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SERIES K: PROTECTION AGAINST INTERFERENCE

Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields

Amendment 3: Updated Appendix IX – Manhole-type base station

Recommendation ITU-T K.91 (2018) – Amendment 3

Recommendation ITU-T K.91

Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields

Amendment 3

Updated Appendix IX – Manhole-type base station

Summary

There are many possible methods of exposure assessment and each of them has its own advantages and disadvantages. Recommendation ITU-T K.91 gives guidance on how to assess and monitor human exposure to radio frequency (RF) electromagnetic fields (EMF) in areas with surrounding radiocommunication installations based on existing exposure and compliance standards in the frequency range of 9 kHz to 300 GHz. This includes procedures of evaluating exposure and how to show compliance with exposure limits with reference to existing standards.

Recommendation ITU-T K.91 is oriented to the examination of the area accessible to people in the real environment of currently operated services with many different sources of RF EMF, but also gives references to standards and Recommendations related to EMF compliance of products.

This Recommendation includes an electronic attachment containing an uncertainty calculator and the Watt Guard modules.

Editorial note – The electronic attachment can be downloaded together with the main edition of this Recommendation.

Amendment 2 adds Appendix X, which includes the concept and method of EMF exposure information platform to enhance general public awareness for EMF exposure status and usage data of EMF related professional.

Amendment 3 revises and improves Appendix IX to include the evaluation of EMF exposure from manhole-type base stations. It also adds a relationship among the evaluation methods and each section of the core text.

History

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1.0	ITU-T K.91	2012-05-29	5	11.1002/1000/11634
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3.1	ITU-T K.91 (2018) Amd. 1	2018-09-21	5	11.1002/1000/13796
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Keywords

EMF monitoring, exposure assessment, exposure evaluation, exposure monitoring, guidance, information platform, manhole base station, RF EMF exposure, small cells.

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[*] 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/11.1002/1000/11 830-en.

FOREWORD

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In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Updated Appendix IX – Manhole-type base station

Editorial note: This is a complete-text publication. Modifications introduced by this amendment are shown in revision marks relative to Recommendation ITU-T K.91 (2018) plus its Amendments 1and 2.

1   Scope

This Recommendation[1] gives guidance on how to assess and monitor human exposure to radio frequency (RF) electromagnetic fields (EMF) in areas with surrounding telecommunication installations, such as base stations as defined in [IEC 62232], radiocommunication installations based on existing exposure and compliance standards in the frequency range of 8.3 kHz to 300 GHz. This Recommendation presents and references in clear and simple ways, procedures of evaluating exposure and how to show compliance with exposure limits. Existing standards are product or service oriented. This Recommendation is oriented to the examination of the area accessible to people in the real environment of currently operated services with many different sources of RF EMF, but also gives references to standards and Recommendations related to EMF compliance of products.

[b-ITU-T K-Suppl.1] provides EMF information and education resources suitable for all communities, stakeholders and governments. It gives answers to questions commonly posed by the public on EMF and to related concerns. This supplement is also available as a mobile application that is available from http://emfguide.itu.int/emfguide.html. In [b-ITU-T K-Suppl.4], EMF considerations for smart sustainable cities is presented.

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 (2018), *Guidance on complying with limits for human exposure to electromagnetic fields.*
[ITU-T K.61]	Recommendation ITU-T K.61 (2018), *Guidance to 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 (2018), *Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations.*

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[1] This Recommendation contains an electronic attachment containing an uncertainty calculator, ITU EMF-guide and the Watt Guard applications. The electronic attachment can be downloaded together with the main edition of this Recommendation.

[ITU-T K.83]	Recommendation ITU-T K.83 (2011), *Monitoring of electromagnetic field levels.*
[ITU-T K.100]	Recommendation ITU-T K.100 (2017), *Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service.*
[ITU-T K.113]	Recommendation ITU-T K.113 (2015), *Generation of radiofrequency electromagnetic field level maps.*
[ITU-T K.121]	Recommendation ITU-T K.121 (2016), *Guidance on the environmental management for compliance with radio frequency EMF limits for radiocommunication base stations.*
[ITU-T K.122]	Recommendation ITU-T K.122 (2016), *Exposure levels in close proximity of radiocommunication antennas.*
[ITU-R BS.1195]	Recommendation ITU-R BS.1195 (2013), *Transmitting antenna characteristics at VHF and UHF.*
[ITU-R BS.1698]	Recommendation ITU-R BS.1698 (2005), *Evaluating fields from terrestrial broadcasting transmitting systems operating in any frequency band for assessing exposure to non-ionizing radiation.*
[IEC 62209-1]	IEC 62209-1:2016, *Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Part 1: Devices used next to the ear (Frequency range of 300 MHz to 6 GHz).* https://webstore.iec.ch/publication/25336
[IEC 62209-2]	IEC 62209-2:2010, *Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Human models, instrumentation, and procedures – Part 2: Procedure to determine the specific absorption rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz).* https://webstore.iec.ch/publication/6590
[IEC 62232]	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.* https://webstore.iec.ch/publication/28673
[ISO/IEC 17025]	ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories.* http://www.iso.org/iso/catalogue_detail.htm?csnumber=39883

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 antenna [ITU-T K.70]: Device that serves as a transducer between a guided wave (e.g., coaxial cable) and a free space wave, or vice versa. It can be used to emit or receive a radio signal. In this Recommendation the term antenna is used only for emitting antenna(s).

3.1.2 antenna gain [ITU-T K.70]: The antenna gain $G\ (\theta,\ \phi)$ is the ratio of power radiated per unit solid angle multiplied by 4π to the total input power. The gain is frequently expressed in decibels with respect to an isotropic antenna (dBi). The formula defining the gain is:

$$G_i(\theta,\phi) = \eta \frac{4\pi}{P_{in}} \frac{dP_r}{d\Omega}$$

where:

θ, φ: the angles in a polar coordinate system

η: the antenna efficiency due to dissipative losses

P_r: the radiated power in the (θ, φ) direction

P_{in}: the total input power

dΩ: an elementary solid angle in the direction of observation.

NOTE – In manufacturers' catalogues the antenna gain is understood as a maximum value of the antenna gain. Gain does not include losses arising from impedance and polarization mismatches. If an antenna is without dissipative loss, then its gain is equal to its directivity D (θ, φ).

3.1.3 average (temporal) power (P_{avg}) [ITU-T K.52]: The time-averaged rate of energy transfer defined by:

$$P_{avg} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} P(t)dt$$

where:

P(t) is the instantaneous power

t_1 and t_2 are the start and stop time of the exposure.

3.1.4 averaging time (T_{avg}) [ITU-T K.52]: The averaging time is the appropriate time period over which exposure is averaged for purposes of determining compliance with the limits.

3.1.5 basic restrictions [ITU-T K.70]: Restrictions on exposure to time-varying electric, magnetic and electromagnetic fields that are based directly on established health effects. Depending upon the frequency of the field, the physical quantities used to specify these restrictions are: current density (J), specific absorption rate (SAR) and power density (S).

3.1.6 body mounted device – body worn device [IEC 62209-2]: A portable device containing a wireless transmitter or transceiver which may be located close to a person's torso except the head during it's intended use or operation of its radio functions (e.g., on a belt clip, holster, pouch, or on a lanyard when worn as necklace)).

3.1.7 compliance distance [ITU-T K.70]: Minimum distance from the antenna to the point of investigation where the field level is deemed to be compliant with the limits.

3.1.8 contact current [ITU-T K.52]: Contact current is the current flowing into the body by touching a conductive object in an electromagnetic field.

3.1.9 continuous exposure [ITU-T K.52]: Continuous exposure is defined as exposure for duration exceeding the corresponding averaging time. Exposure for less than the averaging time is called short-term exposure.

3.1.10 controlled/occupational exposure [ITU-T K.70]: Controlled/occupational exposure applies to situations where the persons are exposed as a consequence of their employment and in which those persons who are exposed have been made fully aware of the potential for exposure and can exercise control over their exposure. Controlled/occupational exposure also applies to the cases where the exposure is of transient nature as a result of incidental passage through a location where the exposure limits may be above the general population/uncontrolled environment limits, as long as the exposed person has been made fully aware of the potential for exposure and can exercise control over his or her exposure by leaving the area or by some other appropriate means.

3.1.11   directivity [ITU-T K.70]: Is the ratio of the power radiated per unit solid angle over the average power radiated per unit solid angle.

3.1.12   equivalent isotropically radiated power (eirp) [ITU-T K.70]: The EIRP is the product of the power supplied to the antenna and the maximum antenna gain relative to an isotropic antenna.

3.1.13   equivalent radiated power (ERP) [ITU-T K.70]: The ERP is the product of the power supplied to the antenna and the maximum antenna gain relative to a half-wave dipole antenna.

3.1.14   exposure [ITU-T K.52]: Exposure occurs wherever a person is subjected to electric, magnetic or electromagnetic fields or to contact currents other than those originating from physiological processes in the body or other natural phenomena.

3.1.15   exposure level [ITU-T K.52]: Exposure level is the value of the quantity used when a person is exposed to electromagnetic fields or contact currents.

3.1.16   exposure limits [ITU-T K.70]: Values of the basic restrictions or reference levels acknowledged, according to obligatory regulations, as the limits for the permissible maximum level of the human exposure to the electromagnetic fields.

3.1.17   exposure, non-uniform/partial body [ITU-T K.52]: Non-uniform or partial-body exposure levels result when fields are non-uniform over volumes comparable to the whole human body. This may occur due to highly directional sources, standing waves, scattered radiation or in the near field.

3.1.18   far-field region [ITU-T K.52]: That region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. In the far-field region, the field has predominantly plane-wave character, i.e., locally uniform distribution of electric field strength and magnetic field strength in planes transverse to the direction of propagation.

3.1.19   general population/uncontrolled exposure [ITU-T K.52]: General population/uncontrolled exposure applies to situations in which the general public may be exposed or in which persons who are exposed as a consequence of their employment may not be made fully aware of the potential for exposure or cannot exercise control over their exposure.

3.1.20   general public [ITU-T K.52]: All non-workers (see definition of workers in clause 3.1.43) are defined as the general public.

NOTE – General public exposure – RF exposure of persons who have not received any form of RF safety awareness information or training. Typically, general public exposure occurs in uncontrolled environments and includes individuals of all ages and varying health status, including children, pregnant women, individuals with impaired thermoregulatory systems, individuals equipped with electronic medical devices, and persons using medications that may result in poor thermoregulatory system performance [b-IEEE C95.7].

3.1.21   hand-held device (mobile handset) [IEC 62209-2]: A portable device containing a wireless transmitter or transceiver which may be located in a user's hand during its intended use or operation of its radio functions. A Hand-held device for this standard is a unit that is essentially not meant to be used close to head or body but it is held in hand. A typical example of a hand-held device is a PDA (personal digital assistant) with integrated RF module.

3.1.22   induced current [ITU-T K.52]: Induced current is the current induced inside the body as a result of direct exposure to electric, magnetic or electromagnetic fields.

3.1.23   intentional emitter [ITU-T K.52]: Intentional emitter is a device that intentionally generates and emits electromagnetic energy by radiation or by induction.

3.1.24   intentional radiation [ITU-T K.70]: Electromagnetic fields radiated through the transmitting antenna even in directions which are not needed (for example to the back of the parabolic microwave antenna).

3.1.25   near-field region [ITU-T K.52]: The near-field region exists in the 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 complicated in structure.

NOTE – For many antennas, the outer boundary of the reactive near-field is taken to exist at a distance of one wavelength from the antenna surface.

3.1.26   point of investigation (POI) [b-EN 50400]: The location within the Domain of Investigation at which the value of E-field, H-field or power density is evaluated.

3.1.27   power density (S) [ITU-T K.52]: Power flux-density is the power per unit area normal to the direction of electromagnetic wave propagation, usually expressed in units of watts per square metre (W/m^2). In this Recommendation, this term is commonly used to refer to equivalent plane wave power density, see clause 3.1.32.

NOTE – For plane waves, power flux-density, electric field strength (E), and magnetic field strength (H) are related by the intrinsic impedance of free space, $Z_0 \approx 377$ or $120 \, \pi \, \Omega$. In particular,

$$S_{eq} = \frac{E^2}{Z_0} = Z_0 H^2 = EH$$

where E and H are expressed in units of V/m and A/m, respectively, and S in units of W/m^2. Although many survey instruments indicate power density units, the actual quantities measured are E or H.

3.1.28   power density, average (temporal) [ITU-T K.52]: The average power density is equal to the instantaneous power density integrated over a source repetition period.

NOTE – This averaging is not to be confused with the measurement averaging time.

3.1.29   power density, peak [ITU-T K.52]: The peak power density is the maximum instantaneous power density occurring when power is transmitted.

3.1.30   power density, plane-wave equivalent (S_{eq}) [ITU-T K.52]: The equivalent plane-wave power density is a commonly used term associated with any electric or magnetic field, that is equal in magnitude to the power flux-density of a plane wave having the same electric (E) or magnetic (H) field strength.

3.1.31   radio frequency (RF) [ITU-T K.70]: Any frequency at which electromagnetic radiation is useful for telecommunication.

NOTE – In this Recommendation, radiofrequency refers to the frequency range of 9 kHz – 300 GHz allocated by ITU-R Radio Regulations.

3.1.32   reference levels [ITU-T K.70]: Reference levels are provided for the purpose of comparison with exposure quantities in air. The reference levels are expressed as electric field strength (E), magnetic field strength (H) and power density (S) values. In this Recommendation the reference levels are used for the exposure assessment.

3.1.33   relative field pattern (radiation pattern) [ITU-T K.70]: The relative field pattern $f(\theta,\phi)$ is defined in this Recommendation as the ratio of the absolute value of the field strength (arbitrarily taken to be the electric field) to the absolute value of the maximum field strength. It is also called antenna pattern. It is related to the relative numeric gain (see clause 3.1.34) as follows:

$$f(\theta, \phi) = \sqrt{F(\theta, \phi)}$$

3.1.34 relative numeric gain (normalized antenna gain) [ITU-T K.70]: The relative numeric gain $F(\theta,\phi)$ is the ratio of the antenna gain at each angle to the maximum antenna gain. It is a value ranging from 0 to 1.

3.1.35 short-term exposure [ITU-T K.52]: The term short-term exposure refers to exposure for a duration less than the corresponding averaging time. Exposure for a duration exceeding the averaging time is called continuous exposure.

3.1.36 specific absorption (SA) [ITU-T K.52]: Specific absorption is the quotient of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of a given density (ρ_m).

$$SA = \frac{dW}{dm} = \frac{1}{\rho_m}\frac{dW}{dV}$$

The specific absorption is expressed in units of joules per kilogram (J/kg).

3.1.37 specific absorption rate (SAR) [ITU-T K.52]: The time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of a given mass density (ρ_m).

$$SAR = \frac{d}{dt}\frac{dW}{dm} = \frac{d}{dt}\left(\left(\frac{1}{\rho_m}\frac{dW}{dV}\right)\right)$$

SAR is expressed in units of watts per kilogram (W/kg).

SAR can be calculated by:

$$SAR = \frac{\sigma E^2}{\rho_m}$$
$$SAR = c\frac{dT}{dt}$$
$$SAR = \frac{J^2}{\rho_m \sigma}$$

where:

E: the rms value of the electric field strength in body tissue in V/m

σ: the conductivity of body tissue in S/m

ρ_m: the density of body tissue in kg/m^3

c: the heat capacity of body tissue in J/kg°C

$\frac{dT}{dt}$: the initial time derivative of temperature (at t=0) in body tissue in °C/s

J: the value of the induced current density in the body tissue in A/m^2.

3.1.38 transmitter [ITU-T K.70]: Is an electronic device used to intentionally generate radio frequency electromagnetic energy for the purpose of communication (in contrast to the definition for intentional emitter in clause 3.1.23). The transmitter output is connected via a feeding line to the transmitting antenna which is the real source of the intentional electromagnetic radiation.

3.1.39 unintentional emitter [ITU-T K.52]: An unintentional emitter is a device that intentionally generates electromagnetic energy for use within the device, or that sends electromagnetic energy by conduction to other equipment, but which is not intended to emit or radiate electromagnetic energy by radiation or induction.

3.1.40   unintentional radiation [ITU-T K.70]: Electromagnetic fields radiated unintentionally, for example through the transmitter enclosure or feeding line.

3.1.41   wavelength (λ) [ITU-T K.52]: The wavelength of an electromagnetic wave is related to frequency (*f*) and propagation velocity (*v*) of an electromagnetic wave by the following expression:

$$\lambda = \frac{v}{f}$$

In free space the propagation velocity is equal to the speed of light (*c*) which is approximately 3×10^8 m/s. In body tissue the propagation velocity is reduced by the square root of the relative dielectric constant so that wavelength in tissue is typically 7 times shorter than in free space.

3.1.42   whole-body-exposure [b-IEEE C95.1]: The case in which the entire body is exposed to the incident fields.

3.1.43   workers [ITU-T K.70]: Any person employed by an employer, including trainees and apprentices but excluding domestic servants (see clause 3.1.9).

3.2   Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1   electromagnetic field (EMF): A field determined by a set of four interrelated vector quantities that characterizes, together with the electric current density and the volumic electric charge, the electric and magnetic conditions of a material medium or of a vacuum.

4   Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AM   Amplitude Modulation

APC   Automatic Power Control

BS   Base Station

CDMA   Code Division Multiple Access

EIRP   Equivalent Isotropically Radiated Power

EM   Electromagnetic

EMC   Electromagnetic Compatibility

EMF   Electromagnetic Field

ERP   Equivalent Radiated Power

FDTD   Finite Difference Time Domain

FM   Frequency Modulation

FPP   Fixed Point-to-Point

GSM   Global System for Mobile communications

HRP   Horizontal Radiation Pattern

ICNIRP   International Commission on Non-Ionizing Radiation Protection

IF   Intermediate Frequency

IMT-2000   International Mobile Telecommunication-2000

LBS   Location-Based Service

LOS	Line of Sight
LTE	Long Term Evolution
LW	Long Wave
MoM	Method of Moments
MW	Medium Wave
OFDM	Optical Frequency Domain Multiplexing
PC	Personal Computer
PCS	Personnel CommunicationSystem
PDA	Personal Digital Assistant
POI	Point of Investigation
RBW	Resolution Bandwidth
RF	Radio Frequency
rms	Root Mean Square
RSS	Root Sum Square
SA	Specific Absorption
SAM	Specific Anthropomorphic Mannequin
SAR	Specific Absorption Rate
SD	Standard Deviation
SW	Shortwave
S-DMB	Satellite-Digital Multimedia Broadcasting
TER	Total Exposure Ratio
TRS	Trucked Radio System
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunication System
VHF	Very High Frequency
VRP	Vertical Radiation Pattern
WCDMA	Wideband Code Division Multiple Access
WHO	World Health Organization
WiBro	Wireless Broadband Internet
WiFi	Wireless Fidelity
WiMAX	Worldwide interoperability for Microwave Access

5　General guidance

In this clause, a general description of the procedure for assessing exposure to electromagnetic fields is presented. The steps of this procedure will be described in more detail in the next part of this Recommendation. This procedure covers all possible steps but in real cases some steps will not be required. This procedure is applicable for the exposure assessment in the areas around radiocommunication installations, i.e., in the areas around transmitting stations and base stations (BSs) (in this Recommendation the term transmitting station will be used). It does not cover exposure

assessment for unintentional radiation from telecommunication equipment (e.g., radiation through the enclosure of the transmitter) or exposure to non-telecommunication equipment such as industrial induction heating equipment or AC power systems. More general information about measurement or calculation methods for base stations can be found in [IEC 62232].

It is recommended to first use the simplest method, even if other methods give higher accuracy. In many cases the exposure level is far below the acceptable limit, and more sophisticated methods (more difficult to apply) are not necessary. The choice between measurement and calculation and the choice between different methods of exposure assessment are discussed in this Recommendation.

In Figure 5-1 the basic concept of the compliance check of human exposure to RF EMF is presented.
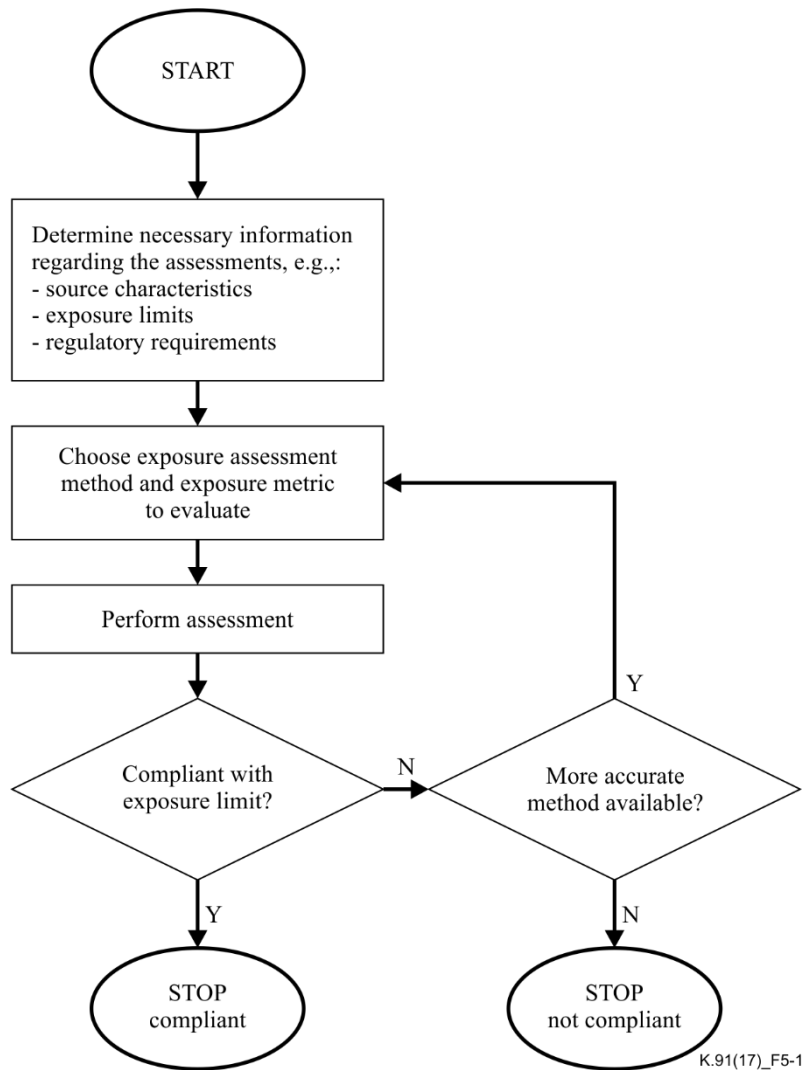
Figure 5-1 – General description of the exposure assessment procedure

The following clauses present a description of the possible activities that may be used during exposure assessment (see Appendix VII), the main problems, the advantages and disadvantages, the characteristics of the radiating sources that are used in radiocommunication and exposure levels that may be expected in the areas around typical radiocommunication antennas.

In general, the exposure assessment is made by measurement or calculation. In some cases it is more efficient to assess exposure to some sources of radiation by measurement and for others by calculation (see [IEC 62232]). Also, in some cases the exposure assessment for certain sources of radiation may be referenced against basic restrictions and for others against the reference level. In any case, all sources of radiation should be considered once and all of them should be combined into total exposure

evaluation. However, exposure due to mobile devices should not be combined with exposure due to sources which are in a fixed location since there would not be any definite positional relationship between these two different types of sources and, more practically, the exposure levels from each different device type would often not be correlated in comparison with the basic restrictions during an assessment to determine compliance with the exposure limits.

5.1 General public and occupational exposure

In general, the RF EMF exposure assessment of the general public and workers (occupational exposure) use the same methods. However, there are some specific features that distinguish the two categories. The most important are:

– exposure limits for the general public are more conservative because workers have better knowledge about possible hazards and location of places with the highest exposure levels and they are exposed during working hours only;

– workers are more likely to approach closer to the RF sources (transmitting antennas) so in more cases the area under examination is located in the reactive near-field region, which, as a consequence, requires more sophisticated methods for the exposure assessment by measurement or by calculation;

– workers in some cases are allowed to stay in areas with exposure levels above the limits but for limited time periods or by using mitigation measures like protective clothes.

5.2 Existing or planned transmitting station

If the area under consideration is covered by emissions from existing RF sources only, then the exposure assessment can be performed either by measurements or by calculations. If in the area under consideration some new RF EMF sources are planned (even if there exist other operating radio systems), the possibility to check compliance is through the exposure assessment by calculation or by a combination of measurement and calculation.

[ITU-T K.121] presents procedure guidance on the environmental management for compliance with RF EMF limits for BSs. The suggested procedure to perform when a BS is put into service is presented in [ITU-T K.100] and [IEC 62232].

5.3 Collection of data concerning the sources of radiation

Collection of data concerning the RF sources is helpful in many respects. If exposure assessment by measurement is planned, it is in principle possible to do without these data, but measurements without data concerning the RF sources are more difficult and results of measurements are less reliable. Data collection is required for exposure assessment by calculation. Generally, more detailed descriptions of the RF sources are available – more exact results of evaluation can be obtained. This Recommendation considers intentional radiation from transmitting antennas. So the description of these antennas is most important. However, much of the detailed information may be commercially sensitive and may be difficult to collect.

5.3.1 Data required for the measurement

In general, measurements can be done without complete knowledge of the radiating sources if proper equipment that covers the full range of frequencies is available, knowing at least the range of frequencies to be measured. If measurements are made with wideband equipment (without frequency selection or shaped response), the results of such measurement will be conservative because it requires the use of the limit value, which is most restrictive. In all cases of measurements, the information concerning the radiating sources is very helpful and makes the measurements more accurate and reliable.

The following data are very helpful during measurements (for each radiating source):

–   operating frequency – this allows use of a probe that has a band covering all operating frequencies;

–   distance to the transmitting antenna – this allows one to determine the field region (for each operating frequency) and to choose a proper measurement procedure;

–   maximum equivalent radiated power (ERP) – this allows estimation of the required dynamic range of the measurement equipment and the expected levels of the measured values;

–   whether the antennas are operating at the maximum transmitter power at the time of the measurements;

–   modulation characteristics – especially pulsed, intermittent or continuous operation.

Usually this information can be obtained from the documentation of the transmitting systems. Some data can be obtained during the site inspection (e.g., distances to the transmitting antennas, operating frequencies based on the types and sizes of the transmitting antennas).

5.3.2   Data required for the calculations

Exposure assessment by calculation in all cases requires information concerning radiating sources. In general, the more detailed the information, the more accurate are the results of calculations. These data are required for each operating (or planned) frequency. The required data put in order of growing level of accuracy of the exposure assessment by calculation are presented below.

The minimum data required for calculation, which leads to the most conservative approach, are:

–   operating frequency;

–   distance to the transmitting antenna;

–   maximum equivalent isotropically radiated power (EIRP).

In this case, the point source model with isotropic antenna may be used for the exposure assessment. The next step is:

–   radiation patterns of the transmitting antenna.

These additional data allow use of the point source model with radiation patterns taken into account.

Many transmitting antennas are built as systems containing many identical radiating elements (panels in broadcasting or patches in mobile communication). The additional data allowing for more accurate results are:

–   geometry of the transmitting antenna (spatial position of each panel or patch);

–   radiation pattern of the individual panel or patch;

–   feeding arrangement (amplitude or power and phase of each panel or patch feeding).

These data allow use of the synthetic model for the exposure assessment.

The data that allow for the most accurate calculations additionally contain:

–   exact location of each metallic and dielectric part of the transmitting antenna;

–   information concerning each excitation in the antenna system;

–   and/or exact location of the metallic and dielectric parts of the antenna tower and the supporting structure in the vicinity of the transmitting antenna.

These data allow for the calculation using full-wave methods such as method of moments (MoM) or finite difference time domain (FDTD).

Additional details can be found in [IEC 62232], [ITU-R BS.1698], [ITU-R BS.1195], [ITU-T K.70] and [b-EN 50413].

5.4 One or more sources of radiation, total exposure

The area under consideration may be affected by one operating source (rare case) or by many sources of radiation, which is a typical case at present. In the case of one source the exposure assessment is relatively simple and the measured or the calculated levels shall be compared with the appropriate exposure limits. If there is more than one source then the total exposure should be considered.

If the assessment is made by measurement, all the operating frequencies have to be covered by the measuring equipment. In the assessment by calculation, the exposure to each radiating source (operating frequency) has to be evaluated separately. In both cases the total exposure to all sources should be evaluated. However, exposure due to mobile devices should not be combined with exposure due to transmitters which are in a fixed location since there would not be any definite positional relationship between these two different types of sources. Thus, the total exposure from all sources in a single mobile device should be considered in a mobile device exposure assessment, and separately the total exposure from all sources in a multiple source environment should be considered in a fixed-source exposure assessment.

The exposure assessment in the multiple source environment, according to the existing standards, requires the evaluation of the total exposure (in some standards called also the total exposure ratio). All the operating frequencies must be considered in a weighted sum, where each individual source is pro-rated according to the limit applicable to its frequency. According to most standards, any sources with values less than 5% of the relevant limit do not need to be included, as the methodology is inherently conservative.

In general, the total exposure for the induced current density and electrical stimulation effects (relevant up to 10 MHz) and for the electric and magnetic field components for the thermal effect (relevant above 100 kHz) should be compared with the limits (see Appendix I).

Outside the reactive near-field region the compliance for the electric field components is sufficient. For the typical radiocommunication antennas exposure limits are more restrictive for the thermal effect than for electro-stimulation.

As a result, for the points of investigation located outside the near-field region and for the sources of radiation used by the radiocommunication systems, it is sufficient to check the compliance for the electric component and for the thermal effect only. In cases where the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines apply, the proper requirement for the total exposure ratio W_t is as follows:

$$W_t = \sum_{i=100kHz}^{1MHz} \left(\frac{E_i}{c}\right)^2 + \sum_{i>1MHz}^{300GHz} \left(\frac{E_i}{E_{Li}}\right)^2 \leq 1 \tag{5-1}$$

where:

E_i: the electric field strength at frequency i

E_{Li}: the reference limit at frequency i

c: 610/f V/m (f in MHz) for occupational exposure and 87/f$^{1/2}$ V/m for the general public.

In most cases (with no long wave (LW) and medium wave (MW) broadcasting (see Table 6-1) only the second component in this equation is needed.

Additional details can be found in [IEC 62232], [ITU-T K.70], [ITU-T K.52] and [b-EN 50413].

5.5 Field regions

Borders of the field regions generally depend on the distance to, and design of, the transmitting antenna. In the reactive near-field region, located closest to the transmitting antenna, the

electromagnetic field has a very complex structure and the calculations or measurements are most complex. Access to this area is mainly for the workers.

Usually, the general public has access to the areas located in the far-field region, or in some cases, in the radiating near-field region. In the far-field region, the electromagnetic field has a simple structure, similar to the plane-wave nature and the calculations or measurements are comparatively easy.

The distance to the beginning of the far-field region is the most important factor. The usually assumed value is $2D^2/\lambda$. It is rather a long distance and some points of investigation can be located at a shorter distance which implies the more complex calculations. According to [IEC 62232] Annex B for antennas with the maximum size $D > 2.5\lambda$, and radiating elements in a linear configuration (this is true for the typical base station panels and also for the faces of the broadcasting antennas) this distance is described by the formula:

$$d = \frac{2D^2}{\lambda}\sin^2\beta - \frac{\lambda}{32} + \frac{D}{2}\left|\cos\beta\right| \tag{5-2}$$

where β is the angle between main axis of the antenna and line from the antenna centre to the point of investigation (POI). This equation gives a substantially smaller distance of the beginning of the far-field region for directions outside the main beam ($\beta=0$) of the antenna, which extends the area of applicability of the methods appropriate for the far-field region. In [IEC 62232] Annex B, there is also a simplified formula valid for the same types of antennas giving distance $d=0.6\ D^2/\lambda$.

Additional details can be found in [IEC 62232] and [ITU-T K.61].

5.6 Basic restrictions and reference levels

Basic restrictions on exposure to RF EMFs are quantities most closely related to established adverse biological effects. They include quantities to be determined in body tissue such as current density (J) or specific absorption rate (SAR) inside the body. In real cases it is difficult or even impossible to calculate or measure these values. Reference levels for human exposure to external electric, magnetic and electromagnetic fields are derived from the basic restrictions using the realistic worst-case assumption about exposure. If the reference limits are met, then the basic restrictions will also be met; if reference levels are exceeded, that does not necessarily mean that the basic restrictions are exceeded. This approach means that the demand for the compliance with reference levels is conservative.

Additional details are given in [IEC 62232] and [ITU-T K.52].

5.7 Exposure limits

Exposure limits are acknowledged, according to obligatory regulations, as the limits for the permissible maximum level of human exposure to electromagnetic fields. Exposure limits based on the established scientific data and currently available knowledge are given in internationally recognized documents: [b-ICNIRP] and [b-IEEE C95.1] (see Appendix I). In many cases, the exposure limits are also given by national authorities and sometimes they are prepared in different ways based on different assumptions. The national regulations are obligatory and they should be respected during exposure assessment. In most countries, the ICNIRP or IEEE exposure limits are valid. In the countries which do not have their own regulations, the ICNIRP or IEEE (recommended by the World Health Organization (WHO)) exposure limits are highly recommended.

