LT-4203A Parallel Plate Test Fixture
Specifications and User's Guide

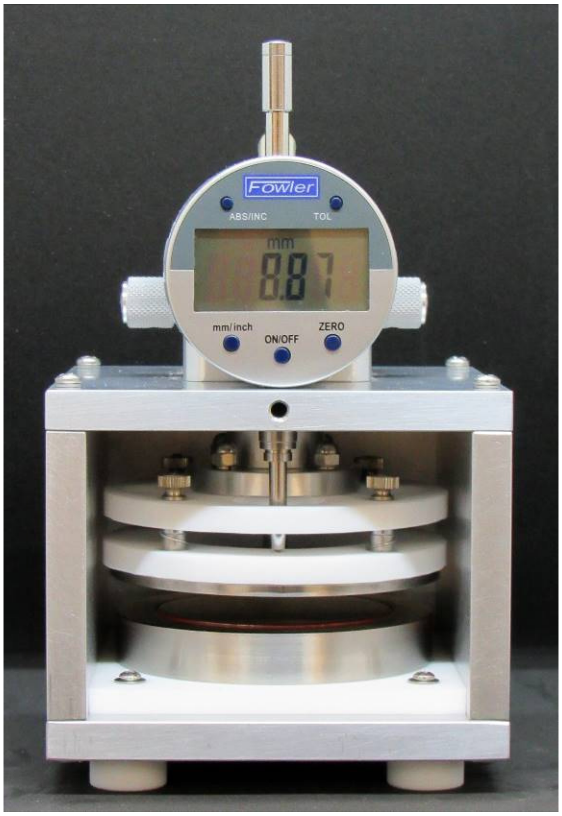

Figure 1
LT-4203A Parallel Plate Test Fixture

DESCRIPTION

The LT-4203A Parallel Plate Test Fixture is designed for measuring the AC loss characteristics and permittivity of solid laminates and panels per ASTM Standard D150-98, and implements the guarded electrode (three terminal) measurement preferred as the referee method.

The standard sense electrode is 6.0 cm in diameter and the electrode separation may be adjusted to accommodate various sample thicknesses. A removable micrometer head permits measurement of electrode separation before testing. The 1.0 cm wide guard electrode eliminates fringing electric fields around the sense electrode for accurate calculation of test cell capacitance. Both electrodes are surrounded by a grounded frame which acts as a Faraday cage to reduce pickup of electrical noise.

Maximum operating temperature of the LT-4203A is 150 °C, allowing measurement of dielectric properties at elevated temperatures. The LT-4203A Parallel Plate Test Fixture may be used with either the Lambient Technologies LT-451 Dielectric Cure Monitor or generic LCR meters. When used with the LT-4203A, the LT-451 can test samples with thicknesses between 0.025 cm and 0.50 cm with optimum accuracy.

LT-4203A Features

- **Removable, electronic thickness indicator**
- **150 °C temperature tolerance**
- **Spring-loaded electrode to ensure full contact with sample**
- **Compatible with generic LCR meters**

SPECIFICATIONS

Dimensions:
Overall (width x depth x height) : 11.4 cm x 15.2 cm x 15.9 cm
(Without digital indicator) (4.5″ x 6.0″ x 6.25″)

Diameter, excitation electrode : 8.00 cm
Diameter, sense electrode : 6.00 cm (Area = 28.27 cm^2)*
Width, guard electrode : 1.00 cm

Weight: : 2.9 kg (6.3 lbs)

Composition:
Electrodes : Stainless steel
Insulator : Teflon
Body : Aluminum

Operational temperature : Ambient to 150 °C (302 °F)

Connections:
Excitation electrode : BNC
Sense electrode : Triax

Recommended sample dimensions : 8.0 cm x 8.0 cm to
9.0 cm x 9.0 cm (maximum)

Optimum sample thickness : 0.025 cm to 0.50 cm

Test Fixture Parameters:
A/D ratio : 28.27 cm^2 / sample thickness in cm
Base (parasitic) capacitance : ~15 pF (actual value may vary)

Micrometer Attachment (Removable for use at elevated temperatures)
Accuracy : 0.03 mm (0.001″)
Resolution : 0.01 mm (0.0005″)

Features—
- On/Off switch
- Adjustable ZERO reference
- Absolute/Incremental readings
- Direct mm-in conversion

*Modification of sense electrode diameter available upon request

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PARTS LIST FOR THE LT-4203A PARALLEL PLATE TEST FIXTURE

1. Carefully remove the LT-4203A and its accessories from the shipping carton.

2. Check that all parts and accessories on the Packing List are included. Contents are subject to change without notice.

The LT-4203A standard package has the following items:

Qty	**Description**
1	LT-4203A Parallel Plate Test Fixture
1	Removable micrometer (electronic indicator)
1	3/32″ Allen wrench
1	User's Manual

If purchased with an LT-451 Dielectric Cure Monitor, the standard package also includes the following items:

1	Transition box
1	BNC cable (tan)
1	Triax cable (yellow)
1	LT-451 extension cable
1	User's Manual/Software manual on USB flash drive

3. Check that all options on the Packing List are included.

4. Please report any missing items to your local Lambient Technologies representative immediately.

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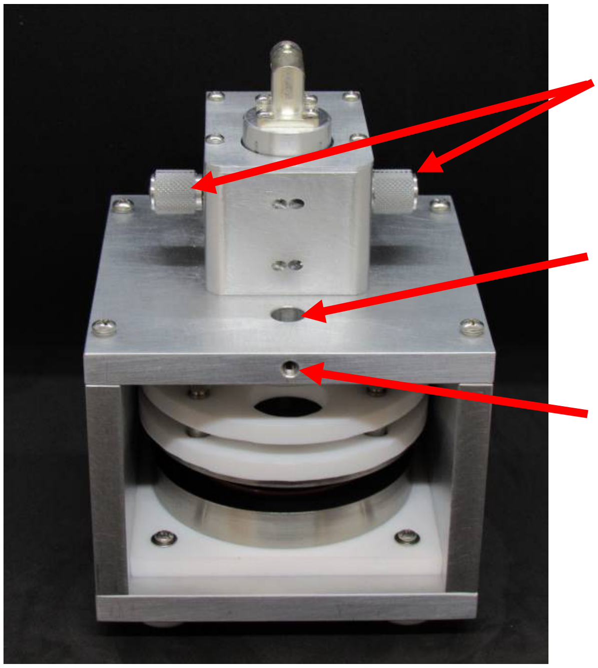
Assembling the LT-4203A Parallel Plate Test Fixture

Figure 2 below shows the LT-4203A Parallel Plate Test Fixture, and identifies the knobs which adjust plate separation.



