** icon of the main window toolbar as shown in Figure 1.

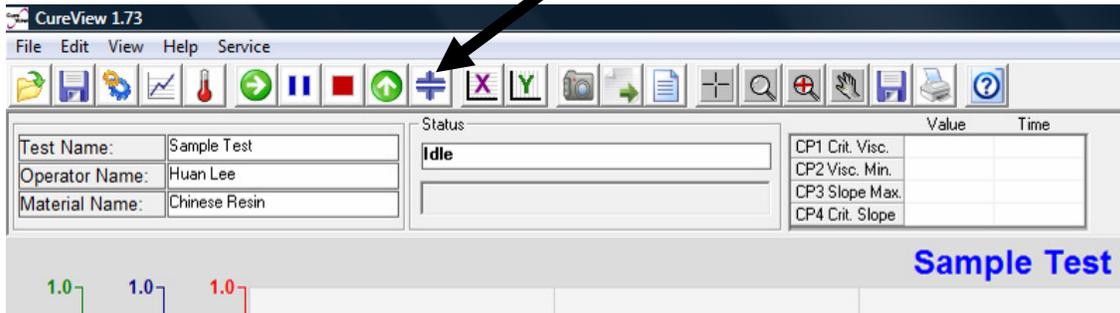


Figure 1
Main window toolbar

The **LT-4203 Parallel Plate** window appears as shown in Figure 2.

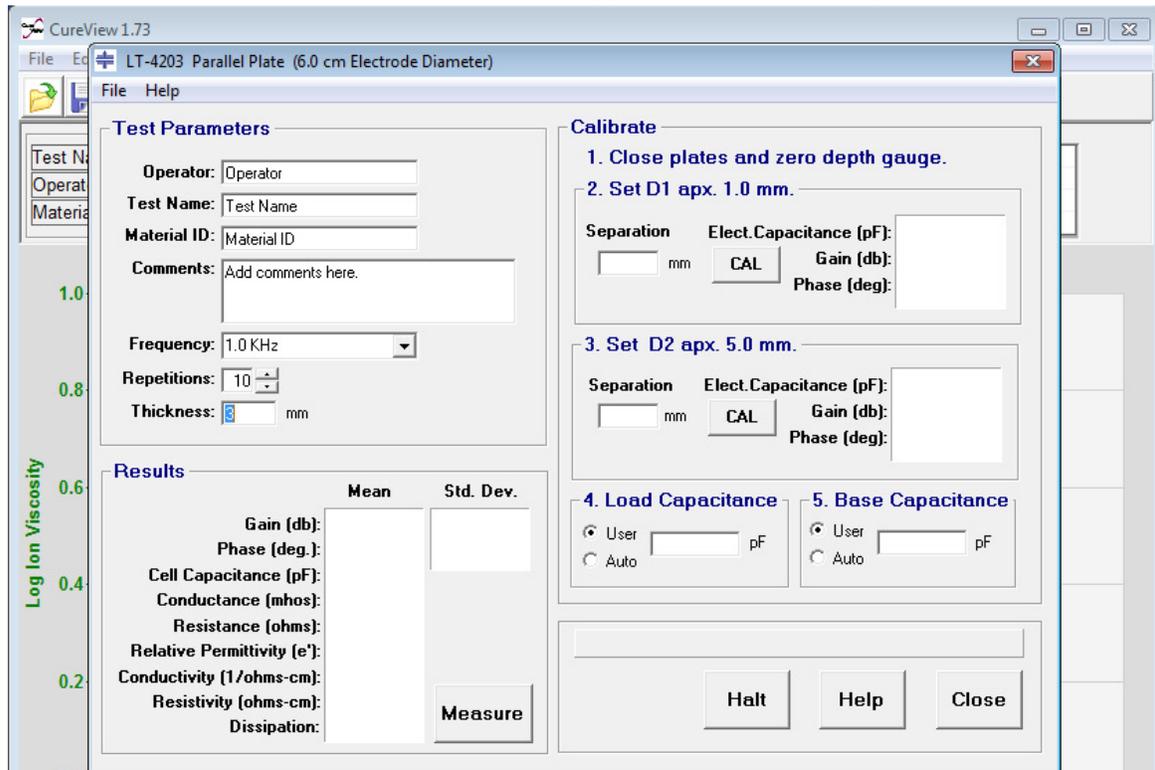


Figure 2
LT-4203 Parallel Plate window

Using the Parallel Plate Option involves these steps:

- Input **Test Parameters** for measurement and sample
- **Calibrate the** LT-451 Dielectric Cure Monitor
- Measure sample dielectric properties and display **Results**

Each of these steps is described in the following sections.

