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Edition 2.0 2017-09

INTERNATIONAL STANDARD

AMENDMENT 1

Ultrasonics – Field characterization – Test methods for the determination of thermal and mechanical indices related to medical diagnostic ultrasonic fields

IEC 62359:2010-10/AMD1:2017-09(en)

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Ultrasonics – Field characterization – Test methods for the determination of thermal and mechanical indices related to medical diagnostic ultrasonic fields

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

This amendment has been prepared by IEC technical committee 87: Ultrasonics.

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

FDIS	Report on voting
87/661/FDIS	87/665/RVD

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

The committee has decided that the contents of this amendment and the base publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

A bilingual version of this publication may be issued at a later date.

Introduction to Amendment

The second edition of IEC 62359 was published in 2010. Since then, IEC 60601-2-37:2007/AMD1:2015 has been published and calls for provision of **attenuated spatial peak temporal average intensity**, $I_{\mathrm{spta},\alpha}$, and **attenuated spatial peak pulse average intensity**, $I_{\mathrm{sppa},\alpha}$, at specific spatial maximum points in the ultrasonic field on the **beam axis**. No IEC standard describes the determination of these quantities at these specific positions. IEC 62359 for determining the thermal indices currently uses similar values at other positions, therefore, the determination of **attenuated spatial peak temporal average intensity**, $I_{\mathrm{spta},\alpha}$, and **attenuated spatial peak pulse average intensity**, $I_{\mathrm{sppa},\alpha}$, has been added as an annex in this amendment.

Additionally, references to newly published collateral standards have been updated.

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2 Normative references

Replace the first reference by the following:

IEC 60601-2-37:2007, *Medical electrical equipment – Part 2-37: Particular requirements for the basic safety and essential performance of ultrasonic medical diagnostic and monitoring equipment*
IEC 60601-2-37:2007/AMD1:2015

Replace the second reference by the following:

IEC 61157:2007, *Standard means for the reporting of the acoustic output of medical diagnostic ultrasonic equipment*
IEC 61157:2007/AMD1:2013

Replace, in the third reference, "IEC 61161:2006" *by* "IEC 61161:2013".

Replace the fifth reference by the following:

IEC 62127-1:2007, *Ultrasonics – Hydrophones – Part 1: Measurement and characterization of medical ultrasonic fields up to 40 MHz*
IEC 62127-1:2007/AMD1:2013

3 Terms and definitions

Replace the first existing paragraph by the following new paragraph:

For the purposes of this document, the terms and definitions given in IEC 60601-2-37, IEC 62127-1, IEC 62127-2, IEC 62127-3, IEC 61157 and IEC 61161 apply. Several of these are repeated below for convenience and others are listed because they have been modified for application to this standard.

3.3
acoustic repetition period
Replace the existing definition by the following new definition:

time interval between corresponding points of consecutive cycles, pulses or scans, depending on the current operating mode

Add the following new NOTES 2 and 3:

NOTE 2 For continuous wave modes, the **acoustic repetition period** is the time interval between corresponding points of consecutive cycles

NOTE 3 For **combined operating modes** where transmit pulsing of the constituent modes may be interrupted, the ***arp*** determination should take into account non-pulsing time to calculate an average period.

Replace "NOTE 2" *by* NOTE 4".

3.4
acoustic working frequency
Replace, in the existing definition, the words "at the position corresponding to the **spatial-peak temporal-peak acoustic pressure**" *by* "on the **beam axis**, beyond the **break-point depth**, corresponding to **depth of maximum pulse-intensity integral** z_{pii}."

Replace, in existing NOTE 2, the words "at the position of maximum **pulse-pressure-squared integral**" *by* "at the **depth for peak pulse-intensity integral**".

3.7
attenuated peak-rarefactional acoustic pressure

Replace, in the existing definition, the words "at a specified distance from" *by* "on a plane perpendicular to the **beam axis** at a specified distance z from".

Replace, in the definition list after Equation (2), the words "z is the distance from the **external transducer aperture** to the point of interest" *by* "z is the distance from the **external transducer aperture** along the **beam axis** to the plane containing the point of interest".

3.8
attenuated pulse-intensity integral

Replace, in the definition, the words "at a specified distance from" *by* "on a plane perpendicular to the **beam axis** at a specified distance z from".

Replace, in the definition list after Equation (3), the words "z is the distance from the **external transducer aperture** to the point of interest" *by* "z is the distance from the **external transducer aperture** along the **beam axis** to the plane containing the point of interest".

Replace "NOTE" *by* "NOTE 1".

Add new NOTE 2:

NOTE 2 For measurement purposes of this standard, pii_{α} is equivalent to $1/(\rho c)$ times the **attenuated pulse-pressure-squared integral** at depth z, with ρc denoting the characteristic acoustic impedance of pure water.

3.9
attenuated spatial-average temporal-average intensity

Replace, in the definition, the words "at a specified distance from" *by* "on a plane perpendicular to the **beam axis** at a specified distance z from".

Replace, in the definition list after Equation (4), the words "z is the distance from the **external transducer aperture** to the point of interest" *by* "z is the distance from the **external transducer aperture** along the **beam axis** to the plane containing the point of interest".

3.10
attenuated spatial-peak temporal-average intensity

Replace, in the definition, the words "at a specified distance from" *by* "on a plane perpendicular to the **beam axis** at a specified distance z from".

Replace, in the definition list after Equation (5), the words "z is the distance from the **external transducer aperture** to the point of interest" *by* "z is the distance from the **external transducer aperture** along the **beam axis** to the plane containing the point of interest".

3.11
attenuated temporal-average intensity

Replace, in the definition, the words "at a specified distance from" *by* "on a plane perpendicular to the **beam axis** at a specified distance z from".

Replace, in the definition list after Equation (6), the words "z is the distance from the **external transducer aperture** to the point of interest" *by* "z is the distance from the **external transducer aperture** along the **beam axis** to the plane containing the point of interest".

3.13
beam-axis

Replace the term "**beam-axis**" *by* "**beam axis**".

3.17
bone thermal index

Delete, in the definition, "or neonatal cephalic (through the fontanelle)".

3.19
break-point depth

Add, after the existing definition, the words "**acoustic working frequency** and intensity parameters (such as **attenuated spatial-peak temporal-average intensity**)"

Add, after "where D_{eq} is the **equivalent aperture diameter**" *the words* "for **non-scanning modes**".

Replace the existing NOTE 2 by the following new note:

NOTE 2 For **scanning modes,** use the **non-scanning mode** D_{eq} value calculation [Equation (8)]. Do this using the **output beam area** of one **ultrasonic scan line**; the central scan line, corresponding to the **beam axis** (i.e. the line where pii, MI, and f_{awf} are measured).

3.21
cranial-bone thermal index

Replace the existing definition by the following new definition:

thermal index for applications in which the ultrasound beam passes through bone near the beam entrance into the body, such as paediatric and adult cranial or neonatal cephalic applications

3.22
default setting

Replace, in the definition, "**ultrasonic diagnostic equipment**" *by* "**medical diagnostic ultrasonic equipment**".

