

INTERNATIONAL STANDARD

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**Ultrasonics – Transducers – Definitions and measurement methods
regarding focsusing for the transmitted fields**

**Ultrasons – Transducteurs – Définitions et méthodes de mesure
pour la focalisation des champs transmis**



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ULTRASONICS –TRANSDUCERS – DEFINITIONS AND MEASUREMENT METHODS REGARDING FOCUSING FOR THE TRANSMITTED FIELDS

FOREWORD

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International Standard IEC 61828 has been prepared by IEC technical committee 87: Ultrasonics.

This second edition cancels and replaces the first edition published in 2001. This edition constitutes a technical revision.

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

- a) Clause 6 on Measurement procedures has been replaced by Clause 6: "Acoustic field measurement: equipment" and Clause 7: "Measurement procedure" and related definitions.
- b) Reorganization of definitions and measurement section to accommodate specific sets of measurements for focusing, nonlinearity, beam axis alignment, beam area, beam maximum, numerical projection, plane wave, high intensity therapeutic ultrasound, multiple sources, spatial impulse response and compound plane waves. Clause 3 has been moved to Annex B.
- c) The normative references have been updated and the Bibliography has been expanded from 8 to 40 references.

- d) Twelve figures have been updated and seven new figures (B.1, B.3, B.7, B.10, B.11, B.12, B.13, B.14) have been added to facilitate measurements and be consistent with measurement terminology.
- e) New measurements have been added for time delays, arrays, plane waves and spatial impulse response.
- f) Annex A has been expanded to provide general guidance on pulsed waves, system responses, focusing gains and minimum beamwidth estimation.
- g) New annexes have been added:
 - Annex B (informative) Rationale for focusing and nonfocusing definitions
 - Annex E (informative) Uncertainties;
 - Annex F (informative) Transducer and hydrophone positioning systems;
 - Annex G (informative) Planar scanning of a hydrophone to determine acoustic output power;
 - Annex H (informative) Properties of water;
 In addition, Annex A was reorganized and new Clauses A.1, A.5 and A.6 were added.
- h) Guidelines for remaining within the manufacturer's pressure and intensity hydrophone limits and the determination of the extent of nonlinearity in the field have been added.

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

FDIS	Report on voting
87/746/FDIS	87/749/RVD

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

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NOTE 1 The following print types are used:

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- Words in **bold** in the text are defined in Clause 3.

NOTE 2 There are some inconsistencies in font type for symbols and formulae between some of the normative references and this document. They will be resolved in a future revision of the normative references.

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

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INTRODUCTION

Focusing transducers are essential in medical applications for obtaining high-resolution images, Doppler and flow data and for concentrating ultrasonic energy at desired sites for therapy. This document provides specific definitions appropriate for describing the focused field from a theoretical viewpoint for transducers with known characteristics intended by design. Other specific definitions included in this document, based on measurement methods, provide a means of determining **focusing** properties, if any, of a transducer of unknown field characteristics. The measurement method and definitions provide criteria for determining if the transducer is focusing, as well as a means of describing the **focusing** properties of the field. **Beam axis** alignment methods and field characterization measurements are given for both **focusing** and **nonfocusing** transducers.

ULTRASONICS –TRANSDUCERS – DEFINITIONS AND MEASUREMENT METHODS REGARDING FOCUSING FOR THE TRANSMITTED FIELDS

1 Scope

This document

- provides definitions for the transmitted field characteristics of focusing and nonfocusing transducers for applications in medical ultrasound;
- relates these definitions to theoretical descriptions, design, and measurement of the transmitted fields of focusing transducers;
- gives measurement methods for obtaining defined field characteristics of focusing and nonfocusing transducers;
- specifies beam axis alignment methods appropriate for focusing and nonfocusing transducers.

This document relates to focusing ultrasonic transducers operating in the frequency range appropriate to medical ultrasound (0,5 MHz to 40 MHz) for both therapeutic and diagnostic applications. It shows how the characteristics of the transmitted field of transducers can be described from the point of view of design, as well as measured by someone with no prior knowledge of the construction details of a particular device. The transmitted ultrasound field for a specified excitation is measured by a hydrophone in either a standard test medium (for example, water) or in a given medium. This document applies only to media where the field behaviour is essentially like that in a fluid (i.e. where the influence of shear waves and elastic anisotropy is small), including soft tissues and tissue-mimicking gels. Any aspects of the field that affect their theoretical description or are important in design are also included. These definitions would have use in scientific communications, system design and description of the performance and safety of systems using these devices.

This document incorporates definitions from other related standards where possible, and supplies more specific terminology, both for defining focusing characteristics and for providing a basis for measurement of these characteristics.

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 61689:2013, *Ultrasonics – Physiotherapy systems – Field specifications and methods of measurement in the frequency range 0,5 MHz to 5MHz*

IEC 62127-3:2007, *Ultrasonics – Hydrophones – Part 3: Properties of hydrophones for ultrasonic fields up to 40 MHz*
IEC 62127-3:2007/AMD1:2013

IEC TS 62556:2014, *Ultrasonics – Field characterization – Specification and measurement of field parameters for high intensity therapeutic ultrasound (HITU) transducers and systems*

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

IEC 62555, *Ultrasonics – Power measurement – High intensity therapeutic ultrasound (HITU) transducers and systems*

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 following terms and definitions 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, a single **tone-burst**, or one cycle of a **continuous wave**

Note 1 to entry: In some cases such as an amplitude-modulated pulse, the overall pulse train can appear as a group of nearly contiguous pulses with spacings much smaller than the overall pulse repetition time.

3.2

annular array

ultrasonic transducer element group having radiating elements in the same plane or curved surface and consisting of concentric elements which are electrically phased to control the characteristics of an acoustic beam

3.3

acoustic frequency

acoustic-working 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.

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 should be given in order to enable any frequency-dependent correction to the signal.

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

[SOURCE: IEC 62127-1:2007, 3.3]

3.3.1

zero-crossing acoustic-working frequency

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 should show evidence of phase change.

Note 2 to entry: This frequency is intended for continuous-wave systems only.

[SOURCE: IEC 62127-1:2007/AMD1:2013, 3.3.1, modified – NOTE 2 and NOTE 3 have been deleted.]

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 magnitude of the acoustic pressure spectrum is 3 dB below the peak magnitude

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 $< 3 f_1$, f_2 is to be understood as the lowest frequency above this range at which the spectrum magnitude is 3 dB below the peak magnitude.

Note 4 to entry: See IEC 62127-1 for methods of determining the arithmetic-mean acoustic-working frequency.

[SOURCE: IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013, 3.3.2, modified – Note 4 to entry has been added.]

3.4

aperture path difference

Δ

difference in path lengths from a specified **geometric focus** to the periphery of the **transducer aperture** and to the intersection of the **beam axis** with the **transducer aperture plane** for a specified **longitudinal plane** and for an **unsteered beam**

SEE: Figure A.5.

Note 1 to entry: Δ is expressed in metres, m.

3.5

apodization

amplitude weighting or shading of the **transducer aperture**

3.6

axial field-point path difference

Δ'

difference in path lengths from a specified field point on the **beam axis** to the periphery of the **transducer aperture** and to the intersection of the **beam axis** with the **transducer aperture plane**

SEE: Figure A.5.

Note 1 to entry: It is specified in the same longitudinal plane as the aperture path difference.

Note 2 to entry: Δ' is expressed in metres, m.

3.7

azimuth axis

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

SEE: Figure B.3, Figure B.13 and Figure B.14.

