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IPC-TM-650 TEST METHODS MANUAL

1.0 Scope

1.1 Summary This method is for measurement of relative permittivity (ϵ_r) and dissipation factor or loss tangent ($\tan \delta$) of circuit board substrates under stripline conditions. Measurements are made by measuring resonances of a length of stripline over a wide frequency range from below 1 GHz to about 14 GHz^(1,2). The method permits a wide variety of specimen configurations, varying in dielectric thickness, width of center conductor, and use of clad or laid up conductor foil⁽³⁾. Sensitivity to differences in $\tan \delta$ are enhanced by the ability to adjust the degree of coupling to the resonator by adjusting an air gap between probes and the resonator ends. Many of the principles used in IPC-TM-650, Method 2.5.5.5, are applied in this method.

1.2 Terminology Terms used in this method include:

Complex Relative Permittivity—The values for relative permittivity and dissipation factor considered as a complex number.

Permittivity—Dielectric constant (see IPC-T-50) or relative permittivity. The symbol used in this document is ϵ_r . K' or κ' are also sometimes used.

Relative Permittivity—A dimensionless ratio of absolute permittivity of a dielectric to the absolute permittivity of a vacuum.

Loss Tangent—Dissipation factor (see IPC-T-50), dielectric loss tangent (see 9.2). The symbol used in this document is $\tan \delta$.

1.3 Limitations The limitations in described in 1.3.1 through 1.3.4 should be noted.

1.3.1 The measured effective permittivity for the resonator element can differ from that observed in an application.

Where the application is in stripline and the line width to ground plane spacing is less than that of the resonator element in the test, the application will exhibit a greater component of the electric field in the X, Y plane. Heterogeneous dielectric composites are anisotropic to some degree, resulting in a higher observed ϵ_r for narrower lines.

Microstrip lines in an application may also differ from the test in the fraction of substrate electric field component in the X, Y plane.

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Bonded stripline assemblies have air excluded between boards and thus tend to show greater ϵ_r values than would be obtained with this method using specimen types A or, to lesser extent, B, as discussed in 3.0.

1.3.2 As with IPC-TM-650, Method 2.5.5.5, with specimen type A, or, to a lesser extent, with B (see 3.0), we expect the method to show a downward bias in measured ϵ_r . This is caused by the electric field crossing clamped dielectric-conductor interfaces with air included in the surface roughness.

1.3.3 With specimen type B, C, or D, the method shows an upward bias in measured $\tan \delta$. This is caused by the surface roughness and/or surface treatment of the clad copper foil required for adequate adhesion to the dielectric.

1.3.4 Compared to IPC-TM-650, Method 2.5.5.5, both done with computer automated data collection, this method requires a greater degree of operator skill and more time to prepare specimens and perform measurements.

1.4 Advantages

1.4.1 The sensitivity of the method to differences in ϵ_r of specimens should be superior to that of IPC-TM-650, Method 2.5.5.5 since the specimen comprises all of the dielectric affecting the measurement.

1.4.2 The method is known to be more sensitive to differences in $\tan \delta$ than IPC-TM-650, Method 2.5.5.5. We believe the ability to adjust the degree of probe-to-resonator coupling to a low enough value that Q_{loaded} is close to Q_{unloaded} (see 7.2.2) makes this possible.

1.4.3 The method is expected to lend itself to use of stable referee specimens of known electric properties traceable to NIST (National Institute of Standards and Technology).

2.0 Applicable Documents

IPC-MF-150 Metal Foil for Printed Wiring Applications

IPC-TM-650 Method 2.5.5.5, Stripline Test for Permittivity and Loss Tangent (Dielectric Constant and Dissipation Factor) at X-Band

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3.0 Test Specimen Specimen length corresponds to an available fixture length L. Longer L values enable lower minimum resonant frequencies to be achieved. L is also the length dimension of the copper plates described in 5.0. Four types of specimens can be used for this method, as shown in Figure 1.

