**RC-11**

# NIR MEASUREMENTS. Principles and practices of EMF characterization and measurements

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**Abstract:** In this short course it is summarized the most important criteria in order to perform non ionizing radiations (NIR) measurements for telecommunication stations. It includes a brief overview of the basic theory to understand electromagnetic fields and non ionizing radiations, propagation zones, exposure zones, installation classification. Then it is developed the theory to predict the electromagnetic field near telecommunication stations with special emphasis on base stations for mobile communications . In order to complement it is presented the results of some predictions performed for real base stations and some examples to calculate the exposure quotient for base stations from mobile communications. Finally this short course includes the basic criteria to perform measurements including types of measurements and their advantages and disadvantages, equipment to be used, protocols, assessment of the results against international limits, definition of uncertainty and error of the measurements and the results of the measurements performed in some Latin American countries


## 1. Introduction

The concern about non-ionizing radiation (NIR) and its study started in the 1950's, just after second world war. Since then, it was established a very comprehensive research that continues until now. According to the WHO- EMF-Project database there are more than 3000 studies [1].

Within the frame of the WHO International EMF Project it have been developed a huge research effort in order to conduct the risk assessment of non-ionizing radiation as a basic step to establish policies and actions to enhance levels of people's radio protection.

One important task to the risk assessment is the evaluation of exposure levels coming from diverse sources from NIR. This is why this short course is aimed to give the basic Principles and practices of EMF measurement.

## 2. Standards for limiting exposure to electromagnetic fields

### *2.1. Guidelines of the International Commission for Non- Ionizing Protection (ICNIRP)*

ICNIRP guidelines are the most accepted guidelines for non ionizing radiation. They are endorsed by the World Health Organization (WHO), for the International Union for Telecommunications (ITU) and for more than 30 countries all over the world including administrations of health, telecommunications, environment and others.

These guidelines are given as a function of basic restrictions and reference levels and are a two- tiers system consisting of general public and occupational exposure limits.

The basic restrictions are physical parameters which are necessary to accomplish to assure that there will not be any adverse health effect, but they are difficult to measure in the field. This is why basic restrictions have to be related to the reference levels which are easy to measure at field. These reference levels are obtained from the basic restrictions by using computational models and measurement methods.

(a) Reference levels

TABLE I. ICNIRP reference levels for occupational exposure (unperturbed rms values) [2]

| Frequency range | E- field strength ($Vm^{-1}$) | H- field strength ($Am^{-1}$) | B- field ($\mu T$) | Equivalent plane wave power density $S_{eq}$ ($Wm^{-2}$) |
|---|---|---|---|---|
| Hasta 1 Hz | - | $1.63 \times 10^5$ | $2 \times 10^5$ | - |
| 1 - 8 Hz | 20 000 | $1.63 \times 10^5 / f^2$ | $2 \times 10^5 / f^2$ | - |
| 8 - 25 Hz | 20 000 | $2 \times 10^4 / f$ | $2.5 \times 10^4 / f$ | - |
| 0.025 - 0.82 kHz | $500 / f$ | $20 / f$ | $25 / f$ | - |
| 0.82 - 65 kHz | 610 | 24.4 | 30.7 | - |
| 0.065 - 1 MHz | 610 | $1.6 / f$ | $2 / f$ | - |
| 1 - 10 MHz | $610 / f$ | $1.6 / f$ | $2 / f$ | - |
| 10 - 400 MHz | 61 | 0.16 | 0.2 | 10 |
| 400 - 2000 MHz | $3 f^{0.5}$ | $0.008 f^{0.5}$ | $0.01 f^{0.5}$ | $f / 40$ |
| 2 - 300 GHz | 137 | 0.36 | 0.45 | 50 |

TABLE II. ICNIRP reference levels for general public exposure (unperturbed rms values) [2]

| Frequency range | E- field strength ($Vm^{-1}$) | H- field strength ($Am^{-1}$) | B- field ($\mu T$) | Equivalent plane wave power density $S_{eq}$ ($Wm^{-2}$) |
|---|---|---|---|---|
| Hasta 1 Hz | - | $3.2 \times 10^4$ | $4 \times 10^4$ | - |
| 1 - 8 Hz | 10 000 | $3.2 \times 10^4 / f^2$ | $4 \times 10^4 / f^2$ | - |
| 8 - 25 Hz | 10 000 | $4000 / f$ | $5000 / f$ | - |
| 0.025 - 0. 8 kHz | $250 / f$ | $4 / f$ | $5 / f$ | - |
| 0.8 - 3 kHz | $250 / f$ | 5 | 6.25 | - |
| 3 - 150 kHz | 87 | 5 | 6.25 | - |
| 0.15- 1 MHz | 87 | $0.73 / f$ | $0.92 / f$ | - |
| 1 - 10 MHz | $87 / f^{0.5}$ | $0.73 / f$ | $0.92 / f$ | - |
| 10 - 400 MHz | 28 | 0.073 | 0.092 | 2 |
| 400 - 2000 MHz | $1.375 f^{0.5}$ | $0.0037 f^{0.5}$ | $0.0046 f^{0.5}$ | $f / 200$ |
| 2 - 300 GHz | 61 | 0.16 | 0.20 | 10 |

* Note

1. $f$ as indicated in the frequency range column.
2. Provided that the basic restrictions are met and adverse indirect effect can be excluded field strength can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, $S_{eq}$, $E^2$, $H^2$ y $B^2$ are to be averaged over any 6- min period.
4. For peak values at frequencies up to 100 kHz see Table …, note 3
5. For peak values at frequencies exceeding see Figs 1 and 2. Between 100 kHz and 10 MHz peak values for the fields strength are obtained by interpolation from the 1.5- fold peak at 100 kHz to the 32- fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density as averaged over the pulse width,does not exceed 1000 times the $S_{eq}$ restrictions or that the field strength does not exceed 32 times the field strength given in the table.
6. For frequencies between 100 kHz and 10 GHz, $S_{eq}$, $E^2$, $H^2$ y $B^2$ are to be averaged over any $68/ f^{1.05}$ -min period ($f$ in GHz).
7. No E-field values is provided for frequencies < 1 Hz which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.

(b) ICNIRP reference levels for telecommunication services

The reference levels for main telecommunication services and systems are given in the Table III

TABLE III. Reference levels for general public exposure from the main telecommunication services and systems

| Services | Frequency range (MHz) | E- field strength ($Vm^{-1}$) | H- field strength ($Am^{-1}$) | B- field (μT) | Equivalent plane wave power density $S_{eq}$ ($Wm^{-2}$) |
|---|---|---|---|---|---|
| FM broadcast | 88- 108 MHz | 28.0 | 0.073 | 0.092 | 2.0 |
| VHF TV | 54- 88 MHz<br>174- 216 MHz | 28.0 | 0.073 | 0.092 | 2.0 |
| UHF TV | 407- 806 MHz | 29.8 | 0.08 | 0.099 | 2.0 |
| Trunking 800 MHz | 806-869 MHz | 40.0 | 0.10 | 0.13 | 4.3 |
| Mobile Telephony 800 MHz | 824-894MHz | 40.6 | 0.11 | 0.14 | 4.4 |
| Mobile Telephony 900 MHz | 890-960 MHz | 41.0 | 0.11 | 0.14 | 4.5 |
| PCS 1800 | 1710- 1880 MHz | 56.9 | 0.15 | 0.19 | 8.6 |
| PCS 1900 | 1850- 1900 MHz | 60.5 | 0.16 | 0.20 | 9.7 |

### *2.2. Standard of the Institute for Electrical and Electronics Engineers (IEEE) - 3 kHz to 300 GHz*

The IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz are aimed to protect people against established adverse health effects in human beings linked to electric, magnetic and electromagnetic fields in the frequency range of 3 kHz to 300 GHz. These recommendations are expressed in terms of basic restrictions (BRs) and maximum permissible exposure (MPE) values.

These recommendations are expressed in terms of basic restrictions (BRs) and maximum permissible exposure (MPE) values and they are a system of two tiers consisting of action- level and controlled-environment exposure limits.

The basic restrictions are exposure restrictions to electromagnetic fields based on the established health effects and the maximum permissible exposure values (MPEs) are derived from the BRs and are limits on external fields and induced and contact current. These recommendations are not intended for the purpose of preventing interference with medical and other devices that may exhibit susceptibility to radiofrequency (RF) fields.

The basic restrictions and maximum permissible exposure values incorporate safety factors that take into account uncertainties and that provide a margin of safety for all. Generally the safety factors incorporated in the MPEs are greater than the safety factors in the BRs, so it is possible to exceed an MPE while still complying with the BRs.

(a) Maximum permissible exposure levels

TABLE IV. Maximum permissible exposures for people in controlled environments [3]

| Frequency range (MHz) | RMS electric field strenght [E][a] (V/m) | RMS magnetic field strenght [H][a] (A/m) | RMS power density (S) E field, H- field ($W/m^2$) | Averaging time $[E]^2$, $[H]^2$ o S (min) |
|---|---|---|---|---|
| 0.1 – 1.0 | 1842 | 16.3 / $f_M$ | (9000, 100000 / $f_M$ $^2$)[b] | 6 |
| 1.0 – 30 | 1842 / $f_M$ | 16.3 / $f_M$ | (9000 / $f_M$ 2, 100000 / $f_M$ $^2$) | 6 |
| 30 – 100 | 61.4 | 16.3 / $f_M$ | (10, 100000 / $f_M$ $^2$) | 6 |
| 100 – 300 | 61.4 | 0.163 | 10 | 6 |
| 300 – 3000 | - | - | $f_{M / 20}$ | 6 |
| 3000 – 30000 | - | - | 100 | 19.63 /$f_G^{1.079}$ |
| 30000- 300000 | - | - | 100 | 2.524 /$f_G^{0.476}$ |

NOTE: $f_M$ is the frequency in MHz, $f_G$ is the frequency in GHz

[a]For exposures that are uniform over the dimensions of the body, such as certain far-field-plane-wave exposures, teh exposures filed strengths and power densities are compared with MPE in the Table. For non- uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area), or a smaller area depending on the frequency, area compared with MPEs

[b]These plane- wave equivalent power density values are commonly used as a convenient comparison with MPE at higher frequencies and are displayed on some instruments.