Note 1 to entry: The selection of this axis is arbitrary for a circularly-symmetric HITU transducer without a hole in its centre but is perpendicular to the elevation axis.

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

3.8

azimuth plane

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

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**.

SEE: Figure B.3, Figure B.13 and Figure B.14.

3.9

bandwidth

BW

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

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

[SOURCE: IEC 62127-1:2007, 3.6]

3.10

beam area

$A_{b,6}$, $A_{b,12}$, $A_{b,20}$

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, e.g.:

- 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 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 square metres (m²).

[SOURCE: IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013, 3.7, modified – The symbol $A_{b,12}$ has been added.]

3.11

beam area focal depth

distance along **beam axis** from **source aperture plane** to **beam area focus**

SEE: Figure B.10.

3.12

beam area focal plane

plane perpendicular to the **beam axis** and containing the **beam area focus**

SEE: Figure B.10.

3.13**beam area focus**

point on the **beam axis** at which the –6 dB **beam area** is a minimum

SEE: Figure B.10.

3.14**beam axis**

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

SEE: Figure B.3, Figure B.13 and Figure B.14.

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 postfocal 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, e.g.:

- 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 3 to entry: Refer to Annex C and Annex D.

[SOURCE: IEC 62127-1:2007, 3.8, modified – In the definition, "external transducer aperture" has been replaced by "external transducer surface plane".]

3.15**beam centrepoint**

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

3.16**beam maximum**

b_m

maximum measured **pulse-pressure-squared integral** on the **beam axis**

SEE: Figure B.7.

[SOURCE: IEC TS 62556:2014, 3.10]

3.17**beam maximum depth**

L_{bm}

smallest distance between two points on the **beam axis** where the **pulse-pressure-squared integral** falls below its maximum on the **beam axis** by 6 dB

SEE: Figure B.7.

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, e.g.: 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.

Note 2 to entry: **Beam maximum depth** is expressed in metres (m).

[SOURCE: IEC TS 62556:2014, 3.11]

3.18

beam maximum length

z_p

distance from the source aperture plane to the position on the **beam axis** where the maximum **pulse-pressure-squared integral** is measured

SEE: Figure B.7.

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, e.g.: in the case of a continuous wave by the mean square acoustic pressure as defined in IEC 61689.

Note 2 to entry: **Beam maximum length** is expressed in metres (m).

[SOURCE: IEC TS 62556:2014, 3.12, modified – Added "distance from the source aperture plane to the" to the definition.]

3.19

beam maximum plane

plane that is perpendicular to the **beam axis** and contains the **beam maximum**

SEE: Figure B.7.

3.20

beam maximum point

position on the **beam axis** of the maximum **pulse-pressure-squared integral**

SEE: Figure B.7.

3.21

beam maximum volume

V_{bm}

volume in a specified space consisting of all points at which the **pulse-pressure-squared integral** is greater than –6 dB of the **pulse-pressure-squared integral** value at the **beam maximum point**

SEE: Figure B.7.

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, e.g.: 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.

Note 2 to entry: **Beam maximum volume** is expressed in cubic metres (m³).

[SOURCE: IEC TS 62556:2014, 3.13]

3.22

beamwidth midpoint

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

Note 1 to entry: The average is taken over as many beamwidth levels as given in Clause C.2 and in Table C.2.

3.23

beam-minimum

location along the **beam axis** in a specified **longitudinal plane** where the field of an **ultrasonic transducer** has minimum –6 dB **beamwidth**

SEE: Figure B.6.

Note 1 to entry: Under ideal conditions, this location corresponds to the **transition distance** for circularly symmetric fields and close to the **transition distance** for other geometries.

3.24**beam-minimum depth** $b_{\min}$

distance from the **beam-minimum** to the **transducer aperture plane**, or in the case of measurement, the **source aperture plane**

SEE: Figure B.6.

Note 1 to entry: The **beam-minimum depth** is expressed in metres (m).

Note 2 to entry: The **beam-minimum depth** for a **nonfocusing transducer** was formerly known as "natural focal length".

3.25**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

SEE: Figure B.4, Figure B.6 and Figure B.12.

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, e.g.:

- 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).

[SOURCE: IEC 62127-1:2007, 3.11]

3.26**beamwidth focal length**

distance from **source aperture plane** along the **beam axis** to the **beamwidth focus**

3.27**beamwidth focal line**

in a specified **longitudinal plane**, the line perpendicular to the **beam axis** which passes through the **beamwidth focus**

SEE: Figure B.6b.

3.28**beamwidth focus**

in a specified **longitudinal plane**, the point on the **beam axis** for which the –6 dB **beamwidth** measured perpendicular to the axis is a minimum and whose beamwidth meets the criteria of a **focusing transducer**

SEE: Figure B.6b.

Note 1 to entry: When two-dimensional focusing has been used for different **longitudinal planes**, the **beamwidths** can, in general, be different.

3.29**broadband signal**

signal with relative –3 dB fractional **bandwidth** greater than 0,25, where the relative –3 dB fractional **bandwidth** is the **bandwidth** divided by the **arithmetic-mean working frequency**

Note 1 to entry: Compare to broadband transducer, IEC 62127-1:2007, 3.12.

3.30

central scan line

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

[SOURCE: IEC 62127-1:2007, 3.13]

3.31

circular wave number

k

ratio of 2π divided by the **effective wavelength**

3.31.1

wave vector's vector component along the x -axis

k_x

<for a plane wave> product of the circular wave number and the cosine of the angle formed between the direction of propagation and the x -axis

$$k_x = k \cdot \hat{r} \cdot \hat{x}$$

where $\hat{r}$ is the unit vector in the direction of propagation and $\hat{x}$ is the unit vector in the direction of the x -axis

3.31.2

wave vector's vector component along the y -axis

k_y

<for a plane wave> product of the circular wave number and the cosine of the angle formed between the direction of propagation and the y -axis

$$k_y = k \cdot \hat{r} \cdot \hat{y}$$

where $\hat{r}$ is the unit vector in the direction of propagation and $\hat{y}$ is the unit vector in the direction of the y -axis

3.32

clinical driving conditions

settings of duty factor and **transducer driving voltage** when an **ultrasonic transducer** is operated for the purposes of treatment

3.33

continuous-wave signal

signal that is monochromatic (single frequency) and is not amplitude-modulated

3.34

curvilinear array

array or **ultrasonic transducer element group** consisting of in-line **ultrasonic transducer** elements which are mounted on a curved surface and can be electrically controlled to alter the characteristics and/or direction of an acoustic beam

3.35

depth-of-field

Δ_{DOF}

in a specified **longitudinal plane**, the distance between two points along the **beam axis** which are defined by the locations on either side of the **beamwidth focus** where the -6 dB **beamwidths** increase by a factor of two

SEE: Figure B.6b.

Note 1 to entry: In a design, if no such point exists between the **beamwidth focus** and the **transducer aperture plane**, the location of the **depth-of-field** point closest to the **ultrasonic transducer** is taken to be the **transducer aperture plane**. In a measurement, if no such point exists between the **beamwidth focus** and the **source aperture plane**, the location of the **depth-of-field** point closest to the **ultrasonic transducer** is taken to be the **source aperture plane**.

Note 2 to entry: Δ_{DOF} is expressed in metres (m).

3.36

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**.

[SOURCE: IEC 62127-1:2007, 3.14]

3.37

distance z_e

z_e

distance along the **beam axis** between the **patient entry plane** and the **external transducer surface plane**

Note 1 to entry: **Distance z_e** is expressed in metres (m).

