



IEEE

IEC/IEEE 62704-4

Edition 1.0 2020-10

INTERNATIONAL STANDARD

NORME INTERNATIONALE



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

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 4: Exigences générales d'utilisation de la méthode des éléments finis pour les calculs du DAS



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2020 IEC, Geneva, Switzerland

Copyright © 2020 IEEE

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing being secured. Requests for permission to reproduce should be addressed to either IEC at the address below or IEC's member National Committee in the country of the requester or from IEEE.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland
Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue
New York, NY 10016-5997
United States of America
stds.ipr@ieee.org
www.ieee.org

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

Electropedia - www.electropedia.org

The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

67 000 electrotechnical terminology entries in English and French extracted from the Terms and definitions clause of IEC publications issued between 2002 and 2015. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

A propos de l'IEC

La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC

Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Recherche de publications IEC - webstore.iec.ch/advsearchform

La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études,...). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished

Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et une fois par mois par email.

Service Clients - webstore.iec.ch/csc

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: sales@iec.ch.

Electropedia - www.electropedia.org

Le premier dictionnaire d'électrotechnologie en ligne au monde, avec plus de 22 000 articles terminologiques en anglais et en français, ainsi que les termes équivalents dans 16 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

Glossaire IEC - std.iec.ch/glossary

67 000 entrées terminologiques électrotechniques, en anglais et en français, extraites des articles Termes et définitions des publications IEC parues entre 2002 et 2015. Plus certaines entrées antérieures extraites des publications des CE 37, 77, 86 et CISPR de l'IEC.



IEEE

IEC/IEEE 62704-4

Edition 1.0 2020-10

INTERNATIONAL STANDARD

NORME INTERNATIONALE



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

**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 4: Exigences générales d'utilisation de la méthode des éléments finis pour les calculs du DAS**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 17.220.20

ISBN 978-2-8322-8535-0

**Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.**

CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
1 Scope.....	8
2 Normative references	8
3 Terms and definitions	8
4 Abbreviated terms	9
5 Finite element method – basic description	9
6 SAR calculation and averaging	10
6.1 General.....	10
6.2 SAR averaging.....	11
6.2.1 General	11
6.2.2 Evaluation of psSAR with an FEM mesh	11
6.3 Power scaling	12
7 Considerations for the uncertainty evaluation	12
7.1 General.....	12
7.2 Uncertainty due to device positioning, mesh density, and simulation parameters	13
7.2.1 General	13
7.2.2 Mesh convergence.....	14
7.2.3 Open boundary conditions	14
7.2.4 Power budget	14
7.2.5 Convergence of psSAR sampling.....	14
7.2.6 Dielectric parameters of the phantom or body model	15
7.3 Uncertainty and validation of the developed numerical model of the DUT	15
7.3.1 General	15
7.3.2 Uncertainty of the DUT model ($d \geq \lambda/2$ or $d \geq 200$ mm)	16
7.3.3 Uncertainty of the DUT model ($d < \lambda/2$ and $d < 200$ mm).....	17
7.3.4 Phantom uncertainty ($d < \lambda/2$ and $d < 200$ mm).....	18
7.3.5 Model validation	19
7.4 Uncertainty budget.....	19
8 Code verification.....	20
8.1 General.....	20
8.1.1 Rationale	20
8.1.2 Code performance verification	21
8.1.3 Canonical benchmarks	21
8.2 Code performance verification	21
8.2.1 Propagation in a rectangular waveguide	21
8.2.2 Planar dielectric boundaries	26
8.2.3 Open boundary conditions	28
8.3 Weak patch test	28
8.3.1 General	28
8.3.2 Free-space weak patch test	29
8.3.3 Dielectric-layer weak patch test	33
8.4 Verification of the psSAR calculation	36
8.5 Canonical benchmarks.....	36
8.5.1 Mie sphere	36

8.5.2	Generic dipole	37
8.5.3	Microstrip terminated with open boundary conditions	38
8.5.4	psSAR calculation SAM phantom / generic phone	39
8.5.5	Setup for system performance check	39
Annex A (informative) Fundamentals of the finite element method		41
A.1	General.....	41
A.2	Model boundary value problem	41
A.3	Galerkin weak form	42
A.4	Finite element approximation	42
A.5	Considerations for using FEM	43
Annex B (informative) File format for field and SAR data.....		44
Annex C (informative) Analytical solution for error calculation in weak patch-test problems.....		45
C.1	Generation of control mesh and FEM field values	45
C.2	Free-space weak patch test	45
C.3	Dielectric-layer weak patch test	45
Bibliography.....		48
Figure 1 – Waveguide filled half with free-space (green) and half with dielectric (blue)		24
Figure 2 – Aligned rectangular waveguide and locations of the sample points E_{01} , E_{10} , E_{11} , E_{12} and E_{21} at which the E_x components are recorded		25
Figure 3 – Weak patch test arrangement: a free-space cube with edge length L illuminated by a plane wave		29
Figure 4 – Dielectric-layer weak patch test arrangement		33
Figure 5 – Geometry of the microstrip line		38
Figure 6 – Geometry of the setup for the system performance check according to [21]		40
Table 1 – Budget of the uncertainty contributions of the numerical algorithm and of the rendering of the test-setup or simulation-setup		13
Table 2 – Budget of the uncertainty of the developed model of the DUT.....		17
Table 3 – Overall assessment uncertainty budget for the numerical simulation results		20
Table 4 – Results of the evaluation of the numerical dispersion characteristics to be reported for each mesh axis and each orientation of the waveguide for at least three increasing numbers of DoF		25
Table 5 – Results of the evaluation of the numerical reflection coefficient to be reported; frequency range is indicated for each value to be reported		27
Table 6 – Guiding parameters for coarse and fine mesh generation for the weak patch test..		30
Table 7 – Results of the evaluation of the error measures on the control mesh for the weak patch test for the lowest order.....		32
Table 8 – Results of the evaluation of the error measures on the control mesh for the weak patch test for the second lowest order		32
Table 9 – Results of the evaluation of the error measures on the control mesh for the weak patch test for the third lowest order.....		33
Table 10 – Guiding parameters for coarse and fine mesh generation for the dielectric-layered weak patch test		34
Table 11 – Results of the evaluation of error measures on the control mesh for the dielectric-layered weak patch test for the lowest order		35

