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Electromagnetic Compatibility Measurements Procedure for Vehicle Components - Part 27 - Immunity to Radiated Electromagnetic Fields - Mode Stir Reverberation Method

RATIONALE

This revision of J1113-27 incorporates updates to the reverberation chamber test methodology which have been developed since the last revision of the standard. These updates include portions and references from ISO 11452-11, IEC 61000-4-21, MIL-STD-461F and RTCA DO-160G.

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. The 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 (Continuous 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.

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2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, 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 International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J1113-1 Electromagnetic Compatibility Measurement Procedures and Limits for Components of Vehicles, Boats (up to 15 m), and Machines (Except Aircraft) (16.6 Hz to 18 GHz)

2.1.2 NBS Publication

Available from National Institute of Standards and Technology, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, Tel: 301-975-6478, www.nist.gov.

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 National Institute of Standards and Technology, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, Tel: 301-975-6478, www.nist.gov.

NIST Technical Note 1506 Electromagnetic Theory of Reverberation Chambers

NIST Technical Note 1508 Evaluation of the NASA Langley Research Center Mode-Stirred Chamber Facility

2.1.4 IEC Publications

Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

IEC 61000-4-21 Electromagnetic compatibility (EMC) - Part 4-21: Testing and measurement techniques – Reverberation chamber test methods

2.1.5 ISO Publications

Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO 11452-11 Road vehicles - Component test methods for electrical disturbances from narrowband radiated electromagnetic energy - Part 11: Reverberation chamber

2.1.6 Military Publications

Available from IHS Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, Tel: 800-854-7179, http://global.ihs.com/ or from http://dodssp.daps.dla.mil/.

MIL-STD-461F Department of Defense Interface Standard, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

2.1.7 RTCA Publications

Available from RTCA Inc., 1828 L Street NW Suite 805, Washington, DC 20036-5133, Tel: 202-833-9339, www.rtca.org.

RTCA DO-160G Environmental Conditions and Test Procedures for Airborne Equipment

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 REVERBERATION CHAMBER QUALITY FACTOR (*Q*)

Q is the chamber quality factor and is a measure of how well the chamber stores energy. For a given chamber, *Q* varies as a function of frequency and can be calculated (See A.1.2).

3.5 NUMBER OF POSSIBLE MODES (*N*)

As a general rule, the lower frequency limit of the chamber is dependent on chamber size and the number of possible modes (*N*) which can exist at a given frequency.

3.6 LOADED REVERBERATION CHAMBER QUALITY FACTOR (Q_{Loaded})

Q_{Loaded} is the chamber quality factor and is a measure of how well the chamber stores energy with the DUT, wiring harness and support equipment. The chamber *Q* will be effected by the DUT, wiring harness and support equipment. Q_{Loaded} with the DUT, wiring harness and support equipment will need to be calculated in order to determine the chamber time constant (τ) for DUT test using pulse modulation.

3.7 REVERBERATION CHAMBER 3dB *Q* BANDWIDTH (BW_{3dB})

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.

3.8 CHAMBER TIME CONSTANT (τ)

For transients or pulsed signals, the rise or decay time constant τ is related to the *Q* of the chamber and frequency. τ is the minimum test pulse width that the loaded reverberation chamber can sustain.

3.9 LOWEST USABLE FREQUENCY (LUF)

Is the lowest frequency for which the field uniformity requirements are met. The LUF is determined during the characterization of the chamber in accordance with Appendix B.

3.10 UNLOADED CHAMBER LOSS FACTOR ($L_{UNLOADED}$)

The ratio (in dB) of the maximum received power (in watts) to the average transmitted forward power (in watts) over one tuner rotation without the DUT and supporting equipment present. The $L_{UNLOADED}$ is determined to provide a baseline for comparison with a loaded chamber.

3.11 DUT LOADED CHAMBER LOSS FACTOR (L_{DUT})

The ratio (in dB) of the maximum received power (in watts) to the average transmitted forward power (in watts) over one tuner rotation with the DUT and supporting equipment present.

3.12 RECEIVE POWER MAXIMUM TO MINIMUM RATIO ($P_{r\ max/min}$)

The difference (in dB) between the maximum received power ($P_{r\ max}$) and the minimum received power ($P_{r\ min}$) over one full rotation of the tuner. This shows the ability of the chamber and tuner to reverberate.

