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**Sound system equipment –
Part 23: TVs and monitors – Loudspeaker systems**

**Équipements pour systèmes électroacoustiques –
Partie 23: Téléviseurs et moniteurs – Systèmes de haut-parleurs**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SOUND SYSTEM EQUIPMENT –

Part 23: TVs and monitors – Loudspeaker systems

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The text of this International Standard is based on the following documents:

Draft	Report on voting
100/3774/CDV	100/3831/RVC

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

A list of all parts in the IEC 60268 series, published under the general title *Sound system equipment*, can be found on the IEC website.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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INTRODUCTION

IEC TC 100 has already standardized loudspeaker measurement methods. However, the locations of the loudspeakers of TVs and monitors vary (e.g. front, bottom, back, side), and TVs and monitors are used on stands or wall-mounted, and methods used for their installation continue to evolve. Since the sound characteristics change according to the installation type and position of the loudspeaker, it is necessary to develop new measurement methods for loudspeakers of TVs and monitors. This document provides measurement methods for the audio system of TVs and monitors that take into account the listening environment.

SOUND SYSTEM EQUIPMENT –

Part 23: TVs and monitors – Loudspeaker systems

1 Scope

This part of IEC 60268 specifies acoustical measurement methods that apply to TV sets, monitors with built-in loudspeakers, and other audio devices having similar acoustical properties (e.g. flat-panel loudspeakers). The acoustical measurements are performed under free-field conditions and in-situ.

This document does not assess the perception and cognitive evaluation of the reproduced sound, nor the impact of perceived sound quality.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60268-2:1987, *Sound system equipment – Part 2: Explanation of general terms and calculation methods*

IEC 60268-21:2018, *Sound system equipment – Part 21 Acoustical (output-based) measurements*

IEC 61094-4, *Measurement microphones – Part 4: Specifications for working standard microphones*

IEC 61260-1:2014, *Electroacoustics – Octave-band and fractional-octave-band filters – Part 1: Specifications*

ISO 3744, *Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for an essentially free field over a reflecting plane*

ISO 3745, *Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Precision methods for anechoic rooms and hemi-anechoic rooms.*

ISO 80000-2, *Quantities and units – Part 2: Mathematics*

ANSI/CTA 2034-A:2015, *Standard Method of Measurement for In-Home Loudspeakers*

3 Terms, definitions and abbreviated terms

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1

equipment under test

EUT

equipment to be measured using the methods described in this document

3.2 Abbreviated terms

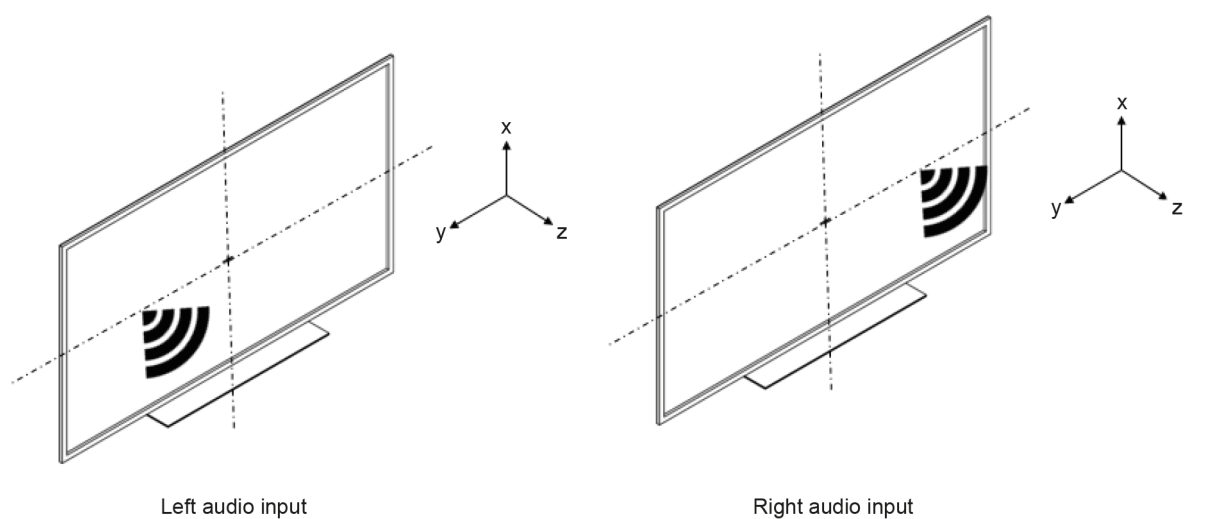
For the purposes of this document, the following abbreviated terms apply.

COG	centre of gravity
dB	decibel
DEF	direct energy fraction
DNR	distortion-to-noise ratio
DSP	digital signal processor
EFR	effective frequency range
EITHD	equivalent input total harmonic distortion
ESP	equivalent sound power
ESPD	equivalent sound power directivity index
EUT	equipment under test
FR	frequency response
Hz	hertz
m	metre
MD	absolute multi-tone distortion
MDS	multi-tone distortion spectrum
NBV	narrow band variation
NF	noise floor
ON	on-axis FR
Pa	pascal
POR	point of rotation
RFR	rated frequency range
RLD	regression line deviation
RMS	root mean square
RMD	relative multi-tone distortion
RNF	relative noise floor
SB	spectral balance
SNR	signal-to-noise ratio
SP	sound power
SPL	sound pressure level
TFA	time-frequency analysis
TH	total harmonic
THD	total harmonic distortion
TMDR	total multi-tone distortion ratio
W	watt

4 Type description

The type description, which includes the following information, shall be provided by the manufacturer.

- Number of input channels: typically, the EUT has two input channels that excite at least one transducer on both the left-hand side and the right-hand side, as shown in Figure 1. The configuration shall be clearly specified for EUTs with more input channels.
- Signal input format: for example, analogue, digital and wireless.
- Type, principles, and the number of the transducers used in the TV and monitor audio systems.
- Power amplification of audio.
- DSP (e.g. equalizer, active protection).



IEC

Figure 1 – Test signal scope

5 Physical characteristics

5.1 Dimensions

The outer dimensions of the EUT should be specified.

5.2 Mass

The total mass of the EUT should be specified.

6 Conditions

6.1 Normal measuring conditions

The EUT shall be understood to be under normal measuring conditions if all of the following conditions are met.

- The acoustical environment is specified and selected from those given in Clause 8.
- Unwanted acoustical signals, electrical signals, and noise generated by other sources shall be kept at the lowest levels possible because their presence may obscure low-level signals. Data related to signals, which are less than 20 dB above the noise level in the frequency band being considered, shall be discarded or marked as corrupted by noise.

- c) The EUT is positioned in accordance with Clause 10.
- d) The EUT is supplied with a test signal with specified properties (spectrum, duration, etc.) in accordance with Clause 7 at a specified RMS input value for the rated frequency range in accordance with 6.3.
- e) Attenuators, equalizers, dynamics, or any other active control elements shall be set to their “normal” position as stated by the manufacturer. If other positions are chosen, for example those providing a maximally flat FR or minimum attenuation, they shall be specified.
- f) Measuring equipment suitable for determining the wanted characteristics is connected in accordance with Clause 9.

6.2 Rated conditions

The rated conditions are physical characteristics that constitute the basis for performing the measurements. The following rated conditions shall be taken from the manufacturer's specification:

- rated frequency range defined in 6.3;
- rated maximum sound pressure level defined in 19.9;
- rated maximum input value defined in 19.8.

6.3 Rated frequency range

The rated frequency range corresponds to the intended use of the EUT in the final application as defined in IEC 60268-21. It is specified by the frequencies f_L and f_U of the lower and upper limits of the audio band for which the maximum sound pressure of the EUT is rated in 19.9.

NOTE The RFR can differ from the EUT's effective frequency range (EFR) as defined in 18.3.

6.4 Climatic conditions

IEC 60268-1 states that tests shall be carried out in the following environment to prevent the influence of temperature and humidity that can affect the properties of the drive unit suspensions [1]¹.

- a) ambient temperature: 15 °C to 35 °C;
- b) relative humidity: 25 % to 75 %;
- c) air pressure: 86 kPa to 106 kPa.

7 Test signals

7.1 General

Acoustical measurements shall be made by using one of the stimuli given in 7.2 to 7.9.

7.2 Sinusoidal chirp signal

As defined in IEC 60268-21:2018, 8.2

7.3 Steady-state single-tone signal

As defined in IEC 60268-21:2018, 8.3

¹ Numbers in square brackets refer to the Bibliography.

7.4 Steady-state two-tone signal

As defined in IEC 60268-21:2018, 8.4

7.5 Sparse multi-tone complex

As defined in IEC 60268-21:2018, 8.5

7.6 Broadband noise signal

As defined in IEC 60268-2:1987, 1.4

7.7 Narrow-band noise signal

As defined in IEC 60268-2:1987, 1.4.

7.8 Hann-burst signal

As defined in IEC 60268-21:2018, 8.8

7.9 Impulsive signal

As defined in IEC 60268-2.

8 Acoustical environment

8.1 General

Acoustical measurements shall be made under one of the conditions stated in 8.2 to 8.5. The acoustical environment used for testing shall be stated.

8.2 Free-field conditions

Acoustical conditions that approach those of free space may be used. Any environment shall be considered satisfactory when the reflected sound components are sufficiently suppressed to ensure accuracy of $\pm 0,5$ dB and $\pm 10^\circ$ in the measured sound pressure amplitude and phase values at the specified frequency, respectively. If the environment (e.g. an anechoic room at low frequencies) does not fulfil these free-field conditions over the rated frequency range of the measurement, the manufacturer shall state the valid frequency range.

NOTE Half-space, free-field conditions are usually not helpful for the acoustical evaluation of monitors, TVs, and other EUTs of similar shape used in applications where the EUT is not operated within a wall of sufficient size.

8.3 Simulated free-field conditions

Acoustical conditions of any environment (e.g., reverberant room) shall be satisfied if the direct sound radiated by the EUT is separated from the room reflections by using measurement techniques such as gating of the impulse response [2], wave separation [3], or acoustical holography [4]. These measurement techniques shall ensure accuracy of $\pm 0,5$ dB and $\pm 10^\circ$ in the measured sound pressure amplitude and phase values at the specified frequency. The frequency resolution $\Delta f = 1 / T$, where T is the effective or truncated impulse response length where the simulated free-field conditions are fulfilled, and any other limitations that impair the measurement results shall be stated.

The condition will be met in any environment (e.g. large rooms with no obstructions) where sound emitted by the TV or monitor speaker reflected from any surface or object in the environment does not reach the measuring microphone before completing the direct sound measurement.

8.4 In-situ environment

There is also a need in product development, manufacturing, installation, maintenance, and service to perform additional measurements in an in-situ environment that does not comply with free-field conditions. For example, an in-situ environment is generated using the wall-mounted, stand-type mounting techniques defined in Clause 12. Test results depend on the particular properties of the in-situ environment and are not comparable with measurements under other conditions.