Exposure limits in various countries can be found on the WHO website:
http://www.who.int/gho/phe/emf/legislation/en/

Additional details are given in Appendix I and can be found in [b-ICNIRP] and [b-IEEE C95.1].

5.8 Compliance assessment

If only one radiating source is considered, the results of calculation or measurement may be directly compared with the exposure limit for the compliance assessment.

In the case of simultaneous exposure to multiple sources, the total exposure ratio should be less than 1.0 to comply with the regulations. In two frequency ranges: below 10 MHz (for the induced current density and electrical stimulation effect) and above 100 kHz (in which the thermal effect is dominating) – the total exposures are calculated in a different way and have to be compared separately with each limit; and both values should be less than 1.0.

Usually the reference levels are used for the compliance assessment. However, if the reference levels are exceeded, this does not necessarily mean that the basic restrictions are violated. In this case the basic restrictions (which are less restrictive) should be evaluated and compared with the exposure limits. Many national regulations allow for the use of the reference levels only. Because of this, the exposure limits in these countries are more restrictive.

Additional details are given in: [IEC 62232], [ITU-T K.52], [ITU-R BS.1698] and [b-IEC TR 62630].

5.9 Uncertainty evaluation

When performing the calculation or measurement, the uncertainty of the results has to be specified. The contributions of each component of uncertainty (the standard uncertainty $u(x_i)$) shall be registered with its name, the probability distribution, the sensitivity coefficient and the value). If any of the standard uncertainty components is not expressed in terms of the measured quantity then it should be converted using the appropriate sensitivity coefficient c_i and the equation $u_i(y)=c_iu(x_i)$. The combined uncertainty $u_c(y)$ shall then be evaluated by taking the square root of the sum of squares of the individual standard uncertainties:

$$u_c(y) = \sqrt{\sum_{i=1}^{m} u_i^2(y)} \tag{5-3}$$

(see [IEC 62232] and [JCGM 100:2008]).

The target expanded uncertainty for in-situ field measurements should be 4 dB or below, which is considered industry best practice. The expanded uncertainty for the RF exposure evaluation used for in-situ field measurements should not exceed 6 dB.

Additional information and examples of evaluation can be found in [b-JCGM 100:2008], [IEC 62232] and [ITU-T K.61].

5.10 Exposure assessment in areas around hospitals, schools, etc.

With respect to human exposure currently there is no technical requirements for any special consideration for locating base stations close to areas such as hospitals and schools due to the fact that existing exposure guidelines incorporate in the exposure limits safety margins that are applicable to all locations.

NOTE – Using the mobile telephone within areas of good reception also decreases exposure as it allows the telephone to transmit at reduced power [b-WHO 193].

6 General characteristics of typical sources of the radiation

Information concerning the mobile base stations, wireless access systems, radiocommunication systems, broadcasting transmitting stations (television (TV), frequency modulation (FM), amplitude modulation (AM)) is presented in Appendix II of [ITU-T K.70]. Important information for some specific systems is presented below, which may be useful for the exposure evaluation for those systems. In Table 6-1 the frequency range and wavelengths range of typical radiocommunication

services are presented. Information concerning additional services for base stations can be found in [IEC 62232].

Table 6-1 – Frequency range and wavelength of typical radiocommunication services

Service	Frequency range (MHz)	Wavelength range (m)
LW broadcasting	0.1485-0.255	2018.8-1175.7
MW broadcasting	0.5265-1.6065	569.4-186.6
SW broadcasting	3.95-26.1	75.9-11.5
FM broadcasting	87.5-108	3.43-2.78
VHF	174-230	1.72-1.30
UHF	470-790 (860)	0.64-0.38 (0.35)
LTE 800	790-860	0.38-0.35
GSM 850	869-894	0.35-0.34
GSM 900	935-960	0.32-0.31
GSM 1800	1805-1880	0.17-0.16
GSM 1900	1930-1990	0.16-0.15
UMTS	2110-2170	0.14-0.14
WiFi	2400-2483	0.12-0.12
LTE 2600	2620-2690	0.11-0.11
WiMAX	3400-3600	0.09-0.08

VHF: Very high frequency.
UHF: Ultra high frequency.
SW: Shortwave.
UMTS: Universal mobile telecommunication system.
WiFi: Wireless fidelity.
LTE: Long term evolution.
WiMAX: Worldwide interoperability for microwave access.

6.1 Amplitude modulation transmitting stations

AM broadcasting uses very long electromagnetic waves see, Table 6-1.

The electromagnetic field has a very complex structure in close proximity to the transmitting antenna – in the reactive near-field whose outer border is equal to one wavelength. Table 6-1 shows that the reactive near-field is largest (in descending order) in LW, MW and SW transmitting antennas. In these cases the areas accessible to people (including the general public) are frequently located in the reactive near-field. Since the magnetic component is not proportional to the electric component in this region, both the electric and magnetic components should be measured. For computation in this case the MoM is especially efficient.

Additional information concerning the measurement and the calculation of RF EMF around LW, MW and SW antennas can be found in [ITU-R BS.1698].

6.2 Shortwave transmitting station – main beam tilt

Shortwave transmitting stations also have their own specificity that is the shape of the vertical radiation pattern (VRP). The typical transmitting antenna in the broadcasting or mobile base stations has VRP with the main beam tilted to the ground direction. This beam tilt is rather small for the broadcasting antennas (usually from 0° to 1°) and bigger for the mobile base station antennas

(usually from 0° to 15°). On the contrary, the SW transmitting antennas usually have VRP pointed upwards (from −7° to −40°) in order to reach the ionosphere. In this case the radiation levels are highest at these high elevation angles.

Additional information concerning the measurement and the calculation of EMF around SW antennas can be found in [ITU-R BS.1698].

6.3 Fixed amateur stations

Measuring the electromagnetic fields of fixed amateur stations is generally a very complex task. In the case of amateur transmitting equipment, it is particularly important that the propagation conditions of the electromagnetic field in the transmitting antenna's near-field region are taken into account as such equipment may use large wavelengths and may operate in densely populated housing areas. Such a complex environment in the near-field region may require time-consuming and expensive near-field measurement.

The calculation tool "Watt Guard" enables a simple and fast assessment of fixed amateur stations. The software module runs on a wide variety of operating systems and is published together with the present Recommendation. Additional information can be found in Appendix IV.

6.4 Fixed point-to-point systems

As opposed to other antennas, microwave radio relay antennas have a main beam with very narrow radiation pattern and very low level side lobes in all other directions. Because of this, the RF EMF levels are higher in the region close to the main beam direction and decrease quickly outside of this direction. Thus, these antennas may be considered as radiating in the point-to-point direction only. Additionally, if there is any large obstacle in the propagation paths between a pair of radio relay antennas then the communication link is broken and this is acted on promptly. Thus, the probability that any object is present on the propagation path, including people, is very low.

RF EMF exposure has to be assessed only in close proximity to such antennas. The evaluation of the total exposure, which has to be performed in the environment where many transmitting antennas are operating simultaneously, may omit the radiation from the radio relay antennas, except in close vicinity to them.

Additional detailed information concerning the measurement and the calculation of RF EMF around radio relay antennas can be found in [ITU-R BS.1698].

6.5 Handsets – isotropic sources

Mobile handsets, two-way radios, palmtops, laptops, desktop computers and body-mounted wireless devices have usually an almost isotropic radiation pattern. This means that in the very conservative approach the isotropic radiation pattern and point source model can be used; in many cases, however, this may lead to a substantial overestimation of exposure. More accurate results require SAR measurement or calculations. For calculation, FDTD is the method of choice because it allows for a very good modelling of the handset and the human body that is close to the handset.

6.5.1 Compliance of mobile phones, cordless phones and headsets

This clause concerns the compliance assessment of RF EMF transmitting devices intended to be used with the radiating part of the device in close proximity to the human head and positioned against the ear, such as mobile phones, cordless phones, and handsets operating in the frequency range between 300 MHz to 3 GHz. The metrics used to quantify the RF EMF exposure is SAR. The measurement of SAR requires specific instrumentation as well as highly advanced techniques and requirements. This is why in line with the agreement between ITU-T and IEC the user of this Recommendation shall refer to the latest version of the [IEC 62209-1] measurement standard in order to assess the SAR compliance with the exposure limits. The compliance assessment shall be achieved by applying measurement requirements and measurement procedures as described in the standard. The objective

of [IEC 62209-1] is to specify the measurement method for demonstration of compliance with the SAR for the above-mentioned devices. In order to give some general idea about the content of the aforementioned standard, a very brief description is provided below.

[IEC 62209-1] has two normative references [b-JCGM 100:2008] and [ISO/IEC 17025]. It starts with explaining terms and definitions. Technical information related to general requirements such as the phantom shell, tissue simulating liquid, specifications of the SAR measurement equipment, scanning system specifications and device holder specifications are explained in the chapter "Measurement system specifications". The measurement-related requirements and information are explained in the chapter titled "Protocol for SAR assessment" where the measurement procedure is explained. The block diagram in Figure 6-1, taken directly from the [IEC 62209-1], explains the procedures which shall be performed for each of the test conditions. The head phantom used in the measurements is the specific anthropomorphic mannequin (SAM), which is described in Annex A of [IEC 62209-1]. As an example case the phantom and handset device is shown in Figure 6-2 and a head SAR measurement system is shown in Figure 6-3.

One of the main issues in measurements is the uncertainty evaluation. A long chapter in [IEC 62209-1] is devoted to uncertainty estimation where all components contributing to the uncertainty are defined and calculated. There are templates for the uncertainty evaluation for the handset SAR test, measurement uncertainty evaluation for system validation and measurement repeatability evaluation for system check. The main text of the standard ends with a chapter describing the measurement report.

In certain cases, local or national regulatory agencies or standards bodies may recommend national or regional measurement practices based on [IEC 62209-1].
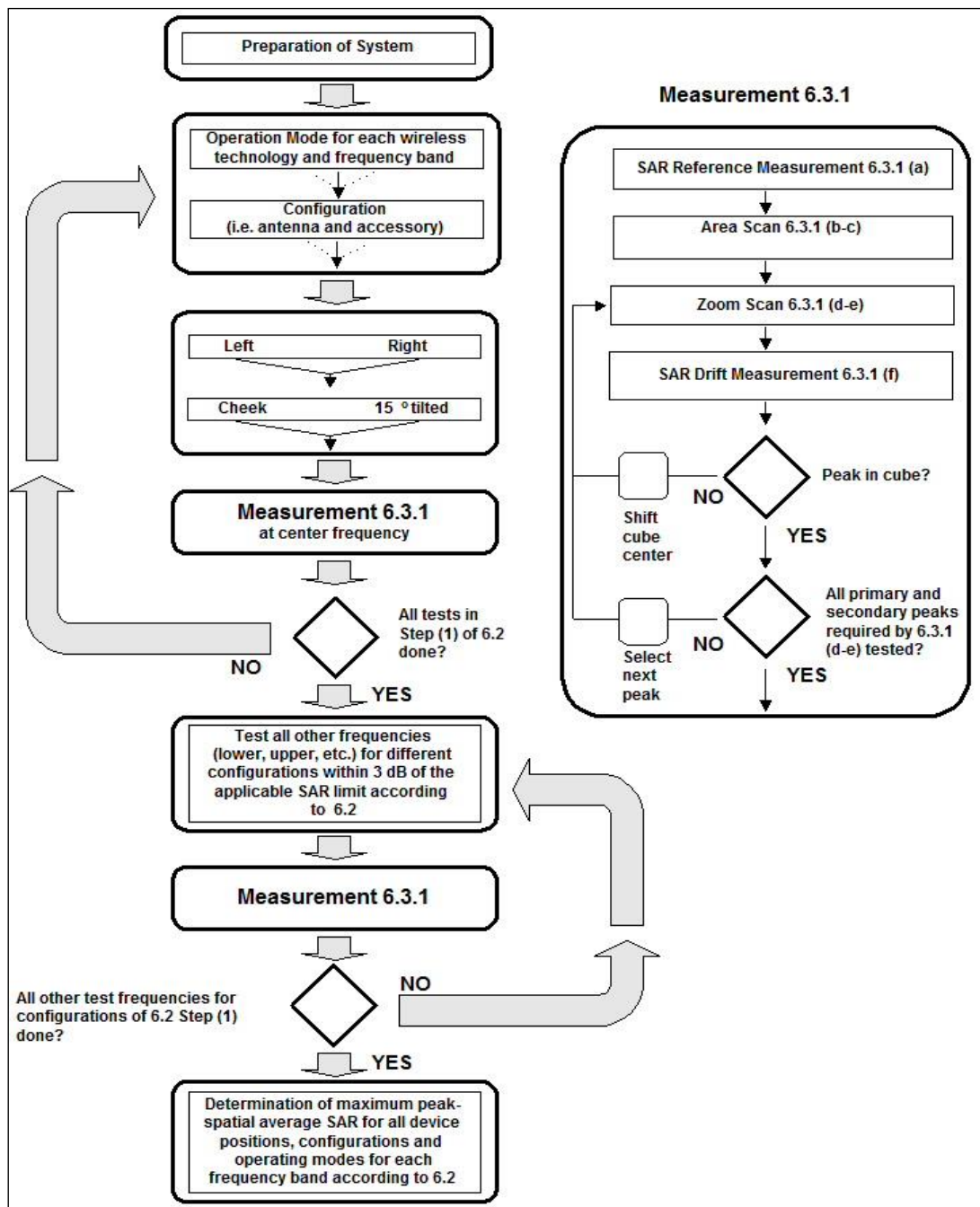
[IEC 62209-1] by courtesy of IEC.

Figure 6-1 – Block diagram of the tests to be performed for the assessment of SAR of a wireless communication device
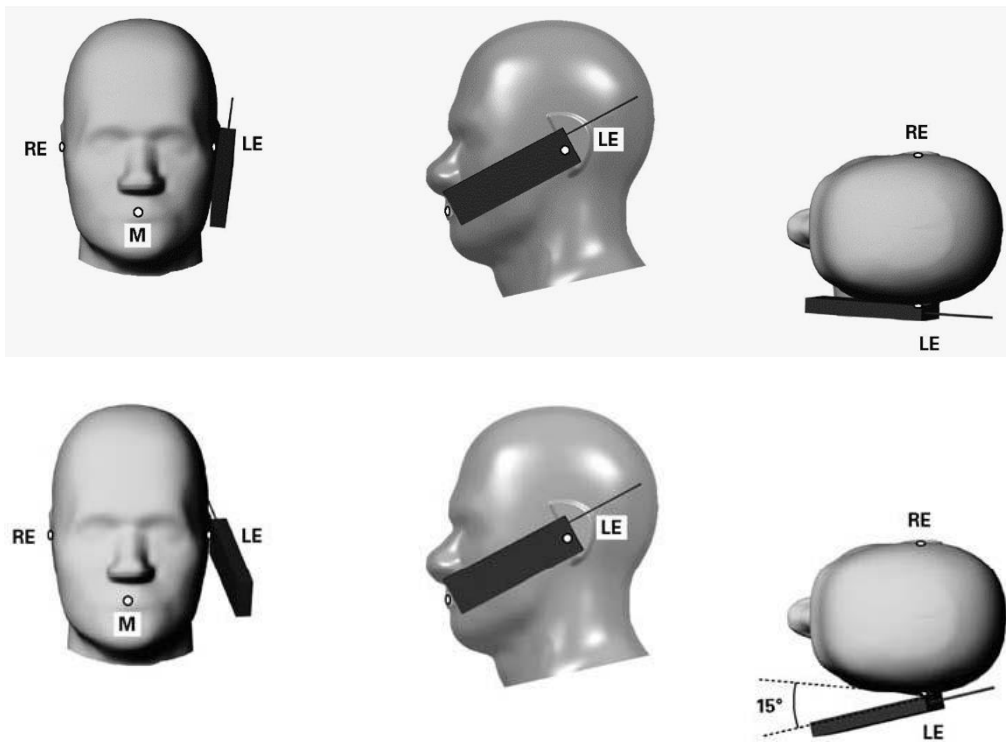
Figure 6-2 – Cheek position (above) and tilt position (below) of the wireless communication device used next to the ear on the left side of SAM phantom

Figure 6-3 – A head SAR measurement system where phantom, robot with calibrated probe, and a post-processing unit is shown

All mobile handsets on the market have to comply with regulations concerning the limits of human exposure to electromagnetic fields. The safety factors are taken into account for the worst-case scenarios and required margins for human exposure limits.

6.5.2 Compliance of wireless communication devices used in close proximity to the human body

This clause considers the compliance assessment of RF EMF transmitting devices intended to be used with the radiating part of the device in close proximity to the human body (excluding holding the device at the ear in the frequency range between 300 MHz to 6 GHz). The user of this Recommendation shall refer to the latest version of [IEC 62209-2] measurement standard in order to assess the SAR compliance with exposure limits. The compliance assessment shall be achieved by applying measurement requirements and measurement procedures as described in the standard. The objective of [IEC 62209-2] is to specify the measurement method for demonstration of compliance with the SAR for the above-mentioned device types. [IEC 62209-2] is applicable to wireless communication devices capable of transmitting RF EMF intended to be used at a position near the human body, in the manner described by the manufacturer, with the radiating part(s) of the device at distances up to and including 200 mm from a human body, i.e., when held in the hand or in front of the face, mounted on the body, combined with other transmitting or non-transmitting devices or accessories (e.g., belt-clip, camera or Bluetooth add-on), or embedded in garments. This standard may also be used to measure simultaneous exposures from multiple radio sources (within the same product/device) used in close proximity to the human body. Definitions and evaluation procedures are provided for the following general categories of device types: body-mounted, body-supported, desktop, front-of-face, hand-held, laptop, limb-mounted, multi-band, push-to-talk, clothing-integrated. The types of devices considered include, but are not limited to, mobile telephones, cordless microphones, two-way radios, auxiliary broadcast devices and radio transmitters in personal computers (PCs). This international standard gives guidelines for a reproducible and conservative measurement methodology for determining the compliance of wireless devices with the SAR limits. This standard also does not apply for exposures from transmitting or non-transmitting implanted medical devices. This standard does not apply for exposure from devices at distances greater than 200 mm away from the human body. [IEC 62209-2] makes cross-reference to [IEC 62209-1] where complete clauses or subclasses apply, along with any changes specified.

The structure of [IEC 62209-2] is almost the same as the structure of [IEC 62209-1]. The main difference between the two standards is the phantom shape for body SAR and head SAR assessment, which is a flat phantom (as shown in Figure 6-4) rather than the SAM phantom. Most of the text in the two standards, such as tissue simulating liquid and uncertainty evaluation, is essentially the same.
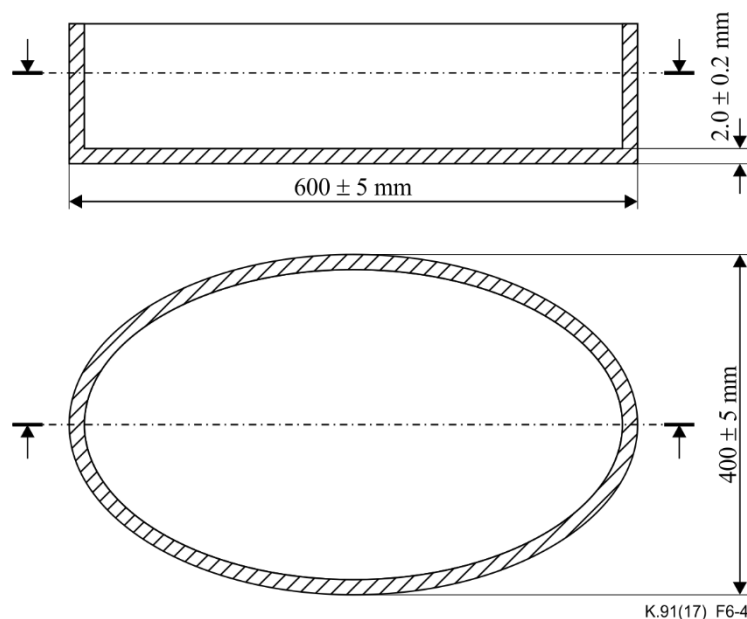

K.91(17)_F6-4

Figure 6-4 – Flat phantom for SAR measurement of wireless communication devices used in close proximity of the torso

6.5.3   Compliance of the wireless communication device with hands-free kit

All wireless communication devices with or without hands-free accessories must comply with exposure limits in all modes of operation.

NOTE – [b-WHO 193] indicates that a person keeping the mobile phone 30-40 cm away from the body will have a much lower exposure to radiofrequency fields than someone holding the handset against their head. This can be achieved by using the phone in loudspeaker mode or by using a "hands free" device such as wireless [b-IEEE 802.15.1] or wired (as separate accessory or built-in) headsets.

6.6   VHF and UHF broadcasting transmitting stations

The antennas for these systems are usually built as a set of panels (up to 64) consisting of dipoles and screens and mounted on the antenna tower. Additional information is presented in [ITU-R BS.1195]. Consideration of real cases shows that FM high power transmitting antennas generally contribute the most to the exposure levels. In most cases the synthetic model (see clause 7.3.1.2) is proper for the exposure assessment by calculations. In many cases of exposure assessment by measurements, frequency selective measurements and post-processing are required.

6.7   2G and 3G mobile base stations

The transmitting antenna of a mobile base station is typically a sector antenna in which one panel is serving a 120° sector. In many cases the points of investigation are located in the far field region and the point source model (see clause 7.3.1.1) is sufficient for the exposure assessment by calculation. Broadband measurement is also sufficient in most cases, especially when close to the antennas.

6.8   Smart (adaptive) antennas

Smart antennas produce a number of narrow beams directed to individual users to reduce interference and optimize communication. Smart antennas are controlled in such a way as to optimize radiation patterns in time depending on the distribution of the users in the served area. Because the maximum exposure level caused by the smart antennas is usually low, the point source model with an isotropic radiation pattern can be considered as the most conservative approach (see Equation B.2 in [ITU-T K.70] or Annex F.10 of [IEC 62232]). If more exact (less conservative) assessment is required then the procedure described in the [IEC 62232] Annex F.10 is recommended.

6.9   Vehicle mounted antennas (such as police car)

The source of intentional RF EMF is the antenna usually located on the body of the vehicle. It is a vertical dipole(s)/monopole so it has an omnidirectional horizontal radiation pattern. Vertical radiation pattern strongly depends on the antenna size, configuration and location. Exposure assessment should be conducted inside and outside of the vehicle. Assessment inside the car should take into account the screening effect of the body of the vehicle. The assessment method may be measurement or calculation.

7   Exposure assessment

In general, the exposure assessment can be done by measurement or calculation. Both methods give similar levels of accuracy and have advantages and disadvantages.

7.1   Pre-analysis

The goal of the pre-analysis is to choose the best and most convenient method for proper exposure assessment. The pre-analysis may contain:

– a collection of the data concerning radiating sources in the area under consideration;
– an evaluation of the field regions for each radiating source.

Based on the national, accessible data and resources it may include:

– a decision if measurements or calculations will be used;

– an estimation of the expected field levels (by calculation and using the most simple formulas);

– an evaluation of the directions and points with the expected highest levels of exposure.

Detailed pre-analysis makes exposure assessment easier and more accurate. It also saves time and costs.

7.2 Measurements

It is recommended to use first the simplest method (i.e., broadband RF EMF measurement). If the measured exposure level is not in compliance with the reference level then the frequency selective RF EMF measurement should be used to get more accurate results. If there is still no compliance with the exposure limit then the most sophisticated method based on the SAR measurement against basic restrictions may be used.

According to [b-ICNIRP] and IEEE guidance, the measuring equipment should respond to, and indicate the root mean square (rms) value; however national regulations may request other values.

When using a spectrum analyser to measure the RF field power density, the resolution bandwidth (RBW) has quite a large effect on the measurement results, particularly for broadband signals such as wideband code division multiple access (WCDMA) and optical frequency domain multiplexing (OFDM). Therefore, it should be carefully selected to sufficiently cover the occupied bandwidth of the target radio source for an accurate field power density measurement (see Appendix VII).

In the reactive near-field region the measurements are complex. It is required to make the measurement of both the electric and magnetic components of the electromagnetic field. All the three orthogonal components should be measured as well. However, this region is very close to the transmitting antenna and such measurements are only required in special cases. In practice these cases are for occupational exposure only.

In the far-field region, and in part of the radiating near-field region, the measurements are not so complex. Measurements only of the orthogonal electric field components of the electromagnetic field are sufficient in this region.

Both broadband and narrowband measurements are possible in this case.

Additional details can be found in [IEC 62232], [ITU-T K.61] and [ITU-R BS.1698].

7.2.1 Selection of the points of investigation

When evaluating the RF EMF exposure in the neighbourhood of any radiocommunication station, the points where the measurements will be performed must be carefully selected. Ideally, the effective EIRP, the antenna height, the azimuth, the downtilt and the radiation pattern should be known to perform a cautious selection of the points of investigation. However, mainly for broadcast antennas, the knowledge of the exact radiation pattern is not easily available. These antennas may be designed for specific scenarios and may contain sets of elements (e.g., panels) with individually designed feeding arrangements.

If the available data are not sufficient, the selection of the POI may be done by careful visual inspection and some calculations taking notes of nearby buildings, and considering their heights and distances to the source.

A single dipole antenna approach (see Equation 7-1) can be considered as a worst-case scenario for almost all situations. This means that if one does not have enough information about the antenna radiation pattern or does not have software tools (or enough time) to perform the estimation of the RF EMF exposure in the region of interest, then it is possible to consider a worst-case scenario. If the RF EMF exposure is compliant in this scenario, it will be in the real conditions as well.

The power density, taking into account the reflection coefficient equal to 1 ($\rho=1$), is given by Equation 7-2.

$$F(\theta,\phi) \approx \cos^2 \theta \qquad (7\text{-}1)$$

$$S(R,\theta,\phi) = (1+\rho)^2 \frac{EIRP}{4\pi R^2} F(\theta,\phi) = \frac{EIRP}{\pi R^2} \cos^2 \theta \qquad (7\text{-}2)$$

The envelope curves for the frequency ranges of 10-400 MHz and 400-2000 MHz can be traced using Equations 7-3 and 7-4, respectively. These equations are valid for the following conditions: general public exposure equals the frequency range limit (S = 2 W/m^2 for 10-400 MHz and S = f / 200 W/m^2 for 400-2000 MHz) and the reflection coefficient equals 1 ($\rho=1$).

$$h = H - \sqrt{-x^2 + x\sqrt{\frac{EIRP}{2\pi}}} \; ; \text{for } 0 \leq x \leq \sqrt{\frac{EIRP}{2\pi}} \qquad (7\text{-}3)$$

$$h = H - \sqrt{-x^2 + x\sqrt{\frac{200 \times EIRP}{f \times \pi}}} \; ; \text{for } 0 \leq x \leq \sqrt{\frac{200 \times EIRP}{f \times \pi}} \qquad (7\text{-}4)$$

where:

- h: the envelope curve height, in metres (m)
- H: the antenna height, in metres (m)
- x: the distance from the base of the antenna to the base of the building, in metres (m)
- f: the frequency, in MHz
- $EIRP$: the equivalent isotropically radiated power in the direction of the largest antenna gain, in watts (W).

In Figure 7-1 a typical scenario of an FM broadcasting station is shown, where technician staff would choose the adjacent building to measure the RF EMF exposure. However, the farther building top may be exposed to higher E-field (or H-field) and should be chosen for the RF EMF exposure assessment. It can be guaranteed that the real E-field on the top of the two closer buildings is compliant. The same is not guaranteed for the farther building, as long as the real radiating pattern is unknown.
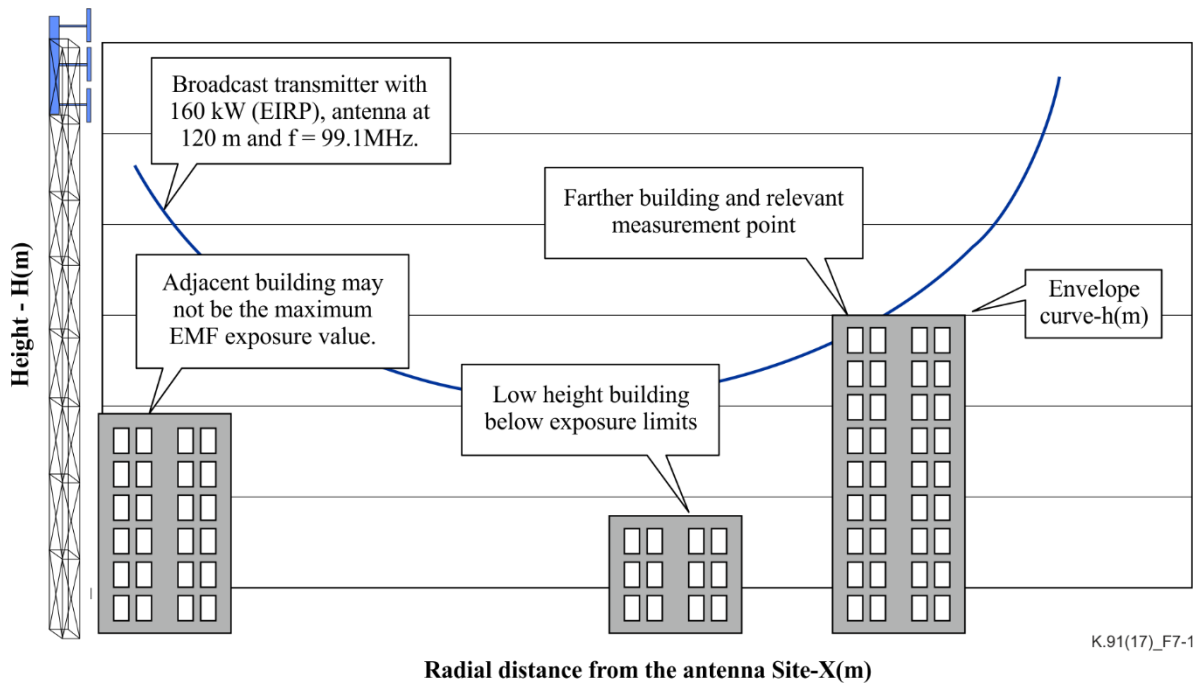
NOTE – The farther building is the place with potentially higher exposure levels.

Figure 7-1 – A big city with an FM broadcasting station located downtown

7.2.2 Spatial averaging

Multi-path reflections can create non-uniform field distributions. Therefore, in some regulations to assess the whole-body human exposure, an averaging process is required. The field values are then determined at N points (3, 6, 9, 20 or other) as described in [IEC 62232] and [ITU-T K.61]. Three points, at the heights of 1.1 m 1.5 m and 1.7 m above the terrain level are basically recommended, but if higher accuracy is required the number can be increased in accordance with national or regional standards and regulations (see [ITU-T K.61]).

7.2.3 Time averaging

Signals used in radiocommunication exhibit a variation with time due to the traffic or modulation (mobile communication systems) or due to the picture content (analogue TV systems) or non-continuous nature of the signal (radars) and for many other reasons (e.g., maintenance time). On the other hand, some signals have very small time variation (e.g., FM signal).

[b-ICNIRP] recommends the use of the 6-minute averaging time for frequencies between 100 kHz and 10 GHz, or 68/f 1.05 minutes for frequencies above 10 GHz for power density evaluation. This reference (6-minute averaging time) in [b-ICNIRP] is expanded for the RF EMF measurements, however the averaging time is based on the heating phenomena (the SAR measurement), not by the time variation of the radiocommunication signals.

In the case of the frequency selective measurement, when spatial averaging is applied and there are many radiating sources, measurement procedures at each POI may take a long time due to the 6-minute averaging time.

