INTERNATIONAL STANDARD

IEC 62092

First edition
2001-08

**Ultrasonics – Hydrophones –
Characteristics and calibration in the
frequency range from 15 MHz to 40 MHz**

*Ultrasons – Hydrophones –
Caractéristiques et étalonnage dans la gamme
de fréquences de 15 MHz à 40 MHz*

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ULTRASONICS – HYDROPHONES – CHARACTERISTICS AND CALIBRATION IN THE FREQUENCY RANGE FROM 15 MHz TO 40 MHz

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.
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International Standard IEC 62092 has been prepared by IEC technical committee 87: Ultrasonics.

The text of this standard is based on the following documents:

FDIS	Report on voting
87/203A/FDIS	87/209/RVD

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

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

Annexes A, B, C, D and E are for information only.

The committee has decided that the contents of this publication will remain unchanged until 2006. At this date, the publication will be

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- withdrawn;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

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 characteristics and calibration of these **hydrophones** have been dealt with in a number of IEC standards in the frequency range 0,5 MHz to 15 MHz. The purpose of this International Standard is to extend this frequency range up to 40 MHz. The main **hydrophone** application in this context is the measurement of ultrasonic fields emitted by medical diagnostic equipment in water. It has turned out in recent years that **hydrophone** operation in the frequency range above 15 MHz is important to characterize fully this equipment, primarily due to the increased appearance of high-frequency components in the ultrasonic signals, caused by nonlinear propagation. In addition, the number of medical ultrasonic systems which use frequencies above 15 MHz, particularly intra-operative probes, is growing.

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 which is used today in various areas of medical ultrasonics and particularly to characterize quantitatively the field structure of medical diagnostic instruments. With regard to other pressure sensor types such as those based on fibre optics, some of the prescriptions of this International Standard 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 characteristics and calibration will have to be dealt with in a revised version of this International Standard or in a separate one.

In agreement with present measurement practice, **hydrophones** are dealt with in this International Standard as amplitude sensors and not as phase sensors. If phase measurements were to become important in the future, this standard would need revision, with more rigorous requirements being necessary for that kind of measurement.

NOTE 1 Accordingly, the **hydrophone** sensitivity is understood as a real quantity (expressing the ratio of amplitudes) throughout this International Standard.

NOTE 2 This International Standard covers the frequency range from 15 to 40 MHz. **Hydrophone** properties and **hydrophone** calibration up to 15 MHz are covered by the International Standards IEC 60866 and IEC 61101. In practice, the useful frequency range of a **hydrophone** may well extend into both frequency ranges, below and above 15 MHz. It has therefore been the aim to keep the regulations of this International Standard as far as possible similar to those of the aforementioned standards. Differences are due either to different technical needs in the respective frequency ranges or to the technical and scientific progress achieved since the publication of the aforementioned standards. At present there are maintenance activities aiming at re-structuring and merging, where possible, all existing **hydrophone** standards. It can be expected that this will lead to unified standards covering the whole field of practical **hydrophone** application.

ULTRASONICS – HYDROPHONES – CHARACTERISTICS AND CALIBRATION IN THE FREQUENCY RANGE FROM 15 MHz TO 40 MHz

1 Scope

This International Standard 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 and in the frequency range between 15 MHz and 40 MHz;
- **hydrophones** with or without an integral amplifier;
- **hydrophones** with a circular piezoelectrically active element.

This International Standard specifies

- relevant **hydrophone** characteristics;
- methods of determining **directional response** and **hydrophone** sensitivity based on relative or comparative measurements;

and describes

- absolute **hydrophone** calibration methods.

Recommendations and references to accepted literature are made for the various relative and absolute calibration methods in the frequency range covered by this International Standard.

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 60866:1987, *Characteristics and calibration of hydrophones for operation in the frequency range 0,5 MHz to 15 MHz*

IEC 61101:1991, *The absolute calibration of hydrophones using the planar scanning technique in the frequency range 0,5 MHz to 15 MHz*

IEC 61102:1991, *Measurement and characterisation of ultrasonic fields using hydrophones in the frequency range 0,5 MHz to 15 MHz*

IEC 61161:1992, *Ultrasonic power measurement in liquids in the frequency range 0,5 MHz to 25 MHz* [1]
Amendment 1 (1998)

IEC 61828:—, *Ultrasonics – Focusing transducers – Definitions and measurement methods for the transmitted fields* [2]

[1] There exists a consolidated edition 1.1 (1998) that includes IEC 61161 (1992) and its amendment 1 (1998).

