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Acoustics — Test methods for the qualification of free-field environments

Acoustique — Méthodes d'essai pour la qualification des environnements en champ libre

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 26101 was prepared by Technical Committee ISO/TC 43, *Acoustics*.

Introduction

This International Standard describes the divergence loss method of measurement of performance of an environment designed to provide a free sound field, or free sound field over a reflecting plane. An acoustical environment is a free sound field if it has bounding surfaces that absorb all sound energies incident upon them. This is normally achieved using specialized test environments, such as anechoic or hemi-anechoic chambers. In practice, these provide a controlled free sound field for acoustical measurements in a confined space within the facility.

The purpose of this International Standard is to promote uniformity in the method and conditions of measurement when qualifying free sound field environments.

It is expected that the qualification procedures outlined in this International Standard will be referred to by other International Standards and industry test codes. In such cases, these documents making reference to this International Standard may specify qualification criteria appropriate for the test method and may require specific traverse paths.

Acoustics — Test methods for the qualification of free-field environments

1 Scope

1.1 This International Standard specifies methodology for qualifying acoustic spaces as anechoic and hemi-anechoic spaces meeting the requirements of a free sound field.

1.2 This International Standard specifies discrete-frequency and broad-band test methods for quantifying the performance of anechoic and hemi-anechoic spaces, defines the qualification procedure for an omni-directional sound source suitable for free-field qualification, gives details of how to present the results and describes uncertainties of measurement.

1.3 This International Standard has been developed for qualifying anechoic and hemi-anechoic spaces for a variety of acoustical measurement purposes. It is expected that, over time, various standards and test codes will refer to this International Standard in order to qualify an anechoic or hemi-anechoic space for a particular measurement.

1.4 In the absence of specific requirements or criteria, Annex A provides qualification criteria and measurement requirements to qualify anechoic and hemi-anechoic spaces for general purpose acoustical measurements.

1.5 This International Standard describes the divergence loss method for measuring the free sound field performance of an acoustic environment.

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.

ISO/IEC 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*[1)]

IEC 61260, *Electroacoustics — Octave-band and fractional-octave-band filters*

IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
free sound field
sound field in a homogeneous, isotropic medium free of boundaries

[ISO/TR 25417:2007[6], 2.17]

3.2
anechoic space
volume which has been qualified as a sound field in a homogeneous, isotropic medium free of boundaries

1) ISO/IEC Guide 98-3 is published as a reissue of the *Guide to the expression of uncertainty in measurement* (GUM), 1995.

3.3
hemi-anechoic space
volume above a reflecting plane which has been qualified as a sound field in a homogeneous, isotropic medium free of boundaries

3.4
acoustic centre
<for a sound source and for a given test signal> position of the point from which approximately spherical wave fronts appear to diverge

3.5
background noise
sum of all the signals except the one under investigation

[ISO 10815:1996[5],3.2]

NOTE Background noise can include contributions from airborne sound, structure-borne vibration, and electrical noise in instrumentation.

3.6
divergence loss
reduction in sound pressure along a straight path due to the spreading of sound when a sound wave propagates away from a source

3.7
frequency range of interest
contiguous one-third-octave band frequencies from the lowest to the highest frequencies to be qualified, inclusive

3.8
referencing document
standard or test code that refers to this International Standard for the purpose of specifying the qualification method of an anechoic or hemi-anechoic space

4 Allowable deviations from inverse square law

The theoretical reduction in mean-square sound pressure along a straight path due to spherical propagation of a sound wave in a free sound field shall be hereafter referred to as the inverse square law.

For a space to be deemed anechoic or hemi-anechoic, as defined by criteria in a referencing document, the deviations of the measured sound pressure levels from those estimated using the inverse square law, obtained according to this International Standard, shall not exceed the values specified by the referencing document.

In the absence of specific criteria for the allowable deviations in a referencing document, the criteria in Annex A shall be used to qualify anechoic and hemi-anechoic spaces for general purpose acoustical measurements.

