



BSI Standards Publication

Electroacoustics — Measurement microphones

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

National foreword

This British Standard is the UK implementation of EN 61094-2:2009+A1:2022. It is identical to IEC 61094-2:2009, incorporating amendment 1:2022. It supersedes BS EN 61094-2:2009, will be withdrawn on 11 March 2025.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to IEC text carry the number of the IEC amendment. For example, text altered by IEC amendment 1 is indicated by **A1** **A1**.

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

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English version

**Electroacoustics -
Measurement microphones -
Part 2: Primary method for pressure calibration
of laboratory standard microphones
by the reciprocity technique
(IEC 61094-2:2009)**

Electroacoustique -
Microphones de mesure -
Partie 2: Méthode primaire
pour l'étalonnage en pression
des microphones étalons de laboratoire
par la méthode de réciprocité
(CEI 61094-2:2009)

Elektroakustik -
Messmikrofone -
Teil 2: Primärverfahren
zur Druckkammer-Kalibrierung
von Laboratoriums-Normalmikrofonen
nach der Reziprozitätsmethode
(IEC 61094-2:2009)

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CENELEC

European Committee for Electrotechnical Standardization
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Foreword

The text of document 29/671/FDIS, future edition 2 of IEC 61094-2, prepared by IEC TC 29, Electroacoustics, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61094-2 on 2009-03-01.

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EN 61094-2:2009 includes the following significant technical changes with respect to EN 61094-2:1993:

- 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.

The following dates were fixed:

- | | | |
|--|-------|------------|
| – latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement | (dop) | 2009-12-01 |
| – latest date by which the national standards conflicting with the EN have to be withdrawn | (dow) | 2012-03-01 |

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Endorsement notice

The text of the International Standard IEC 61094-2:2009 was approved by CENELEC as a European Standard without any modification.

European foreword to A1

The text of document 29/1108/FDIS, future IEC 61094-2/AMD1, prepared by IEC/TC 29 "Electroacoustics" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61094-2:2009/A1:2022.

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- latest date by which the document has to be implemented at national (dop) 2022-12-11 level by publication of an identical national standard or by endorsement
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Annex ZA (normative)

Normative references to international publications with their corresponding European publications

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

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

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 61094-1	2000	Measurement microphones - Part 1: Specifications for laboratory standard microphones	EN 61094-1	2000
ISO/IEC Guide 98-3 - ¹⁾		Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)	-	-

¹⁾ Undated reference.

CONTENTS

1	Scope.....	7
2	Normative references	7
3	Terms and definitions	7
4	Reference environmental conditions	8
5	Principles of pressure calibration by reciprocity	8
5.1	General principles	8
5.1.1	General	8
5.1.2	General principles using three microphones	8
5.1.3	General principles using two microphones and an auxiliary sound source	8
5.2	Basic expressions	9
5.3	Insert voltage technique	10
5.4	Evaluation of the acoustic transfer impedance	10
5.5	Heat-conduction correction	12
5.6	Capillary tube correction.....	13
5.7	Final expressions for the pressure sensitivity	14
5.7.1	Method using three microphones	14
5.7.2	Method using two microphones and an auxiliary sound source	14
6	Factors influencing the pressure sensitivity of microphones.....	15
6.1	General	15
6.2	Polarizing voltage.....	15
6.3	Ground-shield reference configuration.....	15
6.4	Pressure distribution over the diaphragm	15
6.5	Dependence on environmental conditions	16
6.5.1	Static pressure	16
6.5.2	Temperature.....	16
6.5.3	Humidity	16
6.5.4	Transformation to reference environmental conditions	17
A1 6.6	Influence of leakage A1	17
7	Calibration uncertainty components	17
7.1	General	17
7.2	Electrical transfer impedance	17
7.3	Acoustic transfer impedance	18
7.3.1	General	18
7.3.2	Coupler properties	18
7.3.3	Microphone parameters	19
7.4	Imperfection of theory.....	20
7.5	Uncertainty on pressure sensitivity level.....	21
Annex A (normative)	Heat conduction and viscous losses in a closed cavity	23
Annex B (normative)	Acoustic impedance of a capillary tube.....	27
Annex C (informative)	Examples of cylindrical couplers for calibration of microphones	30
Annex D (informative)	Environmental influence on the sensitivity of microphones	35
Annex E (informative)	Methods for determining microphone parameters	38
Annex F (informative)	Physical properties of humid air.....	41

