



ASSOCIATION CONNECTING
ELECTRONICS INDUSTRIES®

3000 Lakeside Drive, Suite 309S
Bannockburn, IL 60015-1219

IPC-TM-650 TEST METHODS MANUAL

1 Scope This test method describes procedure for measuring dielectric permittivity and loss tangent of embedded passive materials. The measurements are made in an APC-7 coaxial configuration where the test specimen represents a load terminating an air-filled coaxial transmission line. The method is suitable for testing high dielectric constant (high-k) polymer-composite materials having nominal thickness of 1 μm to 300 μm at frequencies of 100 MHz to 12 GHz. With proper use and computation the frequency range can be extended to 18 GHz. Existing measurement methods (see Section 2) assume quasi-static conditions in the thin film specimen, whereas this test method produces meaningful results at frequencies greater than hundreds of megahertz and where high-dielectric constant, thin film materials are to be measured.

This test method is for qualification of filled and unfilled, distributed capacitance, thin film materials where the permittivity in the frequency range of 100 MHz to 12 GHz is a critical functional parameter. The method is also applicable to polymer resist materials for embedded passive devices. This method fills a test method gap within the IPC-TM-650 Test Methods Manual for thin film, high-k dielectrics.

2 Applicable Documents

IPC-TM-650 Test Method Manual

- 2.5.5.1 Permittivity (Dielectric Constant) and Loss Tangent (Dissipation Factor) of Insulating Material at 1 MHz (Contacting Electrode Systems)
- 2.5.5.4 Dielectric Constant and Dissipation Factor of Printed Wiring Board Material-Micrometer Method
- 2.5.5.9 Permittivity and Loss Tangent, Parallel Plate, 1 MHz to 1.5 GHz

ASTM D 150 Standard Test Methods for AC Loss Characteristics & Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials

3 Terminology

3.1 Complex Permittivity, ϵ^* , $\epsilon^* = \epsilon_0 (\epsilon' - j\epsilon'')$ where $\epsilon_0 = 8.85419 \cdot 10^{-12}$ F/m is the dielectric permittivity of air [1], ϵ' is the relative dielectric constant and ϵ'' is the relative imaginary dielectric constant (the dielectric loss).

Number 2.5.5.10	
Subject High Frequency Testing to Determine Permittivity and Loss Tangent of Embedded Passive Materials	
Date 07/05	Revision
Originating Task Group Embedded Devices Test Methods Subcommittee (D-54)	

3.2 Relative Permittivity, ϵ_r^* , is a dimensionless ratio of complex permittivity to the permittivity of air, $\epsilon_r^* = \epsilon^*/\epsilon_0 = \epsilon' - j\epsilon''$.

3.3 Dielectric Constant is the real part of the relative permittivity. The symbol used in this document is ϵ' . Other symbols such as K, k, K', k', ϵ_r and ϵ_r' are exchangeable symbols used in the technical literature.

3.4 Dielectric Loss Tangent, $\tan(\delta)$, is a dimensionless ratio of the dielectric loss to the dielectric constant, $\tan(\delta) = \epsilon''/\epsilon'$.

3.5 APC-7, Amphenol 7 mm 50 Ω Coaxial Connector; APC-3.5 Amphenol 3.5 mm Precision 50 Ω Coaxial Connector.

3.6 Scattering Coefficient, S_{11} , is a ratio of incoming and outgoing power waves measured by a network analyzer through Port 1. S_{11} is complex entity consisting of magnitude, $|S_{11}|$, and phase, ϕ . In this document the circuit parameters that are complex numbers are in bold font.

3.7 Input Impedance, Z_{in} , a complex entity consisting of magnitude and phase.

$$Z_{in} = Z_0 (1 + S_{11}) / (1 - S_{11}) \quad (1)$$

where Z_0 is characteristic impedance of the APC-7 air-filled coaxial line, $Z_0 = 50 \Omega$.