TABLE V. Action level (maximum permissible exposure for the general public when an RF safety program is unavailable) [3]

| Frequency range (MHz) | RMS electric field strenght [E][a] (V/m) | RMS magnetic field strenght [H][a] (A/m) | RMS power density (S) E field, H- field ($W/m^2$) | Averaging time $[E]^2$, $[H]^2$ o S (min) | |
|---|---|---|---|---|---|
| 0.1 – 1.34 | 614 | 16.3 /$f_M$ | (1000, 100000 / $f_M$ $^2$)[c] | 6 | 6 |
| 1.34 – 3 | 823.8 / $f_M$ | 16.3 /$f_M$ | (1800/$f_M$ $^2$, 100000 / $f_M$ $^2$) | $f_M$ $^2$ / 0.3 | 6 |
| 3 – 30 | 823.8 / $f_M$ | 16.3/$f_M$ | (1800/$f_M$ $^2$, 100000 / $f_M$ $^2$) | $f_M$ $^2$ / 0.3 | 6 |
| 30 – 100 | 27.5 | 158.3/ $f_M^{1.668}$ | (2, 9 400 000 / $f_M$ $^{3.336}$) | 30 | 6 |
| 100 – 400 | 27.5 | 0.0729 | 2 | 30 | 6 |
| 400 – 2000 | - | - | $f_{M /}$ 200 | 30 | |
| 2000 – 5000 | - | - | 10 | 30 | |
| 5000 – 30 000 | | | 10 | 150 /$f_G$ | |
| 30 000- 100 000 | - | - | 10 | 25.24 /$f_G^{0.476}$ | |
| 100 000- 300 000 | - | - | (90 $f_G$ – 7000)/200 | 5048 / [ (9$f_G$ – 700) $f_G^{0.476}$] | |

NOTE: $f_M$ is the frequency in MHz, $f_G$ is the frequency in GHz

[a]For exposures that are uniform over the dimensions of the body, such as certain far-field-plane-wave exposures, teh exposures filed strengths and power densities are compared with MPE in the Table. For non- uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area), or a smaller area depending on the frequency, area compared with MPEs in the Table

[b]The left column is the averaging time for $[E]^2$, the right column is the averaging time for $[H]^2$. For frequencies greater than 400 MHz, the averaging time is for power density

[c]These plane- wave equivalent power density values are commonly used as a convenient comparison with MPE at higher frequencies and are displayed on some instruments.

The maximum IEEE action levels for main telecommunication services and systems are given in the Table VI

TABLE VI. Maximum permissible exposure action levels from the main telecommunication services and systems

| Service | Frequency range (MHz) | $E_{rms}$ (V/m) | $H_{rms}$ (A/m) | $S_{rms}$ E field, H-field | | Averaging time $[E]^2$, $[H]^2$ o S (min) | |
|---|---|---|---|---|---|---|---|
| VHF TV | 54-88 | 27.50 | 0.13 | 2.00 | 6.27 | 30 | 6 |
| FM broadcast | 88-108 | 27.50 | 0.08 | 2.00 | 2.14 | 30 | 6 |
| VHF TV | 174-216 | 27.50 | 0.07 | 2.00 | 2.00 | 30 | 6 |
| Trunking 800 MHz | 806-869 | - | - | 4.19 | | 30 | |
| Mobile Telephony 800 MHz | 824- 894 | - | - | 4.30 | | 30 | |
| Mobile Telephony 900 MHz | 890-960 | - | - | 4.63 | | 30 | |
| PCS 1800 MHz | 1710-1880 | - | - | 8.98 | | 30 | |
| PCS 1900 MHz | 1850-1900 | - | - | 9.38 | | 30 | |

## 3. Field regions

### *3.1. Reactive near field*

It is region that is immediately surrounding the antenna and where the reactive field predominates. The limit of this region is considered to be at a distance of $\lambda$ from the antenna. The attenuation of electric field and magnetic field is an inverse function of the square and cube of distance respectively: For mobile telephony systems the reactive near field limits is very limited (some dozens of cm). The evaluation of these fields are only important for occupational exposure [4,5,6,7,8,9,11,12].

### *3.2. Reactive-radiating near field*

This region is a transition zone wherein radiating field gets an increasing importance compared with the reactive one. The limit of this region is considered to be at 3 $\lambda$ from the antenna.[4,5,6,7,8,9,11,12].

### *3.3. Radiating near field*

This region only exists if the maximum dimension L of the antenna is large compared with $\lambda$. In this region the radiating field predominates. The field is not considered to propagate as plane waves but the electric and magnetic components of the field can be considered locally normal and related by the intrinsic impedance of the medium $Z_0$. The limit of this region is considered to be $R_{ff} = 2L^2 / \lambda$ [4,5,6,7,8,9,11,12].

Where:
R is the distance between the evaluation location and the antenna
L is the greatest linear dimension of the radiating part of the antenna
$\lambda$ is the wavelength of the electromagnetic field transmitted

### *3.4. Far field* (*Franhoufer region*)

According to the theory of electromagnetic fields the limit between near field and far field is located at

$$R_{ff} \geq \frac{2L^2}{\lambda}$$

The field is considered to propagate as plane waves and the electric and magnetic components of the field are perpendicular and related by the intrinsic impedance of the medium $Z_0$ =377 [4,5,6,7,8,9,11,12]

The boundary curve between the far field and radiating near field is given by [11,12].

$$R_{ff}(\alpha) = \frac{2L^2 \cos^2 \alpha}{\lambda}$$

where:
α: angle between the horizontal axis and the propagation direction
$R_{ff}(\alpha)$: Franhoufer distance in the direction forming an angle α with the horizontal axis

In Table VII it is summarized the main features of the field regions, in Table VIII. it is shown the far field distance for mobile services and in Fig. 1. it is presented a scheme of fields regions

TABLE VII. Main features of electromagnetic fields depending on field region

| | **Distance range** | **Power density** | **Relation between E and H** | |
|---|---|---|---|---|
| **Reactive near- field** | 0- λ | S < EH | Not normal | $E/H \neq Z_0$ |
| **Reactive- radiating near-field** | 0- 3 λ | S < EH | Not normal | $E/H \neq Z_0$ |
| **Radiating near-field** | 3 λ- 2L$^2$/ λ | S ≈EH | Locally | $E/H \approx Z_0$ |
| **Radiating far-field** | 2L$^2$/ λ- ∞ | S = EH | Normal | $E/H = Z_0$ |

TABLE VIII. Far field inner limit for mobile telecommunication services

| **Fabricante** | **Model** | **Frequency range (MHz)** | **fc (MHz)** | **L(m)** | $R_{ff} \geq \frac{2L^2}{\lambda}$ (m) |
|---|---|---|---|---|---|
| Allgon | 7273.03 | 806 - 896 | 851 | 2.580 | 37.76 |
| Decibel | DB848H90E-XY | 806 - 896 | 851 | 2.438 | 33.72 |
| Kathrein | 739 495 | 1710 - 1990 | 1850 | 1.302 | 20.91 |

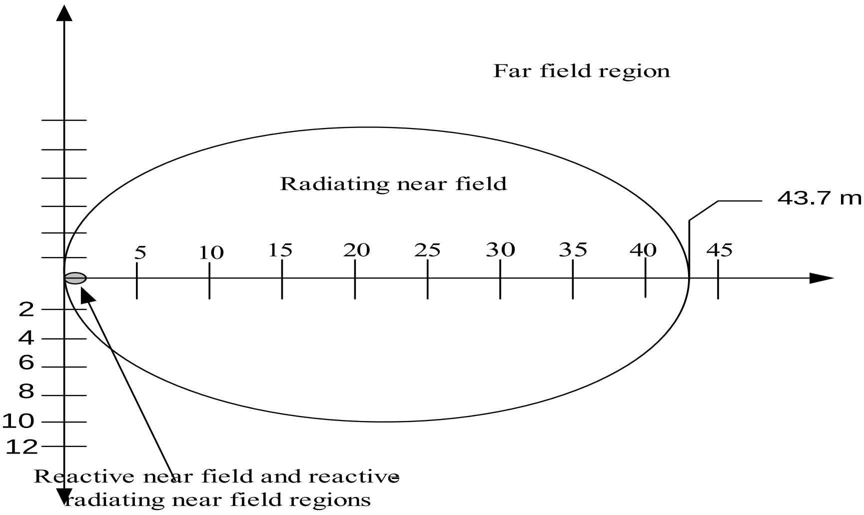


*FIG. 1. Cross-sectional view of field regions for an antenna of 2.7 m high working at 900 MHz band.*

It is important to point out some remarks about the field regions [10,11]

(a) The boundaries of the regions only depend on antenna dimensions and wavelength, they do not depend on any case on the emitted power.
(b) In the reactive near field and reactive –radiating near field regions are not applicable the formulas for far field, but it does not necessarily imply that the field strengths levels are important.
(c) The electric and magnetic fields for the reactive near field and reactive –radiating near field regions could be calculated with relatively complex methods and they can be measured with an spectrum analyzer and the appropriate antennas for every component.

## 4. Exposure assessment of electromagnetic fields (EMF)

### *4.1. Purpose*

The assessment of exposure to EMF has the main objective to provide information in order to implement a plan for protecting people from exposure levels above recommended international or national standards.
The assessment of exposure could be done by calculation or by measurements but normally both evaluations are performed being the calculation the first step before measurements.

### *4.2. Exposure zones*

According to the International Telecommunication Union (ITU) [4,5], it should be performed a exposure for all locations where people might be exposed to EMF. The purpose of the assessment is to classify potential exposure to EMF as belonging to one of the three following zones:

(a) Compliance zone: In this zone, potential exposure to EMF is below the limits for both controlled/occupational exposure and uncontrolled/general public exposure at the operation frequencies.
(b) Occupational zone: In this zone, potential exposure to EMF is below the limits for controlled/occupational exposure but exceeds the limits for uncontrolled/general public exposure at the operation frequencies.

(c) Exceedance zone: In this zone, potential exposure to EMF exceeds the limits for both controlled/occupational exposure and uncontrolled/general public exposure at the operation frequencies.

For many installations, the exceedance zone and the occupational zone are not accessible to people, accessible only under special circumstances to worker, such as a person standing directly in front of the antenna. The risk assessment procedure presented in this Recommendation is concerned primarily with exposure of the general public, and workers in the course of their normal activities, as it can be seen in Fig. 2.