INPUT TEST PARAMETERS

In the **Test Parameters** panel, the following fields record information about the sample and prepare the LT-451 for making measurements:

- **Operator**—The person performing the test.
- **Test Name**—A name to identify the test.
- **Material ID**—The material being tested.
- **Comments**—Any additional information to document the test.
- **Frequency**—The excitation frequency of the LT-451 for the test.
- **Repetitions**—The number of measurements that the LT-451 Dielectric Cure Monitor will make automatically. The results of these measurements are averaged together to increase accuracy of the result.
- **Thickness**—The thickness in millimeters of the sample.

CALIBRATE THE LT-451 DIELECTRIC CURE MONITOR

It is important to calibrate the LT-451 Dielectric Cure Monitor before testing samples with the LT-4203 Parallel Plate Test Fixture. Calibration corrects small errors in the measurement electronics caused by internal warming and external temperature changes.

For most accurate results please note the following:

- The LT-451 should be calibrated before making the first tests of a sample.
- The LT-451 should be re-calibrated periodically to adjust for changes in the measurement circuitry as the instrument becomes warm.

Before calibrating the LT-451 make sure that it is turned on and has completed its boot-up self-calibration procedure.

To calibrate the LT-451, follow the steps described in the **Calibrate** panel:

- 1.a. Close the plates of the LT-4203 so they contact each other.
- 1.b. Press the “ZERO” button on the depth gauge to set the measurement to 0.00 mm.

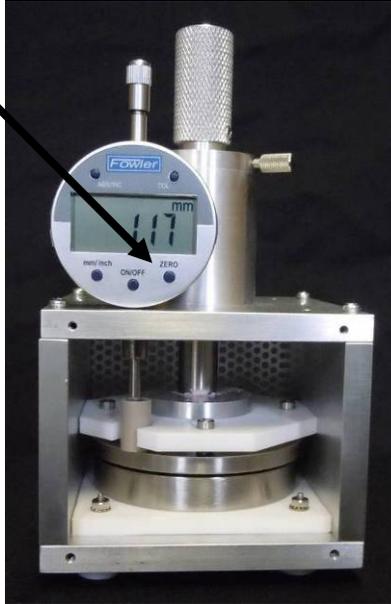


Figure 3
LT-4203 Parallel Plate Test Fixture
(Showing “ZERO” button)

- 2.a. Adjust plate separation until it is approximately 1.00 millimeters.
- 2.b. Input the plate separation.

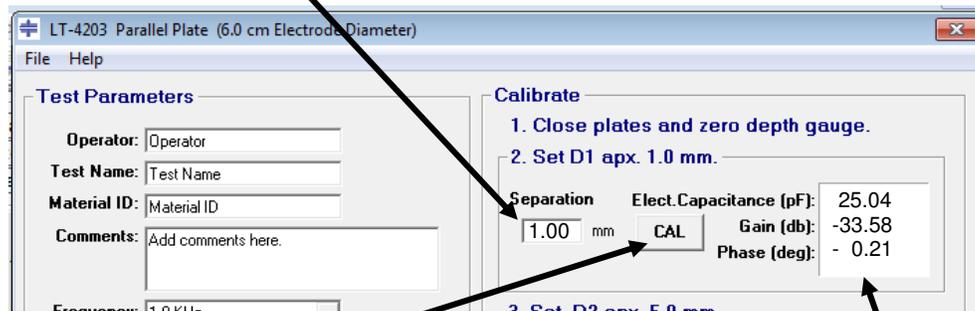


Figure 4

- 2.c. Click the **CAL** button.
- 2.d. The LT-451 will make a measurement and CureView will display the results.

