BS EN 61094-5:2016

BSI Standards Publication

Electroacoustics — Measurement microphones

Part 5: Methods for pressure calibration of working standard microphones by comparison

bsi.

National foreword

This British Standard is the UK implementation of EN 61094-5:2016. It is identical to IEC 61094-5:2016. It supersedes BS EN 61094-5:2002 which is withdrawn.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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Europäisches Komitee für Elektrotechnische Normung

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European foreword

The text of document 29/870/CDV, future edition 2 of IEC 61094-5, prepared by IEC TC 29, Electroacoustics, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61094-5:2016.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-04-04
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2019-07-04

This document supersedes EN 61095-5:2001.

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The text of the International Standard IEC 61094-5:2016 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following note has to be added for the standard indicated:

IEC 61094-2:2009	NOTE	Harmonized as EN 61094-2:2009.

Annex ZA
(normative)
Normative references to international publications with their corresponding European publications

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

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 61094-1	-	Measurement microphones -- Part 1: Specifications for laboratory standard microphones	EN 61094-1	-
IEC 61094-4	-	Measurement microphones -- Part 4: Specifications for working standard microphones	EN 61094-4	-

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTROACOUSTICS – MEASUREMENT MICROPHONES –

Part 5: Methods for pressure calibration of working standard microphones by comparison

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 61094-5 has been prepared by IEC technical committee 29: Electroacoustics.

This edition cancels and replaces the first edition published in 2001. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) details of additional components of uncertainty;
b) revised corrections for type WS3 microphones;
c) provision for the calibration of microphones in driven shield configuration.

The text of this standard is based on the following documents:

CDV	Report on voting
29/870/CDV	29/887A/RVC

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61904 series, published under the general title *Measurement microphones*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

ELECTROACOUSTICS – MEASUREMENT MICROPHONES –

Part 5: Methods for pressure calibration of working standard microphones by comparison

1 Scope

This part of IEC 61094-5 is applicable to working standard microphones with removable protection grids meeting the requirements of IEC 61094-4 and to laboratory standard microphones meeting the requirements of IEC 61094-1.

This part of IEC 61094 describes methods of determining the pressure sensitivity by comparison with either a laboratory standard microphone or another working standard microphone with known sensitivity in the respective frequency range.

Alternative comparison methods based on the principles described in IEC 61094-2 are possible but beyond the scope of this part of IEC 61094.

2 Normative references

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

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61094-1 and the following apply.

3.1
reference microphone
laboratory standard microphone or working standard microphone with known pressure sensitivity

3.2
test microphone
laboratory standard microphone or working standard microphone to be calibrated by comparison with a reference microphone

3.3
monitor microphone
microphone used to measure changes in sound pressure

3.4
coupler
device which, when fitted with microphones, forms a cavity of predetermined shape and dimensions and provides an acoustic coupling element between the microphones and between the microphones and the sound source

3.5
jig
device which, when fitted with microphones, holds them with their diaphragms face to face separated by a small distance but does not enclose the space between them

4 Reference environmental conditions

The reference environmental conditions are:

- temperature 23,0 °C
- static pressure 101,325 kPa
- relative humidity 50 %

5 Principles of pressure calibration by comparison

5.1 Principles

5.1.1 General principle

The pressure sensitivity of a measurement microphone is defined in terms of a sound pressure applied uniformly over the diaphragm. Consequently, the pressure sensitivity can only be realised in principle for microphones from which the protection grid can be removed and the diaphragm exposed to the sound pressure stimulus.

The principle of these comparison methods is that when the reference microphone and the test microphone are exposed to the same sound pressure either simultaneously or sequentially, the ratio of their pressure sensitivities is given by the ratio of their open-circuit output voltages. The sensitivity (both modulus and phase) of the test microphone can then be calculated from the sensitivity of the reference microphone.

The principle of the method allows the test microphone to be attached to a particular preamplifier and the sensitivity of the system may be referred to the output of that preamplifier.

Multi-frequency measurements can be performed particularly rapidly if a wideband sound source is used and the output voltages of the microphones are analysed in narrow bands.

NOTE If the reference and test microphones have significantly different frequency response characteristics, e.g. around resonance frequencies, or when a pressure response microphone is compared with a free-field response microphone, this approach can lead to errors when the intention is to determine the pressure sensitivity at the test frequency, rather than the test frequency band. Due consideration of the analysis bandwidth is advised to avoid such errors. Typically, a bandwidth of $1/6^{th}$-octave or narrower will be sufficient to constrain any error to less than 0,01 dB. However further caution is advised on reducing the bandwidth too severely, as can be possible with FFT (fast Fourier transform) analysers, as this can highlight deficiencies such as standing waves in the sound field, which can also lead to errors (see [1][1] for further details).