3.13 PEAK FIELD STRENGTH INSIDE THE CHAMBER (E_{max})

The maximum field strength inside the chamber (V/m) which is calculated based upon the maximum receive power ($P_{r\ max}$) measured over one tuner rotation.

3.14 FORWARD POWER REQUIRED TO ACHIEVE THE TEST FIELD STRENGTH (P_{Test})

The forward power required, in dBm, to achieve the test field strength is calculated based upon the desired field test field strength ($E_{desired}$), the maximum field strength (E_{max}) measured in the loaded chamber, and the maximum forward power ($P_{f\ max}$) measured in the loaded chamber over one tuner rotation.

3.15 WORKING VOLUME

The working volume is defined as being a distance of $\lambda/4$ from the chamber walls and from any antenna, tuner, or other object at the lowest frequency of operation. For a chamber operating above 100 MHz, this would be 0,75 m. This is the volume within the reverberation chamber that contains the test bench, the DUT, the harness, the support equipment that is located on the test bench and the receiving antenna.

3.16 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 capability 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 RF Circulator with 50 Ω RF Load

An RF Circulator with 50 Ω RF Load is recommended on the output of the Broadband Power Amplifier. The RF Circulator with 50 Ω RF Load shall be rated properly (power handling and frequency range) for use with the Broadband Power Amplifier that it is being used. As the tuner rotates, it will change the boundary conditions of the chamber and will eventually cause a considerable amount of RF power to be reflected back into the Broadband Power Amplifier output port (high VSWR condition). An RF Circulator with a 50 Ω RF Load, on the output of the amplifier, will revert the reflected power back to the 50 Ω RF load instead of the Broadband Power Amplifier RF output port. This will prevent amplifier "fold-back" and/or "tripping" due to the high VSWR condition and will provide for a more consistent forward power condition throughout the full rotation of the tuner.

4.4 Antennas

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

4.4.1 Suggested antennas:

a. 500 (200 optional) MHz to 1 GHz - Log periodic

b. 1 GHz to 2 (10 optional) GHz Double ridged guide

4.5 Spectrum Analyzer

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

4.6 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.

4.6.1 Two directional couplers are needed for the following use:

a. Transmit forward power

b. Transmit reflected power

4.6.2 Typical Bands

a. 0.5 (0.2 optional) to 1 GHz

b. 1 to 2 GHz

c. 2 to 10 GHz (optional)

4.7 10 dB Attenuator

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

4.8 Power Meter

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

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

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

4.9 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 Section 7 of this document.

4.10 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 ft L x 12 ft W x 10 ft H). Key characteristics of the chamber shall be verified to ensure an accurate and valid test (see Appendix B).

4.11 RF Field Monitoring

Two broadband electric field probes are needed for the empty chamber characterization. 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.

4.12 Tuner

A three-dimensional, asymmetrical tuner is recommended. See A.1.4. of Appendix A for design considerations. The tuner shall be made of conductive material (e.g., aluminum or galvanized steel) and capable of changing the electromagnetic boundary conditions in a reverberation chamber as it rotates or moves. The tuner's capability, along with the chamber's interaction, is determined by the receive power max/min ratio ($P_{r\ max/min}$) requirements specified in Table B1, Step B7.

4.13 Artificial Network

See Appendix D for the schematic and impedance curve of the 5uH/50 Ω AN.

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 power to the DUT. The supply voltage to the DUT shall be in accordance with Section 6 of SAE J1113-1.

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 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. Tuner revolution rate is typically 10 to 20 s/rev (3 to 6 rpm). 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. 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, gradually increase the signal amplitude in discrete steps and allow time for one full tuner rotation at each step. This will allow the DUT 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. A full description and discussion of the Function Performance Status Classification including Test Severity Levels are given in SAE J1113-1 Appendix A and should be reviewed 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 un-modulated wave. Peak power conservation shall be used during amplitude and pulse modulated tests. (Refer to SAE J1113-1.)

