SAE International™

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J1113-27

REV. SEP2005

Issued 1995-02
Revised 2005-09

Superseding J1113-27 FEB1995

(R) Electromagnetic Compatibility Measurements Procedure for Vehicle Components—Part 27—Immunity To Radiated Electromagnetic Fields—Mode Stir Reverberation Method

1. Scope

1.1 Vehicle electrical/electronic systems may be affected when immersed in an electromagnetic field generated by sources such as radio and TV broadcast stations, radar and communication sites, mobile transmitters, cellular phones, etc. Reverberation method is used to evaluate the immunity of electronic devices in the frequency range of 500 MHz to 2.0 GHz, with possible extensions to 200 MHz and 10 GHz, depending upon chamber size and construction. Optional pulse modulation testing at HIRF (High Intensity Radiated Fields) test levels, based upon currently known environmental threats, has been added to this revision of the standard. This document addresses the Mode Stir (Continous Stirring) Reverberation testing method which has been successfully utilized as a design and production stage development tool for many years. The Mode Tuned (Stepped Tuner) Reverberation testing method is covered in the SAE J1113-28 document.

1.2 This document provides the component design and test engineers with a test procedure and the performance requirements necessary to quickly evaluate the immunity of electronic devices to radiated electromagnetic fields early in the design stage as well as pilot and production stages. This method is an alternative to testing in an absorber lined chamber. Ensuring electromagnetic compatibility early in the development stage will minimize costly changes later in the program and will prevent excessive component level hardening during full-vehicle level testing.

1.3 The reverberation test method performs a dual function:

1.3.1 The primary function of the method is to provide a bench test procedure correlative to vehicle-level radiated immunity testing in the anechoic chamber and at mobile transmitter sites.

1.3.2 The method can quickly evaluate the relative performance of different designs of the same device.

1.4 Rationale and Application

Vehicle electrical/electronic systems may be affected when immersed in an electromagnetic field generated by sources such as radio and TV broadcast stations, radar and communication sites, mobile transmitters, cellular phones, etc. Reverberation method is used to evaluate the immunity of electronic devices in the frequency range of 500 MHz to 2.0 GHz, with possible extensions to 200 MHz to 10 GHz, depending upon chamber size and construction. Pulse modulation testing at HIRF (High Intensity Radiated Fields) test levels has been aded to this revision of the standard. This document addresses the Mode Stir (Continous Stirring) Reverberation testing method which has been successfully utilized as a design and production stage development tool for many years. The Mode Tuned (Step Dwell) Reverberation testing method is covered in the SAE J1113-28 document

This document provides the component design and test engineers with an test procedure and the performance requirements necessary to quickly evaluate the immunity of electronic devices to radiated electromagnetic fields early in the design stage as well as pilot and production stages. This method is an alternative to testing in an absorber lined chamber. Ensuring electromagnetic compatibility early in the development stage will minimize costly changes later in the program and will prevent excessive component level hardening during full-vehicle level testing.

The primary function of the method is to provide a bench test procedure correlatable to vehicle-level radiated immunity testing in the anechoic chamber and at mobile transmitter sites.

The method can be used to quickly evaluate the relative performance of different designs of the same device.

2. References

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

General information regarding this test, including general definitions, and safety considerations are found in SAE J1113-1.

2.1.1 SAE Publication

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1113-1—Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components (Except Aircraft)

2.1.2 NBS Publication

Available from NIST, U.S. Department of Commerce, Gaithersburg, MD 20899.

NBS Technical Note 1092—Design, Evaluation, and Use of a Reverberating Chamber for Performing Electromagnetic Susceptibility / Vulnerability Measurements

2.1.3 NIST PUBLICATIONS

Available from NIST, U.S. Department of Commerce, Gaithersburg, MD 20899.

NIST Technical Note 1506—Electromagnetic Theory of Reverberation Chambers
NIST Technical Note 1508—Evaluation of the NASA Langley Research Center Mode-Stirred Chamber Facility

3. Definitions

Definitions specific to this test method are included.

3.1 Reverberation Chamber

A high Q shielded room (cavity) whose boundary conditions are changed via a rotating tuner. This results in a time-averaged uniform electromagnetic field. See Appendix A for additional information.

3.2 Tuner

A rotating metallic reflector that changes the boundary conditions in a reverberation chamber as it rotates. As the tuner rotates, the nulls and maximums in the field change location, ensuring the DUT and wiring harness are exposed to a time-averaged uniform field. See Appendix A for additional information.

3.3 Mode Stir

A reverberation method that rotates the tuner continuously while sampling the reference antenna received power, field probe response, and DUT response at rates much faster than the tuner revolution rate.

3.4 Chamber Quality Factor (Q)

(Reference: IEEE Standard Dictionary of Electrical and Electronic Terms, Fourth edition 1988)

Q is two pi times the ratio of the maximum stored energy to the energy dissipated per cycle at a given frequency. A measure of a cavity's ability to reverberate (see A.1.2).

Q, for a cavity, is defined as shown in Equation 1:

$$Q = \frac{\omega * \text{Energy Stored}}{\text{Average Power Dissipated}} \quad \text{(Eq. 1)}$$

where:

ω is 2π * f (radians/sec)
f is frequency (Hz)

An approximate equivalent definition for Q is the ratio of the resonance frequency to the bandwidth between the frequencies on opposite sides of the resonance frequency (known as half-power points) where the response of the resonant structure differs by 3 dB from that at resonance.

$$Q = \frac{f_{resonance}}{BW_{3dB}} \qquad \text{(Eq. 2)}$$

where:

$f_{resonance}$ is Resonance frequency (Hz)
BW_{3dB} is 3 dB bandwidth of the resonance frequency (Hz)

For transients or pulsed signals, the rise or decay time constant τ is related to the Q of the chamber and frequency ω by the equation

$$Q = \omega\tau \qquad \text{(Eq. 3)}$$

3.5 Q_w

Theoretical Q with losses of walls included.

3.6 Q_a

Theoretical Q with losses of antennas included.

3.7 Q_{net}

Theoretical Q with losses of antennas and walls included.

3.8 Q´

Empirical Q, which is the measured cumulative Q of the cavity. This value takes into account chamber loading effects such as the DUT and monitoring equipment (see A.1.2).

