BS EN 60318-1:2009

BSI Standards Publication

Electroacoustics — Simulators of human head and ear

Part 1: Ear simulator for the measurement of supra-aural and circumaural earphones

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National foreword

This British Standard is the UK implementation of EN 60318-1:2009. It is identical to IEC 60318-1:2009. It supersedes BS EN 60318-1:1998 and BS EN 60318-2:1998, which are withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EPL/29, Electroacoustics.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Compliance with a British Standard cannot confer immunity from legal obligations.

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English version

Electroacoustics - Simulators of human head and ear - Part 1: Ear simulator for the measurement of supra-aural and circumaural earphones (IEC 60318-1:2009)

Electroacoustique -
Simulateurs de tête et d'oreille humaines -
Partie 1: Simulateur d'oreille
pour la mesure des écouteurs
supra-auraux et circumauraux
(CEI 60318-1:2009)

Akustik -
Simulatoren des menschlichen Kopfes
und Ohres -
Teil 1: Ohrsimulator zur Kalibrierung
von supra-auralen und circumauralen
Kopfhörern
(IEC 60318-1:2009)

This European Standard was approved by CENELEC on 2009-11-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: Avenue Marnix 17, B - 1000 Brussels

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Foreword

The text of document 29/683/FDIS, future edition 2 of IEC 60318-1, prepared by IEC TC 29, Electroacoustics, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60318-1 on 2009-11-01.

This European Standard supersedes EN 60318-1:1998 and EN 60318-2:1998.

This European Standard includes the following significant technical changes with respect to EN 60318-1:1998:

– an extension of the frequency range to 16 kHz;

– a revised specification for the acoustical transfer impedance, including tolerances;

– a method for measuring the acoustical transfer impedance;

– expanded measurement uncertainties.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2010-08-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2012-11-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60318-1:2009 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 61094-1	NOTE	Harmonized as EN 61094-1:2000 (not modified).
IEC 61094-2	NOTE	Harmonized as EN 61094-2:2009 (not modified).
IEC 61094-6	NOTE	Harmonized as EN 61094-6:2005 (not modified).
ISO 389-1	NOTE	Harmonized as EN ISO 389-1:2000 (not modified).
ISO 389-5	NOTE	Harmonized as EN ISO 389-5:2005 (not modified).
ISO 389-8	NOTE	Harmonized as EN ISO 389-8:2004 (not modified).

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 61094-4	-[1)]	Measurement microphones - Part 4: Specifications for working standard microphones	EN 61094-4	1995 [2)]
ISO/IEC Guide 98-3	-[1)]	Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)	-	-

1) Undated reference.
2) Valid edition at date of issue.

CONTENTS

ELECTROACOUSTICS –
SIMULATORS OF HUMAN HEAD AND EAR –

Part 1: Ear simulator for the measurement of supra-aural and circumaural earphones

1 Scope

This part of IEC 60318 specifies an ear simulator for the measurement of supra-aural and circumaural earphones (used for example in audiometry and telephonometry) applied to the ear without acoustical leakage, in the frequency range from 20 Hz to 10 kHz. The same device can be used as an acoustic coupler at additional frequencies up to 16 kHz.

NOTE 1 This device has alternative configurations for supra-aural earphones and different types of circumaural earphones. In practice, the alternative configurations can be realised through the use of adapters where necessary.

NOTE 2 Repeatability for supra-aural and circumaural earphones may get significantly worse above 10 kHz.

2 Normative references

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

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

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM: 1995)*

3 Terms and definitions

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

3.1
ear simulator
device for measuring the acoustic output of sound sources where the sound pressure is measured by a calibrated microphone coupled to the source so that the overall acoustic impedance of the device approximates that of the normal human ear at a given location and in a given frequency band

3.2
acoustic coupler
device for measuring the acoustic output of sound sources where the sound pressure is measured by a calibrated microphone coupled to the source by a cavity of predetermined shape and volume which does not necessarily approximate the acoustical impedance of the normal human ear

3.3
supra-aural earphone
earphone applied externally to the outer ear and intended to rest on the pinna

3.4
circumaural earphone
earphone which encloses the pinna and rests on the surrounding surface of the head

NOTE Contact with the head is normally maintained by compliant cushions. Circumaural earphones may touch but not significantly compress the pinna.

3.5
acoustic impedance
at a specified surface, quotient of the sound pressure by volume velocity through the surface

NOTE Unit: Pa·s·m^{-3}.

3.6
acoustic transfer impedance of the ear simulator
quotient of the sound pressure acting on the diaphragm of the microphone by volume velocity through the planar surface bounded by the upper rim of the ear simulator

NOTE Unit: Pa·s·m^{-3}.

3.7
level of acoustic transfer impedance
ten times the logarithm to the base of ten of the quotient of the absolute value (modulus) of the squared acoustic transfer impedance of the ear simulator by the squared reference acoustic transfer impedance of one pascal second per cubic meter (Pa·s·m^{-3})

NOTE Unit: decibel (dB).

4 Construction

4.1 General

The measurements of supra-aural and circumaural earphones each require the ear simulator to have a different external configuration. Apart from this, the remaining specifications apply to both types of earphone.

For supra-aural earphones the coupling surface of the ear simulator has sloped sides to match the shape of the earphone cushions. For circumaural earphones, a flat coupling surface is specified to suit the variety of earphone designs that may be encountered. Figure 1 shows the ear simulator configuration for supra-aural earphones and Figure 2 shows that for circumaural earphones.

Internally, the ear simulator is composed of three acoustically coupled cavities. The primary cavity is conical in shape and houses the microphone at its lower surface. The key dimensions of the primary cavity and the acoustical compliances of each cavity are specified in Figure 1 (and replicated in Figure 2). The secondary cavities are coupled to the primary cavity by elements having acoustical mass and resistance. The lumped-parameter values of the coupling elements shall be as follows:

M_{a2} = 4,5 × 10^{2} Pa·s^{2}·m^{-3}

M_{a3} = 1,06 × 10^{4} Pa·s^{2}·m^{-3}

R_{a2} = 6,05 × 10^{6} Pa·s·m^{-3}

R_{a3} = 2 × 10^{7} Pa·s·m^{-3}

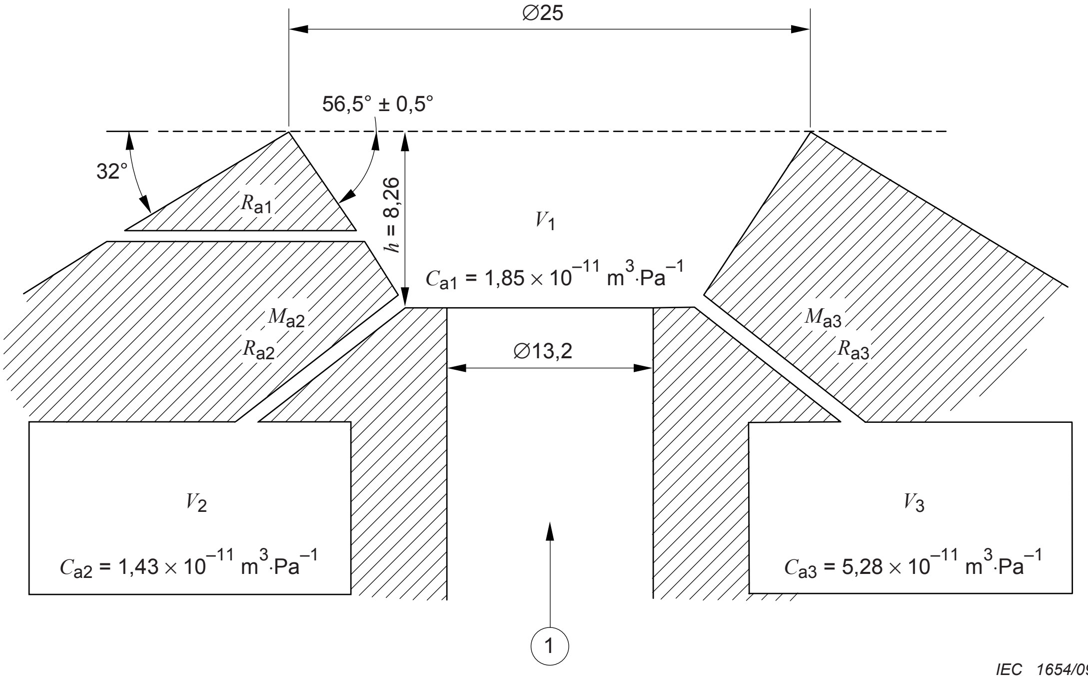
M_{a2} and M_{a3} represent acoustic masses, R_{a2} and R_{a3} represent acoustic resistances. These values are applicable for the reference environment conditions and are subject to the tolerances of 4.2.

A pressure equalization mechanism (R_{a1}) is included.

An electrical analogue of the ear simulator is given in Annex A.

The general construction of the ear simulator and mounting of the microphone shall aim to reduce the response to vibration of any earphone or to sound outside the cavity.

Dimensions in millimeters



Key

1 microphone

NOTE 1 The volume of cavity V_1 includes the total effective volume of the microphone capsule, a corresponding correction for the presence of a protective grid also being taken into account.

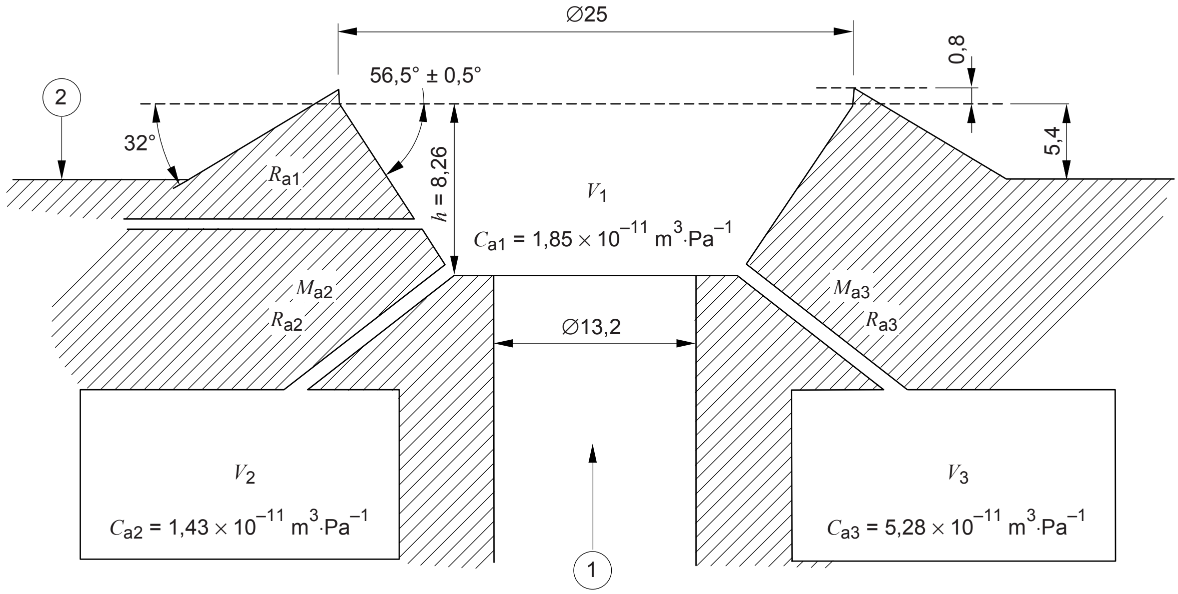
NOTE 2 The acoustical compliance of the cavities may depend on the shape as well as the volume.

NOTE 3 Tolerances on dimensions are specified in 4.2.

Figure 1 – Schematic cross-section of the ear simulator configured for supra-aural earphones

An ear simulator only capable of having the configuration shown in Figure 1, but meeting all other specifications in this standard shall be considered as conforming to this part of IEC 60318 for supra-aural earphones only.

Dimensions in millimeters



Key

1 microphone

2 flat coupling surface

NOTE 1 The external face of the flat surface should be marked with a series of rings concentric with the opening in the ear simulator to aid alignment of the earphone.

NOTE 2 The 0,8 mm lip at the entrance to the ear simulator is an artefact of a typical practical realisation of this configuration, where a flat plate adapter is inserted between the body of the ear simulator and a removable conical ring (see Annex B for details).

NOTE 3 Tolerances on dimensions are specified in 4.2.

Figure 2 – Schematic cross-section of the ear simulator configured for circumaural earphones

The dimensions of the flat coupling surface are not critical, but shall be sized to accommodate the range of circumaural earphones to be measured (together with their headbands. if appropriate), noting that these are often non-circular. A size of approximately 100 mm × 120 mm is appropriate.

An ear simulator only capable of having the configuration shown in Figure 2, but meeting all other specifications in this standard shall be considered as conforming to this part of IEC 60318 for circumaural earphones only.