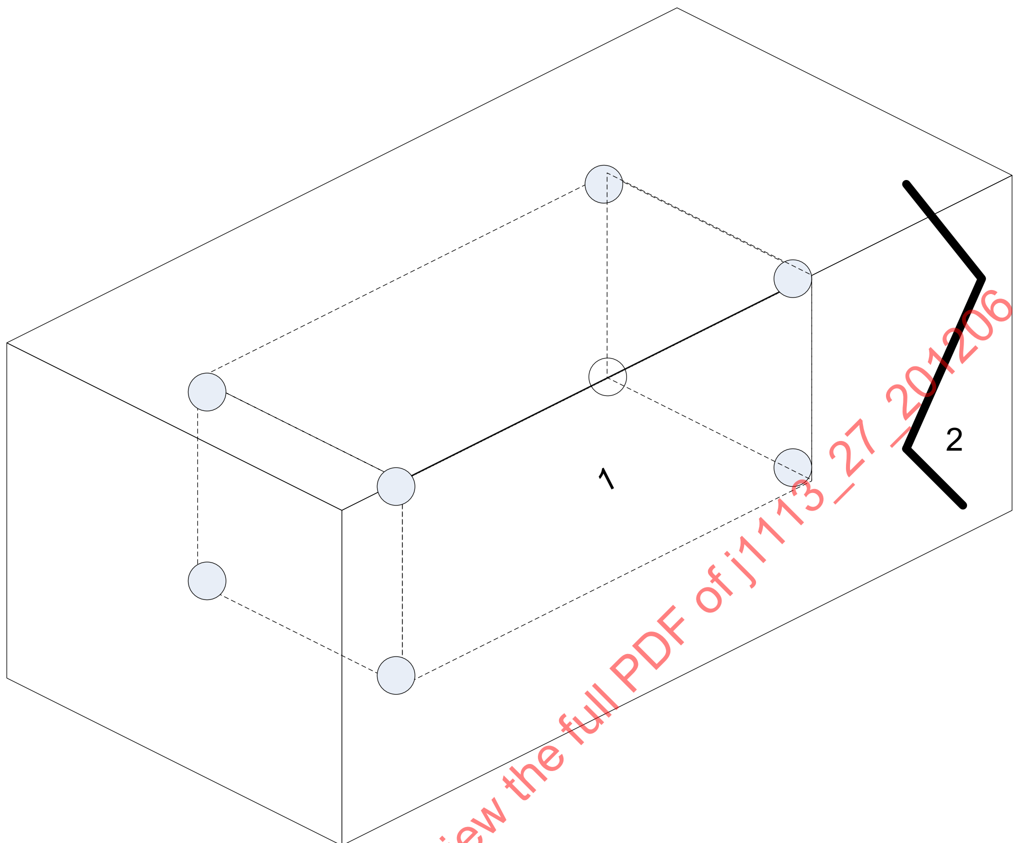
6. TEST SETUP

6.1 A typical layout drawing of a reverberation chamber and its working volume is shown in Figure 1. A general drawing of a DUT test setup is show in 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.

