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INTERNATIONAL STANDARD

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Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz – Part 2: Specific requirements for finite difference time domain (FDTD) modelling of exposure from vehicle mounted antennas

Détermination du débit d'absorption spécifique (DAS) maximal moyenné dans le corps humain, produit par les dispositifs de communications sans fil, 30 MHz à 6 GHz – Partie 2: Exigences spécifiques relatives à la modélisation de l'exposition des antennes sur véhicule, à l'aide de la méthode des différences finies dans le domaine temporel (FDTD)

IEC/IEEE 62704-2:2017-06(en-fr)

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DETERMINING THE PEAK SPATIAL-AVERAGE SPECIFIC ABSORPTION RATE (SAR) IN THE HUMAN BODY FROM WIRELESS COMMUNICATIONS DEVICES, 30 MHz TO 6 GHz –

Part 2: Specific requirements for finite difference time domain (FDTD) modelling of exposure from vehicle mounted antennas

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International Standard IEC/IEEE 62704-2 has been prepared by IEC technical committee 106: Methods for the assessment of electric, magnetic, and electromagnetic fields associated with human exposure, in cooperation with International Committee on Electromagnetic Safety of the IEEE Standards Association[1], under the IEC/IEEE Dual Logo Agreement.

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

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FDIS	Report on voting
106/391/FDIS	106/392/RVD

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

This standard contains attached files in the form of CAD model datasets described in Annex A. These files are available at:
http://www.iec.ch/dyn/www/f?p=103:227:0::::FSP_ORG_ID,FSP_LANG_ID:1303,25

A list of all parts in the IEC/IEEE 62704 series, published under the general title *Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz*, can be found on the IEC website.

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- reconfirmed,
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[1] A list of IEEE participants can be found at the following URL: http://standards.ieee.org/downloads/24748-5/24748-5-2017/24748-5-2017_wg-participants.pdf

INTRODUCTION

Computational techniques have reached a level of maturity which allows their use in compliance assessments of wireless communication devices with vehicle mounted antennas. The increasing complexity of assessing product compliance with exposure standards according to specific absorption rate (SAR) limits calls for new compliance techniques. This technique should be time efficient and cost effective. Experimental compliance assessments for wireless communication devices used in combination with vehicles are extremely complex to perform or even not possible at all. National regulatory bodies (e.g. US Federal Communications Commission) encouraged the development of consensus standards as well as the establishment of the related IEEE TC34 SC2 subcommittee and IEC PT62704-2 working group. The benefits to the user include standardized and accepted protocols, standardized anatomical models, validation techniques, benchmark data, reporting format, means for estimating the overall uncertainty in order to produce valid, accurate, repeatable, and reproducible results.

The results obtained by following the protocols specified in this document represent a conservative estimate of the peak spatial-average and whole-body average SAR induced in the standard human body models and exposure conditions established for this document inside or nearby the vehicles representing typical use cases with transmitting mobile radios. The protocols set forth in this document produce results subject to modelling, simulations and other uncertainties that are defined in this document.

The standardized vehicle and human models, test configurations, and related results are representative of the typical exposure conditions expected by the passengers and bystanders near the vehicle with vehicle mounted antennas. It is not the intent of this document to provide a result representative of the absolute maximum SAR value possible under every conceivable combination of body size, posture, vehicle model, and distance from the vehicle and antenna. The following items are described in detail: simulation concepts, simulation techniques, finite difference time domain (FDTD) numerical method, benchmarking techniques, standardized anatomically correct human body models of the passenger and bystander, exposure conditions, reference exposure configurations for validation of the SAR simulation software, and the limitations of these models and tools when used for simulating the peak spatial-average and whole-body average SAR. Procedures for validating the numerical tools used for SAR simulations and assessing the SAR simulation uncertainties are provided. This document is intended primarily for use by engineers and other specialists who are familiar with electromagnetic (EM) theory, numerical methods, and, in particular, FDTD techniques. This document does not recommend specific SAR limit values since these are found in other documents.