3.9 F_{cr}

The cutoff frequency above which cavity losses are primarily due to wall losses instead of antenna losses.

3.10 L

Chamber loss. The ratio (in dB) of the maximum received power (in watts) to the average transmitted forward power (in watts).

3.11 DUT

Device Under Test.

4. Test Equipment

4.1 RF Signal Generator

500 MHz to 2.0 GHz (200 MHz to 10 GHz optional). Pulse modulation capability optional.

4.2 Broadband Power Amplifier(s)

500 MHz to 2.0 GHz (200 MHz to 10 GHz optional). Power requirements: 50 W minimum below 1 GHz, 250 W above 1 GHz (pulse capibility optional). The amplifier should be able to drive a load of any impedance mismatch for at least 15 s without damage to itself.

4.3 Antennas

Two antennas are needed, one for transmission and one for reception.

4.3.1 Suggested antennas:

a. 500 (200 optional) MHz to 1 GHz - Log periodic
b. 1 GHz to 2 (10 optional) GHz Double ridged guide

4.4 Spectrum Analyzer

500 MHz to 2.0 GHz (200 MHz to 10 GHz optional).

4.5 Directional Couplers

500 MHz to 2.0 GHz (200 MHz to 10 GHz optional). Average power 500 W, peak power 10 kW, coupling factor 20 dB minimum, and directivity 20 dB minimum.

4.5.1 Two directional couplers are needed for the following uses:

a. Transmit forward power
b. Transmit reflected power

4.5.2 TYPICAL BANDS

a. 0.5 (0.2 optional) to 1 GHz
b. 1 to 2 GHz
c. 2 to 10 GHz (optional)

4.6 10 dB Attenuator

500 MHz to 2.0 GHz (200 MHz to 10 GHz optional), power rating 50 W average, 1 kW peak.

4.7 Power Meter

500 MHz to 2.0 GHz (200 MHz to 10 GHz optional), including power sensor heads (peak power sensor heads optional).

4.7.1 Two power meters are needed, one for transmit forward power and one for transmit reflected power.

4.7.2 The power meters should have a sample rate sufficient to capture at least 400 samples per tuner revolution.

4.8 Computer Control (recommended)

Specialized software used in conjunction with a computer and the RF test equipment should be utilized to characterize the chamber performance per Appendix B, prior to any testing. The software should store the characterization information for use during testing. The computer and software will then be used to control the RF test equipment and tuner during the testing. The software shall be capable of performing the tests as described in Para 7 of this document.

4.9 Mode Stir Chamber

Reverberation chamber with a tuner (see Appendix A). The room shall be constructed of steel (preferably galvanized, but cold rolled steel is allowed). Minimum recommended room dimensions are 4.88 m x 3.66 m x 3.05 m (16' L x 12' W x 10' H). Key characteristics of the chamber shall be verified to ensure an accurate and valid test (see Appendix B).

4.10 RF Field Monitoring

Two broadband electric field probes. The probes should be a single linear axis or, if isotropic, should allow access to each individual axis. An isotropic probe with only the root-sum-squares (total field) output may be used but will generally indicate a higher electric field than the receive power calculations. The probes should have a sample rate sufficient to capture at least 400 samples per tuner revolution.

4.11 Tuner

A three-dimensional, asymmetrical tuner is recommended. See Paragraph A.1.4. of Appendix A for design considerations. The tuner shall be made of conductive material (e.g., aluminum or galvanized steel). Tuner examples are shown in Figures A1 through A4.

5. Test Conditions

See SAE J1113-1 section 6 for additional guidance on test conditions.

5.1 Test Temperature and Supply Voltage

The ambient temperature in the test facility shall be recorded. A battery with an electrical charging system shall be used to provide 13.5 VDC +/-0.5 VDC to the DUT.

5.2 Frequency Range

To test automotive electronic systems, the applicable frequency range of this test method is 500 MHz to 2 GHz (200 MHz to 10 GHz optional). Testing over the full frequency range is not required and is should be done at the engineering judgment of the component manufacturer. At a minimum the testing should be performed over the frequency range of 500 MHz to 2.0 GHz. Different field-generating devices may be required for testing over the full frequency range. This does not imply that testing of overlapping frequency ranges is required. Ultimately, the frequency range may be limited to the chamber performance and the method being utilized.

5.3 Modulation

See SAE J1113-1. In addition, the characteristics of the DUT shall be used to determine the type and frequency of modulation. If no values are agreed between the users of this document, the following shall be used: a) No modulation (CW), b) 1 kHz sine wave amplitude modulation (AM) 80%, and c) Pulse Modulation should also be considered at frequencies above 800 MHz (See Table C1 of Appendix C for suggested Pulse Modulations and test severity levels associated with those pulse modulations).

5.4 Dwell Time

See SAE J1113-1. In addition, at each frequency, the DUT shall be exposed to the test level for at least one rotation of the tuner. If multiple tuners are used, the dwell time shall be at least one rotation of the slowest tuner. It is assumed that, during any measurement, the DUT is exposed to a constant field for the duration of the dwell time. Since, in a mode-stirred measurement, the tuner is constantly turning, it is not possible to hold the fields perfectly constant. Therefore, care must be taken to ensure that the tuner is turned slowly enough that the fields remain approximately constant for the duration of the dwell time. This may require a tuner rotation period that is several hundred times longer than the dwell time, and will be a function of frequency.

The rotation rate used at each frequency, as well as the method used to determine the rotation rate, must be documented in the test report.

5.5 Frequency Steps

See SAE J1113-1. The tests will be conducted with the maximum frequency step sizes shown in Table 1. Alternatively, logarithmic frequency steps, with the same minimum number of frequency steps in each frequency band, can be determined using the formula and Table 2 below. The values, as agreed by the users of this document, shall be documented in the test report. In either case, if it appears that the susceptibility thresholds of the DUT are very near the chosen test level, these frequency step sizes should be reduced in the concerned frequency range in order to find the minimum susceptibility thresholds. (Refer to SAE J1113-1.)