A comparison of the measurement results for a 6-minute averaging time and 1-minute averaging time shows that the difference in results is on the level lower than 1 dB. Figure 7-2a shows the results of the RF EMF measurement for seven mobile base stations and for the averaging time of 10, 20, 30, 40, 50, 60, 120, 180 and 360 seconds. In Figure 7-2b a standard deviation (SD) is shown for these measurements. It can be seen that the difference between results of measurement using different averaging times is less than 0.4 dB and is small in comparison with the day-long variation (about 3 dB) and week-long variation (up to 10 dB).
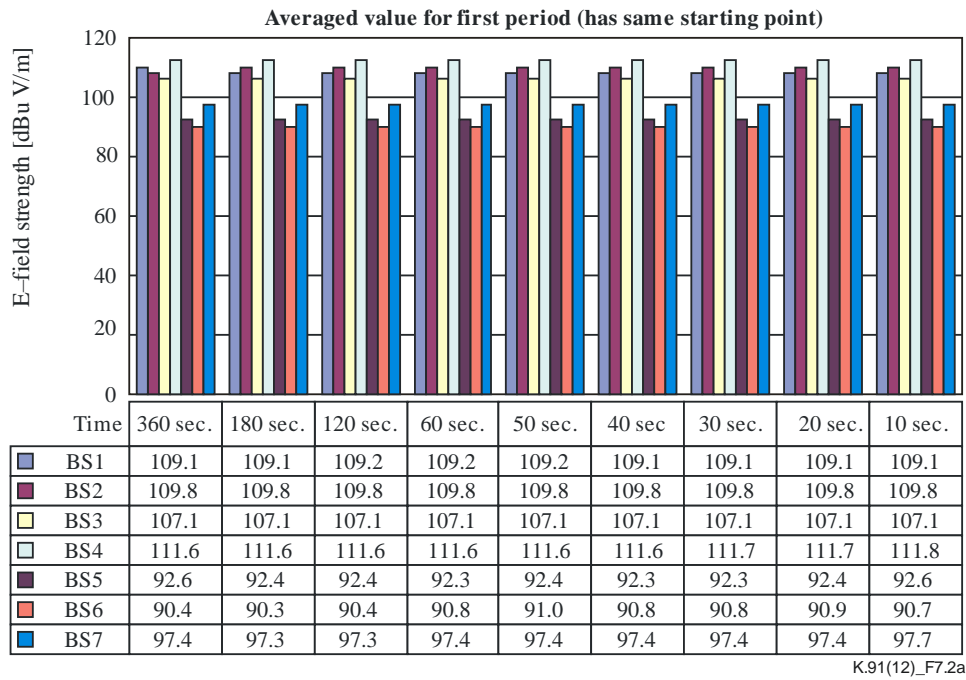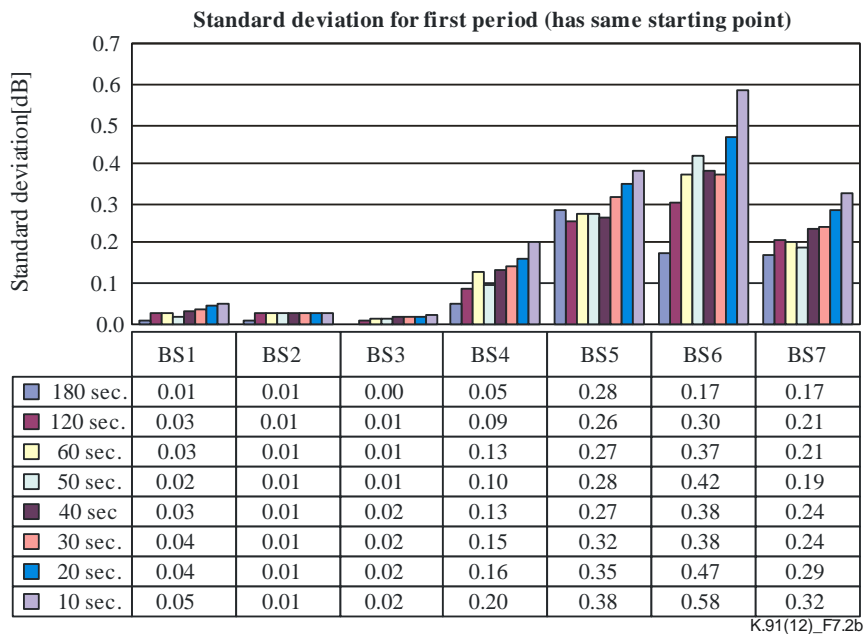
Figure 7-2a – Averaged value

Table for Figure 7-2a:

Time	360 sec.	180 sec.	120 sec.	60 sec.	50 sec.	40 sec	30 sec.	20 sec.	10 sec.
BS1	109.1	109.1	109.2	109.2	109.2	109.1	109.1	109.1	109.1
BS2	109.8	109.8	109.8	109.8	109.8	109.8	109.8	109.8	109.8
BS3	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1
BS4	111.6	111.6	111.6	111.6	111.6	111.6	111.7	111.7	111.8
BS5	92.6	92.4	92.4	92.3	92.4	92.3	92.3	92.4	92.6
BS6	90.4	90.3	90.4	90.8	91.0	90.8	90.8	90.9	90.7
BS7	97.4	97.3	97.3	97.4	97.4	97.4	97.4	97.4	97.7

K.91(12)_F7.2a

Figure 7-2b – Standard deviation

Table for Figure 7-2b:

	BS1	BS2	BS3	BS4	BS5	BS6	BS7
180 sec.	0.01	0.01	0.00	0.05	0.28	0.17	0.17
120 sec.	0.03	0.01	0.01	0.09	0.26	0.30	0.21
60 sec.	0.03	0.01	0.01	0.13	0.27	0.37	0.21
50 sec.	0.02	0.01	0.01	0.10	0.28	0.42	0.19
40 sec	0.03	0.01	0.02	0.13	0.27	0.38	0.24
30 sec.	0.04	0.01	0.02	0.15	0.32	0.38	0.24
20 sec.	0.04	0.01	0.02	0.16	0.35	0.47	0.29
10 sec.	0.05	0.01	0.02	0.20	0.38	0.58	0.32

K.91(12)_F7.2b

For the RF EMF measurement in the case of typical radiocommunication systems such as code division multiple access (CDMA), it looks permissible to make measurements with a 1-minute averaging time if the total exposure is far (3 dB) below the exposure limit. In addition, shorter averaging time is also available if a larger uncertainty is allowed or if a conservatively large margin to the exposure limit due to the averaging is introduced. In such a case, sufficient rationale for the selection of the value should be provided. If the total exposure is closer to the exposure limit then the 6-minute averaging time should be used. This simplification is not valid for signals of a non-continuous nature (radars).

[IEC 62232] recommends time averaging according to the relevant exposure limits at the time of day that would ensure the highest average RF field strength conditions (i.e., under maximum traffic conditions). A long-term measurement (over a day or a week if possible) may be useful to determine

when the highest average RF field strength occurs – if this information is unknown for appropriate time averaging to determine compliance with the relevant exposure limits.

The number of sampling data that is taken in the averaging procedure is also important. It has as much effect on the averaged results as averaging time. In Appendix II this effect is described.

7.2.4   Broadband measurement

Broadband measurement of the RF EMF in the far field region is the simplest measurement method for compliance assessment. In this method, the sum of the RF EMF contributions (electric or magnetic field depending on probe type) from all the radio sources within a wide frequency range is measured. Problems may occur if the radio sources operating outside frequency range of the probe are present. On the market there are electric field probes available that cover these frequency bands, for example, from 100 kHz to 6 GHz or 3 MHz to 18 GHz. These frequency bands cover the operating frequencies of almost all most widely used radiocommunication services. Outside the band of the first probe are many fixed point-to-point (FPP) systems (e.g., 11 GHz, 13 GHz, 23 GHz). However, FPP systems are radiating with very narrow beams, thus they usually can be neglected in the exposure assessment as systems giving very small contributions in the areas accessible to people. Outside the band of the second probe are the AM broadcasting systems (LW, MW and SW) and some FPP systems (e.g., 23 GHz band).

For broadband measurement, the exposure ratio corresponding to the most restrictive reference level at the considered frequency range has to be taken, unless the measurement device incorporates a weighting function consistent with the exposure limits. This means that the broadband measurement usually gives conservative results.

The broadband measurements are simpler and less time consuming than the frequency selective ones but tend to be less sensitive for measurement of low-level exposures. Even though they are less accurate, however, they can be applied in many cases. If the exposure level is not compliant with the limit, then the frequency selective measurements are required.

Additional information can be found in [IEC 62232].

7.2.5   Frequency selective measurement

Frequency selective measurement can provide information on the field strength and the spectral characteristics of the measured RF EMFs. These measurements allow for the use of different exposure limits in the different frequency ranges but require post-processing. These measurements give information about frequencies of measured sources and about contribution of each of them to the total exposure.

The results of the exposure assessment using the frequency selective measurements are more accurate in comparison with the results of the broadband measurements. In Figure 7-3 an example of the results of the frequency selective measurement is presented. Table 7-1 presents another example of the numerical results of the frequency selective measurements (the combined electric field strength is presented for each frequency band).
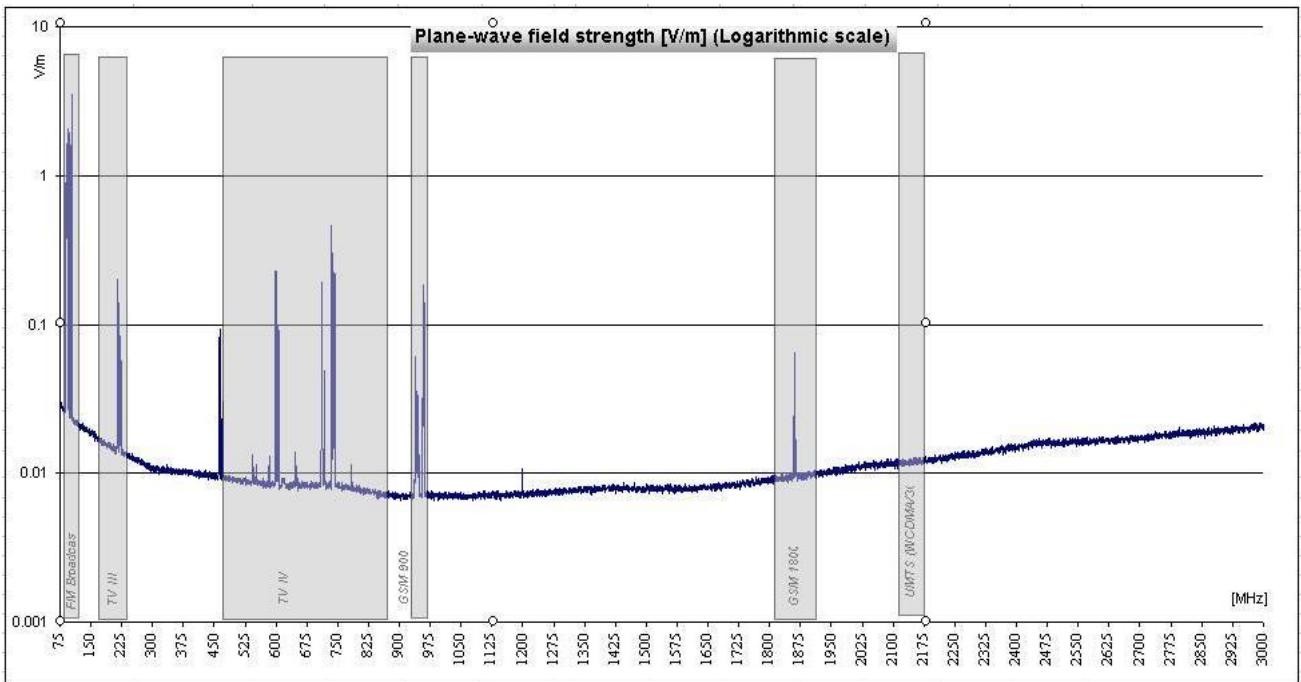
Figure 7-3 – Example of the result of the frequency selective measurement

Table 7-1 – Example of the numerical results of the frequency selective measurements

Measurement point	Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (V/m)	Exposure ratio
1-2	FM broadcast	87.5-108	28	1.1 1.5 1.7	0.5506 0.6673 0.8330 Average	0.0003867 0.0005680 0.0008851 0.0006132
	VHF TV	174-230	28	1.1 1.5 1.7	0.0727 0.0712 0.0700 Average	0.0000067 0.0000065 0.0000063 0.0000065
	UHF TV	470-862	30	1.1 1.5 1.7	0.1598 0.1603 0.1621 Average	0.0000284 0.0000286 0.0000292 0.0000287
	GSM 900	925-960	42	1.1 1.5 1.7	0.1554 0.1436 0.1850 Average	0.0000137 0.0000117 0.0000194 0.0000149
	GSM 1800	1805-1910	58	1.1 1.5 1.7	0.0628 0.0783 0.1107 Average	0.0000012 0.0000018 0.0000036 0.0000022
	UMTS (WCDMA/3G)	2110-2170	61	1.1 1.5 1.7	0.1018 0.1059 0.0839 Average	0.0000028 0.0000030 0.0000019 0.0000026
					Sum	0.0006681

The results in Figure 7-3 and in Table 7-1 correspond to two different points of investigation. For the comparison with the exposure limits post-processing is required in both cases. This is done in Table 7-1 and the results show that the total exposure ratio of this POI is compliant. The reference levels are from [b-ICNIRP].

Additional information can be found in [IEC 62232].

7.2.6 Near-field measurement

In the near-field region the electric (E) and magnetic (H) field components are not proportionally related to each other and depend on the RF EMF source properties. Therefore, both the electric and magnetic field components shall be measured, respectively. The total exposure for the combined E-field component and the combined H-field component shall be compared with exposure limits independently.

7.2.7 Post-processing

Post-processing is not required if only one RF EMF source is measured. If many RF EMF sources are in operation then post-processing consisting in the evaluation of the total exposure is usually required.

If a broadband measurement is performed and the band of the probe covers the whole range of operating frequencies then post-processing is not required. If a broadband measurement needs more than one probe to cover all the operating emissions then post-processing is also required.

Frequency selective measurement usually requires post-processing to evaluate the total exposure, taking into account the measured values and the respective exposure limits for each operating frequency. Some measurement instruments allow for the evaluation of the combined E using the most restrictive exposure limit in the considered frequency band. In this case the following formula is used:

$$E = \sqrt{\sum_{i=1}^{n} E_i^2} < E_{\lim} \qquad (7\text{-}5)$$

where E is the total electric field, due to all emissions.

In the above formulas for the electric field its rms value should be taken but in practice the root sum square (rss) values are measured [EN 50383]. This is a typical approach not only for the wideband equipment but also for the frequency selective one. This result is then compared with the value of the strongest limit for the frequency band covering all emissions. This is very convenient but the evaluation is conservative. If such results show no compliance then appropriate frequency selective measurements should be done together with the post-processing to reassess compliance.

7.2.8 SAR measurement

For cases when compliance with the reference levels cannot be demonstrated, the basic restrictions may instead be used for compliance verification. For mobile communication frequency bands, SAR is usually the exposure metric to consider. Compliance assessments based on SAR are in general required for RF sources used close to the body (see [IEC 62232], [IEC 62209-1] and [IEC 62209-2]). SAR measurements are mainly conducted by specialized laboratories, since the measurements are complex and require special equipment. SAR measurement methodologies make use of phantoms simulating the human head or body which have been developed to provide conservative results with respect to exposure in real humans.

7.3 Calculations

Depending on the distance to the radiating source, different methods of calculation should be used guaranteeing sufficient accuracy of results. In general, if the relative distance (in relation to a

wave-length) is shorter, then more sophisticated and technically difficult methods have to be applied. Calculations are relatively simple in the far-field region.

Additional details are given below and can be found in [IEC 62232], [ITU-T K.52], [ITU-T K.70] and [ITU-R BS.1698].

7.3.1 Methods of calculation in different field regions

There are many methods of calculation with varying degrees of accuracy and complexity. It is advised to use the simplest appropriate method for the exposure assessment. The choice is highly dependent on the field region in which points of investigation are located in relation to the radiating source. Below, the most frequently used methods are presented, starting from the simplest one.

7.3.1.1 Point-source model

The point-source model is a simple but very effective model which may be used for calculating exposure levels to be used in comparison with the reference levels (see [IEC 62232], [ITU-T K.52], [ITU-T K.61] and [ITU-T K.70]). It is assumed that the transmitting antenna is represented only by one point source, situated in the antenna electric centre and having a radiation pattern of the considered transmitting antenna. In this case the equivalent plane-wave power density S_{eq} at the distance R to the antenna is as follows:

$$S_{eq} = \frac{P \cdot G_i}{4\pi R^2} F(\theta, \phi) \tag{7-6}$$

S_{eq}: equivalent plane-wave power density (W/m^2) in a given direction

R: distance (m) from the radiation source

P: average power (W) emitted when the transmitter operates at maximum emission settings (all channels transmitting at their respective maximum power setting) and supplied to the radiation source (transmitting antenna)

G_i: maximum gain of the transmitting antenna, relative to an isotropic radiator

$F(\theta, \phi)$: antenna numeric gain (normalized gain), θ – elevation angle, ϕ – azimuth angle.

is fully acceptable in the far-field region. The boundaries of the field regions are defined according to slightly different criteria which can be found in [IEC 62232], [ITU-R BS.1698], [ITU-T K.52] and [ITU-T K.61]. This model is implemented in the software EMF-estimator ([ITU-T K.70] Appendix I) and in the mobile App "EMF Exposure" (see Appendix VIII).

The simplest version of this method is if the isotropic radiation pattern is used with maximum ERP. In this case the formula for the equivalent plane-wave power density S_{eq} at the distance R to the antenna has simplest form:

$$S_{eq} = \frac{P \cdot G_i}{4\pi R^2} \tag{7-7}$$

The formula above is very useful for the first approximation of the expected field level, especially during pre-analysis. In real cases this formula may give a very high estimate. However, if the calculations based on this formula show compliance then no further assessment is needed.

7.3.1.2 Synthetic model

In the synthetic model [IEC 62232] or [b-EN 50413] each antenna is considered to be a set of elementary sources which have identical parameters. Such an approach is natural, for example, for broadcast antennas which usually contain sets (up to 64) of identical panels operating as one transmitting antenna [ITU-R BS.1195]. In the case of global system for mobile communications (GSM) panels (or similar antennas), they can be divided into "patches" (usually containing one dipole with a screen) and each of them can be considered as a separate radiating source. This model can be

employed for distances beyond the near-field distance, which is calculated with respect to the maximum size of an elementary radiating source (patch in GSM, panel in broadcasting) and not the size of the whole system. In this case the electric field strength E in the POI is as follows:

$$E = \sum_n \frac{\sqrt{30 P_n G_n}}{r_n} e^{j(\gamma_n + \frac{2\pi r r_n}{\lambda})} \qquad (7\text{-}8)$$

P_n: average power (W) delivered to the input of the nth radiating panel or "patch"

r_n: distance between POI and the centre of the nth radiating panel or "patch"

γ_n: relative phase of voltage delivered to the nth radiating panel or "patch"

G_n: gain of nth radiating panel or "patch" towards the POI relative to an isotropic antenna

λ: wavelength

The synthetic model leads to very accurate results, but the accuracy is lower than in the full-wave modelling, because the coupling between radiating sources is neglected. In many cases (e.g., for all the broadcasting antennas or mobile BS panels) this assumption is well fulfilled.

A disadvantage of this model is that the exact information concerning the feeding arrangement (P_n and γ_n) of the antenna system containing many radiating sources is required.

7.3.1.3 Full-wave methods

The highest accuracy of the calculation of the reference levels is achieved by the numerical modelling using one of the full-wave methods based on solving Maxwell's equations in frequency or time domain (see [IEC 62232], [ITU-R BS.1698] and [ITU-T K.61]). It includes the MoM, FDTD and many others. Such methods of calculation may be used for any source region. They use detailed-segmented models of systems where the more detailed-segmented model leads to higher accuracy of the evaluated field distribution.

A typical transmitting station or base station consists of many transmitting antennas. The area required for consideration is usually big and inhomogeneous. In such a case the MoM is more convenient than other methods.

The application of numerical modelling, as described above, requires the appropriate software, experience in electromagnetics, and very detailed input data. There are many commercial packages available. In some cases there are limitations concerning the number of unknowns (the number of segments) that may be used in calculations. The accuracy of the results of calculations strongly depends on the exactness and the range of accessible data concerning a transmitting antenna, which includes antenna geometry and its feeding arrangement. Many antennas (e.g., broadcasting antenna systems, cellular panels) contain a huge number of active radiating elements (up to 256) which are fed with different amplitudes and phases. Without such information the calculation is impossible or may be simplified for a general assessment only. In many cases (e.g., for the GSM panels which also consist of many dipoles) it is very difficult to obtain the required data; it is the manufacturer's proprietary information.

Methods such as MoM also allow for the possibility to take into account all other objects which have an influence on the radiation level as secondary sources causing reflections (e.g., facings made of metallic elements, antenna towers and antenna supporting structures, ground).

In general, the full-wave methods provide a good opportunity to take into account almost all substantial factors influencing radiation, but they are useful in rather simple cases only, or for the reactive near-field region in which other methods are not sufficiently accurate. This is partly so because it is very difficult to collect all the data needed. Additionally, sophisticated software and experience in electromagnetics are required, together with significant computer resources.

7.3.1.4 SAR calculations

For cases when compliance with the reference levels cannot be demonstrated, the basic restrictions may instead be used for compliance verification. For mobile communication frequency bands, SAR is usually the exposure metric to consider. Compliance assessments based on SAR are in general required for RF sources used close to the body (see [IEC 62232]). Numerical models of the device under test and the head or body phantom are required for the SAR calculation. SAR calculations are complex and require experience in numerical modelling. There are several software packages available and the most frequently used method is FDTD, but other methods may also be used.

7.3.1.5 Influence of the reflections

The calculations in many cases are done for free space conditions. A reflection from the ground or from other structures, such as buildings or fencing (especially metallic objects), may lead to an increase in the value of the field level. In the conservative approach the reflections from the ground can be taken into account as in [ITU-T K.52], Appendix II. In typical cases, where an observation point is located up to a few metres above the terrain level, the electric field strength is multiplied by the factor 1.6, which means that the corresponding power density is multiplied by the factor 2.56.

Reflections from other structures are discussed in detail in [IEC 62232] together with the information about factors which can be used in many situations. It should be noted that in a complex environment – with many reflections present – the highest multiplication factor should be used. In practice, the maximum value of the multiplication factor is 2 for the electric field strength, which corresponds to 4 for the power density.

7.3.2 Modelling of the transmitting antennas

The real source of intentional RF EMF is the transmitting antenna – not the transmitter itself, because the transmitting antenna is the radiating source that determines the RF EMF distribution in the vicinity of a transmitting station. From the viewpoint of protection against exposure the most important parameters of the transmitting antenna (or radiating source) are: operating frequency, EIRP and radiation pattern (which also determine the antenna directivity and the antenna gain). The antenna radiation pattern requires modelling.

The transmitting antenna is represented by the 3D radiation pattern $f(\theta,\phi)$ [ITU-R BS.1195]. In the numerical modelling (e.g., MoM, FDTD) the radiation pattern (or directivity) is determined by the numerical solution that depends on the geometry and feeding arrangement of the transmitting antenna. The radiation pattern $f(\theta,\phi)$ is a function of the elevation and azimuth angles. The best accuracy can be achieved if the exact 3D radiation pattern $f(\theta,\phi)$ is known and is directly used in the calculation. However, in practice the telecommunication operator knows only the two cross-sections of the radiation pattern: in a horizontal plane (called horizontal radiation pattern (HRP)):

$$H(\phi) = f(\theta,\phi)\big|_{\theta=\theta_{max}} \qquad (7\text{-}9)$$

$H(\phi)$: HRP

θ: elevation angle

ϕ: azimuth angle

θ_{max}: elevation angle at which the maximum radiation occurs.

and in a vertical plane (called VRP):

$$V(\theta) = f(\theta,\phi)\big|_{\phi=\phi_{max}} \qquad (7\text{-}10)$$

$V(\theta)$: VRP

ϕ_{max}: elevation angle at which the maximum radiation occurs.

The actual values of the radiation pattern for any elevation and azimuth angles are usually approximated by the relationship [ITU-R BS.1195]:

$$f(\theta, \phi) = H(\phi) \cdot V(\theta) \qquad (7\text{-}11)$$

There are many models of transmitting antennas with different degrees of complexity and accuracy that may be used. The most important are the following.

–	antenna with isotropic radiation pattern and with maximum EIRP: This model is the simplest one and may be used to model any transmitting antenna, however, it gives most conservative results with the highest overestimation of the level of exposure;

–	antenna as a point source with HRP and VRP: This model is sufficient for the far field region; radiation patterns may be delivered by the manufacturer or evaluated using specialist antenna software (MoM may be used for this purpose). If the radiation patterns are evaluated the data concerning transmitting antenna configuration (including feeding arrangement) is required;

–	antenna as a point source with radiation pattern as a two-dimensional function $f(\theta, \phi)$: In general the applicability is as above, however, results of exposure assessment will be more accurate because there is no need for interpolation of the radiation pattern for the direction outside HRP and VRP;

–	antenna model in the full-wave software (like MoM or FDTD): This model is most accurate, with applicability even in the reactive near-field region; it also allows for the SAR evaluation (FDTD, MoM/FEM) if compliance with basic restrictions is needed. This model requires very detailed data concerning the configuration of each metal or dielectric part of the antenna (also antenna tower if necessary) and concerning the feeding arrangement.

The radiation pattern is a function of frequency and for a wideband antenna system varies substantially across the antenna band. This means that for wideband transmitting antennas the radiation patterns have to be evaluated for each operating frequency (e.g., FM, VHF, UHF broadcasting); for other radiocommunication systems one radiation pattern is sufficient for all the operating channels (mobile communication – in each band).

### 7.3.3	Radiated power ERP/EIRP evaluation

The ERP is a product of the power supplied to an antenna and the maximum antenna gain relative to the half-wave dipole. If the antenna gain is taken relative to the isotropic antenna than EIRP is evaluated. The following relations hold between ERP and EIRP:

$$EIRP\ [dBd] = ERP\ [dBi] + 2.15 \qquad \text{dB} \qquad (7\text{-}12)$$

$$EIRP\ [W/W] = 1.64\ ERP\ [W/W] \qquad (7\text{-}13)$$

where:

>	2.15 dB is the gain of the half-wave dipole relative to the isotropic antenna.

The EIRP has to include not only the directivity of the antenna and its dissipative losses but also the attenuation of the feeding system. The main contribution to the attenuation of the feeding system is due to the feeder (usually coaxial cable) but also to the connectors and in some cases to the combiners and additional connecting lines. A combiner is used to combine many transmitters into one feeder and in consequence to one antenna system. This is a typical situation in broadcasting where, for example, many FM transmitters are feeding one antenna system. Additional losses may be also present in mobile communication when combining many channels into one transmitting antenna panel or by diplexer giving separation of the transmitting and receiving frequency bands. Thus, the EIRP should be calculated using the formula:

$$EIRP\ [dBm] = P\ [dBm] + G_i\ [dBi] - L \qquad \text{[dB]} \qquad (7\text{-}14)$$

where:

P: average transmitter power in dBm (relative to the 1 mW)

G_i: antenna gain (including internal losses) relative to an isotropic antenna

L: transmission losses in dB (including feeder losses and additional losses).

For example, if the GSM900 antenna (with antenna gain G_i=17 dBi) is fed by 30 m of the foam coaxial cable of diameter 7/8" (attenuation about 6.9 dB/100 m on 925 MHz) then the feeder losses equal 2.07 dB. Additional losses for the connectors may be assumed 0.3 dB so the total losses equal 2.37 dB. If the GSM transmitter has 30 W output power then the EIRP = 871.2 W. If the losses are neglected then EIRP = 1503.6 W. It is seen that if losses are neglected then there is substantial overestimation of the EIRP and in consequence the level of exposure. Typical level of the losses are in the range from 1 to 3 dB but in some cases it may reach 6 dB or more.

In the case of human exposure evaluation, the average transmitter power P should be used. For many services (e.g., all digital, FM.) the average power is equal to the nominal (rated) transmitter power. However, there are some services like analogue TV or LW, MW and SW transmitters in which the average power is different. In this case a conversion factor should be used.

Additional information can be found in [ITU-T K.70] and [ITU-R BS.1698].

7.4 Comparison between measurement and calculations

Measurements require measuring equipment and experienced staff. Measurements referring to basic restrictions are done on phantoms of the human body (especially head) and are very complex and expensive. They are usually performed by specialized laboratories. Measurements of the reference levels are much easier and cheaper, and may be wideband or frequency selective. More accurate are the frequency selective measurements but measuring equipment is more expensive and the measurements are more time consuming.

The main advantages of measurements as the method for exposure assessment are:

– it takes into account all the radiating sources present in a given region, with their real parameters;

– it takes into account the real environment (e.g., reflections, antenna supporting hardware, obstacles);

– it takes into account simultaneous exposure in the real way (the phase differences of different waves);

– it can be done with little knowledge about radiating sources (a preliminary identification of occupied spectrum is required only);

– good quality measurement equipment is available on the market;

– a live demonstration of the measurement to interested people is possible.

The main disadvantages are:

– measurement is not possible when a radiating source (new or additional) is in the design stage unless a temporary transmitter can be installed;

– in many cases (e.g., mobile communication) the exposure level depends on the time of measurement (peak-hours or off peak-hours), so the measurement may not reflect the maximum exposure and the results can be underestimated;

– the influence of personnel and equipment on the local distribution of the electromagnetic field will increase uncertainty and should be minimized;

– it is difficult to confirm and check that all the sources in a given environment are operating at maximum EIRP;

–   in a multiple sources environment a post-processing is required because of different limits for different operating frequencies;

–   there is no probe covering the whole required frequency range, so usually a set of probes is needed for measurements;

–   out-of-band emissions may have an influence on the results of measurements in the considered frequency band (this should be eliminated during the post-processing).

The calculations require specialized software, experienced staff and data concerning the transmitting systems (antennas). There are many commercial packages allowing for the RF EMF evaluation, based on various models offering different level of accuracy, and requiring different experience and input data. Generally, the more sophisticated software the bigger are the requirements concerning input data (parameters of the transmitting antennas) and qualifications of staff, but the results of the evaluation are more accurate.

The calculations of quantities used for basic restrictions (e.g., SAR) or the RF EMF exposure levels (to compare with the reference levels) are possible. The calculations of SAR are more complex and time consuming, and require the numerical model of the human body.

The advantages of calculations as the method for exposure assessment are:

–   the method allows to consider the planned radiating sources (not in operation yet);

–   it allows to apply the maximum possible exposure conditions (EIRPs) that lead to the evaluation of the maximum possible exposure level;

–   the choice among many calculation methods of varying levels of complexity and accuracy is possible;

–   calculations with high levels of overestimation are easy to perform and are sufficient in cases where exposure levels are far below the limits;

–   calculation costs are lower than the costs of measurement;

–   calculations allow the simulation of mitigation techniques if required [ITU-T K.70] provides an analysis of the influence of the variation of transmitting equipment parameters on exposure levels;

–   calculations for areas with no access (e.g., safety reason, no right to access) are possible;

–   the data on the much denser grid (than in measurement) can be obtained and a visualization of the results can be easily prepared for the whole considered area (e.g., horizontal or vertical cross-sections).

The disadvantages of the calculations are:

–   for accurate evaluation, a detailed description of the radiating antennas (e.g., geometry, feeding arrangement, data concerning panels) is necessary;

–   the effect of reflections from various objects is difficult to model;

–   the method requires knowledge of the software and experience in using it (understanding of the background theory is also recommended);

–   it requires at least basic knowledge of the transmitting antennas theory.

There are many methods of measurements and calculations, of varying levels of complexity and accuracy. The uncertainty of the calculations and measurements depends on the method used. In general, the best approach is to start with the simplest method (of measurement or calculation) with the least accuracy and, preferably, high overestimation. If exposure levels appear to be close to exposure limits then a more sophisticated (complex) method, that offers higher accuracy but also needs more precise input data, better tools and more experienced staff, should be used.

[IEC 62232] provides guidance on verification of the software and considers uncertainties in some detail.

7.5 Monitoring RF EMF levels

As an effort to increase the information about RF EMF exposure levels, a long-term RF EMF measurement system may be a good solution. Such a system monitors the exposure levels of the general public in specific locations. The results of continuous measurement of the exposure level in the whole spectrum used in radiocommunication are registered by the automatic system in order to show the exposure as a function of time. The results of measurements may be presented for the general public by a user-friendly tool accessible via Internet (see [ITU-T K.113]). Such a system is more transparent and may be reassuring to citizens worried whether RF EMF levels are under control.

Additional information can be found in [ITU-T K.83].

8 Conclusions following the exposure assessment

If all areas accessible to people are compliant with limits then the exposure assessment can be finished and no further action is required.

If there are areas accessible to people that are not compliant with the limits then immediate action is required and two solutions are possible:

1) areas not compliant with the limits should be properly marked and/or barricaded to prevent the presence of the general public or to limit the time workers are present;

2) some mitigation techniques should be applied to decrease the exposure levels and to achieve compliance with the limits in all the areas accessible to people.

The simplest method of achieving compliance with the limits is to decrease a transmitter (transmitters) output power (it is easy to apply but it decreases the coverage of the radiocommunication service) or adjust the location of the antennas (e.g., BS antennas can be mounted above an accessible rooftop). Many other methods of mitigation are possible which do not lead to degradation of the service quality.

Additional information can be found in [ITU-T K.70] or in [b-IEEE C95.7].

9 Final report

Requirements concerning the form of the final reports may vary in different countries, however some of them are common in most cases. The content of the final report should contain:

– description of the transmitting station (or area) that is the subject of the report;

– description of the RF EMF sources in the area under consideration;

– description of the methods of exposure assessment that are used;

– information concerning measurement equipment or calculation tools;

– information about factors that may influence results of measurements and/or calculations (e.g., humidity, type of terrain, possible reflecting objects);

– results of the exposure assessment;

– the final conclusions – the most important is the statement if the considered area accessible to people is compliant with regulations;

– information concerning authors of the report (affiliation, names).

It is advisable to use tables and charts (especially for the presentation of the results of the exposure assessment) in order to make information as clear as possible even for inexperienced readers.

Additional information can be found in [IEC 62232].

10 Field levels around typical transmitting antennas

In Appendix III some examples of the measured RF EMF levels in the areas accessible to general public are presented. It can be noticed that in general the exposure levels are much lower than exposure limits. This is because it is most important for the telecom operator to achieve as uniform as possible distribution of the RF EMF in the coverage area. It means that the radiation patterns of the antenna systems are designed in such a way that the highest radiation levels are pointed into longer distances and the lower levels into shorter distances. In consequence, the highest part of the energy is radiated above the terrain close to the antenna tower.

[ITU-T K.122] includes information concerning exposure levels that may be expected in the areas in close proximity to the transmitting antennas. Such areas are usually not accessible to the general public, but the presence of maintenance staff may be temporarily required in such places.

