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SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J1113/27

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Submitted for recognition as an American National Standard

ELECTROMAGNETIC COMPATIBILITY MEASUREMENTS PROCEDURE FOR VEHICLE COMPONENTS—PART 27—IMMUNITY TO RADIATED ELECTROMAGNETIC FIELDS

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 to 10 GHz. At a later date, pulse modulation capability will be added for testing above 1 GHz.

1.2 This document provides the component design and test engineers with a test procedure and the performance requirements necessary to evaluate the immunity of electronic devices to radiated electromagnetic fields early in the design stage as well as pilot and production stages. 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 be used to evaluate the relative performance of different designs of the same device.

2. **References**—General information regarding this test, including general definitions, and safety considerations are found in SAE J1113/1.

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

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 Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements

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2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 NBS PUBLICATION—Available from NIST, U.S. Department of Commerce, Gaithersburg, MD 20899.

NBS Information Report 81-1638—Evaluation of a Reverberation Chamber Facility for Performing EM Radiated Fields Susceptibility Measurements

2.2.2 PHILIPS LABORATORY REPORT

Phillips Laboratory Report PL-TR-91-1036—Frequency Stirring: An Alternate Approach to Mechanical Mode-Stirring for the Conduct of EM Susceptibility Testing

3. Definitions—Definitions specific to this test method are included.

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

3.2 Tuner or Stirrer—A rotating metallic reflector that changes the boundary conditions in a reverberation chamber as it rotates. As the stirrer rotates, the nulls and maximums in the field change location, ensuring the DUT is exposed to a time-averaged uniform field.

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

3.4 Chamber Quality Factor (Q)—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:

$$\omega = 2\pi * f \text{ (radians/sec)}$$

$$f = \text{frequency (Hz)}$$

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).

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3.9 K Factor—The ratio of an unloaded chamber theoretical quality factor, Q_{net} , to the chamber empirical quality factor, Q' .

$$K = \text{Theoretical } Q / \text{Empirical } Q \quad (\text{Eq.2})$$

$$K = \frac{Q_{net}}{Q'}$$

3.10 F_{cr} —The cutoff frequency above which cavity losses are primarily due to wall losses instead of antenna losses.

3.11 L—Chamber loss. The ratio (in dB) of the maximum received power (in watts) to the net transmitted power (in watts).

3.12 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 Antennas—Two antennas are needed, one for transmission and one for reception.

4.3.1 Suggested antennas:

- a. 500 MHz to 1 GHz - Log periodic
- b. 1 GHz to 2 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 Three directional couplers are needed for the following uses:

- a. Transmit forward power
- b. Transmit reflected power
- c. Receive power

4.5.1.1 Typical Bands

- a. 0.05 to 1 GHz
- b. 1 to 8 GHz
- c. 8 to 18 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).

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

4.8 Computer Control (recommended)

4.9 Reverberation chamber with a stirrer (see Appendix A). The room shall be constructed of steel (preferably galvanized, but cold rolled steel is allowed). Room dimensions should not be integer multiples of one another. 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 A). Smaller shielded rooms may be used but only at higher frequencies (see Appendix B).

4.10 Two broadband electric field probes. Probe response shall be faster than 10 Hz.

4.11 **Stirrer**—A three-dimensional, asymmetrical stirrer is recommended. The stirrer shall be made of conductive material (e.g., aluminum or galvanized steel). An example is shown in Figures A1 and A2.

5. Test Setup

5.1 A general layout of a reverberation chamber is shown in Figure 1. An equipment setup is shown in Figure 2.

5.2 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.

5.3 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.

5.4 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.

5.5 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 $\lambda/3$ (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 $\lambda/3$ 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.

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

5.5.2 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.

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

5.6 A 1 to 3 m harness shall be used, unless otherwise specified in the test plan. The length of the wiring harness shall be documented in the test report.

5.7 Antennas, probes, and the DUT shall be placed at distances not less than $\lambda/3$ (at lowest frequency) from the chamber walls and corners. The DUT shall be at least $\lambda/6$ away from the stirrer.