8.5 Listening room

A listening room representing the typical in-situ environment used by a customer in the final target application is valuable for combining perceptual and physical testing. In order to create a meaningful listening room, the following criteria shall be specified:

- the volume of the room;
- the shape of the room;
- reverberation time $R_{60}(f)$ of the room versus frequency measured in octaves;
- positioning of the EUT in accordance with Clause 10;
- listening position and acoustical zone in accordance with Clause 17;
- mounting conditions in accordance with Clause 12.

NOTE A perceptual and physical listening room reflects essential properties of the speaker-room interaction and provides repeatable and reproducible data in this room. However, the data measured in different listening rooms have limited comparability.

9 Measurement equipment

Measurements in free-field conditions shall be made using a WS2F or WS3F free-field microphone in accordance with IEC 61094-4.

10 Positioning of the EUT

10.1 Reference plane and normal vector

The normal vector $\mathbf{n}_{\text{ref}}$ should be used to specify the direction of the reference plane. The reference plane of EUT should be set parallel to the display screen, as shown in Figure 2. For other EUTs, the manufacturer shall specify the normal vector $\mathbf{n}_{\text{ref}}$ with the results.

The reference plane with the normal vector $\mathbf{n}_{\text{ref}}$ should be used to define the reference axis and reference point $\mathbf{r}_{\text{ref}}$. The pole of the spherical coordinate system in accordance with ISO 80000-2 shall be on the reference axis pointing in the direction of the normal vector $\mathbf{n}_{\text{ref}}$. The azimuthal angle ϕ should rotate according to the right-hand rule around the normal vector $\mathbf{n}_{\text{ref}}$.

10.2 Reference point

The manufacture shall define the reference point $\mathbf{r}_{\text{ref}}$ within the reference plane and provide this information with the measured results. For an EUT with symmetrical geometry, the reference point $\mathbf{r}_{\text{ref}}$ shall be placed at the axis of reflectional symmetries or at the point of rotational symmetry. The directional properties of the EUT shall be described in a spherical coordinate system. The origin of the Cartesian and spherical coordinate system shall be placed at the reference point, as shown in Figure 2.

NOTE For directional measurements performing a rotation of the EUT, the reference point is identical to the point of rotation (POR) and usually chosen close to or identical to the centre of gravity (COG) of the EUT.

10.3 Reference axis

The reference axis is the line that passes through the reference plane at the reference point r_{ref} in the direction of the normal vector n_{ref} as shown in Figure 2. The pole of the spherical coordinate system shall be placed on the reference axis, and the polar angle θ describes the declination of the observation point r from the reference axis. The on-axis measurements defined in 15.2 shall be performed on the reference axis with a polar angle $\theta=0$. The reference axis shall be used as the reference axis for directional measurements.

10.4 Orientation vector

The orientation vector O_{ref} defines the orientation of the EUT and the azimuthal angle $\phi = 0$ within the reference plane shown in Figure 2. The orientation vector O_{ref} should typically point upwards to the top of the EUT if not stated otherwise. The azimuthal angle should have a positive sign if measured anticlockwise from the orientation vector O_{ref} on the reference plane, as seen from the zenith side of the plane.

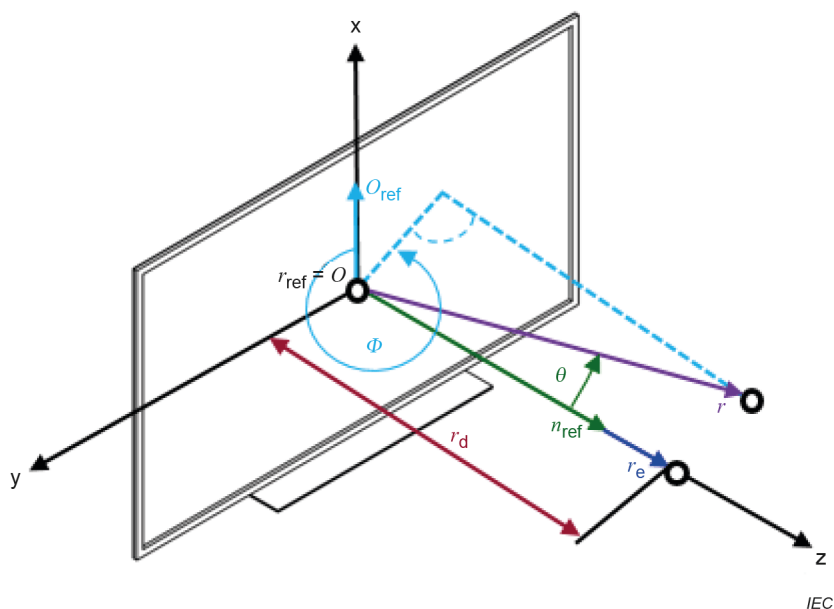


Figure 2 –Recommended position and orientation of the EUT

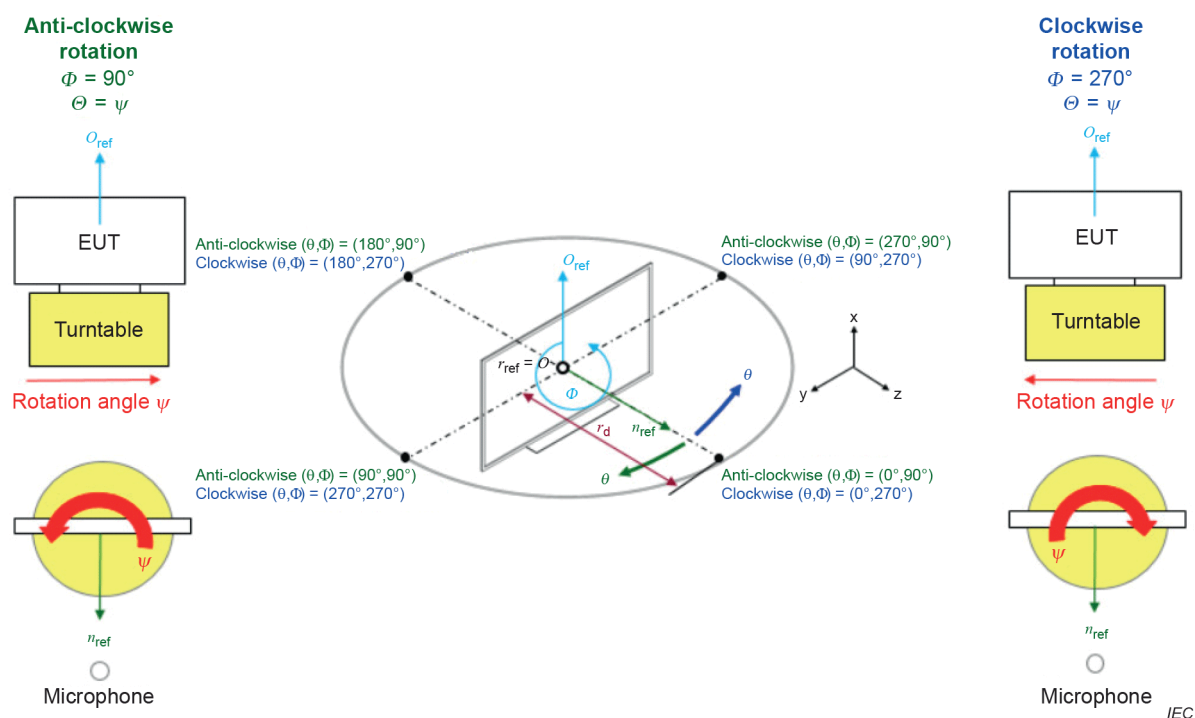


Figure 3 – Measuring the horizontal directivity in spherical coordinates by rotating the EUT (e.g., OLED TV) in upright position

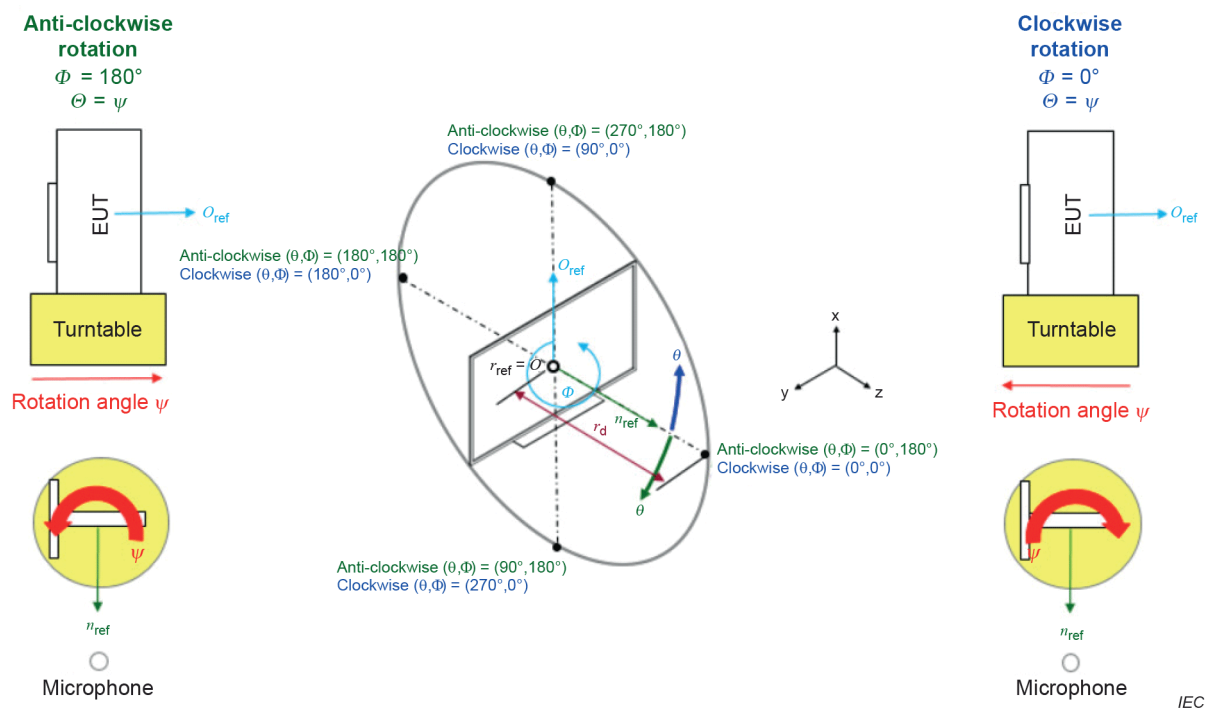


Figure 4 – Measuring the vertical directivity in spherical coordinates by rotating the tilted EUT (e.g., OLED TV)

10.5 Horizontal and Vertical Trajectories

The horizontal and vertical trajectories shown in Figure 3 and Figure 4, respectively, shall be measured versus 360° at distance r_d and expressed in spherical coordinates in accordance with Table 1.

