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Number	
2.5.5.9	
Subject	
Permittivity and Loss Tangent, Parallel Plate, 1 MHz to 1.5 GHz	
Date	Revision
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Originating Task Group	
HDI Test Methods Task Group (D-42a)	

IPC-TM-650
TEST METHODS MANUAL

1 Scope This procedure outlines a test method to determine the permittivity (dielectric constant or E′r) and loss tangent (dissipation factor or Tanδ) of printed wiring materials at various frequencies (from 1 MHz to 1.5 GHz) using a single test fixture for the measurement.

The permittivity and loss tangent are measured using a narrow sweep of frequency around the target or desired frequency. The test method is built around the capability of currently available materials analyzers, which use a capacitance method to determine permittivity.

This test method is not intended for low loss materials, such materials may be tested at fixed frequencies using other IPC test methods.

2 Applicable Documents

HP 4291A-5 Product Note ''Dielectric Constant Evaluation of Rough Surface Materials,'' which describes how to make accurate measurements using the HP 4291A and HP 16453A.

HP Application Note 380-1 ''Dielectric Constant Measurements of Solid Materials,'' which contains a technical background, suitable for this subject.

3 Test Specimen

3.1 Each specimen shall be 50 mm x 50 mm by the thickness of the substrate material. Within the limits of the test fixture, the thicker the sample the less error in the measurements. Multilayer samples can be used to increase the thickness of the sample, but these cannot be simple stacked layers; they must be physically bonded with no air gaps between the layers. A target thickness would be 1.0 mm, but both thinner and thicker samples will work.

3.2 Three specimens are required for this test.

3.3 All materials are affected by moisture, including all reinforced laminates and most films. Therefore, all samples shall be conditioned at 23°C ± 2°C and 50% RH ± 5% RH for a minimum of 24 hours prior to testing. However, if a sample has recently been etched or exposed to excessive moisture, it should be dried in an air-circulating oven for two hours at 105°C +5°C, -2°C prior to testing and conditioned at room temperature as mentioned above.

3.4 Sample Surface Preparation

3.4.1 It is preferred that the sample be patterned with a conductive material in the shape and size of the test electrode. This conductive material is preferably 100 angstroms of vapor deposited copper. Other metals may be used. In all cases, the conductor on the sample must make good electrical contact with the fixture electrode. Such a conductive pattern eliminates air gaps and other potential sample mounting errors.

3.4.2 Bare dielectric materials may be tested with this test method. The fixture electrodes must be applied with some level of force to ensure a gap-free contact area. Determining the correct force setting may require some trial and error testing for each type of sample (see 6.4).

4 Equipment/Apparatus

4.1 The Hewlett-Packard Impedance Material Analyzer, model 4291A, or equivalent is recommended.

4.2 Hewlett-Packard model number 16453A test fixture, or equivalent

4.3 An appropriate calibration-verification kit and a fixture-correction kit as recommended in the instrument's manual (i.e., HP4291A Calibration kit). Such a kit usually includes the following devices:

• OPEN and SHORT for fixture correction

• 50 Ohms impedance

• Dielectric (PTFE) of known characteristic for the purpose of the calibration verification

4.4 Micrometer, capable of 0.001 mm resolution

4.5 Circulating oven capable of 105°C +5°C, -2°C

5 Procedure

5.1 Calibrate the instrument using the calibration kit according to the recommendations of the instrument manufacturer.

Calibrations only last 24 hours, so calibration shall be performed within 24 hours of the measurement. See 6.1 for more calibration notes.

5.2 Set up the unit to sweep the target frequency ± 0.5% of the target.

5.3 Measure the sample thickness with the micrometer and insert into the test fixture. The sample must make good contact with the fixture electrodes (see 6.1 concerning the proper force to be applied). The sample must not touch the back wall of the fixture. The sample electrode placement and thickness measurement shall be obtained from the same area of the sample.

5.4 Run the test and record the average permittivity and loss over the narrow frequency range sweep. The scanned data may also be saved on disk. See 6.2 for comments on expected behavior for permittivity as a function of frequency.

5.5 Repeat 5.1 through 5.4 for all desired frequencies.

5.6 Report the average permittivity and loss at the frequencies requested.

6 *Notes*

6.1 Correct calibration and operation of the test equipment is required to obtain accurate measurement of permittivity and loss. Proper sample preparation is also very important for obtaining useful data from this test. Calibrate the materials analyzer in accordance with manufacturer's instructions. An automatic program has been developed for the HP 4291A, which will ease calibration and setup (see 6.6).