3.23
depth for mechanical index

Replace, in the definition, the words "to the plane of maximum **attenuated pulse-intensity integral** (pii_{α})" *by* "to the plane of maximum **attenuated pulse-pressure-squared-integral** ($ppsi_{\alpha}$)".

Add new NOTE 1:

NOTE 1 Because z_{MI} may occur closer to the transducer than the **break-point depth** z_{bp}, use of $ppsi_{\alpha}$ rather than pii_{α} is technically more appropriate. If $z_{ppsi,\alpha}$ is larger than z_{bp}, then $z_{ppsi,\alpha}$ and $z_{pii,\alpha}$ are equal.

Replace "NOTE" *by* "NOTE 2".

3.24
depth for peak pulse-intensity integral

Replace the existing term, definition and note by the following new term, definition and notes:

3.24
depth for maximum pulse intensity integral
depth z on the **beam axis** and beyond the **break-point depth** z_{bp} from the **external transduscer aperture** to the plane of maximum **pulse-intensity integral** (pii) as approximated by the **pulse-pressure-squared integral** ($ppsi$)

NOTE 1 **Depth for maximum *pii*** is expressed in metres (m).

NOTE 2 **Depth for maximum *pii*** is termed "depth for peak pulse-intensity integral" in IEC 60601-2-37:2007/AMD1:2015.

NOTE 3 At this depth the **acoustic working frequency** is determined.

3.27
Discrete-perating mode

Replace the term "**Discrete-perating mode**" *by* "**discrete-operating mode**".

Replace, in the definition, "**ultrasonic diagnostic equipment**" *by* "**medical diagnostic ultrasonic equipment**".

3.28
equivalent aperture diameter

Replace the existing definition and equation by the following new definition and equation:

diameter of a circle the area A of which is the –12 dB **output beam area** A_{ob} for **non-scanning modes** and the –12 dB **scanned aperture area** A_{sa} for **scanning modes**, given by

$$D_{eq} = \sqrt{\frac{4}{\pi} A} \tag{8}$$

Replace the existing NOTE 1 by the following new note:

NOTE 1 Equation (8) is used in the calculation of the **cranial-bone thermal index**; for **non-scanning modes** with $A = A_{ob}$ and for **scanning modes** with $A = A_{sa}$.

Add new NOTE 2:

NOTE 2 Equation (8) with $A = A_{ob}$ is also used in calculating the **break-point depth**.

Replace "NOTE 2" *by* "NOTE 3".

3.33
medical diagnostic ultrasonic equipment

Replace "NOTE" *by* "NOTE 1".

Add new NOTE 2:

NOTE 2 IEC 60601-2-37:2007 uses the term "ultrasonic diagnostic equipment" instead of **medical diagnostic ultrasonic equipment**.

3.34
non-scanning mode

Replace, in the definition, the words "**ultrasonic diagnostic equipment**" *by* "**medical diagnostic ultrasonic equipment**".

3.37
output power

Replace, in the source, "IEC 61161:2006" *by* "IEC 61161:2013".

3.40
prudent-use statements

Replace the existing definition *by the following new definition:*

affirmations of the principle that only necessary clinical information should be acquired and that high exposure levels and long exposure times should be avoided

3.44
pulse repetition period

Add new NOTE 1:

NOTE 1 In general, for **non-scanning modes** the **pulse repetition period** needs to be adjusted to represent a 'per-second' average taking into account interruptions-in, or non-constant, pulsing; e.g. such as may occur in **combined operating modes**.

Replace "NOTE" *by* "NOTE 2".

3.49
scanning mode
Replace, in the definition, the words "an **ultrasonic diagnostic equipment**" *by* "a **medical diagnostic ultrasonic equipment**".

3.54
spatial-peak temporal-average intensity

Replace the existing NOTE 1 by the following new note:

NOTE 1 For systems in **combined-operating modes,** the averaging time period needs to be sufficient to include periods in which scanning or pulsing is interrupted.

3.56
thermal index

Replace, in the definition, the two occurrences of the words " **attenuated acoustic power"** *by* **"attenuated output power"**

Add the following new definitions:

3.61
instantaneous acoustic pressure
$\boldsymbol{p(t)}$
pressure minus the ambient pressure at a particular instant in time and at a particular point in an acoustic field

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

[SOURCE: IEC 62127-1:2007, 3.33, modified – The reference to IEV 801-01-19 has been removed in the definition]

3.62
attenuated instantaneous acoustic pressure
$\boldsymbol{p_\alpha(z,t)}$
value of the **instantaneous acoustic pressure** at time t after attenuation on a plane perpendicular to the **beam axis** at a specified distance z from the source, and given by

$$p_\alpha(z,t) = p(z,t)10^{(-\alpha\, z\, f_{\text{awf}}/20\ \text{dB})} \tag{26}$$

where

α	is the **acoustic attenuation coefficient**;
z	is the distance from the source to the point (plane) of interest;
f_{awf}	is the **acoustic working frequency**;
$p(z,t)$	is the **instantaneous acoustic pressure**

NOTE **Attenuated instantaneous acoustic pressure** is expressed in pascals (Pa).

3.63
attenuated pulse-pressure-squared integral
***ppsi*$_{\alpha}$(*z*)**
time integral of the square of the **attenuated instantaneous acoustic pressure**, integrated over the acoustic pulse waveform, on a plane perpendicular to the **beam axis** at a specified distance z in an acoustic field

$$ppsi_{\alpha}(z) = \int p_{\alpha}{}^{2}(z,t)dt = \int \left[p(z,t)10^{(-\alpha\, z\, f_{\mathrm{awf}}/20\ \mathrm{dB})}\right]^{2} dt = ppsi(z) \times 10^{(-\alpha\, z\, f_{\mathrm{awf}}/10\ \mathrm{dB})} \quad (27)$$

where

$p(z,t)$ is the **instantaneous acoustic pressure** at depth z.

α is the **acoustic attenuation coefficient**;

z is the distance from the source to the point (plane) of interest;

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

$ppsi$ is the **pulse-pressure-squared integral**

NOTE 1 **Attenuated pulse-pressure-squared integral** is expressed in pascal squared seconds (Pa^2s).

NOTE 2 See definition 3.43 for the non-attenuated version; with the addition here of the perpendicular plane at depth z.

3.64
attenuated scan intensity integral
***sii*$_{\alpha}$(*z*)**
sum of the **attenuated pulse intensity integrals** in one scan (one frame of **ultrasonic scan lines**) at depth z

NOTE 1 **Attenuated scan intensity integral** is expressed in joules per square metre (Jm^{-2}).

NOTE 2 For measurement purposes of this standard, $sii_{\alpha}(z)$ is equivalent to 1/(ρc) times the **sum of attenuated pulse-pressure-squared integrals** at depth z, for $z \geq z_{\mathrm{bp}}$, with ρc denoting the characteristic acoustic impedance of pure water.

NOTE 3 See definition 3.79 for the non-attenuated version.