The allowable deviations specified by a referencing document may be more or less stringent than the criteria given in Annex A.

5 Measurement of free sound field performance

5.1 Divergence loss method

5.1.1 Principle

The divergence loss method shall be used to quantify the performance of an anechoic or hemi-anechoic space within a test environment and to determine the spatial limits of this qualified anechoic or hemi-anechoic space.

The free sound field performance is evaluated by quantifying the contributions of both the direct and the reflected components of acoustic energy.

The spatial decrease of sound pressure emitted from a test sound source shall be compared with the decrease of sound pressure that would occur in an ideal free sound field.

5.1.2 Instrumentation and measuring equipment

5.1.2.1 General

The instrumentation system for measuring sound pressure level, including the microphone and cable, shall be operated within the limit of the linearity errors specified for a Class 1 sound level meter according to IEC 61672-1.

The microphone shall be nominally omni-directional (taking into account any supplementary equipment connected to it, such as the protective grid and mounting arrangement).

For measurements in one-third-octave bands, the filters used shall meet the requirements for Class 1 specified in IEC 61260.

NOTE For measurements above 5 kHz, this method will normally require a microphone of diameter equivalent to that of a WS2F microphone[1] or less.

5.1.2.2 Test sound source

A sound source approximating a point source over the frequency range of interest shall be used for the qualification measurement. The source shall be:

a) compact and of acoustical performance, such that the location of the acoustic centre of the source is known to be located close enough to the origin of the microphone traverses specified in 5.1.3.2 to allow fitting of the sound pressure level versus distance data without an adjustment for the acoustic centre of the source,

b) in compliance with the directionality criteria in Table B.1, when measured according to the procedure in Annex B, so as to ensure the source radiates energy in all directions,

c) able to generate sufficient sound power over the frequency range of interest to yield sound pressure levels at least 6 dB above the background noise levels for all points on each microphone traverse, or while the microphone is moving for continuous traverse systems[13], and

d) of high stability so that the radiated sound power (due to the source, associated signal generation and amplification electronics) as measured by a monitor microphone located at an arbitrary fixed position in the test environment does not vary significantly at the frequency of measurement during the time taken to complete the measurements for each microphone traverse. If the stability of the source varies by more than ± 0,2 dB then the monitor microphone shall be used to apply a correction, according to the following equation:

$$L_{pi} = L'_{pi} - L_{p,\mathrm{ref},i} + L_{p,\mathrm{ref},0} \quad (1)$$

where

L_{pi} is the corrected sound pressure level at measurement point i, expressed in decibels (dB);

L'_{pi} is the measured sound pressure level at measurement point i, expressed in decibels (dB);

$L_{p,\mathrm{ref},i}$ is the sound pressure level measured by the monitor microphone at the reference location for measurement point i, expressed in decibels (dB);

$L_{p,\mathrm{ref},0}$ is the sound pressure level measured by the monitor microphone at the reference location for the initial measurement point 0, expressed in decibels (dB).

Since, in general, two or more sources may be required to cover the overall frequency range of interest, the requirements given above shall be met for each source over its applicable frequency range.

NOTE It is possible to estimate the acoustic centre of a source by evaluating it in an anechoic space already known to meet the requirements in Annex A.

Care should be taken

— to ensure that the sound pressure levels are greater than 6 dB, and preferably 15 dB, above the background noise levels;

— in positioning the monitor microphone to avoid acoustic interference with the traversing mechanism affecting the results;

— to ensure that changes in atmospheric conditions over the duration of the traverse are not confused with those related to the source stability.

5.1.3 Location of test sound sources and microphone traverses

5.1.3.1 Test sound source location

Referencing documents may specify the test sound source location(s) to be used in order to qualify the anechoic or hemi-anechoic space.

In the absence of specific requirements for the sound source location in a referencing document, the requirements in Annex A shall be used to qualify anechoic and hemi-anechoic spaces for general purpose acoustical measurements.

The test sound source should be placed in a chosen orientation and held in that orientation for all microphone traverses.

