

Electromagnetic compatibility (EMC) —

Part 4-21: Testing and measurement techniques — Reverberation chamber test methods

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National foreword

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Electromagnetic compatibility (EMC)
Part 4-21: Testing and measurement techniques –
Reverberation chamber test methods
(IEC 61000-4-21:2003)

Compatibilité électromagnétique (CEM)
Partie 4-21: Techniques d'essai
et de mesure –
Méthodes d'essai en chambre
réverbérante
(CEI 61000-4-21:2003)

Elektromagnetische Verträglichkeit (EMV)
Teil 4-21: Prüf- und Messverfahren -
Verfahren für die Prüfung
in der Modenverwirbelungskammer
(IEC 61000-4-21:2003)

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Foreword

The text of document CISPR/A/455/FDIS, future edition 1 of IEC 61000-4-21, prepared by CISPR SC A, Radio-interference measurements and statistical methods, in cooperation with SC 77B, High-frequency phenomena, of IEC TC 77, Electromagnetic compatibility, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61000-4-21 on 2003-10-01.

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Annexes designated "normative" are part of the body of the standard.

Annexes designated "informative" are given for information only.

In this standard, annexes B, C, D, E and ZA are normative and annexes A, F, G, H, I, J are informative.

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61000-4-21:2003 was approved by CENELEC as a European Standard without any modification.

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INTRODUCTION

IEC 61000 is published in separate parts according to the following structure:

Part 1: General

- General considerations (introduction, fundamental principles)
- Definitions, terminology

Part 2: Environment

- Description of the environment
- Classification of the environment
- Compatibility levels

Part 3: Limits

- Emission limits
- Immunity limits (in so far as they do not fall under the responsibility of the product committees)

Part 4: Testing and measurement techniques

- Measurement techniques
- Testing techniques

Part 5: Installation and mitigation guidelines

- Installation guidelines
- Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts, published either as international standards or as technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and a second number identifying the subdivision (example : 61000-6-1).

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-21: Testing and measurement techniques – Reverberation chamber test methods

1 Scope

This part of IEC 61000 considers immunity and wanted and unwanted emissions tests for electric and/or electronic equipment and screening effectiveness tests. Only radiated phenomena are considered. It establishes the required test procedures for using reverberation chambers for performing radiated immunity, radiated emissions and screening effectiveness testing.

The object of this part is to establish a common reference for using reverberation chambers to evaluate the performance of electric and electronic equipment when subjected to radio-frequency electromagnetic fields and for determining the levels of radio-frequency radiation emitted from electric and electronic equipment.

NOTE Test methods are defined in this part for measuring the effect of electromagnetic radiation on equipment and the electromagnetic emissions from equipment concerned. The simulation and measurement of electromagnetic radiation is not adequately exact for quantitative determination of effects. The test methods defined are structured for the primary objective of establishing adequate repeatability of results at various test facilities for qualitative analysis of effects.

This part of IEC 61000 does not intend to specify the tests to be applied to particular apparatus or system(s). Its main aim is to give a general basic reference to all concerned product committees of the IEC. The product committees are to select emission limits and test methods in consultation with CISPR. The product committees remain responsible for the appropriate choice of the immunity tests and the immunity test limits to be applied to their equipment. This part of IEC 61000 describes other test methods than IEC 61000-4-3 and CISPR 16-2. The other methods may be used in consultation with CISPR and TC 77, if so specified by product committees.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050(161):1990, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

IEC 60068-1, *Environmental testing – Part 1: General and guidance*

IEC 61000-4-3, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-6, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

CISPR 16-1, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1: Radio disturbance and immunity measuring apparatus*

CISPR 16-2, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2: Methods of measurement of disturbances and immunity*

3 Definitions and acronyms

3.1 Definitions

For the purposes of this part of IEC 61000-4, the following definitions, together with those in IEC 60050(161) apply.

3.1.1

antenna

that part of a radio transmitting or receiving system which is designed to provide the required coupling between a transmitter or a receiver and the medium in which the radio wave propagates

[IEV 712-01-01]

NOTE For the purpose of this procedure antennas are assumed to have an efficiency of 75 % or greater.

3.1.2

electromagnetic (EM) wave

variations of the conditions of a material medium or vacuum, characterized by a time-varying electromagnetic field, and moving with a velocity defined at each point and in each direction by the properties of the medium

NOTE An electromagnetic wave is produced by variations of electric charges or of electric currents.

[IEV 121-11-63]

3.1.3

far field region

that region of the electromagnetic field of an antenna wherein the predominant components of the field are those which represent a propagation of energy and wherein the angular field distribution is essentially independent of the distance from the antenna

NOTE 1 In the far field region, all the components of the electromagnetic field decrease in inverse proportion to the distance from the antenna.

NOTE 2 For a *broadside* antenna having a maximum overall dimension, D , which is large compared to the wavelength, λ , the far field region is commonly taken to exist at distances greater than $2D^2/\lambda$ from the antenna in the direction of maximum radiation.

[IEV 712-02-02]

3.1.4

field strength

measurement, made in the far field, of either the electric or the magnetic component of the field and expressed as V/m or A/m; any one of these measurements may be converted into the others

NOTE For measurements made in the near field, the term "electric field strength" or "magnetic field strength" is used according to whether the resultant electric or magnetic field, respectively, is measured. In this field region, the relationship between the electric and magnetic field strength and distance is complex and difficult to predict, being dependent on the specific configuration involved. Inasmuch as it is not generally feasible to determine the time and space phase relationship of the various components of the complex field, the power flux density of the field is similarly indeterminate.

The IEEE Std 100 definition is as follows:

field strength

(electromagnetic wave) A general term that usually means the magnitude of the electric field vector, commonly expressed in V/m, but that may also mean the magnitude of the magnetic field vector, commonly expressed in A/m.

NOTE At frequencies above about 100 MHz, and particularly above 1 000 MHz, field strength in the far zone is sometimes identified with power flux density P . For a linearly polarized wave in free space $P = E^2 \left(\sqrt{\mu_0/\epsilon_0} \right)$, where

E is the electric field strength, and

μ_0 and ϵ_0 are the magnetic and electric constants of free space, respectively.

When P is expressed in W/m² and E in V/m, the denominator is often rounded off to 120π . See also: electric field strength; magnetic field strength; measurement system.

3.1.5

polarization

$\vec{P}$

at a given point within a domain of quasi-infinitesimal volume V , vector quantity equal to the vector electric dipole moment $\vec{p}$ of the substance contained within the domain divided by the volume V

$$\vec{P} = \frac{\vec{p}}{V} \quad (1)$$

NOTE 1 The electric polarization, $\vec{P}$, satisfies the relation

$$D = \epsilon_0 E + \vec{P} \quad (2)$$

where

D is the electric flux density,

E the electric field strength, and

ϵ_0 the dielectric constant.

[IEV 121-11-37, modified]

NOTE 2 Magnetic polarization (symbols B_i , J) is the vector quantity equal to the product of the magnetization, M , and magnetic constant, μ_0 :

$$J = \mu_0 M \quad (3)$$

[IEV 121-11-54]

3.1.6

reverberation chamber

shielded enclosure that is generally equipped with mechanical tuners/stirrers which change (stir) the boundary conditions within the enclosure and, thus, alter the structure of the electromagnetic fields within the enclosure

NOTE Testing in a reverberation chamber can be described as a stochastic process in which the mechanical tuners/stirrers “stir” the “modes” inside the enclosure. The chambers are also called stirred-mode, mode-stirred or mode-tuned chambers.

