



Report ITU-R SM.2452-1
(07/2022)

Electromagnetic field measurements to assess human exposure

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***Note:** This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R SM.2452-1

Electromagnetic field measurements to assess human exposure

(2019-2022)

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1 Introduction

The proliferation of wireless installations of all types around the world obligates careful measurements. This concern is reflected in Question ITU-R 239/1 “Electromagnetic field measurements to assess human exposure”; ITU Plenipotentiary Resolution 176 (Rev. Dubai, 2018) “Measurement and assessment concerns related to human exposure to electromagnetic fields”; and the ITU Handbook on Spectrum Monitoring (Edition 2011), where section 5.6 details non-ionizing radiation measurements.

The Electromagnetic Field (EMF) exposure limits are implemented at national level, mostly with references to international standards that specify different exposure limits for the general public and for workers accessing areas close to wireless installations.

The International Commission for Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE) are the expert groups for setting the safety exposure levels. Many Administrations have adopted or may at some point adopt these guidelines or modified/updated guidelines based on their own experts’ studies.

Compliance with EMF limits should be assessed considering several aspects:

- The power density and field strength are aggregated from different sources;
- The exposure levels in the proximity of wireless installations may occur in the near-field;
- The exposure levels should be measured in areas accessible to people (workers or the public as appropriate);
- Wireless installations may not transmit with their maximum theoretical power at the time of measurement, and so should be power scaled to reflect their maximal power, when determining compliance;
- There may be a need for measuring the E and the H field separately, especially in the near-field domain, where the relationship between E and H field is very complicated as opposed to the far-field;
- The results of the measurements may be presented in a variety of formats concerning the intended use and potential audience.

Compliance of portable user equipment such as handsets or notebooks intended for use close to the head or body is outside the scope of this Report.

While ICNIRP limits have been established to protect the public, concerns on EMF effects encourage measures in some countries to monitor and control the power density and field strength of the emissions. It is necessary to share good practices in EMF monitoring that guides Administrations to check compliance with the limits established by ICNIRP.

2 Regulatory framework

2.1 ICNIRP 2020 and IEEE 2019 exposure levels around transmitters

2.1.1 Overview

ICNIRP aims to protect people and the environment against adverse effects of non-ionizing radiation (NIR). ICNIRP Guidelines have been widely adopted in standards and regulations around the world; where national limits do not exist, or if they do not cover the frequencies of interest, then ICNIRP limits should be used. Those are the ICNIRP Guidelines:

- ICNIRP (1998): Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz);

- ICNIRP (2010): Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz – 100 kHz);
- ICNIRP (2020): Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz).

The limits below 100 kHz are the ones published in ICNIRP (2010), and, with the publication of the 2020 Guidelines, the 1998 Guidelines have become obsolete. It should be noted, however, that in some regions, standards concerning EMF assessment methods continue referring to basic restrictions, and reference levels in the ICNIRP 1998 Guidelines. Until the relevant standards have been updated, the 1998 Guidelines can still be used as the valid basis for compliance framework.

2.1.2 ICNIRP (2020) Tables and Figures

ICNIRP (2020) Table 5 is the most relevant to Monitoring base-stations. It details reference levels for exposure to RF-EMF, averaged, over 30 minutes and the whole body, from 100 kHz to 300 GHz (unperturbed rms values). The re-elaborated Figures depict the values. **Bolds** indicate the significant parameter. The ICNIRP Table and Figures quantify and depict how the exposure depends on the transmitted frequency. The RF-EMF Reference Levels for the Occupational and General Public whole-body exposures decrease 0.1-30 MHz, stay steady 30-400 MHz, increase again between 400-2 000 MHz and stay steady 2-300 GHz.

TABLE 1

(ICNIRP 2020 Table 5) Reference levels for exposure from 100 kHz to 300 GHz

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m ⁻¹)	Incident H-field strength; H_{inc} (A m ⁻¹)	Incident power density; S_{inc} (W m ⁻²)
Occupational	0.1 – 30 MHz	$660/f_M^{0.7}$	$4.9/f_M$	NA
	>30 – 400 MHz	61	0.16	10
	>400 – 2 000 MHz	$3f_M^{0.5}$	$0.008f_M^{0.5}$	$f_M/40$
	>2 – 300 GHz	NA	NA	50
General public	0.1 – 30 MHz	$300/f_M^{0.7}$	$2.2/f_M$	NA
	>30 – 400 MHz	27.7	0.073	2
	>400 – 2 000 MHz	$1.375f_M^{0.5}$	$0.0037f_M^{0.5}$	$f_M/200$
	>2 – 300 GHz	NA	NA	10

NOTE – ‘NA’ signifies ‘not applicable’; f_M is frequency in MHz.