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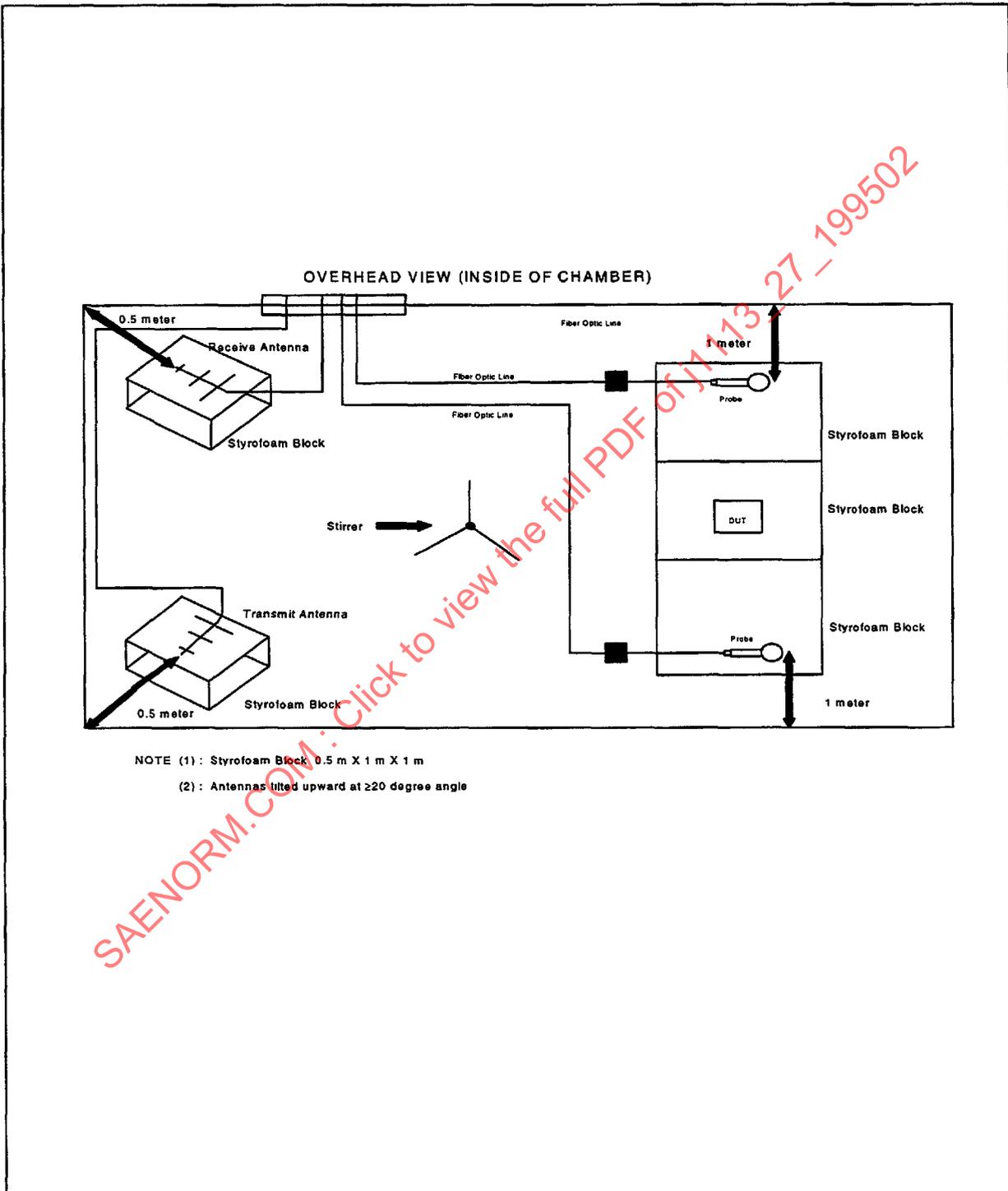


