



BSI Standards Publication

Ultrasonics — Hydrophones

Part 1: Measurement and characterization of medical ultrasonic fields

National foreword

This British Standard is the UK implementation of EN IEC 62127-1:2022. It is identical to IEC 62127-1:2022. It supersedes BS EN 62127-1:2007+A1:2013, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EPL/87, Ultrasonics.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Date	Text affected
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English Version

Ultrasonics - Hydrophones - Part 1: Measurement and characterization of medical ultrasonic fields

Ultrasons - Hydrophones - Partie 1: Mesurage et
caractérisation des champs ultrasoniques médicaux

Ultraschall - Hydrophone - Teil 1: Messung und
Charakterisierung von medizinischen Ultraschallfeldern bis
zu 40 MHz

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

The text of document 87/783/FDIS, future edition 2 of IEC 62127-1, prepared by IEC/TC 87 "Ultrasonics" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN IEC 62127-1:2022.

The following dates are fixed:

- latest date by which the document has to be implemented at national (dop) 2023-01-29 level by publication of an identical national standard or by endorsement
- latest date by which the national standards conflicting with the (dow) 2025-04-29 document have to be withdrawn

This document supersedes EN 62127-1:2007 and all of its amendments and corrigenda (if any).

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In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60500	NOTE Harmonized as EN 60500
IEC 60601-2-5	NOTE Harmonized as EN 60601-2-5
IEC 60601-2-37	NOTE Harmonized as EN 60601-2-37
IEC 60601-2-62	NOTE Harmonized as EN 60601-2-62
IEC 61157	NOTE Harmonized as EN 61157
IEC 61161	NOTE Harmonized as EN 61161
IEC 61828	NOTE Harmonized as EN IEC 61828
IEC 61846	NOTE Harmonized as EN 61846
IEC 61847	NOTE Harmonized as EN 61847
IEC/TS 61949	NOTE Harmonized as CLC/TS 61949
IEC 62359	NOTE Harmonized as EN 62359
IEC 63045	NOTE Harmonized as EN IEC 63045

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60565-1	-	Underwater acoustics - Hydrophones - Calibration of hydrophones - Part 1: Procedures for free-field calibration of hydrophones	EN IEC 60565-1	-
IEC 61689	-	Ultrasonics - Physiotherapy systems - Field specifications and methods of measurement in the frequency range 0,5 MHz to 5 MHz	EN IEC 61689	-
IEC 62127-2	-	Ultrasonics - Hydrophones - Part 2: Calibration for ultrasonic fields up to 40 MHz	EN 62127-2	-
IEC 62127-3	-	Ultrasonics - Hydrophones - Part 3: Properties of hydrophones for ultrasonic fields up to 40 MHz	EN 62127-3	-
IEC 63009	-	Ultrasonics - Physiotherapy systems - Field specifications and methods of measurement in the frequency range 20 kHz to 500 kHz	EN IEC 63009	-
ISO 16269-6	-	Statistical interpretation of data – Part 6: Determination of statistical tolerance intervals	-	-
ISO/IEC Guide 98-3 2008	-	Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)	-	-

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Ultrasonics – Hydrophones –

Part 1: Measurement and characterization of medical ultrasonic fields

Ultrasons – Hydrophones –

Partie 1: Mesurage et caractérisation des champs ultrasoniques médicaux

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ULTRASONICS – HYDROPHONES –

Part 1: Measurement and characterization of medical ultrasonic fields

FOREWORD

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IEC 62127-1 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 and requirements for narrow-band approximation and broadband measurements have been modified; details on waveform deconvolution have been added.
- d) Procedures for spatial averaging correction have been amended.
- e) Annex D, Annex E and bibliography have been updated to support the changes of the normative parts.

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

Draft	Report on voting
87/783/FDIS	87/788/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/standardsdev/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 terms 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.

INTRODUCTION

The main purpose of this document is to define various acoustic parameters that can be used to specify and characterize ultrasonic fields propagating in liquids, and, in particular, water, using hydrophones. Measurement procedures are outlined that may be used to determine these parameters. Specific device related measurement standards, for example IEC 61689, IEC 61157, IEC 61847 or IEC 62359, can refer to this document for appropriate acoustic parameters. In IEC 62359, some additional measurement methods for attenuated parameters and indices are described addressing the specific needs of acoustic output characterization of ultrasonic diagnostic equipment in accordance with IEC 60601-2-37.

The philosophy behind this document is the specification of the acoustic field in terms of acoustic pressure parameters, acoustic pressure being the primary measurement quantity when hydrophones are used to characterize the field.

Intensity parameters are specified in this document, but these are regarded as derived quantities that are meaningful only under certain assumptions related to the ultrasonic field being measured.

ULTRASONICS – HYDROPHONES –

Part 1: Measurement and characterization of medical ultrasonic fields

1 Scope

This part of IEC 62127 specifies methods of use of calibrated **hydrophones** for the measurement in liquids of acoustic fields generated by ultrasonic medical equipment including **bandwidth** criteria and calibration frequency range requirements in dependence on the spectral content of the fields to be characterized.

This document:

- defines a group of acoustic parameters that can be measured on a physically sound basis;
- defines a second group of parameters that can be derived under certain assumptions from these measurements, and called derived intensity parameters;
- defines a measurement procedure that can be used for the determination of acoustic pressure parameters;
- defines the conditions under which the measurements of acoustic parameters can be made using calibrated **hydrophones**;
- defines procedures for correcting for limitations caused by the use of **hydrophones** with finite **bandwidth** and finite active element size, and for estimating the corresponding **uncertainties**.

NOTE 1 Throughout this document, SI units are used. In the specification of certain parameters, such as **beam areas** and intensities, it can be convenient to use decimal multiples or submultiples. For example, **beam area** is likely to be specified in cm^2 and intensities in W/cm^2 or mW/cm^2 .

NOTE 2 The **hydrophone** as defined can be of a piezoelectric or an optic type.

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 60565-1, *Underwater acoustics – Hydrophones – Calibration of hydrophones – Part 1: Procedures for free-field calibration of hydrophones*

IEC 61689, *Ultrasonics – Physiotherapy systems – Field specifications and methods of measurement in the frequency range 0,5 MHz to 5 MHz*

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

IEC 62127-3, *Ultrasonics – Hydrophones – Part 3: Properties of hydrophones for ultrasonic fields up to 40 MHz*

IEC 63009, *Ultrasonics – Physiotherapy systems – Field specifications and methods of measurement in the frequency range 20 kHz to 500 kHz*

ISO 16269-6, *Statistical interpretation of data – Part 6: Determination of statistical tolerance intervals*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62127-2, IEC 62127-3 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 equation) of the **instantaneous acoustic pressure**.

3.2

acoustic repetition period

arp

pulse repetition period for non-automatic scanning systems and the **scan repetition period** for automatic scanning systems, equal to the time interval between corresponding points of consecutive cycles for continuous wave systems

Note 1 to entry: The **acoustic repetition period** is expressed in seconds (s).

3.3

acoustic-working frequency

acoustic frequency

frequency of an acoustic signal based on the observation of the output of a **hydrophone** placed in an acoustic field at the position corresponding to the **spatial-peak temporal-peak acoustic pressure**

Note 1 to entry: The signal is analysed using either the **zero-crossing acoustic-working frequency** technique or a spectrum analysis method. Acoustic-working frequencies are defined in 3.3.1, 3.3.2, 3.3.3, 3.3.4 and 3.3.5.

Note 2 to entry: In a number of cases the present definition is not very helpful or convenient, especially for **broadband transducers**. In that case, a full description of the frequency spectrum is expected to be given in order to enable any frequency-dependent correction to the signal.

Note 3 to entry: **Acoustic frequency** is expressed in hertz (Hz).

3.3.1

zero-crossing acoustic-working frequency

f_{awf}

number, n , of consecutive half-cycles (irrespective of polarity) divided by twice the time between the commencement of the first half-cycle and the end of the n -th half-cycle

Note 1 to entry: None of the n consecutive half-cycles are expected to show evidence of phase change.

Note 2 to entry: The measurement are performed at terminals in the receiver that are as close as possible to the receiving transducer (**hydrophone**) and, in all cases, before rectification.

Note 3 to entry: This frequency is determined according to the procedure specified in IEC TR 60854.

Note 4 to entry: This frequency is intended for continuous-wave systems only.

3.3.2**arithmetic-mean acoustic-working frequency** f_{awf}

arithmetic mean of the most widely separated frequencies f_1 and f_2 , within the range of three times f_1 , at which the level of the acoustic pressure spectrum is 3 dB below the peak level

Note 1 to entry: This frequency is intended for pulse-wave systems only.

Note 2 to entry: It is assumed that $f_1 < f_2$.

Note 3 to entry: If f_2 is not found within the range $< 3f_1$, f_2 is to be understood as the lowest frequency above this range at which the spectrum level is 3 dB below the peak level.

3.3.3**magnitude-weighted acoustic-working frequency** f_{awf}

frequency weighted with the spectral acoustic pressure magnitude in the frequency range where the spectral pressure level is equal to or larger than 3 dB below the peak level

$$f_{\text{awf}} = \frac{\int f |P(f)| df}{\int |P(f)| df} \quad \text{with} \quad |P(f)| = \begin{cases} |P(f)| & \text{if } L_P(f) \geq \max L_P(f) - 3 \text{ dB} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where

f is the frequency of the acoustic pressure spectrum;

$|P(f)|$ is the modulus of the complex-valued spectrum of the **acoustic pulse waveform**;

$L_P(f)$ is the pressure level spectrum given from $L_P(f) = 20 \log_{10} \left(\frac{|P(f)|}{P_{\text{ref}}} \right) \text{ dB}$ with $P_{\text{ref}} = 1 \text{ Pa}$.

Note 1 to entry: This frequency is intended for pulse-wave systems only.

Note 2 to entry: The integrals in Formula (1) are definite, to be taken from the minimum to the maximum of the acquired signal spectrum.

Note 3 to entry: The restriction to the range with pressure levels equal to or larger than –3 dB of the peak level is required to avoid the influence of higher harmonic frequencies on the **acoustic-working frequency**.

Note 4 to entry: Definition 3.3.3 leads to more stable **acoustic-working frequency** results than definition 3.3.2 if there are peaks in the acoustic pressure spectrum close to the –3 dB threshold. This is particularly relevant for the determination of derated field parameters as required in IEC 62359 using a single derating factor depending on the **acoustic-working frequency**.

