IEC 62127-3

Edition 2.0 2022-12

INTERNATIONAL STANDARD

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Ultrasonics – Hydrophones –
Part 3: Properties of hydrophones for ultrasonic fields

Ultrasons – Hydrophones –
Partie 3: Propriétés des hydrophones pour les champs ultrasoniques

IEC 62127-3:2022-12(en-fr)

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ULTRASONICS – HYDROPHONES –

Part 3: Properties of hydrophones for ultrasonic fields

FOREWORD

IEC 62127-3 has been prepared by IEC technical committee 87: Ultrasonics. It is an International Standard.

This second edition cancels and replaces the first edition published in 2007 and Amendment 1:2013. This edition constitutes a technical revision.

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

a) The upper frequency limit of 40 MHz has been removed.

b) Hydrophone sensitivity definitions have been changed to recognize sensitivities as complex-valued quantities.

c) Procedures to determine the effective hydrophone size have been changed according to the rationale outlined in Annex B.

d) Requirements on the frequencies for which the effective hydrophone size shall be provided have been changed to achieve practicality for increased frequency bands.

e) The new Annex B and Annex C have been added.

f) Annex A has been updated to reflect the changes of the normative parts.

The text of this International Standard is based on the following documents:

Draft	Report on voting
87/818/FDIS	87/824/RVD

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 International Standard is English.

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.

A list of all parts of IEC 62127 series, published under the general title *Ultrasonics – Hydrophones,* can be found on the IEC website.

NOTE Words in **bold** in the text are defined in Clause 3.

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

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- withdrawn,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

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

The spatial and temporal distribution of acoustic pressure in an ultrasonic field in a liquid medium is commonly determined using miniature ultrasonic **hydrophones**. The properties of these **hydrophones** have been dealt with in a number of IEC standards in various aspects. The purpose of this document is to bring together all these specifications and to establish a common standard on the properties of ultrasonic **hydrophones**. The main **hydrophone** application in this context is the measurement of ultrasonic fields emitted by medical diagnostic equipment in water. Other medical applications are field measurements for therapy equipment such as that used in lithotripsy, high-intensity focused ultrasound (HIFU) and physiotherapy. **Hydrophones** are also used extensively in non-medical applications for both product development and quality control including:

– mapping of the ultrasound field within ultrasonic cleaning baths;
– characterization of acoustic fields used in transmission measurement systems (e.g. ultrasonic spectrometers, ultrasonic attenuation meters and velocimeters);
– characterization of acoustic fields used in reflection measurement systems (e.g. Doppler flowmeters).

While the term **hydrophone** can be used in a wider sense, it is understood here as referring to miniature piezoelectric **hydrophones**. It is this instrument type that is used today in various areas of ultrasonics and, in particular, to quantitatively characterize the field structure of medical diagnostic instruments. With regard to other pressure sensor types, such as those based on fibre optics, some of the requirements of this document are applicable to these as well but others are not. If in the future these other **hydrophone** types gain more importance in field measurement practice, their properties will have to be dealt with in a revised version of this document or in a separate one.

Underwater **hydrophones** as covered by IEC 60500, IEC 60565-1, and IEC 60565-2 are not included in this document, although there is an overlap in the frequency ranges. Underwater **hydrophones** are used in natural waters, even in the ocean, and this leads to different technical concepts and requirements. In addition, the main direction of acoustic incidence in underwater applications is at various angles and often at right angles to the **hydrophone axis**, whereas in this document it is assumed that the main direction of acoustic incidence is in the direction of the **hydrophone axis**.

Historically, ultrasonic **hydrophones** were used almost exclusively as amplitude sensors. However, the complex-valued nature of a **hydrophone’s** system response function is well understood and IEC 62127-1:2022 makes use of this within the deconvolution procedures it contains. In this document, requirements are specified for the amplitude aspect of the **hydrophone** sensitivity and recommendations are provided for the phase aspect which can be derived either via calibration, or via calculation methods that are discussed in IEC 62127-1:2022.