3.65
attenuated spatial-peak pulse-average intensity
$I_{\mathrm{sppa},\alpha}(z)$
maximum value of the **spatial-peak pulse-average intensity** after attenuation, on a plane perpendicular to the **beam axis** at a specified distance z from the source, and given by

$$I_{\mathrm{sppa},\alpha}(z) = \frac{1}{t_{\mathrm{d}}(z)} pii_{\alpha}(z) \quad (28)$$

where

$t_{\mathrm{d}}(z)$ is the **pulse duration** at the same depth z;

$pii_{\alpha}(z)$ is the **attenuated pulse-intensity integral** at depth z

NOTE 1 **Attenuated spatial-peak pulse-average intensity** is expressed in watts per square metre (Wm^{-2}).

NOTE 2 For measurement purposes of this standard, $pii_{\alpha}(z)$ is equivalent to 1/(ρc) times the **attenuated pulse-pressure-squared integrals** at depth z, $ppsi_{\alpha}(z)$, for $z \geq z_{\mathrm{bp}}$, with ρc denoting the characteristic acoustic impedance of pure water.

NOTE 3 See definition 3.81 for the non-attenuated version.

3.66
attenuated sum of pulse-pressure-squared integrals
$s_{\alpha}ppsi\ (z)$
attenuated value of the sum of **pulse-pressure-squared integrals** in one scan (one frame of **ultrasonic scan lines)** at depth z

NOTE 1 **Attenuated sum of pulse-pressure-squared integrals** is expressed in pascal squared seconds (Pa^2s).

NOTE 2 The **attenuated sum of pulse-pressure-squared integrals** at depth z will be equal to the **sum of attenuated pulse-pressure-squared integrals** if each **ultrasonic scan line** in the frame which is included in the sum has the same **acoustic working frequency**.

NOTE 3 See F.3.1.4.2 for additional explanation.

NOTE 4 See definition 3.83 for the non-attenuated version.

3.67
depth for maximum I_{sppa}
$z_{sppa,max}$
depth z on the **beam axis** and beyond the **break-point depth** z_{bp} of maximum **spatial-peak pulse-average intensity**

NOTE 1 **Depth for maximum I_{sppa}** is expressed in metres (m).

NOTE 2 This depth is equivalent to the **depth for maximum pii**.

3.68
depth for maximum $I_{sppa,\alpha}$
$z_{sppa,\alpha,max}$
depth z on the **beam axis** and beyond the **break-point depth** z_{bp} of maximum **attenuated spatial-peak pulse-average intensity**

NOTE 1 **Depth for maximum $I_{sppa,\alpha}$** is expressed in metres (m).

NOTE 2 This depth is equivalent to the **depth for maximum pii_{α}**.

3.69
depth for maximum I_{spta}
$z_{spta,max}$
depth z on the **beam axis** and beyond the **break-point depth** z_{bp} of maximum **spatial-peak temporal-average intensity**

NOTE 1 **Depth for maximum I_{spta}** is expressed in metres (m).

NOTE 2 For **non-scanning modes**, this depth is equivalent to the **depth for maximum pii**. For **scanning modes**, it is equivalent to the **depth for maximum sii**.

3.70
depth for maximum $I_{spta,\alpha}$
$z_{spta,\alpha,max}$
depth z on the **beam axis** and beyond the **break-point depth** z_{bp} of maximum **attenuated spatial-peak temporal-average intensity**

NOTE 1 **Depth for maximum $I_{spta,\alpha}$** is expressed in metres (m).

NOTE 2 For **non-scanning modes**, this depth is equivalent to the **depth for maximum pii_{α}**. For **scanning modes**, it is equivalent to the **depth for maximum sii_{α}**.

3.71
depth for maximum pii_{α}
$z_{pii,\alpha}$
depth z on the **beam axis** and beyond the **break-point depth** z_{bp} of maximum **attenuated pulse-intensity integral**

NOTE 1 **Depth for maximum** pii_α is expressed in metres (m).

NOTE 2 This depth is equivalent to the **depth for maximum** $ppsi_\alpha$, $z_{ppsi,\alpha}$, when $z_{ppsi,\alpha}$ occurs beyond the **break-point depth** (see 3.73).

NOTE 3 **Depth for maximum** pii_α is termed "depth for peak attenuated pulse-intensity integral" in IEC 60601-2-37:2007+IEC 60601-2-37:2007/AMD1:2015.

3.72
depth for maximum *ppsi*

z_{ppsi}
depth z on the **beam axis** of maximum **pulse-pressure-squared integral**

NOTE 1 **Depth for maximum** $ppsi$ is expressed in metres (m).

NOTE 2 When it occurs beyond the **break-point depth**, this depth is equivalent to the **depth for maximum** pii, z_{pii} (see 3.24).

3.73
depth for maximum $ppsi_\alpha$

$z_{ppsi,\alpha}$
depth z on the **beam axis** of maximum **attenuated pulse-pressure-squared integral**

NOTE 1 **Depth for maximum** $ppsi_\alpha$ is expressed in metres (m).

NOTE 2 When it occurs beyond the **break-point depth**, this depth is equivalent to the **depth for maximum** pii_α, $z_{pii,\alpha}$ (i.e. depth for maximum **attenuated pulse-intensity integral**).

NOTE 3 This depth is the **depth for mechanical index**, z_{MI} (see 3.23).

3.74
depth for maximum *sii*

z_{sii}
depth z on the **beam axis** and beyond the **break-point depth** z_{bp} of maximum **scan-intensity integral**

NOTE 1 **Depth for maximum** sii is expressed in metres (m).

NOTE 2 This depth is equivalent to the **depth for maximum** $sppsi$, z_{sppsi}, when z_{sppsi} occurs beyond the **break-point depth** (see 3.76).

NOTE 3 **Depth for maximum** sii is termed "depth for peak sum of pulse-intensity integrals" in IEC 60601-2-37:2007+IEC 60601-2-37:2007/AMD1:2015.

3.75
depth for maximum sii_α

$z_{sii,\alpha}$
depth z on the **beam axis** and beyond the **break-point depth** z_{bp} of maximum **attenuated scan-intensity integral**

NOTE 1 **Depth for maximum** sii_α is expressed in metres (m).

NOTE 2 This depth is equivalent to the **depth for maximum** $sppsi_\alpha$, $z_{sppsi,\alpha}$, when $z_{sppsi,\alpha}$ occurs beyond the **break-point depth** (see 3.77).

NOTE 3 **Depth for maximum** sii_α is termed "depth for peak sum of attenuated pulse-intensity integrals" in IEC 60601-2-37:2007+IEC 60601-2-37:2007/AMD1:2015.

3.76
depth for maximum *sppsi*

z_{sppsi}
depth z on the **beam axis** of maximum **sum of pulse-pressure-squared integrals**

NOTE 1 **Depth for maximum** $sppsi$ is expressed in metres (m).

NOTE 2 When it occurs beyond the **break-point depth**, this depth is equivalent to the **depth for maximum *sii***, z_{sii} (see 3.74).

NOTE 3 **Depth for maximum *sppsi*** is termed "depth for peak sum of pulse-intensity integrals" in IEC 60601-2-37:2007+IEC 60601-2-37:2007/AMD1:2015.