Figure 1 – Equivalent circuit for evaluating the acoustic transfer impedance $Z_{a,12}$	10
Figure 2 – Equivalent circuit for evaluating $Z'_{a,12}$ when coupler dimensions are small compared with wavelength.....	11
Figure 3 – Equivalent circuit for evaluating $Z'_{a,12}$ when plane wave transmission in the coupler can be assumed	11
Figure C.1 – Mechanical configuration of plane-wave couplers	31
Figure C.2 – Mechanical configuration of large-volume couplers.....	33
Figure D.1 – Examples of static pressure coefficient of LS1P and LS2P microphones relative to the low-frequency value as a function of relative frequency f/f_0	36
Figure D.2 – General frequency dependence of that part of the temperature coefficient for LS1P and LS2P microphones caused by the variation in the impedance of the enclosed air	37
Table 1 – Uncertainty components	22
Table A.1 – Values for Δ_H	25
Table B.1 – Real part of $Z_{a,C}$ in gigapascal-seconds per cubic metre (GPa·s/m ³).....	28
Table B.2 – Imaginary part of $Z_{a,C}$ in gigapascal-seconds per cubic metre (GPa·s/m ³).....	29
Table C.1 – Nominal dimensions for plane-wave couplers.....	32
Table C.2 – Nominal dimensions and tolerances for large-volume couplers	33
Table C.3 – Experimentally determined wave-motion corrections for the air-filled large-volume coupler used with type LS1P microphones	34
Table F.1 – Calculated values of the quantities in Clauses F.1 to F.5 for two sets of environmental conditions	44
Table F.2 – Coefficients used in the equations for humid air properties.....	45

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 ($\text{Pa}\cdot\text{s}/\text{m}^3$).

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:

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

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·s·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·s·m ⁻³), $\underline{M}_p$ being the pressure sensitivity of the microphone in volts per pascal (V·Pa ⁻¹).

NOTE Underlined symbols represent complex quantities.

Equations (1) may then be rewritten as:

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

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:

$$\frac{M_{p,1}}{Z_{a,12}} \frac{M_{p,2}}{i_1} = \frac{1}{Z_{a,12}} \frac{U_2}{i_1} \quad (2)$$

5.3 Insert voltage technique

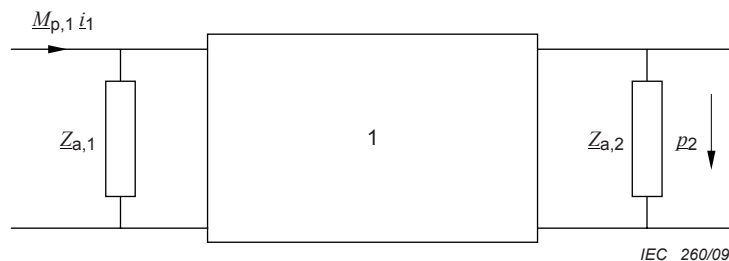
The insert voltage technique is used to determine the open-circuit voltage of a microphone when it is electrically loaded.

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 $Z_{a,12} = p_2 / (M_{p,1} i_1)$ can be evaluated from the equivalent circuit in Figure 1, where $Z_{a,1}$ and $Z_{a,2}$ are the acoustic impedances of microphones (1) and (2) respectively.



