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IPC-TM-650
TEST METHODS MANUAL

Number **2.5.5.6**	
Subject **Non-Destructive Full Sheet Resonance Test for Permittivity of Clad Laminates**	
Date **5/89**	Revision
Originating Task Group	

1 Scope The full sheet resonance (FSR) method is a means for non-destructive measurement of relative permittivity (K') of clad laminates at microwave frequencies.

1.1 Applicability The FSR method is applicable to rectangular laminates consisting of dielectric substrate clad with metal foil on both sides, or clad with thick metal on one side and metal foil on the other. Unlike methods using stripline or microstrip resonator elements, the FSR method is sensitive to specimen permittivity only in the Z direction of the material under test.

It is useful for comparing the permittivity of clad panels of essentially the same dimensions. No means is provided in this method to account for error caused by fringing capacitance at the open edges of the parallel plate waveguide formed by the metal cladding. For a series of panels of the same length, width, dielectric thickness, and nominal permittivity and measured by the same selection of resonant modes, the fringing errors will be essentially constant and the permittivity values obtained should correlate with performance in stripline or microstrip circuit boards fabricated from the laminates tested.

The method may be applied to full size clad laminates as manufactured and trimmed to nominal size or to smaller panels cut from such laminates.

1.2 Limitations While it is convenient to estimate the 1/Q or total D value for the specimen under test, this value will be a sum of dissipative losses in the dielectric, resistive losses in the conductors, and radiation losses from the open edges of the resonant cavity. The radiation losses are a large portion of the D value, so the FSR method is not very sensitive to the dissipation factor of the specimen. The FSR is not recommended for dissipation factor measurements.

The method is not capable of providing useful information on the variation of K' within a panel.

2 Applicable Documents

IPC-TM-650 Test Methods Manual

2.5.5.5 Stripline Test for Permittivity and Loss Tangent (Dielectric Constant an Dissipation Factor) at X-Band

3 Test Specimen Test specimens are clad laminate panels trimmed accurately to a rectangular shape. Specimens should be uniform thickness with clad metal over the entire surface on both sides. Edges must be straight with 90° corners and free of conductive bridges across the edges.

Measure the length and width as the distance between centers of opposite edges with precision to the nearest 0.4 mm or better. The length direction is usually taken to be in the X (grain) direction of the cladding and dielectric, which is not necessarily the longest dimension.

4 Equipment/Apparatus The test method requires a controllable and stable microwave signal source, an accurate means to determine the signal frequency, and an accurate means to measure the microwave power transmitted through the test configuration. The equipment required is the same as that specified in IPC-TM-650, Method 2.5.5.5.

The following equipment in the connection scheme shown in IPC-TM-650, Method 2.5.5.5, or equivalent may be used:

- Sweep Oscillator H.P. 835OB-Option 908
- RF Plug-in 0.01 to 20 GHz H.P. 83592A-Option 002
- Microwave Frequency Counter H.P. 5343A
- Source Synchronizer H.P 5344S-Options 043, 908
- Power Meter H.R 436A
- Power Sensor H.P. 848A
- Power Splitter H.P. 11667A

Although not required, a computer-automated test setup is recommended and the following additional equipment will be required:

- Controlling computer with GPIB interlace
- Appropriate specialized CAT software
- IEEE 488 GPIB cables

4.1 Test Fixture It is recommended that a test fixture be constructed as shown in the Appendix. This design provides the features given in 4.1.1 through 4.1.5.

4.1.1 The probe gap for control of RF coupling is precisely adjustable.

4.1.2 The test specimen is supported to minimize both movement during the test and distortion of the fringing field by proximity of parts of the fixture or the work surface.

4.1.3 Loading and unloading of specimens is easy and fast.

4.1.4 Heavy metal backed laminates may be tested as is.

4.1.5 Very thin laminates may be tested without tending to bend them in the probe region.

5 Procedure

5.1 Preparation for Testing Unless otherwise specified, the specimens shall be stored before testing at 23°C, -1°C, +50°C/50% ± 5% RH. The referee minimum storage time is 16 hours. Shorter storage times may be used if they can be shown to yield equivalent test results.

The temperature for the test is to be in the range of 22°C to 24°C, unless otherwise specified. Control of this temperature may be accomplished by performing the test in a laboratory having ambient temperature in the same range.

The two probe assemblies of the test fixture are placed on a level work surface close to the microwave test equipment. Each part has a type N jack fitting to be connected to a type N plug from the microwave equipment.

Make sure the ends of the jack and plug are free of dirt or metallic particles. Align the axes of the jack and plug and push them together with care to avoid twisting, while turning the knurled retaining nut on the plug to firmly tighten the joint. Misalignment or twisting causes excessive wear of contacting metal surfaces and increases the risk of permanent damage to delicate and critical connector parts. Tighten the retaining nut as tightly as is comfortable with the thumb and forefinger.