In the case of mobile handsets, the antenna radiation pattern is close to omnidirectional because the base station in which the connection is established can be in any direction. It is not reasonable to reduce the radiation level in the direction of the human head because it may be the same direction as to the base station. But in the mobile handsets the radiation level is set as low as possible for the reliable communication (automatic power control (APC)) and it is strictly controlled before the device is put on the market.

In general, digital radiocommunication systems are more efficient and use lower radiated power. This means that, in general, transition from analogue to digital systems leads to lower levels of human exposure.

11 Conclusions

There are many possible methods of the exposure assessment and each of them has its own advantages and disadvantages. This Recommendation gives guidance on the method to be chosen, depending on needs and circumstances.

Additional information can be found in [IEC 62232] and [ITU-T K.52].

Appendix I

Exposure limits

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

I.1 Introduction

There is no international consensus on the EMF exposure limits but WHO recommends the adoption of limits based on the ICNIRP [b-ICNIRP] and IEEE [b-IEEE C.95.1] guidelines. Nevertheless, national regulations have priority. Exposure limits in various countries can be found on the WHO website: http://www.who.int/gho/phe/emf/legislation/en/.

In most cases, the EMF exposure limits are based on [b-ICNIRP] or [b-IEEE C95.1] guidelines that are based on the scientific research and currently available knowledge. The least discrepancy of the exposure limits of these two guidelines is for the frequencies from 30 MHz to 3 GHz, covering ranges of highest interest in radiocommunication. The last revision of [b-IEEE C.95.1] resolves a major harmonization issue with ICNIRP and IEEE RF standards. The efforts to achieve internationally harmonized exposure limits continue. In many cases exposure limits are also given by national authorities (national regulations) and they are often prepared in a different way and based on different assumptions.

I.2 Exposure limits

Exposure limits are defined for the general public (uncontrolled environment) and for occupational exposure (controlled environment). It is understandable that exposure limits for the general public are more conservative (restrictive) than those for occupational exposure.

Two kinds of guidance exist: 1) basic restrictions based directly on established adverse health effects; 2) reference levels provided for practical exposure assessment purposes, to determine whether basic restrictions are likely to be exceeded.

The reference levels as exposure limits are used in all the countries that regulate exposure limits. In contrast, basic restrictions may be defined differently. For example, instead of SAR the energy loading value as the quantity for basic restriction is used, time and space averaging procedures are different, or instead of the average a maximum value over certain space and/or time is used, etc.

As mentioned above the ICNIRP guidelines are used worldwide, either directly or as the basis for national regulations. Even in the countries where the national regulations do not allow using the ICNIRP guidelines, the recommended exposure limits are usually more restrictive. In those countries where the regulations concerning human protection against non-ionizing radiation do not exist, the guidelines give the opportunity to take some protective measures. Thus, the ICNIRP guidelines constitute a reliable and established reference basis for applications, discussion and further development of the domain. A similar role can be played by the IEEE guidelines [b-IEEE C.95.1]. For this reason, both ICNIRP and IEEE/ICES limits are given for information in this appendix.

I.3 ICNIRP exposure limits

The limits for the basic restrictions and for the reference levels are shown in Tables I.1 and I.2.

Table I.1 – ICNIRP basic restrictions limits

Type of exposure	Frequency range	Current density for head and trunk (mA/m^2) (rms)	Whole-body average SAR (W/kg)	Localized SAR (head and trunk) (W/kg)	Localized SAR (limbs) (W/kg)
Occupational	Up to 1 Hz	40			
	1-4 Hz	40/f			
	4 Hz-1 kHz	10			
	1-100 kHz	f /100			
	100 kHz-10 MHz	f /100	0.4	10	20
	10 MHz-10 GHz		0.4	10	20
General public	Up to 1 Hz	8			
	1-4 Hz	8/f			
	4 Hz-1 kHz	2			
	1-100 kHz	f /500			
	100 kHz-10 MHz	f /500	0.08	2	4
	10 MHz-10 GHz		0.08	2	4

NOTE 1 – f is the frequency in Hertz.

NOTE 2 – Due to electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.

NOTE 3 – All SAR values are to be averaged over any 6-minute period.

NOTE 4 – The localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.

Table I.2 – ICNIRP reference levels (unperturbed rms values) limits

Type of exposure	Frequency range	Electric field strength (V/m)	Magnetic field strength (A/m)	Equivalent plane wave power density S_{eq} (W/m^2)
Occupational exposure	Up to 1 Hz	–	1.63×10^5	–
	1-8 Hz	20 000	$1.63 \times 10^5/f^2$	–
	8-25 Hz	20 000	$2 \times 10^4/f$	–
	0.025-0.82 kHz	500/f	20/f	–
	0.82-65 kHz	610	24.4	–
	0.065-1 MHz	610	1.6/f	–
	1-10 MHz	610/f	1.6/f	–
	10-400 MHz	61	0.16	10
	400-2000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	f/40
	2-300 GHz	137	0.36	50

Table I.2 – ICNIRP reference levels (unperturbed rms values) limits

Type of exposure	Frequency range	Electric field strength (V/m)	Magnetic field strength (A/m)	Equivalent plane wave power density S_{eq} (W/m^2)
General public	Up to 1 Hz	–	3.2×10^4	–
	1-8 Hz	10 000	$3.2 \times 10^4/f^2$	–
	8-25 Hz	10 000	$4000/f$	–
	0.025-0.8 kHz	$250/f$	$4/f$	–
	0.8-3 kHz	$250/f$	5	–
	3-150 kHz	87	5	–
	0.15-1 MHz	87	$0.73/f$	–
	1-10 MHz	$87/f^{1/2}$	$0.73/f$	–
	10-400 MHz	28	0.073	2
	400-2000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$f/200$
	2-300 GHz	61	0.16	10

NOTE 1 – f is as indicated in the frequency range column.

NOTE 2 – For frequencies between 100 kHz and 10 GHz, the averaging time is 6 minutes.

NOTE 3 – For frequencies up to 100 kHz, the peak values can be obtained by multiplying the rms value by $\sqrt{2}(\approx 1.414)$. For pulses of duration t_p, the equivalent frequency to apply should be calculated as $f = 1/(2t_p)$.

NOTE 4 – Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 MHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz, it is suggested that the peak equivalent plane-wave power density, as averaged over the pulse width, does not exceed 1000 times the S_{eq} limit, or that the field strength does not exceed the 32 times field strength exposure levels given in the table.

NOTE 5 – For frequencies exceeding 10 GHz, the averaging time is $68/f^{1.05}$ minutes (f in GHz).

I.4 Simultaneous exposure to multiple sources

The exposure assessment in the multiple sources environment, according to the existing standards, requires the calculation of the cumulative exposure (in some standards called also the total exposure ratio). All the operating frequencies must be considered in a weighted sum, where each individual source is pre-rated according to the limit applicable to its frequency. For compliance with the regulations, the total exposure should be less than 1.

I.4.1 Basic restrictions

In the case of simultaneous exposure to fields of different frequencies, the following criteria should be satisfied in terms of the basic restrictions.

For thermal effects, relevant from 100 kHz, specific energy absorption rates and power densities should be added according to:

$$\sum_{i=100\ \text{kHz}}^{10\ \text{GHz}} \frac{SAR_i}{SAR_L} + \sum_{i>10\ \text{GHz}}^{300\ \text{GHz}} \frac{S_i}{S_L} \leq 1$$

where:

J_i is the current density at frequency i

JL, i is the current density basic restriction at frequency i as given in Table I.1

SARi is the SAR caused by exposure at frequency i

SARL is the SAR basic restriction given in Table I.1

Si is the power density at frequency i

SL is the power density basic restriction given in Table I.1.

According to [b-ICNIRP], for simultaneous exposure to fields at different frequencies, the compliance with the exposure limits is evaluated using the equations below. All conditions for the appropriate frequency ranges are to be satisfied.

$$\sum_{i=1\,\text{kHz}}^{1\,\text{MHz}} \frac{E_i}{E_{l,i}} + \sum_{i>1\,\text{MHz}}^{10\,\text{MHz}} \frac{E_i}{a} \leq 1 \tag{I-1}$$

$$\sum_{j=1\,\text{kHz}}^{1\,\text{MHz}} \frac{H_j}{H_{l,j}} + \sum_{j>1\,\text{MHz}}^{10\,\text{MHz}} \frac{H_j}{b} \leq 1 \tag{I-2}$$

where:

E_i: the electric field strength at frequency i

$E_{l,\,i}$: the reference limit at frequency i

H_j: the magnetic field strength at frequency j

$H_{l,\,j}$: the reference limit at frequency j

a: 610 V/m for occupational exposure and 87 V/m for general public exposure

b: 24.4 A/m for occupational exposure and 5 A/m for general public exposure.

$$\sum_{i=100\,\text{kHz}}^{1\,\text{MHz}} \left(\frac{E_i}{c}\right)^2 + \sum_{i>1\,\text{MHz}}^{300\,\text{GHz}} \left(\frac{E_i}{E_{l,i}}\right)^2 \leq 1 \tag{I-3}$$

$$\sum_{j=100\,\text{kHz}}^{1\,\text{MHz}} \left(\frac{H_j}{d}\right)^2 + \sum_{j>1\,\text{MHz}}^{300\,\text{GHz}} \left(\frac{H_j}{H_{l,j}}\right)^2 \leq 1 \tag{I-4}$$

where:

E_i: the electric field strength at frequency

$E_{l,\,i}$: the reference limit at frequency i

H_j: the magnetic field strength at frequency j

$H_{l,\,j}$: the reference limit at frequency j

c: 610/f V/m (f in MHz) for occupational exposure and 87/f$^{1/2}$ V/m for general public exposure

d: 1.6/f A/m (f in MHz) for occupational exposure and 0.73/f for general public exposure.

I.5 IEEE International Committee Electromagnetic Safety (ICES) exposure limits

The IEEE/ICES limits are shown in Tables I.3 and I.4.

Table I.3 – IEEE/ICES basic restrictions for frequencies between 100 kHz and 3 GHz

Type of exposure	Frequency range	Whole-body average SAR (W/kg)	Localized SAR (head, trunk and upper limbs) (W/kg)	Localized SAR (extremities and pinnae) (W/kg)
Controlled environment	100 kHz-3 GHz	0.4	10	20
General public	100 kHz-3 GHz	0.08	2	4

Table I.4 – IEEE/ICES, maximum permissible exposure limits, RF EMF

Type of exposure	Frequency range (MHz)	rms electric field strength (V/m)	rms magnetic field strength (A/m)	rms power density (E-field, H-field) (W/m²)	Averaging time (min) E^2	Averaging time (min) S or H^2
Controlled environment	0.1-1.0	1842	$16.3/f_M$	(9000, 100 000/f_M^2)	6	
	1-30	$1842/f_M$	$16.3/f_M$	(9000/f_M^2, 100 000/f_M^2)	6	
	30-100	61.4	$16.3/f_M$	(10, 100 000/f_M^2)	6	
	100-300	61.4	0.163	10	6	
	300-3000	–	–	$f_M/30$	6	
	3000-30 000	–	–	100	$19.63/f_G^{1.079}$	
	30 000-300 000	–	–	100	$2.524/f_G^{0.476}$	
General public	0.1-1.34	614	$16.3/f_M$	(1000, 100 000/f_M^2)	6	6
	1.34-3.0	$823.8/f_M$	$16.3/f_M$	(1800/f_M^2, 100 000/f_M^2)	$f_M^2/0.3$	6
	3-30	$823.8/f_M$	$16.3/f_M$	(1800/f_M^2, 100 000/f_M^2)	30	6
	30-100	27.5	$158.3/f_M^{1.668}$	(2, 9 400 000/$f_M^{3.336}$)	30	$0.0636 f_M^{1.337}$
	100-400	27.5	0.0729	2	30	30
	400-2000	–	–	$f_M/200$	30	
	2000-5000	–	–	10	30	
	5000-30 000	–	–	10	$150/f_G$	
	30 000-100 000	–	–	10	$25.24/f_G^{0.476}$	
	100 000-300 000	–	–	$(90f_G-7000)/200$	$5048/[(9f_G-700) f_G^{0.476}]$	
NOTE – f_M is the frequency in MHz, f_G is the frequency in GHz.						

Appendix II

Time averaging

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

II.1 Analysis of time variations of measured electric fields from WCDMA mobile base stations

This clause presents the results of investigation of the effect of measurement of the time-variation on the measured E-fields. The measurement has been done around WCDMA mobile base stations in Japan. Figure II.1 shows the standard deviation for different measurement times. The results indicate very small variation in standard deviations. The maximum and minimum standard deviations are 1.7 and 1.5 dB, respectively, obtained for measurement times of 10 and 20 seconds. Table II.1 lists time average E-fields for each measurement time. The values are normalized to the average value obtained for a 6-minute measurement time. In the table, the numbers of measured data are also listed. It can be seen that the variation of the average E-field is very small for measurement times of up to 6 minutes. However, there is a sudden increase in the average value for 1 hour and 24 hours, even though their standard deviations are almost the same as those obtained for measurements of up to 6 minutes.
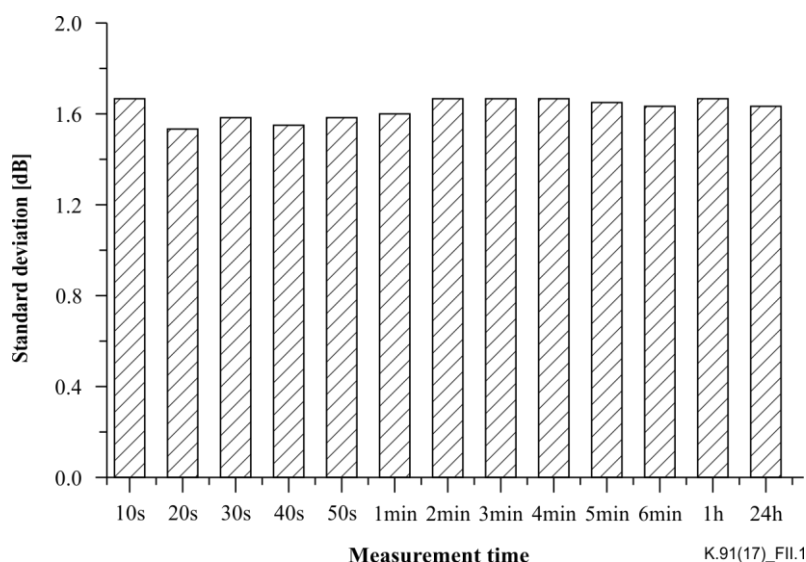
Figure II.1 – Standard deviation as a function of measurement time

Table II.1 – Time average E-fields normalized to the value of the 6-minute measurement time

Time	10 s	20 s	30 s	40 s	50 s	1 mn	2 mn	3 mn	4 mn	5 mn	6 mn	1 h	24 h
Number of measurements	62	115	172	230	280	334	654	976	1299	1660	1940	174	1429
Average E-field (dB)	−0.4	−0.3	−0.2	−0.2	−0.3	−0.4	−0.3	−0.1	−0.1	−0.0	0	−4.0	−4.2
NOTE – The number of measured data for each measurement time is also listed.													

Very small variations of 0.1 and 0.4 dB in standard deviation and time average E-field, respectively, have been obtained for measurement times of up to 6 minutes.

In the Republic of Korea, the effect of time reduction has been considered by the analyses of the RF EMF around CDMA base stations in the eighteen periods of time from 180 to 10 seconds with a 10-sec interval (180, 170, 160, …, 30, 20, 10 s).

Table II.2 shows the variation of time-averaged electric field strengths in one point for several time periods ranging from over 10 to 360 s of the seven target base stations. These values were calculated using the data obtained during the first time-periods that had the same starting time.

Table II.2 – Comparative data of electric field strength for different averaging times
(unit: dBµV/m)

Time (s) Base station No.	360	180	60	40	10
1	109.14	109.14	109.16	109.14	109.08
2	109.80	109.79	109.79	109.79	109.80
3	107.07	107.07	107.09	107.07	107.11
4	111.59	111.55	111.60	111.63	111.81
5	92.56	92.36	92.34	92.33	92.56
6	90.41	90.28	90.76	90.84	90.74
7	97.38	97.26	97.39	97.40	97.67

In Table II.2 each element corresponds to the calculated value using the data obtained during the first period (1~10 s) among 36 periods (1~10, 11~20, 21~30, …, 341~350, 351~360 s). Similarly, in the case of the 40-s column, it is that of the first period (1~40 s) among nine periods (1~40, 41~80, 81~120, 121~160, 161~200, 201~240, 241~280, 281~320, 321~360 s). These average values seem to be nearly the same. As described earlier, since the reference levels can be averaged over any 6 minutes or 360 seconds, this comparison is appropriate.
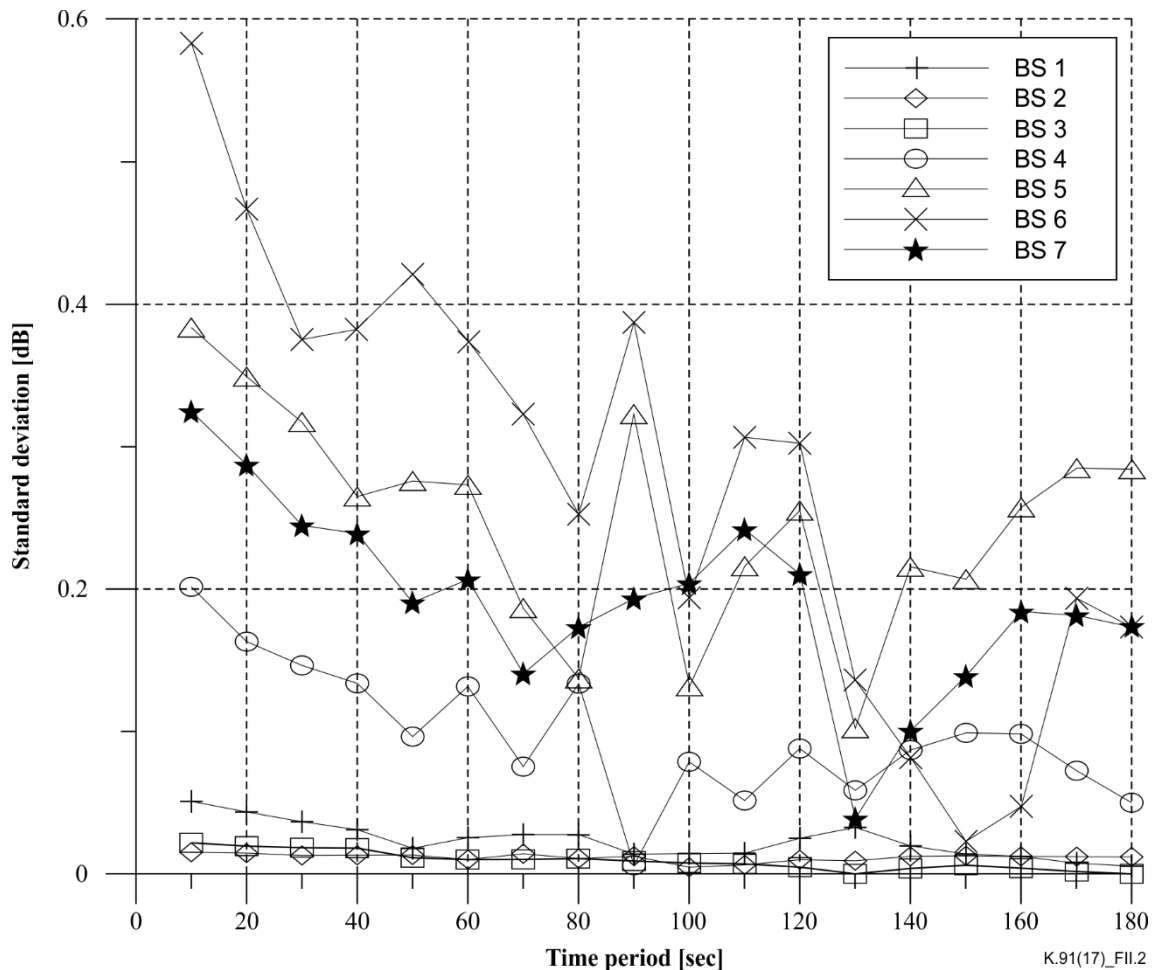
**Figure II.2 – Standard deviation for different averaging times
compared with that of 360 seconds**

In Figure II.2, the SD between the 360-s average value and different time periods is presented. These were estimated by the several average values calculated during successive time periods, which have no overlapping time period. For example, SD values at 60 s were estimated by the six values averaged during 1~60, 61~120, 121~180, 181~240, 241~300, and 301~360 s. The maximum SD among all base stations occurred in the case of base station No. 6, and its value was 0.58 dB at 10 s. As shown in Figure II.2, over 60-s no base stations have an SD exceeding 0.4 dB; the shortest period of 60 s was, therefore, selected as the suitable averaging time for human exposure measurement.

A dataset of measured E-fields of a WCDMA base station signal *in situ* from 10 s to 1 week is presented below.

| **Figure II.3 – Base station** | **Figure II.4 – Field nose (left) and SRM-3000 (right)** |
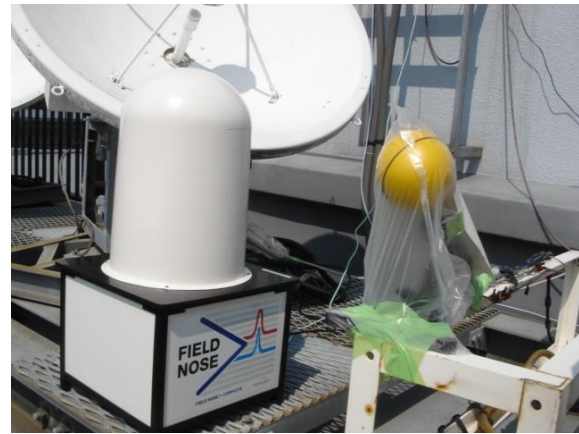
Measurements configurations

Measurements were carried out at 2000 MHz band for *in situ* measurement. A Narda selective radiation meter (SRM-3000) system and field nose (ARC) were located on the rooftop of a building (Figures II.3 and II.4). The measured base station was in an urban area of Tokyo. The distance between the measurement location and the base station was 750 m. The height from the floor to the receiving antenna was set at 85 cm, due to the restriction of positioning the measurement devices at the site. The RBW was set at 100 kHz. During the measurement from 10 seconds to 6 minutes, the time interval of the measurement was set at 10 seconds and 20 seconds for the SRM-3000 and field nose, respectively. For the measurement time longer than 6 minutes, 12-minute time-intervals were employed because of the limitation of the data storage.

Results and discussion

Figure II.5 shows the standard deviation for different measurement times during one day. The results show that the maximum standard deviations of field nose and SRM-3000 are 2.1 and 2.6 dB, respectively, obtained for a measurement time of 1 hour. It can be seen that the standard deviations are similar for measurement times of up to 6 minutes for both systems. Though there is a sudden increase in the standard deviations for 1 hour and 24 hours, the standard deviations are still smaller than 3 dB.

Figure II.6 shows the standard deviations in each measurement day, along with the average of the entire week. In this case, the maximum standard deviations of field nose and SRM-3000 are 1.9 and 2.9 dB, respectively, and it is almost comparable to the standard deviation of the entire week. Figure II.7 shows time average E-fields for each measurement time. The values are normalized to the average value obtained for a 6-minute measurement time. It can be seen that the average E-field from 6-minute measurements are within the standard deviation of one-day measurement for both measurement systems, and the value of shorter averaging time tends to be larger than the week-averaged E-field. One reason for this is the measurements were started during the daytime – when traffic was heaviest, therefore the one-day average tends to be smaller because it includes the quietest time of early morning.

Figure II.8 shows the scatter plot of one-week measurement with SRM-3000. A larger variation (max-min) up to 18 dB is shown.
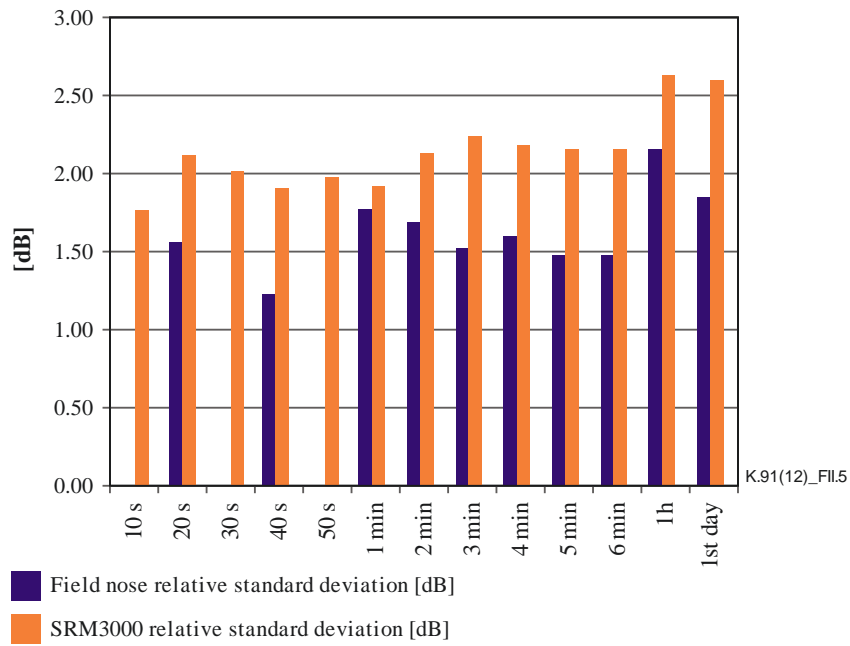
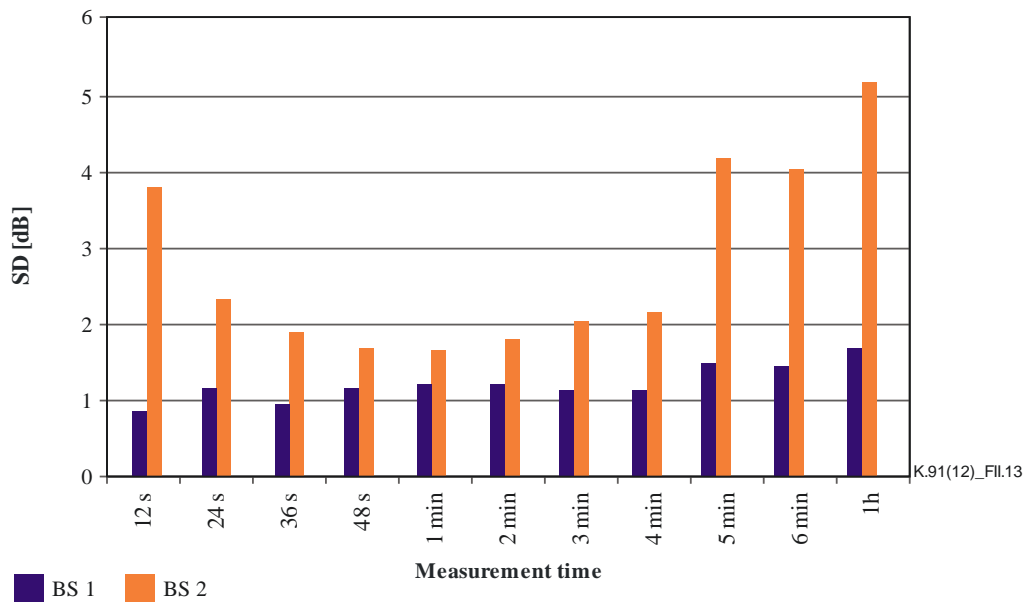**Figure II.5 – Standard deviation as a function of measurement time during one day**
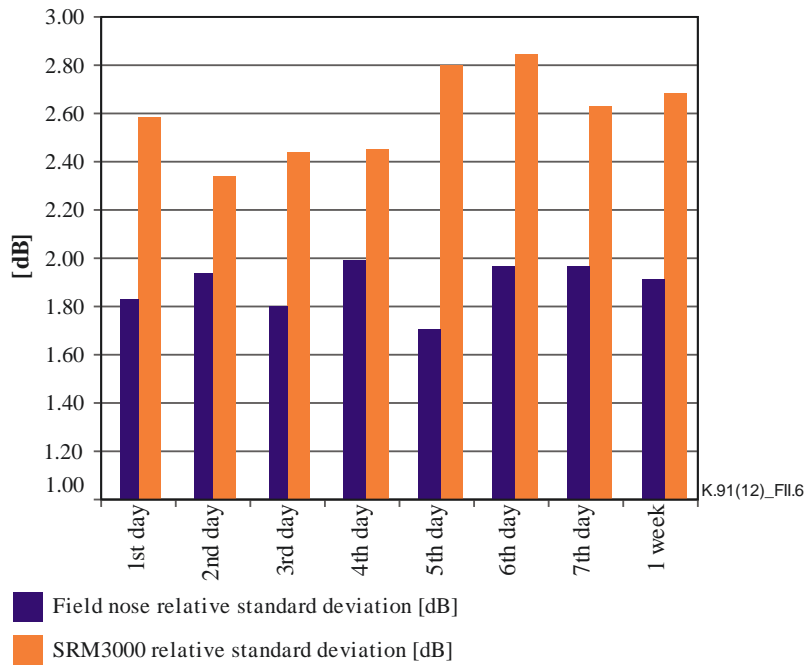
Figure II.6 – Standard deviation as a function of measurement time during one week
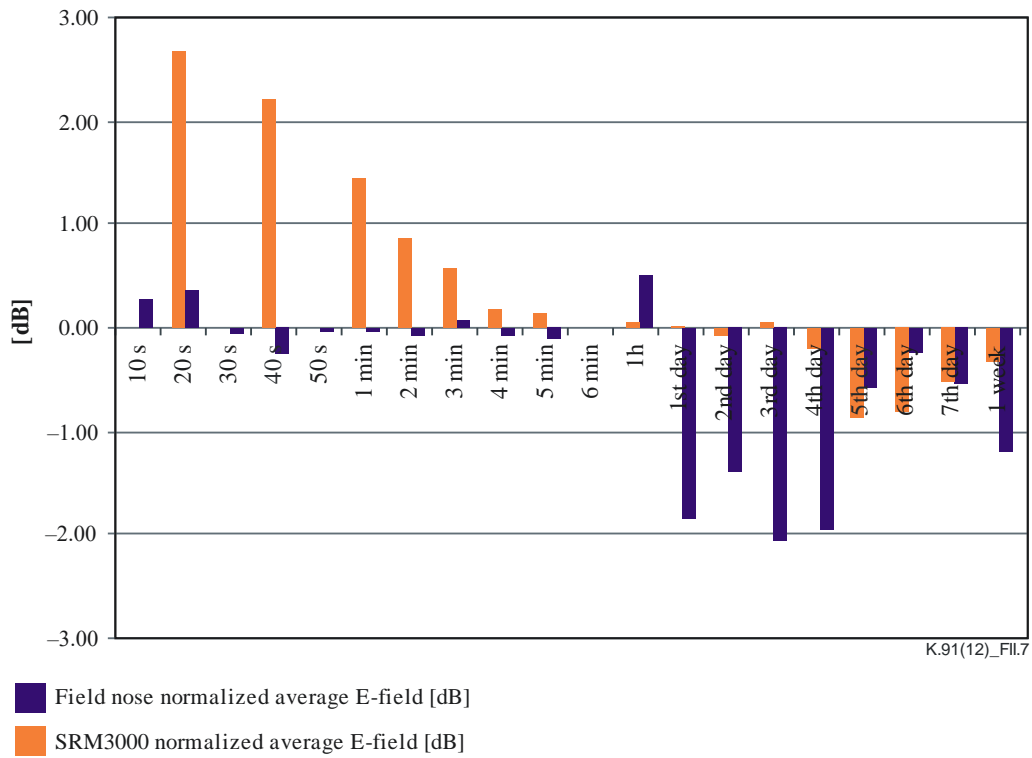
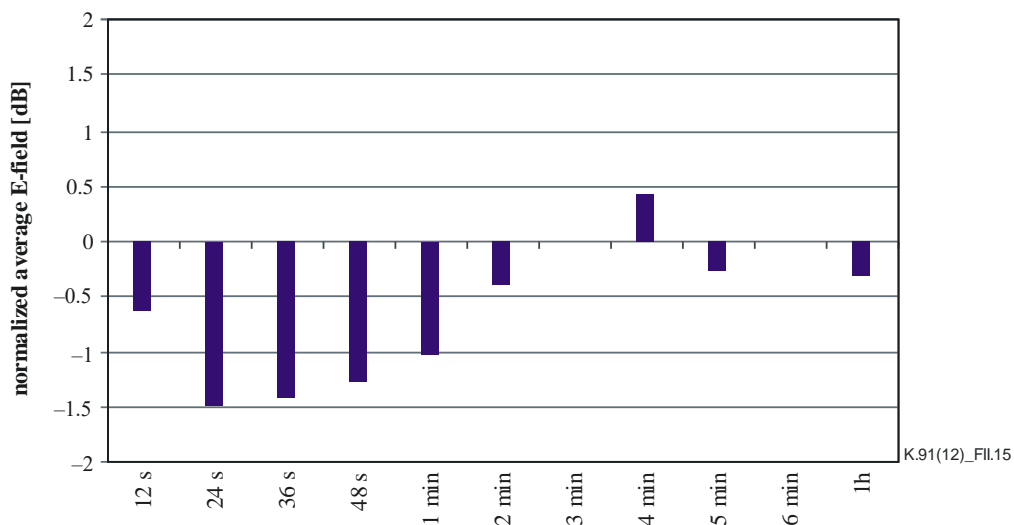**Figure II.7 – Time average E-fields normalized to the value of the 6-minute measurement time**
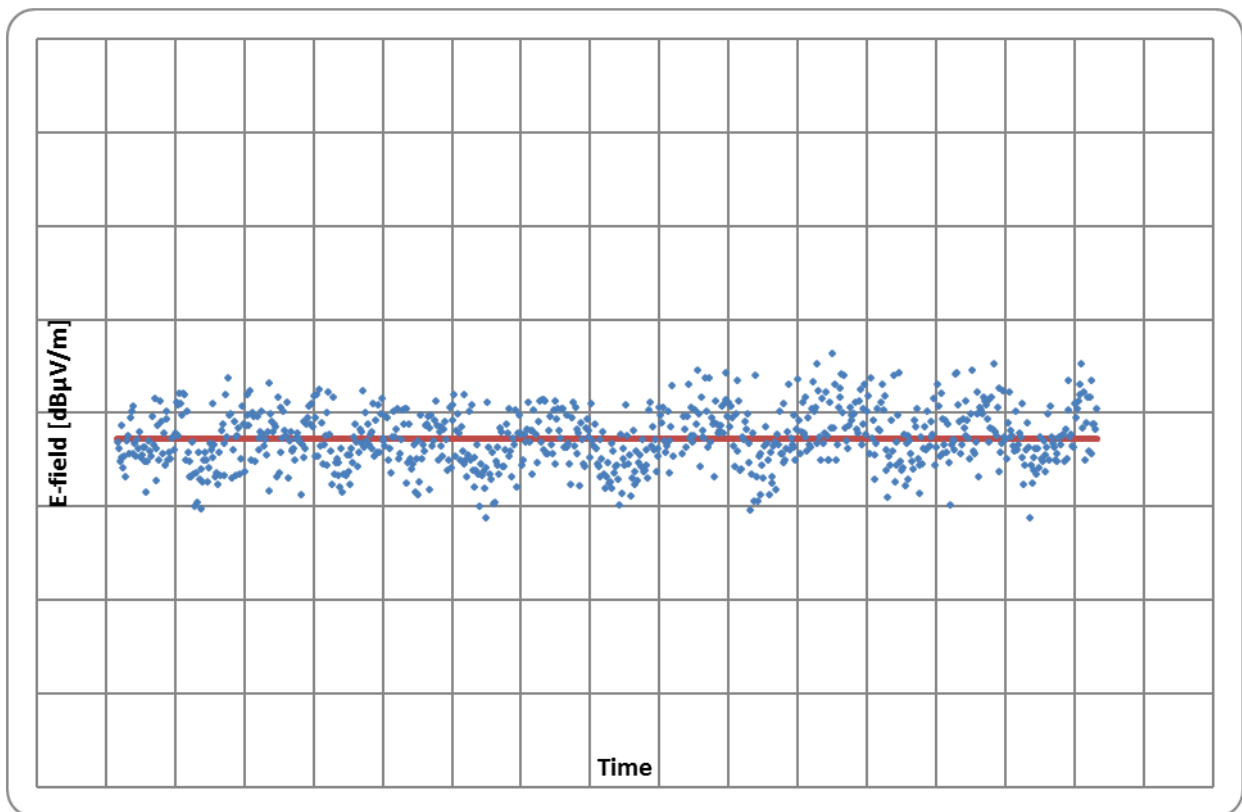
NOTE – Red line represents the averaged value.

