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* **Contact:** Jeffrey Boksiner
Telcordia Technologies
445 South Street
Room MCC 1A-146G
Morristown, NJ 07960
USA

Tel: +1 973 829-2519
Fax: +1 973 829-5866
E-mail: jboksine@telcordia.com

DRAFT RECOMMENDATION K.EMF

GUIDANCE ON COMPLYING WITH LIMITS FOR HUMAN EXPOSURE TO ELECTROMAGNETIC FIELDS

Contents

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Summary

This Recommendation aims to help with compliance of telecommunication installations with safety limits for human exposure to electromagnetic fields (EMFs). It presents general guidance, a calculation method, and an installation assessment procedure. The assessment procedure, based on safety limits provided by ICNIRP, helps users determine the likelihood of installation compliance based on accessibility criteria, antenna properties and emitter power.

1 Introduction

This Recommendation aims to help with compliance of telecommunication installations with safety limits for human exposure to electromagnetic fields (EMFs). This Recommendation does not set safety limits; it seeks to provide techniques and procedures for assessing the compliance of telecommunication installations with national or international EMF safety limits.

2 Scope

This Recommendation aims to help with compliance of telecommunication installations with safety limits for human exposure to electromagnetic fields (EMFs) produced by telecommunications equipment in the frequency range 0 to 300 GHz. The Recommendation provides techniques and procedures for assessing the severity of field exposure and for limiting the exposure to workers and general public to these fields if the limits are exceeded.

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.

The Recommendation covers the exposure of people present on telecommunications premises (e.g., exchange) and the exposure of people outside the telecommunications premises to EMF produced by telecommunication equipment and equipment on telecommunications premises.

The exposure due to the use of mobile handsets or other radiating devices used in close proximity to the human body is not covered.

ITU-T Recommendation K.33, *Limits for people safety related to coupling into telecommunications system from a.c. electric power and a.c. electrified railway installations in fault conditions*, covers safety issues related to people coming in contact with telecommunications circuits exposed to the induction of a.c. electric power or a.c. electrified railway lines.

3 Terms and definition

This Recommendation defines the following terms:

3.1 Antenna gain

The antenna gain $G(\theta,\phi)$ is the ratio of power radiated per unit solid angle to the total input power multiplied by 4π. Gain is frequently expressed in decibels with respect to an isotropic antenna (dBi). The equation defining gain is:

$$G(\theta,\varphi) = 4\pi \frac{dP_r / d\Omega}{P_{in}}$$

Where

θ, ϕ	are the angles in a polar coordinate system
P_r	is the radiated power
P_{in}	is the total input power

3.2 Average (temporal) power (P_{avg})

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 t_1 and t_2 are the start and stop time of the exposure. The period t_1-t_2 is the exposure duration time.

3.3 Averaging time (T_{avg})

The averaging time is the appropriate time over which exposure is averaged for purposes of determining compliance with the limits.

3.4 Continuous exposure

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.

3.5 Contact current

Contact current is the current flowing into the body by touching a conductive object in electromagnetic field.

3.6 Controlled/occupational exposure

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. Occupational/controlled exposure also applies 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 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.

3.7 Directivity

Directivity is the ratio of the power radiated per unit solid angle over the average power radiated per unit solid angle.

3.8 Equivalent Isotropically Radiated Power (EIRP)

The EIRP is product of the power supplied to the antenna and the maximum antenna gain relative to an isotropic antenna.

3.9 Exposure

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.

3.10 Exposure level

Exposure level is the value of the quantity used when a person is exposed to electromagnetic fields or contact currents.

3.11 Exposure, non-uniform/partial body

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.

3.12 Far-field region

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.

3.13 General public

All non-workers (see definition of workers in this document) are defined as general public.

3.14 Induced current

Induced current is the current induced inside the body as a result of direct exposure to electromagnetic fields.

3.15 Intentional emitter

Intentional emitter is a device that intentionally generates and emits electromagnetic energy by radiation or induction.

3.16 Near-field region

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

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

3.17 Power flux density (*S*)

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 meter (W/m^2).

Note: For plane waves. power flux density, electric field strength (*E*), and magnetic field strength (*H*) are related by the impedance of free space, $\eta_0 = 377\Omega$. In particular,

$$S = \frac{E^2}{\eta_0} = \eta_0 H^2 = EH$$

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*.

3.18 Power density, average (temporal).

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.

3.19 Power density, peak

The peak power density is the maximum instantaneous power density occurring when power is transmitted.

3.20 Power flux density, plane-wave equivalent (S_{eq})

The equivalent plane-wave power flux density is a commonly used term associated with any electromagnetic wave, equal in magnitude to the power flux density of a plan wave having the same electric (*E*) or magnetic (*H*) field strength.

3.21 Relative field pattern

The relative field pattern $f(\theta,\phi)$ is defined in this document as the ratio of the absolute value of the field (arbitrarily taken to be the electric field) to the absolute value of the maximum field intensity. It is related to the relative numeric gain (see 3.22) as follows

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

3.22 Relative numeric gain

The relative numeric gain $F(\theta,\phi)$ is the ratio of the antenna gain at each angle and the maximum antenna gain. It is a value ranging from 0 to 1. It is also called antenna pattern.

3.23 Short-term exposure

The term short-term exposure refers to exposure for duration less than the corresponding averaging time.

3.24 Specific absorption (SA)

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).

$$SA = \frac{dW}{dm} = \frac{dW}{\rho dV}$$

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

3.25 Specific absorption rate (SAR)

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 (π)

$$SAR = \frac{d}{dt}\frac{dW}{dm} = \frac{d}{dt}\frac{dW}{\rho dV}$$

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

SAR can be calculated by:

$$SAR = \frac{\sigma E^2}{\rho}$$

$$SAR = c\frac{dT}{dt}$$

$$SAR = \frac{J^2}{\rho\sigma}$$

where

E	is the value of the electric field strength in body tissue in V/m
σ	is the conductivity of body tissue in S/m
ρ	is the density of body tissue in kg/m^3
c	is the heat capacity of body tissue in J/kg°C
$\frac{dT}{dt}$	is the time derivative of temperature in body tissue in °C/s
J	is the value of the induced current density in the body tissue in A/m^2

3.26 General population/uncontrolled exposure

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 for the potential for exposure or cannot exercise control over their exposure.

3.27 Workers

Employed and self-employed persons are termed workers, whilst following their employment.

3.28 Unintentional emitter

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.

wavelength (λ) The wavelength of an electromagnetic wave is related to frequency (f) and velocity (v) of an electromagnetic wave by the following expression:

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

In free space the velocity is equal to the speed of light (c) which is approximately 3×10^8 m/s.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations

EMF Electromagnetic Field

EIRP Equivalent Isotropically Radiated Power

5 General principles

There are many national and international documents that provide safety limits for human exposure to EMFs [1-6]. Although these documents differ in particulars, most documents have several basic principles in common. These include the use of basic and derived limits, the use two-tier exposure limits, averaging times, and separate consideration for exposure to low-frequency and high-frequency fields.

Most documents provide safety limits in terms of basic levels and reference (or derived) levels. The basic limits address the fundamental quantities that determine the physiological response of the human body to electromagnetic fields. Basic limits apply to a situation with the body present in the field. The basic limits for human exposure are expressed as the Specific Absorption Rate (SAR), Specific Absorption (SA) and Current Density.

As the basic quantities are difficult to measure directly, most documents provide derived (reference) levels for electric field, magnetic field and power density. Derived limits may be exceeded if the exposure condition can be shown to produce SAR, SA, and induced current density below the basic limits. The derived limits apply to a situation where the electromagnetic field is not influenced by the presence of a body.

Most documents use a two-tier limit structure where lower levels are specified for uncontrolled/general public exposure than for controlled/occupational exposure.

It is important to emphasize that exposure limits are not emission limits; they apply to locations accessible to workers or members of the general public. Thus, it is possible to achieve compliance by limiting access to areas where the field limits are exceeded.

5.1 Multiple sources and frequencies

Most documents require that the effects of multiple sources be considered. Due to the different physiological effect of lower-frequency sources and higher-frequency sources, they should be considered separately. At lower frequencies (typically below 10MHz) , the important physiological effects are due to the induced current density, while at higher frequencies (typically above 100kHz), the important physiological effects are due to the SAR.

To consider the effects of multiple sources, most documents require that the sources be considered in a weighted sum, where each individual source is prorated according to the limit applicable to its frequency. Appendix 1 shows the procedure in the ICNIRP guidelines.

5.2 Exposure duration

Most documents define the exposure limits in terms of quantities averaged over a time period called the averaging time. In case of short-term exposure with duration less than the averaging time, the applicable limit is

$$\sum_i X_i^2 t_i \le X_i^2 t_{avg}$$

where

X_i	is the field (*E* or *H*) during exposure *i*,
t_i	is the duration of exposure *i*
X_l	is the reference limit, and
t_{avg}	is the appropriate averaging time.

The power density limit is

$$\sum_i S_i t_i \le S_l t_{avg}$$

where

S_i	is the power density during exposure *i*,
t_i	is the duration of exposure *i*
S_l	is the reference limit, and
t_{avg}	is the appropriate averaging time.

6 EMF Safety Limits

In many cases local or national regulatory agencies or standards bodies promulgate the EMF safety limits. If such limits do not exist or if they do not cover the frequencies of interest, then ICNIRP limits (Appendix A) should be used.

7 Achieving compliance to EMF safety limits

The following steps should be taken to achieve compliance:

1. Identify appropriate compliance limits.

2. Determine if EMF exposure assessment for the installation or equipment in question is needed.

3. If the EMF exposure assessment is needed, it may be performed by calculations or measurement. This document presents a risk assessment approach to help the user determine the possibility that EMF exposure limits may be exceeded and help the user select an appropriate method to perform the assessment.

4. If the EMF exposure assessment indicates that pertinent exposure limits may be exceeded in areas where people may be present, mitigation/avoidance measures should be applied.

7.1 Determining the need for assessment for telecommunications equipment

Telecommunications equipment should be classified as an intentional or unintentional EMF emitter in accordance with the definitions. Typically, an intentional emitter is associated with an antenna for radiation of electromagnetic energy.

7.1.1 Unintentional emitters

Unintentional transmitters may produce EMF due to spurious emissions. There are EMC emission standards that limit the magnitude of these spurious fields. Typically, the fields produced by telecommunications equipment that is an unintentional emitter is significantly below the safety limits established by ICNIRP and national standards. The limits established for EMC compliance are orders of magnitude below the EMF safety limits. Even if equipment exceeds the emission limits at certain frequencies, experience indicates that the fields produced are still orders of magnitude below the safety limits. Thus, telecommunications equipment that is an unintentional emitter does not need an EMF safety assessment to assure compliance with safety limits.

7.1.2 Intentional emitters

Intentional emitters use electromagnetic fields for signal transmission. They produce EMF that may exceed the safety limits in some regions depending on the operating power, gain, frequency, orientation and directivity of the transmitting antenna. It is possible to take into account these parameters and the operating environment of the installation to determine the need and the appropriate procedure of exposure assessment. This document presents a risk assessment approach based on classification of exposure zones.

7.2 Procedures for EMF exposure assessment

If it is determined than an EMF exposure assessment is needed due to the presence of intentional transmitters, it should be performed for all locations where people might be exposed to EMF. The intent of the assessment is to classify potential exposure to EMF as belonging to one of the three following zones:

1. **Compliance zone**: In the compliance zone potential exposure to EMF is below the applicable limits for both controlled/occupational exposure and uncontrolled/general public exposure.

2. **Occupational zone**: In the occupational zone potential exposure to EMF is below the applicable limits for controlled/occupational exposure but exceeds the applicable limits for uncontrolled/general public exposure.

3. **Exceedance zone**: In the exceedance zone potential exposure to EMF exceeds the applicable limits for both controlled/occupational exposure and uncontrolled/general public exposure.

For many installations, the exceedance zone and the occupational zone are not accessible to people, or are only accessible under unusual circumstances, such as a person standing directly in front of the antenna. The risk assessment procedure presented in this document is concerned primarily with exposure of general public and workers in the course of their normal activities.

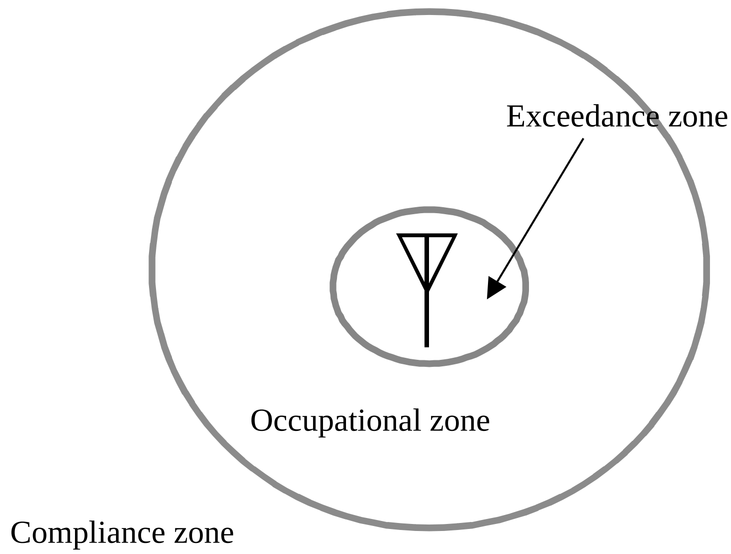


Figure 1/K.EMF – Figurative illustration of exposure zones

7.3 Exposure level assessment procedure

The assessment of the exposure level shall consider:

- The worst emission conditions, i.e. when the maximum power is available to the antenna system.
- The simultaneous presence of several EMF sources, even at different frequencies.

The following parameters should be considered:

- The maximum EIRP of the antenna system , (see definition 3.8)
- The antenna gain *G* or the relative numeric gain *F* (see definition 3.1) , including maximum gain and beam width,
- The frequency of operation, and
- Various characteristics of the installation, such as the antenna location, antenna height, beam direction, beam tilt and the assessment of the probability that a person could be exposed to the EMF.

To manage the procedure and these parameters the following classification scheme is introduced.

7.3.1 The installation classification scheme

Each emitter installations should be classified into the following three classes:

1. **Inherently compliant:** Inherently safe sources produce fields that comply with relevant exposure limits a few centimeters way from the source. Particular precautions are not necessary.
2. **Normally compliant:** Normally compliant installations contain sources that produce EMF that can exceed relevant exposure limits. However, as a result of normal installation practices and the typical use of these sources for communication purposes, the exceedance zone of these sources are not accessible to people under ordinary conditions. Examples include antenna mounted on sufficiently tall towers or narrow-beam earth stations pointed at the satellite. Precaution may need to be exercised by maintenance personnel who come in close vicinity of emitters in certain normally compliant installations.
3. **Provisionally compliant:** These installations require special measures to achieve compliance. This involves determination of the exposure zones and measures presented in clause 9.

7.3.2 Procedure for determining installation class:

Each installation should be categorized into one of the installation classes defined in clause 7.3.1. It is expected that operators providing a particular telecommunication service utilize a limited set of antennas and associated equipment with well-defined characteristics. Furthermore, installation and exposure conditions for many emitter sites are likely to be similar. Therefore, it is possible to define a set of reference configurations, reference exposure conditions and corresponding critical parameters that will enable convenient classification of sites.

A useful procedure is as follows:

1. Define a set of reference antenna parameters or antenna types. These categories can be customized to the types of emitters used for the particular application.
2. Define a set of accessibility conditions. These categories depend on the accessibility of various areas in the proximity of the emitter to people. These categories can be customized to the most commonly occurring installation environment for the particular service or application.
3. For each combination of reference antenna parameters and accessibility condition, determine the threshold EIRP. This threshold EIRP, which will be denoted as $EIRP_{th}$ is the value that corresponds to the exposure limit for the power density or field from the reference antenna for the accessibility condition. The determination may be performed by calculation or measurements as described in Section 8. Provided the categories are sufficiently encompassing, this determination need only be performed once for the majority of installations.
4. An installation belong source belongs to the inherently the inherently compliant class if the emitter is inherently compliant (as defined above). There is no need to consider other installation aspects. Note: Appendix III shows that an inherently compliant source for ICNIRP limits has EIRP less than 2 W.
5. For each site, an installation belongs to the normally compliant class, if the following criterion is fulfilled:

$$\sum_i \frac{EIRP_i}{EIRP_{th,i}} \leq 1$$

Where $EIRP_i$ is the temporal averaged radiated power of the antenna at a particular frequency i, and $EIRP_{th,i}$ is the *EIRP* threshold relevant to the particular antenna parameters and accessibility conditions. For multiple-antenna installation, the following two conditions need to be distinguished:

- If the source have overlapping radiation patterns as determined by considering the half-power beam width, the respective maximum time-averaged EIRP should satisfy the criterion:
- If there is no overlap of the multiple sources, they shall be considered independently.

6. Sites that do not meet the conditions for normally compliant classification are considered provisionally compliant.

For sites where the application of these categories is ambiguous, additional calculations or measurement will need to be performed.

Annex B presents a set of basic configurations, exposure conditions, and parameters. The set of Annex B should be used as a default unless the Operator defines another set that is appropriate for a given service deployment and performs the relevant exposure analysis.

7.3.2.1 Determination of the $EIRP_{th}$

The procedure is the following:

1. Determine the field or the power density for each point O, where exposure can occur, for the particular antenna having an *EIRP* of unity.
2. Find the maximum power density S_{max} within the exposure area from this set.
3. The $EIRP_{th}$ is given by S_{max}/S_{lim} where S_{lim} is the relevant limit given by the EMF exposure standard at the relevant frequency.

This procedure may be performed by calculations shown in Section 8.1, by other more accurate calculation methods or by measurements. If measurements are used, it is necessary to perform then at a number of representative locations for each accessibility configuration and antenna type.

8 EMF evaluation techniques

This section presents methods that can be used to evaluate EMF.

8.1 Calculation methods

8.1.1 Reactive near-field region

In the reactive near-field region, the electric and magnetic fields must be considered separately. In the absences of field-distorting objects, the fields can be calculated using quasi-static formulas if a current distribution is known.

8.1.2 Far-field region

The following material provides methods for conservatively estimating field strength and power density levels.

For a single radiating antenna the approximate power density radiated in the direction described by the angles θ (complementary to the elevation angle) and φ (azimuth angle) can be evaluated by the following expression

$$S(R,\theta,\phi) = \frac{EIRP}{4\pi}\left[f(\theta,\phi)\frac{1}{R} + \rho f(\theta',\phi')\frac{1}{R'} \right]^2$$

where

$S(R,\theta,\phi)$	is the power density in W/m^2
$f(\theta,\phi)$	is the relative field pattern of the antenna (positive number between 0 and 1)
EIRP	is the *EIRP* of the antenna,
ρ	is the absolute value (modulus) of the reflection coefficient and takes into account the wave reflected by the ground. In some cases, the exposure to the reflected wave may be blocked, so that ρ should be set to 0.
R	is the distance between the central point of the radiating source and the putative exposed person.
R'	is the distance between the central point of the image of the radiating source and the putative exposed person.

Near ground level, the values of primed variables is approximately equal to the unprimed, so the power can be calculated as:

$$S_{gl}(R,\theta,\phi) = (1+\rho)^2 \frac{EIRP}{4\pi R^2} F(\theta,\phi)$$

where

$F(\theta,\phi)$	is the relative numeric gain of the antenna relative to an isotropic radiator (positive number between 0 and 1)

The reflection coefficient ρ of earth with conductivity σ, permitivity $\varepsilon = \kappa\varepsilon_0$ ε and grazing angle of incidence Ψ is

$$\rho = \left| \frac{(\kappa - j\chi)\sin\Psi - \sqrt{(\kappa - j\chi) - \cos^2\Psi}}{(\kappa - j\chi)\sin\Psi + \sqrt{(\kappa - j\chi) - \cos^2\Psi}} \right| \qquad \text{vertical polarization}$$

$$\rho = \left| \frac{\sin\Psi - \sqrt{(\kappa - j\chi) - \cos^2\Psi}}{\sin\Psi + \sqrt{(\kappa - j\chi) - \cos^2\Psi}} \right| \qquad \text{horizontal polarization}$$

where ,

$$\chi = \frac{\sigma}{\omega\varepsilon_0}.$$

In general, the reflected wave contains components in vertical and horizontal polarization that vary with the incidence angle. However, for many applications, it is sufficient to consider only the predominant polarization of the incident wave in calculating the reflection coefficient.

The distances and angles are defined in Figure 2. It is assumed that exposure is being evaluated at point O.

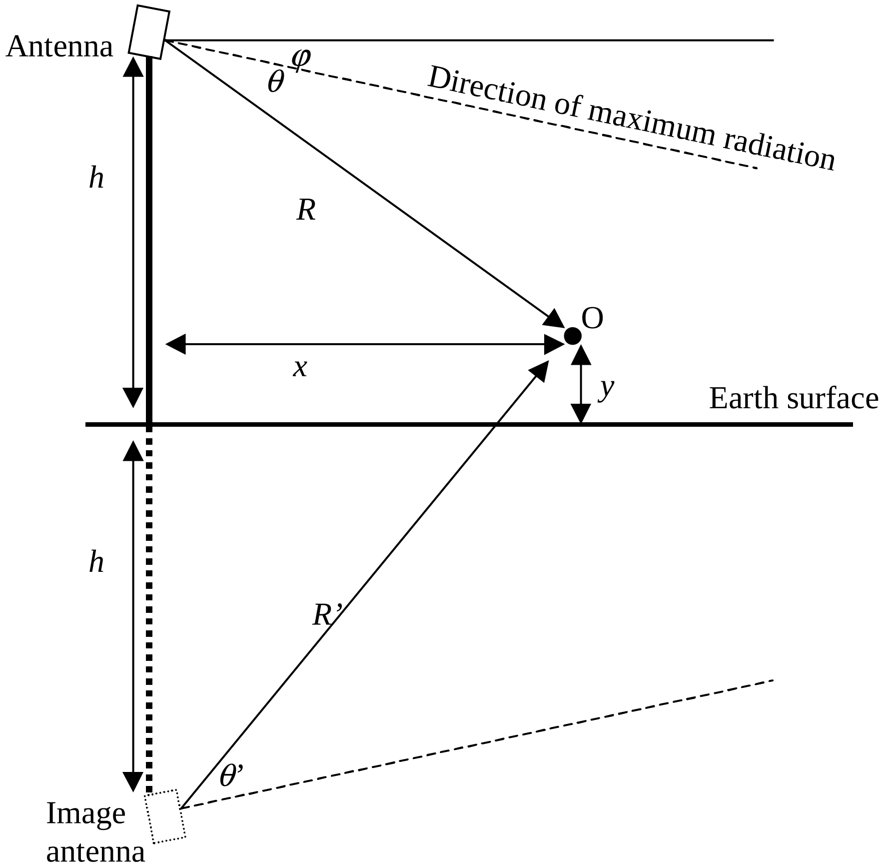


Figure 2. Definition of distances and vertical angles

The FCC in US recommends using a reflection coefficient of 0.6 leading to multiplication of the power density by a factor of 2.56.

For rooftop locations, attenuation caused by building materials in the walls and roof can reduce the exposures inside a building by at least 10-20 dB due to .

The electric and magnetic fields are calculated using

$$E = \sqrt{S\eta_0}$$

$$H = \sqrt{S / \eta_{0s}}$$

where η_0 = 377 is the impedance of free space

The foregoing equations are valid for the far-field region. Their use in the near-filed region may yield inaccurate (overly conservative) results. Thus, these equations can be used to determine compliance with the EMF exposure limits.

8.2 Measurement procedures

Measurements are useful in cases where the fields are difficult to calculate and where the calculations yield values that are near the exposure limit threshold. The publications listed in the References section and any applicable national standards should be consulted for detailed information about measuring EMF. In addition, a number of publications listed in the Bibliography provide detailed information about measuring EMF fields at various frequencies.

When measuring EMF, it is first necessary to determine the frequency range over which the determination of EMF is required based on the characteristics of relevant emitters. Measurement instruments should be selected accordingly. Either single broadband instrument or a combination of several narrow-band instruments (or measurements) can be used to characterize the fields over a given frequency range.

9 Mitigation techniques

It is necessary to control EMF exposure in locations accessible to people where the EMF exceeds human EMF exposure safety limits. An effective way to control exposure is to restrict access to areas where the limits are exceeded.

9.1 Occupational zone

If the EMF exceeds the limits for uncontrolled/general public exposure but does not exceed the limits for occupational exposure, then access to general public should be restricted, but workers may be permitted to enter the area. Physical barriers, lockout procedures or adequate signs can accomplish the access restriction. Workers entering the occupational zone should be informed.

It is recommended not to locate a permanent workplace within the occupational zone.

9.2 Exceedance zone

Where the EMF exceeds the limits for occupational exposure, access to workers and the general public should be restricted. If it necessary for workers to enter the area, steps to controls their exposures should be taken. Such steps include

- Temporarily reducing the power of the emitter,
- Controlling the duration of the exposure so that time-averaged exposure is within safety limits.
- Shielding or use of protective clothing

10 Bibliography

[1] ICNIRP, *Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic field (up to 300 GHz).*

[2] FCC, 96-326, *Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation.*

[3] ANSI/IEEE C95.1, *Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz .*

[4] CENELEC (BSI), ENV 50166-1, *Human Exposure to Electromagnetic Fields — Low Frequency (0 Hz to 10 GHz).*

[5] CENELEC (BSI), ENV 50166-2, *Human Exposure to Electromagnetic Fields — High Frequency (10 kHz to 300 GHz).*

[6] IEC 657, *Non-Ionizing Radiation Hazards in the Frequency Range from 10 MHz to 300 00 MHz.*

[7] ANSI/IEEE C95.3, *Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields — RF and Microwave.*

[8] IEEE 291, *Standard Methods for Measuring Electromagnetic Field Strengths of Sinusoidal Continuos Waves, 30 Hz to 30 GHz.*

[9] IEEE C63.2, *Standard Electromagnetic Noise and Field Strengths Instrumentation, 10 Hz to 40 GHz — Specifications.*

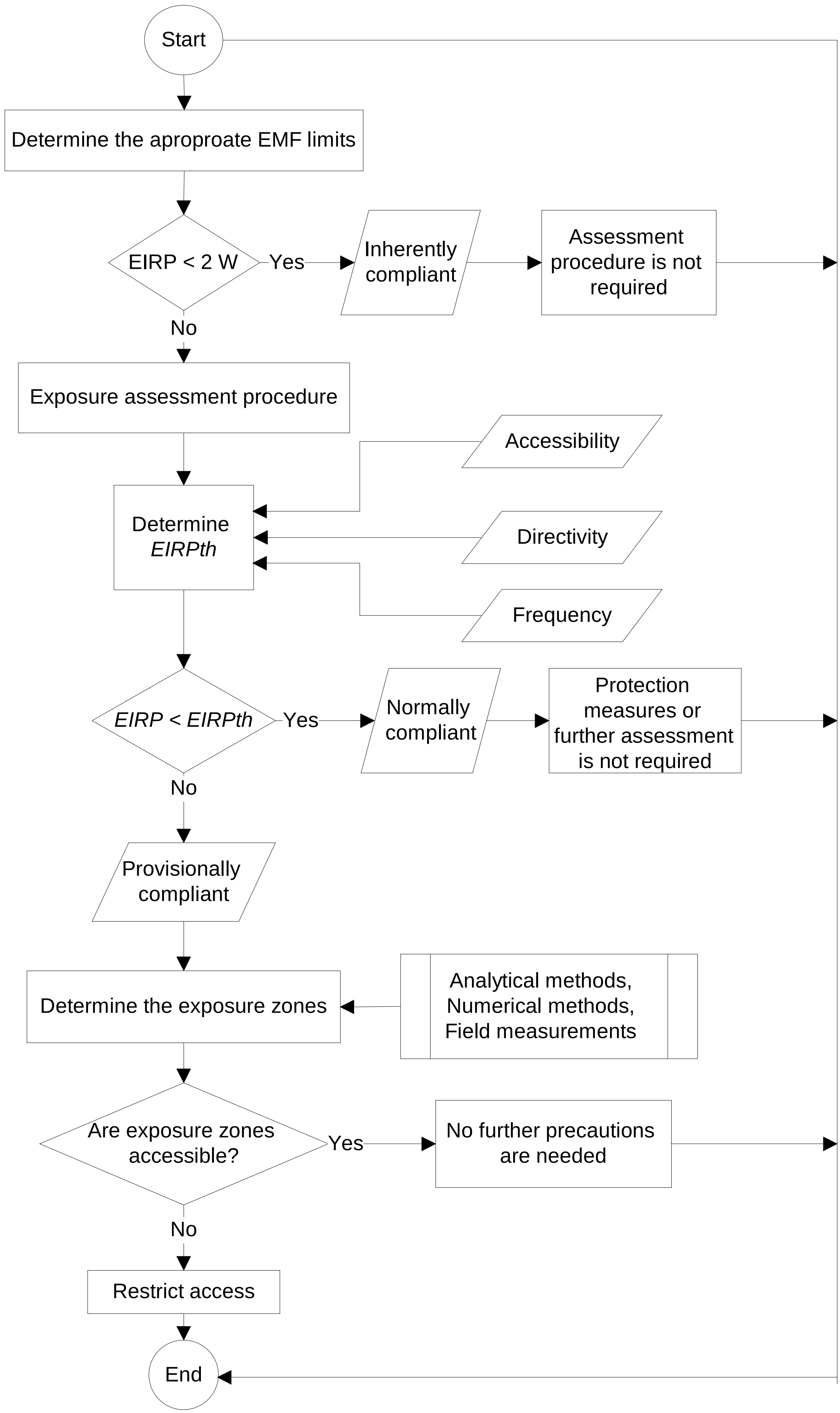
[10] OET Bulletin 65, *Evaluating compliance with FCC guidelines for human exposure to radiofrequency electromagnetic fields.*

[11] IEEE 644, *Standard procedures for measurement of power frequency electric and magnetic fields from ac power lines*.

ANNEX A

The Application Flow Chart

This annex shows the flow chart of the exposure assessment


Start
Determine the aproproate EMF limits
EIRP < 2 W
Yes
Inherently compliant
Assessment procedure is not required
No
Exposure assessment procedure
Accessibility
Determine *EIRPth*
Directivity
Frequency
EIRP < EIRPth
Yes
Normally compliant
Protection measures or further assessment is not required
No
Provisionally compliant
Determine the exposure zones
Analytical methods, Numerical methods, Field measurements
Are exposure zones accessible?
Yes
No further precautions are needed
No
Restrict access
End

ANNEX B

Basic Criteria for Determining the Installation Class

The following facilitate the classification of the installation on the basis of the ICNIRP limits. The criteria are based on a conservative estimate of the likely EMF exposure in the various situations described below. Appendix 3 provides more detailed rationale. The values of this Annex should be used for installation classification unless a set of customized criteria has been developed in accordance with Section 7.3.2 for a particular service.

B.1 Inherently compliant sources

Emitters with maximum EIRP of 2W or less are classified as inherently compliant. No further action is deemed necessary.

In addition where the emitter is so constructed that access to any area where exposure limits may be exceeded is precluded by the construction of the radiating device is classified as inherently compliant.

B.2 Normally compliant installations

Table 2 defines the antenna directivity categories. Antenna directivity is important because it determines the pattern of potential exposure. High directivity means that most of the radiated power is concentrated in a narrow beam, which may allow good control of the location of the exposure zones.

B.2.1 Accessibility categories

The following sections define the accessibility categories. These conditions, which depend on the installation circumstances, assess the likelihood that a person can access the exceedance zone of the emitter.

Table B.1/K.EMF — Accessibility conditions

Accessibility category	Relevant installation circumstances	Figure reference
1	Antenna is installed on an inaccessible tower— the center of radiation is at a height *h* above ground level. There is a constraint *h*>3. Antenna is installed on publicly accessible structure (such as rooftop) — the center of radiation is at a height *h* above the structure.	Figure B.3
2	Antenna is installed at ground level — the center of radiation is at a height *h* above ground level. There is an adjacent building or structure accessible to general public and of approximately height *h* located a distance *d* from the antenna along the direction of	Figure B.4

Accessibility category	**Relevant installation circumstances**	**Figure reference**
	propagation. There is a constraint $h>3$	
3	Antenna is installed at ground level — the center of radiation is at a height *h* ($h>3$) above ground level. There is an adjacent building or structure accessible to general public and of approximately height *h’* located a distance *d* from the antenna along the direction of propagation.	Figure B.5
4	Antenna is installed on a structure at a height *h* ($h>3$). There is an exclusion area associated with the antenna. Two geometries for the exclusion area are defined ▪ A circular area with radius a surrounding the antenna, or ▪ A rectangular area of size $a\times b$ in front of the antenna.	Figure B.6 Figure B.7

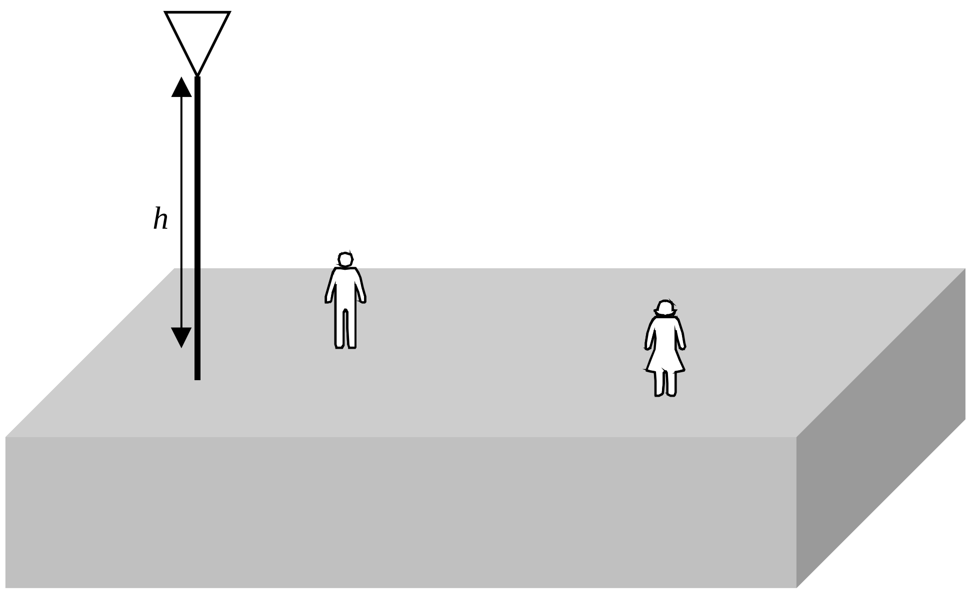


Figure B.3/K.EMF — Illustration of the accessibility category 1

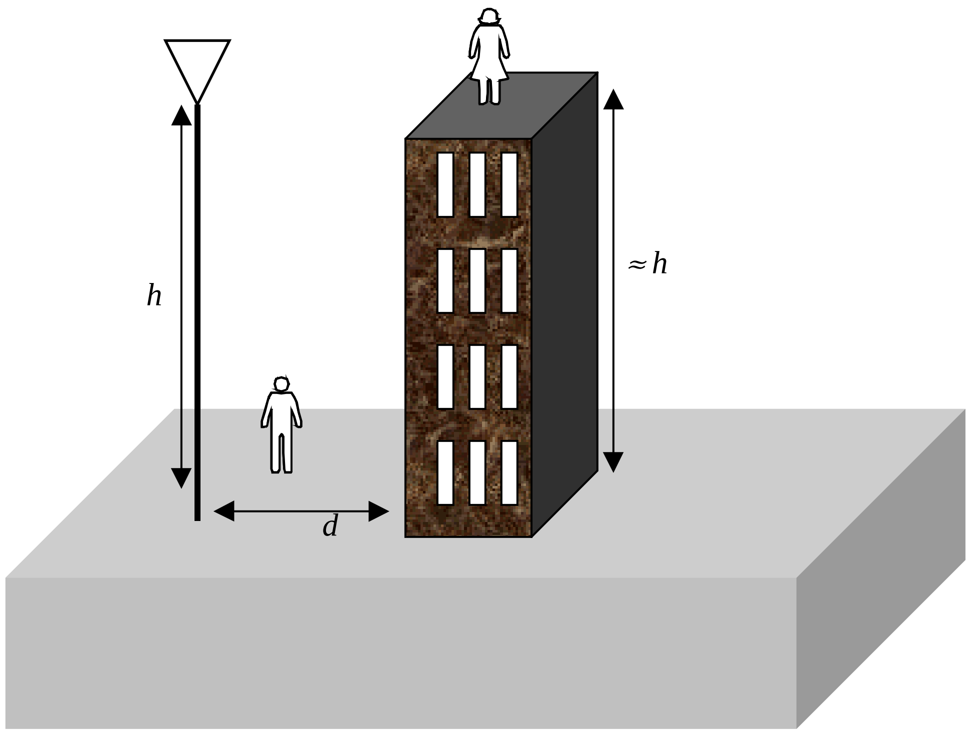


Figure B.4/K.EMF — Illustration of the accessibility category 2

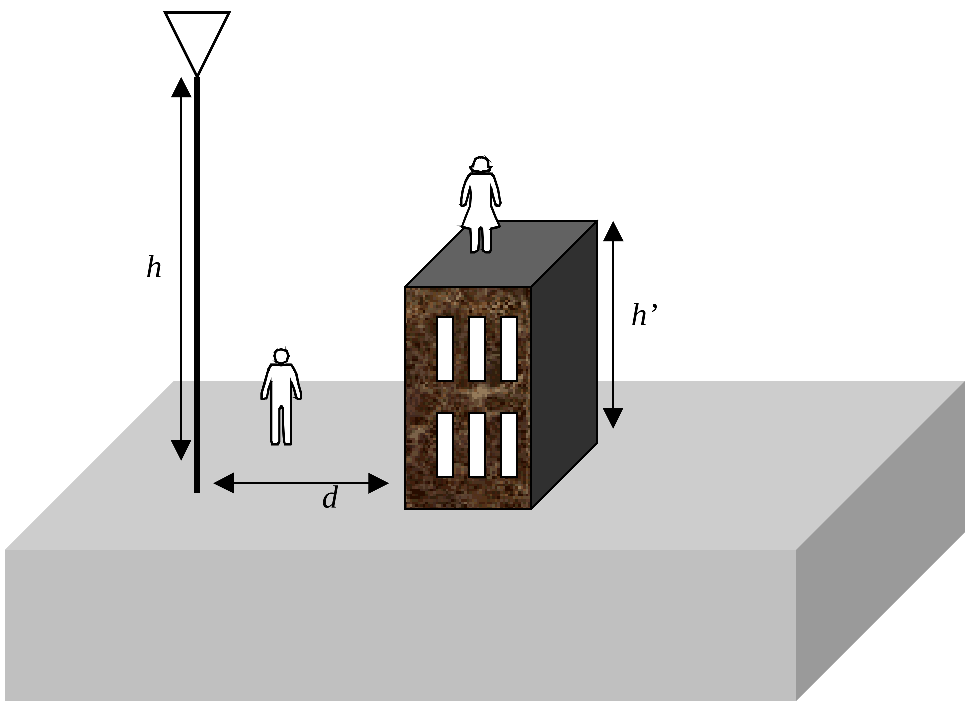


Figure B.5/K.EMF — Illustration of the accessibility category 3

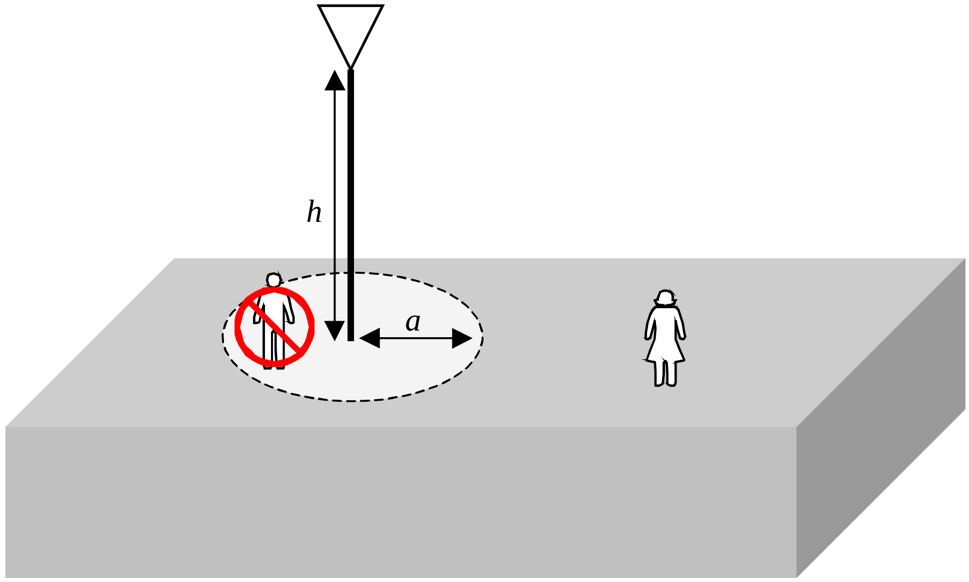


Figure B.6/K.EMF — Illustration of the accessibility category 4, circular exclusion area

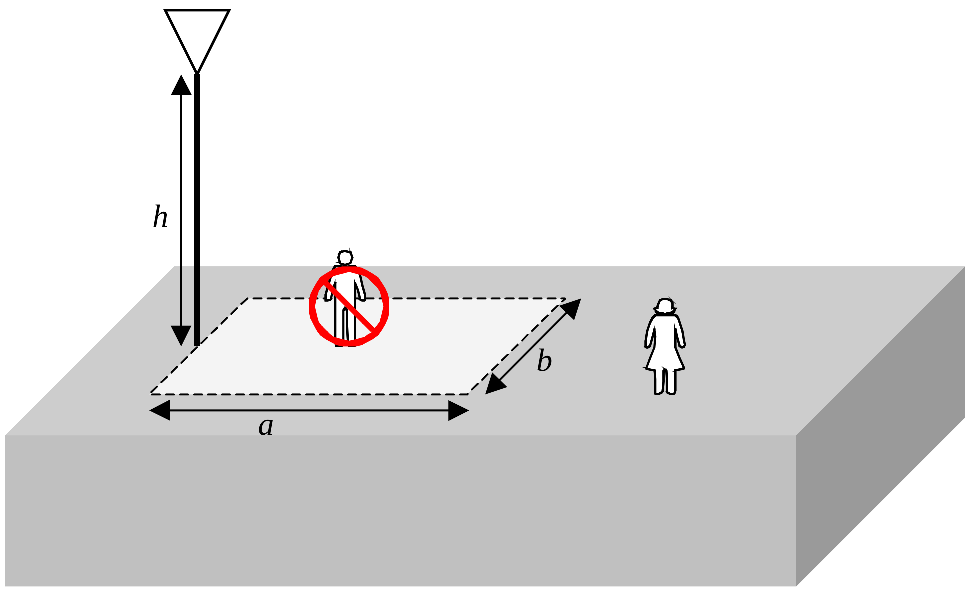


Figure B.7/K.EMF — Illustration of the accessibility category 4, rectangular exclusion area

B.1.1.1 Frequency ranges

The carrier frequency determines the exposure limit for the radiated power density, $S_{lim}(f)$ as reported in the electromagnetic fields exposure standards. It is necessary to point out that the radiated density power can be used only in far field conditions, when it is representative of the electric and magnetic fields. This represents the limit of validity of the proposed assessment procedure for normally compliant installations. Where the procedure is not applicable (e.g. low frequencies or exposure in near field condition) then the installation shall be considered provisionally compliant.

The ICNIRP guidelines define three frequency ranges to which correspond different limit values of radiated power.

f (MHz)	$S_{lim}(f)$ (W/m^2)	
	General public	**Occupational**
100–400	2	10
400–2000	f/200	f/40
$2 \cdot 10^3 – 300 \cdot 10^3$	10	50

B.2.2 Antenna directivity categories

The antenna pattern is a major determinant and a frequently varying factor in determining the field. Table B.2 presents description to facilitate classification of antennas into generic categories. The most important parameter for determining the exposure due to elevated antennas is the vertical (elevation) antenna pattern. The horizontal (azimuthal) pattern is not relevant because the exposure assessment assumes exposure along the direction of maximum radiation in the horizontal plane.

Note, however, that the vertical and horizontal patterns determine the antenna gain, and that horizontal pattern determines the exclusion area for accessibility category 4.

Table B.2/K.EMF - Antenna directivity categories

Directivity category	Antenna description	Relevant parameters
1	Half-wave dipole	None See Figure B.8
2	Broad coverage antenna (omni-directional or sectional) such those used for wireless communication or broadcasting.	• Vertical half-power-beam width — θ_{bw} • Maximum side-lobe amplitude with respect to the maximum — A_{sl} • Beam tilt — α See Figure B.9
3	High-gain antenna producing a "pencil" (circularly symmetrical beam), such those used for point-to-point communication or earth stations	• Vertical half-power-beam width — θ_{bw} • Maximum side-lobe amplitude with respect to the maximum — A_{sl} • Beam tilt — α See Figure B.9

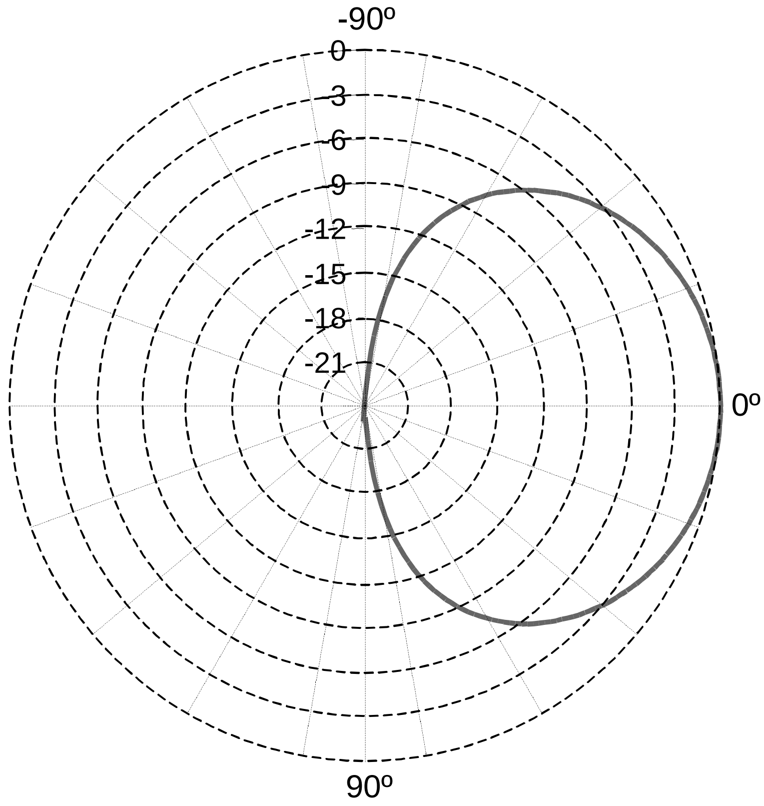


Figure B.8/K.EMF — Vertical pattern for a half-wave dipole

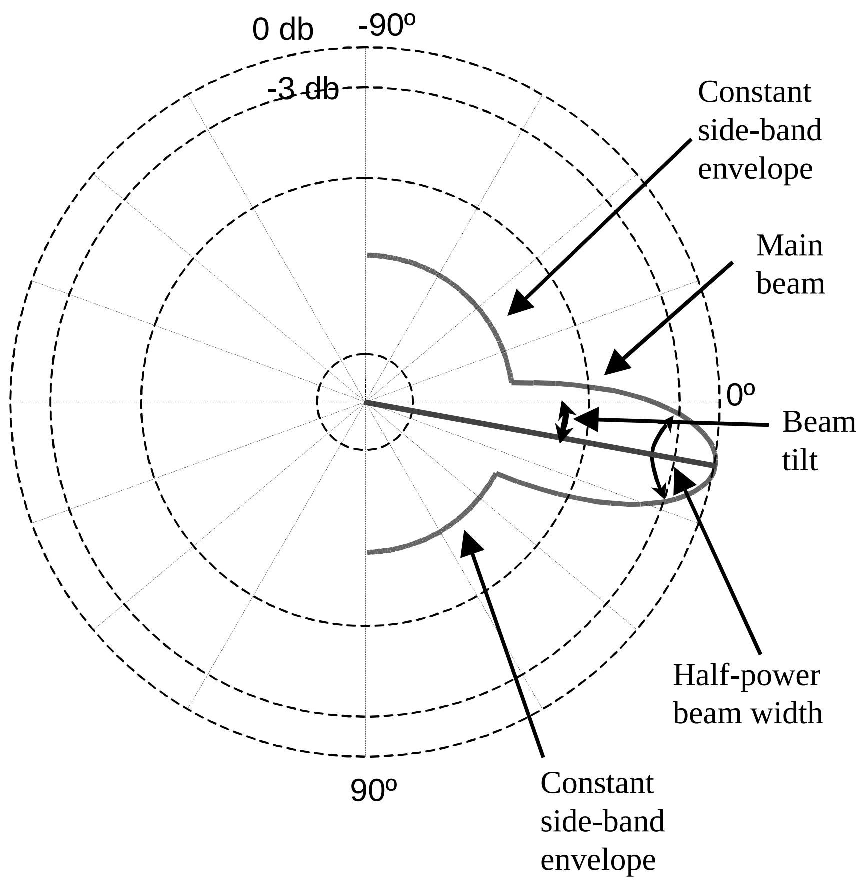


Figure B.9/K.EMF — Illustration of terms relating to antenna patterns

B.2.3 The $EIRP_{th}$ Values

Table B.3 shows the expressions for $EIRP_{th}$ values based on the ICNIRP limits for various frequency ranges, accessibility conditions and antenna directivity categories. The $EIRP_{th}$ values are given as functions of antenna height and other relevant accessibility and directivity parameters defined in Sections B.2.1 and B.2.2.

Table B.3/K.EMF — Conditions for normal compliance of installations based on ICNIRP limits for frequency range 100-400 MHz

Directivity category	Accessibility category	$EIRP_{th}$ (W)	
		General public	**Occupational**
1	1	$8\pi\cdot(h-2)^2$	$40\pi\cdot(h-2)^2$
	2	Lesser of: $8\pi\cdot(h-2)^2$ or $2\pi\cdot d^2$	Lesser of: $40\pi\cdot(h-2)^2$ or $10\pi\cdot d^2$
	3	Lesser of: $8\pi\cdot(h-2)^2$ or $2\pi\cdot\{[d^2+(h-h')^2]/d\}^2$	Lesser of: $40\pi\cdot(h-2)^2$ or $10\pi\cdot\{[d^2+(h-h')^2]/d\}^2$
	4	Lesser of: $8\pi\cdot(h-2)^2$ or $2\pi\cdot\{[a^2+(h-2)^2]/a\}^2$	Lesser of: $40\pi\cdot(h-2)^2$ or $10\pi\cdot\{[a^2+(h-2)^2]/a\}^2$
2	1	Lesser of: $2\pi\cdot(h-2)^2/A_{sl}$ or $2\pi\cdot[h/\sin(\alpha+1.129\theta_{bw})]^2$	Lesser of: $10\pi\cdot(h-2)^2/A_{sl}$ or $10\pi\cdot[h/\sin(\alpha+1.129\theta_{bw})]^2$
	2 (determined by: $h'>h-d\cdot\sin(\alpha+1.129\theta_{bw})$)	Lesser of: $2\pi\cdot(h-2)^2/A_{sl}$ or $2\pi\cdot d^2$	Lesser of: $10\pi\cdot(h-2)^2/A_{sl}$ or $10\pi\cdot d^2$
	3 (determined by: $h'<h-d\cdot\sin(\alpha+1.129\theta_{bw})$)	Lesser of: $2\pi\cdot(h-2)^2/A_{sl}$ or $2\pi\cdot\{[d^2+(h-h')^2]/d\}^2$	Lesser of: $10\pi\cdot(h-2)^2/A_{sl}$ or $10\pi\cdot\{[d^2+(h-h')^2]/d\}^2$
	4	Lesser of: $2\pi\cdot(h-2)^2/A_{sl}$ or $2\pi\cdot\{[a^2+(h-2)^2]/a\}^2/A_{sl}$	Lesser of: $10\pi\cdot(h-2)^2/A_{sl}$ or $10\pi\cdot\{[a^2+(h-2)^2]/a\}^2/A_{sl}$

Directivity category	Accessibility category	$EIRP_{th}$ (W)	
		General public	Occupational
3	1	$2\pi\cdot(h\text{-}2)^2/A_{sl}$	$10\pi\cdot(h\text{-}2)^2/A_{sl}$
	2	N/A (Line of sight is usually required)	N/A (Line of sight is usually required)
	3 (determined by: $h' < h - d\cdot\sin(\alpha + 1.129\theta_{bw})$)	Lesser of: $2\pi\cdot(h\text{-}2)^2/A_{sl}$ or $2\pi\cdot\{[d^2+(h\text{-}h')^2]/d\}^2$	Lesser of: $10\pi\cdot(h\text{-}2)^2/A_{sl}$ or $10\pi\cdot\{[d^2+(h\text{-}h')^2]/d\}^2$
	4	Lesser of: $2\pi\cdot(h\text{-}2)^2/A_{sl}$ or $2\pi\cdot\{[a^2+(h\text{-}2)^2]/a\}^2/A_{sl}$	Lesser of: $10\pi\cdot(h\text{-}2)^2/A_{sl}$ or $10\pi\cdot\{[a^2+(h\text{-}2)^2]/a\}^2/A_{sl}$

Table B.4/K.EMF — Conditions for normal compliance of installations based on ICNIRP limits for frequency range 400-2000 MHz

Directivity category	Accessibility category	$EIRP_{th}$ (W)	
		General public	Occupational
1	1	$f\cdot\pi/50\cdot(h\text{-}2)^2$	$f\cdot\pi/10\cdot(h\text{-}2)^2$
	2	Lesser of: $f\cdot\pi/50\cdot(h\text{-}2)^2$ or $f\cdot\pi/200\cdot d^2$	Lesser of: $f\cdot\pi/10\cdot(h\text{-}2)^2$ or $f\cdot\pi/40\cdot d^2$
	3	Lesser of: $f\cdot\pi/50\cdot(h\text{-}2)^2$ or $f\cdot\pi/200\cdot\{[d^2+(h\text{-}h')^2]/d\}^2$	Lesser of: $f\cdot\pi/10\cdot(h\text{-}2)^2$ or $f\cdot\pi/40\cdot\{[d^2+(h\text{-}h')^2]/d\}^2$
	4	Lesser of: $f\cdot\pi/50\cdot(h\text{-}2)^2$ or $f\cdot\pi/200\cdot\{[a^2+(h\text{-}2)^2]/a\}^2$	Lesser of: $f\cdot\pi/10\cdot(h\text{-}2)^2$ or $f\cdot\pi/40\cdot\{[a^2+(h\text{-}2)^2]/a\}^2$
2	1	Lesser of: $f\cdot\pi/200\cdot(h\text{-}2)^2/A_{sl}$ or $f\cdot\pi/200\cdot[h/\sin(\alpha+1.129\theta_{bw})]^2$	Lesser of: $f\cdot\pi/40\cdot(h\text{-}2)^2/A_{sl}$ or $f\cdot\pi/200\cdot[h/\sin(\alpha+1.129\theta_{bw})]^2$

Directivity category	Accessibility category	$EIRP_{th}$ (W)	
		General public	Occupational
	2 (determined by: $h' > h - d\cdot\sin(\alpha + 1.129\theta_{bw})$)	Lesser of: $f\cdot\pi/200\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/200\cdot d^2$	Lesser of: $f\cdot\pi/40\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/40\cdot d^2$
	3 (determined by: $h' < h - d\cdot\sin(\alpha + 1.129\theta_{bw})$)	Lesser of: $f\cdot\pi/200\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/200\cdot\{[d^2+(h-h')^2]/d\}^2$	Lesser of: $f\cdot\pi/40\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/40\cdot\{[d^2+(h-h')^2]/d\}^2$
	4	Lesser of: $f\cdot\pi/200\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/200\cdot\{[a^2+(h-h')^2]/a\}^2$	Lesser of: $f\cdot\pi/40\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/40\cdot\{[a^2+(h-h')^2]/a\}^2$
3	1	Lesser of: $f\cdot\pi/200\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/200\cdot[h/\sin(\alpha+1.129\theta_{bw})]^2$	Lesser of: $f\cdot\pi/40\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/200\cdot[h/\sin(\alpha+1.129\theta_{bw})]^2$
	2	N/A (Line of sight is usually required)	N/A (Line of sight is usually required)
	3 (determined by: $h' < h - d\cdot\sin(\alpha + 1.129\theta_{bw})$)	Lesser of: $f\cdot\pi/200\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/200\cdot\{[d^2+(h-h')^2]/d\}^2$	Lesser of: $f\cdot\pi/40\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/40\cdot\{[d^2+(h-h')^2]/d\}^2$
	4	Lesser of: $f\cdot\pi/200\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/200\cdot\{[a^2+(h-h')^2]/a\}^2$	Lesser of: $f\cdot\pi/40\cdot(h-2)^2/A_{sl}$ or $f\cdot\pi/40\cdot\{[a^2+(h-h')^2]/a\}^2$

Table B.5/K.EMF — Conditions for normal compliance of installations based on ICNIRP limits for frequency range 2000-300000 MHz

Directivity category	Accessibility category	$EIRP_{th}$ (W)	
		General public	Occupational
1	1	$40\pi\cdot(h-2)^2$	$200\pi\cdot(h-2)^2$

Directivity category	Accessibility category	$EIRP_{th}$ (W)	
		General public	**Occupational**
	2	Lesser of: $40\pi\cdot(h-2)^2$ or $10\pi\cdot d^2$	Lesser of: $200\pi\cdot(h-2)^2$ or $50\pi\cdot d^2$
	3	Lesser of: $40\pi\cdot(h-2)^2$ or $10\pi\cdot\{[d^2+(h-h')^2]/d\}^2$	Lesser of: $200\pi\cdot(h-2)^2$ or $50\pi\cdot\{[d^2+(h-h')^2]/d\}^2$
	4	Lesser of: $40\pi\cdot(h-2)^2$ or $10\pi\cdot\{[a^2+(h-2)^2]/a\}^2$	Lesser of: $200\pi\cdot(h-2)^2$ or $50\pi\cdot\{[a^2+(h-2)^2]/a\}^2$
2	1	Lesser of: $10\pi\cdot(h-2)^2/A_{sl}$ or $10\pi\cdot[h/\sin(\alpha+1.129\theta_{bw})]^2$	Lesser of: $50\pi\cdot(h-2)^2/A_{sl}$ or $50\pi\cdot[h/\sin(\alpha+1.129\theta_{bw})]^2$
	2 (determined by: $h'>h-d\cdot\sin(\alpha+1.129\theta_{bw})$)	Lesser of: $10\pi\cdot(h-2)^2/A_{sl}$ or $10\pi\cdot d^2$	Lesser of: $50\pi\cdot(h-2)^2/A_{sl}$ or $50\pi\cdot d^2$
	3 (determined by: $h'<h-d\cdot\sin(\alpha+1.129\theta_{bw})$)	Lesser of: $10\pi\cdot(h-2)^2/A_{sl}$ or $10\pi\cdot\{[d^2+(h-h')^2]/d\}^2$	Lesser of: $50\pi\cdot(h-2)^2/A_{sl}$ or $50\pi\cdot\{[d^2+(h-h')^2]/d\}^2$
	4	Lesser of: $10\pi\cdot(h-2)^2/A_{sl}$ or $10\pi\cdot\{[a^2+(h-2)^2]/a\}^2/A_{sl}$	Lesser of: $50\pi\cdot(h-2)^2/A_{sl}$ or $50\pi\cdot\{[a^2+(h-2)^2]/a\}^2/A_{sl}$
3	1	Lesser of: $10\pi\cdot(h-2)^2/A_{sl}$ or $10\pi\cdot[h/\sin(\alpha+1.129\theta_{bw})]^2$	Lesser of: $50\pi\cdot(h-2)^2/A_{sl}$ or $50\pi\cdot[h/\sin(\alpha+1.129\theta_{bw})]^2$
	2	N/A (Line of sight is usually required)	N/A (Line of sight is usually required)

Directivity category	Accessibility category	$EIRP_{th}$ (W)	
		General public	**Occupational**
	3 (determined by: $h'<h-d\cdot\sin(\alpha+1.129\theta_{bw})$)	Lesser of: $10\pi\cdot(h-2)^2/A_{sl}$ or $10\pi\cdot\{[d^2+(h-h')^2]/d\}^2$	Lesser of: $50\pi\cdot(h-2)^2/A_{sl}$ or $50\pi\cdot\{[d^2+(h-h')^2]/d\}^2$
	4	Lesser of: $10\pi\cdot(h-2)^2/A_{sl}$ or $10\pi\cdot\{[a^2+(h-2)^2]/a\}^2/A_{sl}$	Lesser of: $50\pi\cdot(h-2)^2/A_{sl}$ or $50\pi\cdot\{[a^2+(h-2)^2]/a\}^2/A_{sl}$

NOTES:

1. f is as indicated in the frequency range column
2. All angles should be expressed in radians
3. A_{sl} should be expressed as a numerical factor. However, usually, t is given in db with respect to the maximum . To convert: $A_{sl} = 10^{A_{sl}[db]/10}$

B.2.4 The exclusion area

This clause describes the exclusion areas for accessibility category 4. The exclusion area depends on the horizontal pattern of the antenna. The relevant parameter is the horizontal coverage of the antenna. Table B.6 presents the exclusion areas for a few typical values of the horizontal coverage of omni-directional, sectional or narrow-beam antennas.

Table B.6/K.EMF — Exclusion area as function of horizontal coverage

Horizontal coverage	Exclusion area
Omni-directional	Circular area (Figure B.6)
120°	Rectangular area (Figure B.7) b=0.866a
90°	Rectangular area (Figure B.7) b=0.707a
60°	Rectangular area (Figure B.7) b=0.5a
30°	Rectangular area (Figure B.7) b=0.259a
Less than 5°	Rectangular area (Figure B.7) b=0.09a

APPENDIX I

ICNIRP Limits

This Appendix presents a synopsis of the limits from the Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic field (up to 300 GHz) [1] published by International Commission on Non-Ionizing Radiation Protection (ICNIRP). The document presents basic limits (SAR and current density) and reference levels for the fields.

I.1 Basic limits

Table I.1 shows the basic limits.

Table I.1/K.EMF – ICNIRP basic 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 1Hz	40			
	1 – 4Hz	40/*f*			
	4Hz – 1kHz	10			
	1 – 100kHz	*f*/100			
	100kHz – 10MHz	*f*/100	0.4	10	20
	10MHz – 10GHz		0.4	10	20
General public	Up to 1Hz	8			
	1 – 4Hz	8/*f*			
	4Hz – 1kHz	2			
	1 – 100kHz	*f*/500			
	100kHz – 10MHz	*f*/500	0.08	2	4
	10MHz – 10GHz		0.08	2	4

Notes:

1. *f* is the frequency in Hertz
2. Because of electrical inhomogeneity of the body, current densities should be averaged over cross-section of 1 cm^2 perpendicular to the current direction.
3. All SAR values are to be averaged over any 6-minute period.
4. The localized SAR averaging mass is any 10g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.

I.2 Reference levels

Table I.2 shows the reference limits.

Table I.2/K.EMF – ICNIRP reference limits (unperturbed rms values)

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	—	2×10^5	—
	1-8 Hz	20000	$2\times10^5/f^2$	—
	8-25 Hz	20000	$2\times10^4/f$	—
	0.025-0.82kHz	$500/f$	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
General public	Up to 1 Hz	—	2×10^4	—
	1-8 Hz	10000	$2\times10^4/f^2$	—
	8-25 Hz	10000	$5000/f$	—
	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

NOTES:

4. *f* is as indicated in the frequency range column
5. For frequencies between 100 kHz and 10 GHz, the averaging time is 6 minutes.
6. For frequencies up to 100 kHz, the peak values can be obtained by multiplying the rms value by √2(≈1.414). For pulses of duration t_p, the equivalent frequency to apply should be calculated as $f=1/(2t_p)$.
7. 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 the 1000 times the S_{eq} limit, or that the field strength does not exceed the field strength exposure levels given in the Table.
8. For frequencies exceeding 10 GHz, the averaging time is $68/f^{1.05}$ minutes (*f* in GHz).

The figures below show the reference fields.

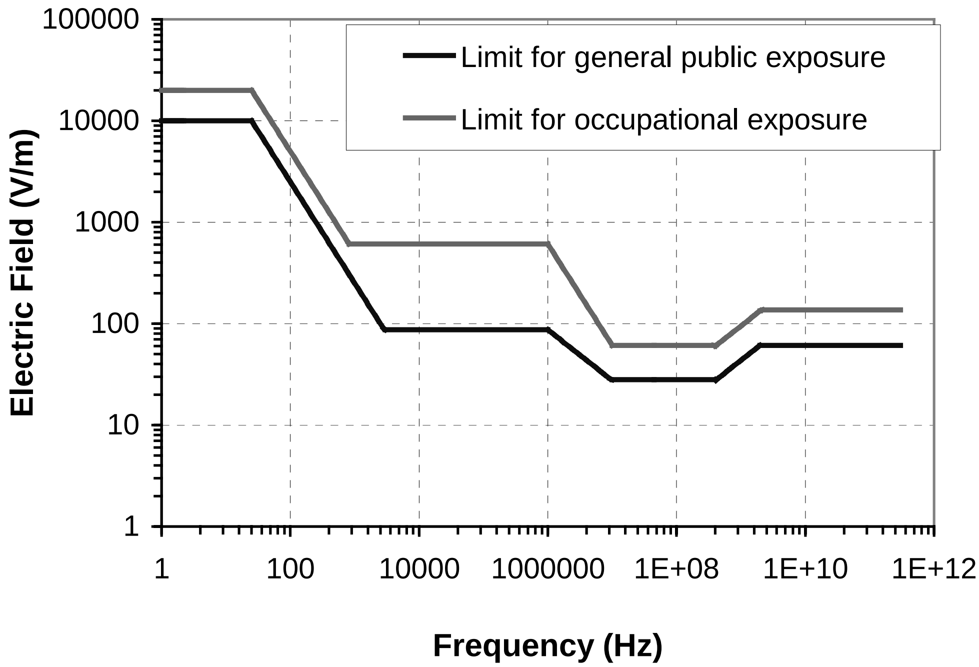


Figure II.10/K.EMF – ICNIRP reference limits for electric field strength

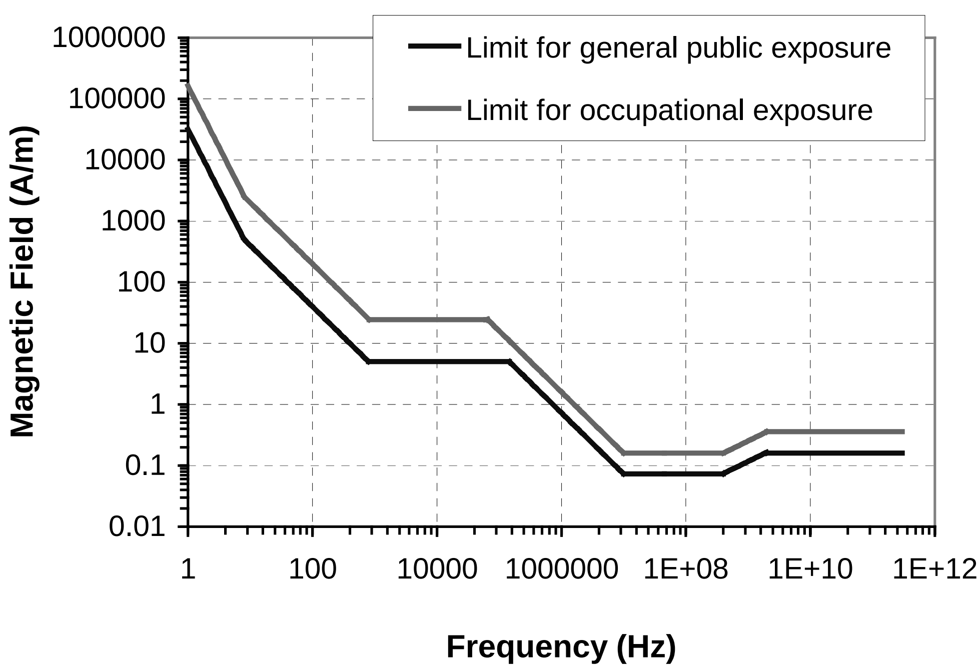


Figure II.11/K.EMF – ICNIRP reference limits for magnetic field strength

I.3 Simultaneous exposure to multiple sources

For simultaneous exposure to fields at different frequencies, the limits are specified in equations below.

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

$$\sum_{j=1\text{Hz}}^{1\text{MHz}} \frac{H_j}{H_{l,j}} + \sum_{j>1\text{MHz}}^{10\text{MHz}} \frac{H_j}{b} \le 1$$

where

E_i is the electric field strength at frequency *i*, and

$E_{l,I}$ is the reference limit at frequency *i*,

H_i is the magnetic field strength at frequency *j*,

$H_{l,I}$ is the reference limit at frequency *j*,

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

b = 24.4 A/m for occupational exposure and 0.73 for general public exposure

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

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

where

E_i is the electric field strength at frequency *i*, and

$E_{l,I}$ is the reference limit at frequency *i*,

H_i is the magnetic field strength at frequency *j*,

$H_{l,I}$ is 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, and

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

APPENDIX II

Example of simple evaluation of EMF exposure

This appendix presents an example of using a simple prediction method to evaluate EMF exposure.

II.1 Exposure at the ground level

The geometry for calculating exposure at the ground level due to an elevated antenna is shown in.

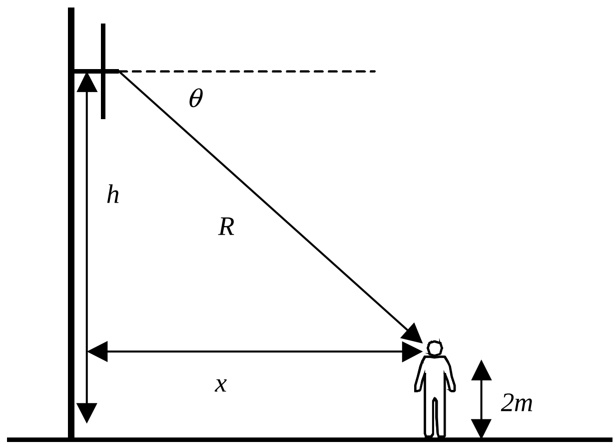


Figure II.12/K.EMF – Sample configuration for calculating exposure at ground level

An antenna is installed so the center of radiation is at the height *h* above the ground. The goal of the calculation is to evaluate the power density at a point 2m above the ground (approximate head level) a distance *x* from the tower. In this example the main beam is parallel to the ground and the antenna gain is axially symmetrical (omni-directional).

To simplify the foregoing, define *h*‘=*h*–2. Using trigonometry,

$$R^2 = h'^2 + x^2,$$

$$\vartheta = \tan^{-1}\left(\frac{h'}{x}\right).$$

Taking into account reflections from the ground, the power density becomes:

$$S = \frac{2.56}{4\pi} F(\theta) \frac{EIRP}{x^2 + h'^2}$$

For example, if the antenna is a half-wave dipole, the relative numeric gain is of the form of

$$F(\theta,\phi) = \left[\frac{\cos\left(\frac{\pi}{2}\sin\theta\right)}{\cos\theta}\right]^2$$

Then for a source with EIRP of 1000W, the exposure power as a function of *x* is shown in Figure Figure II.13 for three different heights.

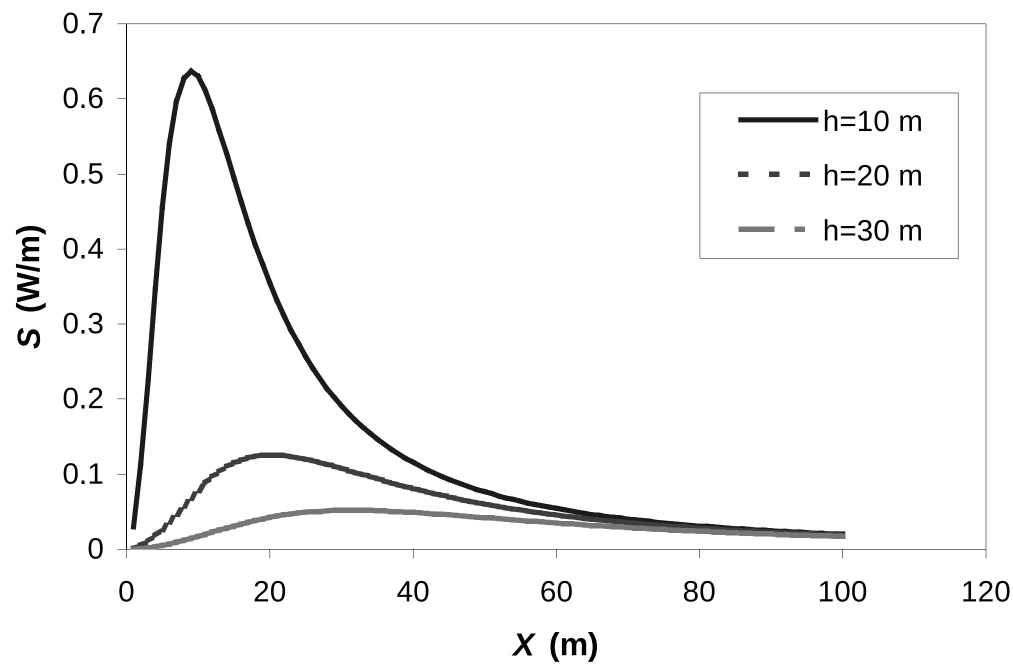


Figure II.13/K.EMF – Power density at the ground level vs. distance from the tower calculated for the example

II.2 Exposure at an adjacent building

The geometry for calculating exposure at a building adjacent to an antenna tower is shown i

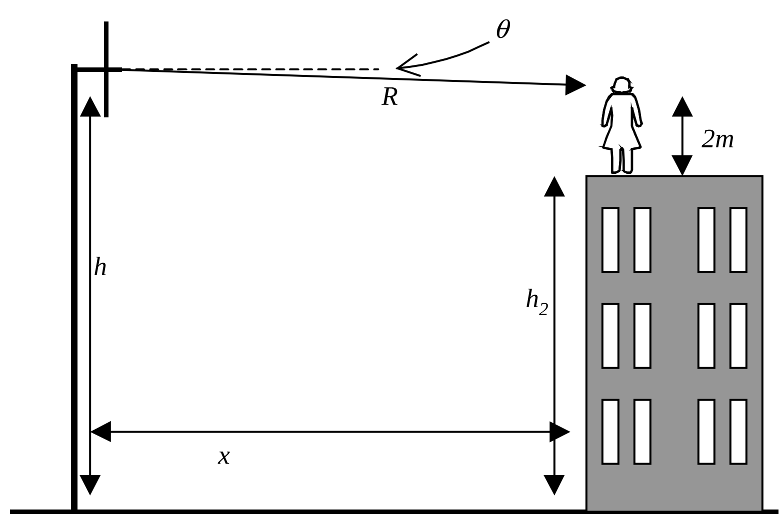


Figure II.14/K.EMF – Sample configuration for calculating exposure at an adjacent building.

An antenna is installed so the center of radiation is at the height *h* above the ground. The goal of the calculation is to evaluate the power density at a point 2m above the roof level (approximate head level) of an adjacent building. The building has a height h_2 and is located a distance *x* from the tower. The most severe exposure is expected at the edge of the roof closest to the antenna. It is assumed that the main beam is parallel to the ground and that the antenna gain is axially symmetrical (omni-directional).

Again, to simplify the foregoing, define $h' = h - h_2 - 2$. Using trigonometry,

$$R^2 = h'^2 + x^2,$$

$$\theta = \tan^{-1}\left(\frac{h'}{x}\right).$$

In this situation, the reflections from the ground may be neglected since the reflected wave is lt is likely to be attenuated by the building, so the power density becomes

$$S = \frac{F(\theta)}{4\pi}\frac{EIRP}{x^2 + h'^2}$$

For example, if the antenna is a half-wave dipole, the relative numeric gain is of the form of

$$F(\theta,\phi) = \left[\frac{\cos\left(\frac{\pi}{2}\sin\theta\right)}{\cos\theta}\right]^2$$

Then for a source with EIRP of 1000W, the exposure power as a function of x is shown in Figure II.15 for three different relative heights (h-h_2).

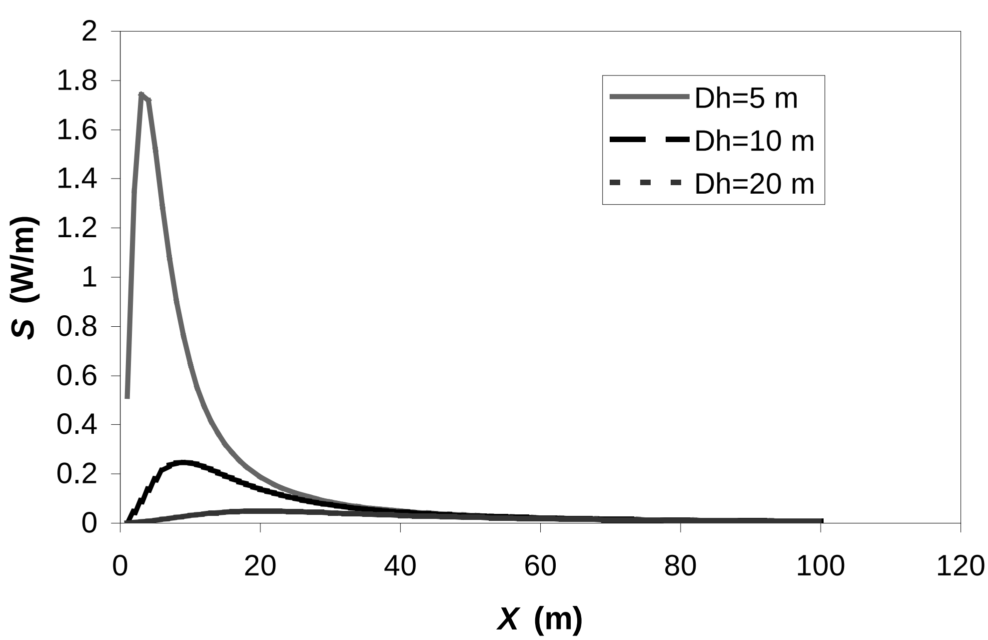


Figure II.15/K.EMF

APPENDIX III

Rationale for the $EIRP_{th}$ values of Table B.3

This appendix presents the rationale for $EIRP_{th}$ values in Table B.3. The rationale is based on calculations using far field expressions for all cases. Therefore the frequency range where this rationale applies is restricted to above 100MHz.

III.1 Inherently compliant sources

The criterion for the inherently compliant source is EIRP of 2W or less. This EIRP corresponds to power density of 0.16 E/m^2 at a distance of 1m, while the lowest ICNIRP power density limit for general public is 2 W/m^2.

The criteria for the normally compliant installations are derived by considering the exposure at ground level and at adjacent buildings or structures. A basic procedure for performing the calculation using the simplified (conservative) approach was shown in Appendix I. The two determining factors are the antenna pattern and the accessibility conditions. For the derivation of the classification criteria, the following additional conservative assumptions are made:

- For ground level exposure, a reflection coefficient of 1 is assumed.
- All exposure is assumed to occur along the maximum of the antenna pattern in the horizontal plane.

The following clauses show the derivation for the different antenna directivity categories

III.1.1 Directivity category 1

The antenna gain function is approximated by the relative numeric gain of an infinitesimal dipole .

$$F(\theta,\phi) = \left[\frac{\cos\left(\frac{\pi}{2}\sin\theta\right)}{\cos\theta} \right]^2 \approx \cos^2\theta$$

The infinitesimal dipole has the broadest vertical gain function for an omni-directional source. Thus, this represents the most severe exposure condition at the ground level with main beam axis parallel to ground or higher.

Using this gain, the exposure power can be obtained analytically as a function of *x*, as

$$S(x) = \frac{EIRP}{4\pi}\left[\frac{x}{x^2 + h_d^{\ 2}} + \frac{x}{x^2 + h_s^{\ 2}} \right]^2,$$

where h_d is the difference between the height of the phase center of the antenna, h, and the height of the observation point, and h_s is the sum of the quantities. The height of the observation point is 2m for ground-level exposure and h' for exposure at adjacent structures. The calculation of maximum exposure is complicated, but a conservative estimate can be obtained by letting h_s=h_d. This approximation should be reasonably accurate near the surface, but produces a significant overestimate at points significantly above the surface. With this approximation, the maximum exposure occurs at x=h_d and is equal to

$$S_{\max}(h) = \frac{1}{4\pi}\frac{EIRP}{h_d^{\,2}}$$

For a given limit values of the equivalent plane wave power density and a given antenna height, it is possible to calculate the maximum value of EIRP that should provide compliance as

$$EIRP_{\max} = 4\pi h_d^{\,2} S_{eq}\,.$$

III.1.2 Directivity category 2

In this case the putative antenna pattern consists of two components, the main beam and the constant amplitude side-lobe envelope. The antenna pattern can be expressed as

$$F(\theta) = \begin{cases} \left[\dfrac{\sin(c\sin(\theta-\alpha))}{c\sin(\theta-\alpha)}\right]^2 & \text{Main beam} \\ A_{sl} & \text{side lobe envelope} \end{cases}$$

The parameter c determines the half-power beam width as follows:

$$c = \frac{1.392}{\sin(\theta_{bw}/2)}$$

The crossover from the main beam to the side-lobe region is difficult to evaluate analytically, however, it may be approximated as the first null of the main beam function. The first nulls occur at

$$\theta_{n1,n2} = \alpha \pm \sin^{-1}\left(\frac{\pi}{c}\right) = \alpha \pm \sin^{-1}\left(\frac{\pi}{1.292}\sin(\frac{\theta_{bw}}{2})\right) \approx \alpha \pm 2.257(\frac{\theta_{bw}}{2})$$

Outside of the main beam, the exposure is calculated using the constant envelope, so that the maximum exposure occurs directly underneath the antenna. In many cases, this is a conservative assumption as the antenna pattern may have a null at this point. However, without additional pattern information, the most conservative assumption is being used. In addition, to simplify calculations, constant power in the main beam is assumed. The condition for a point (x,y) to be within the beam becomes:

$$h - x\sin\theta_{n1} \le y \le h - x\sin\theta_{n2}$$

III.1.3 Directivity category 3

The main difference between exposure calculation for directivity category 3 compared to directivity category 2 concerns the treatment of the reflected field. Antennas in directivity category 3 are used for point-to-point links, so that it is not necessary to consider reflected waves for exposure in the main beam.

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