- 3.a. Adjust plate separation until it is approximately 5.00 millimeters.
- 3.b. Input the plate separation.

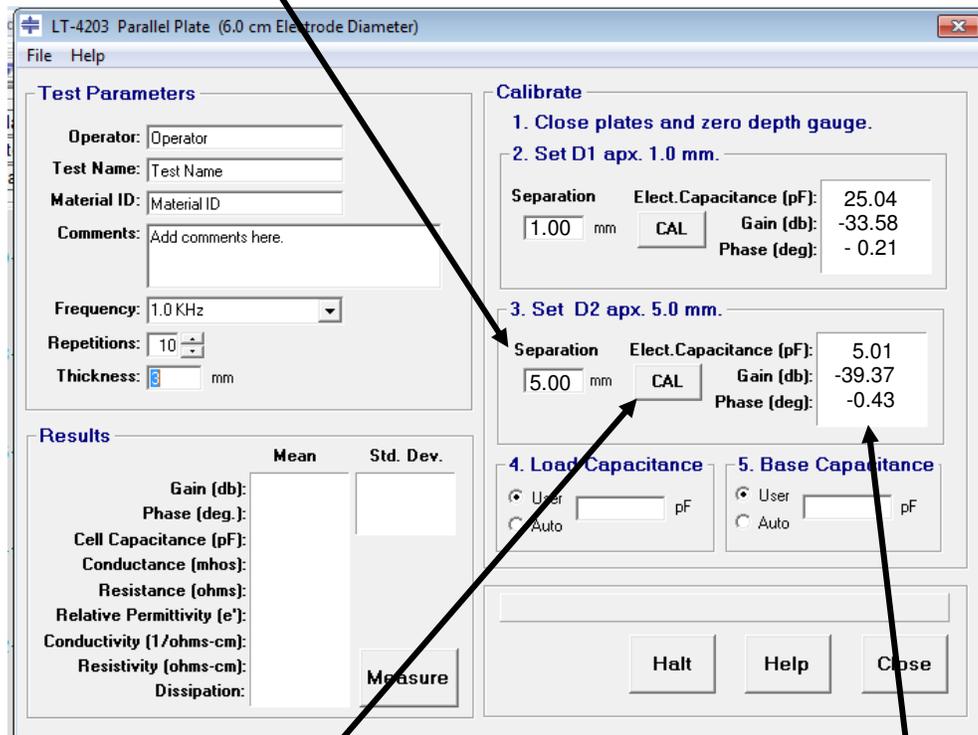


Figure 5

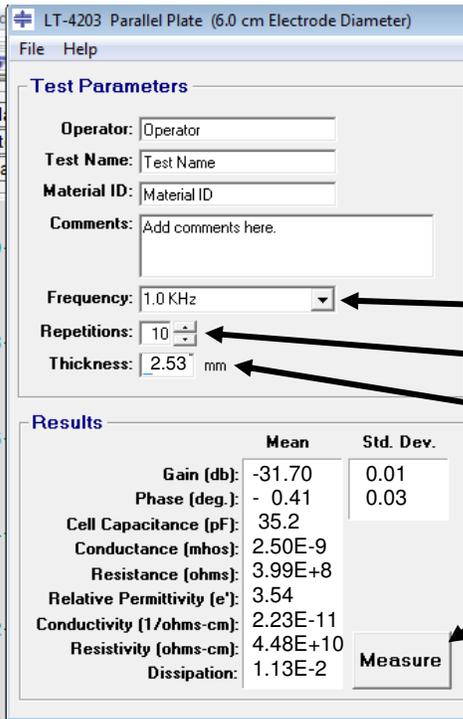
- 3.c. Click the **CAL** button.
- 3.d. The LT-451 will make a measurement and CureView will display the results.