3.1.7 reverberation chamber quality factor

Q

the chamber quality factor or “Q” is a measure of how well the chamber stores energy (see A.6[2]¹⁾). For a given chamber, Q varies as a function of frequency and can be calculated using the following:

$$Q = \frac{16\pi^2 V}{\eta_{Tx} \eta_{Rx} \lambda^3} \left\langle \frac{P_{AveRec}}{P_{input}} \right\rangle \quad (4)$$

where

V is the chamber volume (m³),

λ is the wavelength (m),

$\langle P_{AveRec}/P_{input} \rangle$ is the ratio of the average received power to the input power over one complete tuner/stirrer sequence, and

η_{Tx} and η_{Rx} are the antenna efficiency factors for the Transmit (Tx) and Receive (Rx) antennas, respectively. (If 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.)

3.1.8 reverberation chamber Q-bandwidth (BW_Q)

the BW_Q is a measure of the frequency bandwidth over which the modes in a reverberation chamber are correlated (see Clause A.2). The BW_Q of a reverberation chamber can be calculated using the following:

$$BW_Q = f/Q \quad (5)$$

where

f is the frequency, and

Q is the quality factor defined in 3.1.7.

3.1.9 malfunction

termination of the ability of an equipment to carry out intended functions or the execution of unintended functions by the equipment

3.1.10 radiated emissions

any wanted or unwanted emission from an electrical device

3.1.11 tuner/stirrer

mechanical device constructed from electrically conductive material which alters the electromagnetic boundary conditions within reverberation chambers

NOTE 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 boundary conditions of the resulting multi-mode electromagnetic environment can be “altered” by the mechanical tuner/stirrer. The resulting environment is statistically uniform and statistically isotropic (i.e., the energy having arrived from all aspect angles and at all polarizations) when averaged over a sufficient number of positions of the mechanical tuner/stirrer.

¹⁾ Numbers in brackets refer to the reference documents in the respective annexes.

3.2 Acronyms

ACF	Antenna Calibration Factor
CCF	Chamber Calibration Factor
CDF	Cumulative Distribution Function
CISPR	Comité International Spécial des Perturbations Radioélectriques
CLF	Chamber Loading Factor
CW	Continuous Wave
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EUT	Equipment Under Test
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEV	International Electrotechnical Vocabulary
IF	Image Frequency
IL	Insertion Loss
ISO	International Standardization Organization
JTF	Joint Task Force
LUF	Lowest Usable Frequency
NIST	National Institute of Standards and Technology
OATS	Open Area Test Site
PDF	Probability Density Function
RE	Radiated Emissions
RF	Radio Frequency
RMS	Root Mean Square
RSS	Root Sum of the Squares
Rx	Receive (antenna)
SE	Shielding Effectiveness
SW	Square Wave modulation
TFCF	Test Fixture Calibration Factor
Tx	Transmit (antenna)

4 General

Most electronic equipment is, in some manner, affected by electromagnetic radiation. This radiation is frequently generated by such sources as the small hand-held radio transceivers that are used by operating, maintenance and security personnel, fixed-station radio and television transmitters, vehicle radio transmitters and various industrial electromagnetic sources.

High-level electromagnetic fields are easily and safely generated using reverberation chambers. The high quality factor or “Q” of most chambers allows fairly high field strengths to be generated with moderate input powers, and the absence of absorber makes generation of high field levels safer as the risk of igniting absorbers is eliminated.

In addition to electromagnetic energy deliberately generated, there are also radiated disturbances caused by devices such as welders, thyristors, fluorescent lights, switches operating inductive loads, etc. For the most part, this disturbance manifests itself as conducted electrical disturbance and, as such, is dealt with in other parts of IEC 61000-4. However, this standard does deal with how to measure radiated emissions from such devices. Methods employed to prevent effects from electromagnetic fields will normally also reduce the effects from these sources.

The electromagnetic environment is determined by the strength of the electromagnetic field (electric field strength in V/m and magnetic field in A/m). The field strength is not easily measured without sophisticated instrumentation nor is it easily calculated by classical equations and formulae because of the effect of surrounding structures or the proximity of other equipment that will distort and/or reflect the electromagnetic waves.

5 Test environments and limitations

The reverberation chamber method is suitable for performing testing from extremely low to extremely high field levels. Due to the high level of separation from the ambient environment, both emissions and immunity tests can be performed for most commercial requirements without limitations.

As stated in Annex A, the frequency range of tests is determined by the size and construction of the chamber and the effectiveness of the mechanical tuner(s). Room-sized reverberation chambers (e.g., volumes of between 75 m³ to 100 m³) are typically operated from 200 MHz to 18 GHz without limitations. Operations below 200 MHz require chambers that are larger than the typical shielded room. At present, the IEC sets the transition frequency between radiated and conducted testing at 80 MHz for immunity testing.

NOTE IEC 61000-4-6 also defines test methods for establishing the immunity of electrical and electronic equipment against conducted electromagnetic energy. It covers frequencies below 80 MHz.

6 Applications

6.1 Radiated immunity

The use of reverberation chambers for performing radiated immunity testing is covered in Annex D. This Annex covers test set-up, chamber calibration, and test procedures. Injecting a predetermined level of RF power into the chamber generates the desired field strengths within the chamber. This predetermined level of RF power is derived from chamber calibration data described in Annexes B and/or C.

6.2 Radiated emissions

Using reverberation chambers to measure radiated emissions (both intentional and unintentional) is covered in Annex E. The method described measures the amount of RF power radiated by the EUT within the measurement bandwidth. As with radiated immunity testing, chamber calibration data described in Annexes B and/or C is used to determine radiated emissions levels.

6.3 Screening effectiveness measurements

Three annexes are devoted to conducting screening effectiveness measurements. Screening effectiveness measurements of cables assemblies, cables, connectors, waveguides and passive microwave components are described in Annex F. Annex G covers screening effectiveness of gaskets and materials. The approach outlined in Annex G uses a “nested chamber” methodology (e.g., a reverberation chamber within a reverberation chamber). This annex also covers calibration of test fixtures that are usually necessary for conducting screening measurements on gaskets and materials. Minor differences in test fixture design/construction can have significant influence on test results. Fixture materials, bolt spacing, surface finishes, torque settings, etc. must all be controlled in order to get repeatable results. Due to the large number of variations that would be needed in order to accommodate the many different gaskets and materials that require evaluation, this annex does not contain detailed design guidance for test fixtures. Annex H covers screening effectiveness measurements of enclosures. As in Annex G, the methodology described in Annex H uses the “nested chamber” approach.

7 Test equipment

The following types of test equipment are recommended.

- *Reverberation chamber*: of a size adequate to maintain a multi-mode electromagnetic environment with respect to the lowest test frequency.
- *Mechanical tuner(s)/stirrer(s)*: with one dimension at least one-quarter wavelength at the lowest frequency. Each tuner/stirrer should also be as large as possible with respect to overall chamber size in that one dimension should be at least three-quarters of the smallest chamber dimension. In addition, each tuner/stirrer should be shaped such that a non-repetitive field pattern is obtained over one revolution of the tuner/stirrer.
- *Field generating antennas (see Annex B)*: log periodic or any other linearly polarized antenna system capable of satisfying frequency requirements and avoiding direct illumination of the test volume.
- *Field strength reference antennas (see Annex B)*: log periodic or any other linearly polarized antenna system capable of satisfying frequency requirements.
- *Isotropic field strength monitoring probe (see Annex B)*: capable of monitoring the electric field along all three orthogonal axes. Any probe-head circuitry and opto-electronics shall have adequate immunity to the field strength to be measured, and a fiber-optic link to the indicator outside the chamber. An adequately filtered line may also be used.

