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Acoustics — Determination of sound immission from sound sources placed close to the ear —

Part 1: **Technique using a microphone in a real ear (MIRE technique)**

Acoustique — Détermination de l'exposition sonore due à des sources sonores placées à proximité de l'oreille —

Partie 1: Technique du microphone placé dans une oreille réelle (technique MIRE)

Reference number
ISO 11904-1:2002(E)

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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

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

ISO 11904-1 was prepared by Technical Committee ISO/TC 43, *Acoustics*.

ISO 11904 consists of the following parts, under the general title *Acoustics — Determination of sound immission from sound sources placed close to the ear:*

— *Part 1: Technique using a microphone in a real ear (MIRE technique)*

— *Part 2: Technique using a manikin (manikin technique)*

Annexes A and B of this part of ISO 11904 are for information only.

Introduction

ISO 11904 is a series of standards which specify methods for the determination of sound immissions from sources located close to the ear, in which situations the sound pressure level measured at the position of the exposed person (but with the person absent) does not adequately represent the sound exposure.

In order to make it possible to assess the exposure by means of well established criteria, the exposure of the ear is measured and subsequently converted into a corresponding free-field or diffuse-field level. The result is given as free-field related or diffuse-field related equivalent continuous A-weighted sound pressure level, $L_{\text{FF,H,Aeq}}$ or $L_{\text{DF,H,Aeq}}$ when ISO 11904-1 is used, or $L_{\text{FF,M,Aeq}}$ or $L_{\text{DF,M,Aeq}}$ when ISO 11904-2 is used.

ISO 11904-1 describes measurements carried out using miniature or probe microphones inserted in the ears of human subjects (microphone in real ear, MIRE technique). ISO 11904-2 describes measurements carried out using a manikin equipped with ear simulators including microphones (manikin technique).

ISO 11904 may, for instance, be applied to equipment tests and the determination of noise exposure at the workplace where, in the case of exposure from sources close to the ears, the sound pressure level measured at the position of the exposed person (but with the person absent) does not adequately represent the sound exposure. Examples of applications are head- and earphones used to reproduce music or speech, whether at the workplace or during leisure, nailguns used close to the head, and combined exposure from a close-to-ear sound source and an external sound field.

When specific types of equipment are to be tested (e.g. portable cassette players or hearing protectors provided with radio receivers), test signals suitable for this particular type of equipment have to be used. Neither such test signals nor the operating conditions of the equipment are included in ISO 11904 but might be specified in other standards.

When workplace situations are measured, the various noise sources contributing to the immission should be identified. Operating conditions for machinery and equipment used might be specified in other standards.

Both parts of ISO 11904 strive for the same result: a mean value for a population of the free-field or the diffuse-field related level. ISO 11904-1 does this by specifying the mean of measurements on a number of human subjects; ISO 11904-2 does this by using a manikin, which aims at reproducing the acoustical effects of an average human adult. However, the two methods yield different measurement uncertainties which can influence the choice of method. Only the method described in ISO 11904-1 gives results which indicate the variance in a human population. Information on the uncertainties is given in annexes A and B.

When using the MIRE technique for measurement of sound from earphones of insert and stethoscopic types, practical problems can occur with the positioning of microphones in the ear canal. When using the manikin technique, the head- or earphone has to be coupled to the pinna simulator and ear canal extension as far as possible in the way it is coupled to the human ear. In cases where head- or earphones or other objects touch the pinna, a possible deviation in stiffness or shape of the artificial pinna from human pinnae has a significant impact on the result and can even make the results invalid.

An overview of the differences of the two parts of ISO 11904 is given in Table 0.1.

Table 0.1 — Overview of differences between MIRE and manikin techniques

Parameter	ISO 11904-1	ISO 11904-2
Type of method	Microphone in real ear technique	Manikin technique
Limitation of the method	With earphones of insert and stethoscopic type, practical problems can occur with positioning of microphones in the ear canal.	A proper coupling may not always be obtained if the artificial pinna deviates from human pinnae in stiffness or shape. In some cases the exposed person cannot be replaced by a manikin, e.g. if the person has to operate equipment.
Main issues affecting accuracy	— Number of subjects When tabulated values are used for $\Delta L_{FF,H}$ or $\Delta L_{DF,H}$: — calibration of ear canal microphone — accuracy in positioning of microphones in the ear canal When individual values are used for $\Delta L_{FF,H}$ or $\Delta L_{DF,H}$: — quality of reference sound field — stability of sensitivity and frequency response as well as position of ear canal microphone	— Similarity of manikin to human subjects — Calibration of manikin
Frequency range	20 Hz to 16 kHz	20 Hz to 10 kHz

Acoustics — Determination of sound immission from sound sources placed close to the ear —

Part 1: Technique using a microphone in a real ear (MIRE technique)

1 Scope

This part of ISO 11904 specifies basic framework measurement methods for sound immission from sound sources placed close to the ear. These measurements are carried out with miniature or probe microphones inserted in the ear canals of human subjects. The measured values are subsequently converted into corresponding free-field or diffuse-field levels. The results are given as free-field related or diffuse-field related equivalent continuous A-weighted sound pressure levels. The technique is denoted the microphone-in-real-ear technique (MIRE technique).

This part of ISO 11904 is applicable to exposure from sources close to the ear, for example during equipment tests or at the workplace by earphones or hearing protectors with audio communication facilities.

This part of ISO 11904 is applicable in the frequency range from 20 Hz to 16 000 Hz.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 11904. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 11904 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 8253-2:1992, *Acoustics — Audiometric test methods — Part 2: Sound field audiometry with pure tone and narrow-band test signals*

IEC 60065, *Audio, video and similar electronic apparatus — Safety requirements*

IEC 60268-7:1996, *Sound system equipment — Part 7: Headphones and earphones*

IEC 60601-1, *Medical electrical equipment — Part 1: General requirements for safety*

IEC 60942, *Electroacoustics — Sound calibrators*

IEC 61094-1, *Measurement microphones — Part 1: Specifications for laboratory standard microphones*

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

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

GUM:1993[1], *Guide to the expression of uncertainty in measurement.* BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OILM

1) Corrected and reprinted in 1995.

3 Terms and definitions

For the purposes of this part of ISO 11904, the following terms and definitions apply.

3.1
ear canal measurement position
position in the ear canal where the sound pressure is measured

3.2
ear canal sound pressure level
L_{ear}
equivalent continuous sound pressure level measured at the ear canal measurement position

NOTE When measured during exposure to sound under test, it is denoted $L_{ear,exp}$. When optionally measured during exposure to a reference sound field in the determination of the free-field or diffuse-field frequency response according to clause 10, it is denoted $L_{ear,FF}$ or $L_{ear,DF}$, respectively. When measured in one-third-octave frequency bands with nominal midband frequency f these are denoted $L_{ear,exp,f}$, $L_{ear,FF,f}$ and $L_{ear,DF,f}$.

