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Australian/New Zealand Standard™

Assessment of power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body (frequency range of 6 GHz to 300 GHz)

Part 2: Computational procedure



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Part 2: Computational procedure

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Preface

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee TE-007, Human Exposure to Electromagnetic Fields.

The objective of this document is to specify computational procedures for conservative and reproducible computations of power density (PD) incident to a human head or body due to radio-frequency (RF) electromagnetic field (EMF) transmitting devices. The computational procedures described are finite-difference time-domain (FDTD) and finite element methods (FEM), which are computational techniques that can be used to determine electromagnetic quantities by solving Maxwell's equations within a specified computational uncertainty. The procedures specified here apply to exposure assessments for a significant majority of the population during the use of hand-held and body-worn RF transmitting devices. The methods apply to devices that can feature single or multiple transmitters or antennas, and that can be operated with their radiating part or parts at distances up to 200 mm from a human head or body.

This document can be employed to determine conformity with any applicable maximum PD requirements of different types of RF transmitting devices used in close proximity to the head and body, including those combined with other RF transmitting or non-transmitting devices or accessories (e.g. belt-clip), or embedded in garments. The overall applicable frequency range of these protocols and procedures is from 6 GHz to 300 GHz.

The RF transmitting device categories covered in this document include but are not limited to mobile telephones, radio-transmitters in personal computers, desktop and laptop devices, and multi-band and multi-antenna devices.

The procedures of this document do not apply to PD assessment of electromagnetic fields emitted or altered by devices or objects intended to be implanted in the body.

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IEC/IEEE 63195–2 was prepared by IEC technical committee 106: Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure, in cooperation with the International Committee on Electromagnetic Safety (ICES) of the IEEE Standards Association, under the IEC/IEEE Dual Logo Agreement between IEC and IEEE. It is an International Standard.

This document is published as an IEC/IEEE Dual Logo standard.

This publication contains supplemental files that are required for the code verification according to Annex A. Download links and checksums for these files can be found in Annex I.

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

Draft	Report on voting
106/564/FDIS	106/569/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with the rules given in the ISO/IEC Directives, Part 2, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC/IEEE 63195 series, published under the general title *Assessment of power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body*, can be found on the IEC website.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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Introduction

This document provides a method to evaluate the human exposure from wireless devices using computational methods. This document was developed to provide procedures for the numerical modelling and evaluation of such wireless devices operating close to the head, held in the hand or in front of the face, mounted on the body or embedded in garments. It applies to individual transmitters as well as to transmitters operating simultaneously with other transmitters within a product. The choice of technique, i.e. FDTD or FEM, is optional but can be influenced by the application. The advantages of computational procedures include the capability to provide repeatable, non-intrusive methods for determining exposure in or near an object and without the need for expensive hardware equipment. Device categories covered include but are not limited to mobile telephones, radio transmitters in personal computers, desktop and laptop devices, and multi-band and multi-antenna devices. This document specifies:

- requirements on the numerical software (Clause 5);
- model development and validation (Clause 7);
- power density computation and averaging (Clause 8);
- uncertainty evaluation (Clause 9);
- reporting requirements (Clause 10).

To develop this document, IEC Technical Committee 106 (TC 106) and IEEE International Committee on Electromagnetic Safety (ICES), Technical Committee 34 (TC 34) Subcommittee 1 (SC 1) formed Joint Working Group 11 (JWG 11) on computational methods to assess the power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body.

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Assessment of power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body (frequency range of 6 GHz to 300 GHz)

Part 2: Computational procedure

1 Scope

This document specifies computational procedures for conservative and reproducible computations of power density (PD) incident to a human head or body due to radio-frequency (RF) electromagnetic field (EMF) transmitting devices. The computational procedures described are finite-difference time-domain (FDTD) and finite element methods (FEM), which are computational techniques that can be used to determine electromagnetic quantities by solving Maxwell's equations within a specified computational uncertainty. The procedures specified here apply to exposure evaluations for a significant majority of the population during the use of hand-held and body-worn RF transmitting devices. The methods apply to devices that can feature single or multiple transmitters or antennas, and that can be operated with their radiating part or parts at distances up to 200 mm from a human head or body.

This document can be employed to determine conformity with any applicable maximum PD requirements of different types of RF transmitting devices used in close proximity to the head and body, including those combined with other RF transmitting or non-transmitting devices or accessories (e.g. belt-clip), or embedded in garments. The overall applicable frequency range of these protocols and procedures is from 6 GHz to 300 GHz.