ULTRASONICS – HYDROPHONES –

Part 3: Properties of hydrophones for ultrasonic fields

1 Scope

This part of IEC 62127 specifies relevant **hydrophone** characteristics.

This document is applicable to:

– **hydrophones** employing piezoelectric sensor elements, designed to measure the pulsed and continuous wave ultrasonic fields generated by ultrasonic equipment;
– **hydrophones** used for measurements made in water;
– **hydrophones** with or without an associated pre-amplifier.

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 62127-1, *Ultrasonics – Hydrophones – Part 1: Measurement and characterization of medical ultrasonic fields*

IEC 62127-2, *Ultrasonics – Hydrophones – Part 2: Calibration for ultrasonic fields up to 40 MHz*

3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in IEC 62127-1, IEC 62127-2 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

3.1
acoustic pulse waveform
temporal waveform of the **instantaneous acoustic pressure** at a specified position in an acoustic field and displayed over a period sufficiently long to include all significant acoustic information in a single pulse or tone-burst, or one or more cycles in a continuous wave

Note 1 to entry: Temporal waveform is a representation (e.g. oscilloscope presentation or formula) of the **instantaneous acoustic pressure**.

[SOURCE: IEC 62127-1:2022, 3.1]

3.2
directional response
description of the response of a **hydrophone**, as a function of direction of propagation of the incident plane sound wave, in a specified plane through the **reference centre** and at a specified frequency

Note 1 to entry: Although **directional response** is a complex-valued function, it is generally the modulus of **directional response** that is of most interest and this is commonly presented graphically.

[SOURCE: IEC 60565:2006, 3.5, modified – In the definition, ", generally presented graphically," has been deleted; "electro-acoustic transducer" has been replaced by "hydrophone"; and "radiated or incident sound" has been replaced by "incident plane sound wave,".]

3.3
effective hydrophone size
a_{h}
size of a theoretical receiver **hydrophone** that has a predicted **directional response** function with an angular width equal to the observed angular width

Note 1 to entry: The size is usually a function of frequency. For representative experimental data, see [1].

Note 2 to entry: The **effective hydrophone size** is expressed in metres (m).

Note 3 to entry: For hydrophones with a circular geometry, the **effective hydrophone size** is a radius.

Note 4 to entry: For hydrophones with a rectangular geometry, the **effective hydrophone size** is the half of the largest value of the length or width.

[SOURCE: IEC 62127-1:2022, 3.20]

3.4
electric load impedance
$\underline{Z}_{\mathrm{L}}$
complex electric input impedance (consisting of a real and an imaginary part) to which the **hydrophone** unit output cable is connected or is intended to be connected

Note 1 to entry: The **electric load impedance** is expressed in ohms (Ω).

[SOURCE: IEC 62127-1:2022, 3.22]

3.5
end-of-cable
<**hydrophone** or **hydrophone assembly** with integral output cable> relating to the end of the integral output cable

3.6
end-of-cable
<**hydrophone** or **hydrophone assembly** without integral output cable> relating to the output connector firmly connected with the **hydrophone** or **hydrophone assembly** and not to an extra cable

3.7
end-of-cable loaded sensitivity
$\underline{M}_{\mathrm{L}}(f)$
<of a **hydrophone** or **hydrophone assembly**> quotient of the Fourier transformed **hydrophone** voltage-time signal $\mathcal{F}(u_{\mathrm{L}}(t))$ at the end of any integral cable or output connector of a **hydrophone** or **hydrophone assembly**, when connected to a specified **electric load impedance**, to the Fourier transformed **acoustic pulse waveform** $\mathcal{F}(p(t))$ in the undisturbed

free field of a plane wave in the position of the **reference centre** of the **hydrophone** if the **hydrophone** were removed

$$\underline{M}_{\mathrm{L}}(f) = \frac{\mathcal{F}\left(u_{\mathrm{L}}(t)\right)}{\mathcal{F}\left(p(t)\right)} \tag{1}$$

Note 1 to entry: The **end-of-cable loaded sensitivity** is a complex-valued parameter. Its modulus is expressed in units of volt per pascal (V/Pa), its phase angle is expressed in degrees, and represents the phase difference between the electrical voltage and the sound pressure.