Table 1 – Recommended coordinates of the trajectories at distance r_D

Trajectory	Polar angle θ	Azimuthal angle ϕ	Orientation of the EUT on a turntable
Horizontal	$-180^\circ \leq \theta < 180^\circ$	270°	EUT in upright position rotated clockwise
Horizontal	$-180^\circ \leq \theta < 180^\circ$	90°	EUT in upright position rotated anti-clockwise
Vertical	$-180^\circ \leq \theta < 180^\circ$	0°	tilted EUT rotated clockwise
Vertical	$-180^\circ \leq \theta < 180^\circ$	180°	tilted EUT rotated anti-clockwise

NOTE The loudspeaker directivity of the EUT can be measured versus the horizontal trajectory by performing a first complete (360°) rotation of the EUT placed in normal orientation (orientation vector points upwards) on a turntable. The directivity versus the vertical trajectory requires a second complete (360°) rotation over the tilted EUT placed on the left-hand side on the turntable.

11 Measuring distance between EUT and microphone

11.1 Far-field conditions

Measurements under free-field and half-space conditions shall ideally be carried out in the far-field of the EUT at a distance $r > r_{\text{far}}$ where the sound pressure decreases with the distance r according to the $1/r$ law. The location in the far-field is determined when the following three conditions [5] are fulfilled:

- the distance r is much larger than the geometrical dimension d of the EUT,
- the distance r is much larger than the wavelength λ ,
- the ratio between distance r and dimension d is much larger than the ratio between dimension d and wavelength λ ($r/d \gg d/\lambda$)

However, in practice, limitations of the measuring environment (e.g. room size [4]) and the effects of the background noise set an upper limit to the distance r that can be used.

Measurements under simulated free-field conditions shall be made with the microphone and the EUT positioned within the measuring environment so that the time required for the unwanted first reflection to reach the microphone is maximized.

If the measurement space is an anechoic chamber, reflections from wedge tips, flooring, EUT supports, and microphone supports shall be avoided.

Errors from these sources shall not exceed $\pm 0,5$ dB and $\pm 10^\circ$ in the measured sound pressure amplitude and phase at any frequency within the frequency range of measurement.

11.2 Near-field conditions

The sound pressure in the near field can only be measured by using holographic techniques [4]. In addition, valid far-field information can only be calculated from near-field data by using holographic methods.

The advantages of measurements in the near field [6] are as follows:

- the time available before first reflections is maximized;
- the direct sound pressure is maximized.

The main advantage of holographic techniques is to allow large EUTs to be measured in small rooms [7].

12 Mounting of the EUT

12.1 General

TV and monitor audio systems are measured without any additional baffle.

The manufacturer should use the mounting methods defined in 12.2.1 and 12.2.2. Other mounting methods can be used if the particular type is specified with the results.

12.2 Mounting methods

12.2.1 Stand-type

The EUT is placed on the top of a table, rack, or other furniture, as shown in Figure 5. The manufacturer should specify width, length, and height. The stand-type generates acoustical reflections from the table and rack and requires in-situ testing as defined in Clause 16.

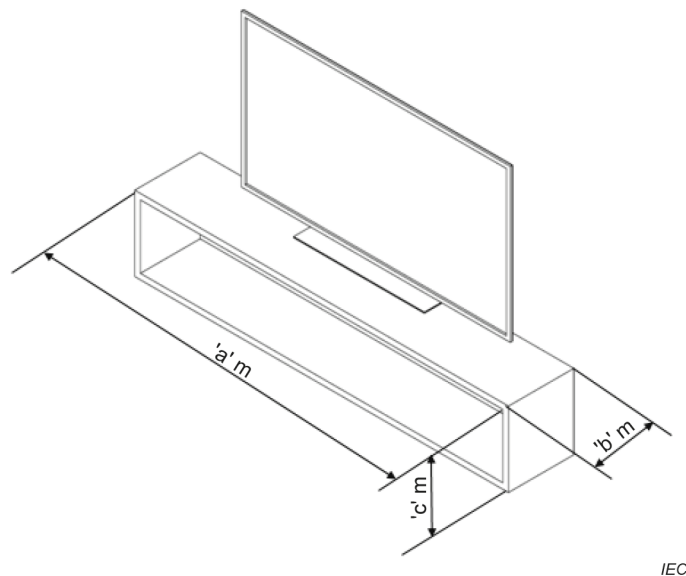


Figure 5 – Example for stand-type

12.2.2 Wall mount-type

The EUT is mounted close to a wall using a stand as shown in Figure 6 or hanging directly on the wall using fixture elements. The manufacturer should specify width, length, and height. The wall mount type generates acoustical reflections from the ground, wall, and stand surface and requires in-situ testing as defined in Clause 16.

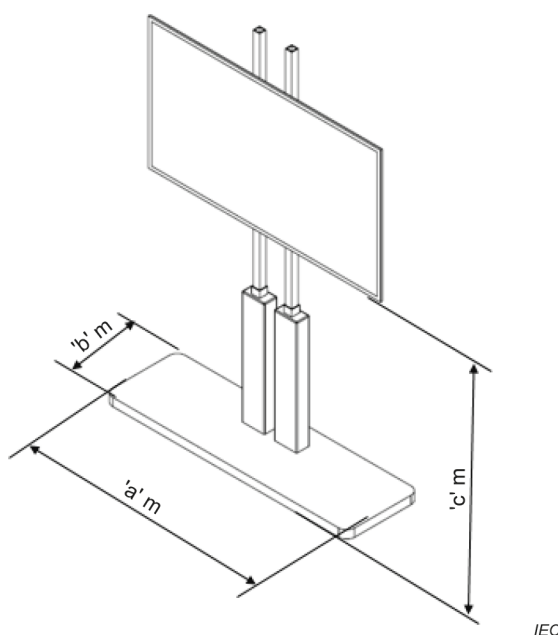


Figure 6 – Example for wall mount-type.

NOTE It can be appropriate to mount TVs and monitors using the VESA standard (Flat Display Mounting Interface Standard: 2006).[8]

12.3 Mounting for free-field conditions

12.3.1 General

The measurement of the spatial transfer function in 15.3 and the directional characteristics in 15.5 can require special mounting conditions to minimize sound reflections on the gear and fulfil the free-field conditions.

12.3.2 EUT rotating condition

This condition is defined as the EUT is rotating while keeping the microphone at a fixed position. It is helpful for convenience and measurement consistency if the rotating platform can be vertically adjusted to compensate for EUTs of different heights.

NOTE It can be appropriate to mount TVs and monitors using the VESA standard (Flat Display Mounting Interface Standard: 2006).[8]

12.3.3 Microphone rotating condition

This condition is defined as the microphone rotating with the EUT fixed. It is helpful for convenience and measurement consistency if the rotating platform can scan the near field and the far field.

13 Rated ambient conditions

13.1 Temperature ranges

13.1.1 Performance limited temperature range

The temperature range over which the variation of the characteristics of the EUT shall not exceed the specified tolerances.

13.1.2 Damage limited temperature range

If exceeded during operation or storage, the temperature range can result in permanent changes in the operating characteristics of the EUT.

13.2 Humidity ranges

13.2.1 Relative humidity range

The relative humidity range over which the variation of the characteristics of the EUT shall not exceed the specified tolerances.

13.2.2 Damage limited humidity range

If exceeded during operation or storage, the relative humidity range can result in permanent changes in the operating characteristics of the EUT.

14 Evaluation point and distance

14.1 Evaluation point

The evaluation point r_e specified by the manufacturer is the position where the rated maximum sound pressure level L_{SPmax} is determined. In agreement with IEC 60268-21 and 19.9, the evaluation point r_e is typically placed on-axis defined by reference axis n_{ref} at a distance r_d from the reference point r_{ref} as shown in Figure 7.

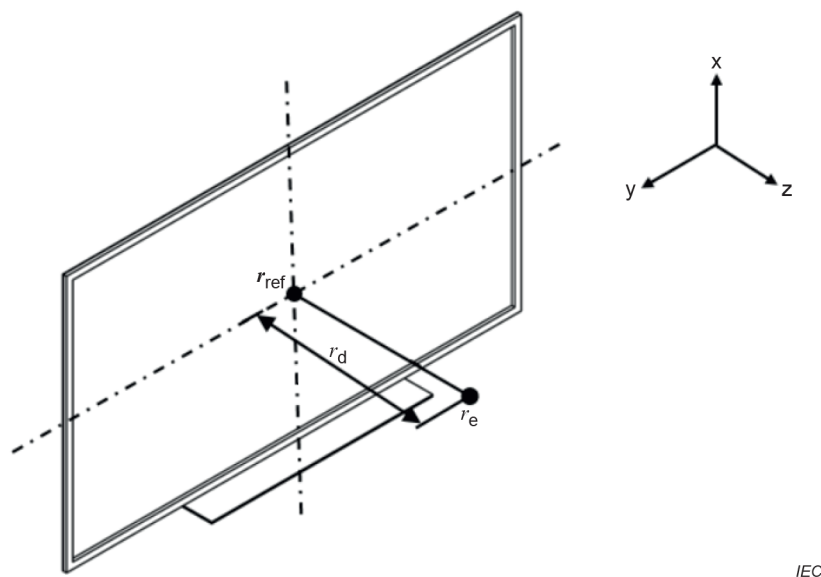


Figure 7 – Evaluation point and distance (centre)

14.2 Evaluation distance

The evaluation distance $r_d = |r_e - r_{ref}|$ is the distance between the evaluation point r_e and the reference point r_{ref} .

This document describes TV and monitors from a consumer perspective. Therefore, the evaluation distance r_d is selected in Table 2. The manufacturer selects and specifies one of these standards. If the manufacturer uses a particular evaluation distance, this shall be reported with the results.

Table 2 – Evaluation distance reference standard

Product	Standard	Condition	Evaluation distance r_d
Monitors	SJT 11157-2	Screen diagonal length shorter than 66 cm:	1 m
TVs		Screen diagonal length longer than 66 cm:	2 m
Common (TVs and monitors)	SMPTE	Viewing angle: $\theta = 30^\circ$ and $\theta = 40^\circ$	It depends on screen size (e.g. 65 inch TV = 2,7 m)
	ITU-R BT.2246-4	video resolution: h (h = height of TV)	It depends on video resolution (e.g. 65" 2k TV and monitor = 2,2 m)

15 Free-field measurements

15.1 General

This clause defines measurement methods and characteristics used to assess the free-field sound radiated from the EUT at low amplitudes where the speaker's nonlinear distortion and time-varying properties can be neglected. Those measurements shall be performed under free-field or simulated free-field conditions in accordance with IEC 60268-21 to suppress the influence of sound reflections by the acoustical environment (room).