3.3
human free-field frequency response
$\Delta L_{FF,H,f}$
difference, as a function of one-third-octave frequency bands f, between

— the sound pressure level at the ear canal measurement position with the subject exposed to a frontally incident plane sound wave, and

— the sound pressure level of the same sound field with the subject absent

NOTE 1 The free-field frequency response is identical to the amplitude of the head-related transfer function (HRTF) for frontal sound incidence.

NOTE 2 This definition is applicable to individual subjects and groups of subjects.

3.4
human diffuse-field frequency response
$\Delta L_{DF,H,f}$
difference, as a function of one-third-octave-frequency bands f, between

— the sound pressure level at the ear canal measurement position with the subject exposed to a diffuse sound field, and

— the sound pressure level of the same sound field with the subject absent

NOTE This definition is applicable to individual subjects and groups of subjects.

3.5
free-field related sound pressure level
$L_{FF,H}$
sound pressure level of a plane sound wave which will give rise to the measured ear canal sound pressure level $L_{ear,exp}$ when the test subject is exposed to a frontally incident plane sound wave

NOTE The definition may be applied to specific frequencies or frequency bands, weighted or unweighted levels, specific time weightings etc., for instance “free-field related equivalent continuous A-weighted sound pressure level” (free-field related $L_{H,Aeq}$, further abbreviated $L_{FF,H,Aeq}$).

3.6
diffuse-field related sound pressure level
$L_{DF,H}$
sound pressure level of a diffuse sound field which will give rise to the measured ear canal sound pressure level, $L_{ear,exp}$, when the test subject is exposed to a diffuse field

NOTE The definition may be applied to specific frequencies or frequency bands, weighted or unweighted levels, specific time weightings etc., for instance “diffuse-field related equivalent continuous A-weighted sound pressure level” (diffuse-field related $L_{H,Aeq}$, abbreviated to $L_{DF,H,Aeq}$).

3.7
open ear canal
ear canal in which possible foreign objects (such as microphone, supporting elements and electrical leads) occupy less than 5 mm^2 of the cross-sectional area at any position along the ear canal

3.8
blocked ear canal
ear canal in which a foreign body (for instance an earplug) occupies the total cross-sectional area at some position along the ear canal

3.9
partly blocked ear canal
ear canal which is neither fully open nor blocked

4 Measurement principle

Miniature microphones or probe microphones are placed to measure the sound pressure at a position in the ear canal, denoted as the ear canal measurement position. The subject is exposed to the sound source(s) in question, and the ear canal equivalent continuous sound pressure level is measured in one-third-octave frequency bands, $L_{ear,exp,f}$.

Each of the one-third-octave band levels is adjusted with the free-field or diffuse-field frequency response, $\Delta L_{FF,H,f}$ or $\Delta L_{DF,H,f}$, to obtain corresponding free-field related or diffuse-field related one-third-octave band sound pressure levels. These one-third-octave band levels are adjusted using A-weighting constants, and subsequently combined to obtain the free-field related or diffuse-field related equivalent continuous A-weighted sound pressure level, $L_{FF,H,Aeq}$ or $L_{DF,H,Aeq}$.

The measurements may be carried out for one or both ears as appropriate. The free-field or diffuse-field frequency response is taken from clause 9, or determined for each individual subject and ear as described in clause 10.

NOTE The accuracy of the final result depends on a number of parameters (e.g. ear canal measurement position, number of subjects, and whether clause 9 or 10 is used).

5 Instrumentation

5.1 Ear canal microphone

The sound pressure in the ear canal shall be measured by a microphone, which is either

— a miniature microphone placed in the ear canal, or

— a probe microphone consisting of a microphone placed outside the ear and equipped with a probe tube placed in the ear canal; to prevent damage to the ear drum and the skin of the ear canal, the tube shall be made of a soft material.

The pressure response of the miniature or the probe microphone shall be without pronounced resonances, and it shall be known except for the situation described in 10.9. The response shall be checked by comparison with a calibrated pressure-type microphone which is in accordance with IEC 61094-1.

In the area of the concha, the microphone (including supporting elements and electrical leads) shall occupy an area not exceeding 10 mm^2 in any plane.

5.2 Reference field microphone

When individual free-field or diffuse-field frequency responses ($\Delta L_{FF,H}$ or $\Delta L_{DF,H}$) are determined as described in clause 10, a reference field microphone is used to determine the sound pressure level in the reference sound field with the subject absent. This microphone and the connected equipment used shall fulfil the requirements of IEC 61672-1 for a class 1 instrument, and shall have a known free-field or diffuse-field frequency response.

5.3 Check of calibration

The calibration of the microphones and the measuring equipment shall be suitably checked. For the reference field microphone, this shall be done using an acoustic calibrator complying with the requirements for class 1 of IEC 60942.

5.4 Filters

Signals shall be analysed with one-third-octave band filters complying with the requirements for class 1 of IEC 61260.

6 Subjects

Only persons free from inflammation and any other disease of the outer ear and the middle ear are suitable subjects. For measurements in the open ear canal, only persons whose ear canals are not too narrow, flat or severely bent, and who reveal no eardrum defects shall be chosen. If cerumen obstructs the ear canals, it shall be removed. All such required actions shall be carried out by a qualified person.

7 Use of ear canal microphone

7.1 Choice of ear canal measurement position

The ear canal measurement point shall be between the entrance to the canal and the eardrum, or, in the case of a blocked ear canal, between the entrance and the blockage, in either case preferably close to the centre axis of the canal.

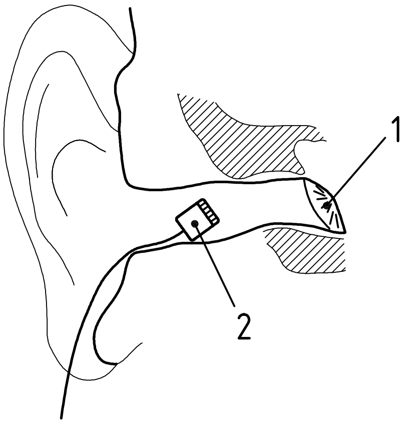
If data from Table 1 are to be used for the free-field or diffuse-field frequency response, only three selected ear canal measurement positions are possible, as stated in clause 9.

For each single subject the ear canal measurement position may be chosen independent of the choice for other subjects.

