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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Ultrasonics – Hydrophones –
Part 2: Calibration for ultrasonic fields up to 40 MHz

Ultrasons – Hydrophones –
Partie 2: Etalonnage des champs ultrasoniques jusqu'à 40 MHz

IEC 62127-2:2007

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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CONTENTS

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ULTRASONICS – HYDROPHONES –

Part 2: Calibration for ultrasonic fields up to 40 MHz

FOREWORD

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International Standard IEC 62127-2 has been prepared by IEC technical committee 87: Ultrasonics.

IEC 62127-1, IEC 62127-2 and IEC 62127-3 are being published simultaneously. Together these cancel and replace IEC 60866:1987, IEC 61101:1991, IEC 61102:1991, IEC 61220:1993 and IEC 62092:2001.

This bilingual version (2012-06) corresponds to the monolingual English version, published in 2007-08.

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

Enquiry draft	Report on voting
87/353/CDV	87/372/RVC

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

The French version of this standard has not been voted upon.

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

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 publication will remain unchanged until the maintenance result date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn;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

The contents of the corrigendum of August 2008 have been included in this copy.

INTRODUCTION

The spatial and temporal distribution of acoustic pressure in an ultrasonic field in a liquid medium is commonly determined using miniature ultrasonic **hydrophones**. These devices are not absolute measurement instruments and require calibration. The purpose of this part of IEC 62127 is to specify those calibration methods to be used in determining the response of a **hydrophone** in the ultrasonic range, i.e. above 20 kHz up to a frequency of 40 MHz. The main **hydrophone** application in this context lies in the measurement of ultrasonic fields emitted by medical diagnostic equipment in water. **Hydrophone** behaviour over this wide frequency band is required in order to reliably characterize the acoustic parameters of the applied acoustic field. In particular, the frequency range above 15 MHz is important to fully characterize this equipment, primarily due to the increased appearance of high-frequency components in the ultrasonic signals, caused by non-linear propagation. In addition, the number of medical ultrasonic systems that use frequencies above 15 MHz, particularly intra-operative probes, is growing. It has turned out in recent years that the **hydrophone** response below 0,5 MHz is also required to reliably determine the peak-negative (rarefactional) acoustic pressure.

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 medical ultrasonics and, in particular, 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 requirements of this 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 standard or in a separate one.

NOTE This standard covers the ultrasonic frequency range, from 20 kHz to an upper frequency of 40 MHz. Standards dealing with **hydrophone** properties (IEC 62127-3) and **hydrophone** use (IEC 62127-1) are being developed in parallel as part of a programme of maintenance activities aimed at restructuring and merging, where possible, all existing ultrasonic **hydrophone** standards. This will eventually lead to unified standards covering the whole field of practical **hydrophone** application.

ULTRASONICS – HYDROPHONES –

Part 2: Calibration for ultrasonic fields up to 40 MHz

1 Scope

This part of IEC 62127 specifies:

- absolute **hydrophone** calibration methods;
- relative (comparative) **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 standard.

This standard is applicable to

- **hydrophones** used for measurements made in water and in the ultrasonic frequency range up to 40 MHz;

  NOTE 1 Although some physiotherapy medical applications of medical ultrasound are developing which operate in the frequency range 40 kHz to 100 kHz, the primary frequency range of diagnostic imaging remains above 2 MHz. It has recently been established that, even in the latter case, the **hydrophone** response at substantially lower frequencies can influence measurements made of key acoustic parameters [1].

- **hydrophones** employing circular piezoelectric sensor elements, designed to measure the pulsed wave and continuous wave ultrasonic fields generated by ultrasonic equipment;

  NOTE 2 Some hydrophones can have non-circular active elements, arising from slight deviations from a circular structure caused, for example by electrode structure, or conversely, the active elements can actually be squares. The clauses within this standard remain valid, although, in these cases, special attention should be paid to the directional response and to the effective radii of the active element through various axes of rotation.

- **hydrophones** with or without a hydrophone pre-amplifier.

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 60050-801:1994, *International Electrotechnical Vocabulary – Chapter 801: Acoustics and electro-acoustics*

IEC 60565, *Underwater acoustics – Hydrophones – Calibration in the frequency range 0,01 Hz to 1 MHz*

IEC 61161:2006, *Ultrasonics – Power measurement – Radiation force balances and performance requirements*

IEC 61828:2006, *Ultrasonics – Focusing transducers – Definitions and measurement methods for the transmitted fields*

IEC 62127-1, *Ultrasonics – Hydrophones – Part 1: Measurement and characterization of medical ultrasonic fields up to 40 MHz*

IEC 62127-3, *Ultrasonics – Hydrophones – Part 3: Properties of hydrophones 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 and the following apply.