15.2 On-axis SPL FR

15.2.1 Definition

The SPL FR is defined as the SPL generated at the evaluation point r_e in accordance with Clause 14 generated under free-field conditions by a sinusoidal input signal at a specified RMS value. This measurement shall be performed in the small-signal domain over a stated frequency range using a sinusoidal chirp giving the best SNR.

15.2.2 Measurement methods

The following two methods shall measure the SPL FR $L_{ON}(f, r_e)$:

- free-field measurement by placing the microphone at evaluation point r_e in accordance with IEC 60268-21;
- holographic near-field scanning technique using a wave separation technique to provide simulated free-field data at the evaluation point r_e as defined in 15.3.3.

Accurate positioning of the microphone is essential for EUTs with large radiating surfaces (e.g., TV using the screen for sound reproduction) generating a complex directivity pattern that can affect the reproducibility of the results.

NOTE The holographic measurement provides a fitting error that shows the accuracy of the measurement. The near field measurements provide maximum SNR and simulated near field conditions by removing room reflections.

15.2.3 Reporting

The on-axis SPL FR shall be plotted versus a logarithmic frequency axis. The measurement condition (evaluation point r_e and RMS value of the stimulus), additional post-processing (e.g., spectral smoothing of the curve), and other influences affecting the accuracy of the measurement shall be stated. The $L_{ON}(f, r_e)$ shall not be applied for assessing the spectral balance, regression line deviation, and narrow band variation of the FR of a EUT with a large radiating surface.

NOTE An EUT with a large radiating surface can generate a complex directivity pattern that cannot be represented by on-axis SPL FR measured at a single point. The SPL FR representing the listening window in 15.5.3.2 or the mean SPL value averaged over the listening zone in Clause 17 is used for assessing the spectral properties of the direct sound radiated by the EUT.

15.3 Spatial transfer function

15.3.1 Definition

The direct sound generated by the EUT at any point $\mathbf{r}$ in the near and far-field of the EUT can be modelled in accordance with IEC 60268-21:2018, 20.2 by a spatial transfer function $H_{FF}(f, \mathbf{r})$ between the input signal $u(t)$ and the sound pressure $p(t, \mathbf{r})$.

NOTE 1 The accurate amplitude and phase information provided by the transfer function $H_{FF}(f, \mathbf{r})$ is the basis for the optimal design of crossovers, beam steering, contrast control, and other spatial audio applications using DSP.

The spatial transfer function $H_{FF}(f, \mathbf{r})$ expressed in spherical coordinates distance r , angles θ and ϕ shall be represented by a spherical wave expansion as

$$\begin{aligned} H_{FF}(f, \mathbf{r}) &= \frac{P_{FF}(f, \mathbf{r})}{U(f)} = C_{FF}(f) \mathbf{B}_{OUT}(f, \mathbf{r}) \\ &= \sum_{n=0}^N \sum_{m=-n}^n c_{n,m}^{FF}(f) h_n^{(2)}(kr) Y_n^m(\theta, \phi) \end{aligned}$$

using general solutions $\mathbf{B}_{OUT}(f, \mathbf{r})$ of the Helmholtz equation weighted by complex coefficients in vector $C_{FF}(f)$ [4]. This expansion is only valid for the direct sound radiated from any source generated inside a surface enclosing the EUT under free-field conditions. The spherical coordinates allow a separation of angular dependency (directional properties) using the spherical harmonics $Y_n^m(\theta, \phi)$ from the radial dependency (near field/far-field properties) using the Hankel function of the second kind $h_n^{(2)}(kr)$, with the wavenumber $k = 2\pi f/c_0$ and the speed of sound c_0 . This expansion can be used for modelling the direct sound generated by the EUT at any point in the near and far-field for $r > a$, where a is a critical distance typically limited by the scanning surface.

NOTE 2 The sound field inside the sphere with the critical distance a can only approximately be modelled by the coefficients $C_L(f)$ identified on the scanning surface.

15.3.2 Measurement method

The coefficients $C_{FF}(f)$ describe the directional properties of the EUT and shall be determined by minimizing the mean squared error between measured data collected by a scanning process at multiple points $\mathbf{r}_k$ in the near field of the EUT and the spherical wave model in accordance with IEC 60268-21:

$$C_{FF}(f) = \arg \min_C \sum_{k=1}^{N_r} |H_{FF}(f, \mathbf{r}_k) - C(f) \mathbf{B}_{OUT}(f, \mathbf{r}_k)|^2$$

A double layer scan shall be used to separate the direct sound from the room reflections occurring in an in-situ measurement environment.

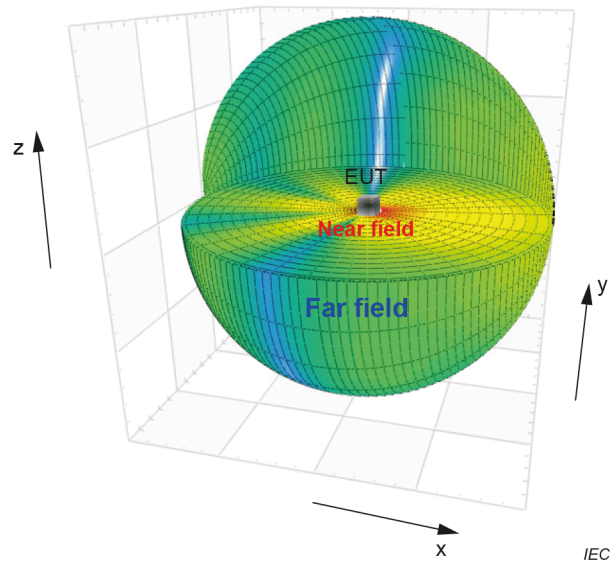


Figure 8 – SPL distribution of the direct sound represented in colour in 3D

The spatial transfer function $\underline{H}_{FF}(f, \mathbf{r})$ shall be measured for each electroacoustic transducer (e.g. woofers, tweeters, exciters) used in the EUT.

15.3.3 Reporting

The complex coefficients $C_{FF}(f)$ of the spherical wave model defined in 15.3 are the basis for calculating the directional function $H_{FF}(f, \mathbf{r})$ giving the SPL and phase responses at any point r outside the scanning surface. Figure 8 shows, for example, the SPL distribution in the near and far fields generated by an EUT for a sinusoidal input signal.

The $1/r$ law can extrapolate the transfer function $H_{FF}(f, \mathbf{r})$ measured under far-field conditions to any other evaluation distance in the far-field at the same angles ϕ and θ . The SPL FR shall be reported as a polar, balloon, or contour plot defined in IEC 60268-21.

The SPL FR $L_{FF}(f, \mathbf{r})$ of the free-field radiated from the EUT shall be calculated in decibels at any point in the near and far-field of the EUT as

$$L_{FF}(f, \mathbf{r}) = 20 \log_{10} \left(\frac{\tilde{u}(f) |\underline{H}_{FF}(f, \mathbf{r})|}{p_0} \right)$$

using the RMS value $\tilde{u}(f)$ of the sinusoidal input signal and the reference sound pressure $p_0 = 20 \mu\text{Pa}$.

15.4 Sound power response

15.4.1 Definition

The acoustic output power may be calculated by integrating the RMS sound pressure $\tilde{p}(f, r)$ on a sphere in the far field with the following equation:

$$\Pi(f) = \frac{r^2}{\rho c} \int_{\Omega} \tilde{p}^2(f, r, \theta, \phi) d\Omega$$

where,

$\Pi(f)$ is the acoustic power, in W;

r is the sphere radius, in m;

ρ and c are the density and the sound speed of air under standard conditions.

15.4.2 Measurement methods

15.4.2.1 General

The acoustic output power is determined by either the method in 15.4.2.2 or the method in 15.4.2.3, in accordance with IEC 60268-21:2018, 20.4:

15.4.2.2 Far-field measurement

The sound pressure shall be measured in the far-field of the EUT on a sphere with radius r at many points evenly distributed around the EUT. If the system has axial symmetry of revolution, measurements in a plane containing this axis can be considered sufficient SNR, provided the measurements are suitably weighted in the averaging process in accordance with Clause 6, Clause 8, Clause 17 and 19.2.

In the case of full-space free-field conditions, the square of the RMS sound pressure $\overline{p^2(f,r)}$ shall be averaged over a large sphere of radius r and, in the case of half-space free-field conditions, over a large hemisphere in accordance with ISO 3744 and ISO 3745.

The acoustic power under free-field full space conditions can be determined by the formula:

$$\Pi(f) = \frac{4\pi r^2}{\rho c} \overline{p^2(f,r)} = 0,031r^2 \overline{p^2(f,r)}$$

The acoustic power under half-space free-field conditions shall be determined by the formula:

$$\Pi(f) = \frac{2\pi r^2}{\rho c} \overline{p^2(f,r)} = 0,016r^2 \overline{p^2(f,r)}$$

15.4.2.3 Near-field measurement

The coefficients $C_{FF}(f)$ of the spherical wave expansion shall be determined based on a near-field measurement in agreement with 15.3.2. The sound power shall be calculated in a defined frequency band at centre frequency f by

$$\Pi(f) = \frac{\tilde{u}(f)^2}{k^2 \rho c} \sum_{n=0}^N \sum_{m=-n}^n \left| \mathcal{C}_{n,m}^{FF}(f) \right|^2$$

using the wavenumber k , the coefficients $C_{FF}(f)$ of the wave expansion, and the RMS value $\tilde{u}(f)$ of the input signal $u(t)$ in this band.

15.4.3 Reporting

Expressed in decibels, the sound power level

$$L_{\Pi}(f) = 10 \log_{10} \left(\frac{\Pi(f)}{\Pi_0} \right)$$

shall be specified as ten times the logarithm of the ratio between the acoustic output power $\Pi(f)$ measured by 15.4.2 and the reference power $\Pi_0 = 10^{-12}$ W.