4 Test Specimen The test specimen consists of a circular disk capacitor having the nominal diameter, a , of 3.0 mm with metal electrodes on both sides. The dielectric thickness, d , may be in the range of 1 μm to 300 μm (1 μm = 1 micrometer).

4.1 Preparation Conducting metal electrodes, thickness of 0.1 μm to 0.5 μm , shall be coated on both sides of the dielectric. Sputtered copper or gold is recommended. To avoid electrical shorting, the diameter of the top electrode, which faces the Section B of the test fixture (Figure 1), may be 2.85 mm to 3.0 mm. The diameter of the bottom electrode that faces the Section A (Figure 1), shall be within 3.0 mm to 3.05 mm, matching the diameter of the center conductor pin (Figure 1). This is the diameter a of the specimen that along with the specimen dielectric thickness, d , determines the specimen geometrical capacitance, C_p (see Equation (3) in

Material in this Test Methods Manual was voluntarily established by Technical Committees of IPC. This material is advisory only and its use or adaptation is entirely voluntary. IPC disclaims all liability of any kind as to the use, application, or adaptation of this material. Users are also wholly responsible for protecting themselves against all claims or liabilities for patent infringement. Fundamentally, the user assumes all responsibility for the use of this material in the convenience of the user and does not imply endorsement by IPC.

Copyright IPC-Association Connecting Electronics Industries
Provided by IHS under license with IPC
No reproduction or networking permitted without license from IHS

Full document details: IPC TM-650 2.5.5.10 2005

Licensee=Sandia National Lab/5932237100, User=sam, albert
Not for Resale, 05/28/2014 10:58:04 MDT



Documents

Page 1 of 8

Document Sharing Hub

IPC-TM-650		
Number 2.5.5.10	Subject High Frequency Testing to Determine Permittivity and Loss Tangent of Embedded Passive Materials	Date 07/05
Revision		

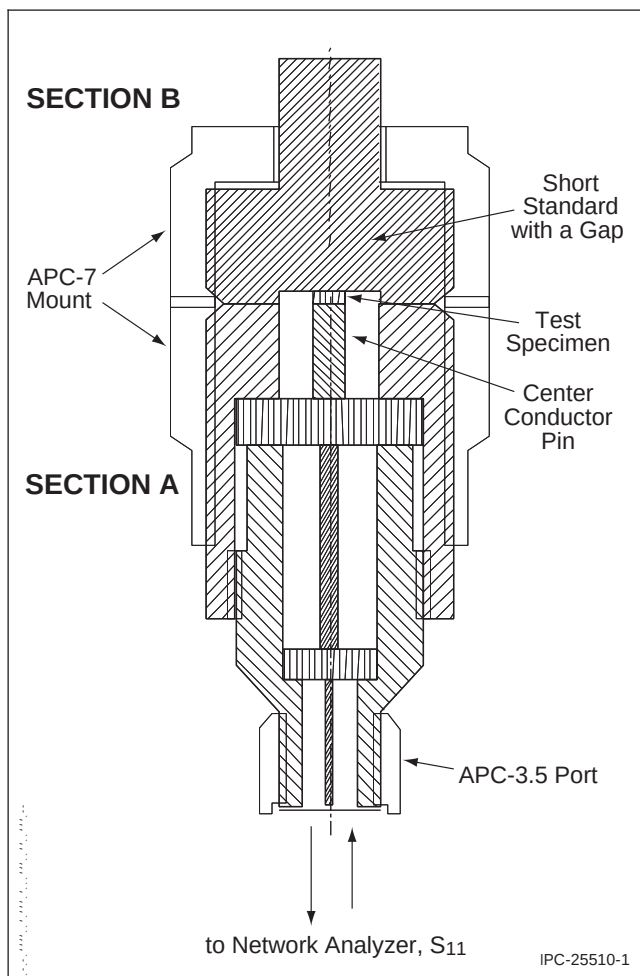


Figure 1 Test fixture with a test specimen between Sections A and B

7.2). The diameter of the dielectric should be equal to the diameter of the bottom electrode.