[2] To be published.

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1
acoustic centre
the point on or near a transducer from which the spherically divergent sound waves emitted by the transducer, and observable at remote points, appear to diverge

[definition 3.3 of IEC 60866]

3.2
beam-alignment axis
used for alignment purposes only, **beam-alignment axis** is a straight line joining two points of spatial-peak temporal-peak acoustic pressure on two hemispherical surfaces whose centres are at the approximate geometrical centre of an ultrasonic transducer or ultrasonic transducer element group. One hemisphere has a radius of curvature of approximately $A_g/\pi\lambda$, where A_g is the geometrical area of the ultrasonic transducer or ultrasonic transducer element group and λ is the wavelength of the ultrasound corresponding to the nominal frequency. The second hemisphere has a radius of curvature either $2A_g/\pi\lambda$, or $A_g/3\pi\lambda$, whichever is the more appropriate. For the purposes of alignment, this line may be projected to the face of the ultrasonic transducer or ultrasonic transducer element group.

For most practical applications, two plane surfaces perpendicular to the direction of propagation of the ultrasound are used. In cases where a unique peak is not located on a hemispherical surface, another hemispherical surface is chosen with a different radius of curvature yielding a unique peak

[definition 3.5 of IEC 61102]

3.3
directional response

directional response of a hydrophone
description, generally presented graphically, 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 **acoustic centre** and at a specified frequency

[definition 3.12 of IEC 60866]

3.4
effective radius
effective radius of a hydrophone active element
radius of a stiff disc receiver **hydrophone** which has a predicted **directional response** function with an angular width equal to the observed angular width. The angular width is determined at a specified level below the peak of the **directional response** function. For the specified levels of 3 dB and 6 dB, the radii are denoted by a_3 and a_6 respectively

[definitions 3.4 of IEC 61101 and 3.13 of IEC 61102]

Symbols: a, a_3, a_6

Unit: metre, m

3.5
electric load impedance
electric input impedance (consisting of a real and an imaginary part) to which the **hydrophone** unit output cable is connected or is to be connected

Symbol: Z_L

Unit: ohm, Ω

3.6
end-of-cable loaded sensitivity
end-of-cable loaded sensitivity of a hydrophone
ratio of the instantaneous voltage at the end of any integral cable or connector of a **hydrophone**, when connected to a specified electrical input impedance, to the instantaneous acoustic pressure in the undisturbed free field of a plane wave in the position of the **acoustic centre** of the **hydrophone** if the **hydrophone** were removed

[definitions 3.5 of IEC 61101 and 3.14 of IEC 61102, modified]

Symbol: M_L

Unit: volt per pascal, V/Pa

3.7
end-of-cable open-circuit sensitivity
end-of-cable open-circuit sensitivity of a hydrophone
ratio of the instantaneous open-circuit voltage at the end of any integral cable or connector of a **hydrophone** to the instantaneous acoustic pressure in the undisturbed free field of a plane wave in the position of the **acoustic centre** of the **hydrophone** if the **hydrophone** were removed

[definition 3.15 of IEC 61102, modified]

Symbol: M_c

Unit: volt per pascal, V/Pa

3.8
far field
the sound field at a distance from the source where the instantaneous values of the sound pressure and particle velocity are substantially in phase

[definition 3.2 of IEC 60866]

NOTE 1 In the **far field** the sound pressure appears to be spherically divergent from a point on or near the radiating surface. Hence the pressure produced by the sound source is approximately inversely proportional to the distance from the source.

NOTE 2 The term "**far field**" is used in this International Standard only in connection with non-focusing source transducers. For focusing transducers a different terminology for the various parts of the transmitted field applies (see IEC 61828).