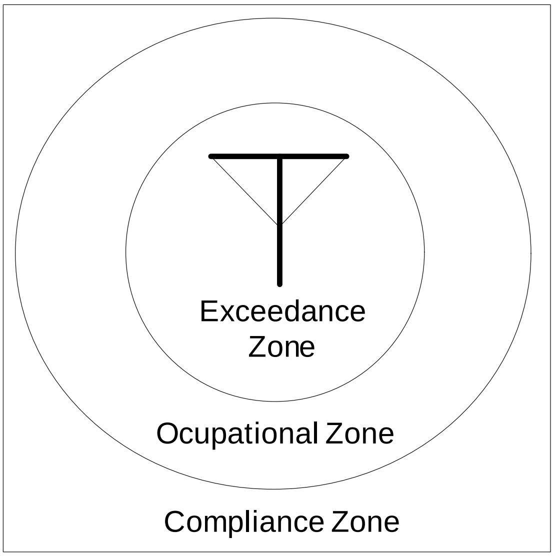


*FIG.2. Exposure zones*

### *4.3. Exposure level assessment procedure*

The assessment of the exposure level shall consider as general criteria: the worst emission conditions and the simultaneous presence of several EMF sources, even at different frequencies [4,5].

The following parameters should be considered:

(a) The maximum EIRP of the antenna system for mean transmitter power.
(b) The antenna gain G including maximum gain and beam width;
(c) The frequencies of operation; and
(d) Various characteristics of the installation, such as the antenna location, antenna height, beam direction, beam tilt.

### *4.4. The installation classification schema:*

Each emitter installation should be classified into the following three classes [4,5]:
(a) Inherently compliant: These are sources that produce fields that comply with exposure limits at the operation frequencies a few centimeters away from the source. It is not necessary special precautions, (EIRP < 2 W).

(b) Normally compliant: These are sources that produce EMF that can exceed exposure limits at the operation frequencies, but for normal installation practices and typical use the exceedance zone of these sources is not normally accessible to people but only to maintenance personnel. ITU states that normally compliant installations include antennas mounted on sufficiently tall towers or narrow-beam and only maintenance personnel who come into the close vicinity of emission antennas need to exercise precaution, (Mobile telephony base stations).

(c) Provisionally compliant: These are installations that require special measures to achieve compliance which involves determination of the exposure zones and measurements, (Broadcasting stations).

### *4.5. Procedure for determining installation class*

In accordance with the telecommunication service or application it is necessary to define [4,5]
(a) A set of reference antenna parameters or antenna types.
(b) A set of accessibility conditions.
(c) For each combination of reference antenna parameters and accessibility condition, it is necessary to calculate or measure the threshold EIRP (EIRPth), which is the value that corresponds to the exposure limit for the installation operation with reference antenna for the accessibility condition.
(d) ITU states that an inherently compliant source for ICNIRP limits has EIRP less than 2 W. In this case there is no need to consider other installation aspects.
(e) According to ITU 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 EIRPi are the temporal averaged radiated power of the antenna, and EIRPth,i is the EIRP threshold to the particular antenna parameters and accessibility conditions for all the operation frequencies of the installation.
(f) 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 measurements will need to be performed.

Annex B of ITU-T Recommendation K.52 presents a set of basic configurations, exposure conditions, parameters and relevant EIRPth values. 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**.**

## 5. Prediction of Exposures from Base Stations

There are several different approaches for calculating the exposure of a person in the vicinity of a transmitting antenna. Guidance for electromagnetic fields predictive calculations in this course is based on the "Guidelines for Limiting Exposure to Time-varying Electric, Magnetic, and Electromagnetic Fields (up to 300GHz)", 1998 [2], the Standard C95.1 "Standard for Safety Levels with Respect to Human Exposure Levels to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz" [3], the Recommendation ITU-T K.52 "Guidance on Complying with Limits for Human

Exposure to Electromagnetic Fields" [4], the Recommendation ITU-T K.61 "Guidance to Measurement and Numerical Prediction of Electromagnetic Fields for Compliance with Human Exposure Limits for Telecommunication Installations" [5], the "Revised ECC Recommendation (02)04 –Measuring Non-Ionizing electromagnetic Radiation (9kHz- 300 GHz)" of the European Conference of Postal and Telecommunications Administration (CEPT) [8] and the IEEE, Std. C95.3 " *IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure"* [10] .

It could be used several methods for theoretical prediction of the exposure to electromagnetic fields from telecommunication transmitters,

### *5.1. Simple Prediction Method to Evaluate Electromagnetic Field Exposure*

The first step to calculate the exposure level is to compute the Maximum Equivalent Isotropically Radiated Power ($EIRP_{max}$) is given in Equation 1.

$$EIRP_{max} = P_{Tx} \; G_{Tx} \, L_{Tx} \qquad \text{(Eq. 1)}$$

$P_{Tx}$ : Transmitter power
$G_{Txm}$ : Maximum Gain of antenna system
$L_{Tx}$ : Losses of antenna system

The EIRP will depend on the $EIRP_{max}$ and the antenna directivity factor F(θ).

Figures 3 and 4 show the parameters used in the calculation of the exposure at the ground level and on adjacent building
.

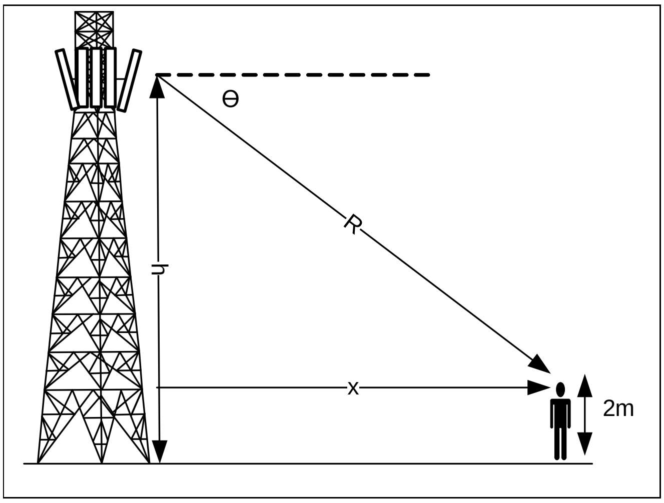


*FIG.3. Exposure at ground level*

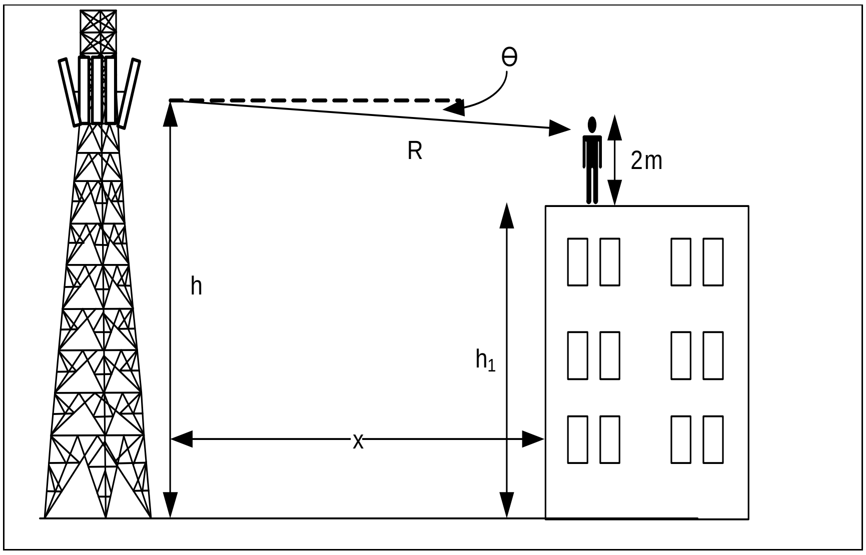


*FIG. 4. Exposure to an adjacent building*

(a) Exposure at ground level

According to ITU-T K.52 Recommendation the radiation centre of the antenna system is assumed to be at a height h and it is evaluated the power density at a point at a height of 2m above ground level at a distance x of the base of the tower. The main bean of the antenna is axially symmetrical and down--.tilted an angle $\phi$. If the main bean is parallel to ground $\phi = 0$.

If h'=h – 2m, then:

$$R^2 = h'^2 + x^2 \ , \quad \theta = \tan^{-1}\left(\frac{h'}{x}\right)$$

and

$$S = \frac{(1+\rho)^2}{4\pi} F(\theta) \frac{EIRP_{max}}{x^2 + h^2} = \frac{2.56}{4\pi} F(\theta - \phi) \frac{EIRP_{max}}{x^2 + h^2} \qquad \text{(Eq. 2)}$$

where ρ is the reflection coefficient.
It is important to point out that the factor 2.56 could be replaced by 4 (that is considering a reflection coefficient equal to 1)

(b) Exposure to an adjacent building

The radiation centre of the antenna system is assumed to be at a height h and it is evaluated the power density at a point at a height of 2m above the roof level of a building of height h1 level and at a distance x of the base of the tower. The main bean of the antenna is axially symmetrical and down tilted an angle $\phi$, so if the main bean is parallel to ground $\phi = 0$
To simplify h' = h – h1 – 2m.

then

$$R^2 = h'^2 + x^2 \quad , \quad \theta = \tan^{-1}\left(\frac{h'}{x}\right) \qquad \text{(Eq. 3)}$$

In this situation it could be neglected the reflected wave because it could be attenuated by the same building, so the reflection coefficient tends to be zero and the resulting power density is as expressed in Equation 4

$$S = \frac{F(\theta - \phi)}{4\pi} \frac{EIRP_{max}}{x^2 + h^2} \qquad \text{(Eq. 4)}$$

(c) Calculation of the exposure quotient

For exposure to radiofrequencies waves composed of only one frequency the exposure quotient is an adimensional quantity and can be expressed as a function of power density or electric field strength, could be calculated using the formula in Equation 5:

$$\text{Exposure Quotient} = \frac{S_{calculated}}{S_{lim}} = \left(\frac{E_{calculated}}{E_{lim}}\right)^2 \qquad \text{(Eq.5)}$$

where:
$S_{calculated}$ : Calculated power density
$S_{lim}$ : ICNIRP power density limit at the frequency of interest

It is important to point out that the formulas that are used for calculating the exposure quotient as a function of electric field strength (E) could be used in a similar way for magnetic field strength.