3.38

distance z_{slpta}

z_{slpta}

distance along the **beam axis** between the plane containing the **sidelobe peak temporal-average intensity** and the **source aperture plane**

Note 1 to entry: **Distance z_{slpta}** is expressed in metres (m).

3.39

distance z_p

z_p

distance along the **beam axis** between the plane containing the **focal** point (or for nonfocusing transducers, to the plane containing the **beam maximum**), and the **source aperture plane**

SEE: Figure B.7 and Figure B.9.

Note 1 to entry: **Distance z_p** is the distance between the source aperture plane and the **pressure focus** for **focusing transducers**.

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

[SOURCE: IEC TS 62556:2014, 3.21, modified – Note 1 to entry has been added.]

3.40

duty factor

F_d

ratio of the **pulse duration** to the **pulse repetition period**

[SOURCE: IEC 60469:2013, 3.2.9, modified – Reference to the specific context of a periodic pulse train has been removed and the original note has been deleted.]

3.41**effective focusing surface**

surface of constant phase whose periphery intersects the **external transducer surface plane**

Note 1 to entry: In the case of arrays, focusing results from applying a phase delay to the electrical excitation applied to each element of an array to produce focusing and steering of a **scan line**. In this case, a total phase delay along a line normal to each element can be calculated by adding the excitation's phase delay to the propagation delay along that line corresponding to the sound speed and distance along the line. A surface of constant phase can then be defined as a surface intersecting all such normals, such that all points of intersection have the same total phase.

[SOURCE: IEC TS 62556:2014, 3.23]

3.42**effective hydrophone radius**

a_h, a_{h3}, a_{h6}

radius of a stiff disc receiver **hydrophone** that has a predicted directional response function with an angular width equal to the observed angular width

Note 1 to entry: The angular width is determined at a specified level below the peak of the **directional response** function. For the specified levels of 3 dB and 6 dB, the radii are denoted by a_{h3} and a_{h6} respectively.

Note 2 to entry: The radius is usually the function of frequency. For representative experimental data, see [5].

Note 3 to entry: Effective hydrophone radius is expressed in metres (m).

[SOURCE: IEC 62127-3:2007, 3.2]

3.43**effective path length**

d_{eff}

distance that is the equivalent total acoustical path length between a specified field point and a specified point on the effective focusing surface of a transducer

Note 1 to entry: In the case of a transducer with a lens, the part of the path through the lens is multiplied by the ratio c_W/c_L where c_L is the speed of sound in a lens and c_W is the speed of sound in water (or measurement medium).

Note 2 to entry: In most cases, this definition applies to transducers of known construction; otherwise, it can be measured as time delay between the two points specified above divided by the speed of sound in water (or measurement medium). See also **geometric focus** and **effective focusing surface**.

Note 3 to entry: **Effective path length** is expressed in metres (m).

3.44**effective radius of a focusing ultrasonic transducer**

a_f

radius of a **focusing ultrasonic transducer** that has a predicted axial acoustic pressure distribution approximately equivalent to the observed axial acoustic pressure distribution in the axial **focal zone**

Note 1 to entry: **Effective radius of a focusing ultrasonic transducer** is expressed in metres (m).

Note 2 to entry: A transducer with a hole in its centre does not have an effective radius.

3.45**effective radius of a nonfocusing ultrasonic transducer**

a_t

radius of a perfect stiff 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 **beam maximum point**

Note 1 to entry: **Effective radius of a nonfocusing ultrasonic transducer** is expressed in metres (m).

Note 2 to entry: A transducer with a hole in its centre does not have an effective radius.

3.46

effective wavelength

λ

longitudinal speed of sound in the propagation medium divided by the **acoustic-working frequency**

Note 1 to entry: **Effective wavelength** is expressed in metres (m).

3.47

electric load impedance

Z_L

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

Note 1 to entry: **Electric load impedance** is expressed in ohms (Ω).

[SOURCE: IEC 62127-3:2007, 3.3, modified – The symbol has changed from $\underline{Z}_L$ to Z_L . "hydrophone or hydrophone assembly output" has been replaced with "assembly output cable".]

3.48

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 B.3 and Figure B.12.

Note 1 to entry: The selection of this axis is arbitrary for a circularly-symmetric HITU transducer without a hole in its centre.

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

3.49

elevation plane

longitudinal plane containing the **elevation axis** and the **beam axis**

SEE: Figure B.3 and Figure B.12.

3.50

end-of-cable loaded sensitivity

$\underline{M}_L(f)$

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

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

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.

3.51

end-of-cable open-circuit sensitivity

$\underline{M}_c(f)$

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

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

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.

3.52

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 B.5.

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.

3.53

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 B.6b, Figure B.7, Figure B.9, Figure B.10, Figure B.13 and Figure B.14.

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 (see Figure B.5).

3.54

f number

N_F

ratio of the **geometric focal length** to the **transducer aperture** width in a specified **longitudinal plane**

Note 1 to entry: N_F is dimensionless.

3.55

far field

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

SEE: Figure B.2.

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 nonfocusing source transducers. For focusing transducers a different terminology for the various parts of the transmitted field applies (see Figure B.4).

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

Note 4 to entry: Identical to the former term "Fraunhofer zone".

[SOURCE: IEC 62127-1:2007/AMD1:2013, 3.28]

3.56

far transition distance

z_{FTD}

distance past which the **postfocal zone** begins for a **focusing transducer**

SEE: Figure B.4.

Note 1 to entry: The **far transition distance** is the greatest distance from the **ultrasonic transducer** at which the modulus of the difference between the aperture path difference and the axial field point path difference is half an effective wavelength.

Note 2 to entry: Also given by Equation (A.16).

Note 3 to entry: See Annex A.

Note 4 to entry: z_{FTD} is expressed in metres (m).

3.57

focal depth

L_6

beam maximum depth for a focusing transducer

SEE: Figure B.9.

Note 1 to entry: **Focal depth** is expressed in metres (m).

[SOURCE: IEC TS 62556:2014, 3.36]

3.58

focal gain at beam maximum

G_p

gain at beam maximum point for a **focusing transducer**

[SOURCE: IEC TS 62556:2014, 3.37, modified – "point" has been added in the definition.]

3.59

focal volume

V_{foc}

beam maximum volume for a **focusing transducer**

SEE: Figure B.7.

Note 1 to entry: **Focal volume** is expressed in cubic metres (m³).

3.60

focal zone

region along the **beam axis** that is bounded by the **near transition distance** and the **far transition distance**

SEE: Figure B.4, Figure A.1, Figure A.4 and Figure A.5.

Note 1 to entry: See Annex A for more details and the spatial extent of this zone.

Note 2 to entry: This term is equivalent to the former term "focal Fraunhofer zone".

Note 3 to entry: Equivalently, the region of an ultrasound field about a **geometric focus** in a specified longitudinal plane where the axial field point path difference is within half a **wavelength** of the **aperture path difference**.

3.61

focusing transducer

electro-acoustic device that produces a narrower –6 dB **beamwidth** in a **longitudinal plane** that is less than that of a flat **transducer** with the same **source aperture** size (and **apodization**, if any) and same excitation at a distance less than the **transition distance** from the **source aperture plane**

SEE: Figure B.6.

3.62

full width half maximum

FWHM

minimum separation between two half maximum amplitude points

SEE: Figure B.12.

Note 1 to entry: **Full width half maximum** is expressed in metres (m)

Note 2 to entry: **Full width half maximum** is equal to w_6 for beamwidths

Note 3 to entry: **Full width half maximum** can also be used for envelopes of signals.

3.63

gain at beam maximum

G_{bm}

ratio of the maximum pressure amplitude at the **beam maximum point** to the average pressure amplitude at the **external transducer surface plane**

[SOURCE: IEC TS 62556:2014, 3.41]

3.64

geometric beam boundary

surface containing straight lines passing through the **geometric focus** and all points around the periphery of the **transducer aperture**

SEE: Figure A.4.

Note 1 to entry: Applies to **ultrasonic transducers** of known construction.

3.65

geometric focal gain

G_{focal}

ratio of amplitude at the geometric focus to the input amplitude

3.65.1

geometric focal gain

<for the measurement case in which **geometric foci** of all **longitudinal planes** coincide>
square root of the ratio of the **pulse-pressure-squared-integral** at the **geometric focus** divided by the average **pulse-pressure-squared-integral** over the active portion of the transducer (i.e. the region corresponding to the **transducer aperture area**)

3.65.2**geometric focal gain**

<for unapodized transducers of known construction> ratio of the transducer aperture area to the product of the geometric focal length and the effective wavelength

$$G_{\text{focal}} = A_{\text{TA}}/(\lambda F_{\text{geo}})$$

3.65.2.1**geometric focal gain**

<for a circularly symmetric source> $G_{\text{focal}} = \pi z_{\text{T}}/F_{\text{geo}}$ with z_{T} the **transition distance**

3.65.2.2**geometric focal gain**

<**focusing transducer**> ratio of the **transducer aperture width** in a specified **longitudinal plane** to the square root of the product of the **effective wavelength** and the **geometric focal length** in that plane

Note 1 to entry: Applicable for **ultrasonic transducer** cases in which the focuses in different **longitudinal planes** are not coincident.

Note 2 to entry: The theoretical definitions of focal gain do not apply to a HITU transducer with a hole in its centre.

3.66**geometric focal length**

F_{geo}

distance from the **geometric focus** to the position where the **beam axis** intersects the **effective focusing surface**

SEE: Figure A.3 and Figure B.4.

Note 1 to entry: Applies to transducers of known construction.

Note 2 to entry: **Geometric focal length** is expressed in metres (m).

Note 3 to entry: This definition applies only to **focusing transducers**.

3.67**geometric focus**

spatial point for which all of the **effective path lengths** in a specified longitudinal plane are equal

SEE: Figure A.3 and Figure A.5.

Note 1 to entry: Equivalently, the spatial point for which the arrival times of all waves from the transducer have the same delay relative to the voltage excitation of the transducer, as viewed in the approximation of geometrical acoustics, neglecting diffraction.

Note 2 to entry: This definition applies only to focusing transducers.

3.68**geometric line focus**

line for which all of the **effective path lengths** are essentially equal in all planes perpendicular to that line

SEE: Figure A.2.

3.69**geometric spherical focus**

point focus

geometric focus for a spherical **ultrasonic transducer** (or reflector) transmitting or **effective focusing surface**

SEE: Figure A.2.

3.70

HITU equipment

high intensity therapeutic ultrasound (HITU) equipment

equipment for the generation and application of ultrasound to a patient for therapeutic purposes with the intention to destroy, disrupt or denature living tissues or non-tissue elements (e.g. liquids, bubbles, micro-capsules) and which aims notably at making treatments through actions of ultrasound having mechanical, thermal and more generally physical, chemical or biochemical effects

Note 1 to entry: Essentially the **HITU equipment** comprises a generator of electric high-frequency power and a transducer for converting this to ultrasound. In many cases this equipment also includes a targeting and monitoring device.

Note 2 to entry: **HITU equipment**, as a side effect by its operation, can induce hyperthermia, which heats much less rapidly and to much lower therapeutic temperatures (in general 42 °C to 50 °C and thermal equivalent times of 0,2 min to 120 min) as compared with the main HITU-induced temperature rises in excess of 55 °C and much shorter times and also ultrasound-induced bioeffects by means other than heat.

Note 3 to entry: This definition does not apply to: **ultrasound equipment** used for physiotherapy, **ultrasound equipment** used for lithotripsy or **ultrasound equipment** used for general pain relief.

Note 4 to entry: See Annex AA of IEC 60601-2-62:2013 [2] for a few examples of equipment for which this document should be used.

[SOURCE: IEC 60601-2-62:2013, 201.3.218, modified – Notes 2 and 3 to entry have been modified.]

3.71

hydrophone

transducer that produces electric signals in response to waterborne acoustic signals

[SOURCE: IEC 60050-801:1994 [3], 801-32-26]

3.72

hydrophone assembly

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

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

3.73

hydrophone compressional pressure limit

P_{+lim}

limit on the maximum compressional pressure that a **hydrophone** can withstand without damage or corruption of the measurement

Note 1 to entry: This quantity is preferably specified by the **hydrophone** manufacturer, or can be set by the user based on measurement evidence.

Note 2 to entry: **Hydrophone compressional pressure limit** is expressed in pascals (Pa).

[SOURCE: IEC TS 62556:2014, 3.48, modified – Supplementary information has been moved from the definition to Note 1 to entry.]

3.74

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]

3.75

hydrophone intensity limit

$I_{ta,lim}$

limit on the maximum **temporal-average intensity** that a **hydrophone** can withstand without damage or corruption of the measurement

Note 1 to entry: This quantity is preferably specified by the hydrophone manufacturer, or can be set by the user based on measurement evidence.

Note 2 to entry: The **hydrophone intensity limit** is expressed in watts per square metre (W/m²).

[SOURCE: IEC TS 62556:2014, 3.50]

3.76

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).

3.77

hydrophone rarefactional pressure limit

p_{-lim}

limit on the maximum rarefactional pressures that a **hydrophone** can withstand without damage or corruption of the measurement

Note 1 to entry: This quantity is preferably specified by the **hydrophone** manufacturer, or can be set by the user based on measurement evidence

Note 2 to entry: The hydrophone rarefactional pressure limit is expressed in pascals (Pa).

[SOURCE: IEC TS 62556:2014, 3.52]

3.78

inset

h

for concave transducers, the distance from the **transducer aperture plane** to the **external transducer surface** along the **beam axis**

SEE: Figure B.4, Figure A.4 and Figure A.5.

3.79

instantaneous acoustic pressure

$p(t)$

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

Note 1 to entry: See also IEC 60050-801:1994, 801-21-19.

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

[SOURCE: IEC 62127-1:2007, 3.33]

3.80

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 watts per square metre (W/m²).

[SOURCE: IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013, 3.34]

3.80.1

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

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

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 should be taken into account for measurements very close to the transducer.

Note 3 to entry: **Derived instantaneous intensity** is expressed in watts per square metre (W/m²).

[SOURCE: IEC 62127-1:2007/AMD1:2013, 3.78]

3.81

local area factor

L_{af}

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

$$L_{af} = \sqrt{\frac{0,69 A_{SAeff}}{A_{b,6}}} \quad (2)$$

Note 1 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 $A_b = A_{b,6} / 0,69$: ($0,69 = 3 \ln(10)/10$).

Note 2 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, e^{-2}) times the maximum value in the cross-section.

[SOURCE: IEC TS 61949:2007, 3.11, modified – The source definition refers to "source area" rather than "**source aperture area**", and the second sentence of the definition has been changed and given in the form of a note to entry.]

