IEC®

IEC 60565-1

Edition 1.0 2020-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Underwater acoustics – Hydrophones – Calibration of hydrophones – Part 1: Procedures for free-field calibration of hydrophones

Acoustique sous-marine – Hydrophones – Étalonnage des hydrophones – Partie 1: Procédures d'étalonnage en champ libre des hydrophones

IEC 60565-1:2020-04(en-fr)

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

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

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

A propos de l'IEC
La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC
Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Recherche de publications IEC - webstore.iec.ch/advsearchform
La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études,…). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished
Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et une fois par mois par email.

Service Clients - webstore.iec.ch/csc
Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: sales@iec.ch.

Electropedia - www.electropedia.org
Le premier dictionnaire d'électrotechnologie en ligne au monde, avec plus de 22 000 articles terminologiques en anglais et en français, ainsi que les termes équivalents dans 16 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

Glossaire IEC - std.iec.ch/glossary
67 000 entrées terminologiques électrotechniques, en anglais et en français, extraites des articles Termes et Définitions des publications IEC parues depuis 2002. Plus certaines entrées antérieures extraites des publications des CE 37, 77, 86 et CISPR de l'IEC.

IEC®

IEC 60565-1

Edition 1.0 2020-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Underwater acoustics – Hydrophones – Calibration of hydrophones – Part 1: Procedures for free-field calibration of hydrophones

Acoustique sous-marine – Hydrophones – Étalonnage des hydrophones – Partie 1: Procédures d'étalonnage en champ libre des hydrophones

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 17.140.50 ISBN 978-2-8322-8039-3

Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

UNDERWATER ACOUSTICS – HYDROPHONES – CALIBRATION OF HYDROPHONES –

Part 1: Procedures for free-field calibration of hydrophones

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of 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, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). 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. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.

4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.

5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 60565-1 has been prepared by IEC technical committee 87: Ultrasonics.

This first edition of IEC 60565-1, together with IEC 60565-2, cancels and replaces the second edition of IEC 60565 published in 2006. This edition constitutes a technical revision.

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

1) removal of all descriptions of methods for pressure calibrations of hydrophones – these are now included in Part 2;
2) removal of the derivations of formulae for free-field reciprocity calibration (both amplitude sensitivity and phase sensitivity) and placement of these into an informative annex;
3) inclusion within the scope of the calibration of the transmitting response of individual source **transducer**s and hydrophones (but not sonar arrays);
4) re-ordering of the sections within the document such that the more general procedures for calibration such as guidance on obtaining conditions of acoustic free-field, far-field, and

steady-state, appear before the descriptions of procedures for absolute or relative calibrations;

5) revision of informative Annex A to include guidance on measurement of directional response of a hydrophone or projector;
6) addition of a new informative Annex B on measurement of electrical impedance of hydrophones and projectors;
7) revision of the previous informative annex on electrical loading corrections to include corrections to account for electrical loading by added cables (now Annex C);
8) addition of a new informative Annex D on acoustic far-field criteria in underwater acoustic calibration;
9) revision of the previous informative annex on pulsed techniques in free-field calibrations (now Annex E);
10) revision of the previous informative annex on assessment of uncertainty in the calibration of hydrophones (now Annex F);
11) deletion of the previous informative annex on equivalent circuit of the excitation system for calibration with a vibrating column;
12) addition of a new informative Annex G on derivation of the formulae for three-**transducer** spherical-wave reciprocity calibration;
13) addition of a new informative Annex H on calibration using travelling-wave tubes;
14) addition of a new informative Annex I on calibration of hydrophones using optical interferometry.
15) addition of a new informative Annex J on calibration in reverberant water tanks using continuous **signal**s.

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

CDV	Report on voting
87/708/CDV	87/736/RVC

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

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

NOTE Words that appear in **bold** in the text are terms explicitly defined in Clause 3.

A list of all parts in the IEC 60565 series, published under the general title *Underwater acoustics – Hydrophones – Calibration of hydrophones*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://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 publication 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

Underwater acoustic measurements are made to provide validation and qualification in a wide range of ocean applications, including oceanography, defence, fisheries, geophysics and in developments in the off-shore energy industries. In addition, the increasing concern about the effect of anthropogenic sound on the marine environment has led to regulation which requires absolute acoustic measurement of the sound radiated by specific sources, and of the ambient sound field.

To be meaningful, it is important that measurements be performed in a technically sound manner, be related to common standards of measurement, and be made using calibrated sensors. **Hydrophone**s are the most commonly-used sensor to measure sound in the ocean. It is important that the **hydrophone**s used to measure sound pressure are calibrated using agreed standard methodologies, with valid uncertainties.