5.1.2 General principles using simultaneous excitation

In order for the two microphones to be simultaneously exposed to essentially the same sound pressure it is usually necessary for the front surfaces of the two microphones to be separated

1 Numbers in brackets refer to the bibliography.

by a small fraction of the wavelength at the highest frequency of interest. For frequencies up to 20 kHz, this can be achieved by mounting the two microphones face-to-face separated by approximately 1 mm in either a coupler or a jig.

The optimum microphone separation is somewhat dependent on the acoustic environment and should be determined for a particular set-up. Details of likely levels of performance can be found in [1][1]

Couplers usually contain an integral sound source; jig mounted microphones are usually exposed to an externally produced sound field. In order to reduce the effect of systematic differences in sound pressure between the two microphone positions, for example caused by some asymmetries, the following procedure shall be used: after the ratio of the microphone pressure sensitivities is first determined, the microphones shall be interchanged, and the measurement repeated. The sensitivity is then calculated from the mean of the two ratios. Examples of practical arrangements and precautions to be taken are given in Annex A.

NOTE Avoiding asymmetry and standing waves in the sound field, especially in jig configurations, has a significant beneficial impact on the reliability of the results.

5.1.3 General principles using sequential excitation

In order for the two microphones to be sequentially exposed to essentially the same sound pressure, either the exchange of microphones shall not change the sound pressure significantly or any significant change shall be detected and corrected. This can be achieved by incorporating a sound source, a monitor microphone, and the test/reference microphone in a coupler. In any design of coupler, the monitor microphone shall accurately sense changes in the sound pressure at the test/reference microphone position. Examples of practical arrangements are given in Annex B.

5.2 Measuring the output voltages of the microphones

The output of a test or reference microphone may be determined as the open-circuit voltage by use of the insert voltage technique (see 5.3 of IEC 61094-2:2009) or by using a measuring system consisting of a high input impedance microphone preamplifier and a voltmeter (see Annex C).

The method used to measure the output voltage of the test microphone shall be stated on any calibration certificate.

6 Factors influencing the pressure sensitivity

6.1 General

The pressure sensitivity of a measurement microphone can depend on environmental conditions. Further, the definition of the pressure sensitivity implies that certain requirements be fulfilled by the measurements. It is essential during a calibration that these conditions are controlled sufficiently well if the resulting uncertainty components are to remain small.

6.2 Microphone pressure equalization mechanism

The normal construction of a measurement microphone has the cavity behind the diaphragm fitted with a narrow pressure-equalizing tube to permit the static pressure to be the same on both sides of the diaphragm. Consequently, at very low frequencies, this tube also partially equalizes the sound pressure. If, during the calibration, the sound which is coherent with that on the diaphragm is incident on the pressure-equalizing tube, then this could change the apparent sensitivity at low frequencies and the result would not be the true pressure sensitivity.

In a jig, where sound is incident on the pressure equalizing tube, the size of this change shall be determined by comparing calibrations made in the jig with calibrations made in a coupler that does not expose the pressure equalizing tube to the sound field.

In a coupler an "O" ring can be used to seal the gap between the coupler and the microphone. If this is done, care shall be taken to ensure that the "O" ring does not exert undue force on the microphone and cause a change in sensitivity.

6.3 Polarising voltage

If the test microphone requires an external polarising voltage, then the polarising voltage used during the calibration shall be reported.

If the reference microphone requires an external polarising voltage, then any difference between that applied when it was calibrated and that applied when it is used as the reference microphone shall be allowed for in the uncertainty calculations (see Annex D).

6.4 Reference shield configuration

When the open-circuit voltage is measured, the shield configurations given in IEC 61094-1 or IEC 61094-4 shall be used.

If a microphone is intended to be used with a preamplifier having a non-standard shield configuration, then it shall be calibrated as a system along with its preamplifier.

When insert voltage calibrations are performed, it shall be stated whether output voltage from the microphone is applied to the shield (driven shield configuration), or whether the shield is grounded.

If the instruction manual specifies a maximum mechanical force to be applied to the central electrical contact of the microphone, this limit shall not be exceeded.

