Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

ECC RECOMMENDATION (02)04 (revised Bratislava 2003, Helsinki 2007)

MEASURING NON-IONISING ELECTROMAGNETIC RADIATION (9 kHz – 300 GHz)

Recommendation adopted by the Working Group "Frequency Management" (FM)

INTRODUCTION

This Recommendation specifies in-situ measurement procedures in order to assess electromagnetic fields for the purpose of comparison against limits for human exposure applying in CEPT countries (e.g. EU 1999/519/EC, ICNIRP guidelines,. national limits, …). It is important to note that this recommendation does not itself standardise or define exposure limits, or cover human exposure to radio signals.

It is considered appropriate that this recommendation should be reviewed every three years, or sooner if appropriate in the light of changing technologies and regulatory requirements. This review should take into account all information coming from any relevant groups within CEPT, CENELEC, IEC/ICES, ITU-T/SG6, and EBU.

It is recognised that such measurements are not within the remit of all Administrations within CEPT. It is hoped that this recommendation will assist other competent bodies in their work and interchange of information.

"The European Conference of Postal and Telecommunications Administrations,

considering

a) that different measurement methods of assessing non-ionising radiation levels are in use in the different CEPT administrations,

b) that there is a need to have agreed measurement methods for assessing non-ionising radiation levels,

c) that common measurement procedures are necessary for mutual acceptance of measurements by the parties concerned.

recommends

1 that general information contained in Annex 1 forms the basis for non-ionising radiation measurements,

2) that non-ionising radiation measurement methods should be applied according to the Annexes 2, 3, 4 and 5,

3) that such measurements should be reported in accordance with Annex 6."

Note:
Please check the Office web site (http://www.ero.dk) for the up to date position on the implementation of this and other ECC Recommendations.

Annex 1

GENERAL INFORMATION

1 SCOPE

This document describes a measurement method that should be used to assess electromagnetic radiation against the appropriate reference levels for exposure of human beings to electromagnetic fields (**9 kHz – 300 GHz**). The measuring method is based on 3 cases which are described in Annex 2:

- **Case 1 Quick overview**
- **Case 2 Variable frequency band scan**
- **Case 3 Detailed investigation**

The present recommendation is based on the application of various methods, the rigour of which is accentuated when the levels reach the limits. Only the execution of Case 3 can determine if the limits are exceeded, thus guaranteeing a confidence in the results.

This method is not suitable for situations where the critical exposure is strongly localised, e.g., with cellular phone handsets in relation to the human head. Licence exempt equipment like microwave ovens, or cellular phone handsets should be ignored for the measurement process, and if it is not the case, the test report should mention the fact.

2 NORMATIVE REFERENCES

IEC "Guide to the expression of uncertainty in measurement", Ed. 1, 1995

3 PHYSICAL QUANTITIES AND UNITS

SI-units are used throughout the present recommendation:

Quantity	Symbol	Unit	Symbol
Frequency	f	Hertz	Hz
Wavelength	*l*	metre	m
Electric field strength	E	Volt per metre	V/m
Magnetic field strength	H	Ampere per metre	A/m
Magnetic flux density	B	Tesla	T
Power density or EM power flux density	S	Watt per square metre	W/m^2
Intrinsic impedance	Z	Ohm	Ω
Largest dimension of the antenna	D	metre	m

4 TERMS AND DEFINITIONS

4.1 Electric field strength

Electric field strength is a vector quantity (E) that corresponds to the force exerted on a charged particle regardless of its motion in space. It is expressed in Volt per metre (V/m).

4.2 Magnetic field strength

Magnetic field strength is a vector quantity (H), which, together with the magnetic flux density, specifies a magnetic field at any point in space. It is expressed in Ampere per metre (A/m).

4.3 Power density (S) or electromagnetic power flux density

Power per unit area perpendicular to the direction of propagation is usually expressed in units of watts per square metre (W/m^2), milliwatts per square centimetre (mW/cm^2), or microwatts per square centimetre ($\mu W/cm^2$).

$$S = \left| \vec{E} \wedge \vec{H} \right|$$

For a plane wave in the far field, power density (S), electric field strength (E) and magnetic field strength (H) are related by the impedance of free space, i.e. Z_0=377 ohms. In particular,

$$S = \frac{E^2}{377} \text{ or } S = 377 \times H^2$$

where E and H are expressed in units of V/m and A/m, respectively, and S in units of W/m².

4.4 Far-field

The far-field region, (also called the Fraunhofer region), is the field region of an antenna in which angular field distribution is more or less independent of distance from the antenna. In this region, the field has a predominantly plane wave character, i.e., local, very uniform distribution of electric and magnetic field strength in planes that are transverse to the propagation direction. The border of this region is at a distance of $R > \lambda + 2D^2/\lambda$, where D is the antenna's largest dimension.

