AN 14–Errors in Parallel Plate Measurements
(The Effect of Surface Texture)

Summary

This application note will examine the effect of a textured sample surface similar to that of a fabric. The resulting measurement of permittivity is less than the true permittivity of the material and results from the contribution of air pockets created by the textured surface. This application note will model the effect of these air pockets to develop an understanding of the measurement error.

Good parallel plate measurements of dielectric constant ε' (also known as the real component of complex permittivity or, simply, relative permittivity) uses an excitation and a sense electrode with a guard 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."

Careful attention to measurement technique will yield good results, but it is often easy to overlook sources of error due to non-ideal samples. An ideal sample will have 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

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 1.

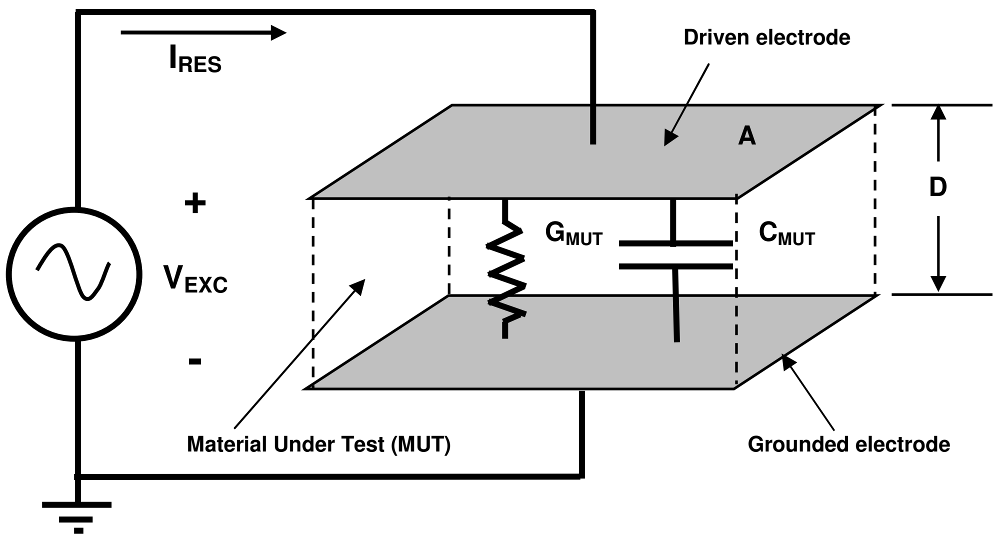

Figure 1
Electrical model of dielectric Material Under Test

The raw measurements at a given frequency f are:

G_{MUT} = conductance (ohms^{-1})
C_{MUT} = capacitance (farads)

With the known quantities of:

$\omega = 2\pi f$
$\varepsilon_0 = 8.86 \times 10^{-14}$ F/cm
A/D = ratio of area to distance for electrodes

then it is possible to calculate the resistance:

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

and the following material properties:

(eq. 2) $\boldsymbol{\rho = R_{MUT} * A/D}$ (resistivity or ion viscosity)
(eq. 3) $\boldsymbol{\sigma' = G_{MUT} / (\varepsilon_o * A/D)}$ (relative conductivity)
(eq. 4) $\boldsymbol{\varepsilon' = C_{MUT} / (\varepsilon_o * A/D)}$ (relative permittivity)
(eq. 5) $\boldsymbol{\varepsilon'' = \sigma' / \omega}$ (loss factor)

Dissipation, or tanδ, at measurement frequency f is the ratio of a material’s relative loss to its relative permittivity, and is given by the relationship:

(eq. 6) $\boldsymbol{\tan\delta = \varepsilon'' / \varepsilon' = 1 / (\omega\, C_{MUT}\, R_{MUT})}$

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 Lambient Technologies LT-4203 Test Fixture are diagrammed below in Figure 2.