3.77
depth for maximum $sppsi_{\alpha}$

$z_{sppsi,\alpha}$

depth z on the **beam axis** of maximum **sum of attenuated pulse-pressure-squared integrals**

NOTE 1 **Depth for maximum** $sppsi_{\alpha}$ is expressed in metres (m).

NOTE 2 When it occurs beyond the **break-point depth**, this depth is equivalent to the **depth for maximum** sii_{α}, $z_{sii,\alpha}$ (see 3.75).

NOTE 3 **Depth for maximum** $sppsi_{\alpha}$ is termed "depth for peak sum of attenuated pulse-intensity integrals" in IEC 60601-2-37:2007+IEC 60601-2-37:2007/AMD1:2015.

3.78
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 This definition applies to pulses and bursts.

NOTE 2 **Pulse-average intensity** is expressed in watts per square metre (Wm^{-2}).

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

3.79
scan intensity integral

sii

sum of the **pulse intensity integrals** in one scan (one frame of **ultrasonic scan lines**) at depth z in the acoustic field

NOTE 1 **Scan intensity integral** is expressed in joules per square metre (Jm^{-2}).

NOTE 2 For measurement purposes of this standard, sii is equivalent to $1/(\rho c)$ times the **sum of pulse-pressure-squared integral** at depth z where ρc is the characteristic acoustic impedance of pure water.

3.80
scan repetition rate

srr

inverse of the **scan repetition period** (see 3.50)

NOTE **Scan repetition rate** is expressed in hertz (Hz).

3.81
spatial-peak pulse-average intensity

$I_{sppa}(z)$

maximum value of the **pulse-average intensity** on a plane perpendicular to the **beam axis** at a specified distance z from the source, and given by

$$I_{\mathrm{sppa}}(z) = \frac{1}{t_{\mathrm{d}}(z)} pii(z) \tag{29}$$

where

$t_{\mathrm{d}}(z)$ is the **pulse duration** at the same depth z;

$pii(z)$ is the **pulse-intensity integral** at depth z

NOTE 1 **Spatial-peak pulse-average intensity** is expressed in watts per square metre (Wm^{-2}).

NOTE 2 For measurement purposes of this standard, $pii(z)$ is equivalent to $1/(\rho c)$ times the **pulse-pressure-squared integral** at depth z, $ppsi(z)$, for $z \geq z_{bp}$, with ρc denoting the characteristic acoustic impedance of pure water.

NOTE 3 See IEC 62127-1:2007, 3.60, which has been modified to specify the perpendicular plane at depth z. Equation (29) and Note 2 have been added, in accordance with IEC 62127-1:2007, Equation (15).

3.82
sum of attenuated pulse-pressure-squared integrals
$sppsi_{\alpha}(z)$
sum of the **attenuated pulse-pressure-squared integrals** in one scan (one frame of **ultrasonic scan lines**) at depth z

NOTE 1 **Sum of attenuated pulse-pressure-squared integrals** is expressed in pascal squared seconds (Pa^2s).

NOTE 2 Closely related to the **attenuated scan intensity integral**, see 3.64.

NOTE 3 The **sum of attenuated pulse-pressure-squared integrals** at depth z will be equal to the **attenuated sum of pulse-pressure-squared integrals** at depth z if each **ultrasonic scan line** in the frame which is included in the sum has the same **acoustic working frequency**.

3.83
sum of pulse-pressure-squared integrals
$sppsi(z)$
sum of **pulse-pressure-squared integrals** in one scan (one frame of **ultrasonic scan lines**) at depth z

NOTE 1 **Sum of pulse-pressure-squared integrals** is expressed in pascal squared seconds (Pa^2s).

NOTE 2 The $sppsi$ at depth z may also be referred to as the scan pulse pressure squared integral and is proportional to the **scan intensity integral** for $z \geq z_{bp}$.

4 List of symbols

Replace the symbols "$TIB_{as,sc}$" and "$TIB_{as,ns}$" *by* "TIC_{sc}" *and* "TIC_{ns}".

Replace "**depth for peak pulse-intensity integral**" *by* "**depth for maximum *pii***".

Add the following new symbols:

I_{sppa}	**spatial-peak pulse-average intensity**
$I_{\text{sppa},\alpha}$	**attenuated spatial-peak pulse-average intensity**
I_{ta}	**temporal-average intensity**
$ppsi_{\alpha}$	**attenuated pulse-pressure-squared integral**
sii	**scan intensity integral**
sii_{α}	**attenuated scan intensity integral**
$sppsi$	**sum of pulse-pressure-squared integrals**
$s_{\alpha}ppsi$	**attenuated sum of pulse-pressure-squared integrals**
$sppsi_{\alpha}$	**sum of attenuated pulse-pressure-squared integrals**
srr	**scan repetition rate**
$z_{pii,\alpha}$	**depth for maximum pii_{α}**
z_{ppsi}	**depth for maximum $ppsi$**
$z_{ppsi,\alpha}$	**depth for maximum $ppsi_{\alpha}$**
z_{sii}	**depth for maximum sii**
$z_{sii,\alpha}$	**depth for maximum sii_{α}**
$z_{\text{sppa,max}}$	**depth for maximum I_{sppa}**
$z_{\text{sppa},\alpha,\text{max}}$	**depth for maximum $I_{\text{sppa},\alpha}$**
$z_{\text{spta,max}}$	**depth for maximum I_{spta}**
$z_{\text{spta},\alpha,\text{max}}$	**depth for maximum $I_{\text{spta},\alpha}$**
z_{sppsi}	**depth for maximum $sppsi$**
$z_{sppsi,\alpha}$	**depth for maximum $sppsi_{\alpha}$**

5.1 General

Replace, in the first and second paragraphs, the words "**ultrasonic diagnostic equipment**" *by* "**medical diagnostic ultrasonic equipment**".

5.4.2.1 Determination of bone thermal index at surface for non-scanning modes, TIC_{ns} (= $TIB_{\text{as,ns}}$)

Delete, in the subclause's title, "(= $TIB_{\text{as,ns}}$*)".*

Replace the existing Equation (17) by the following new equation:

$$TIC_{\text{ns}} = \frac{P / D_{\text{eq}}}{C_{TIC}} \qquad (17)$$

Replace, in the definition list below Equation (17), the words "is the **equivalent aperture diameter**" *by* "is the **equivalent aperture diameter**; calculation for **non-scanning modes** as described in 3.28 using the **output beam area** A_{ob}".

Replace the existing note by the following new note:

NOTE TIC_{ns} applies to the bone-at-surface case for **non-scanning modes**.

5.5.2.1 Determination of bone thermal index at surface for scanning modes, TIC_{sc} (= $TIB_{as,sc}$)

Delete, in the subclause's title, "(= $TIB_{as,sc}$)".

Add, at the end of the first sentence of the first paragraph, the words "A_{sa} as described in 3.28."

Replace the existing Equation (24) by the following new equation:

$$TIC_{sc} = \frac{P / D_{eq}}{C_{TIC}} \tag{24}$$

Replace, in the definition list below Equation (24), the words "is the **equivalent aperture diameter**" *by* "is the **equivalent aperture diameter**; calculation for **scanning modes** as described in 3.28 using the **scanned aperture area** A_{sa}".