TABLE 1—LINEAR FREQUENCY STEPS

Frequency Band	Maximum Frequency Step Size
200 MHz to 1 GHz	20 MHz
1 GHz to 10 GHz	200 MHz

TABLE 2—LOGARITHMIC TEST FREQUENCY CALCULATION

$$f_{test} = f_0 * 2^{\left(\frac{k}{n}\right)}$$

where:

f_0 is base frequency

k is Frequency index number (1,2,3,…)

n is Number of steps per octave

Frequency Range (MHz)	fo (MHz)	n
1…<30	1	7
30…<400	30	25
400…<1000	400	25
1000…<10 000	1000	50

5.6 Test Signal Quality

(See SAE J1113-1).

5.7 Threshold of Response

See SAE J1113-1. In addition for this continuously stirred test method; as a responding frequency is being thresholded, the amplitude should be slowly increased in to allow time for one tuner rotation so that the unit is allowed to be subjected to the high point of the field. The peak field point shall be recorded as the threshold amplitude level.

5.8 Test Severity Levels

The DUT manufacturer shall specify the test severity level(s) over the frequency bands to be tested. Suggested test severity levels are included in Appendix C of this document. A full description and discussion of the Function Performance Status Classification including Test Severity Levels are given in SAE J1113-1 Appendix A. Please review it prior to using the suggested Test Severity Levels presented in Appendix C. These test severity levels are expressed in terms of equivalent root-mean-square (RMS) value of an unmodulated wave. Peak conservation shall be used during amplitude and pulse modulated tests. (Refer to SAE J1113-1).

6. Test Setup

6.1 A general layouts of various types of reverberation chambers are shown in Figure 1 and Figure 2.

6.2 The DUT shall be operated in its designed modes. Appropriate control signals shall be provided. Actual loads should be used for a subsystem test and simulated loads may be used for a component test.

6.3 DUT nominal condition and deviation criteria shall be clearly defined in the test plan. Appropriate instrumentation for monitoring and actuating the DUT shall be provided by the component supplier.

6.4 Steps shall be taken to prevent RF energy from coupling into control and monitoring equipment to prevent erroneous readings. This may require RF hardening of the simulator and the control/monitoring equipment. The simulator may be placed outside the room. Either filtering or fiber optic cables may be required. If filters are used, care should be taken to ensure that the filters do not present additional loading or affect the immunity of the DUT.

6.5 If the outer case of the DUT is intended to be grounded to the vehicle metal structure, the DUT should be mounted to a ground plane during testing. The ground plane should be placed at a distance not less than $\lambda/4$ (at the lowest frequency) above the floor level (preferably on a styrofoam "TM" block). Large DUTs may be placed directly on the floor. The ground plane shall be placed at least $\lambda/4$ from any wall at the lowest frequency of use. If the DUT is not grounded to the vehicle metal structure, the DUT and harness shall be placed directly on a styrofoam block.

6.5.1 The ground plane shall be constructed from either copper, brass or galvanized steel.

6.5.2 The minimum ground plane size is defined in SAE J1113-1. The minimum size of the ground plane depends upon the size of the system under test and shall allow for complete harness and system component placement.

6.5.3 The ground plane shall be bonded to the chamber wall with a bonding strap with a minimum width of 7.6 cm.

6.6 A 1.7 m to 2 m wiring harness shall be used, unless otherwise specified in the test plan. The length of the wiring harness shall be documented in the test report.

6.7 Antennas, probes, and the DUT shall be placed at distances not less than $\lambda/4$ (at lowest frequency) from the chamber walls and corners. The DUT shall be at least $\lambda/6$ away from the tuner.

6.8 The main beam of the field-generating antenna and field-monitoring antenna are aimed into a corner of the chamber or at the tuner to minimize direct coupling to the DUT. Antennas shall be aimed at different corners of the room. An upward tilt of 20 degrees or more should be used. Antenna polarization is not critical, but for standardization, horizontal polarization is suggested.

6.9 Antennas and probes should be placed on styrofoam supports, at least $\lambda/4$ (at lowest frequency) above the floor.

6.10 All unnecessary RF absorbing material shall be removed from the room (e.g., wooden tables, carpeting, extra equipment, etc.).

6.11 Tuner revolution rate is typically 10 to 20 s/rev (3 to 6 rpm). This rate shall be adjusted accordingly for probe and DUT response time.

