ANSI/EIA-364-66A-2000
Approved: May 5, 2000

EIA-364-66A

EIA STANDARD

TP-66A

EMI Shielding Effectiveness Test Procedure for Electrical Connectors

EIA-364-66A

(Revision of EIA-364-66)

MAY 2000

Electronic Components, Assemblies & Materials Association

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(From Standards Proposal No. 4730, formulated under the cognizance of the CE-2.0 National Connector Standards Committee.)

Published by

©ELECTRONIC INDUSTRIES ALLIANCE 2000
Technology Strategy & Standards Department
2500 Wilson Boulevard
Arlington, VA 22201

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TEST PROCEDURE No. 66A

EMI SHIELDING EFFECTIVENESS TEST PROCEDURE
FOR
ELECTRICAL CONNECTORS

(From EIA Standards Proposal No. 4730, formulated under the cognizance EIA CE-2.0 Committee on National Connector Standards, and previously published in EIA-364-66.)

1 Introduction

1.1 Scope

This standard establishes test methods for the measurement of the EMI shielding effectiveness of electrical connectors over the frequency range of 1.0 GHz to 10.0 GHz using the mode-stirred technique. The procedure applies to both circular and rectangular connectors.

1.2 Object

1.2.1 General

1.2.1.1 The mode-stirred method for the measurement of connector shielding effectiveness consists of exposing the Connector Under Test (CUT) and a reference antenna to an electromagnetic field and comparing the ratio of the signal levels induced into each unit.

1.2.1.2 The electromagnetic field within the mode-stirred test chamber is continuously perturbed by the operation of a rotating reflective element called a mode-stirrer (or tuner).

1.2.1.3 With the proper size test chamber and appropriate antennas, the mode-stirred technique can be used over the frequency range of 200 MHz to 40 GHz.

1.2.2 Mode-stirred test chamber

1.2.2.1 The mode-stirred chamber is a large cavity (in terms of a wavelength) with a high quality factor (Q) whose boundary conditions are continuously perturbed by a rotating reflective surface (tuner or mode-stirrer) mounted within the chamber. Electromagnetic power is established inside the chamber by means of an input or transmitting antenna; see figure 1.

1.2.2.2 The time-averaged electromagnetic fields within the chamber are approximately equal in amplitude spatially, and are formed by uniformly distributed plane waves. The field distribution at each point in the chamber is then a composite of randomly polarized plane waves; therefore, the average response for the effective aperture of a receiving antenna (or the connector under test) placed inside the chamber approaches a value equivalent to a gain of unity. [1), 2)]

1.2.3 Measurement of connector Shielding Effectiveness (SE)

1.2.3.1 The measurement of SE is based on the comparison of the rf power induced into the CUT on the rf power induced into a reference antenna; see figure 1. The shielding effectiveness of the CUT (expressed in dB) is then defined as:

$$SE = 10 \log \left(\frac{P_{ref}}{P_{cut}} \right) \quad (dB)$$

where:

P_{cut} = Power coupled to the connector under test
P_{ref} = Power coupled to the reference antenna

1.2.3.2 Both the value of P_{cut} and P_{ref} are determined statistically as a function of tuner position and are determined for the same net input power applied to the chamber.

1.2.3.3 The leakage to be measured is principally that which enters the connector shells under test at the main point of interface. Leakage at the accessory joints is to be prevented by appropriate fixturing.

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1) M. L. Crawford, G. H. Koepke, *"Design, Evaluation, and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements,"* Technical Note 1092, National Bureau of Standard.

2) M. L. Crawford and J. M. Ladbury, *"Mode-Stirred Chamber for Measuring Shielding Effectiveness of Cables and Connectors,"* IEEE August 1988 International Symposium on Electromagnetic compatibility, Seattle, Washington, pp. 30-36.

1.2.4 Methods of measurements

There are two basic methods of operating the mode-tune while performing the measurement of the output levels from the reference antenna and the CUT:

- discrete tuning: step positioning of the mode-tuner,
- continuous tuning: constant rotation of the mode-tuner.

NOTE — It shall be acceptable to use either the discrete-tuned or the continuous tuned method in the measurement of connector shielding effectiveness as described in this test procedure.

1.2.4.1 Discrete tuning

1.2.3.1.1 Discrete tuning provides the optimum accuracy at test frequencies less than or equal to 2 GHz. The mode-tuner is incremented in discrete steps of 1.8 degrees (200 steps) for one full revolution of the tuner, and measurements are performed at each tuner position.

1.2.4.1.2 This method permits the measurement of the net input power supplied to the transmitting antenna, the power from the reference antenna and the power from the CUT at each tuner position. Corrections can then be made to normalize the reference antenna and CUT received power measurements for an equivalent constant net input power as needed to correct for changes in the transmitting antenna’s input impedance as a function of tuner position.

1.2.4.1.3 This technique also allows corrections to be made for impedance mismatch between the CUT, the reference antenna and the power measuring instrumentation as described in annex D.

1.2.4.2 Continuous tuning

1.2.4.2.1 At test frequencies above 2 GHz, the changes in the VSWR of the input antenna vs. tuner position are less significant than at the lower frequencies. This results in improved stability of the net input power to the test chamber, and enables measurements to be made using continuous stepping (or slow rotation) of the mode-turner position with a minimum of error.

1.2.4.2.2 The output signal levels from the reference antenna and the CUT are measured continuously at a data rate that is very fast in comparison to the rate of rotation of the mode-tuner. The large amount of data acquired results in improved measurement accuracy.