3.8
end-of-cable open-circuit sensitivity

$\underline{M}_{\mathrm{c}}(f)$

<of a **hydrophone**> quotient of the Fourier transformed **hydrophone** open-circuit voltage-time signal $\mathcal{F}(u_{\mathrm{c}}(t))$ at the end of any integral cable or output connector of a **hydrophone** to the Fourier transformed **acoustic pulse waveform** $\mathcal{F}(p(t))$ in the undisturbed free field of a plane wave in the position of the **reference centre** of the **hydrophone** if the **hydrophone** were removed

$$\underline{M}_{\mathrm{c}}(f) = \frac{\mathcal{F}\left(u_{\mathrm{c}}(t)\right)}{\mathcal{F}\left(p(t)\right)} \tag{2}$$

Note 1 to entry: The **end-of-cable open-circuit sensitivity** is a complex-valued parameter. Its modulus is expressed in units of volt per pascal (V/Pa), its phase angle is expressed in degrees, and represents the phase difference between the electrical voltage and the sound pressure.

3.9
end-of-cable loaded sensitivity level

$L_{M_{\mathrm{L}}}(f)$

<of a **hydrophone** or **hydrophone assembly**> twenty times the logarithm to the base 10 of the quotient of the modulus of the **end-of-cable loaded sensitivity** $|\underline{M}_{\mathrm{L}}(f)|$ to a reference sensitivity M_{ref}

$$L_{M_{\mathrm{L}}}(f) = 20\log_{10}\frac{\left|\underline{M}_{\mathrm{L}}(f)\right|}{M_{\mathrm{ref}}}\ \mathrm{dB} \tag{3}$$

Note 1 to entry: Commonly used values of the reference sensitivity M_{ref} are 1 V/µPa or 1 V/Pa.

Note 2 to entry: The **end-of-cable loaded sensitivity level** is expressed in decibels (dB).

3.10
free field

sound field in a homogeneous and isotropic medium in which the effects of boundaries are negligible

[SOURCE: IEC 60565:2006, 3.13]

3.11
hydrophone geometrical size
geometrical size of a hydrophone active element
a_g
size defined by the lateral extents of the active element of a **hydrophone**

Note 1 to entry: The **hydrophone geometrical size** is expressed in metres (m).

Note 2 to entry: For **hydrophones** with a circular geometry, the **hydrophone geometrical size** is a radius.

Note 3 to entry: For **hydrophones** with a rectangular geometry, the **hydrophone geometrical size** is a half of the largest value of the length or width.

3.12
hydrophone
transducer that produces electric signals in response to pressure fluctuations in water

[SOURCE: IEC 60050-801:2021, 801-32-26]

3.13
hydrophone assembly
combination of **hydrophone** and **hydrophone pre-amplifier**

3.14
hydrophone axis
nominal symmetry axis of the **hydrophone** active element

Note 1 to entry: Unless stated otherwise (explicitly and quantitatively) by the manufacturer, it is understood for the purposes of this document that this is given by the apparent geometrical symmetry axis of the **hydrophone**.

3.15
hydrophone pre-amplifier
active electronic device connected to, or to be connected to, a particular **hydrophone** and reducing its output impedance

Note 1 to entry: A **hydrophone pre-amplifier** requires a supply voltage (or supply voltages).

Note 2 to entry: The **hydrophone pre-amplifier** may have a forward voltage transmission factor of less than one, i.e. it need not necessarily be a voltage amplifier in the strict sense.

3.16
reference centre
point on or near a **hydrophone** about which its acoustic receiving sensitivity is defined

Note 1 to entry: Unless stated otherwise (explicitly and quantitatively) by the manufacturer, it is understood for the purposes of this document that this is given by the geometrical centre of the front surface of the **hydrophone** active element.