NOTE 1 Reverberation chambers require a field probe that allows the electric field to be measured individually along all three orthogonal axes. If a small single-axis antenna is used it must be repositioned to measure each field component separately.

- *Field strength monitoring antenna* that is a small (calibrated) dipole antenna (i.e., less than $0,1\lambda$) may be substituted for the probe, provided that the antenna is positioned at three non-coplanar orientations (mutually perpendicular preferred) for each measurement location. Care should be taken to maintain the balance of this antenna with respect to its feed cable.
- *EMI filters*: care should be taken to ensure that the filters introduce no additional resonance effects on the connected lines.
- *RF signal generator(s)* capable of covering the frequency band of interest and which, if used for immunity testing, can be amplitude modulated by a 1 kHz sinewave to 80 % depth. They shall have either an automated sweep capability of $1,5 \times 10^{-3}$ decade/s or slower or, in the case of RF synthesizers, be capable of being programmed with frequency-dependent step-sizes and dwell times. They shall also be capable of being set manually.

NOTE 2 Product committees may select alternative modulation schemes.

The use of low-pass or band-pass filters may be necessary to avoid problems caused by harmonics to equipment which is intended to receive signals for monitoring purposes.

- *Power amplifiers*: to amplify signal (unmodulated and modulated) and provide antenna drive power to the necessary field level. The harmonics and distortion produced by the power amplifier shall be at a level less than or equal to 15 dB below carrier level.

WARNING – High reflections are present in reverberation chamber tests, amplifier protection may be required.

- *Associated equipment to record the power levels* necessary for the required field strength and to control the generation of that level for testing.
- *Associated equipment to record the power levels* associated with the required emissions limits.

Care shall be taken to ensure adequate immunity of the auxiliary equipment.

8 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 Annex 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 equipment under test (EUT) within the reverberation chamber. The chamber calibration addresses only mode tuned (stepped tuner rotation) operation of the reverberation chamber: mode-stirred (continuous tuner rotation) operation is addressed separately in Annex C. 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 8 locations for 3 individual axes (x, y, z) at each test location, i.e., 24 measurement points in total (B.1.1). The field within the chamber is considered uniform if the standard deviation is within 3 dB above 400 MHz, 4 dB at 100 MHz decreasing linearly to 3 dB at 400 MHz, and within 4 dB below 100 MHz.

The calibration technique requires the use of linear/passive field monitoring antennas during EUT testing. The antennas are calibrated against a three-axis *E*-field sensor (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.

Prior to the start of each test with the test bench and EUT installed in the chamber, the following is carried out.

- A “quick check” chamber performance measurement is made with the equipment to be tested 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.
- 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 shall be added or the pulse width increased (not to exceed 100 µs).

NOTE The chamber calibration detailed in clause B.1 need only be undertaken after initial chamber construction, and after major modification to the reverberation chamber. The maximum chamber loading verification (A.5.4, B.1.5) need only be undertaken after initial chamber construction or after major modifications to the reverberation chamber. Changes to the tuners/stirrers are considered a major modification if the changes result in changes in tuner efficiency as outlined in clause A.3.

9 Testing

Test set-up and procedures are dependent upon the type of test being performed. Refer to the annex that pertains to the type of test being performed to determine the test requirements for a specific test.

Refer to the annex that pertains to the type of test methodology desired (i.e., mode-tuned or mode-stirred). For guidance on applicability of mode-tuning versus mode-stirring, refer to Annexes A and C.

10 Test results, test report and test conditions

Testing shall be performed according to a test plan, which shall be included in the test report.

Test results and reporting requirements are dependent upon the type of test being performed. Refer to the annex that pertains to the type of test being performed to determine what needs to be included in the test report.

Unless otherwise stated in the test plan, tests shall be carried out in standard climatic conditions in accordance with IEC 60068-1.

Annex A (informative)

Reverberation chamber overview

A.1 Preliminary remarks

Research on reverberation chambers has been performed for more than 20 years and has provided a significant increase in the understanding of the methodology [1]²⁾, [2], [3]. Although the initial intent of this research was for measuring the shielding effectiveness of cables, connectors and enclosures (see [17]), 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 [4].

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 (LUF). 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 LUF. 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., the energy having arrived from all aspect angles and at all polarizations) when averaged over a sufficient number of positions of the mechanical tuner/ stirrer. By “sufficient number,” we mean the number of tuner steps required to give the specified field uniformity. To achieve a statistically uniform and statistically isotropic environment also, means other than mechanical tuners may be acceptable.

The chamber mode density and the effectiveness of the mechanical tuner/stirrer determine the LUF. The LUF is generally accepted to be the frequency at which the chamber meets operational requirements. This frequency generally occurs at a frequency slightly above three 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, the LUF is the lowest frequency at which, the specified field uniformity can be achieved over a volume defined by an 8-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 aluminium sheet offer the highest conductivity and therefore the lowest losses. Other materials such as bare or painted steel or galvanized sheet are also common.

²⁾ Figures in brackets refer to Clause A.6, Reference documents, at the end of this annex.

Copper and aluminium 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 equipment under test (EUT) also can affect the overall Q of the chamber.

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:

$$P_{\text{Net}} = P_{\text{Forward}} - P_{\text{Reflected}} \quad (\text{A.1})$$

The amount of power needed to generate a specific field inside a chamber can be determined from the empty chamber calibration outlined in Annex B. However, the EUT, 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/stirrers 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 or encoder-equipped servo-motors with computer control are recommended. Variable speed, continuous motors are acceptable, but the time response of the EUT must be fast relative to tuner/stirrer speed for this option to be viable. A method of evaluating tuner/ stirrer performance is given in clause A.3.

In the past, testing was performed using 200 samples or steps of the mechanical tuner [1]. This resulted in uncertainties (i.e., statistical 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 A.1, 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.

The procedure described provides an accurate and economic methodology for calibrating reverberation chambers. The procedure is flexible in that it allows for an operator to adjust the number of tuner steps used to obtain the desired level uncertainty as well as maximize the ability of the chamber to generate higher fields by increasing the number of tuner steps.

The calibration procedure does place a stringent requirement on the chamber being evaluated. The data required places the need for the time-averaged fields generated within the test volume to be uniform to within a given uncertainty. To ensure this requirement is met, three measurements are required at each of the eight locations using three mutually perpendicular orientations. Each measurement is independent, which results in a total of 24 measurements being taken. A chamber that passes the calibration procedure will have demonstrated its ability to generate the required field uniformity.

A.2 Cavity theory

The modes in a cavity are determined by the boundary conditions. For an ideal, lossless, empty, 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 (see [1]):

$$F_{l,m,n} = 150 ((l/L)^2 + (m/W)^2 + (n/H)^2)^{0.5} \quad (\text{A.2})$$

where

l , m , and n are the mode indices, and

L , W , and H are the chamber dimensions in meters.

Figure A.2 shows the theoretical mode distribution as a function of frequency for a 10,8 m × 5,2 m × 3,9 m ($L \times W \times H$) 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 ($F_{1,1,0}$) occurs at a frequency of 32,096 MHz.

The cavity quality factor bandwidth, BW_Q , is defined as $F_{l,m,n}/Q$ at the 3 dB points of a second order distribution [5], [6]. A representative BW_Q is shown at $F_{4,2,2}$ (the 60th mode) in Figure A.3. In this case, only a few modes are excited when the cavity is driven at $F_{4,2,2}$.

Figure A.4 shows the effects of decreasing the Q of the cavity. In this case, additional modes can be excited when the cavity is driven at the frequency of the 60th mode. The effective modal structure would be the vector sum of the excited modes with different amplitudes. The spatial field variation will be different than that obtained with the higher Q cavity. Thus varying the cavity Q can change the “effective” modal structure. Note that if the frequency were increased, more modes would be available within a given BW_Q (i.e., correlated). Again, the effective modal structure would be the vector sum of the modes.