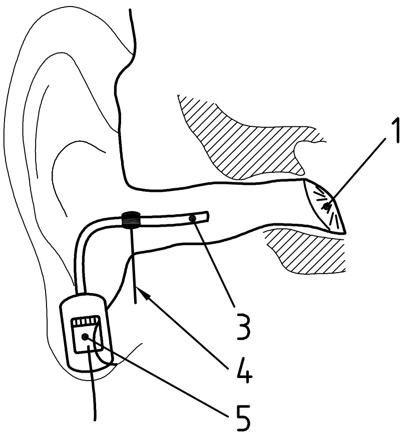
NOTE For earphones and headphones which occupy the majority of the volume immediately outside the ear canal entrance, the choice of a blocked or partly blocked ear canal can reduce the accuracy if the sound under test has significant narrow band components above approximately 3 kHz.

Due to the risk of damaging the eardrum, ear canal measurement position close to the eardrum should only be used by qualified persons and only when using a probe microphone with a soft plastic probe.

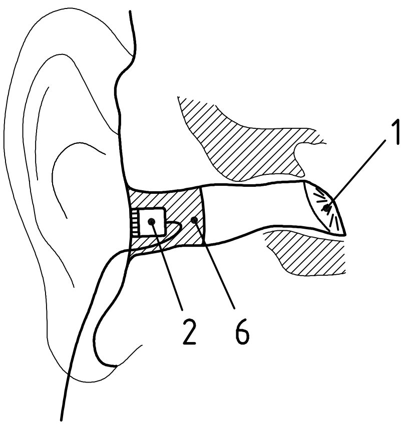
Examples of convenient ear canal measurement positions are illustrated in Figure 1.



a) Miniature microphone in the open ear canal



b) Probe microphone with the probe tube in the open ear canal



c) Miniature microphone at blocked ear canal

Key

1 Eardrum
2 Miniature microphone
3 Probe tube
4 Support wire
5 Microphone
6 Earplug

Figure 1 — Examples of ear canal microphones and their mountings

7.2 Mounting of microphones

Stable positioning during the measurement procedure shall be guaranteed, for instance by using mounting devices. This will normally require flexible microphone leads or a flexible probe tube. Special care shall be taken if the subject is to wear head- or earphones or operate equipment. The microphone, its mounting and electrical leads shall not introduce leakage between the head- or earphone and the ear. The sound field shall be left essentially undisturbed.

Medical plaster and glue are recommended for the attachment of electrical leads and probe tubes.

If a probe microphone is used, it shall be ensured that the probe tube is not squeezed during measurements.

NOTE If the entrance of the blocked ear canal is chosen as the ear canal measurement position, the microphone can be conveniently inserted into a hole in an earplug, or otherwise integrated into the blockage, see Figure 1 c).

7.3 Safety

The ear canal microphone shall be inserted and mounted in such a manner as to avoid any risk of damaging the ear. Special care shall be taken to avoid risk due to a sudden movement of the subject’s head. Safety considerations may prohibit deep insertion into the ear canal.

If electrical leads are introduced into the outer ear, the special electrical safety requirements of IEC 60065 and IEC 60601-1 shall be complied with.

It is recommended that the opinion of a qualified person be sought to provide an expert assessment of the ear canal measurement microphones and their mounting, and to confirm the medically safe use on subjects. The hygiene requirements to ensure safe use shall also be specified by a qualified person.

When a test subject is exposed to potentially hazardous sound levels during test, the blocked ear canal alternative offers a mean of eliminating such a risk, provided that the earplug attenuates the noise to a safe level.

8 Determination of free-field or diffuse-field related equivalent continuous A-weighted sound pressure level

8.1 Measurement of ear canal sound pressure level

With the subject exposed to the sound under test, the sound pressure at the ear canal measurement position shall be measured with the miniature or probe microphone as described in clause 7, and the ear canal sound pressure level determined for each one-third-octave frequency band. The frequency range shall cover all frequencies of significance for the test purpose, and a signal-to-noise ratio of at least 10 dB shall be guaranteed in each one-third-octave frequency band.

The measurement period shall be chosen to give a proper representation of the exposure. For the one-third-octave frequency band with midband frequency f, the measurement period t shall cover a time interval of representative exposure and shall be

$$t \geqslant \frac{5\,000}{f} \qquad \text{for } f \leqslant 2\,000 \text{ Hz}$$

and

$$t \geqslant 2{,}5 \text{ s} \qquad \text{for } f > 2\,000 \text{ Hz}$$

NOTE The specifications given refer to random noise; for other test signal types other periods may be used as long as the measurement uncertainty is not increased.

The level in each one-third-octave frequency band shall be corrected for the pressure frequency response of the ear canal microphone. In certain cases this correction may be omitted, see 10.9.

The result (i.e. the ear canal one-third-octave band sound pressure level during exposure to the sound under test) is denoted $L_{\text{ear,exp},f}$.

8.2 Conversion to free-field or diffuse-field related sound pressure level

To obtain the free-field or diffuse-field related one-third-octave band sound pressure level, $L_{\text{FF,H},f}$ or $L_{\text{DF,H},f}$, the free-field or diffuse-field frequency response, $\Delta L_{\text{FF,H},f}$ or $\Delta L_{\text{DF,H},f}$, shall be subtracted from the ear canal sound pressure level, $L_{\text{ear,exp},f}$:

$$L_{\text{FF,H},f} = L_{\text{ear,exp},f} - \Delta L_{\text{FF,H},f} \tag{1}$$

$$L_{\text{DF,H},f} = L_{\text{ear,exp},f} - \Delta L_{\text{DF,H},f} \tag{2}$$

$\Delta L_{\text{FF,H},f}$ or $\Delta L_{\text{DF,H},f}$ shall be taken from clause 9 or determined according to clause 10 for each individual subject and ear.

8.3 A-weighting and summation

The free-field or diffuse-field related equivalent continuous A-weighted sound pressure level shall be calculated using A-weighting constants A_f specified in IEC 61672-1, and the following formula:

$$L_{\text{FF,H,Aeq}} = 10 \lg \left[\sum_f 10^{\left(L_{\text{FF,H},f} + A_f\right)/10} \right] \text{ dB} \tag{3}$$

$$L_{\text{DF,H,Aeq}} = 10 \lg \left[\sum_f 10^{\left(L_{\text{DF,H},f} + A_f\right)/10} \right] \text{ dB} \tag{4}$$

9 Free-field and diffuse-field frequency responses for selected ear canal measurement positions

If the ear canal measurement position is chosen essentially as

a) the eardrum in an open ear canal,

b) the entrance of an open ear canal, or

c) the entrance of a blocked ear canal, with the blockage at the entrance,

the free-field or diffuse-field frequency response may be taken from Table 1.

10 Determination of free-field or diffuse-field frequency responses

10.1 General

The following procedure shall be used if the free-field or diffuse-field frequency response for each individual subject and ear is to be determined, for example when ear canal measurement positions are used other than those listed in Table 1.

