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TECHNICAL SPECIFICATION

Ultrasonics – Measurements of electroacoustical parameters and acoustic output power of spherically curved transducers using the self-reciprocity method

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ULTRASONICS – MEASUREMENTS OF ELECTROACOUSTICAL PARAMETERS AND ACOUSTIC OUTPUT POWER OF SPHERICALLY CURVED TRANSDUCERS USING THE SELF-RECIPROCITY METHOD

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IEC TS 62903 has been prepared by IEC technical committee 87: Ultrasonics. It is a Technical Specification.

This second edition cancels and replaces the first edition published in 2018. This edition constitutes a technical revision.

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

a) Several quantities are recognized as complex-valued quantities in the definitions and in the main text.
b) Annex I was added to provide typical measurement ranges and to provide example calibration results.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
87/825/DTS	87/829/RVDTS

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

The language used for the development of this Technical Specification is English.

In this document, the following print types are used:

- terms defined in Clause 3: **in bold type**.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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- withdrawn,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

INTRODUCTION

An ultrasonic transducer is an important acoustic device that can act as a transmitter or a receiver in the applications of medical ultrasound, non-destructive testing, and ultrasonic materials processing. The performance of a transducer is a decisive factor that governs the device's range of applicability, efficiency and quality control in the manufacturing. The mechanisms, transmitting fields, performances, and measurement methods used for these transducers have been studied over the past few decades. However, the electroacoustical characterization and measurement methods applied for spherically curved transducers have not been defined in standard documents for either terms or protocols.

This document defines the relevant electroacoustical parameters for these devices and establishes the self-reciprocity measurement method for spherically curved concave focusing transducers.

ULTRASONICS – MEASUREMENTS OF ELECTROACOUSTICAL PARAMETERS AND ACOUSTIC OUTPUT POWER OF SPHERICALLY CURVED TRANSDUCERS USING THE SELF-RECIPROCITY METHOD

1 Scope

This document, which is a Technical Specification,

a) establishes the free-field convergent spherical wave self-reciprocity method for ultrasonic transducer calibration,

b) establishes the measurement conditions and experimental procedure required to determine the transducer's electroacoustic parameters and acoustic output power using the self-reciprocity method,

c) establishes the criteria for checking the reciprocity of these transducers and the linear range of the focused field, and

d) provides guiding information for the assessment of the overall measurement uncertainties for radiation conductance.

This document is applicable to:

1) circular spherically curved concave focusing transducers without a centric hole working in the linear amplitude range,

2) measurements in the frequency range 0,5 MHz to 15 MHz, and

3) acoustic pressure amplitudes in the focused field within the linear amplitude range.

Characterization and sensitivity calibration of hydrophones using the reciprocity method are not addressed in this document but covered in IEC 62127-2 [1][1] and IEC 60565-1 [2].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60050-801, *International Electrotechnical Vocabulary – Chapter 801: Acoustics and electroacoustics*, available at www.electropedia.org

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-801 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

[1] Numbers in square brackets refer to the Bibliography.

3.1
p_{av}
average acoustic pressure
acoustic pressure averaged over the **effective area** of the transducer

Note 1 to entry: **Average acoustic pressure** is expressed in pascals (Pa).

3.2
$r_{av}(\beta)$
average amplitude reflection coefficient
quotient of the **free-field** echo **average acoustic pressure** $p_{av}(\beta)$ reflected by the reflector on the geometric focal plane over the space area coincident with the **effective area** of the spherically curved transducer of focus half-angle β, if the transducer were removed, to the **reference acoustic pressure** p_0 on the **effective area** of the transducer in a non-attenuation medium with negligible diffraction

$$r_{av}(\beta) = p_{av}(\beta)/p_0 \tag{1}$$

3.3
G_{sf}
diffraction correction coefficient
quotient of the **average acoustic pressure** over the spherical segment surface of the spherically curved transducer's virtual image at a position in the distance of twice **geometric focal length** from the transducer, if an ideal reflecting mirror were located on the geometric focal plane, to the **reference acoustic pressure** of the transducer in the **free-field** of a non-attenuation medium

3.4
A
effective area
<transducer> area of the radiating surface of a theoretically predicted transducer with specific field distribution characteristics that are approximately the same as those of a real transducer of the same type

Note 1 to entry: For a spherically curved transducer, the theoretically predicted acoustic pressure distribution on the geometric focal plane of a transducer is expected to be approximately the same as that of the real transducer with the same **geometric focal length** when operating at the same frequency.

Note 2 to entry: The half-aperture of an **effective area** is also named the effective half-aperture or the effective radius.

Note 3 to entry: The **effective area** of a transducer is expressed in units of metre squared (m^2).