3.1
acoustic centre
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

3.2
beam axis
straight line that passes through the **beam centrepoints** of two planes perpendicular to the line which connects the point of maximal **pulse-pressure-squared integral** with the centre of the **external transducer aperture**

NOTE 1 The location of the first plane is the location of the plane containing the maximum **pulse-pressure-squared integral** or, alternatively, is one containing a single main lobe which is in the focal Fraunhofer zone. The location of the second plane is as far as is practicable from the first plane and parallel to the first with the same two orthogonal scan lines (x and y axes) used for the first plane.

NOTE 2 In a number of cases, the term **pulse-pressure-squared integral** is replaced in the above definition by any linearly related quantity, for example

a) in the case of a continuous wave signal the term **pulse-pressure-squared integral** is replaced by mean square acoustic pressure as defined in IEC 61689,

b) in cases where signal synchronisation with the scanframe is not available the term **pulse-pressure-squared integral** may be replaced by **temporal average intensity**.

NOTE 3 See Figure 1 of IEC 62127-1.

NOTE 4 Definition adopted from IEC 62127-1.

3.3
beam centrepoint

position determined by the intersection of two lines passing through the **beamwidth midpoints** of two orthogonal planes, *xz* and *yz*

NOTE Definition adopted from IEC 61828:2001.

3.4
beamwidth
w_6, w_{12}, w_{20}

greatest distance between two points on a specified axis perpendicular to the **beam axis** where the **pulse-pressure-squared integral** falls below its maximum on the specified axis by a specified amount

NOTE 1 In a number of cases, the term **pulse-pressure-squared integral** is replaced in the above definition by any linearly related quantity, for example

a) in the case of a continuous wave signal the term **pulse-pressure-squared integral** is replaced by mean square acoustic pressure as defined in IEC 61689,

b) in cases where signal synchronisation with the scanframe is not available the term **pulse-pressure-squared integral** may be replaced by **temporal average intensity**.

NOTE 2 Commonly used **beamwidths** are specified at – 6 dB, –12 dB and –20 dB levels below the maximum. The decibel calculation implies taking 10 times the logarithm of the ratios of the integrals.

NOTE 3 **Beamwidth** is expressed in metres (m).

NOTE 4 Definition adopted from IEC 62127-1.

3.5
beamwidth midpoint
linear average of the location of the centres of **beamwidth**s in a plane

NOTE 1 The average is taken over 20 beamwidth levels corresponding to intervals in the −0,1 dB to −26 dB range (see IEC 61828, Clause B.2).

NOTE 2 Definition adopted from IEC 61828:2001.

3.6
beam centre
point in a plane in the **far field**, usually perpendicular to the **beam axis**, at which the **spatial-peak temporal-peak acoustic pressure** occurs

3.7
diametrical beam scan
set of measurements of the hydrophone output voltage made while moving the hydrophone in a straight line passing through a point on the beam axis and in a direction normal to the beam axis

NOTE 1 The **diametrical beam scan** may extend to different distances on either side of the **beam axis**.

NOTE 2 Definition adopted from IEC 62127-1.

3.8
directional response
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 **reference centre** and at a specified frequency

NOTE Definition adopted from IEC 60565.

3.9
effective radius of a non-focused ultrasonic transducer
a_t
radius of a perfect disc piston-like ultrasonic source transducer that has a predicted axial acoustic pressure distribution approximately equivalent to the observed axial acoustic pressure distribution over an axial distance until at least the last axial maximum has passed

NOTE 1 The **effective radius of an non-focused ultrasonic transducer** is expressed in metres (m).

NOTE 2 Definition adopted from IEC 62127-1.

3.10
effective hydrophone radius
a_h, a_{h3}, a_{h6}
radius of a stiff disc receiver **hydrophone** that has a predicted **directional response** function with an angular width equal to the observed angular width

NOTE 1 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_{h3} and a_{h6} respectively.

NOTE 2 The **effective hydrophone radius** is expressed in metres (m).

NOTE 3 The radius is usually a function of frequency. For representative experimental data, see [2].

NOTE 4 Definition adopted from IEC 62127-3.

3.11
electric load impedance
$\underline{Z}_L$

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

NOTE 1 The **electric load impedance** is expressed in ohms (Ω).

NOTE 2 Definition adopted from IEC 62127-3.

3.12
end-of-cable loaded sensitivity
end-of-cable loaded sensitivity of a **hydrophone** (or **hydrophone-assembly**)
$M_L(f)$

ratio of the instantaneous voltage 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 **instantaneous acoustic pressure** in the undisturbed free field of a plane wave in the position of the reference centre of the **hydrophone** if the **hydrophone** were removed

NOTE 1 **End-of-cable loaded sensitivity** is expressed in volts per pascal (V/Pa).