15.5 Directional characteristics

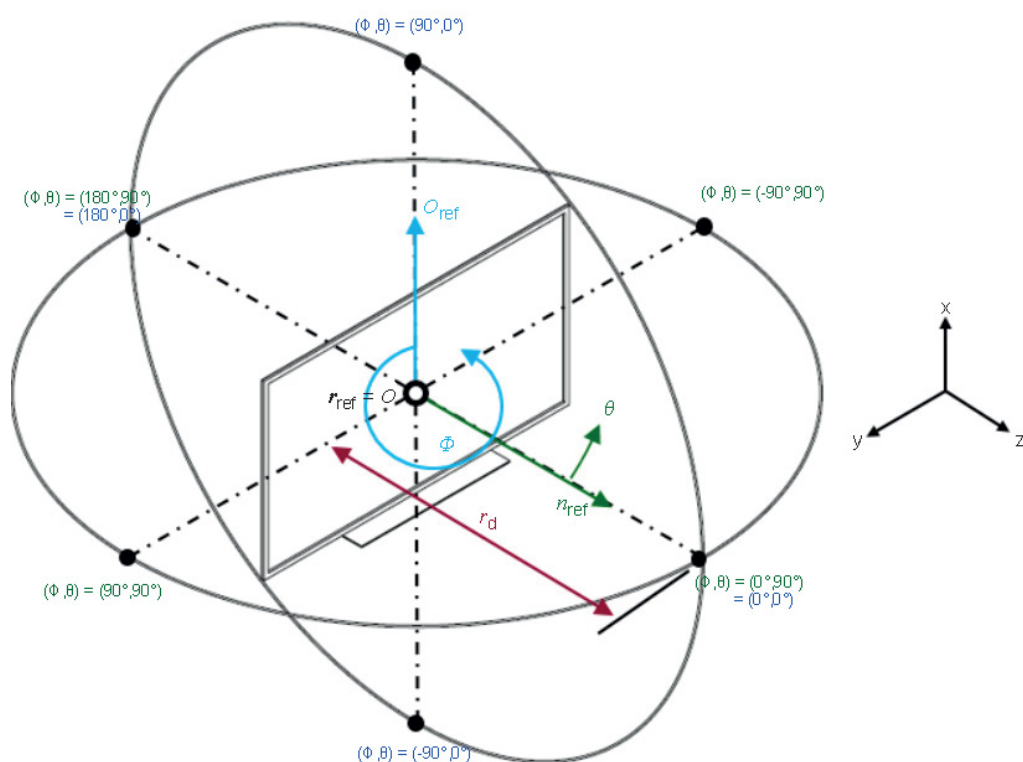
15.5.1 General

The directional properties of the EUT can be described by a set of directional SPL FR $L_{FF}(f, \theta, \Phi)$ determined for selected angles Φ and θ at a constant distance r_d from the reference point r_{ref} .

NOTE The directional characteristics in 15.5 describe the properties of the EUT under free-field conditions. The interaction with a room in the target application is defined in Clause 16.

The reference point r_{ref} is typically placed in the centre of the EUT, as shown in Figure 9, to simplify the rotation of the EUT as defined in 10.2. If the manufacturer specifies a particular reference point r_{ref} for each transducer channel, this shall be specified with the results.

The distance r_d corresponds to the typical distance between EUT and the listener in the final target application. If the distance r_d does not provide a far-field condition as defined in IEC 60268-21, the SPL FR shall not be extrapolated to a larger distance $r > r_d$ using the $1/r$ law.



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Figure 9 – Measurement locations at vertical and horizontal trajectories at distance r_d

15.5.2 Measurement methods

15.5.2.1 General

The SPL FR $L_{FF}(f, \theta, \Phi)$ shall be measured at horizontal and vertical trajectories shown in Figure 9 in agreement with 10.5 under free-field conditions. The measurement points are placed at a distance r_d to the reference point r_{ref} and have a resolution of 10° in the polar angle θ defined in Table 1. One of the following two measurement methods (in 15.5.2.1 and 15.5.2.3) shall be used:

15.5.2.2 Direct measurement

The SPL FR $L_{FF}(f, \theta, \Phi)$ shall be measured by rotating the EUT or the measurement microphone around the reference point r_{ref} .

15.5.2.3 Holographic measurement

The SPL FR $L_{FF}(f, \theta, \Phi)$ shall be calculated in decibels at the measurement points on the horizontal and vertical trajectory as shown in Figure 9 by using the directional transfer function $\underline{H}_{FF}(f, r_D, \theta, \Phi)$ defined in 15.3 in decibels as

$$L_{FF}(f, \theta, \Phi) = 20 \log_{10} \left(\frac{|\tilde{u}(f)| |\underline{H}_{FF}(f, r_D, \theta, \Phi)|}{p_0} \right)$$

using the RMS value $\tilde{u}(f)$ of the sinusoidal input signal and the reference sound pressure $p_0 = 20 \mu\text{Pa}$.

15.5.3 Post-processing

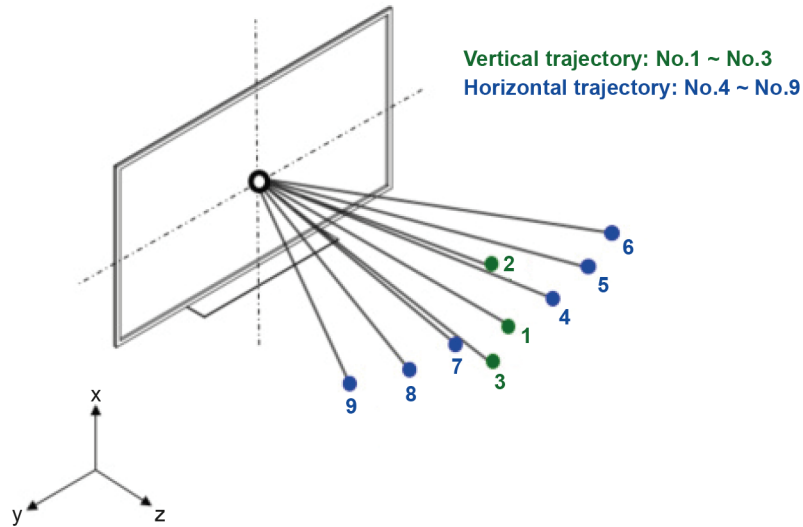
15.5.3.1 General

The SPL FR $L_{FF}(f, \theta, \Phi)$ measured at defined angles θ and Φ defined in Table 1 shall be processed to estimate the following composite responses describing the directional characteristics of the EUT.

The following SPL FRs (in 15.5.3.2 and 15.5.3.3) shall be calculated by using spatial weights defined in ANSI/CTA 2034-A.

15.5.3.2 Listening window (LW)

The listening window curve $L_{LW}(f)$ is an energetic average of the nine SPL FR $L_{FF}(f, \theta, \Phi)$ that take into consideration selected points on the vertical trajectory ($\theta = 0^\circ, \pm 10^\circ$ with $\Phi = 0^\circ$) and on the horizontal trajectory ($\theta = \pm 10^\circ, \pm 20^\circ, \pm 30^\circ$ with $\Phi = 90^\circ$) in accordance with Clause 10 and ANSI/CTA-2034 5.2, as shown in Figure 10.



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Figure 10 – Measurement locations at listening window

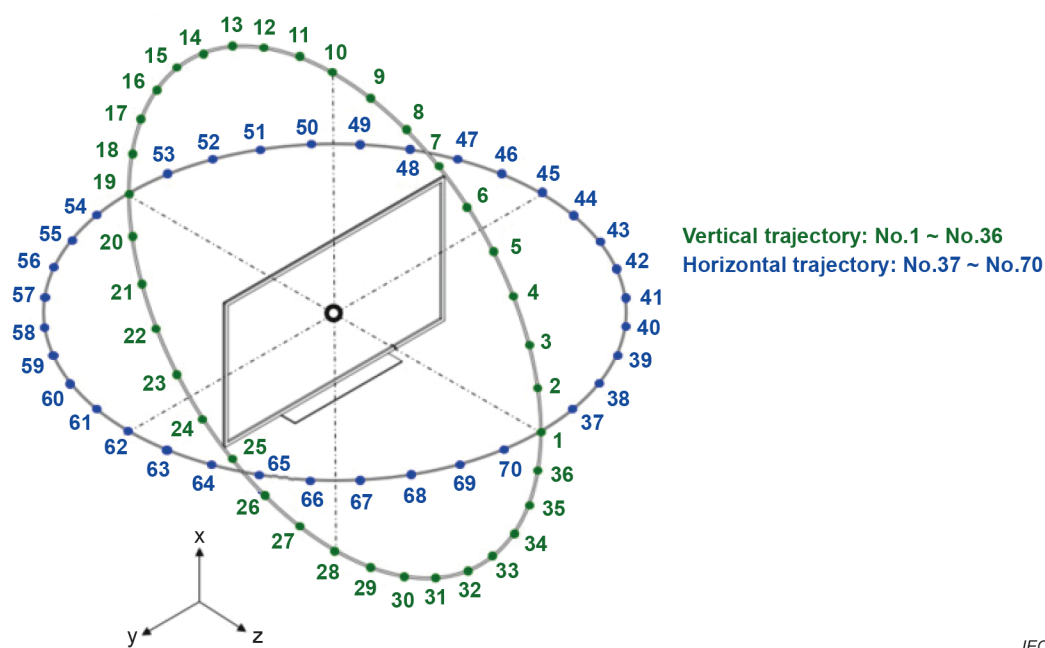
NOTE The averaging of the SPL as used for the acoustic zone according to IEC 62777 is a better way to model the human perception of the SPL distribution with the listening window because a human ear cannot perform an energetic averaging over multiple locations.

15.5.3.3 Equivalent sound power (ESP)

An equivalent sound power curve $L_{ESP}(f)$ is an SPL FR that has the same relative curve shape under the far-field condition as the sound power level response $L_{\Pi}(f)$ in 15.4, but the absolute level depends on the evaluation distance r_d . The equivalent sound power curve is defined in decibels as

$$L_{ESP}(f) = 10 \log_{10} \left(\frac{\overline{\tilde{p}^2(f)}}{p_0^2} \right) \\ \approx L_{\Pi}(f) - 20 \log_{10} \left(\frac{r_d}{1m} \right) - 11$$

using the squared RMS sound pressure averaged over a sphere of radius r_d as defined in 15.4.2.2. In accordance with Clause 10 and ANSI/CTA-2034, 5.2, the averaging can be approximated by performing an energetic averaging of the SPL FR $L_{FF}(f, \theta, \Phi)$ over the horizontal and vertical trajectory with an angular resolution of 10° using an individual weight in Table 3 for each response according to the portion of the spherical surface that they represent. Redundant points in the poles between the horizontal and vertical trajectories are only taken into account once. So, all in all, 70 points are averaged, as shown in Figure 11.



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Figure 11 – Measurement locations at equivalent sound power

Table 3 – Weights for polar angle θ at 10° Increments

Angle θ	Spherical quadrangle weighting
0°	0,000 604 486
±10°	0,004 730 189
±20°	0,008 955 027
±30°	0,012 387 354
±40°	0,014 989 611
±50°	0,016 868 154
±60°	0,018 165 962
±70°	0,019 006 744
±80°	0,019 477 787
±90°	0,019 629 373
±100°	0,019 477 787
±110°	0,019 006 744
±120°	0,018 165 962
±130°	0,016 868 154
±140°	0,014 989 611
±150°	0,012 387 354
±160°	0,008 955 027
±170°	0,004 730 189
±180°	0,000 604 486

NOTE Equivalent sound power requires 70 points of measurement to closely analyze the causes affecting the interaction between the EUT and the room. However, this document defines essential characteristics that can be determined with minimal testing effort. Clause 16 defines acoustical zones in accordance with Clause 17. Large signal characteristics are measured at r_{near} rather than multiple points in accordance with Clause 19.