Figure II.8 – Measured E-field strength during 1 week with SRM-3000

II.2 Analysis of time variations of measured electric fields from GSM mobile base stations

The effect of RBW and measurement times done in the United Republic of Tanzania for GSM signals are presented below. A Narda SRM-3006 with isotropic probe was used in the measurements.

Measurements configurations

Measurements were done at 1800 MHz band for *in situ* measurement of two GSM mobile phone base stations, referred to here as BS 1 and BS 2. An SRM-3006 meter was located on the second-floor balcony of a building, as shown in Figure II.9. The distances between the measurement location and BS 1 and BS 2 were 630 and 750 m, respectively, with a clear line of sight (LOS). Figure II.10 shows BS 1. The two base stations belong to two different service providers. Each of the service providers has a downlink frequency band of 12.5 MHz. All measurements were taken with the isotropic probe fixed at a height of 1.5 m from the floor. Total fields were obtained by integrating E-fields in the downlink frequency band. The result type of the Narda equipment was set to actual.
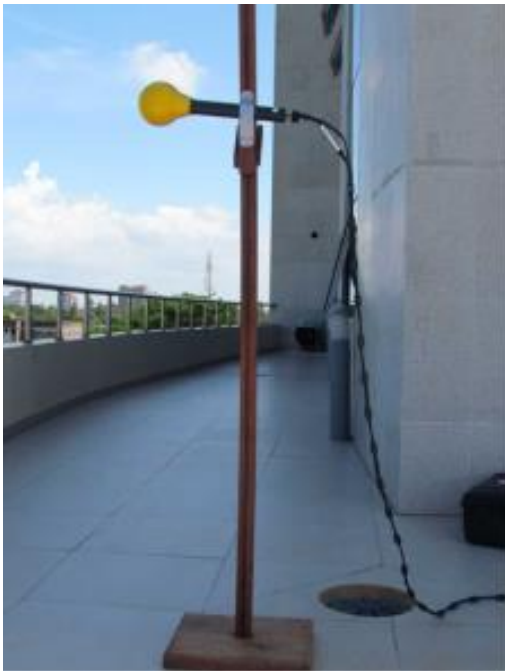
Figure II.9 – Narda probe fixed on a wooden stand

Figure II.10 – BS 1
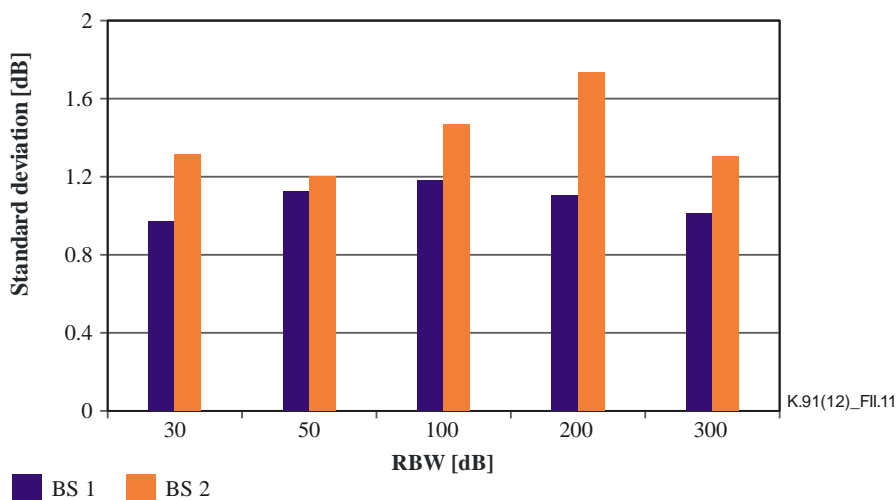
Figure II.11 – Standard deviation as a function of RBW for BS 1 and BS 2
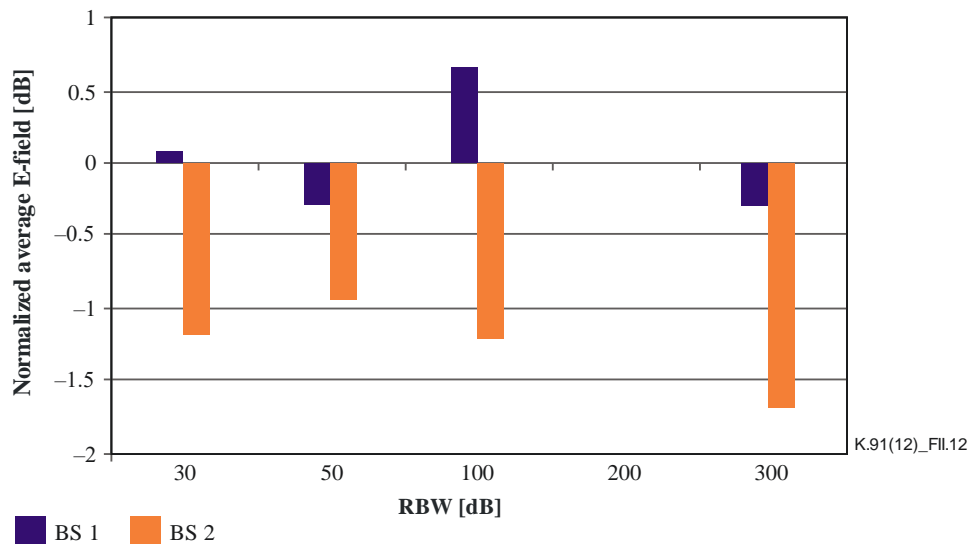
Figure II.12 – Average E-fields normalized to the value of the 200 kHz RBW

II.3 Results and discussion

II.3.1 RBW

In this clause the effect of RBW to the SD and the level of measured signal for both BS 1 and BS 2 were investigated. A measurement time of 6 minutes and time interval of 18 seconds was used.

Figure II.11 shows the SD as a function of RBW. For BS 1, SD increases up to the RBW of 100 kHz and then starts to decrease. The minimum SD is obtained with RBW of 30 kHz. The maximum difference is 0.2 dB. A different trend is observed for the case of BS 2, with maximum and minimum SDs obtained at RBWs of 200 and 50 kHz, respectively. The maximum variation is 0.5 dB.

The effect of RBW on the measured E-field is plotted in Figure II.12. The measured values from the base stations were normalized to the E-field of 200 kHz RBW, which is the channel bandwidth of the GSM signal. The maximum variation (max–min) obtained are 1 and 1.7 dB, respectively, for BS 1 and BS 2. The maximum E-fields were recorded at the frequency of maximum SD for both base stations. The smaller RBW (30 kHz) may be used for accuracy of measured results. Measurement from BS 1 was found to be in agreement because the minimum SD was obtained at an RBW of 30 kHz. This was not the case for BS 2. The simulation may not be able to take into account other external factors such as reflections.

II.3.2 Measurement time

In this investigation, measurements of up to 1 hour were carried out. For measurements from 12 seconds to 6 minutes, the time interval of the measurement was set at 6 seconds; 1-minute time-intervals were employed for the case of 1-hour measurements.

Figure II.13 shows the standard deviation for different measurement times for two different base stations. The results show that the maximum standard deviations of 1.7 and 5.1 dB, respectively, were obtained for measurement time of up to 1 hour. The standard deviations obtained are in the same range with the values obtained for the WCDMA system, and larger than the standard deviation of the CDMA signal. The recorded standard deviations are of similar values for measurement times of up 4 minutes (except for the 12 s value of BS 2) for both base stations. A sudden increase in the standard deviations for 5 minutes, 6 minutes and 1 hour was observed. A standard deviation exceeding 3 dB was obtained for the signal from BS 2.

The time average E-fields of the two base stations are shown in Figures II.14 and II.15. The values are normalized to the average value obtained for a 6-minute measurement time. The maximum average E-fields variations (max–min) are 0.9 and 1.9 dB for BS 1 and BS 2, respectively.

Figure II.13 – Standard deviation as a function of measurement time for BS 1 and BS 2
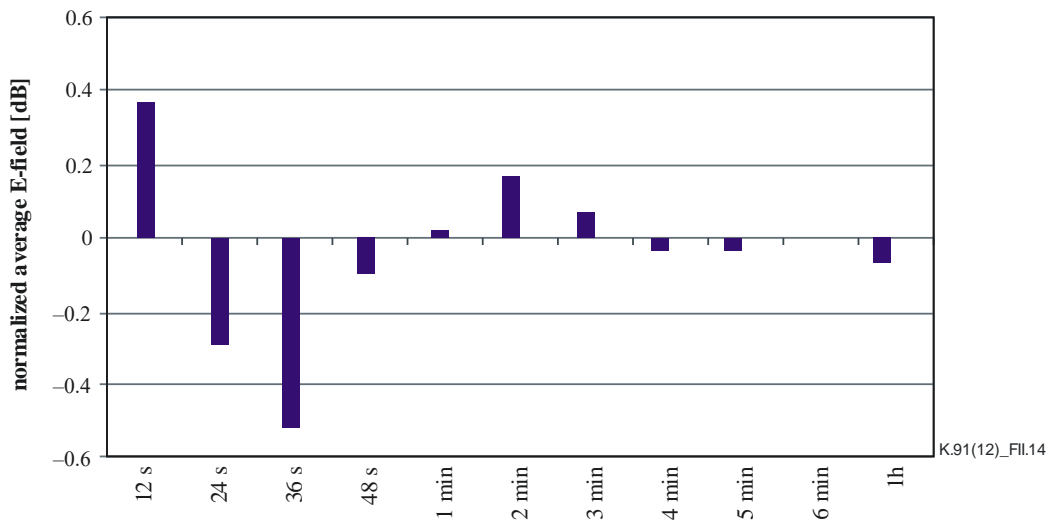
**Figure II.14 – Time average E-fields of BS 1 normalized to the value
of the 6-minute measurement time**

**Figure II.15 – Time average E-fields of BS 2 normalized to the value
of the 6-minute measurement time**

II.4   Discussion about the number of sampling data and averaging time

The measurement data of WCDMA base station measurement have been processed. The measurement has been carried out with a maximum duration of 1 hour. The minimum sampling interval was 10 seconds, due to the restriction by specification of the field measurement system SRM-3000 (Narda). A running average of each measurement time was considered.

Figure II.16 shows the variation of the relative standard deviation of running average at each measurement time during the measurement of two different averaging times with two different sampling intervals: 1-minute averaging with 10-second interval (Scheme 1), 6-minute averaging with 10-second interval (Scheme 2), and 6-minute averaging with 1-minute interval (Scheme 3). The numbers of data for each averaging time are 7, 37 and 7, respectively.

Figure II.16 shows the trend that the shorter the averaging time, the larger the deviation becomes. However, except the quite large fluctuation around 20 minutes, the maximum fluctuations of Schemes 1 and 3 are approximately the same level of 10 dB. This implies that this fluctuation is caused by the same number of the sampling data. Therefore, care must be taken when comparing averaged results. In this measurement, the standard deviation of whole one-hour averaging time was −4.5 dB. Consequently, these data show that a shorter averaging time does not always show larger standard deviation, and it depends on the traffic of the signal at the measured time.

K.91(17)_FII.16
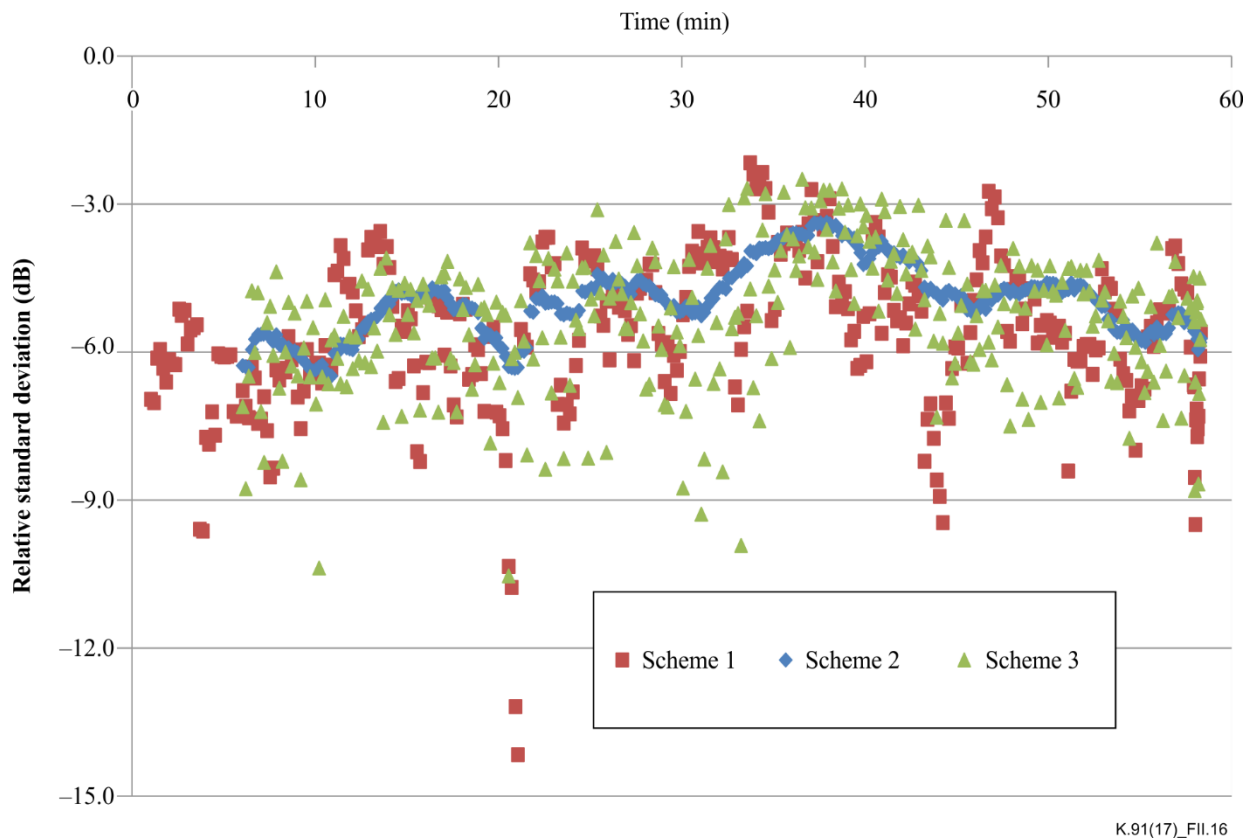
Figure II.16 – Fluctuation of relative standard deviation of a WCDMA base station E-field

Appendix III

Examples of RF EMF levels in areas accessible to the general public

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

The measurements were carried out in the Republic of Korea in areas where people live or spend substantial time, including hospitals, commercial areas (business areas), residential areas (densely built-up areas), schools and apartment complexes. Fifty places were selected: 27 in school areas, 11 in apartment complexes, 5 in commercial areas, 4 in hospitals and 3 in residential areas. Measurement positions in LOS with the nearest CDMA base station were chosen. The measurement was performed at heights of 1.1 m, 1.5 m, and 1.7 m; using these field values, the spatially averaged value was then calculated. At each point the field values were averaged over 1 or 6 minutes. The measurements used an isotropic antenna to ensure all field components (x, y, z in Cartesian coordinates) were evaluated correctly considering the variation in field polarization at some distance from the base station's antenna. The measurement equipment used was a Narda SRM-3000 all-in-one spectrum analyser and an isotropic probe. This setup makes it possible to perform frequency selective measurements. When performing the measurement, the detection mode was maintained as the rms.

The spatially averaged field levels, which were calculated using time-averaged values at several places of concern, are shown in Figures III.1 and III.2. Since the reference levels (field strength) are frequency dependent (i.e., mobile communication is operated in different frequency bands, and due to differences in absorbing conditions different reference levels were set up), the exposure levels are depicted by exposure ratio, which is calculated by the square of the ratio of the measured electric field strength and the reference level, which is expressed as a fraction of the related limit. In Figure III.1, the spatially averaged values were expressed as the median of the specific classification (e.g., hospital, school, rural, single-location) and the horizontal bars denote the highest and lowest spatially-averaged field values recorded at each classification, respectively.
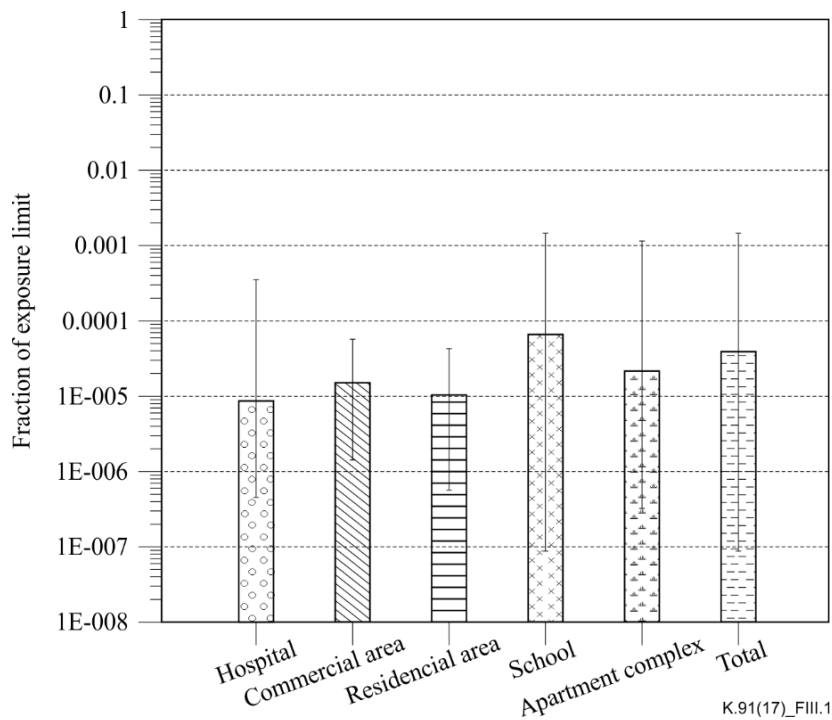
Figure III.1 – Exposure levels at a selection of densely populated areas

At all measured places the spatially averaged RF EMF levels (median value) were below 0.01% (exposure ratio: 0.0001) of the limit in the ICNIRP guidelines in Figure III.1. The highest exposure ratio (highest horizontal bar) occurred at the school, recording a value of 1.5×10^{-3}, which corresponds to a value of 1.5 V/m by the root sum square method (CDMA800: 0.1 V/m, CDMA1800: 1.5 V/m).

Figure III.2 shows roughly the cumulative number of positions less than a specific (total) exposure ratio. For instance, in the case of the total line in the graph, the maximum number of positions is 50, meaning that all the spatially averaged field values measured do not exceed 0.01. Almost all of the positions (48 out of 50; 96%) had no more than 0.1% of the limit (exposure ratio: 0.001).
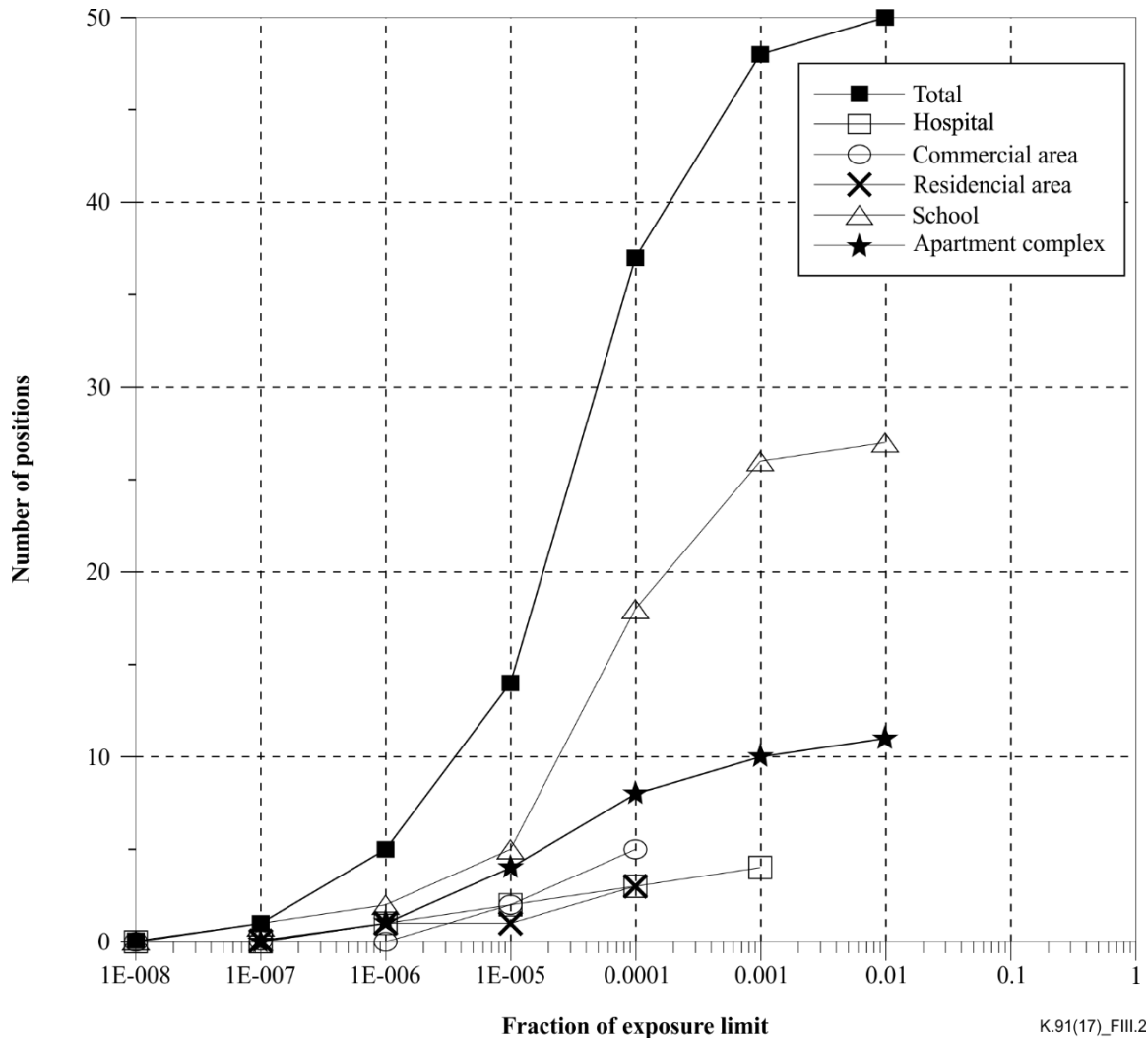
NOTE – Field levels are depicted as a fraction of the exposure limits.

Figure III.2 – Cumulative numbers of positions at a selection of densely populated areas

For the 13 services served and 1250 positions across the Republic of Korea, the electric field strength by population density is presented in Table III.1. Exposure levels at several places classified by population density (rural: 123, urban: 517, suburbs: 610) are shown in Table III.1 and Figure III.3. Urban areas have an exposure level that is high. The figure also shows that the more densely populated the area is, the larger the exposure levels become.

Table III.1 – Average electric field strength of various services by population density (in V/m)

	Frequency band (MHz)	Rural	Urban	Suburbs
TV (VHF)	54~174	0.024	0.023	0.025
FM	88~108	0.016	0.030	0.029
TV (VHF,T-DMB)	174~ 216	0.015	0.032	0.026
LBS	322~328.6	0.006	0.009	0.007
TRS (low)	390~400	0.004	0.004	0.004
TV (UHF, D-TV)	470~806	0.024	0.030	0.034
TRS (high)	851~867	0.008	0.025	0.018
Cellular	869~894	0.023	0.100	0.075
Wireless data	938~940	0.001	0.008	0.008
PCS	1840~1870	0.062	0.152	0.122
IMT-2000	2130~2170	0.054	0.151	0.120
S-DMB	2605~2655	0.021	0.071	0.051
WiBro	2300~2358.5	0.016	0.054	0.029
LBS: Location-based service. TRS: Trucked radio system. PCS: Personnel communication system. IMT-2000: International Mobile Telecommunication-2000. S-DMB: Satellite-digital multimedia broadcasting. WiBro: Wireless broadband Internet.				
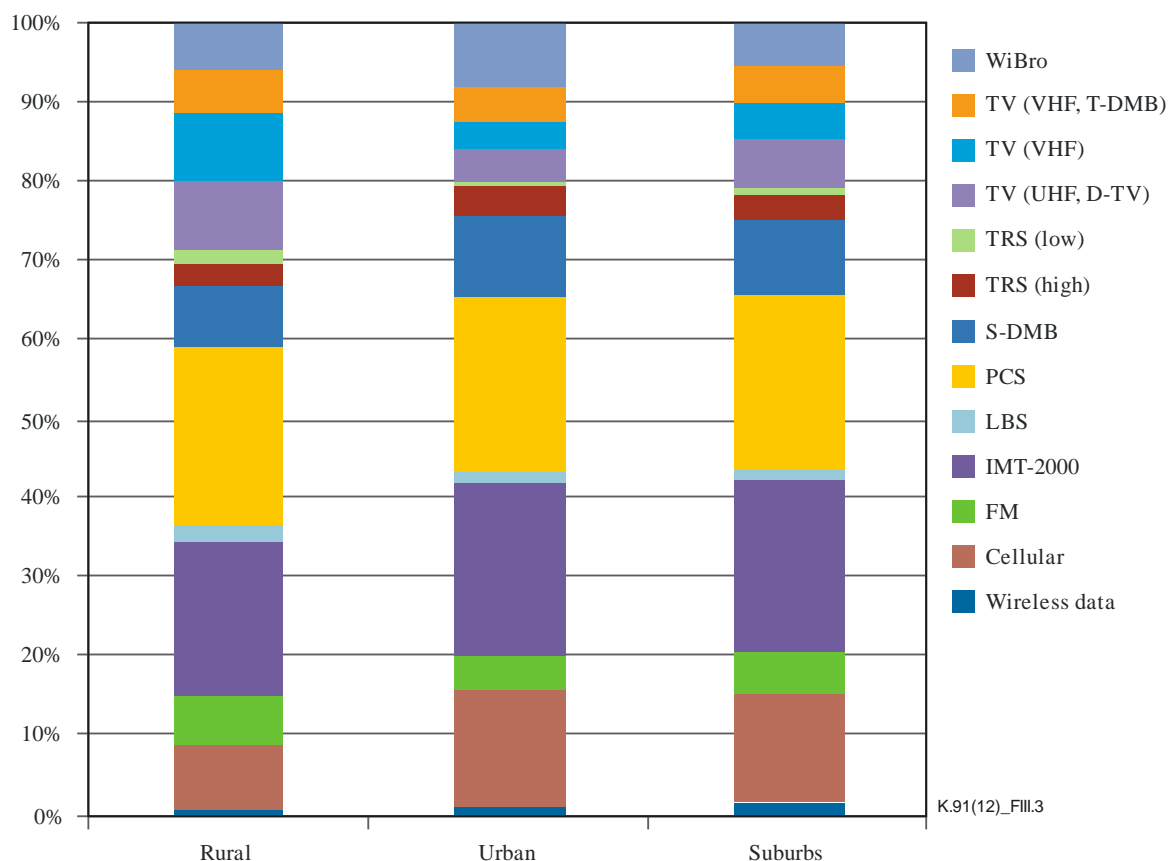
Figure III.3 – Possession rate for various services by population density

During measurement, the following was assumed: the spatial average of three heights: 1.1 m, 1.5 m, and 1.7 m; the number of basic measurement points: three (one dimension); and the number of precise measurements: nine (two dimension). In case of precise measurement, the area is within 0.4 m (horizontal) by 0.6 m (vertical) and the points are placed 0.2 m apart at each height. In addition, to consider incident fields from any direction and polarization, an isotopic probe is used in the measurement system. Moreover, to separate each electromagnetic field source under the multi-frequency environment, a spectrum analyser connected to the probe is used for a narrowband measurement and the detection mode of the spectrum analyser is set to rms.

Appendix IV

Software Watt Guard

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

Within the framework of a study commissioned by the Bundesnetzagentur, a software module has been developed at Karlsruhe University enabling a simple and fast assessment of amateur stations. The software module runs on a wide variety of operating systems.

Features of the Watt Guard

The calculation tool has a graphic user interface at which the relevant data can be entered or the relevant parameters selected. The user enters the parameters frequency, antenna type and antenna gain, transmit power, his/her location, height of the antenna, antenna orientation and environment. The initial screen of the software is presented in Figure IV.1.

Account of the depth of the electromagnetic waves' penetration into the soil and of the reflections is taken by means of correction factors for soil conductance. The height dependence correction factor takes account of effects on the field strength from objects in the vicinity. The required safety distances and protection areas are derived from the fields. The safety factor compensates for exceeded field strength limits which may result from reflections at metallic or dielectric objects or at buildings, for instance. The various correction factors are already contained in the Watt Guard so that the radio amateur does not have to enter them.

When the required parameters have been entered, the process of calculating the necessary safety distances is started and displayed graphically.
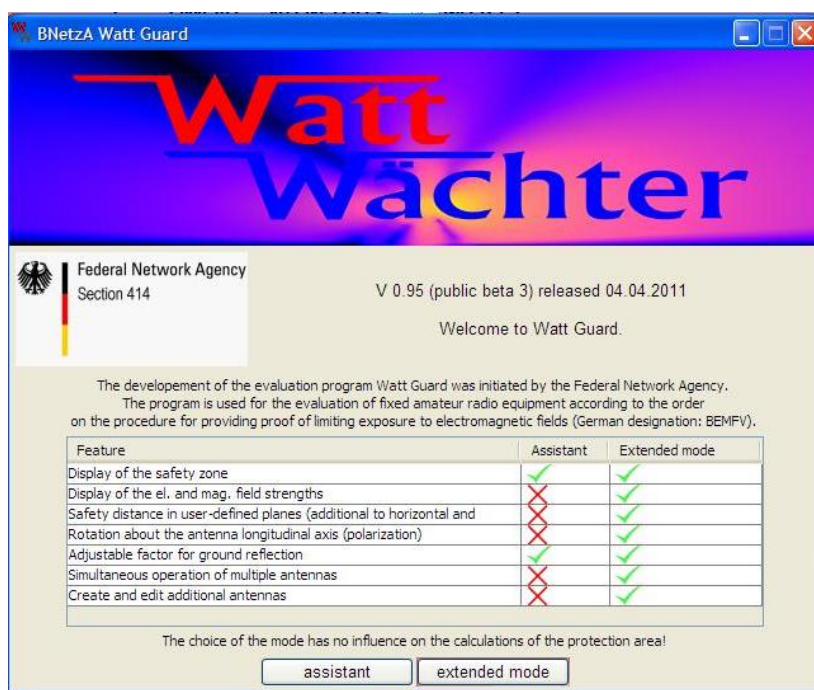
Figure IV.1 – Initial screen of the software Watt Guard

Appendix V

Software "Uncertainty calculator"

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

V.1 Introduction

This software is developed to help in the calculation of the uncertainty.