NOTE 2 Definition adopted from IEC 62127-3.

3.13
end-of-cable open-circuit sensitivity
end-of-cable open-circuit sensitivity of a hydrophone
$M_c(f)$

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

NOTE 1 **End-of-cable open-circuit sensitivity** is expressed in volts per pascal (V/Pa).

NOTE 2 Definition adopted from IEC 62127-3.

3.14
external transducer aperture
part of the surface of the **ultrasonic transducer** or **ultrasonic transducer element group** assembly that emits ultrasonic radiation into the propagation medium.

NOTE 1 This surface is either directly in contact with the patient or is in contact with a water or liquid path to the patient (see Figure 2 of IEC 62127-1).

NOTE 2 Definition adopted from IEC 61828:2001.

3.15
far field
acoustic (sound) field at distances from an **ultrasonic transducer** where the values of the **instantaneous acoustic pressure** and particle velocity are substantially in phase (see also IEC 60050-801, 801-23-30)

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 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).

3.16
free field
sound field in a homogeneous and isotropic medium in which the effects of boundaries are negligible

NOTE Definition adopted from IEC 60565: 2006, 3.13.

3.17
hydrophone
transducer that produces electric signals in response to waterborne acoustic signals.

NOTE Definition adopted from IEC 60050-801, 801-32-26.

3.18
hydrophone assembly
combination of **hydrophone** and **hydrophone pre-amplifier**

NOTE 2 Definition adopted from IEC 62127-3.

3.19
hydrophone axis
nominal symmetry axis of the **hydrophone** active element

NOTE 1 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**.

NOTE 2 Definition adopted from IEC 62127-3.

3.20
hydrophone geometrical radius
geometrical radius of a hydrophone active element
a_g
radius defined by the dimensions of the active element of a **hydrophone**

NOTE 1 The **hydrophone geometrical radius** is expressed in metres (m)

NOTE 2 Definition adopted from IEC 62127-3.

3.21
hydrophone pre-amplifier
active electronic device connected to, or to be connected to, a particular hydrophone and reducing its output impedance

NOTE 1 A **hydrophone pre-amplifier** requires a supply voltage (or supply voltages).

NOTE 2 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.

NOTE 3 Definition adopted from IEC 62127-3.

3.22
instantaneous acoustic pressure
$p(t)$
pressure minus the ambient pressure at a particular instant in time and at a particular point in an acoustic field (see also IEC 60050-801, 801-21-19)

NOTE 1 **Instantaneous acoustic pressure** is expressed in pascal (Pa).

NOTE 2 Definition adopted from IEC 62127-1.

3.23
instantaneous intensity
I(t)

acoustic energy transmitted per unit time in the direction of acoustic wave propagation per unit area normal to this direction at a particular instant in time and at a particular point in an acoustic field

NOTE 1 Instantaneous intensity is the product of instantaneous acoustic pressure and particle velocity. It is difficult to measure intensity in the ultrasound frequency range. For the measurement purposes referred to in this standard, and if it is reasonable to assume **far field** conditions, the **instantaneous intensity**, *I* is approximated as

$$I(t) = \frac{p(t)^2}{\rho c} \tag{1}$$

where

$p(t)$ is the **instantaneous acoustic pressure**;

ρ is the density of the medium;

c is the velocity of sound in the medium.

NOTE 2 Instantaneous intensity is expressed in watts per metre squared (W/m^2).

3.24
reference centre
point on or near a **hydrophone** about which its acoustic receiving sensitivity is defined

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 geometrical centre of the front surface of the **hydrophone** active element.

(See IEC 60565: 2006, 3.25)

3.25
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 See the ISO Guide to the Expression of Uncertainty in Measurement [3], 2.2.3.

4 List of symbols

a_h	effective hydrophone radius (a_{h3}, a_{h6}: with special reference to a 3 dB or 6 dB definition, respectively)
a_g	hydrophone geometrical radius
a_{max}	maximum effective radius for a specific hydrophone application
a_P	lateral distance from the beam axis (a_{PmaxE}, a_{PmaxH}: maximum values with respect to avoiding edge wave and head wave interference, respectively)
a_t	effective radius of an non-focused ultrasonic transducer
A_g	geometrical area of an ultrasonic transducer
B/A	Fox-Wallace non-linearity parameter
c	speed of sound in a medium (usually water)
C_H	end-of-cable capacitance of the hydrophone including any integral cable and connector
$D(\theta)$	normalized directional response function
e	base of natural logarithms
f	frequency
f_f	fundamental drive frequency of a signal used to generate non-linear distortion