Knobs for adjusting plate separation

Digital thickness indicator location

Set screw for securing and removing digital thickness indicator

Figure 2
LT-4203A Parallel Plate Test Fixture
(Digital indicator removed for clarity)

The digital thickness indicator shown in Figure 3 is included for determining plate separation but must be installed by the user.

Figure 3
Digital thickness indicator

Install the digital thickness indicator as shown in Figures 4 a and 4 b.

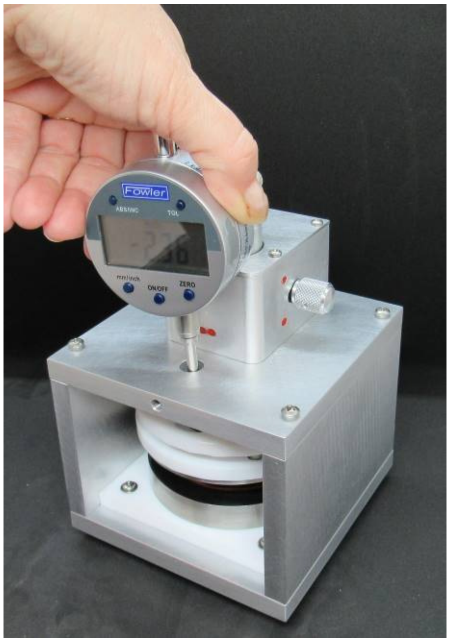


Figure 4 a

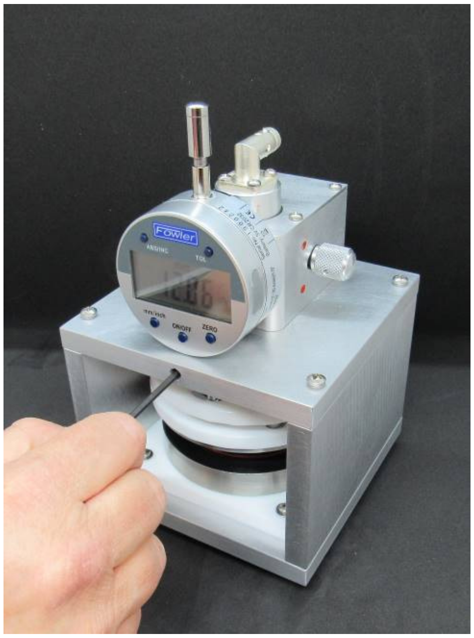


Figure 4 b

Figure 4 a. Insert the probe tip of the digital thickness indicator through the hole on the top plate of the LT-4203A. The probe tip must touch the lower Teflon plate just below the hole (see Figure 1).

Figure 4 b. Use the included 3/32” Allen wrench to tighten the setscrew that secures the indicator in place. Insert the Allen wrench through the hole on the front side of the top plate.

NOTE: REMOVE THE THICKNESS INDICATOR BEFORE SUBJECTING THE TEST CELL TO ELEVATED TEMPERATURES. EXPOSURE TO HIGH TEMPERATURES WILL DAMAGE THE INDICATOR.

The indicator may be removed by loosening the set screw and lifting the indicator from its mounting hole.

Connecting the LT-451 Dielectric Cure Monitor to the LT-4203A

The connections from the LT-451 Dielectric Cure Monitor to the LT-4203A Parallel Plate Test Fixture are shown in Figures 5 a, 5 b, 5 c and 5 d. The LT-4203A has a BNC coaxial cable for the excitation signal and a triaxial cable for the response signal. These two cables connect to a transition box which routes the excitation and response signals into a single LT-451 extension cable. The LT-451 extension cable then plugs into the desired dielectric channel on the rear panel of the LT-451.

Note that the LT-451 extension cable has a fork terminal that is connected to the cable shield/conduit at one end, and a banana plug at the other end. The fork terminal connects the LT-451 chassis to the LT-4203A and is necessary to ground LT-4203A for proper shielding. The banana plug is inserted into the transition box to ground the BNC and triax cables.