(d) Calculation of the total exposure quotient

It is used for the evaluation of the exposure to simultaneus diverse sources which generally implies various NIR sources . All of the signals contribute individually to the total exposure of a person and the Total Exposure Quotient is equivalent to the addition of all signals and is expressed by the equations 6 and 7.

$$\text{Total Exposure Quotient} = \frac{S_1^{calculated}}{S_1^{lim}} + \frac{S_2^{calculated}}{S_2^{lim}} + \cdots\cdots + \frac{S_N^{calculated}}{S_N^{lim}} \qquad \text{(Eq 6).}$$

$$\text{Total Exposure Quotient} = \Sigma_{i=1}^{N} \frac{S_i^{calculated}}{S_i^{lim}} \qquad \text{(Eq. 7)}$$

This formula could also be expressed as a function of electric field and it is given in equations 8 and 9.

$$\text{Total Exposure Quotient} = \left(\frac{E_1^{calculated}}{E_1^{lim}}\right)^2 + \left(\frac{E_2^{calculated}}{E_2^{lim}}\right)^2 + \cdots + \left(\frac{E_N^{calculated}}{E_N^{lim}}\right)^2 \qquad \text{(Eq. 8)}$$

$$\text{Total Exposure Quotient} = \Sigma_{i=1}^{N} \left(\frac{E_i^{calculated}}{E_i^{lim}}\right)^2 \qquad \text{(Eq. 9)}$$

Where N is the total number of signals. The Total Exposure Quotient must not exceed to 1 for complying with maximum exposure limit.

In general any point of the space near a base station receives a direct wave and one or more reflected waves, so the resultant field is a vectorial composition of several contributions. As a consequence there are an spatial variability of the electromagnetic field strength. It is obvious that the Simple Prediction Method does not take into account such a phenomenon, althought , the practical experience shows that the results calculated using this method provides the mean value of the field for short distances (some wavelengths).

### *5.2. Results of the prediction*

The Table IX shows an example of the spreadsheet with results of the exposure quotient prediction of in the vicinity of base stations in Lima city.

TABLE IX. Example of spreadsheet with results of EMF prediction

| Mobile Service Base Station | Coordinates | | h (msnm) | Prediction h = 0m Ground level | | |
|---|---|---|---|---|---|---|
| | | | | S ($Wm^{-2}$) | Exposure Quotient | d (m) |
| Alfonso Ugarte | 18279195E | 8661462N | 116 | 0.1371 | 3.098 | 82.3 |
| Bella Unión | 18273918E | 8669108N | 94 | 0.0247 | 0.574 | 38.3 |
| Vivanco | 18282939E | 8657337N | 93 | 0.0183 | 0.415 | 140.8 |

Based on the results of predictive calculations could be obtained some graphics of the exposure quotient variation with distance for every base station and sector. Fig 5. shows an example of this kind of results.

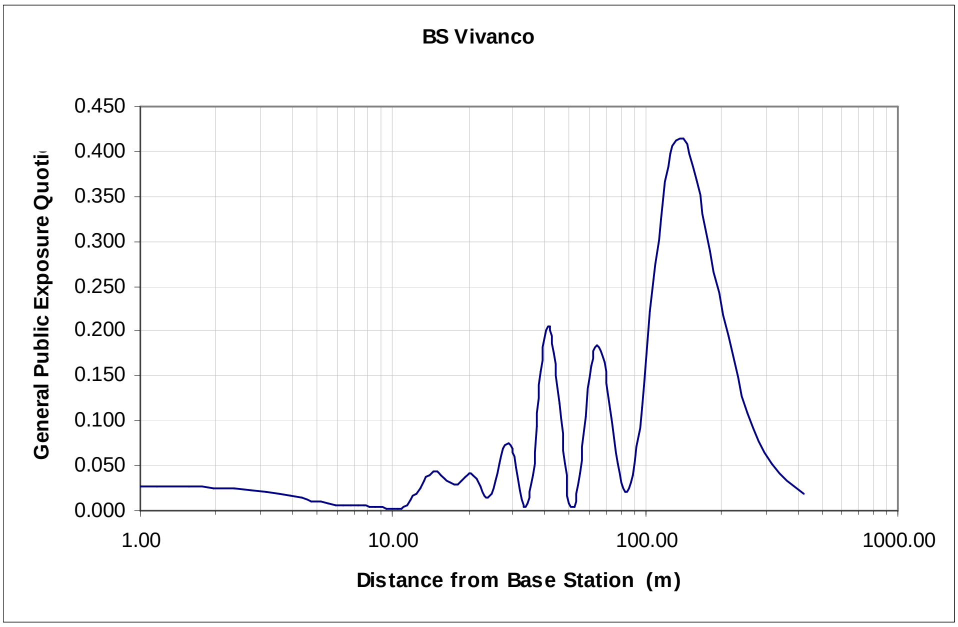


*FIG. 5. Variation of the predicted general public exposure quotient as a function of distance*

### *5.3. Examples of electromagnetic field level predictions in the vicinity of mobile base stations*

**Example 1**. A mobile telephony base station works at the 800 MHz frequency band ($f_C$ = 829.5 MHz) and its sectorial antennas are mounted on the top of a 12 m tower which in turn is located on a 18 m building This base station has a three-sector antenna arrangement, 8 º down tilted and with EIRP of 39 dBm for each sector and the main specifications of antennas are given in Table X and Fig. 6. In figures 7 and 8 are illustrated the exposure situations in the following questions.

(a) Determine the distance to the far field
(b) Determine the distance to the point A at 15 m from the base station and at the ground level in the direction of the main beam of a sector and check if it is in the far field.
(c) Calculate the power density at the point A.
(d) Determine the distance to a point B located in the fourth floor of a building, at a distance of 50m in the main beam direction of a sector.
(e) Calculate the power density at the point B.
(f) Find the ICNIRP maximum exposure limit for general public exposure at the working frequency.
(g) Evaluate the exposure levels at the A and B points against ICNIRP general public limits obtaining the exposure quotients.

TABLE X. Specifications of 800 MHz antenna

| **XPol A-Panel 806-960 30° 18.5 dBi** | |
|---|---|
| **Type N°** | 800 10141 |
| Frequency range | 806 -894 MHz |
| Polarization | +45°, -45° |
| Gain | 21 dBi |
| Half-power beam width | Horizontal 31 ° |
| Copolar +45 °/ -45 ° | Vertical 15° |
| Front-to-back ratio, copolar | > 25 dB |
| Isolation | > 30 dB |
| Impedance | 50 Ω |
| VSWR | < 1.5 |
| IntermodulationIM3 (2 x 43 dBm carrier) | < -150 dBc |
| Max. power per input | 500 W (at 50 ° C ambient temperature) |
| Input | 2 x 7-16 female |
| Connector position | Bottom |
| Weight | 22 kg |
| Wind load (at 150 km/h) | Frontal/Lateral/Rearside 680 N/ 130 N/ 970 N |
| Max. wind velocity | 200 km/h |
| Height/width/depth | 1296 / 560 / 116 mm |

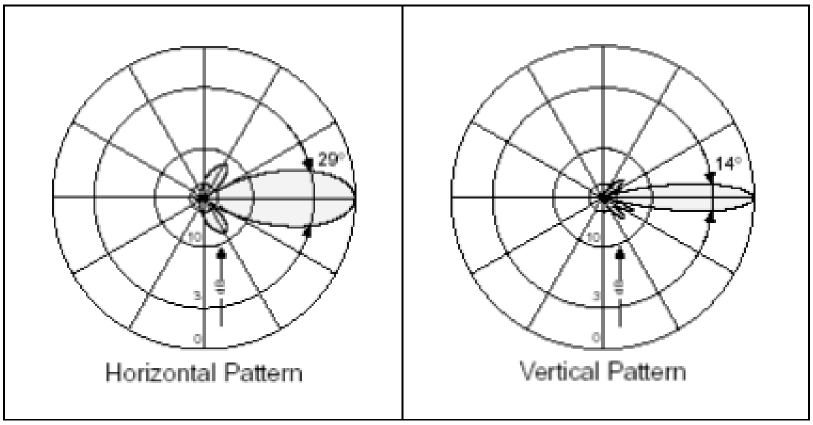


*FIG. 6. Horizontal and vertical patterns for mobile service antenna for 800 MHz band*

*Solution*

(a) According to Recommendation UIT-T K.52 the distance to reach far-field conditions is

$$R_{ff} = \frac{2L^2}{\lambda}$$

$$R_{ff} = \frac{2(1.3)^2}{0.3525} = 9.58 \quad \text{m}$$

(b) The distance R to the point A is

$$R = \sqrt{x^2 + (h-2)^2}$$

$$R = \sqrt{15^2 + (30-2)^2}$$

$$R = \sqrt{15^2 + 28^2}$$

$$R = 31.74 \quad \text{m}$$

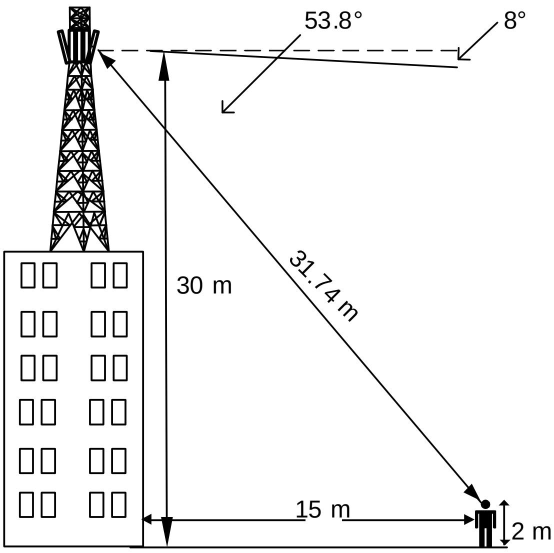


*FIG. 7. Illustration of Example 1 c*

(c) In order to calculate the power density it is used the equation given in Recommendation ITU K.52:

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

where $\rho = 1$ (reflexion factor )
EIRP = 39dBm ≅ 8W

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

$$x = 15 \quad m$$

$$h = 18 + 12 = 30 \quad m$$

$$\theta = \tan^{-1}\left(\frac{30-2}{x}\right) - \beta = \tan^{-1}\left(\frac{28}{15}\right) - 8 = 61.82^o - 8° = 53.82^o$$

$$S = (1+1)^2 \frac{10}{4\pi\left(15^2 + 28^2\right)} F(53.82^o, 0^o)$$

$$F(53.82^o, 0^o) = 0.00147911$$

$$S = (1+1)^2 \frac{10}{4\pi\left(15^2 + 28^2\right)} (0.00147911)$$

$$S = 3.7329 \times 10^{-6} \ (W/m^2)$$

(d) Given that each floor is approximately 3 m height, the fourth floor is at 9m height.

$$R = \sqrt{x^2 + (h - h_2 - 2)^2}$$
$$R = \sqrt{50^2 + (30 - 9 - 2)^2}$$
$$R = \sqrt{50^2 + 19^2}$$
$$R = 53.49 \quad m$$

