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Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service

Recommendation ITU-T K.100

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Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service

Summary

Recommendation ITU-T K.100 provides information on measurement techniques and procedures for assessing compliance with the general public electromagnetic fields (EMFs) exposure limits when a new base station (BS) is put into service, taking into account effects of the environment and other relevant radio frequency sources present in its surrounding.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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Keywords

Base station, compliance, exposure assessment; put into service.

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Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service

1 Scope

This Recommendation specifies the measurement procedure to assess compliance with general public electromagnetic field (EMF) exposure limits for a base station (BS) operating in the frequency range 100 MHz-100 GHz when it is put into service in its operational environment.

Simplified assessment procedures are provided to identify those installations that are known to be compliant with EMF exposure limits without measurements.

With its specific focus on measurements, this Recommendation complements the existing ITU-T K-series Recommendations.

Contact currents due to contact with conductive objects irradiated by EMFs, lie outside the scope of this Recommendation. For commercial market BS products, there could be other requirements specified by the manufacturer that might need to be fulfilled. For such types of product testing, this Recommendation also does not apply.

Where national laws, standards or guidelines on exposure limits to EMF exist and provide procedures that are at variance with this Recommendation, the pertinent national laws, standards or guidelines shall take precedence over the procedures provided in this Recommendation.

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 on measurement and numerical prediction of electromagnetic fields for compliance with human exposure limits for telecommunication installations*.

[ITU-T K.70] Recommendation ITU-T K.70 (2018), *Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations*.

[ITU-T K.91] Recommendation ITU-T K.91 (2018), *Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields*.

[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*.

[IEC 62479] IEC 62479:2010, *Assessment of the compliance of low power electronic and electrical equipment with the basic restrictions related to human exposure to electromagnetic fields (10 MHz – 300 GHz)*.

3 Definitions

3.1 Terms defined elsewhere

None.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 ambient source: A radio frequency (RF) source operating in the frequency range from 8.3 kHz to 300 GHz generating electromagnetic fields other than the emission from the equipment under test (EUT).

3.2.2 assessment domain boundary (ADB): Boundary surrounding an antenna of the equipment under test (EUT) outside of which measurements do not need to be conducted. The ADB defines the maximum possible measurement area where the source is considered to be relevant.

3.2.3 base station (BS): Fixed equipment for radio transmission used in cellular communication or wireless installation for local area networks. For the purpose of this Recommendation, the term base station includes all radio transmitter(s) and associated antenna(s).

3.2.4 compliance boundary (CB): Boundary defining a volume outside which the radio frequency (RF) exposure from the equipment under test (EUT) is below the exposure limit.

3.2.5 domain of investigation (DI): Sub-domain within the assessment domain boundary (ADB) to which the general public have access.

3.2.6 equipment under test (EUT): The base station that shall be put into service, including all transmitting antennas (operating in the frequency range 100 MHz to 100 GHz).

3.2.7 equivalent isotropically radiated power (EIRP): The product of the power accepted by the antenna and the maximum antenna gain relative to an isotropic antenna.

3.2.8 exposure ratio (ER): The assessed exposure parameter at a specified location for each operating frequency of a radio source, expressed as the fraction of the related limit.

For assessment against reference levels:

$$\mathrm{ER} = \max\left[(E/E_{\mathrm{lim}})^2, (H/H_{\mathrm{lim}})^2\right]$$

In the far-field:

$$\mathrm{ER} = (E/E_{\mathrm{lim}})^2 = (H/H_{\mathrm{lim}})^2 = S/S_{\mathrm{lim}}$$

where S, E, and H are the root mean square (r.m.s.) values, respectively, of power density, electric field strength and magnetic field strength measured at frequency f. S_{lim}, E_{lim} and H_{lim} are the corresponding limits at the same frequency.

When exposure is evaluated for a certain frequency band (the total power density or the field strength within the frequency interval $[f_{\mathrm{min}}, f_{\mathrm{max}}]$ is assessed), S_{lim}, E_{lim} or H_{lim} are chosen as the most stringent limits within the band.

3.2.9 far-field formula: Formula that can be used in the far-field to evaluate the power density, S:

$$S = \frac{PG_{\theta,\varphi}}{4\pi d^2}$$

where P is the transmitted power, $G_{\theta,\varphi}$ is the gain of the antenna in the direction (θ,φ) and d is the distance from the antenna to the evaluation point. The associated electric field strength, E, and magnetic field strength, H, can be evaluated as follows:

$$E = \frac{\sqrt{30PG_{\theta,\varphi}}}{d},$$

$$H = \frac{E}{\eta_0},$$

where $\eta_0 \approx 377\ \Omega$.

If the power density is evaluated in the direction of maximum antenna gain:

$$S = \frac{EIRP}{4\pi d^2}.$$

3.2.10 isotropic antenna: A hypothetical, lossless antenna having equal radiation intensity in all directions.

3.2.11 main lobe: The radiation lobe containing the direction of maximum radiation. In certain antennas, such as multilobed or split-beam antennas, there may be more than one major lobe.

3.2.12 reactive near-field region: The reactive near field of an antenna with maximum extension D is in this context defined as max(λ, D, $D^2/4\lambda$) where λ denotes the free space wavelength.

3.2.13 relevant source: A radio source, in the frequency range 8.3 kHz to 300 GHz, which at a given point of investigation has an ER larger than 0.05.

3.2.14 side lobe: A radiation lobe in any direction other than the main lobe.

3.2.15 total exposure ratio (TER): The sum of exposure ratios (ERs) of the equipment under test (EUT) and other relevant sources.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ADB	Assessment Domain Boundary
AMPS	Advanced Mobile Phone System
BCCH	Broadcast Control Channel
BS	Base Station
CB	Compliance Boundary
CDMA	Code Division Multiple Access
CPICH	Common Pilot Channel
DAB	Digital Audio Broadcasting
DI	Domain of Investigation
DVB-T	Digital Video Broadcasting-Terrestrial
EIRP	Equivalent Isotropically Radiated Power
EMF	Electromagnetic Field
ER	Exposure Ratio
EUT	Equipment Under Test
FDMA	Frequency Division Multiple Access
FM	Frequency Modulation

GSM	Global System for Mobile Communications
LOS	Line Of Site
LTE	Long-Term Evolution
MCCH	Multicast Control Channel
OFDM	Orthogonal Frequency-Division Multiplexing
PBCH	Physical Broadcast Channel
RBW	Resolution Bandwidth
RF	Radio Frequency
r.m.s.	root mean square
SAR	Specific Absorption Rate
SD	Standard Deviation
TACS	Total Access Communications System
TDMA	Time Division Multiple Access
TER	Total Exposure Ratio
TETRA	Terrestrial Trunked Radio
TETRAPOL	Terrestrial Trunked Radio for Police
UMTS	Universal Mobile Telecommunication System
WCDMA	Wideband Code Division Multiple Access
Wi-Fi	Wireless Fidelity

5 Assessment procedure

When in a BS, the equipment under test (EUT), is installed and put into service at a site, the procedure described in Figure 5-1 shall be used to assess compliance with exposure limits. In order to allow for accurate and efficient assessments, different routes are possible depending on the characteristic of the EUT or on the installation type. In some specific cases, compliance with relevant exposure limits can be assessed without the necessity to conduct measurements (e.g., because of the low power transmitted, or because of the position or orientation of the transmitters or antennas with respect to areas accessible to the general public, or because simpler calculation methods can be used [ITU-T K.52]). Both broadband and frequency-selective equipment can be used for the assessment (see clause 9.1). Measurements conducted with broadband equipment, however, might lead to overly conservative results. If the exposure level in areas accessible to the general public is found to be above the limits by means of broadband measurements, then compliance should be verified with frequency-selective equipment. Otherwise, the mitigation techniques described in [ITU-T K.70] shall be applied. The step-by-step procedure of Figure 5-1 is specified in clauses 6 to 10.