15.5.3.4 Equivalent sound power directivity index (ESPD)

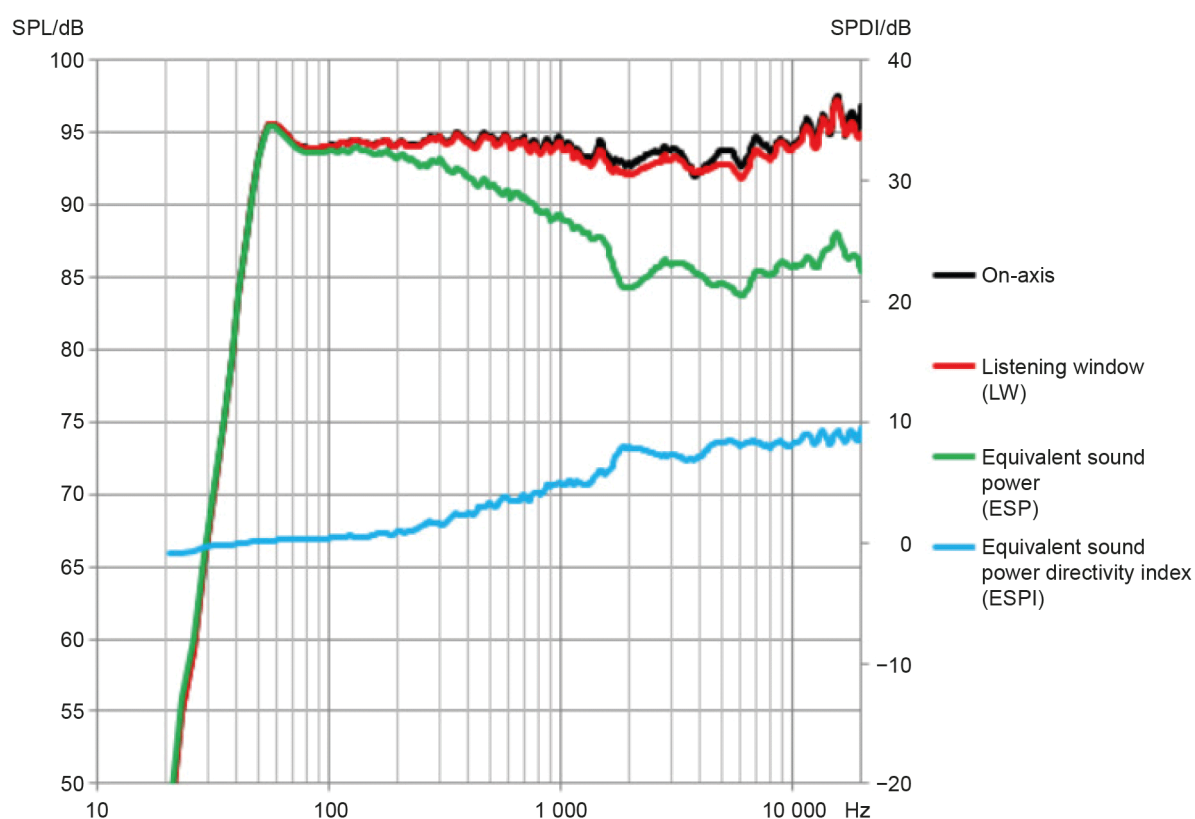
The equivalent sound power directivity index is defined as the difference between the listening window curve and the equivalent sound power curve. An ESPD of 0 dB indicates omnidirectional radiation. The larger the ESPD, the more directional the EUT is in the direction of the reference axis.

NOTE ESPD is defined in ANSI/CTA 2034-A 5.2.

15.5.4 Reporting

Graphical results should conform to one of the preferred aspect ratios in IEC 60263. FR shall be in accordance with 15.5.3.

An example is shown in Figure 12.



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Figure 12 – Example for reporting the directional characteristics measured at distance r_d .

16 In-situ testing

16.1 General

This clause describes the assessment of the EUT under in-situ conditions that do not comply with the ex-situ conditions, such as the anechoic environment in Clause 8, the far-field measurement position in Clause 11, and other normal standard conditions that are required to generate comparable test results. In-situ testing is required to consider the listening environment representing typical customer usage, which reduces the test effort (e.g., number of measurement points) and simplifies the test effort during product development, production

and service. The results of in-situ testing shall be repeatable and reproducible, which depends on the following influences:

- acoustical properties of the in-situ environment (e.g. room, furniture) in the target environment defined in 8.4;
- positioning of the microphone to represent the typical listening position of a customer, which is defined in Clause 17;
- mounting of the EUT defined in Clause 12;
- positioning of the EUT defined in Clause 10.

The manufacturer shall report the results of the test with information on the particular in-situ test conditions.

Subclauses 16.2 to 16.5 describe the acoustical modelling of the sound reproduction under in-situ conditions, the practical measurement, and the numerical prediction of the transfer functions and the SPL responses.

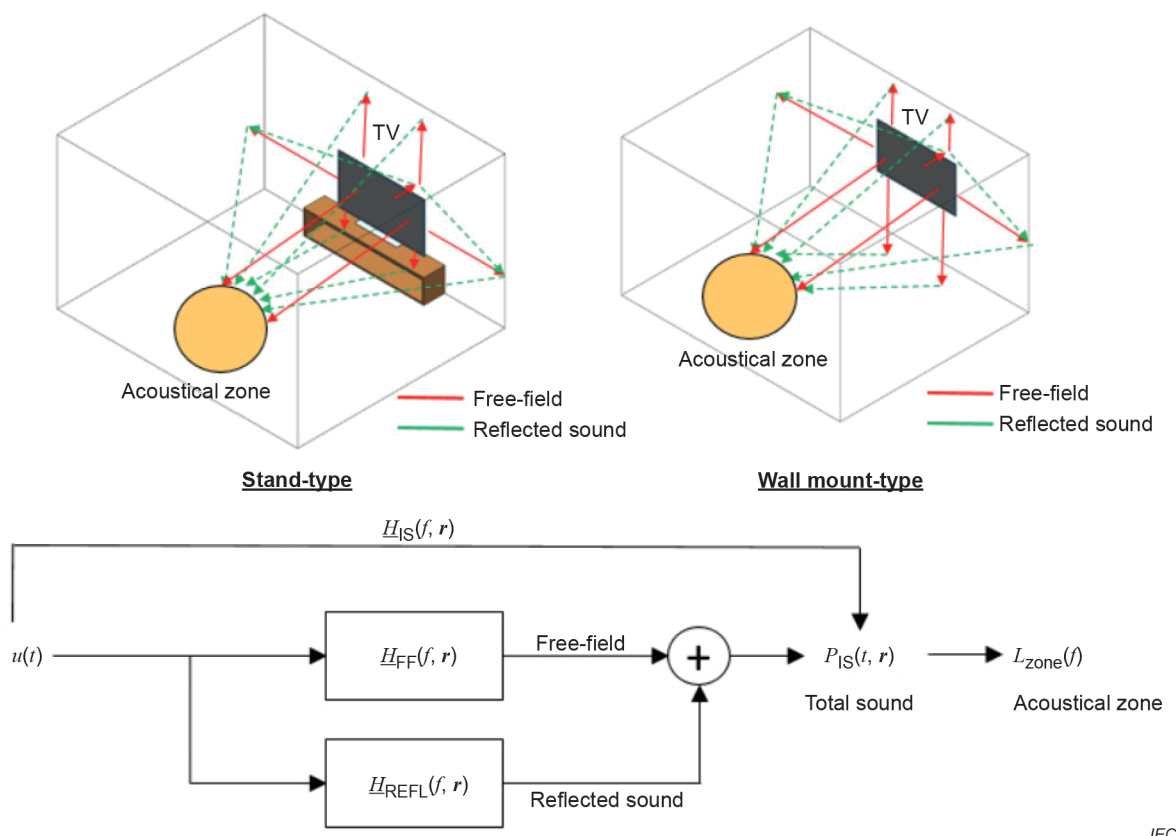
16.2 In-situ transfer function

16.2.1 Definition

The in-situ transfer function $\underline{H}_{IS}(f, \mathbf{r})$ is defined as the complex transfer function between the input signal $u(t)$ of the EUT and the sound pressure $p(t, \mathbf{r})$ at any point $\mathbf{r}$ in the sound field considering the positioning of the EUT and the acoustical influence of furniture, the room and other boundaries in the target application. The in-situ transfer function is modelled as

$$H_{IS}(f, \mathbf{r}) = H_{FF}(f, \mathbf{r}) + H_{REFL}(f, \mathbf{r})$$

which is the sum of the spatial transfer function $\underline{H}_{FF}(f, \mathbf{r})$ representing the direct sound radiated from the EUT under free-field conditions as defined in 15.3 and a reflected sound transfer function $\underline{H}_{REFL}(f, \mathbf{r})$ representing the interaction of the radiation properties of the EUT with the acoustical environment, as shown in Figure 13.



IEC

Figure 13 – Modelling the sound reproduction under in-situ conditions

16.2.2 Measurement method

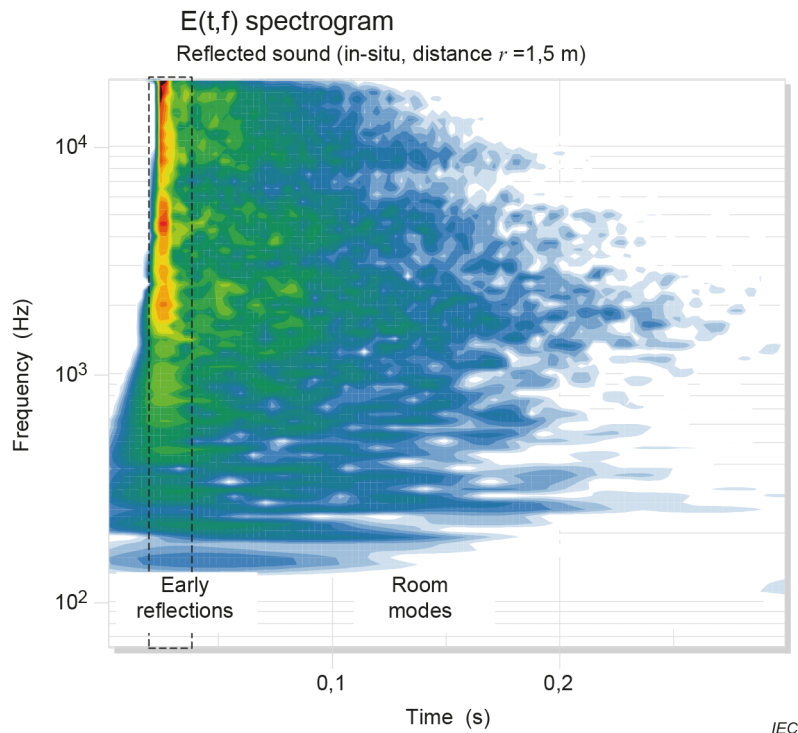
The in-situ transfer functions $\underline{H}_{IS}(f, r)$ shall be measured by using a sinusoidal chirp stimulus $u(t)$ exciting the EUT in a stated frequency range and by measuring the sound pressure signal $p_{IS}(t, r)$ under the steady-state condition at position point r under in-situ conditions.