Key

1 Coupler

Figure 1 ± Equivalent circuit for evaluating the acoustic transfer impedance $Z_{a,12}$

In several cases, $Z_{a,12}$ 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, $Z_{a,12}$ is given by $Z'_{a,12}$ (assuming adiabatic compression and expansion of the gas):

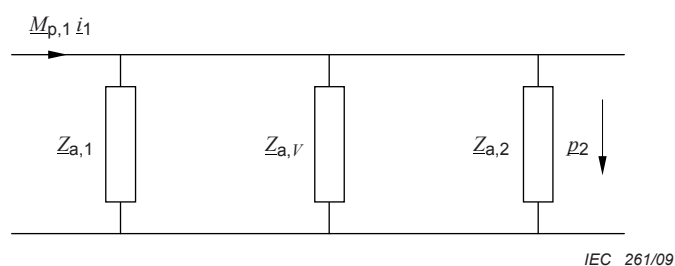


Figure 2 ± Equivalent circuit for evaluating $Z'_{a,12}$ when coupler dimensions are small compared with wavelength

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

where

- V is the total geometrical volume of the coupler in cubic metres (m³);
- $V_{e,1}$ is the equivalent volume of microphone (1) in cubic metres (m³);
- $V_{e,2}$ is the equivalent volume of microphone (2) in cubic metres (m³);
- $Z_{a,V} = \frac{\kappa p_s}{j\omega V}$ is the acoustic impedance of the gas enclosed in the coupler in pascal-seconds per cubic metre (Pa·s/m³);
- 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 $Z_{a,12}$ 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).

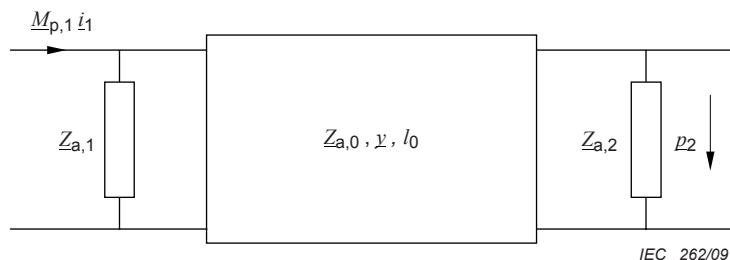


Figure 3 ± Equivalent circuit for evaluating $Z'_{a,12}$ when plane wave transmission in the coupler can be assumed

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

$$\frac{1}{Z'_{a,12}} = \frac{1}{Z_{a,0}} \left[\left(\frac{Z_{a,0}}{Z_{a,1}} + \frac{Z_{a,0}}{Z_{a,2}} \right) \cosh \gamma l_0 + \left(1 + \frac{Z_{a,0}}{Z_{a,1}} \frac{Z_{a,0}}{Z_{a,2}} \right) \sinh \gamma l_0 \right] \quad (4)$$

where

$Z_{a,0}$ is the acoustic impedance of plane waves in the coupler. If losses in the coupler are neglected, then $Z_{a,0} = \rho c / S_0$;

ρ is the density of the gas enclosed in kilograms per cubic metre ($\text{kg}\cdot\text{m}^{-3}$);

c is the free-space speed of sound in the gas in metres per second ($\text{m}\cdot\text{s}^{-1}$);

S_0 is the cross-sectional area of the coupler in square metres (m^2);

l_0 is the length of the coupler, i.e. the distance between the two diaphragms in metres (m);

$\gamma = \alpha + j\beta$ is the complex propagation coefficient in metres to power minus one (m^{-1}).

Values for ρ and c in humid air can be derived from equations given in Annex F.

The real part of γ accounts for the viscous losses and heat conduction at the cylindrical surface and the imaginary part is the angular wave number.

If losses are neglected, γ may be approximated by putting α equal to zero and β equal to ω/c in Equation (4).

Allowance shall be made for any air volume associated with the microphones that is not enclosed by the circumference of the coupler and the two diaphragms (see 7.3.3.1).

5.5 Heat-conduction correction

The evaluation of $Z'_{a,12}$ in the preceding subclause assumes adiabatic conditions in the coupler. However, in practice, the influence of heat conduction at the walls of the coupler causes departure from purely adiabatic conditions, especially for small couplers and low frequencies.

