

Specification for

Characteristics and calibration of hydrophones for operation in the frequency range 0.5 MHz to 15 MHz

UDC 681.883.43:53.089.6:621.3.029:62-11.004.15:620.1

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The preparation of this British Standard was entrusted by the Electronic Equipment Standards Committee (EEL/-) to Technical Committee EEL/35, upon which the following bodies were represented:

- British Institute of Radiology
- British Medical Ultrasound Society
- British Society for Rheumatology
- Confederation of British Industry
- Department of Trade and Industry (National Physical Laboratory)
- Electro Medical Trade Association Limited
- Electronic Engineering Association
- Engineering Industries Association
- Institute of Larynology and Otology
- Institute of Physical Sciences in Medicine (IPSM)
- Institution of Electronic and Radio Engineers
- Medical Research Council

This British Standard, having been prepared under the direction of the Electronic Equipment Standards Committee, was published under the authority of the Board of BSI and comes into effect on 28 February 1989

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The following BSI references relate to the work on this standard:
Committee reference EEL/35
Draft announced in *BSI News* December 1987

ISBN 0 580 17060 8

Amendments issued since publication

Amd. No.	Date of issue	Comments

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National foreword

This British Standard has been prepared under the direction of the Electronic Equipment Standards Committee and is identical with IEC 866:1987 “*Characteristics and calibration of hydrophones for operation in the frequency range 0.5 MHz to 15 MHz*” published by the International Electrotechnical Commission (IEC).

Terminology and conventions. The text of the International Standard has been approved as suitable for publication as a British Standard without deviation. Some terminology and certain conventions are not identical with those used in British Standards; attention is drawn especially to the following.

In Figure 5 and Figure 6 the comma has been used as a decimal marker. In British Standards it is current practice to use a full point on the baseline as the decimal marker.

Cross-references

International Standard	Corresponding British Standard
IEC 500:1974	BS 5653:1978 <i>Specification for hydrophones for calibration purposes</i> (Identical)
IEC 565:1977	BS 5652:1979 <i>Specification for the calibration of hydrophones</i> (Identical)

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 20, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

List of symbols

A_1	Effective area of auxiliary transducer
a	Effective radius of the hydrophone
a_1	Effective radius of auxiliary transducer
a_u	Factor by which the reference voltage U_{ref} must be reduced to make it equal to voltage U
a_{u1}	Factor by which the reference voltage U_{ref} must be reduced to make it equal to voltage U_1
a_{11}	Factor by which the reference voltage U_{ref} must be reduced in order to drive a current I_1 through the impedance R_0
c	Speed of sound in water
d	Distance between hydrophone and reflector
d_1	Distance between auxiliary transducer and reflector
G_1	Correction factor for diffraction loss with auxiliary transducer alone
G_2	Correction factor for diffraction loss with auxiliary transducer and hydrophone
G_c	Correction factor combining G_1 and G_2 , applicable only under certain measurement conditions
I_1	Current through auxiliary transducer
I_k	Current through short circuit introduced in place of the auxiliary transducer
J	Reciprocity coefficient
J_p	$\{= 2A/\rho c\}$ Reciprocity coefficient for plane waves
k_{u1}	Correction to open-circuit voltage for the auxiliary transducer
k_u	Correction to open-circuit voltage at a hydrophone
M	Free-field sensitivity of a hydrophone
M^*	Apparent free-field sensitivity of a hydrophone, assuming ideal plane wave measurement conditions
N	Near field distance
p	Sound pressure
p_1	Sound pressure in plane wave omitted by auxiliary transducer
R_0	Impedance of standard load equal to the characteristic impedance of the precision attenuator
R_L	End-of-cable leakage resistance of hydrophone
r	Amplitude reflection coefficient for the reflector/water interface
s	$\{= (d_1 + d)\lambda/a_1^2\}$ Normalized distance from auxiliary transducer to hydrophone