Figure 6

- 4.a. CureView will calculate and display the **Load Capacitance** and **Base Capacitance**. These are component values that CureView uses to calculate the dielectric properties measured with the LT-4203
- 4.b. **Auto** is the default selection for the Load and Base Capacitances, which instructs CureView to use the calculated values to calibrate the LT-451 measurements. **Auto** is normally the recommended selection.
- 4.c. **User** may be selected to allow input of Load and Base Capacitances if the calculated values are not desired.

MEASURE SAMPLE—CONTACTING ELECTRODE METHOD



After the calibration process is complete, the LT-451 is ready to measure the dielectric properties of a sample. First insert the sample between the electrodes of the LT-4203, then close the electrodes so they make good contact with the sample. Perform a test using the following steps:

- Confirm **Test Parameters** and, if necessary, set
 - Frequency
 - Repetitions
 - Sample thickness
- Click the **Measure** button.
- CureView will then make measurements and display the results.

Figure 7

DIELECTRIC MEASUREMENT PRINCIPLES

Dielectric instrumentation measures electrical properties of the Material Under Test (MUT) between a pair of electrodes, which can be modeled as a conductance in parallel with a capacitance, as shown in Figure 8.

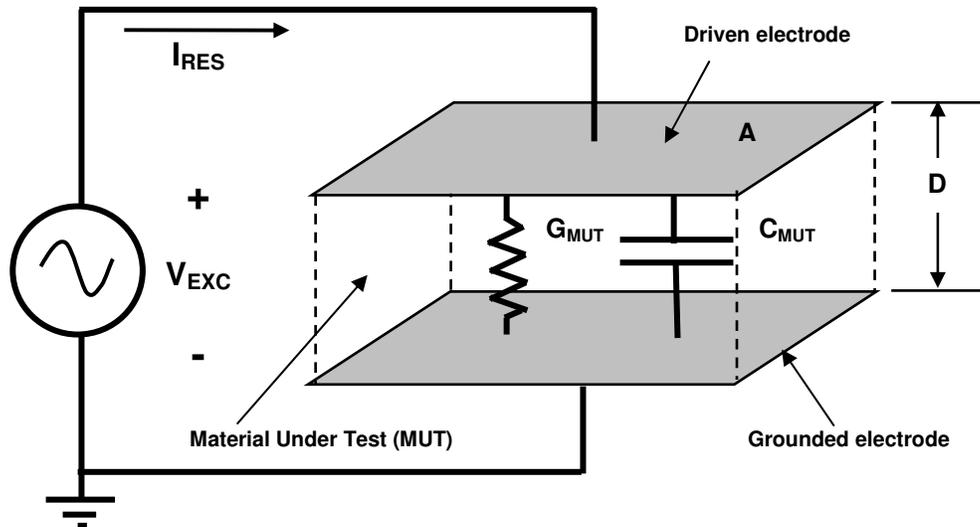


Figure 8
Electrical model of dielectric Material Under Test

The raw measurements at a given frequency f are:

$$G_{MUT} = \text{conductance (ohms}^{-1}\text{)}$$

$$C_{MUT} = \text{capacitance (farads)}$$

With the known quantities of:

$$\omega = 2\pi f$$

$$\epsilon_0 = 8.86 \times 10^{-14} \text{ F/cm}$$

$$A/D = \text{ratio of area to distance for electrodes}$$

then it is possible to calculate the resistance:

$$\text{(eq. 1)} \quad R_{MUT} = 1/G_{MUT} \quad (\text{resistance})$$

and the following material properties:

$$\text{(eq. 2)} \quad \rho = R_{MUT} * A/D \quad (\text{resistivity or ion viscosity})$$

$$\text{(eq. 3)} \quad \sigma' = G_{MUT} / (\epsilon_0 * A/D) \quad (\text{relative conductivity})$$

$$\text{(eq. 4)} \quad \epsilon' = C_{MUT} / (\epsilon_0 * A/D) \quad (\text{relative permittivity})$$

$$\text{(eq. 5)} \quad \epsilon'' = \sigma' / \omega \quad (\text{loss factor})$$

Dissipation, or $\tan\delta$, at measurement frequency f is the ratio of a material's relative loss to its relative permittivity, and is given by the relationship:

$$\text{(eq. 6)} \quad \tan\delta = \epsilon'' / \epsilon' = 1 / (\omega C_{MUT} R_{MUT})$$

For a solid material that can be fabricated as a laminate or a panel, a parallel plate electrode configuration is often used.