The RF transmitting device categories covered in this document include but are not limited to mobile telephones, radio transmitters in personal computers, desktop and laptop devices, and multi-band and multi-antenna devices.

The procedures of this document do not apply to PD evaluation of electromagnetic fields emitted or altered by devices or objects intended to be implanted in the body.

NOTE For the evaluation of the combined exposure from simultaneous transmitters operating on frequencies below 6 GHz, the relevant standards for SAR computation are IEC/IEEE 62704–1:2017 and IEC/IEEE 62704–4:2020.

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/IEEE 62704–1:2017, *Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz – Part 1: General requirements for using the finite difference time-domain (FDTD) method for SAR calculations*

IEC/IEEE 62704–4:2020, *Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz – Part 4: General requirements for using the finite element method for SAR calculations*

IEC/IEEE 63195–1:2021, [1)]*Assessment of power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body (frequency range of 6 GHz to 300 GHz) – Part 1: Measurement procedure*

IEEE Std 145, *IEEE Standard for Definitions of Terms for Antennas*

1) To be published.

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3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO, IEC, and IEEE 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
- IEEE Dictionary Online: available at http://dictionary.ieee.org

3.1 Exposure metrics and parameters

3.1.1
power density
PD
local power density
function of the complex Poynting vector S at the location $\boldsymbol{r}$ that is integrated over a surface to compute the *sPD*

Note 1 to entry: Specifications of power density in terms of the integrands of Formula (4), Formula (5), and Formula (8) are provided in 8.5. See also rationales provided in Annex F for the *PD* specifications of 8.5.

Note 2 to entry: The formula used to compute *PD* can depend on the applicable exposure guidelines or national regulations.

Note 3 to entry: Power density is also referred to as power flux density.

Note 4 to entry: The associated term incident power density refers to quantity of power per unit area that impinges on the body surface. The incident power density just outside the body surface is used to establish local exposure reference levels, which apply at frequencies above 6 GHz in some jurisdictions.

3.1.2
spatial-average power density
sPD
PD (3.1.1) averaged over a surface of area A_{av}

Note 1 to entry: *sPD* is a function of the location vector $\boldsymbol{r}$. It is determined on the evaluation surface, except for the edges where no averaging area can be constructed.

Note 2 to entry: Example averaging area sizes specified in exposure limits are 1 cm^2 and/or 4 cm^2.

3.1.3
peak spatial-average power density
psPD
global maximum value of all the *sPD* (3.1.2) values on the evaluation surface (3.2.2)

Note 1 to entry: *psPD* is given by Formula (1)

$$psPD = \max_{r}\{sPD(r)\} \quad (1)$$

where $\boldsymbol{r}$ is a point on the evaluation surface.

Note 2 to entry: Other local maxima (i.e. secondary peak spatial-average power density values) can exist.

3.1.4
maximized peak spatial-average power density
mpsPD
psPD (3.1.3) of the excitation vector (3.3.5) that maximizes its value

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3.1.5
Poynting vector
S
vector product of the electric field strength ***E*** and the magnetic field strength ***H*** of the electromagnetic field at a given point

Note 1 to entry: The flux of the Poynting vector through a closed surface is equal to the electromagnetic power passing through this surface.

Note 2 to entry: For a periodic electromagnetic field, the time average of the Poynting vector is a vector the direction of which, with certain reservations, can be considered as being the direction of propagation of electromagnetic energy and the magnitude of which can be considered as being the average power flux density.

Note 3 to entry: For a sinusoidal wave of angular frequency ω, the complex Poynting vector is expressed by Formula (2)

$$S = \frac{1}{2} E \times H^* \tag{2}$$

where ***E*** and ***H*** are phasors and the asterisk denotes the complex conjugate.

Note 4 to entry: The Poynting vector has units of watt per square metre (W/m^2).

[SOURCE: IEC 60050–121:2019, 121-11-66 and IEC 60050–705:1995, 705-02-10, modified – The entries have been combined and rearranged; Note 4 has been added.]

3.1.6
conservative estimate
⟨of exposure⟩ estimate of the exposure, including uncertainties as specified in this document, representative of and slightly higher than that expected to occur in the head or body of a significant majority of the human population during intended use of a wireless transmitting device

3.2 Spatial, physical, and geometrical parameters associated with exposure metrics

3.2.1
averaging area
A_{av}
nominal size of the area used for computing *sPD* (3.1.2)

Note 1 to entry: On a planar evaluation surface, *sPD* is computed as the ratio of power density (3.1.1) integrated over the averaging area A_{av}. On a non-planar evaluation surface, the averaging area indicates the dimensions of the projection of the integration area of the power density on a planar surface.