An example of a design of the ear simulator, including the adapter to convert from supra-aural to circumaural configuration, is shown in Annex B.

4.2 Tolerances

The following specified tolerances are for manufacturing the ear simulator and are not normally subject to checking by a test laboratory. The specified dimensions determine the acoustic transfer impedance of the device, which can be tested for conformance (see 4.7).

The distance h between a plane through the upper rim of the ear simulator and the diaphragm of the microphone shall be 8,26 mm ± 0,30 mm.

Other specified linear dimensions shall have a tolerance of ± 0,3 mm.

The angular dimensions 56,5° shall have a tolerance of ± 0,5°.

The angular dimension 32° shall have a tolerance of $^{+3°}_{-1°}$.

The acoustical compliances, masses and resistances shall each have a tolerance of ± 10 %.

4.3 Static pressure equalization

Any change in the static pressure within the ear simulator caused by assembly of the earphone to the cavity and microphone shall decay toward the static ambient pressure with a time constant less than 1,5 s. If this necessitates the introduction of a controlled leak in the ear simulator, it shall have the following characteristics:

a) it shall not alter the total cavity volume by more than 20 mm^3;
b) it shall attenuate external sound reaching the cavity, with the entrance blocked, by at least 16 dB at 100 Hz, increasing by 6 dB per octave for increasing frequency.

NOTE 1 This specification for the static pressure equalization is equivalent to a value for R_{a1} of nominally 500 × 10^6 Pa·s·m^{-3}.

NOTE 2 Equalization can be realised, for example, by a capillary tube with a diameter of 0,3 mm and a length of 9 mm.

4.4 Calibrated pressure-type microphone

A calibrated microphone is located at the base of cavity V_1. The acoustic impedance of the microphone diaphragm shall be high, so that the equivalent volume is less than 20 mm^3 over the specified range of frequencies.

In the frequency range from 20 Hz to 10 kHz, the overall pressure sensitivity level of the microphone and associated measuring system shall be known with an uncertainty not exceeding 0,2 dB for a level of confidence of 95 %. The microphone shall be coupled to the cavity V_1 with a protective grid and without leakage. The microphone shall conform to the requirements of IEC 61094-4 for a type WS2P microphone.

For measurements above 10 kHz the overall pressure sensitivity level of the microphone and associated measuring system over the specified frequency range shall be known with an uncertainty not exceeding 0,5 dB for a level of confidence of 95 %. Furthermore there shall be no protection grid or other obstruction between the microphone diaphragm and cavity V_1.

The make and model of the microphone shall be specified, together with any adapter used.

NOTE 1 The obstruction caused by the protection grid may cause the sound pressure acting on the microphone diaphragm to be non-uniform.

NOTE 2 A microphone conforming with the requirements of IEC 61094-1 [1][1] for a type LS2aP microphone provides a suitable configuration for use above 10 kHz. For some models of type WS2P microphone the manufacturer supplies an ring to be used in place of the grid, that enables the microphone to be converted to type LS2aP.

4.5 Material

The ear simulator and the adapters shall be made of a material that has no negative influences on its performance. For example it should be acoustically hard and dimensionally stable.

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1 Figures in brackets refer to the bibliography.

4.6 Measurement plane

The plane of the microphone diaphragm shall be understood to represent the entrance of the mean human ear canal, up to 10 kHz. Beyond this frequency, the device can only be considered as an acoustic coupler having no direct relation to the mean human ear canal.

4.7 Acoustic transfer impedance

In the frequency range below 10 kHz, the ear simulator is designed so that its acoustic transfer impedance matches the input impedance of the average human ear under sealed conditions. Under reference environmental conditions, the ear simulator shall couple an applied earphone to the microphone with an acoustic transfer impedance given in Table 1. The tolerance on the frequency specified in Table 1 is 0,1 %.

NOTE 1 The acoustic transfer impedance is specified, because for practical reasons the locations of the earphone and microphone are physically separated within the ear simulator. By modelling the acoustic input impedance of real ears with the acoustic transfer impedance of the ear simulator, the sound pressure measured by the microphone represents the sound pressure applied to the entrance of the ear canal.

NOTE 2 The acoustic impedance of an applied earphone will add in parallel to the specified acoustic transfer impedance, when the earphone is modelled by a source of volume velocity in parallel with the acoustic impedance of the earphone.

NOTE 3 The specification is only given in the frequency range where the device acts as an ear simulator.

Annex C gives details of a method for determining the acoustic transfer impedance. The specified tolerance shall be reduced by an amount equal to the expanded uncertainty of measurement before deciding if a device conforms to this specification.

5 Coupling of earphone to ear simulator

5.1 Supra-aural earphones

Supra-aural earphones shall be measured with the ear simulator having the configuration shown in Figure 1.

The earphone to be measured shall be applied to the ear simulator without acoustic leakage with a force 4,5 N ± 0,5 N, not including the weight of the earphone itself. If, for a specific earphone, a different coupling force is specified this shall be stated.

The earphone shall not rest on the sloping side of the ear simulator, but only on the upper rim.

In the case of earphones with a hard ear cushion, a thin film of sealing material or a thin soft rubber ring shall be used on the lip in order to produce an effective seal between the earphone and the upper edge of the coupler.

5.2 Circumaural earphones

Circumaural earphones shall be measured with the ear simulator having the configuration shown in Figure 2.

The earphone shall be positioned symmetrically. For earphones with an asymmetric cushion the manner of placement on the coupler shall be stated by the manufacturer. The coupling force applied for the calibration shall be stated.

Table 1 – Specification for the acoustic transfer impedance level

Frequency Hz	**Impedance level (ref. 1 Pa·s·m^{-3})** dB	**Tolerance on level** ± dB
100	145,8	1,5
126	144,4	1,5
158	143,2	1,5
200	143,0	1,5
251	143,5	1,5
316	144,1	1,5
398	143,4	1,5
501	141,4	1,5
631	139,0	1,5
750*	137,2	1,5
794	136,6	1,5
1 000	134,4	1,5
1 259	132,5	1,5
1 500*	131,4	1,5
1 585	131,1	1,5
1 995	131,5	1,5
2 512	131,5	1,5
3 000*	130,8	1,5
3 162	130,6	1,5
3 982	128,5	1,5
5 012	126,0	1,5
6 000*	124,0	1,5
6 310	123,6	1,5
7 943	121,1	1,5
9 000*	119,9	1,5
10 000	118,5	1,5

NOTE 1 The values of frequency in Table 1 are calculated from 1 000 × $10^{n/10}$, where n is a positive or negative integer or zero, except those marked * which are used specifically in audiometry.