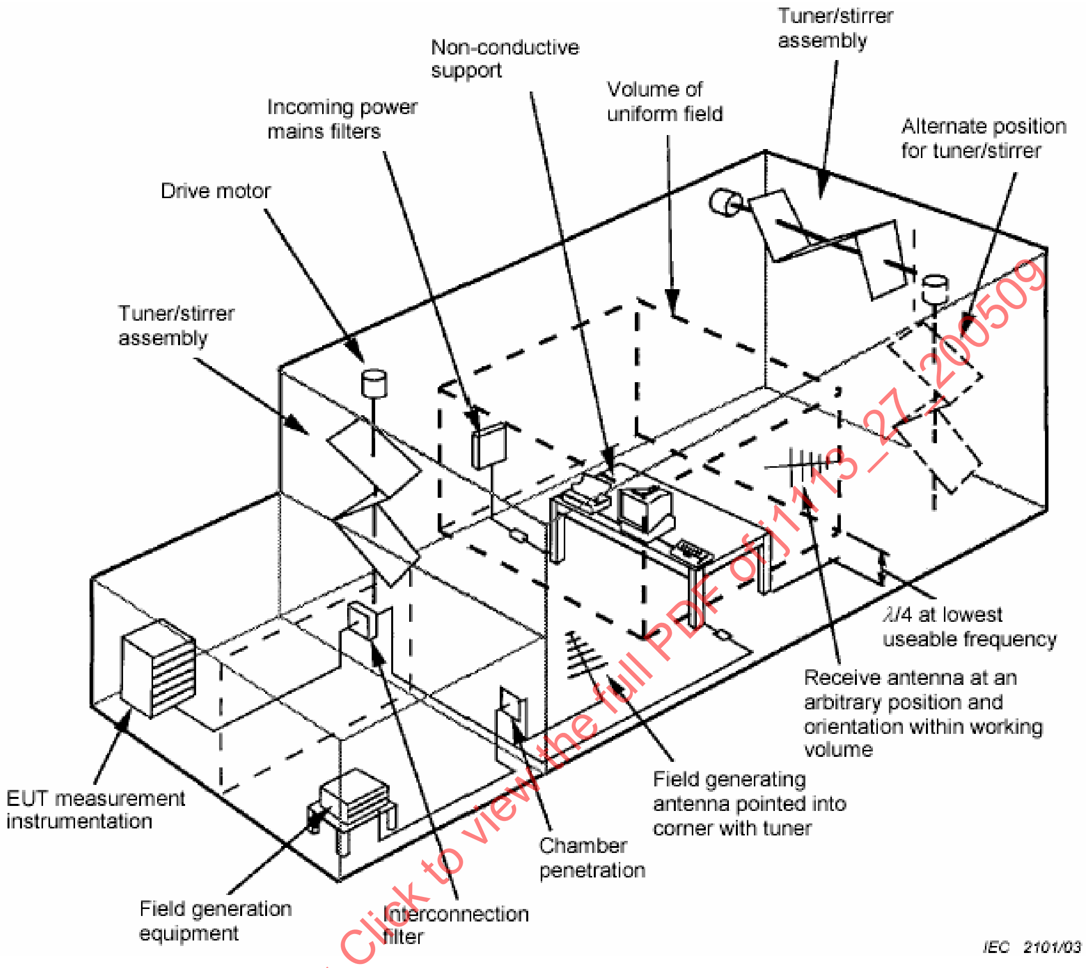

FIGURE 1—TYPICAL REVERBERATION CHAMBER LAYOUT (Z-FOLD TUNER)

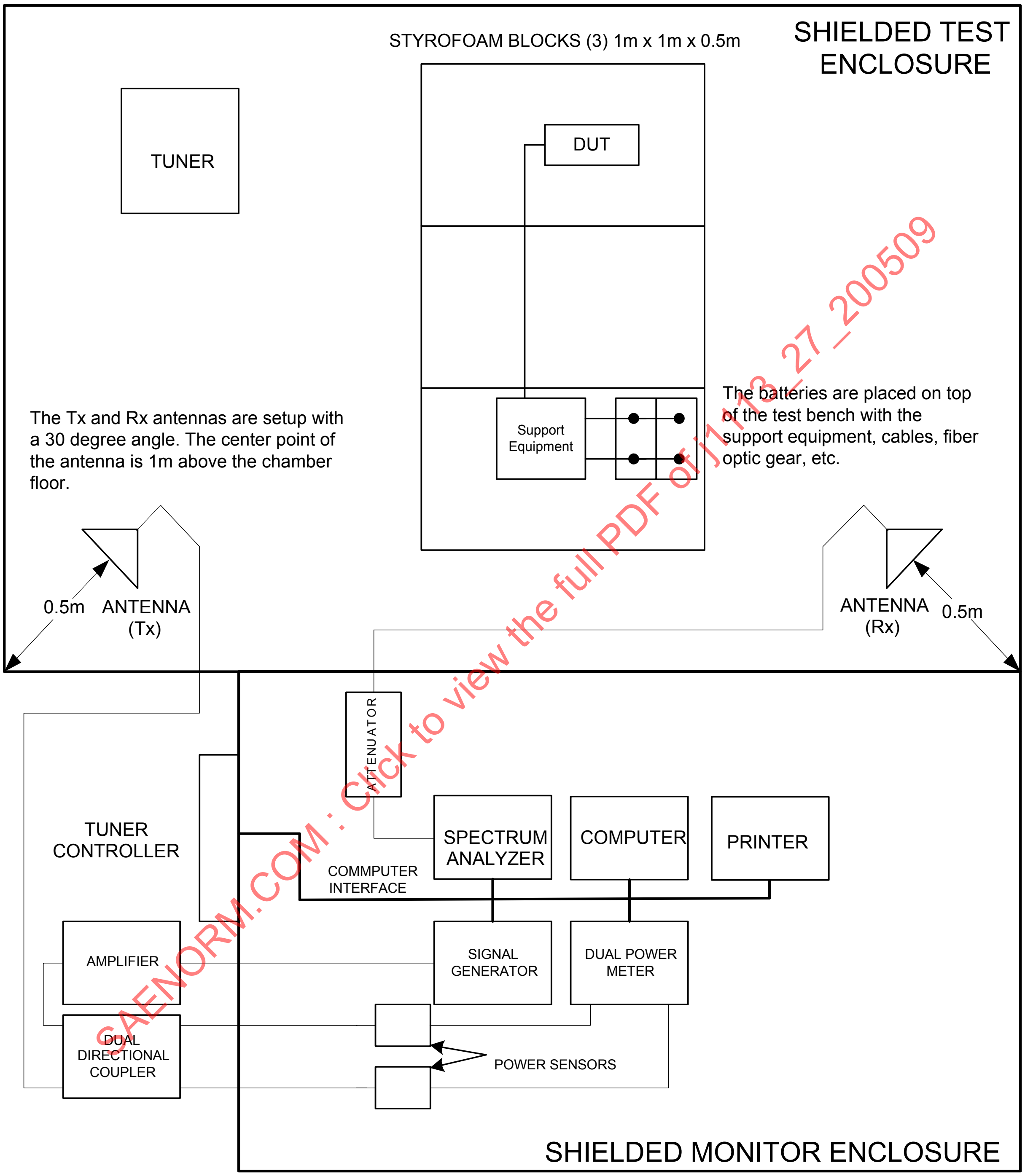

FIGURE 2—TYPICAL REVERBERATION CHAMBER LAYOUT (TOP VIEW)

7. Test Procedure

7.1 CAUTION—*The high RF field level generated inside the test chamber during this test may be hazardous to human health. Safety precautions shall be taken to prevent human exposure to high RF field levels*.

7.2 Setup the DUT in the reverberation chamber according to Section 6.

7.3 Preliminary System Check

Perform the following procedure to verify test chamber operation for the particular combination of antennas, test equipment, and DUT. This preliminary check need only be executed once for each set-up. Perform the system check at the lowest test frequency in the operating band of the set-up. Additional higher frequencies may be tested if necessary. These data are equivalent to that required in section 7.5 (Chamber Field Calibration) and may be used to satisfy 7.5 at the frequencies tested. However, section 7.5 does not require reflected transmit power measurements. The test report shall note all frequencies tested and corresponding results.

7.3.1 Set the signal generator to the test frequency at a low amplitude adequate for stable measurements but which does not overshoot the desired field strength in the chamber.