DETERMINING THE PEAK SPATIAL-AVERAGE SPECIFIC ABSORPTION RATE (SAR) IN THE HUMAN BODY FROM WIRELESS COMMUNICATIONS DEVICES, 30 MHz TO 6 GHz –

Part 2: Specific requirements for finite difference time domain (FDTD) modelling of exposure from vehicle mounted antennas

1 Scope

This part of IEC/IEEE 62704 establishes the concepts, techniques, validation procedures, uncertainties and limitations of the finite difference time domain technique (FDTD) when used for determining the peak spatial-average and whole-body average specific absorption rate (SAR) in a standardized human anatomical model exposed to the electromagnetic field emitted by vehicle mounted antennas in the frequency range from 30 MHz to 1 GHz, which covers typical high power mobile radio products and applications. This document specifies and provides the test vehicle, human body models and the general benchmark data for those models. It defines antenna locations, operating configurations, exposure conditions, and positions that are typical of persons exposed to the fields generated by vehicle mounted antennas. The extended frequency range up to 6 GHz will be considered in future revisions of this document. This document does not recommend specific peak spatial-average and whole-body average SAR limits since these are found in other documents, e.g. IEEE C95.1-2005, ICNIRP (1998).

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 60050 (all parts), *International Electrotechnical Vocabulary (IEV)* (available at: http://www.electropedia.org)

IEC/IEEE 62704-1:—[2], *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*

IEEE Standards Dictionary Online (subscription available at: http://ieeexplore.ieee.org/xpls/dictionary.jsp)

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC/IEEE 62704-1:—, the IEEE Standards Dictionary Online, IEC 60050 (all parts) and the following apply.

3.1
bystander model
heterogeneous human body model in the standing posture defined in this document to represent a bystander near the standardized vehicle

2 Under preparation. Stage at time of publication: IEC/IEEE FDIS 62704-1:2016.

3.2
conservative estimate
estimate of the peak spatial-average SAR and whole-body average SAR as defined in this document that is representative of what is expected to occur in the body of the bystanders and passengers of a significant majority of the population during normal operating conditions of mobile radios with vehicle mounted antennas

Note 1 to entry: Conservative estimate does not mean the absolute maximum SAR value that could possibly occur under every conceivable combination in the human body size, shape, separation from the antenna and/or vehicle.

3.3
heterogeneous standard human body model
anthropomorphic model of the human body with multiple anatomical structures, each of which is composed of the appropriate single, simulated-tissue type, such as skin, skull (bone), muscle, brain, eye tissue, etc., as defined by this document

Note 1 to entry: The standard human body model is based on the Visible Human dataset [1][3].

3.4
insertion loss
loss resulting from the insertion of a component in a transmission system calculated as the ratio of the power delivered to the load when connected to the generator to the power delivered to the load when the component is inserted

Note 1 to entry: Insertion loss is usually expressed in decibels (dB).

3.5
passenger model
heterogeneous human body model in the seating posture defined in this document to represent a passenger inside the standardized vehicle

3.6
vehicle model
numerical CAD-based model of the vehicle suitable for electromagnetic numerical simulations developed specifically for this document

4 Abbreviated terms

CAD	computer-aided design
FDTD	finite difference time domain
MPE	maximum permissible exposure
PEC	perfect electric conductor
PML	perfectly matched layers
PTT	push-to-talk
RF	radio frequency
RSS	root sum square
SAR	specific absorption rate

[3] Numbers in square brackets refer to the Bibliography.

5 Exposure configuration modelling

5.1 General considerations

The three relevant elements that define the exposure conditions in vehicular environments are: the communication device(s) with antenna(s), the vehicle model, and the location of the exposed subject.

The communication device or devices typically consist of one or more transceivers connected to a single antenna. The connection of multiple transceivers may require multiplexers and/or power combiners, in addition to the RF transmission line (e.g. section of coaxial cable) routed from the transceiver (or the combiner) to the antenna connector.

