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Designation: D 3380 – 90 (Reapproved 1995)$^{\epsilon 1}$

Standard Test Method for Relative Permittivity (Dielectric Constant) and Dissipation Factor of Polymer-Based Microwave Circuit Substrates[1]

This standard is issued under the fixed designation D 3380; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—Keywords were added in March 1995.

1. Scope

1.1 This test method permits the rapid measurement of apparent relative permittivity and loss tangent (dissipation factor) of metal-clad polymer-based circuit substrates in the X-band (8 to 12.4 GHz).

1.2 This test method is suitable for testing PTFE (polytetrafluorethylene) impregnated glass cloth or random-oriented fiber mats, glass fiber-reinforced polystyrene, polyphenyleneoxide, irradiated polyethylene, and similar materials having a nominal specimen thickness of 1.6 mm. The materials are applicable to service at nominal frequency of 9.6 GHz.

NOTE 1—See Appendix X1 for additional information about range of permittivity, thickness other than 1.6 mm, and tests at frequencies other than 9.6 GHz.

1.3 The values stated in inch-pound units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 150 Test Methods for A-C Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation[2]

D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[3]

D 1711 Terminology Relating to Electrical Insulation[2]

D 2520 Test Methods for Complex Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials at Microwave Frequencies and Temperatures to 1650°C[4]

2.2 *IPC Standards:*[5]

IPC-TM-650 Test Methods Manual Method 2.5.5.5.

IPC-CF-150E Copper Foil for Printed Wiring Applications.

2.3 *IEEE Standards:*[6]

Standard No. 488.1 Standard Digital Interface for Programmable Instrumentation.

Standard No. 488.2 Standards, Codes, Formats, Protocols and Common Commands for use with ANSI and IEEE Standard 488.1.

3. Terminology

3.1 *Definitions*—See Terminology D 1711 for the definitions of terms used in this test method. See also Test Methods D 2520, D 150, and IPC TM-650 for additional information regarding the terminology.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *D*—a symbol used in this test method for the dissipation factor.

3.2.2 ΔL—a correction factor associated with length which corrects for the fringing capacitance at the ends of the resonator element.

3.2.3 κ'—symbol used in this test method to denote relative permittivity.

NOTE 2—The preferred symbol for permittivity is Greek kappa prime but some persons use other symbols to denote this property such as *DK*, *SIC*, or ϵ'_R.

3.2.4 *microstrip line*—a microwave transmission line employing a flat strip conductor bonded to one surface of a dielectric board or sheet, the other surface of which is clad with, or bonded to, a continuous conductive foil or plate which is substantially wider than the strip. Microstrip provides easier accessibility than stripline for attaching components and devices to the strip circuitry.

3.2.5 *microwave substrate*—a board or sheet of low-loss dielectric material which may be clad with metal foil on one, or both, surfaces. In this test method all metal is removed by etching prior to testing.

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[1] This test method is under the jurisdiction of ASTM Committee D-9 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.12 on Electrical Tests.

Current edition approved Feb. 23, 1990. Published April 1990. Originally published as D 3380 – 75. Last previous edition D 3380 – 89.

[2] *Annual Book of ASTM Standards*, Vol 10.01.

[3] *Annual Book of ASTM Standards*, Vols 08.01 and 10.01.

[4] *Annual Book of ASTM Standards*, Vol 10.02.

[5] Available from The Institute for Interconnecting and Packaging Electronics Circuits, 7380 N. Lincoln Ave., Lincolnwood, IL 60646.

[6] Available from the Institute of Electrical and Electronics Engineers, Inc., 345 E. 47th St., New York, NY 10017.

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3.2.6 *stripline*—microwave transmission line using a flat strip conductor clamped, or bonded, between two substantially wider dielectric boards. The outer surfaces of both boards are bonded to, or in intimate contact with, conducting foils or plates (ground planes). Stripline may be conceived as a flattened version of cylindrical coaxial cable.

3.2.7 *stripline resonator*—a disconnected section of stripline loosely coupled at each end by capacitative gaps to feed or probe lines. The strip becomes resonant at those frequencies at which the strip length, increased by an increment due to the fringing fields at the ends, is equal to an integral multiple of half-wavelengths in the dielectric. As frequency varies gradually, the power transmitted from the input to the output feed lines becomes maximum at resonance, and falls off sharply to essentially zero at frequencies which are a few parts per thousand above and below resonance.

4. Summary of Test Method

4.1 Substrate specimens, with metal cladding removed, become the supporting dielectric spacers of a microwave stripline resonator when properly positioned and clamped in the test fixture. The measured values of resonant frequency of the stripline resonator and the half-power frequencies are used to compute the relative permittivity (dielectric constant or κ′) and the dissipation factor (*D*) of the test specimen. The test specimen consists of one or more pairs of test cards.

5. Significance and Use

5.1 Permittivity and dissipation factor are fundamental design parameters for design of microwave circuitry. Permittivity plays a principal role in determining the wavelength and the impedance of transmission lines. Dissipation factor (along with copper losses) influence attenuation and power losses.

5.2 This test method is suitable for polymeric materials having permittivity in the order of two to eleven. Such materials are popular in applications of stripline and microstrip configurations used in the 1 to 18 GHz range.

5.3 This test method is suitable for design, development, acceptance specifications, and manufacturing quality control.

NOTE 3—See Appendix X1 for additional information regarding significance of this test method and the application of the results.

6. Apparatus

6.1 The preferred assembly fixture shown in Fig. 1, Fig. 2, and Fig. 3 is hereby designated Fixture A. This design of test specimen fixture provides advantages over the design of Fixture B shown in Fig. 4, Fig. 5, Fig. 6, and Fig. 7.

6.1.1 The Fixture B design has been included since this fixture has been, and still is, in service in numerous laboratories.

6.1.2 The Fixture B design relies upon close control of the room temperature in the laboratory for control of the test specimen temperature.

6.1.3 Changing of test pattern cards in the Fixture B design is less convenient than with the Fixture A design.

6.1.4 For Fixture A the preferred assembly for Resonator Card and Specimen uses a Lap Conductor Joint. See Fig. 3 for details.

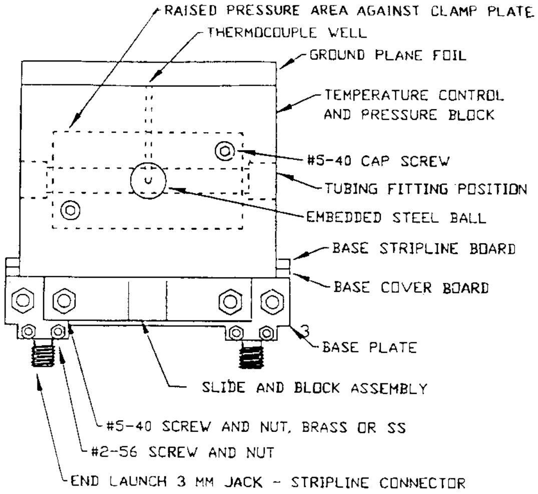

FIG. 1 Face View of Fixture Assembly

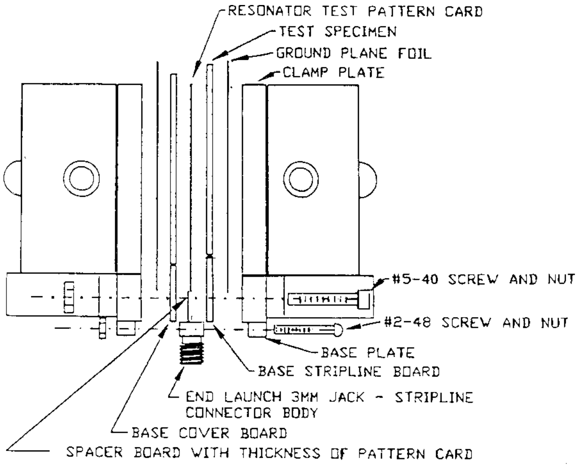

FIG. 2 Exploded Side View of Assembly

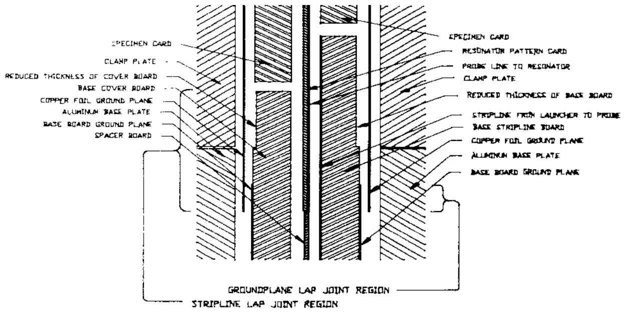

FIG. 3 Enlarged Exploded Side View Sectioned Through a Probe Line Showing a Lap Conductor Joint for Fixture A