7.3.2 Perform the procedure defined in Appendix B sections B.3 through B.10. Replace the empty chamber loss $L_{unloaded}$ in B.8 with L_{DUT}, the chamber loss with all test equipment and DUT in place.

7.3.3 Repeat 7.3.1 and 7.3.2 at higher test frequencies, if necessary, to check the test system and chamber operation.

7.4 Chamber Field Calibration

The calibration is necessary because the electric field depends on the total loading of the chamber by the antennas, test equipment, and DUT. The calibration shall be performed at least once for each setup at every test frequency.

7.4.1 Set the signal generator to the test frequency at a low amplitude adequate for stable measurements but which does not overshoot the desired field strength in the chamber.

7.4.2 Set the spectrum analyzer to zero span at the selected frequency, in sample mode, with the sweep rate equal to the tuner revolution rate. The resolution bandwidth should be wide enough to compensate for frequency uncertainties.

7.4.3 Use a power meter and directional coupler to measure the transmit forward power (P_{tf}), use the spectrum analyzer to measure the receive power (P_r), and if necessary according to 7.4.7, the probes to measure field over a complete tuner rotation. The receive power should be attenuated as necessary to protect the spectrum analyzer. If the sample rate of the power meter is too slow, the transmit forward and receive power may be measured consecutively with the spectrum analyzer over two tuner rotations. Apply corrections due to coupler, attenuator and coax losses to the data in the same manner as in Appendix B.

Typically, with a stable signal generator and amplifier the transmit forward power (P_{tf}) is nearly constant during a complete tuner revolution. Subsequently, at frequencies where the variability of P_{tf} is acceptably small, it can be measured at a fixed tuner position and assumed constant. Receive power, P_r, and the field probes shall be measured for the entire revolution

7.4.4 Rotate the tuner at 10-20 seconds per revolution (slower if using electric field probes or power meters with long response times). Capture at least 400 samples for each revolution. P_r and probe readings should each have the same number of samples as taken in B.6 during empty chamber evaluation. The starting position of the tuner is not critical. The test is not complete until the tuner has moved through all possible positions.

7.4.5 Calculate the chamber loss with the DUT present, L_{DUT}, over one complete tuner revolution as in paragraph B.8 ($L_{unloaded}$ in equation B1 is replaced with L_{DUT}). If L_{DUT} is 6 dB or higher than the value of $L_{unloaded}$ found in B.8 with the chamber empty, check the setup and then record the value in the test report. At frequencies not in compliance, testing with this method is not valid and these frequencies shall be recorded in the test report.

7.4.6 Determine the receive power maximum to minimum ratio. It should be 20 dB or greater. If the ratio is less than 20 dB, check the setup. If the setup is acceptable, note the receive max/min ratio in the test report.

7.4.7 Determine the maximum electric field as in Appendix B, paragraph B.9 using the maximum receive power or maximum probe data. Above 500 MHz, use receive power; below 500 MHz use probe data.

7.4.8 Based on comparison of the results of steps 7.4.3 and 7.4.7, establish the correspondence between forward power and maximum field strength. The relationship is linear (i.e., 1 dB increase in forward power corresponds to a 1 dB increase in field strength).

7.5 DUT Test

7.5.1 Adjust the signal generator output to the forward power necessary to obtain the desired electric field strength as predicted in 7.4.8. This should result in the desired electric field strength. (See section 5.8 for suggested test severity levels.) Measure the field strength to verify that the intended level is reached within ± 1 dB. Measure the same number of data points as in section 7.4.4. If the desired field is not obtained, adjust the signal generator until the desired field strength is reached.

7.5.2 Monitor the DUT functions (as defined in the test plan) continuously for the duration of one revolution of the tuner. Rotate the tuner as defined in 6.11. If no deviation occurs, continue to the next frequency. If a deviation does occur, decrease the forward power (and maximum field strength) and repeat the test. Continue this process until no deviation occurs. The lowest level at which a deviation occurs is recorded as the immunity threshold. Immunity threshold determination shall be for an entire tuner revolution to ensure that the DUT is exposed to the peak field.

7.5.3 Repeat 7.4 and 7.5 for all required test frequencies.

8. Test Report

The following information shall be included in the test report.

8.1 Part Number and/or the Description of the DUT

8.2 DUT Operating Conditions (i.e., test plan)

8.3 Description of the Deviations Monitored

8.4 Date of Test

8.5 Facility Name

8.6 Modulation Status

8.7 Maximum Field DUT Exposed to at Each Frequency

8.8 Equipment Limits, if reached

8.9 Indicate frequencies where L has increased by more than 6 dB and/or receive power max/min ratio is less than 20 dB.

8.10 Requesting Engineer

8.11 Requesting Company

8.12 Data Summary Sheet for Each Deviation

8.13 The rotation rate used at each frequency, as well as the method used to determine the rotation rate, must be documented in the test report.

9. Notes

9.1 Marginal Indicia

The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE EMI STANDARDS COMMITTEE

APPENDIX A
REVERBERATION CHAMBER DESIGN CONSIDERATIONS
(NORMATIVE)

NOTE—This appendix uses excerpts from NBS Technical Note 1092, "Design, Evaluation, and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements."

Some omissions and modifications of text were made. For additional information on the theory of reverberation chambers, refer to NBS Technical Note 1092.