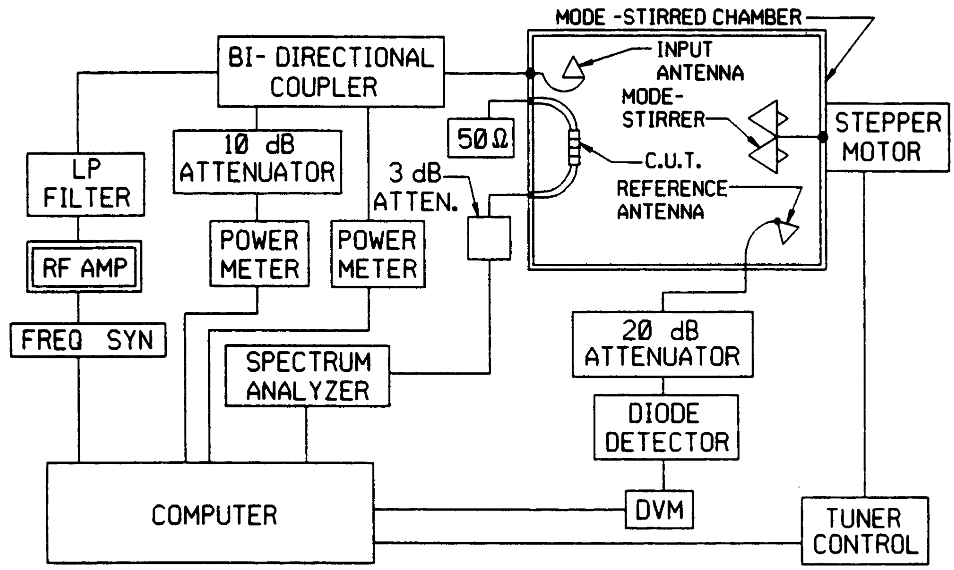

Figure 1 – Mode stirred shielding effectiveness measurement system

2 Test resources

2.1 Equipment

The essential test equipment and components required for an automated mode-stirred shielding effectiveness measurement system are shown in figure 1. The desired performance criteria for each primary item are summarized in annex C.

2.1.1 Test chamber

2.1.1.1 Mode-stirred shielded enclosure

2.1.1.1.1 Details of recommended test chamber design and construction are given in annex A, together with a description of the mode-tuner and the ridged horn antennas.

2.1.1.1.2 The minimum of any chamber internal dimension shall be greater than three wavelengths at the lowest test frequency. For optimum chamber performance at the lower frequencies, the volume of the chamber should be as large (with respect to a wavelength) as possible. The ratio of the squares of the chamber's linear dimensions should be as non-rational as possible. [1] The test chamber is described further in annex A.

2.1.1.1.3 The chamber should have a shielding effectiveness of at least 100 dB as measured by MIL-STD-285. This level of shielding will enable the measurement of CUT shielding effectiveness levels of greater than 100 dB. As a minimum, the test chamber and the test instrumentation shall have a combined shielding effectiveness at each test frequency that is 10 dB greater than the minimum shielding requirements of the CUT.

2.1.1.2 Mode-tuner

The mode-tuner should be large with respect to a wavelength and be bent at angles to the walls of the chamber. The tuner should be at least two wavelengths from tip to tip at the lowest test frequency. The mode-tuner is further described in annex B.

2.1.1.3 Antennas

The input and reference horn antennas should be placed in different corners of the chamber and located so that they face into the corners. This orientation will minimize possible direct-path coupling from the input antenna to the reference antenna or to the CUT. The preferred relative placement of the antennas and the CUT within the test chamber are shown in figure 1.

2.1.2 Input power monitoring

The incident-signal power meter, see figure 1, is used to monitor the level and stability of the incident power to the input antenna. The reflected power meter enables the determination of the new input power to the chamber.

2.1.3 VSWR of components and cables

2.1.3.1 The individual components of the measurement system should be of good quality, with an input and output VSWR of 1.3:1 or less. This applies especially to all components, cables, and instrumentation in the signal paths from both the reference antenna and the CUT assembly. This precaution will minimize the magnitude of mismatch uncertainties, and facilitate measurement error analysis; see annex D for further discussion on corrections for mismatch errors.

2.1.3.2 The range of mismatch uncertainty in dB can be found from the following:

Maximum mismatch loss = -10 log $[1 - (|\Gamma_S| + |\Gamma_L|)^2]$ (dB)

Minimum mismatch loss = -10 log $[1 - (|\Gamma_S| - |\Gamma_L|)^2]$ (dB)

where:

Γ_S = Reflection coefficient of the source (reference antenna or CUT)

Γ_L = Reflection coefficient of the load (detector or receiver/spectrum analyzer)

The magnitudes, $| \Gamma_S |$ and $| \Gamma_L |$ can be obtained from the appropriate VSWR by the equation:

$$\left|\tilde{A}_i\right| = \frac{\mathrm{VSWR} - 1}{\mathrm{VSWR} + 1}$$

where:

i = S or L

2.1.3.3 Cable and component losses

Characterize all cables, attenuators, directional couplers, and switches for VSWR and attenuation (or coupling factor) at each test frequency prior to beginning the test.

2.1.3.3.1 This data will be used to correct the measurement system readings of reference antenna and CUT output levels, and if desired, the input power to the test chamber. These corrections can be made part of the test program for an automated mode-stirred system.

NOTE — All individual data that is to be averaged later should be stored in units of power (milliwatts), not in dBm or other measurement units.

2.1.4 Alternative test equipment configuration

2.1.4.1 The method used in figure 1 to monitor the signal level from the reference antenna provides several advantages. The use of the calibrated attenuator/diode detector assembly enables simultaneous monitoring of both the reference and the CUT signals, reducing errors due to any drift in the rf source power level and decreases the required test time by one half.

2.1.4.2 The use of a switched input to the receiver/spectrum analyzer to enable monitoring the outputs of first the reference antenna, and then the CUT, may be used in lieu of a separate monitoring channel. This alternative test system configuration is shown in figure 2.

NOTE — The coaxial switch configuration used to switch between the reference antenna and the CUT shall provide a 50 ohm termination to the unused signal channel. The maximum crosstalk between inputs should be at least 10 dB greater than the difference between the two test signal levels.