NOTE 2 Using the measurement method described in Annex C, it is not easy to measure the acoustic transfer impedance level below 100 Hz, due to the effects of an imperfectly sealed measurement configuration. However, the acoustic transfer impedance between 20 Hz and 125 Hz is governed predominantly by the volumetric elements of the ear simulator, and their contribution to the overall acoustic transfer impedance can be validated by the measurements at higher frequencies.

6 Calibration

6.1 Reference environmental conditions

The reference environmental conditions are the following:

– static pressure: 101,325 kPa
– temperature: 23 °C
– relative humidity: 50 %

6.2 Method of calibration

The manufacturer shall describe in an instruction manual a method of calibration for the complete ear simulator, including the microphone, and for determining stability.

The quantity to be measured and the calibration method may vary depending on the intended application.

The calibration shall be performed at the reference environmental conditions with the following tolerances:

– static pressure: ± 3 kPa
– temperature: ± 3 °C
– relative humidity ± 20 %

If it is not possible to meet these requirements, or the application requires other conditions to be used, the actual values shall be stated.

7 Maximum permitted expanded uncertainty of measurements

Table 2 specifies the maximum permitted expanded uncertainty U_{max}, calculated with a coverage factor of k = 2 to give a level of confidence of approximately 95 %, associated with the measurements undertaken in this standard, according to ISO/IEC Guide 98-3. One set of values for U_{max} is given for basic type approval measurements.

The expanded uncertainties of measurements given in Table 2 are the maximum permitted for demonstration of conformance to the requirements of this standard. If the actual expanded uncertainty of a measurement performed by the test laboratory exceeds the maximum permitted value in Table 2, the measurement shall not be used to demonstrate conformance to the requirements of this part of IEC 60318.

Table 2 – Values of U_{max} for basic measurements

Measured quantity	Relevant subclause number	U_{max} (k = 2)
Acoustic impedance lumped parameter	4.1	5 %
Angle	4.1, 4.2, 5.1, 5.2	0,2°
Linear dimensions	4.1, 4.2 , 5.1, 5.2	0,10 mm
Static pressure equalization time constant	4.3	0,1 s
Sound attenuation	4.3	0,1 dB
Microphone equivalent volume	4.4	5 mm^3
Microphone sensitivity level (≤10 kHz)	4.4	0,2 dB
Microphone sensitivity level (>10 kHz)	4.4	0,5 dB
Level of acoustic transfer impedance modulus	4.7	0,5 dB
Frequency	4.7	0,03 %
Ambient pressure	7.2	0,1 kPa
Temperature	7.2	0,5 °C
Relative humidity	7.2	5 %

Annex A
(informative)

Lumped parameter electrical network analogue of the ear simulator

In this analogue, one electrical ohm corresponds to 10^5 Pa·s·m^{-3}.

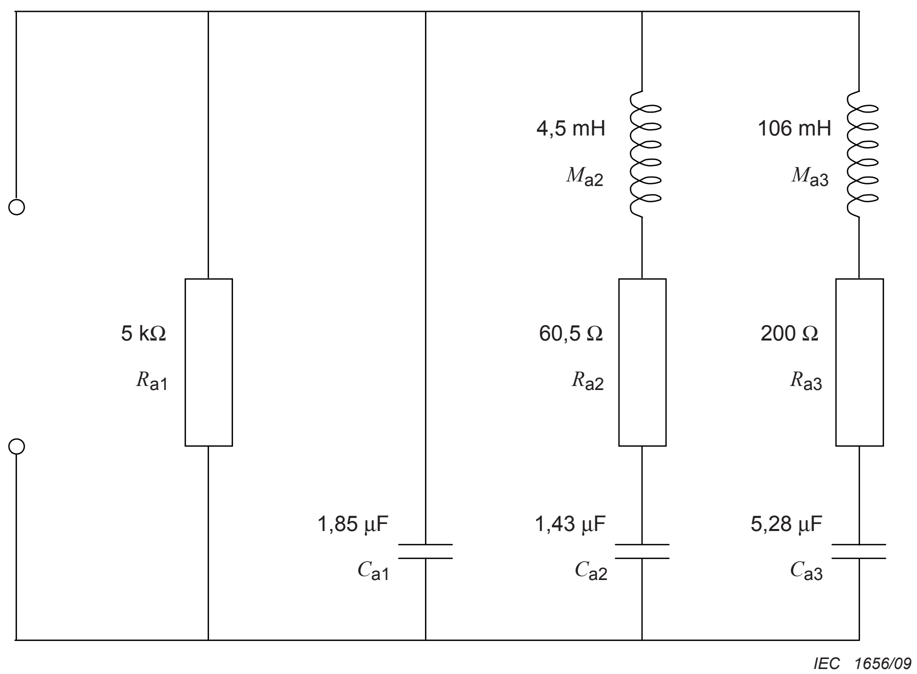


Figure A.1 – Analogue electrical network

A number of independent determinations (see [8], [10], [11]) of the acoustic impedance of the mean human ear under no-leak conditions have been made covering various earphone cushion contours used on audiometric earphones. In each case, an analogue network of the type shown in Figure A.1 was devised with values of the elements adjusted to produce optimum fit to the experimental impedance data. Ear simulators have subsequently been designed and constructed according to these optimised parameters.

The model in Figure A.1 assumes that the sound pressure is spatially uniform in the cavity V_1. It follows that the acoustic transfer impedance between the microphone diaphragm and the plane where the sound source is applied, is constrained in this model to be the same as the acoustic input impedance of the ear simulator. However, the spatial uniformity assumption, and therefore the model overall, has limited validity at frequencies above about 5 kHz.

NOTE 1 The quoted scaling factor produces realistic electrical component values should it be necessary to construct the circuit. However if the response is to be evaluated analytically, the scaling factor is unnecessary and components having the value of the acoustical parameters can be used directly to yield data equivalent with that in Table 1.

NOTE 2 The lumped parameter model is not a precise representation of actual devices. For example the elements corresponding to the acoustical compliances of the cavities can differ from those calculated from the volume of these cavities. Effects such as heat conduction, which depends on the shape as well as the volume, can cause differences.

NOTE 3 The lumped parameter model is a useful tool for designing new models of ear simulators. However, due to its limitations, it cannot be used as the basis for the acoustic transfer impedance specification.