A.1 Physical Design Considerations

The criteria which should be considered in designing a radiated immunity reverberation chamber are addressed under the following categories:

a. Chamber physical shape and volume
b. Chamber quality factor (Q)
c. Chamber auxiliary needs (venting, electrical power, DUT monitoring requirements)
d. Tuner design
e. Chamber excitation and field monitoring

A.1.1 Chamber Physical Shape and Volume

For optimum chamber performance (i.e., spatial field uniformity and accuracy in determining the test field), especially at low frequencies, the volume of the chamber should be as large as possible and the room dimensions should not be integer multiples of one another. Rooms with integer multiple dimensions will have degenerative modes (i.e., the room may not reverberate at all test frequencies). Choice of chamber size will be dictated by test volume size requirements, lowest test frequency requirement, and budget considerations. The usable frequency range of the chamber will be determined mainly by the chamber size and construction. The room shall be constructed of steel (preferably galvanized, but cold rolled steel is allowed). Minimum recommended room dimensions are 4.88 m × 3.66 m × 3.05 m (16 ft L × 12 ft W × 10 ft H). Key characteristics of the chamber shall be verified to ensure an accurate and valid test (see Appendix B). The tuner size and construction will also have an effect on the usable frequency range of the chamber. Smaller shielded rooms may be used but only at higher frequencies (see Appendix B)

A.1.2 Chamber Quality Factor (Q)

Q factor is a measure of a chamber's ability to reverberate. The Q factor is affected by chamber dimensions and material as can be seen from the formula for Theoretical Composite quality factor Qnet for an unloaded chamber (with no DUT, antennas or probes present) (see Equation A1):

$$Q_{net} = \frac{1}{\frac{1}{Q_w} + N_a\left(\frac{1}{Q_a}\right)} \qquad \text{(Eq. A1)}$$

where:

N_a is number of receiving antennas
Q_w is theoretical Q including wall losses
Q_a is theoretical Q including antennas losses

The cut off frequency for the chamber is shown in Equation A2:

$$F_{cr} = \frac{1}{2\pi} * \left(\frac{9\pi^2 \mu_0 \sigma c^6}{32S^2} N^2{}_a \right)^{\frac{1}{5}} \qquad \text{(Eq. A2)}$$

where:

σ is conductivity, (Siemens/m)
S is surface area (m^2)
c is speed of light (m/sec)
μ_0 is free space permeability (H/m)

Above F_{cr}, lossy walls dominate cavity losses and Q_{net} is dominated by Q_w as shown in Equation A3:

$$Q_w = \frac{3}{2} * \frac{V}{S\delta_s \mu_r} * \frac{1}{\left[1 + \frac{3\lambda}{16}\left(\frac{1}{a} + \frac{1}{b} + \frac{1}{d}\right)\right]} \qquad \text{(Eq. A3)}$$

where:

V is chamber volume (m^3)
S is internal surface area (m^2)
δ_s is skin depth (m)
λ is wavelength (m)
a,b,d is chamber internal dimensions(m)
μ_r is relative permeability

Below F_{cr}, antenna losses dominate cavity losses and Q_{net} is dominated by Q_a Equation A4:

$$Q_a = 2\left(\frac{\omega}{c}\right)^3 \frac{V}{\pi} \qquad \text{(Eq. A4)}$$

where:

ω is $2\pi f$ (rad/sec)
f is frequency (Hz)

The empirical quality factor Q´, which takes the chamber loading into consideration, is given by Equation A5:

$$Q' = 16\pi^2 \frac{VP_r}{\lambda^3 Pt} \quad \text{(Eq. A5)}$$

where:

P_t is net transmitted power (watts)
P_r is received power (watts)

The higher the Q the longer the setting time which results in greater pulse distortion during pulsed RF immunity testing. The recommended galvanized steel chamber will typically allow minimum pulse widths of 2 to 6 µs, while a cold-rolled steel chamber (which has a lower Q) will typically allow pulse widths of approximately 1 µs without distortion. It is anticipated that future pulse modulation requirements will coincide with galvanized steel chamber capabilities.

It should be standard practice to keep the chamber clear of lossy material such as wood, carpeting, and RF absorbers (e.g., windows).

A.1.3 Chamber Auxiliary Needs

Chamber auxiliary needs shall be established based on the intended upper amplitude and test frequency of use. Venting panels should use screens with apertures equal to or smaller than waveguide beyond cutoff at the maximum intended test frequency (honeycomb is recommended). Electrical power supplied to outlets inside the chamber should meet shielded enclosures requirements. A bulkhead panel should be used to access the transmit and receive antennas, and the DUT. Care shall be taken to ensure that the shielding integrity of the enclosure is not compromised by access holes or cables, etc. This may require the use of fiber-optic cables for monitoring the DUT. In addition, waveguide beyond cutoff access ports is useful.

A.1.4 Tuner Design

The criterion for tuner design is to ensure its effectiveness in redistributing the energy inside the enclosure. To achieve this, the tuner should be electrically large (≥ λ at the lowest frequency of operation) and be shaped or oriented to achieve a receive power maximum/minimum ratio ≥20 dB for all test frequencies. The tuner mounting should include provisions to prevent RF leakage from the chamber via the tuner shaft to the motor. The tuner controller and motor should allow continuous tuner rotation at rates from 2 s to 10 min per revolution and to stop at an electrical "home position" definable within ±1 degree accuracy. The tuner shall be made of a conductive material, and should be asymmetrical. The tuner shall be at least λ/6 away from the DUT and its harness. Figures A1 and A2 show an example of a specific foam board tuner design proven to work effectively in a room with dimensions of 4.88 m × 3.66 m × 3.05 m (16 ft × 10 ft × 10 ft). Figures A3 and A4 show an example of the Z-Fold tuner design. The typical size of a Z-Fold tuner for the test room described above is approximately 2.44 m × 0.76 m × 0.76 m (8 ft × 2.5 ft × 2.5 ft).