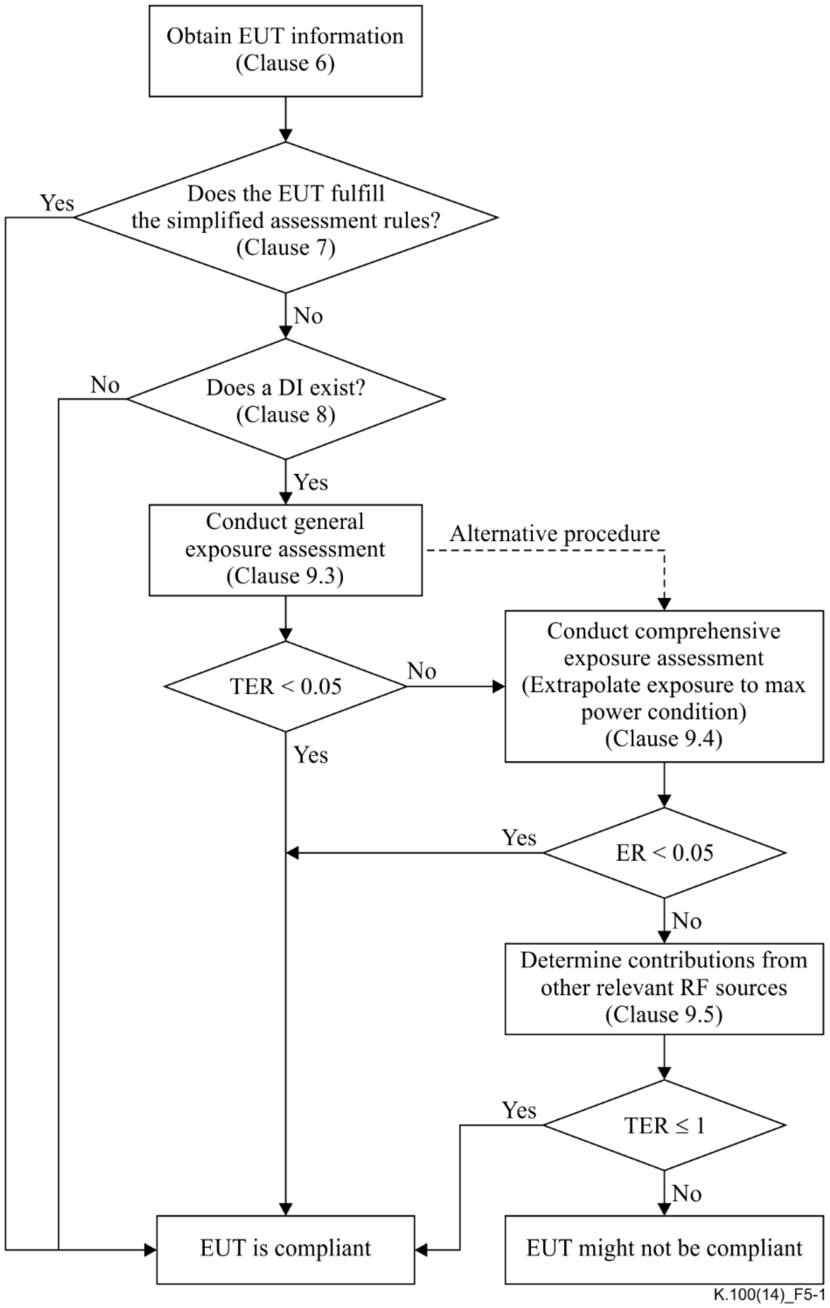

Figure 5-1 – Flowchart describing the measurement procedure specified in this Recommendation

6 Equipment under test data collection

The following information shall be obtained for the EUT:

- technology, frequency band and channel bandwidth[1] (e.g., wideband code division multiple access (WCDMA), band 4: 2 110 MHz-2 170 MHz, 2 164.7 MHz-2 169.7 MHz);[2]
- power level on the input socket and gain for each EUT antenna.

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[1] For multicarrier and multiple radio access technology, BS information shall be gathered for every technology and frequency band to put into operation.

[2] This information is useful also for nearby RF sources, if available.

When *comprehensive* assessments supporting extrapolation to maximum traffic are needed (see clause 9.4), the following information may be used for the global system for mobile communications (GSM), WCDMA and long-term evolution (LTE):

- GSM: Central frequency of the broadcast control channel (BCCH) and number of carriers (channels) used by the EUT.
- WCDMA: Common pilot channel (CPICH) frequency and power level relative to total power.
- LTE: Centre frequency of the EUT channels and bandwidth.

7 Simplified assessment procedures

Simplified assessment procedures [IEC 62232] are provided to identify an EUT that is known to be in compliance with relevant exposure limits without the necessity to follow general or comprehensive exposure assessment processes. This is relevant, for example, because of the low power transmitted or because of the position of the transmitters or antennas (EUT and relevant sources) with respect to the general public.

The simplified assessment procedures are based on knowledge of the EUT equivalent isotropically radiated power (EIRP), and depending on the EIRP level, antenna installation characteristics, such as mounting height, main lobe direction and distance to other ambient sources, as specified in Table 7-1.[3] If the criteria are met, the EUT is compliant. Otherwise, the procedure as described in clauses 8 to 10 shall be applied.[4] The installation class names in Table 7-1 are from [IEC 62232].

Table 7-1 – Simplified assessment procedure criteria to meet compliance

Installation class	Equivalent isotropically radiated power[a] (W)	Equivalent isotropically radiated power[a] (dBm)	Installation criteria[b]
E0	N/A	N/A	The product complies with [IEC 62479] or the product compliance boundary dimensions are zero. No specific requirement for installation.
E2	≤2	≤33	Compliance with the exposure limits is generally obtained at zero distance or within a few centimetres. No specific requirement for installation[c].
E10	≤10	≤40	EUT installed so that the lowest radiating part of the antenna(s) is at a minimum height of 2.2 m above the general public walkway.
E100	≤100	≤50	EUT installed so that: (i) the lowest radiating part of the antenna(s) is at a minimum height of 2.5 m above the general public walkway; (ii) the minimum distance to areas accessible to the general public in the main lobe direction is D_m m;

[3] The criteria are based on [b-ICNIRP] limits. If other limits are used, the requirements in Table 7-1 may need to be adjusted.

[4] In no case can an EUT be deemed non-compliant based solely on its transmitted power.

Table 7-1 – Simplified assessment procedure criteria to meet compliance

Installation class	Equivalent isotropically radiated power[a] (W)	Equivalent isotropically radiated power[a] (dBm)	Installation criteria[b]
			(iii) no other radio frequency (RF) sources with EIRP above 10 W are located within a distance of 5 D_m m in the main lobe direction (as determined by considering the half-power beam width) and within D_m m in other directions.[d] D_m is the compliance distance in the main lobe. If D_m is not available, a value of 2 m can be used or 1 m if all product transmit frequencies are equal to or above 1 500 MHz.
E+	>100	>50	EUT installed so that: (i) the lowest radiating part of the antenna(s) is at a minimum height of H_m m above the general public walkway; (ii) the minimum distance to areas accessible to the general public in the main lobe direction is D_m m; (iii) no other RF sources with EIRP above 100 W is located within a distance of 5D_m m in the main lobe direction and within D_m m in other directions.[e] D_m is the compliance distance in the main lobe. If D_m is not available, it can be calculated using Equations 7-1 to 7-3. H_m is given by Equations 7-1 to 7-3.

[a] EIRP transmitted by the installed antenna(s) including all its active bands.

[b] In addition to the requirements given in this table, the product shall be installed according to instructions given by the manufacturer and/or entity putting it into service.

[c] According to [ITU-T K.52] emitters with a maximum EIRP of 2 W or less are inherently compliant.

[d] When such condition is not fulfilled, the installation is still compliant if the sum of the EIRPs of the EUT and nearby sources is less than 100 W. If the total EIRP is above 100 W, then the EUT is still compliant if it is installed at a minimum height of H_m m above the general public walkway and at a minimum distance from areas accessible to the general public in the main lobe direction of D_m m, where H_m and D_m are obtained using Equations 7-1 to 7-3 for the sum of the EIRPs including those of nearby sources.

[e] When such condition is not fulfilled, the installation is still exempted from measurements if the EUT is installed at a minimum height of H_m m above the general public walkway and at a minimum distance from areas accessible to the general public in the main lobe direction of D_m m, where H_m and D_m are obtained using Equations 7-1 to 7-3 for the sum of the EIRPs including those of nearby sources.

The criteria on the installation height for values of the EIRP ≤100 W were developed using the specific absorption rate (SAR) estimation formula provided in [IEC 62232] to ensure compliance with the basic restrictions. For an EIRP value >100 W, H_m and D_m (in metres) are given by Equations 7-1 to 7-3.[5]

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[5] For values of the EIRP ≤100 W, Equations 7-1 to 7-3, based on a far-field condition, are not suitable.

For frequencies between 100 MHz and 400 MHz:

$$H_m = \max\begin{cases} 2+\sqrt{\dfrac{EIRP\cdot A_{sl}}{2\pi}} \\ 2+\sqrt{\dfrac{EIRP}{2\pi}}\sin(\alpha+1.129\theta_{\mathrm{bw}}) \end{cases} \qquad D_m = \sqrt{\frac{EIRP}{2\pi}} \tag{7-1}$$

For frequencies between 400 MHz and 2 000 MHz:

$$H_m = \max\begin{cases} 2+\sqrt{\dfrac{EIRP\cdot 200A_{sl}}{f\pi}} \\ 2+\sqrt{\dfrac{200\cdot EIRP}{f\pi}}\sin(\alpha+1.129\theta_{\mathrm{bw}}) \end{cases} \qquad D_m = \sqrt{\frac{EIRP\cdot 200}{f\pi}} \tag{7-2}$$

For frequencies between 2 000 MHz and 40 000 MHz:

$$H_m = \max\begin{cases} 2+\sqrt{\dfrac{EIRP\cdot A_{sl}}{10\pi}} \\ 2+\sqrt{\dfrac{EIRP}{10\pi}}\sin(\alpha+1.129\theta_{\mathrm{bw}}) \end{cases} \qquad D_m = \sqrt{\frac{EIRP}{10\pi}} \tag{7-3}$$

NOTE – Equations 7-1 to 7-3 are based on the reference levels in [b-ICNIRP] for general public exposure and reflect the fact that these are frequency dependent.

where:

- f is the frequency, in megahertz, of operation of the BS[6]
- A_{sl} is the side lobe suppression value[7]
- α is the downtilt in radians (both electrical and mechanical)
- θ_{bw} is the vertical half power beamwidth in radians.

Equations 7-1 to 7-3 have been obtained conservatively using the equations in the tables of Appendix III[8] of [ITU-T K.52]. In Figure 7-1 and Figure 7-2, D_m and H_m are given for some frequencies for the most stringent case based on a realistic choice of parameters for sector-coverage antennas ($\theta_{bw} = \pi/12$[9], $\alpha = \pi/12$, and $A_{sl} = 0.05$[10]).

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6 To be conservative, f shall be chosen as the lowest limit in the frequency band of the EUT.

7 Maximum side lobe amplitude with respect to the overall peak value. A_{sl} should be expressed as a numerical factor, however, it is usually given in decibels with respect to the maximum. To convert: $A_{\mathrm{sl}} = 10^{A_{sl}[\mathrm{dB}]/10}$

8 Corresponding to directivity category 2 and accessibility category 1 of [ITU-T K.52] for H_m and accessibility category 2 for D_m.

9 $\pi/12$ corresponds to 15°.

10 0.05 corresponds to −13 dB.

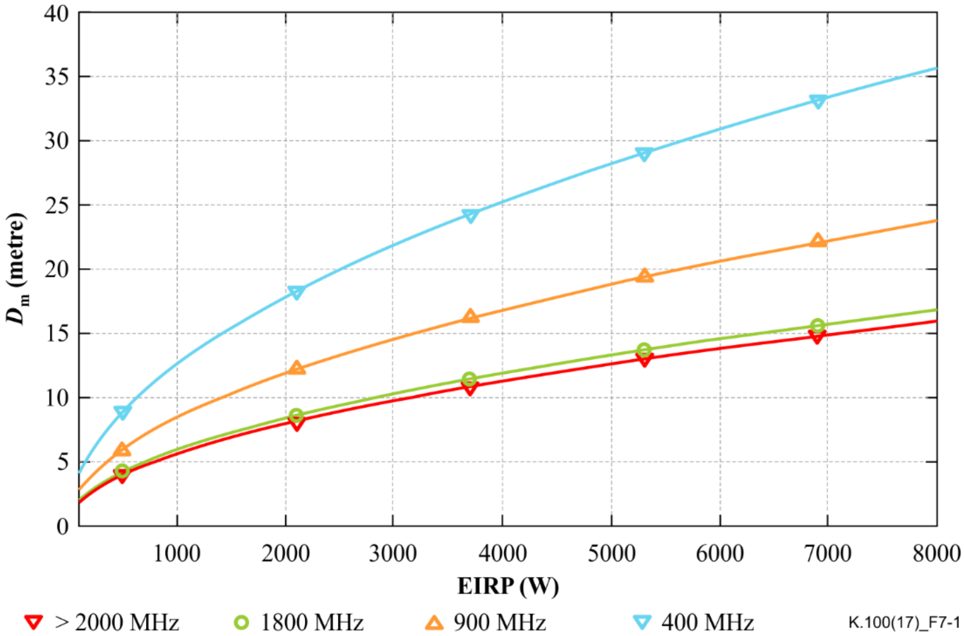

Figure 7-1 – D_m as a function of the equivalent isotropically radiated power obtained from Equations 7-1 to 7-3

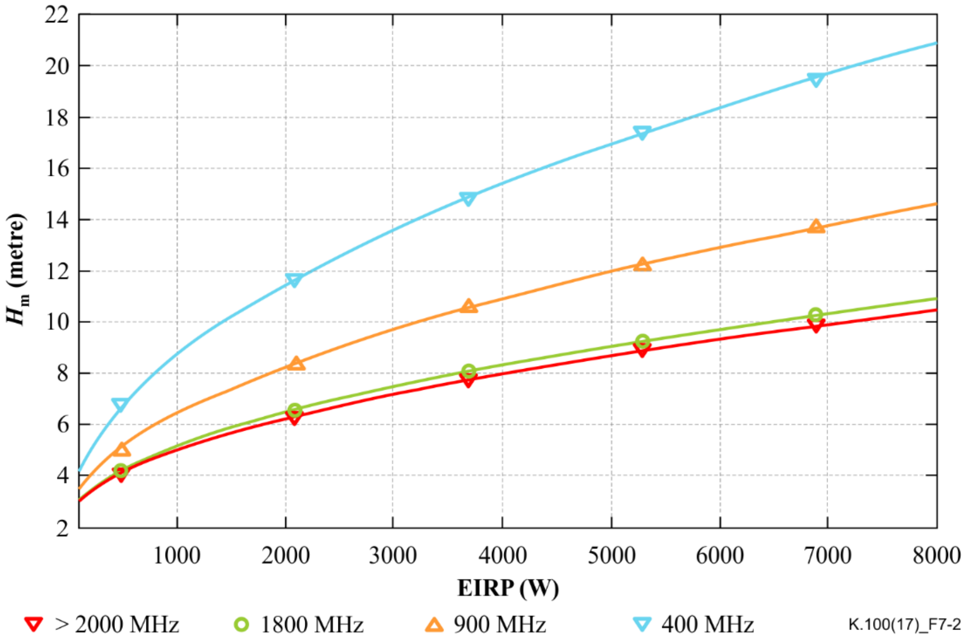

Figure 7-2 – H_m as a function of the equivalent isotropically radiated power obtained from Equations 7-1 to 7-3 based on a conservative choice of antenna parameters: π12 half-power beamwidth (θ_{bw}), $\pi/12$ antenna downtilt (α, electrical and mechanical) and side lobe suppression (A_{sl}) of 0.05. H_m will decrease by decreasing θ_{bw}, α and the side lobe suppression

The criteria in Table 7-1 were developed to be applicable for a wide range of BS installations and provide general means to identify EUT exempted from measurements. Other sets of formulas (e.g., the ones in [b-ANFR DR17] and [b-MSIP]) can be designed and used, e.g., for more specific installation types and exposure conditions, provided that their rationale and applicability are defined and documented. In general, when the impact of the environment and of ambient sources on the exposure of the EUT are known to be negligible or not relevant, the EUT is known to be compliant, without requiring further measurements, if the general public does not have access to its compliance boundary (CB). The CB of the EUT for the specific EUT configuration, if not already provided by the manufacturer, can be determined following procedures specified in [ITU-T K.61] and [IEC 62232]).

8 Measurement area selection

The domain of investigation (DI) represents the area where a general exposure assessment (clause 9.3) shall be conducted. The DI is the part of the assessment domain boundary (ADB) of the EUT to which the general public has access.

Outside the ADB, the exposure ratio (ER) from the EUT is less than 0.05, i.e., the EUT is not a relevant source and an assessment is not needed. The ADB for the EUT can be determined following procedures in [ITU-T K.61] and [IEC 62232]. Equation 8-1 is a simplified expression to obtain a conservative estimate of the ADB if the shape of a box (Figure 8-1) is provided.

$$D = 1.3\sqrt{\frac{EIRP}{S_{\text{lim}}}}, \qquad (8\text{-}1)$$

where D is the side length of the ADB (in metres) in the main beam direction and S_{lim} is the relevant power density exposure limit (in watts per square metre). A plot of D as a function of the EIRP is provided in Figure 8-2 for some frequencies.

For multiband antennas having more than one active band (e.g., WCDMA 1900, LTE 800), the ADB may be calculated using Equation 8-2:

$$D = 1.3\sqrt{\sum_i \frac{EIRP_i}{S_{\text{lim,i}}}}, \qquad (8\text{-}2)$$

where $EIRP_i$ is the EIRP of the EUT for band i and $S_{\text{lim,i}}$ is the relevant power density exposure limit (in watts per square metre) for band i.

The dimensions of the ADB, if determined using Equation 8-1 or Equation 8-2, will be largely overestimated in the vertical direction of the antenna. Therefore, the following rules shall be applied.

- Regions placed H_{b} or more below the antenna mounting height (measured from the centre point of the antenna) shall not be considered as part of the ADB, where H_{b} (in metres) is given by[11]

  $$H_{\text{b}} = \max\left(D \tan\alpha, 3.5\right)$$

  Here, α is the antenna downtilt (mechanical and electrical) in radians. If α is not known it can be conservatively assumed to equal to $\pi/15$.

- Regions placed ≥3.5 m above the antenna mounting height (measured from the centre point of the antenna) shall not be considered as part of the ADB.

Equations 8-1 and 8-2 apply for downtilted antennas. If the antenna is tilted upward, the values shall be exchanged.

[11] The first term in brackets corresponds to the height of the ADB given by the main beam for downtilted antennas. The second term takes into consideration that, for small tilt angles, the ADB in the vertical direction might be given by the antenna side lobe (or by the extension of the main lobe in the vertical plane). Since the maximum side lobe amplitude and direction might be difficult to estimate, a minimum height of 3.5 m is conservatively chosen.

In addition, for rooftop or wall installations, regions within the building on which the antenna is mounted shall be excluded from the ADB if the antenna main beam is pointing away from the building.[12]

Based on observations of the EUT installation and environment, calculation by means of numerical tools (such as the EMF estimator [ITU-T K.70]), as well as on experience gained by assessments of similar sites, the DI can be restricted only to those points where the level of exposure is expected to be relevant or maximum (see, for instance, Appendix III).

If the general public has no access to the ADB, there is no DI and the EUT is compliant, i.e., no measurements are needed.

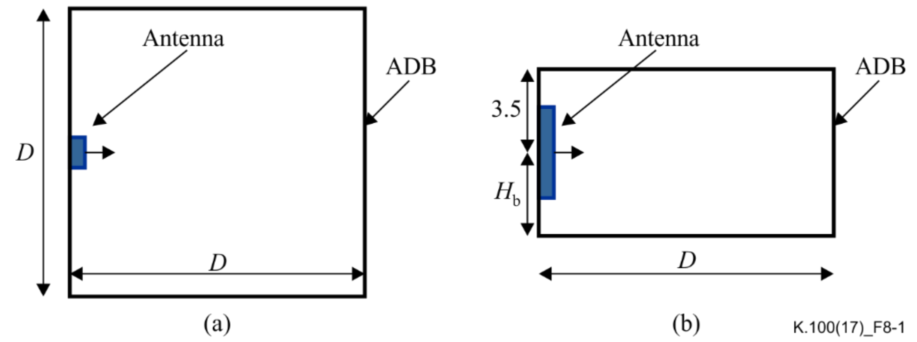

Figure 8-1 – a) Top-view of the square-shaped assessment domain boundary (ADB) with side length *D*.
The ADB is oriented according to the antenna direction.
b) Side-view of the ADB determined according to clause 8

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[12] Transmission in these directions corresponds to the side lobe of the antenna. In addition, the attenuation in the walls and roof can reduce the power density by 10-20 dB or more.

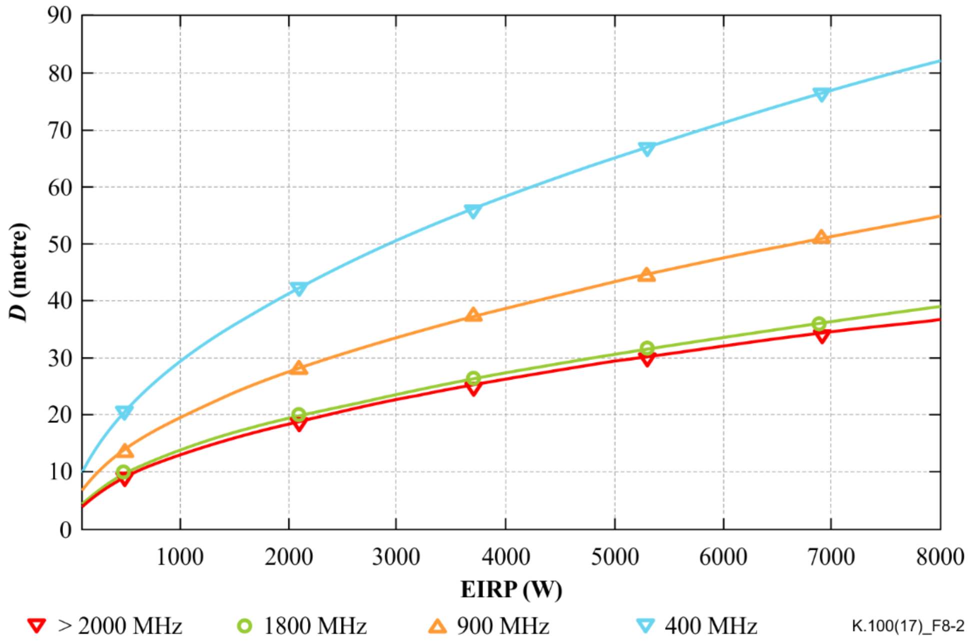

Figure 8-2 – Side length of the assessment domain boundary as a function of the equivalent isotropically radiated power for some frequencies, estimated using equation 8-1[13]

9 Measurement

9.1 Measurement equipment

Frequency-selective or broadband measurement equipment can be used to assess compliance of the EUT. Broadband measurements provide directly the sum of all power density values from signals over the frequency range of the probe without distinguishing the contribution of different frequencies (whether from the EUT or from ambient sources). Broadband measurement results may be extrapolated to estimate the maximum possible RF field strength (see clause 9.4). Such extrapolation, however, can result in a vast overestimation depending on the characteristic of the probe and the characteristics of the EUT and the ambient signals. Therefore, frequency-selective measurements are recommended where accurate extrapolation is required.

For broadband and frequency-selective equipment, the RF field strength measurement shall consider contributions from all directions and polarizations. An isotropic probe is best suited for this, but other antennas may be used. For instance a single-axis probe (e.g., dipole) can be used by positioning the probe in three orthogonal directions and summing the individual contributions, E_N, so that:

$$E = \sqrt{\sum_{N=1}^{N=3} E_N^2}$$

Additional requirements on the measurement equipment are provided in Appendix I and in [IEC 62232].

[13] Curves are based on [b-ICNIRP] limits.

9.2 Measured quantity

At sufficiently large distances from the source, only the r.m.s. electric (E) or magnetic (H) field strength need to be measured and the ER can be calculated as:

$$ER = \frac{E^2}{E^2_{\mathrm{lim}}} \cong \frac{H^2}{H^2_{\mathrm{lim}}} \cong \frac{S}{S_{\mathrm{lim}}}$$

where S is the plane wave equivalent power density ($S = E^2/\eta_0 = \eta_0 H^2$ for $\eta_0 \approx 377\ \Omega$). This relation is verified already outside the reactive near-field region of the antenna [IEC 62232], where measurements are typically conducted.

When exposure is evaluated for a certain frequency band (the total power density or the field strength within the frequency interval [f_{min}, f_{max}] is assessed), S_{lim}, E_{lim} or H_{lim} are chosen as the most stringent limits within the band.

The relevant exposure standard may specify the applicable time averaging period relevant for the field strength and power density measurements (e.g., any 6 min in [b-ICNIRP]). For general exposure assessment of the instantaneous exposure level, time averaging over other periods may be acceptable (r.m.s. field strength values averaged over a shorter time can be used, see [b-Kim, 2010] and Appendix V).

9.3 General exposure assessment

The general exposure assessment consists of measurement of the total field strength over the entire frequency range covered by the Recommendation or at least in the range of frequencies used by the technologies present on site, including EUT and ambient sources. Broadband equipment is therefore suitable for this type of measurement. Frequency-selective instruments can also be used by integrating the field strength over the entire bandwidth.

No further assessments are required, and the site is deemed compliant, if the maximum measured total power density level in DI is lower than $S_{\mathrm{lim}}/20$,[14] where S_{lim} is the lowest power density exposure limit for the frequency bands used by the EUT and other relevant sources. Otherwise, the location(s) where the maximum level of exposure was found shall be selected for comprehensive measurements (see clause 9.4).

The application of the condition above is recommended since it provides an efficient tool to show compliance of the EUT with simple broadband measurements. Despite the total exposure ratio (TER) value measured during general exposure assessment the user of this guide may always choose to conduct a comprehensive assessment (see dotted line in the flowchart of Figure 5-1).

During general exposure assessments, measurements should be taken 1.5 m above the ground. Good practice is to move the probe slowly through the DI since probes generally are sensitive to fast movements.

9.4 Comprehensive exposure assessment

For mobile communications systems using adaptive power control, including GSM, WCDMA and LTE, the BS does not transmit at a constant power level; the emitted power varies with time depending on factors such as traffic variation and dynamic power control (see e.g., [b-ETSI TS 125 331]). In particular, it has been shown that the typical BS output power levels for mobile communication technologies are well below the available maximum power. See [b-Colombi, 2013a; 2013b] and [b-Mahfouz, 2012; 2013].

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[14] An equivalent threshold can be expressed in terms of the electric and magnetic field strength as $(E_{\mathrm{lim}}, H_{\mathrm{lim}})/\sqrt{20}$.

The comprehensive exposure assessment is conducted in order to obtain a conservative estimate of the exposure level of the EUT, corresponding to the ER of the EUT when it operates at the 95th percentile of its time averaged output power[15] (realistic maximum). If knowledge of the 95th percentile is not available, the theoretical maximum output power of the EUT shall be used.

The assessment is performed using broadband or frequency-selective measurement equipment. For this purpose, broadband measurements generally result in a large overestimation of the maximum RF field strength, and the extent of the overestimation shall be considered and reported.

Comprehensive measurements are conducted in the point(s) where general exposure assessments have reported maximum field strength. During measurements the distance between the measurement equipment and reflecting objects should be at least 1 m. Each measurement point should be assessed at three heights: 1.1 m, 1.5 m, and 1.7 m (see Figure 9-1).[16] Among those, the largest value reported shall be used for comparison with the exposure limit.

No further assessments are required, and the site is deemed compliant, if the ER of the EUT obtained with comprehensive measurements is less than 0.05.

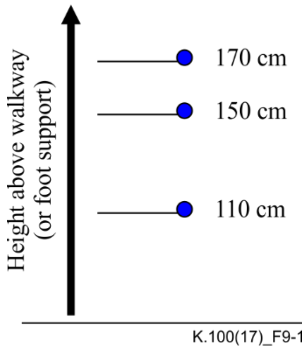

Figure 9-1 – Location of measurement points

9.4.1 Comprehensive assessment with frequency-selective equipment

To extrapolate time variant signals to either realistic or theoretical maximum output power conditions, a time invariant component of the signal is evaluated. This component is transmitted at constant power level for specific frequencies within a certain band. To measure this signal, frequency-selective equipment and in some cases a specific decoder is needed (see Appendix III). The time invariant signals used for different technologies are the BCCH for GSM,[17] the CPICH for universal mobile telecommunication system (UMTS),[18] and the primary broadcast channel, physical broadcast channel (PBCH) or the reference signal, RS, for LTE. The ratio between maximum possible signal and the time invariant component of the signal is determined based on knowledge of the technology and the specific BS configuration. This ratio corresponds to the extrapolation factor, *N*:

$$S_{\mathrm{max}} = NS_{\mathrm{narrow}}$$

[15] Knowledge of the statistical distribution of the output power may, for example, be obtained by conducting network-based measurements via the operations support system normally used by operators to monitor, control and analyse the network performance ([b-ETSI TS 125 331] and [b-Mahfouz, 2013]).

[16] When justified, measurements at other heights may be conducted.

[17] For terrestrial trunked radio (TETRA), terrestrial trunked radio for police (TETRAPOL), advanced mobile phone system (AMPS) and total access communications system (TACS) analogous channels can be measured.

[18] For CDMA, an analogous channel can be measured.

where S_{narrow} is the measured power density for the time invariant component of the signal and S_{max} the corresponding value that would be measured if the BS transmitted at theoretical maximum power.

Note that the extrapolation factors are valid for power density values. For electric and magnetic field strength levels, the square root of the extrapolation factor for power density shall be used:

$$E_{\mathrm{max}} = \sqrt{N} E_{\mathrm{narrow}}$$

The values of N for different technologies are provided in Appendix II together with the recommended measurement settings.

If knowledge of the actual power level distribution is available, the realistic maximum power density corresponding to the 95th percentile time averaged output power is calculated as:

$$S_{95th} = S_{\mathrm{max}}\,\rho,$$

where ρ is the ratio between the 95th percentile and the theoretical maximum output power.

9.4.2 Comprehensive assessment with broadband equipment

When broadband equipment is used for comprehensive assessments, the measurement data shall be scaled to the maximum power (or to the 95th percentile when available) in the same way as described for frequency-selective equipment and using the same extrapolation factors.[19] In this way, however, all the field strength contributions in the frequency range of the probe (including ambient sources) will be scaled, which can lead to a large overestimation of the maximum field strength.

9.5 Exposure contribution of ambient sources

If extrapolation of the field strength to the maximum power has been obtained by means of broadband measurements, the contribution from ambient sources is implicitly and conservatively assessed and no additional measurements need to be conducted.

If a frequency-selective instrument has been used for comprehensive measurements of the EUT exposure, and the resulting ER is equal to or larger than 0.05, it shall be identified whether RF sources other than the EUT are to be considered as relevant. Each RF source (other than the EUT) with a measured (non-extrapolated) ER ≥0.05 is considered as a relevant source. Sources with lower ER values should be excluded.

If the operating bands of nearby ambient sources are known, the ER contribution of each source is measured with the frequency-selective equipment by integrating the field strength over the corresponding band. When this information is not directly available, it can be retrieved by inspection of the significant peaks in the spectrum.

The field strength from relevant source contributions shall be scaled to maximum power in a manner similar to the description in clause 9.4. If the extrapolation factors are unknown and cannot be recovered or the time invariant signals used as reference are not accessible, the power density for each of the relevant bands shall be measured during high-traffic hours using a max-hold trace in order to store the maximum value of all measurement values until the equipment reading stabilizes (typically 1 min or less).

For broadcasting systems such as frequency modulation (FM) radio, digital audio broadcasting (DAB), digital radio and digital video broadcasting-terrestrial (DVB T) extrapolation is not needed, since their transmitted power is typically time invariant. Information about assessment of Wi-Fi is given in Appendix II.

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[19] For multitechnology or multiband EUT, the extrapolation factor is chosen as the largest among the active technologies (or bands).

9.6 Determination of the total exposure ratio

When the extrapolated field strength E_i in each band (B_i) used by the EUT and by relevant ambient sources is known in the points of the DI where general exposure assessment have reported maximum field strength, the total level of exposure shall be calculated by summing the ERs.

$$TER = \sum_{i=1}^{N} ER_i$$

where ER_i is the ER for the band B_i.

10 Uncertainty

Uncertainty estimates shall be performed in accordance with the recommendations of [b-JCGM 100:2008]. The measurement uncertainty should be obtained including the sources of uncertainty identified in Table 10-1 or Table 10-2 (see [IEC 62232]) and in [ITU-T K.91]. A description of the uncertainty factors can be found in [IEC 62232].

The target expanded uncertainty is 4 dB or below, which is considered industry best practice. The expanded uncertainty for the RF exposure evaluation used for the product installation compliance assessment should not exceed 6 dB.

Table 10-1 – Sample template for estimating the expanded uncertainty of a radio frequency field strength measurement that used a frequency-selective instrument [IEC 62232]

Source of uncertainty (influence quantity)	Unit	Probability distribution type	Uncertainty or semi span *a*	Divisor *d*	Sensitivity coefficient *c*	Standard uncertainty *u = a/d*	Corr. fact *t*	c^2u^2
Measurement equipment								
Calibration of the meter (or spectrum analyser)	dB	normal		1.96	1			
Calibration of the antenna factor	dB	normal		1.96	1			
Calibration of the cable loss	dB	normal		1.96	1			
Combined frequency response of the meter/cable/antenna	dB	rect.		√3	1			
Combined linearity deviation of the meter/cable/antenna	dB	rect.		√3	1			
Isotropy of the antenna	dB	rect.		√3	1			
Combined temperature and humidity response of meter/cable/antenna	dB	rect.		√3	1			
Mismatch between antenna and meter/spectrum analyser	dB	U		√2	1			

Table 10-1 – Sample template for estimating the expanded uncertainty of a radio frequency field strength measurement that used a frequency-selective instrument [IEC 62232]

Source of uncertainty (influence quantity)	**Unit**	**Prob-ability distri-bution type**	**Uncertainty or semi span** ***a***	**Divisor** ***d***	**Sensi-tivity coeffi-cient** ***c***	**Standard uncertainty** ***u = a/d***	**Corr. fact** ***t***	c^2u^2
Methodology								
Field scattering from surveyor's body	dB	rect.		√3	1			
Mutual coupling between measurement antenna or isotropic probe and object	dB	rect.		√3	1			
Source and environment								
Field reflections from movable large objects near the source during measurement	dB	rect.		√3	1			
Scattering from nearby objects and the ground	dB	rect.		√3	1			
Combined correction factor, $t_c = \sum_{i=1}^{N} t_i$								N/A
Combined standard uncertainty, $u_c = \sqrt{\sum_{i=1}^{N} (c_i^2 \; u_i^2)}$								
Coverage factor for required (e.g., 95 %) confidence interval, k								
Expanded uncertainty, $U = k \times u_c$								
NOTE 1 – The value of divisor *d* for normal probability distribution is for 95 % confidence. NOTE 2 – See [IEC 62232] for guidance on the variables in this table.								

Table 10-2 – Sample template for estimating the expanded uncertainty of a radio frequency field strength measurement that used a broadband instrument [IEC 62232]

Source of uncertainty (influence quantity)	**Unit**	**Prob-ability distri-bution type**	**Uncertainty or semi span *a***	**Divisor *d***	**Sensi-tivity coeffi-cient *c***	**Standard uncertainty *u* = *a*/*d***	**Cor-relatio n factor *t***	c^2u^2
Measurement equipment								
Calibration of field probe	dB	normal		1.96	1			
Frequency response of field probe	dB	rect.		√3	1			
Isotropy of the field probe	dB	rect.		√3	1			
Temperature response of the field probe	dB	rect.		√3	1			
Linearity deviation of the field probe	dB	rect.		√3	1			
Methodology								
Field reflections from surveyor's body	dB	rect.		√3	1			
Mutual coupling between measurement antenna or isotropic probe and object	dB	rect.		√3	1			
Source and environment								
Scattering from nearby objects and the ground	dB	rect.		√3	1			
Field reflections from movable large objects near the source	dB	rect.		√3	1			
Combined correction factor, $t_c = \sum_{i=1}^{N} t_i$								N/A
Combined standard uncertainty, $u_c = \sqrt{\sum_{i=1}^{N} (c_i^2 \ u_i^2)}$								
Coverage factor for required (e.g., 95 %) confidence interval, k								
Expanded uncertainty, $U = k \times u_c$								
NOTE 1 –The value of divisor *d* for the normal probability distribution is for 95 % confidence. NOTE 2 – See [IEC 62232] for guidance on the variables in this Table.								

An example where uncertainty estimation for some of the factors listed in Tables 10-1 and 10-2 is described in [b-Kim, 2012].

Appendix I

Radio frequency field strength measurement equipment requirements

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

The measurement equipment should be calibrated at a sufficient number of frequencies to achieve the declared uncertainty of the equipment over the measurement frequency range. Table I.1 summarizes the performance requirements for a broadband measurement system [IEC 62232].

Table I.1 – Broadband measurement system requirements

Frequency response	Minimum detection level	Dynamic range	Linearity	Probe isotropy (Note)
900 MHz to 3 GHz ±1.5 dB	<2 mW/m^2 (i.e., 1 V/m or 0.003 A/m)	>40 dB	±1.5 dB	<2.5 dB for isotropic probe
<900 MHz and >3 GHz ±3 dB for the frequencies to be measured				
NOTE – Probes and measurement antennas with isotropic response are recommended. Single-axis (e.g., dipole) and directional measurement antennas are permitted, provided that the measurements are post-processed to obtain the total field strength (equivalent to a measurement with an isotropic probe or measurement antenna).				

Table I.2 summarizes the performance requirements for the frequency-selective measurement system [IEC 62232].

Table I.2 – Frequency-selective measurement system requirements

Frequency response	Minimum detection level	Dynamic range	Linearity	Probe isotropy (Note)
900 MHz to 3 GHz ±1.5 dB	<0.01 mW/m^2 (i.e., 0.05 V/m) Signal to noise ratio of at least 10 dB in the measurement bandwidth	>60 dB	±1.5 dB	<900 MHz: <2 dB 900 MHz to 3 GHz: <3 dB >3 GHz: <5 dB
<900 MHz and >3 GHz ±3 dB for the frequencies to be measured				
NOTE – Probes and measurement antennas with isotropic response are recommended. Single-axis (e.g., dipole) and directional measurement antennas are permitted provided that the measurements are post-processed to obtain the total field strength (equivalent to a measurement with an isotropic probe or measurement antenna).				

Appendix II

Guidance on comprehensive measurements for specific technologies

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

This appendix provides guidance on the spectrum analyser settings required to measure signals from different technologies and to extrapolate them to the maximum emitted power condition. Accurate measurements with a spectrum analyser require the settings of parameters such as:

– detection mode;
– resolution bandwidth (RBW);
– frequency span or central frequency (f_{cent}).

II.1 Time division multiple access/frequency division multiple access technology

Time division multiple access (TDMA) mobile phone technology (e.g., GSM or TETRA) and frequency division multiple access (FDMA) mobile phone technology (e.g., TETRAPOL) utilize a time invariant BS radio channel that operates at constant full power and can be used as a stable reference.

For example, in the GSM system, this constant power channel is known as the BCCH. Table II.1 lists constant power components for various technologies.

Table II.1 – Example constant power components for specific technologies

Technology	Constant power component
GSM	BCCH
TETRA	Multicast Control Channel (MCCH)
TETRAPOL	MCCH

If the traffic channels each operate at a maximum power equal to the constant power component, which is the case for GSM, then a conservative maximum transmit power, P_{max}, can be determined by multiplying the power of the constant power component, P_{const}, by the total number of radio channels that feed into the antenna, N_{GSM}. Therefore, the power density corresponding to the maximum emitted power condition, S_{max}, can be obtained by measuring the power density in the BCCH (S_{BCCH}) of the EUT scaled by N_{GSM}:

$$S_{max} = S_{BCCH} N_{GSM}$$

For measuring the BCCH, the following settings for the frequency-selective equipment are recommended:

– f_{cent}: BCCH central frequency;
– RBW: 200 kHz (smaller RBW can be used as long as all the contributions in the occupied bandwidth of the BCCH signal are summed, higher RBW would include the power of adjacent channels);
– detection mode: r.m.s.

II.2 Code division multiple access/wideband code division multiple access technology

Code division multiple access (CDMA)/WCDMA mobile phone systems use spread spectrum technology employing a constant power control or pilot channel that has a fixed power relationship to the maximum allocated power. Dedicated decoders are available that enable the constant power reference channel (e.g., CPICH in UMTS/WCDMA) to be measured allowing calculation of maximum RF field strength.

If the ratio of the maximum allocated power to the power in the control channel of the EUT is N_{CPICH} and the measured RF power density from the control channel is S_{CPICH} then the extrapolated value is:

$$S_{\max} = S_{\mathrm{CPICH}} N_{\mathrm{CPICH}}$$

The parameter N_{CPICH} is set by the telecommunications operator. A typical value is 10 (i.e., 10% of total power allocated to CPICH).

II.3 ODFM technology

For LTE, which uses orthogonal frequency-division multiplexing (OFDM) technology, two types of reproducible methods are described: one method requires the use of a dedicated decoder (similar to existing methods based on pilot signals as for WCDMA) and another method for which a decoder is not needed.

Method using a dedicated decoder

By means of an LTE decoder, the reference signal RS, transmitted by the BS at a constant power level, is measured and extrapolated to the maximum power density according to the following expression:

$$S_{\max} = \frac{N_{\mathrm{RS}}}{BF}\left(S_{\mathrm{RS\_PORT1}} + S_{\mathrm{RS\_PORT2}} + \ldots S_{\mathrm{RS\_PORTn}}\right)$$

where $S_{\mathrm{RS\_PORT1}}$, $S_{\mathrm{RS\_PORT2}}$ … $S_{\mathrm{RS\_PORT}n}$ are the measured power density values of the reference signal (RS)[20] transmitted by each antenna port, N_{RS} is the ratio of the BS maximum power to the power of the RS and BF is the power boosting factor.[21] N_{RS} corresponds to the number of subcarriers and is dependent by the LTE channel bandwidth, see Table II.2.

Table II.2 – Theoretical extrapolation factor, N_{RS}

Bandwidth [MHz]	**N_{RS} (linear/dB)**
1.4	72/18.57
3	180/22.55
5	300/24.77
10	600/27.78
15	900/29.54
20	1 200/30.79

Since the RSs are uniformly distributed over the occupied radio bandwidth, this method is recommended in environments with strong selective fading.

[20] The RS field strength is measured as the linear average over the field strength contributions of all resource elements that carry the RS within the operating bandwidth. Thus, the measured value corresponds to the average power transmitted for one 15 kHz subcarrier.

[21] The RS can be transmitted from either one, two or four antennas (or antenna ports). The instrument should be able to determine the RS power for all antennas separately. The BF value can be obtained by the operator.

Method using a spectrum analyser

A basic spectrum analyser is less expensive and more commonly available compared with a dedicated LTE decoder. However, the powers of the RSs cannot be accurately detected, since they are transmitted on single resource elements spread in frequency and time.

To overcome this issue and to avoid requirements on access to *a priori* knowledge regarding band occupation or service characteristics, the PBCH power can be measured. The PBCH is transmitted with the same characteristics regardless of the configuration or service bandwidth and spans a bandwidth of approximately 1 MHz over the centre frequency of the LTE signal.

Please note that the signal from each LTE BS cannot be identified using this method due to frequency spectrum overlapping.

The measured peak power density, S_{PBCH}, corresponds to the received PBCH signal power over the bandwidth of 72 subcarriers (each of 15 kHz). The maximum power density, S_{max}, of the LTE signal at each measurement location is then given by:

$$S_{\max} = N_{\mathrm{PBCH}} S_{\mathrm{PBCH}}$$

where N_{PBCH} is the extrapolation factor for the PBCH, which is the ratio of the maximum transmission power to the transmission power corresponding to the PBCH over six resource blocks. N_{PBCH} can be calculated theoretically according to:

$$N_{\mathrm{PBCH}} = \frac{N_{\mathrm{RS}}}{72}$$

where N_{RS} denotes the number of subcarriers in the transmission bandwidth used, see Table II.2.

To measure the PBCH, the following settings for the frequency-selective equipment are recommended:

– f_{cent}: central frequency LTE signal;

– RBW: 1 MHz (smaller RBW can be used as long as all the contributions in the bandwidth of the PBCH signal occupied are summed);

– detection mode: r.m.s.;

– frequency span set to zero (scope mode);

– sweep time: 70 μs*SA_{points}, where SA_{points} is the number of display points of the spectrum analyser (this is done in in order to obtain an integration time close to the symbol duration of each pixel on the screen of the spectrum analyser);

– minimum 20 s sweep time and peak trace of the power.

Appendix III

Maximum exposure location for a base station in the line of sight

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

The probable location of maximum exposure to EMF associated with an antenna main lobe for line of sight scenarios (see Figure III.1) can be estimated using the following equation [b-Linhares]:

$$X_{\max}^{\exp} = \frac{\sqrt{\left[(H-h)\tan\alpha\left(1+\frac{q}{2}\right)\right]^2 + 2q(H-h)^2} - (H-h)\tan\alpha\left(1+\frac{q}{2}\right)}{2}$$

where $X_{\max}^{\exp}$ (in metres) indicates the estimated horizontal distance from the antenna in the direction of the main lobe where maximum exposure is expected, H is the antenna height (in metres) from ground to the centre of the antenna, h is the reference point height at which measurements should be conducted (in metres), α is the antenna downtilt (mechanical and electrical) and q is calculated by:

$$q = \frac{\log(0.5)}{\log\left[\cos\left(\frac{\theta_{bw}}{2}\right)\right]}$$

where θ_{bw} is the antenna half-power beamwidth.

The estimated location $X_{\max}^{\exp}$ indicates the probable region of maximum exposure. Nevertheless, it must be taken into account that scattered and diffracted fields may shift the real local maximum in other regions. Moreover, due to the presence of other relevant sources, the largest exposure level may be outside the antenna main beam direction of the EUT. In general, it is therefore recommended to sweep the instruments in the DI (see clause 8) to locate the point(s) of maximum exposure.

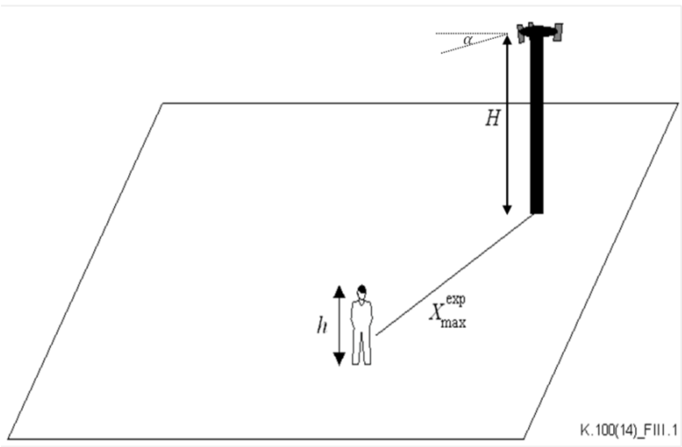

Figure III.1 – Geometry set-up for a line of sight scenario

Appendix IV

Exposure limits

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

IV.1 Introduction

Where national laws, standards or guidelines on exposure limits to EMF exist and provide procedures that are at variance with this Recommendation, those pertinent national laws, standards or guidelines should take precedence over the procedures provided in this Recommendation. In the absence of national requirements, the World Health Organization (WHO) recommends the adoption of limits based on the [b-ICNIRP] guidelines. The relevant exposure limits from [b-ICNIRP] are reproduced in this annex to support the full implementation of this Recommendation's guidelines.

NOTE – This Recommendation is consistent with [ITU-T K.52], which recommends that if national limits do not exist or if they do not cover the frequencies of interest, then the limits given in [b-ICNIRP] should be used.

IV.2 General description of exposure limits

Exposure limits are defined for general public exposure (i.e., an uncontrolled environment) and for occupational exposure (i.e., a controlled environment). Exposure limits for the general public are more conservative (restrictive) than those for occupational exposure.

Two kinds of guidance exist: Basic restrictions – based directly on established adverse health effects and Reference levels – provided for practical exposure assessment purposes, to determine whether basic restrictions are likely to be exceeded.

IV.3 [b-ICNIRP] exposure limits

The limits for the basic restriction and for the reference levels are shown in Tables IV.1 and IV.2.

Table IV.1 – [b-ICNIRP] basic restrictions limits

Type of exposure	Frequency range	Current density for head and trunk (mA/m^2)(r.m.s.)	Whole-body average specific absorption rate (W/kg)	Localized specific absorption rate (head and trunk) (W/kg)	Localized specific absorption rate (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

Table IV.1 – [b-ICNIRP] basic restrictions limits

NOTE 1 – f is the frequency in Hertz.
NOTE 2 – Because of 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 min 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 IV.2 – [b-ICNIRP] reference levels (unperturbed r.m.s. 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
	400-2 000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$f/40$
	2-300 GHz	137	0.36	50
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	$4\,000/f$	–
	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
	400-2 000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$f/200$
	2-300 GHz	61	0.16	10

Table IV.2 – [b-ICNIRP] reference levels (unperturbed r.m.s. values) limits

NOTE 1 – f is as indicated in the frequency range column.
NOTE 2 – For frequencies between 100 kHz and 10 GHz, S_{eq} and the magnetic and electric field strength are to be averaged over any 6 min period.
NOTE 3 – For frequencies up to 100 kHz, the peak values can be obtained by multiplying the r.m.s. value by $\sqrt{2}$ (≈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 1 000 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).