The purpose of this document is to establish procedures for calibration under free-field conditions of **hydrophone**s used in underwater acoustics for ocean applications. Also covered are calibration procedures for individual underwater **electroacoustic transducer**s which can be used as a **hydrophone** and/or source **transducer**. Principles, procedures, and sources of uncertainty are also provided in this document. The calibration methods described include absolute methods which do not require an acoustic reference **transducer**, and relative methods which make use of a calibrated acoustic reference **hydrophone** or **projector**. The methods described cover the frequency range from 200 Hz to 1 MHz.

UNDERWATER ACOUSTICS – HYDROPHONES – CALIBRATION OF HYDROPHONES –

Part 1: Procedures for free-field calibration of hydrophones

1 Scope

This part of IEC 60565 specifies methods and procedures for free-field calibration of **hydrophone**s, as well as individual **electroacoustic transducer**s that can be used as **hydrophone**s (receivers) and/or **projector**s (source **transducer**s). Two general types of calibration are covered within this document: absolute calibration using the method of three-**transducer** spherical-wave reciprocity, and relative calibration by comparison with a reference device which has already been the subject of an absolute calibration.

The maximum frequency range of the methods specified in this document is from 200 Hz to 1 MHz. The lowest acoustic frequency of application will depend on a number of factors, and will typically be in the range 200 Hz to 5 kHz depending mainly on the dimensions of the chosen test facility, The highest frequency of application for the methods described here is 1 MHz.

Procedures for pressure **hydrophone** calibration at low frequencies can be found in IEC 60565-2 [1][1]. Procedures for **hydrophone** calibration at acoustic frequencies greater than 1 MHz are covered by IEC 62127-2 [2].

Excluded from the scope of this document are low-frequency pressure calibrations of **hydrophone**s, which are described in IEC 60565-2 [1]. Also excluded are calibrations of digital **hydrophone**s and systems, calibration of marine autonomous acoustic recorders, calibration of acoustic vector sensors such as particle velocity sensors and pressure gradient **hydrophone**s, calibration of passive sonar arrays consisting of multiple **hydrophone**s, and calibration of active sonar arrays consisting of projectors and **hydrophone**s.

This document presents a description of the requirements for free-field calibration in terms of test facility, equipment and instrumentation, **signal** processing, and frequency limitations. A description of achievable uncertainty and rules for the presentation of the calibration data are provided. Also included are informative annexes that provide additional guidance on

- measurement of directional response of a **hydrophone** or projector,
- measurement of electrical impedance of **hydrophone**s and projectors,
- electrical loading corrections,
- **acoustic far-field** criteria in underwater acoustic calibration,
- pulsed techniques in free-field calibrations,
- assessment of uncertainty in the free-field calibration of **hydrophone**s and projectors,
- derivation of the formulae for three-**transducer** spherical-wave reciprocity calibrations,
- calibration using travelling-wave tubes,
- calibration of **hydrophone**s using optical interferometry, and
- calibrations in reverberant water tanks using continuous **signal**s.

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

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 http://www.electropedia.org/)

IEC 60500:2017, *Underwater acoustics – Hydrophones – Properties of the hydrophone in the frequency range 1 Hz to 500 kHz*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-801, IEC 60500:2017 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 far-field
sound field at a sufficient distance from a sound source in a uniform medium where the sound pressure and sound particle velocity are substantially in phase and the direct-path sound pressure amplitude, compensated for absorption loss, varies inversely with distance

Note 1 to entry: The range (distance from the source) is taken along a direct path between the source and the receiver.

Note 2 to entry: The inverse dependence on range does not imply that the source radiates equally in all directions.

[SOURCE: IEC 60050-801:1994, 801-23-30, modified – In the definition, "and the direct-path sound pressure amplitude, compensated for absorption loss, varies inversely with distance" has been added, sourced from ISO 18405:2017, 3.3.1.1.]

3.2
electrical transfer impedance
$\underline{Z}_{\mathrm{PH}}$
<of a transducer pair> quotient of the Fourier transform of the **hydrophone** open-circuit output voltage $\mathcal{F}(U_{\mathrm{H}}(t))$ to the Fourier transform of the electrical drive current through the **projector** $\mathcal{F}(I_{\mathrm{P}}(t))$, for a **transducer** pair at a specified separation distance with one used as a **hydrophone** and one as a **projector**

$$\underline{Z}_{\mathrm{PH}} = \frac{\mathcal{F}\left(U_{\mathrm{H}}(t)\right)}{\mathcal{F}\left(I_{\mathrm{P}}(t)\right)} \tag{1}$$

Note 1 to entry: The **electrical transfer impedance** is a complex-valued parameter. The modulus of the **electrical transfer impedance** is expressed in units of ohm, Ω. The phase angle of the **electrical transfer impedance** is the argument of the **electrical transfer impedance** and represents the phase difference between the **hydrophone** voltage and the **projector** current [IEC 60050-351:2013, 351-45-45]. The unit of phase angle is the radian.

Note 2 to entry: Because the **electrical transfer impedance** depends on the field conditions, the hydrostatic pressure, water temperature and the length of the cable attached to the **transducer**, these parameters, as well as the frequency are specified.