An environment may be qualified for more than one source location.

5.1.3.2 Microphone traverses

Microphone traverses shall be made along paths that will characterize and qualify the anechoic or hemi-anechoic space for the types of acoustical measurements to be conducted in the test environment. The origin of the microphone traverse shall be within the physical volume occupied by the test sound source.

Referencing documents may specify the traverse paths to be conducted in order to qualify the anechoic or hemi-anechoic space.

In the absence of specific requirements for the traverse paths in a referencing document, the requirements in Annex A shall be used to qualify anechoic and hemi-anechoic spaces for general purpose acoustical measurements.

Sound reflection from the microphone support system should be carefully avoided.

5.1.4 Test procedure

5.1.4.1 Qualification bandwidth

The qualification measurements of the anechoic or hemi-anechoic space shall be made using a bandwidth that is typical of the spectral characteristics of the type of sources that will be measured or evaluated.

Discrete-frequency qualification may be accomplished by using a test source that generates discrete tone(s) or by using a test source that generates broad-band noise and a measurement system that provides discrete-frequency measurement capabilities, such as an FFT analyser[13].

Broad-band qualification may be accomplished by using a test source that generates broad-band noise and a measurement system that provides one-third-octave-band filtering.

Referencing documents may specify the bandwidth for the qualification measurement.

In the absence of specific requirements for the bandwidth in a referencing document, the requirements in Annex A shall be used for the selection of the appropriate qualification measurement bandwidth for their intended purpose.

5.1.4.2 Generation of sound

The test source described in 5.1.2.2 may be operated with a test signal of pure tones, multiple pure tones, band-limited or broad-band noise.

If pure tones or multiple pure tones are used for discrete-frequency qualification, the measured signal after any filtering shall not contain energy at frequencies not being characterized that are within 15 dB of the frequencies being characterized. If broad-band noise is used as a test signal for either broad-band or discrete-frequency qualification, then the test signal shall consist of either random noise or broad-band test signals derived from random noise.

In the absence of specific requirements for the test signal in a referencing document, the requirements in Annex A shall be used for the selection of the appropriate test signal for qualification of anechoic or hemi-anechoic spaces for their intended purpose.

NOTE Use of a mix of pure tones spaced apart by more than a one-third-octave band can be much more rapid than sequential traverses, each at a single pure tone.

When using tonal, or mixed tone signals, care should be taken to avoid distortion due to excessive signal levels.

5.1.4.3 Measurement of sound pressure level

The sound pressure levels shall be measured using fractional octave band filters or FFT analysis.

The microphone shall be moved along the paths described in 5.1.3.2 for each test signal. The measurement of sound pressure level shall be carried out starting, at most, a quarter of a wavelength (at the lowest frequency to be qualified) from the origin of the traverse, traversing at least half a wavelength (at the lowest frequency to be qualified) and to the hypothetical boundary of the anechoic or hemi-anechoic space to be qualified.

Sound pressure levels shall be measured along each microphone traverse using equally spaced measurement points at each frequency. Referencing documents may specify the maximum spacing of the measurement points in order to qualify the anechoic or hemi-anechoic space for their intended purpose.

In the absence of specific requirements for the spatial resolution of the measurement points, the requirements in Annex A shall be used to qualify anechoic and hemi-anechoic spaces for general purpose acoustical measurements.

Alternatively, for discrete-frequency measurements using pure tone signals, the microphone may be moved slowly and continuously along the traverse and the sound pressure levels recorded[13]. Sound pressure level versus distance data should then be determined, using the spatial sampling guidelines for discrete measurements.

If broad-band test signals are used, measurement times should be of sufficient duration to achieve stable levels.

5.1.5 Expression of results

5.1.5.1 Method of calculation

5.1.5.1.1 General

Measured sound pressure levels are compared with the theoretical sound pressure level decay according to the inverse square law in a free sound field.