3.3.4**peak pulse acoustic frequency** f_p

acoustic-working frequency of the pulse with the largest **peak negative acoustic pressure** measured at the point of maximum **peak negative acoustic pressure**

3.3.5**temporal-average acoustic frequency** f_t

acoustic-working frequency of the time averaged acoustic pressure spectrum of the acoustic signals measured at the point of maximum **temporal-average intensity**

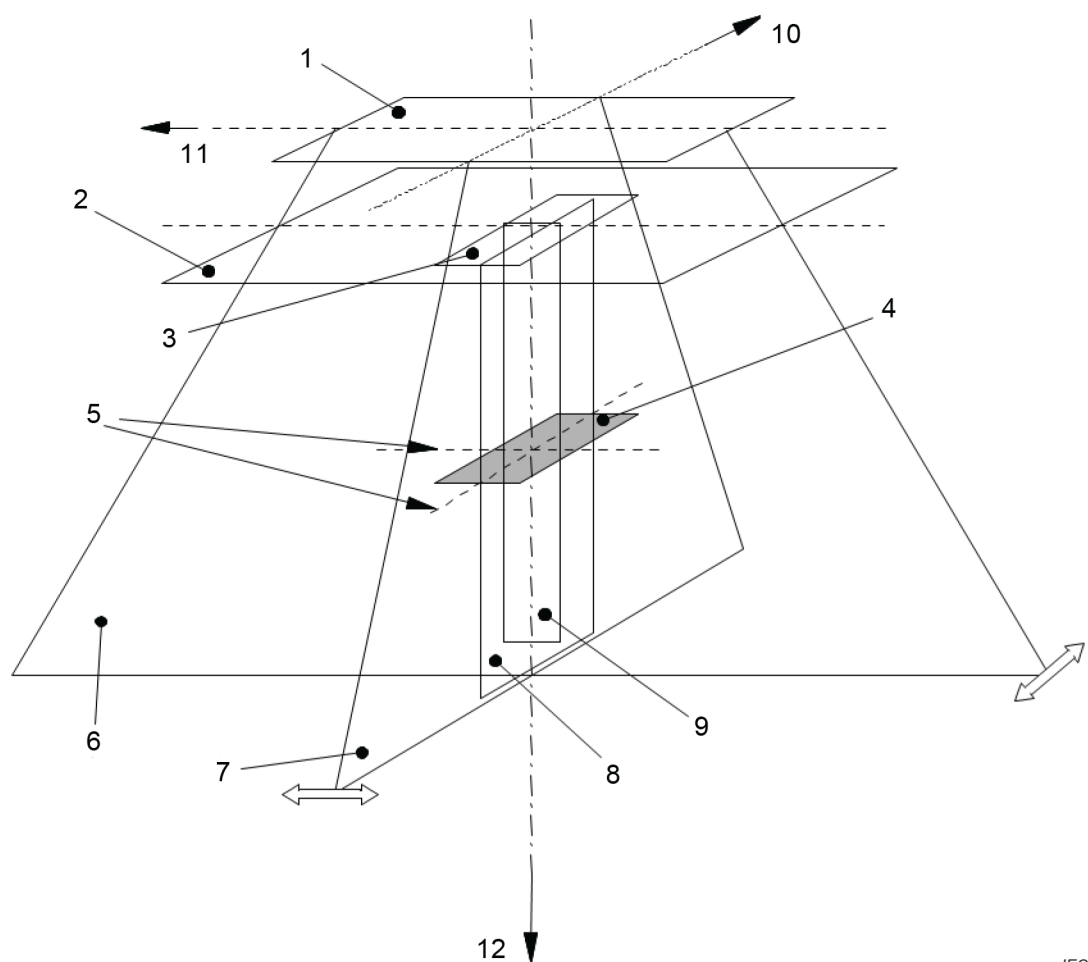
3.4

azimuth axis

axis formed by the junction of the **azimuth plane** and the **source aperture plane** (measurement) or **transducer aperture plane** (design)

SEE: Figure 1

[SOURCE: IEC 61828:2020, 3.7]



IEC

Key

1	external transducer surface plane	7	azimuth plane, scan plane
2	source aperture plane	8	principal longitudinal plane
3	source aperture	9	longitudinal plane
4	beam area plane	10	X, azimuth axis
5	beamwidth lines	11	Y, elevation axis
6	elevation plane	12	Z, beam axis

[SOURCE: IEC 61828:2020]

Figure 1 – Schematic diagram of the different planes and lines in an ultrasonic field

3.5

azimuth plane

plane containing the **beam axis** and the line of the minimum **full width half maximum beamwidth**

SEE: Figure 1

Note 1 to entry: For an **ultrasonic transducer** array, this is the imaging plane.

Note 2 to entry: For a single **ultrasonic transducer** with spherical or circular symmetry, it is any plane containing the **beam axis**.

[SOURCE: IEC 61828:2020, 3.8]

3.6 bandwidth

BW

difference in the most widely separated frequencies f_1 and f_2 at which the level of the acoustic pressure spectrum becomes 3 dB below the peak level, at a specified point in the acoustic field

Note 1 to entry: **Bandwidth** is expressed in hertz (Hz).

3.7 beam area

$A_{b,6}$, $A_{b,20}$

area in a specified plane perpendicular to the **beam axis** consisting of all points at which the **pulse-pressure-squared integral** is greater than a specified fraction of the maximum value of the **pulse-pressure-squared integral** in that plane

Note 1 to entry: If the position of the plane is not specified, it is the plane passing through the point corresponding to the maximum value of the **pulse-pressure-squared integral** in the whole acoustic field.

Note 2 to entry: In a number of cases, the term **pulse-pressure-squared integral** is replaced everywhere 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 synchronization with the scanframe is not available the term **pulse-pressure-squared integral** may be replaced by **temporal average intensity**.

Note 3 to entry: Some specified fractions are 0,25 and 0,01 for the –6 dB and –20 dB beam areas, respectively.

Note 4 to entry: **Beam area** is expressed in units of metre squared (m^2).

3.8 beam axis

straight line that passes through the **beam centrepoin**ts 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**

SEE: Figure 1

Note 1 to entry: 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 to entry: 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 synchronization with the scanframe is not available the term **pulse-pressure-squared integral** may be replaced by **temporal average intensity**.

3.9 beam centrepoin

position determined by the intersection of two lines in the same beam area plane xy passing through the **beamwidth midpoints** of two orthogonal planes, xz and yz , perpendicular to their respective beamwidth lines

[SOURCE: IEC 61828:2020, 3.15, modified – In the definition, "in the same beam area plane xy " and ", perpendicular to their respective beamwidth lines" have been added.]

3.10**beamwidth midpoint**

linear average of the location of the centres of **beamwidths** in a plane

Note 1 to entry: The **beamwidth** midpoint method is described in Annex K.

Note 2 to entry: The average is taken over as many **beamwidth** levels given in Table K.1 as signal level permits.

[SOURCE: IEC 61828:2020, 3.22, modified – Note 1 to entry has been replaced by new Notes to entry.]

3.11**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 to entry: 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 synchronization with the scanframe is not available the term **pulse-pressure-squared integral** can be replaced by **temporal average intensity**.

Note 2 to entry: 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 to entry: **Beamwidth** is expressed in metres (m).

3.12**broadband transducer**

transducer that generates an acoustic pulse of which the **bandwidth** is greater than the **acoustic-working frequency**

3.13**central scan line**

<for automatic scanning systems> **ultrasonic scan line** closest to the symmetry axis of the **scan plane**

3.14**derived instantaneous intensity**

quotient of squared **instantaneous acoustic pressure** and characteristic acoustic impedance of the medium at a particular instant in time at a particular point in an acoustic field

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

where

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

ρ is the density of the medium;

c is the speed of sound in the medium

Note 1 to entry: For measurement purposes referred to in this document, the **derived instantaneous intensity** is an approximation of the **instantaneous intensity**.

Note 2 to entry: Increased **uncertainty** is expected to be taken into account for measurements very close to the transducer.

Note 3 to entry: **Derived instantaneous intensity** is expressed in units of watt per metre squared (W/m^2).

3.15

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 to entry: The **diametrical beam scan** can extend to different distances on either side of the **beam axis**.

3.16

distance z_r

z_r

distance along the **beam axis** between the plane containing the **peak-rarefactional acoustic pressure** and the **external transducer aperture**

Note 1 to entry: The **distance z_r** is expressed in metres (m).

3.17

distance z_c

z_c

distance along the **beam axis** between the plane containing the **peak-compressional acoustic pressure** and the **external transducer aperture**

Note 1 to entry: The **distance z_c** is expressed in metres (m).

3.18

distance z_{psi}

z_{psi}

distance along the **beam axis** between the plane containing the maximum **pulse-pressure-squared integral** and the **external transducer aperture**

Note 1 to entry: The **distance z_{psi}** is expressed in metres (m).

3.19

distance z_{spta}

z_{spta}

distance along the **beam axis** between the plane containing the **spatial-peak temporal-average intensity** and the **external transducer aperture**

Note 1 to entry: In practice, this distance is equal to the distance z_{psi} .

Note 2 to entry: The **distance z_{spta}** is expressed in metres (m).

3.20

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 62127-3:2007, 3.2, modified – In the term, "radius" has been replaced with "size". In the definition, "radius of a stiff disc receiver" has been replaced with "size of a theoretical receiver". The NOTES have been replaced.]

3.21

effective radius of a non-focusing ultrasonic transducer

a_t

radius of a perfect disc piston-like **ultrasonic 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 to entry: The **effective radius of a non-focusing ultrasonic transducer** is expressed in metres (m).

3.22

electric load impedance

Z_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 62127-3:2007, 3.3, modified – In the definition, "**hydrophone** or **hydrophone assembly** output" has been replaced by "**hydrophone** unit output cable".]

3.23

elevation axis

line in the **source aperture plane** (measurement) or **transducer aperture plane** (design) that is perpendicular to the **azimuth axis** and the **beam axis**

SEE: Figure 1

[SOURCE: IEC 61828:2020, 3.48, modified – Notes to entry have been omitted.]

3.24

elevation plane

longitudinal plane containing the **elevation axis**

SEE: Figure 1

[SOURCE: IEC 61828:2020, 3.49, modified – The words "and the beam axis" have been deleted since this is already included in the definition of longitudinal plane.]

3.25

end-of-cable loaded sensitivity

$\underline{M}_L(f)$

<of a **hydrophone** or **hydrophone assembly**> quotient of the Fourier transformed **hydrophone** voltage-time signal $\mathcal{F}(u_L(t))$ 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

$$\underline{M}_L(f) = \frac{\mathcal{F}(u_L(t))}{\mathcal{F}(p(t))} \quad (3)$$

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.

3.26

end-of-cable loaded sensitivity level

$L_{M_L}(f)$

<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** $|M_L(f)|$ to a reference sensitivity M_{ref}

$$L_{M_L}(f) = 20 \log_{10} \frac{|M_L(f)|}{M_{ref}} \text{ dB} \quad (4)$$

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).

3.27

end-of-cable open-circuit sensitivity

$\underline{M}_c(f)$

<of a **hydrophone**> quotient of the Fourier transformed **hydrophone** open-circuit voltage-time signal $\mathcal{F}(u_c(t))$ 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

$$\underline{M}_c(f) = \frac{\mathcal{F}(u_c(t))}{\mathcal{F}(p(t))} \quad (5)$$

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.

3.28

external transducer surface

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

SEE: Figure 1

Note 1 to entry: This surface is assumed to be accessible for measurements using a hydrophone in a chosen propagation medium (usually water).

Note 2 to entry: This surface is either directly in contact with the patient or is in contact with a water or liquid path to the patient.

[SOURCE: IEC 61828:2020, 3.52]

3.29

external transducer surface plane

external transducer aperture plane

plane that is orthogonal to the **beam axis** of the unsteered beam, or the axis of symmetry of the **azimuth plane** for an automatic scanner, and is adjacent physically to the **ultrasonic transducer** and **external transducer surface**

SEE: Figure 2

Note 1 to entry: If the **ultrasonic transducer** is flat, the plane is coplanar with the radiating surface of the **ultrasonic transducer**; if it is concave, the plane touches the periphery of the radiating surface; if it is convex, the plane is tangent to the centre of the radiating surface at the point of contact.

[SOURCE: IEC 61828:2020, 3.53]

3.30

far field

region of the field where $z > z_T$ aligned along the **beam axis** for planar non-focusing transducers

Note 1 to entry: 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 to entry: The term **far field** is used in this document 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).

Note 3 to entry: If the shape of the transducer aperture produces several **transition distances**, the one furthest from the transducer is used.