5.2 Zero Gap Setting The zero gap setting for each probe assembly on the fixture should be determined. Use the micrometer screw to raise the pusher dock so the surface for supporting the specimen is above the probe block. Mount a flat metal plate or clad board specimen in the fixture as described in 5.3. Lower the pusher by turning the micrometer screw until there is a slight change in torque. To detect it electrically, connect a low voltage battery powered portable Ohmeter across the center pin of the type N jack fitting and a clip on the mounted specimen. A sudden drop in resistance reading indicates the point at which the probe has made contact with the surface. Record this micrometer setting as the zero gap point on a label on the fixture for convenience.

5.3 Positioning the Specimen for K' Measurement Use the bead chains and notches to lift and hold the grounding assemblies in a raised position. Place the specimen on the support surfaces of the dielectric pusher blocks with the thin toil clad side down toward the probe. The specimen should rest flat on the top 0.25 mm long flat surface and push against the 1.27 mm vertical surface as a stop as illustrated in Figure 1. Set the probe gap either at the zero setting or a predetermined value. Gaps on both probe assemblies should be set at the same value.

Release the bead chain from the notch so the springs pull the copper bar down against both the top cladding on the specimen and the vertical ground plate. It is important to have good ground contact of the top metal cladding of the specimen at both probes.

5.4 Selection of Unambiguous Resonant Modes In a conventional waveguide cavity, reflections at the metal bounded sides show a current maximum, while in the parallel plate waveguide, reflections at open edges or corners show a voltage maximum. When the waveguide is a rectangle, as for clad panels, each resonance mode is a grid array pattern of maxima and may be designated (M:N), where M is the integer number of times (nodes) the pattern repeats along the length and N along the width. For a rectangular waveguide with either closed or open edges having length L and width W, the resonant frequency $f_{r,[M:N]}$ for a given mode is predicted by

$$f_{r,[M:N]} = (C/2)[\{(M/L)^2 + (N/W)^2\}/e_r]\ 0.5 \qquad \text{[Equation 1]}$$

Where,

C = speed of light = 299.792 mm/ns
e_r = dielectric constant of the dielectric filling the waveguide
$f_{r,[M\ N]}$ = resonant frequency in GHz (cycles/ns)

Equation 1 can be used to predict a series of expected resonances for a given panel size. Rearranged in order of frequency, they become proportionately more closely spaced as the frequency increases. In many cases, different modes have very nearly the same frequency

It is possible to select a resonant mode and predict a frequency that falls in a region of the spectrum where there are so many frequencies for different modes that one is bound to find a resonance close to where it was expected, even though it could be a different mode for a considerably different actual dielectric constant value.

The resonance for a given dielectric constant at different modes will differ somewhat from the prediction of Equation 1.

Part of this is due to variability of thickness or dielectric constant of the panel. Part of it is due to the effect of fringing effects on the edge of the panel.

For a given aspect ratio (length/width) panel, there should be a certain pattern of resonances versus frequency. This pattern will change somewhat as individual panels differ slightly from the nominal dimensions, as well as differing as mentioned before.

These cases of uncertainty about the test can be largely avoided by selecting, for a given nominal aspect ratio with its tolerance, a series of resonances that are well separated from their nearest neighbors and that, when actually found in a test, are certain to be the mode expected, even though deviating from expected frequency for the above several reasons.

If the probes are positioned at opposite corners of the specimen, then the mode selection process must take into account modes with all combinations of all integer values from 0 upward for both M and N, excluding the [0:0] mode and any combinations predicting a resonance exceeding the frequency range to be used.

If the probes are positioned at the centers of opposite edges, then the modes with an odd node number in the transverse direction are excluded from consideration in the selection process.

If the specimen has length and width equal within close tolerance, making it a square, and the probes are positioned at corners, the only truly unambiguous modes will be those where M and N are equal. For a given nominal panel size, selection of a series of three or more resonant modes with differing widthwise node numbers is advised. To obtain equivalent data on a series of panels of the same size and nominal permittivity, all should be measured at the same series of resonant modes.

5.5 Measure the Resonant Frequency for Each Mode Selected The following steps are followed for each selected mode. If the test is performed correctly, one (and only one) distinct resonance should be found for each selected mode. This procedure is greatly aided by computer automation.

5.5.1 Use Equation 1 with measured specimen length and width, the selected mode's M and N values, and the range of possible K' values to calculate a frequency range where the resonance should appear

5.5.2 By taking transmitted power readings across the frequency range, determine the resonant frequency where the transmitted power is maximum. If the transmitted power reading exceeds the sensor capacity, the source power should be reduced by about 3 dB and the procedure restarted.

5.5.3 Record the resonant frequency and resonant mode.

5.6 Calculations The effective permittivity for each resonant mode measured is calculated by the formula.

$$e_r = (C/2f_{r,[M:N]})^2[(M/L)^2 + (N/W)^2]$$

Normally, the permittivity values for the selected modes are averaged to give an agreed upon K' value for the test as applied to a specific specimen size and type.

5.7 Report The report should contain the everything given in 5.7.1 through 5.7.4.

5.7.1 Measured length, width and dielectric thickness of the specimen

5.7.2 For each selected mode, the (M:N) node numbers, the resonant frequency observed, and the calculated effective permittivity value. If computer-automated testing and calculation of permittivity is used, the resonant frequency may optionally be omitted from the report.

5.7.3 The conditioning of the specimen and ambient temperature at the time of measurement, if either of these differs from the standard values given in 5.1

5.7.4 A mean permittivity value calculated from the values obtained for each of the selected modes

6 *Notes*

6.1 Comments on Precision and Accuracy Precision has been found to be excellent, based on repeated measurements on a series of specimens among a series of three laboratories with ambient temperature identified as the major cause of variation.

Where measurements on specimens over a range of permittivity values have been compared to measurements by IPC-TM-650, Method 2.5.5.5, there was good correlation in that both methods ranked the specimens in the same order; however, the FSR method showed greater differences between the extremes. Unlike the stripline test, in which the dielectric of the pattern card is a part of the material measured, the FSR measurement does not involve any dielectric material other than the specimen.

The permittivity value observed is not necessarily an accurate measure, since the open edges allow fringing field error. For a ceramic filled composite at K' of about 10, specimens of the same length and width have been observed to vary in effective K' as the thickness of the specimen is varied.

6.2 Reference

1 Howell, John O., A Quick Accurate Method to Measure the Dielectric Constant of Microwave Integrated-Circuit Substrates, IEEE Trans., MTT, pp. 112-113, March.

2. Olyphant, Murray, Microwave Permittivity Measurements Using Disk Cavity Specimens, IEEE Trans. Instrumentation and Measurement, November 1971.

3. Lenzing, H. F, Measurement of Dielectric Constant of Ceramic Substrates at Microwave Frequencies, Washington D.C., May 1972.

4. Ladbrooke, P.H., Potok, M.H.N., England, E. H.,Coupling Errors in Cavity-Resonance Measurements on MIC Dielectrics, IEEE Trans. MTT, pp. 560-562, August 1973.

5. Aiken, J. E., Ladbrooke, P H., Potok, M. H. N., Microwave Measurement of the Temperature Coefficient Permittivity for Sapphire and Alumina, IEEE Trans. MTT, pp. 526-529, June 1975.

6. Kent, Gordon, An Evanescent-Mode Tester for Ceramic Dielectric Substrates, IEEE Trans. MTT, pp. 1451-1454, October 1988.

APPENDIX

List of drawings for the FSR test fixture.

Note: All dimensions and sizes are in inches.

Parts List for FSR Fixture

Item	Description	Figure No.	Required No.	Material
A	Frame	2	2	Aluminum
B	Base	2	2	Aluminum
C	Brace	2	2	Aluminum
D	3.2 mm x 12.7 mm Machine Screw For Joining A, B & C	2	10	steel
E	Flange mount OSM plug receptacle	1,3	2	as supplied
F	Flange mount N jack to OSM plug adapter	1,3,7	2	stainless steel
G	Block mounted on pin of E	3	2	brass
H	Vertical ground plate	4	2	brass
I	2.4 mm x 5 mm machine screw for attaching E to H	3	8	brass
J	1.6 mm x 6.4 mm machine screw for attaching H to A	none	4	steel
K	Contact bar connects specimen to H	1,4,5	2	copper
L	Body piece holds K	1,4,5	2	steel
M	#0 x 6.4 mm cap screw for attaching K to L	1,5	4	steel
N	Top plate slides and pivots on H	1,4,5	2	steel
0	#2 x 6.4 mm flat head screw for attaching N to L	5	4	steel
P	Tension spring to N pulls K against specimen and H	1	4	steel
Q	Pin for attaching P to A	1,2	4	steel
R	Bead chain to N for lifting K,L.N assembly when changing specimens	1	2	steel
S	Notched plate for retaining R as lifted for specimen change steel	1	2	
T	1.6 mm x 6.4 mm machine screws for attaching S to A	1	4	steel
U	Dielectric pusher lifts specimen for gap to G	4	2	molded PTFE
V	Micrometer screw unit for lifting U	1	2	as supplied
W	Bracket Mounts on A and supports E	1,7	2	steel
X	#4-40 x 6.4 mm cap screw fastens E to W	1,7	8	steel
Y	3 mm semirigid coaxial cable with jack fitting on both ends is bent to connect E to F	none	2	as supplied

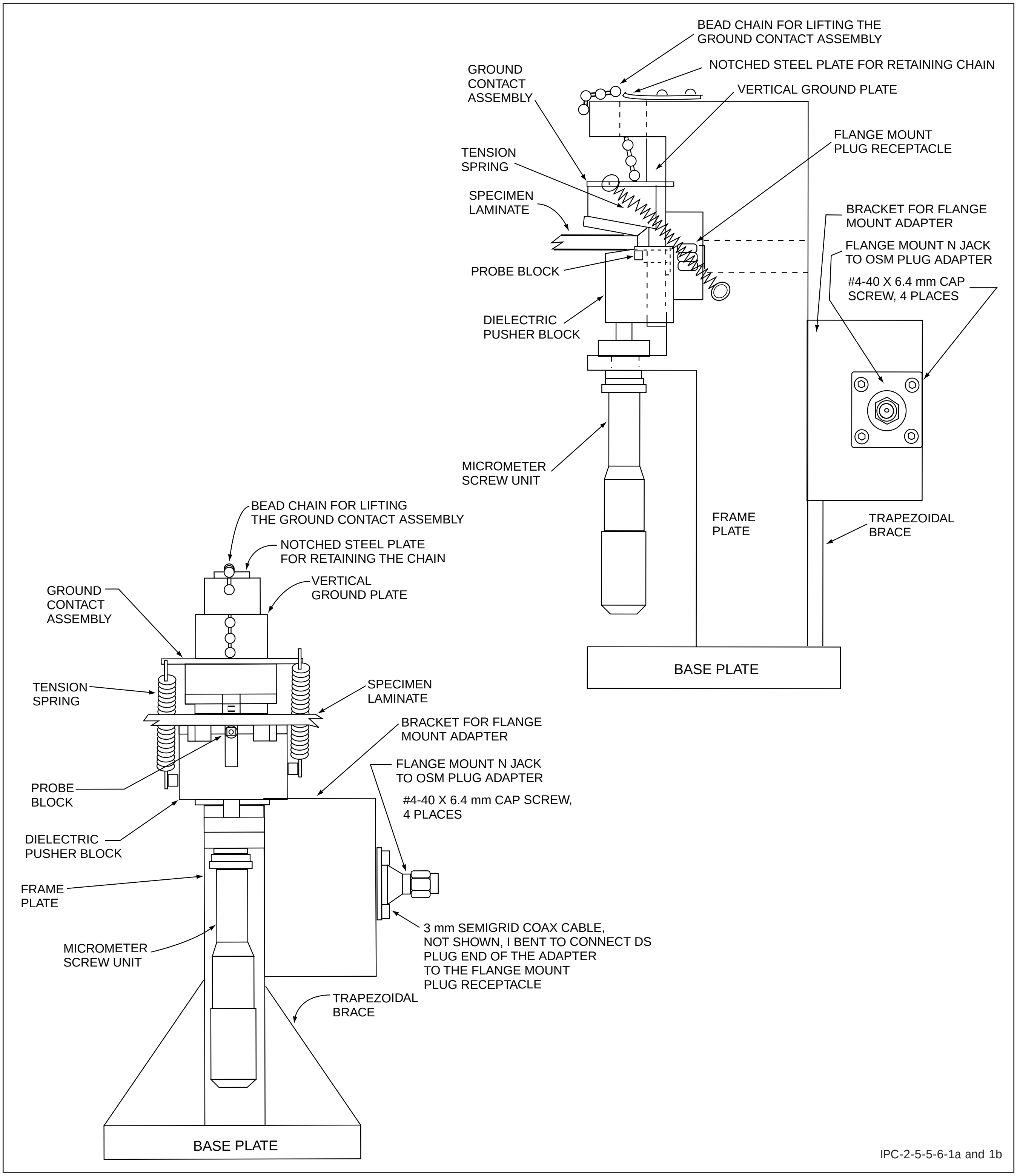

Figure 1 Side and Face Views of One of Two Fixture Assemblies

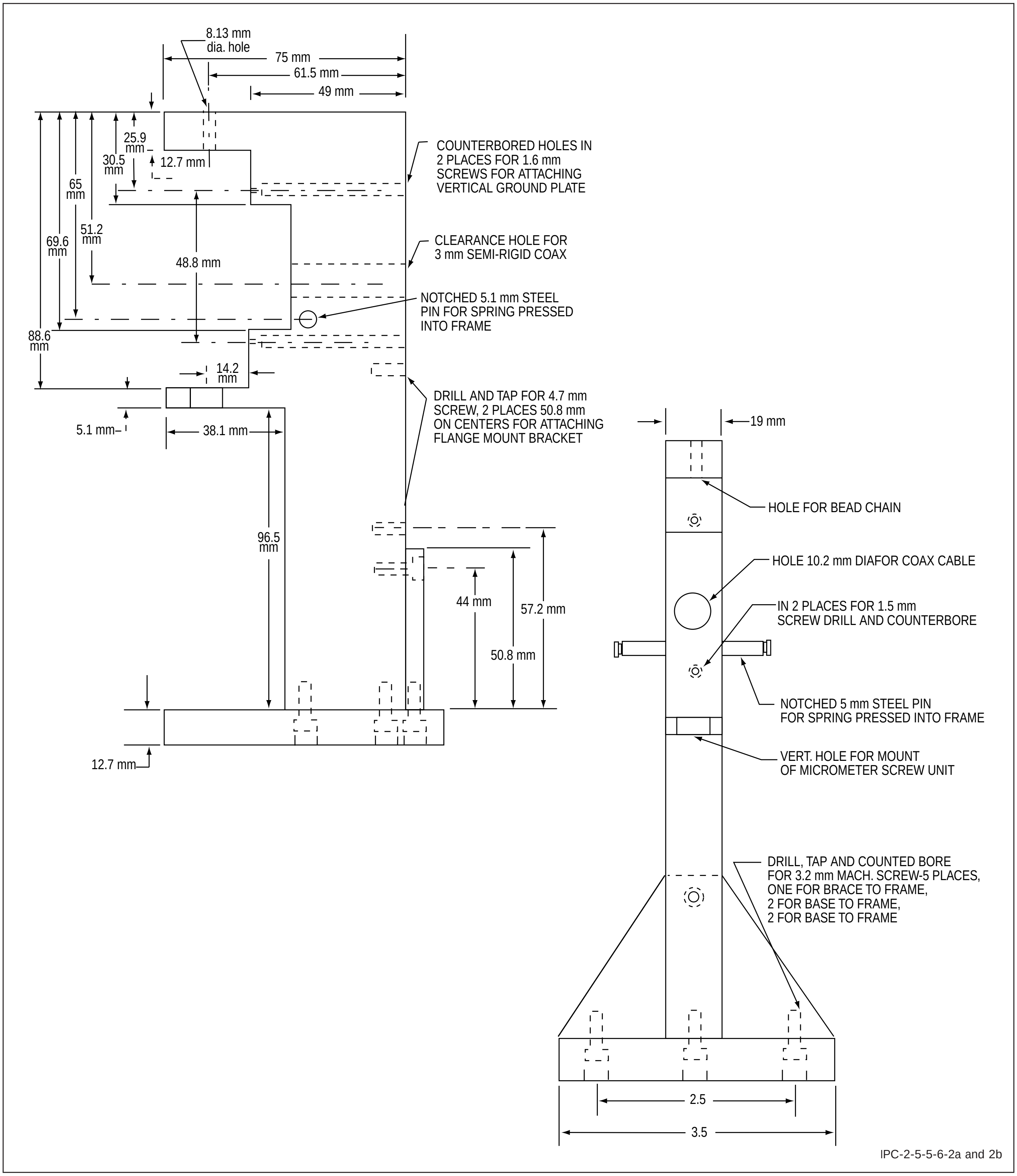

Figure 2 Side and Face Views of Frame, Base, and Brace

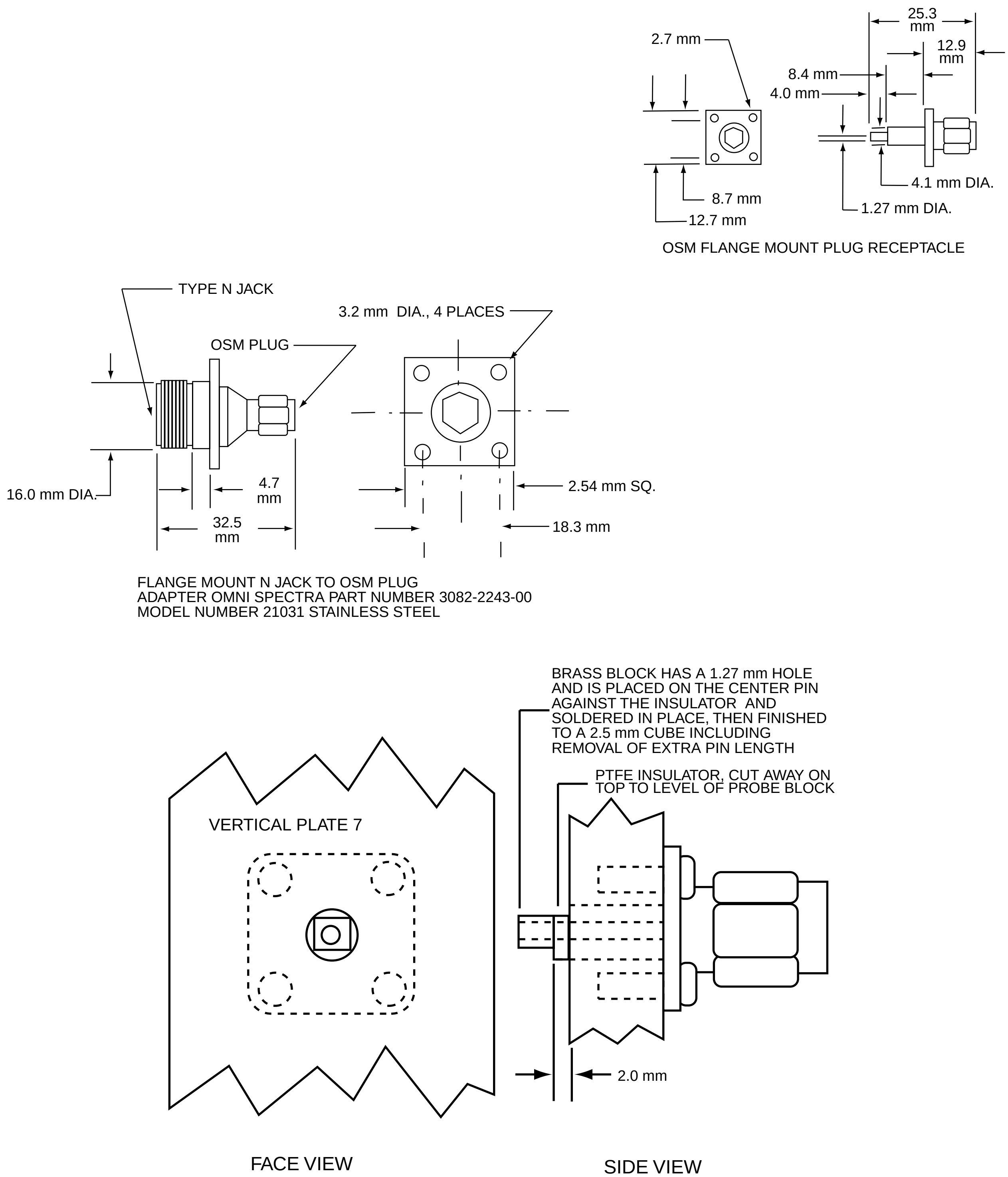

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Figure 3 Detail of Flange Mount Coaxial Fittings and of Probe Block in Position with Flange Plug and Ground Plate

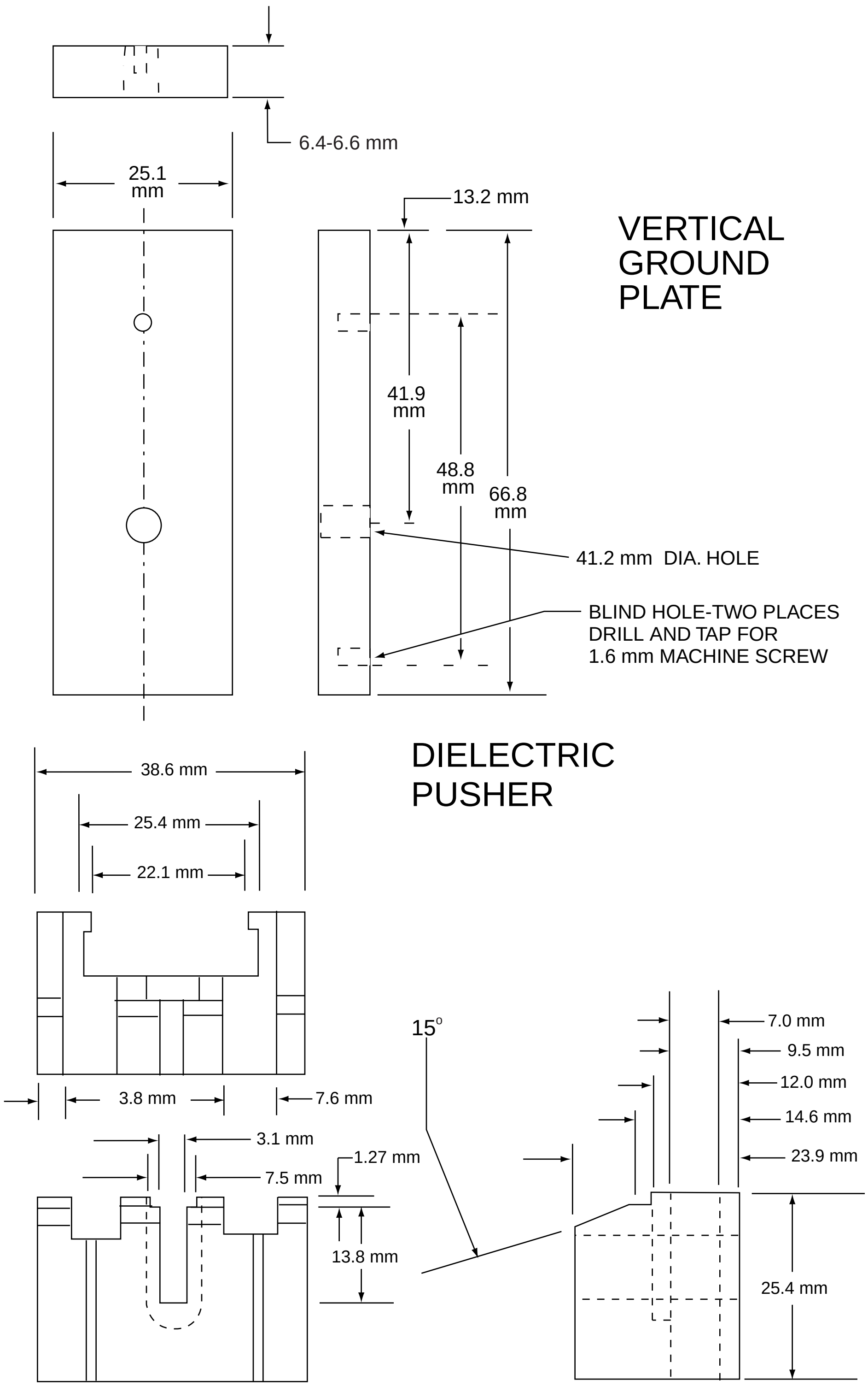

Figure 4 Details of Vertical Ground Plate and Dielectric Pusher

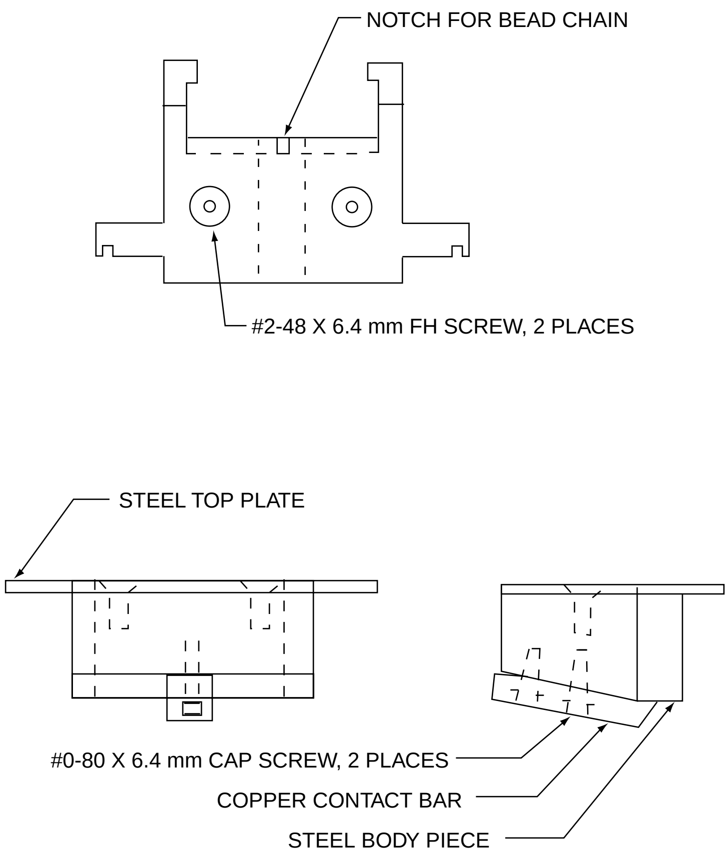

Figure 5 Detail of Ground Contact Assembly

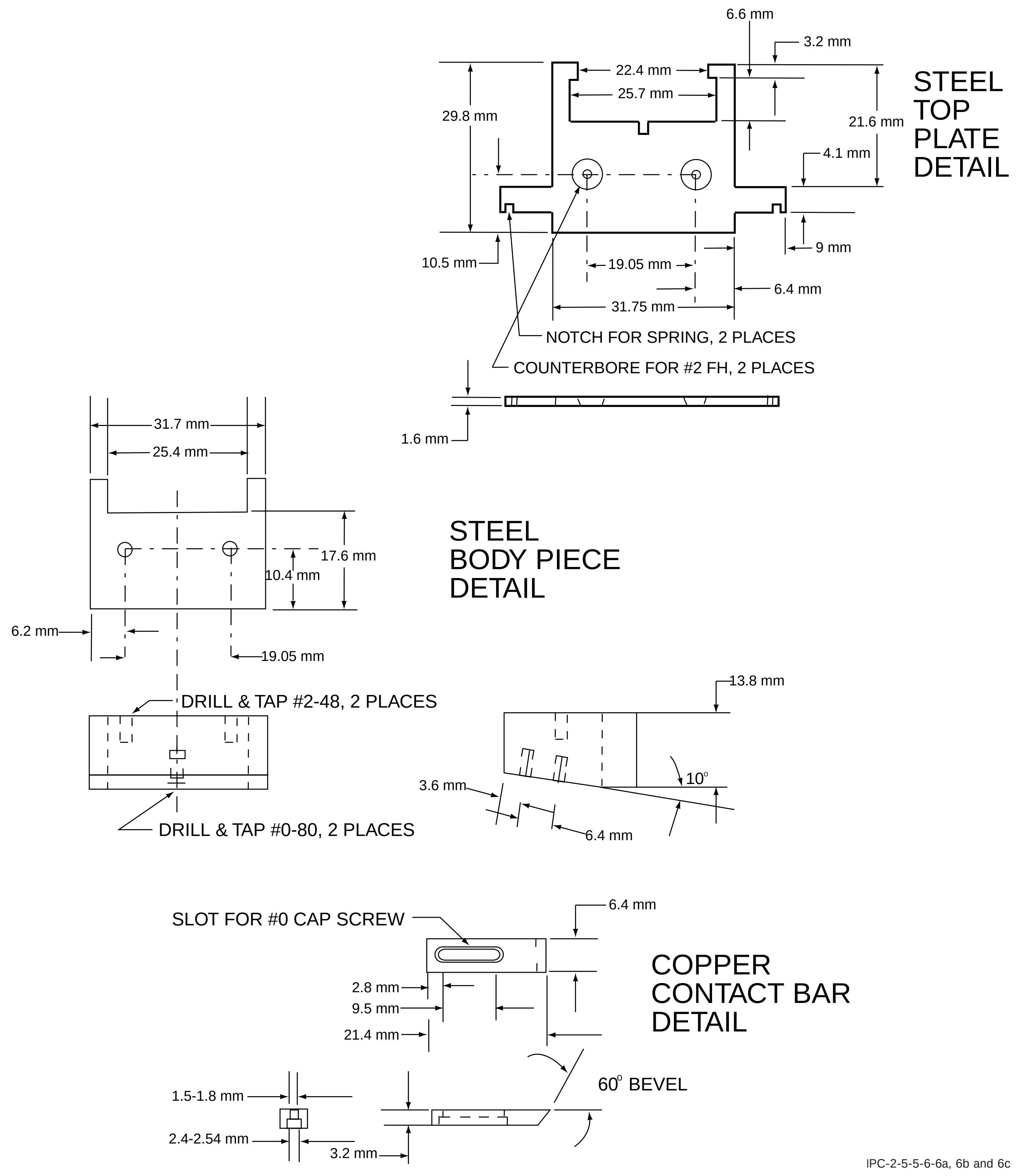

Figure 6 Detail of Parts for Ground Contact Assembly

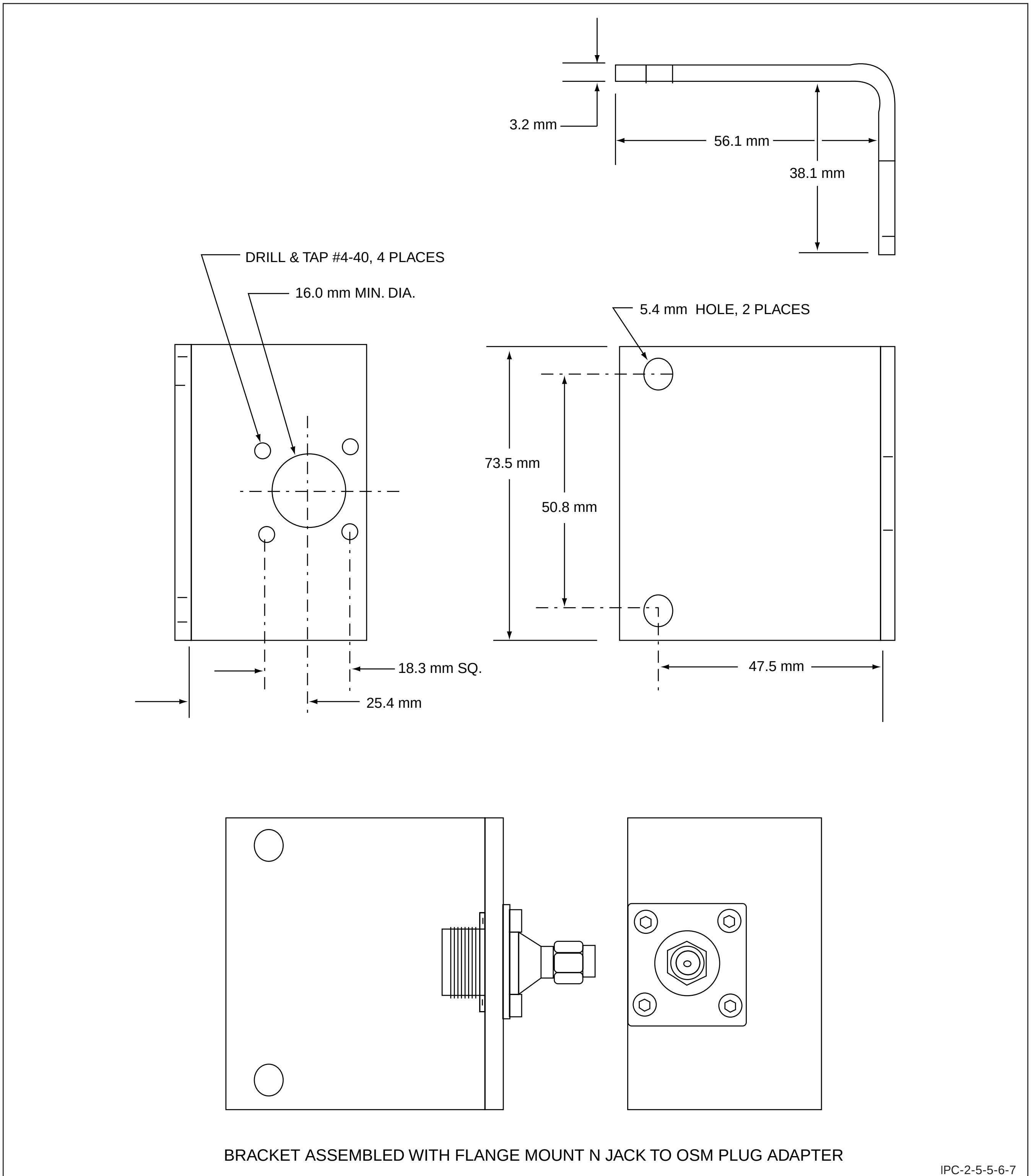

Figure 7 Details of Bracket for Mounting the Flange Mount Adapter