Table 1 — Free-field and diffuse-field frequency response for selected ear canal measurement positions

One-third-octave midband frequency	Free-field frequency response $\Delta L_{FF,H,f}$			Diffuse-field frequency response $\Delta L_{DF,H,f}$		
Hz	Eardrum dB	Open entrance dB	Blocked entrance dB	Eardrum dB	Open entrance dB	Blocked entrance dB
⩽ 100	0,0	0,0	0,0	0,0	0,0	0,0
125	0,2	0,2	0,2	0,2	0,2	0,2
160	0,4	0,4	0,4	0,4	0,4	0,4
200	0,6	0,6	0,6	0,6	0,6	0,6
250	0,8	0,8	0,8	0,8	0,8	0,8
315	1,1	1,1	1,1	1,1	1,1	1,1
400	1,5	1,5	1,5	1,5	1,5	1,5
500	2,0	1,6	1,7	2,1	1,7	1,7
630	2,3	1,8	1,8	2,8	2,1	2,2
800	3,1	1,3	1,4	3,3	2,5	2,3
1 000	2,7	0,6	− 0,4	4,1	2,9	2,3
1 250	2,9	1,5	1,3	5,5	3,6	3,1
1 600	5,8	5,2	4,1	7,7	4,7	3,8
2 000	12,4	8,6	6,6	11,0	6,4	4,4
2 500	15,7	9,5	7,1	15,3	8,2	5,9
3 150	14,9	7,8	10,1	15,7	5,8	8,1
4 000	13,2	5,7	12,8	12,9	3,0	10,3
5 000	8,9	5,6	10,5	10,6	5,1	10,0
6 300	3,1	2,9	2,8	9,4	6,9	7,3
8 000	− 1,4	− 2,0	− 1,2	9,5	5,6	6,0
10 000	− 3,8	− 5,0	0,2	6,8	− 0,9	3,8
12 500	− 0,1	5,1	6,1	3,8	1,0	2,0
16 000	− 0,4	2,2	2,4	0,7	− 0,9	− 0,2

NOTE Data for free-field eardrum are from references [5], [6], [7] and [18]; for free-field open entrance from references [4] and [5]; for free-field blocked entrance from references [4], [5], [7], [8] and [9]; for diffuse-field eardrum from references [7], [10] and [11]; for diffuse-field open entrance from references [4] and [12]; for diffuse-field blocked entrance from references [4], [8], [9] and [12]. For frequencies of 800 Hz and higher the weighted mean was taken (weighted by number of subjects in studies). Below 800 Hz adjustments were carried out (see reference [19]).

10.2 Measurement principle

The ear canal sound pressure level shall be measured while the subject is exposed to a reference sound field approximating either a plane sound wave reaching the subject from the front or a diffuse sound field. The sound pressure level of the reference sound field shall also be measured with the subject absent, using the reference field microphone (see 5.2). The difference between these two levels constitutes the free-field or diffuse-field frequency response.

10.3 Establishment of a free reference sound field

A free reference sound field is created by having a loudspeaker radiating sound into a free field and exposing the subject frontally.

The set-up shall be as described in B.1 to B.5 of IEC 60268-7:1996, except that a standing subject is also allowed. Additionally, it is required that the sound pressure levels in neighbouring one-third-octave frequency bands shall not differ by more than 3 dB.

10.4 Establishment of a quasi-free reference sound field

If the conditions of B.1 to B.3 of IEC 60268-7:1996 for the free reference sound field cannot be complied with, and reduced accuracy is acceptable, a quasi-free sound field as described in 5.3 of ISO 8253-2:1992 may be used.

10.5 Establishment of a diffuse reference sound field

The set-up shall be as described in C.1 to C.5 of IEC 60268-7:1996, except that a standing subject is also allowed. Additionally, it is required that the sound pressure levels in neighbouring one-third-octave frequency bands shall not differ by more than 3 dB.

10.6 Measurement of the reference sound field

In the reference sound field, the sound pressure level at the reference point (the midpoint of the line connecting the subject's ear canal openings) shall be measured with the reference field microphone and analysed in one-third-octave frequency bands. A signal-to-noise ratio of at least 10 dB shall be guaranteed for each one-third-octave frequency band. The measurement period shall comply with the requirements of 8.1.

The measurement shall include a correction for the free-field or diffuse-field frequency response of the microphone. The result is denoted $L_{\mathrm{ref,FF},f}$ for a free reference sound field and $L_{\mathrm{ref,DF},f}$ for a diffuse reference sound field.

10.7 Measurement of ear canal sound pressure level in reference sound field

With the subject exposed to the reference sound field, the sound pressure at the ear canal measurement position shall be measured with the miniature or probe microphones as described in clause 7, and the ear canal sound pressure level determined for each one-third-octave frequency band.

The miniature or probe microphone shall remain in position between measurement of the sound under test and measurement in the reference sound field, unless it can be guaranteed that it is placed at essentially the same position.

The measurement period shall comply with the requirements of 8.1.

A signal-to-noise ratio of at least 10 dB shall be guaranteed for each one-third-octave frequency band. If this cannot be obtained, the reference sound field may be established for each single one-third-octave frequency band at a time, and the free-field or diffuse-field sound pressure level raised to a maximum of 85 dB.

The measurement shall include a correction for the pressure frequency response of the ear canal microphone. In certain cases this correction may be omitted, see 10.9.

The result of the ear canal sound pressure level during exposure to the reference sound field is denoted $L_{\mathrm{ear,FF},f}$ for a free reference sound field and $L_{\mathrm{ear,DF},f}$ for a diffuse reference sound field.

10.8 Determination of free-field or diffuse-field frequency response

The free-field or diffuse-field frequency response is given as:

$$\Delta L_{\text{FF,H},f} = L_{\text{ear,FF},f} - L_{\text{ref,FF},f} \qquad (5)$$

$$\Delta L_{\text{DF,H},f} = L_{\text{ear,DF},f} - L_{\text{ref,DF},f} \qquad (6)$$

For frequencies below 100 Hz, $\Delta L_{\text{FF,H},f}$ and $\Delta L_{\text{DF,H},f}$ are set at 0,0 dB.

10.9 Simplifications in specific cases

When the same miniature or probe microphone is used for measurements of the sound under test and in the reference sound field, the corrections for the pressure frequency response of the miniature or probe microphone as stated in 8.1 and 10.7 may be omitted since they cancel in the final result. In addition, and for the same reason, the exact calibration of the miniature or probe microphone becomes less critical in these cases.

10.10 Optional check of the measurement arrangement

An optional and partial check of the measurement set-up and procedure may be carried out by observing the agreement between the one-third-octave band levels (optional A-weighted) of

a) the reference sound field measured with a sound level meter according to IEC 61672-1, and

b) the free-field or diffuse-field related level $L_{\text{FF,H},f}$ or $L_{\text{DF,H},f}$ of the reference sound field determined with the procedure given in clause 8.