S	Transmitting response to current of a projector
S_1	Transmitting response to current of auxiliary transducer
S_1^*	Apparent transmitting response to current of auxiliary transducer, assuming ideal plane wave measurement conditions
U	Open-circuit voltage at a hydrophone
U_1	Open-circuit voltage for auxiliary transducer
U_{ref}	Reference voltage
v	Velocity of the radiating surface of the transducer
z	Distance along the acoustic axis from the transducer
α'	Amplitude attenuation coefficient for sound in water
λ	Wavelength of sound in water
ρ	Density of water

1 Scope

This standard relates to hydrophones, employing piezoelectric sensor elements, designed to measure the pulsed and continuous-wave ultrasonic fields generated by ultrasonic medical equipment operating in the frequency range 0.5 MHz to 15 MHz. It covers the design and performance requirements of standard hydrophones and the data required to specify their characteristics, and defines a standard method for the measurement of the sensitivity of such hydrophones.

NOTE 1 These recommendations are not intended to cover hydrophones designed specifically and/or exclusively for the detection of ultrasonic pulses or bursts.

NOTE 2 Hydrophones for operation in the frequency range from 1 Hz to 1 MHz are covered by IEC Publication 500: IEC Standard Hydrophone, and IEC Publication 565: Calibration of Hydrophones.

2 Object

2.1 To define the performance characteristics that are required of hydrophones intended for use in a specified range of applications over the frequency band from 0.5 MHz to 15 MHz, particularly those associated with the measurement of pulsed and continuous-wave ultrasonic fields used in medical diagnosis.

2.2 To establish a scheme for the specification of the performance of these hydrophones.

2.3 To describe a standardized procedure for their calibration.

3 Definitions

Where indicated the following definitions are as used in IEC Publication 565.

3.1

free field

a sound field in a homogeneous and isotropic medium in which the effects of boundaries are negligible (IEC Publication 565, Sub-clause 3.1), see also IEC 801-03-28

3.2

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 (IEC Publication 565, Sub-clause 3.2), see also IEC 801-03-30

NOTE 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 inversely proportional to the distance from the source.

3.3

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 (IEC Publication 565, Sub-clause 3.3), see also IEC 801-05 (under consideration)

3.4

hydrophone (or receiver)

a transducer that produces electrical signals in response to waterborne acoustic signals (IEC Publication 565, Sub-clause 3.4), see also IEC 801-12-26

NOTE Hydrophones used to measure high frequency ultrasonic fields usually consist of a small, thin piezoelectric element, often mounted on the tip of a needle-like probe. The active element is generally no more than 1.0 mm in diameter. It is this type of miniature hydrophone that is being considered throughout this standard and to which the word "hydrophone", used alone, will be held to apply. Whenever it is necessary to refer to a larger transducer being used as a hydrophone, the term "receiver" will be used.

3.5

reversible transducer

a transducer capable of acting as a hydrophone and as a projector, the latter being a device which converts electrical signals into sound (IEC Publication 565, Sub-clause 3.6), see also IEC 801-05 (under consideration)

3.6

reciprocal transducer

a linear, passive and reversible transducer (IEC Publication 565, Sub-clause 3.7)

3.7

open-circuit voltage at a hydrophone

the voltage appearing at the electrical terminals of a hydrophone when no current passes through the terminals (IEC Publication 565, Sub-clause 3.8)

Symbol: U

Unit: volt, V

NOTE Throughout this standard, all voltages, currents and sound pressures are root mean square quantities, unless otherwise stated.

3.8

free-field sensitivity of a hydrophone

the ratio of the open-circuit voltage at the output terminals of a hydrophone to the sound pressure in the undisturbed free field of a plane wave in the position of the acoustic centre of the hydrophone if the hydrophones were removed (IEC Publication 565, Sub-clause 3.9)

Symbol: M

Unit: volt per pascal, V/Pa

NOTE 1 The pressure may be either sinusoidal or narrow band filtered noise, the geometric mean value between the frequency band limits being considered as the given frequency.

NOTE 2 The frequency as well as the terminals to which the sensitivity refers should be specified.