The following two ICNIRP figures appear in the ‘Differences Between the ICNIRP (2020) and Previous Guidelines’¹. The reference-levels of ICNIRP (2020) stop electric-field at frequencies above 2 000 MHz and start power-density above 30 MHz. The two following Figures² reference for the whole-body average and 30 min time-averaging. Thus, to focus the reader and depict the differences, the titles are simplified, and the titles’ specifics are underlined:

¹ The units of the two y-axes (i.e. electric field and power density) are independent of each other.

² Retrieved on 28 June 2022 from <https://www.icnirp.org/en/differences.html>

FIGURE 1

Comparing general public reference levels for ICNIRP (1998), (2010) and (2020) Guidelines

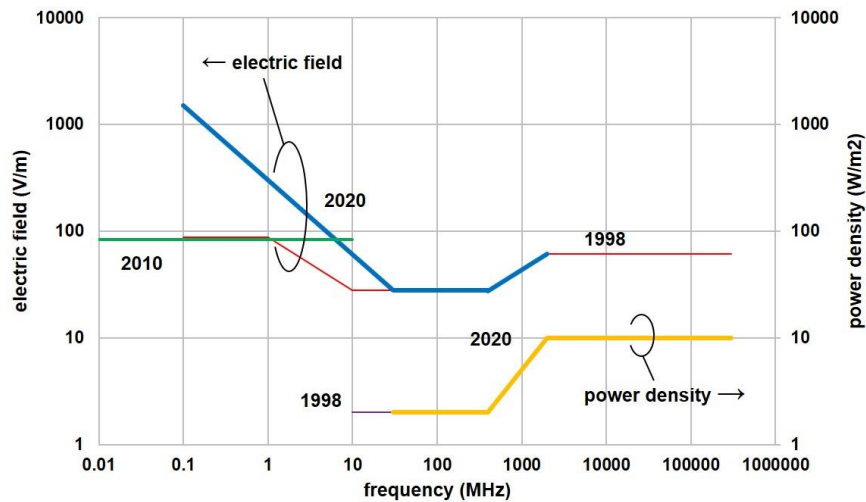
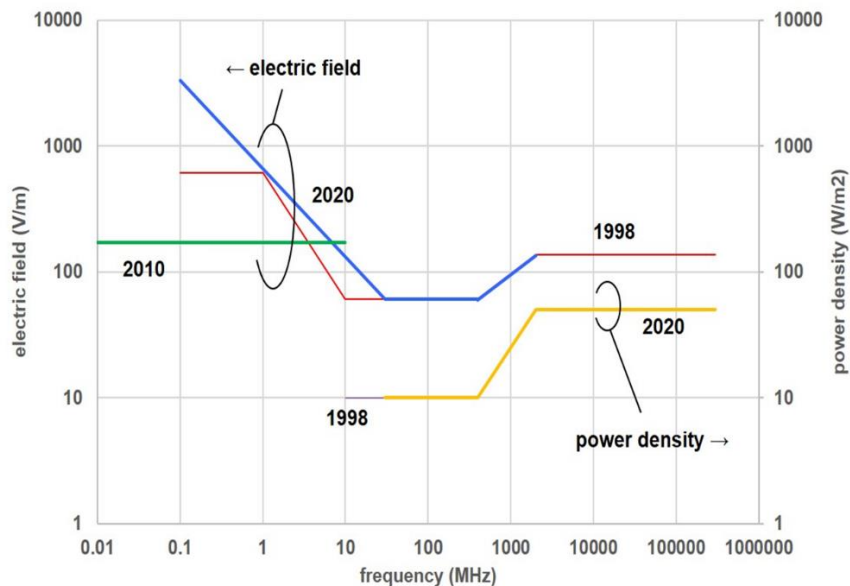


FIGURE 2

Comparing workers reference levels for ICNIRP (1998), (2010) and (2020) Guidelines