6.5 Pressure distribution over the diaphragms

The definition of the pressure sensitivity assumes that the sound pressure over the diaphragm is applied uniformly. The output voltage of a microphone presented with a non-uniform pressure distribution over the surface of the diaphragm will differ from the output voltage of the microphone when presented with a uniform pressure distribution having the same mean value, because the microphone is usually more sensitive to a sound pressure at the centre of the diaphragm.

Uniformity of sound pressure over the diaphragm of the microphone can be optimised by maintaining the radial symmetry of the sound field around the circumferences of the microphones. This can be achieved using a radially symmetric sound source positioned coaxially with the microphones and, when the microphones are mounted in a jig, with the microphones positioned in the far field of the sound source. Although pressure non-uniformity over the surface of the diaphragm can be minimised by using a radially symmetric sound source, some non-uniformity at high frequencies can remain even with a perfect source.

It is difficult to control the uniformity of the sound field in an actual calibration set-up. However, the combined effect of asymmetries in the sound field and in the microphones becomes evident when the microphones are rotated relative to each other about their axis of symmetry. Thus, the related component of measurement uncertainty can be reduced by averaging results from a number of such measurement configurations.

NOTE When comparing microphones of the same model, the requirement for uniformity of the sound field reduces to a requirement of rotational symmetry of the sound field.

Alternatively, issues with sound field non-uniformity can be overcome if excitation is made with a diffuse sound field, for example in a reverberation room. Care should be taken to avoid creating standing waves in the sound field surrounding the microphones as these can cause significant and unpredictable measurement errors. A broadband source, or repeated measurements at different positions within the field, is also necessary to achieve a sufficiently low measurement uncertainty.

The effect of a non-uniform pressure distribution over the surface of the diaphragm will be significantly greater if the test and reference microphones are of different diameters. A theoretical model which can be used to apply corrections and assess the uncertainties in this case is given in the literature (for example [1]).

6.6 Dependence on environmental conditions

The sensitivity of a microphone can depend on static pressure, temperature or humidity. This dependence can be determined by comparison with a well characterised laboratory standard microphone over a range of conditions.

If the reference microphone and the test microphone are different manufacturer models, then the sensitivity of the reference microphone shall be corrected to the actual environmental conditions during the test. Alternatively, if they are of the same model, there can be an advantage in assuming that they have the same dependence on environmental conditions so that the calibration of the test microphone can be referred to the conditions at which the calibration of the reference microphone is valid.

Alternatively, when reporting the results of a calibration, the pressure sensitivity can be corrected to the reference environmental conditions if reliable correction data are available.

The actual conditions during the calibration shall be reported.

6.7 Validation

Calibrations performed in any particular jig or coupler shall be validated by comparison with calibrations performed in other jigs and couplers and alternative sound sources. A separate validation is necessary for each different type of microphone. If the test microphone is a laboratory standard microphone, then the jig or coupler can be validated by comparing a comparison calibration with a reciprocity calibration. For some microphones, it can be necessary to use more than one jig and/or coupler to cover a full frequency range with low uncertainty.

7 Calibration uncertainty components

7.1 General

In addition to the factors influencing the pressure sensitivity mentioned in Clause 6, further uncertainty components are introduced by the method, the equipment and the degree of care under which the calibration is carried out. Factors which affect the calibration in a known way should be measured or calculated with an accuracy necessary to achieve the desired overall measurement uncertainty, and with as high an accuracy as practicable if their influence is to be minimised.

7.2 Sensitivity of the reference microphone

The uncertainty in the sensitivity of the reference microphone directly affects the uncertainty in the sensitivity of the test microphone.

7.3 Measurements of microphone output

Uncertainties of random or time-varying nature in the measurement of the outputs of the microphones directly affect the uncertainty in the sensitivity of the test microphone.

Uncertainties of systematic nature in the measurement of the outputs of the microphones can affect the uncertainty in the sensitivity of the test microphone. The uncertainty can be reduced if the same system is used for both the test and reference microphones.

If test and reference microphone are measured simultaneously, systematic uncertainty can be reduced using the procedure described in Annex C.

7.4 Differences between the sound pressure at the test microphone and that at the reference microphone

With simultaneous or sequential excitation, differences in the acoustic impedance between the test and reference microphones can cause the sound pressure at the test and reference microphones to differ. A theoretical model which may be used to assess the resulting uncertainty can be found in the literature (for example [2]).