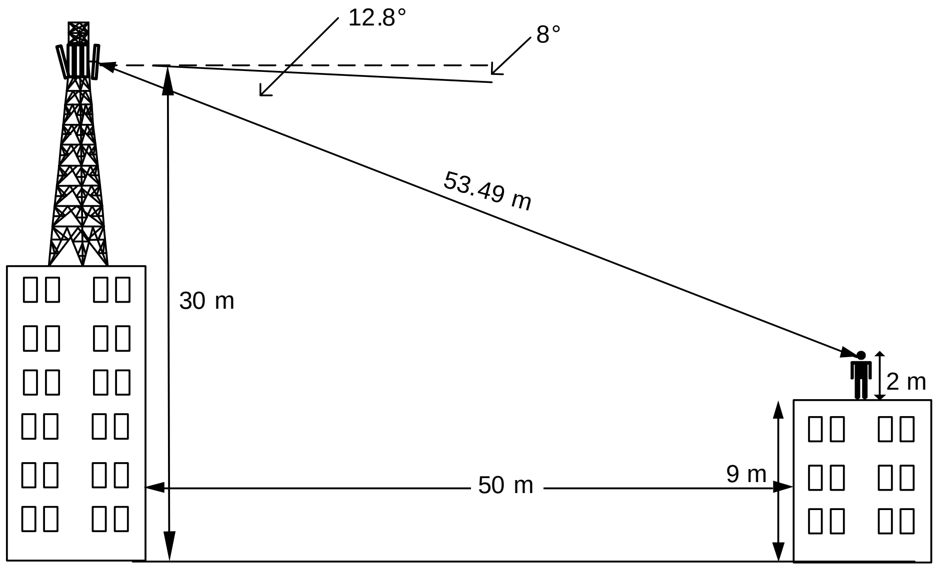


*FIG. 8. Illustration of Example 1 e*

(e) For calculating the power density it is used the formula given in the Recommendation ITU-T K.52

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

Considering $\rho = 1$ (reflexion factor) and EIRP = 39dBm ≈ 8W

$$S_{gl}(R,\theta,\phi) = (1+\rho)^2 \frac{EIRP}{4\pi \left(x^2 + (h - h_2 - 2)^2\right)} F(\theta,\phi)$$

$$\theta = \tan^{-1}\left(\frac{h - h_2 - 2}{x}\right) - \beta = \tan^{-1}\left(\frac{19}{50}\right) - 8 = 20.8^{\circ} – 8^{\circ} = 12.8^{\circ}$$

$$S = (1+1)^2 \frac{8}{4\pi\left(50^2 + 18^2\right)} F(12.8^{\circ}, 0^{\circ})$$

$$S = (2.25 \times 10^{-5}\ W/m^2)$$

(f) ICNIRP has established the following limits for general public exposure. For evaluating this base station it is necessary to use the limit formula for the frequency range 400 - 2000 MHz.

| Frequency range (MHz) | Electric field strength ($Vm^{-1}$) | Magnetic field strength ($Am^{-1}$) | Magnetic flux density (µT) | Power density ($Wm^{-2}$) |
|---|---|---|---|---|
| 400 – 2000 | $1.375f^{0.5}$ | $0.0037f^{0.5}$ | $0.0046f^{0.5}$ | f/200 |

For the 800 MHz mobile telephony frequency band:
The uplink (handset to base station): 824 – 835 MHz
The downlink (base station to handset): 869 – 880 MHz

For this example the band frequency of interest is the one assigned to the downlink..

$$f_C = 829.5 \text{ MHz}$$

$$S_{lim} = f / 200$$

Then

$$S_{lim} = 829.5 / 200$$

$$S_{lim} = 4.1475 \quad W / m^2$$

For the point A:

$$S = 0.00000252 \, (W/m^2)$$

$$\text{Exposure Quotient } (\%) = \frac{S}{S_{lim}} \times 100$$

$$\text{Exposure Quotient } (\%) = \frac{0.00000252}{4.1475} \times 100$$

$$\text{Exposure Quotient } (\%) = 6.08 \times 10^{-7}$$

As it can be observed the power density is below the relevant ICNIRP maximum exposure limit for general public exposure

For the point B:

$$S = 0.0000225 \, (W/m^2)$$

$$\text{Exposure Quotient } (\%) = \frac{S}{S_{lim}} \times 100$$

$$\text{Exposure Quotient } (\%) = \frac{0.0000225}{4.1475} \times 100$$

$$\text{Exposure Quotient } (\%) = 5.42 \times 10^{-6}$$

As it can be seen the power density is below the relevant ICNIRP maximum exposure limit for general public exposure

**Example 2.** A trunking base station works at the A frequency band of 1900 MHz and its sectorial antennas are mounted on the top of a 35 m tower. This base station has a three-sector antenna arrangement, 4 º down tilted and with EIRP of 55 dBm for each sector. In Table XI and in Fig. 9 are shown the main antennas' specifications. In figures 10 and 11 are shown the exposure situations for this example.

(a) Calculate the power density at a point 50 m from the base station at the ground level in the direction of the main beam of a sector.
(b) Calculate the power density at a point located in the fourth floor of a building, at a distance of 30m in the main beam direction of a sector.
(c) Evaluate the power density levels for both cases against general public ICNIRP maximum exposure limit at the working frequency. Obtain the exposure quotients for both cases

TABLE XI Specifications of 1900 MHz antenna

| **XPol F-Panel 1710-1990 65° 18 dBi 6° T** | |
|---|---|
| **Type N°** | 739 496 |
| Frequency range | 1710 -1990 MHz |
| Polarization | +45°, -45° |
| Gain | 21 dBi |
| Half-power beam width<br>Copolar +45 °/ -45 ° | Horizontal 65 °<br>Vertical 7° |
| Electrical tilt | 6 °, fixed |
| Sidelobe suppression for first sidelobe above horizon | ≥ 14 dB |
| Front-to-back ratio, copolar | > 30 dB |
| Isolation, between ports | > 30 dB |
| Impedance | 50 Ω |
| VSWR | < 1.4 (1710 – 1880 MHz)<br>< 1.5 (1800 – 1900 MHz) |
| IntermodulationIM3<br>(2 x 43 dBm carrier) | < -150 dBc |
| Max. power per input | 200 W (at 50 ° C ambient temperature) |
| Input | 2 x 7-16 female |
| Connector position | Bottom |
| Weight | 6 kg |
| Wind load (at 150 km/h) | Frontal/Lateral/Rearside<br>310 N/ 110 N/ 250 N |
| Max. wind velocity | 200 km/h |
| Height/width/depth | 1302 / 155 / 49 mm |

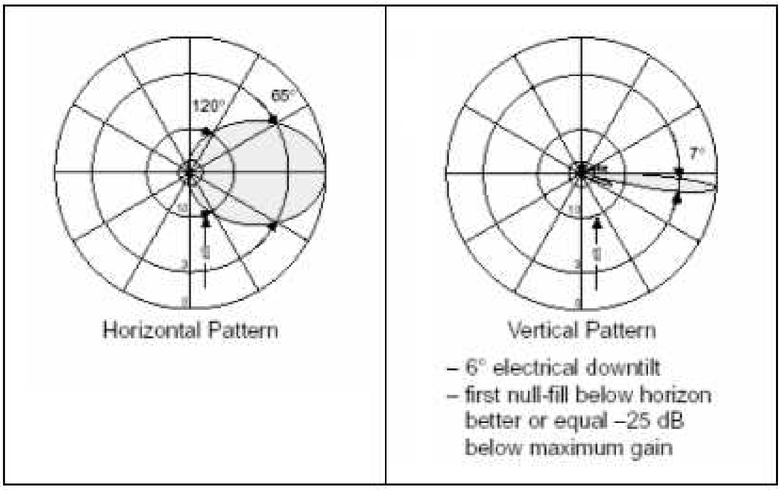


*FIG.9. Horizontal and vertical patterns for mobile service antenna for 1900 MHz band*

*Solution:*

In order to calculate the power density it is used the equation given in Recommendation ITU K.52:

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

where ρ = 1 (reflexion factor )
EIRP = 55 dBm ≈ 316.22 W

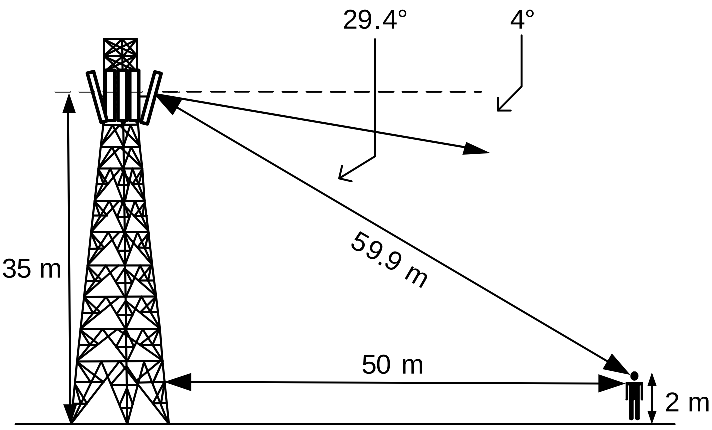


*FIG. 10. . Illustration of Example 1 a*

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

$$x = 50 \quad m$$

$$h = 20 + 15 = 35 \quad m$$

$$\theta = \tan^{-1}\left(\frac{35-2}{x}\right) - \beta = \tan^{-1}\left(\frac{33}{50}\right) - \beta = 33.4^o – 4^o = 29.4^o$$

$$S = (1+1)^2 \frac{316.22}{4\pi\left(50^2 + 33^2\right)} F(29.4^o, 0^o)$$

$$F(29.4^o, 0^o) = 0.02630268$$

$$S = (1+1)^2 \frac{316.22}{4\pi\left(50^2 + 33^2\right)} (0.02630268)$$

$$S = 0.00073768\ (W/m^2)$$

Using Recommendation UIT-T K.52

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

Given that each floor is approximately 3 m heigth the four floor will be at 9m height.
Considering ρ = 1 (reflexion factor) and EIRP = 55 dBm ≈ 316.22 W