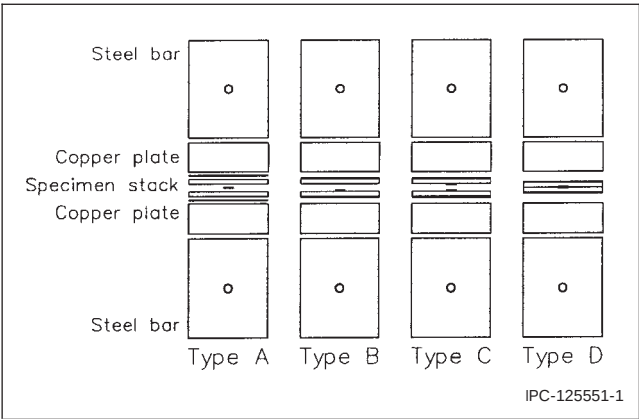


Figure 1 Exploded End Views of Stacked Specimen Types A, B, C and D (See 3.0) with Copper Foil Thickness Exaggerated and Including the Copper Plates (See 5.1.2) and Steel Bars (See 5.1.1) of the Fixture

3.1 Type A Two 25.4 mm wide by L long cards etched free of copper cladding. These are placed on either side of a center strip of smooth copper foil of specified thickness and width and will be assembled between 25.4 mm wide by L long copper foil cards.

3.2 Type B One 25.4 mm wide by L long card with clad copper on one side and copper etched off the other side, and a second card of matching size with clad copper on one side and copper etched off the other side except for a centered strip of specified width extending to both ends of the card. The copper free surface of the first card is assembled against the etched strip of the other to form the stripline resonator.

3.3 Type C Two 25.4 mm wide by L long cards with clad copper on one side and copper etched off the other side except for a centered strip of specified width extending to both ends of the card. The etched strip surfaces of both cards face together to form the stripline resonator.

3.4 Type D Oversize cards similar to type B are bonded together with a selected bonding film and then trimmed to size to form the stripline resonator assembly. This could be a test coupon cut from a bonded stripline circuit board assembly.

For types B, C, and D, the specimen card should first be prepared with about 5 mm or more excess length. Wide pressure sensitive adhesive (PSA) tape can be used to mask the ground plane side, and a narrow PSA tape can be used to mask for the centered strip before etching off exposed copper. Trimming the excess length after etching removes any undercut areas at the ends. Trimming to length should be done in a way that leaves the end surfaces with sharp edges and no conductor edge distortion or smears over that surface. Sanding specimens clamped between paper-phenolic laminate drill-entry boards is an advised method for finishing the end surfaces.

Type A specimens with untreated smooth copper foil will provide the most accurate values for $\tan \delta$, but will tend to have a low bias on ϵ_r . Type C eliminates all clamped interfaces with the air layer between the dielectric and the conductor to give the most accurate ϵ_r value but, with the copper surfaces treated for adhesion, tends to have a high bias on dissipation factor. Type D gives a good measure of practical performance in an application.

4.0 Suggested Electronic Apparatus The principal components required for the test setup consist of the test fixture described in 5.0 combined with the components described in 4.1, Figure 2, Type A and Type B, or preferably with the system in 4.2, Figure 2, Type C.

4.1 A Test Setup for Computer Automation of Data This requires a microwave signal source, an accurate means of measuring the signal frequency, an accurate means for detecting power level, and an accurate method of determining frequency values above and below the resonant frequency at the half-power level for the test fixture loaded with the specimen.

4.1.1 The following components or equivalent, properly interconnected, can be used most effectively with a computer control program for automated testing.

- Sweep Frequency Generator Mainframe HP8350B
- RF Plug-In, 0.01 to 20 GHz HP83592A
- Power Splitter HP11667A
- Automatic Frequency Counter HP5343A
- Source Synchronizer HP5344A
Obtained as an interconnected assembly with the counter.
- Coaxial cables and adapters