7.5 Acoustic impedances of the microphones

When the reference microphone and the test microphone have significantly different acoustic impedances (for example, pressure and free-field response microphones at frequencies above 10 kHz), they can respond differently to the same sound field because of differing volume velocities at the diaphragms. It is recommended that wherever possible a reference microphone of similar acoustic impedance to that of the test microphone be used. If no suitable reference microphone is available, the size of the error caused should be estimated and added to the uncertainty budget.

7.6 Microphone separation distance

The ideal microphone separation distance used in simultaneous excitation measurements should be established for each acoustic environment in which jig measurements are to be carried out. The distance can be determined by making a series of measurements at different separations and comparing the results with a primary pressure calibration for the same microphone. Measurements made in some sound fields can be very sensitive to very small changes in microphone separation distance and microphone position relative to the sound field. In these cases it is preferable to improve the sound field rather than the positioning system because a very reproducible positioning system can introduce repeatable systematic errors that are not easily detected.

7.7 Microphone capacitance

In some calibration methods (for example the approach outlined in Annex C), the gain of the microphone preamplifier(s) used is assumed to be constant when fitted with different microphones. However the gain of the preamplifier is typically a function of the attached microphone capacitance.

Therefore a correction should be made or a component of uncertainty allowed if the capacitances of the reference microphone and test microphone are sufficiently different for the influence on the preamplifier gain to be significant.

NOTE This effect is avoided if the insert voltage technique is used.

7.8 Microphone configuration during calibration

It may be necessary to fit a microphone with one or more adapters suiting a particular calibration coupler or configuration. Such adapters may have an influence on the sensitivity of the microphone, and this shall be included as an uncertainty component.

NOTE Both the reference and test microphones can be influenced by the fitting of adapters.

7.9 Uncertainty on pressure sensitivity level

For determining the pressure sensitivity level of working standard microphones, when the reference microphone has been calibrated in accordance with IEC 61094-2, it is estimated that a comparison calibration of microphones of the same diameter can achieve an expanded uncertainty with coverage factor 2 (see ISO/IEC Guide 98-3) of approximately 0,1 dB at low and middle frequencies. The uncertainty increases to about 0,2 dB at 10 kHz and 20 kHz for WS1P and WS2P working standard microphones, respectively. Annex D contains an example of an uncertainty analysis.

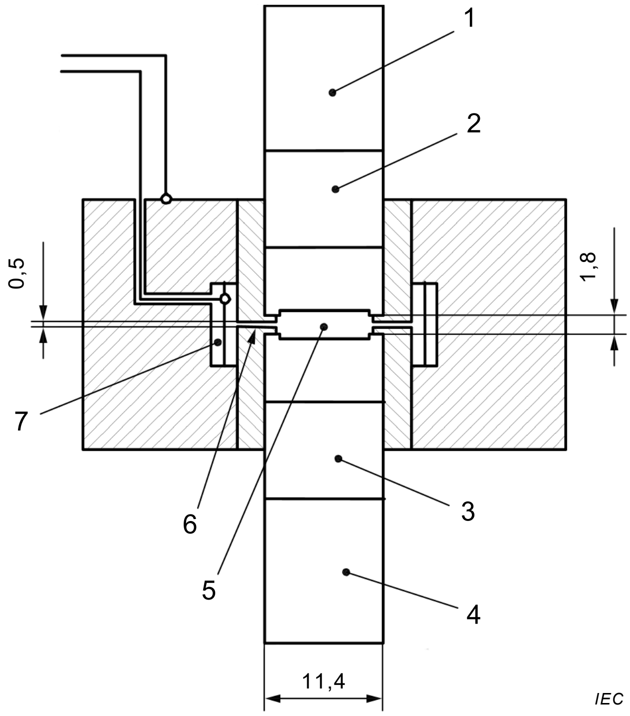
Annex A
(informative)

Examples of couplers and jigs for simultaneous excitation

A.1 A coupler for use with WS2 microphones at frequencies up to 10 kHz

The coupler shown in Figure A.1 allows two microphones with exposed diaphragms to be inserted face-to-face separated by about 2 mm. The coupler contains a radial sound source that generates a radially symmetric acoustic field between the diaphragms. In this example the grid of the test microphone has been removed and replaced with an adaptor ring to give the configuration of an LS2 microphone. Variations on the principle could include a slightly larger diameter coupler where the test microphone would be supported by other means.