4.5 Near-Field

The near-field region is the region in the field of an antenna, located near the antenna, in which electric and magnetic fields do not have a substantial plane-wave character, but vary considerably from point to point. The term "near-field region" does not have a very precise definition, with different meanings for large and small antennas. The near-field region is further subdivided into the radiating near-field region and the reactive near-field region – that is closest to the antenna and contains most/almost all stored energy associated with the antenna's field. In the event that the maximum overall dimension of the antenna is small compared to the wavelength, the radiating near-field region may not exist. For antennas that have a large wavelength, the radiating near-field region is sometimes referred to as the Fresnel region – by way of analogy to optical terminology.

4.6 Root-Mean-Square Value (rms)

Certain electrical effects are proportional to the square root of the mean of the square of a periodic function (over one period). This value is known as the effective, or root-mean-square (rms) value, since it is derived by first squaring the function, determining the mean value of the squared amounts obtained, and then taking the square root of that mean value. It is mathematically defined as the root mean square of the squares of the instantaneous values of the signal :

$$\text{RMS value} = \sqrt{\frac{1}{T}\int_0^T [x(t)]^2 \, dt}$$

where x(t) is time variant signal and T the signal period.

4.7 Peak Value

It corresponds to the maximum absolute value of the function.

4.8 Mean Value

Mathematically, the mean value can be defined as:

$$\bar{x} = \lim_{T \to \infty} \frac{1}{T} \int_0^T x(t) dt$$

The mean, by itself, does not provide sufficient information in order to differentiate the phenomenon that can be completely different in terms of time variation, even though it has the same mean value.

4.9 Reference level

The reference levels are derived from the basic limits of exposure of human beings to electromagnetic fields adopted by competent bodies within the different CEPT countries for comparison against measured electromagnetic fields. Measurements below the reference level guarantee that the requirement that basic limits of exposure are not exceeded is satisfied.

4.10 Decision level

The decision levels are the thresholds (x dB below the reference level) which are set by the Administration to allow for measurement uncertainties, taking into account the measurement equipment used, the environment and spectrum characteristics, allowing:

- to make the bridge between the different cases (Case 1 to Case 2 and Case 2 to Case 3) and
- to decide whether a spatial average according to § 6.2 has to be established.

4.11 Exposure quotient

The exposure quotient is the ratio of the measured maximum electromagnetic power density to the appropriate reference level at a given frequency. A value greater than "1" signifies that levels to which people may be exposed exceed the reference level. Several reference levels and thus several exposure quotients may be applicable for one frequency (e.g. E and H-field), and different quotients may apply across the frequency band of interest.

4.12 Total exposure quotient

The total exposure quotient is a summation of all the individual frequency exposure quotients in the measured frequency band at a single location. The calculation of this value from the individual frequency quotients is defined in the exposure limits. Several total exposure quotients may be applicable (e. g. for E and H).

5 EXAMPLES OF EMISSIONS IN THE FREQUENCY BAND FROM 9 kHz to 300 GHz

Symbols	Frequency range (lower limit exclusive, upper limit inclusive	Services
VLF	9 to 30 kHz	Induction heating
LF	30 to 300 kHz	Industrial induction heating, AM broadcasting, clock transmitters
MF	300 to 3 000 kHz	AM radio, industrial induction heating
HF	3 to 30 MHz	Broadcasting, Radio-amateurs, Armed Forces
VHF	30 to 300 MHz	PMR, TV, Armed Forces, Radio-amateurs, FM broadcasting, Aeronautical services
UHF	300 MHz to 3 000 MHz	TV, GSM, DCS, DECT, UMTS, Bluetooth, earth station, Radars
SHF	3 to 30 GHz	Radars, Earth stations, Microwave links
EHF	30 to 300 GHz	Radars, microwave links

6 GENERAL CONSIDERATIONS FOR MEASUREMENT OPERATION

6.1 Electric and Magnetic fields:

Electromagnetic fields can be sub-divided into two components: the electric field E [measured in V/m] and the magnetic field H [measured in A/m]. The **E-field** and the **H-field** are **mathematically interdependent** in the **far-field**, that means only one component has to be measured. For example, in free space if the H-field is measured in this region, it can be used to calculate the magnitude of the E-field and power density S [W/m^2]:

$$E = H \times Z_0 \,,\; S = H^2 \times Z_0 \text{ knowing } Z_0 = 377\Omega$$

In contrast, the **H-field** and **E-field** must be **measured separately** in the **reactive near-field region**.