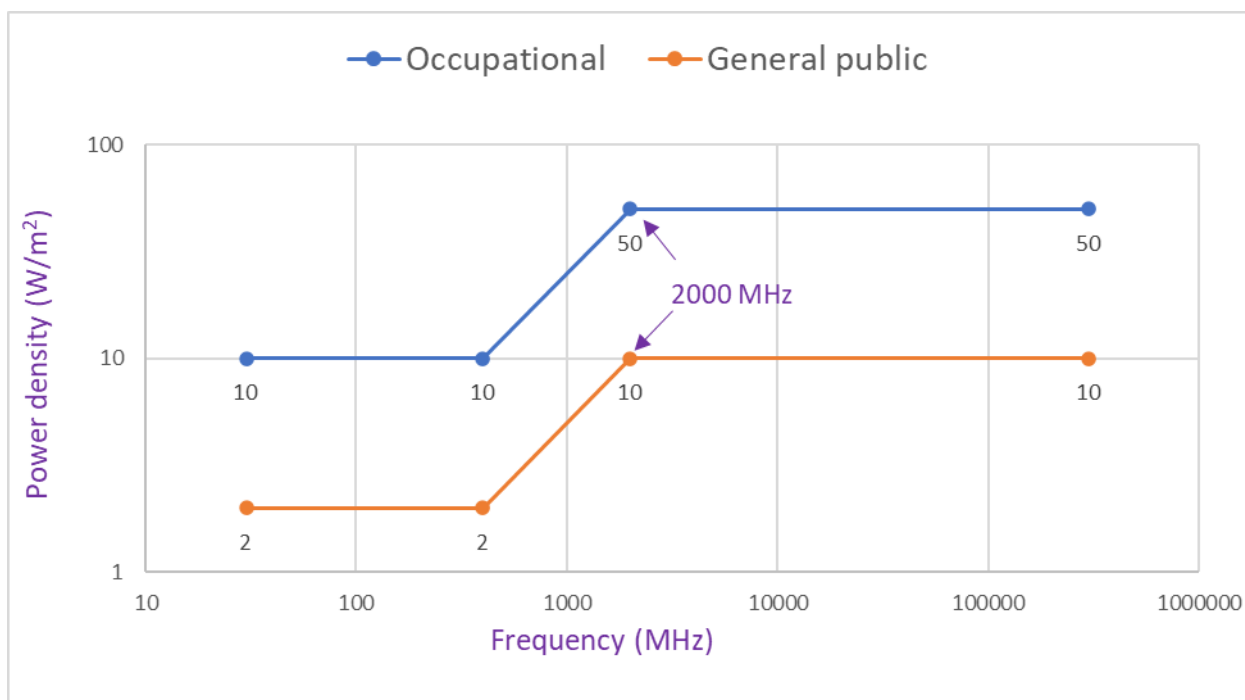
The values in Figs 1 and 2 above represented by the green lines in comparing (2010 reference levels) are included in a separate table in ICNIRP (2020). Table 8 provides reference levels for local exposure for frequencies in the range 100 kHz – 10 MHz. Since these localized values are lower than the whole body values, for frequencies below around 7 MHz, it follows that, in many cases, the higher, whole body reference levels will be relevant only when aggregating the thermal effect from multiple sources.

The following Figure³ depicts the differences between the ICNIRP (2020) field-strength and power-density exposure levels above 30 MHz of occupational and general-public exposure, averaged over

³ Mazar 2016, Wiley ‘[Radio Spectrum Management: Policies, Regulations and Techniques](#)’ revised 2021 [Chapter 9](#) Figure 9.6.

30 min and the whole body. The power-density ratio of 5 in ICNIRP (2020) Table 5 (e.g. at 30-400 MHz, Watts ratio 50/10) results in V/M ratio $61.0/27.7 = 2.2 \sim \sqrt{(5)}$.

FIGURE 3
Comparing ICNIRP (2020) Table 5, power-density 30 MHz– 300 GHz



ICNIRP (2010) and ICNIRP (2020) are based on two different biological mechanisms, and averaging is diverse:

- nerve stimulation- instantaneous below 10 MHz;
- thermal effect, produced by power over time (for frequencies above 100 kHz).

Below 100 kHz, ICNIRP (2010) should be applied. Between 100 kHz and 10 MHz both mechanisms may exist, in that case, restrictions for every frequency should be met simultaneously.