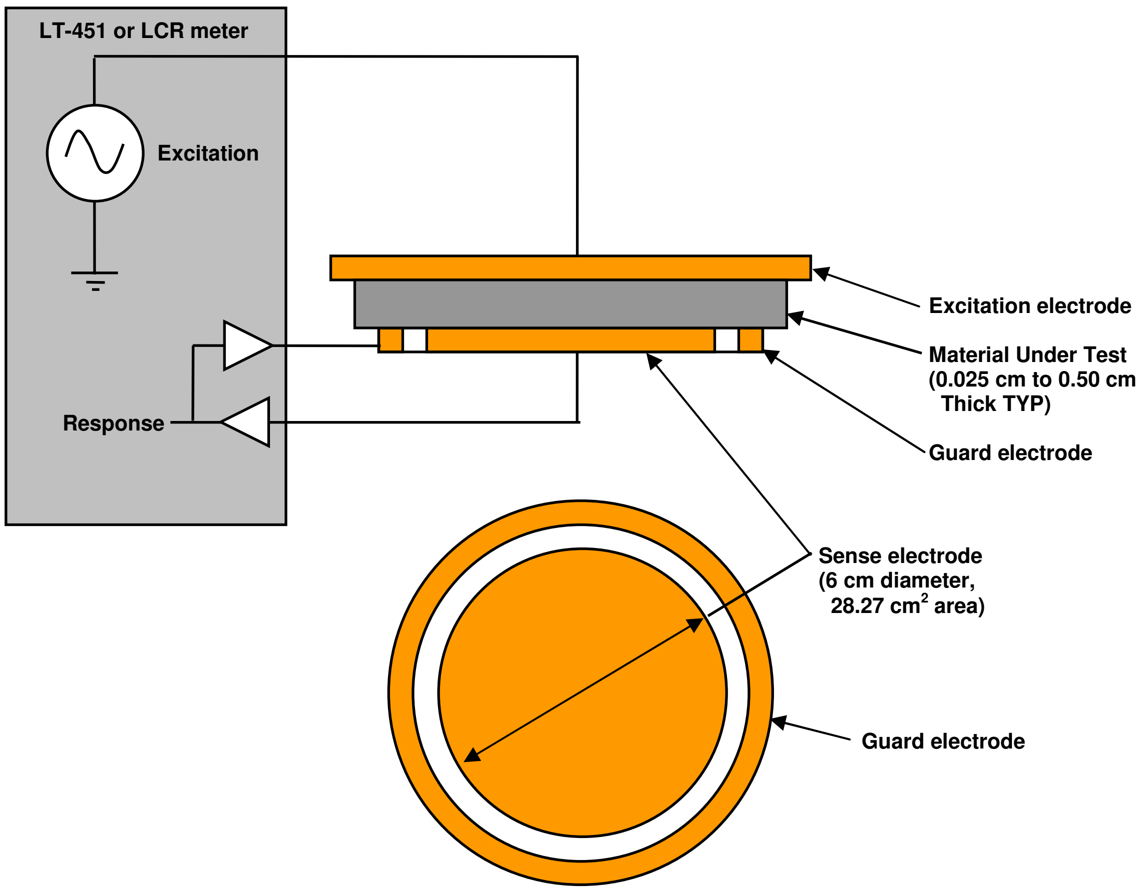

Figure 2
Diagram of LT-4203 guarded parallel plate configuration

For the configuration and electrode dimensions of Figure 2, the air capacitance of the test cell, and the capacitance when filled with a material of relative permittivity ε' = 4.0 (typical for polyimide-glass composites) are listed below in Table 1:

Table 1

Parameters of Example Parallel Plate Configuration

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

CONTACTING ELECTRODE MEASUREMENTS

The contacting electrode method requires only one measurement with the electrodes in direct contact with the MUT as shown in Figure 3. 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.