5.1.5.1.2 Equation for estimation of sound pressure levels based on the inverse square law

From the sound pressure levels measured at positions specified in 5.1.4.3, the estimation of sound pressure levels based on the inverse square law shall be determined for each measurement traverse from the following equation:

$$L_p(r_i) = b - 20\lg\left(\frac{r_i}{r_0}\right)\text{dB} \qquad (2)$$

where

$L_p(r_i)$ is the sound pressure level at distance r_i estimated by the inverse square law, expressed in decibels (dB);

r_i is the distance of measurement point i from the acoustic centre of the sound source, expressed in metres (m);

r_0 is the reference value, $r_0 = 1$ m;

b is a parameter that is adjusted to optimise the fit of the measured sound pressure levels into the tolerance range, to maximise the qualified distance from the test sound source.

If a continuous traverse is used, an “analogue” recording of level versus distance is obtained. To use the equations in this clause, sound pressure levels at a large number of points at regularly spaced intervals shall be derived from the records. The selection of point spacing shall be based on the criteria of 5.1.4.3.

NOTE 1 An iterative process can be used to determine b; a starting value is given by the following equation:

$$b = \frac{\sum_{i=1}^{N} 20\lg\left(\frac{r_i}{r_0}\right)\text{dB} + \sum_{i=1}^{N} L_{pi}}{N} \qquad (3)$$

where

L_{pi} is the measured sound pressure level (corrected for source stability) at measurement point i, expressed in decibels (dB);

N is the number of measurement points along the measurement traverse.

NOTE 2 Over long traverses and especially at high frequency, air absorption might not be negligible, it might be necessary to correct the measured sound pressure level for absorption of sound by the atmosphere in accordance with ISO 9613-1[4]. For example, atmospheric absorption can be 0,3 dB/m at 10 kHz.

5.1.5.1.3 Deviations from the inverse square law

Using the estimation of sound pressure levels based on the inverse square law, the deviation of the measured sound pressure level from the inverse square law is determined at each measurement point by the following equation:

$$\Delta L_{pi} = L_{pi} - L_p(r_i) \qquad (4)$$

where

ΔL_{pi} is the deviation from the inverse square law, expressed in decibels;

L_{pi} is the measured sound pressure level (corrected for source stability) at measurement point i, expressed in decibels.

5.1.6 Measurement uncertainty

The uncertainty of the results obtained from measurements according to this International Standard shall be evaluated, preferably in compliance with the *Guide to the expression of uncertainty in measurement* (ISO/IEC Guide 98-3). The expanded uncertainty together with the corresponding coverage factor for a stated coverage probability of 95 % as defined in ISO/IEC Guide 98-3 shall be given. Guidance on the determination of the expanded uncertainty is given in Annex C.

5.2 Information to be recorded

For measurements according to this International Standard, the following information shall be recorded:

a) the time and date of the measurements;

b) the person responsible for the measurements and calculations;

c) a description of the environment to be qualified, including dimensions and a description of the physical treatment of walls, ceiling and floor;

d) a sketch showing the location of the test sound source and any unique features or non-uniformities;

e) air temperature in degrees Celsius, relative humidity in per cent and barometric pressure in pascals;

f) equipment used for the measurements, including name, type, serial number and manufacturer;

g) the sound source(s) used for the test;

h) position of the acoustic centre of each test sound source used;

i) clear identification of the traverse paths used for the test;

j) the locations and orientation of the traverse paths, any reflecting planes, bounding surfaces and the assumed acoustic centre of the source (a sketch shall be included, if necessary);

k) for each path, the start location relative to the test source and the path length;

l) the test signal(s) and measurement bandwidth;

m) the frequency range of interest (see 3.7);

n) for each path, the number of measurement points and the averaging time at each measurement point, or for continuous measurements, the speed of the traverse and the response time of the instrumentation;

o) a table or chart of the sound pressure levels or deviations from the inverse square law in the measurement band of interest and position relative to the test sound source, measured along each traverse;

p) the qualification criteria for the allowable deviations from the inverse square law;

q) the dimensions and location of the anechoic or hemi-anechoic space, qualified in accordance with the requirements of the referencing document or Annex A, as applicable.