3.82**local distortion parameter** σ_q

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

$$\sigma_q = z_p p_m \frac{2\pi f_{awf} \beta}{\rho \cdot c^3} \frac{1}{\sqrt{L_{af}}} \quad (3)$$

where:

z_p is the axial distance of the point of interest to the **source aperture plane**;

p_m is the **mean-peak-cycle acoustic pressure** at the point in the acoustic field corresponding to the **spatial-peak temporal-peak acoustic pressure**;

β is the nonlinearity parameter ($\beta = 3,5$ for pure water at 20 °C);

f_{awf} is the **acoustic-working frequency**;

L_{af} is the **local area factor**

Note 1 to entry: If the **offset distance** is not zero, its value can be estimated and added to the value of z in Equation (3). This will yield a new and more accurate calculation of the **local distortion parameter**.

[SOURCE: IEC TS 61949:2007, 3.12, modified – The definition has been changed to refer to nonlinear distortion of ultrasound, and a note to entry has been added.]

3.83**longitudinal plane**

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

SEE: Figure B.6, Figure B.13 and Figure B.14.

3.84**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 equal to $(p_r + p_c)/2$.

[SOURCE: IEC TS 61949:2007, 3.13]

3.85**near field**

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

SEE: Figure B.2.

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.

[SOURCE: IEC 62127-1:2007/AMD1:2013, 3.37]

3.86**near transition distance** z_{NTD} distance past which the **focal zone** begins for a **focusing transducer**

SEE: Figure B.4.

Note 1 to entry: **Near transition distance** is the distance closest to the **ultrasonic transducer** at which the modulus of the difference between the aperture path difference and the axial field point path difference is half an effective wavelength.

Note 2 to entry: See Annex A for details.

Note 3 to entry: Also given by Equation (A.14).

Note 4 to entry: z_{NTD} is expressed in metres (m).

3.87**nonfocusing transducer****ultrasonic transducer** whose field does not meet the criteria for a **focusing transducer**

SEE: Figure B.2.

3.88**non-scanning mode**mode of operation of a **system** that involves a sequence of ultrasonic pulses which give rise to ultrasonic **scan lines** that follow the same acoustic path**3.89****normalized focal length** S_F for a given **longitudinal plane**, for design, the **geometric focal length** divided by the **transition distance**

Note 1 to entry: S_F is dimensionless.

3.90**offset distance** d_{offset} distance between the **source aperture plane** and the **external transducer surface plane**, measured along the beam axis

SEE: Figure B.5, Figure B.6b, Figure B.7, Figure B.9, Figure B.10, Figure B.13 and Figure B.14.

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

3.91**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** can be 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 single contact transducers, this area can be taken as the active geometrical area of the **ultrasonic transducer** or **ultrasonic transducer element group**.

Note 3 to entry: Compare the **output beam area** (–12 dB with reference to the **source aperture area**).

Note 4 to entry: The **output beam area** is expressed in metres squared (m²).

[SOURCE: IEC 62127-1:2007, 3.40, modified – Notes 2 and 3 to entry have been added.]

3.92

output beam dimensions

X_{ob} , Y_{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** can be 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).

[SOURCE: IEC 62127-1:2007, 3.41]

3.93

output power

P

time-average ultrasonic power emitted by an **ultrasonic transducer** into an approximately free field under specified conditions in a specified medium, preferably water

Note 1 to entry: **Output power** is expressed in watts (W).

[SOURCE: IEC 61161:2013, 3.3]

3.94

output power under clinical driving conditions

P_c

output power emitted by an **ultrasonic transducer** when it is operated under **clinical driving conditions** of **transducer driving voltage** and **duty factor**

3.95

P_q

output power emitted by an **ultrasonic transducer** when it is driven under reduced quasi-linear conditions

3.96

patient entry plane

plane that is closest to the **external transducer surface**, that is orthogonal to the **beam axis**, and that intersects any portion of a patient

3.97

peak acoustic pressure

p_- or p_+

peak-compressional acoustic pressure or **peak-rarefactional acoustic pressure**, whichever is largest

Note 1 to entry: The term is used in relative determinations.

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

Note 3 to entry: p_r is an equivalent form of p_- .

Note 4 to entry: p_c is an equivalent form of p_+ .

[SOURCE: IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013, 3.43, modified – The phrase "whichever is largest" has been added to the definition.]

3.98

peak-compressional acoustic pressure

p_c

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.

Note 3 to entry: p_+ is an archaic but equivalent form of p_c .

[SOURCE: IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013, 3.45]

3.99

peak-rarefactional acoustic pressure

p_r

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 as a positive 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.

Note 4 to entry: p_- is an archaic but equivalent form of p_r .

[SOURCE: IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013, 3.44]

3.100

phased array

ultrasonic transducer element group consisting of **ultrasonic transducer** elements that can be electrically configured to control the characteristics and direction of an acoustic beam

SEE: Figure B.3.

3.101

postfocal zone

region beyond the **focal zone** for a **focusing transducer** in a specified **longitudinal plane**

SEE: Figure B.4, Figure A.1, Figure A.4 and Figure A.5.

Note 1 to entry: Refer to Equation (A.16)

Note 2 to entry: This term is identical to former term "far Fresnel zone".

Note 3 to entry: There will be no postfocal zone if the geometric focal length is greater than the transition length.

3.102

clinical beam maximum power

$P_{c,6}$

power contained within the –6 dB contour in the plane perpendicular to the beam axis at the **beam maximum point** under **clinical driving conditions**

3.103**quasi-linear beam maximum power** $P_{q,6}$

power contained within the –6 dB contour in the plane perpendicular to the beam axis at the **beam maximum point** under **reduced quasi-linear driving conditions**

3.104**pre-focal peak temporal-average intensity** I_{pfpta}

largest local maximum of the **temporal-average intensity** on the **beam axis** which is not within the –6 dB **focal volume** or **beam maximum volume** and is located between the source aperture plane and the **focal volume** or **beam maximum volume**

SEE: Figure B.11.

Note 1 to entry: **Pre-focal peak temporal-average intensity** is expressed in watts per square metre (W/m²).

3.105**prefocal zone**

region between the **ultrasonic transducer** and the **near transition distance** for an ultrasonic **focusing transducer** in a specified **longitudinal plane**

SEE: Figure B.4, Figure A.1, Figure A.4 and Figure A.5.

Note 1 to entry: Refer to Equation (A.17).

Note 2 to entry: This term is identical to former term "near Fresnel zone".

3.106**pressure focal gain** G_{pfocal}

for a focusing transducer, the square root of the **pulse-pressure-squared-integral** at the **pressure focus**, divided by the square root of **source aperture average pressure-squared-integral**

Note 1 to entry: Pressure focal gain is dimensionless.

3.107**pressure focal length for a focusing transducer** F_{pres}

distance from either the **transducer aperture plane** (design definition) or the **source aperture plane** (measurement definition) to the **pressure focus** position

SEE: Figure B.8 and Figure B.9.

Note 1 to entry: The pressure focal length is expressed in metres (m).

3.108**pressure focal plane for a focusing transducer**

plane perpendicular to the **beam axis** that contains the **pressure focus**

SEE: Figure B.5 and Figure B.9.

3.109**pressure focus for a focusing transducer**

position of **beam maximum** on the **beam axis** for a **focusing transducer**

SEE: Figure B.7 and Figure B.8.

[SOURCE: IEC TS 62556:2014, modified – Changed from a **position of maximum pulse-pressure-squared-integral** throughout the field to definition above only for a **focusing transducer**.]

3.110

principal longitudinal plane

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

SEE: Figure B.6, Figure B.13 and Figure B.14.

Note 1 to entry: The selection of this axis is arbitrary for a circularly-symmetric HITU transducer without a hole in its centre.

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.

3.111

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 watts per square metre (W/m^2).

[SOURCE: IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013, 3.47]

3.112

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

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).