Only electric field strength is normally measured, since measurements are typically made in the far field. The magnetic field level can then be calculated using the intrinsic impedance of free space (Z_0=377Ω). If both the electric field and magnetic field values are lower than the more stringent reference value, the power flux density must also be lower.

Table below indicates the method at different distances from radio-stations:

	Reactive near-field region	**Radiating near-field region**	**Far-field region**
Lateral edge of the region, measured from antenna	0 to λ	λ to λ+2D²/λ	λ+2D²/λ to ∞
E ⊥ H	No	Quite Yes	Yes
Z = E / H	≠ Zo	≈ Zo	= Zo
Component to be measured	E & H	E or H	E or H

Measurements are usually made further than the distance where both E and H measurements are required and in particular, the measurement of one component E field (or H field) is sufficient in the following situations:

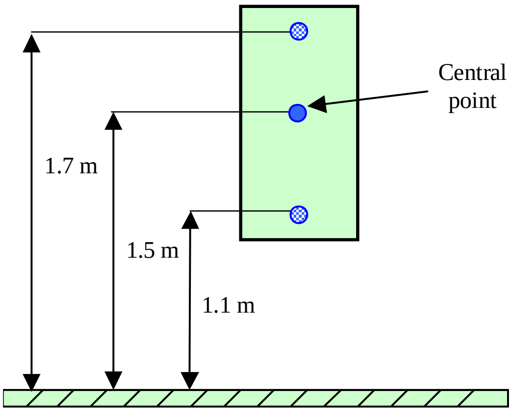
- LF broadcast at a approximate distance of 2000 m (λ for 150 kHz), it can be lower (for example some hectometres for a quarter wavelength antenna) depending on the type of antenna,
- Radio broadcasting at a distance of 3 m (λ for 100 MHz),
- TV broadcasting at a distance of 6 m (λ for band I), 1,5 m (λ for band III), and 50 cm (λ for IV-V),
- GSM base station at a distance of 30 cm (λ for 935 MHz) and 15 cm (λ for 1800 MHz),
- RADAR station with parabolic antenna (D=1,5m and f=1367 MHz) at a distance of 21 m.

6.2 Measurement point (s):

Location of measurement points:
Measurement point(s) should be chosen to represent the highest levels of exposure to which a person might be subjected, considering the positions of neighbouring antennas. These locations can either be found by a quick check using measuring equipment (see case 1 and case 2), or, if that doesn't succeed, by calculation based on the theoretical propagation from neighbouring antennas.

Number of point(s) :
The measurement shall be made for a single point, 1.5 m above ground (or floor) level.

In case 1 and 3, if the measurement result reaches the decision level, a spatial average of 3 points to match the dimensions of the human body shall be performed.



The field strength value to be used in further calculations is the averaged value of the three values, obtained for each spatial point :

$$E_{spatial\_average} = \sqrt{\frac{\sum_{i=1}^{3} E_i^2}{3}} \, , \quad H_{spatial\_average} = \sqrt{\frac{\sum_{i=1}^{3} H_i^2}{3}}$$

Annex 2

APPLICABILITY OF NON-IONISING RADIATION MEASUREMENT METHODS

CASE 1: QUICK OVERVIEW

The QUICK OVERVIEW method should be applied when just the summation of non-ionising radiation level is required.

The QUICK OVERVIEW method has some restrictions. This method should not be applied:

- a - If it is necessary to know the non-ionising radiation levels by frequency,
- b - If the value given by this method exceeds the lowest reference level (adopted by that CEPT administration) for the frequency band covered by the equipment,
- c - If the value given by this method or the spatial average according to Annex 1 - § 6.2 where appropriate exceeds the decision level defined in 4.10,
- d - If, for sensitivity reasons of the equipment, no value is measurable (non-ionising radiation level is below the threshold level of equipment) but legislation in force requires a value so that it is insufficient to just indicate that fields are less than the equipment sensitivity.

In these situations, CASE 2 should be applied as appropriate.

CASE 2: VARIABLE FREQUENCY BAND SCAN

The VARIABLE FREQUENCY BAND SCAN method should be applied when non-ionising radiation levels are required by frequency within the scanned band.

The VARIABLE FREQUENCY BAND SCAN method has some restrictions. This method should not be applied :

- a - Where near-field measurements are required,
- b - Where measurements of strong electric or magnetic field are required,
- c - If pulsed, discontinuous, or wide-band emissions have to be measured,
- d - If the resulting values exceed the decision level,
- e - If one of the total exposure quotients (cumulative effect) exceeds the value "1".

In these situations, CASE 3 should be applied.