4.1.1 Preparation of the Test Specimen from Metal Clad Laminates The metal cladding should be removed from the dielectric, unless the thickness of the conductor is already within the recommended range of $0.1\ \mu\text{m}$ to $0.5\ \mu\text{m}$. The surfaces of the bare dielectric should be cleaned from conducting contaminants such as traces of ions to avoid possible corrosion of sputtered thin film metals, by rinsing in deionized water, drying, and then remetalizing by sputtering with copper or gold (see 4.1).

4.1.2 Thin Dielectric Films that are Not Free-Standing and Require Support The supporting conductor can be

used as the bottom electrode of the specimen. The topside conductor should be removed and then the top surface of the dielectric should be recoated to make the top electrode (see 4.1). The thickness of the bottom conductor can be compensated during measurements by adding an equivalent electrical delay (see 6.3.1).

5 Test Fixture The test fixture consists of two Sections A and B, where the specimen is placed in between, as shown in Figure 1. The detailed drawings are given in Section 11. Section A is an APC-7 to an APC-3.5 microwave adapter with characteristic impedance of $50\ \Omega$ (Agilent 1250-1746). Section B is an altered APC-7 short termination (Agilent 04191-85300 or equivalent may be used), with a custom-machined gap to accommodate a specimen of particular thickness. When Sections A and B are assembled, the depth, d , of the gap is equal to the specimen thickness. Specimens with different thickness will require separate Sections B. In the case of a specimen thinner than $10\ \mu\text{m}$, the center conductor of the APC-7 Section A may be replaced with a fixed $3.05\ \text{mm}$ diameter pin, machined precisely to achieve a flat and parallel contact between the film specimen and the terminating Section B. The diameter of the outer conductor, b , of Section A is $7.0\ \text{mm}$ (see drawing in Section 11).

6 Measurement Procedure

6.1 Apparatus The measurement requires an automatic vector network analyzer operating in the frequency range of $100\ \text{MHz}$ to $18\ \text{GHz}$, for example an Agilent 8720D or equivalent. The instrument should be equipped with a IEEE 488.2 I/O interface for transferring data between the network analyzer and a computing unit, e.g., a personal computer (PC) with a General Purpose Input/Output Board (GPIB).

Connection between the test fixture (APC 3.5 adapter of Section A) and the network analyzer shall be made using a phase preserving coaxial cable, for example an Agilent 85131-60013 or equivalent.

6.2 Calibration Procedure Set the measurements range to be between $100\ \text{MHz}$ and $12\ \text{GHz}$. The number of data points should be in the range of 800. The power level should be set to $0\ \text{dBm}$ with a dynamic range of at least $-40\ \text{dBm}$ (desirably to $-60\ \text{dBm}$). Select the one Port S_{11} measuring mode and Smith-Chart format. Connect the phase preserving cable to the Port-1 of the network analyzer and to Section A of the test fixture. Attach a calibration standard to Section A of the test fixture. Perform an APC-7 Open, Load, Short calibration using suitable calibration standards (Agilent 85050B

IPC-TM-650		
Number 2.5.5.10	Subject High Frequency Testing to Determine Permittivity and Loss Tangent of Embedded Passive Materials	Date 07/05
Revision		

7 mm calibration kit or equivalent) in accordance with the manufacturer specification for the network analyzer. After calibration verify the following:

- The Open Standard produces an 'open trace' on the Smith Chart.
- The Broad Band 50 Ω Standard Load produces a dot trace located in the middle of the Smith Chart at 50 Ω , with phase angle equal to zero degree.
- The Short Standard produces a dot trace at 0 Ω , with a phase angle of 180°.

6.3 Measurements Determine the specimen dielectric thickness, d . The thickness of the sputtered conductor may be neglected. However, if the specimen was made on a conducting support (see 4.1.2) thicker than 0.5 μm , the thickness of the bottom conductor should be compensated by adding an equivalent electrical delay (see 6.3.1.). Verify that the diameter of both electrodes satisfies the required values (see 4.1). Ensure that the diameter of the bottom electrode facing the center conductor of Section A is in the range of 3.0 mm to 3.05 mm. Place the test specimen at the center conductor of Section A. Attach Section B of the test fixture.