[SOURCE: IEC 62127-1:2007, 3.48]

3.113

pulse-intensity integral

p_{ii}

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 joules per square metre (J/m^2).

[SOURCE: IEC 62127-1:2007, 3.49]

3.114

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 pascals squared seconds (Pa²s).

[SOURCE: IEC 62127-1:2007, 3.50]

3.115

pulse repetition period

prp

time interval between equivalent points on successive pulses or tone-bursts

Note 1 to entry: This applies to single element non-automatic scanning systems and automatic scanning systems.

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

[SOURCE: IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013, 3.51]

3.116

pulse repetition rate

prf

reciprocal of the pulse repetition period

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

[SOURCE: IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013, 3.52]

3.117

quasi-linear

condition of the ultrasonic field between the source and a plane at a specified axial depth for which, at every point, less than a specified small proportion of the energy has transferred from the fundamental frequency to other frequencies through nonlinear propagation effects

Note 1 to entry: For purposes of this document, this condition is met when the local distortion parameter σ_q is less than 0,5.

[SOURCE: IEC TS 61949:2007, 3.17, modified – Note 1 to entry has been added.]

3.118

Rayleigh length

R_L

for a given **longitudinal plane**, for design, **transducer aperture area** of the **ultrasonic transducer** aperture width divided by the **effective wavelength**, λ

Note 1 to entry: **Rayleigh length** is equal to the **transition distance** multiplied by π .

Note 2 to entry: The **Rayleigh length** is expressed in metres (m).

3.119

reduced quasi-linear driving conditions

settings under which transducer driving voltage achieves quasi-linear conditions in the field, and under which the duty factor is set so that hydrophone measurements stay below the hydrophone intensity limit

3.120

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).

[SOURCE: IEC 62127-1:2007, 3.53]

3.121

scaling factor

S

ratio of the acoustic pressure at a location close to the transducer to the acoustic pressure at the same location under **quasi-linear** conditions

[SOURCE: IEC TS 61949:2007, 3.18, modified – The definition has been shortened and the references to "mean peak acoustic pressure" have been replaced by "acoustic pressure".]

3.122

scan-area

A_s

for automatic scanning systems, the 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 surface plane**.

Note 2 to entry: The **scan-area** is expressed in square metres (m²).

[SOURCE: IEC 62127-1:2007, 3.54, modified – Note 1 to entry refers to the "**external transducer surface plane**" instead of "**external transducer aperture**".]

3.123

scan line

for automatic scanning systems, the **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: This is the same as the definition of "ultrasonic scan line" in 3.71 of IEC 62127-1:2007.

3.124

scanning mode

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

Note 1 to entry: The sequence of pulses is not necessarily made up of identical pulses. For instance, the use of sequential multiple focal-zones is considered a scanning mode.

3.125

scan plane

for automatic scanning systems, a plane containing all the ultrasonic **scan lines**

[SOURCE: IEC 62127-1:2007, 3.56, modified – NOTE 1 and NOTE 2 have been deleted.]

3.126

scan repetition period

s_{rp}

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

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

[SOURCE: IEC 62127-1:2007, 3.57, modified – NOTE 1 has been deleted.]

3.127**scan repetition rate***srr*reciprocal of the **scan repetition period**

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

[SOURCE: IEC 62127-1:2007, 3.58]

3.128**sidelobe**

secondary peak near a primary main lobe

SEE: Figure B.12.

Note 1 to entry: For lateral beam measurements (beamplots), there are lobes usually lower than and deviating from the direction of the main beam or grating lobes. A **sidelobe** is narrower and weaker than the main lobe and is a result of the finite size and weighting of the transducer aperture.

Note 2 to entry: **Sidelobe** is also used to describe axial secondary lobes away from the axial main lobe. Frequently it is applied to describing secondary lobes trailing past a main pulse signal envelope.

Note 3 to entry: In abnormal cases, such as in defective physiotherapy transducers, **sidelobes** off the beam axis can exceed the magnitude of the main lobe.

3.129**sidelobe peak temporal-average intensity** I_{slpta}

maximum value of the **temporal-average intensity** measured at a local maximum which is not within the –6 dB **focal volume** (for focusing transducers) or **beam maximum volume** (for nonfocusing transducers)

SEE: Figure B.11.

Note 1 to entry: **Sidelobe peak temporal-average intensity** is expressed in watts per square metre (W/m²). See related definition, **temporal-average intensity**.

3.130**signal envelope**

magnitude of a signal derived from the square root of the sum of the real part squared and the imaginary part squared

Note 1 to entry: The imaginary part can be derived from the real part through a Hilbert transform.

3.131**signal type**

classification of the **acoustic pulse waveform** into **continuous-wave signal**, **tone-burst signal** or **broadband signal** types

3.132**source aperture**

equivalent aperture for an **ultrasonic transducer**, defined by the contour of the **source aperture area** in the **source aperture plane**

SEE: Figure B.6b and Figure B.10.

3.133**source aperture area** A_{SAeff}

equivalent aperture area for an **ultrasonic transducer**, measured as the –20 dB **pulse-pressure-squared-integral** contour, in the **source aperture plane**

SEE: Figure B.10 and Figures B.3 and B.4 of IEC TS 62556:2014.

Note 1 to entry: If the transducer is circularly symmetric without a hole in its centre, a radial line scan is sufficient to determine the contour.

Note 2 to entry: If a transducer has a hole in its centre within it, the –20 dB contour does not include the hole. In this case, there will be an outer –20 dB contour and an inner contour which encloses the region of the hole.

Note 3 to entry: **Source aperture area** is expressed in square metres (m²).

[SOURCE: IEC 62127-1:2007/AMD1:2013, 3.82, modified – The definition has been shortened and two new notes to entry have been added.]

3.134

source aperture average pressure-squared-integral

$p_{i20\text{mean}}$

pulse-pressure-squared-integral averaged over the –20 dB beam area in the **source aperture plane**

SEE: Figure B.9.

Note 1 to entry: The **source aperture average pressure-squared-integral** is expressed in pascals squared seconds (Pa²s).

3.135

source aperture plane

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

SEE: Figure B.5, Figure B.7, Figure B.9 and Figure B.10.

Note 1 to entry: If the **offset distance** is zero, the **source aperture plane** can be coincident with the **external transducer aperture plane** (see Figure B.1 to Figure B.4).

[SOURCE: IEC 62127-1:2007/AMD1:2013, 3.83, modified – The definition refers to the "external transducer surface plane" rather than the "external transducer aperture", and Note 1 to entry has been added.]

3.136

source aperture width

L_{SA}

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

SEE: Figure B.5 and Figure B.6b.

Note 1 to entry: If the HITU transducer is circularly-symmetric without a hole in its centre, 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 62127-1:2007/AMD1:2013, 3.84, modified – Two notes to entry have been added.]

3.137 spatial average intensity under linear conditions

 I_{sal}

intensity spatially averaged over the area enclosed by the half-pressure-maximum contour in the plane containing the **pressure focus** (for focusing transducers) or **beam maximum** (for nonfocusing transducers), as determined under linear conditions

Note 1 to entry: **Spatial average intensity under linear conditions** is expressed in watts per square metre (W/m^2).

3.138 spatial-peak temporal-peak acoustic pressure

 p_{sptp}

larger of the **peak-positive acoustic pressure** and the **peak-negative acoustic pressure**

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

[SOURCE: IEC 62127-1:2007, 3.63, modified – The definition refers to "peak-positive acoustic pressure" and "peak-negative acoustic pressure" rather than "peak-compressional acoustic pressure" and "peak-rarefactional acoustic pressure".]

3.139 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 can not be taking place.