3.9

free-field sensitivity level

twenty times the logarithm to the base 10 of the ratio of the free-field sensitivity M to a reference sensitivity M_{ref} (IEC Publication 565, Sub-clause 3.9.1)

Unit: decibel, dB

NOTE M_{ref} is equal to 1 V/ μ Pa.

3.10

transmitting response to current of a projector

at a given frequency, the ratio of the acoustic pressure in the sound wave, at a point to be specified, in the absence of interference effects, to the current flowing through the electrical terminals

Symbol: S

Unit: pascal per ampere, Pa/A

3.11

reciprocity coefficient

for any system in which a reciprocal transducer acts as a projector and receiver, the reciprocity coefficient J is defined as the ratio of the free-field voltage sensitivity of the transducer, M , to its transmitting response to current, S

where the transmitted sound waves approximate plane waves, the reciprocity coefficient approaches $2A/\rho c$ and is called the plane wave reciprocity coefficient

NOTE The plane wave reciprocity coefficient applies to plane wave propagation, as realized in the far field of a transducer, but pure far field conditions are not used in the procedure described in Sub-clause 7.3.6. To cope with this, a correction factor is described in Sub-clause 7.2.3, which includes an allowance for deviations from plane wave conditions.

Symbol: J

Unit: watts per pascal squared, W/Pa^2

3.12

directional response of a hydrophone

a 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 (IEC Publication 565, Sub-clause 3.19)

3.13

end-of-cable leakage resistance

the ratio of the voltage across the electrical terminals at the end of the hydrophone cable to the direct current flowing through these terminals

Symbol: R_L

Unit: ohm, Ω

NOTE The value of the voltage used during the determination of R_L should be stated.

3.14

mechanical Q of hydrophone element

the ratio of the resonance frequency to the bandwidth between the two frequencies at which the motional impedance of the hydrophone is $1/\sqrt{2}$ times that at resonance, as indicated in Figure 1, page 17

4 General introduction

This standard is concerned with the measurement of high-frequency ultrasonic fields in liquids, particularly measurement of the spatial and temporal pressure distribution within the fields emitted by medical ultrasonic transducers, covering the frequency range from 0.5 MHz to 15 MHz.

4.1 Choice of measurement method

A number of well-known and documented physical methods exist for the quantitative characterization of the fields generated by the high-frequency transducers used in medical ultrasonic equipment. These methods generally require that measurements are carried out on the ultrasonic fields emitted by the transducers into a water-filled test tank, and provide a measure in absolute terms of the local or spatially integrated values of particular parameters of the ultrasonic field (e.g. intensity, particle velocity or pressure amplitude). That is to say, these methods permit measurements to be made by reference only to independently established fundamental quantities such as mass, time and length. These methods include the measurement of acoustic radiation force, the use of certain acousto-optical effects, calorimetry and measurement by reciprocity techniques. For the complete characterization of an ultrasonic field, measurements are required with sufficient resolution in both the space and time domains to allow the detailed structure of the field to be recorded. For fields with component frequencies up to 15 MHz, this requires spatial and temporal measurement resolutions of the order of 0.1 mm and 0.06 μs respectively.

See references [1] and [2] of Appendix E.

4.2 Basis of recommendations

This standard recommends that medical ultrasonic fields should be quantified by means of hydrophones which allow the instantaneous acoustic pressure to be measured at any point within the field. Such hydrophones provide the most convenient and versatile method of measuring the spatial and temporal behaviour of ultrasonic fields available at this time, and offer resolutions approaching those required for a complete field determination.

4.3 Effect of the finite size of hydrophones

The active element of a hydrophone generates a voltage across its electrodes proportional to the average acoustic pressure over its surface. If full spatial resolution is to be achieved, therefore, it is necessary that the probe be small compared with the scale of spatial variations in pressure, and hence, in practice, small compared with the wavelength of the highest frequency component in the ultrasonic fields to be measured. Furthermore, the actual acoustic pressure on the hydrophone's sensitive surface is influenced by the diffraction of the hydrophone itself.