Dimensions in millimetres



Key

1 Preamplifier A
2 Microphone A
3 Microphone B
4 Preamplifier B
5 Coupler cavity, diameter 9,3 mm
6 Sound inlet
7 Cylindrical source diaphragm

Figure A.1 – A coupler for use with WS2 microphones

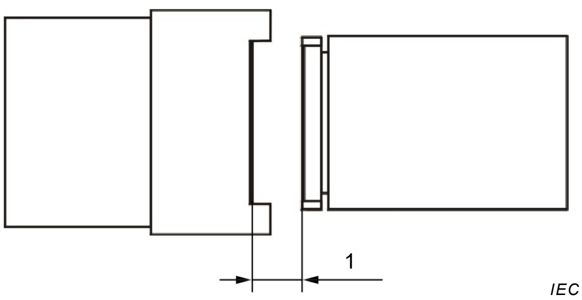
This method may also be used without removing any protection grid from the test microphone provided that the presence of the grid is allowed for in the uncertainty calculation. The grid can cause an unacceptable level of measurement uncertainty at high frequencies, effectively reducing the frequency range over which the coupler can be used.

A.2 A jig for use with WS2 or WS3 microphones at frequencies up to 20 kHz

A simple arrangement for holding and positioning an LS2 microphone and a WS2 microphone in a suitable position for a simultaneous calibration is shown in Figure A.2. The jig is enclosed in an acoustic chamber with a loudspeaker providing the sound source. The preferred location for the sound source is on the axis of symmetry of the microphones. The detailed positioning for WS2 and WS3 microphones is shown in Figures A.3 and A.4 respectively. Note that the protection grids have been removed.

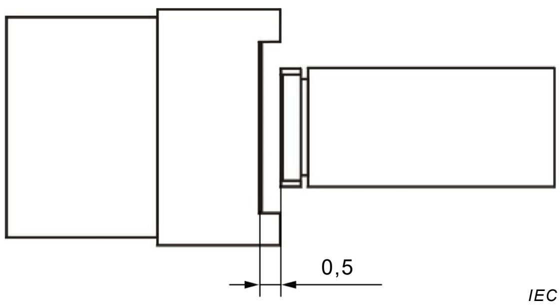
Figure A.2 – A jig fitted with an LS2 and WS2 microphone

Dimensions in millimetres



NOTE The dimension shown is the diaphragm-to-diaphragm separation

Figure A.3 – Example arrangement of LS2 and WS2 microphones in a jig



NOTE The dimension shown is the diaphragm-to-diaphragm separation. This separation distance is the only one for which the corrections specified in Table A.1 are valid

Figure A.4 – Example arrangement of LS2 and WS3 microphones in a jig

When the arrangement of Figure A.4 is used, corrections are required to account for the radial sensitivity of the microphones and the fact that the test microphone is smaller than the reference microphone. Table A.1 gives corrections to be added to the sensitivity level of the WS3 microphone assuming that the reference microphone is of type LS2aP (see [1]) and that the sound field is radially symmetrical. The expanded uncertainty on the corrections is estimated to be 10 % of their value (in dB) which is approximately the change observed by doubling the distance between the microphones.

If the sound arrives from a direction other than the axis of symmetry of the jig, measurements should be made with the sound arriving from several different directions and an average taken. A convenient means of achieving this is to use a diffuse sound field.

Table A.1 – Calculated corrections to be added to the sensitivity level of the WS3 microphone when using the arrangement in Figure A.4

Frequency kHz	**Correction** dB
1	–0,004
1,25	–0,006
1,6	–0,009
2	–0,015
2,5	–0,023
3,15	–0,036
4	–0,059
5	–0,092
6,3	–0,146
8	–0,235
10	–0,367
12,5	–0,572
16	–0,933
20	–1,443
NOTE The expanded uncertainty is estimated to be 1/10th of the value of the correction (in decibels).	

Annex B
(informative)