Note 2 to entry: See details on averaging in 8.4.

3.2.2
evaluation surface
virtual surface for the evaluation of the spatial-average power density (*sPD*) emitted by a DUT

Note 1 to entry: Typical evaluation surfaces that can be applied in this document are the inner shell of the SAM phantom with an added pinna, or a planar surface with finite or infinite extension.

Note 2 to entry: The evaluation of the *psPD* (3.1.3) on the evaluation surface should yield a conservative estimate (3.1.6) of the exposure.

Note 3 to entry: In practice, an evaluation surface can be different from a measurement surface or area.

3.2.3
near-field
region encompassed by the reactive near-field and the radiative near-field

Note 1 to entry: See also 3.2.5 and 3.2.4 for definitions of reactive near-field and radiative near-field, respectively.

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3.2.4
radiative near-field
region of space between the reactive near-field and the far-field, wherein the predominant components of the electromagnetic field are those that represent a propagation of energy, and wherein the angular field distribution is dependent upon the distance from the antenna

Note 1 to entry: In the radiative near-field, the out-of-phase (i.e. evanescent) component of the electromagnetic field decays, and the in-phase (i.e. propagating) component of the electromagnetic field emerges.

3.2.5
reactive near-field
region of space immediately surrounding an antenna, where the predominant components of the electric field and magnetic field are those that represent an exchange of reactive energy between the antenna and the surrounding medium, and where electric field and magnetic field components are 90° out of phase

[SOURCE: IEC 60050–712:1992, 712-02-01, modified – In the definition, the electric field and magnetic field component phase difference has been added.]

3.2.6
far-field
region of the electromagnetic field of an antenna where the predominant components of the field are those that represent energy propagation, the angular field distribution is essentially independent of the distance from the geometrical centre of the antenna, and the ratio of predominant electric field and magnetic field components is constant and equal to the wave impedance of 377 Ω

[SOURCE: IEC 60050–712:1992, 712-02-02, modified – In the definition, the distance to geometrical centre of the antenna has been clarified, and a phrase on the ratio of the electric and magnetic components has been added.]

3.3 Test device technical operating and antenna parameters

3.3.1
channel
RF channel
part of the frequency spectrum intended to be used for the transmission of signals and which may be defined by two specified limits, or by its centre frequency and the associated bandwidth, or by any equivalent indication

Note 1 to entry: The number of RF channels and the corresponding channel bandwidth can vary among individual wireless technologies and is subject to national frequency allocations. For the purposes of this document, *PD* computations are performed at specific channels; for example, the high, middle, and low channels of the transmission band.

3.3.2
antenna sub-array
subset of radiating elements in an array that operate collectively

Note 1 to entry: Antenna elements can be used separately by two or more sub-arrays.

3.3.3
array
⟨of antennas⟩ antenna comprised of a number of generally identical radiating elements, arranged, oriented and excited to obtain a prescribed radiation pattern

3.3.4
codebook
set of all possible excitation vectors

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3.3.5
excitation vector
vector of all phasors that represent the input signal to an antenna array or sub-array

Note 1 to entry: The entries of a codebook are excitation vectors.

3.3.6
module
sub-assembly
self-contained RF transceiver that only needs power and communication to its host through a connector, ball grid arrays or pins and is designed to be incorporated into a final product

3.4 Computational parameters

3.4.1
computational domain
set of all spatial locations at which the electric field or magnetic field is computed by a mathematical equation or a computational algorithm

3.4.2
lumped source
source with an inner impedance which is applied to an electric field component on an edge of the computational mesh

3.4.3
perfect electric conductor
PEC
material with infinite electrical conductivity which does not dissipate any energy

3.4.4
surface equivalence principle
theorem that states that sources within a closed region can be replaced by substitute sources on the region surface giving rise to the same field outside the enclosed regions

Note 1 to entry: Details can be found in [1].