FIGURE 1—TYPICAL REVERBERATION CHAMBER LAYOUT

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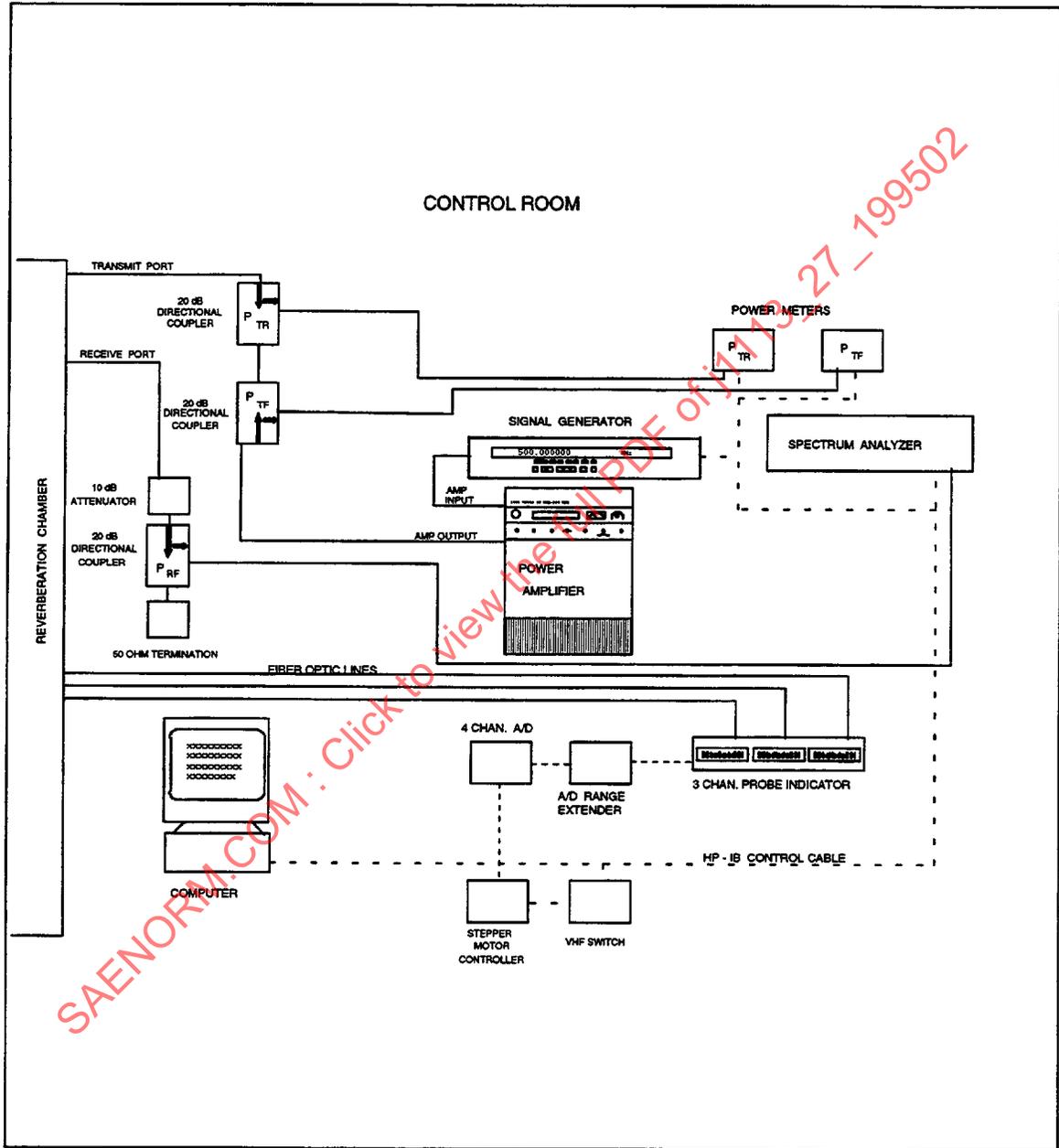


FIGURE 2—REVERBERATION EQUIPMENT SETUP

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- 5.8 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.
- 5.9 Antennas and probes should be placed on styrofoam supports, at least $\lambda/3$ (at lowest frequency) above the floor.
- 5.10 All unnecessary RF absorbing material shall be removed from the room (e.g., wooden tables, carpeting, extra equipment, etc.).
- 5.11 Stirrer 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.