Moreover, ICNIRP (2020) Table 8 states (pay attention to the bold text) “reference levels for **local exposure** to EMFs from 100 kHz to 10 MHz (unperturbed rms values), for **peak values**, the occupational limit is 170 V/m and the general public is 83 V/m.”.

2.1.3 Comparison of ICNIRP (1998), IEEE 95-1 (2019) and ICNIRP (2020)

The ICNIRP Guidelines (1998, and 2020) and the IEEE Standard (2019) separate between persons in unrestricted environments (general public) and persons permitted in restricted environments (occupational). The most relevant to Monitoring base-stations ICNIRP (1998) Tables 6⁴ and 7⁵, IEEE C95.1 (2019) Tables 7⁶ and 8⁷ are compared with ICNIRP (2020) Table 5⁸. The exposure

⁴ Reference levels for occupational exposure to time-varying electric and magnetic fields.

⁵ Reference levels for general public exposure to time-varying electric and magnetic fields.

⁶ Exposure Reference Levels (ERLs) for whole-body exposure of persons in unrestricted environments (100 kHz to 300 GHz).

⁷ ERLs for whole-body exposure of persons permitted in restricted environments (100 kHz to 300 GHz).

⁸ Reference levels for exposure, averaged over 30 min and the whole body, to electromagnetic fields from 100 kHz to 300 GHz.

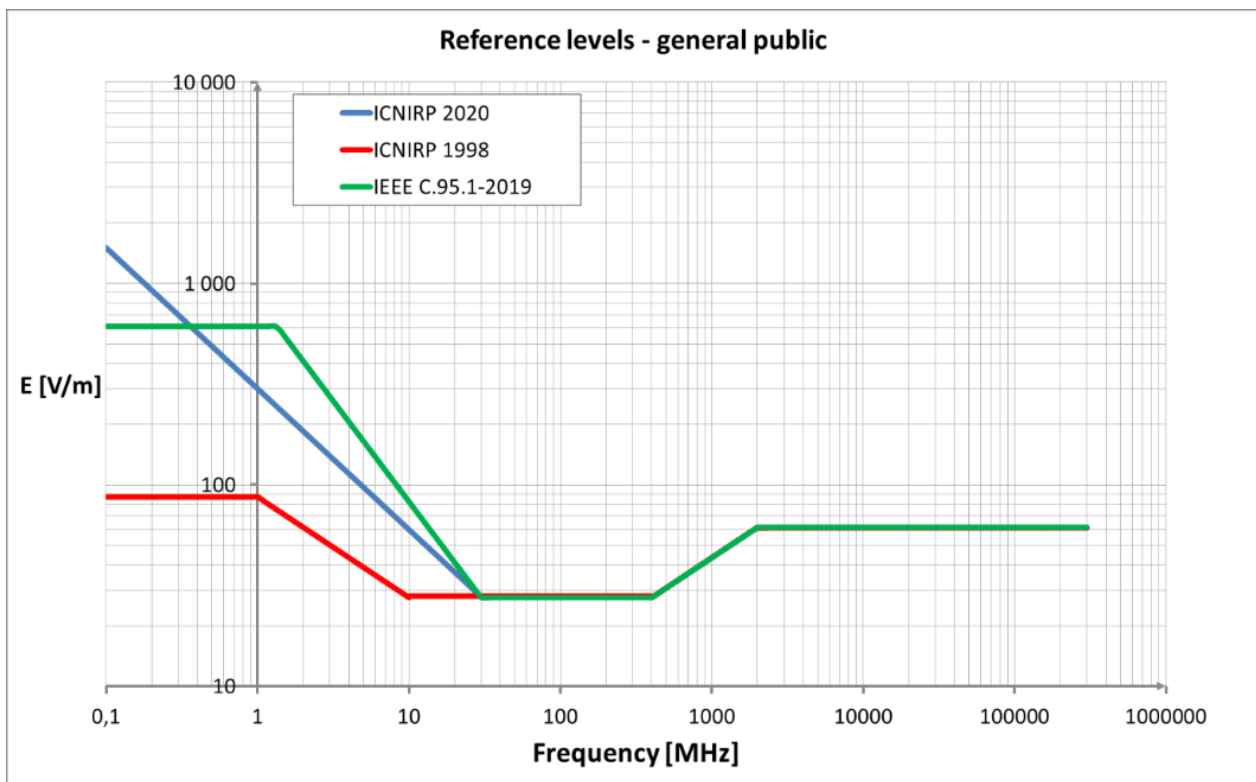
levels of ICNIRP 2020 and the IEEE Standard are largely harmonized, and the power-density limits whole-body levels above 30 MHz are identical!