Figures A.3 and A.4 show that at the lower frequencies the modal population of a chamber is sparse. The figures also show that as frequency is increased the number and density of the modes increases. The effective modal structure combined with the ability of the tuner to change the boundary conditions of the chamber determines how well a chamber will perform.

NOTE A chamber may be any arbitrary geometry. However, some shapes, such as spherical and circular cylindrical, are generally not used for reverberation chambers; because the curved surfaces can produce caustics (focusing of rays) that make it difficult to obtain spatial field uniformity [2].

The effective modal structure depends on both the theoretical mode density and the quality factor bandwidth at the frequency of interest. The number of modes, M , excited in a BW_Q can be estimated by

$$M = \frac{8\pi Vf^3}{c^3 Q} \quad (\text{A.3})$$

where

f is the frequency, in Hz, and

V , is the cavity volume, in m³.

M is independent of the shape of the cavity [1].

Second-order corrections to Equation (A.3) for relatively low frequencies can be calculated for chambers of arbitrary geometry and are proportional to f [7].

Theories at present suggest that an “overmoded” condition exists when a sufficient number of modes are excited. In the overmoded condition, the power distribution has been shown to fit a chi squared (χ^2) distribution [2]. At lower mode densities, the distributions of received power do not fit the χ^2 distribution but a more complicated compound exponential distribution [8].

It is not practical to define a minimum size test chamber and it is outside the scope of this standard to provide detailed design guidance. The critical factor is that if a chamber fulfils the calibration procedure (see B.1.1) then this demonstrates that it will provide the required electromagnetic environment at the desired level of statistical confidence.

A.3 Tuner efficiency

In order to apply statistics to data obtained from a reverberation chamber, the number of independent samples must be known. For a given frequency, a tuner (or tuners) must alter the boundary conditions sufficiently to effect a statistically significant change in the field pattern of the chamber. Once such a change has occurred in the field structure, any samples obtained from the fields resulting from the new tuner position are said to be statistically independent from those of the previous tuner position. Tuner performance data must be obtained in order to determine the number of statistically independent samples a given tuner (or tuners) can provide at a desired frequency. Tuner performance data is obtained by monitoring the received power at evenly spaced intervals over one tuner rotation. The tuner performance can be estimated by calculating the correlation coefficient between tuner steps [9]. A typical correlation coefficient calculation involves consecutively shifting the data file by one sample for each tuner step as shown below, assuming a total set of 450 samples.

D1, D2, D3, D4, D5, D6, ... D450

D450, D1, D2, D3, D4, D5, D6, ... D449

D449, D450, D1, D2, D3, D4, D5, D6, ... D448

D448, D449, D450, D1, D2, D3, D4, D5, D6, ... D447

The correlation coefficient r can be calculated using the following formula:

$$r = \frac{\frac{1}{n} \sum_i^n (x_i - u_x)(y_i - u_y)}{\sqrt{\left(\frac{\sum_i^n (x_i - u_x)^2}{n-1} \right) \left(\frac{\sum_i^n (y_i - u_y)^2}{n-1} \right)}} \quad (\text{A.4})$$

$\uparrow$
 σ_x^2

$\uparrow$
 σ_y^2

y_i is the same distribution as x_i but shifted by one sample for each tuner step, and n is the number of samples taken over one tuner rotation.

NOTE

- x_i and y_i are received power values.
- u_x and u_y are the mean of the original received power vs. tuner position data set.

Since the y distribution is the same as the x distribution (there is only one data set, the distribution of the shifted data is the same as the original data set):

$$u_y = u_x \text{ and } \sigma_x = \sigma_y$$

The correlation coefficient r can be obtained using the correlation function built into most spreadsheets by comparing the original data set to the shifted data sets. The data is regarded as uncorrelated when the magnitude of the correlation coefficient is less than 0,37. Dividing the total number of samples (e.g., 450 above) by the number of steps necessary to reduce the correlation coefficient to less than 0,37 yields an estimate of the number of independent samples the tuner can provide at a particular frequency.

EXAMPLE Carry out the above procedure on a chamber rotating the mechanical tuner 360° in 450 evenly spaced steps at 80 MHz, 100 MHz, and 500 MHz. If the correlation coefficient became less than 0,37 after 25, 15, and 5 steps of the tuner, respectively; then the tuner could be expected to deliver 18 independent samples at 80 MHz, 30 independent samples at 100 MHz, and 90 independent samples at 500 MHz. As shown in Clause A.4, the number of tuner steps required may exceed the ability of a single tuner to provide. In such cases, a second tuner will be necessary.

A.4 Reverberation chamber statistics

The calibration procedure for this standard is based on the statistical nature of complex cavities [2], [4]. It has been experimentally validated that the fields in a reverberation chamber can be theoretically predicted using the appropriate statistical models [5], [6], [10], [11]. These models define distribution functions for 1) the received power by an antenna which is related to the chamber scalar power density and the electric field squared, 2) the maximum received power or the maximum electric field squared, 3) a rectangular component of the electric field and 4) the maximum of a rectangular component of the electric field. These four distributions are different but relatable. There will be no attempt to cover reverberation chambers statistics in detail in this annex although some specific properties of some of the distributions will be discussed below. The function of a reverberation chamber is to generate a statistically uniform (i.e., statistically isotropic) test environment within acceptable uncertainty and confidence limits. This is accomplished by introducing a mechanical tuner into a shielded room, which is used to redistribute the field energy. The tuner changes the boundary conditions within the chamber when it is moved or rotated. Once the tuner has been moved to a sufficient number of independent positions, the field variations resulting from rotating the tuner provide a set of fields covering almost all directions and polarizations. This implies that the magnitude and directionality of the fields was the same, within bounded uncertainty limits, for all points within the chamber. The term "isotropic" is often used to refer to the environment generated by a reverberation chamber. This term is somewhat misleading since the environment did not arrive with equal magnitude from all directions and polarizations simultaneously. For this reason, the term should be used with caution when referring to reverberation chambers.

For the following discussion, it is assumed that the chamber dimensions are large compared to the excitation wavelength (the chamber is overmoded [5]) and that the chamber has a complex configuration. The introduction of antennas and tuners assure the required complexity in an otherwise regular cavity. In addition, we will restrict our discussion to the fields within the working volume of the chamber. 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. A typical reverberation chamber facility is shown in Figure A.5.

A.4.1 Number of samples required

Given the distribution of the fields within a cavity, the number of samples that would have to be taken in order to determine the field level to within a given uncertainty can be determined. Figure A.6 shows a theoretical prediction for the number of independent samples (boundary condition changes or steps of the mechanical tuners) required to obtain a 6 dB field uncertainty at a 95 % level of confidence for a given cavity. As Figure A.6 shows, at lower mode densities, as defined by Equation (A.3), the number of samples required increases rapidly. If the confidence level is lowered, then the number of samples required to obtain the same uncertainty is reduced. As shown in Figure A.7, the number of samples can be reduced if the field uncertainty is lowered moderately. As noted above, the number of samples depicted in Figures A.6 and A.7 are based on statistical theory [2], [10]. In practice, the mechanical tuner may not be capable of providing the number of independent samples required to give the desired performance. For this reason, tuner performance should be evaluated as detailed in Clause A.3 to determine the number of samples, which can be provided by a given tuner at a given frequency.