3.5
$\eta_{a/e}$
electroacoustic efficiency
quotient of the acoustic output power to the electric input power

3.6
electroacoustical reciprocity principle
electroacoustical reciprocity theorem
principle that the quotient of the **free-field voltage (current) sensitivity** of a **reciprocal transducer** as a receiver, to the **transmitting response to current (voltage)** of the **reciprocal transducer** as a projector is constant

Note 1 to entry: This principle is independent of the construction of the **reciprocal transducer**.

3.7
free-field
sound field in a homogeneous isotropic medium whose boundaries exert a negligible effect on the sound wave

[SOURCE: IEC 61161:2013, 3.2]

3.8
$\underline{M}(f)$
free-field voltage sensitivity
receiving voltage response
<of a spherically curved transducer> quotient of the Fourier transform of the open-circuit output voltage signal $\mathcal{F}(U(t))$ of a spherically curved transducer within the field of a point source at its **geometric focus** to the Fourier transform of the **free-field** acoustic pressure waveform $\mathcal{F}(p(t))$ for a specified frequency f and incidence on the surface of the transducer if the transducer were removed

$$\underline{M}(f) = \frac{\mathcal{F}(U(t))}{\mathcal{F}(p(t))} \quad (2)$$

Note 1 to entry: The **free-field voltage sensitivity** of a spherically curved transducer is a complex-value parameter. The modulus of the **free-field voltage sensitivity** of a spherically curved transducer is expressed in units of volt per pascal (V/Pa). The phase angle is the argument of the sensitivity and represents the phase difference between the electrical transducer output voltage and the incident pressure. The unit of phase is the radian.

3.9
geometric beam boundary
surface containing straight lines passing through the **geometric focus** and all points around the periphery of the transducer aperture

Note 1 to entry: Applies to ultrasonic transducers of known construction.

[SOURCE: IEC 61828:2020, 3.64]

3.10
F_{geo}
geometric focal length
distance from the **geometric focus** to the position where the beam axis intersects the effective focusing surface

Note 1 to entry: Applies to transducers with known construction.

Note 2 to entry: **Geometric focal length** is expressed in metres (m).

Note 3 to entry: This definition applies only to focusing transducers.

[SOURCE: IEC 61828:2020, 3.66]

3.11
geometric focus
point for which all of the effective path lengths in a specified longitudinal plane are equal

Note 1 to entry: Equivalently, the spatial point for which the arrival times of all waves from the transducer have the same delay relative to the voltage excitation of the transducer, as viewed in the approximation of geometrical acoustics, neglecting diffraction.

Note 2 to entry: This definition applies only to focusing transducers.

[SOURCE: IEC 61828:2020, 3.67]

3.12
$L_{M\mathrm{pe}}$
pulse-echo sensitivity level
twenty times the logarithm to the base 10 of the ratio of the received open-circuit voltage U_1 for the first echo signal of the spherically curved transducer when acting as a receiver to the exciting voltage of the transducer U_T when it is transmitting a tone burst ultrasonic beam in a direction perpendicular to an ideal plane reflector (r = 1) at the geometric focal plane for a specified frequency

$$L_{M\mathrm{pe}} = 20\log_{10}\left(\frac{U_1}{U_\mathrm{T}}\right)\mathrm{dB} \tag{3}$$

Note 1 to entry: The logarithmic ratio is expressed in decibels (dB).

3.13
G
radiation conductance
quotient of the acoustic output power and the squared effective transducer input voltage

Note 1 to entry: It is used to characterize the electrical to acoustical transfer of ultrasonic transducers.

Note 2 to entry: The frequency of the input voltage (or current) should be noted.

Note 3 to entry: **Radiation conductance** is expressed in siemens (S).

[SOURCE: IEC 61161:2013, 3.8, modified – In the definition, "RMS" has been replaced with "effective" and "ratio" has been replaced with "quotient".]

3.14
reciprocal transducer
linear, passive and reversible electroacoustic transducer such that the coupling coefficients are equal for transduction regardless of whether transduction is electrical to mechanical or vice versa

[SOURCE: IEC 60565-1:2020, 3.7]

3.15
$\underline{J}$
reciprocity coefficient
<of a transducer> quotient of the **free-field** voltage sensitivity of a **reciprocal transducer** as a receiver to the **transmitting response to current** of the transducer as a projector, or the quotient of the **free-field current sensitivity** of a transducer as a receiver to the **transmitting response to voltage** of the transducer as a projector

$$\underline{J} = \frac{\underline{M}}{\underline{S}_I} \tag{4}$$

Note 1 to entry: The modulus of the **reciprocity coefficient** of a spherically curved transducer, $|\underline{J}| = J_\mathrm{sf}$, is equal to the quotient of twice the **effective area** of the transducer to the acoustic characteristic impedance of the medium, i.e.

$$J_\mathrm{sf} = \frac{|\underline{M}|}{|\underline{S}_I|} = \frac{2A}{\rho c} \tag{5}$$

where

A is the **effective area** of curved surface of the spherically curved transducer;

ρ is the (mass) density of the medium;

c is the speed of sound in the medium (usually water).

