

	SURFACE VEHICLE STANDARD	
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Superseded by ISO 11452-11		
Electromagnetic Compatibility Measurements Procedure for Vehicle Components—Part 28— Immunity to Radiated Electromagnetic Fields—Reverberation Method (Mode Tuning)		

RATIONALE

SAE J1113-28 is being cancelled in favor of ISO 11452-11.

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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 400 MHz – 18GHz. Pulse modulation is used for testing above 800 MHz.
- 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 correlatable 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 document, including definitions, references, and general safety considerations are found in SAE J1113-1.

2.1 Applicable Publications

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

2.1.1 SAE PUBLICATIONS

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

SAE J1113-1—Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components (Except Aircraft) (60 Hz to 18 GHz)
SAE J1812—Function Performance Status Classification for EMC Immunity Testing

2.1.2 IEC PUBLICATIONS

Available from International Electrotechnical Commission, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneve 20, Switzerland.

IEC 61000-4-21—Electromagnetic Compatibility (EMC)—Part 4: Testing and Measurement Techniques—Section 21: Reverberation Chamber Test Methods

^[1] IEC 61000-4-3—Electromagnetic Compatibility (EMC)—Part 4: Testing and Measurement Techniques—Section 3: Radiated, "Radio-Frequency, Electromagnetic Field Immunity Test"

2.1.3 NBS/NIST PUBLICATIONS

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

^[15] NBS Technical Note 1092—Design, Evaluation, and Use of a Reverberating Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements

^[14] NIST Technical Note 1506—Electromagnetic Theory of Reverberation Chambers

^[16] NIST Technical Note 1508—Evaluation of the NASA Langley Research Center Mode Stirred Chamber Facility

2.1.4 MILITARY PUBLICATIONS

Available from the U.S. Government, DOD SSP, Subscription Service Division, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094

^[11] MIL-STD-461E—Department of Defense Interface Standard—Requirements for the Control of Electromagnetic Interface Characteristics of Subsystems and Equipment, 1999

MIL-STD-1377—Effectiveness of Cable, Connector, and Weapon Enclosure Shielding and Filters in Precluding Hazards of Electromagnetic Radiation to Ordinance, Measurement of

2.1.5 IEEE PUBLICATIONS

Available from Institute of Electrical and Electronic Engineers, 445 Hoes Lane, Piscataway, NJ 08854.

^[6] Olof Lunden, and Mats Backstrom, "Stirrer Efficiency in FOA Reverberation Chambers, Evaluation of Correlation Coefficients and Chi-Squared Tests," presented at the *IEEE International Symposium on EMC*, Washington, DC, August 2000.

^[8] G. J. Freyer, M.O. Hatfield, D.M. Johnson, and M.B. Slocum, "Comparison of Measured and Theoretical Statistical Properties of Complex Cavities," presented at the *IEEE International Symposium on EMC*, Santa Clara, CA, August 1996.

^[12] J. M. Ladbury, and K. Goldsmith, "Reverberation Chamber Verification Procedures or How to Check if Your Chamber Ain't Broke and Suggestions on How to Fix it if it is," presented at the *IEEE International Symposium on EMC*, Washington DC, Aug 2000.

^[13] J. M. Ladbury, "Reverberation Chamber Relationships: Corrections and Improvements or Three Wrongs Can (Almost) Make a Right," presented at the *IEEE International Symposium on EMC*, Seattle, WA, August 1999.

^[4] T. H. Lehman, G.J. Freyer, M.L. Crawford, and M.O. Hatfield, "Statistical Theory of Reverberation I: Overmoded Case," *Proceedings of the 1997 Mode-Stirred Chamber, Anechoic Chamber, and OATS Users Meeting*, Vail, Colorado April 28-May 2, 1997.

^[5] T. H. Lehman, G.J. Freyer, M.L. Crawford, and M.O. Hatfield, "Statistical Theory of Reverberation Chambers—Part II: Undermoded Case," *Proceedings of the 1997 Mode-Stirred Chamber, Anechoic Chamber, and OATS Users Meeting*, Vail, Colorado April 28-May 2, 1997.

2.1.6 RCTA PUBLICATION

Available from RCTA, Inc., 1140 Connecticut Avenue, NW, Suite 1020, Washington, DC 20036.

^[10] RTCA/DO-160D, "Environmental Conditions and Test Procedures for Airborne Equipment" (Change Notice to Section 20), November 2000.