3.9
hydrophone geometrical radius
geometrical radius of a hydrophone active element
radius defined by the dimensions of the active element of a **hydrophone**

[definition 3.18 of IEC 61102]

Symbol: a_g

Unit: metre, m

3.10
hydrophone
transducer that produces electrical signals in response to waterborne acoustic signals

[See 3.4 of IEC 60866 and 3.19 of IEC 61102]

3.11
hydrophone axis
nominal symmetry axis of the **hydrophone** active element

NOTE Unless stated otherwise (explicitly and quantitatively) by the manufacturer, it is understood for the purposes of this standard that this is given by the apparent geometrical symmetry axis of the **hydrophone**.

3.12
integral amplifier
active electronic device connected firmly to the **hydrophone** and reducing its output impedance

NOTE 1 An **integral amplifier** requires a supply voltage (or supply voltages).

NOTE 2 The **integral 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.

3.13
pulse duration
1,25 times the interval between the time when the time integral of the square of the instantaneous acoustic pressure reaches 10 % and 90 % of its final value

[definition 3.30 of IEC 61102, modified]

3.14
uncertainty
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

[See 2.2.3 of the ISO/IEC Guide to the Expression of Uncertainty in Measurement [1][3]]

4 List of symbols

a	=	**effective radius** (a_3, a_6: with special reference to a 3 dB or 6 dB definition, respectively)
a_g	=	**hydrophone geometrical radius**
a_{max}	=	maximum **effective radius**
a_t	=	radius of a source transducer
A_g	=	geometrical area of a source transducer
B/A	=	Fox-Wallace non-linearity parameter
c	=	speed of sound in the measurement liquid (water)
e	=	base of natural logarithms
f	=	frequency
f_f	=	fundamental drive frequency of a signal used to generate non-linear distortion
f_u	=	upper frequency limit of the stated frequency band of a **hydrophone**
F	=	geometric focal length of a focusing transducer
k	=	circular wave number
M_c	=	**end-of-cable open-circuit sensitivity**

[3] Numbers in square brackets refer to the bibliography in annex F.

M_L = **end-of-cable loaded sensitivity**

n = harmonic number

p_0 = pressure amplitude

r = path length from the transducer rim to a field point

R = lateral distance from the **beam-alignment axis** (R_{maxE}, R_{maxH}: maximum values with respect to avoiding edge-wave and head-wave interference, respectively)

t_H = arrival time of the nearest head wave

t_{TDS} = time available for a free-field measurement in time delay spectrometry

T = acoustic transmission factor

v_t = speed of a radial wave in a transducer plate

w_f = beam width of the fundamental-frequency field component

x = coordinate along the **beam-alignment axis** and starting from the transducer surface (x_1, x_2, x_3 and x_4 are special distance values according to certain criteria involving edge waves and head waves)

x_{min} = minimum distance for a finite-size **hydrophone** from a transducer

x_{pf} = distance of the pressure focus from a focusing transducer

Δx = distance difference

Z_h = electric output impedance of a **hydrophone**

Z_L = **electric load impedance**

α = small-signal, plane-wave amplitude attenuation coefficient of the measurement liquid (water)

β = non-linearity parameter in the sense of $\beta = 1 + B/(2A)$

γ = ratio of beam diameter to **hydrophone** diameter

δ = pressure amplitude correction for finite **hydrophone** size

ζ = acoustic displacement as measured by an optical interferometer

θ = angle of incidence of an ultrasonic wave with respect to the **hydrophone axis** (θ_3, θ_6: with special reference to a 3 dB or 6 dB definition, respectively)

λ = ultrasonic wavelength

λ_1 = optical wavelength

ξ = $\pi/2$ times the Rayleigh length (a_t^2/λ , see IEC 61828) of a focusing transducer

ρ = (mass) density of the measurement liquid (water)

σ, σ_m = non-linear distortion parameter

τ = **pulse duration** or burst duration (τ_{maxE} , τ_{maxH} : maximum values with respect to avoiding edge-wave and head-wave interference, respectively)

ω = circular frequency

5 Hydrophone characteristics

5.1 General

For a full characterization of the **hydrophone** performance in the frequency range of this International Standard, the following information is required.

5.2 Basic information

The following shall be briefly stated:

- the basic physical principles of the transduction process, the type of material involved and the form and geometrical dimensions (diameter, thickness) of the **hydrophone** active element;
- the configuration and design of the **hydrophone**;

NOTE 1 In the case of a membrane **hydrophone**, for example, it is important to know whether the **hydrophone** is of the coplanar or the bilaminar type.