6.2 *Fixture A*—The elements of the fixture include the following:

6.2.1 *Resonator Pattern Card* (see Fig. 8),

6.2.2 *Base Stripline Board* (see Fig. 9),

6.2.3 *Base Cover Board* (see Fig. 10),

6.2.4 *End-Launcher Bodies*, adapted (see Fig. 11),

6.2.5 *Aluminum Base Plates* (see Fig. 12),

6.2.6 *Aluminum Clamping Plates* (see Fig. 13),

6.2.7 *Aluminum Blocks*, for temperature control (see Fig. 14).

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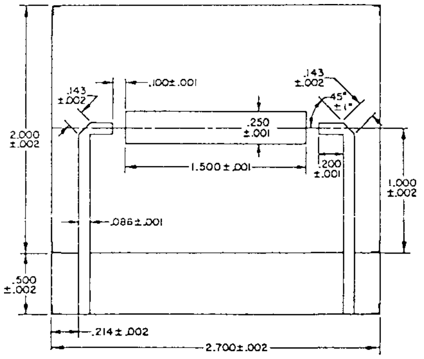

In.	mm
0.001	0.03
0.002	0.05
0.086	2.18
0.100	2.54
0.143	3.63
0.200	5.08
0.214	5.44
0.250	6.35
0.500	12.70
1.000	25.40
1.500	38.10
2.000	50.80
2.700	68.58

NOTE 1—Dimensions are in inches.

NOTE 2—Metric equivalents are given for general information only.

FIG. 4 Generalized Resonator Pattern Card for Fixture B Showing Dimensions of Table 1 and Made of Laminate Matching the Nominal Permittivity of Material to be Tested

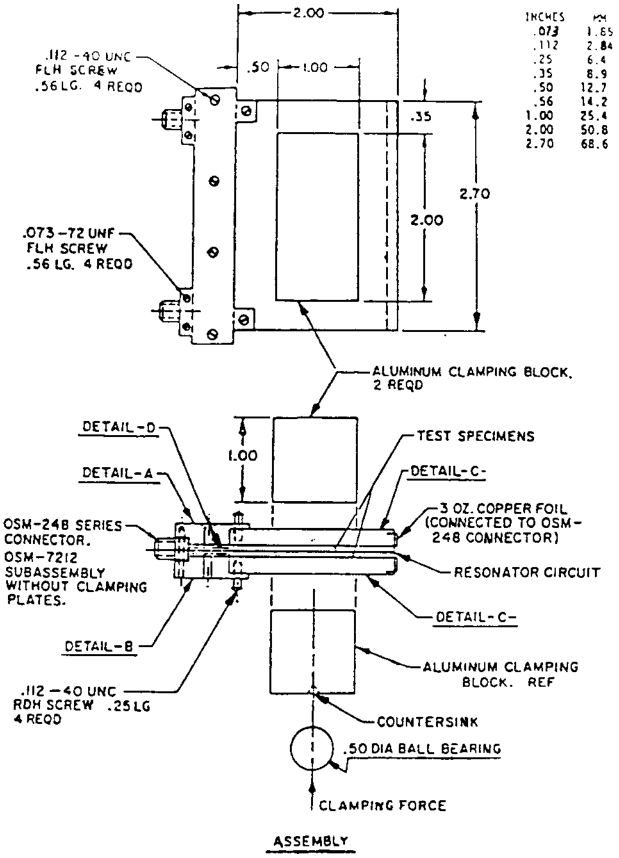

FIG. 5 Test Fixture Construction, Older Design (Fixture B)

6.2.8 *Sliders and Blocks* (see Fig. 15), and

6.3 *Microwave Signal Source*, capable of providing an accurate signal. An accurate signal provides a leveled power output that falls within a 0.1 dB range during the required time period and over the range of frequency needed to make a permittivity and loss measurement, and maintains output within 5 MHz of the set value for the time required to make a measurement when the signal source is set for a particular frequency.

6.4 *Frequency Measuring Device*, having a resolution 5 MHz or less.

6.5 *Power Level Detecting Device*, having a resolution of 0.1 dB or less and capable of comparing power levels within a 3-dB range with an accuracy of 0.1 dB.

6.6 *Compression Force Gage*,[7] capable of measuring to 5000 N (1100 lb) with an accuracy of ±1 % of full scale.

6.7 *Vise*, or a press, for exerting a controlled force of 4448 N (1000 lb) on the test fixture and having an opening of at least 5 in. (130 mm) to accept the force gage and test fixture.

6.8 *Apparatus for Manual Test Setup*:

6.8.1 *Sweep Frequency Generator.*[8]

6.8.2 *X-Band Frequency Plug-In Unit.*[9]

6.8.3 *Frequency Meter.*[10]

6.8.4 *Crystal Detector*,[11] two required.

6.8.5 *Matched Load Resistor*,[12] for one of the crystal detectors.

6.8.6 *Standing Wave Rectified (SWR) Meter*,[13] two required.

6.8.7 *Directional Coupler.*[14]

6.8.8 *Attenuator*,[15] rated at 10 dB.

6.8.9 *Semi-Rigid Coaxial Cable and Connectors.*

6.8.10 *Adapter*,[16] for waveguide to coaxial interconnection.

6.8.11 The assembly of this equipment is shown schematically in Fig. 16.

6.9 *Apparatus for Computer Acquisition of Data*—The following alternative equipment or its equivalent, when properly interconnected, may be used effectively with a computer-control program for automated testing:

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[7] A Dillon force gage, Compression Model X, part #381612301, has been found satisfactory for this purpose.

[8] The Hewlett Packard (HP) 8350B or 8620C generator has been found satisfactory for this purpose.

[9] The Hewlett Packard (HP) 83545A or 86251A plug-in unit has been found satisfactory for this purpose.

[10] The Hewlett Packard (HP) X532B meter has been found to be satisfactory for this purpose.

[11] The Hewlett Packard 423B Neg. detector has been found to be satisfactory for this purpose.

[12] The Hewlett Packard 11523A option .001 resistor has been found to be satisfactory for this purpose.

[13] The Hewlett Packard 415E meter has been found to be satisfactory for this purpose.

[14] The Hewlett Packard 779D coupler has been found to be satisfactory for this purpose.

[15] The Hewlett Packard attenuator 8491B has been found to be satisfactory for this purpose.

[16] The Hewlett Packard adapter X281A has been found to be satisfactory for this purpose.