3. Definitions

3.1 Reverberation Chamber

A high Q shielded room (cavity) whose boundary conditions are changed via a stepped rotating paddle. This results in a time-averaged uniform electromagnetic field.

3.2 Paddle

A large metallic reflector capable of changing the electromagnetic boundary conditions in a reverberation chamber as it rotates or moves. As the paddle moves, the nulls and maximums in the field change location, ensuring the Device Under Test (DUT) is exposed to a time-averaged uniform field. The paddle has also been referred to as a tuner or stirrer.

3.3 Chamber Calibration Factor (CCF)

The normalized average received power over one tuner rotation with the DUT and supporting equipment present,

$$CCF = \left\langle \frac{P_{\text{Avg Rec}}}{P_{\text{Input}}} \right\rangle_n \quad (\text{Eq. 1})$$

where:

$P_{\text{Avg Rec}}$ = the average received power over one tuner rotation

P_{Input} = the forward power averaged over one tuner rotation

n = the number of antenna locations the CCF is evaluated for. Only one location is required; however, multiple locations may be evaluated and the data averaged over the number of locations, n .

NOTE— $\langle \rangle$ denotes arithmetic mean

3.4 Chamber Quality Factor (Q)

The chamber Quality factor or "Q" is a measure of how well the chamber stores energy^[14]. For a given chamber, Q varies as a function of frequency and can be calculated using the following:

$$Q = \left(\frac{16\pi^2 V}{\eta_{Tx} \eta_{Rx} \lambda^3} \right) * CCF \quad (\text{Eq. 2})$$

where

η_{Tx} and η_{Rx} are the antenna efficiency factors for the transmit and receive antenna respectively and can conservatively be assumed to be 0.75 for a log periodic antenna and 0.9 for a horn antenna

V is the chamber volume (m^3)

λ is the free space wavelength (m) at the specific frequency.

3.5 Antenna Calibration Factor (ACF)

The ratio of the average received power to input power obtained in the antenna calibration in Appendix B, Section 1.2.

3.6 Chamber Loading Factor (CLF)

$$CLF = \frac{CCF}{ACF} \quad (\text{Eq. 3})$$

4. Test Equipment

4.1 Reverberation Chamber

Sized large enough to test a DUT within the chamber's test volume.

4.2 Mechanical Tuner

As large as possible with respect to overall chamber size (at least three-quarters of the smallest chamber dimension) and test volume considerations. In addition each tuner should be shaped such that a non-repetitive field pattern is obtained over one revolution of the tuner.

4.3 Isotropic E-Field Probe

Capable of reporting electric field strength in three orthogonal axes.

4.4 RF Signal Generator

Capable of covering the frequency bands and modulations specified.

4.5 Transmit Antenna

Linearly polarized antenna capable of satisfying frequency requirements. The transmit antenna shall avoid direct illumination of the test volume.

4.6 Receive Antenna

Linearly polarized antenna capable of satisfying frequency requirements. The receive antenna shall avoid pointing at the transmit antenna and center of the test volume.

4.7 Power Amplifiers

To amplify the RF signal and provide the necessary power to the transmit antenna to produce the field strengths specified.

4.8 Associated equipment to record the power levels necessary for the required field strength and to control the generation of that level for testing.

4.9 DUT Monitoring Instrumentation

Instrumentation and/or observation is used to monitor the parameters of the DUT in order to determine its performance during the test. The monitoring instrumentation and technique shall be documented in the test report. Monitoring of particular DUT functions must not disturb its operation or couple in any extraneous RF energy that it would not normally experience.

5. Chamber Calibration

Following the initial construction or after any major modifications, a performance-based field uniformity calibration technique to demonstrate adequate reverberation chamber performance is carried out in accordance with Appendix B. The procedure is used to determine the lowest useable frequency (LUF) of the reverberation chamber employed. The chamber field uniformity calibration described is to be carried out over a test/working volume, which includes the location of the test bench and DUT within the reverberation chamber. The chamber calibration addresses mode tuned operation of the reverberation chamber: The field uniformity measurement should be carried out with all support equipment (including the test bench) removed from the reverberation chamber. The calibration is to be carried out at 9 locations for 3 individual axes (x,y,z) at each test location, i.e., 27 measurement points in total (B.1.1). The field within the chamber is considered uniform if the standard deviation is within 3dB above 400 MHz, 4dB at 100 MHz decreasing linearly to 3 dB at 400 MHz, and within 4 dB below 100 MHz.