A.4.2 Tuner effect on the mean chamber field

For an ideal reverberation chamber, the volume (spatial) mean value of the field for a fixed boundary condition and an “ensemble” average are equivalent [2], [10]. An ensemble average is the average of the field at a fixed location for multiple boundary conditions. In reverberation chambers, boundary condition changes are typically achieved by rotating a mechanical tuner. However, boundary condition changes also occur for any change in the configuration of objects such as antennas, test devices, and supporting instrumentation and equipment.

Figure A.8 is the probability density function (PDF) of the field at a location within an ideal reverberation chamber normalized by the “true” volume or ensemble average. As shown in Figure A.8, the field in the chamber at an arbitrary location and a single boundary condition or at a single location and an arbitrary boundary condition can vary more than 30 dB. Figure A.8 also shows that about 98 % of the data for a single sample ($N = 1$) would be between +10 dB and -20 dB. Figure A.9 shows that, as the number of boundary condition samples (tuner steps) is increased, the measured mean of the chamber field at any given location in the chamber converges toward the “true” mean value. The measured mean value is the “expected value” of multiple samples. The width of each curve is a measure of the uncertainty that would be expected at an arbitrary location in the working volume for N samples. Note that the improvement in the uncertainty of the mean field is very rapid as the number of tuner steps is first increased and then slows as N gets larger. Figure A.9 also shows that for 12 tuner steps the uncertainty of the mean field is about 5 dB at the 95 % confidence interval and about 2,4 dB for 100 tuner steps. This would correspond to an eight-fold increase in test time for a 2,6 dB reduction in measurement uncertainty in the mean field level.

A.4.3 Tuner effect on the maximum chamber field

The distribution for $N = 1$ shown in Figure A.8 is valid for both mean and maximum fields, because the maximum, minimum, and mean measured at a location are all the same value, for a fixed position of the tuner. The PDF for the maximum field at an arbitrary location within a chamber is shown in Figure A.10. As N increases, the distribution moves to the right and gets narrower (improved uncertainty). Also, like the mean field level, the improvement in uncertainty for the maximum field level is very rapid as the number of tuner steps is first increased and then slows as N gets larger.

Figure A.10 shows that for 12 tuner steps the uncertainty of the maximum field is about 7,2 dB at the 95 % confidence interval and about 4,8 dB for 100 tuner steps. This would correspond to an eight-fold increase in test time for a 2,4 dB reduction in measurement uncertainty in the maximum field level. Also, note that increasing the number of tuner steps from 12 to 100 steps increases the expected value of the maximum field by about 3 dB.

Since the PDF for the maximum field applies at any arbitrary location, as it does with the mean field, the PDF is also a measure of the spatial uniformity for N samples of the maximum field over the working volume of the chamber.

A.5 Chamber calibration

For this standard, the purpose of the calibration is to verify that the fields generated have the same magnitude, within defined uncertainty limits, for all polarizations (i.e., for all directions of arrival at all locations within the working volume) for a given number of tuner steps. In order to meet this requirement the use of isotropic probes, which allow access to each axis of the probe, is required in order to perform the calibration. The calibration procedure should be performed once in the life of the chamber and after major modifications.

The empty chamber calibration procedure is based on a comparison of the peak fields measured by E -field probes to the mean received power of a reference antenna. To enhance accuracy the reference antenna mean data is obtained for eight locations within the working volume.

The number of samples recommended for calibration is based on a “theoretical” chamber of approximately 3 m × 7 m × 15 m size and typical Q for a chamber constructed of welded steel. The number of samples required was rounded up to account for variations from this “theoretical” chamber in order to ensure a conservative test. It is possible that a larger chamber or one with a lower Q than the “theoretical” chamber could meet this calibration requirement using less than the recommended number of steps.

A.5.1 Calibration Procedure

The calibration procedure collects E -field probe data (maximum data only) as well as chamber input power and the maximum and mean received power from a reference antenna placed within the working volume. The probe data are used to determine field uniformity. The probe data and chamber input power is used to determine the chamber calibration factor. The mean received power from the reference antenna and chamber input power is used to calculate an antenna calibration factor (ACF). The ACF is used as a reference value when determining if the chamber has been “loaded” by equipment under test (EUT). The maximum received power from the reference antenna is used to verify the probe readings. Probe data are collected from the eight locations that form the corners of the “volume of uniform field” or “working volume” as shown in Figure A.11. Each time the probe is moved to a new location, the reference antenna is moved to a new location within the working volume. The orientation of the reference antenna relative to the chamber axes is also changed at least 20° relative to each axis at each position. This ensures that any bias in the field is detected (e.g., no dominate polarisation exists within the chamber). A minimum of eight locations for both the probe and reference antenna is required.

NOTE Once a chamber has been shown to operate properly over a frequency span of 300 MHz to 400 MHz at the minimum number of tuner steps (i.e., 12), the number of locations may be reduced to three. For the chamber used to collect the data presented in this annex, the reduction in the number of locations occurred at 1 000 MHz.

As previously shown, the uniformity of the field depends on the number of tuner positions (N) used to collect the data. Recall that for a relatively modest number of tuner steps (i.e., 12), a reasonably uniform field can be obtained. As previously stated, this is true for overmoded cavities. Every chamber will have a frequency at which it is no longer overmoded [6] and hence can no longer be used as reverberation chamber. This frequency will mostly be dependent on chamber size, and the cutoff will be gradual rather than abrupt as frequency decreases.

In some cases, it is possible to compensate for decreased modal density that results as the operational frequency approaches the “undermoded” condition. In general and with care, compensation can be achieved by increasing the number of tuner steps, but effects may be limited. Table A.1 lists the number of tuner steps “recommended” for performing the calibration. The number of steps may need to be decreased or increased to optimise performance. The minimum number of tuner steps should not be less than 12.

Table A.1 – Sampling requirements

Frequency Range	Number of samples ^a recommended for calibration and test	Number of frequencies ^b required for calibration
f_s to $3 f_s$ ^c	50	20
$3 f_s$ to $6 f_s$	18	15
$6 f_s$ to $10 f_s$	12	10
Above $10 f_s$	12	20/decade
^a (i.e. independent tuner positions or intervals, 12 positions minimum.) ^b Logarithmically spaced. ^c f_s = start frequency (see A.1 for lowest useable frequency).		

A.5.2 Field uniformity

The goal of a reverberation chamber is to generate a statistically uniform environment, within some bounded uncertainty, for all locations within the defined working volume. The procedure just described is designed to measure the expected magnitude and uniformity for a given chamber using a given number of tuner steps. A typical set of probe data obtained using the calibration procedure (x-axis only for clarity) is shown in Figure A.12. Figure A.13 shows the data of Figure A.12 normalized to the mean of the eight maximum x-axis probe readings at each frequency [B.1.1 (10) (a)]. The data show that the measured field uniformity is about ± 10 dB at 100 MHz and decreases as frequency increases. Also, note how the data at the higher frequencies show good uniformity even though the number of tuner steps is decreased.

NOTE 1 Due to the optimization of the number of tuner steps to fit the characteristics of the chamber used, the number of steps used to collect the data shown in Figure A.13 does not match Table A.1.

At present, there are two schools of thought as to which is the best method to determine acceptable uniformity. For the first method [12], acceptable uniformity is decided by throwing away 25 % of the data that have the most variation and then requiring the remaining data to be within a given limit. In the second method [13] [14], acceptable uniformity is determined by calculating the standard deviation of the data and requiring that the standard deviation be within a given limit. The first method's major drawback is that there is no "weight" given to the data that are thrown away. This could result in the uncertainties being essentially unknown. For the purposes of this standard, it has been agreed to use the standard deviation method. The reason for adopting the standard deviation method is that all data are considered and given appropriate weight.

