IEC TR 63377

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TECHNICAL REPORT

colour inside

Procedures for the assessment of human exposure to electromagnetic fields from radiative wireless power transfer systems – Measurement and computational methods (frequency range of 30 MHz to 300 GHz)

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PROCEDURES FOR THE ASSESSMENT OF HUMAN EXPOSURE TO ELECTROMAGNETIC FIELDS FROM RADIATIVE WIRELESS POWER TRANSFER SYSTEMS – MEASUREMENT AND COMPUTATIONAL METHODS (FREQUENCY RANGE OF 30 MHz TO 300 GHz)

FOREWORD

IEC TR 63377 has been prepared by IEC technical committee 106: Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
106/568/DTR	106/578/RVDTR

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 Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has 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

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- withdrawn,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

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

IEC TC 106 is tasked with preparing International Standards on measurement and simulation methods used to assess human exposure to electric fields, magnetic fields, and electromagnetic fields. Wireless power transfer (WPT) systems operating at 30 MHz to 300 GHz utilize electric fields, magnetic fields, or electromagnetic fields to provide power to equipment nearby or at distances up to several metres or more. Users or bystanders in close proximity to both the transmitting equipment and receiving equipment or in between them could be exposed to these fields. Assessment methods are needed to demonstrate compliance with applicable human exposure limits. A working group (WG9) was established by IEC TC 106 to address assessment methods of human exposure to WPT equipment.

This document consists of an overview of radiative WPT, exposure assessment methods, procedures, and case studies, to help in the development of international standards for WPT exposure assessment. This document addresses the frequency range of 30 MHz to 300 GHz. For lower frequencies, WPT equipment operating below 10 MHz is covered by IEC TR 62905:2018, and below 30 MHz is covered by IEC PAS 63184:2021, with an associated subsequent International Standard currently under consideration by IEC TC 106. The methods and procedures described in this document are based on the techniques of other exposure standards covering the same frequency range. Other methods are referenced when deviations from these assessment methods are needed.

PROCEDURES FOR THE ASSESSMENT OF HUMAN EXPOSURE TO ELECTROMAGNETIC FIELDS FROM RADIATIVE WIRELESS POWER TRANSFER SYSTEMS – MEASUREMENT AND COMPUTATIONAL METHODS (FREQUENCY RANGE OF 30 MHz TO 300 GHz)

1 Scope

This Technical Report describes assessment methods to evaluate the compliance of radiative wireless power transfer (WPT) systems operating in the frequency range from 30 MHz to 300 GHz with electromagnetic guidelines on human exposure (electromagnetic field strength, specific absorption rate (SAR), and power density). This document includes but is not limited to systems that focus the electromagnetic energy emitted by the transmitter to regions surrounding the receiver, for example, by narrow beam-forming systems, wide-beam systems and spatially closed systems. Implementations without transmitter, for example, applications that harvest energy from the environment, are not included in the scope of this document.

2 Normative references

There are no normative references in this document.

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

3.1
basic restriction
BR
human exposure limits for compliance with time-varying electric, magnetic, and electromagnetic fields evaluated inside the body that are based on established adverse health effects

Note 1 to entry: Within the scope of this document, the physical quantity used as a basic restriction is the specific absorption rate (SAR) or absorbed (epithelial) power density.

3.2
equipment under test
EUT
equipment that is tested according to the procedures described in this document

3.3
plane-wave equivalent power density
electromagnetic wave, magnitude of the power density of a plane wave having the same ratio of electric (E) field strength to magnetic (H) field strength

Note 1 to entry: The SI unit of plane-wave equivalent power density is watt per square metre (W/m^2).

3.4
exposure
<for a person> situation that occurs wherever a person is subjected to electric, magnetic, or electromagnetic fields

3.5
far-field region
<of an antenna> region of the electromagnetic field of an antenna wherein the predominant components of the field are those which represent a propagation of energy and wherein the angular field distribution is essentially independent of the distance from the antenna

[SOURCE: IEC 60050-712:1992 [1], 712-02-02, modified – Hyphen added to the term, notes to entry omitted.]

3.6
incident field
field that would exist in the absence of a person over a volume where a person could be located

Note 1 to entry: In some documents, the incident field is called an unperturbed field or environmental field.

3.7
reactive near-field region
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 the electric field and magnetic field components are 90° out of phase

[SOURCE: IEC/IEEE 63195-1:2022 [2], 3.2.10, modified – The word "region" has been added to the term.]

3.8
peak spatial-average SAR
psSAR
maximum SAR averaged within a local region based on a specific averaging mass, e.g. any 1 g or 10 g of tissue in the shape of a cube

[SOURCE: IEC/IEEE 62209-1528:2020 [3], 3.37, modified – The note to entry has been omitted.]

3.9
phantom
physical model with an equivalent human anatomy and comprised of a tissue-equivalent medium with dielectric properties specified in IEC/IEEE 62209-1528:2020

[SOURCE IEC/IEEE 62209-1528 [3], 3.39, modified – The wording "in this document" is replaced with "IEC/IEEE 62209-1528:2020".]

3.10
radiative wireless power transfer system
radiative WPT system
system that transfers power by radiation of electromagnetic energy from a transmitter to a receiver in the frequency range from 30 MHz to 300 GHz

3.11
reference level
RL
level of field strength or power density derived from the basic restrictions using conservative assumptions about exposure

Note 1 to entry: If the reference levels are met, then the basic restrictions will be complied with, but if the reference levels are exceeded, that does not necessarily mean that the basic restrictions will not be met.

[SOURCE IEC 62311:2019 [4], 3.1.22, modified – Abbreviated term "RL" added.]

3.12
specific absorption rate
SAR
measure of the rate at which energy is absorbed by the human body when exposed to a radio frequency electromagnetic field

Note 1 to entry: The SAR in the tissue-equivalent medium can be determined by the rate of temperature increase or by E-field measurements, according to the following formula:

$$SAR = \frac{\sigma E^2}{\rho} = c_\mathrm{h} \left.\frac{\partial T}{\partial t}\right|_{t=0}$$

where

SAR	is the specific absorption rate in W/kg;
E	is the RMS value of the electric field strength in the tissue-equivalent medium in V/m;
σ	is the electrical conductivity of the tissue-equivalent medium in S/m;
ρ	is the mass density of the tissue-equivalent medium in kg/m^3;
c_h	is the specific heat capacity of the tissue-equivalent medium in J/(kg K);
$\left.\frac{\partial T}{\partial t}\right\|_{t=0}$	is the initial time derivative of temperature in the tissue-equivalent medium in K/s.

[SOURCE IEC/IEEE 62209-1528:2020 [3], 3.5.1, modified – The two formulae now appear on one line and units have been formatted as symbols rather than as written words.]

3.13
beamwidth
<of an antenna> in a specified plane containing the direction of maximum radiation or the axis of symmetry of a beam or a radiation lobe, angle between two directions (corresponding, for example, to a given fraction of the maximum radiation or to the first minimums) on both sides of this direction or axis

Note 1 to entry: The most generally used fraction is half-power beamwidth.

[SOURCE IEC 60050-712:2021 [1], 712-01-33, modified – Note 2 to entry omitted.]

3.14
whole-body SAR
wbSAR
SAR averaged over the whole body

3.15
epithelial power density
power flow through the epithelium per unit area directly under the body surface

[SOURCE IEEE Std C95.1™-2019 [5], 3.1, modified – Note 1 and Note 2 omitted.]

4 Symbols and abbreviated terms

4.1 Physical quantities

The internationally accepted SI units are used throughout this document.

Symbol	Quantity	Unit	Dimensions
c_h	Specific heat capacity	joule per kilogram per kelvin	J/(kg K)
E	Electric field strength	volt per metre, RMS	V/m
f	Frequency	hertz	Hz
H	Magnetic field strength	ampere per metre, RMS	A/m
J	Current density	ampere per square metre	A/m^2
P	Average (temporal) absorbed power	watt	W
S	Power density	watt per square metre	W/m^2
T	Temperature	kelvin	K
ε	Permittivity	farad per metre	F/m
λ	Wavelength	metre	m
σ	Electric conductivity	siemens per metre	S/m
μ	Permeability	Henrys per metre	H/m

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

4.2 Constants

Symbol	Physical constant	Magnitude
η_0	Intrinsic impedance of free space	120π Ω or 377 Ω
ε_0	Permittivity of free space	8,854 × 10^{-12} F/m
μ_0	Permeability of free space	4π × 10^{-7} H/m

4.3 Abbreviated terms

RF	radio frequency
RMS	root mean square
RSS	root sum square
CW	continuous wave
WPT	wireless power transfer
DRL	dosimetric reference limit
E-field	electric field strength
ERL	exposure reference level
EUT	equipment under test
H-field	magnetic field strength
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IC	integrated circuit
PD	power density
TE	transverse electric
TM	transverse magnetic
TEM	transverse electromagnetic

5 Description of radiative wireless power transfer systems

5.1 General

Radiative WPT represents a solution to remotely charge low-power devices (e.g. sensors, RF identification tags, mobile and wearable devices [6][1], [7]) and high power applications [8] over large distances.

Radiative WPT allows for greater distances to be covered than non-radiative WPT and does not require mutual coupling between the transmitter and receiver. However, the longer distances generally result in lower beam efficiency at the receiving end.

In a radiative WPT system, highly directional antennas are mostly used to transmit electromagnetic power and the system efficiency benefits from a highly directive receiver antenna when operated outside the near-field zone. The main theory of WPT via RF beam is based on the Friis transmission formula:

$$\frac{P_\mathrm{r}}{P_\mathrm{t}} = G_\mathrm{r} G_\mathrm{t} \left(\frac{\lambda}{4\pi R} \right)^2 \quad (1)$$

where

P_r and P_t are the receive power and transmit power, respectively,

G_t and G_r are the gains of the transmit antenna and receive antenna,

λ is the wavelength representing the effective aperture area of the receive antenna, and

R is the distance between the two antennas.

A rectenna [9] is normally used to convert the received electromagnetic power into usable direct current (DC) power.

5.2 Radiative WPT systems technology and applications

5.2.1 General

Radiative WPT systems can be classified according to the following list of technologies, and as shown in Figure 1:

a) wide beamwidth transmission to multiple receivers at short range;

b) space diversity WPT to a single receiver (using multi-path propagation);

c) narrow beamwidth transmission to a single receiver at either short or long range [10].

NOTE Narrow beamwidth and space diversity systems apply directed beams in order to maximize efficiency of the transmitted power towards a single receiver. Directive antennas can be used on the transmitter and/or the receiver side. Wide beamwidth systems transmit power to multiple receivers and might not necessarily direct the transmitted power towards them. Because of the large number of possible configurations of transmitter and receiver antennas, a more detailed specification of wide and narrow beamwidth systems might be too restrictive for present and upcoming technologies.

Each of the technologies in the preceding list can be used in different WPT applications (Table 1). A detailed description of these WPT applications can be found in [10].

Energy harvesting is another wireless power technology that converts environmental electromagnetic energy into electric power. Due to its typically low conversion efficiency and low collection of power, it can be adequate to run or recharge small wireless micropower devices

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

such as remote sensors. It does not include a transmitter for the RF power and therefore does not fall under the scope of this document.

Table 1 – Representative characteristics of potential radiative WPT applications

WPT application	Frequency band	Condition	Distance	Tx antenna gain	Transmit power
Wirelessly powered sensor network	915 MHz band, 2,45 GHz band, 5,8 GHz band	Indoor, Outdoor	Several metres to dozens of metres	6 dBi (Typically 915 MHz band), 25 dBi (Typically 2,45 GHz and 5,8 GHz bands)	< 50 W
Wireless charging of mobile devices	2,45 GHz band, 915 MHz band	Indoor	Several metres to dozens of metres	25 dBi (Typically 2,45 GHz band)	< 50 W
WPT to moving/flying target	2,45 GHz band, 5,8 GHz band	Indoor, Outdoor	several metres to 20 km	10 dBi to 30 dBi (Typically 5,8 GHz band)	50 W to 1 MW
Point-to-point WPT	2,45 GHz band, 5,8 GHz band	Outdoor	1 m to 20 km		100 W to 1 MW
Wireless charging for electric vehicle	2,45 GHz band, 5,8 GHz band	Outdoor	0,1 m to 1 m		100 kW to 500 kW
Solar power satellite	5,8 GHz band	Space to ground	36 000 km		1,3 GW
IoT devices, automation, point-to-point, etc.	24 GHz band, 61 GHz band, 122 GHz band, 244 GHz band	Indoor, Outdoor	1 m to 1 000 m		100 W