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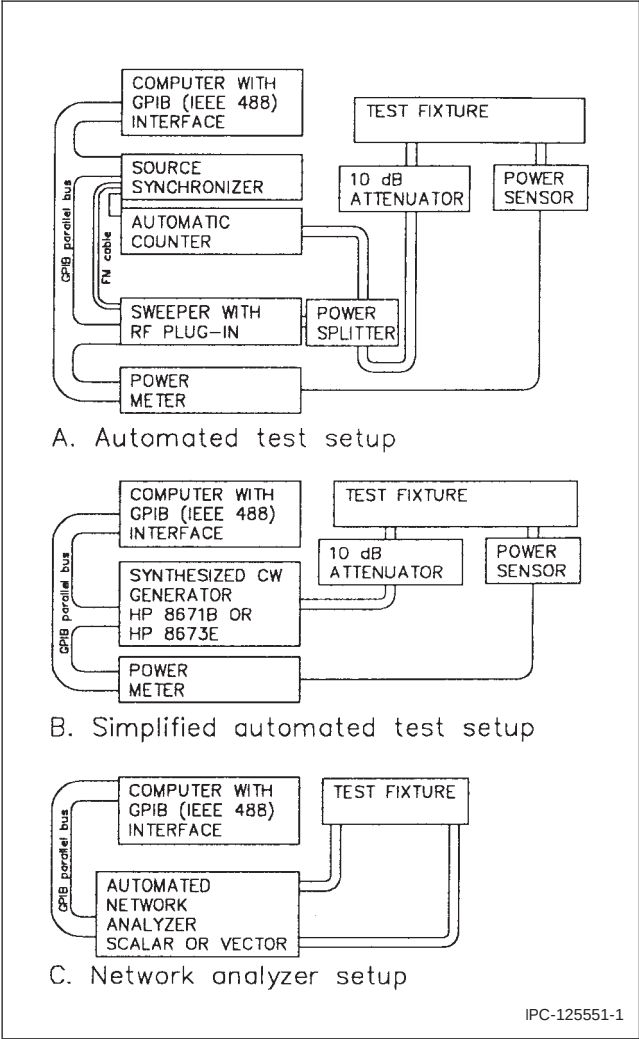


Figure 2 Schematic Drawings of Instrumentation Setups Suitable for Measurements of Permittivity

- 10 dB Attenuator HP8491B
- Programmable Power Meter HP436A
- Power Sensor HP8484A with 70 to 10 dBm range
- IEEE 488 (GPIB) cables
- Controlling computer with GPIB interface

The above equipment is connected as explained in 4.1.1.1 through 4.1.1.3, and as illustrated in Figure 2, Type A.

4.1.1.1 RF Connections The power splitter connects directly to the RF plug-in output. One output of the splitter

connects by RF cable to the counter input. The other output is connected by RF cable to the attenuator which connects to one of the test fixture probe lines.

4.1.1.2 Control Connections Connections between counter and synchronizer are provided as specified by the manufacturer. The FM output from the synchronizer connects by BNC to the FM input on the sweeper. GPIB cables connect in parallel to the sweeper, synchronizer, power meter, and computer interface.

4.1.1.3 Other Connections The power sensor is connected to the other probe of the fixture, and its special cable connects into the power meter.

4.1.2 The microwave signal source must be capable of providing an accurate signal. During the required time period and range of frequency needed to make a permittivity and loss tangent measurement, the source must provide a leveled power output that falls within a 0.1 dB range. When the source is set for a particular frequency, the output must be capable of remaining within 5 MHz of the set value for the time required to make a measurement.

The means for measuring frequency shall have a resolution of 0.05% or less and an accuracy of 0.08% or less. An error of +8 MHz in measurement of a resonant frequency near 10 GHz for a material with nominal permittivity of 2.50 represents a -0.004 error in permittivity.

The means for detecting the power level shall have a resolution of 0.1 dB or less and be capable of comparing power levels within a 3 dB range with an accuracy of 0.1 dB. An error of 0.1 dB in estimating half power frequency points can result in an error in the loss tangent of about 0.0001 for a material with 2.5 permittivity. See equation 5 in 7.2.

4.1.3 A synthesized CW generator can be used to replace the sweeper, plug-in, power splitter, connector, and source synchronizer for the simpler set-up shown in Figure 2, Type B.

4.2 Automated Network Analyzer for the Test Setup

The instrumentation described in 4.1 may be replaced with either a scalar or vector network analyzer, with test cables connected to the test fixture of 5.0 as the device under test (DUT), as shown in Figure 2, Type A. Examples of automated network analyzers known to be suitable include the Hewlett-Packard 8510 vector network analyzer or the Wiltron Model 561 scalar network analyzer. These or equivalent may be used.

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Such instruments may be operated either manually or under computer control with suitable programming to locate the resonant frequency and the frequencies above and below resonance where transmitted power is 3 dB below that at resonance. Network analyzers have several advantages over the instrumentation described in 4.1. Data collection is rapid and may be continuously refreshed with averaging. The log magnitude response curve for ratio of transmitted to incident power (the S21 parameter) as dB versus frequency is visible on a screen for easy verification of a valid resonance. A large number of dB, frequency data points near the resonance, are readily available for optional use of non-linear regression analysis techniques to determine the frequency and Q values with statistically better degrees of uncertainty than those attainable by the three point (f_r , $f_{1\%}$, and $f_{2\%}$) method in either section 6.2 or 6.3.