Note 2 to entry: The **reciprocity coefficient** is expressed in units of watt per pascal squared ($\mathrm{W/Pa^2}$).

3.16
p_0
reference acoustic pressure
product of the uniform normal particle velocity on the spherically curved surface of the transducer and the characteristic impedance of the medium

Note 1 to entry: **Reference acoustic pressure** is expressed in pascals (Pa).

3.17
reversible transducer
transducer capable of acting as a projector as well as a receiver

[SOURCE: IEC 60565-1:2020, 3.8, modified – In the definition, "hydrophone" has been replaced with "receiver".]

3.18
self-reciprocity method
transducer calibration method based on the reciprocity principle that uses the received echo signal from the plane reflector that is set perpendicular to the incident beam axis of the transducer

3.19
$\underline{S}_I(f)$
transmitting response to current
transmitting current response
<of a transducer> quotient of the Fourier transform of the **reference acoustic pressure** $\mathcal{F}(p_0(t))$ on the radiating surface of a transducer in the **free field** in the absence of interference effects to the Fourier transform of the exciting electrical current $\mathcal{F}(I(t))$ through the electrical terminals of the transducer for a specified frequency f

$$\underline{S}_I(f) = \frac{\mathcal{F}\left(p_0(t)\right)}{\mathcal{F}\left(I(t)\right)} \tag{6}$$

Note 1 to entry: The **transmitting response to current** of a transducer is a complex-valued parameter. The modulus of the **transmitting response to current** is expressed in units of pascal per ampere, Pa·A^{-1}. The phase angle is the argument of the transmitting response and represents the phase difference between the acoustic pressure at the surface of the transducer and the electric current. The unit of phase angle is the radian.

3.20
$\underline{S}_U(f)$
transmitting response to voltage
transmitting voltage response
<of a transducer> quotient of the Fourier transform of the **reference acoustic pressure** $\mathcal{F}(p_0(t))$ on the radiating surface of a transducer in the **free field** in the absence of interference effects to the Fourier transform of the electrical exciting voltage across the terminals of the **projector** $\mathcal{F}(U_\mathrm{T}(t))$, for a specified frequency f

$$\underline{S}_U(f) = \frac{\mathcal{F}\left(p_0(t)\right)}{\mathcal{F}\left(U_\mathrm{T}(t)\right)} \tag{7}$$

Note 1 to entry: The **transmitting response to voltage** of a transducer is a complex-valued parameter. The modulus of the **transmitting response to voltage** is expressed in units of pascal per volt, Pa·V^{-1}. The phase angle is the argument of the transmitting response and represents the phase difference between the reference acoustic pressure at the surface of the transducer and the exciting electrical voltage. The unit of phase angle is the radian.

4 Symbols

a	effective half-aperture, effective radius of transducer
A	**effective area** of transducer
c	speed of sound in sound propagating medium usually in water
d	distance from the centre of the transmitting surface of the transducer to the reflecting plane of the reflector in the geometric focal plane
f_0	resonant frequency
f_c	central frequency
F_geo	**geometric focal length** ($F_\mathrm{geo} = R$)
G	**radiation conductance**
G_sf	**diffraction correction coefficient** for spherically curved transducer in free-field self-reciprocity calibration
h	height (depth) at the centre of a spherical segment
I	acoustic intensity
I_T, I_Trms	exciting current amplitude, effective exciting current
I_k	short-circuit current amplitude of the generator
I_echo	first echo current amplitude
$\underline{J}$	**reciprocity coefficient** of transducer
J_sf	modulus of the **reciprocity coefficient** of spherically curved transducer
k	circular wave number ($k = 2\pi/\lambda$)
k_m	ratio of the acoustic pressure at the **geometric focus** to the **reference acoustic pressure** on the radiation surface of the transducer in a non-attenuating medium
l	distance from the centre of receiving surface of the hydrophone to the centre of the transmitting surface of the transducer along their common axis after alignment
$L_{M\mathrm{pe}}$	**pulse-echo sensitivity level**
$\underline{M}$	**free-field voltage sensitivity (receiving voltage response)** of a spherically curved transducer
p_0	**reference acoustic pressure** of a radiating surface
P	acoustic output power
P_e	electrical input power
q	ratio of the true time-average intensity I to the time-average derived intensity I_p at the **geometric focus** ($q = (1 + \cos\beta)/2$)
Q_m	mechanical quality factor
r	amplitude reflection coefficient
$r_\mathrm{av}(\beta)$	**average amplitude reflection coefficient** on a plane reflector in the geometric focal plane in water for a spherically curved transducer
R	radius of curvature
$\underline{S}_I$	**transmitting response to current**
$\underline{S}_{I\mathrm{f}}$	transmitting response at **geometric focus** to current
$\underline{S}_U$	**transmitting response to voltage**
$\underline{S}_{U\mathrm{f}}$	transmitting response at **geometric focus** to voltage