Good parallel plate measurements of dielectric constant (ϵ') and dissipation ($\tan\delta$) use an excitation electrode and a sense electrode. The guard surrounds the sense electrode to eliminate fringing electric fields around the sense electrode. This guarded electrode configuration allows accurate calculation of test cell capacitance. Consequently, ASTM D150-98 states that “the guarded electrode (three terminal method) is to be used as the referee method unless otherwise agreed upon.”

The guarded parallel plate electrodes of the Lambient Technologies LT-4203 Test Fixture are diagrammed below in Figure 9.

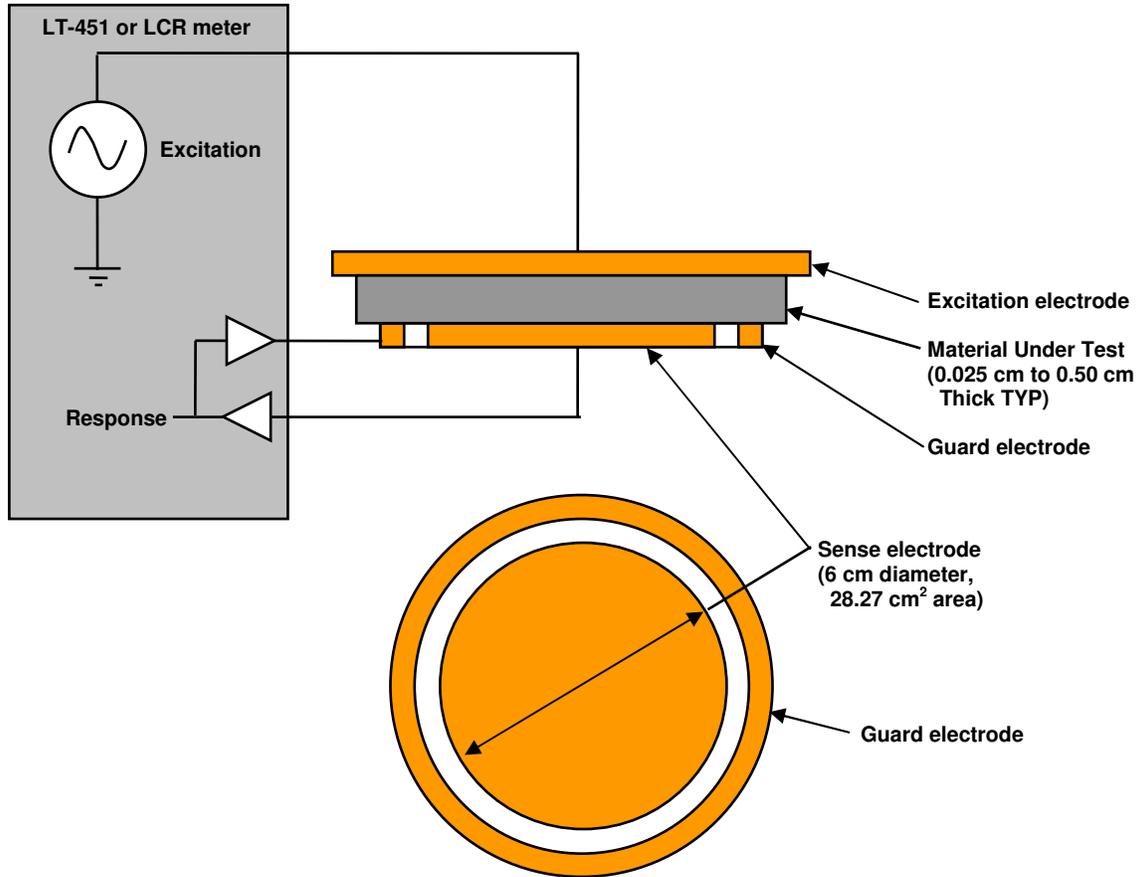


Figure 9
Diagram of LT-4203 guarded parallel plate configuration

CALIBRATING THE LT-451 FOR USE WITH THE LT-4203

The LT-451 Dielectric Cure Monitor is designed for making dielectric measurements of materials with very high resistivities, and has an architecture that is different from standard LCR meters. Its measurement circuitry uses a floating electrode with a load capacitance (C_{LOAD}). This load capacitance varies slightly with changes in temperature. Also, the internal electronics and cabling have a parasitic base capacitance (C_{BASE}) that varies from instrument to instrument. (See App. Note 3, *Dielectric Measurement Techniques* and App. Note 5, *Data Processing for the Floating Electrode Configuration*)

These variations in load capacitance and base capacitance necessitate calibrating the LT-451 before testing samples with the LT-4203. The LT-4203 option in CureView calibrates the LT-451 using the following two-point process:

- User sets LT-4203 electrode separation (D) to 1.00 mm