The following Figures A.2 and A.3 show the level of impedance modulus of the electrical analogue network and the phase of the impedance of the electrical analogue network respectively.

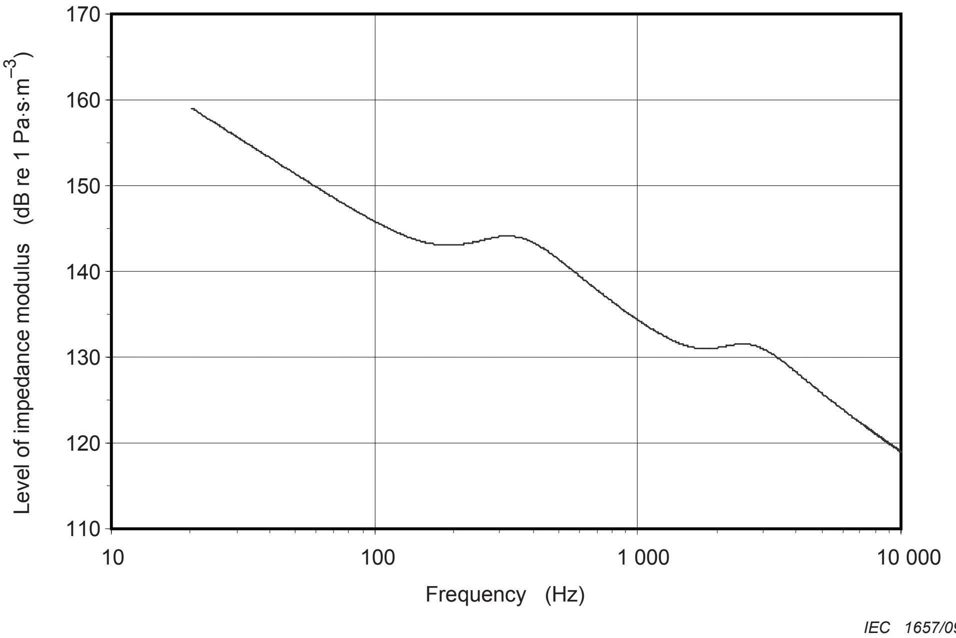


Figure A.2 – Level of impedance modulus of the electrical analogue network

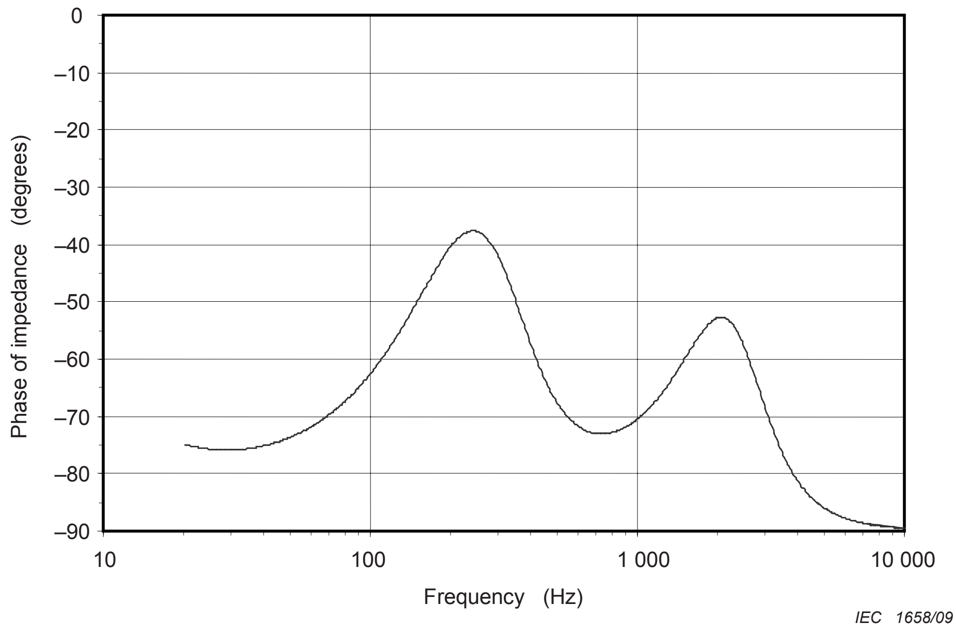


Figure A.3 – Phase of the impedance of the electrical analogue network

Annex B
(informative)

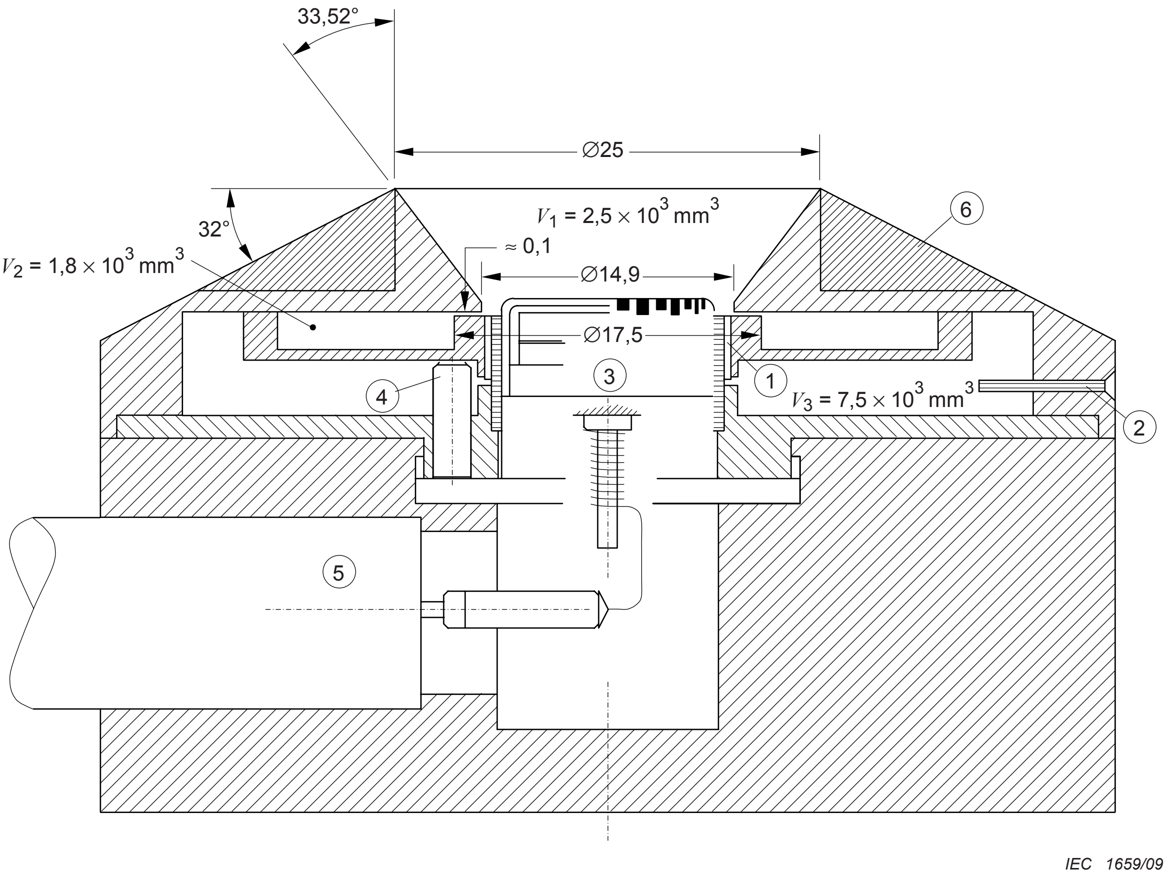
Example of one specific design of ear simulator