Replace the existing note by the following new note:

NOTE TIC_{sc} applies to the bone-at-surface case for **scanning modes**.

Table 1 – Summary of combination formulae for each of the THERMAL INDEX categories

Replace, in the equation in the first row, "$TIC_{as,ns}$" *by* "TIC_{ns}" *and* "$TIC_{as,sc}$" *by* "TIC_{sc}".

Table 2 – Summary of the acoustic quantities required for the determination of the indices

Delete, in the last column of the top row, "(TIB_{as})".

A.3.1 Rationale

Replace, in the second paragraph, the three occurrences of the words "**ultrasonic diagnostic equipment**" *by* "**medical diagnostic ultrasonic equipment**".

A.4.1.3 Rationale for choosing a break-point depth (z_{bp})

Replace, in the first sentence of the existing Note 1, the words "acoustic power" *by* "acoustic **output power**".

A.4.1.5 Rationale for at surface TI in non-scanning mode and scanning mode

Replace the existing text of A.4.1.5 by the following new text:

Implementation of the **soft tissue thermal index** (TIS) assumes a homogenous tissue-path model. One basic equation covers all cases for the at-surface case, **scanning modes** (such as colour-flow mapping and B-mode) and **non-scanning modes** (such as Doppler and M-mode).

In this document, the at-surface TIS-equations for all modes (**scanning** and **non-scanning**) use P_{1x1} and the at-surface TIS is calculated for all aperture sizes. See A.4.1.4 for the rationale for using the **attenuated bounded-square output power** in the numerator of the thermal index equations.

There is an expectation that **scanning mode** and **non-scanning mode** TI values should converge smoothly as the number of scan lines narrows to 1 (non-scanned), and as the depth of interest moves from below the surface (z > 0) to the surface (z = 0).

For the at-surface TIS equation, $P_{1\text{x}1,\alpha}(z)$ is the **bounded-square output power** $P_{1\text{x}1}$ and equation A results (see Table A.2).

The TIB (bone below-surface) and TIC (bone at surface) equations are fundamentally the same. For TIC, the non-attenuated power is used, since it is an at-surface estimate. These approximations are discussed in A.4.3 (see Table A.2).

If the dimensions of the active aperture are larger than 1 cm × 1 cm, then the thermal perfusion length of one centimetre (1 cm) is assumed to be exceeded. In this case the **bounded-square output power** is measured by a radiation force balance using an intermediate absorbing mask with a one-square centimetre window (the mask is 1 cm × 1 cm square), or by other masking means (e.g. electronic), or the **bounded-square output power** may be measured via hydrophone planar scanning.

NOTE Temperature rise in tissue due to transducer surface self-heating has not been taken into account in the determination of the **thermal index** [10] (see Annex C).

A.4.2.1 Derivation of break-point depth

Add, after "where A_{ob} is the **output beam area**" *in the second paragraph, the following new note:*

NOTE 1 Equation (A.3) is a re-statement of Equation (8) (from 3.28), with a single pulse corresponding to a **non-scanning mode**.

Table A.2 – Consolidated thermal index formulae

Delete, in the row labelled "C", *the symbols* "= TIB_{as}".

A.4.3.4 Derivation notes for bone at-focus for non-scanning modes ($TIB_{\text{bs,ns}}$)

Replace, in the definition list below Equation (A.17), the words "I_{sata} is spatial-average **temporal-average intensity**" *by* "$I_{\text{sata},\alpha}$ is the **attenuated spatial-average temporal-average intensity**".

Replace, in the fourth paragraph, the words "Since **output power**…" *by* "Since **attenuated output power** …".

A.4.3.6 Derivation notes for bone at-surface [TIC] for non-scanning modes ($TIB_{\text{as,ns}}$) and for scanning modes ($TIB_{\text{as,sc}}$)

Replace, in the subclause's title, "$TIB_{\text{as,ns}}$" *by* "TIC_{ns}" *and* "$TIB_{\text{as,sc}}$" *by* "TIC_{sc}".

Replace the existing Note 2 by the following new note:

NOTE 2 For **non-scanning modes** D_{eq} is calculated as described in A.4.2.1 and in 3.28 using the **output beam area** A_{ob}, and for **scanning modes** D_{eq} is calculated as described in 3.28 using the **scanned aperture area** A_{sa}.

B.1 General

Replace the last sentence of the fourth paragraph by "Steered beams are dealt with in the same way".

Replace, in the sixth paragraph, "20 %" *by* "30 %".

Delete, in Note 2, the words "Edition 2".

B.4.1 General

Replace the existing second paragraph by the following new paragraph:

The two techniques of defining the apertures in Clause B.4 have somewhat different sources of error. Agreement of the compared results from these methods, or compared to results from the method of Clause B.5, should give reasonable confidence that the aperture is defined accurately. Use of these methods, absorbing mask (B.4.2) or absorbing target (B.4.3), to limit detection to a 1 cm × 1 cm area at the front surface of the active scan aperture is recommended when the method of Clause B.5 is not feasible (e.g. for testing mechanically scanned sector probes, or third-party testing of all ultrasonic transducers).

B.4.2 1 cm × 1 cm aperture in a mask

Replace, in the last sentence of the note, the words "**beam-width**" by "**beam width**".

Figure B.4 – Suggested orientation of transducer and 1 cm-square RFB target

Replace, the axis labelling "Mask x or y axis" *by* "Target x or y axis".

B.5 Creating a 1 cm × 1 cm window using electronic control

Add, at the end of the clause's title, the words "**or using calculations**".

*Replace, in last paragraph, the two occurrences of "*mathematically*" by "*mathematical*".*

Delete, in the last paragraph, the last sentence.

B.6 Measurement of bounded-square output power

Replace, in the first paragraph, the words "of B.4.2 or B.4.3 to mask" *by* "of B.4.2 or B.4.3 or Clause B.5 to eliminate".

Replace, in the second paragraph, the words "in either B.4.2 or B.4.3" *by* "in either B.4.2 or Clause B.5, or the target used in B.4.3".

E.1 General

Add, after the last paragraph, the following new paragraph and note:

Annex F was added to Edition 2 of this standard to support the definition and determination of maximum positions and values of I_{spta}, $I_{\mathrm{spta},\alpha}$, I_{sppa} and $I_{\mathrm{sppa},\alpha}$ specified by IEC 60601-2-37.

NOTE Similar to the below-surface TI values, these are also specified to be found on the **beam axis** beyond the **break-point depth** z_{bp}.

E.2 Differences from IEC 62359 Edition 1

Add, after the third paragraph "Table E.1 summarizes some of the major changes"*, the following new note:*

NOTE The $I_{\mathrm{spta},\alpha}(z_{\mathrm{b,ns}})$ and $I_{\mathrm{spta},\alpha}(z_{\mathrm{s,ns}})$ values shown in Table E.1 are not the "maximum" **attenuated spatial-peak temporal-average intensity** values described in Annex F, because they are at the **depth for** $\boldsymbol{TIB}$ and the **depth for** $\boldsymbol{TIS}$, respectively.