6.2 The permittivity should decrease slightly with increasing frequency. If it increases greatly or decreases more than 0.2 units from approximately 20 MHz to 1.2 GHZ, reposition (reset) the sample in the fixture and measure again (check for debris between the electrodes; blow out with air).

6.3 Testing at temperatures and humidities other than room temperature may be performed with this instrument, as a specialized fixture can be placed in a temperature chamber. A temperature chamber must be used when testing with this fixture under conditions where condensation might contaminate the electrodes, as such contamination gives spurious results.

6.4 The pressure of the test fixture on the specimen affects the measured permittivity and loss values, in particular for un-metallized test specimens. Too light of pressure reduces the area of electrode/sample contact, thus leaving air gaps, which result in erroneous measurements. If the pressure is too high, the sample can be reduced in thickness and the measured values would be incorrect because the thickness is unknown. Making measurements while adjusting the force should lead the operator to a force setting where the measured value is independent of the force applied.

6.5 The HP 4291 Materials Analyzer and related fixtures and calibration kits are available from Hewlett Packard, (800) 452-4844.

6.6 Reference Program for Automatic Calibration and Operation This automatic calibration and operation program was developed for the HP 4291A and is published in this method as a reference. Although the program listed in this section has been tested and used, it is given here for ''reference only.''

6.6.1 Procedure Using Automatic Program Turn on the analyzer with the program/calibration disk in the drive and follow the user friendly calibration instructions, which appear on the monitor. The calibration on the HP4291 lasts about 24 hours; after that, it begins to drift and provides slightly higher values as a function of time. The calibration procedure in 6.6.1.1 through 6.6.1.10 should therefore be performed, at a minimum, on a daily basis. During the calibration procedure, the line traces on the monitor should be observed during each step. Noisy or erratic traces are an indication of external interference. If noise is observed, the calibration procedure should be aborted and rerun. Clean the electrode on the test head, standards, and fixture connections and electrodes on a regular (weekly) basis. Blow dry.

6.6.1.1 Allow at least 30 minutes for the unit to warm up and stabilize.

6.6.1.2 As the unit is a frequency sweeping unit, enter the start and stop frequency (in megahertz) of the test (single frequency tests use close start/stop frequencies, which should be ± 0.5% of the target frequency).

6.6.1.3 Place the OS (open) calibration standard on the test head as prompted on the unit's monitor and press Return on the unit's keyboard or ''x1'' on the unit.

6.6.1.4 Place the 0Ω (short) calibration standard on the test head as prompted on the unit's monitor and press Return on the unit's keyboard or ''x1'' on the unit.

6.6.1.5 Place the 50Ω calibration standard on the test head as prompted on the unit's monitor and press Return on the unit's keyboard or ''x1'' on the unit.

6.6.1.6 Place the HP 16453A test fixture or equivalent on the test head as specified in accordance with the manufacturer's instructions as prompted on the unit's monitor.

6.6.1.7 Open the fixture gap and lock it open as prompted on the monitor and press Return on the unit's keyboard or ''x1'' on the unit.

6.6.1.8 Short the fixture gap as prompted on the monitor and press Return on the unit's keyboard or ''x1'' on the unit.

6.6.1.9 Place the pure PTFE specimen in the fixture in close contact with electrodes and with the PTFE specimen not touching the back wall of the fixture, then press Return on the unit's keyboard or ''x1'' on the unit. Pull out the PTFE and recheck. Permittivity should be within ± 0.01 or ± 0.02 units. If not, recalibrate starting at ''Fixture.'' If it is still off, redo the calibration from beginning.