- whether or not an **integral amplifier** is included in the **hydrophone** unit;
- the nominal direction of ultrasonic incidence in relation to the **hydrophone**.

NOTE 2 The last point is important, as it has been found in the literature [2] that even with membrane **hydrophones**, the response may change upon reversal of the ultrasonic propagation direction in relation to the **hydrophone**.

The frequency of the fundamental thickness resonance of the **hydrophone** active element should also be stated.

5.3 Hydrophone class

Since **hydrophones** are used for many different types of measurement, it is not necessary to demand the highest performance specifications for every standard device. Two classes of **hydrophones**, Class 1 and Class 2, to be used for standardized measurement purposes in the frequency range dealt with (15 MHz to 40 MHz) are therefore specified as follows.

The end-of-cable sensitivity level of the **hydrophone** unit (with or without an **integral amplifier**) as a function of frequency shall be constant, over a stated bandwidth of at least one octave in the frequency range from 15 MHz to 40 MHz, with a tolerance of ±2 dB for Class 1 and ±4 dB for Class 2. In addition, it shall not vary by more than ±0,5 dB (Class 1) and ±1 dB (Class 2) within any frequency increment of 1 MHz falling inside the frequency band stated.

NOTE 1 The upper frequency limit of the stated frequency band establishing the class of the **hydrophone** will appear frequently and be referred to as f_u in this International Standard.

NOTE 2 The bandwidth criteria for Class 1 and Class 2 **hydrophones** relate to their ability to measure accurately acoustic fields within which a range of frequency components are present. Typically, but not exclusively, the full quantitative characterization of ultrasonic fields within the frequency range of this standard will require the use of a Class 1 **hydrophone**. In contrast, Class 2 **hydrophones** will be appropriate for use when relative measurements are required, for example in the determination of the spatial characteristics of a field.

NOTE 3 Rather similar **hydrophone** classes having, however, different names, namely Class A and Class B, have been defined in IEC 60866. Note that the two standards cover different frequency ranges and that the class definitions in the two standards therefore do not interfere with each other. If a **hydrophone** whose useful frequency range is sufficiently broad is to be qualified under both standards, four combinations of **hydrophone** classes are possible as follows: Class A + Class 1; Class A + Class 2; Class B + Class 1; Class B + Class 2.

5.4 Sensitivity

The end-of-cable sensitivity of the **hydrophone** unit shall be stated in V/Pa or in decimal submultiples, or as a logarithmic level in dB with reference to a stated sensitivity value.

If an **integral amplifier** contributes to the sensitivity value given, this shall be stated.

NOTE 1 "End-of-cable" refers to the end of the output cable of the **hydrophone** unit, with or without an **integral amplifier**.

It shall be stated whether the sensitivity value given is understood as **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.

NOTE 2 Table A.1 summarizes overall measurement **uncertainties** of the most widely used calibration techniques.

The frequency interval over which the sensitivity is given and over which the **uncertainty** applies shall be stated. For the purposes of this standard, 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.

5.5 Frequency response

The **hydrophone** sensitivity 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 5.3. If it is given as a list of values or as discrete points in a graph, the frequency distance between adjacent points should not be greater than 1 MHz, as far as the frequency range of this International Standard is concerned.

The frequency response may be given in terms of absolute sensitivity values or in a relative representation, relative with reference to the absolute **hydrophone** sensitivity 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 statement of the frequency response should refer to the same conditions as the sensitivity statement according to 5.4. If it is understood as referring to different conditions, this shall be clearly stated and formulas shall be given for interrelating the various sensitivities.

If the **uncertainty** of the sensitivity values in the frequency response representation differs from the general **uncertainty** assessment of 5.4, this shall be clearly stated and the new or additional **uncertainty** be given. In case the frequency response is presented graphically only, the additional **uncertainty** due to reading of the graph shall be less than 10 % of the total **uncertainty** listed.

If the frequency response is given as a list of absolute sensitivity values, the sensitivity statement according to 5.4 may be omitted.

NOTE 1 The frequency response and, hence, the **hydrophone** class, may depend on the electric load conditions.

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