- LT-451 measures cell capacitance with air at D = 1.00 mm
- User sets LT-4203 electrode separation (D) to 5.00 mm
- LT-451 measures cell capacitance with air at D = 5.00 mm

For the configuration and electrode dimensions of Figure 9, the ideal cell capacitance with air can be calculated directly from the following equation:

(eq. 7) $C_{\text{Air}} = \epsilon_0 * A/D$ (Cell capacitance with air)

Results for various electrode separations are listed below in Table 1:

Table 1
Test cell capacitance for various electrode separations

Electrode Separation D (cm)	A/D Ratio (cm)	Ideal Air Capacitance (e' = 1.0)
0.025	1130	100 pF
0.050	565	50.0 pF
0.075	377	33.3 pf
0.100	282.5	25.0 pF
0.250	113.0	10.0 pF
0.500	56.5	5.0 pF

Using the ideal and measured values of cell capacitance with air at two known plate separations, CureView calculates the exact values for C_{LOAD} and C_{BASE} for that particular instrument at its current operating temperature. CureView then automatically uses these values in subsequent measurements to obtain accurate results for dielectric constant and dissipation.

CONTACTING ELECTRODE MEASUREMENTS

The contacting electrode method requires only one measurement with the electrodes in direct contact with the MUT as shown in Figure 10. The surface of the MUT must be flat to prevent an air gap between the sample and the electrodes, which can cause a measurement error. The MUT should also be incompressible so the separation between the electrodes is the same as the true thickness of the sample.

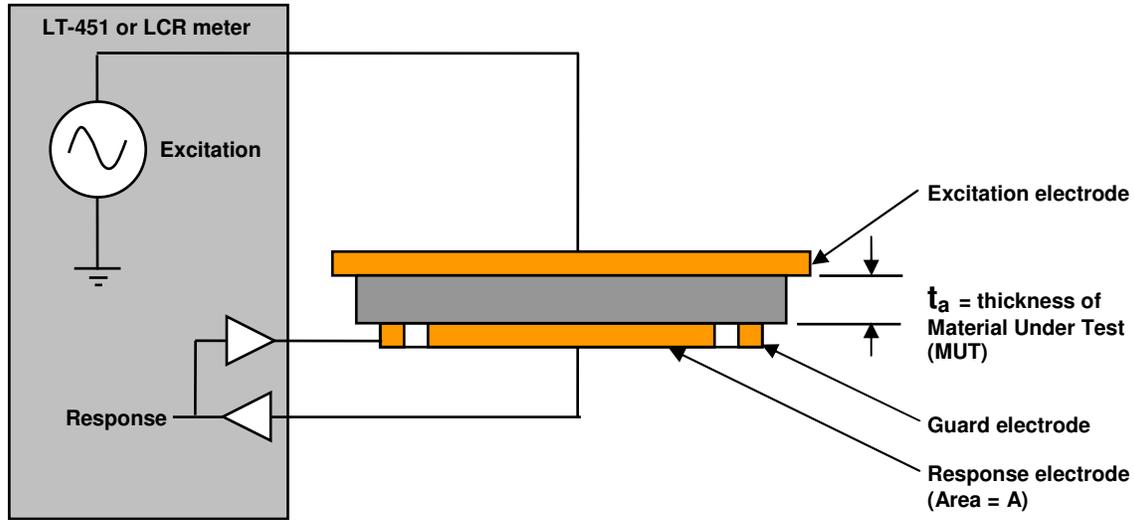


Figure 10
Configuration for contacting electrode measurements

Dielectric properties at frequency of measurement f are calculated below:

(eq. 8) $\epsilon' = C_{MUT} / (\epsilon_0 * A / t_a)$ (relative permittivity)

(eq. 9) $\tan\delta = \epsilon'' / \epsilon' = 1 / (\omega C_{MUT} R_{MUT})$ (dissipation)

(eq. 10) $\epsilon'' = \epsilon' * \tan\delta$ (loss factor)

Where:

$$\omega = 2\pi * f$$

$$\epsilon_0 = 8.86 \times 10^{-14} \text{ F/cm}$$

C_{MUT} = Capacitance of measurement

R_{MUT} = Resistance of measurement

NON-CONTACTING ELECTRODE MEASUREMENTS

The non-contacting electrode method can obtain accurate results for dielectric properties in the presence of an air gap, but requires two measurements. One measurement determines the capacitance and dissipation of the test fixture at a known separation with only air between the electrodes, as shown in Figure 11a. The other measurement determines the capacitance and dissipation at the same separation with the sample inserted between the electrodes, as shown in Figure 11b. For this method the air gap and the compressibility of the MUT do not affect the results.

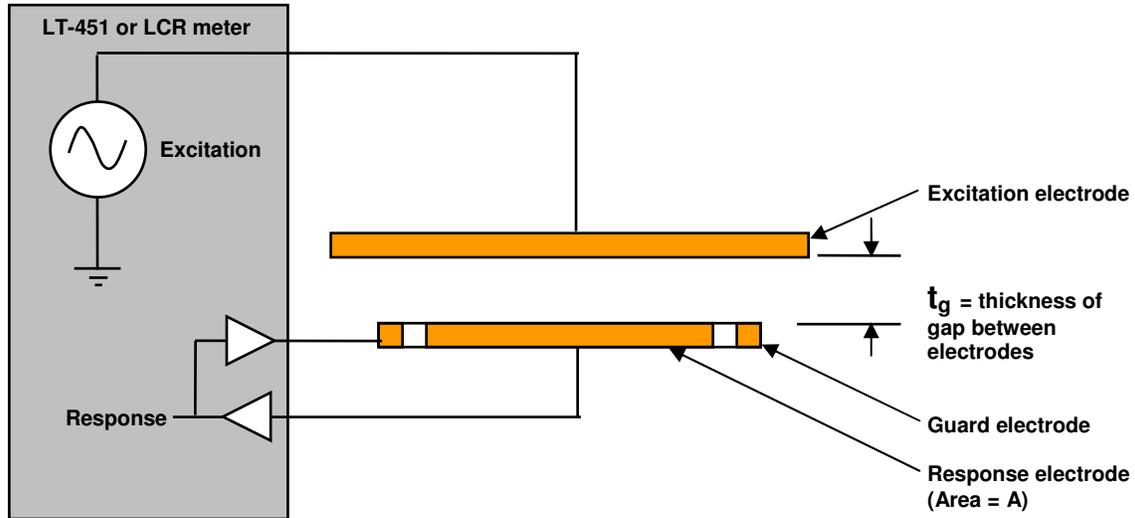


Figure 11a
Non-contacting electrode measurement with air only between electrodes
(First measurement)

