International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

K.113
(11/2015)

SERIES K: PROTECTION AGAINST INTERFERENCE

Generation of radio-frequency electromagnetic field level maps

Recommendation ITU-T K.113

ITU-T

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Generation of radio-frequency electromagnetic field level maps

Summary

Recommendation ITU-T K.113 provides guidance on how to make radio-frequency electromagnetic field (RF-EMF) maps for assessing existing exposure levels over large areas of cities or territories and for an appropriate public disclosure of the results, in a simple and understandable way.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T K.113	2015-11-29	5	11.1002/1000/12666

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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Introduction

One of the problems for deployment of telecommunication infrastructure, with regard to public opinion, is the distrust generated by the general population's lack of knowledge of electromagnetic field emissions and their resulting exposure levels.

In some countries, this distrust inhibits the deployment of these critical infrastructures, causing unnecessary tensions among the parties involved: citizens, governments, telecommunication operators.

This Recommendation provides a practical tool for assessing exposure levels in large areas of cities or territories, which complements the simulations, specific measurements and continuous monitoring already being carried out in many countries. (Technical guidance can be found in [ITU-T K.52], [ITU-T K.61], [ITU-T K.70], [ITU-T K.83], [ITU-T K.91] and [ITU-T K.100].) This Recommendation describes methods and tools for the development of the radio-frequency electromagnetic field (RF-EMF) maps.

This Recommendation also describes methods for communicating RF-EMF exposure data in a visual manner, i.e., through exposure maps, that may be better understood by the general public.

Recommendation ITU-T K.113

Generation of radio-frequency electromagnetic field level maps

1 Scope

This Recommendation describes methods and characteristics of the systems used for generating radio-frequency electromagnetic field (RF-EMF) maps to assess and communicate RF-EMF exposure levels that people can expect to find in certain areas.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T K.52] Recommendation ITU-T K.52 (2014), *Guidance on complying with limits for human exposure to electromagnetic fields*.

[ITU-T K.61] Recommendation ITU-T K.61 (2008), *Guidance on measurement and numerical prediction of electromagnetic fields for compliance with human exposure limits for telecommunication installations*.

[ITU-T K.70] Recommendation ITU-T K.70 (2007), *Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations*.

[ITU-T K.83] Recommendation ITU-T K.83 (2011), *Monitoring of electromagnetic field levels*.

[ITU-T K.91] Recommendation ITU-T K.91 (2012), *Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields*.

[ITU-T K.100] Recommendation ITU-T K.100 (2014), *Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service*.

[EN 50383] Cenelec EN 50383 (2010), *Basic standard for the calculation and measurement of electromagnetic field strength and SAR related to human exposure from radio base stations and fixed terminal stations for wireless telecommunication systems (110 MHz – 40 GHz)*.

[EN 50413] Cenelec EN 50413 (2008), *Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz – 300 GHz)*.

[EN 50492] Cenelec EN 50492 (2008), *Basic standard for in-situ measurement of electromagnetic field strength related to human exposure in the vicinity of base stations*.

[IEC 60529] IEC 60529 (1989), *Degrees of protection provided by enclosures (IP Code)*.

[ISO/IEC 17025]	ISO/IEC 17025 (2005), *General requirements for the competence of testing and calibration laboratories*.
[ISO/IEC Guide 98-3]	ISO/IEC Guide 98-3 (2008), *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 averaging time [ITU-T K.52]: Appropriate time period over which exposure is averaged for purposes of determining compliance with the set limits.

3.1.2 electric field strength (*E*) [ITU-T K.83]: Magnitude of a field vector at a point that represents the force (F) on a small test charge (q) divided by the charge:

$$E = F/q$$

The electric field strength is expressed in units of volts per metre (V/m).

3.1.3 exposure [ITU-T K.83]: Exposure occurs whenever a person is exposed to electric, magnetic or electromagnetic fields.

3.1.4 far-field region [ITU-T K.83]: Region of the field of an antenna where the radial field distribution is essentially dependent inversely on the distance from the antenna. In this region, the field has a predominantly plane-wave character, i.e., locally uniform distribution of electric field and magnetic field in planes transverse to the direction of propagation.

NOTE – In the far-field region, the vectors of the electric field $\boldsymbol{E}$ and the magnetic field $\boldsymbol{H}$ are perpendicular to each other, and the quotient between the value of the electric field strength E and the magnetic field strength H is constant and equals the impedance of free space Z_0.

3.1.5 IP (ingress or international protection) [IEC 60529]: The IP Code, International Protection Marking, sometimes interpreted as Ingress Protection Marking, classifies and rates the degree of protection provided against intrusion (body parts such as hands and fingers), dust, accidental contact, and water by mechanical casings and electrical enclosures.

3.1.6 linearity [ITU-T K.83]: Maximum deviation over the measurement range of the measured quantity from the closest linear reference curve defined over the range.

3.1.7 magnetic field strength (*H*) [ITU-T K.83]: The magnitude of a field vector at a point that results in a force (F) on a charge q moving with the velocity v:

$$F = q(v \cdot \mu H)$$

The magnetic field strength is expressed in units of amperes per metre (A/m).

3.1.8 near-field region [ITU-T K.83]: Region generally in proximity to an antenna or other radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave character, but vary considerably from point to point. The near-field region is further subdivided into the reactive near-field region, which is closest to the radiating structure and that contains most or nearly all of the stored energy, and the radiating near-field region where the radiation field predominates over the reactive field, but lacks substantial plane-wave character and is complex in structure.

3.1.9 power density (*S*) [ITU-T K.83]: Radiant power incident perpendicular to a surface, divided by the area of the surface.

The power density is expressed in units of watt per square metre (W/m²).

3.1.10 root mean square (rms) [ITU-T K.83]: Effective value or rms value obtained by taking the square root of the average of the square of the value of the periodic function taken throughout one period.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 measurement period: Time between the beginning of a measurement and the start of the next measurement.

3.2.2 measurement time: Time that the measuring equipment needs to perform each measurement, i.e., to take each sample.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CW Continuous Wave

EMF Electromagnetic Field

GPS Global Positioning System

RF Radio-Frequency

RF-EMF Radio-Frequency Electromagnetic Field

rms root mean square

5 Conventions

5.1 Physical quantities, units and constants

The following physical quantities, units and constants, based on international system of units (SI), are used throughout this Recommendation.

Quantity	***Symbol***	***Unit***	***Unit symbol***
Current density	J	ampere per square meter	A/m^2
Electric field strength	E	volt per meter	V/m
Electric flux density	D	coulomb per square meter	C/m^2
Frequency	f	hertz	Hz
Magnetic field strength	H	ampere per meter	A/m
Magnetic flux density	B	tesla (Vs/m^2)	T
Permeability	μ	henries per meter	H/m
Permittivity	ε	farads per meter	F/m
Wavelength	λ	meter	m
Physical constant		***Value***	
Speed of light in a vacuum	c	2.997×10^8 m/s	
Permittivity of free space	ε_0	8.854×10^{-12} F/m	
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ H/m	

6 Methods

Three possible methods to generate RF-EMF maps are described in clauses 7.1 to 7.3; however, other methods providing similar information may also be used.

6.1 Drive test measurements

RF-EMF maps can be generated according to the drive test method, which is widely known in the telecommunication sector, as it is regularly employed to assess coverage and other related telecommunication network parameters.

The drive test method consists of continuously collecting metrics from a moving vehicle. This method requires the installation of the measuring instruments on a vehicle. It is also imperative to include global positioning system (GPS) equipment to enable geographical and simultaneous positioning of the measurements. In this approach, the measurement equipment may also respond to up-link radio-frequency (RF) signals from mobile phones and other radio transmitters. Unless frequency-selective measurements are taken, measurement staff should not use mobile phones and other radio transmitters.

Using this method, the following data may be obtained for each point:

[GPS position] [date/time] [sample value]

Since the measurements are taken on the move, the measurement time (or integration time) of the equipment used should be taken into account (see the definition for measurement time in clause 3.2.2). Samples (measurements) must be completed within a distance of 5 m for urban areas and within 10 m for non-urban areas. Therefore, the maximum allowed speed of the vehicle must be calculated according to the measurement time of the equipment being used.

Example 1: measuring equipment with measurement time of 300 ms:

– if moving at 50 km/h, it will require 4.2 m for each sample to be taken;
– the maximum speed would be 60 km/h in order to stay within the 5 m distance between samples (urban area).

Example 2: measuring equipment with a measurement time of 1 s:

– the maximum speed to stay within the limit of 5 m between samples is 18 km/h (urban areas);
– the maximum speed to stay within the limit of 10 m between samples is 36 km/h (non-urban areas).

Given that most common GPS devices provide position information every second, a measurement period of 1 s is recommended (see the definition for measurement period in clause 3.2.1).

In any case, speed requires adaptation to the state of the road, since measurement sensors can generate erroneous readings due to sudden movements in the presence of static fields.

The movement of the vehicle does not permit measurements to be taken over an average time of six minutes, as recommended by [b-ICNIRP 1998] and other national and international organizations. However, it does give an approximation of the RF-EMF levels over large areas that otherwise would be impossible to cover. To overcome this limitation, the vehicle should stop at least every hour to get a statistically valid sample of specific averaged measurements to be taken as reference. These samples of averaged measurements are compared with the measurements taken in motion, to ensure that the order of magnitude is similar. In all cases, the system checks that all measurements taken in motion are at least 6 dB below the most restrictive limit of the entire frequency band being measured with the probe. If the value of any measurement is above this threshold, the measuring equipment is moved to that point to perform specific 6-minute averaged measurements of the unperturbed root mean square (rms) field (with a non-conductive tripod and the operator keeping an appropriate distance).

Example:

– probe for measuring electromagnetic fields (EMFs) in the frequency range 100 kHz – 3 GHz (see clause 8);
– most restrictive reference level for general public in this band according to [b-ICNIRP 1998]: 28 V/m (or 2 W/m^2);
– acceptance threshold (6 dB under the most restrictive limit): 14 V/m (0.5 W/m^2).

Therefore, when measuring in the 100 kHz – 3 GHz band, all values below the acceptance threshold are considered adequate, and values above the acceptance threshold are specifically re-measured with a 6-minute average.

6.2 Theoretical calculations

Alternatively, RF-EMF maps can be constructed by theoretical calculations. In this case, it is essential to carry out periodic tests in a representative sample of locations averaged over six minutes, or demonstrate through other techniques that calculated values are representative of actual measured levels. Technical guidance can be found in [ITU-T K.61], [ITU-T K.70], [ITU-T K.91] and [ITU-T K.100].

Check that the calculated levels do not underestimate the measurement levels, taking into account environmental and others factors (e.g., call traffic on mobile networks).

6.3 Grid method

Measurements may be taken in cities using the following procedure:

– check the geographic size of the city;
– build a grid on a map of the city forming boxes of no more than 500 m on each side (considering that a base station has coverage averages between 1 and 2 km); a 500 m measurement permits representative samples to be taken of all stations in all four directions. In a dense urban area, the coverage radius of the base station may be much less than 1 km;
– take the coordinates of the spots located at the vertices of the grid;
– at each vertex on the grid, measure the RF-EMFs. Time averaging over periods less than six minutes may be acceptable (in accordance with [ITU-T K.100]). Whenever the measurement is generated with a longer period, both the amount of information and the time spent to acquire it increase the amount of resources used in generating the RF-EMF map;
– for vertices at which the value set as a limit is exceeded, the individual in charge must check both the spot and the surroundings, meeting the recommendations of [b-ICNIRP 1998] and [b-ICNIRP 2010] or the national limits and the specific measuring methodology already established in [ITU-T K.52] and [ITU-T K.61].

Mobile phones should not be used by measurement staff during a measurement.

With the information obtained from each of the measured vertices (geographic coordinates, date/time, the average value of the taken sample), the results should be plotted on the corresponding RF-EMF level maps.

6.4 Combined method

A method that combines two or three of the methods in clauses 7.1 to 7.3 or any other appropriate technique may also be applied. For example, a combined method could use theoretical calculations in some areas and drive tests in others.

6.5 Discrepancies between results

Regardless of the method, if there is discrepancy between results, data obtained through averaged measurements over six minutes (either with broadband or frequency selective equipment) are to prevail.

7 Specifications of the equipment to be used

7.1 Equipment for the drive test

The system to be installed in the vehicle consists of four main parts:

1) electromagnetic isotropic field probe;
2) data acquisition electronics;
3) GPS;
4) protection of measurement equipment from environmental conditions (see clause 7.1.4);
5) optional: laptop.

7.1.1 Electromagnetic field probe

Every time a sample is taken, the full value of the electric field strength (*E*) should be obtained. In order to avoid errors, the reading of the three axes of the broadband isotropic field probe (composed of *E* or *H* antennas) should preferably be simultaneous.

The frequency band of the probe should be appropriate for the frequencies to be measured. Such probes provide a flat response in very large frequency ranges. In many cases, a response between 100 kHz and 3 GHz is sufficient, but alternatively probes that provide broader responses or narrower responses can be used if the contributions for particular RF services are of interest.

The probe should take rms measurements.

Other important features of this type of probes are:

– measurement range: minimum rms value 0.3-20 V/m; minimum continuous wave (CW) value 0.3-100 V/m;
– sensitivity: minimum 0.3 V/m;
  (NOTE – This is approximately equal to the arithmetic mean reported in European cities [b-Urbinello]).
– frequency response: maximum ±3 dB in the band under consideration;
– linearity: maximum ±1 dB;
– isotropy: maximum ±2.5 dB up to 3 GHz (±3.5 dB up to 6 GHz);
– temperature range: −10ºC to 45ºC.

The position of the field probe on the vehicle should be between 1.5 and 3 m above ground level.

7.1.2 Data acquisition electronics

The electronics should enable data capture by the probe and storage of each piece of information with its date and time, plus its geographical position.

7.1.3 GPS

The GPS permits geographic location data to be obtained at any time via the satellite network. It can be an external element of the system or it can be integrated into the continuous measurement equipment, to directly associate the measurement data at each spot with the geographical position.

7.1.4 Environmental protection

Having to always work outdoors, a minimum IP55 environmental protection level [IEC 60529] is recommended.

7.1.5 Laptop (optional)

The direct connection between the measuring equipment and the GPS (if it is external) permits data to be monitored and visualized in real time and the evolution of the drive test to be checked by suitable mapping.

7.2 Equipment for spot measurements

Spot measurements refer to all measurements made with the vehicle stopped (clause 6.1), measurements to compare with theoretical calculation (clause 6.2) and grid method measurements (clause 6.3).

Either broadband or frequency selective equipment can be used.

Broadband equipment permits the total value of the field in the frequency band of interest to be obtained and the results to be directly compared with those obtained by theoretical calculation or the drive test. Broadband equipment mounted on vehicles can also calculate averaged measurements, in which case it is only necessary to stop the vehicle during the six minutes needed to obtain the desired measurement.

Otherwise, the measurement should be performed using a tripod and then included in the file. The values measured by broadband probe are compared with the lower limit of the working band of the probe, unless the probe has a shaped frequency response. If the value is more than 6 dB below this limit, the result is valid, otherwise it is necessary to repeat the measurements using frequency selective equipment.

The recommended height for spot measurements taken with equipment not mounted on the vehicle is 1.5 m.

Frequency selective equipment permits specific values for each telecommunication service to be obtained. The sum of the contributions should be calculated in order to obtain the total RF-EMF exposure value and include the results in the file. The sum of the contributions must be made as specified by [b-ICNIRP 1998] (described in Appendix I of [ITU-T K.52]).

7.3 Calibration

All measuring equipment should be individually calibrated by an accredited ISO/IEC 17025 laboratory. It is advisable to make accredited calibrations and calibrations recognized by the International Laboratory Accreditation Cooperation (ILAC).

8 Uncertainties

The uncertainties shall be estimated in compliance with methods described in [EN 50413], [EN 50383], [ITU-T K.91] and [ISO/IEC Guide 98-3]. The contributions to the total uncertainty of the measurement can be obtained through the appropriate measurements performed on the equipment or according to the manufacturer's specifications. Normally, tolerances with rectangular distribution can be considered.

The expanded uncertainty with a confidence interval of 95 per cent shall not exceed 4 dB.

The contributions of each component of uncertainty shall be registered with their name, probability distribution, sensitivity coefficient, and uncertainty value. The results shall be recorded as described in Table 1. The combined uncertainty shall then be evaluated according to equation 1:

$$u_c = \sqrt{\sum_{i=1}^{m} c_i^2 u_i^2} \qquad (1)$$

where c_i is the weighting coefficient (sensitivity coefficient). The expanded uncertainty shall be evaluated using a confidence interval of 95 per cent which can be obtained with coverage factor k = 1.96 for a near-normal distribution, typical in most measurements.

Table 1 gives a practical guideline for assessing the uncertainty in measurements of EMFs.

There may be other uncertainties, which are not listed in Table 1. If the concerned parties find other relevant uncertainties, these should be added and taken into account for the overall calculation.

Table 1 – Uncertainty assessment

Error sources	**Uncertainty value % uv_i**	**Probability distribution**	**Divisor k_i**	c_i	**Standard uncertainty % $u_i = uv_i/k_i$**
Measurement equipment					
Calibration		Normal	2	1	
Isotropy		Rectangular	$\sqrt{3}$	1	
Linearity		Rectangular	$\sqrt{3}$	1	
Frequency response		Rectangular	$\sqrt{3}$	1	
Environmental parameters					
Influence of temperature and humidity in the measuring equipment		Rectangular	$\sqrt{3}$	1	
Influence of the vehicle		Rectangular	$\sqrt{3}$	1	
Post-processing					
Combined standard uncertainty		$u_c = \sqrt{\sum_{i=1}^{m} c_i^2 \cdot u_i^2}$			
Expanded uncertainty (confidence interval of 95%)		Normal			$u_e = 1.96 \cdot u_c$

9 Report on the radio-frequency electromagnetic field levels

The ultimate goal of RF-EMF maps is to relay information on RF-EMF levels to the public in an understandable visual format.

RF-EMF levels are plotted based on the total number of samples and in relation to the percentage of the national limits. It is advisable to use a colour code to reflect the levels of the different spots on the maps.

The colour code should always be part of the map. A map without a colour code may not be understandable and may lead to misunderstandings. An example of colour code can be found in Appendix I.

NOTE – Appendix I also suggests an alternative monochrome approach for displaying results.

The map shall also be accompanied by the following information:

– measurement or calculation location;
– date;
– description of the system or equipment used, or of calculation tools;
– calibration record of the equipment used;
– measurement or calculation uncertainty;
– entity in charge of making the RF-EMF maps;
– scale and limit values.

Appendix I

Example of colour code and alternatives to use of colours for displaying RF-EMF map levels

(This appendix does not form an integral part of this Recommendation.)

I.1 Example of colour code

Table I.1 is an example of a unified colour code for better understanding and comparison among maps performed in different countries or by different agencies using the same RF-EMF limit values.

This colour code may not be appropriate for people with red–green colour blindness.

Table I.1 – Example of colour code for displaying RF-EMF map levels

Colour										
Name	**Maya blue**	**Dodger blue**	**Cerulen blue**	**Light green**	**Lime green**	**Green**	**Golden Yellow**	**Orange**	**Orange red**	**Red**
Hexadecimal colour code	#73c2fb	#1e90ff	#2a52be	#90ee90	#32cd32	#008000	#ffdf00	#ffa500	#ff4500	#ff0000
Percentage (P) in relation to the E-field limit %	$\boldsymbol{P} \leq 1$	$1 < \boldsymbol{P} \leq 2$	$2 < \boldsymbol{P} \leq 4$	$4 < \boldsymbol{P} \leq 8$	$8 < \boldsymbol{P} \leq 15$	$15 < \boldsymbol{P} \leq 20$	$20 < \boldsymbol{P} \leq 35$	$35 < \boldsymbol{P} \leq 50$	$50 < \boldsymbol{P} \leq 100$	$\boldsymbol{P} > 100$

I.2 Alternative example of colour code

It may be that users of this Recommendation are affected by colour blindness. Colour blindness derives from different sensitivities in the light cones of the human eye and varies in level and quality by individual person. For this reason, it is difficult to recommend a set of colours that can work well for all possibly affected people.

Alternative schemes can be used, e.g., employing monochromatic representations of levels with different patterns. Two possible ways are identified in Figure I.1, for the same levels as those of Table I.1. The specification of a recommended monochrome pattern scheme is for further study.

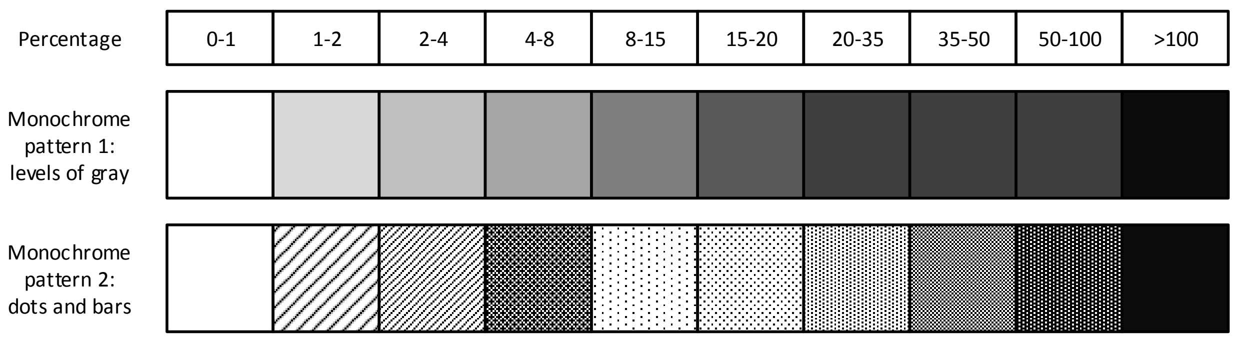

Figure I.1 – Monochrome alternative to colour codes for displaying RF-EMF map levels

Bibliography

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[b-ICNIRP 2010] International Commission on Non-Ionizing Radiation Protection (2010), *ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (1Hz -100 kHz)*, Health Physics, Vol. 99, No. 6; pp. 818-836.

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Printed in Switzerland
Geneva, 2016