The standard deviation of the data shown in Figure A.13 is shown in Figure A.14. The data show the standard deviation exceeded 3 dB below about 200 MHz. For reference, the tolerance for the commercial aircraft avionics standard is also shown [13].

NOTE 2 The limit for this standard is the same as the proposed limit in [13] at frequencies common to both standards. The chamber is considered to pass the field uniformity requirements provided that the standard deviation for both the three individual field components (E_x , E_y , and E_z) and the total data set (E_{Total}) are within the specified tolerance. The total data set consists of the 24 measurements made by combining the three individual field components (E_x , E_y , and E_z) from the 8 probe locations.

NOTE 3 The total data set is NOT the more commonly used root sum of the squares (RSS) of E_x , E_y , and E_z . The chamber used to collect this data could not be used below 130 MHz, according to the proposed limit, unless the field uniformity is improved [15]. The proposed limit was developed by a committee made up of representatives from both industry and government.

A.5.3 Chamber *E*-field

The "expected" amplitude of the chamber *E*-field during the calibration is simply the average of the 24 maximum probe readings (the mean of the maximums). The "expected value" is the value to which the chamber is calibrated (see Figure A.10).

It is also possible to estimate the chamber *E*-field (E_{Est}) based on the reference antenna measurements. Equation (A.5), which was derived using methods similar to those used to derive expressions for the mean field in [16], gives an estimate of the chamber *E*-field based on the maximum readings from the reference antenna averaged over the number of antenna locations (n).

$$E_{Est} = \left\langle \frac{8\pi}{\lambda} \sqrt{5 \frac{P_{MaxRec}}{\eta_{rx}}} \right\rangle_{n \text{ antenna locations}} \quad (A.5)$$

where

P_{MaxRec} is the maximum received power over the given number of tuner steps at an antenna location, and

η_{rx} is the antenna efficiency factor for the receive antenna which can be assumed (if not known) to be 0,75 for a log periodic antenna and 0,9 for a horn antenna [4]. This element can be determined from the information contained in Annex I.

For all measurements, it is assumed that the forward input power is the same for all data collected. If so, then the data can be normalized after taking the average of the probe readings. If not, then the probe readings need to be normalized to the input power, which corresponds to that probe reading. Normalizing the *E*-field to the chamber input power is done by dividing the probe reading by the square root of the input power. This can also be done for the estimated *E*-field based on the reference antenna.

It is recommended that a cross check be performed by comparing the expected *E*-field measured by the probes and the expected *E*-field estimate based on the eight antenna measurements. Any discrepancies greater than ± 3 dB between the probe and antenna based measurements should be resolved. Note that significant disagreement at the lower frequencies is expected. This is primarily due to loading caused by the transmit and receive antennas. For this reason, the agreement between the two methods is not expected at frequencies where the difference between the chamber input power and the measured maximum received power from the reference antenna is 10 dB or less.

A.5.4 Loading effects

When an EUT is placed into a reverberation chamber there is the possibility that the EUT will “load” the chamber. If the EUT loads the chamber, the energy absorbed by the EUT is no longer available to generate the desired environment. For this reason, the chamber input power needs to be increased to compensate for this loading.

NOTE 1 This is one of the more abstract aspects of reverberation chamber testing. The source of the fields is actually the reflection of RF energy from the walls. Although an antenna is used to inject RF energy into the chamber, that energy is not directed at the EUT. If the EUT absorbs energy then that energy is no longer available to contribute to the generation of the test environment. The following data will demonstrate the concept.

Prior to performing any test, a check for loading effects must be made. This is done by measuring the mean power received by the reference antenna for the same number of tuner steps used to perform the calibration with the EUT in place. The data from this single measurement are then compared to the eight measurements from the calibration. If the mean received power measured with the EUT in place does not exceed the uniformity of the mean field measured during the calibration (i.e., it is not greater or less than the calibration data), then the chamber is considered to not have been loaded by the EUT. If the measurement exceeds the uniformity of the mean field measured during calibration, a correction factor will be required when calculating the input power necessary to generate the desired test field. This factor is referred to as the chamber loading factor (CLF). The CLF is obtained by taking the ratio between the measurement taken with the EUT in place and the mean or “expected value” from the eight measurements taken during the calibration [13].

To determine the limit to which a chamber may be loaded, an evaluation must be performed to evaluate the field uniformity under severe loading conditions (B.1.5). An example of such an evaluation is shown in Figure A.15. The working volume of this reverberation chamber was loaded with 27 pieces of 122 cm pyramidal absorber. Figure A.16 shows the amount of loading induced into the chamber by the absorbers. The chamber loading, or the amount of loading, over the frequency range of 100 MHz to 18 GHz varied from a maximum of about 23 dB to a minimum of 10 dB with a mean loading of about 14 dB. Figure A.17 shows the standard deviation of the fields in the loaded chamber. The standard deviation of the loaded chamber, while varying slightly from the empty chamber calibration shown in Figures A.13 and A.14, did not show significant degradation.

NOTE 2 Standard deviation increased (instead of decreasing) by approximately 0,5 dB, most probably due to probe proximity to absorber.

A.5.5 Generating a test environment – immunity

The desired test environment is generated by injecting the proper amount of power into the chamber. The power necessary to generate the desired field strength can be calculated using Equation (A.6).

$$P_{\text{input}} = \left[\frac{E_{\text{Test}}}{\bar{E} \cdot \sqrt{CLF}} \right]^2 \quad (\text{A.6})$$

where

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

CLF is the chamber loading factor [B.2(7)], and

$\bar{E}$ is the average of the maximum E-field measured by the probes divided by the square root of the input power used during calibration ((V/m)/W^{0,5}) [B.1.1(9)].

Note that the probe measurements used to determine the chamber E-field are the rectangular components of the probe, not the RSS.

A.5.6 Determining radiated power – emissions

The amount of RF power radiated by a device placed in the chamber can be determined by measuring the amount of power received by the reference antenna and correcting for the insertion loss of the chamber. The power radiated from a device can be calculated using either average or peak received power from a given number of tuner steps and/or tuner rotations. Equation (A.7) is used for mean-received-power-based measurements and Equation (A.8) is used for peak-received-power-based measurements. The advantage to using measurements based on mean power is a lower uncertainty. The disadvantage is that the measurement system must have sensitivity of 20 dB lower than the actual mean to get an accurate average measurement and intermittent signals may be artificially lowered due to insufficient sampling.

$$P_{\text{Radiated}} = \frac{P_{\text{AveRec}} \times \eta_{\text{Tx}}}{CCF} \quad (\text{A.7})$$

$$P_{\text{Radiated}} = \frac{P_{\text{MaxRec}} \times \eta_{\text{Tx}}}{CLF \times IL} \quad (\text{A.8})$$

where

P_{Radiated} is the radiated power from the device within the measurement band width,

CCF is the chamber calibration factor [B.2(6)],

CLF is the chamber loading factor [B.2(7)],

IL is the chamber insertion loss (B.1.3),

P_{AveRec} is the received power as measured by the reference antenna averaged over the number of tuner steps, [B.1.1(5)]

P_{MaxRec} is the maximum power received over the number of tuner steps [B.1.1(5)], and

η_{Tx} is the antenna efficiency factor for the Tx antenna used in calibrating the chamber and can be assumed to be 0,75 for a log periodic antenna and 0,9 for a horn antenna.

NOTE CISPR 16-1 should be consulted when selecting detectors of measuring receivers.

