

PUBLICLY AVAILABLE SPECIFICATION

PRE-STANDARD



Assessment methods of the human exposure to electric and magnetic fields from wireless power transfer systems – Models, instrumentation, measurement and numerical methods and procedures (frequency range of 1 kHz to 30 MHz)



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2021 IEC, Geneva, Switzerland

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 from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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 It also gives information on projects, replaced and withdrawn publications.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.

IEC online collection - oc.iec.ch

Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

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 18 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

Preview generated by EVS

PUBLICLY AVAILABLE SPECIFICATION

PRE-STANDARD



Assessment methods of the human exposure to electric and magnetic fields from wireless power transfer systems – Models, instrumentation, measurement and numerical methods and procedures (frequency range of 1 kHz to 30 MHz)

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 17.220.20

ISBN 978-2-8322-9542-7

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	8
INTRODUCTION.....	10
1 Scope.....	11
2 Normative references	11
3 Terms and definitions	11
4 Symbols and abbreviated terms.....	15
4.1 Physical quantities	15
4.2 Constants	15
4.3 Abbreviated terms.....	15
5 Assessment procedures	16
5.1 General.....	16
5.2 Conformity assessment considering direct effects	17
5.2.1 General	17
5.2.2 Evaluation based on coil current.....	17
5.2.3 Evaluation of incident fields against reference levels	18
5.2.4 Evaluation of incident fields against basic restrictions.....	18
5.2.5 Evaluation of internal E-field, current density and/or SAR against basic restrictions.....	22
5.3 Conformity assessment considering indirect effect	22
6 Measurement methods	24
6.1 Incident fields	24
6.1.1 General procedure.....	24
6.1.2 Equipment	25
6.2 SAR.....	26
6.3 Contact currents	27
6.3.1 General	27
6.3.2 Equipment	28
6.3.3 Measurements.....	29
7 Computational assessment methods.....	30
7.1 General.....	30
7.2 Quasi-static approximation.....	30
7.3 Computational assessment against the basic restrictions.....	31
7.3.1 General	31
7.3.2 Peak spatial-average SAR.....	31
7.3.3 Whole-body average SAR.....	31
8 Combination of measurement and computational assessment methods	32
8.1 General.....	32
8.2 Measurement of magnetic field	32
8.3 Computational analyses of induced quantities.....	32
8.4 Computational assessment against the basic restrictions.....	33
9 Uncertainty assessments.....	33
9.1 Measurement methods.....	33
9.2 Numerical methods	34
9.3 Assessment of combining measurement and numerical methods	35
Annex A (informative) Exposure evaluations using approximations	37
Annex B (normative) Calibration methods	39

B.1	General.....	39
B.2	E-field and H-field calibration	39
B.2.1	Standard field generation methods	39
B.2.2	Characteristics to be measured	39
B.2.3	Frequency domain calibration	40
B.2.4	E-field calibration.....	44
B.3	Gradient response verification	48
B.3.1	General	48
B.3.2	H-field gradient verification: Main steps	48
B.3.3	Uncertainty for H-field gradient verification	48
B.4	Dosimetric probe calibration.....	49
B.4.1	General	49
B.4.2	Calibration with short dipole antennas via transmit antenna factor	49
B.4.3	Uncertainty	52
Annex C (normative)	Verification and validation methods for measurement.....	53
C.1	General.....	53
C.2	Objective	53
C.3	Measurement setup and procedure for system verification and system validation	53
C.4	Measurement system verification: test procedure.....	54
C.5	Measurement system validation: test procedure.....	54
Annex D (informative)	Dependency of SAR on phantom property and size	55
D.1	Phantom property	55
D.2	Phantom size	58
Annex E (informative)	Extrapolation methods of SAR measurement.....	61
E.1	General.....	61
E.2	Measurement and interpolation of electric field inside a phantom.....	61
E.2.1	General	61
E.2.2	Extrapolation functions	61
E.2.3	Three steps for determination of spatial-peak SAR	62
E.2.4	Validation of measurement methods using extrapolation.....	62
E.2.5	Uncertainty	64
Annex F (informative)	Numerical calculation methods	66
F.1	General.....	66
F.2	Quasi-static finite element method	66
F.3	Scalar potential finite difference method	67
F.4	Impedance method	67
F.5	Finite-difference time-domain method	68
F.6	Hybrid technique of MoM and FDTD method	68
F.7	Hybrid technique of FEM and SPFD method	69
Annex G (informative)	Averaging algorithms	70
G.1	Current density averaging over an area	70
G.1.1	General	70
G.1.2	Calculation of the current density in a Cartesian voxel.....	70
G.1.3	Calculation of the current density in a tetrahedron	71
G.1.4	Calculation of J_{av}	71
G.2	E-field averaging in a cubical volume	72
G.3	E-field averaging along an averaging distance	72

G.3.1	General	72
G.3.2	Algorithm to construct the integration path	73
Annex H (informative)	Code verification and model validations	74
H.1	Code verification	74
H.1.1	Introduction	74
H.1.2	Quasi-static codes	74
H.1.3	Quasi-static codes for the calculation of the incident magnetic field	75
H.1.4	Averaging algorithms	76
H.2	Model validation	77
H.2.1	Introduction	77
H.2.2	Recommendations for the development of the numerical model	78
H.2.3	Determining the validity of the field source	78
Annex I (informative)	Use cases	80
I.1	EV (SWPT)	80
I.1.1	Determination of user position	80
I.1.2	Assessment procedures considering direct effects for WPT system for EV	81
I.1.3	Assessment procedures considering indirect effects for WPT system for EV	86
I.2	Heavy duty vehicle EMF measurement procedure	91
I.2.1	General	91
I.2.2	Step 1	91
I.2.3	Step 2	93
I.2.4	Step 3	93
I.3	Drone	94
I.3.1	Introduction	94
I.3.2	Assessment procedures of WPT system for drone	94
Annex J (informative)	Examples of assessment results	98
J.1	General	98
J.2	Assessment procedure of heavy-duty WPT EV system	98
J.2.1	Outline of assessment procedure	98
J.2.2	Test condition	98
J.2.3	Test result 1	99
J.2.4	Test result 2	99
J.3	Drone	100
J.3.1	Introduction	100
J.3.2	Description of WPT system for drone	100
J.3.3	Measurement of magnetic field around the WPT system for drone	100
J.3.4	Modelling for the WPT system for drone	101
J.3.5	Evaluation of incident field against basic restrictions	102
J.3.6	Evaluation of current density, internal electric field, and SAR against basic restrictions	104
J.4	Combined method of experimental and numerical analysis	105
J.4.1	General	105
J.4.2	Measurement of magnetic field	105
J.4.3	Numerical analyses of induced quantities	106
J.4.4	Example of exposure assessment for WPT systems using combined method	106
J.5	SAR measurement for WPT system	110

Annex K (informative) Proximity detection sensor considerations for compliance assessment	112
K.1 Proximity detection sensor considerations	112
K.1.1 General	112
K.1.2 Phantom definition	112
K.1.3 Test preparation	112
K.1.4 Procedures for determining stationary living objects	113
K.1.5 Procedures for determining proximity detection sensor triggering distance	114
Bibliography	115
Figure 1 – Flowchart for the assessment procedure	16
Figure 2 – Flowchart for the assessment procedure considering the direct effect	17
Figure 3 – Trend of the approximation formulas as a function of the gradient [10]	22
Figure 4 – Two exposure situations for ungrounded and grounded metal objects	23
Figure 5 – Flowchart for assessment procedures for indirect effects	23
Figure 6 – Human body equivalent circuit proposed in IEC 60990 [23]	28
Figure 7 – Impedance frequency characteristics of adult male and equivalent circuits proposed in IEC 60990 [23] and evaluated values [24], [25], [26], [27]	28
Figure 8 – Example of contact current measurement equipment	29
Figure B.1 – H-field and E-field generation setup for probe calibration	41
Figure B.2 – H-field generation setup for dynamic range calibration	42
Figure B.3 – E-field generation setup for frequency response calibration	44
Figure B.4 – E-field generation setup for dynamic range calibration	45
Figure B.5 – Illustration of the transmit antenna factor evaluation setup [38]	51
Figure B.6 – Illustration of the sensitivity coefficients evaluation setup [38]	52
Figure C.1 – A recommended magnetic and electric field setup for measurement system verification and validation	54
Figure D.1 – Simulation model of large WPT system operating close to a) elliptical phantom and b) human body model	56
Figure D.2 – Different exposure conditions for human body model	56
Figure D.3 – Calculated SAR for circular coils with a 50 cm diameter operating at 6 cm from the elliptical phantom and heterogeneous human model	57
Figure D.4 – Simulation model of small WPT system operating close to a) elliptical phantom and b) human body model	57
Figure D.5 – Calculated SAR for the small squared coils with dimensions 10 cm × 10 cm operating at 2 cm from the elliptical phantom and heterogeneous human model	58
Figure D.6 – Layout of large WPT system for exposure condition of a) case A and b) case C with respect to the elliptical phantom surface	59
Figure D.7 – Calculated 10 g-averaged SAR versus the smaller axis of elliptical phantom v normalized by coil outer diameter D for a) case A ($f_{\text{high}} = 7,54$ MHz) and b) case C ($f_{\text{low}} = 6,14$ MHz, $f_{\text{high}} = 7,18$ MHz)	59
Figure D.8 – Layout of small WPT system for exposure conditions of case C with respect to a) elliptical phantom and b) rectangular phantom	60
Figure D.9 – Calculated 10 g-averaged SAR versus the smaller axis v or width W normalized by square coil diagonal K for a) elliptical phantom ($f_{\text{low}} = 6,6$ MHz, $f_{\text{high}} = 7,64$ MHz) and b) rectangular phantom ($f_{\text{low}} = 6,59$ MHz)	60

Figure E.1 – Schematic diagram of measurement system	63
Figure E.2 – Measurement system	63
Figure E.3 – Measured and simulated electric field distributions in the measurement plane 2,5 cm away from the phantom boundary in the case of the solenoid-type WPT system	63
Figure E.4 – Measured and simulated electric field distributions in the measurement plane 2,5 cm away from the phantom boundary in the case of the flat-spiral-type WPT system	64
Figure E.5 – 10 g averaged SAR obtained by measurement with extrapolation and MoM-derived 10 g averaged SAR	64
Figure G.1 – Field components on voxel edges	71
Figure I.1 – Example for areas of protection, for ground mounted systems (vehicle) [61]	80
Figure I.2 – Example for areas of protection, for ground mounted systems (using vehicle mimic plate)	81
Figure I.3 – Flowchart for EV and vehicle mimic plate assessment (direct effect)	82
Figure I.4 – Area 2 measurement position (SWPT)	83
Figure I.5 – Area 3 measurement position	84
Figure I.6 – Area 2 measurement position of vehicle mimic plate (SWPT)	85
Figure I.7 – Area 2 measurement position of vehicle mimic plate (SWPT)	85
Figure I.8 – Flowchart for EV use and vehicle mimic plate assessment (indirect effect)	87
Figure I.9 – Configuration example of contact current with grounded condition: (1) with vehicle	88
Figure I.10 – Configuration example of contact current with grounded condition: (2) with vehicle mimic plate	89
Figure I.11 – Configuration example of contact current with ungrounded condition: (1) with vehicle	90
Figure I.12 – Configuration example of contact current with ungrounded condition: (2) with vehicle mimic plate	91
Figure I.13 – EMF measurement for heavy duty vehicle: top view	92
Figure I.14 – EMF measurement for heavy duty vehicle: side view	92
Figure I.15 – Measurement points on the inside floor of WPT bus	94
Figure I.16 – Measurement position	95
Figure J.1 – EMF test of an electrical bus (August 7, 2015, Sejong City)	98
Figure J.2 – Test result 1 from side-view	99
Figure J.3 – Test result 2 on separation distance from bus surface	99
Figure J.4 – Geometry and measurement position of WPT system for drone	101
Figure J.5 – Measured magnetic field strength	101
Figure J.6 – Measured and computed magnetic field strength	102
Figure J.7 – Measurement system for the magnetic near-field of WPT systems [33]	106
Figure J.8 – Schematic view and picture of the fabricated magnetic-field probes [33]	106
Figure J.9 – Schematic view (left) and picture (right) of WPT systems [33]	107
Figure J.10 – Exposure conditions for WPT coils [33]	108
Figure J.11 – Amplitude and phase distributions of magnetic fields measured near WPT systems without and with ferrite tiles [33]	109
Figure J.12 – Distribution of the internal electric field strength with adult male model for an input power of 7,7 kW [33]	109
Figure J.13 – WPT system operating at 6,78 MHz	110

Figure J.14 – SAR distribution on a plane at 25 mm from the bottom of the phantom	111
Figure K.1 – Test side consideration drawing.....	113
Figure K.2 – Positioning of the phantom and the DUT WPT for determining the detection sensor triggering distance, an example of charging an electric vehicle with a WPT system	113
Table 1 – Dielectric properties of the tissue equivalent liquid as specified in IEC/IEEE 62209-1528	27
Table 2 – Dielectric properties of the tissue equivalent NaCl solution of 0,074 mol/L	27
Table 3 – Computational methods.....	30
Table 4 – Example of uncertainty evaluation of the exposure assessment using measurement methods.....	33
Table 5 – Example of uncertainty evaluation of numerical methods.....	34
Table 6 – Example of uncertainty evaluation of the exposure assessment combining measurements and numerical methods	35
Table B.1 – EM field generation setups for probe and sensor calibrations.....	39
Table B.2 – Main components of H-field and E-field generation setup for frequency response calibration.....	41
Table B.3 – Template for uncertainty in frequency response calibration	42
Table B.4 – Main components of H-field generation setup for dynamic range calibration.....	43
Table B.5 – Template for uncertainty in H-field dynamic range calibration.....	43
Table B.6 – Main components of E-field generation setup for frequency response calibration.....	44
Table B.7 – Template for uncertainty in E-field frequency response calibration	45
Table B.8 – Main components of E-field generation setup for dynamic range calibration	46
Table B.9 – Template for uncertainty in E-field frequency response calibration	47
Table B.10 – Template for uncertainty in H-field dynamic range calibration.....	49
Table B.11 – Uncertainty template for evaluation of average electric field produced by short dipole antenna via transmit antenna factor	52
Table E.1 – Measurement uncertainty of 10 g averaged SAR.....	65
Table H.1 – Interpolation and superposition of vector field components; maximum permissible deviation from the reference results is $\pm 1,0$ %	76
Table J.1 – Computed coupling factor k_L	103
Table J.2 – Evaluation results using coupling factor k_L	103
Table J.3 – Evaluation results using coupling factor k_G	104
Table J.4 – Numerical computation results of current density (J), internal electric field (E), and spatial peak 10 g average SAR ($SAR_{10\text{ g}}$).....	105

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ASSESSMENT METHODS OF THE HUMAN EXPOSURE TO ELECTRIC AND MAGNETIC FIELDS FROM WIRELESS POWER TRANSFER SYSTEMS – MODELS, INSTRUMENTATION, MEASUREMENT AND NUMERICAL METHODS AND PROCEDURES (FREQUENCY RANGE OF 1 kHz TO 30 MHz)

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. IEC collaborates closely with the International Organization for Standardization (ISO) 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.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC 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 transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is 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 its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees 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 Publication or any other IEC 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 Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

A PAS is an intermediate specification made available to the public and needing a lower level of consensus than an International Standard to be approved by vote (simple majority).

IEC PAS 63184 has been processed by IEC technical committee 106: Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure.

The text of this PAS is based on the following document:

This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document

Draft PAS	Report on voting
106/529/DPAS	106/532/RVDPAS

Following publication of this PAS, which is a pre-standard publication, the technical committee or subcommittee concerned may transform it into an International Standard.

This PAS shall remain valid for an initial maximum period of 2 years starting from the publication date. The validity may be extended for a single period up to a maximum of 2 years, at the end of which it shall be published as another type of normative document, or shall be withdrawn.

IMPORTANT – The "colour inside" logo on the cover page of this document 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

The scope of this document falls under the IEC work item "development of standard for measurement and calculation methods used to assess human exposure to electric, magnetic and electromagnetic fields." Wireless power transfer (WPT) is the transmission of electrical power from a transmitter to a receiver without current-carrying wires. This technology is increasingly being implemented in a wide range of applications at different frequency ranges from consumer electronics (e.g. mobile phones, tablet PCs) to automotive (electric vehicles (EVs)). The human exposure is limited to avoid hazardous nerve effects (< 10 MHz) and thermal effects (> 100 kHz). An ITU-R published report (ITU-R SM. 2303-1) from June 2015 on WPT systems describes RF exposure assessment methodologies, yet no definitive assessment method was introduced. An exposure assessment method of WPT for EV was described in IEC 61980-3:2019, however, there is currently no other product standard related to WPT. As WPT systems will become ubiquitous in a multitude of applications in the near future, IEC and IEEE established a joint working group to address WPT assessment methods related to human exposures to electric, magnetic and electromagnetic fields.

In this document, IEC TC 106 describes the basic methods to assess the direct and indirect effects of exposure to WPT systems, case studies, and relevant research. These methods mainly focus on frequency up to 30 MHz to consider both stimulation and thermal effects. The document specifies:

- assessment procedures (Clause 5);
- measurement methods (Clause 6);
- numerical assessment methods (Clause 7);
- assessment combining measurement and numerical methods (Clause 8).

ASSESSMENT METHODS OF THE HUMAN EXPOSURE TO ELECTRIC AND MAGNETIC FIELDS FROM WIRELESS POWER TRANSFER SYSTEMS – MODELS, INSTRUMENTATION, MEASUREMENT AND NUMERICAL METHODS AND PROCEDURES (FREQUENCY RANGE OF 1 kHz TO 30 MHz)

1 Scope

The objective of this document is to specify the assessment methods to evaluate compliance of stationary and dynamic wireless power transfer (WPT) systems with electromagnetic human exposure guidelines (external electric and magnetic fields, specific absorption rate (SAR), internal electric fields or current density including contact currents). The frequency range of this document is from 1 kHz to 30 MHz.

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* (available at <http://www.electropedia.org>)

ISO/IEC Guide 98-1:2009, *Uncertainty of measurement – Part 1: Introduction to the expression of uncertainty in measurement*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

IEC 61786-1:2013, *Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part 1: Requirements for measuring instruments*

IEC 61786-2:2014, *Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part 2: Basic standard for measurements*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>