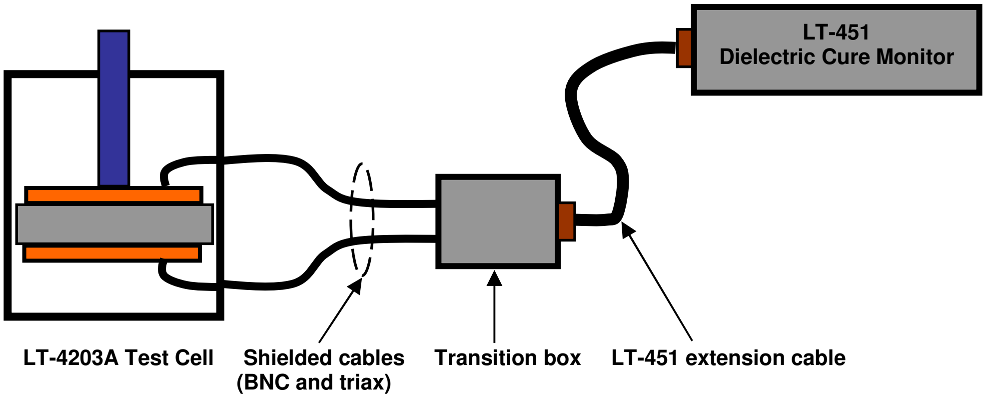


Figure 5 a
Connections from the LT-451 to the LT-4203A

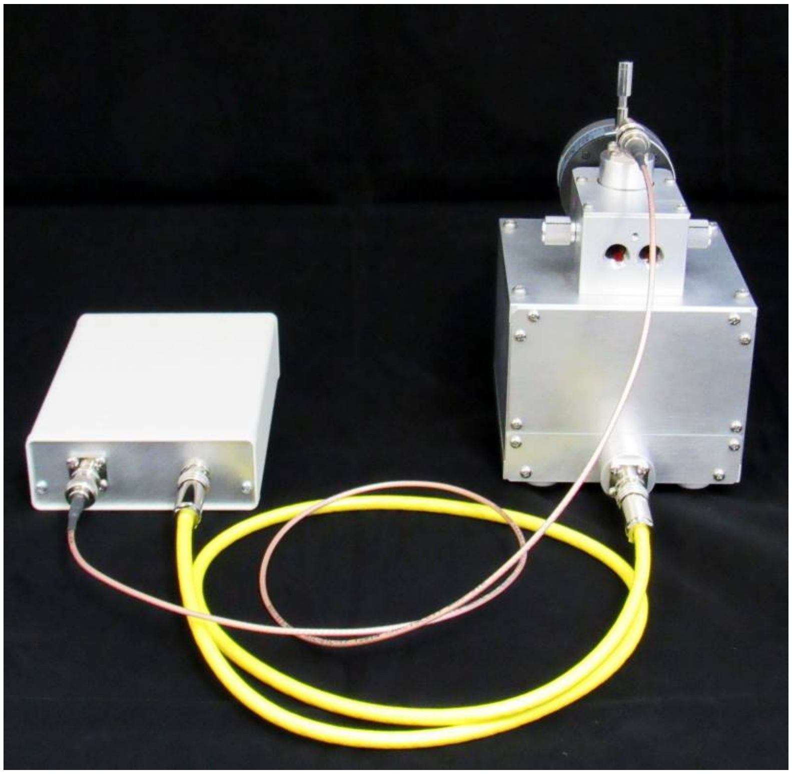


Figure 5 b
Cable connections from LT-4203A to transition box

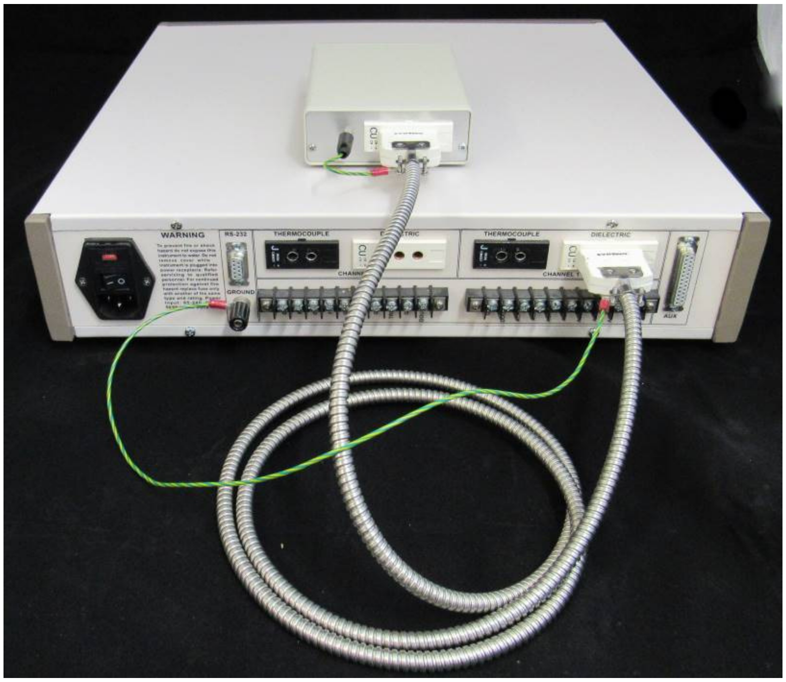


Figure 5 c
Cable connections from LT-451 to transition box

Connect the cables as follows:

- Plug yellow triax cable into LT-4203A triax bulkhead connector (Figure 5 b)
- Plug tan BNC cable into LT-4203A BNC bulkhead connector (Figure 5 b)
- Plug yellow triax cable into transition box bulkhead connector (Figure 5 b)
- Plug black BNC cable into transition box bulkhead connector (Figure 5 b)
- Plug LT-451 extension cable into transition box three-terminal connector (Figure 5 c)
- Insert LT-451 extension cable ground plug into transition box jack (Figure 5 c)
- Plug LT-451 extension cable into LT-451 three-terminal connector (Figure 5 d)
- Connect fork terminal of LT-451 extension cable ground wire to LT-451 ground contact point (Figure 5 d)

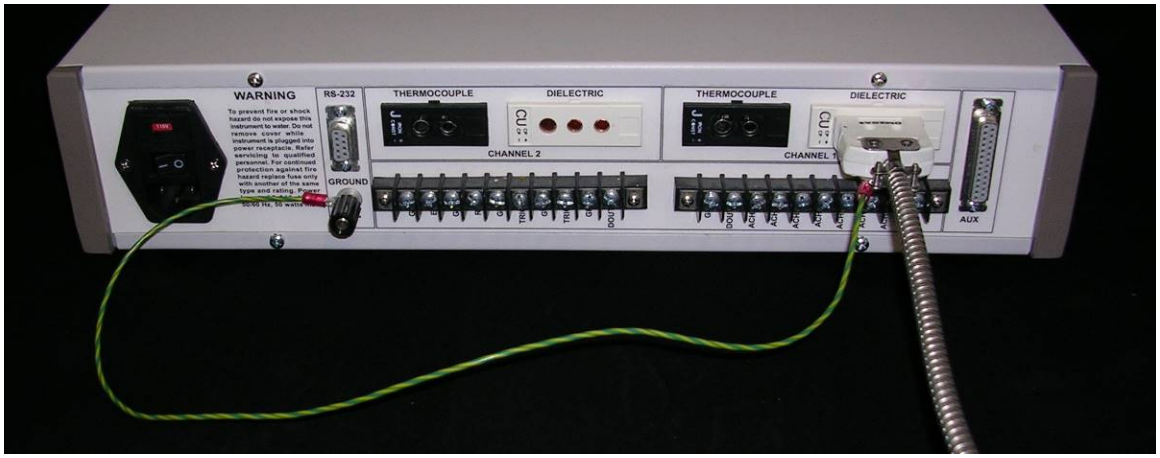


Figure 5 d
Ground connection from LT-451 extension cable to LT-451 chassis

Connecting a generic LCR meter to the LT-4203A

The connection from a generic LCR (*I*nductance-*C*apacitance-*R*esistance) meter to the LT-4203A is shown in Figure 6. The LT-4203A has a BNC coaxial cable for the excitation signal and a triaxial cable for the response signal. The BNC cable must connect to the excitation output of the LCR meter. The triaxial cable must connect to the response input of the LCR meter. Typically the LCR meter input is a BNC and the user must provide a means of making the transition from a triax connector to a BNC connector.