CASE 3: DETAILED INVESTIGATION

The DETAILED INVESTIGATION method should be applied where Case 1 and 2 are not applicable.

The DETAILED INVESTIGATION should be applied in the following cases:

- a - Where near-field measurements are required,
- b - Where measurements of strong electric or magnetic fields are required,
- c - To the measurement of non-classic services (for example : pulsed, discontinuous or wide-band emissions, …).

Annex 3

MEASUREMENT METHOD APPLICABLE TO CASE 1

1 SCOPE & SPECIFIC REQUIREMENTS

The QUICK OVERVIEW method should be applied when the summation of non-ionising radiation level is required. The present method should be applied to a far field situation.

2 MEASUREMENT EQUIPMENT

"RF radiation meters with isotropic field probes" should be used for these measurements. The intrinsic idea of such equipment is to assess general radiation value in a specific location. The radiation meter and the probe must be able to measure the effective value of field strength, also known as the root mean square" or "rms" value (RF radiation meters generally use "peak" detectors, which will give an artificially high result for elliptically polarised signals).

3 MEASUREMENT PROCEDURE

The procedure should follow these steps:

3.1 Choose the most suitable probe(s) for the frequency emissions to be studied:

Probes should be selected to cover the emissions of interest, in certain cases two or more probes would be required to survey the band of interest. In this case, the final result will be calculated using the values given by each equipment (processed as if individually obtained) by using the following formula:

$$E = \sqrt{\sum_{i=1}^{n} E_i^2} \quad \text{or} \quad H = \sqrt{\sum_{i=1}^{n} H_i^2}$$

where n is the number of probes covering the frequency band in study and E_i or H_i are the value obtained individually by each equipment.
The obtained value is always over-evaluated, since sometimes the probe frequency bands overlap each other, and the formula does not correct this.

3.2 Measurement:

The choice of measurement point (location and number of points) will be in accordance with the general considerations (Annex 1 - § 6.2).

The measurement duration should be referenced to the exposure guidelines used (For example, 6 minutes in EU 1999/519/EC & ICNIRP guidelines).

The RF radiation sensors should be mounted on a non conductive tripod, in order not to perturb electromagnetic field, and will derive the effective, or root-mean-square (rms) value of E (or H). Personnel should be retreat from the antenna during measurements.

4 POST-PROCESSING

4.1 According to the value obtained:

- If the value is below the sensitivity level of the probe, the value must be ignored,
- A probe specific correction factor may be applied according to the probe manufacturer's instructions

4.2 Calculation of Electric field (E) / Magnetic field (H) / Power density (S)

Under far field conditions, unmeasured quantities can be calculated using the following formulae:

$$S = EH \text{ or } S = \frac{E^2}{Z_0} \text{ or } S = H^2 Z_0$$

where E and H are expressed in units of V/m and A/m, respectively, and S in units of W/m².

4.3 Exposure to single / multiple frequency fields

Exposure to a single frequency field is an ideal situation. Nevertheless, in practice we can assume a single frequency field situation may be predominant. Considering simultaneous exposure to multiple frequency fields, it is easy to prove mathematically that if the value given by the RF meter does not exceed the more stringent value of the frequency band covered by the probes, then the contributions of all individual frequencies will also fall below that value, since:

$$E_{sum} = \sqrt{\sum_{i=1}^{n} E_i^2}$$

Where E_{sum} is the display value of the RF meter (probe) and n, the number of emissions

If the exposure level given by the equipment exceeds any reference level within the frequency band of interest, the method of Case 2 should be applied.

5 UNCERTAINTY ESTIMATION

The measurement uncertainty should be evaluated for those measurements addressed in the following sub-clauses, taking into consideration each of the quantities listed there. The standard uncertainty $\mathbf{u_{(xi)}}$ and the sensitivity coefficient $\mathbf{c_i}$ shall be evaluated for the estimate $\mathbf{x_i}$ of each quantity. The combined standard uncertainty $\mathbf{u_c(y)}$ of the estimate y of the measurand is calculated as a weighted root sum square (r.s.s.) :

$$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i * u_{(x_i)})^2}$$

The expanded measurement uncertainty u_e is calculated as :

$$u_e = 1{,}96\, u_c$$ [1]

and should be stated in the measurement report.