6. Test Procedure

- 6.1 **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.
- 6.2 Setup the DUT in the reverberation chamber according to Section 5.
- 6.3 **Start of Test**
 - 6.3.1 Position the stirrer in the "Home Position." Wait for the stirrer to stop moving. (Home position should be repeatable within ± 1 degree.)
 - 6.3.2 Select the test frequency. Set signal generator to a low initial setting which does not overshoot the desired field strength.
 - 6.4 Using the two power meters and the directional couplers, measure the transmit forward and reflected power. Calculate the transmit net power (forward power less reflected power, in watts).
 - 6.5 Rotate the stirrer as defined in 5.11. During a complete revolution measure the maximum and minimum receive power, using the spectrum analyzer. The receive power max/min ratio should equal or exceed 20 dB to ensure that reverberation takes place and that a time-averaged uniform field exists. If it is less than 20 dB, check the setup. If the setup is acceptable, note the receive power max/min ratio in the test report.
 - 6.6 Calculate the chamber loss with the DUT present, L_{DUT} , over one complete stirrer revolution. If L_{DUT} is 6 dB or higher than the maximum value of $L_{unloaded}$ found in B.12, 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.
 - 6.7 Measure and/or calculate the maximum electric field as in Appendix B, B.8. Above 500 MHz, use calculated electric field; below 500 MHz use measured probe data.
 - 6.8 Based on comparison of the results of steps 6.4 and 6.7, establish the correspondence between net power and maximum field strength. The relationship is linear (i.e., 1 dB increase in net power corresponds to a 1 dB increase in field strength).
 - 6.9 Adjust the signal generator output until the desired net power is obtained. This should result in the desired electric field strength. (See Section 7 for suggested test severity levels.) Measure the field strength 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.

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6.10 Monitor the DUT functions (as defined in the test plan) continuously for the duration of one revolution of the stirrer. If no deviation occurs, continue to the next frequency. If a deviation does occur, decrease the RF level sweep for one revolution, continuing 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 the entire stirrer revolution to ensure that the DUT is exposed to the peak field.

7. Test Severity Levels

7.1 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.

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

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APPENDIX A
REVERBERATION CHAMBER DESIGN CONSIDERATIONS

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/stirrer 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.

A.1.2 Chamber Quality Factor (Q) and Chamber K Factor (K)—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 Q_{net} for an unloaded chamber (with no DUT, antennas or probes present) (see Equation A1):

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

where:

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

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

$$F_{cr}^{(1)} = \frac{1}{2\pi} * \left[\frac{9\pi^2 \mu_o \sigma c^6}{32S^2} N_a^2 \right]^{1/5} \quad (\text{Eq.A2})$$

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where:

- σ = conductivity, (Siemens/m)
- S = surface area (m^2)
- c = speed of light (m/sec)
- μ_0 = 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:

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

where:

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

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

$$Q_a^{(1)} = 2 \left(\frac{\omega}{c} \right)^3 \frac{V}{\pi} \quad (\text{Eq.A4})$$

where:

- $\omega = 2\pi f$ (rad/sec)
- f = frequency (Hz)

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

$$Q'^{(1)} \cong 16\pi^2 \frac{V P_r}{\lambda^3 P_t} \quad (\text{Eq.A5})$$

where:

- P_t = net transmitted power (watts)
- P_r = received power (watts)

The higher the Q the longer the settling 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.

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

A measure of goodness of a chamber is called the K factor (K). It is the ratio of the theoretical Q , Q_{net} , divided by the empirical Q , Q' . For a chamber without a DUT, K should be less than 5.

NOTE—Since Q' changes with stirrer position, the maximum value of Q' for a given revolution is used in the calculation of K.

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 Stirrer Design—The criterion for stirrer design is to ensure its effectiveness in redistributing the energy inside the enclosure. To achieve this, the stirrer 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 ≥ 20 dB for all test frequencies. The stirrer mounting should include provisions to prevent RF leakage from the chamber via the stirrer shaft to the motor. The stirrer controller and motor should allow continuous stirrer 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 stirrer shall be made of a conductive material, and should be asymmetrical. The stirrer shall be at least $\lambda/6$ away from the DUT and its harness. Figures A1 and A2 show an example of a specific stirrer design proven to work effectively in a room with dimensions of 4.88 m x 3.66 m x 3.05 m (16 ft x 12 ft x 10 ft).

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 2.0 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 stirrer changes the chamber boundary conditions which in turn affects the VSWR of the antennas.