A.5.7 Other concerns

The calibration is based on using CW excitation. When using modulated waveforms, consideration must be given to distortion caused by the chamber quality factor or “Q” (B.3). The chamber Q can be calculated using Equation (A.9).

$$Q = \left(\frac{16\pi^2 V}{\eta_{Tx} \eta_{Rx} \lambda^3} \right) \left\langle \frac{P_{AveRec}}{P_{input}} \right\rangle_{n \text{ Antenna Locations}} \quad (\text{A.9})$$

where

η_{Tx} and η_{Rx} are the antenna efficiency factors for the Tx and Rx 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,

P_{AveRec} is the averaged received power from the reference antenna,

P_{Input} is the chamber input power [13], and

the n Antenna Locations is the number of antenna locations used to collect the calibration data at the frequency being evaluated.

For pulse testing the chamber time constant τ , is given by Equation (A.10)

$$\tau = \frac{Q}{2\pi f} \quad (\text{A.10})$$

where

Q is the value calculated using Equation (A.9) above, and

f is the test frequency (Hz) [13].

The chamber time constant should not be greater than 0,4 of any test waveform pulse width. If it is, absorber must be added to the chamber or the pulse width increased. If absorber is used, add absorber until the time constant requirement is satisfied with the least possible absorber. A new CLF must be defined if absorber material is required. If the loading due to the absorber is greater than that obtained in the chamber loading verification (B.1.5), then the chamber calibration must be repeated.

A.6 Reference documents

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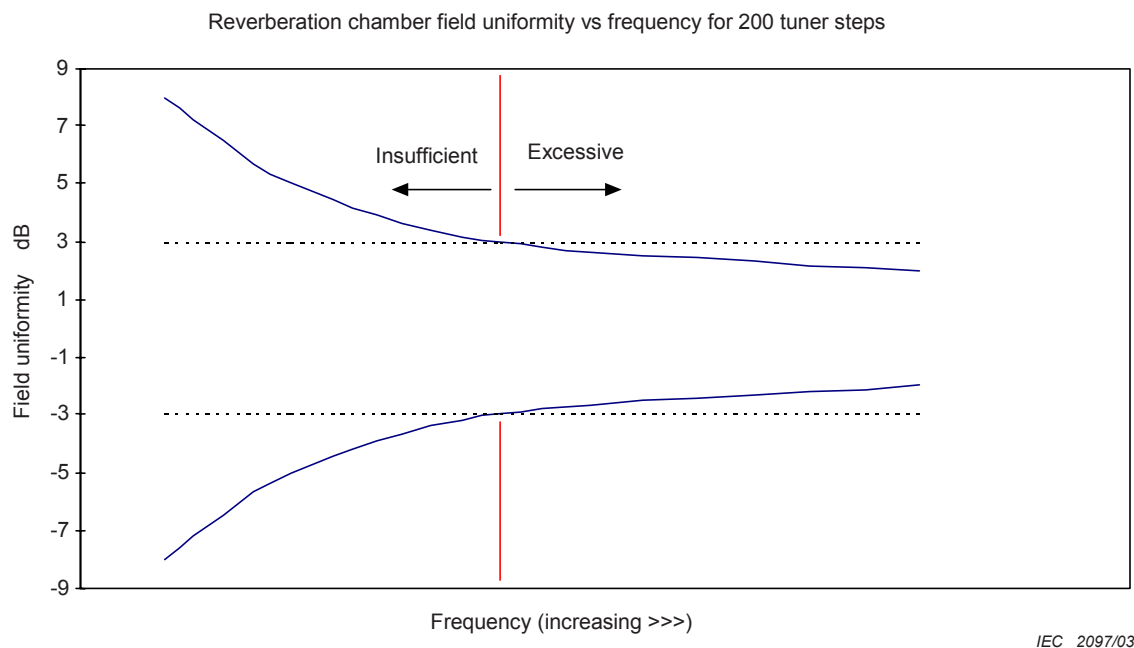
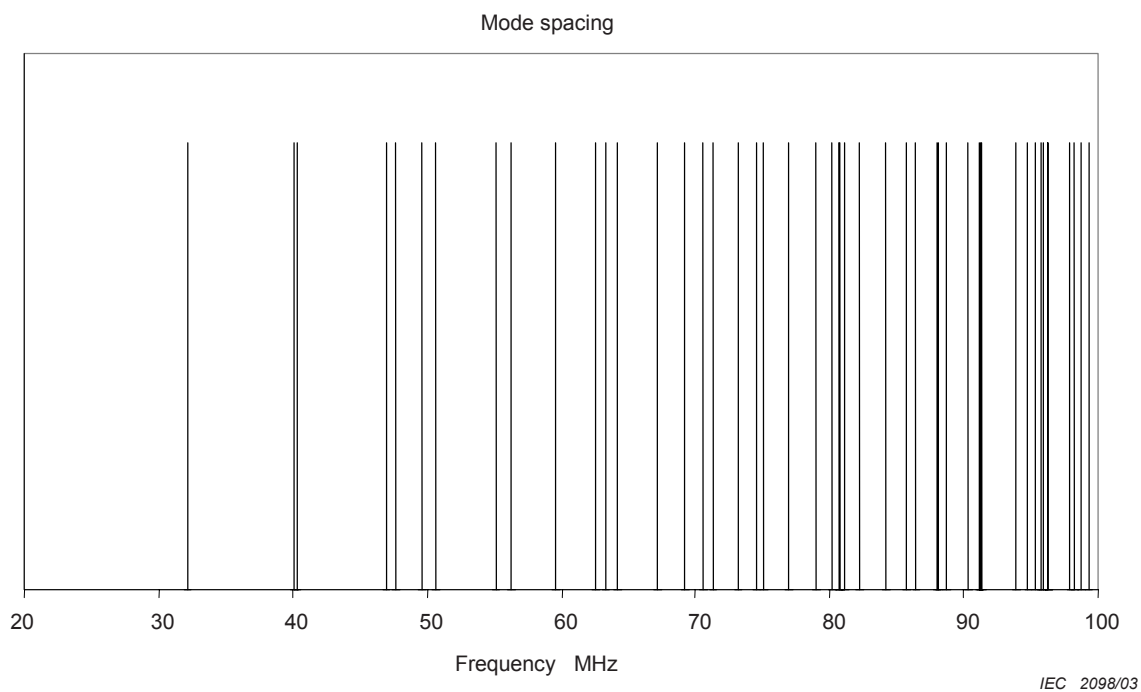


Figure A.1 – Typical field uniformity for 200 tuner steps



NOTE Vertical axis has no meaning other than to represent a mode is present.