11 Test report

The following is the minimum information which shall be included in the test report:

a) date and place of measurements, reference to this part of ISO 11904 and clauses used for the measurements, together with the name of the measuring institution and the person responsible for the measurements;

b) description of all relevant information about the sound under test, the source(s) emitting it, operating conditions, frequency range, etc.;

c) description of the measurement place with special consideration of the acoustical properties;

d) description of the instrumentation including information about measurement period(s), and date and place of calibration;

e) description of subject(s) (number, sex, age) and choice of ear canal measurement position(s);

f) description of the reference sound field, if used;

g) for each subject and ear, $L_{\text{ear,FF},f}$ or $L_{\text{ear,DF},f}$, $L_{\text{ref,FF},f}$ or $L_{\text{ref,DF},f}$ and $\Delta L_{\text{FF,H},f}$ or $\Delta L_{\text{DF,H},f}$, if determined according to clause 10; data may be given graphically;

h) for each subject and ear, $L_{\text{ear,exp},f}$, $L_{\text{FF,H},f}$ or $L_{\text{DF,H},f}$ and $L_{\text{FF,H,Aeq}}$ or $L_{\text{DF,H,Aeq}}$; data may be given graphically;

i) the arithmetic mean and standard deviation for $L_{\text{FF,H,Aeq}}$ or $L_{\text{DF,H,Aeq}}$ between ears tested;

j) estimation of measurement uncertainty according to the GUM (an example is given in annex B); other relevant information influencing the measurement results.

Annex A
(informative)

Example of sources of measurement uncertainty

A.1 General

This annex is identical in both parts of this International Standard. The uncertainty of the final result depends on whether the MIRE technique (as described in this part of ISO 11904) or the manikin technique (as described in ISO 11904-2) has been used.

For the MIRE technique, a key issue is the extent to which a limited number of subjects represent a population, and whether data for the free-field or diffuse-field frequency response have been taken from tables or determined individually. For the manikin technique, the corresponding issue is the extent to which the manikin represents an average human subject.

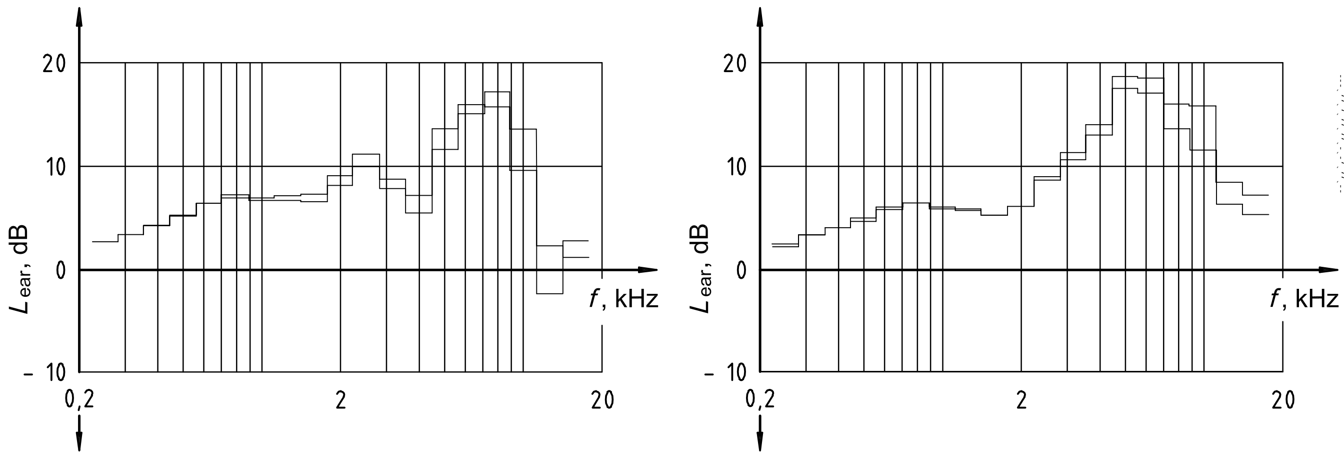
Table A.1 gives an overview of the impact on the final result of some typical sources of measurement uncertainty when using the two parts of ISO 11904. Some typical magnitudes of selected sources of measurement uncertainty are given in A.2 to A.4. The information may be useful for estimating the uncertainty of a measurement and, for the MIRE technique, for determining the required number of subjects in order to achieve the desired uncertainty.

In addition, each of the parts of ISO 11904 contains a separate annex with an example of an uncertainty calculation for the respective technique.

Formulae and data in this annex have been taken from reference [19].

A.2 Inaccurate position of ear canal microphone

Figure A.1 shows examples of errors from inaccurate positioning of an ear canal microphone.



a) **Open entrance** b) **Blocked entrance**

Figure A.1 — Example of change in sound pressure level for a 3 mm displacement of ear canal measurement position at open and blocked entrance

Table A.1 — Overview of typical sources of measurement uncertainty and their impact in various situations

Source of measurement uncertainty	ISO 11904-1 MIRE technique		ISO 11904-2 Manikin technique
	$\Delta L_{FF,H}$ or $\Delta L_{DF,H}$ taken from table	$\Delta L_{FF,H}$ or $\Delta L_{DF,H}$ determined individually	$\Delta L_{FF,M}$ or $\Delta L_{DF,M}$ taken from table
Inaccurate calibration of reference-field microphone, or inaccurate data used for its frequency response	–	+	–
Inaccurate calibration of ear canal or manikin microphone, or inaccurate data used for its frequency response	+	o	+
Unstable sensitivity or frequency response (between measurements) of ear canal or manikin microphone	–	+	–
Inaccurate position of ear canal microphone	+ (see A.2)	o	–
Deviation of reference sound field from intended sound field	–	+	–
Deviation of manikin from human population	–	–	+ (see A.4)
Use of finite number of subjects	+ (see A.3.2)	+ (see A.3.3)	–
Variations in the sound under test	+	+	+

+ has direct impact on final result,
o it cancels in final result,
– not applicable.

A.3 Use of finite number of subjects

A.3.1 General

The fact that only a limited number of subjects are used results in a statistical uncertainty of the result. Two terms may contribute:

— statistical variation in $L_{ear,exp,f}$, and

— statistical variation in $\Delta L_{FF,H,f}$ or $\Delta L_{DF,H,f}$

The variance of tabulated data which can be used for $\Delta L_{FF,H,f}$ or $\Delta L_{DF,H,f}$ is assumed to be very small and is ignored (A.3.2). However, this does not mean that use of tabulated data necessarily gives the smallest deviation in the final result, since correlation between the two terms can cause individual characteristics in the two terms which cancel out (A.3.3).