6.6.1.10 Test the sample in accordance with Section 5.

6.6.2 The following calibration/test program is the latest version of what was developed for the P H4291A. Using a text editor (no embedded coding), enter this program on a DOS-formatted disk and name it ''AUTOST.'' Place the disk in the unit and turn it on (If you have any improvements PLEASE forward them to the IPC): The program disk will calibrate and configure the instrument's screen. Two windows will appear. The top window should be permittivity (E'r) and the bottom window should be loss tangent (δ). Both windows should be set to the frequency range entered in 6.3.1.2. If they are not, return to 6.3.1 and repeat the process.

```
100 !**** PLEASE SET PTFE THICKNESS ON LINE 1610 AND
2600 ****
110 !**** PLEASE SET PTFE PERMITTIVITY ON LINE 2580
****
120 !**** PLEASE SET PTFE LOSS TANGENT ON LINE 2590
****
130 !****
200 !**** SAVE THIS PROGRAM ON A DOS FORMATTED
210 !**** DISK USING A TEXT EDITOR (LINES 100-5000
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220 !**** NAME THE PROGRAM ''AUTOST'' WITH NO
EXTENSION
230 !**** PLACE DISK IN UNITS DRIVE AND TURN UNIT ON
240 !**** PROGRAM WILL AUTOMATICALLY RUN. TO
RESET
250 !**** UNIT FOR NEW FREQUENCY RANGE PRESS
''STOP''
260 !**** ON UNITS FACE THEN ''START'' ON UNITS FACE.
270 !**** IF YOU WANT TO RE-CALIBRATE ANSWER YES [1]
280 !**** WHEN PROMPTED
290 !****
1000 !**** INITIALIZE UNIT FOR TEST ***
1010 ASSIGN @Hp4291 TO 800
1020 Scode=8
1030 CLEAR @Hp4291
1040 ABORT Scode
1050 OUTPUT @Hp4291;''DISP:ALL BST''
1070 !
1100 !**** CALIBRATION STATE CHECKING ****
1110 OUTPUT @Hp4291;''SENS:CORR1?''
1120 ENTER @Hp4291;Stat
230 IF Stat THEN
1130 INPUT ''RE-CALIBRATE NOW? [1] Yes; [0] No
[RETURN OR x1]'',Ans$
1140 IF Ans$<>''1'' THEN GOTO Test_loop
1150 END IF
1160 !
1200 !**** SETTING UP START/STOP FREQUENCY ****
1210 INPUT ''Enter Start Frequency in MHz, [RETURN OR
x1]'',A
1220 B=A*1000000
1230 OUTPUT @Hp4291;''SENS:FREQ:STAR '';B
1240 INPUT ''Enter Finish Frequency in MHz, [RETURN OR
x1]'',A
1250 B=A*1000000
1260 OUTPUT @Hp4291;''SENS:FREQ:STOP '';B
1270 !
1300 !**** SETTING ENABLE REGISTER FOR SRQ ****
1310 OUTPUT @Hp4291;''STAT:INST:ENAB 256''
1320 OUTPUT @Hp4291;''*SRE 4''
1330 !
1400 !**** SETTING TRIGGER SOURCE INTERNAL, CON-
TINUOUS OFF ****
1410 OUTPUT @Hp4291;''TRIG:SOUR INT''
1420 OUTPUT @Hp4291;''INIT:CONT OFF''
1430 !
1500 !**** SETTING CAL MODE TO FIXED/USER ****
1510 OUTPUT @Hp4291;''SENS:CORR1:COLL:FPO USER''
1520 OUTPUT @Hp4291;''SENS:CORR2:COLL:FPO USER''
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1530 !
1600 !**** SET PTFE STANDARD THICKNESS IN METERS
ON LINE 1610****
1610 OUTPUT @Hp4291;''CALC:MATH1:DIM1 0.00075''