3.31

hydrophone geometrical radius

a_g

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

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

[SOURCE: IEC 62127-3:2007, 3.8]

3.32

hydrophone

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

Note 1 to entry: A **hydrophone** is principally a passive device designed and built to respond to sound pressure.

Note 2 to entry: In some applications, a **hydrophone** is used as an active device to transmit sound.

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

3.33

hydrophone assembly

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

[SOURCE: IEC 62127-3:2007, 3.10]

3.34

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.

[SOURCE: IEC 62127-3:2007, 3.12]

3.35

instantaneous acoustic pressure

$p(t)$

pressure at a particular instant in time and at a particular point in an acoustic field, minus the ambient pressure

Note 1 to entry: **Instantaneous acoustic pressure** is expressed in pascals (Pa).

[SOURCE: IEC 60050-802:2011, 802-01-03]

3.36

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 to entry: **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 document and under conditions of sufficient distance from the **external transducer aperture** (at least one transducer diameter, or an equivalent transducer dimension in the case of a non-circular transducer) the **instantaneous intensity** can be approximated by the **derived instantaneous intensity**.

Note 2 to entry: **Instantaneous intensity** is expressed in units of watt per metre squared (W/m²).

3.37

local area factor

F_a

square root of the ratio of the **source aperture area** to the **beam area** at the point of interest

$$F_a = \sqrt{\frac{A_{SAeff}}{A_b}} \quad (6)$$

Note 1 to entry: The relevant local **beam area**, A_b , is that for which the **pulse-pressure-squared integral** is greater than 0,135 (that is, $1/e^2$) times the maximum value in the cross-section.

Note 2 to entry: If the beam profile is approximately Gaussian at the distance of interest and the area at the -6 dB level, $A_{b,6}$, is known, the local **beam area** can be calculated as $A_b = A_{b,6}/0,69$: ($0,69 = 3 \ln(10)/10$): $F_a = \sqrt{\frac{0,69 A_{SAeff}}{A_{b,6}}}$.

[SOURCE: IEC TS 61949:2007, 3.11, modified – "source aperture" has been replaced by "source aperture area"; the formula for the general case has been added; the second sentence of the original definition has been moved to a Note 1 to entry; the third sentence of the original definition has been changed into a Note 2 to entry and provides more details and the symbol for the -6 dB **beam area** was changed to conform with Clause 4.]

3.38

local distortion parameter

σ_q

index which permits the prediction of nonlinear distortion of ultrasound for a specific **ultrasonic transducer**

$$\sigma_q = z p_m \frac{2\pi f_{awf} \beta}{\rho \cdot c^3} \frac{1}{\sqrt{F_a}} \quad (7)$$

where

- z is the axial distance of the point of interest to the transducer face;
- p_m is the **mean-peak acoustic pressure** at the point in the acoustic field corresponding to the **spatial-peak temporal-peak acoustic pressure**;
- β is the nonlinearity parameter ($\beta = 1 + B/2A = 3,5$ for pure water at 20 °C);
- f_{awf} is the **acoustic-working frequency**;
- F_a is the **local area factor**.

Note 1 to entry: If the transmitting system comprises an internal standoff utilizing a water or water-equivalent propagation medium, the offset distance between the transducer element and the transducer face increases the actual path length z to be considered. The nominal distance between the **beam axis**'s intersection with the crystal and the transducer face can be used.

[SOURCE: IEC TS 61949:2007, 3.12, modified – The text of the definition has changed substantially, the formula however is unchanged; Note 1 to entry has been added.]

3.39

longitudinal plane

plane defined by the **beam axis** and a specified orthogonal axis

SEE: Figure 1

3.40

mean peak acoustic pressure

p_m

arithmetic mean of the **peak-rarefactional acoustic pressure** and the **peak-compressional acoustic pressure**

Note 1 to entry: **Mean peak acoustic pressure** is expressed in pascals (Pa).

[SOURCE: IEC TS 61949:2007, 3.13, modified – Note 1 to entry has been added.]

3.41

near field

region of the field where $z < z_T$ aligned along the **beam axis** for planar non-focusing transducers

Note 1 to entry: For circular planar transducers, this is at a distance less than $A_{ob}/\pi\lambda$, where A_{ob} is the **output beam area** and λ is the wavelength of the ultrasound corresponding to the **acoustic frequency**.

Note 2 to entry: If the shape of the transducer aperture produces several **transition distances**, the one closest to the transducer is used.

3.42

number of pulses per ultrasonic scan line

n_{pps}

number of acoustic pulses travelling along a particular **ultrasonic scan line**

Note 1 to entry: Here **ultrasonic scan line** refers to the path of acoustic pulses on a particular **beam axis** in **scanning modes** and **non-scanning modes**.

Note 2 to entry: This number can be used in the calculation of any ultrasound temporal average value from **hydrophone** measurements.

Note 3 to entry: The following shows an example of the **number of pulses per ultrasonic scanline** and the **number of ultrasonic scanlines** (shows the end of a frame):

1 2 3 4; 1 2 3 4; 1 2 3 4... $n_{pps} = 1$; $n_{sl} = 4$
 1 1 2 2 3 3 4 4; 1 1 2 2 3 3 4 4; ... $n_{pps} = 2$; $n_{sl} = 4$
 1 1 1 1 2 2 2 2 3 3 3 3 4 4 4 4; 1 1 1 1 2 2 2 2 3 3 3 3 4 4 4 4; ... $n_{pps} = 4$; $n_{sl} = 4$
 1 1 2 2 3 3 4 4 1 1 1 2 2 2 3 3 4 4 4; 1 1 2 2 3 3 4 4 1 1 1 2 2 2 3 3 4 4 4; ... $n_{pps} = 5$; $n_{sl} = 4$ (within one frame the pulses down each line may not occur contiguously)

Note 4 to entry: Within one frame, all scan lines possibly do not have the same n_{pps} value.

An example is: 1 2 2 3 3 4; 1 2 2 3 3 4; ... avg $n_{pps} = 1,5$; max $n_{pps} = 2$; $n_{sl} = 4$

[SOURCE: IEC 61157:2007/AMD1:2013, 3.45 modified – the fourth example in Note 3 to entry has been corrected and the last example has been moved to a Note 4 to entry.]

3.43 number of ultrasonic scan lines

n_{sl}

quantity of **ultrasonic scan lines** that are excited during one **scan repetition period**

Note 1 to entry: This number can be used in the calculation of temporal average values for **scanning modes** from **hydrophone** measurements.

[SOURCE: IEC 61157:2007/AMD1:2013, 3.46]

3.44 offset distance

d_{offset}

distance between the **source aperture plane** and the **external transducer surface plane**, measured along the **beam axis**

SEE: Figure 2

Note 1 to entry: **Offset distance** is expressed in metres (m).

[SOURCE: IEC 61828:2020, 3.90]

3.45 operating mode mode of operation of a **system**

3.45.1 combined-operating mode operating mode that combines more than one **discrete-operating mode**

Note 1 to entry: Examples of **combined-operating modes** are real-time B-mode combined with M-mode (B+M), real-time B-mode combined with pulsed Doppler (B+D), colour M-mode (cM), real-time B-mode combined with M-mode and pulsed Doppler (B+M+D), real-time B-mode combined with real-time flow-mapping Doppler (B+rD), i.e. flow-mapping in which different types of acoustic pulses are used to generate the Doppler information and the imaging information.

3.45.2 discrete-operating mode operating mode of **medical diagnostic ultrasonic equipment** in which the purpose of the excitation of the **ultrasonic transducer** or **ultrasonic transducer element group** is to utilize only one diagnostic methodology

Note 1 to entry: Examples of **discrete-operating modes** are A-mode (A), M-mode (M), static B-mode (sB), real-time B-mode (B), continuous wave Doppler (cwD), pulsed Doppler (D), static flow-mapping (sD) and real-time flow-mapping Doppler (rD) using only one type of acoustic pulse.

3.45.3**inclusive mode**

combined-operating mode having acoustic output levels (p_r and I_{spta}) less than those corresponding to a specified **discrete-operating mode**

3.45.4**non-scanning mode**

operating mode that involves a sequence of ultrasonic pulses which give rise to **ultrasonic scan lines** that follow the same acoustic path

3.45.5**scanning mode**

operating mode that involves a sequence of ultrasonic pulses which give rise to **ultrasonic scan lines** that do not follow the same acoustic path

3.46**output beam area**
 A_{ob}

area of the ultrasonic beam derived from the –12 dB **beam area** at the **external transducer aperture**

Note 1 to entry: For reasons of measurement accuracy, the –12 dB **output beam area** is derived from measurements at a distance chosen to be as close as possible to the face of the transducer, and, if possible, no more than 1 mm from the face.

Note 2 to entry: For contact transducers, this area can be taken as the geometrical area of the **ultrasonic transducer** or **ultrasonic transducer element group**.

Note 3 to entry: The **output beam area** is expressed in units of metre squared (m^2).

3.47**output beam dimensions**
 $X_{\text{ob}}, Y_{\text{ob}}$

dimensions of the ultrasonic beam (–12 dB **beamwidth**) in specified directions perpendicular to each other and in a direction normal to the **beam axis** and at the **external transducer aperture**

Note 1 to entry: For reasons of measurement accuracy, the –12 dB **output beam dimensions** is derived from measurements at a distance chosen to be as close as possible to the face of the transducer, and, if possible, no more than 1 mm from the face.

Note 2 to entry: For contact transducers, these dimensions can be taken as the geometrical dimensions of the **ultrasonic transducer** or **ultrasonic transducer element group**.

Note 3 to entry: **Output beam dimensions** are expressed in metres (m).

3.48**output beam intensity**
 I_{ob}

temporal-average power output divided by the **output beam area**

Note 1 to entry: **Output beam intensity** is expressed in units of watt per metre squared (W/m^2).

3.49**peak acoustic pressure**
 p_c (or p_+) or p_r (or p_-)

peak-compressional acoustic pressure or **peak-rarefactional acoustic pressure**

Note 1 to entry: **Peak acoustic pressure** is expressed in pascals (Pa).

3.50**peak-compressional acoustic pressure** p_c (or p_+)

maximum positive **instantaneous acoustic pressure** in an acoustic field or in a specified plane during an **acoustic repetition period**

Note 1 to entry: **Peak-compressional acoustic pressure** is expressed in pascals (Pa).

Note 2 to entry: The definition of **peak-compressional acoustic pressure** also applies to peak-positive acoustic pressure, which is also in use in literature.

3.51**peak-rarefactional acoustic pressure** p_r (or p_-)

maximum of the modulus of the negative **instantaneous acoustic pressure** in an acoustic field or in a specified plane during an **acoustic repetition period**

Note 1 to entry: **Peak-rarefactional acoustic pressure** is expressed using a positive number for the numerical value.

Note 2 to entry: **Peak-rarefactional acoustic pressure** is expressed in pascals (Pa).

Note 3 to entry: The definition of **peak-rarefactional acoustic pressure** also applies to peak-negative acoustic pressure, which is also in use in literature.

3.52**principal longitudinal plane**

plane containing the **beam axis** and two points that define the minimum –6 dB **beamwidth**

SEE: Figure 1

Note 1 to entry: The selection of this axis is arbitrary for a circularly-symmetric transducer.

Note 2 to entry: For a HITU transducer with a hole in its centre within which is a diagnostic imaging transducer, this axis is aligned with the azimuth axis of the imaging transducer.

Note 3 to entry: For rectangular **ultrasonic transducers**, it is the plane parallel to their longest side.

[SOURCE: IEC 61828:2020, 3.110 modified – the reference to HITU transducers has been deleted in Note 1 to entry.]

3.53**pulse-average intensity** I_{pa}

quotient of the **pulse-intensity integral** to the **pulse duration** at a particular point in an acoustic field

Note 1 to entry: This definition applies to pulses and bursts.

Note 2 to entry: **Pulse-average intensity** is expressed in units of watt per metre squared (W/m^2).

3.54**pulse duration** t_d

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

SEE: Figure 4

Note 1 to entry: The final value of the time integral of the square of the **instantaneous acoustic pressure** is the **pulse-pressure-squared integral**.

Note 2 to entry: **Pulse duration** is expressed in seconds (s).

3.55 pulse-intensity integral

pii

time integral of the **instantaneous intensity** at a particular point in an acoustic field integrated over the **acoustic pulse waveform**

Note 1 to entry: For measurement purposes referred to in this document, **pulse-intensity integral** is proportional to **pulse-pressure-squared integral**.

Note 2 to entry: The **pulse-intensity integral** is expressed in units of joule per metre squared (J/m^2).

3.56 pulse-pressure-squared integral

ppsi

time integral of the square of the **instantaneous acoustic pressure** at a particular point in an acoustic field integrated over the **acoustic pulse waveform**

Note 1 to entry: The **pulse-pressure-squared integral** is expressed in units of pascal squared times second (Pa^2s).

3.57 pulse repetition period

prp

time interval between equivalent points on successive pulses or tone-bursts of pulses comprising a **discrete operating mode**

Note 1 to entry: The **pulse repetition period** is expressed in seconds (s).

3.58 pulse repetition rate

prf

reciprocal of the **pulse repetition period**

Note 1 to entry: The **pulse repetition rate** is expressed in hertz (Hz).

3.59 reference centre

<of a **hydrophone**> point on, within or near a **hydrophone** about which its electro-acoustic characteristics are defined

Note 1 to entry: The **reference centre** often corresponds to the geometrical centre of a **hydrophone** active element, unless otherwise stated.

[SOURCE: IEC 60500:2017, 3.26, modified – The context <of a **hydrophone**> and the term "active element" in Note 1 to entry have been added. In the definition, the word "geometrical" has been deleted.]

3.60 RMS acoustic pressure

p_{RMS}

root-mean-square (RMS) of the **instantaneous acoustic pressure** at a particular point in an acoustic field

Note 1 to entry: The mean should be taken over an integral number of **acoustic repetition periods** unless otherwise specified.

Note 2 to entry: **RMS acoustic pressure** is expressed in pascals (Pa).

3.61 scan-area

 A_s

<for automatic scanning systems> area on a specified plane (or surface) consisting of all points within the **beam area** of any beam passing through the surface during the scan

Note 1 to entry: The specified plane (or surface) follows the same shape as the **external transducer aperture**.

Note 2 to entry: The **scan-area** is expressed in units of metre squared (m²).

3.62 scan plane

<for automatic scanning systems> plane containing all the **ultrasonic scan lines**

Note 1 to entry: Some scanning systems have the ability to steer the ultrasound beam in two directions. In this case, there is no **scan plane** that meets this definition. However, it might be useful to consider a plane through the major-axis of symmetry of the **ultrasonic transducer** and perpendicular to the transducer face (or another suitable plane) as being equivalent to the **scan plane**.

3.63 scan repetition period

 srp

<for automatic scanning systems with a periodic scan sequence> time interval between identical points on two successive frames, sectors or scans

Note 1 to entry: In general, this document assumes that an individual scan line repeats exactly after a number of acoustic pulses. In case an **ultrasonic transducer** or **ultrasonic transducer element group** radiates ultrasound without any sequence of repetition, it will not be possible to characterize a scanned mode in the way described in this document. The approach described in Annex F can be useful when synchronization cannot be achieved.

Note 2 to entry: The **scan repetition period** is expressed in seconds (s).

3.64 scan repetition rate

 srr

reciprocal of the **scan repetition period**

Note 1 to entry: The **scan repetition rate** is expressed in hertz (Hz).

3.65 source aperture area

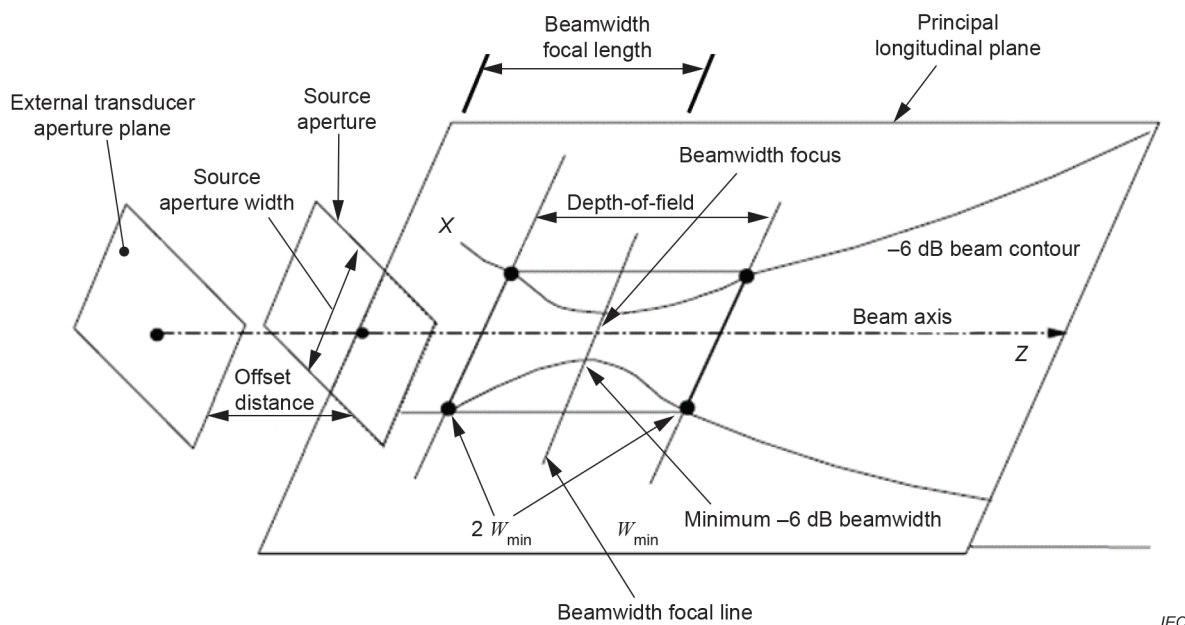
 A_{SAeff}

equivalent aperture area for an **ultrasonic transducer** of unknown characteristics, measured as the area inside the **-20 dB pulse-pressure-squared-integral** contour in the closest possible measurement plane (source aperture plane) to the **external transducer aperture**

SEE: Figure 2

Note 1 to entry: The nominal transmitting area of the source can be used for the calculation of the **local distortion parameter** σ_q in cases where there is a significant offset between the transducer crystal and the front face due to an internal standoff.

Note 2 to entry: **Source aperture area** is expressed in units of metre squared (m²).



[SOURCE: IEC 61828:2020]

Figure 2 – Several apertures and planes for a transducer of unknown geometry

3.66

source aperture plane

closest possible measurement plane to the **external transducer surface plane** that is perpendicular to the **beam axis**

SEE: Figure 2

Note 1 to entry: If the **offset distance** is zero, the **source aperture plane** can be coincident with the **external transducer aperture plane**.

[SOURCE: IEC 61828:2020, 3.135]

3.67

source aperture width

L_{SA}

<in a specified **longitudinal plane**> greatest -20 dB **beamwidth** along the line of intersection between the designated **longitudinal plane** and the **source aperture plane**

SEE: Figure 2

Note 1 to entry: If a transducer is circularly-symmetric, a radial line scan is sufficient to determine the width.

Note 2 to entry: If a HITU transducer has a hole in its centre, the beginning and ending -20 dB points of the width are measured and noted with reference to the centre.

Note 3 to entry: **Source aperture width** is expressed in metres (m).

[SOURCE: IEC 61828:2020, 3.136, modified – the reference to HITU transducers has been deleted in the Note 1 to entry.]

3.68**spatial-average pulse-average intensity** I_{sapa}

pulse-average intensity from one **ultrasonic transducer** or **ultrasonic transducer element group** averaged over the **beam-area** for that particular **ultrasonic transducer** or **ultrasonic transducer element group**

Note 1 to entry: A burst is also to be understood to be a pulse.

Note 2 to entry: **Spatial-average pulse-average intensity** is expressed in units of watt per metre squared (W/m^2).

3.69**spatial-average temporal-average intensity** I_{sata}

temporal-average intensity averaged over the **scan-area** or **beam area** as appropriate

Note 1 to entry: **Spatial-average temporal-average intensity** is expressed in units of watt per metre squared (W/m^2).

3.70**spatial-peak pulse-average intensity** I_{sppa}

maximum value of the **pulse-average intensity** in an acoustic field or in a specified plane

Note 1 to entry: **Spatial-peak pulse-average intensity** is expressed in units of watt per metre squared (W/m^2).

3.71**spatial-peak RMS acoustic pressure** p_{spr}

maximum value of the **RMS acoustic pressure** in an acoustic field or in a specified plane

Note 1 to entry: **Spatial-peak RMS acoustic pressure** is expressed in pascals (Pa).

3.72**spatial-peak temporal-average intensity** I_{spta}

maximum value of the **temporal-average intensity** in an acoustic field or in a specified plane

Note 1 to entry: For systems in **combined-operating mode**, the time interval over which the temporal average is taken is sufficient to include any period during which scanning is not taking place.

Note 2 to entry: **Spatial-peak temporal-average intensity** is expressed in units of watt per metre squared (W/m^2).

3.73**spatial-peak temporal-peak acoustic pressure** p_{sptp}

larger of the **peak-compressional acoustic pressure** and the **peak-rarefactional acoustic pressure**

Note 1 to entry: **Spatial-peak temporal-peak acoustic pressure** is expressed in pascals (Pa).

3.74**spatial-peak temporal-peak intensity** I_{sptp}

maximum value of the **temporal-peak intensity** in an acoustic field or in a specified plane

Note 1 to entry: **Spatial-peak temporal-peak intensity** is expressed in units of watt per metre squared (W/m^2).

3.75 temporal-average intensity

I_{ta}

time-average of the **instantaneous intensity** at a particular point in an acoustic field

Note 1 to entry: The time-average is considered over an integral number of **acoustic repetition periods**.

Note 2 to entry: In principle, the **temporal-average intensity** is an average over a relatively long time interval. For ultrasonic medical diagnostic systems in **non-scanning modes**, the **instantaneous intensity** is averaged over one or more **pulse repetition periods**. For ultrasonic medical diagnostic systems in **scanning modes**, the **instantaneous intensity** is averaged over one or more **scan repetition periods** for a specified **operating mode**.

Note 3 to entry: **Temporal-average intensity** is expressed in units of watt per metre squared (W/m^2).

3.76 temporal-peak acoustic pressure

p_{tp}

maximum value of the modulus of the **instantaneous acoustic pressure** at a particular point in an acoustic field

Note 1 to entry: **Temporal-peak acoustic pressure** is expressed in pascals (Pa).

3.77 temporal-peak intensity

I_{tp}

maximum value over time of the **instantaneous intensity** at a particular point in an acoustic field

Note 1 to entry: **Temporal-peak intensity** is expressed in units of watt per metre squared (W/m^2).

3.78 time-window-average intensity

$I_{w,\Delta t/s}(t)$

time-varying value of the **instantaneous intensity** averaged over a window of duration Δt

$$I_{w,\Delta t/s}(t) = \frac{1}{\Delta t} \int_{t-\Delta t/2}^{t+\Delta t/2} I(t') dt' \quad (8)$$

where

$I(t)$ is the **instantaneous intensity**;

$\Delta t/s$ is the numerical value of the moving time window width in seconds;

t' is the variable of integration.

Note 1 to entry: The time varying **time-window-average intensity** for a time window width of 20 s, for instance, is denoted by $I_{w,20}(t)$.

Note 2 to entry: **Time-window-average intensity** is expressed in units of watt per metre squared (W/m^2).

3.79 transducer aperture area

A_{TA}

effective active area of an **ultrasonic transducer** in the **transducer aperture plane**

Note 1 to entry: **Transducer aperture area** is expressed in square metres (m^2).

[SOURCE: IEC 61828:2020, 3.145]

3.80**transducer aperture plane**

plane that is orthogonal to the **beam axis** of the **unsteered beam** and is adjacent physically to the **ultrasonic transducer**

SEE: Figure 1

Note 1 to entry: If the **ultrasonic transducer** is flat, the plane is coplanar with the transmitting surface of the **ultrasonic transducer**; if it is concave, the plane touches the periphery of the transmitting surface; if it is convex, the plane is tangent to the centre of the transmitting surface at the point of contact.

[SOURCE: IEC 61828:2020, 3.146]

3.81**transducer aperture width**

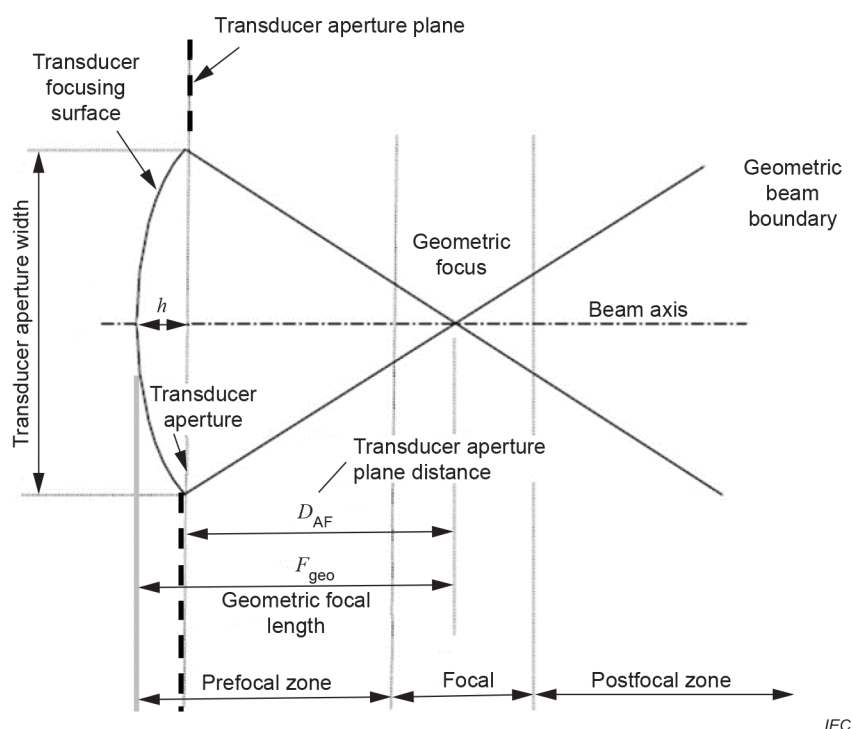
L_{TA}

full width of the transducer aperture along a specified axis orthogonal to the **beam axis** of the unsteered beam at the centre of the transducer

SEE: Figure 3

Note 1 to entry: **Transducer aperture width** is expressed in metres (m).

[SOURCE: IEC 61828:2020, 3.148, modified – The phrase "at the centre of the transducer" has been added to the definition.]



The radius of curvature is $D = D_{AF} + h$.

[SOURCE: IEC 61828:2020]

Figure 3 – Parameters for describing a focusing transducer of known geometry

3.82

transducer assembly

set of parts of **medical diagnostic ultrasonic equipment** comprising the **ultrasonic transducer** and/or **ultrasonic transducer element group**, together with any integral components, such as an acoustic lens or integral stand-off

Note 1 to entry: The **transducer assembly** is usually separable from the **ultrasound instrument console**.

3.83

transition distance

z_T

aperture area divided by π times the effective wavelength λ

[SOURCE: IEC 61828:2020, 3.153, modified – The words "effective wavelength" have been added to the definition.]

3.83.1

transition distance for design

z_{TD}

<for a given **longitudinal plane**> **transducer aperture area** A_{TA} of the **ultrasonic transducer** divided by π times the effective wavelength λ

$$z_{TD} = A_{TA}/(\pi\lambda) \quad (9)$$

Note 1 to entry: For design, for an unapodized **ultrasonic transducer** with circular symmetry about the **beam axis**, the **source aperture area** is πa_e^2 , where a_e is the effective radius; therefore the **transition distance** is $z_T = a_e^2/\lambda$.

Note 2 to entry: For a spherically focusing transducer, the **transition distance** is approximately the same but more exactly it is $z_T = 2D^2 \left(1 - \sqrt{1 - (a/D)^2}\right) / \lambda$, where D is the radius of curvature.

Note 3 to entry: For design, for an unapodized rectangular **ultrasonic transducer** which has a **transducer aperture width**, L_{TA1} , in a specified **longitudinal plane**, the effective in-plane area is $(L_{TA1})^2$. Therefore, for this plane, the **transition distance** is $z_{T1} = (L_{TA1})^2/(\pi\lambda)$. The **transition distance** for the orthogonal **longitudinal plane** including the second **transducer aperture width** is $z_{T2} = (L_{TA2})^2/(\pi\lambda)$.

Note 4 to entry: For apodized transducers with a symmetric even apodization or weighting function W (normalized to a maximum value of one for the particle velocity distribution), the **transition distances** are the following.

For circularly symmetric transducers with an active radius a :

$$z_T = \left(\frac{2}{\lambda}\right) \int_0^a W(r) r dr$$

For a rectangular transducer with a physical aperture length L in a given longitudinal plane, for example, xz :

$$z_T = \left(\frac{4}{\pi\lambda}\right) \left| \int_0^{L/2} W(x) dx \right|^2$$

Note 5 to entry: For symmetric shapes other than the most common cases of circular symmetry and rectangular geometry, the same definition of **transition distance** can be used. For example, for apertures with n -fold symmetry ($n > 2$) such as hexagons and octagons, the **transition distance** in a symmetry plane perpendicular to a side is equal to the area of the aperture divided by $(\pi\lambda)$. For annular arrays with several rings, the equivalent area is the total (all rings) area of the active aperture. For cases in which unique phasing is used, such as annular arrays with alternate phase shifts (0° or 180°) in addition to intended focusing or for cases of apertures with unusual shapes and phasing, three-dimensional diffraction computation is employed to determine the minimum beamwidth corresponding to the appropriate **transition distance**.

Note 6 to entry: **Transition distance for design** is expressed in metres (m).

[SOURCE: IEC 61828:2020, 3.153.1, modified – Note 6 to entry has been omitted here.]

3.83.2

transition distance for measurement

z_{TM}

<for a given **longitudinal plane**> **source aperture area**, A_{SAeff} , of the **ultrasonic transducer** divided by π times the effective wavelength λ

$$z_{\text{TM}} = A_{\text{SAeff}}/(\pi\lambda) \quad (10)$$

Note 1 to entry: For measurements in each specified **longitudinal plane**, the **source aperture width** in that plane is used, or $z_{\text{T1}} = (L_{\text{SA1}})^2/(\pi\lambda)$; in the other orthogonal plane, $z_{\text{T2}} = (L_{\text{SA2}})^2/(\pi\lambda)$.

Note 2 to entry: **Transition distance for measurement** is expressed in metres (m).

[SOURCE: IEC 61828:2020, 3.153.2]

3.84

treatment head

assembly comprising an **ultrasonic transducer** and associated parts for local application of **ultrasound** to the patient

[SOURCE: IEC 60601-2-5:2009, 201.3.214, modified – A note in the original has been deleted.]

3.85

ultrasound instrument console

electronic unit to which the **transducer assembly** is attached

3.86

ultrasonic scan line

<for scanning systems> **beam axis** for a particular **ultrasonic transducer element group**, or for a particular excitation of an **ultrasonic transducer** or **ultrasonic transducer element group**

Note 1 to entry: In this document, **ultrasonic scan line** refers to the path of acoustic pulses and not to a line on an image on the display screen of a system.

Note 2 to entry: In general, this document assumes that an individual scan line repeats exactly after a given number of acoustic pulses. In case an **ultrasonic transducer** or **ultrasonic transducer element group** radiates ultrasound without any sequence of repetition, it will not be possible to characterize a scanned mode in the way described in this document. The approach described in Annex F can be useful when synchronization cannot be achieved.

Note 3 to entry: The case where a single excitation produces ultrasonic beams propagating along more than one **beam axis** is not considered.

3.87

ultrasonic scan line separation

s_s

<for automatic scanning systems> distance between the points of intersection of two consecutive **ultrasonic scan lines** of the same type and a specified line in the **scan plane**

Note 1 to entry: For this definition it is assumed that consecutive **ultrasonic scan lines** are spatially adjacent; this is not true for all types of scanning equipment.

Note 2 to entry: The **ultrasonic scan line separation** is expressed in metres (m).

3.88

ultrasonic transducer

device capable of converting electrical energy to mechanical energy within the ultrasonic frequency range and/or reciprocally of converting mechanical energy to electrical energy

3.89**ultrasonic transducer element**

element of an **ultrasonic transducer** that is excited in order to produce an acoustic signal

3.90**ultrasonic transducer element group**

group of elements of an **ultrasonic transducer** which are excited together in order to produce an acoustic signal

3.91**ultrasonic transducer element group dimensions**

dimensions of the surface of the group of elements of an **ultrasonic transducer element group** which includes the distance between the elements, hence representing the overall dimensions

Note 1 to entry: **Ultrasonic transducer element group dimensions** are expressed in metres (m).

3.92**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, 2.2.3.

4 Symbols

a_h	effective hydrophone size
a_g	hydrophone geometrical radius
a_t	effective radius of a non-focusing ultrasonic transducer
$a_{\max}$	maximum effective radius for a specific hydrophone application
arp	acoustic repetition period
$A_{b,6}, A_{b,20}$	beam area corresponding to –6 dB beam area and –20 dB beam area
A_g	geometrical area of an ultrasonic transducer
A_{ob}	output beam area
A_s	scan-area
A_{SAeff}	source aperture area
A_{TA}	transducer aperture area
BW	bandwidth
c	speed of sound in the medium (usually water)
C	end-of-cable capacitance of a hydrophone
C_{el}	parallel input capacitance of an electrical load
d_{offset}	offset distance
f_{awf}	acoustic frequency, acoustic-working frequency
f_p	peak pulse acoustic frequency
f_t	time average acoustic frequency
F_a	local area factor
I	instantaneous intensity
I_{ob}	output beam intensity

I_{pa}	pulse-average intensity
I_{sapa}	spatial-average pulse-average intensity
I_{sata}	spatial-average temporal-average intensity
I_{sppa}	spatial-peak pulse-average intensity
I_{ta}	temporal-average intensity
I_{tp}	temporal-peak intensity
I_{spta}	spatial-peak temporal-average intensity
I_{sptp}	spatial-peak temporal-peak intensity
$I_{w,\Delta t/s}$	time-window-average intensity
k	$2\pi/\lambda$
K_{sa}	spatial averaging correction factor
$L_{M_L}(f)$	end-of-cable loaded sensitivity level
$L_P(f)$	pressure level spectrum
$\underline{LP}(f)$	low-pass filtering function
L_{TA}	transducer aperture width
L_{SA}	source aperture width
$\underline{M}_C(f)$	end-of-cable open-circuit sensitivity
$\underline{M}_L(f)$	end-of-cable loaded sensitivity
n_{pps}	number of pulses per ultrasonic scan line
n_{sl}	number of ultrasonic scan lines per image for spatial distribution
p	instantaneous acoustic pressure
p_{ii}	pulse-intensity integral
p_{psi}	pulse-pressure-squared integral
p_m	mean peak acoustic pressure
p_{tp}	temporal-peak acoustic pressure
p_{rr}	pulse repetition rate
p_{rp}	pulse repetition period
p_{spr}	spatial-peak RMS acoustic pressure
p_{sptp}	spatial-peak temporal-peak acoustic pressure
p_{RMS}	RMS acoustic pressure
$p_C(p_+)$	peak-compressional acoustic pressure
$p_r(p_-)$	peak-rarefactional acoustic pressure
P	total ultrasonic power
P_{beam}	total power emitted by one acoustic scan line
R_{bh}	ratio of the –6 dB beamwidth to the effective hydrophone diameter
s_s	ultrasonic scan line separation
srp	scan repetition period
srr	scan repetition rate

t_d	pulse duration
$\underline{U}_L(f)$	end-of-cable voltage for a hydrophone
v	instantaneous particle velocity
w_6, w_{12}, w_{20}	beamwidth (at –6 dB and –12 dB and –20 dB levels)
X_{ob}, Y_{ob}	output beam dimensions
z	distance between a hydrophone and an ultrasonic transducer
z_c	distance z_c
z_{psi}	distance z_{psi}
z_r	distance z_r
z_{spta}	distance z_{spta}
z_T	transition distance
z_{TD}	transition distance for design
z_{TM}	transition distance for measurement
Z_h	complex electric output impedance of a hydrophone or hydrophone assembly
Z_L	electric load impedance
β	nonlinearity parameter
θ	angle of incidence of an ultrasonic wave with respect to the hydrophone axis
λ	acoustic wavelength in a liquid
ρ	density of the medium (usually water)
σ_q	local distortion parameter
ω	$(2\pi f_{awf})$ circular frequency

5 Measurement requirements

5.1 Requirements for hydrophones and amplifiers

5.1.1 Preface

In order to select a **hydrophone** and amplifier that is appropriate for the type of measurement to be undertaken, it shall be ensured that the selected devices conform with the following requirements. Requirements for **hydrophone** performance in this clause are either in addition to or supersede those for **hydrophones** in IEC 62127-3.

5.1.2 General

It is assumed throughout this document that a **hydrophone** is a device that responds to waterborne acoustic waves [see [IEV 801-32-26](#)] in such a way that the output voltage is proportional to the acoustic pressure. Generally, this relationship is frequency dependent; thus, if $\underline{M}_L(f)$ is the **end-of-cable loaded sensitivity** of a **hydrophone** (see 3.25 and Annex C), the **instantaneous acoustic pressure** $p(t)$ is related to the measured end-of-cable voltage $u_L(t)$ by

$$p(t) = \mathcal{F}^{-1}[\underline{U}_L(f) / \underline{M}_L(f)] \quad (11)$$

where

$\mathcal{F}^{-1}$ denotes the inverse Fourier transform;

$\underline{U}_L(f)$ is the Fourier transform result of $u_L(t)$.

NOTE 1 See 5.1.7.2 and Annex D to implement this method.

NOTE 2 For mathematical completeness, Formula (11) needs to include the real part operator, Re, on the right-hand side. However, for the type of spectra relevant here, the time domain data is not likely to comprise imaginary components with the exemption of a possible constant numerical residue, and thus Re is omitted in this formula throughout the document.

If the **hydrophone** or **hydrophone assembly** meets the requirements of a narrow-band approximation as specified in 5.1.7.1, then **instantaneous acoustic pressure** can be determined from Formula (12):

$$p(t) = u_L(t) / |\underline{M}_L(f_{\text{awf}})| \quad (12)$$

where

$|\underline{M}_L(f_{\text{awf}})|$ is the modulus of the **end-of-cable loaded sensitivity** of the **hydrophone** at the **acoustic-working frequency**.

5.1.3 Sensitivity of a hydrophone

When no **hydrophone pre-amplifier** is used, the sensitivity of the **hydrophone** shall refer to the **end-of-cable loaded sensitivity** and shall be determined for the particular electrical loading conditions (see 3.22).

When a **hydrophone pre-amplifier** is used, the sensitivity of the **hydrophone** shall refer to the **end-of-cable loaded sensitivity** which relates to the particular **hydrophone assembly**.

NOTE 1 The method outlined in IEC 62127-3 can be used for the determination of **end-of-cable loaded sensitivity** assuming the **end-of-cable open-circuit sensitivity of the hydrophone** is known.

NOTE 2 See Clause B.10 for tabulated examples of specification parameters.

5.1.4 Directional response of a hydrophone

The directional response of the **hydrophone** shall be known.

Symmetry of the directional response shall conform to IEC 62127-3.

NOTE There are two reasons to know the directional response of a **hydrophone**. First, it can be necessary as part of the field characterization procedures described in Annex B, in which case the directional response needs to be known at the appropriate **acoustic-working frequency**. Secondly, the directional response is used to derive the **effective hydrophone size**.

5.1.5 Effective hydrophone size

The **effective hydrophone size** shall be known and determined following the method described in IEC 62127-3.

5.1.6 Choice of the size of a hydrophone active element

5.1.6.1 General

The choice of the **effective hydrophone size** for a specific application shall be determined by consideration of the following.

The effective size of the element should ideally be comparable with or smaller than one quarter of the acoustic wavelength, so that phase and amplitude variations do not contribute significantly to measurement **uncertainties**.

It is not possible, because of the large range of types of **ultrasonic transducers**, to establish a simple relationship between the optimum effective element size of the **hydrophone** and parameters such as the **ultrasonic transducer** dimension, the acoustic wavelength and the distance from the **ultrasonic transducer**. However, in the **far field** it is reasonable to relax the above criterion. For circular **ultrasonic transducers**, the following criterion may be used as a guide to the determination of the maximum effective radius $a_{\max}$ of a **hydrophone** active element. $a_{\max}$ is given by Formula (13):

$$a_{\max} = \frac{\lambda}{8a_1} (l^2 + a_1^2)^{1/2} \quad (13)$$

where

a_1 is the effective radius of the **ultrasonic transducer**;

l is the distance between the **hydrophone** and the **ultrasonic transducer** face;

λ is the acoustic wavelength corresponding to the **acoustic-working frequency**.

See [2]¹ and [3].

For a focused **ultrasonic transducer**, the above relationship may still be used.

For an **ultrasonic transducer** with a non-circular element, the above relationship may still be used by replacing a_1 by one half the maximum **ultrasonic transducer dimension** or **ultrasonic transducer element group dimension**.

Requirements of the size of the **hydrophone** active element are relaxed for measurements of ultrasonic fields generated by physiotherapy systems (see 8.3.1).

For representative experimental data, see [1].

5.1.6.2 Spatial averaging effect

The practical requirement of an adequate signal-to-noise ratio or other considerations can lead to the use of a **hydrophone** with an element size greater than that recommended above. In this case, care should be taken in interpreting measurements as a piezoelectric **hydrophone** is a phase sensitive detector that integrates the complex acoustic pressure over its active element.

When the **hydrophone** is translated from the position of maximum received signal in any direction normal to the **beam axis** by an amount equal to the **effective hydrophone size** element, the decrease in signal should be less than 1 dB. If this is not the case, corrections for spatial averaging should be made. See Annex E.

Improved corrections can also be made using diffraction corrections, see [2], [3], [4], [5].

The spatial averaging effect may also be addressed by spatial deconvolution of the **hydrophone** aperture as proposed in [6], [7], [8]. However, the method may suffer from signal-to-noise ratio issues in practical cases.

For nonlinear broadband **acoustic pulse waveforms**, the method of inverse spectral filtering as outlined in Clause E.2 should be applied to correct for spatial averaging.

¹ Numbers in square brackets refer to the Bibliography.

5.1.7 Bandwidth

5.1.7.1 Narrow-band approximation

Narrow-band approximations shall be considered as being appropriate whenever the **local distortion parameter** is less than 0,5 (see 7.2.4).

In this case, it is sufficient to consider the sensitivity value at the **acoustic-working frequency** as being representative of the sensitivity value at all frequencies of interest.

NOTE 1 When measuring narrow-band acoustic signals, it is assumed that all the significant frequency components within the signal are located at frequencies close to the **acoustic-working frequency**. In this case, there will be little variation in the **end-of-cable loaded sensitivity** of the **hydrophone**.

NOTE 2 The simplifying assumption given above can also be used when measuring acoustic fields with a broader frequency content provided that the **end-of-cable loaded sensitivity** of the **hydrophone** shows only limited variations over the frequency range necessary to accurately represent the acoustic signal.

If the value of the **local distortion parameter** exceeds 0,5 (see 7.2.4), then the **end-of-cable loaded sensitivity level** of the **hydrophone** or **hydrophone assembly** shall vary by less than ± 3 dB over the frequency range (f) from one octave below to three octaves above the **acoustic-working frequency**, where the 0 dB reference point is located at the **acoustic-working frequency**, f_{awf} . That is, for

$$f_{awf} / 2 \leq f \leq 8 f_{awf} \quad (14)$$

$$L_{M_L}(f_{awf}) - 3 \text{ dB} \leq L_{M_L}(f) \leq L_{M_L}(f_{awf}) + 3 \text{ dB} \quad (15)$$

where $L_{M_L}(f) = 20 \log_{10} \frac{|M_L(f)|}{M_{ref}} \text{ dB}$ and $M_{ref} = 1 \frac{\text{V}}{\text{Pa}}$.

NOTE 3 There is scientific justification for using an extended range $f_{awf}/16 \leq f \leq 8f_{awf}$ (i.e. four octaves below to three octaves above f_{awf}), based on [9] and [10] (see also Annex A). However, experimentally determined **hydrophone** calibration data is available for a limited **bandwidth** only, for instance from 1 MHz to 100 MHz. To judge whether the narrow-band approximation is appropriate according to Formulas (14) and (15), **hydrophone** frequency response extrapolation can be applied as an alternative method in the same way as described in 5.1.7.2.2 including Notes 1, 2 and 3, and Annex D for broadband measurements, if necessary. That is, extrapolation of $M_L(f)$ can be used to cover frequencies f outside the calibration range available, at maximum below half of the **acoustic-working frequency** towards zero and above the lesser of four times the **acoustic-working frequency** or 100 MHz towards the Nyquist frequency $f_{Nyquist}$, e.g. for $0 \leq f < f_{awf}/2$ and for $\min[4f_{awf}, 100 \text{ MHz}] < f \leq f_{Nyquist}$. Details on considerations for appropriate extrapolation are provided in D.4.2.

If the narrow-band approximation requirements are not fulfilled the broadband measurement method of 5.1.7.2 shall be followed.

If the broadband measurement method of 5.1.7.2 is implemented in the measurement system, it may be used for all situations including those covered by the narrow-band approximation requirements.

Measurements performed in conformity with the first edition of IEC 62127-1 may have considered frequency contributions up to 40 MHz only. The changed requirements of this second edition do not imply that such measurements of the past shall be repeated for output measurements on equipment already characterized in conformity with the first edition. If necessary, the systematic error of the limited bandwidth may in such cases then be attributed by an additional **uncertainty** contribution.