At low frequencies, where the sound pressure can be considered the same at any point and under the assumption that the walls remain at a constant temperature, the influence of the heat conduction losses can be calculated and expressed in terms of a complex correction factor Δ_H to the geometrical volume V in Equation (3). Expressions for the correction factor Δ_H are given in Annex A.

At high frequencies, wave-motion will be present inside the coupler and the sound pressure will no longer be the same at all points. For right-cylindrical couplers where the transmission line theory can be applied (see 5.4), the combined effect of heat conduction and viscous losses along the cylindrical surface can be accounted for by the complex propagation coefficient and acoustic impedance for plane-wave propagation in the coupler. The additional heat conduction at the end surfaces of the coupler, the microphone diaphragms, can be accounted for by including further components in the acoustic impedances of the microphones. Expressions for the complex propagation coefficient and acoustic impedance for plane-wave propagation are given in Annex A.

[A1] At medium frequencies, transmission line theory, Equation (4), is applied to account for plane wave propagation in the coupler, but the influence of heat conduction at the ends of the coupler cannot be modelled accurately as impedances at the end surfaces. However, it

can be demonstrated that, at frequencies where the pressure variations in the length direction of the coupler are moderate, the usable frequency range of the correction factor Δ_H can be extended by application of Δ_H to the cross-sectional area of the coupler, S_0 , for the calculation of the acoustic impedance of the plane waves in the coupler, $Z_{a,0} = \rho c/S_0$ and setting α equal to zero and β equal to ω/c in Equation (4). A1

At high frequencies, wave-motion will be present inside the coupler and the sound pressure will no longer be the same at all points. For right-cylindrical couplers where the transmission line theory can be applied (see 5.4), the combined effect of heat conduction and viscous losses along the cylindrical surface can be accounted for by the complex propagation coefficient and acoustic impedance for plane-wave propagation in the coupler. The additional heat conduction at the end surfaces of the coupler, the microphone diaphragms, can be accounted for by including further components in the acoustic impedances of the microphones. Expressions for the complex propagation coefficient and acoustic impedance for plane-wave propagation are given in Annex A.

A1 NOTE 1 At the lowest frequencies, application of the correction factor Δ_H to the cross-sectional area of the coupler in Equation (4) is effectively the same as application of the factor to the volume in Equation (3).

NOTE 2 The two methods described in this standard for accounting for heat conduction and viscosity are not entirely consistent at any frequency. However, a transition frequency range can be identified for plane wave couplers used for reciprocity calibration. Estimates for the frequency range of validity are given in Annex A. A1

At high frequencies, wave-motion will be present inside the coupler and the sound pressure will no longer be the same at all points. For right-cylindrical couplers where the transmission line theory can be applied (see 5.4), the combined effect of heat conduction and viscous losses along the cylindrical surface can be accounted for by the complex propagation coefficient and acoustic impedance for plane-wave propagation in the coupler. The additional heat conduction at the end surfaces of the coupler, the microphone diaphragms, can be accounted for by including further components in the acoustic impedances of the microphones. Expressions for the complex propagation coefficient and acoustic impedance for plane-wave propagation are given in Annex A.

5.6 Capillary tube correction

The coupler is usually fitted with capillary tubes in order to equalize the static pressure inside and outside the coupler. Two such capillary tubes also permit the introduction of a gas other than air.

The acoustic input impedance of an open capillary tube is given by:

$$Z_{a,C} = Z_{a,t} \tanh \gamma l_C \quad (5)$$

where

$Z_{a,t}$ is the complex acoustic wave impedance of an infinite tube in pascal-seconds per cubic metre ($\text{Pa} \cdot \text{s} \cdot \text{m}^{-3}$);

l_C is the length of the tube in metres (m).

The shunting effect of the capillary tubes can be taken into account by introducing a complex correction factor Δ_C to the acoustic transfer impedances given in Equations (3) and (4):