Appendix V

Averaging time reduction

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

V.1 Introduction

The [b-ICNIRP] guidelines specify that the reference levels at any point are to be averaged over any 6 min period for frequencies between 100 kHz and 10 GHz. This appendix shows that for compliance assessments of a BS, a shorter averaging time introduces only a negligible variation in the measured field strength.

V.2 Rationale and methodology

In [b-Kim, 2010], the time variation of the electric field strength was investigated for seven target BSs using CDMA technology. Measurements were conducted in the far-field and therefore only the electric field strength was measured. The distance between these seven BSs and the investigation location ranged from over 50 m to 450 m. The investigation locations were selected considering several conditions such as the tilt of the target BS's antenna and the distance of nearby BSs. Such a selection minimized the possible reception of the adjacent BS's signals that use the same transmitting frequency.

The target BSs were located in city centre areas (BS Nos. 1, 2, 3 in Table V.1), suburbs (Nos. 4, 5), and rural areas (Nos. 6, 7). While measuring the electric field strength, a line-of-site (LOS) condition was maintained. The receiving probe was positioned at a height of 1.5 m above the ground. The surrounding conditions around the receiving probe were different at the different locations. In the downtown area, conditions could be classified as open-site (no object within 3 m of the receiving antenna). In the suburbs or rural areas, however, there were some obstacles (house walls, trees, bushes, etc.) resulting in a larger field strength variation. The detection mode of the spectrum analyser was set to r.m.s. To consider all propagation routes and field strength polarizations, an isotropic electric field probe was used (SRM-3000 made by NARDA STS). A spectrum analyser was used for frequency-selective measurement at a single frequency band. The RBW was set to equal the signal bandwidth.

V.3 Results and discussion

Averaging times ranging from 360 s to 10 s with a 10 s interval were analysed. Table V.1 shows the variation in the electric field strengths measured around the seven BSs for a range of averaging times. These values were calculated using periods that had the same starting time. For example, in the case of the 10 s column in Table V.1, each element corresponds to the calculated value using the data obtained during the first 1 to 10 s.

Table V.1 – Comparison of electric field strength for different averaging times

BS No.	Electric field strength (dBµV/m)				
	Time (s)				
	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

The field strength for each BS seems to be nearly the same for all averaging times.

Figure V.1 shows the standard deviation (SD) between the 360 s average value and different time periods. These were estimated by several average values calculated during successive time periods. 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 BSs occurred in the case of BS No. 6, and its value was 0.58 dB at 10 s.

In [b-Kim, 2010] these deviations were compared with the standard uncertainty for measurement drift. That is, the maximum permissible SD that is less than the standard uncertainty for repeated measurements was found. The estimated standard uncertainties by repeated measurements were in the range of 0.09 to 0.40 dB (t-distribution; $t_{.025}$ = 2.05, degree of freedom 29 for each of the BSs). So, a maximum value of 0.4 dB was selected in [b-Kim, 2010] as the criterion for averaging time reduction. According to Figure V.1 this corresponds to a minimum averaging period of 60 s for field strength measurements in a BS.

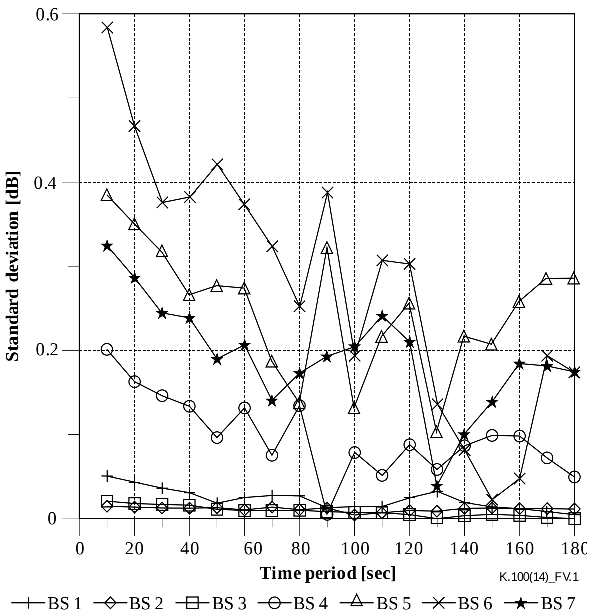

Figure V.1 – Standard deviation for different averaging times compared with that of 360 s

Based on these results, in Korea, 1 min is considered sufficient to evaluate human exposure to EMFs from mobile telephone BSs. Other measurements averaging time may be used, provided that their rationale and applicability are defined and documented.

Bibliography

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

[b-ITU-R SM] ITU-R Handbook (2011), *Handbook on Spectrum Monitoring*.

[b-ANFR DR17] Guide Technique ANFR DR17-4 (2014). *Agence Nationale des Fréquences – Modélisation des sites radioélectriques et des périmètres de sécurité pour le public [*National Frequencies Agency – Modelling radio sites and safety perimeters for the public]. https://www.anfr.fr/fileadmin/mediatheque/documents/expace/2014-10-09_ANFR-DR17-4_Guide_Perimetres_de_Securite_v2-02.pdf

[b-Colombi, 2013a] Colombi, D. Thors, B., Persson, T., Wirén, N., Larsson, L.-E., Jonsson, M., Törnevik, C. (2013a). Downlink power distributions for 2G and 3G mobile communication networks. *Radiat. Prot. Dosimetry*, **157**, pp. 477-487.

[b-Colombi, 2013b] Colombi, D., Thors, B., Wirén, N., Larsson, L.-E., Törnevik, C. (2013b). Measurements of downlink power level distributions in LTE networks. In: *Electromagnetics in Advanced Applications* (ICEAA), *International Conference, 2013*, pp. 98-101.

[b-ETSI TS 125 331] ETSI TS 125 331 (2013). Universal mobile telecommunications system (UMTS); radio resource control (RRC); protocol specification (3GPP TS 25.331 version 11.5.0 Release 11). http://www.etsi.org/deliver/etsi_ts/125300_125399/125331/11.05.00_60/ts_125331v110500p.pdf

[b-ICNIRP] International Commission on Non-Ionizing Radiation Protection (1998). Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). *Heal. Phys.*, **74**, pp. 494-522.

[b-JCGM 100:2008] JCGM 100:2008, Joint Committee for Guides in Metrology (2008), *Evaluation of measurement data – Guide to the expression of uncertainty in measurement*.

[b-Kim, 2010] Kim, B.-C., Park, S.-O. (2010). Reduction of averaging time for evaluation of human exposure to radiofrequency electromagnetic fields from cellular base stations [Letter]. *IEICE Trans. Commun.*, **E93-B**(7), pp. 1862-1864.

[b-Kim, 2012] Kim, B.C., Yun, J.-H., Park, S.-O. (2012). Uncertainty estimation for evaluating human exposure levels to RF electromagnetic fields from cellular base stations. *IEEE Trans. Electromagn. Compat.*, **54**(2), pp. 246-253.

[b-Linhares] Linhares, A., Terada, M.A.B., Soares, A.J.M. (2013). Estimating the location of maximum exposure to electromagnetic fields associated with a radio communication station. *J. Microw. Optoelectron. Electromagn. Appl.*, **12**(1), pp. 141-157.

[b-Mahfouz, 2012] Mahfouz, Z., Gati, A., Lautru, D., Wong, M.F., Wiart, J., Hanna, V.F. (2012). Influence of traffic variations on exposure to wireless signals in realistic environments. *Bioelectromagnetics*, **33**, pp. 288-297.

[b-Mahfouz, 2013] Mahfouz, Z., Verloock, L., Joseph, W., Tanghe, E., Gati, A., Wiart, J., Lautru, D., Hanna, V.F., Martens L. (2013). Comparison of temporal realistic telecommunication base station exposure with worst-case estimation in two countries. *Radiat. Prot. Dosimetry*. **157**, pp. 331-338.

[b-MSIP] MSIP (Korean Ministry of Science, ICT and Future Planning) (2011), *Technical requirements for the human protection against electromagnetic waves*.

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