Figure A.2 – Theoretical modal structure for a 10,8 m × 5,2 m × 3,9 m chamber

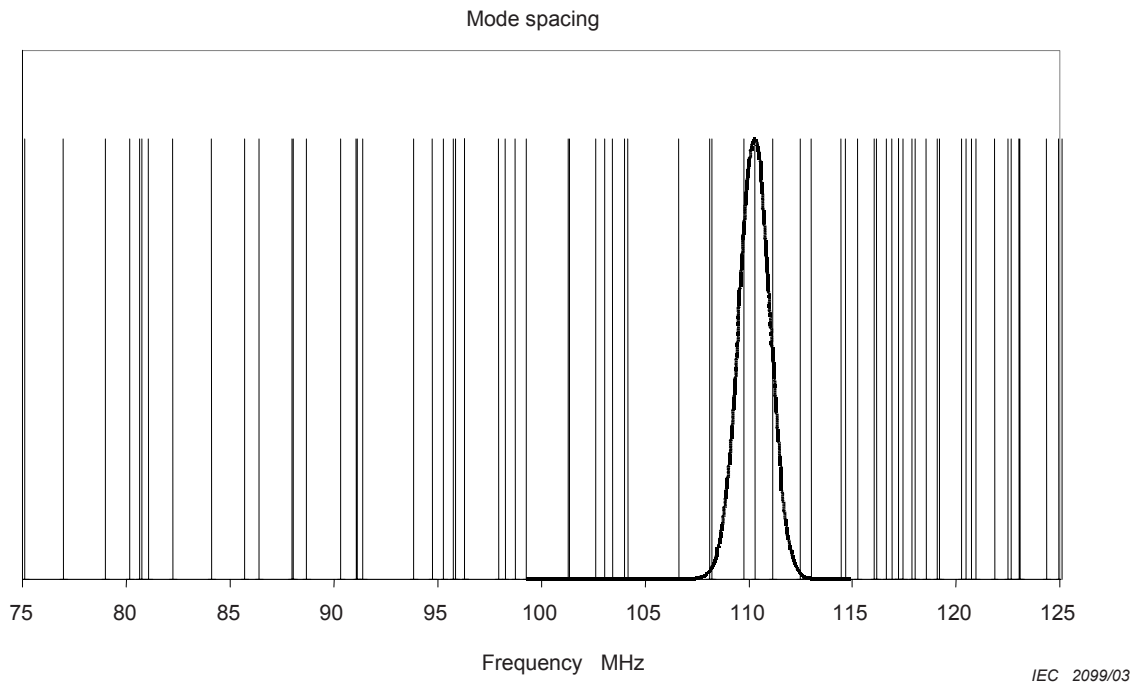


Figure A.3 – Theoretical modal structure with quality factor bandwidth superimposed on 60th mode

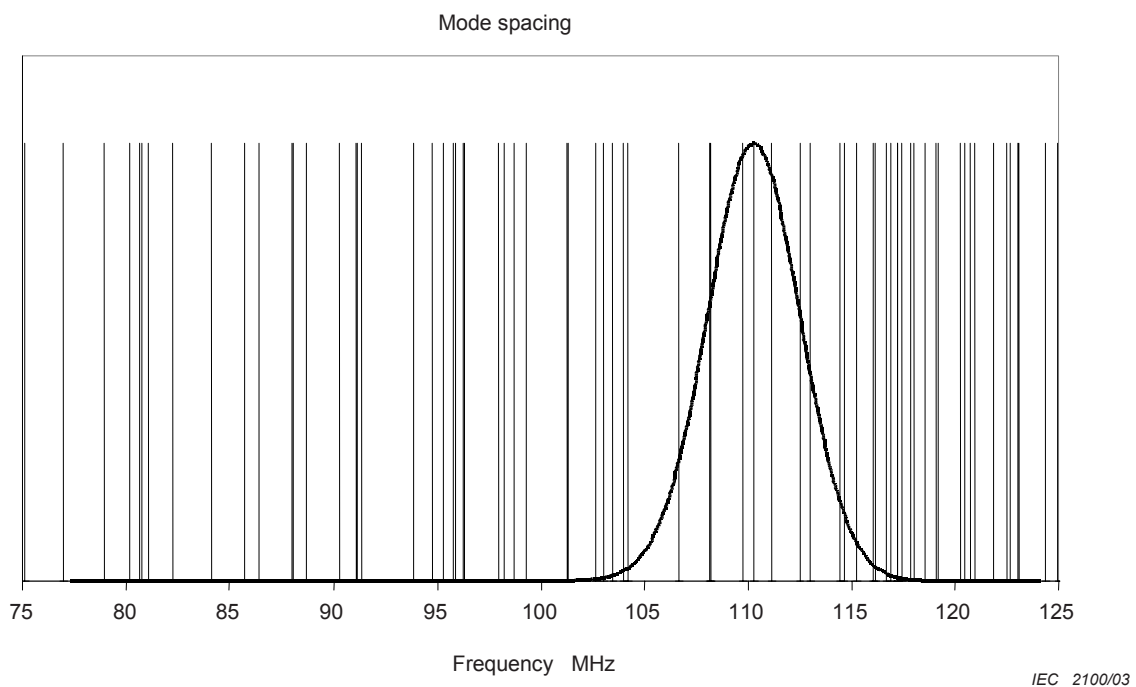
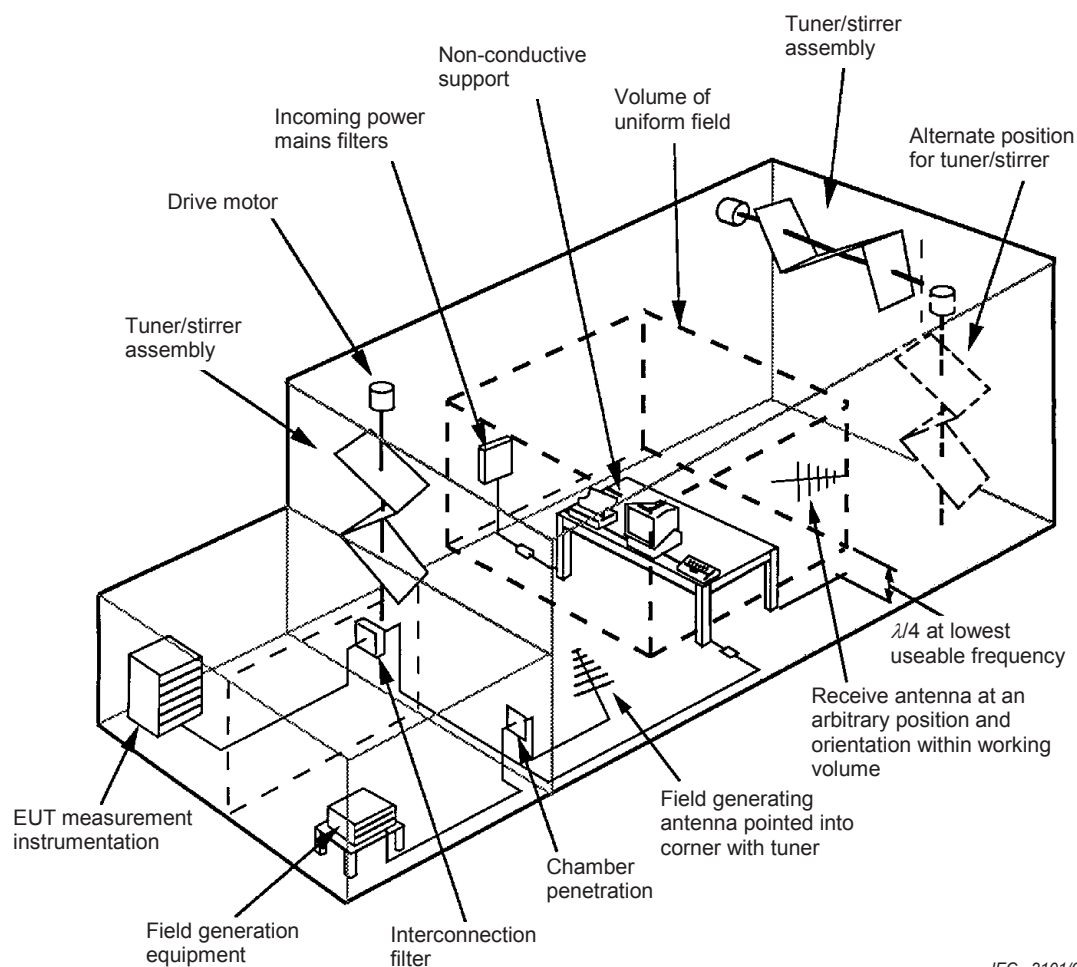


Figure A.4 – Theoretical modal structure with greater quality factor bandwidth (lower Q) superimposed on 60th mode



IEC 2101/03

Figure A.5 – Typical reverberation chamber facility