Note 3 to entry: In a spherically-spreading sound field, the **electrical transfer impedance** of the **transducer** pair depends on the distance between the source and the receiver, with the modulus varying inversely with separation distance d and phase angle varying as $\exp(\mathrm{j}kd)$ where j is the square root of −1 and k is the **wavenumber** (see 3.14).

3.3
underwater electroacoustic transducer
electroacoustic transducer
underwater transducer
transducer
device which transforms electrical **signal**s into acoustic **signal**s in water, or vice versa

Note 1 to entry: An **electroacoustic transducer** which is used as an acoustic receiver in water is called a **hydrophone**.

Note 2 to entry: An **electroacoustic transducer** which is used as an acoustic transmitter in water is called a **projector**.

3.4
free-field receive sensitivity
M_f
<of a **hydrophone**> quotient of the Fourier transform of the **hydrophone** open-circuit voltage **signal** $\mathcal{F}(U_\mathrm{H}(t))$ to the Fourier transform of the acoustic pressure **signal** $\mathcal{F}(p(t))$, for specified frequency and specified direction of plane wave sound incident on the position of the reference centre of the **hydrophone** in the undisturbed free-field if the **hydrophone** was removed

$$M_\mathrm{f} = \frac{\mathcal{F}\left(U_\mathrm{H}(t)\right)}{\mathcal{F}\left(p(t)\right)} \tag{2}$$

Note 1 to entry: The **hydrophone free-field receive sensitivity** is a complex-valued parameter. The modulus of the **free-field receive sensitivity** of a **hydrophone** is expressed in units of volt per pascal, V·Pa^{-1}. The phase angle is the argument of the sensitivity, and represents the phase difference between the **hydrophone** electrical voltage and the sound pressure. The unit of phase angle is the radian.

Note 2 to entry: The term "response" is sometimes used instead of "sensitivity".

[SOURCE: IEC 60500:2017, 3.15, modified – In the definition, "the root-mean-square" has been deleted, and "Fourier transform of the" has been added before "open-circuit output voltage" and "sound pressure".]

3.5
free-field receive sensitivity level
L_M
twenty times the logarithm to the base 10 of the ratio of the modulus of the free-field sensitivity M_f to a reference value of sensitivity, M_ref, in decibels

$$L_\mathrm{M} = 20 \log_{10} \frac{|M_\mathrm{f}|}{M_\mathrm{ref}} \ \mathrm{dB} \tag{3}$$

Note 1 to entry: The unit of **free-field receive sensitivity level** is the decibel, dB. The reference value of sensitivity, M_ref, is 1 V·Pa^{-1} or any valid SI multiple or submultiple thereof. The most common reference value used for underwater acoustics is 1 V·µPa^{-1}.

[SOURCE: IEC 60500:2017, 3.16, modified – In the definition, "modulus of the" has been added before "free-field sensitivity".]

3.6
omnidirectionality
feature of a **transducer** response such that it is invariant to direction to within a specified tolerance

Note 1 to entry: The tolerance is specified.

Note 2 to entry: **Omnidirectionality** can be specified in a two-dimensional space in one plane only, while in three dimensions a **transducer** can be omnidirectional in all planes through the reference centre.

Note 3 to entry: As a rule, a **transducer** directional response approaches **omnidirectionality** when the **transducer** dimensions are much smaller than the acoustic wavelength.

3.7
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 60050-801:1994, 801-25-08, modified – In the definition, "in either direction" has been replaced by "regardless … vice versa".]

3.8
reversible transducer
transducer capable of acting as a **projector** as well as a **hydrophone**

3.9
projector
underwater sound projector
electro-acoustic **transducer** that converts electrical **signal**s into sound that propagates in water

[SOURCE: IEC 60565:2006, 3.37, modified – The term "underwater sound **projector**" has been added.]

3.10
transmitting response to current
S_I
quotient of the product of the Fourier transform of the sound pressure $\mathcal{F}(p(t))$ at a position in the **acoustic far-field** of a **projector** (compensated for absorption loss) and the distance, d, from the reference centre of the **projector**, to the Fourier transform of the electrical current through the **projector** $\mathcal{F}(I(t))$, at a specific frequency and in a specified direction, under acoustic free-field conditions in a uniform medium

$$\underline{S}_I = \frac{\mathcal{F}\left(p(t)d\right)}{\mathcal{F}\left(I(t)\right)}\exp\left[jk\left(d-d_0\right)\right] \quad (4)$$

where d_0 is the reference distance, chosen to be equal to 1 m

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

Note 2 to entry: The term "sensitivity" is sometimes used instead of "response".

3.11
transmitting current response level
$L_{S,I}$
twenty times the logarithm to the base 10 of the ratio of the modulus of the **transmitting response to current**, S, to a reference value of the transmitting response, $S_{I,ref}$, in decibels