The term "transceiver" in the following refers to a single transceiver or a more complex system comprising an arbitrary number of transceivers and combiners, and possibly other devices along the RF signal path. Conventionally, any components inserted before the cable (if any) leading to the antenna will be considered part of the transceiver. The transceiver features an RF port (typically the connector where the cable is attached). The relevant RF signal characteristics (frequency, bandwidth, average power) at this port shall be known.

Relevant features of the antenna(s) are the geometrical dimensions, physical construction (e.g. materials), electrical characteristics (e.g. frequency response of the return loss, gain and radiation pattern), electrical/mechanical tuning mechanisms (if any), and mounting locations.

The metallic portions of the vehicle body and the antenna location are the most important parameters that define an exposure scenario. The shape and features of the vehicle body (e.g. windows) shall be representative of the typical application of the communication device without complicating the computational modelling unnecessarily. The model of the pavement shall also be included in the simulation.

5.2 Vehicle modelling

To obtain reliable and repeatable simulation results, a specific CAD model of the vehicle has been defined and is available with this document. To conduct a successful simulation according to this document, the CAD model of this standardized vehicle shall be used. Some results obtained using this standardized vehicle model may not be applicable for certain other vehicle types or different antenna installation conditions, e.g. if non-metallic roof installation is allowed.

The standardized vehicle model defined in this document for compliance assessment is applicable to all vehicle models when the following conditions are met. For either roof mount or trunk mount antenna, the distance to the bystander shall be defined with the antenna mounted according to the installation requirements. To help ensure the most conservative configuration(s) are considered for exposure assessment, the bystander separation distance shall be no greater than the minimum separation distance required for compliance as stated in the installation instructions. The same conditions shall apply to the separation distance between the antenna and the passenger except for the roof mount antenna configurations where the passenger is partially shielded by the metal roof. With such considerations, the impact of the vehicle model does not need to be considered when performing simulations using the standardized vehicle model, which makes this evaluation process practical.

Depending on the FDTD code, uniform or graded meshing algorithms can be employed. In the former case, the computational model resolution is usually determined by the anatomical details of the human model employed to represent the exposed subject. In the latter case, outside of the human body model, it is possible to relax the mesh resolution in some regions of the computational model (following the guidelines for graded mesh set forth in 5.2) in order to increase the execution speed of the numerical simulations and/or increase the geometrical dimensions of the computational domain. However, it is important that the same meshing resolutions as defined and used for the validation and reference models are also used for all related exposure simulations.

The computational model of the vehicle body comprises mainly metal sheets with perfect electric conductor (PEC) properties. It is important that the meshed representation of the standard CAD model be inspected to help ensure continuity of the metal sheets forming the vehicle body and also to ensure that the required gaps and small separations between the different metal parts in the vehicle are not shorted and become continuous in the meshing process. The metal sheets can be modelled as a collection of thin layers, i.e. where the PEC condition is enforced only on a series of contiguous voxel faces along one coordinate plane, properly interconnected among them; or as a combination of thin and volumetric objects. For consistency and to help ensure that the mesh generated for the standard vehicle model defined in this document is valid, a maximum mesh step of 10 mm shall be used.

Compared to PEC, electromagnetic field scattered by the glass surfaces and other dielectric parts is a second order effect; therefore, they are not present in the standard vehicle model. Likewise, rear window defogger elements contain high resistivity conductors and are electromagnetic scatterers, which may attenuate the flow of RF energy through the window. For the purpose of this document, the effect of defoggers is neglected.

5.3 Communications device modelling

Before addressing the exposure to the RF energy emitted by the mobile radio antenna, it shall be verified that electromagnetic emissions contributed by the transceiver equipment are insignificant compared to the exposure level. This can be done by referring to the available radiated emission data in the EMC compliance report for the transceiver evaluated according to measurements or other suitable means recommended by internationally recognized EMC standards.