3.5 Uncertainty parameters

3.5.1
uncertainty
confidence range of the evaluated value

3.5.2
standard uncertainty
estimated standard deviation of a measurement or computation result, equal to the positive square root of the estimated variance

3.5.3
combined uncertainty
estimated standard deviation of the measurement or computation result obtained by combining the individual standard uncertainties of both Type A and Type B evaluations using the "root-sum-square" method of combining standard deviations that are obtained by taking the positive square root of the estimated variances

3.5.4
expanded uncertainty
quantity defining an interval about the result of a measurement or computation that is expected to encompass a distribution of values within a specified confidence interval that can reasonably be attributed to the measurand

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3.5.5
uncertainty evaluation
evaluation of uncertainty by the statistical analysis of series of observations (Type A) or by other means (Type B)

4 Symbols and abbreviated terms

4.1 Symbols

4.1.1 Physical quantities

The internationally accepted SI units are used throughout the document.

Symbol	Quantity	Unit	Dimensions
α	attenuation coefficient	reciprocal metre	1/m
P	power	watt	W
J	current density	ampere per square metre	A/m^2
σ	electric conductivity	siemens per metre	S/m
E	electric field strength	volt per metre	V/m
f	frequency	hertz	Hz
S	Poynting vector	watt per square metre	W/m^2
H	magnetic field strength	ampere per metre	A/m
ρ	mass density	kilogram per cubic metre	kg/m^3
δ	penetration depth	metre	m
μ	permeability	henry per metre	H/m
sPD	spatial-average power density	watt per square metre	W/m^2
sPD_{n+}	spatial-average power density, surface normal, directed into the phantom	watt per square metre	W/m^2
sPD_{tot+}	spatial-average power density, total, directed into the phantom	watt per square metre	W/m^2
sPD_{mod+}	spatial-average power density, modulus	watt per square metre	W/m^2
psPD	peak spatial-average power density	watt per square metre	W/m^2
mpsPD	maximized peak spatial-average power density	watt per square metre	W/m^2
c_h	specific heat capacity	joule per kilogram per kelvin	J/(kg K)
ε	permittivity	farad per metre	F/m
SAR	specific absorption rate	watt per kilogram	W/kg
T	temperature	kelvin	K
λ	wavelength	metre	m

NOTE In this document, temperature is quantified in degrees Celsius, as defined by: $T(°C) = T(K) - 273,15$.

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4.1.2 Constants

Symbol	Physical constant	Magnitude
c	speed of light in vacuum	$2{,}998 \times 10^{8}$ m/s
η_0	characteristic impedance of free space	376,73 Ω
ε_0	permittivity of free space	$8{,}854 \times 10^{-12}$ F/m
μ_0	permeability of free space	$4\pi \times 10^{-7}$ H/m

4.2 Abbreviated terms

ABC absorbing boundary condition
CAD computer aided design
DFT discrete Fourier transform
DUT device under test
EIRP equivalent isotropically radiated power
FDTD finite-difference time-domain
FEM finite element method
HDF5 hierarchical data format Version 5
ICNIRP International Commission on Non-Ionizing Radiation Protection
IF intermediate frequency
MEE maximum exposure evaluation (technique)
P_A power available from the generator
P_M power to matched transmission line
P_0 power accepted by the antenna
P_R power radiated by the antenna
PD power density
PEC perfect electric conductor
RF radio frequency
SAM specific anthropomorphic mannequin
SAR specific absorption rate
SI système international
STL stereolithography

5 Overview and application of this document

5.1 Overview of the numerical evaluation

This document specifies procedures for the evaluation of the spatial-average electromagnetic power density of wireless communication devices operating at frequencies from 6 GHz to 300 GHz using computational methods applying the finite-difference time-domain (FDTD) technique or the finite element method (FEM). The evaluation of the power density is carried out in different steps, which are the following:

a) determination of the evaluation required;

b) selection of the methodology and of an applicable, verified computational software package;

c) definition of the tests to be performed;

d) development and validation of the numerical DUT model;

e) evaluation of the power density;

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f) quantification of the uncertainty.

Figure 1 gives a high-level overview of these steps and references the subclauses that describe them in detail.

Clause 6 to Clause 10 present the procedures that are required for the numerical power density evaluation of a DUT. The evaluation shall be carried out with software that is verified for the correct technical implementation of this document. The complementary procedures that describe the verification of the numerical computation software and that are mainly relevant for the software manufacturers are given in the annexes. Software may alternatively be verified by the user of this document, e.g. as part of the power density evaluation of a DUT, according to these methods.