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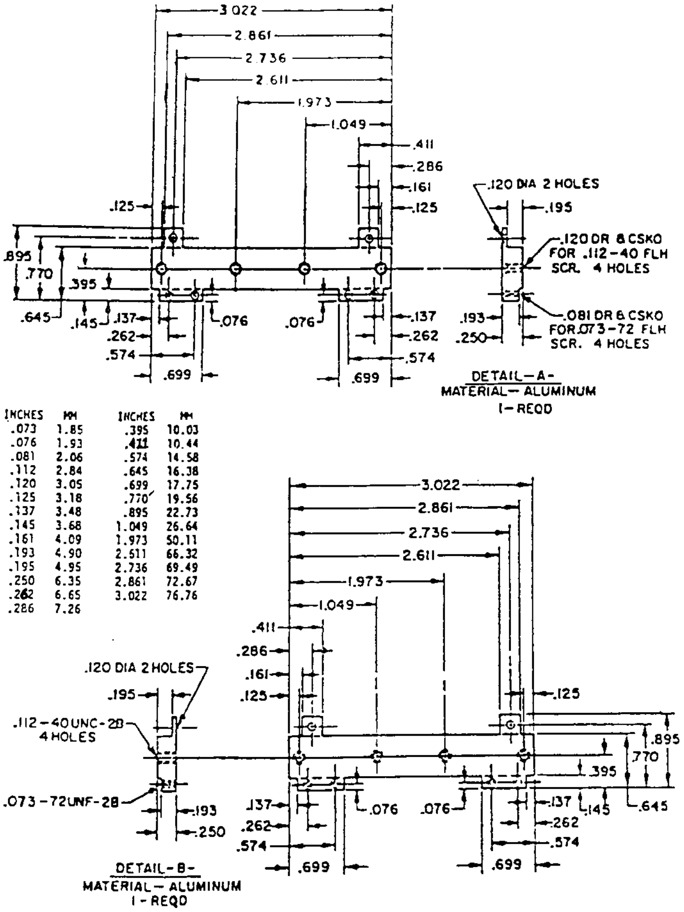


INCHES	MM	INCHES	MM
.073	1.85	.395	10.03
.076	1.93	.411	10.44
.081	2.06	.574	14.58
.112	2.84	.645	16.38
.120	3.05	.699	17.75
.125	3.18	.770	19.56
.137	3.48	.895	22.73
.145	3.68	1.049	26.64
.161	4.09	1.973	50.11
.193	4.90	2.611	66.32
.195	4.95	2.736	69.49
.250	6.35	2.861	72.67
.262	6.65	3.022	76.76
.286	7.26		

FIG. 6 Test Fixture Construction, Older Design (Fixture B)

6.9.1 *Sweep Frequency Generator,*[17] see also 6.8.1.

6.9.2 *Radio Frequency (RF) Plug-In Unit,*[18] having a range from 0.01 to 20 GHz.

NOTE 4—A plug-in of a narrower frequency range (in the X-band from 5.9 to 12.4 GHz) may be selected at significant cost savings.[19]

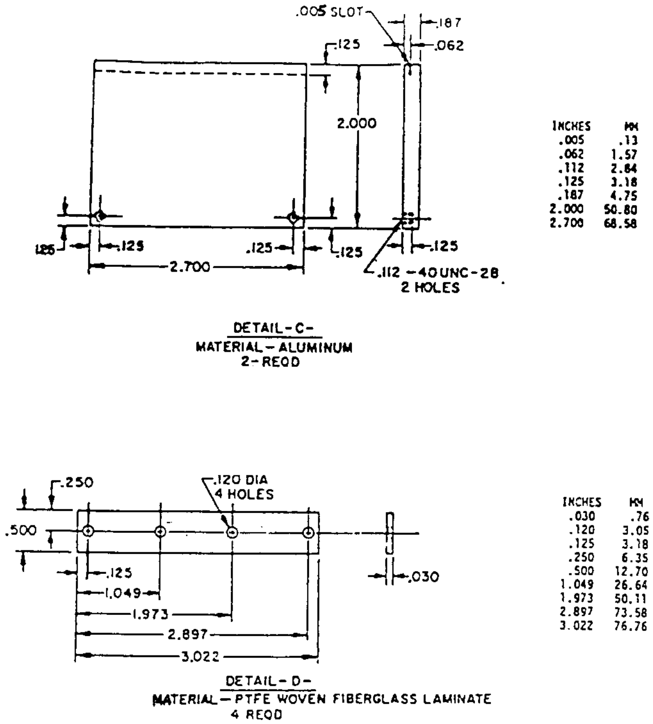
6.9.3 *Power Splitter.*[20]

6.9.4 *Automatic Frequency Counter.*[21]

6.9.5 *Source Synchronizer.*[22]

6.9.6 *Attenuator,*[23] 10 dB, see also 6.8.8.

6.9.7 *Programmable Power Meter.*[24]



INCHES	MM
.005	.13
.062	1.57
.112	2.84
.125	3.18
.187	4.75
2.000	50.80
2.700	68.58

INCHES	MM
.030	.76
.120	3.05
.125	3.18
.250	6.35
.500	12.70
1.049	26.64
1.973	50.11
2.897	73.58
3.022	76.76

FIG. 7 Test Fixture Construction, Older Design (Fixture B)

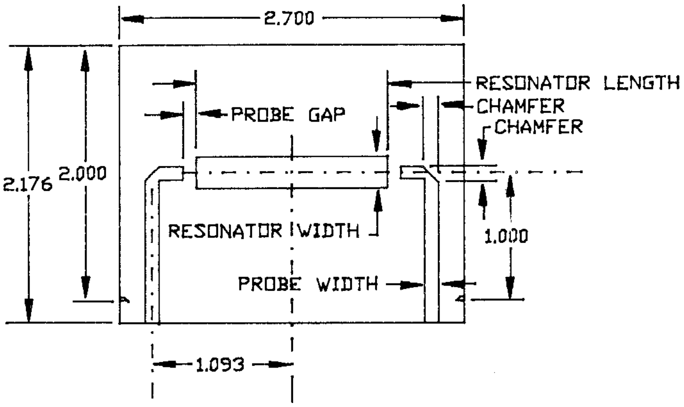


FIG. 8 Generalized Resonator Pattern Card for Fixture A Showing Dimensions of and Made of Laminate Matching the Nominal Permittivity of Materials to be Tested

6.9.8 *Power Sensor,*[25] having a range from −70 to +10 dBm.

6.9.9 *Controlling Computer*, with a General Purpose Interface Bus (GPIB) interface.

6.9.10 *IEEE 488 (GPIB) Cables, Adapters, and Coaxial Cables*, suitable for proper interconnecting of all of the components as illustrated in Fig. 17 and described in 6.9.11.

6.9.11 *Interconnecting Instructions* (applicable to 6.9 only):

6.9.11.1 Connect the power splitter directly to the RF plug-in output. Connect one output of the splitter to the counter input using an RF cable. With another RF cable, connect the other output to the attenuator. Connect the attenuator to one of the test fixture probe lines.

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[17] The Hewlett Packard generator 8350B has been found to be satisfactory for this purpose.

[18] The Hewlett Packard plug-in #83592A has been found to be satisfactory for this purpose.

[19] The Hewlett Packard plug-in #83545A has been found to be satisfactory for this purpose.

[20] The Hewlett Packard power splitter #11667A has been found to be satisfactory for this purpose.

[21] The Hewlett Packard frequency counter #5343A has been found to be satisfactory for this purpose.

[22] The Hewlett Packard synchronizer #5344A has been found to be satisfactory for this purpose.

[23] The Hewlett Packard attenuator #8491B has been found to be satisfactory for this purpose.

[24] The Hewlett Packard power meter #436A has been found to be satisfactory for this purpose.

[25] The Hewlett Packard power sensor #8484A has been found to be satisfactory for this purpose.

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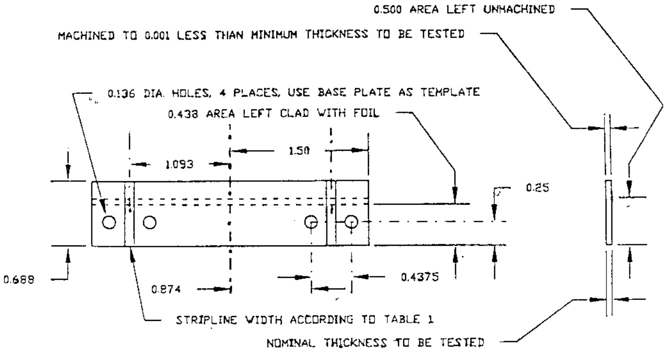


FIG. 9 Base Stripline Board with Copper Foil and Dielectric Matching the Nominal Permittivity of the Material to be Tested

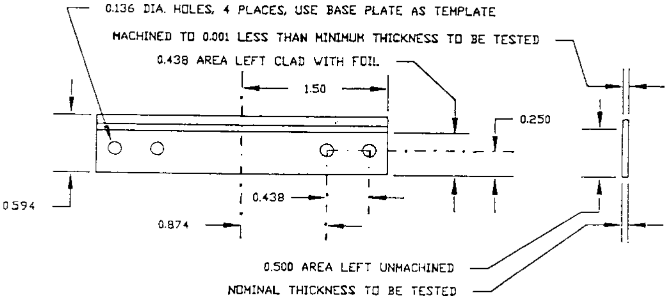


FIG. 10 Base Cover Board with Copper Foil Ground Plane

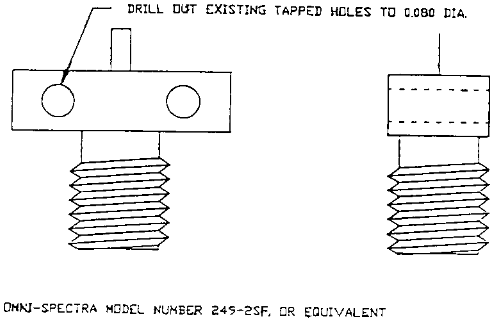


FIG. 11 Detail of the Supplied End Launcher Body Adapted by Boring Out the Tapped Holes

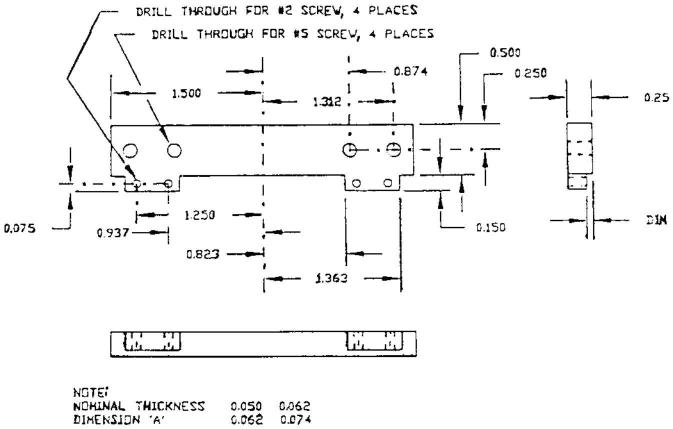


FIG. 12 Aluminum Base Plate for Clamping the Base Cards and Connecting Launcher Bodies to the Base Card

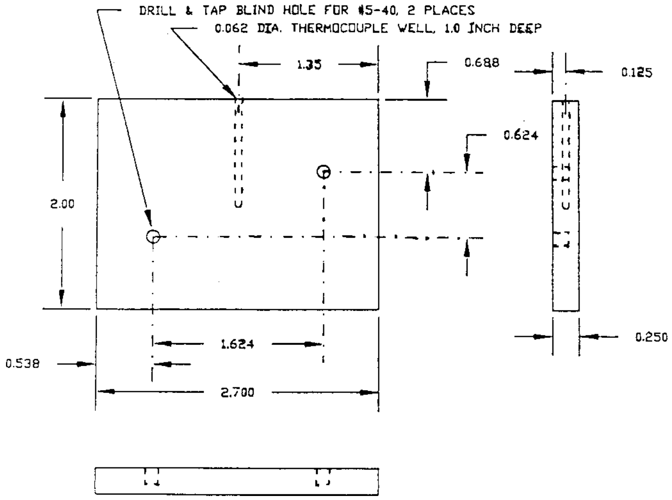


FIG. 13 Aluminum Clamping Plate Provided with Tapped Holes for the Pressure Block and a Thermocouple Well

6.9.11.2 Connect the counter and the synchronizer as specified by the manufacturer of this equipment. Connect the FM output from the synchronizer to the FM input on the sweep frequency generator using a BNC connector.

6.9.11.3 Use GPIB cables to parallel connect sweeper, synchronizer, power meter, and computer interface.

6.9.11.4 Connect the power sensor to the other probe of the test fixture and connect its special cable to the power meter.

6.9.11.5 A synthesized continuous wave (CW) generator may be used to replace the sweeper, plug-in, power splitter connector, and the source synchronizer to provide the simplified automated set-up shown in Fig. 18.

6.10 *Signal Source*—The type of signal source used in a manual test setup will dictate the method by which the half-power points are determined. If the power input to the test fixture is maintained constant as the frequency is varied, then an SWR meter may be used to determine the half-power points at the output of the test fixture. This may be accomplished by using a sweep generator or by using a tunable klystron (at a significantly lower cost) and manually adjusting the power input to the test fixture to a prescribed level using a variable attenuator.

6.11 *Alternative Equipment*—Alternative types or models of equipment may be used if it can be demonstrated that equivalent results are obtained. For example, if a power levelling system is not used, and the power output of the source varies widely with frequency, a ratiometer may be substituted for the two SWR meters. If only a measurement of permittivity is desired, it may not be necessary to level the input.

6.11.1 *Frequency Measurement Apparatus Alternatives*:

6.11.1.1 Digital frequency meter with automatic phase-locking (requires unmodulated signal).

6.11.1.2 Digital frequency meter, manually tuned heterodyne type.

6.11.1.3 Manually tuned resonant wavemeter (less accurate than digital types). Use of this requires a resonance indicator.

6.11.2 *Resonance Indicator Alternatives*:

6.11.2.1 Power meter with thermistor transducer.

6.11.2.2 SWR meter with crystal transducer, (requires modulated signal).

6.11.2.3 Dual-trace oscilloscope when a sweep generator is used.

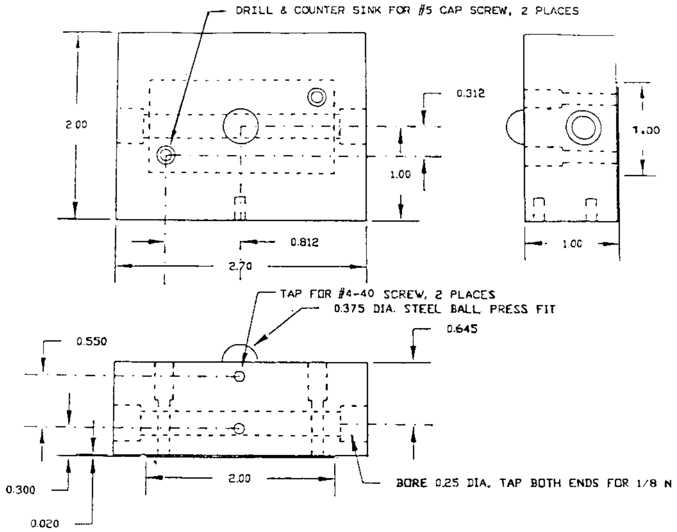


FIG. 14 Aluminum Block for Temperature Control and Transfer of Pressure to the Clamp Plates, Fitted with Tapped Holes for Slide, Embedded Steel Ball, and Tapped for Tubing Fittings for Circulating Fluid

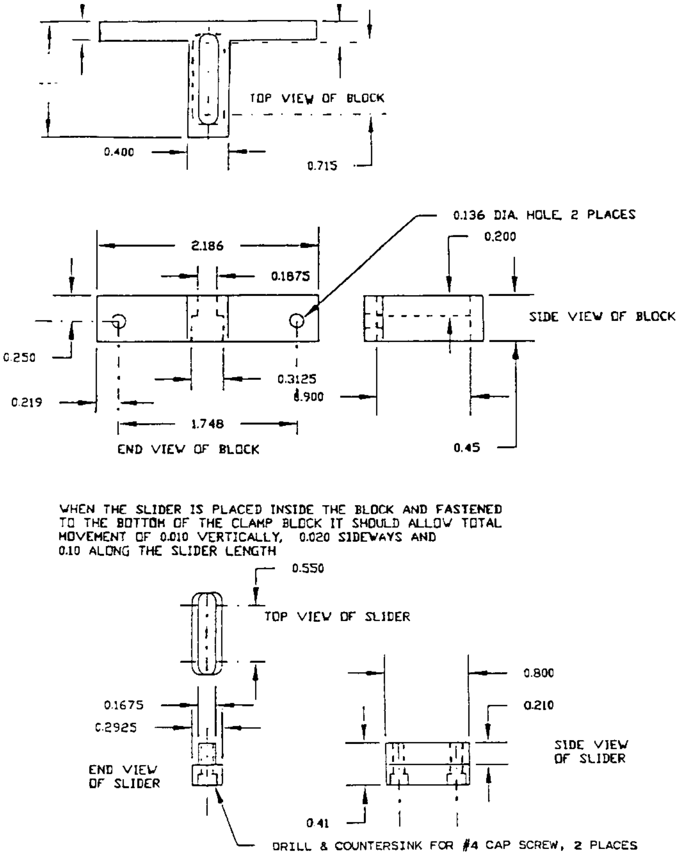


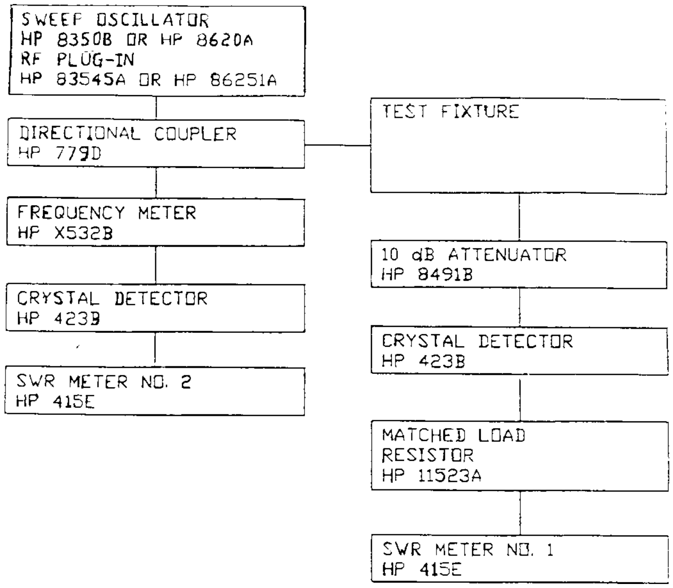
FIG. 15 Slider and Block for Connecting Pressure Block and Base Plate with Allowance for Opening the Fixture

6.11.3 *Power Measurement Alternatives*:

6.11.3.1 Calibrated variable attenuator in conjunction with one of the above resonance indicators (see 6.11.1).

6.11.3.2 Calibrated power meter with thermister transducer.

6.11.3.3 Calibrated SWR meter with crystal transducer (requires modulated signal) and must be operated in the square law range of the crystal).



NOTE 1—All coaxial cable connections.

NOTE 2—Equivalent makes and models of equipment may be substituted where it can be shown that equivalent results are obtained.

NOTE 3—Alternate test setups may be used provided that equivalent results are obtained.

FIG. 16 X-Band Permittivity Test Setup

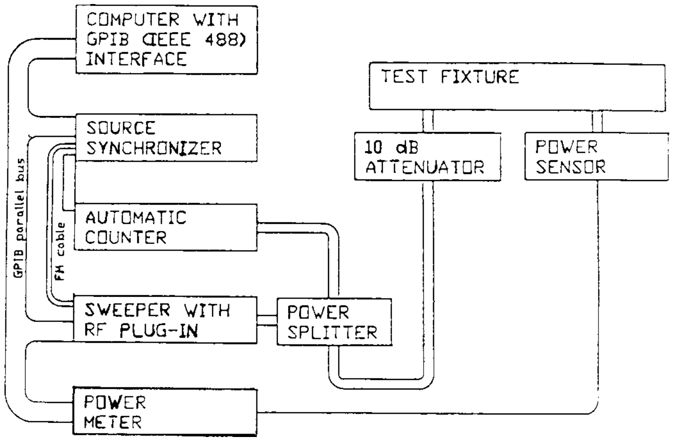


FIG. 17 Automated Permittivity Test Setup

6.11.3.4 Calibrated dual-trace oscilloscope when a sweep oscillator is used.

6.11.4 *Signal Generator Alternatives*:

6.11.4.1 Variable-frequency signal generator with a variable attenuator and internal square-wave modulation (may be operated either modulated or unmodulated). Square-wave modulation may also be obtained from a PIN modulator between the signal generator and the resonant cavity.

6.11.4.2 Klystron tube and mount with power supply and the means for varying the frequency.

6.11.4.3 Variable-frequency sweep oscillator with expanded sweep capability for bandwidths of 25 MHz or less.

6.12 *Temperature Control Apparatus*— Temperature control apparatus for use with Fixture A design shall include the following:

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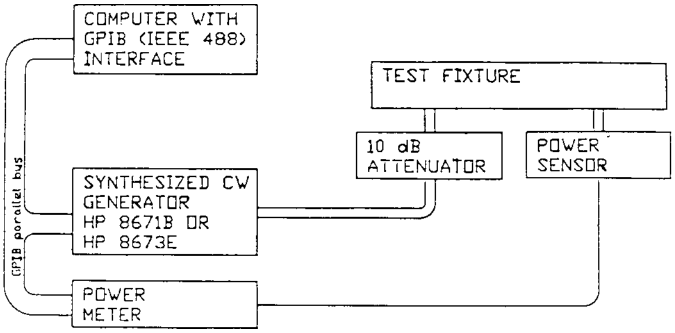

FIG. 18 Simplified Automated Permittivity Test Setup

6.12.1 A laboratory constant temperature bath with circulator connected in series with the clamping blocks using 0.25 in. (6 mm) inside diameter tubing and a return line to the bath.

6.12.2 Two fine diameter thermocouple probes,[26] with leads, and suitable instrumentation for readout or recording of temperature. A digital thermometer is convenient for monitoring of the temperature.

7. Test Specimens

7.1 The test specimen shall consist of two sheets, or two packets of sheets if thin materials are to be tested. Each sheet shall be at least 2 by 2.7 in. (50 by 70 mm).

7.2 Remove the metal cladding from the dielectric sheet using any standard etching process, including rinsing and drying. In case of referee tests, this metal removal process shall be in accordance with I.P.C. TM-650, section 2.3.7.1.

7.3 The test fixture design provides spacing for total specimen thickness of 0.125 ± 0.009 in. or 0.100 ± 0.007 in. (3 or 2.5 mm) from an even number of sheets, or layers.

NOTE 5—The testing of specimens comprised of layers will introduce some error due to air gaps between layers. The magnitude of such errors can be as much as 5 % of the permittivity. Exact correlation factors and techniques of measurement should be mutually agreed upon or other methods of test used. Method 2.5.5.3 of I.P.C. TM-650 at 1 MHz may be used to generate a correlation factor by testing specimens of nominal thickness shown in Table 1 using both the techniques of this ASTM test method and the IPC method.

7.4 For certain materials not based on woven glass cloth construction, specimens may be machined to a desired thickness so as to fit the fixture.

8. Preparation of Resonator Pattern Cards

8.1 The resonator circuit shown is an example of a pattern suitable for use in testing a material having a nominal permittivity of 2.20. For use in testing materials of other permittivity values, different pattern dimensions will be required as outlined in Table 1 and Fig. 4.

8.2 Select a copper-clad laminate for fabrication of the test pattern card using the following criteria:

8.2.1 The dielectric shall be a material similar to the type of material to be tested and shall be clad on both sides with copper having basis weight of one ounce per square foot.

8.2.2 The dielectric thickness shall be 0.0085 ± 0.0007 in. (0.216 ± 0.018 mm).

8.2.3 The copper foil shall meet the requirements of I.P.C. MF-150, Type 1 (electro-deposited), Type 5 (wrought), or Type 7 (wrought-annealed). The *Q* (quality factor) measurement will be affected by the type of copper foil and the surface treatments thereon which may have been applied for bond strength enhancement. The reciprocal *Q* values listed in Table 1 do not take into account any of these variables upon the resistivity of the copper due to type of foil or surface treatment.

8.3 The test pattern card shall have a permittivity within± 2.5 % of the nominal value of the material to be tested. This permittivity shall be measured on plies stacked to the total thickness requirements for specimens as set forth in Section 7.

8.4 Use a photo resist and an etching process capable of reproducing the circuit dimensions within ±0.001 in. (25 µm) of the requirements of Table 1.

8.5 Remove all copper from the side of the pattern card that does not contain the circuit.

8.6 Pattern cards made from soft, compliant, PTFE-ceramic substrate laminates may require additional steps in the preparation of resonator test pattern cards. The extra steps involve the embedding of the conductors into the surface of the substrate so that the thickness of the card is uniform and the same in both the pattern and non-pattern areas. Embedding is accomplished as follows:

8.6.1 Clamp the pattern card between stainless steel or aluminum release foils.

8.6.2 Clamp at 100 to 200 psi (0.7 to 1.4 MPa) between accurately planar metal blocks while heating the blocks to a temperature above the polymer melt point. Hold at that temperature until permanent conformance is attained. Cool to

TABLE 1 Stripline Test Pattern Cards: Dimensions versus Permittivity (κ′)[A]

Nominal [B]		Pattern Card Thickness	Probe Width	Chamfer *X, Y*	Probe gap	Resonator		$1/Q_c$ Conductor Loss
κ′	Thick					Width	Length, 4 node	
2.20	0.0625	0.0085	0.108	0.120	0.100	0.25	1.50	0.00055
2.33	0.0625	0.0085	0.105	0.115	0.100	0.25	1.50	0.00055
2.50	0.0625	0.0085	0.098	0.110	0.100	0.25	1.50	0.00055
3.00	0.0625	0.0085	0.084	0.095	0.100	0.20	1.25	0.00058
3.50	0.0625	0.0085	0.073	0.085	0.100	0.20	1.25	0.00058
4.00	0.0625	0.0085	0.064	0.076	0.100	0.20	1.25	0.00058
4.50	0.0625	0.0085	0.057	0.068	0.100	0.20	1.25	0.00058
6.00	0.0625	0.0085	0.042	0.051	0.090	0.15	1.00	0.00062
6.00	0.0500	0.0085	0.034	0.042	0.090	0.15	1.00	0.00072
10.5	0.0500	0.0085	0.0165	0.0214	0.080	0.10	0.68	0.00079

[A] Dimensions are in inches.
[B] The two left columns list the nominal κ′ and thickness for the material being tested.

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[26] The Omega model DSS-115 has been found suitable for this purpose.

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room temperature while under pressure, then release the clamping force.

8.7 The clamping force applicable to the pattern cards in Table 1 is 1000 lbf (4448 N). See also 8.6.

8.7.1 Pattern card size is 2.70 in. wide by 2.18 in. length (68.6 by 55.4 mm) and is designed for the fixture hardware apparatus described in 6.8.

8.8 The resonator length is such that when the pattern card is clamped for the lap-joint with the striplines on the base card, the resonator is centered in the area which is 2.0 in. (50 mm) above the base plates of the fixture.

8.9 For materials having permittivity higher than shown in Table 1, equivalent results can be obtained using a modified fixture design to accept smaller area specimens. If the area of transferred force from the aluminum clamping plates is smaller than the 1290 square millimetres area shown in Fig. 1 or Fig. 2, reduce the clamping force proportionately to the area reduction.

8.10 Probe line widths in Table 1 are based on ground plane spacing of twice the nominal thickness of the pair of specimens, plus the thickness of the pattern card and the copper foil thickness (0.00135 in. or 0.034 mm) of the pattern. The width is computed as if the stripline were centered between ground planes.[27,28]

8.11 Chamfer values are based on published design curves.[29]

8.12 Table 1 shows four-node resonator length. Resonators of lower node values (for measuring ΔL in accordance with 11.2) will be proportionately shorter and the probe length modified so that the gap is the same.

8.13 The value for conductor losses, $1/Q_c$, in Table 1 are calculated using published formulas[30] from known properties of copper, test frequency, the characteristic impedance of that section of the stripline which comprises the resonator, and the cross-sectional geometry. Because the conductor actually used may not have a perfectly smooth surface and may include oxides or microvoids (any of which are potential sources for increasing the resistivity of the conductor), the values for $1/Q_c$ in Table 1 are usually lower than actual. This results in calculated dissipation factor values being higher than actual performance.

9. Temperature Control

9.1 For PTFE there is a well-known transition region near 292 K in which the polymer crystalline structure is altered. This produces a step-like change in the permittivity. Measurements made in the temperature range of about 18 to 21°C will show excessive variation because of this transition. Test values will depend upon the temperature at the instant of measurement and on the time-temperature history of the specimen prior to test. The transition, if plotted as permittivity versus temperature, will shift and vary in slope depending upon whether the specimen is heating or cooling and upon the rate of this change. The reporting of permittivity for PTFE materials in this temperature range as a single number can be in error if the precise temperature of the test fixture and all of its parts is unknown.

9.2 By controlling the fixture temperature with apparatus described in 6.2 and 6.12, rather than relying upon the control of the laboratory room ambient, more precise data for the variations in permittivity and loss with temperature can be collected.

10. Procedure

10.1 Measure the length of the resonator element to the nearest 0.0002 in. (5 µm). An optical comparator has been found useful for measurements of this precision.

10.2 Unless otherwise specified, store all test specimens and pattern cards at 22 to 28°C and 45 to 55 % relative humidity prior to testing. For referee tests, storage shall be 16 h minimum. Other times may be used if it can be shown that such other storage times yield equivalent results to the minimum 16-h storage time.

10.3 If the apparatus of 6.9.11 is used, turn the electronic devices to ON at least 30 min prior to testing. This allows warm-up and stabilization of the electronic equipment.

10.3.1 Many automatic frequency counters will contain a provision for temperature control of the clock crystal which operates even when the power switch is OFF. If power is continuously supplied to this unit a longer warm-up time is avoided.

10.3.2 Other equipment using vacuum-tube devices may require different warm-up times as may be specified by the equipment manufacturer.

10.4 Place the test fixture in the ambient at which the testing will be performed. Unless otherwise specified, this ambient shall be standard laboratory condition in accordance with Practice D 618. If the manual apparatus of 6.9 is to be used, store the test fixture at standard conditions for at least 24 h prior to using it for measurements.

10.5 If the specified temperature of test is not that of the recommended standard condition of 22 to 24°C, and Fixture A is to be used, then the following procedure shall apply:

10.5.1 Prior to any electrical measurements, start the circulator and adjust the desired temperature to within 1°C of the test temperature specified.

10.5.2 Allow time for thermal equilibrium to be established. This time will depend upon the specific temperature control device used, the constancy of the laboratory temperature, the size of the circulating bath tank, and the magnitude of the specified temperature. Additional stabilization time may be required for each specimen pair to reach the specified test temperature after clamping in the fixture.

10.6 Place the test specimen pair in the test fixture of Fig. 1 and Fig. 2 such that an even number of cards lie on either side of the resonator pattern card.

10.7 Place the test fixture containing the specimen in the clamping device and apply the specified force (1000 lb or 4448 N) through the calibrated force gauge to the 1290 mm^2 area

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[27] Cohn, S. B., "Problems in Strip Transmission Lines," *IRE Transactions* MTT-3, March 1955, pp. 119–126.

[28] Cohn, S. B., "Characteristic Impedance of the Shielded-Strip Transmission Line," *IRE Transactions MTT*, July 1954, pp. 52–57.

[29] Matthaei, G. L., Young, L., and Jones, E. M. T., *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*, McGraw-Hill, 1964, p. 206.

[30] Altschuler, H. M., and Oliner, A. A., "Discontinuities in the Center Conductor Strip Transmission Line," *IRE Transactions*, MTT-8, May 1960, p. 328.

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centered directly on the resonant element of the pattern card in the assembly as shown in Fig. 1 or Fig. 5.

10.8 *Specimen Measurement Using Manual Apparatus Specified in* 6.8:

NOTE 6—The apparatus of 6.9 can also be operated manually.

10.8.1 The word "cavity" below refers to the stripline resonator formed by the fixture pattern card and the ground planes with the specimen pair inserted. The word "sweeper" below refers to the sweep oscillator (same as 6.8.1 sweep frequency generator and the X-band frequency plug-in of 6.8.2).

10.8.2 Find the resonant frequency of the cavity by scanning the sweeper over the expected transmission range of the test resonator.

10.8.3 Adjust the sweeper to that exact frequency at which a maximum reading is observed on the SWR meter #1.

NOTE 7—Be sure that the input selector of SWR meter #1 is set for low impedance input so as to provide proper square law detection.

10.8.4 Adjust the frequency meter of 6.8.3 to provide a minimum dB reading (maximum power) on the SWR meter #2 and record as f_R.

10.8.5 Determine the cavity half-power points by setting the incident signal to maximum resonator transmission and adjusting the gain on the SWR meter #1 until the meter reads zero dB.

10.8.6 Adjust the frequency of the sweeper above f_R until a 3 dB power decrease shows on SWR meter #1.

10.8.7 Adjust the frequency meter to a minimum decibel reading on SWR meter #2 and record this frequency as f_1.

10.8.8 Adjust the frequency of the sweeper below f_R until a 3 dB power decrease shows on SWR meter #1.

10.8.9 Adjust the frequency meter to a minimum decibel reading on SWR meter #2 and record this frequency as f_2.

10.9 *Specimen Measurement Using the Automated Setup of* 6.9:

NOTE 8—To perform the measurements with an automated setup, computer software is needed which will collect paired values of frequency and transmitted power. From these data the frequency for maximum power transmission and the frequencies of the half-power points are determined. The software program may optionally include computation of permittivity and dissipation factor as described in Section 11. Results and data may be displayed upon a screen, stored in a disk file, sent to a printer, or any combination of these.

10.9.1 In one possible mode of operation with the apparatus of 6.9, the following sequence of steps is performed as many times as is necessary to obtain enough data to complete the test procedure. The computer is designated as the controller on the GPIB (General Purpose Interface Bus).

10.9.2 The computer sets the sweeper to a selected carrier wave frequency without an AM or FM audio signal. The computer also sets the output power level to some desired or specified value, such as 10 dBm.

10.9.3 This selected carrier wave frequency is sent to the synchronizer with instruction to lock the frequency of the sweeper to the specified value.

10.9.4 The computer monitors the synchronizer until the status value indicates that the frequency is locked.

10.9.5 The power meter reading is obtained by the computer. Since it takes a finite time for the power sensor to stabilize, either a delay is used or the reading may be taken repeatedly until consecutive readings meet a specified requirement for stability.

11. Calculation

11.1 At resonance the electrical length of the resonator circuit is an integral number of half-wavelengths. Calculate the effective stripline permittivity, using Eq 1:

$$\kappa' = \left[\frac{nC}{2\, f_R\, (L + \Delta L)}\right]^2 \tag{1}$$

where:

n = the number of half-wavelengths along the resonant strip,
L = the measured length of the resonant strip,
ΔL = the correction factor for length due to the fringing capacitance at the ends of the resonator element,
f_R = the measured resonant (maximum transmission) frequency,
C = a conversion constant numerically equal to the velocity of light in units consistent with L and f.

NOTE 9—This method uses 3.000×10^{10} cm/s as the value for C. The more precise value of 2.9978×10^{10} cm/s is avoided for this revision of the standard to minimize confusion with material specifications and proven component designs based upon previous versions of this standard which used 3.000×10^{10} as the value for C. The use of the more exact value for the velocity of light would yield a permittivity value 0.15 % less than that calculated with $C = 3.000 \times 10^{10}$.

11.2 *Calculation of* ΔL, the correction factor for length due to the fringing capacitance at the ends of the resonator element:

11.2.1 ΔL is affected by the value of ground-plane spacing and by the degree of anisotropy in permittivity of the material being tested. If the material to be tested contains fiber reinforcement, the anisotropy will be influenced by: orientation of fibers, the volume ratio of fiber to polymer matrix resin, and the difference between the permittivities of the fibers and the resin. In polymer resin systems incorporating inorganic fillers, the degree of anisotropism can be affected in a similar manner.

11.2.2 In view of the reality of 11.2.1 above, it is mandatory that the value for ΔL used in testing a specific material be determined experimentally, as specified in paragraphs 11.2.3 to 11.2.5.

11.2.3 Prepare a series of resonator circuit cards having patterns in which only the resonator element length is varied to provide n values of 1, 2, 3, and 4 at close to the same frequency. For example; lengths of ⅜ in., ¾ in., 1⅛ in., and 1½ in. might be selected.

11.2.4 Prepare specimen pairs from typical material to be tested. Measure resonant frequency on at least three specimen pairs at each value for L selected in 11.2.3 above. Using linear graph paper, plot $L(f_R/n)$ on the y-axis versus (f_R/n) on the x-axis. The slope is equal to the negative value of ΔL. A preferred alternative to plotting is to use a numeric regression analysis procedure to determine the slope of the least squares fit through the four data points.

11.2.5 The ΔL values for each of the specimen pairs may be averaged to provide a suitable working value for ΔL.

11.2.6 IMPORTANT—For any given type of material a

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working value for ΔL shall be agreed upon as a standard for use in a material specification.

11.2.7 IMPORTANT—See Annex A1 for discussion about the effect of specimen thickness on the calculation of a working ΔL. Depending upon the type of material being tested, this correction of ΔL may or may not be important.

11.3 *Calculation of Dissipation Factor*:

11.3.1 The attenuation and quality factor or factor of merit (Q) of stripline circuits are a function of the combined conductor and dielectric losses. The value of $1/Q$ for the dielectric loss is obtained by subtraction of the conductor loss $1/Q_c$(see Table 1) from the total loss $1/Q$ as shown by Eq 2 and Eq 3:

$$D = \frac{1}{Q} - \frac{1}{Q_c} \tag{2}$$

$$D = \left(\frac{f_1 - f_2}{f_R}\right) - \frac{1}{Q_c} \tag{3}$$

where:

$1/Q$ or $(f_1 - f_2)/f_R$ or $\Delta f/f_R$ = total loss due to dielectric, copper, and the copper/dielectric interface,
D = dissipation factor,
$f_1 - f_2$ = Δf, and

Δf is the positive difference between f_1 and f_2.

NOTE 10—In Eq 3 and Eq 4 the procedure for identifying f_1 and f_2 should ensure that the absolute value of the difference between them is used in the calculation. In practice, operators are often more likely to reverse the identification when manually collecting data. In practice, one usually observes that f_1 has a lower value than f_2. Use the positive value of the differences in the calculations.

11.3.2 Another calculation scheme may be used that does not require that the values for f_1 and f_2 be at exactly half the power level of the maximum at resonance. This scheme is especially suited to automatic testing. The formula is shown as Eq 4:

$$D = \frac{(f_1 - f_R)}{f_R\sqrt{(10^{0.1\ \mathrm{dB}_1} - 1)}} + \frac{(f_R - f_2)}{f_R\sqrt{(10^{0.1\ \mathrm{dB}_2} - 1}} - \frac{1}{Q_c} \tag{4}$$

where:

dB_1 = dB below the peak power level at f_1, and
dB_2 = dB below the peak power level at f_2.

11.3.3 IMPORTANT—Combinations of resonant frequency, resonator width, ground plane spacing, and nominal permittivity may be encountered in practice which result in values for $1/Q_c$ which differ from the values shown in Table 1. If this occurs, a value of $1/Q_c$ calculated in accordance with 11.3.4 shall be used unless otherwise stated by specification or mutual agreement.

11.3.4 The following equations apply:

$$\frac{1}{Q_c} = \frac{\alpha_c C}{\pi f\sqrt{\kappa'}} \tag{5}$$

$$\alpha_c = 4R_s\kappa' Z_0 Y[(376.6)^2 B]^{-1} \tag{6}$$

where:

α_c = attenuation constant, nepers per inch, and
R_s = $0.00825\sqrt{(f)}$, surface resistivity copper, Ω.

$$Y = X + \left(\frac{2WX\,2}{B}\right) + \left(\frac{X^2}{\pi}\left[\left(1 + \frac{T}{B}\right)\ln\left(\frac{X+1}{X-1}\right)\right]\right) \tag{7}$$

where:

X = $(1 - T/B)^{-1}$
κ' = nominal permittivity,
Z_0 = characteristic impedance of resonator, Ω,
B = ground plane spacing, in.,
C = velocity of light: 11.803 in./ns,
f = nominal resonant frequency, GHz,
W = resonator width, in., and
T = resonator conductor thickness, in.

12. Report

12.1 The calculated effective stripline permittivity (κ').

12.2 The calculated effective dielectric dissipation factor (D or loss tangent).

12.3 The maximum transmission (resonant) frequency.

12.4 The temperature of the test fixture during the test.

12.5 The measured thickness of the specimen stacks.

12.6 The measured length of the resonator and the delta L value.

12.7 The frequency at each of the two 3-dB points on the resonance curve, or the frequency and the actual decibel values at the two points.

12.8 The grade of copper used on the laminate selected for the test pattern card.

12.9 The directionality involved during the testing of materials in which any significant anisotropy may exist. State the orientation of the resonator with respect to the following:

12.9.1 *X*-axis (machine direction) of the specimen substrate, or

12.9.2 *Y*-axis (cross-machine direction) of the specimen substrate. The machine direction is parallel to the direction in which most of the fibers are oriented in any glass-fiber, or ceramic-fiber, reinforced PTFE laminate.

12.10 A complete identification of the material tested.

12.11 If the test apparatus of 6.8. was used, (Fig. 5, Fig. 6, and Fig. 7), this fact shall be reported.

13. Precision and Bias

13.1 The precision of this test method is in the process of being determined.

13.2 A statement of bias cannot be made because of the unavailability of a standard reference material.

14. Keywords

14.1 dielectric constant; dissipation; loss tangent; permittivity; polymer-based substrates; relative permittivity; resonator; stripline; x-band

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ANNEX

(Mandatory Information)

A1. PRECISE CALCULATIONS OF Δ *L* TAKING INTO ACCOUNT THICKNESS EFFECTS UPON Δ *L*

A1.1 Determination of the Effect of Specimen Thickness upon Δ*L*

A1.1.1 The Δ*L* correction for end fringing capacitance will vary with the thickness of the specimen. Ignoring this effect by use of a fixed Δ*L* value for calculation of test results will bias the permittivity results upward for thicker specimens and downward for thinner specimens.

A1.1.2 In the case of very low permittivity materials, where the resonator has a longer length, this bias is quite small and of interest only in applications requiring very close tolerances.

A1.1.3 In the case of very high permittivity materials where the resonator has a shorter length, this thickness effect can be very significant.

A1.1.4 There are two ways in which this thickness effect may be handled. One way uses an empirical determination of Δ *L* for various thicknesses. A second way assumes a proportionality to the published prediction of Δ*L*.

A1.1.5 If the empirical approach is chosen, use 11.2 to obtain Δ*L* with specimens having extremes of thickness variation expected in day-to-day testing. Use numerical linear regression analysis of the collected Δ*L*/specimen thickness data pairs to determine B_0 and B_1 for the equation:

$$\Delta L = B_0 + B_1 \tag{A1.1}$$

where:

B_0 and B_1 = constants for any given material and must be agreed upon for a particular material type either by specification or other mutually acceptable means.

A1.1.6 If the empirical approach of A1.1.5 is not selected, an alternate method may be used to derive a Δ *L* correction factor as follows. A Δ*L* correction factor can be derived for a given material type, within a range of permittivity values, by determining, using specimens of known thickness, the ratio of Δ*L* derived according to 11.2 to that predicted by the published formulas.[4] An average of the ratios so determined shall become, by mutual agreement, the specified value for the term *R* in Eq 2. Eq 2 is used to compute the correction factor to be used as Δ *L* in Eq 1 of 11.1 when tests are conducted on the specific material type for which the correction factor is derived.

$$\Delta L = R(K^2 + 2KW)/(2K + W) \tag{A1.2}$$

where:

R = average ratio of observed to predicted ΔL,
K = (B/π) $(\ln 2)$,
W = width of resonator, and
B = total ground-plane spacing (two specimen thicknesses plus thickness of test pattern card).

APPENDIX

(Nonmandatory Information)

X1. ADDITIONAL INFORMATION

X1.1 Permittivity or κ′

X1.1.1 The material comprising the dielectric of a stripline circuit affects the electrical response of all of the circuits printed thereon. Velocity of signal propagation, wavelength, and characteristic impedance all vary with permittivity. If the permittivity varies from the design value, degradation of performance in those circuits can be expected.

X1.1.2 Throughout this test method, "permittivity," or κ′, has been used to denote relative permittivity of the dielectric. This practice conforms with the intent of Definitions D 1711.

X1.1.3 This test method uses the symbol κ′ to denote relative permittivity. The symbol *DK* is sometimes used by some personnel in the electronics industry in the U.S.A.

X1.2 Loss Tangent, *D*, Dissipation Factor

X1.2.1 The attenuation and the quality factor, *Q*, of stripline circuits are each a function of the dielectric loss and the conductor loss. An excessively low quality factor (high loss tangent) leads to loss in signal strength and to degraded performance in frequency selective circuits such as filters. In this test method a great saving in time and cost of testing is achieved by using a permanent strip circuit pattern which is part of the test fixture. With this fixture, variations in loss tangent due to the dielectric can be monitored, but not the additional losses due to the type of metal used in the laminate nor to the surface treatments upon the metal which may have been used for bond enhancement.

X1.3 Measurements at Other Frequencies

X1.3.1 The test apparatus of 6.8 can be modified at some additional cost to make measurements at other frequency bands. The apparatus of 6.9 will be able to handle these other bands as is.

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X1.4 Other Metal-Clad Dielectrics

X1.4.1 This test method can be adapted for measurements on other metal-clad dielectrics. For each such material it will be necessary to determine a ΔL for that material.

X1.4.2 Measurements upon materials which are not somewhat compliant may yield significant errors due to air gaps between specimen layers in the test fixture created by a material which is very rigid.

X1.5 Anisotropic Materials

X1.5.1 When measuring materials which contain fibers that are oriented principally in one direction, a test procedure may require that the stripline configuration be oriented such that the applied electric field and the principal direction of fiber orientation are parallel. Test methods in which the electric field is not imposed on the dielectric in a stripline configuration can give misleading values for effective stripline permittivity and loss tangent. This method measures an effective stripline permittivity.

X1.6 Soft Substrates Having High Permittivity

X1.6.1 Soft substrates consisting of PTFE highly filled with inorganic fillers will require additional steps in the preparation of test pattern resonator cards. Such steps embed the conductor pattern into the surface of the substrate so that the thickness of the card is uniform and that the thickness is the same in both the pattern and the non-pattern areas.

X1.6.2 If this preparative step is omitted or inadequately done, a bias in the permittivity value will be seen for a given resonator card in the fixture. For a specimen held in the fixture for a period of time, there will be an initial bias high that drifts downward over several hours. When removed, the specimen will have an embossed image of the resonator pattern. If repeated testing is done among several specimens using comparatively short clamping times of 1 or 2 min before reading resonant frequency, the bias is initially high and then decreases with the frequency of test runs. This drift in performance is observable when reference specimens are repeatedly tested.

X1.6.3 The drifting bias in X1.6.2 is believed to be related to the combination of concentration of clamping force (in the smaller resonator area required for these soft materials) and the soft material's higher degree of conformance. Initially the clamping excessively compresses material on both sides of the resonator element which raises its permittivity. With time the material in both pattern card and the specimen pair conforms by deformation flow away from the high compressive stress area so that the bias decreases. The use of a card with embedded patterns leads to a lower stress and a stress more evenly distributed over the entire specimen. This is believed to result in little or no bias.

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