The general guidelines set forth in IEC/IEEE 62704-1 for modelling the RF source as a resistive generator in the FDTD model should be applied. Except for special or unique circumstances, which shall be explained and justified in the assessment report, source excitation should be applied at the antenna feed-point.

The fixed losses should be identified and quantified when possible to determine overestimation of exposure. The effect of the cable insertion losses leading to the antenna feed-point may be neglected in computations through proper RF power scaling at the feed point. This introduces a conservative bias in RF exposure assessment. However, if cable losses can be reasonably well quantified according to cable specifications and length required for mounting the antenna at specific locations, the effect of cable losses can be considered in the assessment by reducing the net input power, by an amount equal to the cable loss minus 0,5 dB. For instance, if the cable loss is 1,25 dB, a radiated power of 0,75 dB less than the power available at the transceiver port is applied to the antenna feed-point in the simulation. If the cable loss is less than 0,5 dB, it shall be neglected. This intentional bias is introduced to account for minor variations in cable lengths and cable specifications or properties to help ensure the conservative nature of the RF exposure assessment. Furthermore, return loss due to the antenna mismatch may also be neglected, thus introducing additional conservative bias. In any case, proper justification shall be provided to quantify the cable insertion losses and return loss if they are introduced in the computational analysis.

Because of the linearity of the simulated fields in a defined electromagnetic exposure condition, FDTD simulations can be performed at any desired power level and then scaled to the actual maximum average output power of the communication device.

The antenna shall be modelled to represent the physical antenna to help ensure the results are valid. This might require assembling the model as a collection of wires, patches, volumetric dielectric or metallic objects, etc. It is possible to introduce simplifications to reduce the complexity of the antenna model. For instance, it may be possible to introduce lumped reactive elements in the FDTD model in lieu of electrically small reactances, such as loading coils (sometimes called “traps”) used to phase different wire sections of electrically long antennas. The antenna components that are smaller than one-tenth of the wavelength in the local dielectric material shall be deemed electrically small. Any such lumped element in the antenna model shall be validated according to the procedures set forth in 6.1.

Antenna models shall be located on the vehicle at the locations consistent with the test setup supported by this document and according to the antenna installation and product manual requirements. Test requirements for roof top and trunk mount antennas are specified in this document. The antenna and vehicle both contribute as radiating structures. In most cases, the antenna feed-point is located at the base of the antenna, where it makes contact with the vehicle body. This configuration is the one most frequently encountered. However, there might be cases where the feed-point is located elsewhere, for instance in the middle of a sleeve dipole antenna. Proper justification for the choice of antenna feed-point location shall be provided in the simulation report. There are also cases where matching networks are employed at the antenna feed-point to realize proper matching to the RF source impedance. In these cases, the matching network may be omitted from the FDTD model since the computed results can always be scaled to produce the desired amount of antenna input power as shown below.

The antenna feed-point impedance and total power radiated under impedance match conditions at the test frequency can be obtained from simulations. The input impedance is calculated upon integrating the steady-state magnetic field surrounding the edge on which the feed-point is located to compute steady-state feed-point current (I), which is then used to derive the steady-state voltage (V) across the feed-point gap. The net average input power is computed as

$$P_{\text{in}} = \frac{1}{2}\text{Re}\{VI^*\} \tag{1}$$

where the asterisk indicates the complex conjugate.

SAR can be normalized to P_{in} to obtain SAR per watt input power. Whole-body average and peak spatial-average SAR for 1 g or 10 g can be determined by scaling the normalized SAR by the maximum power rating at the transceiver/antenna port. The final results may also take into consideration the time averaging allowed by national regulatory exposure requirements (e.g., the 50 % duty cycle afforded to certain PTT mobile radios).

A Thevenin model of the source feeding the antenna is shown in Figure 1. The voltage source

V_S and the real source impedance R_S are employed in the computations.