NOTE 4 See 8.2.4 for specific consideration of diagnostic equipment of low acoustic output.

5.1.7.2 Broadband measurements

5.1.7.2.1 General

In case the narrow-band approximation requirements cannot be met, the **uncertainty** in the measurement can become unacceptably large due to limited bandwidth and frequency dependent sensitivity variation of the **hydrophone**. Voltage-to-pressure conversion shall then be performed using the frequency-dependent sensitivity of the **hydrophone** and the frequency content of the **acoustic pulse waveform**. The measurement method based on deconvolution of the acquired waveform with the **hydrophone** response as described here in 5.1.7.2 and in Annex D produces more accurate results. For performing deconvolution, specific aspects of hydrophone calibration data conditioning, regularization filtering of signal spectra, and **uncertainty** determination shall be considered in accordance with 5.1.7.2.2, 5.1.7.2.3 and 5.1.7.2.4.

5.1.7.2.2 Deconvolution bandwidth

Application of Formula (11) to determine the **acoustic pulse waveform** requires the complex division of the voltage spectrum $\underline{U}_L(f)$ by the sensitivity $\underline{M}_L(f)$. For this operation data sets must match, e.g. the frequency increment and range of both spectra must be the same. The frequency increment of $\underline{U}_L(f)$ depends on the length of the acquired **acoustic pulse waveform** (including zero padding if applicable) and the frequency range extends from 0 to the Nyquist frequency associated with the sample rate used. Experimentally obtained **hydrophone** calibration data $\underline{M}_L(f)$, however, may provide different frequency increments and ranges. If necessary, calibration data can be interpolated between consecutive sensitivity data points available for the **hydrophone** (see Annex D). If necessary, extrapolation of $\underline{M}_L(f)$ may be used to cover frequencies f outside the calibration range available, at maximum below half of the **acoustic-working frequency** towards zero and above the lesser of four times the **acoustic-working frequency** or 100 MHz towards the Nyquist frequency f_{Nyquist} , e.g. for $0 \leq f < f_{\text{awf}}/2$ and for $\min[4 f_{\text{awf}}, 100 \text{ MHz}] < f \leq f_{\text{Nyquist}}$. Details on considerations for appropriate extrapolation are provided in D.4.2.

NOTE 1 The maximum lower limit of 100 MHz for extrapolating at higher frequencies in the above requirement assumes availability of hydrophone calibration certificates up to 100 MHz at the time this document is published. If only a lower upper limit is available at this time, then that limit can be used instead for practicability.

NOTE 2 Secondary pulse calibration techniques have been developed [11], [12] and can be applied by the hydrophone user to determine the sensitivity of the individual hydrophone in frequency ranges where calibration service is not available. The same techniques can be used, in general, for hydrophone calibration data extrapolation, and to check conformity with the narrow-band approximation through Formulas (14) and (15).

NOTE 3 For some types of hydrophones, the variation of sensitivity at higher frequency can possibly be predicted from calibration data obtained at lower frequencies. For example, above the resonance frequency of a membrane hydrophone, the sensitivity is likely to follow a predictable trend. In such cases, the sensitivity prediction can be used in place of direct measurements so long as the **uncertainty** in the prediction is accounted for, based on calibration measurements of similar hydrophones throughout the frequency range where the prediction is used.

5.1.7.2.3 Regularization

Deconvolution is mathematically speaking an ill-posed inverse problem, which in the discrete time domain results in an ill-conditioned estimation problem [13], [14]. For instance, at very high frequency the acquired **hydrophone** signal may still comprise some noise contribution but the sensitivity may be close to zero. Formula (11) then leads to a large impact of such noise within the deconvolution, see Annex D for a waveform example. To obtain waveforms with acceptable overall noise, in general, appropriate low-pass filtering is necessary; this also reduces the occurrence of Gibbs oscillations. Including such a regularization, Formula (11) is then extended towards

$$p(t) = \mathcal{F}^{-1} \left(\underline{LP}(f) \cdot \frac{\underline{U_L}(f)}{\underline{M_L}(f)} \right) \quad (16)$$

where $\underline{LP}(f)$ denotes the complex-valued low-pass filtering function. Different filter functions can be used for **hydrophone** signal deconvolution [14], [15], [16], [17], [18], [19], [20], [21]. Since any low-pass filtering induces additional **bandwidth** limitation and hence possibly cutting of peak pressure parts of the waveform, the filter cut-off frequency shall be kept as large as possible while still providing enough noise suppression to achieve reasonable **uncertainties** for waveform parameters. The –3 dB cut-off frequency of the low-pass filtering shall be 8-times the **acoustic-working frequency** f_{awf} determined from the pressure spectrum without low-pass filtering or higher.

NOTE 1 In measurement situations with stable pulse repetition, high-frequency noise suppression can be improved by increasing signal averaging.

NOTE 2 In general, **bandwidth** reduction of nonlinearly distorted ultrasonic waveforms through additional low-pass filtering will affect the peak compressional pressure stronger than the peak rarefactional pressure and derived intensity data.

NOTE 3 For high amplitude nonlinearly distorted waveforms of high intensity therapeutic ultrasound or lithotripsy comprising up to 100 harmonics, cut-off frequencies larger than 8-times the **acoustic-working frequency** are needed to avoid cutting of the peak compressional waveform parts and excessive systematic **uncertainty** contribution of the regularization. Specifications are provided in 8.3.2.

NOTE 4 A good choice for the numerical filter type sufficient in many applications is of the form $\underline{LP}(f) = 1 / \left(1 + \frac{if}{f_g} \right)^2$ with $i = \sqrt{-1}$ and f_g denoting the –6 dB corner frequency. The –3 dB corner frequency then is approximately $f_g / 1,555$ [17].

NOTE 5 In principle, the regularization filter and cut-off frequency choice can be supported by optimizing the overall **uncertainty** of the deconvolved waveform including the partly competing noise and regularization components [14].

NOTE 6 Of the acoustic parameters listed in 7.2.1, the **peak compressional acoustic pressure** is most likely to be affected by the choice of the regularization filter.

5.1.7.2.4 Uncertainty estimation for broadband measurement method

Due to the application of Fourier transforms and inverse Fourier transforms, regularization filtering, as well as complex-valued **hydrophone** calibration data, the **uncertainty** estimation for the broadband measurement method may appear less straightforward than in other situations. However, a GUM-compliant **uncertainty** evaluation (ISO/IEC Guide 98-3 and ISO/IEC Guide 98-3/Suppl.2 [22]) can be performed utilizing closed formulae for the propagation of **uncertainties** when discrete Fourier and inverse Fourier transforms are applied, and an open-source software tool GUM2DFT² is available [21]. The method enables, for instance, to propagate to the time domain the frequency dependent **uncertainties** of the **hydrophone** calibration data provided for modulus and phase in the frequency domain.

The introduction of additional numerical low-pass filtering for regularizing the deconvolution problem introduces an additional **uncertainty** contribution to the measurement and data evaluation procedure. The impact of the induced systematic error can be quantitatively assessed, for instance, by considering a continuous upper bound function in the frequency domain for the pressure magnitude spectrum based on a simple one-parametric basis functions approach and incorporating additional prior knowledge, like monotonously decreasing spectral components with frequency expected for nonlinearly distorted **acoustic pulse waveforms**, and typical signature of high frequency noise in distinction to waveform signal contribution [14].

² This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product.

5.1.8 Linearity

The linear response, as defined in IEC 62127-3, should extend to 5 MPa.

The upper limit of known dynamic range shall be stated, in particular if below 5 MPa.

5.1.9 Hydrophone signal amplifier

5.1.9.1 General

Hydrophone amplifiers shall meet the following performance requirements.

5.1.9.2 Requirements for all amplifiers

The amplifier gain shall allow the **hydrophone assembly** to meet the requirements given in 5.1.7.

The sensitivity level shall not vary by more than 0,5 dB per 100 kHz frequency increment inside the stated **bandwidth**. The requirement can be verified using an appropriate representation of the frequency response that resolves all important details of the frequency dependence.

The linearity with input signal over a dynamic range of 50 dB shall be $\pm 0,3$ dB.

The spectral noise measured generated by the **hydrophone assembly** shall be sufficiently low to allow measurements to be performed with an adequate signal-to-noise ratio for any frequency within the **bandwidth** considered.

The following performance parameters shall be specified:

- the gain as a function of frequency;
- the input impedance as a function of frequency, either the real and imaginary components (Z_L) (see 3.22), or the equivalent parallel resistive and capacitive components;
- the output impedance.

5.1.9.3 Additional requirements for differential amplifiers

The impedance requirements given above shall apply except that the impedance is measured between the two active inputs.

The common mode rejection shall be at least 40 dB (referred to the input) over the frequency range one octave below to two octaves above f_{awf} . See [23], [24].

5.1.10 Hydrophone cable length and amplifiers

A connecting cable of a length and characteristic impedance which ensures that electrical resonance in the connecting cable does not affect the defined **bandwidth** of the **hydrophone** or **hydrophone assembly** shall be chosen. The cable shall also be terminated appropriately.

To minimize the effect of resonance in the connecting cable, the length of the **hydrophone** cable (in metres) shall be much less than $50/(f_{awf} + BW_{20})$, where f_{awf} is the **acoustic-working frequency** in MHz and BW_{20} is the -20 dB **bandwidth** in MHz of the **hydrophone** signal. In most cases a cable length of ≤ 15 cm is usually adequate (see [25]).

NOTE 1 Attention is to be paid to the appropriateness of the output impedance of the **hydrophone**/amplifier in relation to the input impedance of the connected measuring device.

NOTE 2 Methods that can be used to correct the effects of finite **bandwidth** of the **hydrophone**/amplifier on waveforms suffering distortion from nonlinear propagation are given in Annex D.

5.2 Requirements for positioning and water baths

5.2.1 General

There are various possible systems that may be used to mount the **ultrasonic transducer** and **hydrophone**. The general performance requirements for such systems are specified here, and these are considered as optimum for the purposes of this document. Alternative positioning systems may be used providing equivalence with those described in this subclause is demonstrated.

Annex J shows a simple configuration of tank, **ultrasonic transducer** and **hydrophone** intended to show only the coordinate axes and degrees of freedom referred to in this document.

5.2.2 Positioning systems

5.2.2.1 Transducer positioning

The **ultrasonic transducer** under test shall be supported using a positioning system such that its face is fully immersed in the water bath and at a distance from any adjacent surface, for instance, a water/air interface, so that reflected ultrasound from this surface does not interfere with the main received signal. For the situation when the surface is parallel to the **beam axis**, the following criteria shall be satisfied.

If z is the distance between the active element of a **hydrophone** and the face of an **ultrasonic transducer** and t is the time between the arrival of the direct pulse at the **hydrophone** and the end of the measurement acquisition period, then the minimum distance, h , between the **beam axis** and the reflecting surface shall be determined from Formula (17):

$$(z^2 + 4h^2)^{1/2} - z > c t \quad (17)$$

It is preferable to immerse the transducer and not to use a membrane between the face of the **ultrasonic transducer** and the water bath. If, however, a membrane is needed, then the membrane should be as thin as practicable and should be kept as close to the front surface of the **ultrasonic transducer** as is possible. Close acoustic coupling should be ensured by using a water-based coupling agent, taking care to exclude bubbles of air. Measurements of acoustic parameters should be corrected for transmission loss of the membrane.

5.2.2.2 Hydrophone positioning

The **hydrophone** shall be set up in the coordinate positioning system such that the direction of maximum sensitivity of the **hydrophone** is approximately parallel to the anticipated direction of the **beam axis** of the **ultrasonic transducer** to be measured.