[SOURCE: IEC 60565:2006, 3.25, modified – In the definition, "transducer" has been replaced by "hydrophone" and "transmitting responses" has been omitted. The note has been replaced.]

3.17
uncertainty
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

Note 1 to entry: See ISO/IEC Guide 98-3:2008 [2], 2.2.3.

[SOURCE: IEC 62127-1:2022, 3.92]

4 List of symbols

a_g	**hydrophone geometrical size**
a_h	**effective hydrophone size**
c	speed of sound in a medium
D_H	model function used during the determination of **effective hydrophone size** from a measured **directional response** of a **hydrophone**
f	frequency
k	wavenumber, equal to $2\pi/\lambda$
$L_{M_L}(f)$	**end-of-cable loaded sensitivity level**
$\underline{M}$	general symbol for the complex **hydrophone** sensitivity, $M = \lvert \underline{M} \rvert$ being its modulus and arg($\underline{M}$) being its argument (equal to phase angle)
$\underline{M}_c$	**end-of-cable open-circuit sensitivity**
$\underline{M}_L$	**end-of-cable loaded sensitivity**
$\underline{Z}_h$	complex electric output impedance of a **hydrophone** or **hydrophone assembly**
$\underline{Z}_L$	**electric load impedance**
θ	angle of incidence of an ultrasonic wave with respect to the **hydrophone axis**

5 Hydrophone characteristics

5.1 General

For a full characterization of the hydrophone performance in the frequency range of this document, the following information is required. Examples of information on hydrophone characteristics are provided in Annex A.

NOTE Determination methods are covered in IEC 62127-2.

5.2 Basic information

The following shall be briefly stated:

– the basic physical principles of the transduction process, the type of sensor material involved, the form and geometrical dimensions (diameter, thickness) of the **hydrophone** active element and the needle diameter in case of a needle **hydrophone**;

– the configuration and design of the **hydrophone**;

– whether or not a pre-amplifier is associated with the **hydrophone**; if the pre-amplifier can be disconnected from the **hydrophone**, clear information shall be given as to which pre-amplifier type belongs to which **hydrophone** type;

– the nominal direction of ultrasonic incidence in relation to the **hydrophone.**

NOTE The last point is important, as it has been found in the literature [3][1] that even with membrane **hydrophones**, the response can change upon reversal of the ultrasonic propagation direction in relation to the **hydrophone**.

The following should be briefly stated:

– the lateral and thickness dimensions of the **hydrophone** active element;

– the frequency of the fundamental thickness resonance of the **hydrophone** active element;

– the size and mass of the **hydrophone**;

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

– the recommended **directional response** model (see 5.6.2) appropriate for the **hydrophone**;
– in the case of a membrane **hydrophone**, the acoustic reflection and transmission factor (preferably as a function of frequency);
– information on preamplifier roll-off at low frequencies outside the hydrophone calibration range, if applicable, to support appropriate calibration data extrapolation in accordance with IEC 62127-1:2022.

General note relating to 5.3 and 5.4: if phase information is available, the phase angle (which equals the argument of the complex **hydrophone** sensitivity) should be stated in addition to the sensitivity (which equals the modulus of the complex **hydrophone** sensitivity), as well as the frequency dependence of the phase angle in addition to the frequency dependence of the sensitivity.

5.3 Sensitivity

The modulus of the **end-of-cable** sensitivity of the **hydrophone** or **hydrophone assembly** shall be stated in units of volt per pascal (V/Pa) or in decimal submultiples, or as a logarithmic level in decibels (dB) with reference to a stated sensitivity value.

NOTE 1 Refer to 3.9 regarding the definition of the **end-of-cable loaded sensitivity level**.

If a pre-amplifier contributes to the sensitivity value given, this shall be stated.