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

[SOURCE: IEC 62127-1:2007, 3.62]

3.140 steered beam

ultrasound field whose **beam axis** is intentionally not coincident with an axis perpendicular to the **transducer aperture plane**

3.141 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 should be taken over an integral number of **acoustic repetition periods**.

Note 2 to entry: **Temporal-average intensity** is expressed in watts per square metre (W/m^2).

[SOURCE: IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013, 3.65, modified – The note concerning diagnostic equipment has been deleted.]

3.142 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).

[SOURCE: IEC 62127-1:2007, 3.67]

3.143**tone-burst signal**

pulse with relative –3 dB fractional **bandwidth** less than 0,25 where the relative –3 dB fractional **bandwidth** is equal to the **bandwidth/arithmetic-mean working frequency**

3.144**transducer aperture**

effective or projected area of the active ultrasound radiating portion of an **ultrasonic transducer** in the **transducer aperture plane**

SEE: Figure B.6a.

Note 1 to entry: The **transducer aperture** is known from design, geometry or construction details.

3.145**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 (m²).

3.146**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 B.6a and Figure B.8.

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.

3.147**transducer aperture plane distance**

D_{AF}

distance between the **geometric focus** and the **transducer aperture plane**

SEE: Figure A.3.

Note 1 to entry: The **transducer aperture area plane distance** is expressed in metres (m).

3.148**transducer aperture width**

L_{TA}

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

SEE: Figure B.6a, Figure A.4 and Figure A.5.

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

3.149**transducer assembly**

those parts of the ultrasound equipment comprising the **ultrasonic transducer** 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.

[SOURCE: IEC 62127-1:2007, 3.69, modified – This definition specifies "ultrasound equipment" rather than "medical diagnostic ultrasonic equipment".]

3.150 transducer driving voltage

U

voltage supplied to the terminals of the HITU source transducer

Note 1 to entry: **Transducer driving voltage** is expressed in volts (V).

3.151 transducer driving voltage at clinical levels

U_c

transducer driving voltage representative of clinical use

3.152 transducer driving voltage at quasi-linear levels

U_q

maximum **transducer driving voltage** when the acoustic field is **quasi-linear** at depths less than the position of **spatial-peak-temporal average intensity**

3.153 transition distance

z_T

aperture area divided by $\pi\lambda$

3.153.1 transition distance for design

z_{TD}

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

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

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: A transducer with a hole in its centre does not have an effective radius; for these cases see [6].

Note 7 to entry: **Transition distance for design** is expressed in metres (m).

3.153.2

transition distance for measurement

z_{TM}

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

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

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 61828:2001, 4.2.75, modified – The definition is worded differently and two notes to entry have replaced the original notes.]

3.154

transverse plane

plane that is perpendicular to the **beam axis**

3.155

two-dimensional array

ultrasonic transducer element group array that can be configured to control the characteristics and direction of an acoustic beam in at least two (usually orthogonal) scan planes

3.156

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

[SOURCE: IEC 62127-1:2007, 3.73]

3.157

ultrasonic transducer element

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

[SOURCE: IEC 62127-1:2007, 3.74]

3.158

ultrasonic transducer element group

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

[SOURCE: IEC 62127-1:2007, 3.75]

3.159**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).

[SOURCE: IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013, 3.76]

3.160**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 Annex D.

Note 2 to entry: See ISO/IEC Guide 98-3:2008, 2.2.3.

[SOURCE: IEC 62127-1:2007, 3.77]

3.161**unsteered beam**

ultrasound beam selected to be in the forward propagation direction without angular deflection

Note 1 to entry: This direction is along the central **scan line** of a sector scan. When the **ultrasonic transducer** is symmetric, the **unsteered beam** can be chosen to be near the symmetry axis or a symmetry plane of the **ultrasonic transducer**.

4 Symbols

a_f	effective radius of a focusing ultrasonic transducer
a_h	effective hydrophone radius
a_g	hydrophone geometrical radius
a_t	effective radius of a nonfocusing ultrasonic transducer
a_{h3}, a_{h6}	effective hydrophone radius , determined from directional response measurements, at the –3 dB and –6 dB levels
a_{max}	maximum effective radius for a specific hydrophone application
arp	acoustic repetition period
A_b	beam area
$A_{b,6}, A_{b,12}, A_{b,20}$	beam area (at –6 dB and –12 dB and –20 dB levels)
A_g	geometrical area of an ultrasonic transducer
A_{ob}	output beam area
A_s	scan-area
A_{TA}	transducer aperture area
A_{SAeff}	source aperture area
BW	bandwidth
bm	beam maximum
b_{min}	beam-minimum depth
c	speed of sound in the medium (usually water)
D	radius-of-curvature

D_{AF}	transducer aperture plane distance
d_{eff}	effective path length
d_{offset}	offset distance
f_{awf}	acoustic frequency, acoustic-working frequency
F	focal length
F_d	duty factor
F_{geo}	geometric focal length
F_{pres}	pressure focal length for a focusing transducer
$FWHM$	full width half maximum
G_{focal}	geometric focal gain
G_{pfocal}	pressure focal gain
G_p	focal gain at beam maximum point
G_{bm}	gain at beam maximum
h	inset
$I(t)$	instantaneous intensity
I_{ob}	output beam intensity
I_{pa}	pulse-average intensity
I_{pfpta}	pre-focal peak temporal-average intensity
I_{spta}	spatial-peak temporal-average intensity
I_{slpta}	sidelobe peak temporal-average intensity
I_{ta}	temporal-average intensity
$I_{ta,lim}$	hydrophone intensity limit
k	circular wave number ($2\pi/\lambda$)
k_x	wave vector's vector component along the x-axis
k_y	wave vector's vector component along the y-axis
L_{af}	local area factor
L_{SA}	source aperture width
L_{TA}	transducer aperture width
L_6	focal depth
L_{bm}	beam maximum depth
$\underline{M}_L(f)$	end-of-cable loaded sensitivity of a hydrophone or hydrophone assembly
$\underline{M}_C(f)$	end-of-cable open-circuit sensitivity
N_F	f number
P	output power of an ultrasonic transducer
P_c	output power under clinical driving conditions
P_q	output power under reduced quasi-linear driving conditions
$P_{c,6}$	clinical beam maximum power
$P_{q,6}$	clinical beam maximum power

$p(t)$	instantaneous acoustic pressure
p_0	average pressure amplitude over transducer aperture area
p_{0S}	average pressure amplitude over source aperture area
p_{ii}	pulse-intensity integral
p_{psi}	pulse-pressure-squared integral
p_m	mean peak acoustic pressure
p_{tp}	temporal-peak acoustic pressure
prr	pulse repetition rate
prp	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_{+lim}	hydrophone compressional pressure limit
p_{-lim}	hydrophone rarefactional pressure limit
R_L	Rayleigh length
srp	scan repetition period
srr	scan repetition rate
S	scaling factor
S_F	normalized focal length
t_d	pulse duration
$u_L(t)$	end-of-cable voltage
$U_L(f)$	end-of-cable spectrum
U	transducer driving voltage
U_c	transducer driving voltage at clinical levels
U_0	transducer output voltage
U_q	transducer driving voltage at quasi-linear levels
$v(t)$	instantaneous particle velocity
V_{bm}	beam maximum volume
V_{foc}	focal volume
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_e	distance between the external transducer surface plane and the patient entry plane
z_{FTD}	far transition distance
z_{NTD}	near transition distance
z_T	transition distance
z_{TD}	transition distance for design

z_{TM}	transition distance for measurement
z_p	distance between the source aperture plane and the plane containing the beam maximum
z_{slpta}	distance between the source aperture plane and the position of the sidelobe peak temporal-average intensity
z_L	transition distance
Z_L	electric load impedance
β	nonlinearity parameter
Δ	aperture path difference
Δ'	axial field-point path difference
Δ_{DOF}	depth-of-field
λ	effective wavelength
ρ	density of the medium (usually water)
σ_q	local distortion parameter
ω	$(2\pi f_{awf})$ circular frequency

5 Independent measurement of total acoustic output power

If called for by the output parameter set, measurements of total **output power** shall be performed according to the methods of IEC 61161 and IEC 62555. In some cases, the power can be measured using planar scanning of a **hydrophone**, as described in Annex F. In these cases, care should be taken to assure that the **hydrophone** measurement is within the **hydrophone's** pressure and intensity limits (see 6.1.6 and 6.1.7).