A.3.2 Using tabulated data for free-field or diffuse-field frequency response

The standard deviation of the mean free-field related sound pressure level (across subjects), $\sigma(\overline{L_{FF,H,f}})$, or the standard deviation of the mean diffuse-field related sound pressure level (across subjects), $\sigma(\overline{L_{DF,H,f}})$, can be calculated from

— the standard deviation (across subjects) of the ear canal sound pressure level, $\sigma\ (L_{\mathrm{ear,exp},f})$, and

— the number of subjects, n.

$$\sigma(\overline{L_{\mathrm{FF,H},f}}) \approx \sigma(\overline{L_{\mathrm{DF,H},f}}) \approx \sqrt{\frac{\sigma^2(L_{\mathrm{ear,exp},f})}{n}} \qquad \text{(A.1)}$$

Examples of values of $\sigma\ (L_{\mathrm{ear,exp},f})$ for ear canal measurement positions at the eardrum, open ear canal entrance and blocked ear canal entrance are shown in Figure A.2.

An example calculation shows that, for eight subjects and for frequencies up to and including the 5 kHz one-third octave frequency band, $\sigma(\overline{L_{\mathrm{FF,H},f}})$ and $\sigma(\overline{L_{\mathrm{DF,H},f}})$ will typically be below 1,0 dB for the eardrum, below 1,4 dB for the open entrance, and below 0,7 dB for the blocked entrance.

A.3.3 Free-field or diffuse-field frequency responses determined individually

The standard deviation of the mean free-field related sound pressure level (across subjects), $\sigma(\overline{L_{\mathrm{FF,H},f}})$, or the standard deviation of the mean diffuse-field related sound pressure level (across subjects), $\sigma(\overline{L_{\mathrm{DF,H},f}})$, can be estimated from

— the standard deviation (across subjects) of the free-field related sound pressure level, $\sigma\ (L_{\mathrm{FF,H},f})$, or the standard deviation (across subjects) of the diffuse-field related sound pressure level, $\sigma\ (L_{\mathrm{DF,H},f})$, and

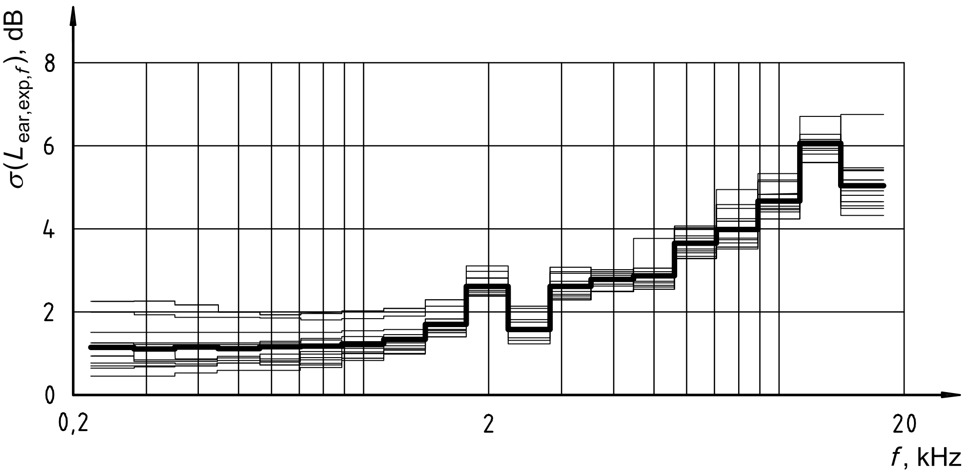
— the number of subjects, n:

$$\sigma(\overline{L_{\mathrm{FF,H},f}}) = \sqrt{\frac{\sigma^2(L_{\mathrm{FF,H},f})}{n}} \qquad \text{(A.2)}$$

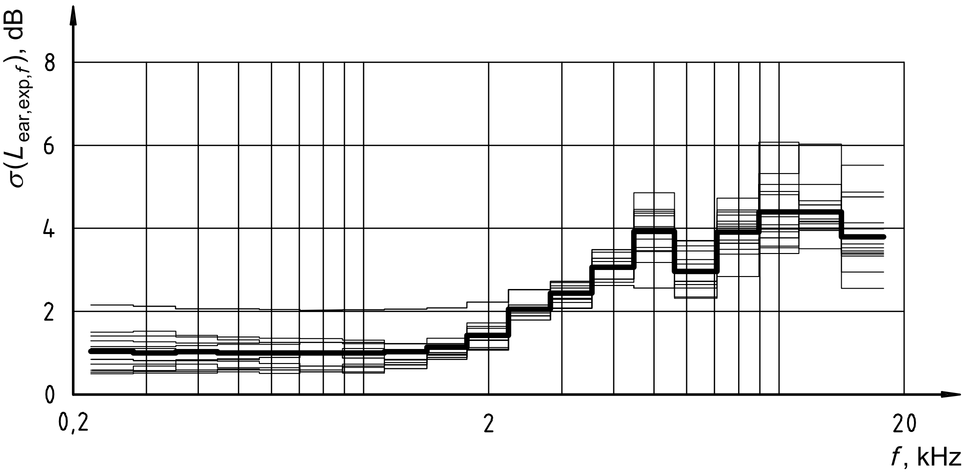
$$\sigma(\overline{L_{\mathrm{DF,H},f}}) = \sqrt{\frac{\sigma^2(L_{\mathrm{DF,H},f})}{n}} \qquad \text{(A.3)}$$

Examples of values of $\sigma\ (L_{\mathrm{FF,H},f})$ and $\sigma\ (L_{\mathrm{DF,H},f})$ are shown in Figure A.3.

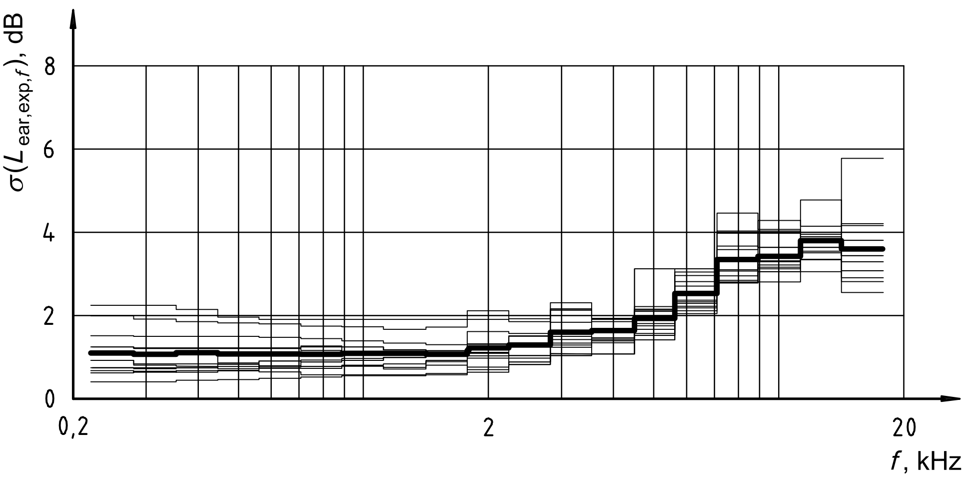
An example calculation shows that, for eight subjects and for frequencies up to and including the 5 kHz one-third-octave frequency band, $\sigma(\overline{L_{\mathrm{FF,H},f}})$ will typically be below 0,7 dB, and $\sigma(\overline{L_{\mathrm{DF,H},f}})$ will typically be below 0,6 dB.