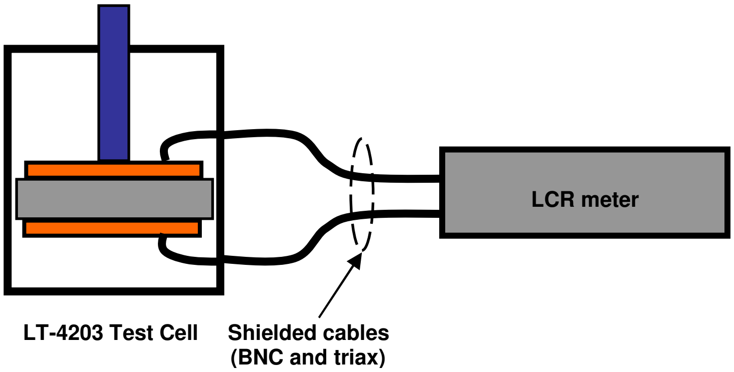


Figure 6
Typical connection from an LCR meter to the LT-4203A

The guard electrode of the LT-4203A is connected to the internal (not outermost) shield of the triaxial cable as shown in Figure 7. Many LCR meters use a virtual ground input, and simply ground the guard electrode of dielectric test cells through the shield of the response BNC connector. For an LCR meter with this configuration, the user must connect the internal shield of the LT-4203A triaxial cable to the response BNC ground.

Upon request Lambient Technologies can modify the LT-4203A connectors or provide appropriate transition boxes for connection to specific LCR meters.

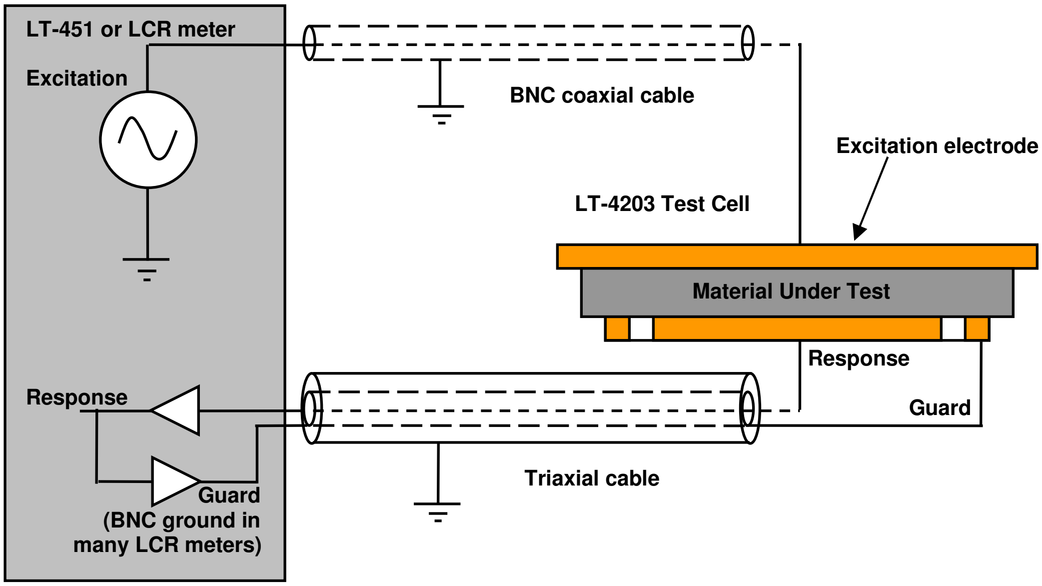


Figure 7
Typical excitation and response cabling to the LT-4203A

Connecting an LCR meter with four-wire inputs to the LT-4203A

Many LCR meters have four-wire inputs for Kelvin connections, which exclude the effect of wire resistance as shown in Figure 8. Kelvin connections are used when the resistance of the Material Under Test (MUT) is very low and comparable to the wire resistance. *For applications with higher resistances, the four-wire measurement does not significantly increase accuracy*.

Typically, a current-to-voltage converter outputs a signal for measurement of the current through the MUT. By Ohm's law, current I_{res} through wire resistances produces voltage drops that reduce the response voltage V_{res} across the electrodes.

In a Kelvin connection, a differential amplifier with high input impedance measures the voltage across these electrodes, using leads that pass no current and therefore produce no voltage drop from the wire resistance. With V_{res} and $I_{res,}$ it is possible to calculate the complex admittance, and the capacitance and conductance, of the material between the electrodes with equation 1.

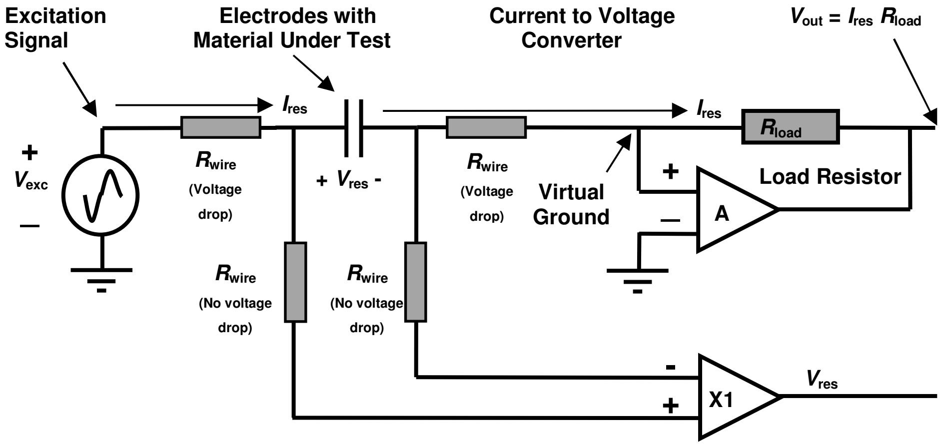


Figure 8
Kelvin (4-wire) connection for dielectric measurements

(eq. 1) $$Y_{MUT} = G_{MUT} + i\omega C_{MUT} = I_{res} / V_{res}$$

Where:

I_{res} = AC current through MUT (a complex number, amps)
V_{res} = AC voltage across MUT (a complex number, volts)
C_{MUT} = Capacitance of MUT (a real number, Farads)
G_{MUT} = Conductance of MUT (a real number, ohms^{-1})
f = Excitation frequency (Hz)
ω = $2\pi f$ (angular frequency, radians/sec)

The connection from an LCR meter with four-wire inputs to the LT-4203A is shown in Figure 9.

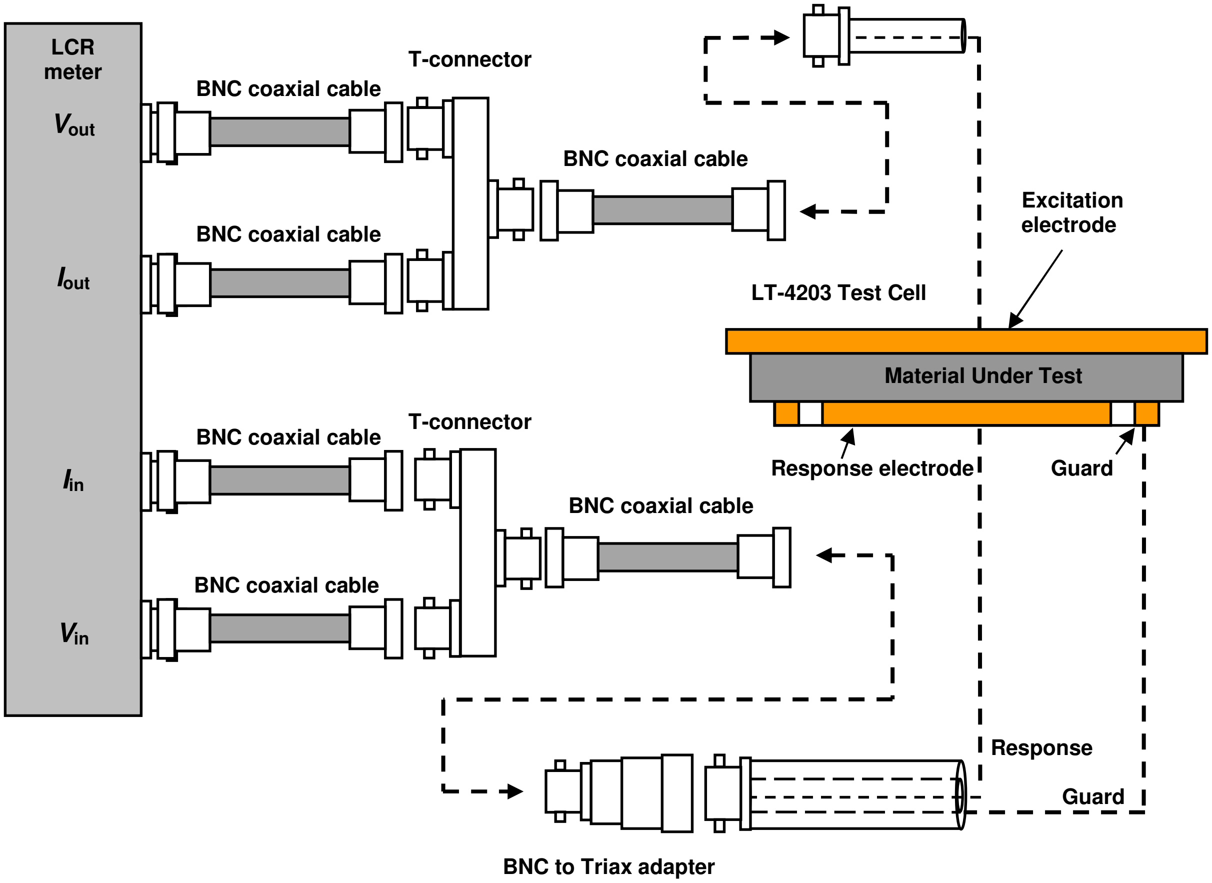


Figure 9
Four-wire connection from an LCR meter to the LT-4203A

Determining base capacitance of the LT-4203A

The base capacitance C_{base}, also known as the parasitic or cable capacitance, must be determined for accurate measurements of the capacitance between the electrodes. This base capacitance tends to be constant for a particular configuration of the LT-4203A, cabling and instrumentation, but it does depend on the length and type of cabling, and the input characteristics of the instrument.

The base capacitance is in parallel with the capacitance between the electrodes of the test cell, and its effect may be removed by simple subtraction from the raw measurement:

(eq. 2) $$C_{\text{electrode}} = C_{\text{measurement}} - C_{\text{base}}$$

Where: C_{electode} = True capacitance between electrodes
$C_{\text{measurement}}$ = Measured capacitance between electrodes
C_{base} = Parasitic cable capacitance

Following is the recommended procedure for determining the base capacitance:

1. Adjust electrodes of the LT-4203A until they contact each other.
2. Zero digital indicator by pressing the "ZERO" button.
3. Adjust electrodes of the LT-4203A until the indicator reads 1.00 mm.
4. Measure air capacitance $C_{\text{meas 1 mm}}$ with electrode separation of 1.00 mm.
5. Adjust electrodes of the LT-4203A until the indicator reads 5.00 mm.
6. Measure air capacitance $C_{\text{meas 5 mm}}$ with electrode separation of 5.00 mm.
7. Calculate ideal air capacitance between electrodes. Electrode diameter is 6.00 cm and the ideal air capacitance is:

(eq. 3) $$C_{\text{electrode}} = \varepsilon_0 \, (A/D)$$

Where: $\varepsilon_0 = 8.85 \times 10^{-14}$ F/cm
$A = \pi\,(3.00\text{ cm})^2 = 28.27\text{ cm}^2$
D = separation between electrodes