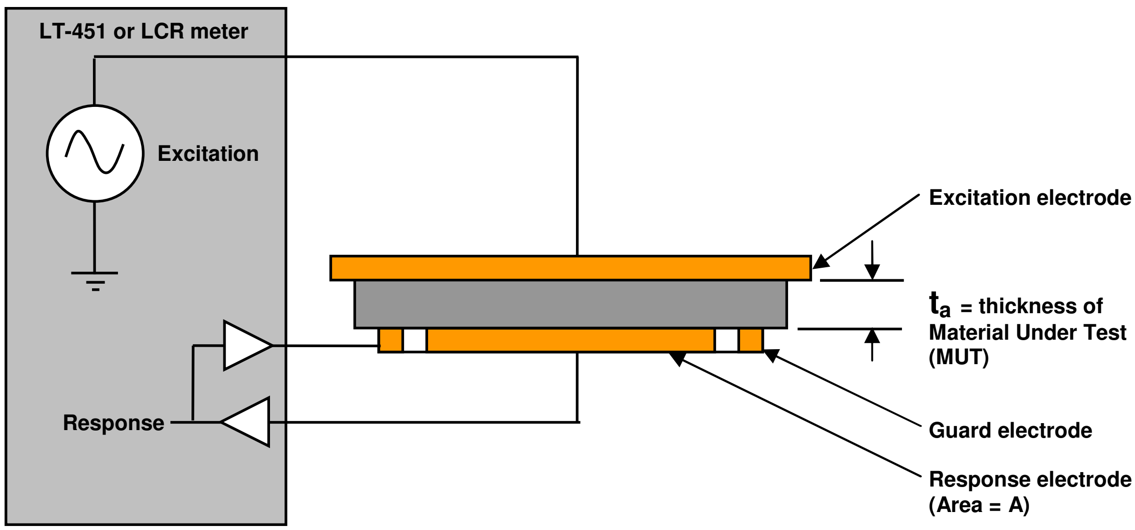

Figure 3
Configuration for contacting electrode measurements

Dielectric properties at frequency of measurement f are calculated below:

(eq. 7)	$\varepsilon' = C_P / (\varepsilon_0 * A / t_a)$	(relative permittivity)
(eq. 8)	$\tan\delta = \varepsilon'' / \varepsilon' = 1 / (\omega C_P R_P)$	(dissipation)
(eq. 9)	$\varepsilon'' = \varepsilon' * \tan\delta$	(loss factor)

Where:
$\omega = 2\pi * f$
$\varepsilon_0 = 8.86 \times 10^{-14}$ F/cm
C_P = Capacitance of measurement
R_P = Resistance of measurement

If the sample has an irregular surface which creates air gaps, then the results of this measurement will have an error because the electrodes do not make close and uniform contact with the sample.

Sample with Textured Surface

The following discussion will examine the errors in measuring relative permittivity caused by a sample with a textured surface, as shown in Figure 4.

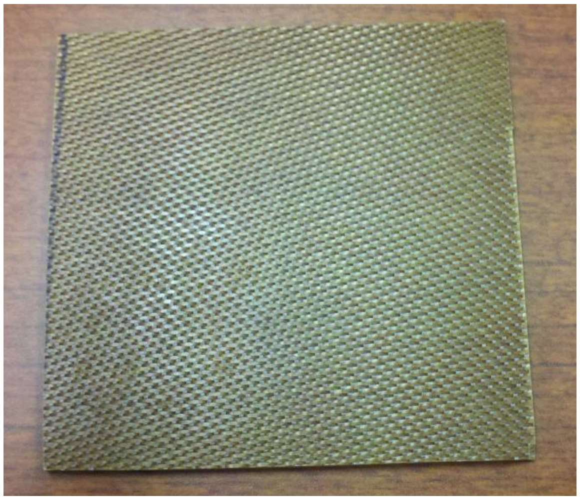

Figure 4
Sample with "fabric-like" textured surface

The surface of this sample has a regular texture created by the weave of the fiberglass substrate. The combination of the fiberglass and the polymer which impregnates the weave has an expected relative permittivity of approximately 3.0. When using the setup and assumptions of Figure 3, measurement of relative permittivity in a parallel plate test fixture such as the Lambient Technologies LT-4203 results in a value of approximately 1.9--significantly lower than expected.

The Material Under Test (MUT), however, is not a homogeneous slab, and so equation 7, which was used to calculate relative permittivity, cannot apply. A more realistic cross section of the MUT is shown in Figure 5, showing air pockets resulting from the weave of the sample.

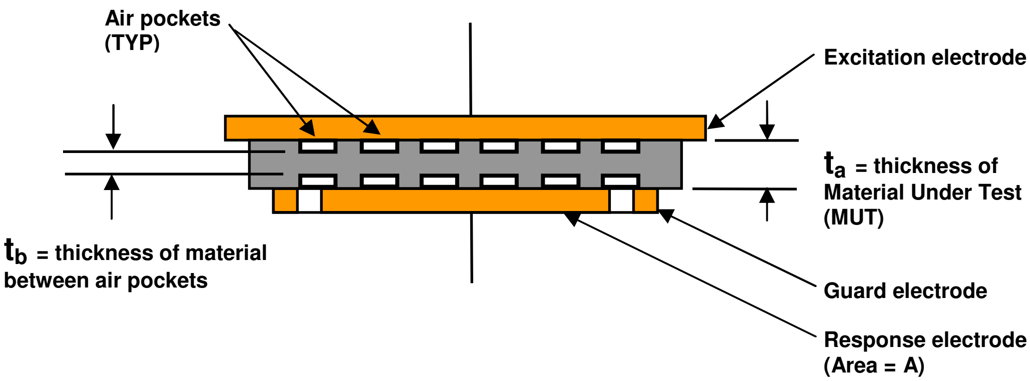

Figure 5
Cross section of textured sample between parallel plate electrodes

The electrical model of this sample is not that of Figure 1, but the more complex one shown below in Figure 6.

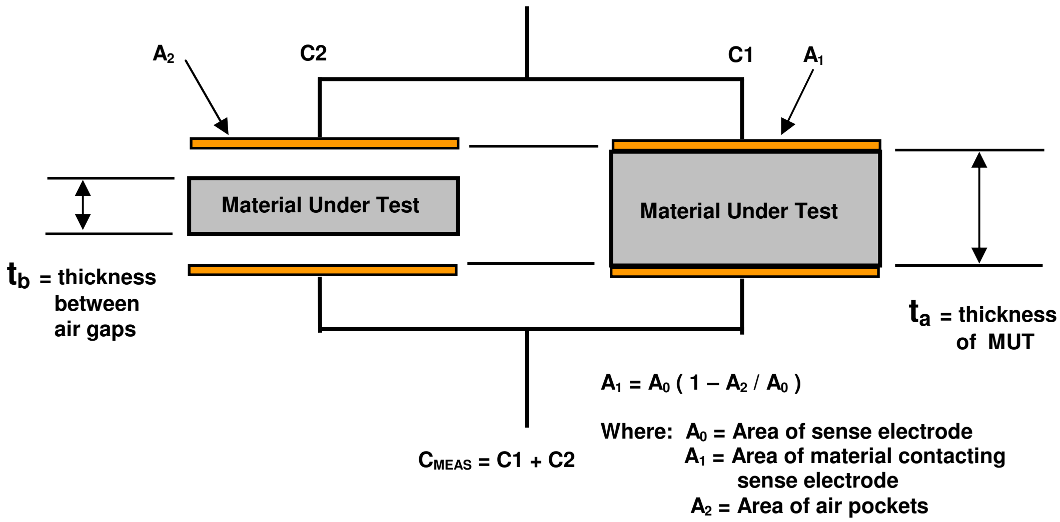

Figure 6
Electrical model of sample with "fabric-like" textured surface

The model of Figure 6 is two capacitors in parallel. One capacitor (C1) is filled with the dielectric material and the other capacitor (C2) is only partly filled with the dielectric material. The measured capacitance of this model is $C_{MEAS} = C1 + C2$ and the resulting *apparent* relative permittivity is ε'_{MEAS}. They are given by the expressions:

(eq. 10) $$C_{MEAS} = \varepsilon_0 \varepsilon' [(D / B) + (1 - D)] [A_0 / t_a]$$

(eq. 11) $$\varepsilon'_{MEAS} = C_{MEAS} / (\varepsilon_0 * [A_0 / t_a])$$
$$= \varepsilon' [(D / B) + (1 - D)]$$

Where: ε' = True relative permittivity of MUT (unitless)

t_a = Full thickness of sample (cm)
= Electrode separation (cm) for contacting electrode method

t_b = Thickness of sample between air gaps (cm)

A_0 = Area of sense electrode (cm^2)

A_2 = Area of air pockets covered by sense electrode (cm^2)

$B = \varepsilon' - [(t_b / t_a) * (\varepsilon' - 1)]$

$D = A_2 / A_0$ = ratio of area of air pockets to area of sample

Discussion

Using the model of Figure 6, equation 11 and the following parameters:

ε’ = 3.0 (true relative permittivity of MUT)

D = 0.75 (ratio air pocket area to sample area)

t_b / t_a = 0.6 (ratio sample thickness between air pockets to sample thickness)

a value of 2.0 was calculated for the expected measured relative permittivity. This value is of course incorrect and illustrates how a textured surface can reduce the measured relative permittivity from its true value.

Conclusion

A properly prepared sample is necessary when using a parallel plate test fixture. The sample surface must be smooth and flat to allow close contact of the parallel plate electrodes over their entire area. Any surface irregularity such as a texture which creates air gaps will result in inaccurate measurements.