5.0 Test Fixture

5.1 Fixture Parts for Clamping L is the selected length for the specimen. A fixture may include hardware for more than one value of L. Suggested L values are 50.8, 76.2, 152.4, and 304.8 mm. Since the fundamental resonant frequency and its harmonics are inversely proportional to the value of L for a given ϵ_r , the selection of an L value determines the low frequency at which the material may be measured for ϵ_r and $\tan \delta$. Figure 1 shows the end views of a series of specimen configurations and includes the parts for clamping.

5.1.1 For each L value, two ground tool steel clamping bars 25.4 mm x 28.58 mm x (L-6.35), as shown in Figure 3. These are intended to provide uniformly distributed force along the length of the specimen, transferred through part 5.1.2. A recommended practice is to provide these with a small diameter threaded rod, such as #4-40, centered on each end and extending about 20 mm to serve as a means for attaching the probe assembly of 5.2 used in 6.1.5 or the alignment jig of 5.1.3 used in 6.1.1.

5.1.2 For each L value, two pure copper ground plates 25.4 mm x 9.52 mm x L with all edges sharp as in Figure 4. These provide at the ends a copper surface perpendicular to the specimen length direction, which serves as a contact area over a range of specimen thicknesses for making ground continuity to the coaxial probe. When these are clamped with 5.1.1 as described in 6.1.1, the inside corners at each end between the outer face of 5.1.2 and the end surface of 5.1.1 form reference locations equidistant from the center line of the stripline resonator element that are used by the probe assembly 5.2 to align the coaxial probe with that center line.

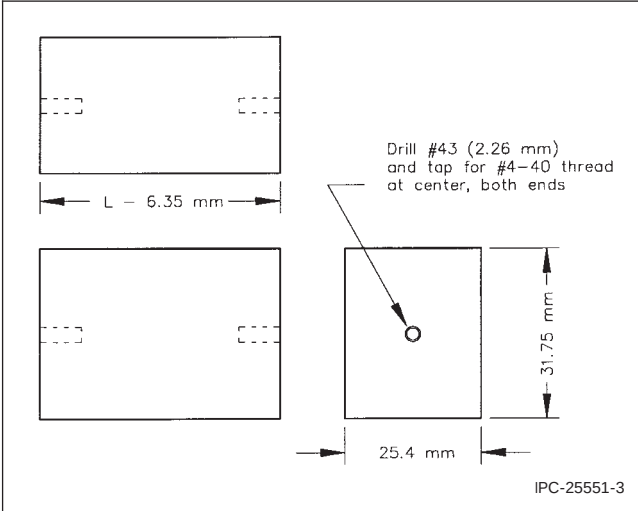


Figure 3 Three View Drawing of a Steel Clamping Bar (See 5.1.1) Cut to Length for the 50.8 mm L Value (Extended #4-40 Threaded Rod Both Ends is Not Shown)

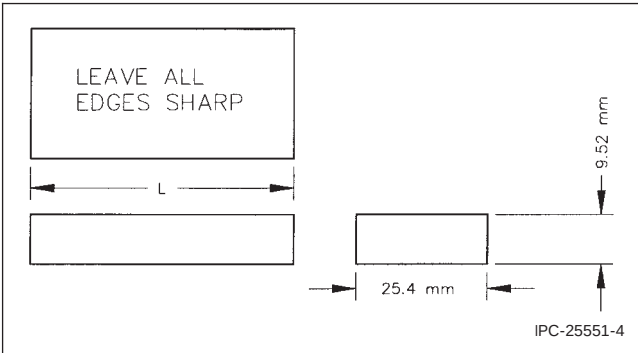


Figure 4 Three View Drawing of a Copper Ground Plate (See 5.1.2) for the 50.8 mm L Value

5.1.3 A stacking alignment jig as used in 6.1.1 of an appropriate design. Figure 5 shows a suggested design.

5.1.4 A low profile mechanical force gage with 4.45 kN compression capacity such as a Dillon Model U, PN 30482-0053, available from Dillon Quality Plus, Inc., 1140-T Avenida Acaso, Camarillo, CA 993012. One is needed for each of part 5.1.5.

5.1.5 A clamping arrangement with 5.1.4 properly mounted in the line of force and with alignment parts for assuring the line of force is properly located through the stack assembled