Therefore: $C_{\text{electrode 1 mm}} = 25.05$ pF (D = 1 mm)
$C_{\text{electrode 5 mm}} = 5.01$ pF (D = 5 mm)

8. Calculate base capacitance at 1 mm and 5 mm:

$$C_{\text{base 1 mm}} = C_{\text{meas 1 mm}} - C_{\text{electrode 1 mm}}$$

$$C_{\text{base 5 mm}} = C_{\text{meas 5 mm}} - C_{\text{electrode 5 mm}}$$

9. Calculate average base capacitance:

$$C_{\text{base}} = (\, C_{\text{base 1 mm}} + C_{\text{base 5 mm}} \,) / 2$$

10. Example:

$C_{\text{electrode 1 mm}} = 25.05$ pF
(calculated air capacitance for D = 1 mm)

$C_{\text{electrode 5 mm}} = 5.01$ pF
(calculated air capacitance for D = 5 mm)

$C_{\text{meas 1 mm}}$ = 40.4 pF
(measured air capacitance for D = 1 mm)

$C_{\text{meas 5 mm}}$ = 20.1 pF
(measured air capacitance for D = 5 mm)

$C_{\text{base 1 mm}} = C_{\text{meas 1 mm}} - C_{\text{electrode 1 mm}}$
= 15.35 pF

$C_{\text{base 5 mm}} = C_{\text{meas 5 mm}} - C_{\text{electrode 5 mm}}$
= 15.09 pF

$C_{\text{base}} = (C_{\text{base 1 mm}} + C_{\text{base 5 mm}}) / 2$
= 15.22 pF

Parallel plate measurements

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 10.

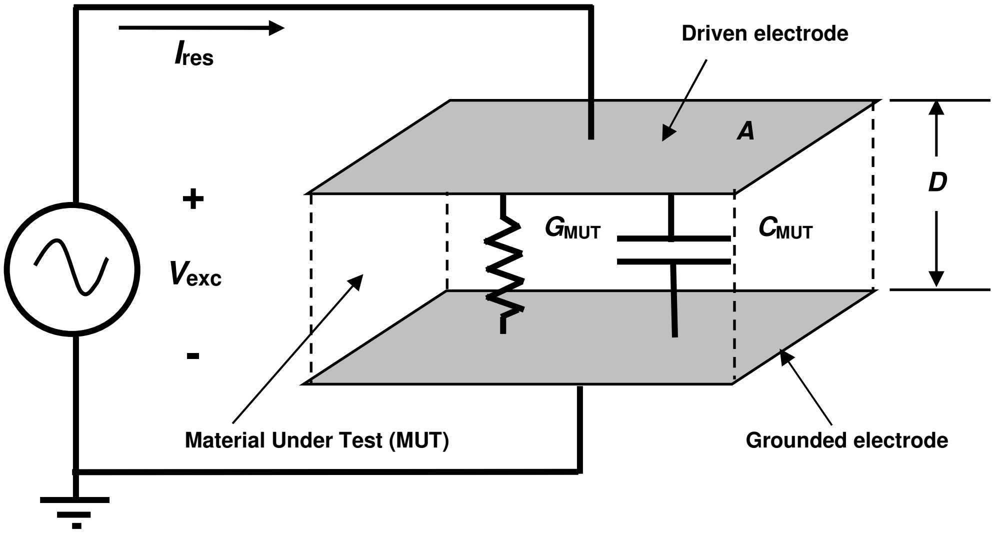


Figure 10
Electrical model of dielectric Material Under Test

From raw measurements of conductance G_{MUT} and capacitance C_{MUT}, it is possible to calculate the following:

(eq. 4) $R_{MUT} = 1/G_{MUT}$ (resistance)
(eq. 5) $\rho = R_{MUT}\ (A/D)$ (resistivity)
(eq. 6) $\sigma = G_{MUT}/(A/D)$ (conductivity)
(eq. 7) $\varepsilon' = C_{MUT}/(\varepsilon_o\ (A/D))$ (relative permittivity)
(eq. 8) $\varepsilon'' = \sigma/(\varepsilon_o\ \omega)$ (loss factor)
(eq. 9) $\tan\delta = 1/(\omega\, C_{MUT}\, R_{MUT})$ (dissipation)

Where: f = excitation frequency
$\omega = 2\pi f$
$\varepsilon_0 = 8.85 \times 10^{-14}$ F/cm
A/D = ratio of electrode area and separation
$\tan\delta = \varepsilon''/\ \varepsilon'$

These dielectric properties can be measured in a test cell. In the case of a solid material, which can be fabricated as a laminate or a panel, a parallel plate electrode configuration is often used. The guarded parallel plate electrodes of the LT-4203A are diagrammed below in Figure 11.