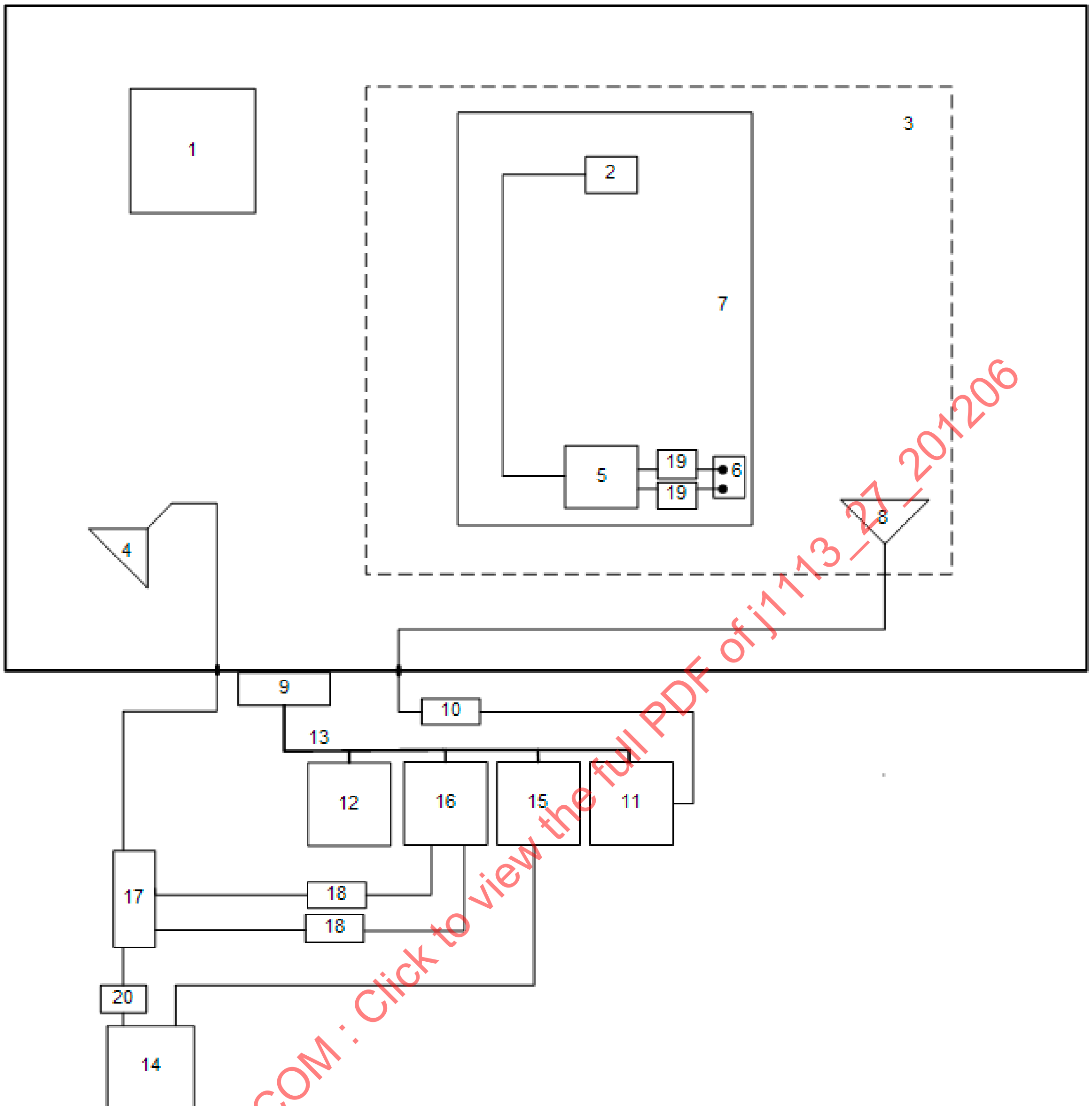
6.4 Steps shall be taken to prevent RF energy from coupling into control and monitoring equipment to prevent erroneous readings. This may require RF hardening of the simulator and the control/monitoring equipment. The simulator may be placed outside the room. Either filtering or fiber optic cables may 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.



1. Volume of Uniform Field/Working Volume

2. Tuner

FIGURE 1 - TYPICAL REVERBERATION CHAMBER LAYOUT (WORKING VOLUME)



1. Tuner
2. DUT
3. Chamber Working Volume
4. Tx Antenna
5. Load Simulator
6. Battery(s) on Test Bench
7. Test Bench - Styrofoam Blocks (3) 1m x 1m x 0.5m (with ground plane if required)
8. Rx Antenna
9. Tuner Controller
10. Attenuator
11. Spectrum Analyzer
12. Computer System w/Software
13. Computer Interface
14. RF Amplifier
15. RF Signal Generator
16. Dual Channel Power Meter
17. Dual Directional Coupler
18. Power Sensor
19. AN(s) (used with ground plane setup)
20. RF Circulator w50 Ω RF Load (optional)

FIGURE 2 - TYPICAL REVERBERATION CHAMBER LAYOUT FOR DUT TEST (TOP VIEW)

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 λ/4 (at the lowest frequency) above the floor level (preferably on a Styrofoam™ block). Large DUTs may be placed directly on the floor. The ground plane shall be placed at least λ/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. The ground plane (with the exception of the grounding straps) shall be located within the chamber's working volume.