B.1 General

Figure B.1 shows an ear simulator design having the basic configuration for the calibration of supra-aural earphones. Adapters are then specified to convert the design to have the external configuration for circumaural earphones.

NOTE The configuration shown in Figure B.1 is the one used in ISO 389-5 [5] and ISO 389-8 [6].

Dimensions in millimeters



Key

1 four holes 0,45 Ø × 3,8 long

2 one hole 0,3 Ø × 9 long

3 microphone

4 three adjustment screws

5 microphone preamplifier

6 removable conical ring

NOTE 1 The three adjusting screws are set so that the corresponding acoustic resistance is $6{,}05 \times 10^6$ Pa·s·m^{-3}.

NOTE 2 At higher frequencies, the configuration of the microphone will not be as shown (see 4.4).

Figure B.1 – Example of one specific design of ear simulator

B.2 Adapter for use with circumaural earphones

The ear simulator should be fitted with an adapter in order to use it with circumaural earphones. The manufacturer of the earphone shall state whether the earphone is compatible with this adapter.

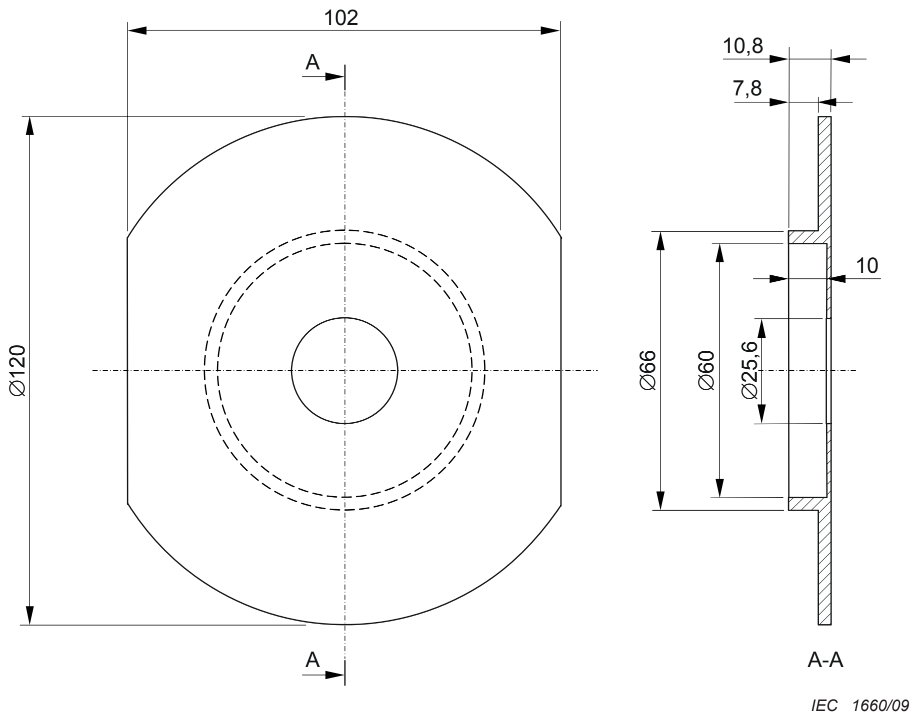
Figure B.2 shows the design of the adapter to convert the configuration shown in Figure B.1.

The adapter is used in conjunction with a conical ring. The design of this ring is shown in Figure B.3.

The tolerance on the linear dimensions and angles specified in Figure B.2 and Figure B.3 are ± 0,3 mm and ± 2° respectively.

The adapter and the conical ring should be made from an acoustically hard, dimensionally stable and non-magnetic material.

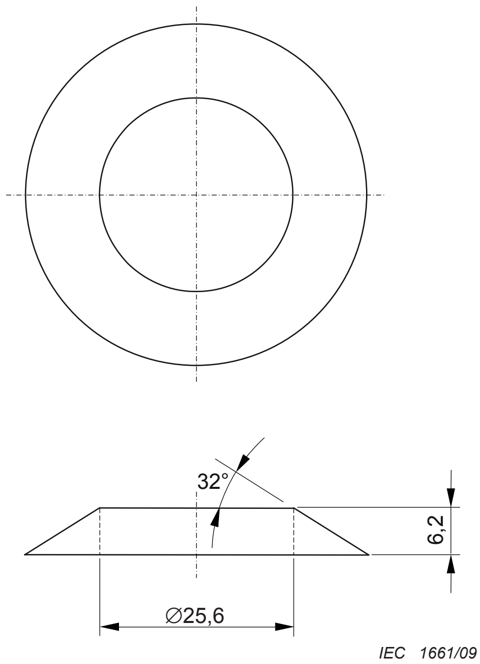
Dimensions in millimeters



NOTE Tolerances on dimensions : ± 0,3 mm.

Figure B.2 – Adapter for use with circumaural earphones

Dimensions in millimeters



NOTE 1 Tolerances on dimensions : ± 0,3 mm.

NOTE 2 Tolerances on angles : ± 2°.