Add, at the end of the existing text in the first row, right column of Table E.1, the following new sentence:

z_{bp} is also applied to I_{spta}, $I_{spta,\alpha}$, I_{sppa} and $I_{sppa,\alpha}$ determination described in Annex F.

Add, after Annex E, the following new Annex F:

Annex F
(informative)

Rationale and determination of maximum non-attenuated and attenuated spatial-peak temporal-average intensity and spatial-peak pulse-average intensity values

F.1 Rationale

This standard establishes parameters and methods related to thermal and non-thermal exposure aspects of diagnostic ultrasonic fields sufficient to calculate **mechanical index** (MI) and **thermal index** (TI) for display as specified in IEC 60601-2-37.

In the process of describing the determination of the **thermal index** and the **mechanical index**, this standard defines and describes the key components for deriving maximum non-attenuated and attenuated spatial-peak temporal-average and spatial-peak pulse-average intensities at any depth z in the acoustic field. Meanwhile, the acoustic output reporting tables specified in IEC 60601-2-37 require the provision of the spatial maximum values of these parameters in the acoustic field at specific depths z; including providing spatial maximum values over all depths z on the **beam axis** beyond the **break-point depth**, and "local" spatial maximum values at other depths on the **beam axis**.

NOTE 1 Other interested parties also require provision of these parameters at 'global' spatial maximum positions, and in some cases have established regulatory limits on their values.

NOTE 2 Recall from the definitions in Clause 3 that "spatial peak" in the terms "**attenuated spatial-peak temporal-average intensity**" and "**attenuated spatial-peak pulse-average intensity"** is the peak value at a given depth, z (i.e. not the peak value over all depths, z).

NOTE 3 The depths at which the MI and below-surface TIS and below-surface TIB are determined will not generally be the same depths at which the maximum values of I_{spta}, $I_{\text{spta},\alpha}$, I_{sppa} or $I_{\text{sppa},\alpha}$ occur.

This standard refers to IEC 62127-1, IEC 62127-2 and IEC 62127-3 for definitions, specifications of properties and calibration of measurement equipment and for hydrophone-based measurement methods. IEC 62127-1 defines various acoustic parameters which can be used to specify and characterize ultrasonic fields propagating in water using hydrophones. IEC 61157 also defines various acoustic parameters which can be used to specify and characterize ultrasonic fields propagating in water.

While these standards provide valuable information on the measurement of ultrasound fields, they do not describe standardized determination of maximum non-attenuated or **attenuated spatial-peak temporal-average intensity**, I_{spta} and $I_{\text{spta},\alpha}$ nor non-attenuated or **attenuated spatial-peak pulse-average intensity** I_{sppa} and $I_{\text{sppa},\alpha}$. Therefore, standardized means and definitions for their determination are provided in Annex F.

In combination with IEC 62127 and IEC 61161, this standard describes a complete set of methods for determining all acoustic output parameters for **medical diagnostic ultrasonic equipment** used within the ultrasound community, including those parameters called for by IEC 60601-2-37.

F.2 Overview

The goal of this Annex F is to describe standardized methods for determination of maximum positions and values of non-attenuated and **attenuated spatial-peak temporal-average intensity** I_{spta} and $I_{\text{spta},\alpha}$, and non-attenuated and **attenuated spatial-peak pulse-average intensity** I_{sppa} and $I_{\text{sppa},\alpha}$, in the acoustic field of a medical diagnostic ultrasound device.

Other, non-IEC, measurement standards define the determination of $I_{\text{spta},\alpha}$ and $I_{\text{sppa},\alpha}$ for regulatory agency purposes. Reference [44] is used widely and is referenced in IEC 62127-1. The methods listed in this Annex F are intended to be consistent with [44].

The standard attenuation coefficient value chosen is 0,3 dB cm^{-1} MHz^{-1}; the same value is introduced and used by this standard in the derivation of the below-surface **thermal index** and the **mechanical index**.

Another key similarity to the below-surface **thermal index** and the **mechanical index** is to remain on the **beam axis** when finding the position of spatial maximum values.

Similarly, this standard defines the **break-point depth**, and applies it in the determination of the below-surface thermal indices TIS and TIB for **non-scanning modes**. This same **break-point depth** is used for maximum I_{spta}, I_{sppa}, $I_{\text{spta},\alpha}$ and $I_{\text{sppa},\alpha}$ and is applied for both **scanning modes** and **non-scanning modes**.

As shown, for **non-scanning modes** one depth $z_{pii,\alpha}$ is used for the **depth of maximum $I_{\text{spta},\alpha}$** and **depth of maximum $I_{\text{sppa},\alpha}$**, and one depth z_{pii} is used for the **depth of maximum I_{spta}** and **depth of maximum I_{sppa}**.

However, as shown, for **scanning modes** the depths of maximum $I_{\text{spta},\alpha}$ and $I_{\text{sppa},\alpha}$ (and I_{spta} and I_{sppa}) can be different, and the depths of maximum I_{spta} and $I_{\text{spta},\alpha}$ often are not at the same depth as they occur for **non-scanning** modes.

Describing the determination of the $I_{\text{spta},\alpha}$ and I_{spta} for **scanning modes** is the most complicated and large part of Annex F. F.3.3.2 and F.3.1.4.2 give the summarized expressions while Clause F.4 gives more detailed information.

F.3 Test methods

F.3.1 Common parameters

F.3.1.1 Attenuation coefficient and frequency

The **acoustic attenuation coefficient** value α used for the determination of maximum $I_{\text{spta},\alpha}$ and $I_{\text{sppa},\alpha}$ is 0,3 dB cm^{-1} MHz^{-1} with linear frequency dependence.

NOTE 1 This value is the same as is used in the determination of the MI and TI, and it matches the attenuation coefficient used in [41] and [44].

Repeating Equation (A.6) in A.4.2.3:

The **attenuated spatial-peak temporal-average intensity** is denoted:

$$I_{\text{spta},\alpha}(z) = I_{\text{spta}}(z) 10^{(-\alpha z f_{\text{awf}} / 10\text{dB})}$$

where

$I_{\text{spta}}(z)$ is the **spatial-peak temporal-average intensity** at distance z,

α is the **acoustic attenuation coefficient**,

f_{awf} is the **acoustic-working frequency**, and

z is the distance from the **external transducer aperture** to the point of interest.

NOTE 2 In accordance with 3.4, NOTE 2, and 3.24, the **acoustic-working frequency** is determined at the **depth for peak pulse-intensity integral** on the **beam axis**.

NOTE 3 See A.4.2.3, 5.1 and Clause D.2 for additional discussion.

F.3.1.2 Use of the beam axis

Measurements for I_{sppa}, $I_{\text{sppa},\alpha}$, I_{spta} and $I_{\text{spta},\alpha}$ in **non-scanning modes** should be made on the **beam axis**.

NOTE While there can be side-lobes with higher intensity and pressure values, the same methodology and justification as is employed for the below-surface **thermal index** and the **mechanical index** is used, for the sake of measurement repeatability and ease.