V.2 Brief descriptions of the software

This software can calculate in three steps: Type A uncertainty calculation, Type B uncertainty calculation and expanded uncertainty calculation. The software references the method of calculating in [IEC 62232] clause 9.

In the main user interface (see Figure V.1), complete the following operations:

1) select unit (strength or power density);

2) call another interface to calculate Type A uncertainty, Type B uncertainty and expanded uncertainty;

3) show results; and

4) export results.
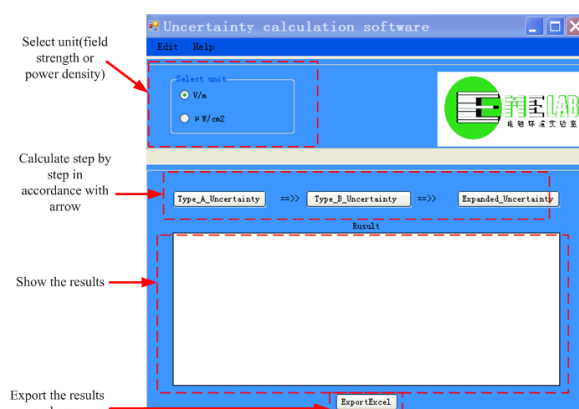
Figure V.1 – Main user interface

– Step 1: Type A uncertainty calculation

Sometimes the probability distribution of an influence quantity can be determined by a simple repeated measure, n independent observations x_k will be obtained under the same conditions of RF field measurement. For convenience, the experimental standard deviation of the mean $S(\overline{x})$ is sometimes called a Type A standard uncertainty.

Press the Type_A_Uncertainty key in the main interface (the user can call up the Type A uncertainty calculation interface).

In this window (Figure V.2), the user can complete the following operation:

1) input the measurement data (the user can generate and fill a form or import Excel data);

2) calculate Type A uncertainty.
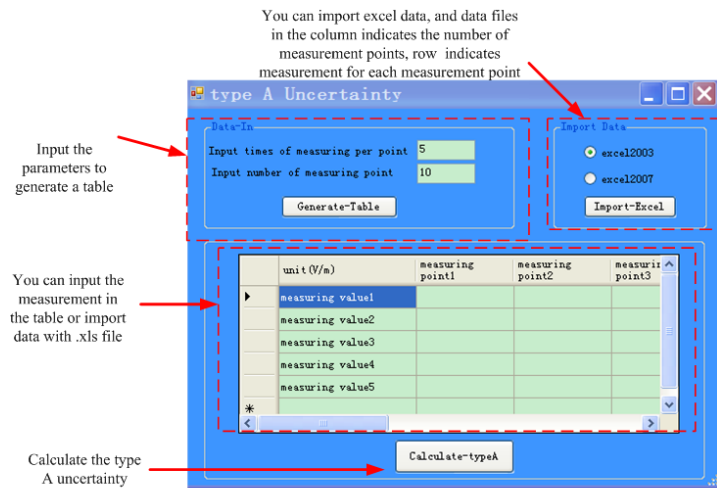
Figure V.2 – Type A uncertainty

NOTE – If the measurement at each point appears only one time, the Type A uncertainty equals 0.

– Step 2: Type B uncertainty calculation

Type B evaluation is based on information as follows: associated with authoritative published quantity values; associated with the quantity value of certified reference material; obtained from a calibration certificate about drift; obtained from the accuracy class of a verified measuring instrument; or obtained from limits deduced through personal experience.

Press the Type_B_Uncertainty key in the main interface (the user can call the Type B uncertainty calculation interface).

In this window (Figure V.3), the user can complete the following operation:

1) input the error sources and data. (The software supports three ways to calculate Type B uncertainty: default value, generate tables and import Excel.);

2) select unit. (dB: uncertainty calculation with logarithmic values; %: uncertainty calculation with linear scale values.);

3) calculate Type B uncertainty.
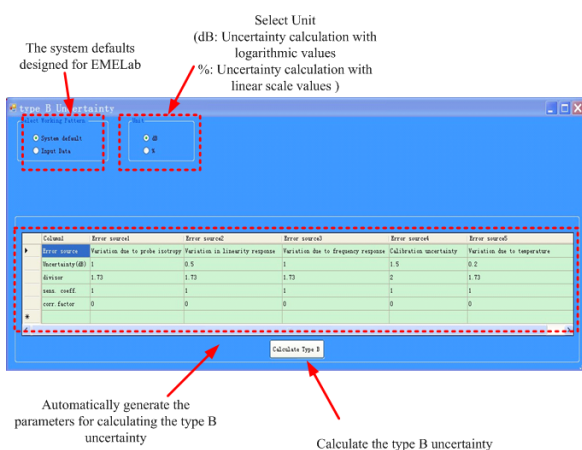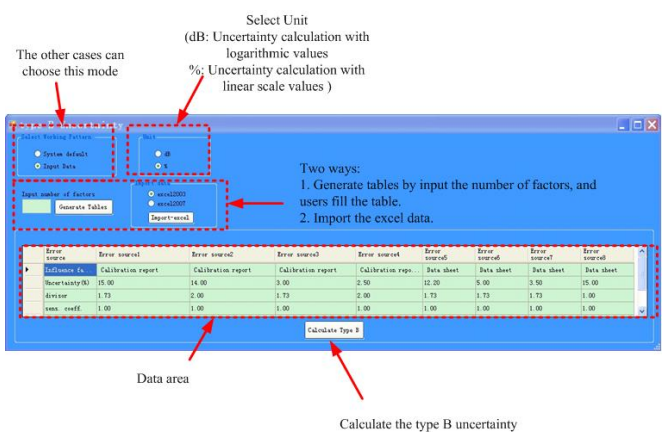
(a) System default   (b) Input data

Figure V.3 – Type B uncertainty

– Step 3: Expanded uncertainty

The additional measure of uncertainty that meets the requirement of providing an interval is termed expanded uncertainty and is denoted by U. The expanded uncertainty U is obtained by multiplying the combined standard uncertainty $u_c(y)$ by a coverage factor k:

$$U = ku_c(y)$$

Usually (it frequently occurs in practice) it can be assumed that taking k = 1.96 produces an interval having a level of confidence of approximately 95%, so in the software k = 1.96 is used.

The final result will be shown in the main interface, which can be exported as an Excel file, see Figure V.4.
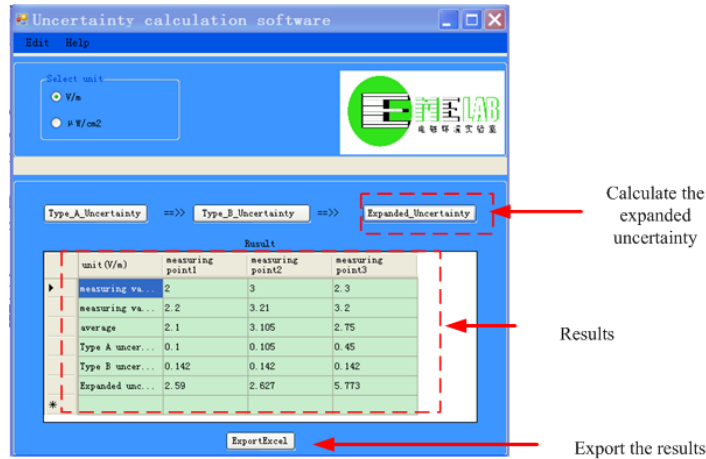
Figure V.4 – Expanded uncertainty

V.3   Examples

Example 1

Annex C2.1 of [b-EN 50413] is an example of a software operation to calculate the uncertainty that only contains Type B uncertainty. No repeated measurement is assumed here, which means five points are chosen and just one test is conducted for every point. The measurement results can be found in the following table.

Unit (V/m)	Point 1	Point 2	Point 3	Point 4	Point 5
value 1	0.6	1.3	3.1	2.5	1.9

Operating steps can be seen in Figure V.5, and the Type A uncertainty result in the main interface is shown, which is 0 dB and 0%.
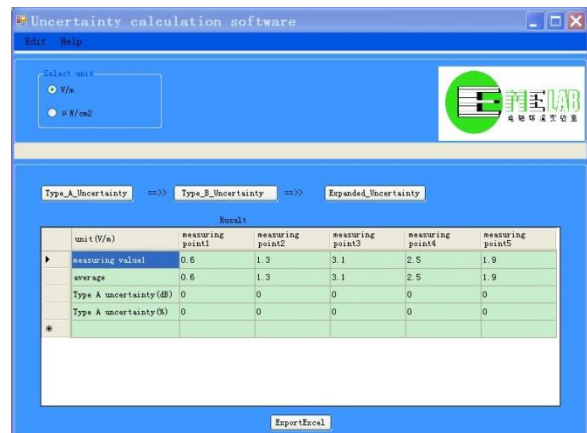
| (a) Input data | (b) Type A uncertainty results |

Figure V.5 – Type A uncertainty, example 1

Type B uncertainty needs to be calculated next. The user needs to choose the unit "dB", because the uncertainty calculation in this example includes logarithmic values. The data are input into tables, shown below, which contain 13 influence factors, and an Excel file is generated.

Error source	Error source 1	Error source 2	Error source 3	Error source 4	Error source 5	Error source 6	Error source 7	Error source 8	Error source 9	Error source 10	Error source 11	Error source 12	Error source 13
Influence factor	Frequency response	Input atte-nuation	Reso-lution band-widths	IF-am-plifier	Tem-perature res-ponse	Modul-ation res-ponse	Display reading uncer-tainty	Calibra-tion uncer-tainty	Cable attenua-tion frequency inter-polation	Calibra-tion uncer-tainty	Antenna factor frequency inter-polation	Uncer-tainty caused by reflec-tions	Limited repea-tability
Uncer-tainty (dB)	0.50	0.10	0.05	0.50	1.00	0.50	0.05	0.20	0.10	1.00	0.10	0.80	2.30
divisor	2.00	2.00	2.00	2.00	1.73	1.73	1.73	2.00	1.73	2.00	1.73	1.41	2.00
sens. coeff.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
corr. factor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Operating steps can be seen in Figure V.6 and the Type B uncertainty result in the main interface is shown, which is 1.568 dB.
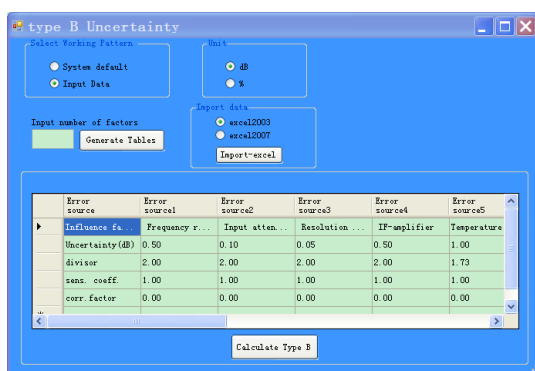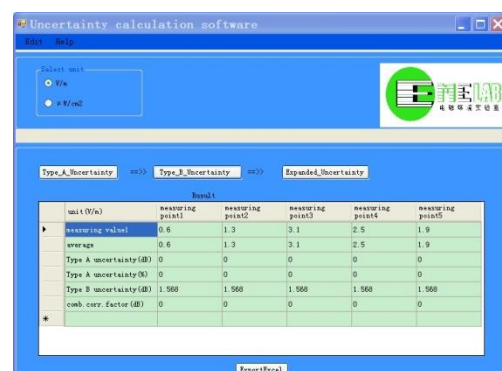
| (a) Input data | (b) Type B uncertainty results |

Figure V.6 – Type B uncertainty, example 1

In the last step the expanded uncertainty is obtained and the results can be seen in Figure V.7. The result with logarithmic values is 3.073 dB and the result with linear scale is 42.446%.
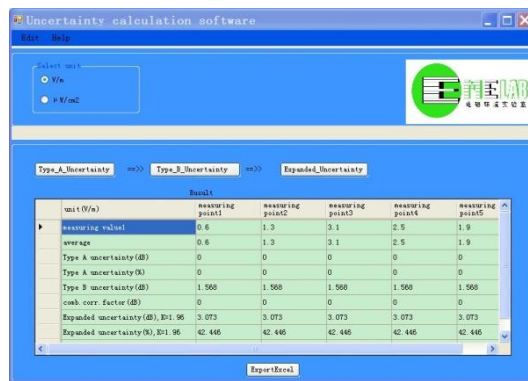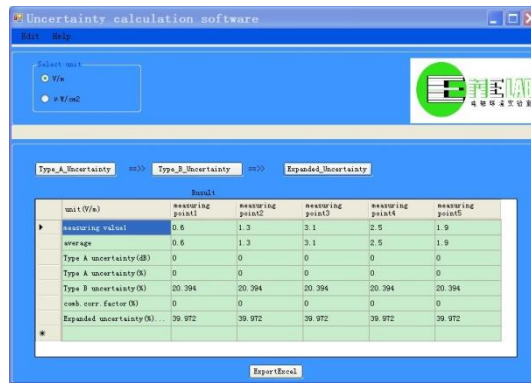

Figure V.7 – Expanded uncertainty, example 1

The results that are calculated by the software are basically in accordance with the results in Annex C2.1 of [b-EN 50413]. The reason of error is due to the number of decimal places.

Example 2

The example in Annex C2.2 of [b-EN 50413] also can be calculated similarly to Example 1. The calculation steps and assumption of Type A uncertainty are the same as in Example 1. However in the calculation step of Type B uncertainty, the user needs to choose the unit "%", because of the uncertainty calculation in this example with linear scale, see Figure V.8.

(a) Input data   (b) Type B uncertainty results

Figure V.8 – Type B uncertainty, example 2

Type B uncertainty is the result in the main interface, which is 20.394%. In the last step, the expanded uncertainty is calculated; the results can be seen in Figure V.9. The result with linear scale is 39.972%.

Figure V.9 – Expanded uncertainty, example 2

The results calculated by the software are also basically in accordance with the results in Annex C2.2 of [b-EN 50413]. The reason of error is due to the number of decimal places.

Appendix VI

Examples for evaluating electromagnetic fields in general public environments with broadband radio signals

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

VI.1 Method for evaluating electromagnetic fields in general public environments with broadband signals

When using a spectrum analyser to measure the RF field power density, the RBW has quite a large effect on the measurement results, particularly for broadband signals such as WCDMA and OFDM. Therefore, it should be carefully selected to sufficiently cover the occupied bandwidth of the target radio source for an accurate field power density measurement. On the other hand, in current radio environments there are various types of radio signals that have different occupied bandwidths in a wide frequency range. Therefore, the RBW should not be sufficiently narrow and as a result, multiple signals are included in the RBW. It increases the uncertainty of the measurement. However, such broadband RBW setting can be applicable with proper consideration of the total power density.

Figure VI.1(a) shows an example of the measured frequency spectra of broadband or narrowband RBW settings. Suppose the received signals, $S(f_1)$ and $S(f_2)$, are narrowband signals and $S(f_3)$ and $S(f_4)$ are broadband signals. Figure VI.1(b) is a magnified section of the measured frequency spectrum around frequency f_i, which consists of a set of sampled points the number of which is $M(f_i)$. At frequency f_i, the received level, $S(f_i)$, is given by:

$$S(f_i) = \sum_{j=1}^{M(f_i)} \frac{p(f_j)\Delta f_i}{f_{RBW}[M(f_i)-1]} \tag{VI-1}$$

When the number of detected radio signals is N, the normalized total power density is calculated by

$$s_{total} = \sum_{i=1}^{N} \left(\frac{S(f_i)}{S_{limit}(f_i)} \right)_t \tag{VI-2}$$

where $S_{limit}(f_i)$ is the frequency dependent limit of the field power density and s_{total} is the total power density normalized by $S_{limit}(f_i)$.

For instance, a measurement system comprises an isotropic sleeve dipole sensor, an RF switch box, a spectrum analyser, and a laptop computer, as shown in Figure VI.2. The field sensor is based on a sleeve dipole, and the dipole elements have a periodical configuration to reach a wide frequency response in the frequency range from 30 MHz to 3 GHz. Three sleeve dipoles are orthogonally established on a tripod for isotropic response. The laptop computer controls the spectrum analyser and the RF switch box, and calculates the received level, $S(f_i)$, and s_{total}.
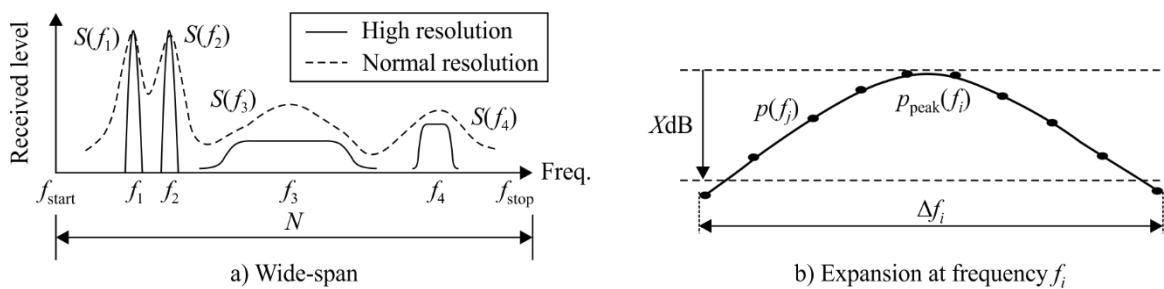
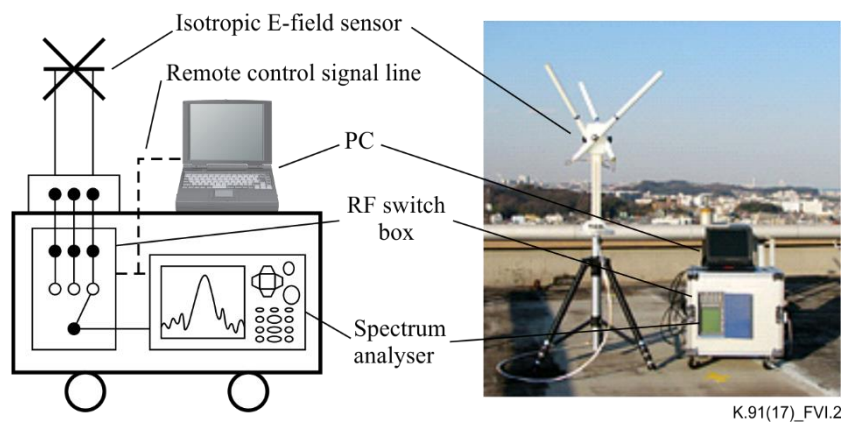**Figure VI.1 – Measured frequency spectrum**

Figure VI.2 – Measurement system

VI.2 Effect of RBWs on measured electromagnetic fields from mobile phone base stations

In order to investigate if RF exposure from mobile phone base stations complies with the exposure limits, electromagnetic field measurements are carried out. Although frequency-selective measurements using a spectrum analyser do not provide as much information as signal analysers when measuring WCDMA signal, it is still the method of choice taking in to consideration the simplicity and cost. Resolution bandwidth is one of the important parameters of the frequency-selective equipment and has influence on the cost of the equipment. Usually equipment with wide RBW, such as signal analysers, are more expensive. However, for wideband signals such as WCDMA, which has a signal bandwidth of 5 MHz, it is important to confirm if the use of equipment with narrow RBW can accurately measure these signals and be adopted in compliance testing. In this contribution, data obtained using Narda SRM-3000 operating in frequency analysis mode are provided. Indoor (i.e., inside an anechoic chamber) and *in situ* measurements for different RBW values were taken. When spatial averaged E-fields were considered, the maximum difference of less than 2.7 dB between values obtained using different RBWs was recorded. For the time averaged measurements, the maximum difference of less than 1.6 dB was obtained.

Measurements at 800 and 2000 MHz for indoor and *in situ* measurements were taken. For the case of the indoor measurements, a Narda SRM-3000 is connected to its isotropic probe and the base station simulator (MT8820A) is connected to a transmitting antenna (double ridged horn antenna EMC03115) through an amplifier. This configuration is shown in Figure VI.3. In the case of the *in situ* measurements, some results obtained in two mobile phone base stations are provided. Base station 1, for the 2000 MHz band, was in an urban area of Tokyo, while base station 2, which was on the outskirts of Tokyo, was chosen for the 800 MHz band. For each of these base stations, three locations were chosen for measurements. In this contribution, the three measurement locations for both base stations are referred to as location 1, 2 and 3. The distances between these locations and their base stations were between 240 and 270 m.
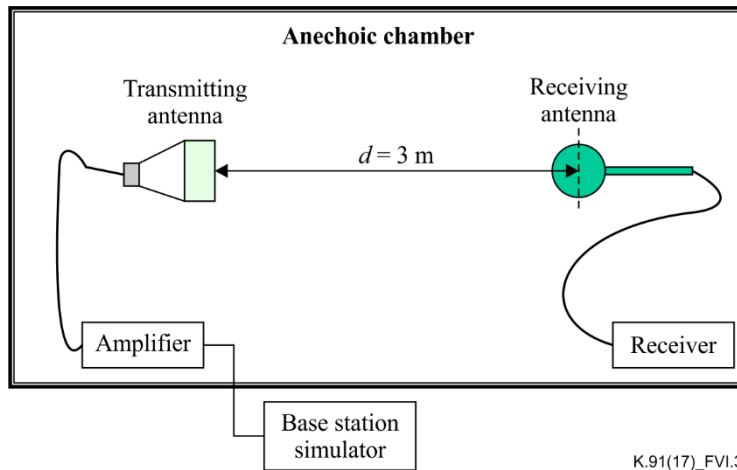
Figure VI.3 – Measurement configuration inside an anechoic chamber

Table VI.1 – Time averaged E-fields normalized to the 5 MHz value: *in situ* measurements were obtained at location 1 of each base station

RBW	*f = 882.5 MHz*		*f = 2137.6 MHz*	
	Indoor	*In situ*	*Indoor*	*In situ*
50 kHz	1.0	−0.1	0.3	−0.1
500 kHz	1.6	−0.0	1.1	−0.2
5 MHz	0	0	0	0
NOTE – Results are indicated in dB.				

Table VI.1 lists the time average E-field strength. They are normalized to the average E-field obtained for the RBW of 5 MHz. In this case, the measurements were taken for 6 minutes and the average values were calculated from the measured data points obtained. Because the time between measurements was automatically set, the number of data points was different for each RBW. During this measurement, the antenna was positioned at the height of 1.5 m above the ground. For the *in situ* measurements, results from base station 1 are presented. The maximum difference of 1.6 dB is obtained in the indoor measurements at 800 MHz.
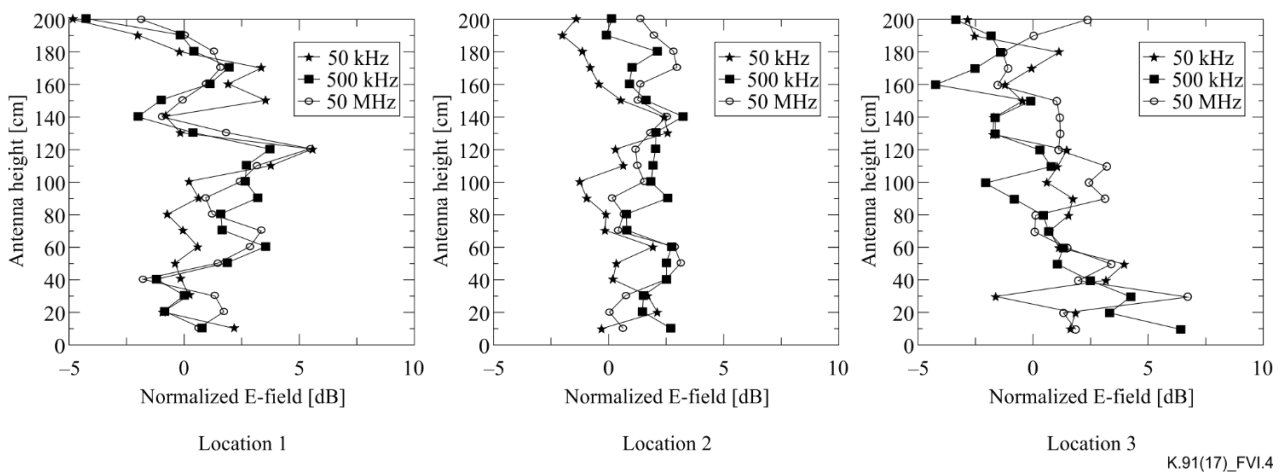
Figure VI.4 – Height pattern of the measured E-fields at 800 MHz band

Figure VI.4 shows the height pattern of the E-field measured at base station 1. The E-fields were measured up to the height of 200 cm, at an interval of 10 cm for RBWs of 50, 500 kHz and 5 MHz.

The difference in the spatial average E-fields obtained using the Japanese Notice No. 300 scheme, which uses 20 points, and 3 points average are summarized in Table VI.2. The difference is referenced to the values obtained with the RBW of 5 MHz. Although, for a given height, large differences in the measured E-fields for different RBWs of up to 6 dB was recorded (as shown in Figure VI.4) the difference in the spatial average E-fields obtained using different RBW is less than 2.7 dB.

Table VI.2 – Difference in spatial average E-fields referenced to the E-field obtained with RBW of 5 MHz for BS 1 and BS 2. Results are indicated in dB

	f = 882.5 MHz		*f = 2137.6 MHz*	
RBW	*20 points*	*3 points*	*20 points*	*3 points*
50 kHz	0.9	2.2	−2.5	1.2
500 kHz	0.3	2.7	−0.9	2.5
5 MHz	0	0	0	0

(a) LOCATION 1

	f = 882.5 MHz		*f = 2137.6 MHz*	
RBW	*20 points*	*3 points*	*20 points*	*3 points*
50 kHz	1.4	1.7	1.6	1.1
500 kHz	1.6	1.4	0.9	0.1
5 MHz	0	0	0	0

(b) LOCATION 2

	f = 882.5 MHz		*f = 2137.6 MHz*	
RBW	*20 points*	*3 points*	*20 points*	*3 points*
50 kHz	−1.1	−0.6	−1.8	2.5
500 kHz	0.6	1.0	−0.7	0.8
5 MHz	0	0	0	0

(c) LOCATION 3

Appendix VII

Example of block diagram with possible activities during exposure assessment

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

Figure VII.1 presents the block diagram of the possible activities during exposure assessment. More general block diagram and detailed information can be found in [IEC 62232].
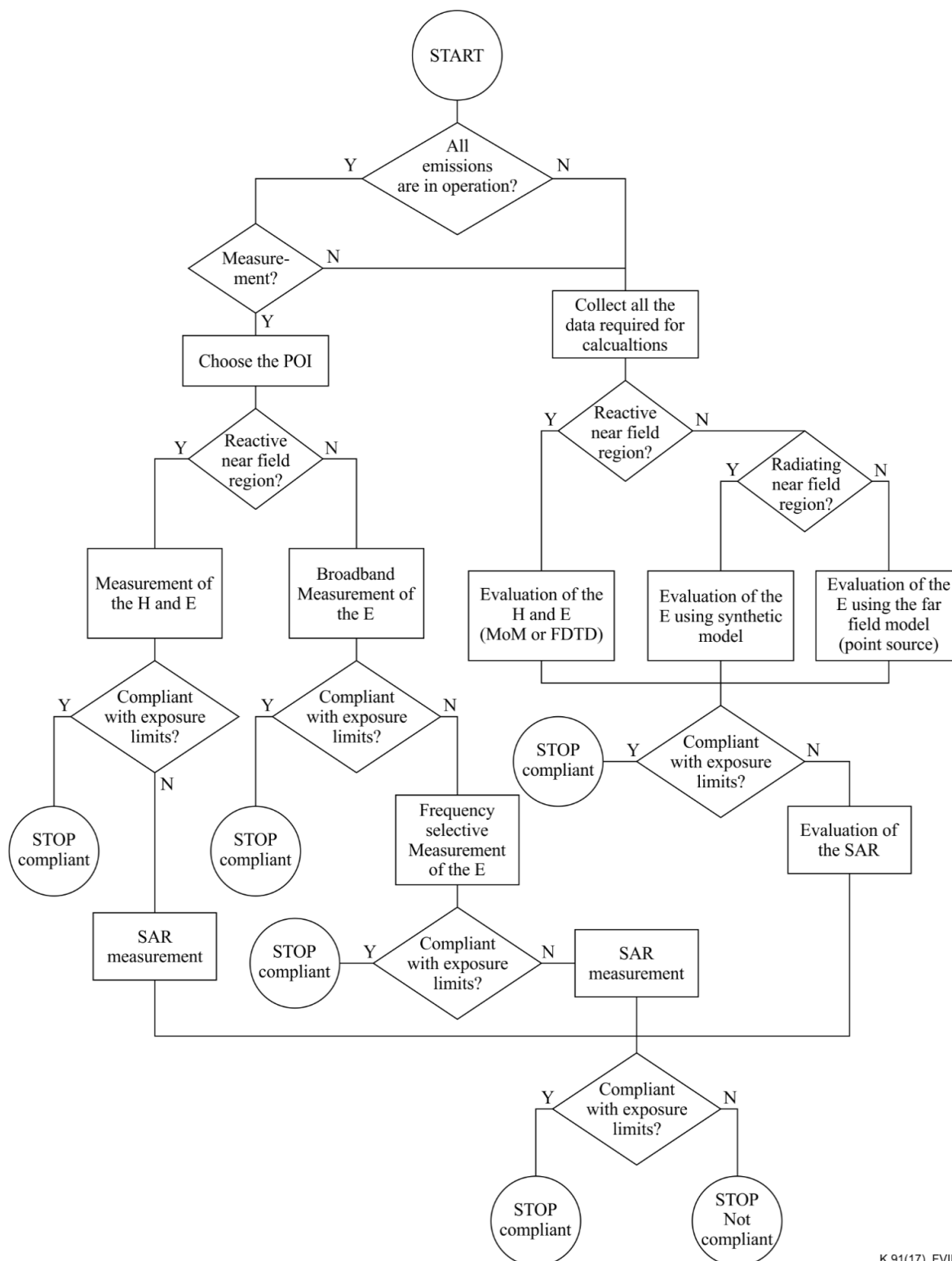
K.91(17)_FVII.1

Figure VII.1 – Block diagram of the exposure assessment procedure

Appendix VIII

Mobile App "EMF Exposure"

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

VIII.1 Introduction

"EMF Exposure" is a mobile app (App) available for Android users. The user of this application should have knowledge about how to conduct the RF exposure assessment using the parameters defined in [ITU-T K.52]. It allows the user to add base stations on the map and to calculate the approximate total exposure ratio due to the emissions from the inserted base stations. The user must have access to the base station input data. The App was developed with the support of the Spectrum, Orbit and Broadcasting Office of Anatel, the Brazilian Regulatory Telecommunications Agency. The source code is available from https://github.com/carisio/emf-exposure.

Disclaimer

This open-source implementation tool is provided "as is" with no warranties, express or implied, including but not limited to, the warranties of merchantability, fitness for a particular purpose and non-infringement of intellectual property rights and neither the developer (or its affiliates) nor the ITU shall be held liable in any event for any damages whatsoever (including, without limitation, damages for loss of profits, business interruption, loss of information, or any other pecuniary loss) arising out of or related to the use of or inability to use this tool.

The evaluations are based on conservative models and may overestimate real exposure.

VIII.2 Brief description of EMF Exposure's main features

The App provides a simple user interface that allows the user to manually add base stations and calculate the total exposure ratio due to them. Figure VIII.1 shows its main screen.
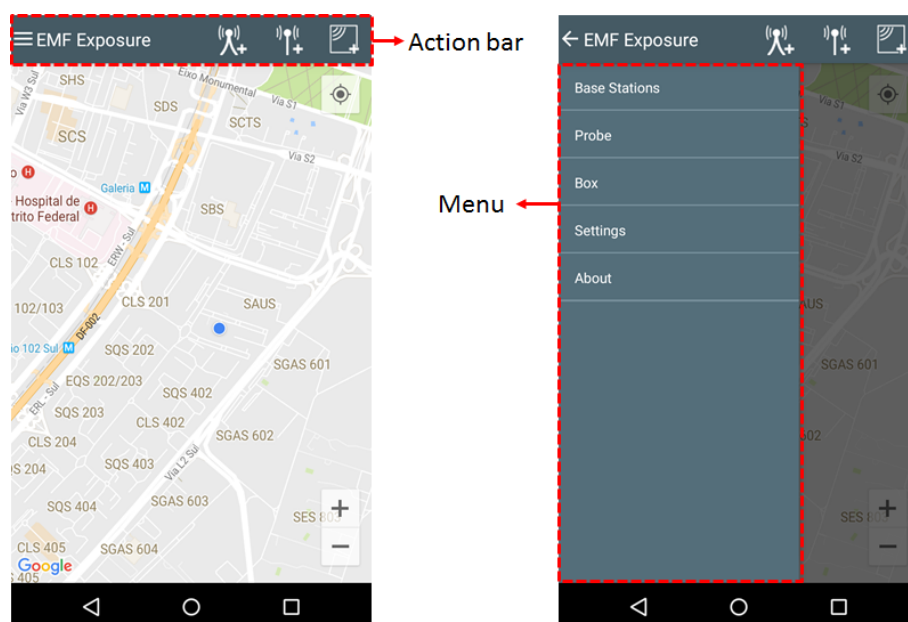
NOTE – EMF Exposure has three icons that allow the user to access the most common operations (add base station, add probe and add box); (Right) The lateral menu is highlighted. It allows the user to access all the functions of the app.