Figure B.3 – Conical ring

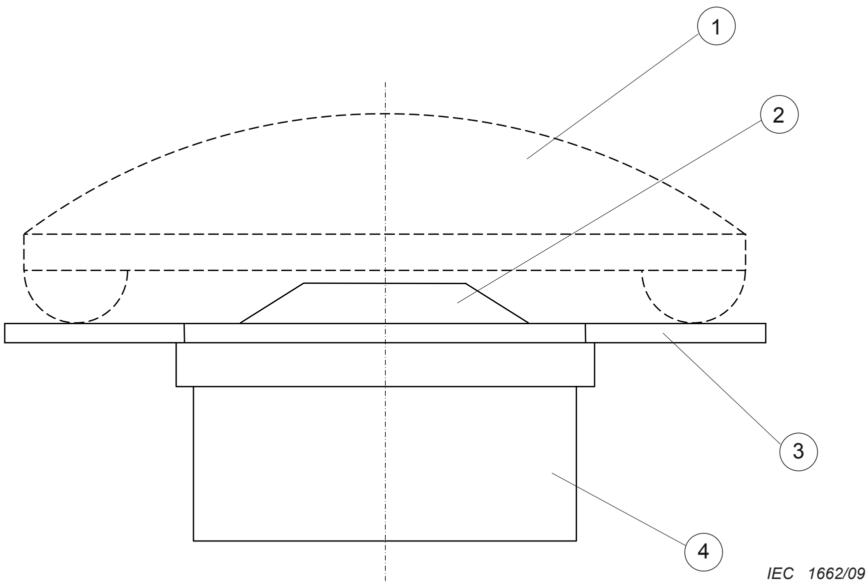
B.3 Configuration using the adapter

For circumaural earphones designed to be calibrated using the adapter, the ear simulator should be adapted in the following manner:

– the conical ring shown in Figure B.1 should be removed from the ear simulator and the adapter fitted in its place, with the flat side uppermost;

– the conical ring should then be placed on top of the adapter as shown in Figure B.4.

Figure B.4 illustrates the final configuration.



Key
1 example of a circumaural earphone
2 conical ring
3 adapter
4 IEC 60318-1 ear simulator

Figure B.4 – Configuration when using the adapter and the conical ring

Annex C
(informative)

Measurement method for the determination of the acoustical transfer impedance of the ear simulator

C.1 Measurement method

Consider an electroacoustic transmitter, coupled acoustically to a remote receiver. For a given volume velocity developed by the transmitter, the pressure resulting at the receiver position is determined by the acoustic transfer impedance coupling the two transducers. For close-coupled transducers, the pressure sensitivity of the transmitter will determine the volume velocity produced for a given electrical current. Similarly, the receiver pressure sensitivity will determine the corresponding output voltage produced.

If both transducers are measurement microphones of known sensitivity, and if they are coupled appropriately by an ear simulator conforming to this standard, the arrangement then provides the basis for determining the acoustic transfer impedance of the ear simulator. Let the transmitter microphone, having a pressure sensitivity M_1, be driven by an electrical current i. If the acoustic transfer impedance of the ear simulator is Z_a, then by the chain of actions noted above, the output voltage U_2 of the receiver microphone system is given by

$$U_2 = M_2 Z_a . M_1 \, i \qquad \text{(C.1)}$$

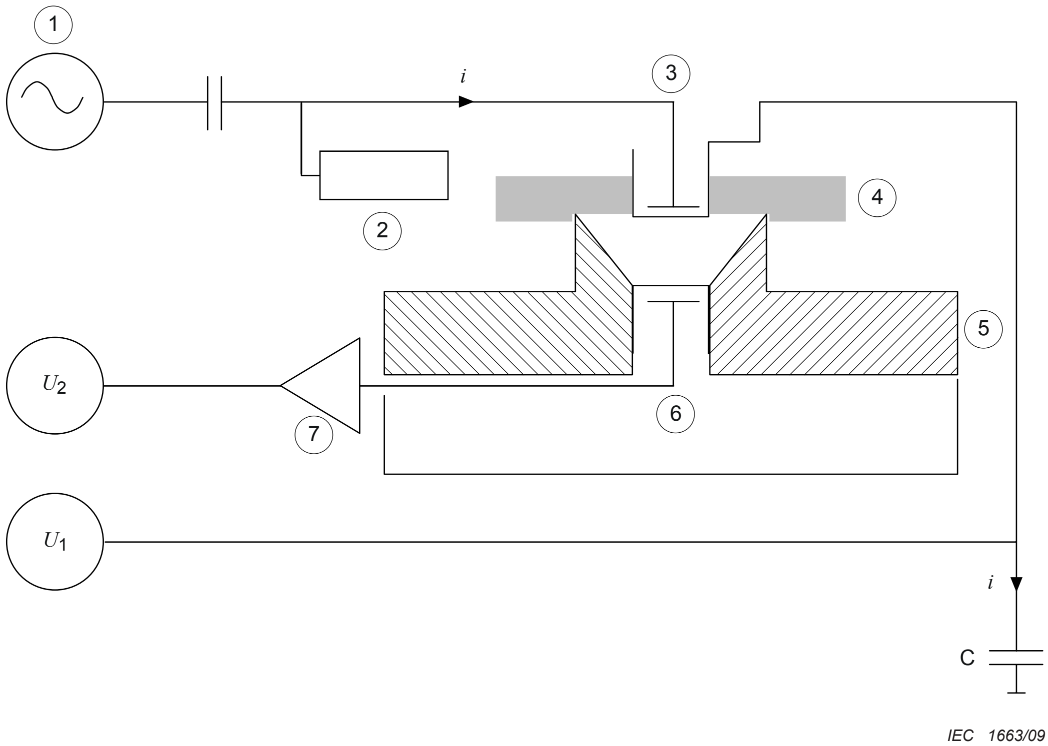
This relationship holds true whether the receiver system is considered to be the microphone capsule or the combination of a microphone, preamplifier and any other elements, provided M_2 corresponds to the pressure sensitivity of the system considered.

In practice the sensitivity of the transmitter microphone is likely to be taken as its response as a receiver, while assuming that this particular device is reciprocal.

Then directly from Equation (C.1):

$$Z_a = \frac{1}{M_1 M_2} \frac{U_2}{i} \qquad \text{(C.2)}$$

Figure C.1 shows a generalized equipment set-up for conducting the necessary measurements to implement Equation (C.2).



Key

1 signal generator
2 microphone power supply
3 transmitter microphone
4 transmitter microphone
5 ear simulator
6 receiver microphone in ear simulator
7 microphone preamplifier and power supply

Figure C.1 – Key elements of measurement system

Here the electric current driving the transmitter microphone is determined by placing a known electric impedance in series with the microphone and measuring the voltage U_1 developed across it. Any type of stable electric impedance element can be used, but a capacitor has the advantage that U_1 remains approximately constant as a function of frequency when a fixed voltage drives the transmitter microphone.