NOTE To avoid effects on the measurements made on continuous wave fields due to reflection of ultrasound from the surface of membrane **hydrophones**, the **hydrophone** can be tilted. Tilting ensures that the reflected ultrasound either does not interfere significantly with the transducer or is not subsequently reflected from the transducer face, producing interference effects. Two methods used to determine the rotation required are described in Annex B.

5.2.2.3 Spatial positioning

The **hydrophone** and/or the **ultrasonic transducer** shall be supported from a positioning system to allow them to be positioned relative to each other at any desired point within a space with the following degrees of freedom:

- spatial positioning along three orthogonal axes (named x , y and z), one (designated the z -axis) being the **beam axis** of the active element of the **ultrasonic transducer**;
- to be able to reproduce positions, all translation and rotation systems should be provided with position indicators;

c) the repeatability of positioning should be 0,10λ or 0,05 mm, whichever is smaller.

NOTE 1 After alignment, the z-axis is expected to be parallel to the **beam axis** of the **ultrasonic transducer**.

NOTE 2 It is possible to relax the requirement of the reproducibility for many measurements. A reasonable basis is to relate the precision of the positioning system to the diameter of the active element of the **hydrophone**. In the direction perpendicular to the direction of propagation of the ultrasound, a precision equivalent to 10 % of the diameter of the active element of the **hydrophone** is usually adequate, while in a direction parallel to the propagation direction a precision equivalent to the diameter of the active element is usually adequate.

5.2.3 Water bath

5.2.3.1 General

The size of the measurement vessel shall be such that the **ultrasonic transducer** and **hydrophone** can be moved relative to each other by an amount large enough to permit the active element of the **hydrophone** to be positioned at any point in the acoustic field at which measurements are required.

Means shall be incorporated to minimize effects on the measurement of reflection from any part within the water bath or the walls (see also 5.2.3.2).

In a direction parallel to the **beam axis** for non-automatic scanning systems or the symmetry axis of the **azimuth plane** for automatic scanning systems, the wall of the water bath should be at a distance from the **ultrasonic transducer** which is significantly greater (30 % to 100 %) than the maximum separation distance between the **ultrasonic transducer** and the **hydrophone**.

In a direction perpendicular to the **beam axis** for non-automatic scanning systems or the symmetry axis of the **azimuth plane** for automatic scanning systems, the wall of the water bath should be at a distance which is significantly greater (30 % to 100 %) than the maximum distance of the **hydrophone** from the **beam axis** in the case of non-automatic scanning systems, or from an extreme **scan line** in the case of automatic scanning systems.

NOTE 1 The size of the **hydrophone** also needs consideration; for membrane **hydrophones**, extra width in the direction perpendicular to the **beam axis** might be needed.

NOTE 2 The criteria for the choice of the size of the water bath referred to above are adequate for **pulse durations** less than 10 μs. For longer **pulse durations**, refer to 5.2.2.1 and [26].

5.2.3.2 Lining material

The measurements should be performed under conditions that approximate an acoustic free field. In the case of **ultrasonic transducers** excited under continuous wave conditions, acoustic absorbers should be placed to intercept as much of the ultrasound incident on the walls of the water bath as is possible. For pulsed **ultrasonic transducers**, and when techniques using gated signals are employed for detection of the **hydrophone** signal, it is not essential to use acoustic absorbers. However, it is often advisable to place absorbers on the walls of the water bath at positions so that they intercept the main incident acoustic field from the **ultrasonic transducer**.

The following tests may be used to determine the necessity for acoustic absorbers.

The criterion that may be applied is that acoustic absorbers should be used if reflected ultrasound increases the general background noise level of the **hydrophone** signal uniformly or if spurious **hydrophone** signals are detected in the vicinity of the main received signal.

A convenient test for the presence of spurious signals consists in changing the distance between the **ultrasonic transducer** and the **hydrophone** while observing the signal with an oscilloscope. Some spurious signals are observed to move at least twice the speed of the directly received signal, others are received in an incorrect time window when comparing the **ultrasonic transducer** to **hydrophone** distance. This test is possible only on pulsed systems.

With continuous wave excitation, it is necessary to observe phase changes and distortion of the main signal when the **ultrasonic transducer** is moved. A partial standing wave pattern may also be observed in many cases.

The free field conditions will be met sufficiently when the overall echo is reduced by more than 25 dB. Various methods may be used to check the conformity of the echo reduction of the tank lining materials used, with this subclause. The procedures described in IEC TS 63081 can be applied to check the absorbing or scattering materials.

5.2.3.3 Water quality

For measurements in high pressure fields or on high power continuous wave excited **ultrasonic transducers**, cavitation effects can be significant, and, in this case, degassed water should be used (see Annex G for guidance).

The water should be distilled or de-ionized water at a known temperature. When a single-layer, electrically unshielded membrane [polyvinylidene fluoride (PVDF)] **hydrophone** is used, the electrical conductivity of the water should be less than $5 \mu\text{S cm}^{-1}$.

5.3 Requirements for data acquisition and analysis systems

The transfer characteristics of the data acquisition and analysis system shall be adequate to ensure that, when used in combination with the **hydrophone**, pre-amplifier and amplifier, the requirements of 5.1.6 to 5.1.9 are met for the combination.

5.4 Recommendations for ultrasonic equipment being characterized

If the scanning in automatic scanning systems can be "frozen", appropriate acoustic measurements should be undertaken to ensure that there is no significant variation between a "frozen" beam and a scanning beam.

NOTE 1 This exercise is not trivial and depends on the type of scanning system. Also, true determination of temporal average parameters is not possible for a "frozen" beam.

If an electrical signal synchronized to the excitation of the **ultrasonic transducer** or **ultrasonic transducer element group** is not available, alternative methods may be used to obtain such a trigger signal.

NOTE 2 Such alternative methods include the use of an external electromagnetic pick-up coil or an auxiliary acoustic sensor placed in the ultrasonic field. See [27], [28], [29].

In case an **ultrasonic transducer** or **ultrasonic transducer element group** radiates ultrasound without any sequence of repetition, it will not be possible to synchronize the measurement system in the way described in this document. A subset of acoustic measurements, mostly related to safety aspects, is described in Annex F and may be useful when synchronization cannot be achieved.

Any system that controls the acoustic output of the **ultrasonic transducer** as a result of changing acoustic impedance should be switched off. In case this cannot be achieved, an additional measurement **uncertainty** should be taken into account.

6 Measurement procedure

6.1 General

The procedures described in Clause 6 and in Clause 7 are those that are particularly suitable for the characterization of ultrasonic fields using piezoelectric **hydrophones**. Other procedures based on the use of piezoelectric **hydrophones** may be employed provided equivalence with the techniques described in Clause 6 is demonstrated.

6.2 Preparation and alignment

6.2.1 Preparation

It may be necessary to seal various parts of the **ultrasonic transducer** to prevent ingress of water, especially around the cable entry point if the whole of the device is immersed. The manufacturer's advice should be sought.

Prior to use, the surfaces of the **ultrasonic transducer** and the **hydrophone** should be checked for contamination. If this is present, the surfaces should be cleaned according to the manufacturer's instructions. Any special precautions should be followed for the reliable use of **hydrophones** or **transducers** which may be specified by the manufacturer or which may have been found necessary by the user, such as immersion of a **hydrophone** for a certain time before use.

On insertion of both the **ultrasonic transducer** and the **hydrophone** in the water, care should be taken to ensure that all air bubbles are removed from the active faces. Checks should be made during the course of the measurements to ensure bubbles do not appear.

6.2.2 Aligning an ultrasonic transducer and a hydrophone

The z -axis of the **hydrophone**, which is the direction of maximum sensitivity, shall be aligned such that it is parallel to the direction of propagation of the ultrasound. A proper alignment procedure is given in IEC 61828.

6.3 Measurement

Make the measurements with an appropriate **hydrophone assembly**. Carry out observation at any point for long enough that a fully representative part of the acoustic signal is sampled. Typically, this would be less than one second.

Ensure that the **bandwidth**, sampling rate and/or temporal resolution of the acquisition system are sufficient to accurately represent the **hydrophone** signal.

NOTE 1 New technology oscilloscopes and digital capture cards are now available which allow extremely long record lengths to be captured and analysed. In general, use of such a device is likely to be the most flexible way to determine all the necessary parameters.

NOTE 2 Since it is no longer assumed that the acoustic signal will repeat, equivalent-time sampling is not possible and, consequently, the single-shot digital **bandwidth** will need to be sufficient to accurately represent the **hydrophone** signal.

6.4 Analysis

6.4.1 Corrections for restricted bandwidth and spatial resolution

Corrections shall be applied if the measurements are affected by a limited **bandwidth** (see 5.1.7) or cable resonances (see 5.1.10). If the narrow-band requirements (see 5.1.7.1) are not fulfilled the deconvolution method shall be applied (see 5.1.7.2).

Corrections shall be applied if the measurements are affected by spatial averaging effects as identified in 5.1.6.2. Corrections shall be made following the methods given in Annex E.

6.4.2 Uncertainties

In evaluating and expressing the **uncertainty** in the calibration, the guidance provided by ISO/IEC Guide 98-3:2008 [see Clause 2] shall be followed.

More guidance on assessment of **uncertainties** is given in Annex I.

7 Beam characterization

7.1 General

Table 1 provides a guide to the acoustic parameters that may be used to specify the acoustic output of various types of medical ultrasonic equipment.

Table 1 – Acoustic parameters appropriate to various types of medical ultrasonic equipment

Equipment type		Primary pressure parameters	Derived intensity parameters	Other parameters	
Pulse-echo	– static	1, 2	4 to 6	7, 8, 10 to 16, 18 to 20	
	– auto scanning	1, 2	4 to 6	7, 8, 10 to 20	
Doppler	– vascular	1 ^a , 2	4 to 6	7, 10, 11, 14, 18, 19	
	– foetal heart	1 ^a , 2	4 to 6	7, 10, 11, 14, 18, 19	
	– pulsed	1, 2	4 to 6	7, 8, 10 to 16, 18 to 20	
Therapy (physical)	– continuous	1 ^a , 2, 3	5, 6	7, 9, 12, 14, 18, 19	
	– tone-burst	1 ^a , 2, 3	4 to 6	7, 9, 12, 14 to 16, 18, 19	
NOTE Key to table as follows:					
	Clause			Clause	
1	3.50	Peak-compressional acoustic pressure	8	3.11	Beamwidth
2	3.51	Peak-rarefactional acoustic pressure	9	3.7	–20 dB beam area
3	3.60	RMS acoustic pressure	10	3.7	–6 dB beam area
4	3.70	Spatial-peak pulse-average intensity	11	3.47	–12 dB output beam dimensions
5	3.72	Spatial-peak temporal-average intensity	12	3.38	Local distortion parameter
6	3.69	Spatial-average temporal-average intensity	13	3.1	Acoustic pulse waveform
7	7.3.2.4	Derived ultrasonic power (or from IEC 61161)	14	3.16 to 3.19	Location of any of the parameter values
			15	3.54	Pulse duration
			16	3.58	Pulse repetition rate
			17	3.64	Scan repetition rate
			18	3.3	Acoustic-working frequency
			19	3.90	Ultrasonic transducer element group
			20	3.91	Ultrasonic transducer element group dimensions
^a For this type of application the peak-compressional acoustic pressure is assumed to be of equal magnitude to the peak-rarefactional acoustic pressure.					

Subclause 7.2 deals with the determination of some of the primary pressure parameters.

NOTE See Figure 4 for a schematic representation of some of the pulse parameters.