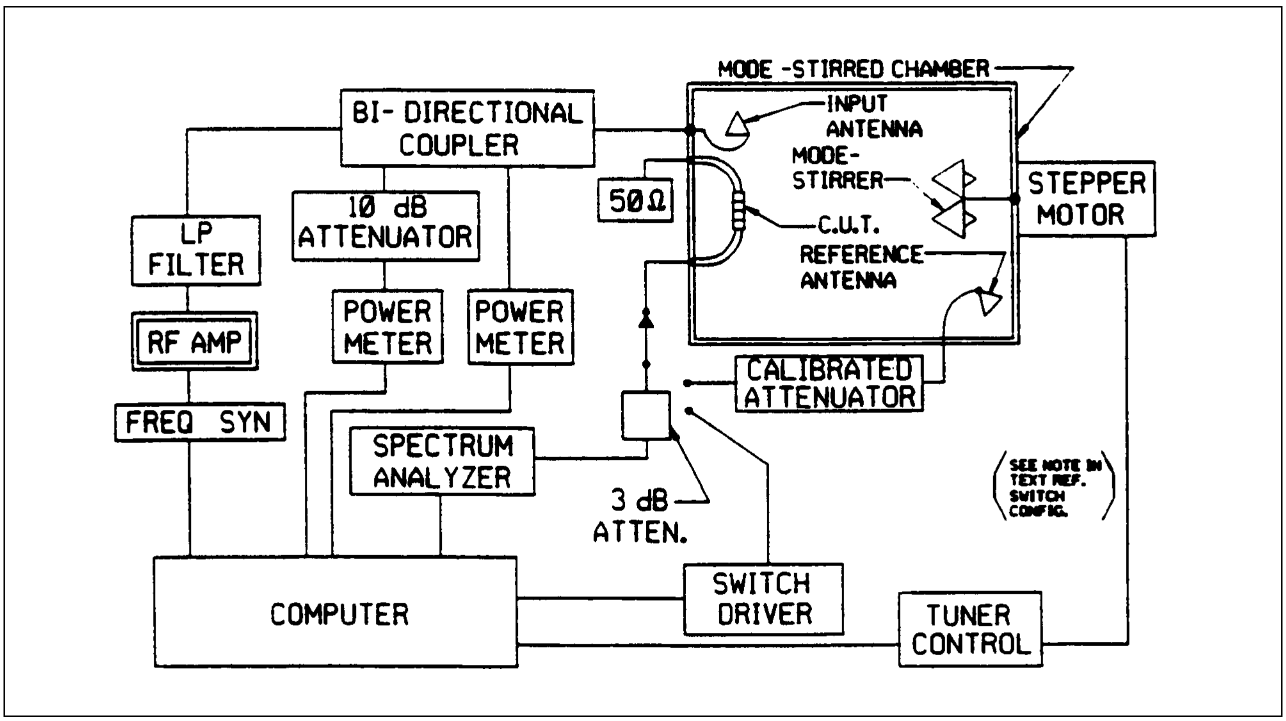

Figure 2 – Alternate test equipment configuration

2.1.4.3 The use of the receiver/spectrum analyzer for the measurement of both the reference antenna and the CUT channels places added importance on the amplitude stability of the rf power source. The source power shall be stable for the time required to make all of the required readings from both channels.

2.1.4.4 The large difference between the power level from the reference antenna and the signal level from the CUT may make it necessary to place a calibrated attenuator in the reference antenna signal path to prevent damage to the receiver/spectrum analyzer and/or to eliminate receiver nonlinearity errors.

3 Test specimen

3.1 Description

The test specimen (CUT) shall consist of mated connector plug and receptacle shells without inserts. All other components of the connector except the inserts shall be installed. Exterior items not affecting the shielding properties of the assembly may be removed.

3.2 Preparation

3.2.1 Impedance match requirements

3.2.1.1 The CUT is converted into a 50 ohm impedance air transmission line by the use of a suitable center conductor as shown in figure 3. Low loss dielectric support spacers may be used in the design. Center conductor dimensions are modified as required to compensate for the dielectric constant of the spacers and thereby maintain a 50 ohm impedance throughout the length of the CUT.

3.2.1.2 Adapters shall be used to connect the CUT to the 50 ohm conduit (or semi-rigid cable) with the least possible leakage and to maintain an impedance match between the CUT and the 50 ohm conduit. The design of the impedance-matching adapters is discussed in annex E.

3.2.1.3 The overall length of the CUT/conduit assembly shall be 4.0 ± 0.1 wavelengths at the lowest test frequency.

> NOTE — At test frequencies below 1 GHz, the length of the CUT/conduit assembly may be reduced to a length of greater than or equal to 2.0 wavelengths at the lowest test frequency. The distance of the test specimen from the wall of the chamber, see figure 3, shall then be greater than or equal to 0.5 wavelength. [1)]

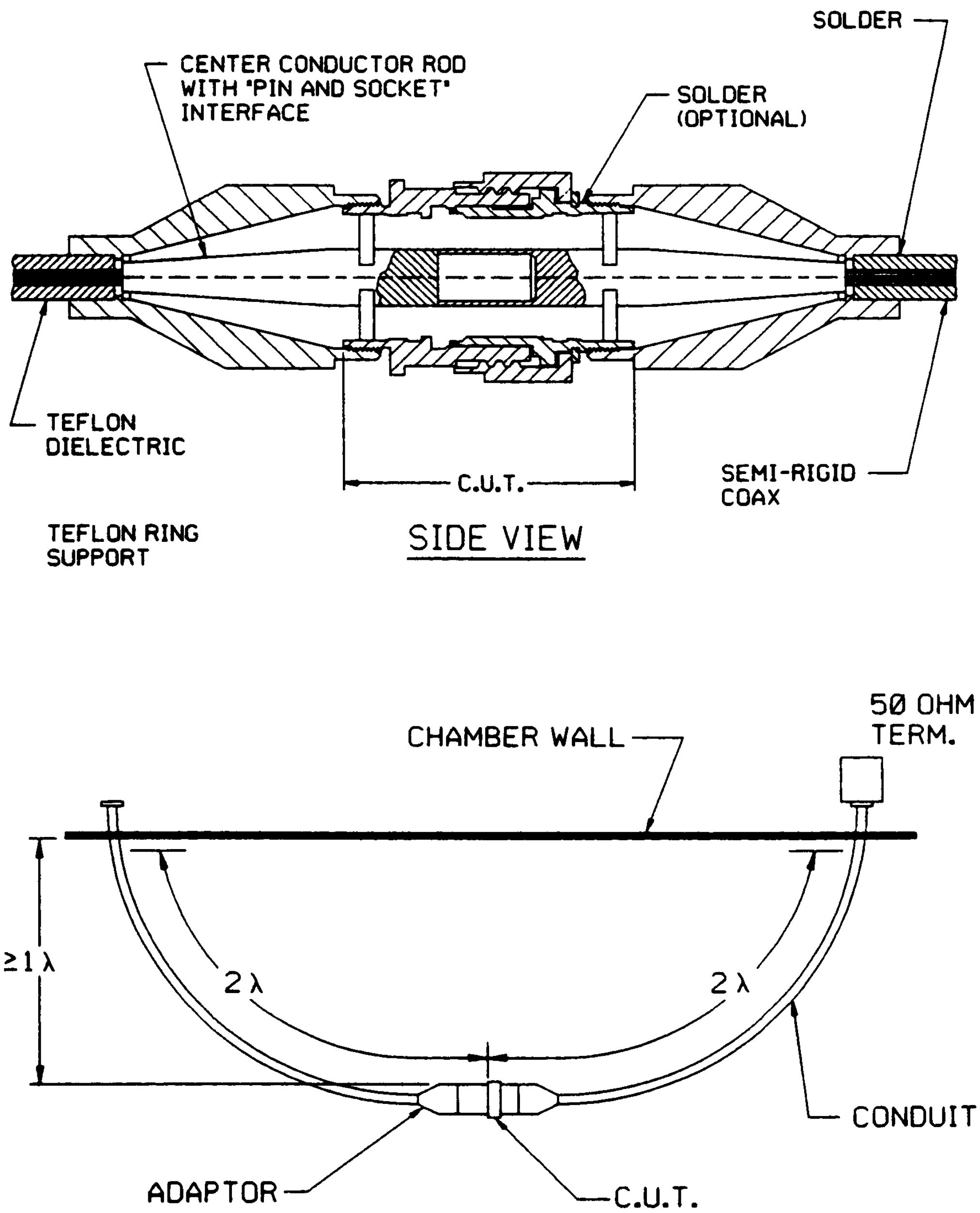

Figure 3 - Preparation and installation of test/specimen/conduit assembly

3.2.2 VSWR measurements

3.2.2.1 With the test specimen assembly terminated with a 50 ohm load, perform a swept-frequency VSWR measurement over the test frequency range.

3.2.2.2 The VSWR of the complete test specimen assembly (including conduit and terminating connectors) should not exceed 2.5:1 over the test frequency range. A graph of VSWR vs. frequency is to be included in the documentation.

NOTE — The impedance match requirement shall be limited to an upper frequency above that non-TEM modes might propagate; see annex E.

3.2.3 Test specimen installation

3.2.3.1 Install the CUT/cable assembly in the chamber and terminate it with 50 ohm load as shown in figure 3. The CUT shall be placed in the chamber so that the shortest distance between any point on the CUT and any chamber wall is at least one wavelength at the lowest test frequency.

NOTE — At test frequencies below 1 GHz, the length of the CUT/conduit assembly may be reduced to a length of greater than or equal to 2.0 wavelengths at the lowest test frequency. The distance from the test specimen from the wall of the chamber (see Figure 3) shall then be greater than or equal to 0.5 wavelength. [1)]

3.2.3.2 The points where the test specimen conduit penetrates the test chamber should be well shielded. The shielding effectiveness at these points should be equal to or exceed that of the test chamber.

4 Test procedure

4.1 Test frequencies

4.1.1 The shielding effectiveness tests are to be performed over the frequency range of 1.0 GHz to 10 GHz in steps of 1 GHz unless otherwise specified in the referencing document.

4.1.2 The mode-stirred method may exhibit significant changes in measured shielding effectiveness at a specific frequency, see footnote 1), p24 (indicated on page 2). Therefore, it shall be acceptable to utilize test frequencies that are up to 10 MHz above or below the frequencies listed above. The actual test frequency shall be set to an accuracy of 0.01 percent.

4.2 Measurement of power from reference antenna and CUT

4.2.1 It shall be acceptable to use either the peak power or the calculated average power received from the reference antenna and the CUT as the mode-tuner is rotated. This applies to both the discrete and the continuous-tuning methods.

4.2.2 The peak-level approach greatly reduces the amount of data that shall be acquired, thereby simplifying the measurement process. Using a receiver or spectrum analyzer with a "peak hold" function will facilitate this measurement.

4.3 Discrete tuning, test frequencies of 1 GHz to 2 GHz

4.3.1 Acquiring test data

4.3.1.1 At each test frequency, take 200 readings of the signal level from the reference antenna, and 200 readings of the signal from the CUT using the following steps:

4.3.1.1.1 Read the reference antenna signal power level.

4.3.1.1.2 Read the CUT signal power level.

4.3.1.1.3 Rotate the tuner by 1.8 degrees (1/200 of one full rotation).

4.3.1.1.4 Repeat 4.3.1.1.1 through 4.3.1.1.3 for a total of 200 readings.

NOTE — Variations in net input power to the test chamber (due to changes in transmitting antenna VSWR with tuner position) should be corrected for by the automated system. Monitoring the incident and reflected power at the test chamber input will enable the determination of net input power at each position of the mode-tuner. The power levels for P_{ref} and P_{cut} can then be normalized as if the net input power to the chamber were constant for all 200 positions of the mode-tuner.

4.3.2 The automated system should include a time delay after incrementing the position of the tuner to allow it to come to rest before starting to take data.

4.3.3 The signal power levels measured may be in the form of the maximum peak level obtained from each signal channel during one full rotation of the tuner; see 4.2.

4.3.3.1 Alternatively, the signal levels measured at the reference antenna and at the CUT for each of the 200 positions of the mode-tuner may be stored as two separate groups of data. Each group of data is then averaged individually.

NOTE — Data shall be converted to units of power before averaging.

4.4 Continuous tuning, test frequencies above 2 GHz

4.4.1 Acquiring test data

4.4.1.1 At each test frequency, take 3000 readings of the signal level from the reference antenna, and 3000 readings of the signal from the CUT using the following steps:

4.4.1.1.1 Set the mode-tuner drive for continuous stepping (or rotation) at a rate of between two and four minutes for one full revolution; see note.