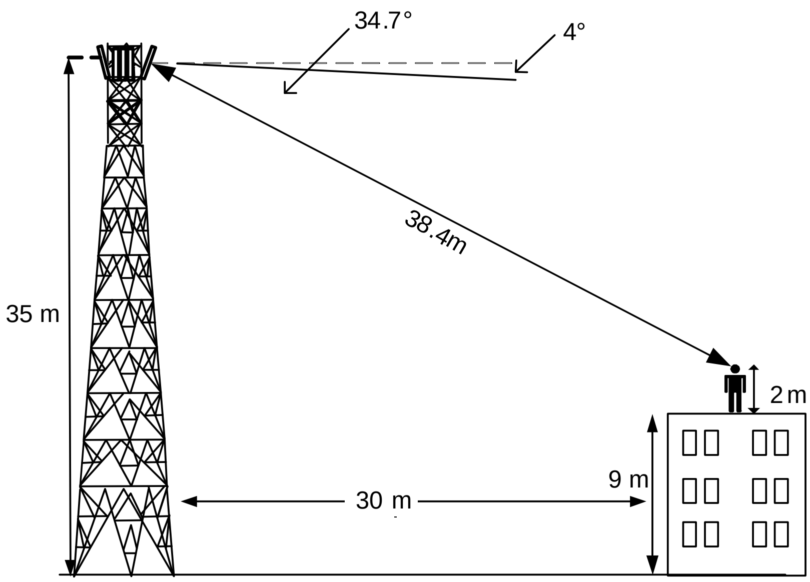


*FIG. 11. Illustration of Example 1 b*

$$S_{gl}(R,\theta,\phi)=(1+\rho)^2\frac{EIRP}{4\pi\left(x^2+(h-h_2-2)^2\right)}F(\theta,\phi)$$

$$x=30 \quad m$$

$$h=20+15=35 \quad m$$

$$h_2=9 \quad m$$

$$\theta=\tan^{-1}\left(\frac{h-h_2-2}{x}\right)-\beta=\tan^{-1}\left(\frac{24}{30}\right)-\beta=38.66^o-4^o=34.66^o$$

$$S=(1+1)^2\frac{316.22}{4\pi\left(30^2+24^2\right)}F(34.66^o,0^o)$$

$$F(34.66^o,0^o)=0.01995262$$

$$S=(1+1)^2\frac{316.22}{4\pi\left(30^2+24^2\right)}(0.01995262)$$

$$S=(1+1)^2\frac{316.22}{4\pi\left(30^2+24^2\right)}(0.01995262)$$

$$S=0.00136067\ (W/m^2)$$

ICNIRP has established the following limits for general public exposure. For evaluating this base station it is necessary to use the limit formula for the frequency range 400 - 2000 MHz.

| Frequency range (MHz) | Electric field strength ($Vm^{-1}$) | Magnetic field strength ($Am^{-1}$) | Magnetic flux density (μT) | Power density ($Wm^{-2}$) |
|---|---|---|---|---|
| 400 – 2000 MHz | $1.375f^{0.5}$ | $0.0037f^{0.5}$ | $0.0046f^{0.5}$ | f/200 |

For the 1800 MHz Personal Communication Service (PCS) frequency band:
The uplink (handset to base station): 1850 – 1865 MHz
The downlink (base station to handset): 1930 – 1945 MHz
For this example the band frequency of interest is the one assigned to the downlink.

$$S_{lim}=f/200$$

Considering the central band frequency:

$$f_c=1937.5 \quad MHz$$

Therefore:

$$S_{\lim} = 1937.5 / 200$$

$$S_{\lim} = 9.6875 \quad W / m^2$$

For question (a):

$$S = 0.00073768 \,(W/m^2)$$

$$\text{Exposure} \quad \text{Quotient} \quad (\%) = \frac{S}{S_{\lim}} \times 100$$

$$\text{Exposure} \quad \text{Quotient} \quad (\%) = \frac{0.00073768}{9.6875} \times 100$$

$$\text{Exposure} \quad \text{Quotient} \quad (\%) = 0.00761$$

As it can be seen the power density is below the relevant ICNIRP maximum exposure limit for general public exposure

For question (b):

$$S = 0.00136067 \,(W/m^2)$$

$$\text{Exposure} \quad \text{Quotient} \quad (\%) = \frac{S}{S_{\lim}} \times 100$$

$$\text{Exposure} \quad \text{Quotient} \quad (\%) = \frac{0.00136067}{9.6875} \times 100$$

$$\text{Exposure} \quad \text{Quotient} \quad (\%) = 0.0140$$

As it can be seen the power density is below the relevant ICNIRP maximum exposure limit for general public exposure

## 6. Exposure Measurement

### *6.1. Site Analysis*

It is necessary to clearly identify the measurement regions in order to restrict the measurements to only one of the components electric (E) or magnetic (H). This objective can be met by assuring far field conditions otherwise it is necessary to measure both of the fields.

Measurement of electromagnetic fields from telecommunications must be performed according to telecommunications service and the purpose of the evaluation. In most of the cases the measurement will be done in the far field region or in the worst case in the radiating near field, so it is only necessary to measure E field (see Table XII).

TABLE XII. Distances for radiating near field for different telecommunication services

| Telecommunication service | Approximate distance to radiating near field (3λ) |
|---|---|
| FM radiobroadcast | 9 m |
| Low band VHF TV broadcasting | 18 m |
| High band VHF TV broadcasting | 4.5 m |
| UHF TV broadcasting | 1.5 m |
| 900 MHz GSM mobile communications | 90 cm |
| 1900 MHz GSM mobile communications | 45 cm |

### *6.2. Types of measurements*

According to the "Guidance on complying with limits for human exposure to electromagnetic fields". (ITU-T Recommendation K.52).and the "Guidelines on the measurement and the numeric prediction of the electromagnetic fields to check that the telecommunications facilities comply with public exposure limits" (ITU-T Recommendation K.61) [4,5] two types of measurements could be carried out:

#### *6.2.1. Broadband measurement*

In broadband measurements the total contribution over a large frequency range is obtained without distinction of the contribution of different sources operating at different frequencies.
The broadband measurement is based on an electromagnetic field analyzer (see Fig. 12) controlled with its probe which could controlled by a portable computer. The exposure level could be given rms or peak value in V/m, W/m$^2$ or percentage of the international exposure limits recommended by standardization organizations (ICNIRP, IEEE) through the serial port using an optical fiber cable and an optical/electrical converter being stored the measurements readings for the three axes X, Y and Z as a percentage occupational exposure limits recommended by ICNIRP. In Fig. 13 it is shown a simple diagram of the broadband measurement system.
Owing to their limited sensitivity, the broadband meters are often used for compliance assessment. With a typical sensitivity of around 0.1 V/m such measurements can be carried out with enough accuracy and it is recommended that broadband measurement has to be used for making measurements at locations where the exposure quotient is dominated by emissions from the base station of interest which has to be proven with narrow band measurements

The probe generally consists of short-electric dipoles (or loops) that detect the field. The corresponding current flows through a conductor wire (with high resistance) to the field meter. Isotropic probes measure the field components in the three orthogonal directions in space and calculate the magnitude of the resultant field strength and thus facilitating the assessment procedure. On the field meter, the value obtained is shown as rms or peak value.

*FIG. 12. Electromagnetic field analyzer and its electric field probe*

(a) Advantages

- Broadband frequency range coverage which depends on the meter and the probe to be used
- Isotropic directivity
- Measurements are simple and less time –consuming than narrow-band measurements.
- Some meters are designed with frequency response shaped to meet the frequency variation of a particular international or national guideline (ICNIRP, IEEE) given the fields levels as a exposure quotient.

(b) Limitations

- These instruments are relatively insensitive, but they are getting better the typical sensitivity is around 0.1 V/m.
- General public exposures They are unable to responds to rapid signal changes due to modulation, access mode and for base stations are near or below the detection threshold difficulting reliable measurements.
- Lack of frequency selectivity so the results could be the addition of several signals.

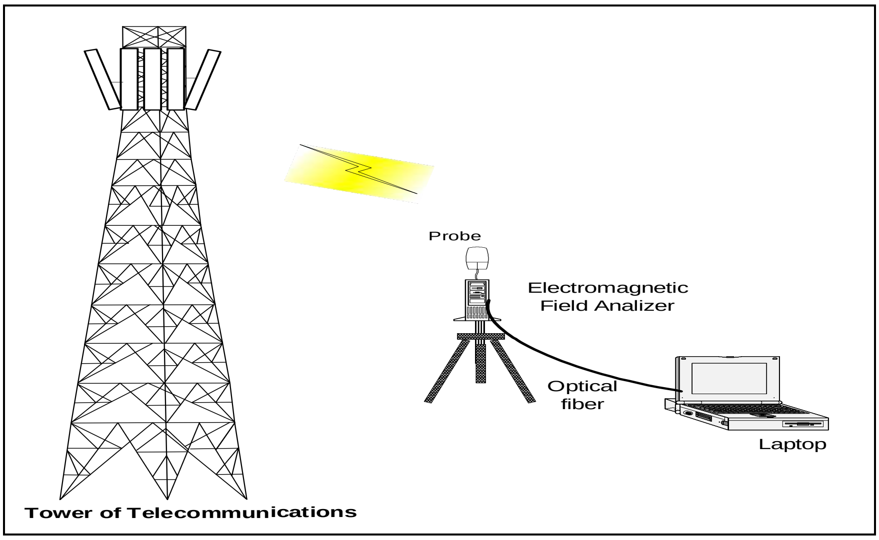


*FIG. 13. Simplified schema of setup for broadband measurement*

(c) Measurement uncertainty (accuracy):

The main sources of uncertainty or broadband measurements are linked to:
- Electrical factors: These factors are linked to the calibration of the field analyzer and its probe. The calibration certificate provides information on isotropic value and its uncertainty. The data sheet provides information on calibration factor, frequency response, linearity, drift and their uncertainties
- Factors coming from measurement practices: During measurement the electromagnetic field analyzer with its probe is mounted on a tripod and the measurement is performed without no contact with the operator, but there are additional uncertainty factor which depend on the coupling or positioning related to fixed structures or the use of the meter by hand rather than on tripod.

Total expanded uncertainty uncertainty for broadband measurement can be estimated as 3 dB [7,8,9].

*6.2.2. Narrow band measurement*

Narrow band measurements allow distinguishing between the specific contributions in the different frequency ranges. They are based on the use of a spectrum analyzer (see Fig. 14.) in conjunction with one or several different antennas according to the frequency range to evaluate: tuned dipoles, bi-conical dipoles (30-300 MHz, 20- 600 MHz, 250- 1000 MHz), log- periodic antennas (200-1000 MHz), horn antennas (1-18 GHz), double ridge waveguide horn antennas (1 -18 GHz) among others. Spectrum analyzers can detect signals being at least 8 to 10 orders of magnitude lower as the limits specified in the guidelines, standards or other documents. In Fig. 15 it is shown a simple diagram of narrow band measurement system.