6.5.3 The ground plane shall be bonded to the chamber with bonding straps with a minimum width of 7.6 cm such that the d.c. resistance shall not exceed 2.5 mΩ. The bond straps shall be placed at a distance no greater than 0.3m apart edge to edge.

6.6 When a d.c. power supply is needed to maintain battery voltage, the d.c. power supply shall be located outside the test chamber. All power lines entering the chamber shall be filtered. The d.c. power leads used for battery maintenance within the chamber may be shielded from the chamber filter to the battery connection point. The d.c. power leads within the test chamber should be routed along the wall and chamber floor in order to minimize field coupling to these leads.

6.7 If no ground plane is used, then artificial networks shall not be used. The power feeds to the DUT shall be connected directly to the battery terminals.

6.8 If a ground plane is used, then each power supply lead shall be connected to the power supply through an AN. Power shall be applied to the DUT through a 5uH/50 Ω AN. (See Appendix D for the schematic.) The number of ANs required depends upon the intended DUT installation in the vehicle.

6.8.1 For a remotely grounded DUT (vehicle power return line longer than 200 mm), two ANs are required: one for the positive supply line and another for the power return line. The power supply negative terminal shall be connected to the ground plane on the source (input) side of the return line AN.

6.8.2 For a locally grounded DUT (vehicle power return line 200 mm or shorter), only one AN is required for the positive supply line. The DUT power return line shall be no longer than 200 mm and connected directly to the ground plane. The power supply negative terminal shall be connected to the ground plane near the AN case ground.

6.9 A 1700 mm + 300/-0 mm 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.

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

6.11 The location of the transmitting (Tx) antenna shall be the same for both characterization and testing. The transmitting antenna shall not directly illuminate the working volume. The transmitting antenna should be directed into a corner of the chamber if possible (see Figure 1 for location of transmit antenna). Directing the antenna into the tuner is also acceptable. The transmitting antenna should be supported by a non-conductive stand (e.g. non-conductive tripod or polystyrene fixture) and should be placed at a distance not less than λ/4 (at lowest frequency) from the chamber walls and corners.

NOTE: An upward tilt of the antenna is advisable to avoid direct incident wave illumination of the chamber wall resulting in a potentially high VSWR situation.

6.12 The receiving (Rx) antenna may be placed at an arbitrary position within the chamber working volume and should be placed on a polystyrene support. The receiving antenna shall avoid pointing at the transmit antenna and centre of the working volume.

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

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

6.15 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.

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 7.4. (Chamber Field Calibration) and may be used to satisfy 7.4 at the frequencies tested. However, 7.4 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, 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}) and the spectrum analyzer to measure the receive power (P_r) 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) shall be measured for the entire revolution.

7.4.4 Rotate the tuner at 10 to 20 seconds per revolution. Capture at least 400 samples for each revolution. P_r 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 B.8 ($L_{unloaded}$ in equation B1 is replaced with L_{DUT}). If the Δ L_{DUT} and $L_{unloaded}$ is > 6 dB, 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 max/min ratio ($P_{r\ max/min}$). 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 E_{max} as in Appendix B, B.9 using the maximum receive power.

7.4.8 For pulse modulation testing, determine the pulse distortion inside the reverberation chamber using the transmit forward power (P_{tf}) and receive power (P_r) measured in 7.4.3. See A.1.4 for calculation and use of the chamber time constant.

7.4.9 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 Using the information from the Chamber Field Calibration of 7.4, calculate the test forward power (P_{Test}) using the following equation:

$$P_{Test} = 20 * \log\left(\frac{E_{desired}}{E_{\max}}\right) + P_{f\,\max} \quad \text{(Eq. 1)}$$

where:

P_{Test} = the forward power required to achieve the test field strength (dBm)

$E_{desired}$ = the desired test field strength inside the chamber (V/m)

E_{max} = the maximum field strength inside the chamber as determined in 7.4.7 (V/m)

$P_{f\,max}$ = the maximum forward power measured in 7.4.3 over one tuner rotation (dBm)

7.5.2 Adjust the signal generator output to achieve the test forward power (P_{Test}) necessary to obtain the desired test electric field strength as predicted in 7.5.1. This should result in the desired electric field strength (See Appendix C for suggested test severity levels). Measure P_r over one complete tuner rotation. Measure the same number of data points as in 7.4.4. Calculate the maximum field strength as in 7.4.7 to verify that the intended level is reached within ±1 dB. If the desired field is not obtained, adjust the signal generator until the desired field strength is reached. If power is not detected on the receive antenna, further investigation is warranted to ensure that the field is actually present in the reverberation chamber.