- Localised SAR limits in the Head/Torso equals 2 W/kg for general-public and 10 W/kg for occupational.
- Whole-body average SAR limit equals 0.08 W/kg for general-public and 0.4 W/kg for occupational.
- Exposure power-density reference-levels equal at:
 - 30 to 400 MHz: 2 W/m² for general-public and 10 W/m² for occupational;
 - 400 to 2 000 MHz: $f_M/200$ W/m² for general-public and $f_M/40$ W/m² for occupational;
 - 2 000 to 300 000 MHz: 10 W/m² for general-public and 50 W/m² for occupational.

Figures 4 to 6 illustrate that IEEE C95.1 (2019) and ICNIRP (2020) Guidelines are **largely harmonized**.

In Fig. 4 (source Dr Lewicki Fryderyk)⁹, note that the ICNIRP (2020) electric field reference-levels for general-public stop at frequencies above 2 000 MHz. Electric-field units and measurements are convenient for administrations to monitor field strengths if needed. As between 100 kHz and 10 MHz, the more stringent value of ICNIRP (2010) or ICNIRP (2020) for every frequency should be followed, below 6.27 MHz the general public limit is 83 V/m.

FIGURE 4
Reference levels- for ICNIRP (1998), IEEE (2019) and ICNIRP (2020) guidelines



⁹ Presentation at the ITU Regional Symposium for Europe and CIS on Spectrum Management and Broadcasting 02 July 2020, Electromagnetic Fields and 5G Implementation.

2.2 Presenting maps of calculated field-strength around transmitters

2.2.1 Definitions, free-space calculation and some assumptions

- p_t : transmitter power (watts)
- g_t : transmitter antenna gain (numeric)
- e.i.r.p.¹⁰: equivalent isotropically radiated power (watts)
- d : distance from transmitter (meter)
- e : electric field-strength Volt/metre (V/M).

For free-space propagation loss, $e = \frac{\sqrt{30 e.i.r.p.}}{d}$ and $d = \frac{\sqrt{30 e.i.r.p.}}{e}$

To exemplify, disregarding buildings and other obstacles, the safety distance for e.i.r.p. 60 kW, under free-space propagation conditions, the safety-contours are 45 m for 30 V/m (general-public exposure reference-level at 482 MHz), and 20 m for 66 V/m (occupational exposure reference-level). Taking into account terrain map and buildings, non-free-space propagation loss, the calculated safety-distances are lower.

In the following simulations, the propagation model takes into account the attenuation due to buildings.

Except for the point to point links, the receiver altitude Above Ground Level (AGL) is assumed at 1.5 m. The Figures depict field-strength values (V/m); for example, at 482 MHz: 5, 15, 30 (the ICNIRP general public reference-level), 45 and 66 (the occupational reference-level) V/m.

The calculations performed are the following:

- 3D: three dimensions coverage on buildings facades is performed for a receiving antenna height varying from 1 m to rooftop. The highest power received on each building is used to provide the field-strength colour to the whole building.
- 2D: two dimensions similar to 3D, but shown in 2D top view.

2.2.2 Calculated field-strength around digital TV (DTV) transmitters

The following analysis refers to UHF Channel 22 (in Region 1):

- 478-486 MHz (centre RF 482 MHz),
- transmitter of 60 000 Watts e.i.r.p.,
- 60 m above ground level.

At 482 MHz the electric field-strength ICNIRP general-public exposure reference-level (see Table 1) equals 30 V/m: $1.375 f^{1/2}$ (MHz) = $1.375 \times 482^{1/2}$. The field strength (V/m) ICNIRP occupational exposure reference-level is 66 V/m: $3 f^{1/2}$ (MHz) = $3 \times 482^{1/2}$.

The following Figure depicts buildings impacted in 3D view.

¹⁰ “The product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna”, ITU Radio Regulations, volume 1 provision No. **1.161**. e.i.r.p. is not necessarily the product of maximum power and maximum gain; it is the power radiated toward the point of investigation. The cellular transmitters are power controlled and they do not transmit all time at maximal level. Near a cellular antenna, below it, the e.i.r.p. is low, as a side lobe in elevation is much attenuated relatively to the antenna main-beam.