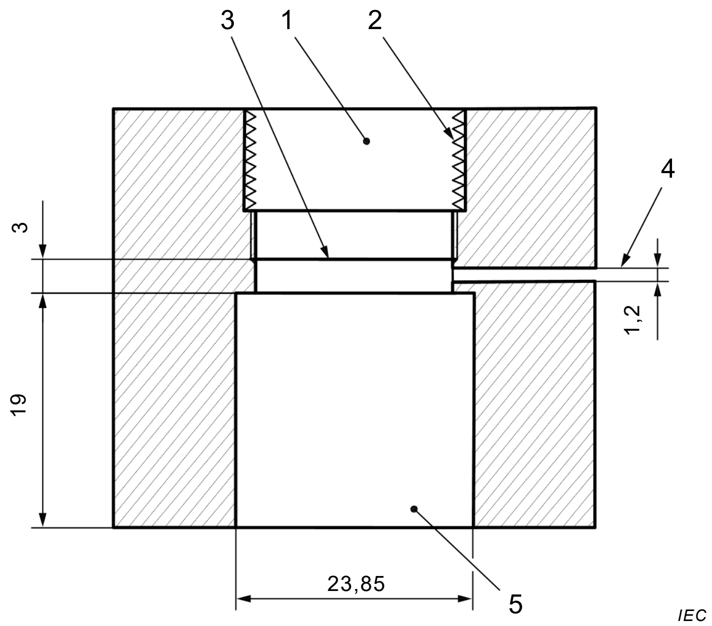
Examples of couplers for sequential excitation

B.1 A coupler for use with LS1 microphones at frequencies up to 8 kHz

A coupler for use with LS1 microphones is shown in Figure B.1. A WS1P microphone, used as the sound source, is screwed directly into the upper port of the coupler without any protection grid or adaptor. A probe tube microphone is inserted from the side of the coupler so that the probe tip is one-third of the distance along a radius from the wall, and is used to control the sound pressure in the coupler. The acoustic impedance of the probe tube microphone used can affect the results, but a tube with an acoustic impedance of 800 MPa·s·m^{-3} has been used successfully. The test and reference microphones are held in the coupler by a yoke and spring arrangement.

If both test and reference microphones are WS1 microphones converted to the LS1 configuration with an adaptor ring, the same adaptor ring should be used on both microphones.

Dimensions in millimetres



Key

1 Aperture for source microphone

2 Thread to fit source microphone

3 Position of source microphone diaphragm

4 Probe tube

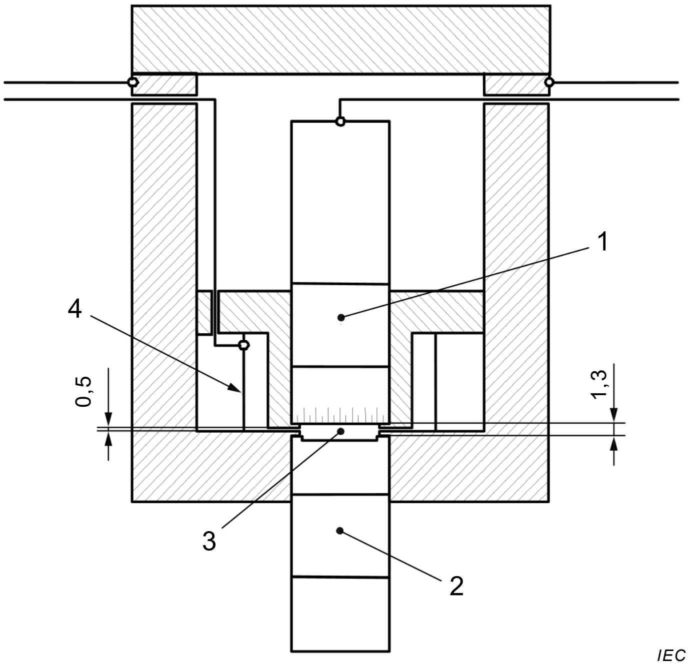
5 Aperture for test and reference microphone

Figure B.1 – A coupler for use with LS1 microphones

B.2 A coupler for use with WS2 microphones at frequencies up to 16 kHz

Figure B.2 shows a coupler that can be used for sequential comparison calibrations of WS2 microphones. A cylindrical source diaphragm generates a radially symmetric sound field and a monitor microphone detects the change in sound pressure when the test microphone is replaced by the reference microphone.

Dimensions in millimetres



Key

1 Monitor microphone

2 Test/reference microphone

3 Coupler cavity, diameter 9,3 mm

4 Cylindrical source diaphragm

Figure B.2 – A coupler for use with WS2 microphones

This method may also be used without removing any protection grid from the test microphone provided that the presence of the grid is allowed for in the uncertainty calculation.

Annex C
(informative)

Determining the open-circuit sensitivity of a measurement microphone without using the insert-voltage method

When a comparison calibration is being performed, it is possible to determine the open-circuit sensitivity of the test microphone without using the insert-voltage method. It is necessary for the open-circuit sensitivity of the reference microphone to be known and a correction (or uncertainty) to be included for any difference due to the test and reference microphone presenting a different electrical source impedance to the preamplifier. The principle is that by interchanging the microphones between the two measuring channels and repeating the measurements, any difference in the gains of the two channels (and some other systematic effects) can be eliminated. This can be demonstrated by the following.