NOTE — The rate of rotation of the mode-tuner is to be adjusted to meet the response time requirements of the monitoring instrumentation in the reference antenna and the CUT signal lines.

4.4.1.1.2 Adjust the receiver to capture data at a rate of at least 3000 specimens per complete rotation of the mode-tuner.

4.4.1.1.3 As the mode-tuner slowly rotates through one full rotation, read the signal levels from the reference antenna and the signal levels from the CUT.

4.4.1.1.4 Monitor the incident power level to the test chamber to ensure that it remains constant during 4.4.1.1.1 through 4.4.1.1.3.

4.4.2 The signal power levels measured may be in the form of the maximum peak level obtained from each signal channel during one full rotation of the mode-tuner; see 4.2.

4.4.2.1 Alternatively, the 3000 data points measured at the reference antenna and the 3000 data points at the CUT during one full rotation of the mode-tuner may be stored as two separate groups. Each group of data is then averaged individually.

NOTE — Data shall be converted to units of power before averaging.

4.5 Calculation of shielding effectiveness

4.5.1 Determine the actual signal power levels at the reference antenna and the CUT at each test frequency.

4.5.2 Apply correction factors for cable losses and attenuation errors for components in the signal paths of the reference antenna and the CUT. These corrections should be automatically applied as the operating program for the automated measurement system collects data.

4.5.3 Apply any known mismatch error corrections for the signal paths of the reference antenna and the CUT.

4.5.4 Calculate shielding effectiveness

4.5.4.1 Using the corrected data for the power received from the reference antenna and the CUT at each test frequency, calculate the shielding effectiveness of the CUT as follows:

$$SE = 10 \log \left(\frac{P_{ref}}{P_{cut}} \right) \quad \text{(dB)}$$

where:

P_{cut} = Power coupled to the connector under test
P_{ref} = Power coupled to the reference antenna

NOTES

1 P_{cut} and P_{ref} may be in the form of either the peak or the average signal power levels recorded in 4.3 and 4.4.

2 The net input power to the chamber shall be the same when measuring both P_{cut} and P_{ref} . If the net input power is not the same for both measurements, P_{cut} and P_{ref} shall be normalized as if the input power for the two sets of measurements were constant.

5 Details to be specified

The following details shall be specified in the referencing document:

5.1 Test frequencies to be used if other than those listed in clause 4

5.2 Minimum shielding effectiveness requirement at each test frequency for the connector plug and receptacle assembly (CUT) to be tested

6 Documentation

Documentation shall contain the details specified in clause 5, with any exceptions, and the following:

6.1 Title of test

6.2 Description of the CUT (test specimen)

6.3 Test equipment used, and date of last and next calibration

6.4 Plot of VSWR of test specimen over entire test frequency range

6.5 Measured shielding effectiveness at each test frequency, and the actual test frequency used

6.6 Name of operator and date of test

Annex

A Mode-stirred test chambers and antennas (informative)

A.1 Design of the mode-stirred test chamber

A.1.1 For optimum chamber performance at the lower frequencies, the volume of the chamber should be as large as possible and the ratio of the squares of the chamber's linear dimensions should not be rational numbers. [1)] This will provide spatial field uniformity and therefore accuracy in determining the shielding effectiveness of the test specimen.

A.1.2 The objective in selecting the chamber dimensions is to maximize the number of modes and to achieve as uniform a mode density as possible. Selecting the right relationship among the linear dimensions optimizes the uniformity in the mode density, thus minimizing "gaps" in the frequency spectrum.

A.1.3 A typical test chamber designed for use at test frequencies from 1 GHz to 10 GHz and meeting the above guidelines would have internal dimensions of 1.164 m X 1.427 m X 1.487 m.

A.1.4 Further detail in calculating the optimum test chamber dimensions is given in footnote 1)

A.1.5 The test chamber can be constructed from sheet aluminum to minimize weight and to obtain a relatively high Q. Any objectionable material present should be removed from the chamber prior to use.

A.2 Input and reference antennas

A.2.1 The antennas should be broad-brand ridged horns rated for operation at frequencies from 1 GHz to 10 GHz.

A.2.2 The antennas should be located in different corners of the chamber, and faced into the corners to minimize cross-coupling between them or between an antenna and the test specimen assembly.

B Mode-tuner (informative)

B.1 General

B.1.1 The design of the mode-tuner is not critical, although it should be as large as possible consistent with available space. The tuner should be a minimum of two wavelengths in size and bent at angles to the walls of the chamber.

B.1.2 Construction is accomplished with simple hand tools and final adjustment is performed by hand bending.

B.1.3 A metal shaft is attached to the center of the mode-tuner to provide mechanical rotation. The tuner shaft is mounted to the test chamber through a conductive collet to prevent rf energy from being coupled outside the chamber.

B.1.4 The mode-tuner is constructed from a sheet of aluminum as shown in figure B-1 and figure B-2.

B.1.5 The dimension “d” in figure B-1 shall be a minimum of two wavelengths at the lowest test frequency (0.6 meter at 1 GHz), and should be as large as available space will allow.

B.2 Construction

B.2.1 The following procedures are in accordance with the circled numbers of figure B-1(A).

B.2.1.1 Cut a rectangular aluminum sheet to conform to the overall dimensions shown on figure B-l(A).

> NOTE — The dimension “d” shall be a minimum of two wavelengths at the lowest test frequency.

B.2.1.2 Referring to figure B-l(A), measure up from lower left hand corner a distance 0.465d and place a mark on the sheet ①. Scribe a line ② on the sheet from the ① to the lower right-hand corner of the sheet. Repeat the above procedure, placing a mark ③ on the upper portion of the sheet and scribing a line ④ to the upper right-hand corner of the sheet.

B.2.1.3 From the center right-hand side of sheet, make a cut in sheet ⑤ parallel to short side for a distance of 0.18d. Make a mark ⑥ on right-hand side of the sheet at a distance of 0.125d up from the lower right-hand corner. Scribe a line ⑦ from vertex of the cut to the mark ⑥. Place another mark ⑧ on the sheet at a distance of 0.215d down from the upper right-hand corner. Scribe a line ⑨ from the vertex of the cut to this last mark ⑧.

B.2.1.4 Place a scribe mark ⑩ at the center of the sheet.

As shown on figure B-l(B), starting with the lower left-hand corner, bend the triangle formed by this corner and scribe line ② along the scribe line away from the observer. Hand-adjust this angle to be approximately 45 degrees measured with respect to the plane of the sheet. Repeat the same procedure to bend the upper left-hand corner along scribe line ④ away from the observer at a 45 degree angle.

B.2.1.5 Starting at the corner where the cut ⑤ intersects the right side of the sheet, bend the triangle formed by this corner and scribe line ⑦ along the scribe line toward the observer. Hand-adjust this angle to be approximately 30 degrees measured with respect to the plane of the sheet. Repeat the same procedure to bend the triangle formed by the ⑤ and scribe line ⑨. This triangle should also be bent toward the observer at an approximate 30 degree angle.

B.2.1.6 Attach the tuner shaft to the completed mode-tuner at the center of the rectangle ⑩ at the top of the tuner, and extending toward the observer.

B.2.1.7 The design of a collet for mounting the tuner shaft to the wall of the chamber and to the drive motor is shown in figure B-2.

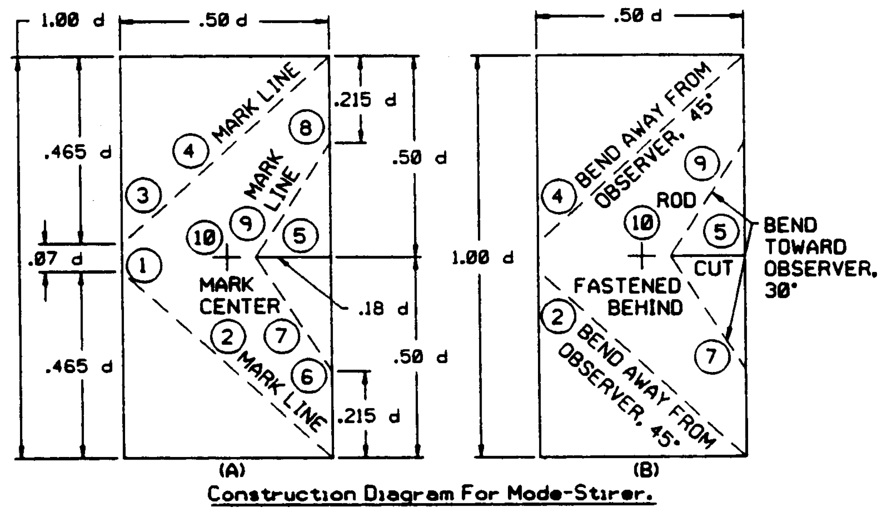

Figure B.1 – Mode-tuner construction

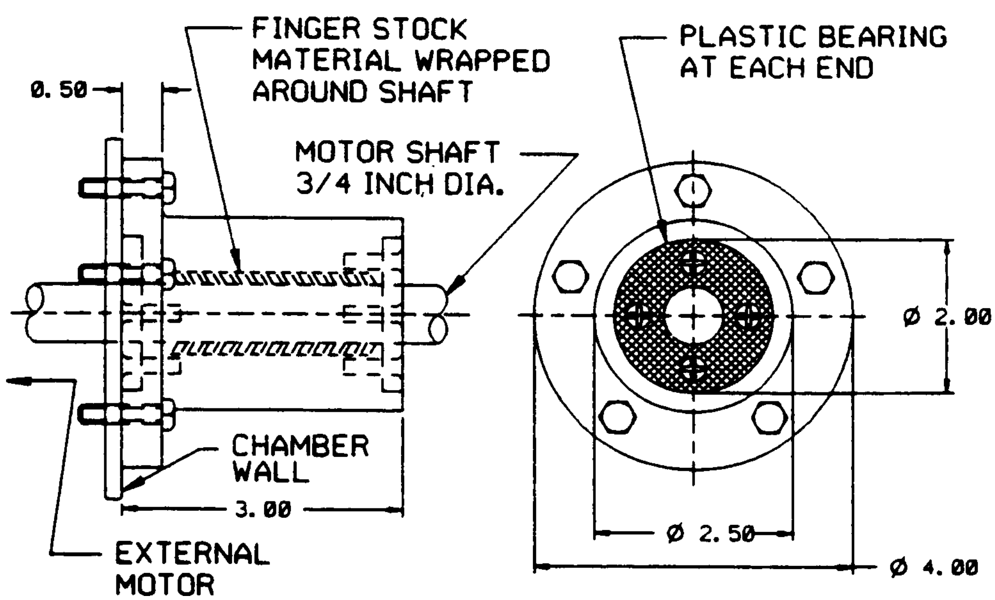

Figure B.2 - Details of collet for mounting tuner shaft to drive motor through wall of test chamber

C Test equipment and ancillary components (informative)

C.1 General

The following is given as a guide to the performance requirements of the key instrumentation used to make up the mode-stirred system.

C.2 Test Equipment

Receiver/Spectrum Analyzer

C.2.1 The low signal levels associated with the measurement of shielding effectiveness dictates the requirement for a receiver/spectrum analyzer with the following characteristics:

- narrow bandwidth,
- tuned frequency stability,
- high sensitivity,
- low noise figure.

C.2.2 The receiver should be capable of high-speed data sampling to enable the capture of a large number of data points during the continuous tuning test; see 4.4.

C.3 Signal source

The signal source should have the following characteristics to enable the proper operation of the receiver/spectrum analyzer, and thereby enable the measurement of the low-level signals from the CUT:

- frequency synthesizer stability,
- low residual frequency modulation,
- sufficient output level to drive the power amplifiers to rated output.

C.4 Power amplifier

C.4.1 The rf power level required at each test frequency to satisfactorily perform the shielding effectiveness measurement of the CUT is dependent upon several factors:

- required range of shielding effectiveness to be measured,
- Q of the mode-stirred test chamber,
- sensitivity of receiver/spectrum analyzer.