6 Acoustic field measurement: equipment

6.1 Hydrophone

6.1.1 General

It is assumed throughout this document that a **hydrophone** is a device which responds to acoustic waves in such a way that the output voltage is proportional to the acoustic pressure at a specified frequency. If $\underline{M}_L(f)$ is the **end-of-cable loaded sensitivity** of the **hydrophone**, the **instantaneous acoustic pressure** $p(t)$ is related to the measured end-of-cable voltage $u_L(t)$ by

$$p(t) = \mathcal{F}^{-1}[\underline{U}_L(f) / \underline{M}_L(f)] \quad (4)$$

where $\mathcal{F}^{-1}$ represents an inverse Fourier transform, and $\underline{U}_L(f)$ is the Fourier transform result of $u_L(t)$. Because this document prescribes measurements to be made in linear conditions, a narrow-band approximation as given in IEC 62127-1 can be applied:

$$p(t) = u_L(t) / |\underline{M}_L(f_{awf})| \quad (5)$$

6.1.2 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.

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 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.

6.1.3 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.

There are two reasons to know the directional response of a **hydrophone**. First, it is necessary as part of the field characterization procedures described in Clause 7, in which case the directional response should be known at the appropriate **acoustic-working frequency**. Secondly, the directional response is used to derive the **effective hydrophone radius**.

6.1.4 Effective hydrophone radius

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

6.1.5 Choice of the size of a hydrophone active element

6.1.5.1 General

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

The effective radius of the element should ideally be comparable with or smaller than one quarter of the effective 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 **effective wavelength** and the distance from the **ultrasonic transducer**. However, in the **far field** it is reasonable to relax the above criterion. For nonfocusing circular **ultrasonic transducers**, the following criterion can 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 [7]¹:

$$a_{\max} = \frac{\lambda}{8a_1} (l^2 + a^2)^{1/2} \quad (6)$$

where

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

l is the distance between the **hydrophone** and the **source aperture plane**;

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

See [7] and [8].

¹ Numbers in square brackets refer to the Bibliography.

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

For representative experimental data see [5].

6.1.5.2 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 in 6.1.5.1. 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 radius** 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 of IEC 62127-1:2007 and IEC 62127-1:2007/AMD1:2013.

6.1.6 Hydrophone pressure limits

In order to avoid making corrupted measurements or damaging a **hydrophone**, pressure limits shall be defined for the **hydrophone** or **hydrophone assembly** and the user shall not expose the **hydrophone** to pressures beyond these limits. These need to be specified both as a separate positive (i.e. compressional) limit, known as the **hydrophone compressional pressure limit**, p_{+lim} and a negative (rarefactional) limit, known as the **hydrophone rarefactional pressure limit**, p_{-lim} .

p_{+lim} is most likely to arise from electrical saturation limits in a pre- or buffer-amplifier or from severe nonlinearity in the **hydrophone's** response (see, for example, [9] and 3.5.1.2 of [10]) and can be defined as a property of the **hydrophone assembly**. p_{+lim} can be determined according 6.1.8.2 in this case.

p_{-lim} is most likely to arise from delamination of internal **hydrophone** structures, cavitation, or other nonlinearity. This quantity is preferably specified by the **hydrophone** manufacturer, or can be set by the user based on measurement evidence.

NOTE p_{+lim} and p_{-lim} can be frequency dependent.

It is expected that pressure levels within the limits can be maintained by reducing the **driving voltage**, as discussed in 7.2.1 and 7.2.2, if necessary.

6.1.7 Hydrophone intensity limits

In order to avoid making corrupted measurements or damaging a **hydrophone**, a **temporal-average intensity limit** $I_{ta,lim}$ shall be defined for the **hydrophone** or **hydrophone assembly** and the user shall not expose the **hydrophone** to intensities beyond these limits. $I_{ta,lim}$ can be independent of the pressure limits of 6.1.6, because high **temporal-average intensities** can result in heating of the **hydrophone** beyond acceptable limits, even though peak pressures can be below safe limits in accordance with 6.1.6. It is expected that safe intensity levels can be maintained by reducing the **duty factor** of the driving voltage signal, as illustrated in 7.2.1 and 7.2.2, if necessary.

$I_{ta,lim}$ is preferably specified by the **hydrophone**'s manufacturer, although it can be set by the user based on measurement evidence. This limit can be frequency dependent, because the absorption of sound energy and its conversion to heat within the **hydrophone** is likely to be frequency dependent.

6.1.8 Hydrophone cable length and amplifiers

6.1.8.1 Cable length

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 located between the **hydrophone**'s sensitive element and a preamplifier or waveform digitizer input, the numerical value of the length of that cable in metre shall be much less than $50/(f_{awf} + BW_{20})$, where f_{awf} is the **acoustic-working frequency** and BW_{20} is the –20 dB **bandwidth** of the **hydrophone** signal in megahertz (MHz). In most cases a cable length of ≤ 15 cm would be adequate (see [9]).

Attention should be paid to the appropriateness of the output impedance of the **hydrophone** amplifier in relation to the input impedance of the connected measuring device.

6.1.8.2 Preamplifier linearity

The manufacturer of any pre- or buffer-amplifier shall state the maximum voltage over which the output of the amplifier will be linear with respect to the input voltage, to within 10 %. The manufacturer shall then provide all information necessary to calculate the maximum pressure corresponding to this maximum voltage for the **hydrophone assembly**.

6.2 Requirements for positioning and water baths

6.2.1 General

There are various possible systems that can 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 can be used providing equivalence with those described in 6.2 is demonstrated.

Annex F 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.

6.2.2 Positioning systems

6.2.2.1 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, such 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 criterion shall be satisfied.

If z is the distance between the active element of a **hydrophone** and the **source aperture plane** of an **ultrasonic transducer**, c is the speed of sound, 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, q , between the **beam axis** and the reflecting surface shall be determined from:

$$(z^2 + 4q^2)^{1/2} - z > c t$$

It is preferable to immerse the transducer and not to use a membrane between the **source aperture plane** 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, if significant.

6.2.2.2 Hydrophone positioning

The **hydrophone** shall be set up in the coordinate positioning system such that the normal to 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. 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.

NOTE 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 of IEC 62127-1:2007.

6.2.2.3 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:

- a) Spatial positioning is aligned 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**.
- b) To be able to reproduce positions, all translation and rotation systems should be provided with position indicators.
- c) The repeatability of positioning should be $0,10 \lambda$ or $0,05 \text{ mm}$, whichever is smaller.

After alignment, the z -axis should be parallel to the **beam axis** of the **ultrasonic transducer**.

NOTE It is possible to relax the requirement of the repeatability 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.

6.2.3 Water bath

6.2.3.1 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 6.2.3.2).

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**.