5.3 Information to be reported

For measurements according to this International Standard, the following information shall be reported:

a) the time and date of the measurements;

b) a description of the environment to be qualified, including dimensions, and a description of the physical treatment of walls, ceiling and floor;

c) a description of the measuring instrumentation used;

d) a description of the sound source(s) used for the test, including a statement that the directionality of the source(s) comply with this International Standard;

e) the test signal(s) and measurement bandwidth;

f) the frequency range of interest (see 3.7);

g) clear identification of the traverse paths and the position of the source(s) used for the test;

h) the qualification criteria for the allowable deviations from the inverse square law;

i) the dimensions and location of the anechoic or hemi-anechoic space, qualified in accordance with the requirements of the referencing document or Annex A, as applicable;

j) the measurement results of the divergence loss of the sound pressure level or deviations from inverse square law versus distance;

k) a statement of the measurement uncertainty;

l) a statement whether the environment can be used for its intended use;

m) a statement that the qualification was made in accordance with this International Standard.

Due to the quantity of measurement results, it can be impractical to present these in a table and presentation in a graphical form is recommended.

Annex A
(normative)

Qualification criteria and measurement requirements

A.1 General

In the absence of specific requirements and criteria in a referencing document, the requirements and criteria provided in this annex shall be used to qualify anechoic and hemi-anechoic spaces for general purpose acoustical measurements.

A.2 Qualification criteria

A.2.1 Deviations from the inverse square law

For a space within an environment to be deemed anechoic or hemi-anechoic, the deviations of the measured sound pressure levels from those estimated using the inverse square law, obtained according to this International Standard, shall not exceed the values given in Table A.1.

Table A.1 — Maximum allowable deviations of measured sound pressure levels from theoretical levels using the inverse square law

Type of test environment	One-third-octave-band frequency Hz	Allowable deviations dB
Anechoic	≤630	±1,5
	800 to 5 000	±1,0
	≥6 300	±1,5
Hemi-anechoic	≤630	±2,5
	800 to 5 000	±2,0
	≥6 300	±3,0

The deviations in Table A.1 may be used to determine the extent of the anechoic or hemi-anechoic space, the largest volume surrounding the test source within which measurements may be made within a free sound field.

The deviations in Table A.1 also determine the frequency range over which measurements may be made within a free-field environment provided that the one-third-octave bands comprising the frequency range are contiguous.

A.3 Location of test sound sources and microphone traverses

A.3.1 Test sound source location

The test sound source shall be located to coincide with the usual source position. In an anechoic space, this is preferably in the centre of the test environment. In a hemi-anechoic space, this is preferably in the centre of and on the surface of the reflecting plane.

A.3.2 Microphone traverses

Microphone traverses shall be made along at least five straight paths away from the acoustic centre of the sound source in different directions.

The traverse paths shall be located in the working area of the environment, i.e. the part of the environment normally used for measurements.

The traverse paths shall be selected as follows:

a) at least one traverse path shall be towards a dihedral corner of the environment that has the most uniform acoustic treatment properties and is most likely to be representative of the overall free sound field performance;

b) at least one traverse path shall be towards a trihedral corner of the environment that has the most uniform acoustic treatment properties and is most likely to be representative of the overall free sound field performance;

c) at least one traverse path shall be towards the centre of the environment boundary surface that has the most uniform acoustic treatment properties and is most likely to be representative of the overall free sound field performance;

d) if the environment is not square in the plan area, then one traverse path shall be towards the closest boundary surface and one traverse path shall be towards the farthest boundary surface;

e) additional traverse paths shall be selected towards other boundary surfaces that contain unique features or non-uniformities in acoustic treatment (e.g. doors, viewing ports, ventilation openings and sound transmission openings).

In a hemi-anechoic space, paths shall be chosen that are within the angular limits over which the source directionality was qualified as specified in Annex B.