C.4.2 Power amplifiers rated up to 20 watts cw may be required to enable measurement of shielding effectiveness levels of 100 dB or more.

NOTE — The overall range of the mode-stirred shielding effectiveness measurement system should be at least 10 dB greater than the minimum specified for the test specimen at each test frequency.

C.5 Components

C.5.1 Attenuators, directional couplers, and cables

The input and output VSWR of all attenuators, directional couplers, and cables in the signal lines from the reference antenna and the CUT should be less than or equal to 1.3:1. The use of high quality components with low VSWR will minimize measurement uncertainties due to impedance mismatch errors.

C.5.2 Low-pass filters

C.5.2.1 Low pass-filter with a cutoff frequency equal to the test frequency should be used between the power amplifier and the input antenna to suppress unwanted harmonics.

C.5.2.2 The presence of harmonics in the rf input power to the test chamber can cause errors in the output level of the diode detector used in the reference antenna line; see figure 1.

D Mismatch error corrections (informative)

D.1 The following applies to the determination of actual mismatch losses during mode-tuned operation (test frequencies below 2 GHz). The largest variations in the VSWR of the reference antenna and the test specimen assembly, and therefore the largest potential error in signal level measurements, occur over this frequency range.

D.2 The actual mismatch loss between the sources (reference antenna and CUT), and the loads (detector and receiver/spectrum analyzer) at each position of the mode-tuner can be determined. The amount of signal power loss from the reference antenna or from the CUT can be found from the following.

D.3 The fraction of the maximum available power that is absorbed by the load is:

$$P_f = \frac{\left(1-\left|\Gamma_S\right|^2\right)\left(1-\left|\Gamma_L\right|^2\right)}{\left|1-\Gamma_S\Gamma_L\right|^2} \quad i = S \text{ or } L$$

where:

Γ_S and Γ_L denote the complex reflection coefficients for the source and load. The magnitudes, can be obtained from the appropriate VSWR by the equation:

$$\left|\Gamma_i\right| = \frac{\mathrm{VSWR}-1}{\mathrm{VSWR}+1}$$

where:

i = S or L

D.4 The reference antenna or the CUT is considered the source and the detector or the receiver/spectrum analyzer is the load. Corrections for mismatch can be made only if measurements of the complex reflection coefficients for the detector, receiver, and the reference antenna and the CUT are made. If just the VSWR is measured, then only an estimate of the magnitude of the uncertainty can be obtained.

E Test specimen and impedance matching (informative)

E.1 General

E.1.1 The CUT is converted into a 50 ohm impedance air transmission line by the use of a suitable center conductor assembly. The transition between the CUT and the 50 ohm conduit can be achieved by the use of tapered or otherwise compensated adapters with matching center conductors. The use of dielectric spacers to support the center conductor within the CUT and the adapters is acceptable.

E.1.2 The upper frequency limit for which the matched impedance requirement of Section ;7.0 can be met (VSWR ≤ 2.5) is theoretically limited to the TEM mode of transmission line propagation.

E.1.3 For circular connectors, the shortest wavelength for TEM propagation is approximated by the mean circumference of the annular space in the coaxial structure (equal to 4.1 GHz for a shell size 25 circular connector).

> NOTE — The above frequency limit is a theoretical value. In short structures (such as a standard MIL-C-38999 connector), high order modes occur at significantly higher frequencies than indicated by the theoretical limit given above.

E.1.4 For rectangular connectors, the theoretical upper frequency limit is one that the internal width of the connector is greater than a half-wavelength. The overall length of the CUT/adapter assembly should be kept as short as possible.

> NOTE — Swept-frequency VSWR or transmission loss measurements may be used as an aid in determining at what frequency any non-TEM modes occur. However, the CUT/conduit adapters may mask spurious modes within the connector itself.

E.2 Circular connectors

E.2.1 A circular connector with an impedance-matching center conductor rod and tapered adapter is shown in figure 3.

> NOTE — It shall be acceptable to use matching structures other than the tapered adapter to achieve the required impedance match.

E.2.2 The outer diameter of the round-rod center conductor for typical MIL-C-38999 connectors is given for the examples listed in table E.1. The associated theoretical upper frequency limit is also given.

E.2.3 The dimensional data in Table E-1 was calculated from:

$$Z_o = \frac{138}{\sqrt{\varepsilon_r}} \log_{10} \frac{D}{d}$$

where:

ε_r = Dielectric constant
D = Inner diameter of outer conductor
d = Outer diameter of inner conductor

Table E.1 - Circular connectors center conductor diameter

MIL-C-38999 shell size	Internal diameter, nominal	Center conductor, outer diameter	TEM frequency, maximum
11	11.12 (0.438)	4.95 (0.195)	12.0 GHz
17	20.32 (0.800)	9.02 (0.355)	6.5 GHz
25	31.75 (1.250)	14.22 (0.560)	4.1 GHz

E.3 Rectangular connectors

E.3.1 A rectangular connector with an impedance-matching flat strip center conductor and tapered adapter is shown in figure E.2.

NOTE — It shall be acceptable to use matching structures other than a tapered adapter to achieve the required impedance match.

E.3.2 The width and thickness of the flat-strip center conductor for three examples of rectangular connectors are listed in table E.2, together with the theoretical upper frequency limit.

E.3.3 The initial dimensions of the strip center conductor are calculated from strip transmission line equation (E.1). A Time Domain Reflectometer (TDR) can then be used to determine what trimming of center conductor dimensions may be needed to meet the controlled impedance requirement.

NOTE — A round rod may be used as the center conductor for a square (internal dimensions) connector.

E.3.4 The dimensional data in table E.2 was calculated from:

$$Z_o = \frac{94.15}{(\varepsilon_r)^{1/2}\left[\dfrac{w}{b\left(1-\dfrac{t}{b}\right)} + \dfrac{C^f}{0.0885\varepsilon_r}\right]} \quad \text{ohms} \qquad \text{(E.1)}$$

where:

$\in_r$ = Dielectric constant of the medium between the conductors
C^f = Fringing capacitance in picofarads per centimeter
w, t, and b are given in figure E.1

NOTE — C^f was assumed to be 0.053 pF/cm for the examples in table E.2.