Measure the complex scattering coefficient, S_{11} . For a capacitive load (a dielectric specimen), the trace should represent a semicircle on the lower half portion of the Smith Chart (Figure 2), going from a high impedance region at lowest frequencies towards a low impedance region as the frequency increases. The radius of the semicircle represents the reflection coefficient, which for a loss-less dielectric approaches the value of one. In the case of an inductive specimen, the trace should represent a semicircle on the higher half portion of the Smith Chart, going from a low impedance region, $Z \approx 0$ at lowest frequencies, towards a high impedance region as the frequency increases.

Example measurements obtained for a specimen having the dielectric thickness of 80 μm , dielectric constant of 69 and the dielectric loss tangent of 0.0023 are shown in Figure 2. The trace crosses the zero impedance point at the series resonance frequency, f_{LC} , of 5.1 GHz, beyond which the load character changes from capacitive to inductive. A local loop on the chart indicates the first cavity resonance at f_{cav} of 14.65 GHz.

After the frequency scan is completed, transfer the entire digitized trace spectrum containing the S_{11} amplitude and S_{11} phase at each measured frequency to a PC via a GPIB link.

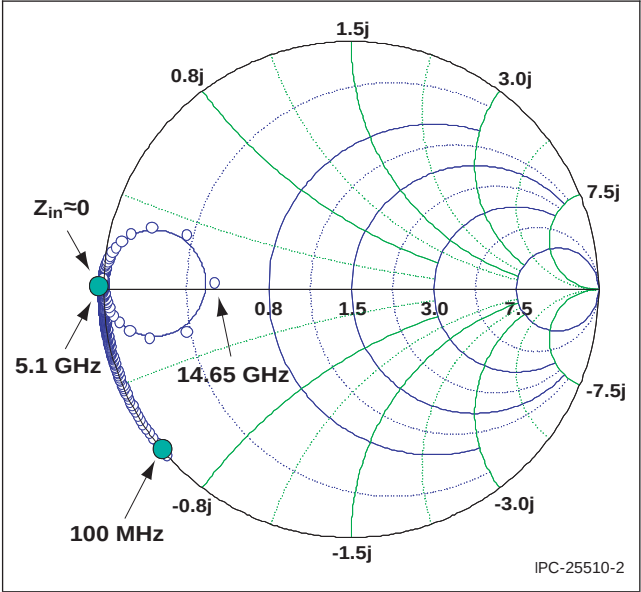


Figure 2 Example measurements plotted in a Smith chart Format for an 80 μm thick specimen with permittivity of 69 - j0.16.

6.3.1 Compensation for a Finite Thickness of the Specimen Bottom Conductor

Adding an electrical delay to the test structure can compensate thickness of the bottom electrode conductor. This procedure moves the reference plane established during calibration (see drawings of the test fixture in Section 11), to a new position located at the interface between the bottom conductor and the dielectric. The plane should be moved away from the generator a distance equal to the actual thickness of the bottom conductor. The electrical delay procedure should be conducted in accordance to the operating manual for the network analyzer before transferring the data to a PC.

7 Calculations

7.1 Impedance Determine the experimental complex impedance, Z_{in} , of the specimen at each frequency point, f , according to Equation (1) presented in 3.7. Example results obtained for a 25 μm thick dielectric with ($\epsilon' = 10$ and $\tan(\delta)$ of 0.01 are shown in Figure 3.

7.2 Specimen Permittivity At frequencies where the specimen may be treated as a lumped capacitance, where $|Z|$ is larger than 5 Ω (see Figure 3, References [2,3]), the input impedance is given by Equation (2a) and the real (ϵ') and imaginary (ϵ'') component of the dielectric permittivity can be