It shall be stated whether the sensitivity value given is understood as the **end-of-cable open-circuit sensitivity** or as the **end-of-cable loaded sensitivity**. In the latter case, the relevant electric loading conditions shall be stated, i.e. the **electric load impedance**, in order to obtain the stated sensitivity.

The **uncertainty** of the stated sensitivity shall be given.

The frequency interval over which the sensitivity is given and over which the **uncertainty** applies shall be stated. For the purposes of this document, sensitivity and **uncertainty** values may be given separately for several frequency intervals.

The methods by which the sensitivity and its **uncertainty** have been obtained shall be described.

The temperature dependence of the sensitivity shall be given. The **hydrophone** sensitivity shall be stated as a function of the water temperature, at least over the temperature range 19 °C to 25 °C, or the particular water temperature to which the stated sensitivity relates shall be stated together with the temperature coefficient of the sensitivity.

A recommended calibration period shall be provided in the instructions for use. This recommendation applies unless otherwise stated by specific device application standards.

NOTE 2 A calibration period of one year will be appropriate in most cases.

The **reference centre** shall be stated if the sensitivity does not relate to the geometrical centre of the front surface of the **hydrophone** active element.

NOTE 3 This is particularly important for any phase considerations.

The direction of acoustic incidence shall be stated if the sensitivity does not relate to an incidence in the direction of the **hydrophone axis**.

5.4 Frequency response

5.4.1 Stated frequency band

The frequency band claimed for the **hydrophone** or **hydrophone assembly** shall be stated by giving the lower frequency limit and the upper frequency limit. The modulus of the **end-of-cable** sensitivity of the **hydrophone** or **hydrophone assembly** shall be constant over the stated frequency band with a tolerance which shall also be stated.

5.4.2 Frequency dependence

The modulus of the **end-of-cable** sensitivity or sensitivity level of the **hydrophone** or **hydrophone assembly** as a function of frequency shall be stated either graphically or as a list of values and over a frequency range containing at least the frequency band claimed under 5.4.1. If it is given as a list of values or as discrete points in a graph, the frequency distance between adjacent points should be low enough so that all important details of the frequency dependence are shown and the sensitivity level does not vary by more than ±1 dB between adjacent points.

The frequency response may be given in terms of absolute sensitivity values or in a relative representation, relative with reference to the absolute sensitivity of the **hydrophone** or **hydrophone assembly** at a certain frequency. In the case of the relative representation, the reference sensitivity and the frequency to which it applies shall be stated.

The phase of the **end-of-cable** sensitivity may be given as a function of frequency either graphically or as a list of values.

The statement of the frequency response shall refer to the same conditions (i.e. loaded or open-circuit output of the **hydrophone** or **hydrophone assembly**) as the sensitivity statement in accordance with 5.3.

If the **uncertainty** of the sensitivity values in the frequency response representation differs from the **uncertainty** assessment of 5.3, this shall be clearly stated and the new or additional **uncertainty** shall be given.

If the frequency response is given as a list of absolute sensitivity values (**end-of-cable**, loaded or open-circuit), the sensitivity statement in accordance with 5.3 may be omitted.

NOTE 1 The frequency response can depend on the electric load conditions.

NOTE 2 If, in a practical application, the **hydrophone** or **hydrophone assembly** is used with subsequent electronic components such as an amplifier, oscilloscope, etc., the frequency response of the whole system will also be, of course, influenced by the frequency response of these additional components.

5.5 Directional response

5.5.1 General

Directional response, and quantities derived from it, are subject to numerous changes relative to the first edition of IEC 62127-3. Details for the rationale behind these changes can be found in Annex B.

5.5.2 Determination of the directional response

The **directional response** of the **hydrophone** shall be stated at a minimum of three frequencies where the lowest and highest frequencies are as widely separated as possible.

– The lowest frequency at which the **directional response** of the **hydrophone** has been determined should be the lower limit of the frequency band claimed under 5.4.1. If not, the reason(s) for variation shall be stated.