Table 12 – Results of the evaluation of error measures on the control mesh for the dielectric-layered weak patch test for the second lowest order	35
Table 13 – Results of the evaluation of error measures on the control mesh for the dielectric-layered weak patch test for the third lowest order	36
Table 14 – Results of the SAR evaluation of the Mie sphere	37
Table 15 – Results of the dipole evaluation.....	38
Table 16 – Results of the microstrip evaluation.....	39
Table 17 – 1 g and 10 g psSAR for the SAM phantom exposed to the generic phone for 1 W accepted power as specified in [19]	39
Table 18 – Dielectric parameters of the setup (Table 1 of [21])	40
Table 19 – Mechanical parameters of the setup (Tables 1 and 2 of [21]).....	40
Table 20 – 1 g and 10 g psSAR normalized to 1 W accepted power and feed-point impedance (Table 3 and Table 4 of [21]).....	40

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

Part 4: General requirements for using the finite element method for SAR calculations

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation.

IEEE Standards documents are developed within IEEE Societies and Standards Coordinating Committees of the IEEE Standards Association (IEEE SA) Standards Board. IEEE develops its standards through a consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of IEEE and serve without compensation. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information contained in its standards. Use of IEEE Standards documents is wholly voluntary. IEEE documents are made available for use subject to important notices and legal disclaimers (see <http://standards.ieee.org/IPR/disclaimers.html> for more information).

IEC collaborates closely with IEEE in accordance with conditions determined by agreement between the two organizations.

- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees. The formal decisions of IEEE on technical matters, once consensus within IEEE Societies and Standards Coordinating Committees has been reached, is determined by a balanced ballot of materially interested parties who indicate interest in reviewing the proposed standard. Final approval of the IEEE standards document is given by the IEEE Standards Association (IEEE-SA) Standards Board.
- 3) IEC/IEEE Publications have the form of recommendations for international use and are accepted by IEC National Committees/IEEE Societies in that sense. While all reasonable efforts are made to ensure that the technical content of IEC/IEEE Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications (including IEC/IEEE Publications) transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC/IEEE Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC and IEEE do not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC and IEEE are not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or IEEE or their directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees, or volunteers of IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board, for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC/IEEE Publication or any other IEC or IEEE Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

9) Attention is drawn to the possibility that some of the elements of this IEC/IEEE Publication may require use of material covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. IEC or IEEE shall not be held responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patent Claims or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

International Standard IEC/IEEE 62704-4 has been prepared by IEC technical committee TC 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, under the IEC/IEEE Dual Logo Agreement.

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

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

FDIS	Report on voting
106/515/FDIS	106/521/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.

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.

The IEC technical committee and IEEE technical committee have decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Finite element methods have reached a level of maturity that allows their application in specific absorption rate (SAR) assessments of professional-use and consumer-use wireless communication devices. In the recent past, SAR compliance assessments for small transmitters were performed almost exclusively using measurements. Some wireless communication devices are used in situations where experimental SAR assessment is extremely complex or not possible at all. National regulatory bodies (e.g. US Federal Communications Commission) encourage the development of consensus standards and encouraged the establishment of the ICES Technical Committee 34 Subcommittee 2. The benefits to the users and the regulators include standardized and accepted protocols, verification and validation techniques, benchmark data, reporting format and means for estimating the overall assessment uncertainty in order to produce valid, repeatable, and reproducible data.

The purpose of this document is to specify numerical techniques and models to determine peak spatial-average specific absorption rates (SAR). SAR will be determined by applying finite element method simulations of the electromagnetic field conditions produced by wireless communication devices in models of the human anatomy. Intended users of this document are (but are not limited to) wireless communication device manufacturers, service providers for wireless communication that are required to certify that their products comply with the applicable SAR limits, and government agencies.

Several methods described in this document are based on techniques specified in IEC/IEEE 62704-1:2017.

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

Part 4: General requirements for using the finite element method for SAR calculations

1 Scope

This part of IEC/IEEE 62704 describes the concepts, techniques, and limitations of the finite element method (FEM) and specifies models and procedures for verification, validation and uncertainty assessment for the FEM when used for determining the peak spatial-average specific absorption rate (psSAR) in phantoms or anatomical models. It recommends and provides guidance on the modelling of wireless communication devices, and provides benchmark data for simulating the SAR in such phantoms or models.

This document does not recommend specific SAR limits because these are found elsewhere (e.g. in IEEE Std C95.1 [1]¹ or in the guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [2]).

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 62209-1, *Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Part 1: Devices used next to the ear (Frequency range of 300 MHz to 6 GHz)*

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*

IEEE Std 1528, *IEEE Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head From Wireless Communications Devices: Measurement Techniques*

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>

¹ Numbers in square brackets refer to the Bibliography.