A.4 Test procedure

A.4.1 Qualification bandwidth

In the absence of guidance from a referencing document, the space shall be qualified using a discrete-frequency qualification method. If the expected application of the test environment is for devices that radiate only broad-band noise, the procedure may be carried out using random noise and a one-third-octave-band filter instead of discrete frequencies.

A.4.2 Generation of sound

A.4.2.1 General

The test source described in 5.1.2.2 shall be operated using pure tone or broad-band test signals.

A.4.2.2 Pure tone test signals

For discrete-frequency qualification using pure tones, the test source described in 5.1.2.2 shall be operated at frequencies that cover the entire frequency range over which the environment is being qualified. The frequencies of the tones shall approximate to the mid-band frequencies of the one-third-octave bands in the frequency range of interest.

NOTE For general purposes, normally nominal one-third-octave mid-band frequencies from 100 Hz to 10 000 Hz are used (see ISO 266[3] for the preferred frequencies for one-third octave intervals).

The frequency range may be extended or reduced, provided that the test environment and instrument specifications are satisfactory for use over the modified frequency range. Changes to the frequency range of interest should be made clear in the test report.

A.4.2.3 Broad-band test signals

For broad-band qualification procedures or discrete-frequency qualification using a broad-band test signal, the test source described in 5.1.2.2 shall be excited by random noise or broad-band test signals derived from random noise.

A.4.3 Spatial resolution of the measurement points

Sound pressure levels shall be measured along each microphone traverse described in A.3.2 using equally spaced measurement points at each frequency. The spacing shall not exceed one-tenth wavelength at each frequency of interest below (1 kHz) and shall not exceed (25 mm) at frequencies above 1 kHz. At least 10 measurement points should be taken per traverse.

Alternatively, for pure tone signals, the microphone may be moved slowly and continuously along the traverse and the sound pressure levels recorded. Sound pressure level versus distance data should be determined using the spatial sampling guidelines for discrete measurements.

A spatial resolution of one-tenth wavelength may be needed to fully characterize the spatial patterns in the reflections and to ensure that peak deviations are detected. If a (25 mm) spatial resolution traverse indicates that any point on the traverse is within 10 % of the criteria being evaluated, then it is recommended that spatial resolution be further decreased to ensure that the maximum deviation is detected.

Annex B
(normative)

General procedure for evaluation of sound source directionality

B.1 General

The test sound source directionality is evaluated by measuring the sound pressure levels at positions lying on a sphere or hemisphere surrounding the device.

B.2 Instrumentation and measuring equipment

B.2.1 Installation of the test sound source

The test source shall be installed in its normal qualification position in the centre of a test room and operated at an output level representative of the level to be used for the free-field qualification.

B.3 Test procedure

B.3.1 Generation of sound

The test source shall be excited by the same sound signal as that used for the free-field qualification.

B.3.2 Measurement of sound pressure level

A spherical coordinate system shall be selected with the source at the centre, $r = 0$ m, and with the plane for angle of elevation, $\varphi = 90°$, corresponding to the reflecting plane for a hemi-anechoic space or to a plane parallel with the floor and ceiling in an anechoic space. The plane with the angle of azimuth $\Theta = 0°$ (or 90°, 180°, 270°) shall be parallel to the walls of the space if the space is rectangular. The position $r = 1{,}5$ m, $\Theta = 0°$ shall be selected and the one-third-octave-band sound pressure levels at $\varphi = 80°$, 60°, 40° and 20° shall be measured. For a source used in the qualification of an anechoic space, additional measurements shall be made at $\varphi = 100°$, 120°, 140°and 160°. For each of the φ angles, measurements shall be made at $\Theta = 0°$, 45°, 90°, 135°, 180°, 225°, 270° and 315°, for a total of 32 measurements in a hemi-anechoic space, or 64 measurements in an anechoic space. For each one-third-octave band, the arithmetic mean of the decibel levels and the maximum positive and negative deviations from the mean shall be computed. If the deviations are within the allowable limits, the test source is suitable for conducting the qualification. A position directly above the source at $\varphi = 0°$ may be added for each of the 8 angular positions for information and as a check on the stability of the sound source, but it is not required for determining the directionality of the source.