- 5.1** The calibration technique permits the use of linear/passive field monitoring antennas during DUT testing. The antennas are calibrated against an Isotropic E-field probe (calibrated in free space). The purpose of this aspect of the procedure is to allow continuous monitoring of the field during the test with an antenna and associated monitoring equipment with a fast response time. Again, this test is performed with the measurement bench removed and performed at the same time as the field uniformity test. In addition, following initial construction or after major modification to the reverberation chamber a check on the impact on field uniformity of chamber loading is performed (B.1.5) to determine the maximum acceptable loading of the chamber for future testing.

NOTE—If the chamber was initially tested under maximum loading conditions – an optional “quick check” chamber performance measurement may be made with the DUT and test bench installed in the chamber (B.2). The purpose of this test is to confirm that the loading of the chamber is less than that simulated during the initial chamber calibration.

- 5.2** Calculations based on the calibration measurements are used to determine the minimum pulse width (B.3) that can be sustained in a given chamber for pulse modulation testing. If the chamber time constant is greater than 0.4 times the required pulse width for more than 10% of the test frequencies, absorbers must be added or the pulse width increased (not to exceed 100 μ s).

NOTE—The chamber calibration detailed in B.1 need only be undertaken after initial chamber construction, annually, and after major modification to the reverberation chamber. The maximum chamber loading verification (B.1.5) need only be undertaken after initial chamber construction or after major modifications to the reverberation chamber. Changes to the tuners/stirrers shall be considered a major modification if the changes result in changes in tuner efficiency as outlined in A.3.

6. Test Setup

- 6.1** The typical test setup should be as shown in Figure 1. The equipment layout should be representative of the actual installation. The DUT shall be at least $\lambda/4$ meter from the chamber walls at the lowest usable frequency (LUF) of the chamber. DUTs designed for tabletop operation must be located $\lambda/4$ meter from the chamber floor. Floor standing DUTs shall be supported 2.5 cm above the floor, in the area beneath the uniform volume, by a dielectric support.

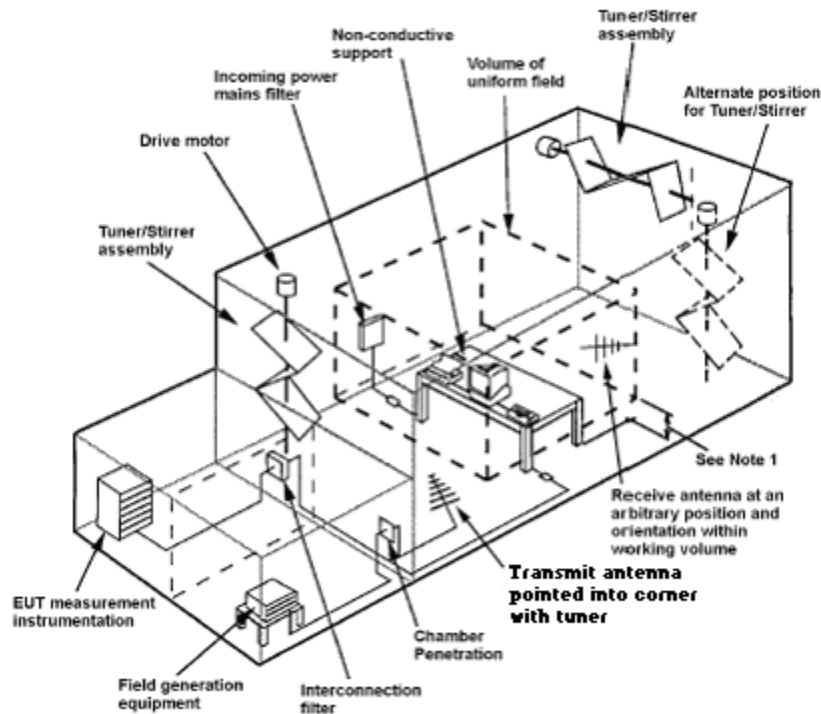


FIGURE 1— EXAMPLE OF SUITABLE TEST FACILITY

- 6.2** The transmit antenna should be in the same location as used for calibration. The transmit antenna shall not directly illuminate the DUT or the receive antenna. Directing the transmit and receive antennas into the corners of the chamber is a recommended configuration. Appropriate modes of operation, software installation, and stability of the DUT, test equipment, and all monitoring circuits and loads must be established.
- 6.3** If the DUT may load the chamber beyond that of the maximum loading verification, prior to collecting data a check must be performed to determine if the DUT and/or its support equipment have adversely loaded the chamber. This check shall be performed as outlined in Appendix B, Section B.2.