Figure VIII.1 – Main user interface. (Left) Action bar is highlighted

To add base stations, users can tap on the "Add base station" icon on the action bar or they can use the lateral menu, as shown in Figure VIII.2. Then, the user taps on the map to add a base station. EMF

Exposure will show a screen for the user to enter the base station information. Note that one base station can have multiple radio sources. In this case, the data should be provided separated by an empty space. Once a base station has been added, a base station icon is shown on the map. If the user taps on it, the base station properties are shown.
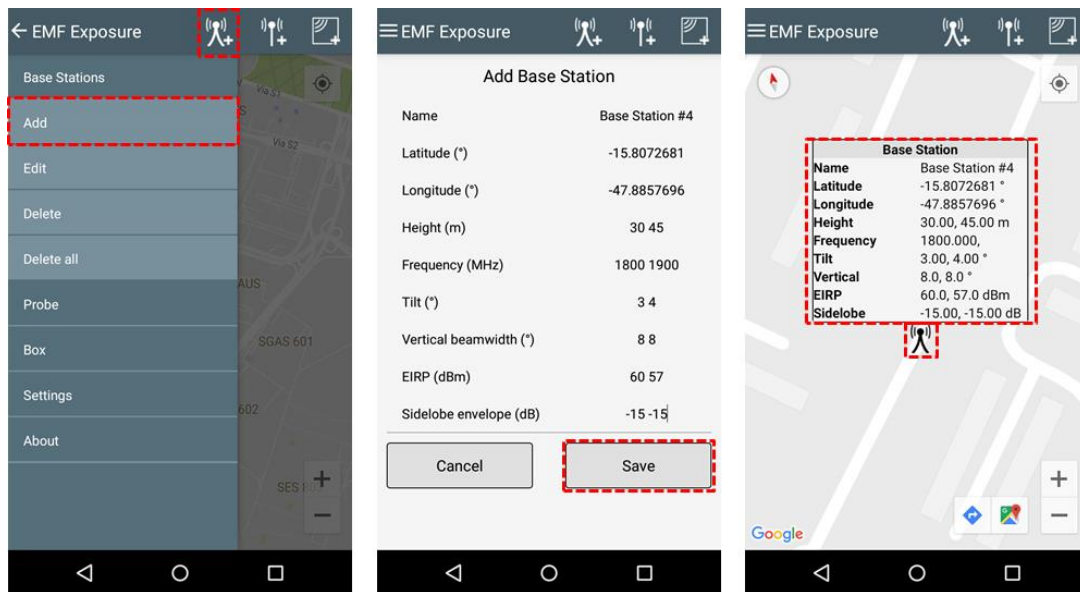
NOTE – The diagram on the left shows the possibilities to add a base station; (Center) add base station screen; (Right) base station shown on the map and its information.

Figure VIII.2 – Procedure for adding base stations

When the base stations are configured, the user can check the total exposure level using the probe function. To add a probe, the user can tap on the "Add probe" icon on the action bar or use the lateral menu as shown in Figure VIII.3. The user can then, tap on the map to add a probe. The App will show electric field and the total exposure rate (TER) at that location.
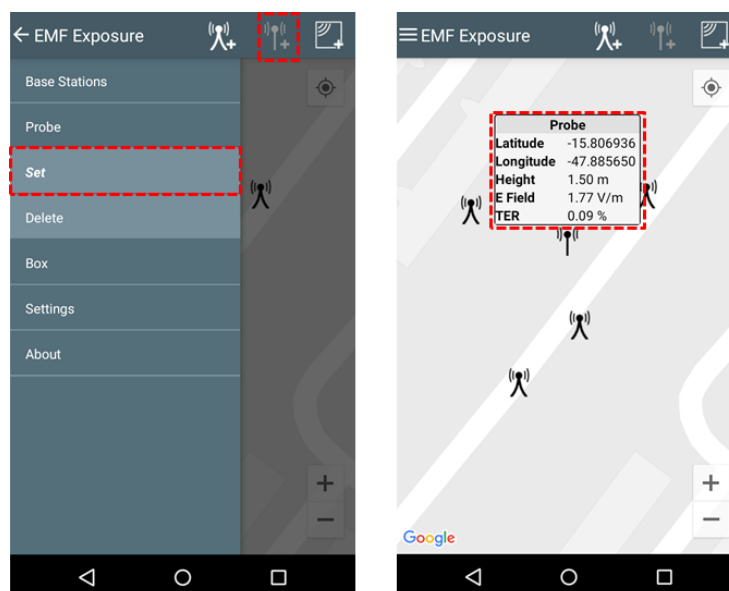
NOTE – (Left) Possibilities to add a probe; (Right) Probe shown on the map and its information.

Figure VIII.3 – Procedure to add a probe

In Figure VIII.3, the information is shown for a probe height of 1.5 meters. This height can be changed using the settings options (Figure VIII.4).
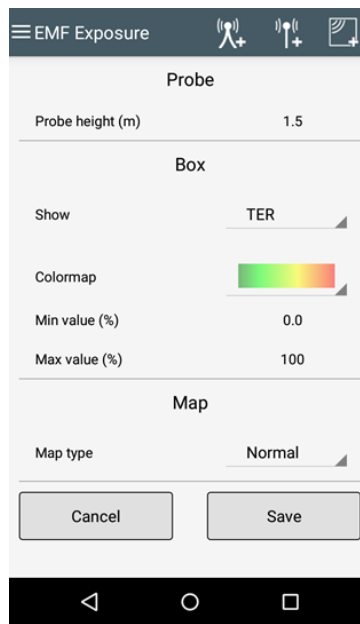
Figure VIII.4 – Changing settings

VIII.3 Brief description of the calculations done by EMF Exposure

EMF Exposure calculates the TER as defined in clause 9.6 of [ITU K.100]. The transmitting antennas of the base stations are modelled as omnidirectional in the horizontal pattern (assumes equal energy in all horizontal directions, which is not the case for all mobile network antennas) and as a "Directivity type-2 antenna" (defined in clause IV.2.2 of [ITU K.52]) in the vertical pattern. The propagation model is defined by equation (7-6) of ITU K.91. A detailed description of EMF Exposure can be found in [b-LCF 2017a] and the App can also be downloaded at [b-LCF 2017b].

Appendix IX

Manhole-type base station

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

IX.1 Introduction

This appendix presents the measurement results of radio frequency exposure from manhole-type base stations installed underground using the measurement methods introduced in this guideline, in order to evaluate the exposure from these base stations.

IX.2 Overview of manhole-type base station

Manhole-type base stations are for use in small cells of 4G networks and are installed underground. They have been developed to secure communication areas mainly in places where there are no suitable places for the installation of antennas such as tourist spots and scenic spots. An overview of their structure and service area is shown in Figure IX.1. The main specifications are given in Table IX.1.

a) Actual implementation of base station

b) Structure and service area

K.91(18)-Amd.3(19)_FIX.1
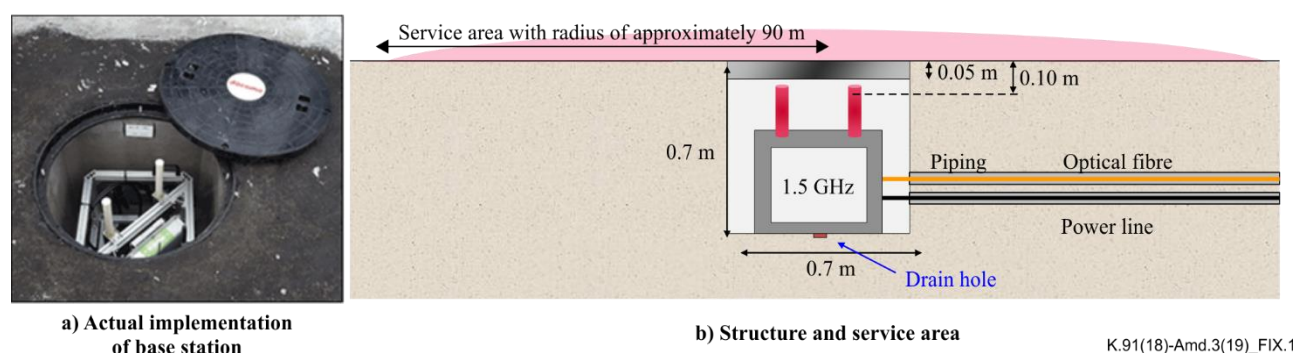
Figure IX.1 – Overview of structure and service area of manhole-type base stations

Table IX.1 – Main specifications of manhole-type base stations

Items	Values
Wireless access system	FDD-LTE
Frequency	1.5 GHz band (BAND 21)
Frequency bandwidth	15 MHz
MIMO	2×2

IX.3 Measurement points and spatial averaging

The spatial averaging methods defined in [IEC 62232] and [ITU-T K.61] introduced in clause 7.2.2 were used for the evaluation of exposure of the whole-body human because the manhole-type base station forms non-uniform field distributions. The 20-point method was used among several spatial averaging methods because the same spatial averaging method is stipulated by national regulations in Japan for the compliance assessment of EMF human exposure to mobile base stations [b-MIC].

All the points to be evaluated are shown in Figure IX.2. The evaluation points in the horizontal direction are defined by [b-MIC], and the points in the vertical direction for spatial averaging are defined by [IEC 62232], [ITU-T K.61] and [b-MIC].

The evaluation points in the horizontal direction are defined radially at less than wavelength/10 (approximately 20 mm at 1.5 GHz) steps around the wave source as shown in Figure IX.2(b). The

evaluation points in the vertical direction at a certain horizontal evaluation point are defined from height 0.1 m to 2.0 m at intervals of 0.1 m or less (when the frequency is 300 MHz or higher) assuming the space occupied by a human body as shown in Figure IX.2(c).
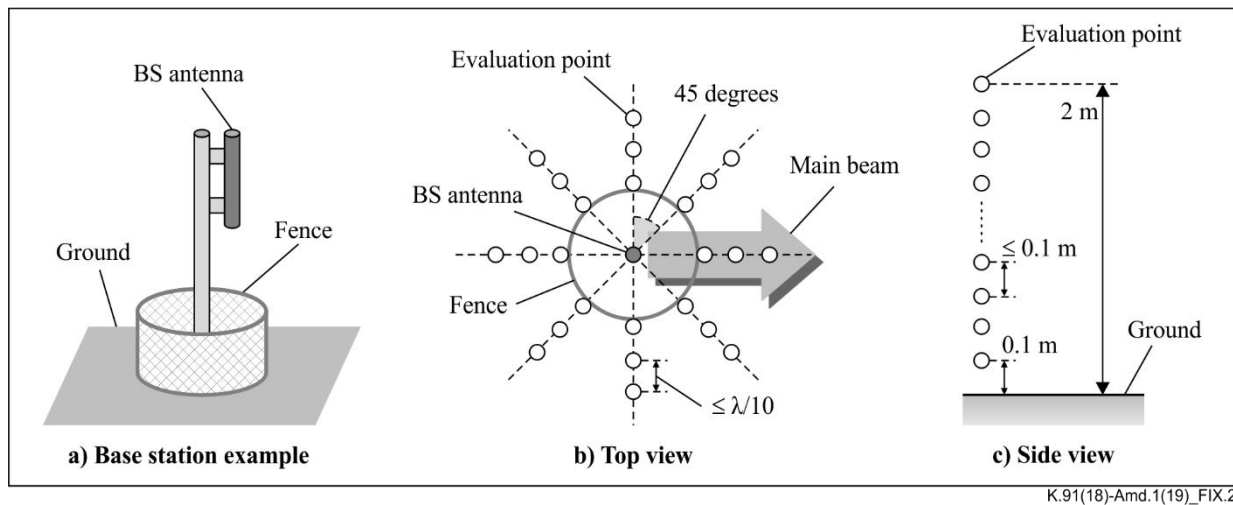

Figure IX.2 – All measurement points for spatial averaging

IX.4   Reference levels

Reference levels for compliance assessment defined in [b-MIC] were used because these levels are almost the same as those given in [b-ICNIRP] introduced in clause 5.6. The reference levels are regulated by a six-minute averaged value of the electric field strength, the magnetic field strength and power density (when the frequency is 300 MHz or higher). The reference levels in the 1.5-GHz band in [b-MIC] are 10 W/m^2 for spatial averaging and 20 W/m^2 for the spatial maximum.

IX.5   Frequency selective measurement

Frequency selective measurement methods defined in [IEC 62232] introduced in clause 7.2.5 were used for more accurate exposure evaluation. In this case, since there were no other base stations in the vicinity using the same frequency, it was possible to obtain the power densities of only the manhole-type base station.

Furthermore, the measurement method for the FDD-LTE base station using a spectrum analyzer given in [IEC 62232] was applied in order to obtain the power densities equivalent to the maximum traffic. In the method, the power densities of the resource blocks that regularly become the peak power are measured with zero span frequency under the condition that the resolution bandwidth is 1 MHz and the time resolution coincides with 1 symbol (about 71 µs) of the FDD-LTE signal. The obtained measurement value is extrapolated by the ratio of the number of resource blocks corresponding to the employed bandwidth to the number of measured resource blocks.

The SRM-3006 (Narda) analyser was used as the measuring equipment, which has isotropic sensitivity and frequency selectivity. However, the minimum time resolution that can be set in the isotropic axis mode of this equipment is greater than 1 symbol. Therefore, the detector and the trace were set to maximum so that they are not underestimated. The set parameters of the measuring equipment for this evaluation are given in Table IX.2.

Table IX.2 – Set parameters of SRM-3006 for this evaluation

Items	Values
Axis	Isotropic
Resolution bandwidth	1 MHz
Video bandwidth	100 kHz
Result (Detector)	Max
Trace	Max

Since there is an excessive number of evaluation points in the horizontal direction for measurements, in order to reduce the measurement time and obtain conservative evaluation results, the sensor scanned slowly in the horizontal direction in the range of 3 m around the base station maintaining a constant height while repeatedly sweeping with the maximum trace as shown in Figure IX.3. The maximum value in the horizontal direction was measured at each evaluation point in the vertical direction. Furthermore, the maximum value was obtained in all horizontal directions at each height, and the maximum and the averaged value of those in the vertical direction were calculated.
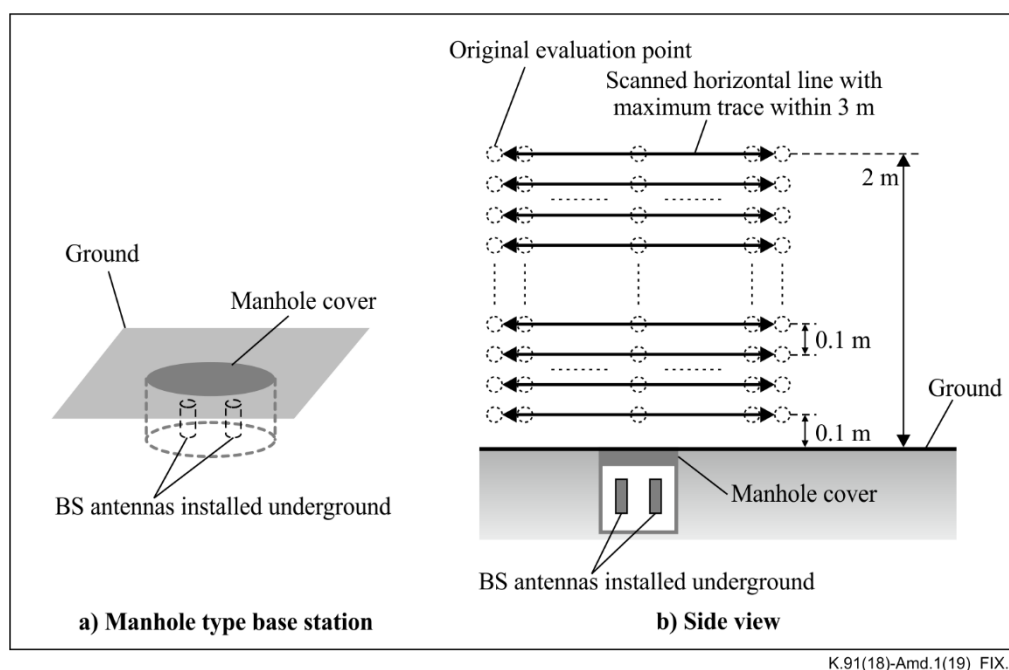
K.91(18)-Amd.1(19)_FIX.3

Figure IX.3 – Scanned horizontal lines with maximum trace to reduce measurement time and obtain conservative evaluation results

IX.6   Results

The vertical direction dependence of the maximum power density in all horizontal directions at each height normalized by the equivalent isotropically radiated power (EIRP) of 1 W per MIMO branch as shown in Figure IX.4. The maximum value and the averaged value of those in the vertical direction are 1.9 W/m^2 and 0.27 W/m^2, respectively. These values are lower than both the spatial maximum reference level, and the spatial average reference level regulated by [b-MIC].
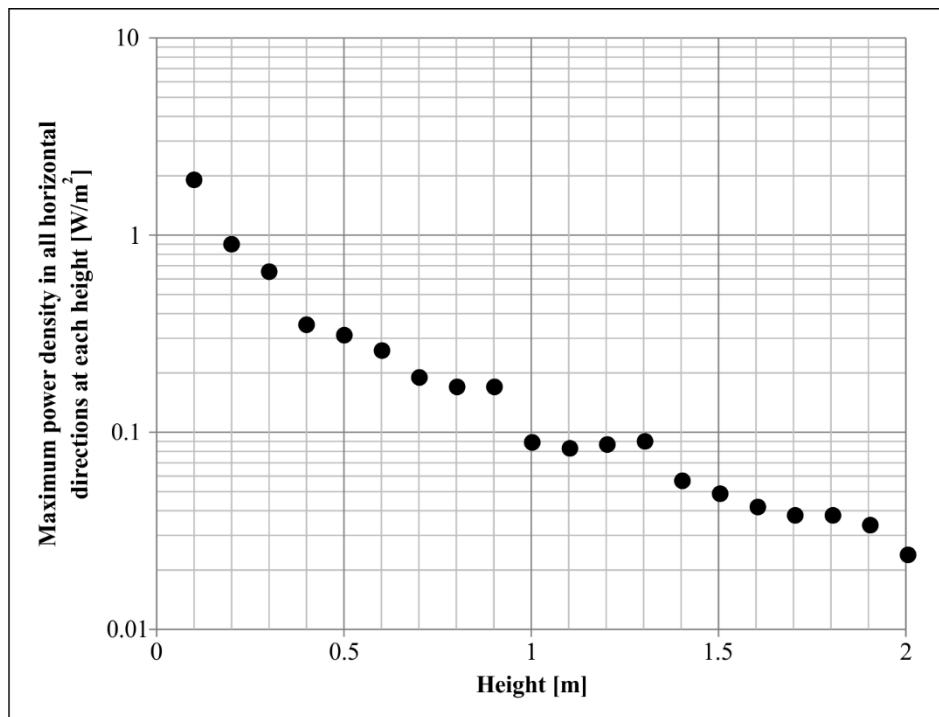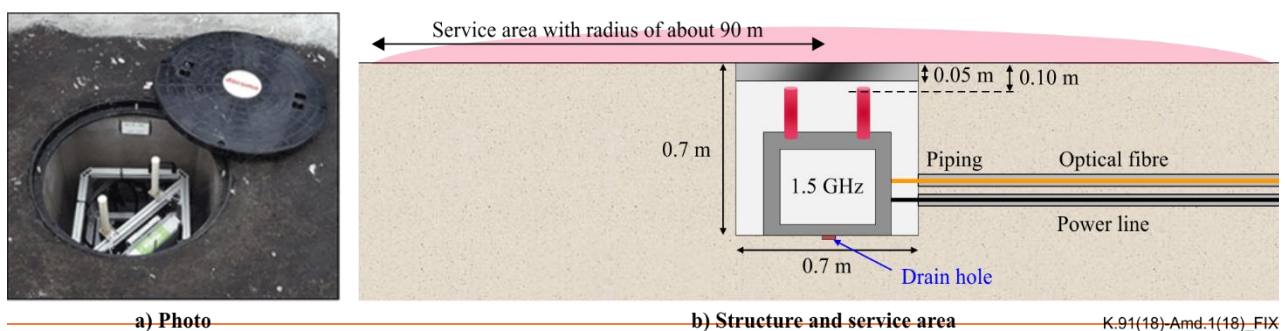
K.91(18)-Amd.1(19)_FIX.4

Figure IX.4 – Vertical direction dependence of the maximum power density in all horizontal directions at each height normalized with EIRP 1 W per MIMO branch

IX.7 Conclusion

Exposure evaluation based on the measurements of power densities for the manhole-type base station installed underground was carried out using the measurement method defined in [IEC 62232], [ITU-T K.61] and [b-MIC] introduced in this guideline. The maximum power density normalized by EIRP 1 W per MIMO branch was lower than the reference levels for spatial averaging defined in [b-MIC], which are almost the same as those given in [b-ICNIRP].

IX.1 Introduction

Manhole type base stations are for small cells of 4G network installed in the ground and have been developed to secure the communication area mainly in places where there are no suitable places for installation of antennas such as tourist spots and scenic spots. An overview of their structure and service area are shown in Figure IX.1; the main specifications are shown in Table IX.1. The technical application of the investigation results to 5G are also considered.

a) Photo   b) Structure and service area   K.91(18)-Amd.1(18)_FIX

Figure IX.1 – Overviews of the structure and the service area of manhole type base stations

~~IX.2~~ ~~Regulations regarding compliance assessment methods for EMF human exposure in Japan~~

~~The compliance assessment methods for EMF human exposure from mobile base stations are stipulated by national regulations in Japan; these are basically assumed for base stations installed on the ground [b-MIC]. In the compliance assessment, electromagnetic field strengths from radio sources evaluated by calculations or measurements must comply with the reference level.~~

~~In assessments based on measurements, isotropic sensitivity, frequency selectivity, etc. are required to be measured by equipment.~~

~~All the points to be evaluated are shown in Figure IX.2. The evaluation points in the horizontal direction are defined radially at less than wavelength/10 (about 20 mm at 1.5 GHz) steps around the wave source. The evaluation points in the vertical direction at a certain horizontal evaluation point are defined from height 0.1 m to 2.0 m at intervals of 0.1 m or less (when the frequency is 300 MHz or more) assuming the space occupied by a human body.~~

~~The reference levels are regulated by a 6 minute averaged value of the electric field strength, the magnetic field strength and power density (when the frequency is 300 MHz or more). The first step of the compliance assessment in measurements is to confirmed whether the maximum value of the EMF strengths in the vertical direction is equal to or less than the normal reference level (10 W/m² at 1.5 GHz) at each evaluation point in the horizontal direction. If it exceeds the reference level and human body is not uniformly exposed to radio wave, it is confirmed whether the maximum value and the averaged value of the EMF strengths in the vertical direction are equal to or less than the spatial maximum reference level (20 W/m² at 1.5 GHz) and the spatial averaged reference level (10 W/m² at 1.5 GHz), respectively.~~
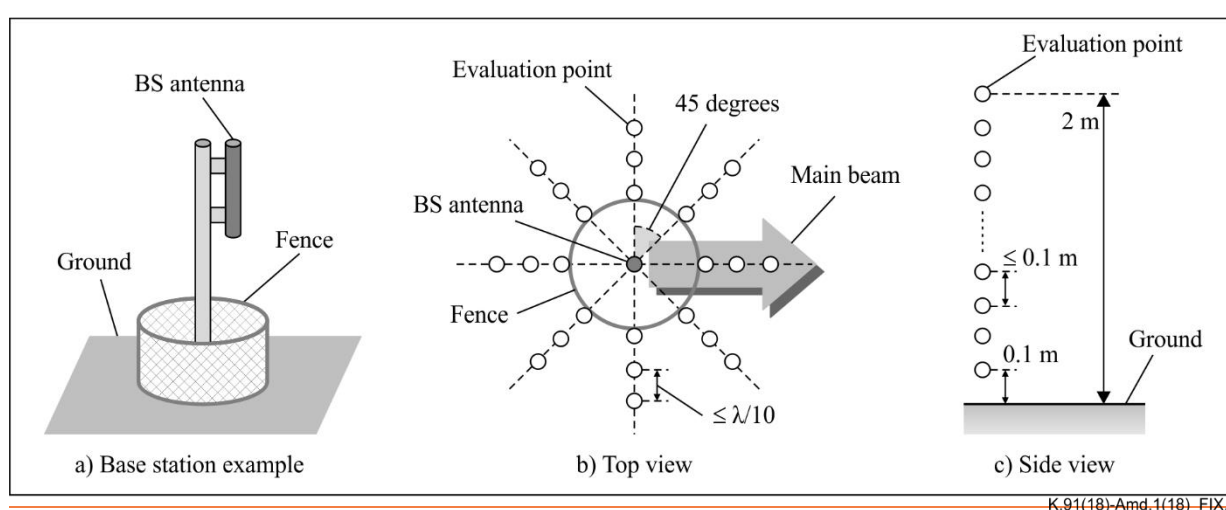
K.91(18)-Amd.1(18)_FIX.2

## IX.3 Compliance assessment method applied to manhole type base station

The compliance of the manhole type base station was assessed based on the measurement of power density, even though antennas for that are installed in the ground. The SRM-3006 (Narda) was used as measuring equipment, which has isotropic sensitivity, and frequency selectivity.

Although the reference levels are specified by 6-minute averaged values as mentioned above, the power density assuming maximum traffic was measured for conservative evaluation. Annex F.7 in [b-IEC 62232] provides two types of the measurement methods for the EMF strength assuming maximum traffic of FDD-LTE base station under normal traffic conditions [b-IEC 62232]. In the method using spectrum analysers, the power density of the resource blocks that regularly become peak power is measured with zero span frequency under the condition that the resolution bandwidth is 1 MHz and the time resolution coincides with 1 symbol (about 71 μs) of the FDD-LTE signal, and the obtained measurement value is extrapolated by the ratio of the number of resource blocks corresponding to used bandwidth to the number of measured resource blocks. However, the minimum time resolution that can be set in the isotropic axis mode of this equipment is greater than 1 symbol. Therefore, the detector and the trace were set to max as not to be underestimated. The setting parameters of the measuring equipment for this evaluation are shown in Table IX.2.

Table IX.2 – Setting parameters of the SRM-3006 for this evaluation

Items	Values
Axis	Isotropic
Resolution bandwidth	1 MHz
Video bandwidth	100 kHz
Result (Detector)	Max
Trace	Max

Since the evaluation points in the horizontal direction are very large, for reducing the measurement time and conservative evaluation, the sensor was scanned slowly in the horizontal direction in the range of 3 m around the base station keeping the height constant while repeatedly sweeping with max trace as shown in Figure IX.3, and the maximum value in the horizontal direction was measured at each evaluation point in the vertical direction. Further, the maximum value in the all horizontal directions at each height was obtained, and the maximum value and the averaged value of those in the vertical direction were calculated.

a) Manhole type base station   b) Side view
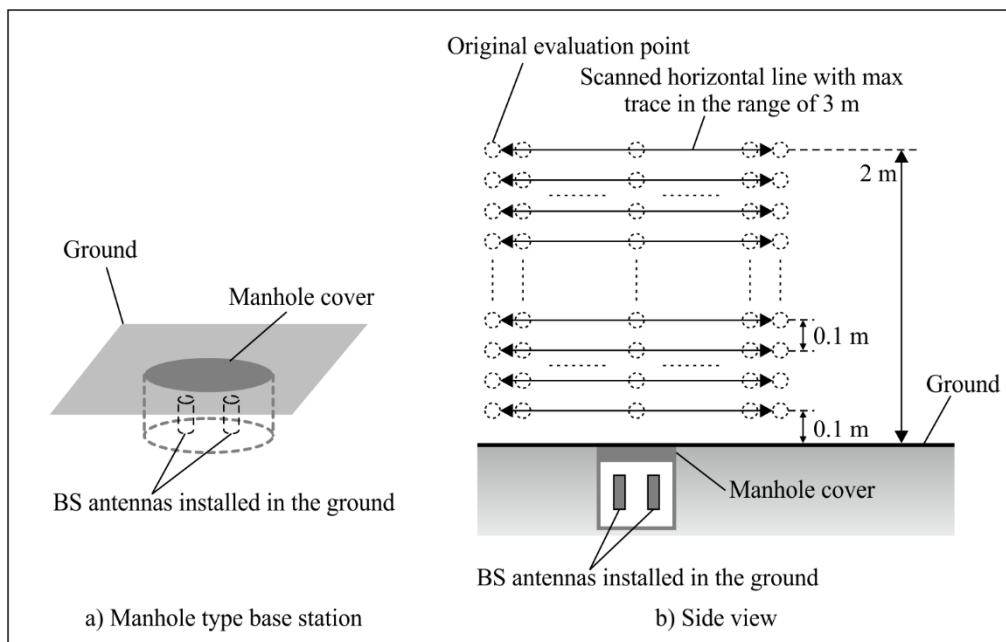
Figure IX.3 – Scanned horizontal lines with max trace for reducing the measurement time and conservative evaluation

IX.4 Result

The vertical direction dependence of the maximum power density in the all horizontal directions at each height normalized with EIRP 1 W per MIMO branch shown in Figure IX.4, and the maximum value and the averaged value of those in the vertical direction are 1.9 W/m^2 and 0.27 W/m^2, respectively. They comply with both the normal reference level, the spatial maximum reference level, and the spatial averaged reference level stipulated by the radio law in Japan.
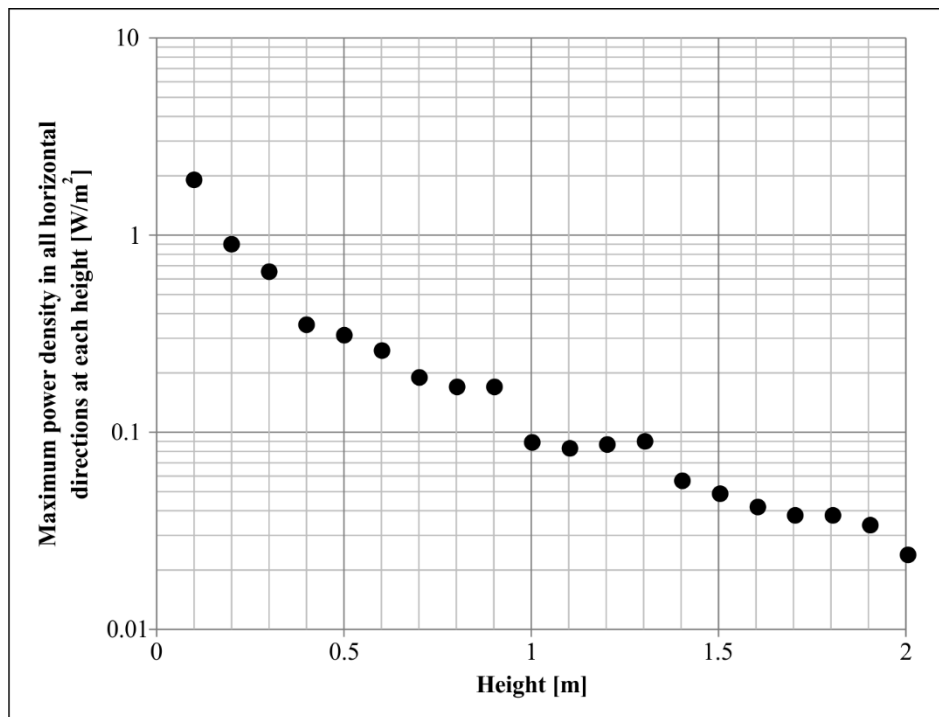
K.91(18)-Amd.1(18)_FIX.4

Figure IX.4 – The vertical direction dependence of the maximum power density in the all horizontal directions at each height normalized with EIRP 1 W per MIMO branch

IX.5 Conclusion

The compliance of the manhole-type base station where antennas are installed in the ground was assessed based on the measurement of power density based on the stipulated evaluation methods by the radio law in Japan which are basically assumed for base stations installed on the ground. In the future, the validity of this evaluation and the EMF strengths using other spatial averaging schemes defined in Annex B of [b-IEC 62232] will be confirmed based on EMF simulations and further measurements.

Appendix X

EMF monitoring and information platform

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

X.1 Introduction

This appendix specifies the concept and method of an EMF exposure information platform to enhance general public awareness of EMF exposure status and usage data for the EMF related professional.

It provides technical system level guidance on how to provide EMF exposure level information for selected areas that are of interest to the general public. The purpose of this platform is to enable consistency of management by national regulators of EMF under their control and the national limits, and for providing EMF related data to professionals for the improvement of EMF policy and research.