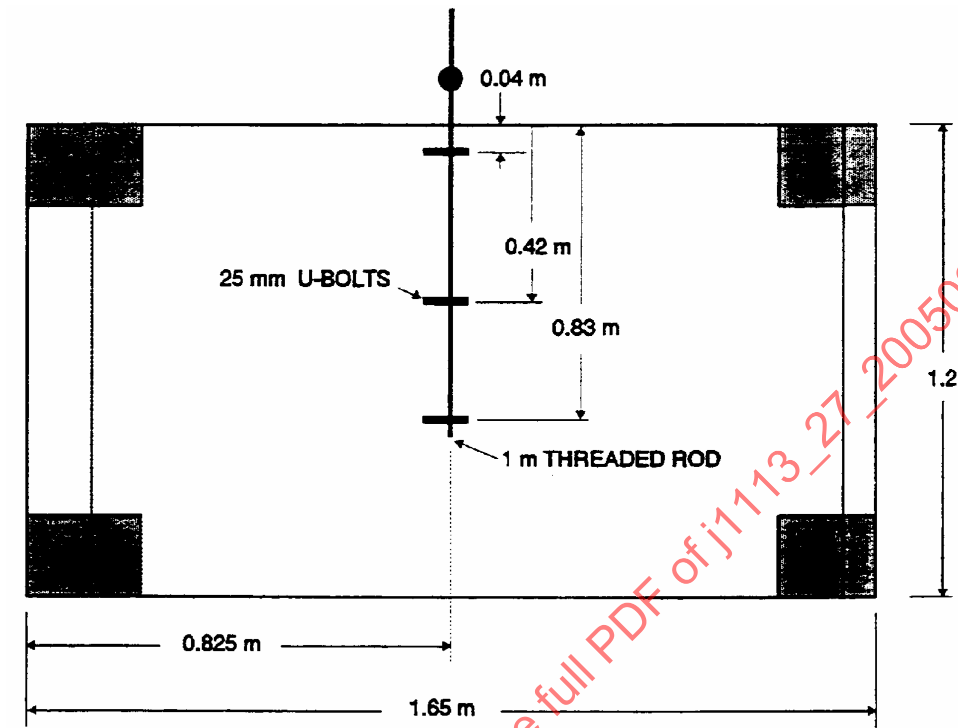

FIGURE A1—FRONT VIEW OF FOAM BOARD TUNER

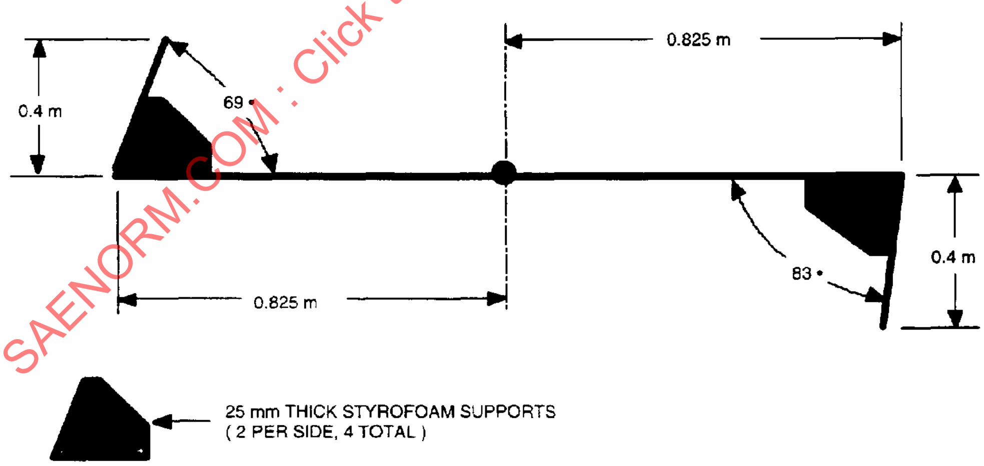

FIGURE A2—TOP VIEW OF FOAM BOARD TUNER

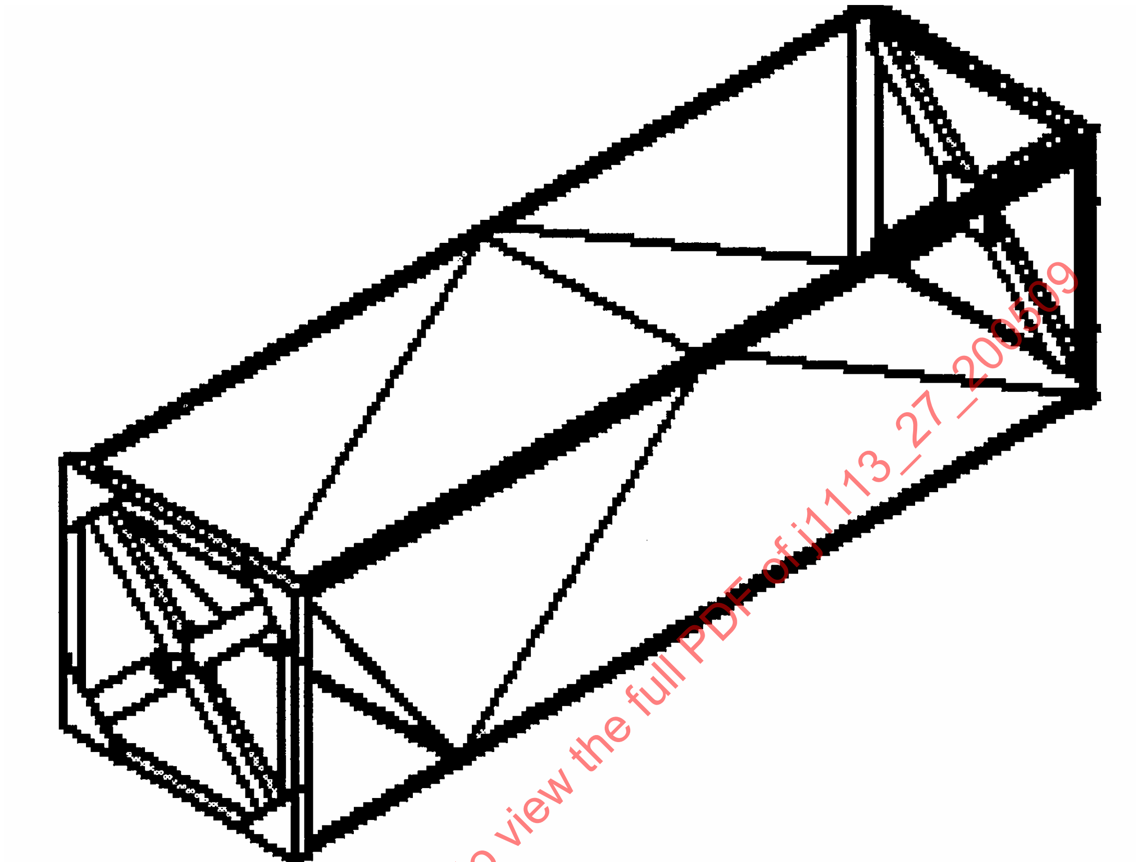

FIGURE A3—ISOMETRIC VIEW OF A Z-FOLD TUNER

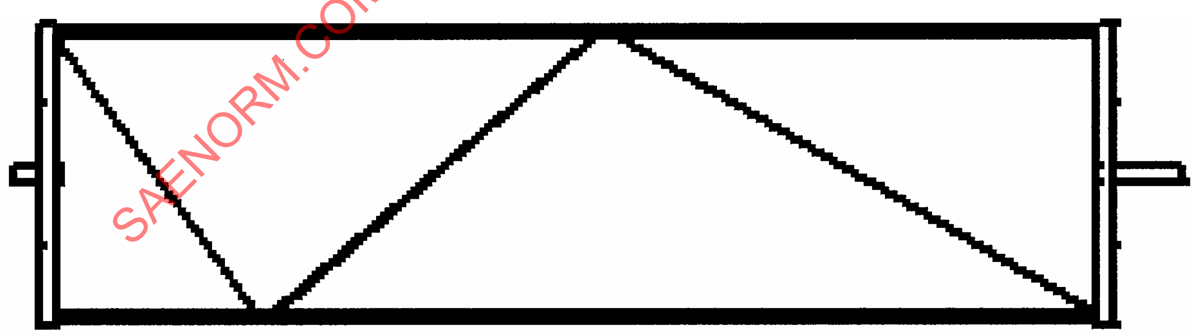

FIGURE A4—SIDE VIEW OF A Z-FOLD TUNER

A.1.5 Antennas and Field Monitoring

The following parameters are used in selecting the antennas (both transmit and receive):

a. Frequency range of interest
b. Input power rating
c. Bandwidth
d. Minimum VSWR (low as possible)
e. Efficiency
f. Maximum allowable size
g. Durability

The frequency range specific to this procedure is from 500 MHz to 2.0 GHz, and can be extended down to 200 MHz and up to 10 GHz or higher. A number of candidate antennas could be used in this range. No single antenna has sufficient bandwidth to cover the full range. The following antennas are recommended:

a. Log periodic 200 MHz to 1 GHz
b. Double ridged guide 1.0 GHz to 10.0 GHz

A key factor in selecting antennas is the voltage standing wave ratio (VSWR) of the antennas (i.e., the impedance match between the RF source and the transmitting antenna or between the receiving antenna and receiver). In addition, rotating the tuner changes the chamber boundary conditions which in turn affects the VSWR of the antennas. The average VSWR over a complete tuner rotation is equivalent to the free-space value.

Another factor is the radiation efficiency of the antennas. Inefficient antennas and/or VSWR problems can result in a receive power maximum/minimum ratio less than 20 dB. This can result in large uncertainties in determining the input and received power. Poor efficiency (large ohmic losses in the antenna structure) will cause underestimates of the received power and the electric field.

The placement and orientation of the transmitting and receiving antennas can also influence the operation of the chamber. Two positions or orientations are recommended: (a) position the transmitting and receiving antenna in different corners of the chamber, pointed toward the corners (preferred) or (b) position the receiving antenna in a corner pointed toward the corner, with the transmitting antenna sufficiently far away from it and pointed toward the tuner. No direct path should exist between the transmitting antenna and the receiving antenna; the transmitting antenna and the DUT and harness; or the receiving antenna and the DUT and harness.

A.2 Test Plan Considerations

A.2.1 Planning the Measurements

A number of issues should be considered when planning the measurements, writing the test plan, and documenting the test results.

One consideration is the test equipment immunity to RF. All simulators and monitoring equipment, which are located inside of the chamber, shall be RF hardened.

A second consideration is the RF dwell time versus reaction time of the DUT. Some DUTs have components with relatively long time constants and may require a few seconds to generate meaningful readings. The DUT should be exposed to test fields with sufficient duration to allow reaction and interaction, otherwise the test may not be a true indicator of the DUT's performance. DUT response time requirements determine the revolution rate of the tuner .