*FIG. 14. Spectrum analyzer*

(a) Advantages
- Sensitivity of narrowband systems is higher than broadband systems'
- They are frequency selective so it is possible to identified the source of the non compliance in case it is.

(b) Limitations
- The equipment is bulky, especially because of some antennas which are large and could be susceptible to wind load when mounted on a tripod.

- Most of the antennas are directional and have to be rotated or positioned at a number of orientations in order to ensure all of the signals to be detected properly which could deteriorate accuracy.
- The narrowband measurement process is more time-consuming than broadband measurement, but modern equipments are getting better performances.

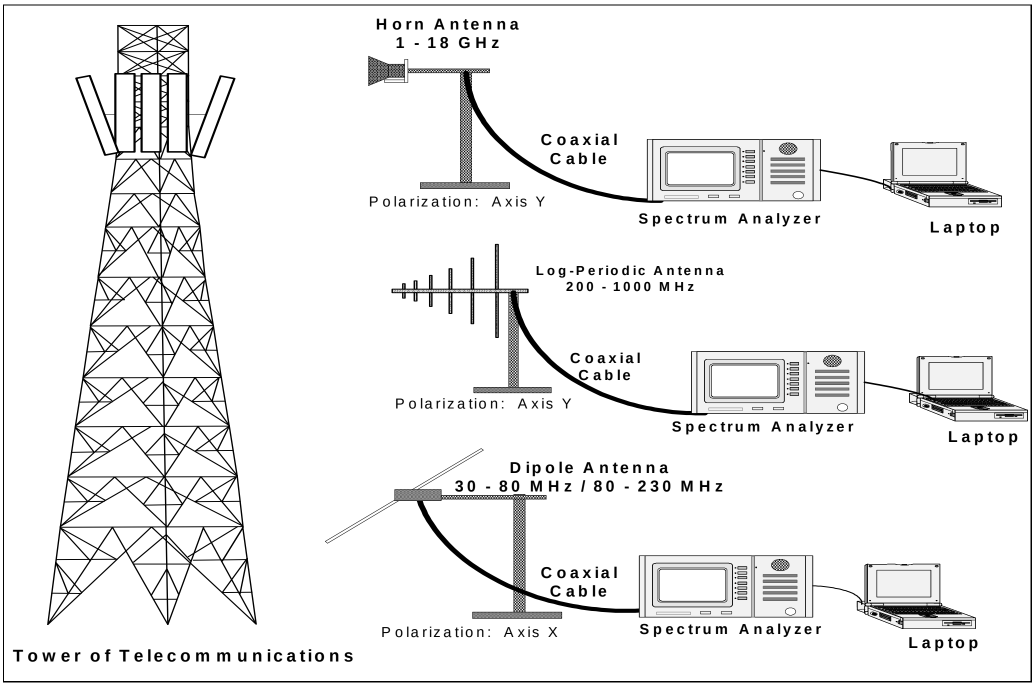


*FIG. 15. Simplified schema of setup for narrowband measurement*

(c) Measurement uncertainty

The main sources of uncertainty or narrow band measurements are linked to:

- Electrical factors: These factors are linked to the calibration of the field analyzer and antennas
- Factors coming from measurement practices: During measurement the antennas are on tripods and the measurement includes some rotations or positioning which could result in additional uncertainty because of the coupling or positioning related to fixed structures in the vicinity or the operator's body.

Total expanded uncertainty for narrowband measurements can be estimated as 2 dB [7,8,9].

### *6.3. Contribution of measurement equipment to error and uncertainty [7,8,9]*

(a) Calibration factor

The calibration factor for broadband probes depends on the frequency with a recommended uncertainty less than 1 dB over the entire frequency range and is defined as, but when there is non-linearity error CF is also a function of field strength and it is given in Equation 10.

$$CF = \frac{E_{ref}}{E_{meas}} \qquad \text{(Eq. 10)}$$

where:

$E_{ref}$ : expected electric reference field strength

$E_{meas}$ : read field

(b) Antenna factor

The antenna factor (AF) is defined for antennas an the frequency selective probes as it is given in Equation 11

$$AF = \frac{E_{ref}}{V} \qquad (m^{-1}) \qquad \text{(Eq. 11)}$$

where:

$E_{ref}$ : is the electric field reaching the antenna or the probe

V : is the voltage measured at he input of the spectrum analyzer

AF primarily depends on the frequency but when there is non-linearity error it could also depend on field strength. It is recommended a to take into account an expanded uncertainty of 2 dB

(c) Isotropy

It is the quality of the probe of having an isotropic response to incident waves. The difference between the real response of an isotropic probe with the ideal one is known as isotropic error and it is recommended to be less than 1 dB

(d) Linearity

It is the quality of the probe of having a linear response to the field strength. The non- linearity error comes from a dependence on test field strength of the antenna and calibration factor and should be less than 1 dB.

### *6.4. Contribution of external factors to error and uncertainty*

*(a) Source pointing*

In case of using a non-isotropic antenna for the measurement there is an uncertainty of antenna pointing which could be estimated as 5 º. This uncertainty must in turn be considered to estimate the antenna gain uncertainty.

*Spatial variations of the field*

When the measurement is not performed within the antenna main beam, the field is often the result of adding several contributions coming from diverse directions. This addition of fields coming from multiple directions, particularly important inside buildings, follows the Rayleigh distribution. The theoretical analysis shows that the field could vary between the maximum (with a probability of 66 %) and the 3 dB statistics mean (for k=1). If it is performed a statistics sampling, the uncertainty will be divided by n (where n is the number of samples), 1.732 in the case of three measurements for spatial averaging.

For measurements within the antenna main beam it is not necessary to take into account the Rayleigh uncertainty.

### ***6.5 Measurement Protocol*** *[8,9]*

*6.5.1. General considerations*

(a) Taking into account the azimuths of antennas arrangement for each sector of the base stations (the measurements points are located at 2, 10, 20, 50 and 100 m from the base of the antenna in the direction of the main beam of the antennas arrangement, whenever the measurements locations at these distances be accessible).

(b)The measurements shall be made for a single point at 1.5 m over the floor (temporal average).

In order to avoid interferences and/or errors in the field measurement, the operator maintained a minimum distance of 2.5 m from the probe.

(c) The average time for temporal average will depend on the standard used to the assessment: for example for ICNIRP is 6 minutes and for IEEE is 6 and 30 minutes.

(d) Depending on the measured value it could be done measurements for Spatial Average along a vertical line with three measurements points located to 1.1 m, 1.5 m and 1.7 m. over the reference surface as it is illustrated in Fig. 16.

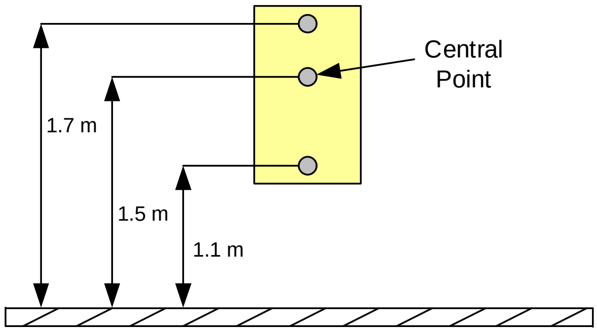


*FIG. 16. Schema for spatial averaging*

In this case the field strength value used for further calculations is the average of the three values obtained for each spatial point., as it is shown in equations 12 and 13.

$$E_{spatial-average} = \sqrt{\frac{\sum_{i=1}^{3} E_i^2}{3}} \qquad \text{(Eq. 12)}$$

$$S_{spatial-average} = \frac{\sum_{i=1}^{3} S_i}{3} \qquad \text{(Eq. 13)}$$

6.5.2. Measurement methods [8,9]

There are three cases for measurement methods
CASE 1- Fast analysis: This method is performed with an electromagnetic field analyzer for strength levels lower than 0.28 V/m.
CASE 2- Band frequency analysis: This method is performed with a spectrum analyzer for strength levels higher than 0.28 V/m and lower than 2.8 V/m.
CASE 3- Detailed analysis: This method could be done with a an electromagnetic field analyzer y/or a spectrum analyzer for strength levels 2.8 V/m.
In Fig. 17 it is shown the procedure for the application of these measurement methods.

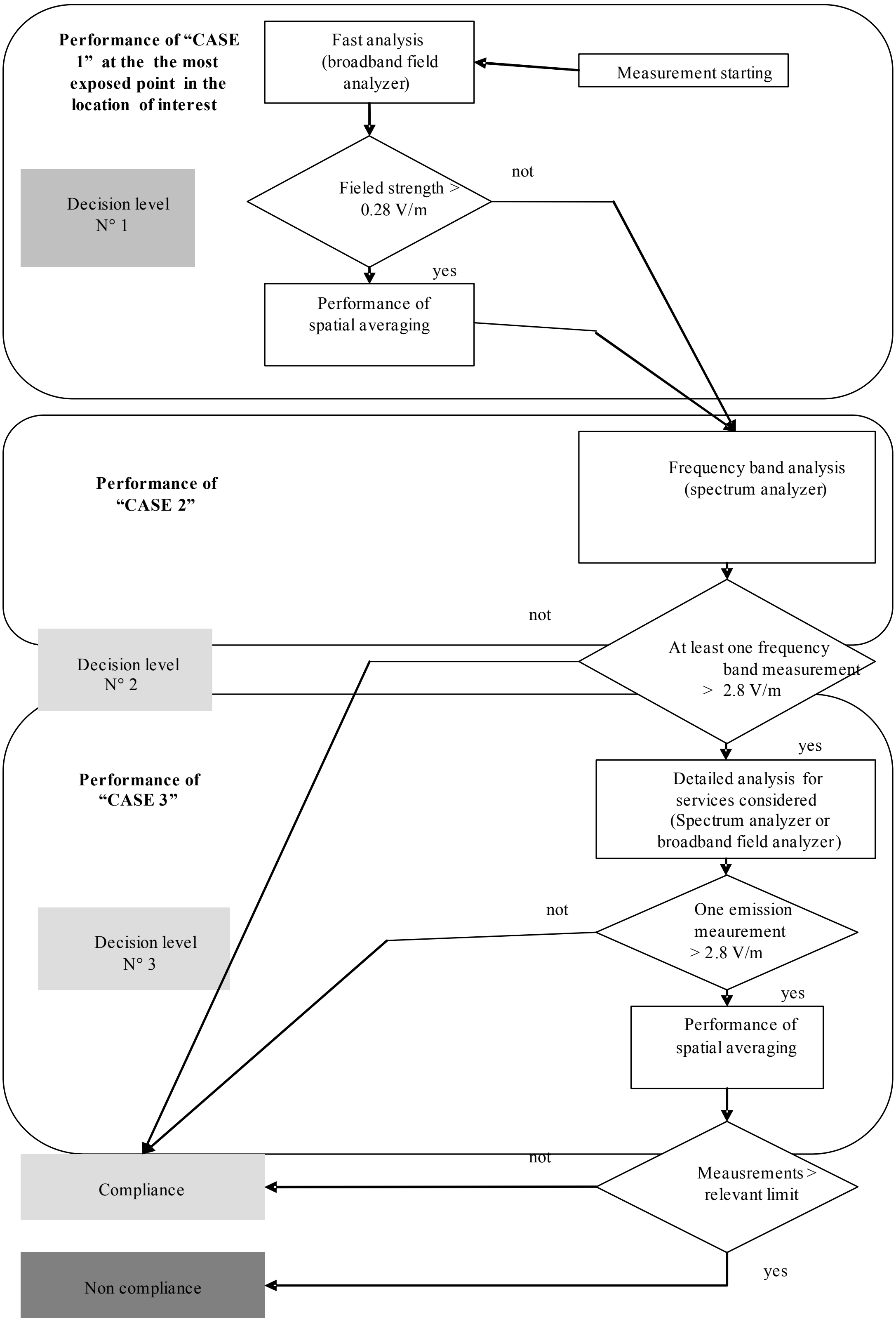


FIG. 17. Procedure for application of measurement methods

6.5.3 Quick overview method [8,9]

This method is based on broadband measurement and basically is aimed to evaluate compliance with NIR standards, so it can not be applied in the following cases.

- When it is necessary to know the contributions of different sources by frequency.
- If the equipment threshold is of the same order of expected measurement values.

(a) Measurement procedure

- The equipment that it is necessary to use is the same as expressed in 6.2.1.
- Choose of the most suitable probes for the frequencies of interest.
- The choice of the points shall be according to general considerations
- In some cases, it could be necessary two or more probes in this case the total values are given by the equations 14 and 15.

$$E_{total} = \sqrt{\sum_{i=1}^{n} E_i^2} \qquad \text{(Eq. 14)}$$

$$S_{total} = \sum_{i=1}^{n} S_i \qquad \text{(Eq. 15)}$$

where n is the number of probes covering the frequency band of interest and Ei y Sí are the values obtained for each probe.

(b) Post- processing

- If the value is below the threshold sensitivity of the probe, the value has to be discarded.
- A probe specific correction factor may be applied according to manufacturers' instructions.
- In order to relate the different quantities measured it could be used the formula in Equation 16.

$$S = EH = \frac{E^2}{Z_0} = H^2 Z_0 \qquad \text{(Eq. 16)}$$

- In case of multiple-frequency exposure it is necessary to applied equations 17 and 18

$$E_{total} = \sqrt{\sum_{i=1}^{n} E_i^2} \qquad \text{(Eq. 17)}$$

$$S_{total} = \sum_{i=1}^{n} S_i \qquad \text{(Eq. 18)}$$

*5.5.4. Variable frequency scan [8,9]*

This method is a kind of narrow band measurement and is applied when it is necessary to known non-ionizing radiation levels in a more detailed way, for example by telecommunication service band.

TABLE VI. Frequency bands considered for variable frequency scan

| Frequency band | Telecommunication service | Minimum reference level | Detection Threshold |
|---|---|---|---|
| 54- 88 MHz | Low band VHF TV | 28 V/m | 0.3 Vm |
| 88- 108 MHz | FM Radio | 28 V/m | 0.3 Vm |
| 174- 216 MHz | High band VHF TV | 28 V/m | 0.3 Vm |
| 470- 806 MHz | UHF TV | 28 V/m | 0.3 Vm |
| 851- 869 MHz | Trunking | 40 V/m | 0.4 V/m |
| 869- 894 MHz | Mobile Telephony | 40 V/m | 0.4 V/m |
| 1930-1945 MHz | PCS | 60 V/m | 0.6 V/m |

(a) Measurement procedure
- The equipment is the same as expressed in 6.2.2.
- The choice of the points shall be according to general considerations
- It is recommended to use the following bandwidth combination settings for spectrum analyzers:
  30 MHz -300 MHz Bw= 100 kHz with a sweep time of 50-100 ms
  300 MHz – 3 GHz Bw = 100 kHz with a sweep time of 700 ms to 1 s
  The threshold level has to be 40 dB below the reference level
- It must be performed the electric field strength measurement for every frequency band of main telecommunications services.
- It is necessary to carry out electric field strength measurement in 03 polarizations (x, y, z) at 2 m high over the floor.
- Average time depending on the reference standard (6 minutes for ICNIRP) in each polarization
- It should be used max-hold and peak mode detector.

(b) Post- processing
In order to relate the different quantities measured it could be used the formula in Equation 19.

$$S = EH = \frac{E^2}{Z_0} = H^2 Z_0 \qquad \text{(Eq.19)}$$

*5.55. Detailed investigation [8,9]*

This method should be applied in the following situations:
- Where near field measurements are required.
- Where measurements of strong electric or magnetic fields are required.
- When it is necessary to measure pulsed, discontinuous or wide-band signals.
- If one of the total exposure quotients exceed the value “1”.

(a) Measurement procedure
- It could be use both types of equipment; broad band and narrow band meters which are expressed in 6.2.1 y 6.2.2.
- The choice of the points shall be according to general considerations.
- For spectrum analyzers it is recommended to use the following bandwidth combination settings:
  30 MHz -300 MHz, Bw= 100 kHz with a sweep time of 50-100 ms
  300 MHz – 3 GHz , Bw = 100 kHz with a sweep time of 700 ms to 1 s

The threshold level has to be 40 dB below the reference level

*Reactive near –field measurement*

- It could be done by broadband or narrow band measurements. In any case it is necessary to independently measure the E-field and the H-field.
- For broadband measurements it is necessary to use probes for electric and magnetic fields.

- For narrowband measurements of E field it could be used dipole, bi-conical, log- periodic and horn antennas among others and for measuring H-field it is usually used loop antennas.

*Strong electric or magnetic field measurement*

- For spectrum analyzers it is necessary to use passive antennas and appropriately protection features.
- Set the centre frequency on each channel of the emission with a resolution equal or larger than the bandwidth of the channel.
- Select average mode and "rms detector" during the time recommended in the applicable standard.
- If the antenna used has a single polarization it is necessary to perform the measurement for the three orthogonal directions to obtain the different components of the field. In this case the total field is given by Equation 20

$$E_{total} = \sqrt{E_x^2 + E_y^2 + E_z^2} \qquad \text{(Eq. 20)}$$

*Pulsed emissions measurements*

For this type of signals, the energy is carried in short bursts and the pulse is usually short compared to the signal period. The power peak usually ranges form 1 W to 50 MW and it is necessary to assess the peak and the rms level.

Assessment of the peak value

- Choose a frequency band enough to cope with impulse bandwidth
- Select max-hold mode for 1 or several rotations of the radar (until stabilization of signal)
- Select "positive peak detection mode"
- The peak power should not exceed the reference by a 1000 factor for power density or 32 for field strength

Evaluation of rms field strength

- Carried out the average of the instantaneous signal in the rms mode.

*Emissions from mobile communications*

- As these systems consist of a permanent control channel and traffic channels. A base station could be understood as n transmitters.
- In order to perform the measurement it could used the control channel (identified with a spectrum analyzer because of its features: permanence and stable level).
- Select centre frequency with resolution equal or larger to the bandwidth of the channel, max hold mode and peak detector
- If the antenna used has a single polarization it is necessary to perform the measurement for the three orthogonal directions to obtain the different components of the field. In this case the total field is given by the Equation 21

$$E_{total} = \sqrt{E_x^2 + E_y^2 + E_z^2} \qquad \text{(Eq. 21)}$$

- Obtain the data of the number of transmitter for maximum load.
- The maximum traffic field strength is calculated by the Equation 22:

$$E_{max} = E_{contorl-channel}\sqrt{n_{trasnmitters-max}} \qquad \text{(Eq. 22)}$$

- If the transmitters are using different power levels from control channel it has to be applied the Equation 23:

$$E_{max} = E_{contorl-channel}\sqrt{\frac{P_{total}}{P_{control-channel}}} \quad \text{(Eq. 23)}$$

**7. Results of measurements carried out in South America**

***7.1 Argentina***

According to Government of Buenos Aires City [13] there have been carried out broad band measurements on non-ionizing radiation in the frequency range 200 kHz - 40 GHz at more than 750 locations. The maximum exposure level was 3.03 W/m2, and the average was 0.1495 W/m2.

***7.2 Ecuador***

According to the SuperIntendency for Telecommunications [14] from June 2004 until February 2008 there have been carried out measurements at approximately 700 locations on non-ionizing radiation near mobile base stations and the average exposure level was 0.02380 $W/m^2$ (0.55 % of ICNIRP limits for general public exposure as a worst case scenario).

***7.3 Peru***

According to the National Institute for Research and Training in Telecommunications there have been carried out measurements on non-ionizing radiations near base stations at approximately 200 locations. For the 800 MHz band the average and maximum levels were approximately 0.727 % and 4 % of ICNIRP limits respectively and for the 1900 MHz band were about 0.045 % and 1 % of ICNIRP limits [15]. In a survey conducted in 2005 on 40 base stations [16] it was also found that the maximum exposure level near base stations was 2.9 %.

**8. Conclusions**

There are two basic guidelines for non-ionizing radiations: ICNIRP guidelines and IEEE standards, being the ICNIRP guidelines the most accepted one.

There are two basic types of measurements for radiofrequency sources from telecommunications: broadband and narrowband

The broadband measurements are aimed to test compliance including all of the sources in the location which is tested. This type of measurements is not very sensitive so sometimes it is not very useful.

The narrowband measurements are aimed to know the sources of different emissions because is frequency selective. This type of measurement is very sensitive and could measure levels orders of magnitude below the international exposure limits.

There are three kind of measurement methods: Quick overview, Variable frequency scan and Detailed investigation.

Levels of exposure coming from base stations are very low typically 100 to 1000 times below international limits

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