a) Eardrum



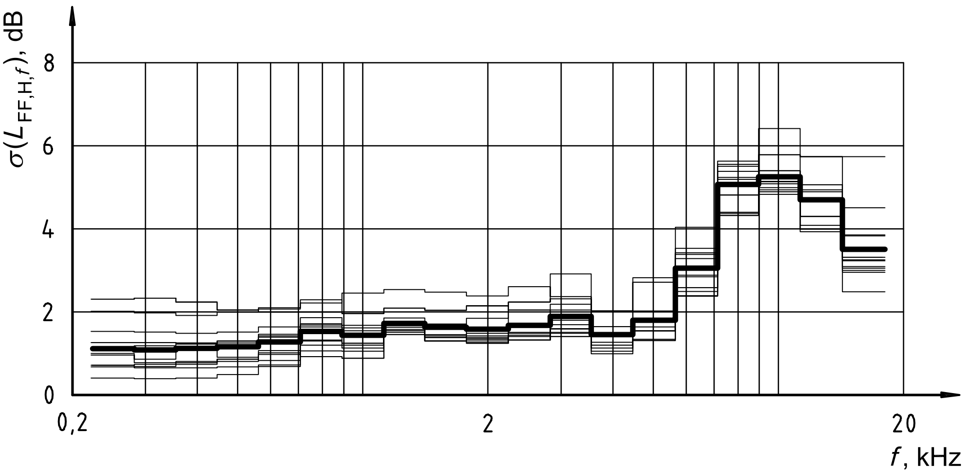
b) Open entrance



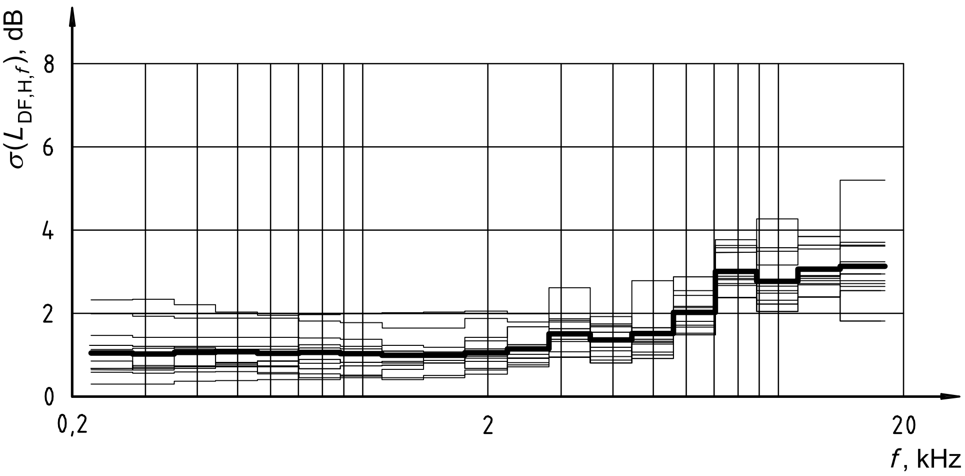
c) Blocked entrance

NOTE Data are for 14 headphones (thin line) and their mean (heavy line).

Figure A.2 — Examples of σ ($L_{ear,exp,f}$) for three ear canal measurement positions



a) Free field



b) Diffuse field

NOTE Data are for 14 headphones (thin line) and their mean (heavy line).

Figure A.3 — Examples of $\sigma(L_{FF,H,f})$ and $\sigma(L_{DF,H,f})$ when individual values of $\Delta L_{FF,H,f}$ and $\Delta L_{DF,H,f}$ are used

A.4 Deviation of manikin from human population

Possible deviations of the manikin from an average human subject result in uncertainty. Two terms can contribute:

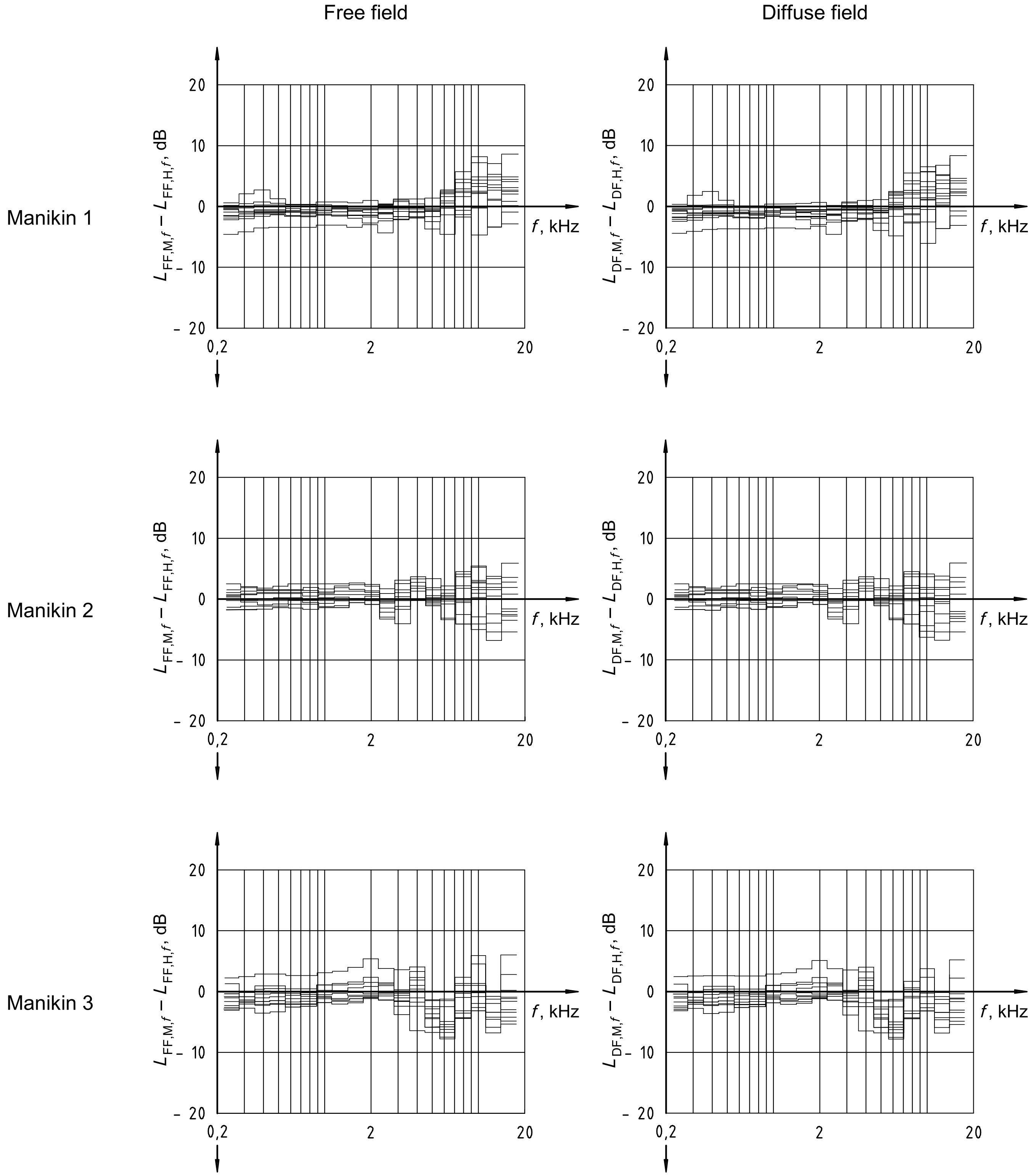
— the deviation in $L_{M,exp,f}$, and

— the deviation in $\Delta L_{FF,M,f}$ or $\Delta L_{DF,M,f}$.

Assuming that tabulated data for $\Delta L_{FF,M,f}$ or $\Delta L_{DF,M,f}$ are correct, the second term is zero.

Figure A.4 shows examples of deviations of results obtained with the manikin technique from those obtained with the MIRE technique using a large group of human subjects.

For frequencies up to and including the 5 kHz one-third-octave frequency band, deviations are typically below 2,5 dB for $L_{\text{FF},f}$ and below 2 dB for $L_{\text{DF},f}$ However, some combinations of headphone and manikin deviate considerably more, in particular for certain frequency bands.



NOTE For the manikin technique, tabulated data were used for $\Delta L_{\text{FF,M},f}$ or $\Delta L_{\text{DF,M},f}$

Figure A.4 — Examples of deviations of $L_{\text{FF},f}$ or $L_{\text{DF},f}$ measured with the manikin technique from similar data measured with the MIRE technique using a large group of human subjects (data for three manikins)

Annex B
(informative)

Example of an uncertainty analysis

The following is an example of how the measurement uncertainties could be estimated for a hypothetical determination of $L_{\text{FF,H,Aeq}}$ or $L_{\text{DF,H,Aeq}}$ from a supra-aural, open-type earphone. It should not be assumed to be an exhaustive list of possible uncertainties, nor a guide to typical values, but just an example of an uncertainty analysis for a specific situation. The analysis complies with the rules given in the GUM.

The uncertainties were estimated for measurements using the following conditions:

— miniature microphones according to 5.1;

— the individual free-field or diffuse-field frequency responses of the test subjects according to clause 9;

— pink noise or noise which simulates speech and music according to IEC 60268-1 as test signal input to the earphone;

— the mean result of measurements on both ears of eight test subjects;

— six measurements on one ear of each of eight test subjects;

— a supra-aural, open-type earphone using always the left capsule on the left ear and the right capsule on the right ear;

— the reference measurement of the frequency response was repeated immediately after the measurement of the sound under test and was carefully checked by comparison with the first measurement; if unexpected deviations occurred the whole measurement procedure was repeated.

The uncertainty analysis was carried out for the final result of $L_{\text{FF,H,Aeq}}$ or $L_{\text{DF,H,Aeq}}$. The value of $L_{\text{FF,H,Aeq}}$ or $L_{\text{DF,H,Aeq}}$ as a function of the influencing components was approximated by a linear model.

For this example (see Table B.1), figures are given for the conditions specified above and for a well-experienced laboratory. In practice the calculation would have to be repeated if there were different conditions (e.g. other test signals, other types of earphones). The expanded uncertainty is obtained by multiplying the combined standard uncertainty by a coverage factor $k = 2$, providing a coverage probability of approximately 95 %.

The uncertainty arises from six different sources. The corresponding components are evaluated as type B uncertainties.

Table B.1 — Uncertainty analysis

Component	Standard uncertainty dB
Microphone sensitivity level and sound pressure level meter uncertainty	
The uncertainty of L_{Aeq} associated with the calibration of the microphone and the use of a precision sound level meter to measure the reference sound field is assumed to be ± 0,2 dB. The semi-range is 0,2 dB with a rectangular distribution. This is equivalent to a standard uncertainty of 0,2 dB / $\sqrt{3}$ = 0,12 dB	0,12
Deviation of frequency response	
The uncertainty of L_{Aeq} associated with (accepted) deviations of the frequency response of test subjects at the measurement of the sound under test and the reference measurement (when carefully checked again after the measurement of the sound under test) and associated with the deviation of the individual frequency responses $\Delta L_{FF,H,f}$ or $\Delta L_{DF,H,f}$ of the test subjects from that averaged on a large number of humans is assumed to be ± 0,7 dB.	0,7
Test signal level	
The uncertainty of L_{Aeq} associated with deviations of the test signal of the target test signal is ± 0,12 dB.	0,12
Climate deviation	
The climate in the laboratory for the measurement of the reference sound field, was within a range, where such measurements usually are carried out [for example (21 ± 2)°C, and (50 ± 15)% RH]. The uncertainty of L_{Aeq} associated to climate deviation is ± 0,4 dB. The semi-range is 0,4 dB with a rectangular distribution. This is equivalent to a standard uncertainty of 0,4 dB / $\sqrt{3}$ = 0,23 dB	0,23
Deviation of L_{ear}	
Found from the standard uncertainty of the measurements of L_{ear} with normal distribution	0,8
Rounding error	
The result of L_{Aeq} is quoted with a resolution of 0,1 dB, giving a semi-range of this component of 0,05 dB with a rectangular distribution. This is equivalent to a standard uncertainty of 0,05 dB / $\sqrt{3}$ = 0,03 dB	0,03
Combined and expanded uncertainty The combined standard uncertainty of L_{Aeq} is found by adding the squares of each standard uncertainty and then taking the square root which gives 1,1 dB. The expanded uncertainty with $k = 2$ is 2,2 dB.	

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