For the directionality measurements, the source shall be installed and evaluated in a different anechoic or hemi-anechoic space than the one being qualified (e.g. one known to have good free-sound-field properties over the frequency range of interest).

NOTE 1 Sound sources that can be suitable for use in qualification of anechoic and hemi-anechoic spaces are described in the Bibliography[13].

For qualification of a hemi-anechoic space, the acoustic centre of the test source should be located as close as possible to the plane of the reflecting surface. Therefore, it is useful to have a small cavity in the centre of the floor into which the source may be installed.

At frequencies below 800 Hz, sources meeting the requirements of ISO 10140-5[2] may be suitable. An alternative is an electro-dynamic loudspeaker in a sealed box having dimensions less than one-tenth of a wavelength.

For frequencies up to 20 kHz, a source that may be suitable is an acoustically shielded compression driver attached to a cylindrical tube. The tube should have a length of 1,5 m and an outlet diameter of 6 mm. For use at lower frequencies, a shorter or larger diameter tube may be acceptable[13].

NOTE 2 It is advisable to use a source that meets the requirements of B.4 at a radius of 0,5 m from the source. Sources tend to be more omni-directional in the far field, and any difference in source directionality in the near and far field will make it more difficult to qualify the test room.

B.4 Test sound source directionality

The directionality of the test source shall be uniform to within the allowable deviations given in Table B.1 when determined according to the procedure given in B.3.

Table B.1 — Allowable deviations in directionality of the test source

Type of test environment	One-third-octave-band frequency Hz	Allowable deviations in directionality dB
Anechoic	≤630	±1,5
	800 to 5 000	±2,0
	6 300 to 10 000	±2,5
	>10 000	±5,0
Hemi-anechoic	≤630	±2,0
	800 to 5 000	±2,5
	6 300 to 10 000	±3,0
	>10 000	±5,0

Annex C
(informative)

Measurement uncertainty

C.1 General

The accepted format for expression of uncertainties generally associated with methods of measurement is that given in the ISO/IEC Guide 98-3. This format incorporates an uncertainty budget, in which all the various sources of uncertainty are identified and quantified, from which the combined total uncertainty can be obtained. The data necessary to enable such a format to be adopted in the case of this International Standard were not available at the time when it was being prepared. However, the intention of this annex is to provide a basis for the development of suitable information by which the ISO/IEC Guide 98-3 could be applied. It remains the final responsibility of a laboratory performing a measurement to determine its uncertainty (which might be higher or lower than the data given) and this annex should only be regarded as a guide.

C.2 Expression for the calculation of deviations from the inverse square law

Using the estimation of sound pressure levels based on the inverse square law, the deviation of the sound pressure level at each measurement point from the inverse square law determined, according to this International Standard, is a function of a number of parameters, indicated by the following equation:

$$\Delta L_{pi} = L'_{pi} - b + 20\lg\left(\frac{r_i}{r_0}\right)\mathrm{dB} + F\left(\delta_{\mathrm{instr}};\delta_{\mathrm{offset}};\delta_{\mathrm{dir(s)}};\delta_{\mathrm{stable}};\delta_{\mathrm{dir(m)}};\delta_{\mathrm{app}};\delta_{\mathrm{method}};\delta_{\mathrm{atten}};\delta_{\mathrm{resid}}\right) \quad \text{(C.1)}$$

where

ΔL_{pi} is the deviation from the inverse square law, expressed in decibels (dB);

L'_{pi} is the indicated sound pressure level at measurement point i, expressed in decibels;

b is the source strength parameter, which has been adjusted to optimise the fit of the measured data to the reference decay curve;

r_i is the distance between the origin of the traverse and measurement point i, expressed in metres;

r_0 is the reference value, $r_0 = 1$ m;

δ_{instr} is an input quantity to allow for any uncertainty due to the measuring instrumentation;