The spatial transfer function $\underline{H}_{FF}(f, r)$ shall be measured by using a holographic measurement technique based on near-field scanning in accordance with 15.3 to provide accurate data at the point r .

The sound reflection transfer function $\underline{H}_{REFL}(f, r)$ shall be calculated as

$$\underline{H}_{REFL}(f, r) = \underline{H}_{IS}(f, r) - \underline{H}_{FF}(f, r)$$

The sound reflection impulse response $h_{REFL}(t, r) = FT^{-1}\{\underline{H}_{REFL}(f, r)\}$ shall be calculated as the inverse Fourier transform of the transfer functions $\underline{H}_{REFL}(f, r)$ time-frequency analysis (TFA of the impulse response reveals the spectral energy over time). The direct sound and the early room reflections decay with a steep slope while the room modes generate an exponential decay at later times according to the reverberation time $T_{60}(f)$ in the room, as shown in Figure 14.



NOTE The spectrogram of the reflected sound impulse response $h_{\text{REFL}}(t, \mathbf{r})$ reveals the early reflections generated by the table, ground floor, ceiling, and walls and the reverberant sound generated by the room modes.

Figure 14 – Example of time-frequency analysis (spectrogram) applied to reflected sound impulse response $h_{\text{REFL}}(t, \mathbf{r})$ measured at a distance $r = 1,5$ m from the EUT in an office room

16.2.3 Reporting

The transfer functions $\underline{H}_{\text{IS}}(f, \mathbf{r})$, $\underline{H}_{\text{FF}}(f, \mathbf{r})$ and $\underline{H}_{\text{REFL}}(f, \mathbf{r})$ of the total in-situ sound, the direct and reflected sound components, respectively, shall be reported together with the position of the listening point $\mathbf{r}$, reference point $\mathbf{r}_{\text{ref}}$, normal vector $\mathbf{n}_{\text{ref}}$, and the orientation vector $\mathbf{O}_{\text{ref}}$ of the EUT.

16.3 Room transfer function

16.3.1 Definition

The room transfer function $\underline{H}_{\text{R}}(f, \mathbf{r})$ describes the relationship between the sound power radiated by the EUT and the sound pressure at point $\mathbf{r}$ in the target application. The room gain $G_{\text{R}}(f, \mathbf{r})$ is the magnitude of the room transfer function $\underline{H}_{\text{R}}(f, \mathbf{r})$ normalized and expressed in decibels.

16.3.2 Measurement method

- The sound reflection transfer function $\underline{H}_{\text{REFL}}(f, \mathbf{r})$ shall be measured in accordance with 16.2.2.
- The sound power response $\Pi(f)$ shall be measured in accordance with 15.4.
- The room transfer function $\underline{H}_{\text{R}}(f, \mathbf{r})$ shall be calculated as

$$\underline{H}_{\text{R}}(f, \mathbf{r}) = \frac{\underline{H}_{\text{REFL}}(f, \mathbf{r}) \tilde{u}(f)}{\sqrt{\Pi(f) |\tilde{u}(f)|}}$$

d) The room gain shall be expressed in decibels as

$$G_R(f, \mathbf{r}) = 20 \log_{10} \left(\left| \underline{H}_R(f, \mathbf{r}) \right| \frac{\sqrt{\Pi_0}}{p_0} \right)$$

using the reference power $\Pi_0 = 10^{-12}$ W and the standard reference sound pressure p_0 .

NOTE The room gain $G_R(f, \mathbf{r})$ describes essential properties of the room and early reflections on other boundaries (e.g., table).

16.4 Reflected sound SPL response

16.4.1 Definition

The SPL response $\underline{L}_{\text{REFL}}(f, \mathbf{r})$ of the reflected sound is defined in decibels as

$$\underline{L}_{\text{REFL}}(f, \mathbf{r}) = 20 \log_{10} \left(\frac{\tilde{u}(f) |\underline{H}_{\text{REFL}}(f, \mathbf{r})|}{p_0} \right)$$

using RMS value of the stimulus supplied to the EUT, reference sound pressure p_0 , and sound reflection transfer function $\underline{H}_{\text{REFL}}(f, \mathbf{r})$ in 16.2.

16.4.2 Measurement method

16.4.2.1 General

The reflected sound SPL response $\underline{L}_{\text{REFL}}(f, \mathbf{r})$ shall be determined by one of the following methods:

16.4.2.2 Calculation based on sound pressure measurements

- The reflected sound SPL FR shall be calculated based on the sound reflection transfer function $\underline{H}_{\text{REFL}}(f, \mathbf{r})$ measured in accordance with 16.2.2.
- The room gain shall be calculated as

$$G_R(f, \mathbf{r}) = \underline{L}_{\text{REFL}}(f, \mathbf{r}) - L_{II}(f)$$

- A mean room gain $\bar{G}_R(f, \mathbf{r})$ should be determined by averaging the $G_R(f, \mathbf{r})$ measured on multiple EUTs under identical setup conditions (room, positioning of the EUT, measurement point $\mathbf{r}$).

16.4.2.3 Prediction based on room modelling

- The coefficients $C_{FF}(f)$ of the spherical wave expansion representing the direct sound radiated by EUT shall be measured by using a near field measurement in accordance with 15.3.2.
- The sound power level response $L_{II}(f)$ of the EUT shall be calculated based on the coefficients $C_{FF}(f)$ of the spherical wave expansion in accordance with 15.4 or approximated in decibels by

$$L_{II}(f) \approx L_{\text{ESP}}(f, r_d) + 20 \lg \left(\frac{r_d}{1m} \right) + 11$$

using the equivalent sound power level $L_{\text{ESP}}(f, r_d)$ defined in 15.5.3.3.

- c) The reverberation time $T_{60}(f)$ in the room shall be determined in accordance with 16.2.
- d) The mean room gain can be calculated by assuming a diffuse sound field in accordance with IEC 60268-21:2018, 20.3.4.2 in decibels as

$$\bar{G}_R(f, r) \approx 10 \lg \left(\frac{T_{60}(f)}{1} \right) - 10 \lg \left(\frac{V}{1} \right) + 14$$

considering the volume V of the room in cubic metres.

NOTE The diffuse sound field approximation does not consider early sound reflections from boundaries close to the EUT (e.g. the EUT is placed on a table or mounted at the wall).

- e) The reflected sound SPL response $L_{\text{REFL}}(f, r)$ at any point r in the room shall be calculated in decibel as:

$$L_{\text{REFL}}(f, r) \approx L_{\text{II}}(f) + \bar{G}_R(f, r)$$

using the sound power level response $L_{\text{II}}(f)$ and the mean room gain $\bar{G}_R(f, r)$ approximated by the diffuse field assumption or measured in accordance with 16.4.2.2.

16.4.3 Reporting

The reflected sound SPL FR $L_{\text{REFL}}(f, r)$ can be smoothed by spectral averaging with a defined relative bandwidth (typically 1/3rd octave) and shall be plotted versus a logarithmic frequency axis. The $L_{\text{REFL}}(f, r)$ shall be reported together with information about the method applied.

16.5 In-situ SPL FR

16.5.1 Definition

The in-situ SPL FR in decibels is defined as

$$L_{\text{IS}}(f, r) = 20 \lg_{10} \left(\frac{\tilde{u}(f) |H_{\text{IS}}(f, r)|}{p_0} \right)$$

using the transfer functions $H_{\text{IS}}(f, r)$ defined at point r , reference sound pressure p_0 , and the RMS value $\tilde{u}(f)$ of the sinusoidal chirp signal.

16.5.2 Measurement methods

16.5.2.1 General

The in-situ SPL FR $L_{\text{IS}}(f, r)$ shall be determined by the method of 16.5.2.2 or the method of 16.5.2.3.

16.5.2.2 Sound pressure measurement

The in-situ SPL FR shall be calculated based on the definition in 16.5.1 using the transfer function $H_{\text{IS}}(f, r)$ measured at point r in accordance with 16.2.2.

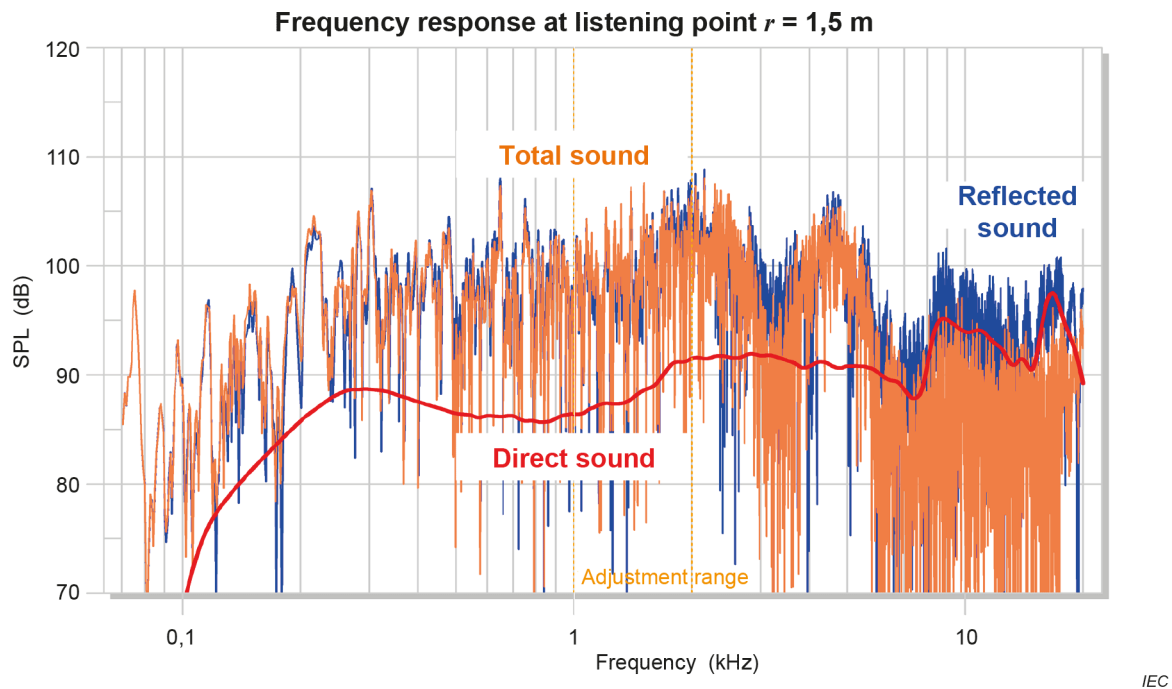
16.5.2.3 Prediction based on room modelling

- The coefficients $C_{FF}(f)$ of the spherical wave expansion representing the direct sound radiated by EUT shall be measured by using a near-field measurement in accordance with 15.3.2.
- The SPL FR $L_{FF}(f, r)$ of the direct sound shall be calculated at the point r based on the spatial transfer function in 15.3.
- The SPL response $L_{REFL}(f, r)$ of the sound reflections shall be determined in accordance with 16.4.2.3.
- The in-situ SPL FR $L_{IS}(f, r)$ shall be calculated as:

$$L_{IS}(f, r) = 10 \log_{10} \left(10^{L_{FF}(f, r)/10} + 10^{L_{REFL}(f, r)/10} \right)$$

16.5.3 Reporting

The in-situ SPL FR $L_{IS}(f, r)$ can be smoothed by spectral averaging with a defined relative bandwidth (typically 1/3rd octave) and shall be plotted versus logarithmic frequency axis. The FRs of the free-field sound $L_{FF}(f, r)$ and the reflected sound $L_{REFL}(f, r)$ shall be reported in the same plotting style as the in-situ SPL FR $L_{IS}(f, r)$ to reveal the dominant signal component, as shown in Figure 15.