During mode-stirred operation, the number of samples (the number of response intervals of the EUT) may be increased or decreased dramatically depending on the rotation rate of the tuner and the response time of the equipment. If the number of samples is increased, then the expected value of the maximum field (radiated or received) will increase and the chamber field uniformity will be improved. The parameter that requires careful consideration is the tuner speed versus the equipment response/cycle time.

Very often, no prior information is available related to the response time or cycle times of the equipment under test. Due to this lack of information, the mode-stirred measurement must be applied only with careful consideration of the equipment response time and the speed of the tuner. If in fact, the equipment response/cycle time is fast, relative to the rate of change of the field, the mode-stirred technique can be more thorough because all intermediate tuner states are also covered. In addition, stirring can be faster than the mode-tuned technique. The definition of a fast responding EUT is one able to obtain at least one sample per 1 dB change in the field when within 3 dB of the maximum field. For equipment with slow response/cycle times, where it is necessary to dwell for some pre-defined time at each tuner step, the mode-tuned technique is usually faster and more accurate.

Some devices are more sensitive to the average field than the maximum field (e.g., thermal effects). In cases where the EUT is capable of averaging or integrating the field to which it is being exposed, rapidly turning tuners may be advantageous. In such cases the test is no longer to the maximum chamber field but to the average chamber field. The maximum permitted speed of the tuner is not defined within this technique.

Determination of the appropriate tuner rotation rate is the key to using the mode-stirred technique. The speed of rotation shall allow sufficient time for the EUT to respond and any upset to be detected. Often the EUT must exhibit upset in order to determine if the selected tuner rotation rate is appropriate. Once an upset has occurred the rotation rate can be adjusted, increased or decreased, to determine if any change in the upset threshold occurs. Any significant change in the equipment upset threshold would indicate a problem with the original tuner rotation rate. The mode-stirred technique is most appropriate for EUTs that have a very short (i.e., fast) response time.

It is not within the scope of this test procedure to provide limits on the tuner speed and detailed test procedures for ensuring the tuner speed is adequately slow (or fast) for equipment to respond. The technique (mode-stirred or mode-tuned) shall be highlighted and agreed within the individual equipment test plan. Justifications for the use of either one of the reverberation chamber techniques (mode-stirred or mode-tuned) shall be recorded within the test report for the equipment being tested.

Another important consideration is the need to simulate as closely as possible "real world" operating conditions. Ideally, immunity tests should be performed with the DUT connected and operated in its intended environment. Since this is not always possible, these conditions should be carefully simulated. This includes testing the DUT and harness in its intended configuration. One advantage of the reverberation method is that the test results are independent of DUT wiring harness orientation. All connecting leads shall be terminated with equivalent impedances as in actual use.