δ_{offset} is an input quantity to allow for any uncertainty due to the location of the acoustic centre of the sound source;

$\delta_{\mathrm{dir(s)}}$ is an input quantity to allow for any uncertainty due to the directionality of the sound source;

δ_{stable} is an input quantity to allow for any uncertainty due to the stability of the sound source;

$\delta_{\mathrm{dir(m)}}$ is an input quantity to allow for any uncertainty due to the directionality of the microphone;

δ_{app} is an input quantity to allow for any uncertainty due to reflections from the measuring apparatus;

δ_{method} is an input quantity to allow for any uncertainty due to the applied measurement method;

δ_{atten} is an input quantity to allow for any uncertainty due to the correction for absorption of sound by the atmosphere;

δ_{resid} is an input quantity to allow for any unaccounted for residual uncertainties.

NOTE 1 The input quantities included in Formula (C.1) to allow for uncertainties are those thought to be applicable in the state of knowledge at the time when this International Standard was being prepared, but further research could reveal that there are others.

NOTE 2 For simplification in the context of this document, potential correlation between any of the input quantities is neglected at present, though further research could reveal that correlation has to be taken into account.

A probability distribution (normal, rectangular, Student-t, etc.) is associated with each of the input quantities. Its expectation (mean value) is the best estimate for the value of the input quantity and its standard deviation is a measure of the dispersion of values. The uncertainty in the estimate of the input quantity is termed the standard uncertainty. It is a function of the standard deviation, probability distribution and number of degrees of freedom.

C.3 Contributions to measurement uncertainty

The combined uncertainty associated with the value of the deviation from inverse square law depends on each of the input quantities, their respective probability distributions and sensitivity coefficients, c_i. The sensitivity coefficients are a measure of how the values of the deviations are affected by changes in the values of the respective input quantities. Mathematically, these coefficients are equal to the partial derivatives of the function ΔL_{pi} [Formula (C.1)] with respect to the relevant input quantities. The contributions of the respective input quantities to the overall uncertainty are then given by the products of the standard uncertainties and their associated sensitivity coefficients. For the case of negligible correlation between the input quantities, the combined standard uncertainty of the determination of the deviation from inverse square law, $u\left(\Delta L_{pi}\right)$, is given by the following equation:

$$u\left(\Delta L_{pi}\right) = \sqrt{\sum (c_i u_i)^2} \quad \text{(C.2)}$$

The standard uncertainties from the various contributions remain to be established by research. An estimate of the type of information needed to derive the overall uncertainty is given in Table C.1.

The expanded uncertainty is typically twice the combined standard uncertainty for a coverage probability of 95 % and assuming a normal distribution.

Table C.1 — Uncertainty budget for determinations of deviations from inverse square law

Quantity	Estimate	Standard uncertainty, u_i dB	Units	Probability distribution	Sensitivity coefficient, c_i	Uncertainty contribution, $c_i u_i$ dB
L'_{pi} indicated sound pressure level			dB			
b, source strength			dB			
r_i	r_i'		m	Normal	$8{,}7/r_i'$ dB/m	
δ_{instr}, measuring instrumentation			dB			
δ_{offset}, sound source acoustic centre offset			dB			
$\delta_{dir(s)}$, sound source directionality			dB			
δ_{stable}, sound source stability			dB			
$\delta_{dir(m)}$, microphone directionality			dB			
δ_{app}, measuring apparatus reflections			dB			
δ_{method}, applied measurement method			dB			
δ_{atten}, atmospheric absorption			dB			
δ_{resid}, residual uncertainty			dB			

NOTE 1 Values left blank have yet to be determined and are likely to be a function of frequency.

NOTE 2 The estimate of the correction due to atmospheric absorption will be different from zero if a correction is applied (see NOTE 2 in 5.1.5.1.2).

NOTE 3 The sensitivity coefficient for the distance between the origin and the measurement point is calculated from the partial derivative of the component from Formula (C.1), i.e. 20/ln(10) = 8,7.