1620 !
1700 !**** MEASUREMENT TYPE er' AND tan delta ****
1710 OUTPUT @Hp4291;''DUAM DRLT''
1720 !
1800 !**** FORMAT LINES LIN Y-AXIS ****
1810 OUTPUT @Hp4291;''DISP:TRAC:Y:SPAC LIN''
1820 !
1900 !**** SWEEP SETTINGS ****
1910 OUTPUT @Hp4291;''SENS:SWE:SPAC LOG''
1920 OUTPUT @Hp4291;''SENS:SWE:TIME:AUTO ON''
1930 OUTPUT @Hp4291;''SENS:SWE:POIN 256''
1940 OUTPUT @Hp4291;''SENS:SWE:DWEL1:AUTO ON''
1950 !
2000 !**** CHANNEL 1 SETUP ****
2010 OUTPUT @Hp4291;''INST CH1''
2020 OUTPUT @Hp4291;''CALC:FORM REAL''
2030 OUTPUT @Hp4291;''DISP:TRAC1:STAT ON''
2040 OUTPUT @Hp4291;''DISP:TRAC1:Y:BOTT 1''
2050 OUTPUT @Hp4291;''DISP:TRAC1:Y:TOP 12''
2060 OUTPUT @Hp4291;''CALC:EVAL:ON''''TR1''''''
2070 OUTPUT @Hp4291;''CALC:EVAL:Y:XPOS 1MHZ''
2080 OUTPUT @Hp4291;''CALC:EVAL:MST ON''
2090 !
2200 !**** CHANNEL 2 SETUP ****
2210 OUTPUT @Hp4291;''INST CH2''
2220 OUTPUT @Hp4291;''CALC:FORM LTAN''
2230 OUTPUT @Hp4291;''DISP:TRAC1:STAT ON''
2240 OUTPUT @Hp4291;''DISP:TRAC1:Y:BOTT -0.5''
2250 OUTPUT @Hp4291;''DISP:TRAC1:Y:TOP 1.5''
2260 OUTPUT @Hp4291;''CALC:EVAL:ON''''TR1''''''
2270 OUTPUT @Hp4291;''CALC:EVAL:Y:XPOS 1MHZ''
2280 OUTPUT @Hp4291;''CALC:EVAL:MST ON''
2290 OUTPUT @Hp4291;''INST CH1''
2300 !
2400 !**** SETUP AVERAGING ****
2410 OUTPUT @Hp4291;''SENS:AVER1 ON''
2420 OUTPUT @Hp4291;''SENS:AVER1:COUN 10;STAT
ON''
2430 !
2500 !**** SELECT 16453A FIXTURE AND COMPENSATE ****
2510 !**** PLEASE SET PTFE STANDARD PERMITTIVITY ON
LINE 2580 ****
2520 !**** PLEASE SET PTFE STANDARD LOSS TANGENT
ON LINE 2590 ****
2530 !**** PLEASE SET PTFE STANDARD THICKNESS IN
METERS ON LINE 2600 ****
2540 OUTPUT @Hp4291;''DISP:FORM ULOW''
2550 OUTPUT @Hp4291;''DISP:ALL BST''
2560 OUTPUT @Hp4291;''SYST:FIXT HP16453''
2570 OUTPUT @Hp4291;''SENS:CORR2:CKIT2 TEFL''
2580 OUTPUT @Hp4291;''SENS:CORR2:CKIT2:STAN6:PRE
2.1''
2590 OUTPUT @Hp4291;''SENS:CORR2:CKIT2:STAN6:PLF
0.0001''
2600 OUTPUT @Hp4291;''SENS:CORR2:CKIT2:STAN6:
THIC 0.00075''
2610 OUTPUT @Hp4291;''SENS:CORR2:CKIT2:SAVE''
2620 !
2700 !**** OPEN STANDARD MEASUREMENT ****
2710 ON INTR Scode GOTO Open_end
2720 OUTPUT @Hp4291;''*CLS;*OPC?''
2730 ENTER @Hp4291;Opc
2740 INPUT ''CONNECT OPEN (OS) STANDARD, THEN
PRESS [RETURN OR x1]'',A$
2750 ENABLE INTR Scode;2
2760 OUTPUT @Hp4291;''SENS:CORR1:COLL STAN1''
2770 Wait_open:GOTO Wait_open
2780 Open_end:!
2790 !
2900 !**** SHORT STANDARD MEASUREMENT ****
2910 ON INTR Scode GOTO Short_end
2920 OUTPUT @Hp4291;''*CLS;*OPC?''
2930 ENTER @Hp4291;Opc
2940 INPUT ''CONNECT SHORT (0 OHM) STANDARD,
THEN PRESS [RETURN OR x1]'',A$
2950 ENABLE INTR Scode;2
2960 OUTPUT @Hp4291;''SENS:CORR1:COLL STAN2''
2970 Wait_short:GOTO Wait_short
2980 Short_end:!
2990 !