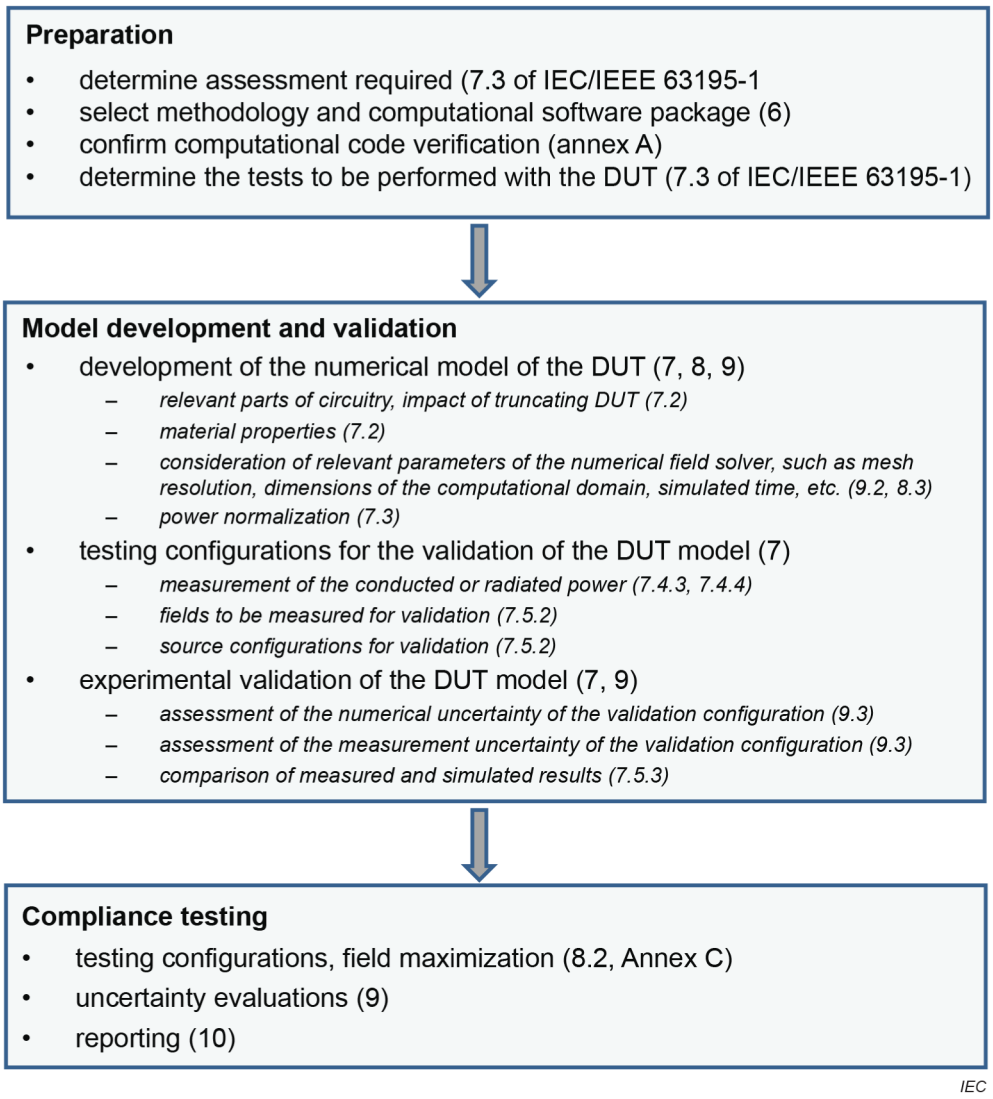


Figure 1 — Overview of the numerical power density evaluation procedure

5.2 Application of this document

This document and IEC/IEEE 63195–1 were developed in parallel in two joint working groups of IEC and IEEE to prepare procedures for conformity evaluation to exposure limits on the incident power density under particular consideration of the exposure from wireless devices of the new fifth generation (5G) mobile technology operating in a frequency range from 6 GHz to 300 GHz. This document specifies computational procedures, and IEC/IEEE 63195–1 specifies measurement procedures.

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After the fundamental work on the measurement procedures for conformity evaluation at frequencies above 10 GHz had been documented in IEC TR 63170:2018 [2][2)], both IEC/IEEE 63195–1 and this document were developed in a comparatively short time period of two years. In parallel, the ICNIRP and TC95 of the IEEE ICES revised their exposure guidelines and included new basic restrictions and reference levels for the frequency range of 6 GHz and above. These are based on the incident and absorbed/epithelial power density or incident power density, respectively, averaged over a square area of 1 cm^2 or 4 cm^2.