7. Test Procedures

CAUTION—RF fields can be hazardous. Observe applicable national RF exposure limits

7.1 Determining Chamber Input Power Requirements

7.1.1 Determine the chamber input power for the test requirements for the electric field intensity using the equation:

$$P_{\text{input}}(\text{W}) = \left[\frac{E_{\text{Test}} \left(\frac{\text{V}}{\text{m}} \right)}{\langle \vec{E} \rangle_{27\text{ or }9} * \sqrt{\text{CLF}(f)}} \right]^2 \quad (\text{Eq. 4})$$

where:

E_{Test} (V/m) is the required field strength

CLF(f) is the chamber loading factor from Appendix B (B.2.7) and

$\langle \vec{E} \rangle_{27\text{ or }9}$ is the normalized E field from the empty chamber calibration from Appendix B (B.1.1.10.(b)or(c)). It will be necessary to interpolate (linear interpolation) between the calibration frequency points (calibration at a finer step interval is also an option).

7.2 Selecting Frequency Sweep/Step Rates/Intervals

Frequency sweep or step rates shall be selected with consideration of DUT response time, DUT susceptibility bandwidths, and monitoring test equipment response time. The scan rate selected shall be justified by this criterion, and documented in the test report.

7.2.1 DISCRETE FREQUENCY TESTING

For test equipment that generates discrete frequencies, the minimum number of test frequencies shall be 100 frequencies per decade. The test frequencies shall be logarithmically spaced. As an example (above 100 MHz), a formula which can be used to calculate these frequencies in ascending order is:

$$f_{n+1} = f_n * 10^{(1/99)} \quad (\text{Eq. 5})$$

where:

f_n is a test frequency and $n = 1$ to 100,

f_1 is the start frequency,

and

f_{100} is the end frequency

The dwell time at each test frequency shall be at least seconds, exclusive of test equipment response time and the time required to rotate the tuner (to a full stop). Additional dwell time at each test frequency may be necessary to allow the DUT to be exercised in appropriate operating modes and to allow for the "off time" during low frequency modulation. At least two full cycles of modulation must be applied. For example, if the applied modulation is a 1 Hz square wave modulation (SW), the dwell time shall not be less than two seconds. The dwell time selected shall be justified based on DUT and test equipment response time, as well as applied modulation, and documented in the test report.

7.3 Performing the Test

For mode-tuned operation, the minimum number of steps is outlined in Table B1.. The tuner should be rotated in evenly spaced steps so that one complete revolution is obtained per frequency. Assure that the DUT is exposed to the field level for the appropriate dwell time.

Monitor and record P_{MaxRec} and P_{AveRec} with the receive antenna used in the calibration of each frequency band to ensure that the required field strength is being generated. Use P_{AveRec} to ensure that the chamber loading has not changed from the calibration in B.2. Differences greater than 3 dB in P_{AveRec} from that obtained in B.2 must be resolved.

Monitor and record the average values of P_{Input} and $P_{\text{Reflected}}$. Variations in P_{Input} over a tuner rotation greater than 3 dB should be noted in the test report.

Modulate the carrier as specified in the test plan. When modulation is applied, ensure that the peak amplitude complies with the definitions of the test plan.

Scan the frequency range to the upper frequency limit using the appropriate antennas and modulations.

NOTE 1—Linear interpolation between calibration points will be required.

NOTE 2—Test volume should be at least $\lambda/4$ at the LUF from any chamber surface, field generating antenna or tuner assembly. (See Note 5 of Figure B1, Appendix B)

NOTE 3—A non-conductive/non-absorbing support shall be utilized. Wooden tables should be avoided. Polystyrene foam is a suitable support in most cases. Foam materials may present a fire hazard if the DUT generates sufficient heat and/or when testing to field strengths that can induce arcing.

NOTE 4—The chamber should remain free of any unnecessary absorbing materials. Items such as wooden tables, carpeting, wall and floor coverings, and ceiling tiles should not be used. Also exposed light fixtures are a source of potential loading. For new chambers, it is recommended that an evaluation of the chamber be performed prior to installation of any support equipment other than doors, vents and access panels. Support equipment such as tables etc., should be non-metallic and non-absorbing. The DUT and all supporting equipments should not occupy more than 8% of the total chamber volume.

8. Test Severity Levels

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 D.

9. Test Report

The test report should include the following parameters for each test frequency, in addition to the reporting requirements related to the DUT.