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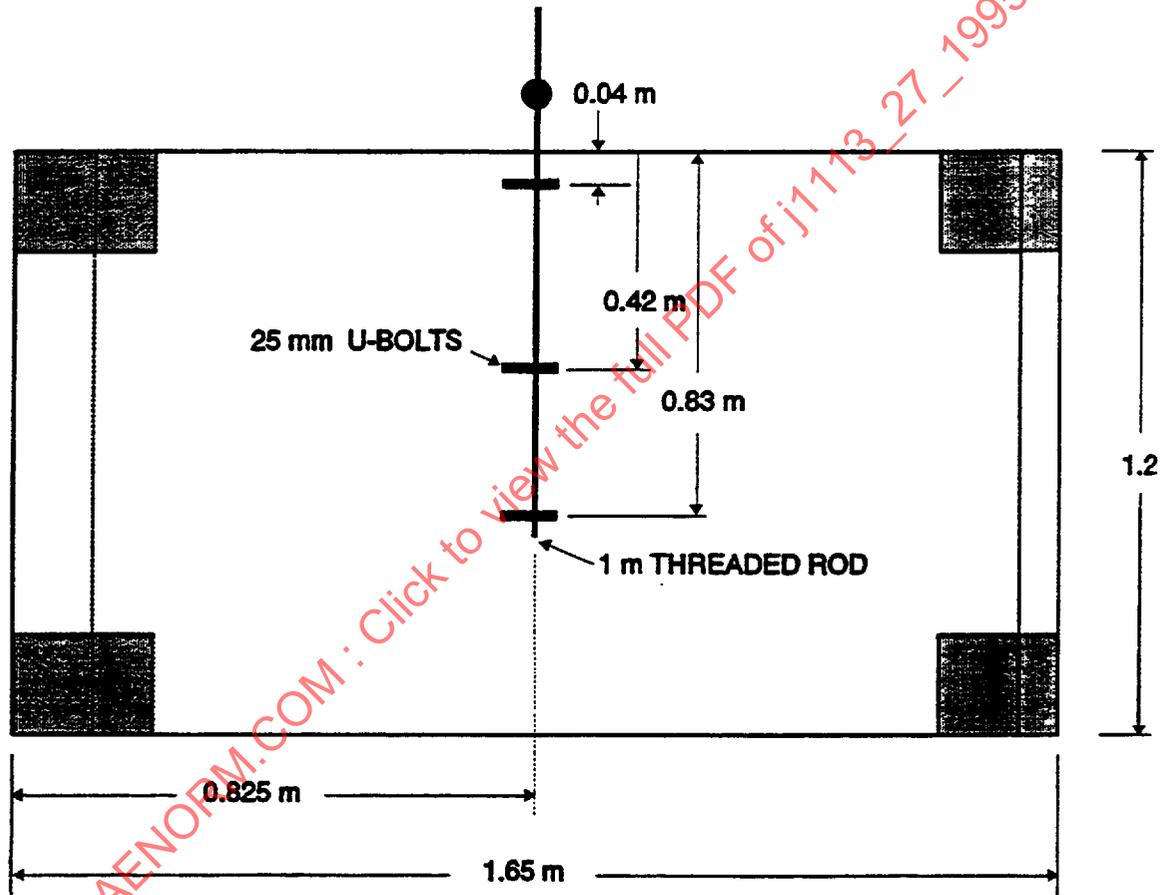