IEC/IEEE 63195–1 contains all relevant specifications for the application of measurement procedures for conformity evaluation. While it can be applied independently from this document, it refers to the post processing methods for power density averaging and maximization of the incident power density that are common to both IEC/IEEE 63195–1 and this document, but are specified only in this document. Likewise, computational conformity evaluation is described in this document. For validations of numerical modelling results by measurements, the methods of IEC/IEEE 63195–1 are required.

5.3 Stipulations

Due to the constraints on the time available for the development of IEC/IEEE 63195–1 and this document, practical options needed to be found regarding the interpretation of the new exposure guidelines for the evaluation of the conformity with the new limits. These concern the construction of the averaging area and the computation of the spatial-average power density on this averaging area. Regarding the computation of the spatial-average power density, different methods are specified with the objectives to warrant compatibility with exposure evaluations obtained according to IEC TR 63170:2018 [2] and to consider exposure conditions other than perpendicular incidence in the far-field. Annex F discusses the options and their rationales.

These options do not impair the applicability of the methods specified in IEC/IEEE 63195–1 and this document for the conformity evaluation with the reference levels specified in the exposure guidelines.

6 Requirements on the numerical software

This Clause 6 describes the characteristics and features of the numerical software to be used for the computation of the peak spatial-average power density (*psPD*) that are required for both the application of the software according to Clause 7, Clause 8, and Clause 9, and for the verification of its correct implementation according to Annex A. The following characteristics and features of the numerical software are required:

a) Maxwell's equations solver based on FDTD or FEM in the frequency domain according to the definitions in IEC/IEEE 62704–1:2017 and IEC/IEEE 62704–4:2020, respectively;

b) modelling environment and mesh generator for the representation of the electrically relevant parts of the DUT and of nearby objects for the rendering of its electric and magnetic fields at specifiable geometrical resolution limited only by the available computer memory;

c) representation of isotropic perfect electric conductors;

d) representation of isotropic dielectric materials with relative permittivities $\varepsilon_r \geq 1$ and electric conductivities $\sigma \geq 0$;

e) representation of uniaxial anisotropic dielectric materials with relative permittivities $\varepsilon_r \geq 1$ and electric conductivities $\sigma \geq 0$;

f) isotropic electric losses $\sigma < \infty$ in metallic conductors that are represented as thin sheets or filaments;

g) interpolation of the frequency domain computation results to specifiable points within the computational domain;

2) Numbers in square brackets refer to the Bibliography.

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h) superposition of the computed *E*-vector and *H*-vector fields in the frequency domain of a specifiable number of computation results using specifiable complex scaling factors, e.g. for the evaluation of the beam steering of phased array antennas;

i) computation of the dissipated power considering losses in dielectrics and in metallic conductors for a specifiable number of superimposed computation results on specifiable meshes;

j) superposition of the far-field patterns of a specifiable number of computation results using specifiable complex scaling factors including the evaluation of P_R, e.g. for the evaluation of the beam steering of phased array antennas;

k) computation of the *sPD* and *psPD* according to 8.5;

l) computation of the *mpSPD* according to Annex C.

Extensions of FDTD or FEM that include the required characteristics and features a) through l) but provide additional features may be applied provided that they have been fully validated and that their implementation has been verified. These alternative methods shall provide at least the same accuracy as FDTD or FEM methods specified in IEC/IEEE 62704–1:2017 and IEC/IEEE 62704–4:2020. The finite integration technique (FIT) in the time domain can be regarded as an extension of FDTD in this context.

NOTE 1 IEC/IEEE 62704–1:2017 and IEC/IEEE 62704–4:2020 specify procedures to determine the peak spatial specific absorption rate in the human body using computational methods.

NOTE 2 IEC/IEEE 62704–1:2017 and IEC/IEEE 62704–4:2020 cover the application of FDTD and FEM in the frequency range from 30 MHz to 6 GHz. In addition to the code verification described in the two standards, there is a large body of scientific literature that validates the two numerical methods for exposure evaluation in this frequency range. For the extended frequency range up to 300 GHz that is covered in this document, there is little literature available that demonstrates the validity of the two methods. Application examples for this frequency range can be found, e.g. in [3]. In general, FDTD and FEM can be considered as intrinsically frequency independent. If the discretization of the computational domain and the geometry to be computed appropriately consider the conventional discretization criteria, the methods can be expected to work with the same accuracy as in the frequency ranges for which experimental validation has been done. Appropriate discretization of the computational domain and the geometry is asserted by the uncertainty evaluation (Clause 9).