- Max received power from the receive antenna used to monitor the field in the chamber.
- Mean received power from the receive antenna used to monitor the field in the chamber.
- Forward power delivered to the chamber transmit antenna.
- Reflected power from the chamber transmit antenna.
- Variations in forward power during the data collection period greater than 3 dB.

PREPARED BY THE SAE EMI STANDARDS COMMITTEE

APPENDIX A (INFORMATIVE) REVERBERATION CHAMBER OVERVIEW

A.1 Introduction

Research on reverberation chambers has been performed for more than 20 years and has provided a significant increase in the understanding of the methodology^[14,15]. Although the initial intent of this research was for measuring the shielding effectiveness of cables, connectors and enclosures, (MIL-STD-1377) the scope of the work was expanded to include susceptibility testing of electronic equipment, immunity testing of ordnance, and emissions testing.

A reverberation chamber is an electrically large, highly conductive enclosed cavity or chamber used to perform electromagnetic (EM) measurements (both emissions and immunity) on electronic equipment. Any facility that fits this description can be considered a reverberation chamber (also called a mode-stirred chamber). Other conditions, however, may be required before such a facility can be used with acceptable uncertainty^[16].

In general, a reverberation chamber is a shielded enclosure with the smallest dimension being large with respect to the wavelength at the lowest useable frequency. The chamber is normally equipped with a mechanical tuning/stirring device whose dimensions are a significant fraction of the chamber dimensions and of the wavelength at the lowest useable frequency. When the chamber is excited with RF energy the resulting multi-mode electromagnetic environment can be "stirred" by the mechanical tuner/stirrer. The resulting environment is statistically uniform and statistically isotropic (i.e. having arrived from all aspect angles and at all polarizations) when averaged over a sufficient number of positions of the mechanical tuner/stirrer.

The chamber mode density and the effectiveness of the mechanical tuner/stirrer determine the lowest useable frequency. The lowest useable frequency is generally accepted to be the frequency at which the chamber meets operational requirements. This frequency generally occurs at a frequency slightly above 3 times the first chamber resonance. In practice the chamber size, tuner/stirrer effectiveness and the chamber quality factor determine the lowest useable frequency. For the reverberation chamber procedure described in this standard, it is the lowest frequency at which, the specified field uniformity can be achieved over a volume defined by an 9-location calibration data set.

Quality factor is used to describe the ability of a chamber or cavity to store energy. The ability of a chamber to store energy is determined by the losses present in the chamber. The dominant loss in an empty chamber is the chamber walls. The higher the conductivity of the materials used to construct the chamber walls the lower the chamber losses. Materials such as copper and aluminum sheet offer the highest conductivity and therefore the lowest losses. Other materials such as bare or painted steel or galvanized sheet are also common. Copper and aluminum screen and flame spray however, have large surface areas and do not result in high Q environments. Additional losses such as antennas, support structures, and the DUT also can affect the chamber Q. The chamber input power (P_{Input}) is normally taken to be the forward power delivered to the antenna terminals. In some cases it is necessary to take into account the reflected power caused by antenna/excitation induced mismatch. In such cases the input power shall be the net input power which is equal to:

$$P_{\text{Net}} = P_{\text{Forward}} - P_{\text{Reflected}} \quad (\text{Eq. A1})$$

The amount of power needed to generate a specific field inside a chamber can be determined from the empty chamber calibration outlined in Appendix B. However, the DUT, the required support equipment, or any absorbing material present may load the chamber, reduce the chamber Q, and hence reduce the test fields for the same input power. Therefore, the fields in a loaded chamber must be monitored and input power increased, if necessary, to compensate for this loading as described in B.2.7.

The tuners should be adequate to provide the desired field uniformity. In some chambers, it may be necessary to use multiple tuners/stirrers to obtain the desired field uniformity at the required frequencies. Stepping motors with computer control are recommended. Variable speed, continuous motors are acceptable, but the time response of the DUT must be fast relative to tuner/stirrer speed for this option to be viable. A method of evaluating tuner/stirrer performance is given in Section A.3. In the past, testing was performed using 200 samples or steps of the mechanical tuner^[15]. This resulted in uncertainties (i.e. inhomogeneity) in the field that varied as a function of frequency due to the increase in modal density at the higher frequencies. As shown in Figure A1, the uncertainty for a typical chamber varied considerably as a function of frequency as the number of tuner steps remained constant. The procedure developed for this standard optimises the number of steps or samples to obtain a fixed uncertainty as a function of frequency.