F.3.1.3 Determination and use of the break-point depth

Measurements for I_{sppa}, $I_{\text{sppa},\alpha}$, I_{spta} and $I_{\text{spta},\alpha}$ in **scanning modes** and **non-scanning modes** are made at or beyond (farther-than) the **break-point depth** z_{bp}.

Care is to be taken when determining the z_{bp} so that the **equivalent aperture diameter** is correctly determined using only the –12 dB **output beam area.**

For **scanning modes** where **ultrasonic scan lines** that comprise a frame do not have the same –12 dB aperture size, the aperture size corresponding to the central scan line of each *sppsi* sum is to be used in the determination of **the break-point depth**.

For **combined-operating modes** where measurement of multiple modes and **transmit patterns** is being performed simultaneously, the smallest **break-point depth** of the active modes is to be used.

For **combined-operating modes** in which measurements of contributing modes and **transmit patterns** are being performed sequentially, the **break-point depth** of each separated mode is to be used.

F.3.1.4 Calculation of $ppsi_\alpha(z)$, $ppsi(z)$, $sppsi_\alpha(z)$ and $sppsi(z)$

F.3.1.4.1 $ppsi_\alpha(z)$

The calculation of $ppsi_\alpha(z)$ is accomplished by using Equation (27) (see 3.63).

NOTE 1 For measurement purposes of this standard, pii_α is equivalent to $1/(\rho c)$ times the **attenuated pulse-pressure-squared integral** at depth z, when z is beyond the **break-point depth,** with ρc denoting the characteristic acoustic impedance of pure water.

NOTE 2 3.43 gives the non-attenuated version of this quantity.

F.3.1.4.2 $s_\alpha ppsi(z)$ and $sppsi_\alpha(z)$ and $sppsi(z)$

The following discussion is for the **sum of attenuated pulse-pressure-squared integrals**. Application to non-attenuated sum is the same, but can be more simple because the **acoustic working frequency** does not need to be known or estimated for each scan line.

The determination of the **sum of attenuated pulse-pressure-squared integrals** and the **attenuated sum of pulse-pressure-squared integrals** for adjacent **ultrasonic scan lines** at any depth z may be accomplished using one of the following methods. Generally, these methods require knowledge, a priori or determined, of the number of **ultrasonic scan lines** per scan frame, the number of transmit pulses per scan line and the **acoustic working frequency** or a frame trigger that signals the start/stop of repeating frames.

NOTE 1 See F.4.2 for additional discussion of these methods.

NOTE 2 See IEC 62127-1:2007, Annex F, for additional discussion of these $sppsi(z)$ determination methods.

While either method a) or b) can be employed, it can be seen that as the pulse sequencing becomes increasingly complicated, increased knowledge of the pulses and the pulse sequencing is required.

a) Scanning **ultrasonic scan lines** past a stationary hydrophone

This may be accomplished by:

1) using a long record digitizer to sum the $ppsi$ values in one long record, or

2) via an electronic mask or electronic trigger which signals one **ultrasonic scan line** at a time so that the $ppsi(z)$ for each transmit pulse down that line, n, can be acquired and added to the $sppsi$ sum.

For either method 1) or 2) above, if all transmit pulses included in the sum are NOT identical, then the f_{awf} value of each pulse is to be obtained and the **attenuated pulse-pressure-squared integral** $ppsi_{\alpha}(z)$ calculated for each transmit pulse. The **sum of attenuated pulse-pressure-squared integrals** $sppsi_{\alpha}(z)$ is thus obtained.

If all transmit pulses included in the sum are identical, then the $sppsi(z)$ value may be determined separately and one attenuation factor applied to obtain the **attenuated sum of pulse-pressure-squared integrals** $s_{\alpha}ppsi(z)$ which in this case is equivalent to the $sppsi_{\alpha}(z)$.

b) Scanning a hydrophone past a single stationary **ultrasonic scan line**

This method can yield estimates of the **attenuated sum of pulse-pressure-squared integrals** $s_{\alpha}ppsi(z)$ and the **sum of attenuated pulse-pressure-squared integrals** $sppsi_{\alpha}(z)$ which are reasonably accurate when all **ultrasonic scan lines** use identical transmit pulses (f_{awf}, pulse length, pulse shape, pulse focusing and aperture, etc.).

This method consists of scanning a hydrophone past a single stationary **ultrasonic scan line**, collecting **pulse-pressure-squared integrals** at multiple lateral beam (profile) locations with sufficient spatial step size (sampling) such that the **pulse-pressure-squared integrals** corresponding to the equivalent locations of adjacent **ultrasonic scan lines** scanning past a stationary hydrophone are calculated.

This method requires knowledge of the spacing between successive **ultrasonic scan lines**.

NOTE 1 A method for experimentally determining the spacing between **ultrasound scan lines** is provided in IEC 62127-1:2007, 7.2.6.3.

NOTE 2 Another reference is IEC 62127-1:2013+IEC 62127-1:2013/AMD1:2013, 8.2.

If the transmit pulses for all **ultrasonic scan lines** (pulse shape, **beamwidth**, etc.) are not all identical, then choosing a worst case pulse and scan line may provide a reasonable over-estimate. The **ultrasonic scan line** and pulse yielding the largest $s_{\alpha}ppsi(z)$ value should be chosen. Choosing an **ultrasonic scan line** in the centre of the scan should be sufficient.

NOTE 3 Multiple $s_{\alpha}ppsi$ sums may be needed at each depth z in order to find the largest sum.

F.3.1.5 Measurement depth for maximum $I_{\text{spta},\alpha}$, I_{spta}, $I_{\text{sppa},\alpha}$ and I_{sppa}

For **non-scanning modes**, the **depth for maximum $I_{\text{spta},\alpha}$**, $z_{\text{spta},\alpha,\text{max}}$ is the depth on the **beam axis**, at or beyond the **break-point depth**, where the maximum **attenuated pulse-pressure-squared integral** $\max\limits_{z \geq z_{\text{bp}}}\left[ppsi_{\alpha}(z)\right]$ occurs. This is the **depth for maximum pii_{α}**, $z_{pii,\alpha}$.

NOTE 1 The **depth for maximum $I_{\text{spta},\alpha}$**, $z_{\text{spta},\alpha,\text{max}}$, for **non-scanning modes** is equal to the **depth for maximum $I_{\text{sppa},\alpha}$**, $z_{\text{sppa},\alpha,\text{max}}$, both occurring at $z_{pii,\alpha}$.

For **non-scanning modes**, the **depth for maximum I_{spta}**, $z_{\text{spta,max}}$ is the depth on the **beam axis,** at or beyond the **break-point depth**, where the maximum **pulse-pressure-squared integral** $\max\limits_{z \geq z_{\text{bp}}}\left[ppsi(z)\right]$ occurs. This is the **depth for maximum pii**, z_{pii}.

NOTE 2 The **depth for maximum I_{spta}** ($z_{\text{spta,max}}$) for **non-scanning modes** is equal to the **depth for maximum I_{sppa}**, $z_{\text{sppa,max}}$, both occurring at z_{pii}.