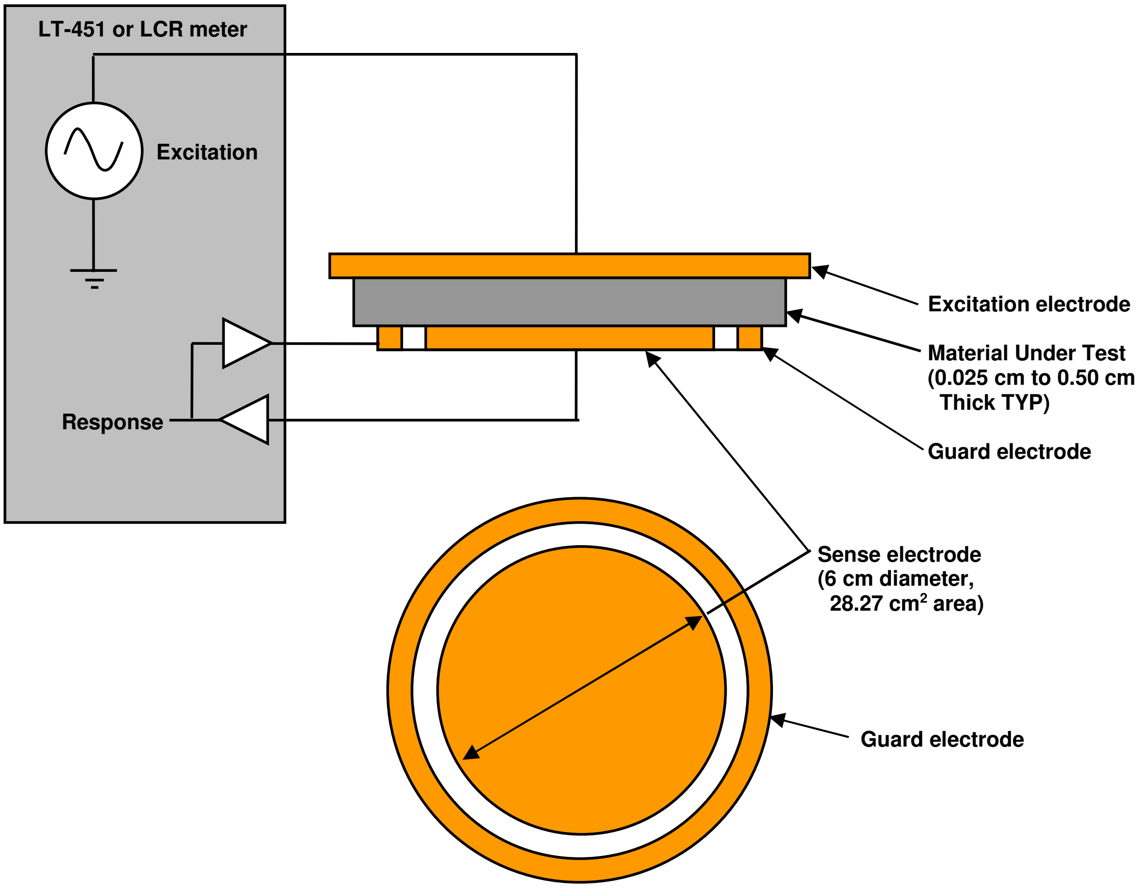


Figure 11
Diagram of LT-4203A guarded parallel plate configuration

For the configuration and electrode dimensions of Figure 11, the capacitance with air and with an example material of relative permittivity $\varepsilon' = 4.0$ are listed in Table 1:

Table 1
Parameters of Example Parallel Plate Configuration

Electrode Separation *D* (cm)	*A*/*D* Ratio (cm)	Air Capacitance ($\varepsilon' = 1.0$)	Material Capacitance ($\varepsilon' = 4.0$)
0.025	1130	100 pF	400 pF
0.25	113.0	10.0 pF	40.0 pF

The LT-451 uses the floating electrode method, which allows measurement of very high resistances with reduced noise at low frequencies (Ref. Lambient Technologies AN 3.25—Dielectric Measurement Techniques).

From the definition of tanδ, the capacitance of the MUT and the maximum resistance that an instrument can measure, it is possible to calculate the smallest measurable dissipation at a given frequency. Nominal performance limits of the Lambient Technologies LT-451 are listed in Table 2:

Table 2
LT-451 Nominal Performance Limits

Frequency Range	0.001 Hz to 100 Khz
Optimal Capacitance Range	~20 pF to ~2000 pF
Optimal Resistance Range	~1 KΩ to ~100,000 MΩ

The results for the LT-451 are shown in Table 3 for a frequency of 60 Hz, commonly used to determine dielectric loss at AC mains frequency. Details for the calculations supporting these results are beyond the scope of this document, but may be obtained from Lambient Technologies upon request.

Table 3
Comparison of Minimum Measurable tanδ at 60 Hz

Material Capacitance	LT-451 Max R_P	LT-451 Min tanδ
30 pF	1000 MΩ	0.09
100 pF	300 MΩ	0.09
300 pF	100 MΩ	0.09
1000 pF	20 MΩ	0.13

To achieve a capacitance of 1000 pF for the LT-4203A Parallel Plate Test Fixture, the film must be 0.017 cm (< 0.007”) thick. While use of such thin films is possible and routine, air gaps can cause inaccuracies; in this case techniques which account for contributions due to air gaps should be used.

Contacting electrode measurements

The contacting electrode method requires only one measurement with the electrodes in direct contact with the MUT as shown in Figure 12. The surface of the MUT must be flat to prevent an air gap between the sample and the electrodes. The MUT should also be incompressible so the separation between the electrodes is the same as the true thickness of the sample.

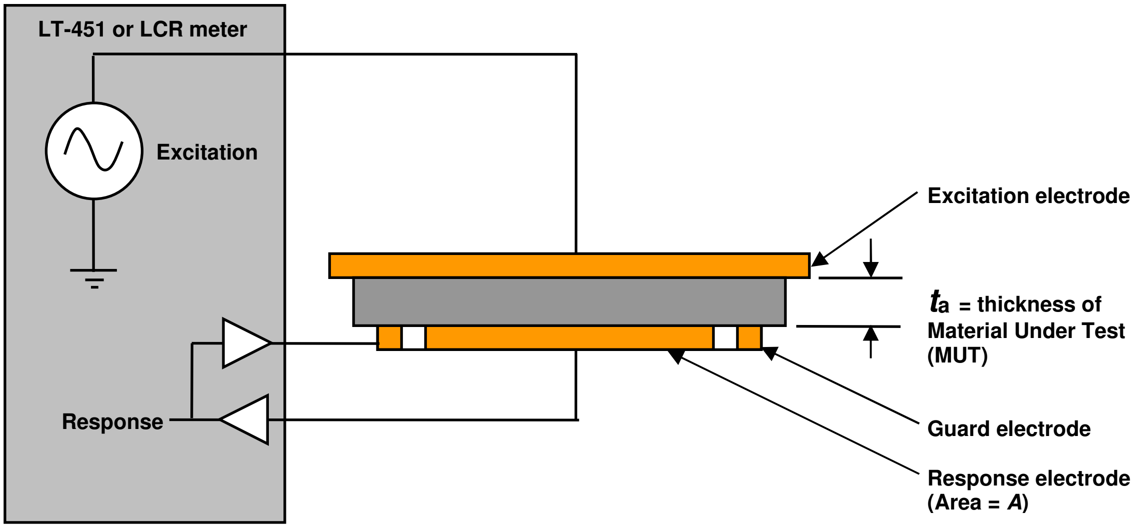


Figure 12
Configuration for contacting electrode measurements

Dielectric properties at excitation frequency *f* are calculated below:

(eq. 9) $\varepsilon' = C_P / (\varepsilon_o (A / t_a))$

(eq. 10) $\tan\delta = \varepsilon''/\varepsilon' = 1/(\omega C_P R_P)$

(eq. 11) $\varepsilon'' = \varepsilon' \tan\delta$

Where:
$\omega = 2\pi f$
$\varepsilon_0 = 8.85 \times 10^{-14}$ F/cm
C_P = Capacitance of measurement
R_P = Resistance of measurement

Non-contacting electrode measurements

The non-contacting electrode method can measure dielectric properties in the presence of an air gap, but requires two steps. One step measures the capacitance and dissipation of the test fixture at a known separation with only air between the electrodes, as shown in Figure 13 a. The other step measures the capacitance and dissipation at the same separation with the sample between the electrodes, as shown in Figure 13 b. For this method the air gap and the compressibility of the MUT do not affect the results.

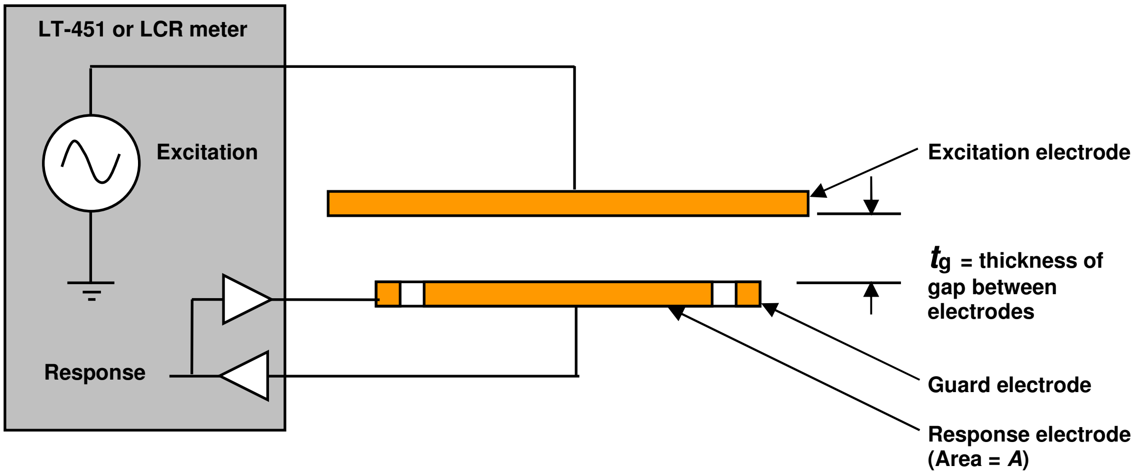


Figure 13 a
Non-contacting electrode measurement with air only between electrodes (First measurement)

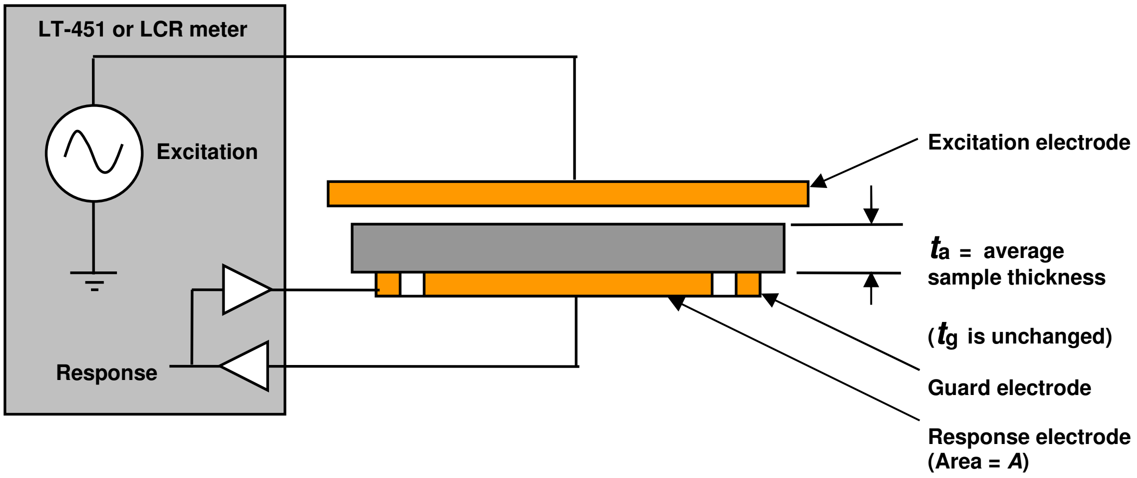


Figure 13 b
Non-contacting electrode measurement with sample between electrodes (Second measurement)

For low dissipation, $(\tan\delta)^2 << 1$, the dielectric properties at excitation frequency f are calculated below:

(eq. 12) $\varepsilon' = 1 / [1 - (a\ b)]$

(eq. 13) $\tan\delta = \tan\delta_{P2} + (\varepsilon'\ c\ d)$

(eq. 14) $\varepsilon'' = \varepsilon' \tan\delta$

Where: $\omega = 2\pi f$

C_{P1} = Capacitance (F) without MUT inserted (Fig. 14 a)

R_{P1} = Resistance (Ω) without MUT inserted (Fig. 14 a)

$\tan\delta_{P1}$ = Dissipation without MUT inserted (Fig. 14 a)
$= 1 / (\omega\, C_{P1}\, R_{P1})$

C_{P2} = Capacitance (F) with MUT inserted (Fig. 14 b)

R_{P2} = Resistance (Ω) with MUT inserted (Fig. 14 b)

$\tan\delta_{P2}$ = Dissipation with MUT inserted (Fig. 14 b)
$= 1 / (\omega\, C_{P2}\, R_{P2})$

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 non-contacting electrode measurements can be as accurate as the measurements of electrode separation and sample thickness. When the air gap is a large fraction of the sample thickness, calculations to determine dielectric properties 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.

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