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NORME INTERNATIONALE

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**Electroacoustics – Measurement microphones –
Part 2: Primary method for pressure calibration of laboratory standard microphones by the reciprocity technique**

**Électroacoustique – Microphones de mesure –
Partie 2: Méthode primaire pour l'étalonnage en pression des microphones étalons de laboratoire par la méthode de la réciprocité**

IEC 61094-2:2009-02+AMD1:2022-02 CSV(en-fr)

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ELECTROACOUSTICS – MEASUREMENT MICROPHONES –

Part 2: Primary method for pressure calibration of laboratory standard microphones by the reciprocity technique

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IEC 61094-2 edition 2.1 contains the second edition (2009-02) [documents 29/671/FDIS and 29/676/RVD] and its amendment 1 (2022-02) [documents 29/1108/FDIS and 29/1112/RVD].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

International Standard IEC 61094-2 has been prepared by IEC technical committee 29: Electroacoustics.

This second edition constitutes a technical revision.

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

- an update of Clause 6 to fulfil the requirements of ISO/IEC Guide 98-3;
- an improvement of the heat conduction theory in Annex A;
- a revision of Annex F: Physical properties of humid air.

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

A list of all parts of the IEC 61094 series, published under the general title *Electroacoustics – Measurement microphones*, can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under 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- withdrawn,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.

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ELECTROACOUSTICS –
MEASUREMENT MICROPHONES –

Part 2: Primary method for pressure calibration of laboratory standard microphones by the reciprocity technique

1 Scope

This part of International Standard IEC 61094

– is applicable to laboratory standard microphones meeting the requirements of IEC 61094-1 and other types of condenser microphone having the same mechanical dimensions;

– specifies a primary method of determining the complex pressure sensitivity so as to establish a reproducible and accurate basis for the measurement of sound pressure.

All quantities are expressed in SI units.

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 61094-1:2000, *Measurement microphones – Part 1: Specifications for laboratory standard microphones*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61094-1 and ISO/IEC Guide 98-3 as well as the following apply.

3.1
reciprocal microphone
linear passive microphone for which the open circuit reverse and forward transfer impedances are equal in magnitude

3.2
phase angle of pressure sensitivity of a microphone
for a given frequency, the phase angle between the open-circuit voltage and a uniform sound pressure acting on the diaphragm

NOTE Phase angle is expressed in degrees or radians (° or rad).

[1] ISO/IEC Guide 98-3:2008 is published as a reissue of the Guide to the expression of uncertainty in measurement (GUM), 1995.

3.3
electrical transfer impedance
for a system of two acoustically coupled microphones the quotient of the open-circuit voltage of the microphone used as a receiver by the input current through the electrical terminals of the microphone used as a transmitter

NOTE 1 Electrical transfer impedance is expressed in ohms (Ω).

NOTE 2 This impedance is defined for the ground-shield configuration given in 7.2 of IEC 61094-1:2000.

3.4
acoustic transfer impedance
for a system of two acoustically coupled microphones the quotient of the sound pressure acting on the diaphragm of the microphone used as a receiver by the short-circuit volume velocity produced by the microphone used as a transmitter

NOTE Acoustic transfer impedance is expressed in pascal-seconds per cubic metre ($Pa \cdot s/m^3$).

3.5
coupler
device which, when fitted with microphones, forms a cavity of predetermined shape and dimensions acting as an acoustic coupling element between the microphones

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 reciprocity

5.1 General principles

5.1.1 General

A reciprocity calibration of microphones may be carried out by means of three microphones, two of which shall be reciprocal, or by means of an auxiliary sound source and two microphones, of which one shall be reciprocal.

NOTE If one of the microphones is not reciprocal it can only be used as a sound receiver.

5.1.2 General principles using three microphones

Let two of the microphones be connected acoustically by a coupler. Using one of them as a sound source and the other as a sound receiver, the electrical transfer impedance is measured. When the acoustic transfer impedance of the system is known, the product of the pressure sensitivities of the two coupled microphones can be determined. Using pair-wise combinations of three microphones marked (1), (2) and (3), three such mutually independent products are available, from which an expression for the pressure sensitivity of each of the three microphones can be derived.

5.1.3 General principles using two microphones and an auxiliary sound source

First, let the two microphones be connected acoustically by a coupler, and the product of the pressure sensitivities of the two microphones be determined (see 5.1.2). Next, let the two microphones be presented to the same sound pressure, set up by the auxiliary sound source. The ratio of the two output voltages will then equal the ratio of the two pressure sensitivities.

Thus, from the product and the ratio of the pressure sensitivities of the two microphones, an expression for the pressure sensitivity of each of the two microphones can be derived.

NOTE In order to obtain the ratio of pressure sensitivities, a direct comparison method may be used, and the auxiliary sound source may be a third microphone having mechanical or acoustical characteristics which differ from those of the microphones being calibrated.

5.2 Basic expressions

Laboratory standard microphones and similar microphones are considered reciprocal and thus the two-port equations of the microphones can be written as:

$$\begin{aligned} \underline{z}_{11}\,\underline{i} + \underline{z}_{12}\,\underline{q} &= \underline{U} \\ \underline{z}_{21}\,\underline{i} + \underline{z}_{22}\,\underline{q} &= \underline{p} \end{aligned} \qquad (1)$$

where

$\underline{p}$	is the sound pressure, uniformly applied, at the acoustical terminals (diaphragm) of the microphone in pascals (Pa);
$\underline{U}$	is the signal voltage at the electrical terminals of the microphone in volts (V);
$\underline{q}$	is the volume velocity through the acoustical terminals (diaphragm) of the microphone in cubic metres per second (m^3/s);
$\underline{i}$	is the current through the electrical terminals of the microphone in amperes (A);
$\underline{z}_{11} = \underline{Z}_e$	is the electrical impedance of the microphone when the diaphragm is blocked in ohms (Ω);
$\underline{z}_{22} = \underline{Z}_a$	is the acoustic impedance of the microphone when the electrical terminals are unloaded in pascal-seconds per cubic metre ($Pa \cdot s \cdot m^{-3}$),
$\underline{z}_{12} = \underline{z}_{21} = \underline{M}_p\,\underline{Z}_a$	is equal to the reverse and forward transfer impedances in volt-seconds per cubic metre ($V \cdot s \cdot m^{-3}$), $\underline{M}_p$ being the pressure sensitivity of the microphone in volts per pascal ($V \cdot Pa^{-1}$).

NOTE Underlined symbols represent complex quantities.

Equations (1) may then be rewritten as:

$$\begin{aligned} \underline{Z}_e\,\underline{i} + \underline{M}_p\,\underline{Z}_a\,\underline{q} &= \underline{U} \\ \underline{M}_p\,\underline{Z}_a\,\underline{i} + \underline{Z}_a\,\underline{q} &= \underline{p} \end{aligned} \qquad (1a)$$

which constitute the equations of reciprocity for the microphone.

Let microphones (1) and (2) with the pressure sensitivities $\underline{M}_{p,1}$ and $\underline{M}_{p,2}$ be connected acoustically by a coupler. From Equations (1a) it is seen that a current $\underline{i}_1$ through the electrical terminals of microphone (1) will produce a short-circuit volume velocity ($\underline{p}$ = 0 at the diaphragm) of $\underline{M}_{p,1}\,\underline{i}_1$ and thus a sound pressure $\underline{p}_2 = \underline{Z}_{a,12}\,\underline{M}_{p,1}\,\underline{i}_1$ at the acoustical terminals of microphone (2), where $\underline{Z}_{a,12}$ is the acoustic transfer impedance of the system.

The open-circuit voltage of microphone (2) will then be:

$$\underline{U}_2 = \underline{M}_{p,2} \cdot \underline{p}_2 = \underline{M}_{p,1}\,\underline{M}_{p,2}\,\underline{Z}_{a,12}\,\underline{i}_1$$

Thus the product of the pressure sensitivities is given by:

$$\underline{M}_{p,1}\,\underline{M}_{p,2} = \frac{1}{\underline{Z}_{a,12}}\frac{\underline{U}_2}{\underline{i}_1} \qquad (2)$$

5.3 Insert voltage technique

The insert voltage technique is used to determine the open-circuit voltage of a microphone when it is electrically loaded.

Let a microphone having a certain open-circuit voltage and internal impedance be connected to a load impedance. To measure the open-circuit voltage, an impedance, small compared to the load impedance, is connected in series with the microphone and a calibrating voltage applied across it.

Let a sound pressure and a calibrating voltage of the same frequency be applied alternately. When the calibrating voltage is adjusted until it gives the same voltage drop across the load impedance as results from the sound pressure on the microphone, the open-circuit voltage will be equal in magnitude to the calibrating voltage.

5.4 Evaluation of the acoustic transfer impedance

The acoustic transfer impedance $\underline{Z}_{a,12} = \underline{p}_2 / (\underline{M}_{p,1}\underline{i}_1)$ can be evaluated from the equivalent circuit in Figure 1, where $\underline{Z}_{a,1}$ and $\underline{Z}_{a,2}$ are the acoustic impedances of microphones (1) and (2) respectively.

Key

1 Coupler

Figure 1 – Equivalent circuit for evaluating the acoustic transfer impedance $\underline{Z}_{a,12}$

In several cases, $\underline{Z}_{a,12}$ can be evaluated theoretically. Assume the sound pressure to be the same at any point inside the coupler (this will take place when the physical dimensions of the coupler are very small compared to the wavelength). The gas in the coupler then behaves as a pure compliance and, from the equivalent circuit in Figure 2, $\underline{Z}_{a,12}$ is given by $\underline{Z}'_{a,12}$ (assuming adiabatic compression and expansion of the gas):

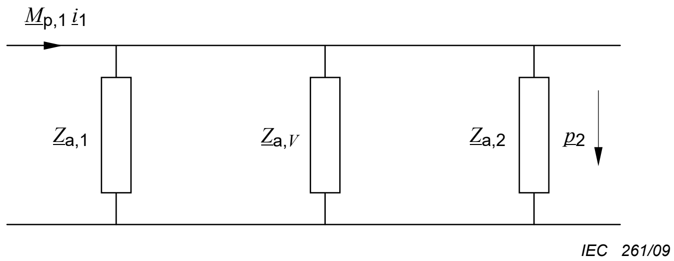

Figure 2 – Equivalent circuit for evaluating $\underline{Z}'_{a,12}$ when coupler dimensions are small compared with wavelength

$$\frac{1}{\underline{Z}'_{a,12}} = \frac{1}{\underline{Z}_{a,V}} + \frac{1}{\underline{Z}_{a,1}} + \frac{1}{\underline{Z}_{a,2}} = j\omega\left(\frac{V}{\kappa\, p_s} + \frac{\underline{V}_{e,1}}{\kappa_r\, p_{s,r}} + \frac{\underline{V}_{e,2}}{\kappa_r\, p_{s,r}}\right) \qquad (3)$$

where

V	is the total geometrical volume of the coupler in cubic metres (m^3);
$\underline{V}_{e,1}$	is the equivalent volume of microphone (1) in cubic metres (m^3);
$\underline{V}_{e,2}$	is the equivalent volume of microphone (2) in cubic metres (m^3);
$\underline{Z}_{a,V} = \frac{\kappa p_s}{j\omega V}$	is the acoustic impedance of the gas enclosed in the coupler in pascal-seconds per cubic metre ($Pa \cdot s/m^3$);
ω	is the angular frequency in radians per second (rad/s);
p_s	is the static pressure in pascals (Pa);
$p_{s,r}$	is the static pressure at reference conditions in pascals (Pa);
κ	is the ratio of the specific heat capacities at measurement conditions;
κ_r	is κ at reference conditions.

Values for κ and κ_r in humid air can be derived from equations given in Annex F.

At higher frequencies, when the dimensions are not sufficiently small compared with the wavelength, the evaluation of $\underline{Z}_{a,12}$ generally becomes complicated. However, if the shape of the coupler is cylindrical and the diameter the same as that of the microphone diaphragms, then, at frequencies where plane-wave transmission can be assumed, the whole system can be considered as a homogeneous transmission line (see Figure 3).

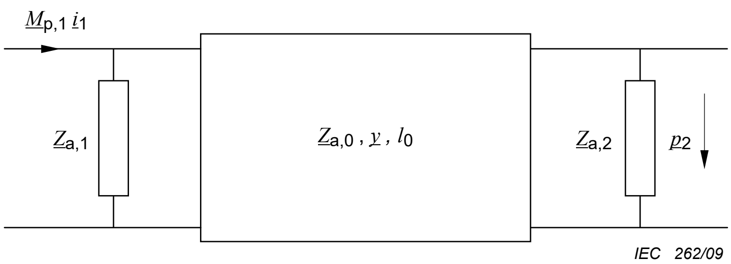

Figure 3 – Equivalent circuit for evaluating $\underline{Z}'_{a,12}$ when plane wave transmission in the coupler can be assumed

$\underline{Z}_{a,12}$ is then given by $\underline{Z}'_{a,12}$ (assuming adiabatic compression and expansion of the gas):