When two microphones with their diaphragms facing are at close proximity to each other, and their outputs measured as levels on two measurement channels, then the level reading difference, L_{C12}, between the two channels (neglecting any influence of microphone capacitance) is

$$L_{\mathrm{C12}} = (L_1 + L_{\mathrm{m1}} + L_{\mathrm{d1}} + L_{\mathrm{WA}}) - (L_2 + L_{\mathrm{m2}} + L_{\mathrm{d1}} + L_{\mathrm{WB}}) \qquad \text{(C.1)}$$

where

L_1 and L_2 are the pressure sensitivity levels of the microphones;

L_{m1} and L_{m2} are the gains of the measuring systems;

L_{d1} is the sound pressure level that the excitation sound source produces at the centre point mid-way between the microphone diaphragms;

L_{WA} represents the difference between the sound pressure level at the microphone diaphragm at position A and L_{d1};

L_{WB} represents the difference between the sound pressure level at the microphone diaphragm at position B and L_{d1}.

Equation (C.1) assumes that the microphones have different sensitivities, but are otherwise identical in their mechanical and electroacoustic characteristics.

When the microphones are interchanged, the level reading difference between the two channels is

$$L_{\mathrm{C21}} = (L_2 + L_{\mathrm{m1}} + L_{\mathrm{d2}} + L_{\mathrm{WA}}) - (L_1 + L_{\mathrm{m2}} + L_{\mathrm{d2}} + L_{\mathrm{WB}}) \qquad \text{(C.2)}$$

where

L_{d2} is the sound pressure level that the excitation sound source produces at the centre point mid-way between the microphone diaphragms after the interchange.

From the difference between Equation (C.1) and Equation (C.2), the sensitivity level difference between the two microphones is

$$(L_1 - L_2) = \tfrac{1}{2}(L_{\mathrm{C12}} - L_{\mathrm{C21}}) \qquad \text{(C.3)}$$

If L_1 is the pressure sensitivity level of a reference microphone, then the pressure sensitivity level L_2 of the test microphone can be deduced without any knowledge of L_{m1}, L_{m2}, L_{d1}, L_{d2}, L_{WA} or L_{WB}.

Annex D
(informative)

Typical uncertainty analysis

D.1 Introduction

The following is an example uncertainty calculation for a hypothetical calibration protocol. It should not be taken as an exhaustive list of possible uncertainty components, or an indication of typical uncertainty values.

D.2 Analysis

The uncertainties given in Table D.1 are calculated for the example of a simultaneous calibration of a low sensitivity type WS2P microphone using an LS2P reference microphone. The coupler shown in Figure A.1 is used, and there are three repeats of the calibration. The microphones are interchanged in the coupler ports and on the pre-amplifiers to eliminate the effects of any asymmetry in the coupler and any differences in gain in the two measurement channels (see Annex C). The results are not referred to the reference environmental conditions.

The sensitivity M_{test} of the test microphone is calculated from the formula:

$$M_{\text{test}} = M_{\text{ref}} \times R_{\text{V}} / R_{\text{P}}$$

where

M_{ref} is the pressure sensitivity of the reference microphone;

R_{V} is the ratio of the output voltages of the test and reference microphones;

R_{P} is the ratio in the effective sound pressure acting on the two microphones. R_{P} is often reduced to unity by the process described in Annex C and the corrections such as those given in Annex B, but it will have some residual uncertainty.

For this example, figures are given for a frequency of 2 kHz only. In practice, the calculation is repeated for each frequency used. The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, providing a level of confidence of approximately 95 %.

The measurement uncertainty arises from eight different sources, but additional components can be required in particular set ups or microphone configurations. The component due to repeatability is evaluated as a type B uncertainty based on limits established by a large number of similar measurements; the remaining components are also evaluated as type B. It is assumed that the sensitivity of the microphone is linearly dependent on each component and that the calibration of the reference microphone refers to the actual measurement conditions.

Table D.1 – Example uncertainty budget

Component	Standard uncertainty dB
Sensitivity of reference microphone The uncertainty associated with the calibration of the laboratory standard microphone used as the reference, is quoted on its calibration certificate as ±0,05 dB with a coverage factor of k = 2. This is equivalent to a standard uncertainty of 0,05/2 dB = 0,025 dB.	0,025
Microphone capacitance As the insert voltage technique is not used, and the preamplifiers used in the system have a non-zero input capacitance, the measurement will be influenced by the capacitance of the microphone. In a comparison calibration, the effects will cancel out if the test and reference microphone have the same nominal capacitance. However when this is not the case, an uncertainty will be introduced. From a knowledge of the input impedance of the pre-amplifiers and the manufacturer's specification for the capacitance of the microphones, it is possible to calculate that, in this particular instance, the semi-range of this component is 0,01 dB with a rectangular distribution. This is equivalent to a standard uncertainty of 0,01/√3 dB = 0,006 dB.	0,006
Non-linearity The response of the analyser to signals of different magnitudes could be in error by a small amount. Tests of the analyser are performed with two different calibrated attenuators which are separately placed to mimic the level differences that are expected to be measured in the actual calibration. The microphone calibration is only allowed to proceed if the difference between the results of these tests and the known values of the attenuators is within 0,03 dB. Hence the semi-range of this component is 0,03 dB with a rectangular distribution. This is equivalent to a standard uncertainty of 0,03/√3 dB = 0,017 dB.	0,017
Microphone impedance The acoustical impedance of the microphone acts in series with that of the air in the space between the two microphones. Microphones with different acoustic impedance therefore see slightly different pressures when simultaneously exposed to the same pressure field (see 7.4 and [2]). The magnitude of the effect when high sensitivity and low sensitivity type WS2P microphones are compared, is a worse case and taken as the uncertainty in this example. At 2 kHz, the semi-range of this component is 0,005 dB with a rectangular distribution. This is equivalent to a standard uncertainty of 0,005/√3 dB = 0,003 dB. When microphones have significantly differing impedances (for example WS2F microphone compared against LS2P at frequencies above 10 kHz), the measurement uncertainty can be considerably larger and should be established experimentally.	0,003
Polarising voltage The polarising voltage affects the sensitivity of both the reference and test microphones. If the same polarising voltage is applied to both microphones the effect will be negligible. However if one microphone is pre-polarised, this will not be the case and the error will persist. The polarising voltage is set to (200,0 ± 0,2) V giving a semi-range for this component of 20 lg (200,2/200) dB with a rectangular distribution. This is equivalent to a standard uncertainty of 0,005 dB.	0,005
Repeatability Found from the standard uncertainties of a large number of similar measurements.	0,025
Drift in reference microphone sensitivity since last calibration The sensitivity of the reference microphone can have changed since it was calibrated. Two calibrated reference microphones are compared against each other as a check before the calibration of test microphones. The comparison calibration and the reference calibration of the reference microphone should agree within 0,03 dB. However, the value used during a calibration must be further reduced by the uncertainty associated with the comparison measurement. The standard uncertainty of this component is 0,03/√3 dB = 0,017 dB.	0,017
Rounding of reported results The result is reported with a resolution of 0,01 dB, giving a semi-range of 0,005 dB with a rectangular distribution. This is equivalent to a standard uncertainty of 0,005/√3 dB = 0,003 dB.	0,003

Additional components for special cases	**Standard uncertainty** in dB
Corrections for the difference in diaphragm diameter when calibrating a type WS3 microphone against a type LS2 reference microphone. The expanded uncertainty directly associated with the calculated correction is estimated to be 10 % of the value of the correction (in decibels). The unaccounted for difference between the corrected comparison calibration of a WS2 microphone compared against an LS1 reference microphone and a pressure reciprocity calibration of the same WS2 performed as a validation of the method. The uncertainty associated with variations in the diaphragm and microphone diameters of WS3 microphone models.	Frequency dependent (see Table A.1.)
Uncertainties associated with system calibrations When microphones are calibrated as a system (i.e. in conjunction with a preamplifier) the effect due to any deviation from 200 V in the polarisation voltage supplied by the power supply unit is not cancelled out during the measurement. The component associated with microphone capacitance should be re-considered to account for the capacitance presented by the microphone system to each of the measurement system preamplifiers.	0,002 Frequency dependent $<$0,02 above 200 Hz

D.3 Combined and expanded uncertainties

The combined standard uncertainty is found from the root-sum-square of the uncertainty components, which gives a value of 0,040 dB (a strict calculation would require each component to be converted from logarithmic to linear form before doing the combination but as the values are very small, the result would be essentially the same). The expanded uncertainty with a coverage factor of 2 is then 0,08 dB.

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