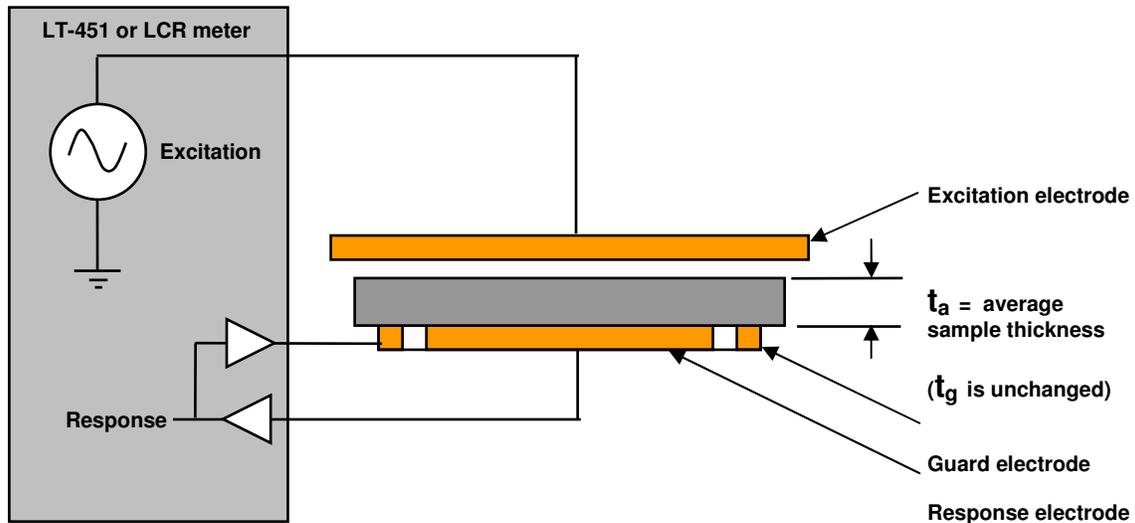


Figure 11b
Non-contacting electrode measurement with sample between electrodes
(Second measurement)

The current implementation of the LT-4203 option does not automate measurements for the non-contacting electrode method; however, the results from single measurements can be used to calculate the dielectric properties by hand.

As with the contacting electrode method, the software must first calibrate the LT-451. Then two separate measurements must be made as described for the contacting electrode method. The dielectric properties are calculated using results from these measurements as outlined below:

For low dissipation the dielectric properties at frequency of measurement, f , are calculated below:

(eq. 10) For $(\tan\delta)^2 \ll 1$
 $\epsilon' = 1 / [1 - (a * b)]$ (relative permittivity)

(eq. 11) $\tan\delta = \tan\delta_{P2} + [\epsilon' * c * d]$ (dissipation)

(eq. 12) $\epsilon'' = \epsilon' * \tan\delta$ (loss factor)

Where:

$\omega = 2\pi * f$

C_{P1} = Capacitance (F) without MUT inserted (Fig. 11a)

R_{P1} = Resistance (Ω) without MUT inserted (Fig. 11a)

$\tan\delta_{P1}$ = Dissipation without MUT inserted (Fig. 11a)
 $= 1 / (\omega C_{P1} R_{P1})$

C_{P2} = Capacitance (F) with MUT inserted (Fig. 11b)

R_{P2} = Resistance (Ω) with MUT inserted (Fig. 11b)

$\tan\delta_{P2}$ = Dissipation with MUT inserted (Fig. 11b)
 $= 1 / (\omega C_{P2} R_{P2})$

t_g = Separation (m) between response and excitation electrodes

t_a = Average sample thickness (m)

$a = 1 - (C_{P1} / C_{P2})$

$b = t_g / t_a$

$c = \tan\delta_{P2} - \tan\delta_{P1}$

$d = (t_g / t_a) - 1$

Results for the non-contacting electrode measurements can be as accurate as the measurements of electrode separation and sample thickness. But for situations where the air gap is a large fraction of the sample thickness, the calculations for relative permittivity, ϵ' , and dissipation, $\tan\delta$, are very sensitive to uncertainties in t_g and t_a . Consequently, non-contacting electrode measurements are best used for thicker samples where the air gap can be relatively small.

CONCLUSION

The LT-4203 option in CureView automates the process of calibrating the LT-451. After calibration, the LT-4203 option can make accurate measurements of dielectric properties using the LT-4203 Parallel Plate Test Fixture and the contacting electrode method. The LT-4203 option can also provide the measurements necessary for hand-calculation of dielectric properties using the non-contacting electrode method.