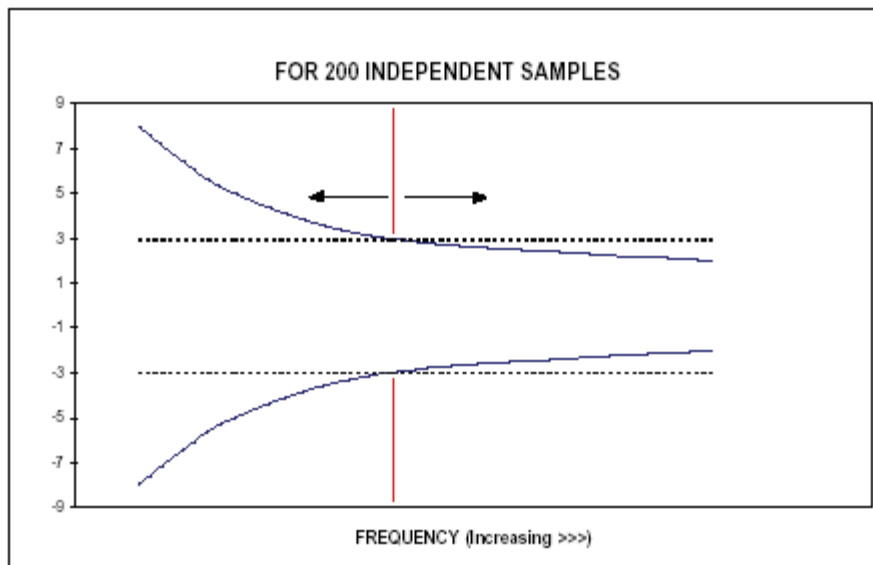


FIGURE A1—TYPICAL FIELD UNIFORMITY FOR 200 TUNER STEPS

A.2 Cavity Theory

The modes in a cavity are determined by the boundary conditions. For a rectangular cavity of dimensions L (length), W (width) and H (height), the mode frequencies $F_{l,m,n}$, in MHz, can be shown to be^[15]

$$F_{l,m,n} = 150 \sqrt{\left(\frac{l}{L}\right)^2 + \left(\frac{m}{W}\right)^2 + \left(\frac{n}{H}\right)^2} \quad (\text{Eq. A2})$$

where:

- l, m and n are the mode indices,
- L, W and H are the chamber dimensions in meters.

Figure A2 shows the theoretical mode distribution as a function of frequency for a 10.8m x 5.2m x 3.9m rectangular chamber. Each mode represents a unique field variation (modal structure) as a function of spatial location throughout the cavity. The first resonance of this chamber ($F_{l,m,n}$) occurs at a frequency of 32.096 MHz.

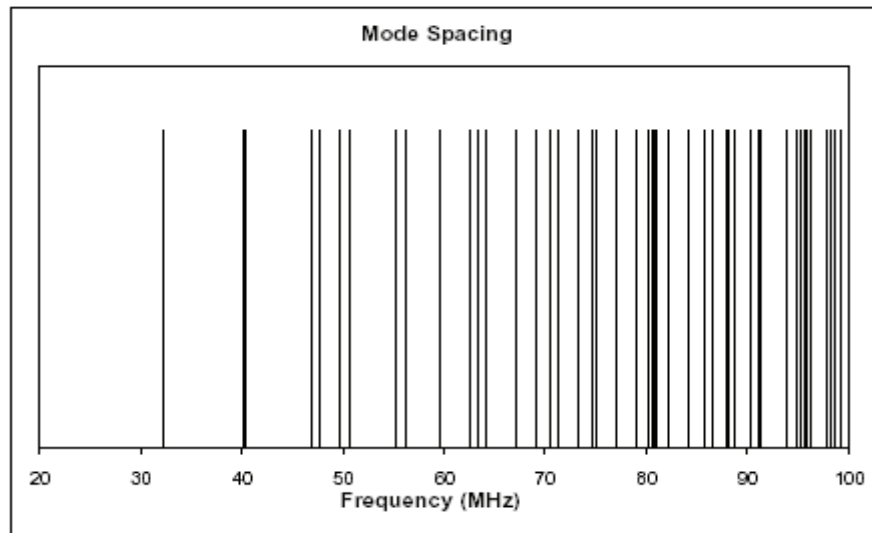


FIGURE A2—THEORETICAL MODAL STRUCTURE FOR A 10.8m x 5.2m x 3.9m CHAMBER
(VERTICAL AXIS HAS NO MEANING OTHER THAN TO REPRESENT MODE FREQUENCY)