NOTE The SPL FR of the total in-situ sound, free-field, and reflected components reveal essential information about the speaker-room interactions in the target application. The FR of the reflected sound in the example shown exceeds the direct sound by more than 10 dB and generates high variations in the total in-situ SPL response versus frequency.

Figure 15 – SPL FR of the in-situ condition.

The Direct Energy Fraction (DEF) defined by Thompson [14] should be calculated in decibels as

$$L_{DEF}(f, r) = L_{FF}(f, r) - L_{IS}(f, r)$$

using the free-field and in-situ SPL FR at the point $\mathbf{r}$. The data shall be reported with information about the properties of the room, such as size and reverberation time $T_{60}(f)$ and the positioning of the EUT.

It is strongly recommended to calculate the weighted mean value and variance of the in-situ SPL FR $L_{IS}(f, \mathbf{r})$ in an acoustical zone as defined in Clause 17.

17 Mean SPL in an acoustical zone

17.1 General

The larger screen sizes of modern TVs and monitors allow operating EUT in larger rooms, generating new user expectations for a wider listening area with good audio performance. The increased complexity of the direct sound field and the interaction with room, furniture, and other acoustical boundaries generates significant SPL variations at points $\mathbf{r}_n$ within the listening area. The active control of the 3D sound field, especially the reproduction of different audio content by contrast control in multiple zones, requires simple metrics describing sound distribution quality.

The weighted mean sound pressure level shall be calculated by weighting the SPL at multiple measurement points $\mathbf{r}_n$ with $n = 1, \dots, N$ representing an acoustical zone under free field or in-situ conditions. The manufacturer shall state the coordinates of the acoustical zone, the number of points and a weighting function, and whether the measurement environment is a free-field or in-situ environment.

NOTE The directional characteristics in 15.5 are calculated as the weighted sum of the energy assumptions (adding squared sound pressure values) to describe the different signal paths where the sound travels to the human ear. However, the weighted mean value within the acoustical zone is calculated as the weighting of the SPL (without adding squared sound pressure values) to describe the likely distribution of listeners in the zone.

17.2 Definition

The acoustical zone is defined as a 2D or 3D region in the nearfield or far-field of the EUT under free-field conditions or in a room that represents the typical application of the EUT.

The weighted mean sound pressure level in an acoustical zone expressed in decibels is defined in agreement with IEC 62777 and IEC 60268-21 as

$$L_{\text{zone}}(f) = \frac{1}{\sum_{n=1}^N w(f, \mathbf{r}_n)} \sum_{n=1}^N w(f, \mathbf{r}_n) L(f, \mathbf{r}_n)$$

where $L(f, \mathbf{r}_n)$ represents direct sound SPL FR $L_{FF}(f, \mathbf{r}_n)$ under free field condition in 15.3.3 or the in-situ SPL FR $L_{IS}(f, \mathbf{r}_n)$ in 16.5.

NOTE 1 If the acoustical zone is close to the EUT where the reflected sound is much smaller than the total sound, then the direct sound $L_{FF}(f, \mathbf{r}_n)$ can be used for calculating $L_{\text{zone}}(f)$.

The weighting function $w(f, \mathbf{r}_n)$ describes the likelihood of a human ear being placed at a particular point $\mathbf{r}_n$ in the acoustical zone and determines the expectation value of the SPL for random ear position.

NOTE 2 Using a rectangular weighting function $w(f, \mathbf{r}_n)$ that is constant inside and null outside the acoustical zone, then $L_{\text{zone}}(f)$ is the mean value of the SPL responses in decibel in the zone.

The biased weighted variance of the sound pressure level in an acoustical zone expressed in decibels is defined as

$$\sigma_{\text{zone}}^2(f) = \frac{1}{\sum_{n=1}^N w(f, \mathbf{r}_n)} \sum_{n=1}^N w(f, \mathbf{r}_n) (L(f, \mathbf{r}_n) - L_{\text{zone}}(f))^2$$

17.3 Measurement

- The in-situ SPL FR $L_{\text{IS}}(f, \mathbf{r}_n)$ or direct sound SPL FR $L_{\text{FF}}(f, \mathbf{r}_n)$ under free-field condition shall be measured in accordance with 16.2.2.
- The weighted mean SPL $L_{\text{zone}}(f)$ and weighted variance $\sigma_{\text{zone}}^2(f)$ shall be calculated in the acoustical zone defined in 17.2.

17.4 Numerical prediction

In order to minimize the measurement effort for providing the SPL FR $L(f, \mathbf{r}_n)$ at points $\mathbf{r}_n$ with sufficient spatial resolution in the acoustical zone, the following method shall be used:

- The SPL FR $L_{\text{FF}}(f, \mathbf{r}_n)$ under free-field conditions at all points in the acoustical zone shall be determined at points $\mathbf{r}_n$ based on the spatial transfer function in 15.3.3.

NOTE If all points $\mathbf{r}_n$ in the acoustical zone are in the far-field of the EUT, extrapolation of the directional characteristics in section to the point $\mathbf{r}_n$ based on the $1/r$ law can be used to calculate the SPL FR $L_{\text{FF}}(f, \mathbf{r}_n)$. The coefficients $C_{\text{FF}}(f)$ of the spherical wave expansion provide the SPL FR $L_{\text{FF}}(f, \mathbf{r}_n)$ at all points in the near and far-field of the EUT.

- The sound power level response $L_{\Pi}(f)$ of the EUT shall be calculated based on the equivalent sound power in 16.4.2.3 or by using the coefficients $C_{\text{FF}}(f)$ of the spherical wave expansion in accordance with 15.4.
- The in-situ SPL FR $L_{\text{IS}}(f, \mathbf{r})$ at all points $\mathbf{r}_n$ in the acoustical zone shall be calculated in accordance with 16.5.2.3.
- The weighted mean SPL $L_{\text{zone}}(f)$ and weighted variance $\sigma_{\text{zone}}^2(f)$ shall be calculated in the acoustical zone defined in 17.2.

17.5 Reporting

The weighted mean SPL of the acoustical zone shall be plotted in decibel versus a logarithmic frequency axis. The geometrical shape of the acoustical zone, the relationship to the EUT and room boundaries, and the position of the points $\mathbf{r}_n$ shall be reported.

18 FR characteristics

18.1 General

The FR characteristics shall extract essential physical information from the FR that is important for quality assessment of the EUT, benchmarking of products, and simplifying the interpretation. The characteristics defined in this clause shall be marked with an index XX, representing the selected FR $L_{\text{XX}}(f)$ under free-field conditions:

- the listening window $L_{\text{LW}}(f)$ for SPL FR in 15.5.3.2;
- sound power level response $L_{\Pi}(f)$ in 15.4 or equivalent sound power FR $L_{\text{ESP}}(f)$ in 15.5.3.3;

- equivalent sound power directivity index $L_{\text{ESPD}}(f)$ in 15.5.3.4 or under in-situ conditions;
- weighted mean SPL FR $L_{\text{zone}}(f)$ based on the in-situ SPL FR $L_{\text{IS}}(f, \mathbf{r})$ in an acoustical zone under typical application conditions (e.g. room).

The selected FRs shall have high importance for the quality assessment of the EUT.

18.2 Mean value of SPL in a rated frequency range

18.2.1 Definition and unit

This item defines the mean SPL value in the RFR in accordance with 60268-21. Unit: dB (decibel)

18.2.2 Setup

- Conditions shall be in accordance with Clause 6.
- The test signal shall be in accordance with Clause 7.
- The acoustical environment shall be in accordance with Clause 8.
- Positioning of EUT shall be in accordance with Clause 10.
- Measurement of the distance between the EUT and the microphone shall be in accordance with Clause 11.

18.2.3 Procedure

- Mounting of EUT shall be in accordance with Clause 12.
- Designate the measurement voltage and apply the signal.
- The evaluation point and distance shall be calculated in accordance with Clause 14.
- Measure the SPL FR $L_{\text{FF}}(f, \theta, \Phi)$ in accordance with 15.3.3.
- Calculate the FR $L_{\text{XX}}(f)$ of the EUT by applying smoothing with 1/3rd octave filter to the selected FR in 18.1 as shown in Figure 16.

NOTE An EUT with a large radiating surface can generate a complex directivity pattern that cannot be represented by on-axis SPL FR measured at a single point. The SPL FR representing the listening window in 15.5.3.2 or the mean SPL value averaged over the listening zone in Clause 17 is used for assessing the spectral properties of the direct sound radiated by the EUT

- Define the RFR in accordance with 6.3.

18.2.4 Analysis

The L_{mean} is derived from the mean sound-pressure value $\tilde{p}_{\text{mean}}$ in the rated frequency range

$$\tilde{p}_{\text{mean}} = \left[\frac{1}{K} \sum_{k=1}^K (\tilde{p}_k)^2 \right]^{1/2} = \left[\frac{1}{K} \sum_{k=1}^K 10^{L_{\text{XX}}(f_k)/10} \right]^{1/2}$$

where frequency f_k is logarithmically spaced, and $k = 1$ represents the first value in the RFR. L_{mean} is determined by the formula

$$L_{\text{mean}} = 20 \log_{10} \left(\frac{\tilde{p}_{\text{mean}}}{p_0} \right)$$

and shall be expressed in decibels relative to the standard reference sound-pressure $p_0 = 20 \mu\text{Pa}$.