7.5.3 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 6.15. 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.

7.5.4 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

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

APPENDIX A - REVERBERATION CHAMBER DESIGN CONSIDERATIONS
(NORMATIVE)

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).

As a general rule, the lower frequency limit is dependent on chamber size. To determine the lower frequency limit for a given chamber, use the following formula to determine the number of possible modes (*N*) which can exist at a given frequency. If, for a given frequency, N is less than 100 then the chamber should not be used at or below that frequency (Reference MIL-STD-461F).

$$N = \frac{8\pi}{3} abd \frac{f^3}{c^3} \qquad \text{(Eq. A1)}$$

where:

a, b, and d are the chamber internal dimensions in meters
f is the operation frequency in Hz
c is the speed of propagation (3×10^8 m/s)

A.1.2 Chamber Quality Factor (*Q*) (Reference: IEC 61000-4-21 and RTCA DO-160G)

Q factor is a measure of a chamber's ability to reverberate. Q, for a cavity, is defined as shown in Equation A2:

$$Q = \frac{16\pi^2 V}{\eta_{Tx}\eta_{Rx}\lambda^3} \left\langle \frac{P_{AveRec}}{P_{AveInput}} \right\rangle \qquad \text{(Eq. A2)}$$

where:

V = the chamber volume (m^3)

λ = the wavelength (m)

($<P_{AveRec}/P_{AveInput}>$) is the ratio of the average received power to the average input power over one complete tuner rotation

η_{Tx} and η_{Rx} are the antenna efficiency factors for the Transmit (T_x) and Receive (R_x) antennas respectively. If the manufacturer's data is not available, then the efficiency can be assumed to be 0.75 for log periodic antennas and 0.9 for horn antennas.

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 Reverberation Chamber 3dB *Q* Bandwidth (BW_{3dB})

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.

$$BW_{3dB} = \frac{f_{resonance}}{Q} \quad \text{(Eq.A3)}$$

where:

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

A.1.4 Chamber Time Constant (τ)

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

$$\tau = \frac{Q}{2\pi f} \quad \text{(Eq. A4)}$$

where:

f is the frequency (Hz)
Q is the Chamber Quality Factor calculated in Eq. A2

The chamber time constant must be added to any required pulse width during pulse modulation testing. For example, if the chamber time constant is 6 microseconds and the required pulse width is 4 microseconds, it is required to perform the test at a 10 microsecond pulse width during pulse modulated testing (Reference RTCA DO-160G).

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.

A.1.5 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.1.6 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 ($\geq \lambda$ at the lowest frequency of operation) and be shaped or oriented to achieve a receive power maximum/minimum ratio $\geq$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 $\lambda/6$ away from the DUT and its harness.

A.1.7 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 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.

The exposure field parameters should be selected as part of the test plan, such as: frequency, electric field strength, modulation type (CW or pulse modulation), and in the case of pulse modulation, repetition rate, rise time, and pulse width. For validation testing, these parameters will be similar from test to test.

One limitation of the reverberation method for development testing is the loss of polarization information. For validation testing, loss of polarization information is not an issue since validation testing uses pass/fail criteria which do not include polarization effects. In addition, the maximum coupling response of the DUT can be determined without repositioning the DUT or the transmit antenna since the RF field is rotated around the DUT. Determining how the RF is coupled into the DUT may require shielding DUT input/output and power line leads. RF may leak through the DUT case slots and apertures. Determining the coupling mechanism requires a systematic process of shielding and filtering various leads, slots, and apertures of the DUT while conducting the test.

A.2.2 Measurement Approach (Tuned versus Stirred)

Two approaches are used for performing EMC measurements using the reverberation chamber.

NOTE: This procedure specifies the mode stir approach for the DUT test. However, if a person has access to a facility utilizing the mode-tune approach the test results may be acceptable. This section describes both approaches for completeness. (See NBS Technical Note 1092 for mode tune definition.)