In this case, and referring to Figure C.1, Equation (C.2) becomes

$$Z_a = \frac{1}{M_1 M_2} \frac{U_2}{U_1} \frac{1}{j\omega C} \tag{C.3}$$

where ω is the angular frequency.

The transmitter microphone should be a type WS2P having a nominal pressure sensitivity of approximately 12 mV/Pa, used without any protection grid in place. The microphone should be mounted in a flat plate, such that the microphone diaphragm is flush with the face that couples to the ear simulator. It is recommended that this coupling surface be set in a shallow recess to facilitate reproducible coupling to the upper edge of the ear simulator. The microphone should be placed concentrically in this recess. Figure C.2 shows an adapter suitable for the design of ear simulator given in Annex B.

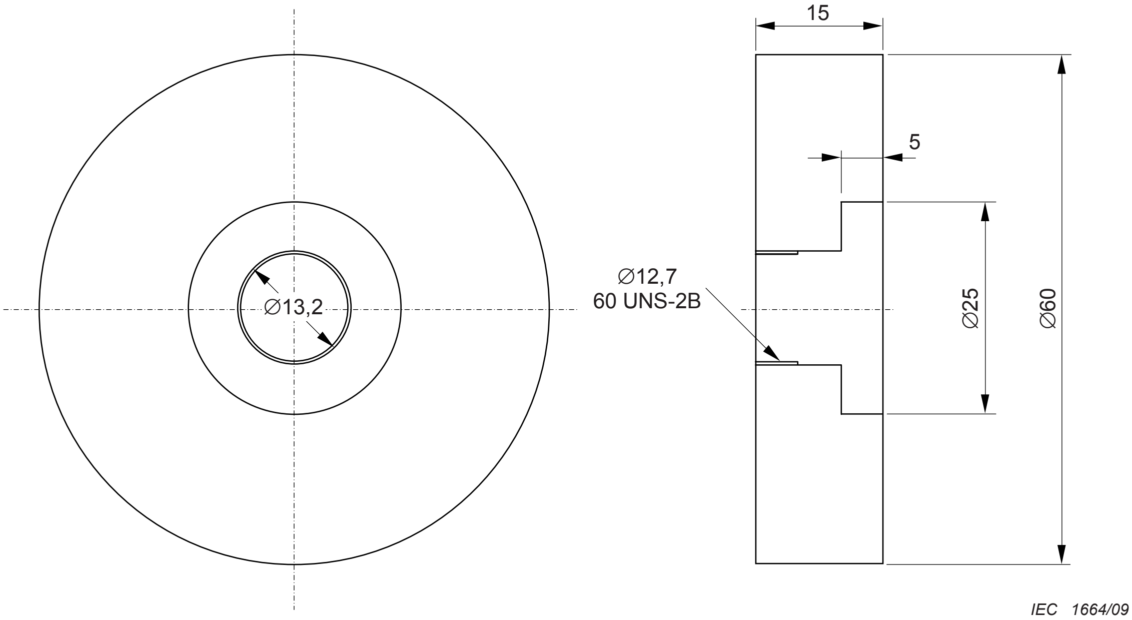


Figure C.2 – Transmitter microphone adapter to couple a transmitter microphone to the ear simulator

The receiver microphone is housed in the ear simulator and should be fitted with its protection grid if the acoustic transfer impedance is to be determined in the frequency range where it is specified (see Table 1). The microphone and its preamplifier can be calibrated as a system. While it is possible to use the devices normally fitted to the ear simulator, they will not necessarily be suitably calibrated. However, it is possible to use an alternative microphone system, calibrated specifically for this purpose, in their place. Acoustical calibration can be considered, but given that the acoustic transfer impedance is likely to be determined at closely spaced frequency intervals, calibration by electrostatic actuator may be preferred for convenience. However, it should be noted that the actuator response only approximates the pressure response of the microphone. Frequency dependent differences of up to 0,3 dB can be expected and should be allowed for in the overall uncertainty budget.

Output signals U_1 and U_2 can be measured conveniently by a two-channel analyser. To reduce the effect of the measuring channel linearity, cross-talk etc. on the measurement uncertainty, it is useful to select the capacitance so that $U_1 \approx U_2$, noting that the variation in the acoustic impedance with frequency, makes this possible only within an order of magnitude. When both microphones are type WS2P with nominal pressure sensitivities of 12 mV/Pa, then a capacitor having a nominal value of 100 nF is optimal.

Given the frequency dependence of the acoustic transfer impedance, it is recommended that measurements be made with a frequency resolution of at least 1/12th-octaves in the frequency range from 125 Hz to 10 kHz. Appropriate test signals include stepped or swept sinusoids. Broadband noise can also be considered but may not produce the required signal-to-noise ratio.

The acoustic transfer impedance is sensitive to atmospheric pressure, which mainly influences the acoustical compliance of the volumes, and to the temperature which has greatest effect on the acoustical mass. The microphones will also have dependencies on the environment parameters. It is therefore recommended that measurements be performed at the reference environment conditions specified in 6.1, or an allowance be made in the measurement uncertainty for any variation.

C.2 Measurement uncertainty

Table C.1 lists components of expanded measurement uncertainty and their typical value. This table is intended to be a guide only and should not be used as a substitute for an uncertainty analysis based on a specific measurement set up.

Table C.1 – Typical components of measurement uncertainty in the measurement of acoustic transfer impedance

Component of uncertainty	U_{typ} (k = 2)
Transmitter microphone sensitivity	0,2 dB
Receiver microphone sensitivity	0,2 dB
Capacitance (or other reference impedance)	1 nF
Linearity of voltage measurement system	0,1 dB
Transmitter microphone equivalent volume	10 mm^3
Polarisation voltages	0,1 V
Temperature – deviation from reference conditions	2 °C
Atmospheric pressure variation - deviation from reference conditions	2 kPa
Cross-talk	0,1 dB
Frequency	0,01 %
Repeatability	0,2 dB
Rounding error	0,01 dB

It is estimated that a determination of the acoustic transfer impedance according to this method can achieve an expanded uncertainty with coverage factor k = 2, of between 0,4 dB and 0,5 dB, depending on the method used to calibrate the microphones and whether measurements can be conducted (or corrected to be) close to the reference atmospheric pressure.

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