FIGURE A1—FRONT VIEW OF FOAM BOARD STIRRER FIGURE

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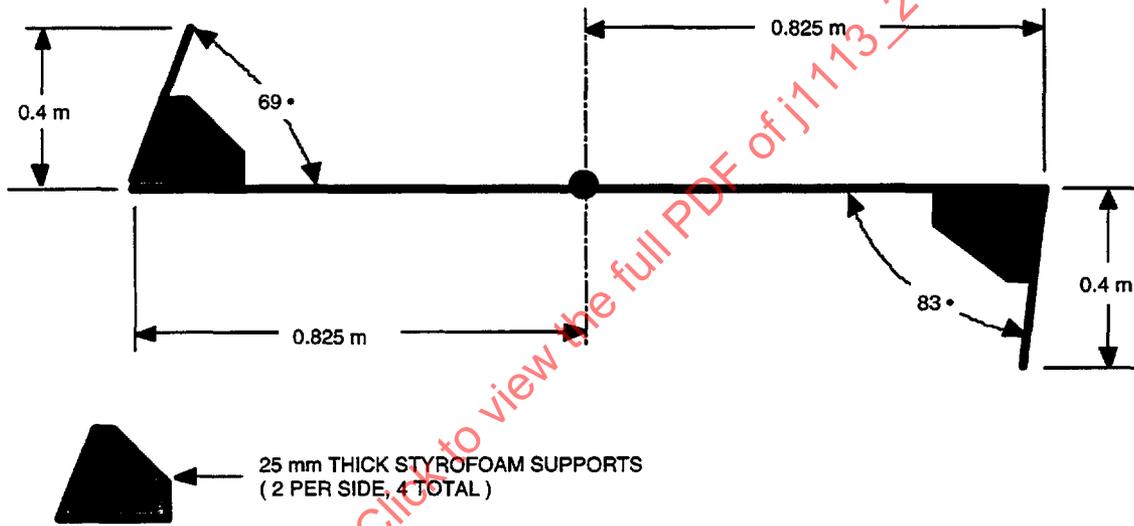


FIGURE A2—TOP VIEW OF FOAM BOARD STIRRER

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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.

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 stirrer. 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.

A.2.1.1 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.2.1.2 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 stirrer.

A.2.1.3 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.

A.2.1.4 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 only the mode stir approach, which is faster than the mode tune approach. However, if a person has access to a facility utilizing the mode-tune approach, and is willing to expend the time needed to use it, the test results may be acceptable. This section describes both approaches for completeness. (See NBS Technical Note 1092 for mode tune definition.)

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A.2.2.1 The mode tuned approach steps the tuner at selected, uniform increments, permitting measurements of the net 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 number of tuner steps per revolution that should be used is a function of frequency and chamber Q. Typically, at least 200 steps or more are required to provide sufficient sampling to accurately determine the statistical parameters of the test field and DUT response (maximum and average amplitudes). If the sample size is too small, the accuracy of the measurements suffers and true maxima, minima, etc., are not recorded. The mode tuned approach also allows the operator to select long test field exposure times as needed to accommodate long DUT response times.

A.2.2.2 Mode stirred approach rotates the stirrer continuously for a given 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 samples for a single stirrer revolution. Stirrer revolution rates are adjusted to meet DUT response time and output monitor response time requirements. Revolution periods can range from 2 s to 10 min, with typical values of 10 to 20 s. This large sample, as compared to mode tuned, improves the accuracy in determining the statistics of the measured parameters, but, at the expense of increased uncertainty due to failure to correct for net transmit power variations.

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 $\lambda/3$ from any wall. The DUT shall be placed more than $\lambda/6$ away from the stirrer. 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 x 3.66 m x 3.05 m (16 ft L x 12 ft W x 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.

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TABLE A1

Frequency (MHz)	Variation (dB)
200	$\leq \pm 8$
500	$\leq \pm 5$
1000	$\leq \pm 3$
2000	$\leq \pm 2$

A.5 Summary of Features of a Reverberation Chamber—A reverberation chamber is a high-Q environment making efficient use of RF power for generating a test field. The typical useful frequency range of operation is from 200 MHz to >10 GHz depending on the dimensions of the chamber.

A reverberation chamber (depending on its size and material) may distort the amplitude and rise time of a pulsed signal (i.e., for pulse modulation) when the pulse width is in the order of magnitude of a few microseconds.

The directional and polarization characteristics of an antenna or a DUT placed inside a reverberation chamber are lost.

The E-field distribution inside a reverberation chamber is statistical in nature. The maximum E-Field is approximately 8 dB higher than the average E-field. Maximum and average field response can be derived from one another. The presence of large metal objects does not affect the statistical field distribution.

The field inside of a reverberation chamber is a time-averaged uniform field. Inside the test volume, all receivers, either probes or antennas, will see approximately the same peak field strength and field distribution during a complete revolution of the stirrer but not simultaneously.

The DUT should not load the room by more than 6 dB.

A reverberation chamber can accommodate large DUTs due to its large test volume.

Test time is minimized, since multiple antenna locations and polarizations are not needed.

DUT exposure time to the RF field is selectable.