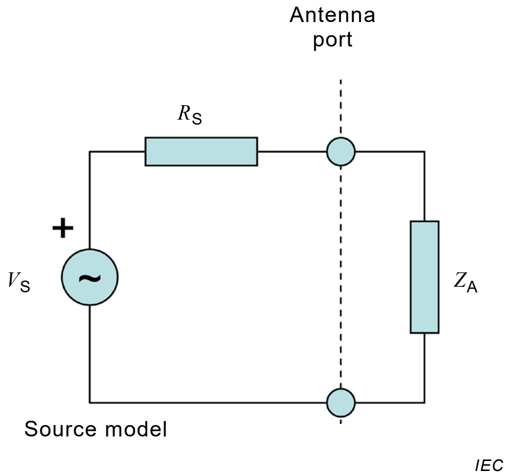

Figure 1 – Antenna feed model

The antenna impedance is $Z_A = R_A + jX_A$. The available power from the source is the maximum amount that would be dissipated in the load under perfect impedance matching condition (also known as conjugate matching condition $Z_A = R_S$):

$$P_{av} = \frac{1}{2}\mathrm{Re}\left\{V_A I_A^*\right\} = \frac{1}{2}\frac{V_S}{2}\frac{V_S^*}{2R_S} = \frac{|V_S|^2}{8R_S} \tag{2}$$

The operating condition for maximum power at R_S is represented in Figure 2. Note that this is the same condition, where the matched load resistance is represented by a power metering device, used to measure the maximum conducted power from a radio.

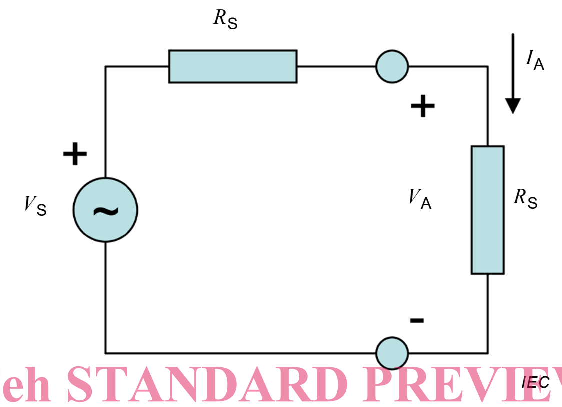

Figure 2 – Voltage and current at the matched antenna feed-point

Therefore, it is possible to establish the Thevenin voltage V_S that would be representative of a radio transmitter with maximum rated power P_{max} and the source impedance R_S as follows:

$$P_{max} = P_{av} = \frac{|V_S|^2}{8R_S} \Rightarrow |V_S| = \sqrt{8R_S P_{max}} \tag{3}$$

When the transmitter is connected to an antenna that exhibits the input impedance Z_A, the power radiated can be no greater than the maximum rated power P_{max} because of two physical mechanisms: energy dissipation in the antenna structure and energy reflection at the antenna port. The first mechanism is due to dielectric and ohmic losses while the second one is due to impedance mismatch at the antenna port. Neglecting energy dissipation introduces a conservative bias in compliance assessments. In computations, this is accomplished by applying ideal (lossless) material properties for the radiating structures, and in such case the radiated power P_{rad} is equal to the antenna input power P_{in}. An additional conservative bias is introduced by neglecting the mismatch losses. The mismatch loss factor is:

$$\eta = \frac{P_{rad}}{P_{max}} = 1 - |\Gamma|^2 = 1 - \left|\frac{Z_A - R_S}{Z_A + R_S}\right|^2 = \frac{4R_A R_S}{|Z_A + R_S|} \tag{4}$$

where Γ is the reflection coefficient at the antenna port. Therefore, in order to neglect the mismatch loss, the computed fields are scaled up by a factor $\sqrt{1/\eta}$ after simulations. This is equivalent to setting $P_{rad} = P_{max}$ and therefore $\Gamma = 0$, which is equivalent to saying that there are no mismatch losses and that the maximum power of the radio transmitter is radiated.

By following the approach described above, the effect of any ohmic losses due to the matching network components is omitted in the FDTD model, thus introducing a further conservative bias in the assessment.