X.2 EMF monitoring platform concept

The concept of an EMF information platform for the general public and its usage by experts is referred to in Figure X.1.
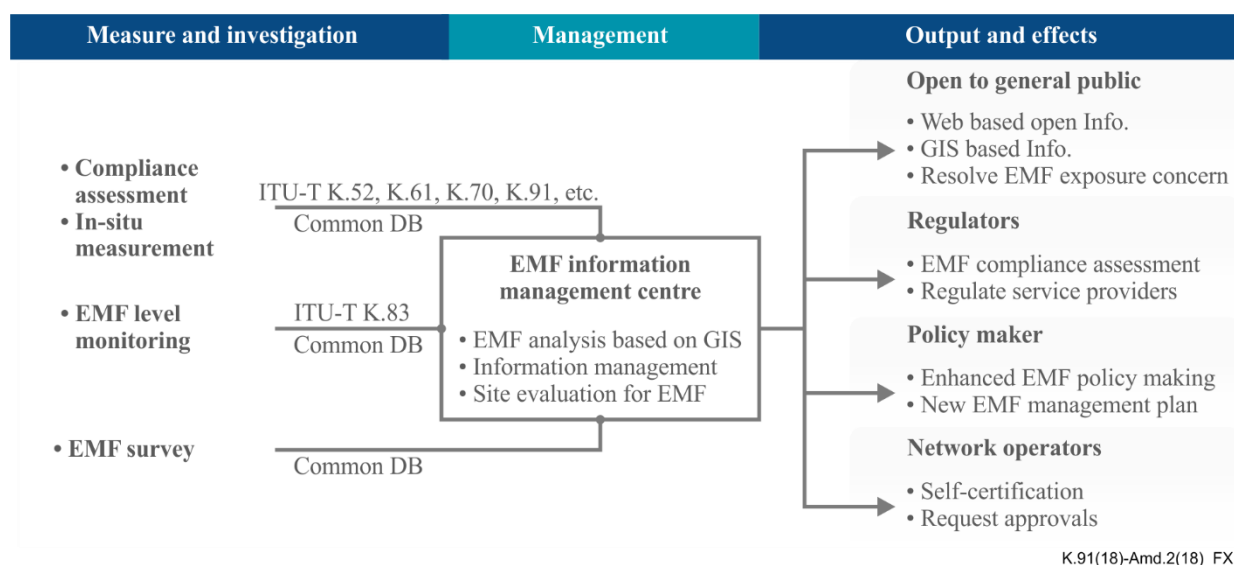
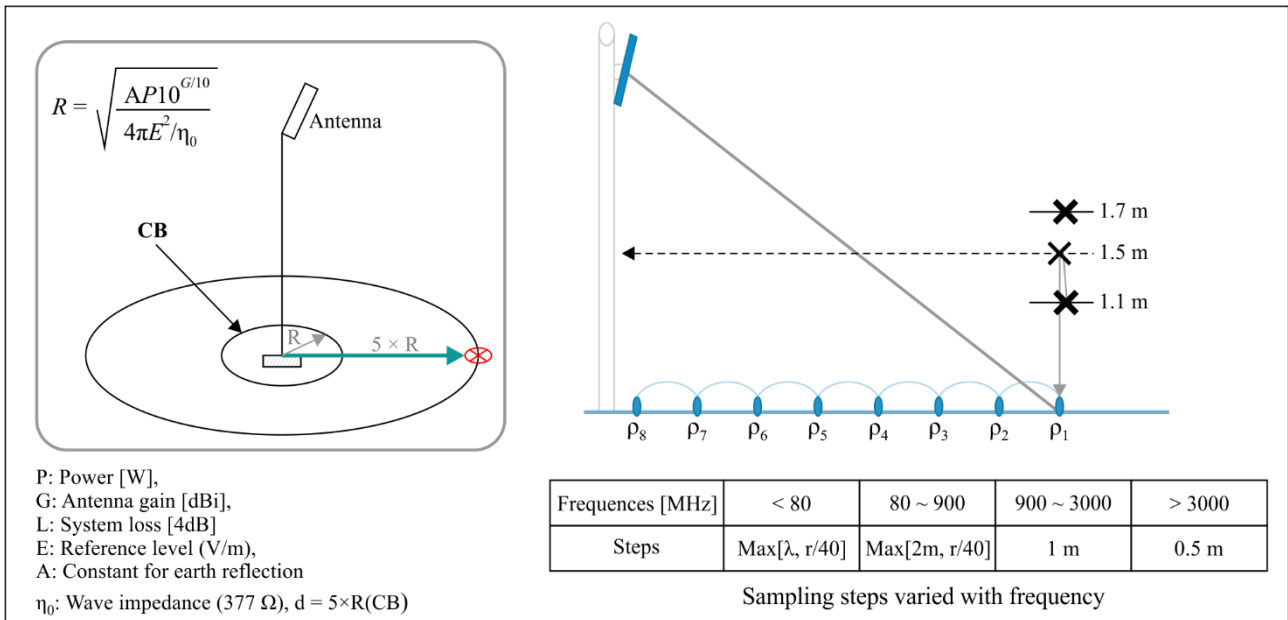**Figure X.1 – Concept of EMF information platform**

All EMF related information collected and delivered to the information platform is open to various people as indicated in the Figure X.1 concept. The concept of an EMF information platform provides a user interface based on geographic information system (GIS) for easy understanding and convenient access by the general public, industry, researcher and policy makers. All measured and collected data need to be in a common database format in order to be handled by the open platform. The platform has two types of data handling: the evaluated result and measured raw data, which can be made accessible to professionals via an open application programming interface (API).

The detail platform architecture consists of data collection, data classification, standard database, interactive system and data transaction with a user interface component. To overcome difficult access to the platform server directly, a local database (DB) can be used for changing common DB and sending server in platform system. The general public can access the system using a smartphone application (app) or web-based user interface (UI) or a dedicated UI for professionals.

X.3   Data collection of RF EMF

X.3.1   Compliance assessment

–   Measurement start point: 5 times distance from compliance boundary (CB);

–   Step measurement at 1.5 m from start point to antenna and 1.1, 1.5, 1.7 at the maximum strength point;

  •   investigation step varied with frequency, to the nearest point general public can access from 5CB.

$$R = \sqrt{\frac{AP10^{G/10}}{4\pi E^2/\eta_0}}$$

CB

P: Power [W],
G: Antenna gain [dBi],
L: System loss [4dB]
E: Reference level (V/m),
A: Constant for earth reflection
η_0: Wave impedance (377 Ω), d = 5×R(CB)

Frequences [MHz]	< 80	80 ~ 900	900 ~ 3000	> 3000
Steps	Max[λ, r/40]	Max[2m, r/40]	1 m	0.5 m

Sampling steps varied with frequency

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Figure X.2 – Example of Korea EMF compliance assessment

X.4   Broadband EMF area monitoring

This Recommendation defines the methods that shall be used to determine the total exposer ratio (TER) over a certain period to perform a time dependent evaluation of EMF exposure. The measurement is continuously and automatically carried out over the frequency range from 100 kHz to 3 GHz. Installation height is 1.5 m from the floor level.

The average measurements time is 6 minutes according to the national guideline. The measured data shall be transferred to designated server or personal computer (PC) via wireless modem every day or defined time interval.

The measurement equipment consists of:

–   broadband probe based on diode detection;

–   signal processing and system control unit;

–   GPS and wireless communication module;

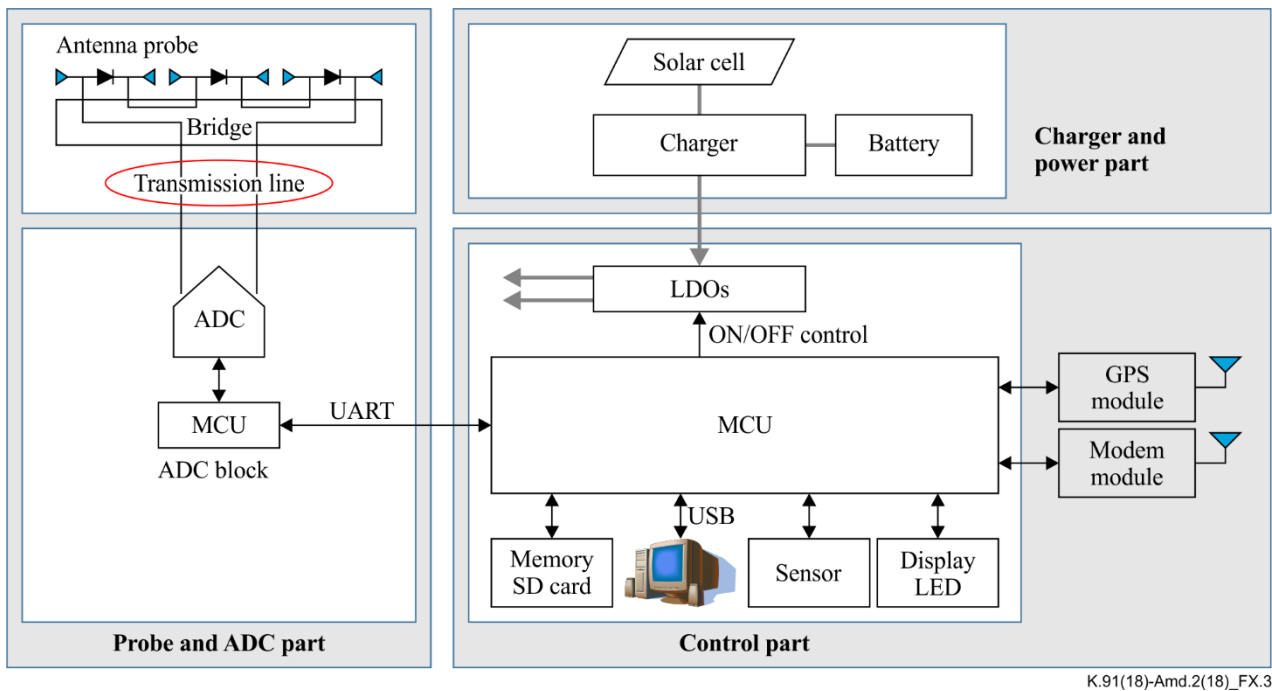–   solar power system and system protection.

Figure X.3 – Example of broadband EMF area monitor block diagram

The measured data is the rms value of the electric field. This probe is tri-axial isotropic. The sampling rate is 1 second and measurement interval is 6 minutes, as recommended in [ITU-T K.83], All various sources are measured with the broadband area monitor, but not identifying each source frequency. It is designed with Schottky diode detector generally. The result of broadband monitoring is the electric field strength variation along with time.
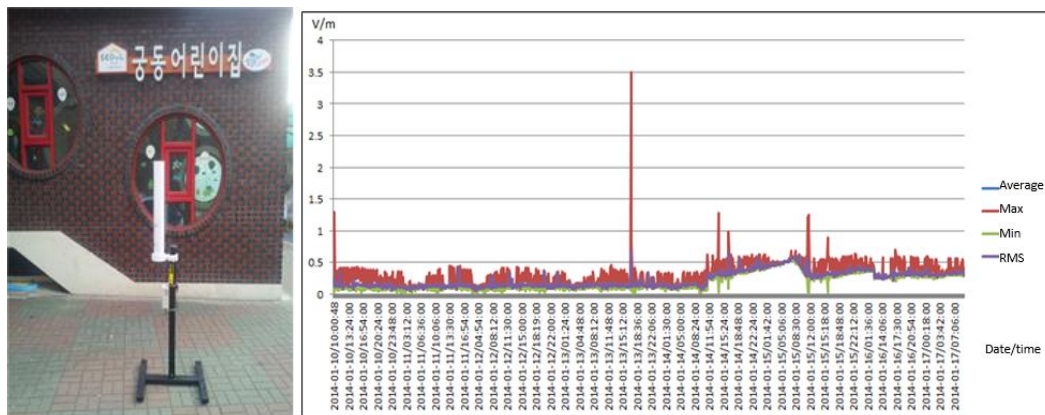
Figure X.4 – Example result of broadband EMF monitoring survey

The long-term measurement result is shown with location based EMF monitor along with time. The daily, weekly, monthly and yearly based statistic results show on the web or app on the smartphone.

X.5 Frequency selective EMF area monitoring
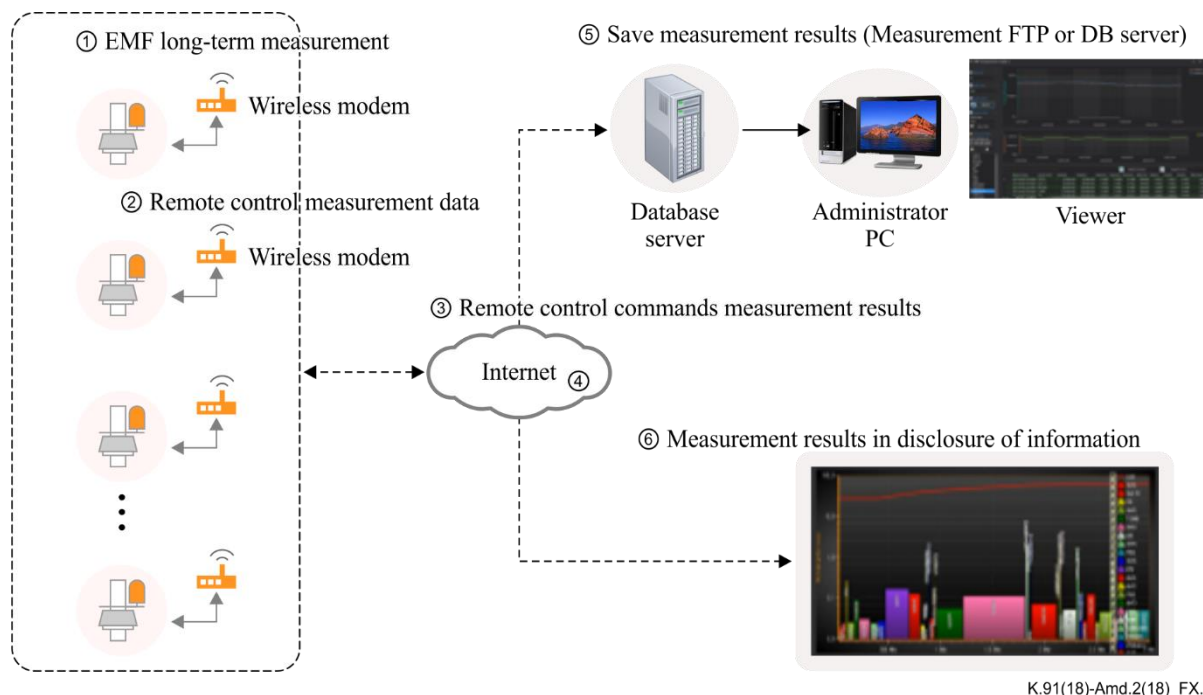
Figure X.5 – Concept of frequency selective EMF area monitoring

The frequency selective EMF area monitoring can be distributed at local interested sites, measuring EMF strength continuously and sending data to the server via wireless modem. The results show each EMF strength value and percentage of limit for all frequency subranges in the chart with graphic results and level of variation along with time (1, 2, 6, 15 minute intervals) for daily, weekly, monthly, yearly variation results.

The measurement equipment consists of the following parts:

–   tri-axial isotropic probe;

–   frequency selective measuring instrument, which processes the signal from the probe and indicates the value of the EM field quantity;

–   measurement automation with GPS;

–   mechanical and protective housing with solar power system.

The frequency subrange is the frequency bandwidth list or table in the instrument. The frequency ranges are listed as FM, TV, TRS, GSM, CDMA, WCDMA, LTE, WiFi and etc., as an example.

The parameters (e.g., attenuation, preamplifier) for each subrange are adopted automatically during each cycle to achieve best possible sensitivity without signal distortion due to overload (e.g., in preamplifiers, mixers) from other emitters in the same or other sub bands.

The built-in spectrum analyser is frequency range from 100 kHz to 6 GHz based on fast Fourier transform (FFT) scanning. The instrument has GPS for the location information, wireless modem for the data transmission to server and alarms for security, system status and over limit.

Measurement result consists of values achieved according measurement method and frequency subranges that fulfil the criteria as user defined stored as relevant emissions and used for the TER calculation. As additional information date, time, actual measurement position, ambient temperature and system status and warnings are added to the measurement result. This result is stored internally (offline evaluation) or transmitted automatically via data link to a server (online evaluation).
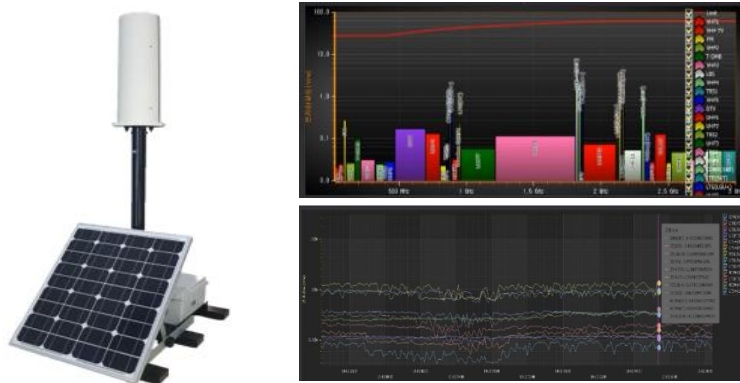
Figure X.6 – Example of frequency selective EMF area monitor with AGOS SDSM6000

X.6 EMF area scanning with vehicle

EMF area scanning procedure starts with the measurement set-up and scenario which include scanning area and frequency subranges, as well as the scanning targeted area along with all loads as possible. The measured spectrum and electric field strength data is recorded at each coordinate and mapping on the commercial map. The measured results are expressed with colour dots that show electric field intensity.
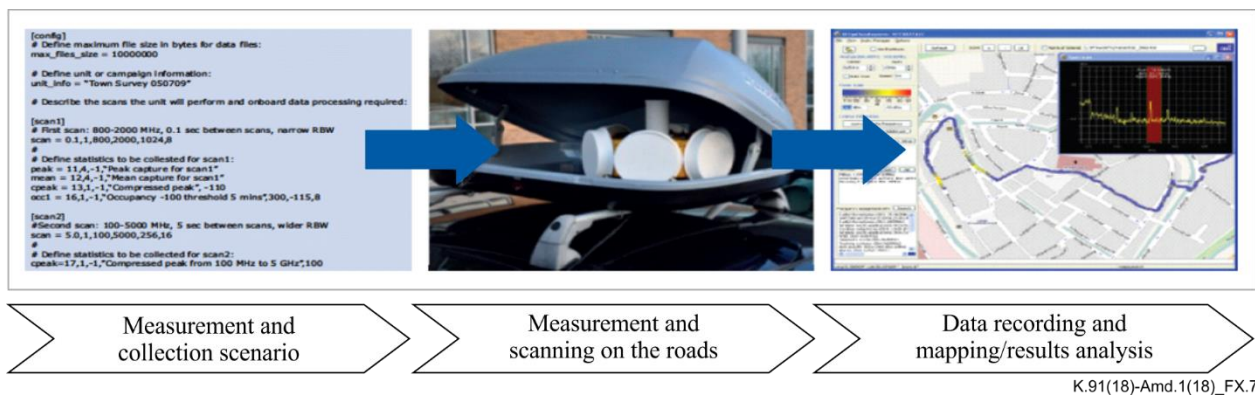
Figure X.7 – EMF area scanning process

For each sub-band, the maximum detectable level is at least the limit value. The minimum detectable level is required in case no emissions above the threshold value are present. It can be achieved with adopted settings of e.g., attenuation, bandwidth. An instantaneous dynamic range of 60 dB must be achieved for each level setting. Any other signal present in any other subrange and bigger than 25% or at least 3 MHz off the measurement frequency, must cause no overload or measurement error, if its field strength is below the exposure limit.

Scanned and measured data need to upload to the DB server for area analysis with huge amount of data size. This database needs to be built for the measured electric field strength to generate analysis of exposure ratio and power density based on geographic information.

The measurement equipment consists of the following parts:

– measurement probe;
– frequency selective measuring instrument, which processes the signal from the probe and indicates the value of the EM field quantity;
– measurement automation;
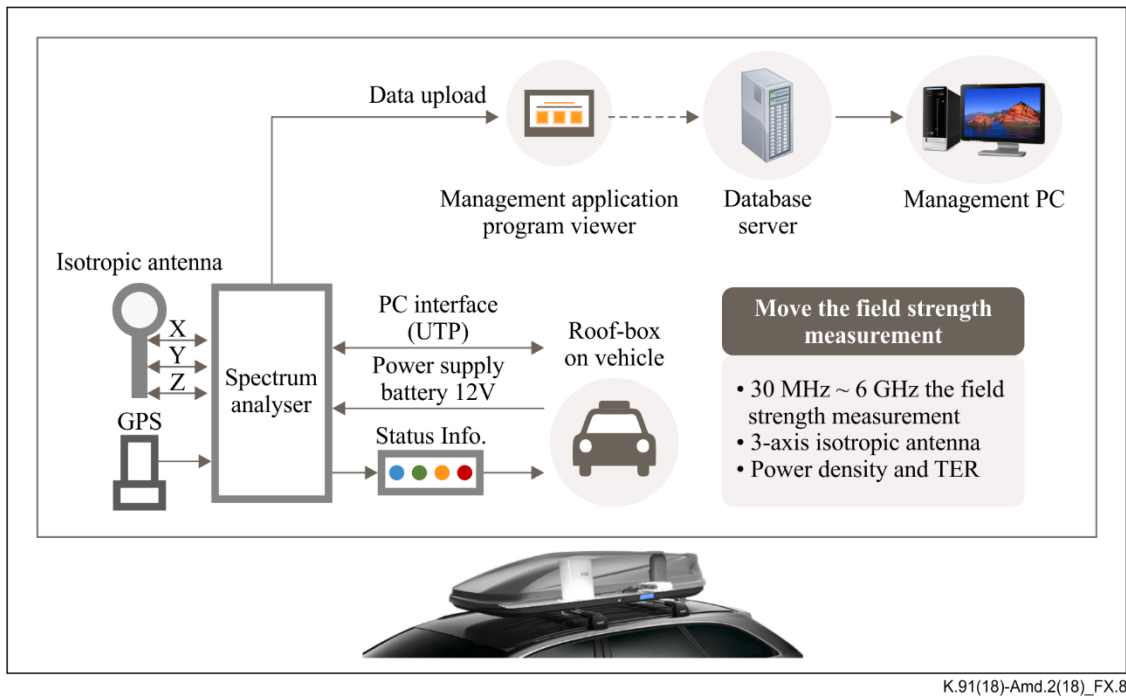– mechanical and protective housing.

Figure X.8 – Example of EMF area scanning system

For the EMF mobile measurement, all measuring parts need to be installed in the roof-box on the vehicle to protect against outside environmental impacts such as dust, rain and vibration. The measurement and scanning control shall monitor the system status and measuring status with auto script which be made in scanning scenario automatically. The measured data shall be saved to the internal memory with every 1 second GPS interval.

Each measured pixel is a small square area which can be decided with vehicle moving speed and GPS data update rate. Thus, 1 degree of coordinate is the basic resolution unit of the scanning data. The size of the pixel is 24.6m for longitude and 30.8m for the latitude in grid mapping.
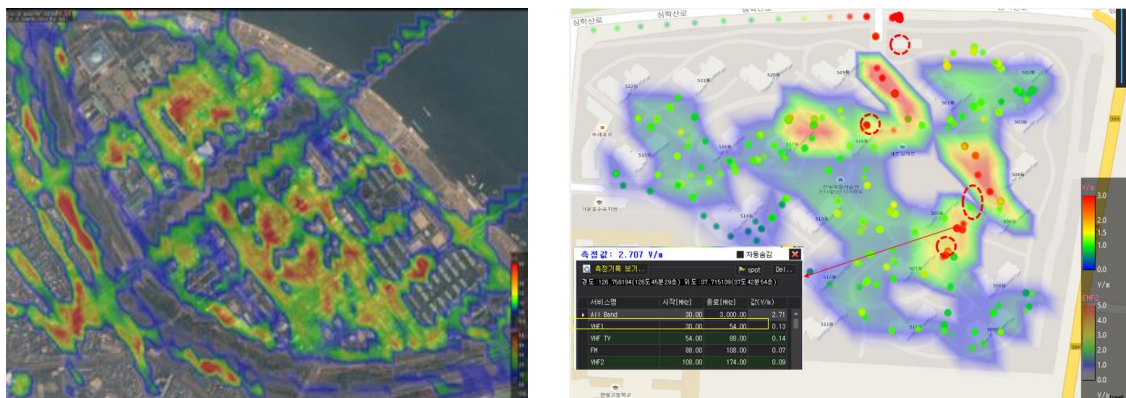

Figure X.9 – Example of scanning results GIS based

Mapping data shows the highpoint of electric field strength or power density. In the right picture of Figure X.9, the red dots are wireless repeater or mobile base stations.

X.7 Information platform for general public and expert

Web based information

All possible information about how the measurements are taken is provided:

– measurement location (by its geographical positioning on a map);
– description of the measurement site;
– date and time;
– description of the measurement method: broadband, frequency selective, average time, position of the probe, etc.;
– identify the measurement equipment;
– record calibration details for any instrumentation used;
– identify who has done the assessment;
– record when and where the assessment was performed;
– record the relevant sources considered and associated parameters.

GIS based interface method

The current measuring device shows all information related system and result of EMF strength values in interested area. Measured points are also shown with various chart which includes daily, weekly, monthly, yearly based result statistics.
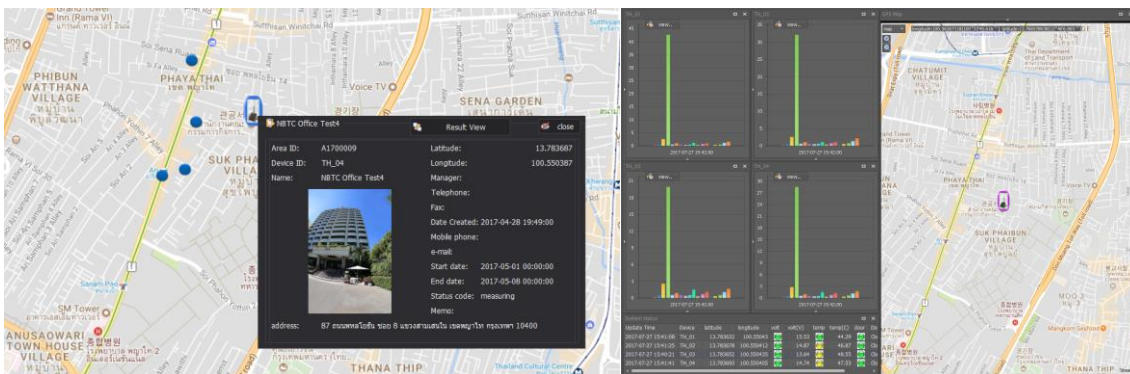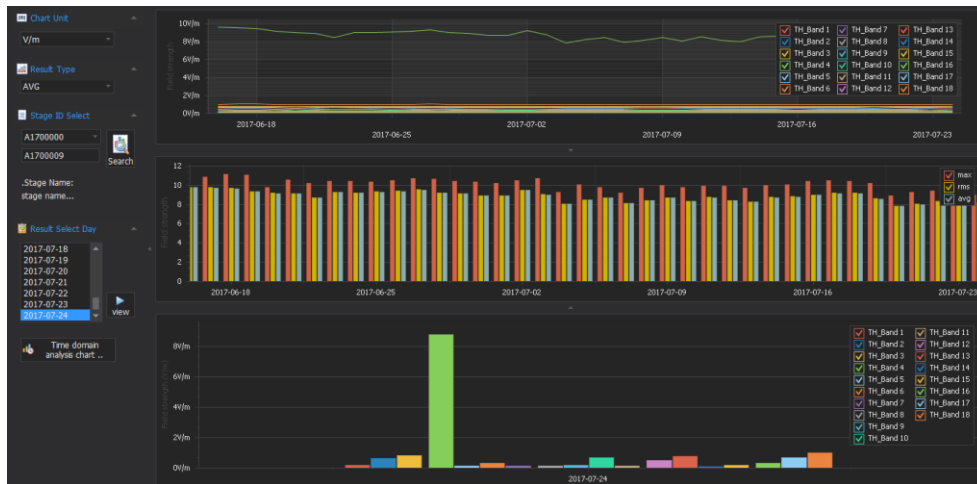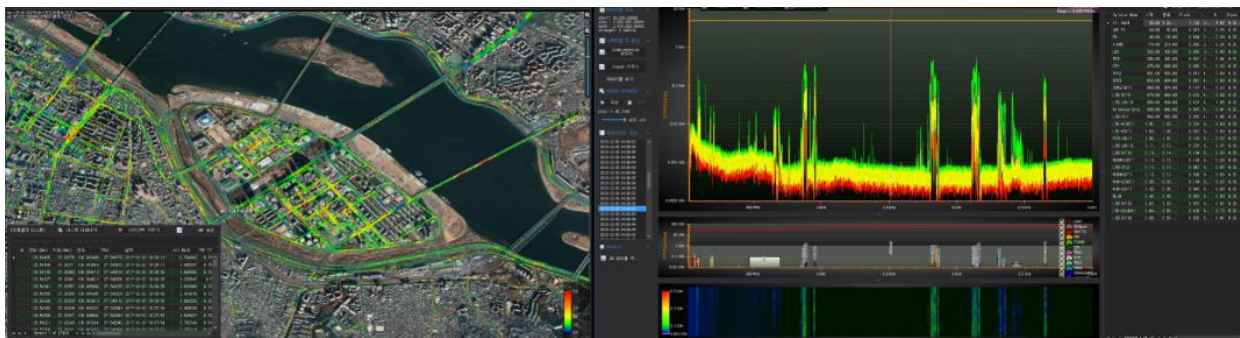

Figure X.10 – Web based general public access view (Thailand NBTC & Korea: KCA)
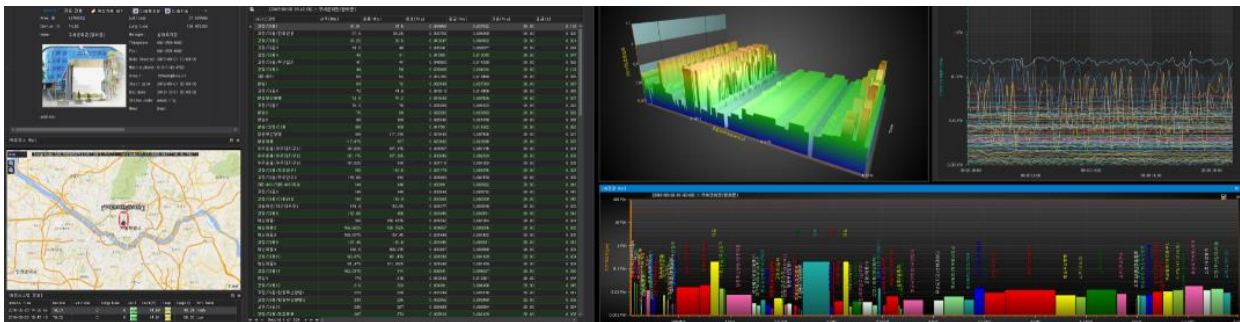
Statistics analysis

The results are provided as the time chart, bar chart, each frequency subranges chart for better understanding to general public.
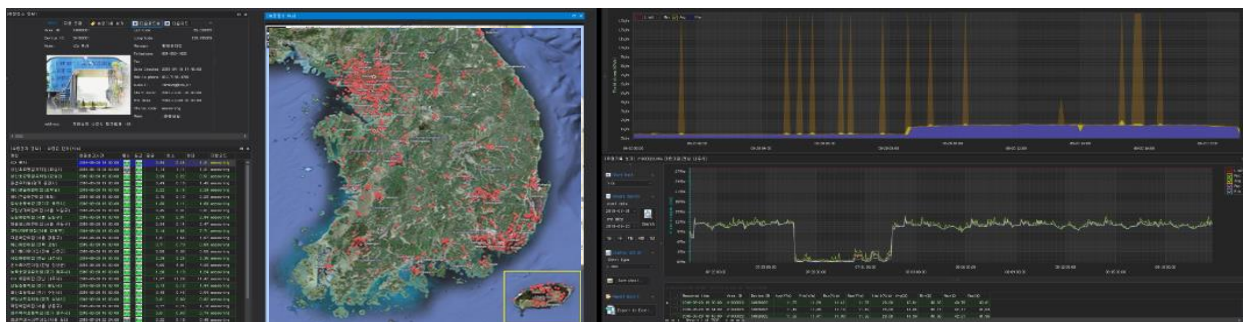
(a) EMF time variation analysis (Thailand NBTC & Korea: KCA)

(b) EMF area scanning result analysis (Korea Communication Agency)

(c) Frequency selective EMF monitoring analysis (Korea Communication Agency)

(d) National wide management analysis (Korea Communication Agency)

Figure X.11 – Example of result analysis views

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[b-ITU-T K-Suppl.1]   Recommendation ITU-T K-Suppl.1 (2014), *ITU-T K.91 – Guide on electromagnetic fields and health*.

[b-ITU-T K-Suppl.4]   Recommendation ITU-T K-Suppl.4 (2015), *ITU-T K.91 – Electromagnetic field considerations in smart sustainable cities*.

[b-DOCOMO]   NTT docomo Website, *Developed prototype of manhole type base station for the first time in Japan*. (Japanese only)
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