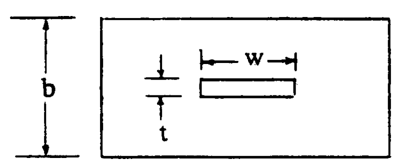

Figure E.1 - Cross sectional view of rectangular test specimen with flat-strip center conductor

Table E.2 - Rectangular connectors nominal dimensions for strip center conductor

Connector		**Center conductor**		**TEM frequency, maximum**
Height (see note)	**Width (see note)**	**Thickness**	**Width**	
12 (0.5)	25 (1.0)	2.5 (0.10)	13.2 (0.52)	5.9 GHz
25 (1.0)	50 (2.0)	3.0 (0.12)	27.9 (1.10)	2.9 GHz
38 (1.5)	75 (3.0)	5.1 (0.20)	41.9 (1.65)	1.9 GHz
NOTE — Internal dimensions				

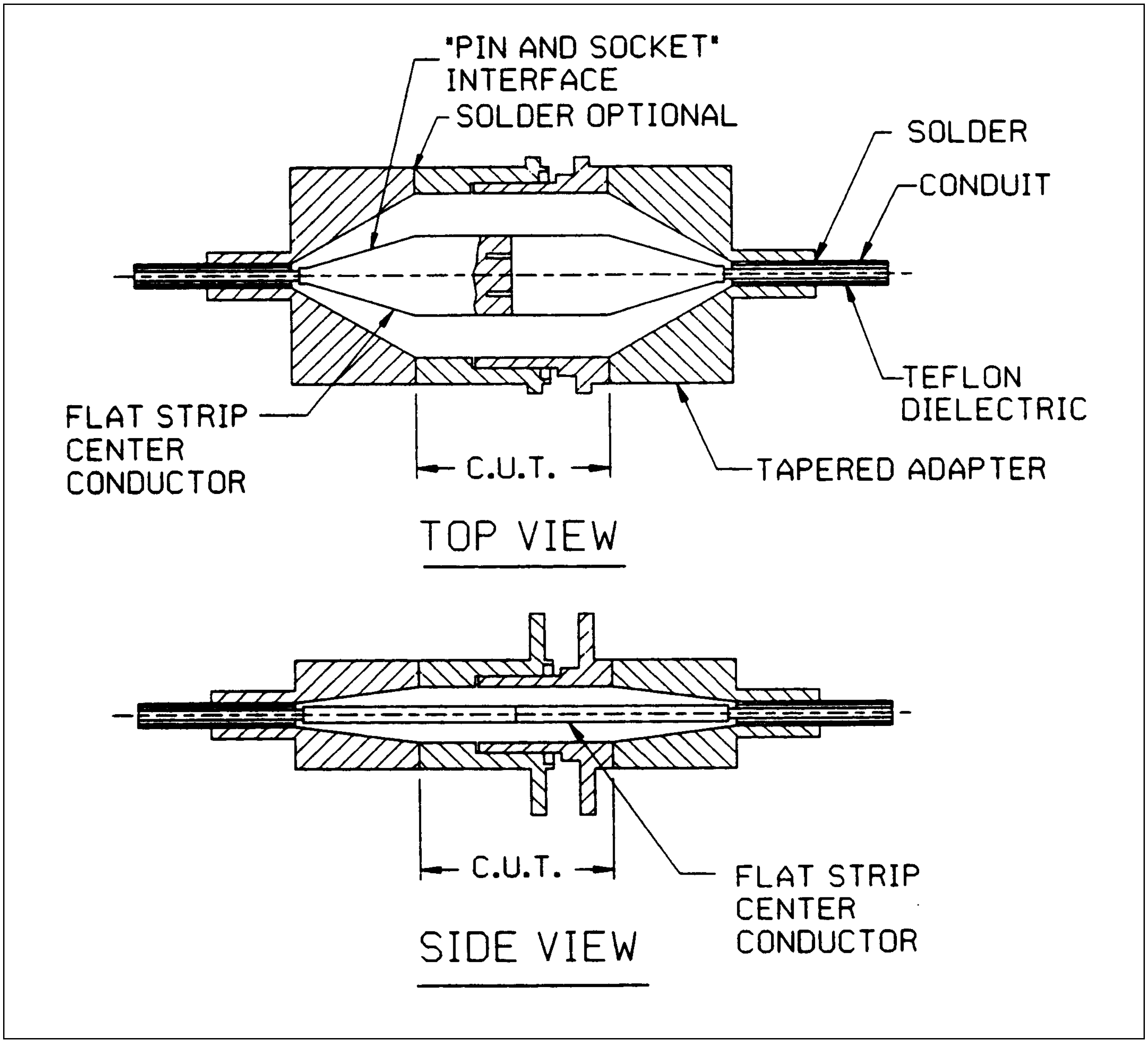

Figure E.2 – Rectangular connector/tapered adapter/conduit assembly

F Test system dynamic range (informative)

F.1 The minimum signal level, or maximum shielding effectiveness, that can be measured by a specific mode-stirred system is a useful indicator of system performance.

F.2 This maximum range of shielding effectiveness can be measured by substituting a continuous section of conduit in place of the normal test specimen assembly, and performing the shielding effectiveness measurements as described in the test procedure. The resulting SE should be at least 10 dB greater than the minimum specified for the test specimen at each test frequency.

G References (informative)

The following documents are provided as reference information:

G.1 P. I. Pressel, *"Mismatch: A Major source of Error In Shielding Effectiveness Measurements,"* Seventeenth Annual Connectors and Interconnection Technology Symposium Proceedings, September, 1984. Published by the Electronic Connector Study group.

G.2 M. L. Crawford, *"Generation of Standard EM Fields Using TEM Transmission Cells,"* IEEE Transactions On Electromagnetic Compatibility, VOL. EMC-16, No. 4, November 1974

G.3 MIL-C-38999: Connector, Electrical. Circular, Miniature, High Density Quick Disconnect, (Bayonet, Threaded and Breech Coupling) Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification for

G.4 MIL-STD-285: Attenuation Measurements for Enclosures, Electromagnetic Shielding for Electronic Test Purposes, Method of

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