The numerical software may compute electric and magnetic fields outside the computational domain using the surface equivalence principle if all sources and parts of the DUT are contained in the computational domain (8.3). If the software implements field computation using the surface equivalence principle, it shall be validated according to Clause A.7.

7 Model development and validation

7.1 General

In experimental power density evaluation, the unmodified DUT is evaluated according to a standardized protocol using measurement equipment with known uncertainty contributions. Numerical computations of a wireless device are more flexible with respect to the tests to be performed or the modelling of real-world operation conditions, or may even be necessary where experimental evaluation is overly cumbersome or even technically impossible. An essential requirement on the application of numerical methods for power density evaluation with respect to exposure limits is the validation of the numerical model of the DUT using experimental methods. The experimental validation may be carried out in a configuration that is technically simpler than the full evaluations for DUT according to IEC/IEEE 63195–1:2021. Hence, an appropriately validated DUT model can be evaluated numerically in a large number of tests to be performed thereby reducing the overall effort to demonstrate conformity. The requirements and recommendations on DUT modelling and validation, testing equipment and tests to be performed are specified in 7.2, 7.3, 7.4, and 7.5. The evaluation of the uncertainty of results obtained with the applied methods is described in Clause 9.

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7.2 Development of the numerical model of the DUT

The development of a numerical model of a DUT for power density evaluation requires a large number of decisions on the level of detail to be represented in the computational domain. Because of the large number of modern devices and the high level of technical innovations in the field, generalized guidelines for the model development cannot be given. In the following, the steps for the development of the DUT model are described.

a) The model of the DUT should be based on its original CAD data in order to avoid errors or inaccuracies when modelling dielectrics or conductors.

NOTE 1 The development of a numerical model of the DUT based on its CAD data can require individual simplifications or extensions of the available data, such that specific requirements on the CAD data and on the data-importing procedure cannot be made here. The verification of the numerical model according to 7.5 is regarded as an adequate demonstration that the model agrees with the original DUT for the purpose of this document.

b) All conducting parts shall be integrated into the CAD model because even conductors that are far away from the antenna may couple parasitically and act as radiators. Particular considerations apply if device truncation is used (see step g) and 9.2.5).

c) The dielectric properties of all major parts in the environment of radiators and RF transmission lines should be modelled correctly considering frequency dependency. References for the dielectric properties should be documented as far as available.

d) Anisotropic dielectrics should be included in the DUT model if they are relevant for its RF characteristics.

e) Metallic losses should be included in the DUT model if they are relevant for its RF characteristics or for power normalization.

f) Modelling of the feeding or matching networks is required if the fields of these networks are not confined in a closed environment. Otherwise, lumped sources can be placed directly at the antenna feed-point. Computations of handheld devices with integrated multiband antennas have shown that it is often difficult to obtain good agreement of the computed feed-point impedance with measurement data. Nevertheless, the normalization of the exposure evaluation results to P_R yields satisfactory accuracy [4].

g) The computer system should have sufficient computational resources (working memory, processors, storage) to compute the entire DUT model and the evaluation surface. Under some circumstances, a DUT model may be truncated. However, the reactive fields of the model should not be truncated. This shall be demonstrated by comparison of the input reflection coefficients of the antenna or the elements of the antenna array or by identification of the volume storing the reactive energy of the DUT. The latter may be identified by comparison of the ratio of the local electric field and magnetic field amplitudes to the free space wave impedance. The impact of truncating the model shall be indicated in the uncertainty budget.

h) Guidance on the dimensions of the computational domain can be found in 8.3. The evaluation surface need not be included in the computational domain as the fields on it may be computed using the surface equivalence principle (8.3).

i) The testing report (Clause 10) shall summarize how these recommendations are considered for the development of the DUT model.

NOTE 2 Additional guidance on the development of the DUT model can be found in 5.4 of IEC/IEEE 62704–3:2017 [5]. Although IEC/IEEE 62704–3:2017 refers to the computation of handheld devices operating at frequencies up to 6 GHz using the FDTD method, 5.4 of IEC/IEEE 62704–3:2017 can be regarded as general enough to provide guidance beyond its original scope, i.e. for devices operating at the frequency range considered in this document and on importing CAD models into computational software using FEM.

