

# 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-RECIPROCALITY 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:

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## 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.

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# 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:

- i) circular spherically curved concave focusing transducers without a centric hole working in the linear amplitude range,
- ii) measurements in the frequency range 0,5 MHz to 15 MHz, and
- iii) 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]<sup>1</sup> 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:~~1994~~, *International Electrotechnical Vocabulary – Chapter 801: Acoustics and electroacoustics*, available at [www.electropedia.org](http://www.electropedia.org)

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-801:~~1994~~ 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>

<sup>1</sup> Numbers in square brackets refer to the Bibliography.

**3.1** $p_{av}$ **average acoustic pressure**acoustic pressure averaged over the **effective area** of the transducerNote 1 to entry: **Average acoustic pressure** is expressed in pascals (Pa).**3.2** $r_{av}(\beta)$ **average amplitude reflection coefficient**

**ratio** 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  $\beta$ , 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

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

**3.3** $G_{sf}$ **diffraction correction coefficient**

**ratio** 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 ~~should~~ 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<sup>2</sup>).

**3.5** $\eta_{a/e}$ **electroacoustic efficiency**

**ratio** quotient of the acoustic output power to the electric input power

**3.6****electroacoustical reciprocity principle****electroacoustical reciprocity theorem**

principle that the ~~ratio~~ 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 of a spherically curved transducer receiving voltage response of a spherically curved transducer**

~~ratio of the open-circuit output voltage of a spherically curved transducer within the field of a point source at the geometric focus to the free-field acoustic pressure acting on the space surface where the transducer surface was present, if that transducer were removed~~

Note 1 to entry: ~~Free-field voltage sensitivity of a spherically curved transducer is expressed in volts per pascal (V/Pa).~~

<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

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

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 61828:20062020, 3.64]

**3.10**

$F_{\text{geo}}$

**geometric focal length**

distance from the **geometric focus** to the ~~ultrasonic transducer's~~ position where the beam axis intersects the effective focusing surface

Note 1 to entry: Applies to transducers with known construction ~~and is equal to the radius of curvature of the radiating surface.~~

~~Note 2 to entry: The focusing surface is the surface of constant phase, whose periphery is coincident with the transducer's aperture.~~

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: ~~The geometric focus is also~~ 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 61828:2006, 4.2.39, modified — In the definition, the added explanation for the definition "Also, the point for which all...diffraction." has been moved to a Note to entry.~~ IEC 61828:2020, 3.67]

### 3.12

$L_{Mpe}$

#### 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

$$L_{Mpe} = 20 \log_{10} \left( \frac{U_1}{U_T} \right) \text{ dB} \quad (3)$$

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

### 3.13

$G$

#### radiation conductance

~~ratio~~ 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

~~Note 1 to entry: An example of a non-reciprocal transducer is one that mixes a magnetic field device with an electric field device.~~

[SOURCE: ~~IEC 60565:2006, 3.24~~ IEC 60565-1:2020, 3.7]

### 3.15

$J$

#### reciprocity parameter coefficient

<of a transducer> ~~ratio~~ 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 ~~ratio~~ 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

~~Note 1 to entry: The reciprocity parameter of a spherically curved transducer,  $J = J_{\text{eff}}$ , is equal to the quotient of twice the effective area of the transducer divided by the acoustic characteristic impedance of the medium, i.e.~~

$$J_{sf} = 2A(\rho c)$$

where

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

$\rho$  is the (mass) density of the medium;

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

$$J = \frac{M}{S_I} \tag{4}$$

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

$$J_{sf} = \frac{|M|}{|S_I|} = \frac{2A}{\rho c} \tag{5}$$

where

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

$\rho$  is the (mass) density of the medium;

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

Note 2 to entry: The **reciprocity parameter coefficient** is expressed in units of watt per pascal squared (W/Pa<sup>2</sup>).

### 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 60565:2006, 3.26~~ 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

$S_I(f)$

#### transmitting response to current

#### transmitting current response

~~ratio of the reference acoustic pressure on the radiating surface of a transducer in the free-field in the absence of interference effects to the current flowing through the electrical terminals of a projector at a given frequency~~

Note 1 to entry: ~~Transmitting response to current~~ is expressed in pascals per ampere (Pa/A).

<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  $f$