For **scanning modes**, the **depth for maximum $I_{\mathrm{spta},\alpha}$**, $z_{\mathrm{spta},\alpha,\max}$, is the depth, on the **beam axis**, at or beyond the **break-point depth**, where the maximum **sum of attenuated pulse-pressure-squared integrals** $\max\limits_{z \geq z_{\mathrm{bp}}}\left[sppsi_{\alpha}(z)\right]$ occurs. This is the **depth for maximum sii_{α}**, $z_{sii,\alpha}$.

For **scanning modes**, the **depth for maximum I_{spta}**, $z_{\mathrm{spta,max}}$, is the depth, on the **beam axis**, at or beyond the **break-point depth**, where the maximum **sum of pulse-pressure-squared integrals** $\max\limits_{z \geq z_{\mathrm{bp}}}\left[sppsi(z)\right]$ occurs. This is the **depth for maximum sii**, z_{sii}.

NOTE 3 See F.3.1.3 regarding the **break-point depth** to use when the **ultrasonic scan lines** do not have the same –12 dB aperture size.

For **non-scanning modes** and for **scanning modes**, the **depth for maximum $I_{\mathrm{sppa},\alpha}$**, $z_{\mathrm{sppa},\alpha,\max}$, is the depth on the **beam axis**, at or beyond the **break-point depth**, where the maximum attenuated pulse-pressure-squared integral $\max\limits_{z \geq z_{\mathrm{bp}}}\left[ppsi_{\alpha}(z)\right]$ occurs. This is the depth for maximum pii_{α}, $z_{pii,\alpha}$.

NOTE 4 This is the same depth as for maximum $I_{\mathrm{spta},\alpha}$ for **non-scanning modes**.

For non-scanning modes and for scanning modes, the depth for maximum I_{sppa}, $z_{\mathrm{sppa,max}}$, is the depth on the beam axis, at or beyond the break-point depth, where the maximum pulse-pressure-squared integral $\max\limits_{z \geq z_{\mathrm{bp}}}\left[ppsi(z)\right]$ occurs. This is the depth for **maximum pii**, z_{pii}.

NOTE 5 This is the same depth as for maximum I_{spta} for **non-scanning modes**.

F.3.2 Determination of maximum I_{sppa} and $I_{\mathrm{sppa},\alpha}$

F.3.2.1 Non-scanning and scanning modes

For **non-scanning modes** and **scanning modes**, the maximum **attenuated spatial-peak pulse-average intensity** should be calculated using

$$I_{\mathrm{sppa},\alpha} = \frac{1}{t_{\mathrm{d}}\left(z_{\mathrm{sppa},\alpha,\max}\right)\rho c}\, ppsi_{\alpha}\left(z_{\mathrm{sppa},\alpha,\max}\right) \tag{F.1}$$

and the maximum **spatial-peak pulse-average intensity** should be calculated using:

$$I_{\mathrm{sppa}} = \frac{1}{t_{\mathrm{d}}\left(z_{\mathrm{sppa,max}}\right)\rho c}\, ppsi\left(z_{\mathrm{sppa,max}}\right) \tag{F.2}$$

where

ρc	is the characteristic acoustic impedance of pure water (= 1,48 × 10^{6} kg m^{-2} s^{-1} at 20 °C);
$t_{\mathrm{d}}(z_{\mathrm{sppa},\alpha,\max})$	is the **pulse duration** at the **depth for maximum $I_{\mathrm{sppa},\alpha}$**;
$t_{\mathrm{d}}(z_{\mathrm{sppa,max}})$	is the **pulse duration** at the **depth for maximum I_{sppa}**;
$ppsi_{\alpha}(z_{\mathrm{sppa},\alpha,\max})$	is the **attenuated pulse-pressure-squared integral** at the **depth for maximum $I_{\mathrm{sppa},\alpha}$**;
$ppsi(z_{\mathrm{sppa,max}})$	is the **pulse-pressure-squared integral** at the **depth for maximum I_{sppa}**.

NOTE 1 In contrast to Equations (28) and (29), Equations (F.1) and (F.2) describe one depth each.

NOTE 2 As shown in Equations (F.1) and (F.2) and per definition 3.65 and 3.81, the pulse duration value, t_d, is determined at $z_{sppa,\alpha,max}$ and $z_{sppa,max}$, respectively.

F.3.2.2 Combined-operating modes

For **combined-operating modes**, the maximum **attenuated spatial-peak pulse-average intensity** $I_{sppa,\alpha}$ value should be the largest of the $I_{sppa,\alpha}$ values of the constituent **transmit patterns**

$$I_{\text{sppa},\alpha}\left(z_{\text{sppa},\alpha,\text{max}}\right)=\max_{\text{all transmit patterns}}\left[I_{\text{sppa},\alpha}\left(\text{transmit pattern } k, z_{pii,\alpha,k}\right)\right] \tag{F.3}$$

and the maximum **spatial-peak pulse-average intensity** I_{sppa} value should be the largest of the I_{sppa} values of the constituent **transmit patterns**

$$I_{\text{sppa}}\left(z_{\text{sppa,max}}\right)=\max_{\text{all transmit patterns}}\left[I_{\text{sppa}}\left(\text{transmit pattern } k, z_{pii,k}\right)\right] \tag{F.4}$$

F.3.3 Determination of maximum $I_{spta,\alpha}$ and I_{spta}

F.3.3.1 Non-scanning modes

For **non-scanning modes**, the maximum **attenuated spatial-peak temporal-average intensity** should be calculated using:

$$I_{\text{spta},\alpha}=\frac{prr}{\rho c}\left(\max_{z\geq z_{\text{bp}}}\left[ppsi_{\alpha}(z)\right]\right)=\frac{prr}{\rho c}\,ppsi_{\alpha}\left(z_{pii,\alpha}\right) \tag{F.5}$$

and the maximum **spatial-peak temporal-average intensity** should be calculated using:

$$I_{\text{spta}}=\frac{prr}{\rho c}\left(\max_{z\geq z_{\text{bp}}}\left[ppsi(z)\right]\right)=\frac{prr}{\rho c}\,ppsi\left(z_{pii}\right) \tag{F.6}$$

where

$ppsi_\alpha$ is the **attenuated pulse-pressure-squared integral**;

$ppsi$ is the **pulse-pressure-squared integral**;

z_{bp} is the **break-point depth**;

z_{pii} is the **depth for maximum *pii*** (= $z_{spta,\alpha,max}$) on the **beam axis**;

$z_{pii,\alpha}$ is the **depth for maximum pii_α** (= $z_{spta,\alpha,max}$) on the **beam axis**;

ρc is the characteristic acoustic impedance of pure water ($1{,}48 \times 10^6$ kg m^{-2} s^{-1} at 20 °C);

prr is the pulse **repetition rate** of the **non-scanning mode**.

NOTE 1 In contrast to Equation (5) in 3.10 and to the description in 3.54, Equations (F.5) and (F.6) describe one depth each.

NOTE 2 Equation (F.6) is modified from IEC 62127-1:2007, as the **break-point depth** is applied to it.

NOTE 3 For these calculations, an average **pulse repetition period** is used (see 3.3, 3.44 and 3.55).

F.3.3.2 Scanning modes

For **scanning modes**, the maximum **attenuated spatial-peak temporal-average intensity** should be calculated using: