International Telecommunication Union

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Electromagnetic field measurements to assess human exposure

SM Series
Spectrum management

International Telecommunication Union

Foreword

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REPORT ITU-R SM.2452-0

Electromagnetic field measurements to assess human exposure

(2019)

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1 Introduction

The proliferation of wireless installations of all types around the world obligates careful measurements. Question ITU-R 239/1 is titled "Electromagnetic field measurements to assess human exposure". ITU Plenipotentiary Resolution 176 (Rev. Dubai, 2018) is titled "Measurement and assessment concerns related to human exposure to electromagnetic fields". The ITU Handbook on Spectrum Monitoring (Edition 2011), section 5.6 details non-ionizing radiation measurements. The Electromagnetic Field (EMF) exposure limits are implemented at national level. The exposure limits are different for the general public and 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; administrations are encouraged to follow the guidelines set by these expert groups, or limits set by their own experts. Compliance with EMF limits should be assessed, taking into account that 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 also 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 separate measurements of both the E and the H fields, especially when in the near-field domain, which behaves differently 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 1998[1] Guidelines around Transmitters: Reference Levels

Quoting ICNIRP 1998, page 495: 'If the measured or calculated value exceeds the reference level, it does not necessarily follow that the basic restriction will be exceeded. However, whenever a reference level is exceeded, it is necessary to test compliance with the relevant basic restriction and to determine whether additional protective measures are necessary.'

The ICNIRP 1998 and the IEEE C95.1-2005[2] reference levels are accepted by a number of countries and countries' threshold are compared to these reference levels.

ICNIRP 1998 Tables 6 and 7 define the exposure thresholds. The following Tables and Figures specify the reference ICNIRP levels at different frequencies; the exposure values in the figures are general public and occupational exposure. The guidelines specify a time-averaging period of six minutes. Below 10 MHz (wavelength 30 metres) exposures are due to mostly near-field conditions;

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[1] ICNIRP and IEEE are revising their EMF limits. Other exposure limits may apply depending on policies and procedures established by various national regulatorty bodies.

[2] IEEE C95.1-2005 exposure values in Table 9 are similar to the ICNIRP 1998 level (f_{MHz}/200 W/m^2); at10-400 MHz the IEEE Electric Field (E) and FCC are 27.5 (V/m), compared to 28 (V/m) in the ICNIRP 1998. IEEE provides an additional equation above 100 GHz: {(90xf_{GHz} -7,000)}/200 W/m^2.

the reference levels used are mainly for the electric field-strength (V/m). Between 10 MHz and 300 GHz the basic restrictions are also provided on the basis of power-density (W/m^2). The power-density of the general public exposure is five times lower than the occupational exposure.

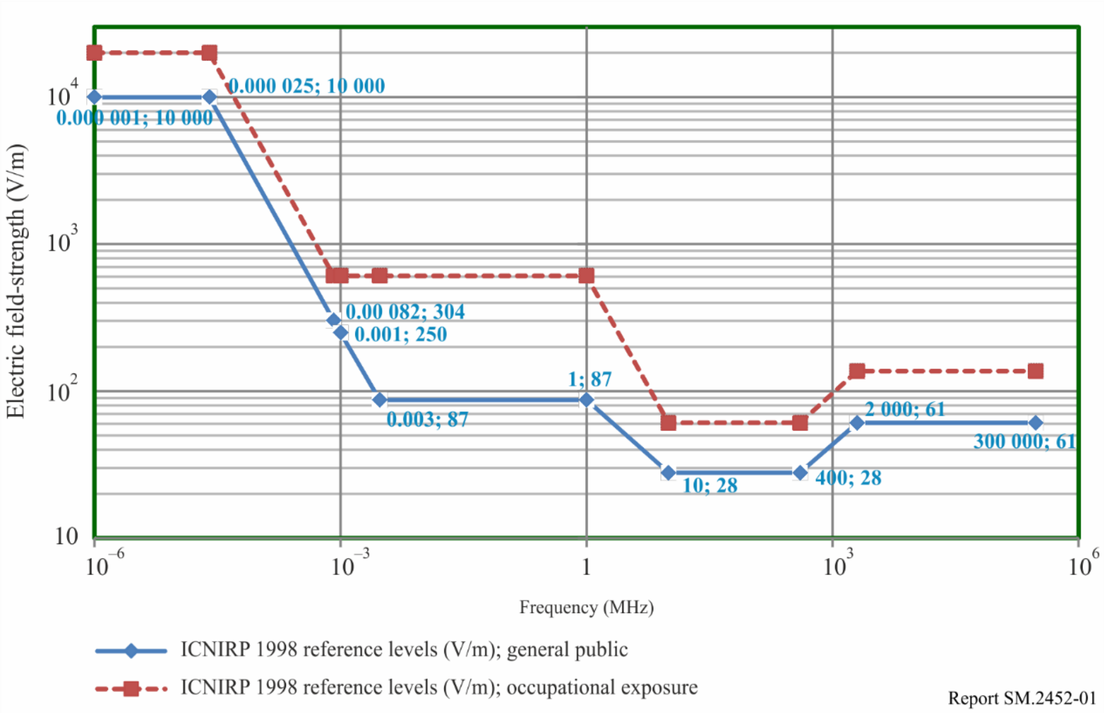
TABLE 1

ICNIRP 1998 reference levels for occupational and general public exposure

Frequency range	Electric field-strength (V/m) *f*: frequency		Equivalent plane wave power-density S_{eq} (W/m^2)	
	general public	**occupational**	**general public**	**Occupational**
1-25 Hz	10 000	20 000	No Data on Power-Density	
0.025-0.82 kHz	250/*f* (kHz)	500/*f* (kHz)		
0.82-3 kHz	250/*f* (kHz)	610		
3-1 000 kHz	87	610		
1-10 MHz	$87/f^{1/2}$ (MHz)	610/*f* (MHz)		
10-400 MHz	28	61	2	10
400-2 000 MHz	$1.375f^{1/2}$ (MHz)	$3f^{1/2}$ (MHz)	*f*/200	*f*/40
2-300 GHz	61	137	10	50

FIGURE 1[3]

ICNIRP 1998 electric field-strength for occupational and general public exposure



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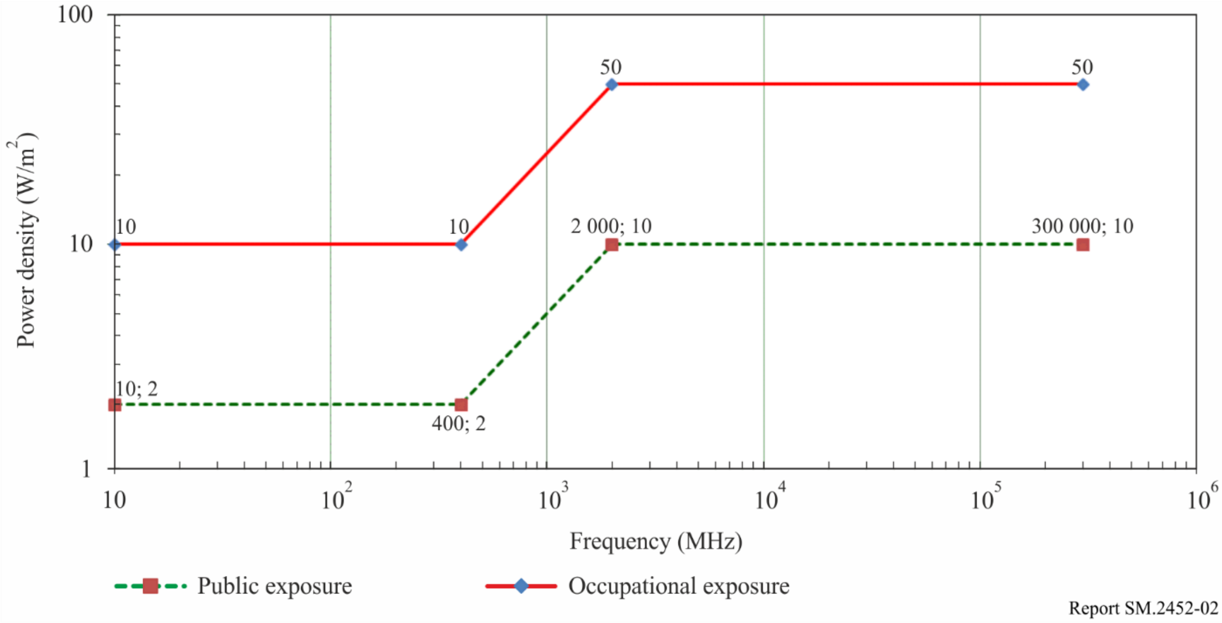
3 See Radio Spectrum Management: Policies, Regulations and Techniques, Chapter 9. Mazar, H. (http://mazar.atwebpages.com/Downloads/Chapter9RF-EMF_HumanHazards_Mazar2019.pdf).

FIGURE 2

ICNIRP 1998 power-density reference levels; above 10 MHz only



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.[4]: equivalent isotropically radiated power (watts)

d: distance from transmitter (meter)

e: electric field-strength (FS) Volt/meter (V/M).

For free-space propagation loss, $e = \frac{\sqrt{30 eirp}}{d}$ and $d = \frac{\sqrt{30 eirp}}{e}$

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.

4 "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.

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.,

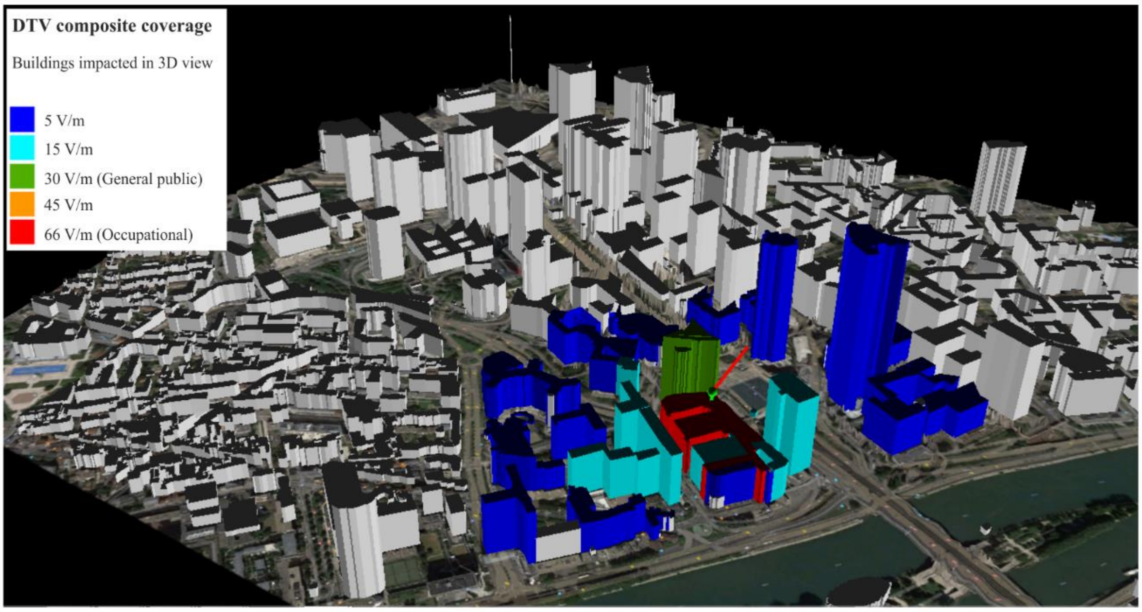
– 60 m above ground level.

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

The following Figure depicts buildings impacted in 3D view.

FIGURE 3

Three dimensions DTV general-public and occupational exposure-contours



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2.2.3 Calculated field-strength around land mobile transmitters

The following figures refer only to the downlink signals: from base stations to the mobile device. In general, the cellular patterns may be non-directive in Azimuth, or sectorial (such as three 120^0 sectors).

2.2.3.1 Field-strength around cellular transmitters

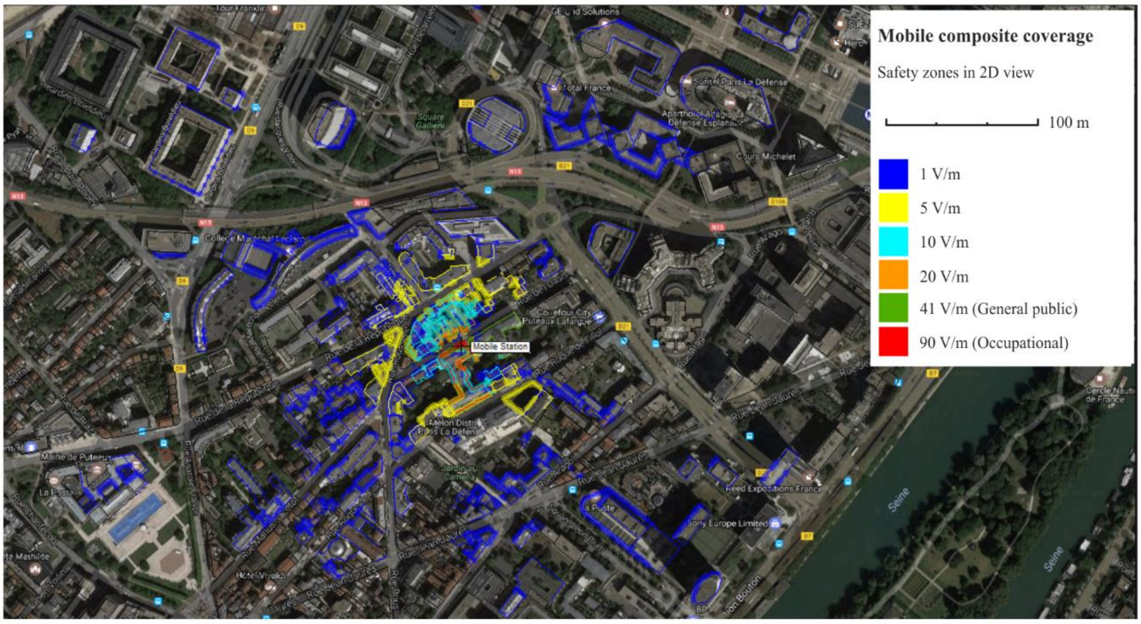
At 900 MHz, 30 metres above the roof, for maximum downlink power of 100 W and antenna gain (including losses) 17 dBi, e.i.r.p. is 5 kW, the receiver 1.5 m AGL.

The ICNIRP general-public reference-level is 41 ($1.375f^{1/2} = 1.375 \times 30$) V/m and the occupational reference-level is 90 V/M: $3f^{1/2}$ (MHz); the FS scales are 1, 5, 10, 20, 41 (general-public) and 90 (occupational) V/m.

Figure 4 depicts the buildings impacted.

FIGURE 4

Two dimensions satellite view of cellular exposure distances



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3 A practical guide for EMF measurements to assess human exposure

3.1 Basic knowledge for a successful EMF assessment measurement process

Current guidelines provide limits for the effects of electrostimulation and thermal heating. At frequencies below 100 kHz, the main effect is described by the induction law and Lapicque's law for electrostimulation. At frequencies above 10 MHz the main effect is the thermal effect. In the frequency range between 100 kHz and 10 MHz both effects can occur. Note that both effects have to be assessed separately because they do not aggregate and their assessment methods are completely different.

The appropriate assessment method for electrostimulation effects is called weighted peak method and is described in the ICNIRP 2010guidelines. Only highly specialized EMF measurement systems have implemented this assessment method yet. Common spectrum analysers are not suitable for the assessment of the electrostimulation effect. Note that the ICNIRP Guidelines from 1998 are superseded by the ICNIRP 2010 guidelines, regarding the electrostimulation effect, only.

The assessment method for the exposure due to the thermal effect of external electromagnetic fields is described by equations (9) and (10) of the ICNIRP 1998 guidelines. These equations refer to the squared RMS (root mean square) value of the weighted external electric and magnetic field strength. The result is a normalized exposure value. Exposure values up to unity are permissible. The frequency response of the weighting filter is the reciprocal of the reference levels, which vary with frequency. The integration time of the RMS detector can be as high as 6 minutes for frequencies below 10 GHz. For higher frequencies, the maximum permissible integration time decreases with increasing frequency. Note that shorter integration times may be used, but they may lead to an overestimation of the actual exposure. If the level fluctuations of the assed field are fast, compared to the actual integration time, an overestimation will not occur.

Note that above 10 MHz the ratio between the reference levels of the electric and magnetic field is constant and has the same value as the free space field impedance. Both reference levels also correspond with the reference level of the power density. Below 10 MHz, however, there is no reference level of the power density and the ratio between the reference levels of the electric and magnetic fields is smaller than the free space field impedance for the general public reference levels.

In IEC 62232, three source regions around a transmitting antenna are defined: I, II and III. Source region I is defined as the reactive near field and the part of the radiative near field where the reactive power components are still not negligible. Source region II is the part of the radiative near field where the reactive power components are already negligible. Source region III is the far field region. For the boundary distance d_I between region I and II the following three conservative limit values are depicted in Table A.2 of IEC 62232: λ, D and $D^2/4\lambda$. Therein, λ is the wavelength of the transmitted field and D is the largest dimension of the transmitting antenna. The highest of the three values is the relevant value for d_I, and it is a conservative estimate for the minimum distance where reactive power components are negligible. In other words, for distances higher than d_I the ratio of the magnitude of electric field strength to the magnitude of the magnetic field strength, measured at the same point in space, can be assumed to be the free space field impedance.

In source region II or III only the electric field component needs to be assessed because the exposure due to the magnetic field component is the same for the frequency range above 10 MHz. Only in case of the general public reference values and in the frequency range below 10 MHz the exposure due to the magnetic field is different and namely lower. In source region I however both field components need to be assessed. The higher of both exposure values is the relevant one. Above 1 GHz only the electric field component is assessed in practice because in this frequency range probes or antennas for the magnetic field component are barely available, and they are also not necessary because in the majority of cases source region II or III can be assumed.

Note that the reference levels in Tables 6 and 7 of ICNIRP 1998 describe the complete frequency range from DC to 300 GHz. Only down to 1 MHz, these reference levels are relevant for thermal effects. Equations (9) and (10) of the ICNIRP guidelines clearly state that between 100 kHz and 1 MHz the reference levels must be substituted by parameters *c* or *d*. Using the reference levels of Tables 6 and 7 of the ICNIRP guidelines below 1 MHz for assessing the exposure due to thermal effects would lead to an overestimation of the actual exposure. In state of the art EMF measurement systems, the reference level curves of the ICNIRP guidelines are available in a 'non-electrostimulation effects only' version and can be used to assess compliance, without overestimation.

The ICNIRP guidelines assume maximum coupling of the external field to the exposed individual. This implies that an exposure estimate for a specific point in space must be independent of the polarization and propagation direction of the external field. In practice this is done by measuring the RMS values of three collocated orthogonal sensors or antenna elements and calculating the isotropic RSS (root of sum of squares) value from these three RMS values. Isotropic probes are available for frequencies up to 90 GHz. Isotropic antennas are available for frequencies up to 6 GHz.

The ICNIRP guidelines assume that the unperturbed external field strength is averaged over the entire body of the exposed individual before they are compared with the reference levels, but with the important proviso that the basic restrictions on localized exposure are not exceeded. This means that averaging over the volume of a human body is allowed in principal but could lead to an underestimation in some cases. In practice therefore, the following conservative method is often used:

Measure the local exposure values in the entire area of interest without humans being present and use only moderate or no spatial averaging at all around each of the measurement points. Use the maximum exposure as the relevant exposure for the area of interest. It is good practice to exclude any measurement points with distances closer than 0.5 m to conductive objects. Doing so means that overestimation due to coupling effects between the measuring antennas and the objects and due to re-radiation from the objects can be avoided.

As a summary, an ideal assessment method for the exposure due to non-electrostimulation effects of external electromagnetic fields in an area of interest can yet be clearly formulated:

– Measure the squared, isotopic and weighted RMS value of the electric and/or the magnetic field strength at any position in the area of interest where humans are likely to be exposed.
– Use only moderate or no spatial averaging around each position.
– Make sure that the humans to be exposed are not present during the measurements.
– Exclude any position from the measurements where the distance to conductive objects is less than 0.5 m.
– Use an RMS integration time, which is not longer than the maximum permissible integration time.
– Measure over a time span, which is long enough to ensure that the maximum exposure over time will occur within this time span.
– Use the maximum exposure value of all positions and over the complete observation time as the final exposure result. If this result is less than unity, the exposure in area of interest is permissible.

Of course, this ‘ideal’ assessment method cannot be used in practice because too many points in space and time must be assessed but it clearly shows the objective of real assessment methods.

There is another effect, the microwave hearing effect with limits specified by ICNIRP, which can occur at frequencies higher than 100 kHz. This effect can only be dominant when the electromagnetic signals have an extremely high crest factor. In this case the envelope of a RF signal can become audible by humans. This is the reason why ICNIRP 1998 also has additional reference values for the peak values in this frequency range. In practice, this effect is only relevant for signals generated by radar systems.

The next sections will concentrate on assessment of compliance with non-electrostimulation effects only because assessment of the other ICNIRP limits is very different from the assessment of thermal effects and not relevant for most wireless transmitters. The next sections will instead show how such exposures can confidently, precisely and yet effectively be assessed.

3.2 Measurement instruments with specific features for EMF assessment

3.2.1 Personal monitors

Personal EMF Monitors are designed to be carried on the body of persons who are likely to be exposed to high electromagnetic fields. The monitors invoke an acoustic, optical or vibrational alert once a certain threshold value of the actual exposure is exceeded. During measurements of the EMF exposure, also the personal which executes the measurements is likely to be exposed to high EMF. It is therefore a good idea to carry a personal monitor during the measurements. Figure 5 depicts a personal monitor equipment for persons working near the antenna.

FIGURE 5

Personal monitor for occupational exposure

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3.2.2 Broadband meters

Broadband meters with "shaped probes" measure the EMF exposure directly because they display the squared, isotropic and weighted RMS value of the electric field strength. The RMS integration time can be set from about 100 ms up to some 10 minutes. Shaped probes are available for frequencies up to 50 GHz and for several standards including ICNIRP 1998 and IEEE C95.1-2005.

Broadband meters for EMF measurement are able to measure exposure values much greater than unity. This implies that their electronic must be immune to such high field strength levels. This also implies that the personal executing the measurements must be able to read out the measurement results from a safe distance. Therefore, broadband meters for EMF measurement usually have an optical link and can display their results on a second meter acting as a controller or on a common computer device.

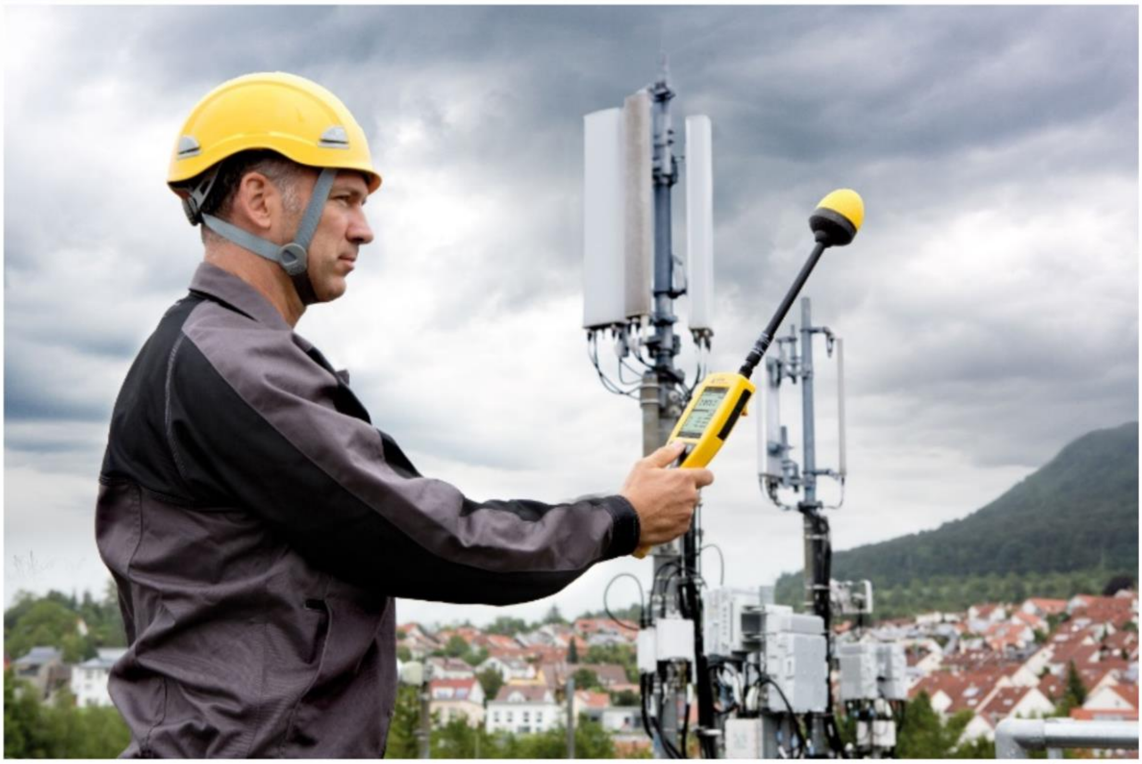
Some very helpful features of broadband meters are a graph displaying the exposure values over time, the support of spatial averaging and a maximum hold function.

If the exposure due to all relevant transmitters has to be assessed a broadband meter with a shaped probe is sufficient to carry out all necessary measurements in most cases. If diodes instead of thermocouples are used as detectors in the probes, it must be noted that signals with high crest factors may lead to significant measurements' uncertainties, if the measured RMS values are higher than the true RMS range of the probes. Even if the exposure due to several transmitters has to be assessed separately, broadband meters are extremely useful for a quick overview of the spatial and temporal structure of the total exposure values. After the local hot spots and the temporal structures at the hot spots are known, a selective measurement procedure can be set up much more effectively.

Also isotropic, broadband probes with flat frequency response are available for broadband meters: magnetic field up to 1 GHz and electric field up to 90 GHz.

FIGURE 6

Broadband meter with isotropic probe



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3.2.3 Frequency selective meters

Frequency selective measurement is necessary if the exposure due to several transmitters has to be assessed separately. Selective meters for EMF are either regular spectrum analysers or dedicated selective meters without the additional features of normal spectrum analysers. Useful features for EMF measurements are:

- Handheld and battery powered;
- Immune against high field strength levels;
- Remote control (electrical or optical);
- Direct support of isotropic antennas;
- RMS detector with configurable integration time and Max Hold function in all measurement modes;
- Automatic RSS value calculation;
- Results in field strength and exposure units;
- Measurement of each service with dedicated settings;
- Demodulators for UMTS and LTE;
- Channel power options;
- Traceable calibration of the meter and the antennas;
- Frequency range at least 9 kHz to 6 GHz, preferably 9 kHz to 18 GHz or 40 GHz, to cover new wireless communication bands. Further extension by external mixers is useful for wireless systems like short range devices 60 to 66 GHz, wireless-gigabit (WiGig) devices, automotive radars and scanners.

Figure 7 depicts frequency-selective monitoring meters, using isotropic antennas.

FIGURE 7

Frequency selective meters for EMF

3.3 Reducing the number of measurement points in space

The exposure of humans due to electromagnetic fields can vary extremely between different points in space. The distance to and the directional pattern of the transmitter antennas have a huge effect on the exposure level even under free space conditions. In real scenarios also obstacles and reflecting objects can have an additional huge effect on the exposure level at a different points in space. It is very helpful to get an overview of all potentially relevant transmitters and the electromagnetic environment before starting a measurement campaign.

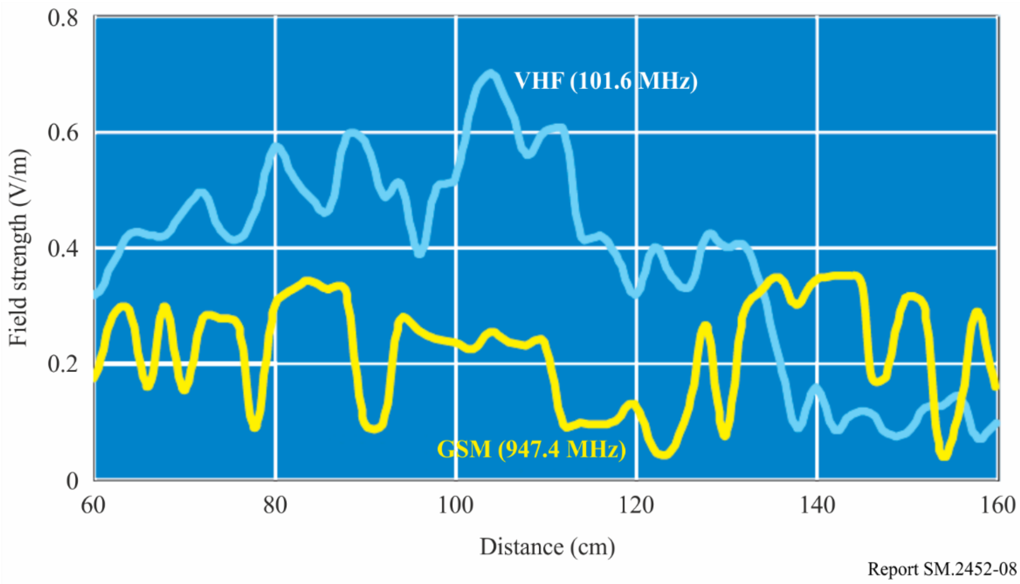
One way to get the desired overview is an optical inspection of the area of interest. At least all visible transmitter antennas should be discovered and their potential relevance should be assessed by estimating their transmitted power and directional patterns. The most relevant obstacles and reflectors should be identified too. With this information, smaller areas, which are likely to contain the positions of the highest exposure, can be identified. Especially areas with line of sight within the main lobes of the directional patterns of the transmitter antennas are likely candidates for such hot spot areas. For indoor measurements it is important to note that windows can attenuate electromagnetic field significantly. Thus, windows should be kept open during indoor measurements if possible.

The second way to get the desired overview is to make quick exposure overview measurements using broadband meters with shaped probes. If flat-frequency probes are used for this purpose, it must be noted that the spatial field strength maxima are indeed strongly correlated with the spatial exposure maxima, but they are not identical. If only the exposure due to a single transmitter has to be measured, and if this transmitter is not clearly dominating the total exposure, then frequency selective meters are mandatory for the quick overview measurement. Merely, areas with high exposure values need to be assessed in more detail in a second step. Moving the probe of a broadband meter with a constant speed on straight lines in a recognized hot spot area and watching the recorded exposure values on graphs over time shows which space resolution is necessary to find the local maxima in this hotspot area in a second step.

Figure 8 shows an FM signal measured at 101.6 MHz, and GSM down-link at 947.4 MHz.

FIGURE 8

Field-strength distribution in a room



Once hot spot areas are recognized, the local exposure maxima in these areas have to be found. Note that spatial averaging over moderate volumes is permissible, referring to ICNIRP. Avoiding spatial averaging at all may lead to a significant overestimation of the actual exposure. Finding a local maximum with isotropic probes or antennas is easy. The fastest method is to scan the hot spot area by a random movement of the probe or antenna in this area and use a maximum hold function during the scan. Moderate spatial averaging can be done in the same procedure just by setting an RMS integration time, which suits the desired integration volume and the actual speed of the movement. The second method is called grid method: a grid of points within the hotspot area is defined with a sufficient spatial resolution and the exposure is measured at each point in the grid. The grid method can be combined with moderate spatial averaging too. For a small grid consisting of 3 or 6 points, this is a useful alternative, avoiding the influence of the person carrying out the measurement. For large grids this method is quite time consuming.

For frequencies higher than 6 GHz, isotropic antennas are not yet available. Thus broadband meters with isotropic probes or spectrum analysers with biconical or directional antennas are used in this frequency range. Finding a local maximum of the exposure with biconical or directional antennas takes more time compared to isotropic probes or antennas. In practice the stirring method is used most often with such antennas: the antenna position, direction and polarization is changed randomly within the volume of interest by moving the antenna by hand. The local maximum is detected by using a maximum hold function in the selective meter or spectrum analyser during the stirring process. A grid method with directional antennas would be extremely time consuming because for each point of the grid the polarization and direction of the antenna would need to be changed many times in order to ensure that a exposure value with the maximum coupling of the field to the antenna has been captured for each point.

3.4 Reducing the observation time and extrapolation to the maximal exposure

The radiated power of some transmitters may vary extremely over time. Especially for base stations of cellular mobile services the transmitted power depends highly on the actual traffic load and user behaviour. Even during an observation time of 24 h the maximum power might not be reached because the traffic load may also depend on the day of the week or even the season. It is essential to reduce the observation time to a reasonable value in practical measurements. Therefore, it is common practice to measure the exposure due to some signal components, which are transmitted with a power that does not depend on the traffic load or the user behaviour. In a second step, the exposure is extrapolated to that exposure that would occur when the maximum transmitter power would be used. Extrapolation is however not necessary if the transmitter power is more or less constant over time. In this case, even short observation times are sufficient to assess the maximum exposure.

3.5 How to assess the exposure due to specific services

With broadband meters and shaped probes the current total exposure can be assessed comfortably. However, if the exposure due to several transmitters needs to be assessed separately, selective measurement technique is necessary. The following subsections describe how to assess the exposure due to specific services with selective measurement technique. The extrapolation process is described where adequate.

3.5.1 General approach for services where extrapolation is not of interest

Extrapolation is not necessary for systems, which transmit with more or less constant power. Examples for such services are FM Radio, digital radio and digital terrestrial television. Such transmitters can be assessed very easily. A frequency selective meter can be used for such assessments. Also, if the transmitted average e.i.r.p. is not constant, the following measurement can be applied, but it will result in the actual exposure only, not in the maximum one.

The first step is to select an appropriate selection filter in order to capture nearly 100% of the power of the channel of interest and as less power of the adjacent channels as possible.

The usage of the Gaussian selection filters in spectrum modes can lead to significant measurements' uncertainties if systems with narrow channel spacing are measured. These additional uncertainties can be avoided by using channel power options or receiver modes with appropriate channel filters.

The next step deals with the appropriate integration time of the RMS detector. The integration time must be selected long enough to reduce the fluctuations of the detected power to a negligible value but should not be much longer, in order to speed up the measurement process. It must also be shorter than the maximum permissible integration time of the relevant exposure limits. Finally, the integration time must be long enough to contain at least 100 samples.

3.5.2 Approaches for specific services

3.5.2.1 GSM base stations

The GSM cellular network is one of the services where the transmitted power depends highly on the traffic load and user behaviour. As with every service, the actual exposure can be assessed with the general approach described in previous sections. But the maximum possible exposure due to a base station often has to be judged also by regulators or operators.

At least one time slot of the eight time slots of a GSM frame is transmitted with the maximum power on the broadcast control channel (BCCH) of a GSM cell. Other time slots can transmit the same or lower power. Some time slots may use Gaussian Minimum Shift Keying (GMSK) modulation and some enhanced data rates for GSM evolution (EDGE) modulation. The power of EDGE time slots fluctuates around the mean power of the timeslot because this modulation type generates noise like signals. The RMS integration time for BCCH measurements must be less than the length of a time slot (577 µs) in order to ensure that the maximum power of a single timeslot can be captured without attenuation. The integration time should not be much shorter because the power fluctuations due to EDGE modulation have to be reduced to negligible values. The maximum of the RMS values over time then corresponds with the maximum transmitted power of the BCCH. A cell also transmits on traffic channels (TCHs) at different frequencies. The maximum possible exposure due to all channels of a GSM cell can be extrapolated now. It is the maximum possible exposure due to the BCCH multiplied with the total number of frequency channels of the cell which can be operated simultaneously. The exposure due to all cells receivable at the location of interest is the addition of all cell specific exposure values.

3.5.2.2 UMTS base stations

The UMTS cellular network is also one of the services where the transmitted power depends highly on the traffic load and user behaviour. The following procedure is state of the art, if extrapolation to the maximum possible exposure is desired:

UMTS is a code division multiple access (CDMA) system. Up to 512 data channels can be transmitted per cell. The different relatively low data rate channels are spread by different channelization codes over the relatively high bandwidth of a UMTS frequency channel. Because different cells use different scrambling codes, signals from different cells using the same frequency channel can also be separated. In each cell there is a P-CPICH (primary common pilot channel) which is transmitted with a constant power. The service provider can set the ratio of the maximum cell power to the P-CPICH power. Usually this power ratio lies in range from 8 to 15. Thus measuring the exposure due to the P-CPICH of a specific cell and multiplying it with the power ratio of this cell results in the maximum possible exposure due to this cell. The exposure due to all cells is the sum of all cell specific exposure values.

3.5.2.3 LTE base stations

The LTE cellular network is also one of the services where the transmitted power depends highly on the traffic load and user behaviour. The following procedure is state of the art, if extrapolation to the maximum possible exposure is desired:

LTE is a orthogonal frequency division multiplexing (OFDM) system. It can use frequency division duplex (FDD) or time division duplex (TDD) mode. There are one, two or four cell specific reference signals embedded in the resource grid of a LTE frame. The number of the reference signals is the same as the number of the transmitting antennas. Each reference signal is transmitted over its associated antenna only and with constant power. Note that the transmitted power of traffic dependent symbols is distributed equally over all antennas in use.

The mean value of the exposure due to single resource elements transmitting cell specific reference signals is measured in a first step for each antenna and cell separately. The sum over all antennas used by a specific cell is calculated in a second step. In a third step, this sum is multiplied with an extrapolation factor which results in the maximum possible exposure due to the specific cell. The exposure due to all cells is the addition of all cell specific exposure values.

According to IEC 62232, the extrapolation factor for cells in FDD mode is the number of subcarriers divided by a “boost factor”. The number of the subcarriers depends on the bandwidth of the cell only (72, 180, 300, 600, 900 or 1 200 subcarriers for a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz). The “boost factor” may depend on the cell settings and has to be requested from the service provider if in doubt. The correct “boost factor” in the sense of IEC 62232 is identical to the number of antennas in many cases.

For a cell in TDD mode the extrapolation factor is the same as for a cell in FDD mode, but multiplied with a correction factor, defined by the ratio of the time used for downlink within a frame to the frame length. The actual ratio can be measured roughly in “scope” mode of a selective meter or it can be calculated exactly if the uplink-downlink configuration, special-subframe configuration and the cyclic prefix length of the specific cell is known. The possible range of the correction factor is 34/140 up to 106/120. If in doubt or, if the service provider does not guarantee not to change the uplink-downlink configuration, the maximum correction factor should be used.

3.5.2.4 Wi-Fi access points

Wi-Fi networks are an application where the transmitted power depends highly on the traffic load and user behaviour. The OFDM RF signal is emitted in bursts, so all the carriers of the channel are active at certain times, depending on the traffic. As a consequence, the most difficult scenario for assessing the exposure is the idle mode, in which only 0.5 ms duration sequence of beacons is transmitted every some tens of milliseconds. With the following measurement procedure, it is possible to extrapolate the maximum exposure.

The channel power of the Wi-Fi signal is measured continuously with a RMS integration time less than 0.5 ms. The maximum channel power over time is determined. This maximum channel power should be converted to the corresponding field strength. This field strength can be compared with the exposure limit. If the duty cycle of the Wi-Fi system is limited to values lower than 100%, the maximum exposure must be adjusted, according to the duty cycle.

4 References

ITU Handbook on Spectrum Monitoring, Chapter 5.6

ITU-D Question 7/2 - Strategies and policies concerning human exposure to electromagnetic fields

ITU-T Recommendations

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- K.61: Guidance on measurement and numerical prediction of electromagnetic fields for compliance
- K.70: Mitigation techniques to limit human exposure to EMFs in the vicinity stations
- K.83: Monitoring of electromagnetic field levels
- K.90: Evaluation techniques and working procedures for compliance with exposure limits of network
- K.91: Guidance for assessment, evaluation and monitoring of human exposure to radio frequency exposure
- K Suppl.1: ITU-T K.91 – Guide on electromagnetic fields and health
- K Suppl.4: ITU-T K.91 – Electromagnetic field considerations in smart sustainable cities
- K.100: Measurement of radio frequency electromagnetic fields to determine compliance with human
- K.113: Generation of radiofrequency electromagnetic field level maps
- K.122: Exposure levels in close proximity of radio-communication antennas
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ICNIRP

ICNIRP Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz), ICNIRP Guidelines, Health Physics, vol.74, pp. 494-522, 1998

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IEC 62232:2017: Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure

5 Glossary and abbreviations

2D	Two dimensions
3D	Three dimensions
AGL	Above ground level
BCCH	Broadcast control channel
DTM	Digital terrain mapping
DTV	Digital TV
e.i.r.p.	Equivalent isotropically radiated power
EMF	Electromagnetic field
FDD	Frequency division duplex
FS	Field-strength
ICNIRP	International commission on non-ionizing radiation protection
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMT	International mobile communications
LTE	Long-term evolution
OFDM	Orthogonal frequency division multiplexing
P-CPICH	Primary common pilot channel
RF	Radio frequency
RMS	Root mean square
RSS	Root of sum of squares
TDD	Time division duplex
UMTS	Universal Mobile Telecommunications System
WiGig	Wireless gigabit
WHO	World Health Organization