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7.3 Power normalization

Figure 2 shows the different power reference planes in a DUT and its computational model. The available power at the source P_A is fed to the antenna via a transmission line and/or a matching circuit leading to losses (P_M) due to impedance mismatching and dissipation of the available power in the circuitry resulting in the output power P_O that is accepted by the antenna. Additional losses can occur in the antenna itself, such that the power that is emitted by the DUT is referred to as the radiated power P_R. All power related quantities are defined in IEEE Std 145.

Typically, the computational model of a DUT has a simplified feeding or matching network, which can lead to

a) specific deviations in the feed-point impedance of the antenna(s),

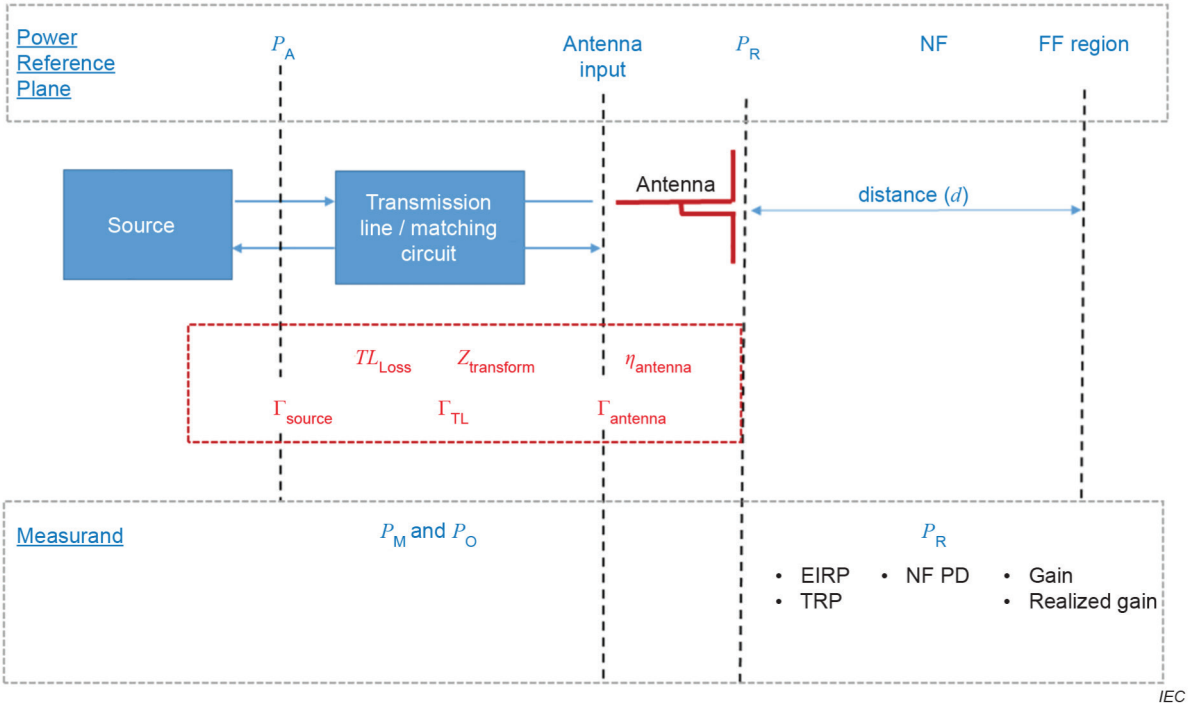
b) inaccurate representation of the cross coupling, or

c) differences in the dielectric or conducted transmission losses.

While these quantities are always available in the computational model, they need not necessarily be an exact representation of those of the actual DUT. Moreover, the feeding or antenna ports of the DUT may not be accessible for conducted power measurements. In the general case, only the EIRP or the P_R of the DUT can be evaluated experimentally to quantify P_R (Annex B).

NOTE Many documents refer to P_R as total radiated power or TRP.

All quantities (Poynting vector, *PD*, *sPD*, *psPD* and *mpsPD*) shall be normalized to the radiated power P_R both for the evaluation of the computational power density according to 8.2 and for the validation of the computational DUT model described in 7.2. If the feeding or antenna ports of the DUT are accessible for conducted power measurements, the radiated power P_R may be computed from P_A or P_M provided that all losses in the DUT are characterized with specified uncertainty.



Key

P_A available power at the source
P_M power to matched transmission line
P_O output power accepted by the antenna
P_R radiated power

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