3100 !**** 50 OHM LOAD STANDARD MEASUREMENT ****
3110 ON INTR Scode GOTO Load_end
3120 OUTPUT @Hp4291;''*CLS;*OPC?''
3130 ENTER @Hp4291;Opc
3140 INPUT ''CONNECT 50 OHM STANDARD, THEN
PRESS [RETURN OR x1]'',A$
3150 ENABLE INTR Scode;2
3160 OUTPUT @Hp4291;''SENS:CORR1:COLL STAN3''
3170 Wait_load:GOTO Wait_load
3180 Load_end:!
3190 !
3300 !**** SAVE UNIT CALIBRATION ****
3310 OUTPUT @Hp4291;''SENS:CORR1:COLL:SAVE''
3320 !
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3330 !**** END CALIBRATION OF UNIT ****
3340 !
3400 !**** OPEN 16453A FIXTURE MEASUREMENT ****
3410 ON INTR Scode GOTO Open_end1
3420 OUTPUT @Hp4291;''*CLS;*OPC?''
3430 ENTER @Hp4291;Opc
3440 INPUT ''CONNECT FIXTURE AND LOCK GAP OPEN, THEN PRESS [RETURN OR x1]'',A$
3460 ENABLE INTR Scode;2
3470 OUTPUT @Hp4291;''SENS:CORR2:COLL STAN4''
3480 Wait_open1:GOTO Wait_open1
3490 Open_end1:!
3500 !
3600 !**** 16453A FIXTURE SHORT MEASUREMENT ****
3610 ON INTR Scode GOTO Short_end1
3620 OUTPUT @Hp4291;''*CLS;*OPC?''
3630 ENTER @Hp4291;Opc
3640 INPUT ''CLOSE AND SHORT FIXTURE GAP, THEN PRESS [RETURN OR x1]'',A$
3650 ENABLE INTR Scode;2
3660 OUTPUT @Hp4291;''SENS:CORR2:COLL STAN5''
3670 Wait_short1:GOTO Wait_short1
3680 Short_end1:!
3690 !
3800 !**** TEFLON LOAD IN 16453A MEASUREMENT ****
3810 ON INTR Scode GOTO Load_end1
3820 OUTPUT @Hp4291;''*CLS;*OPC?''
3830 ENTER @Hp4291;Opc
3840 INPUT ''PLACE TEFLON STANDARD INTO FIXTURE, THEN PRESS [RETURN OR x1]'',A$
3850 ENABLE INTR Scode;2
3860 OUTPUT @Hp4291;''SENS:CORR2:COLL STAN6''
3870 Wait_load1:GOTO Wait_load1
3880 Load_end1:!
3890 !
4000 !**** SAVE FIXTURE COMPENSATION SETTINGS ****
4010 OUTPUT @Hp4291;''SENS:CORR2:COLL:SAVE''
4020 !
4030 !**** REPLACE PROGRAM DISK WITH DATA DISK ****
4040 INPUT ''Replace Program with Data Disk, [RETURN OR x1]'',A$
4050!
4100 !**** PERMITTIVITY TEST LOOP ****
4110 Test_loop:!
4120 OUTPUT @Hp4291;''INIT:CONT OFF''
4130 Sweep1_Begin:!
4140 INPUT ''Place Sample In Fixture, Enter Thickness In mm, [RETURN OR x1]'',A
4150 B=A/1000

4160 OUTPUT @Hp4291;''CALC:MATH1:DIM1 '';B
4170 ON INTR Scode GOTO Sweep1_end
4180 OUTPUT @Hp4291;''STAT:INST:ENAB 1''
4190 OUTPUT @Hp4291;''*SRE 4''
4300 OUTPUT @Hp4291;''*CLS;*OPC?''
4310 ENTER @Hp4291;Opc
4320 OUTPUT @Hp4291;''ABOR''
4330 ENABLE INTR Scode;2
4340 OUTPUT @Hp4291;''INIT''
4350 Waiting:GOTO Waiting
4360 Sweep1_end:!
4370 !
4400 !**** SAVE DATA ROUTINE ****
4410 INPUT ''SAVE DATA? [1] Yes; [0] No [RETURN OR x1]'',Ans$
4420 IF Ans$<>''1'' THEN GOTO Sweep1_Begin
4430 INPUT ''Input Job Number [RETURN OR x1]:'',Job$
4440 OUTPUT @Hp4291;''MMEM:STOR:DINT:TRAC SEL, '''''';Job$;'''''','''''DISK''''';''
4450 GOTO Sweep1_Begin
4460 !**** END MEASUREMENT LOOP ****
4470 !
5000 END