



IPC-TM-650 TEST METHODS MANUAL

1.0 Scope This method describes a technique to determine the volume permittivity (dielectric constant) and loss tangent (dissipation factor) of insulating materials at 1 MHz using contacting electrodes. Several techniques are described using the actual thickness of the material measured, the geometry of the test specimen and values for capacitance and conductance of material to calculate the desired properties. The accuracy of this test is inherently limited by the ability to measure thickness accurately, however, use of an estimated value for effective electrode area, stray capacitance and equipment tolerances may also result in significant errors. Use of the preferred method (A) on metal clad materials should reduce errors on permittivity to those associated with thickness measurement (which should be under 2% for material over .005 inch), and an error (under 1%) associated with the effective area determination. Values determined with method B, C or D can be 5% or more from the actual value. Except for thickness determination, errors increase with specimen thickness due to the reduction in actual specimen capacitance. Method B and C are intended for thin materials while Method D is primarily for materials over .020 inch. For more accurate measurement of permittivity (dielectric constant) the two fluid method¹ easily permits measurement to better than 1%. For thin films under .005 inch, the two-fluid method IPC-TM-650, Method 2.5.5.3 is recommended.

2.0 Applicable Documents

ASTM-D-150 Standard Test Method for A-C Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Material

3.0 Test Specimens

3.1 Number Three specimens shall be prepared unless otherwise specified.

Method A Etched pattern silver painted with 1/2 inch soldered leads, see Figure 1.

Method B and C 2.0 inch diameter silver painted disks (from which 1.000 inch diameter disks are punched after painting).

Note: For thin films, samples may be cut into smaller specimens if capacitance exceeds instrument capacity.

1. Two Fluid Method, IPC-TM-650, Method 2.5.5.3

Number 2.5.5.1	
Subject Permittivity (Dielectric Constant) and Loss Tangent (Dissipation Factor) of Insulating Material at 1 MHz (Contacting Electrode Systems)	
Date 5/86	Revision B
Originating Task Group N/A	

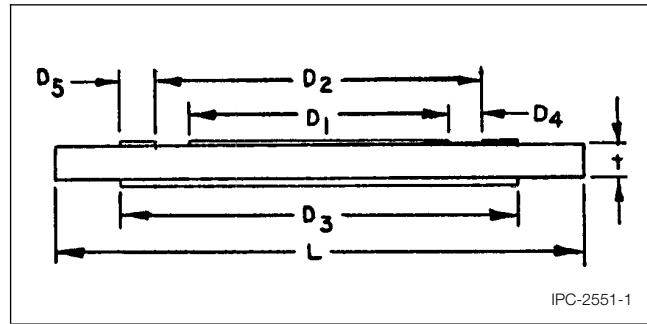


Figure 1 Electrode Configuration for Permittivity Tests Using a Three Terminal Bridge

Method D Silver painted disks or squares of the appropriate size with short leads attached by small residual copper pads or other means. (See Appendix 1 for appropriate size.)

3.3 Location One specimen from each edge and one from the center of a sheet. (This normally will provide the highest and lowest values of dielectric properties of a reinforced material.)

3.4 Metal Clad Materials Foil shall be removed by etching, leaving a metal outline for method "A".

3.5 Uncured Materials Materials which are not fully cured must be cured under normal conditions. Two ply minimum laminations are recommended for testing of bonding sheets while coverlays and similar materials may be tested in single ply or may be laminated together to produce a thicker specimen reducing the error induced by thickness measurement. Films coated on one side shall be laminated such that one coated side remains on the exterior.

4.0 Apparatus/Materials

4.1 All Methods Paper Cutter Silver Paint (DuPont 4929, or DuPont 4817 if material is attacked by cellosolve acetate) Micrometer with .00005 inch resolution Optical measuring device capable of measuring 1.0 inch to 1.2 inch with .001 inch resolution.

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4.2 Method A and Method D

1 MHz three terminal capacitance bridge with 100-1000 PF capacity

#20 tinned copper wire

Rosin flux solder

Soldering iron

Remote test fixture or binding post electrodes directly attached to the bridge

4.3 Method B 1 MHz capacitance bridge, two or three terminal Test fixture (Figure 2) Punch and die set, 1.0 inch diameter.

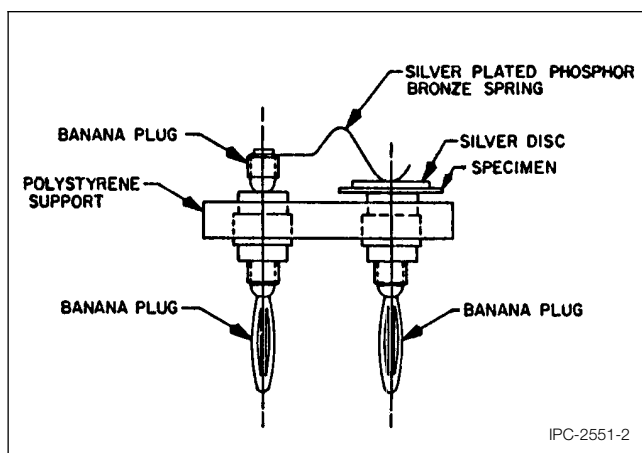


Figure 2 Test Fixture Permittivity and Loss Tangent of Thin Insulating Materials

4.4 Method C Q meter with 1 MHz capability Q Coils Test fixture (Figure 2) Punch and die set, 1.0 inch diameter.

5.0 Procedure

5.1 Preconditioning Unless otherwise specified the prepared painted sample shall be maintained at $23^{\circ}\text{C} \pm 5^{\circ}\text{C}$ and $50\% \text{ RH} \pm 10\% \text{ RH}$ for a minimum of 24 hours.

5.2 Test Conditions Unless otherwise specified specimens shall be tested at $23^{\circ}\text{C} \pm 2^{\circ}\text{C}$. Testing may be performed at $50\% \pm 10\% \text{ RH}$ or may be performed at ambient humidity within 5 minutes of removal from the 50% conditioning chamber.

5.3 Equipment Set Up

5.3.1 Warm up the capacitance measuring device in accordance with the manufacturer's recommendation.

5.3.2 Set the equipment to measure capacitance and conductance (or Q for Method C) at 1 MHz.

5.4 Test

5.4.1 Determine the thickness of the test specimen to the nearest .00005 inch or better at four locations (use corners for Figure 1 specimen used in Method A and make measurements prior to painting the specimen used for Methods B, C and D). **Note:** For films under .005 inch the known or measured density and the specimen weight and geometry may be used to determine effective thickness.

5.4.2 Measure the diameter (or length and width) of the electrode to the nearest .001 inch using a suitable device. For Figure 1 specimen record both the outer diameter of the inner electrode D_1 and inner diameter of the outer guard electrode D_2 .

5.4.3 Determine the capacitance and conductance or Q using Method A, B, C or D depending on equipment and test specimen type.

5.4.3.1 Method A capacitance bridge with Figure 1 specimen.

5.4.3.1.1 Connect the low terminal to the guarded (center) electrode shown as D_1 on the specimen.

5.4.3.1.2 Connect the guard electrode, shown as D_5 in Figure 1, to the bridge or fixture ground.

5.4.3.1.3 Zero the bridge for capacitance and conductance.

5.4.3.1.4 Connect the solid electrode shown as D_3 to the "high" terminal.

5.4.3.1.5 Determine and record the specimen capacitance as C_s and Conductance as G_s .²

5.4.3.2 Method B Capacitance Bridge with Fixture (Figure 2).

2. G_s —For many bridges the loss tangent (dissipation factor) may be read directly from the meter eliminating the need to calculate it from the conductance.

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5.4.3.2.1 Connect the fixture in Figure 2 to the bridge.

5.4.3.2.2 With the spring removed (or set at a right angle with the free end at least one half inch from the specimen support), zero the bridge for capacitance and conductance.

5.4.3.2.3 Insert the specimen on the fixture and place the free spring such that the specimen is in the circuit.

5.4.3.2.4 Determine the capacitance and conductance of the specimen and record as C_s and G_s .

5.4.3.3 Method C - Q Meter with Fixture (Figure 2)

5.4.3.3.1 Connect a coil to the Q meter which will result in resonance at a suitable value of capacitance at 1 MHz. *Note:* The value at which the Q meter resonates with the coil and electrode assembly in place must exceed the minimum capacitance of the meter (20 pf.) by at least the capacitance of the specimen. The higher the capacitance is at resonance without the specimen the larger the capacitance that can be measured. The highest possible capacitance that can be measured is 455 pf., however, this is seldom achievable. Smaller or thicker specimens may be required.

5.4.3.3.2 Connect the fixture to the Q meter.

5.4.3.3.3 With the spring removed (or set at a right angle with the free end at least 1/2 inch from the specimen support), adjust the capacitance until a resonance (maximum Q) is reached.

5.4.3.3.4 Record the capacitance as C_n and the Q as Q_n .

5.4.3.3.5 Insert the specimen into the fixture and place the free end of the spring such that the specimen is in the circuit.

5.4.3.3.6 Determine the capacitance and Q of the specimen and record as C_s and Q_s respectively.

5.4.3.4 Method D Capacitance Bridge two terminal measurement.

5.4.3.4.1 Connect one side of the specimen to the low terminal of the capacitance bridge.

5.4.3.4.2 Zero the bridge for capacitance and conductance on the appropriate range for the specimen. Connect the free lead of the specimen to the high terminal of the bridge.

5.4.3.4.3 Determine and record the specimen capacitance and conductance as C_s and G_s^2 , respectively.

6.0 Calculations

6.1 Calculate the average thickness of the specimen to the nearest .00001 inch.

6.2 Calculate the diameter of the electrode

$$D_e = \frac{D_1 \pm D_2}{2}$$

(D in inches) for the Figure 1 specimen used in Method A. Use the measured diameter for the 1.0 inch diameter specimen used in Method B and C.

6.3 Calculate the effective area of the electrode in square inches:

$$A = \pi \frac{(D_e)^2}{4} = \frac{\pi}{4} D_e^2$$

or $A = L \times W$ for square or rectangular specimens

6.4 Calculate the permittivity and loss tangent² of the specimen using the following equation.

For Methods A, B and D

$$\text{Permittivity} = \frac{C_s t}{.225A} \text{ where:}$$

C_s = capacitance in picofarads

t = avg. thickness of specimen in inches

A = effective area of specimen in square inches

$$\begin{aligned} \text{Loss Tangent} = D &= \frac{G_s}{wC_s} \times 10^6 \\ &= \frac{G_s \times 10^6}{6.28 \times 10^6 \times C_s} \\ &= \frac{G_s}{6.28 C_s} \end{aligned}$$

G_s = conductance in microsiemen

$w = 2\pi \times \text{frequency in Hz}$

$= 6.28 \times 10^6 \text{ (at 1 MHz)}$

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For Method C

$$\text{Permittivity} = \frac{Ct}{.225A}$$

$$= \frac{C_n - C_s}{.225 A} t$$

$$\text{Loss tangent} = D = \frac{C_n | Q_n - Q_s |}{| C_n - C_s | Q_s Q_n}$$

C = Capacitance in picofarads

t = Average thickness of specimen in inches

A = Effective area of specimens in square inches

C_n = Capacitance in picofarads of circuit without specimen

C_s = Capacitance in picofarads of circuit with specimen

Q_n = Q of circuit without specimen

Q_x = Q of circuit with specimen

7.0 Report

7.1 Report the average value of the permittivity to the nearest .1, e.g. 4.7.

7.2 Report the average value of the dissipation factor to two significant figures, e.g. .026.

7.3 Report the Method used A, B, C or D and the size of the specimen if Method D is used.

7.4 Report the preconditioning.

7.5 Report actual test temperature and humidity.

7.6 Report any anomalies in the test or variations from prescribed procedures or tolerances.

8.0 Notes

8.1 The capacitance of the specimen depends on the thickness, electrode area and dielectric constant. For thin plastic films under .005 inch with permittivity of 3 – 5, the 1.0 inch diameter specimen may exceed 1000 pf., hence, a smaller specimen is often required. Due to the high capacitance, the errors associated with edge and stray capacitance are not normally significant.

8.2 The capacitance of thicker materials may be quite low, for example, a typical .062 inch laminate with a permittivity of 4 will be under 20 pf/in². Small errors due to edge or stray capacitance may result in very significant errors in permittivity. Errors can be reduced by using proper correction factors (see ASTM-D-150).

Table 1

Dimensions						
Thickness (t)	D ₁ dia.	D ₂ dia.	D ₃ dia.	D ₄	D ₅	Length of one side of specimen (L)
0.020 or less (.79)	1.000	1.020	1.375	0.010	0.177	2.000
	(25.40)	(25.91)	(34.93)	(.25)	(4.50)	(50.80)
	±0.005	±0.005	±0.005	±0.001	±0.005	±.015
	(.13)	(.13)	(.13)	(.03)	(.13)	(.38)

1. Outlines for D₁, D₂, D₃, D₄ and D₅ are .062 inches wide.
2. Interior of electrodes defined by D₁ and D₃ are silver painted.
3. Short lengths of #20 tinned copper wire are soldered to each of the 3 electrodes. Use of small copper pads are recommended to facilitate soldering without damaging the specimen.

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Table 2

Electrode Size (in.)		.5 diameter	1 diameter	2.0 x 2.0	3.16 x 3.16	7.07 x 7.07
Electrode area sq. in.		.2	.79	4	10	50
Thickness	Property					
.001 inches	C (pf)	180	700	3600	–	–
	G (μs)	11	44	230	–	–
	R (ohms)	88K	23K	4K	–	–
.0101 inches	C (pf)	18	70	360	900	–
	G (μs)	1	4	23	56	–
	R (ohms)	880K	230K	44K	18K	4K
.060	C (pf)	NR	11	60	150	750
	G (μ)	NR	.7	3.7	9.4	48
	R (ohms)	NR	1.4M	2.70K	106K	21K
.125 inches	C (pf)	NR	NR	28.8	72	360
	G (μs)	–	–	1.8	4.5	23
	R (ohms)	–	–	550K	220K	44K

NR = Not recommended
K = x 1,000
M = x 1,000,000

Appendix A

Approximate Specimen Capacitance and Conductance

Permittivity = DK = 4 (For DK = 8 double C value)
Loss Tangent = DF = .01 (For DF = .02 [DK = 4] multiply R by 2 or divide JG by 2)