A.2.2.1 The mode tuned approach steps the tuner at selected, uniform increments, permitting measurements of the forward and reflected input power, received power, field measuring probe response, and the DUT response at each tuner position. This allows for corrections and normalization of the received power, field measurements, and DUT response due to variations in the net transmit power. The mode tuned approach also allows the operator to select long test field exposure times as needed to accommodate long DUT response times. The number of tuner steps per revolution that should be used is a function of frequency, chamber *Q*, and desired uncertainties. Typically, at least 20 steps are required to provide sufficient sampling to reasonably determine the statistical parameters of the test field and DUT response (maximum and average amplitudes). Additional steps (samples) will reduce the uncertainty in the measurements. If the sample size is too small, the accuracy of the measurements suffers and true maximum, minimum, etc. Are not recorded.

A.2.2.2 Mode stirred approach rotates the tuner continuously for a complete revolution while sampling the received power, field probe response, and DUT response at rates much faster than the tuner revolution rate. The mode stirred approach allows large data sets (400 samples or more is recommended) for a single tuner revolution. Tuner revolution rates and test instrumentation sampling rates are adjusted to meet DUT response time and output monitor response time requirements. The optimum settings result in a nearly identical number of samples for the DUT and test instrumentation (see A.5.4). Revolution periods can range from 2 s to 10 min, with typical values of 10 to 20 s. A larger sample set can improve the accuracy in determining the statistics of the measured parameters. However, this technique may have increased uncertainty due to failure to correct for transmit power variations, unknown DUT response times, or the interactions between the DUT and the continuously changing fields in the chamber.

A.3 DUT PLACEMENT CONSTRAINTS AND LOADING EFFECTS

A.3.1 Placement Constraints of DUT

Constraints on the placement of a DUT inside the reverberation chamber are a result of the proximity effect of the chamber walls on the test field and on the DUT. Maintain a minimum spacing of at least $\lambda/3$ (at the lowest test frequency) from the chamber walls, the transmitting and receiving antennas, the field measurement probe(s), and DUT. This equates to 0.5 m at 200 MHz. Placing the DUT on the chamber floor is an acceptable exception to this guideline. Scattering effects discussed in A.3.3 suggest shadowing is not a significant problem if the DUT is placed further than $\lambda/4$ from any wall. The DUT shall be placed more that $\lambda/6$ away from the tuner. The probes shall be placed more than $\lambda/6$ away from any metal object.

A.3.2 Placement Constraints of Harness

The same requirements as above apply to the harness, except where the harness penetrates the wall. Precise control of harness routing and orientation is not necessary.

A.3.3 Scattering Effects of Metal Objects on E-field Distribution

Results of tests performed, using test objects placed in the chamber, to evaluate their scattering effect on the statistical field distribution inside the chamber, indicate that little or no difference was noted in the distribution measured.

A.3.4 Loading Effects of DUT on Chamber

If the DUT absorbs energy from the chamber the *Q* of the chamber is reduced thus affecting the measurement results. Typically, this is compensated for by simply increasing the net transmit power to the chamber. This may not be sufficient if the DUT lowers the chamber *Q* to the extent that the chamber no longer reverberates properly (i.e., the receive power max/min ratio <20 dB). DUT loading effects are determined by comparing the unloaded chamber net transmit power to the net transmit power needed to generate the same field with the DUT present in the room (see B.12). The DUT should not load the room by more than 6 dB. If the loading effect is greater than 6 dB, verify that the receive power max/min ratio is greater than or equal to 20 dB, with the DUT present. At frequencies not in compliance, testing with this method is not valid and these frequencies shall be recorded in the test report.

A.4 ELECTRIC FIELD UNIFORMITY

Given in Table A1, is the field variation versus frequency for one Reverberation Chamber with dimensions of 4.88 m × 3.66 m × 3.05 m (16 ft L × 12 ft W × 10 ft H). The field variation is based on the maximum difference between the calculated electric field (see B.13) and the electric field levels indicated by two field probes (placed anywhere in the test volume). Field variation is inversely proportional to chamber size.

TABLE A1 - TYPICAL ELECTRIC FIELD UNIFORMITY

Frequency (MHz)	Variation (dB)
200	≤±8
500	≤±5
1000	≤±3
2000	≤±2