Input Quantity	Uncertainty of x_i		$u(x_i)$	c_i	$(c_i\, u_{(xi)})^2$ %
	Value %	Probability distribution ; Divisor k			
Isotropy		rectangular; $\sqrt{3}$		1	
Linearity		rectangular; $\sqrt{3}$		1	
Flatness		normal; k=1		1	
Temperature		rectangular; $\sqrt{3}$		1	
…..	….	…..	….	...	…….
Combined standard uncertainty	$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i * u_{(x_i)})^2}$				
Expanded uncertainty (confidence interval of 95%)	$u_e = 1.96\, u_c$				

[1] The coverage factor of 1.96 yields a 95% level of confidence for the near-normal distribution typical of most measurement results

In most of cases, figures above are given for a high of confidence (of 95%) typically values for "RF radiation meters with isotropic field probes" are the following ones:

Input quantity	Uncertainty (dB) (confidence interval of 95%)	Uncertainty (num.) (confidence interval of 95%)	$u(x_i)$ Standard uncertainty (num.) (confidence interval of 66%)
Isotropy	1.5 dB	0.19	0.095
Linearity	1.0 dB	0.12	0.06
Flatness	1.0 dB	0.12	0.06

The following combined standard and expanded uncertainty result from standard uncertainties above :

Combined standard uncertainty	$u_c(y) = \sqrt{\sum_{i=1}^{n}(c_i * u_{(x_i)})^2}$	1.045 dB
Expanded uncertainty (confidence interval of 95%)	$u_e = 1.96\, u_c$	1.94 dB

6 MEASUREMENT REPORT

The measurement report shall follow the structure defined in Annex 6. For Case 1 the following particularities have to be taken into account.

Measured component E (or H)

PROBE (type and reference)	VALUE	Used correction factor	RESULT	UNIT	START TIME	STOP TIME	DATE
				V/m	hh : mm : ss	hh : mm : ss	dd-mm-yyyy
				A/m			

Calculated component(s)
H (or E), S can be calculated taking into account the remarks in § 4.2 Post processing "*Calculation of Electric field / Magnetic field H / Power density"*

Application of recommendation / guidelines
Measured and calculated quantities have to be compared to the lowest reference level of the legislation in force. If the quantities of measured and/or calculated values are higher than the most stringent limit, the method of CASE 2 should be applied.

Annex 4

MEASUREMENT METHOD APPLICABLE TO CASE 2

1 SCOPE & SPECIFIC REQUIREMENTS

The VARIABLE FREQUENCY BAND SCAN method should be applied when non-ionising radiation levels are required by frequency within the scanned band or CASE 1 is inappropriate. This method is applicable under far field conditions.

2 MEASUREMENT EQUIPMENT

This type of survey is best carried out using a lightweight battery powered receiver or spectrum analyser (SA). The receiver or spectrum analyser should be capable of software control. Software control is essential due to the vast amount of frequency and amplitude data to be collected during the survey and to maintain consistent results over several sets of survey equipment being operated by several different survey officers. This software should also make provision for the programming of antenna factors and feeder cable insertion loss. This will allow the survey system to use a variety of antennas and cables allowing for a degree of customisation for specific band surveys. In this way human error can be kept to a minimum. Survey receivers or spectrum analysers will occasionally be required to operate in hostile RF environments. Good dynamic range and inter-modulation performance will be essential for reliable and repeatable results.

Survey antennas should be lightweight and robust, and good quality feeder cables should be used. Preferred types of antennas to be used are :

- Magnetic loop for HF,
- Broadband dipole antenna or (encapsulated) log periodic antenna,
- Bi-conical antenna,
- Directional antenna for the other types of emissions (it is recommended to use when there is a main contribution and the secondary contributions are negligible),
- Selective Probe " 3 axis ".

For lower frequencies, taking into account the significant wavelength, electrically small antennas should be chosen. Using passive electric antennas, the minimum distance between the antenna and any obstacle (e. g. wall or ground for example) must be at least 1 λ. Measurements of frequencies lower than 600 MHz with a 50 cm height above ground-level should use broad band, electrically small magnetic or electric antennas rather than a dipole. Personnel should retreat from the antenna during measurements, which should be mounted on non conductive tripods in order not to perturb the electromagnetic field.

3 PRE PROCESSING

Equipment checks

All measurement equipment should be calibrated (according to the manufacturer’s recommendations or the Administration’s quality management procedures) to traceable standards. RF cables, waveguides and connectors should be individually marked and checked prior to use for mechanical damage and checked regularly for insertion and return loss characteristics. Any changes in antenna factors and cable loss should be programmed into the measurement receiver.

It is the responsibility of the survey team to confirm the calibration factors are correct and updated as necessary prior to each task. A record in the survey notebook should show that the check/update has been made. A check should be made to verify that the correct cable and antenna parameters are loaded and activated in the receiver.

4 MEASUREMENT PROCEDURE

The procedure should be conducted according to the following steps:

1. *Measurement point:*
The choice of measurement point (location and number of points) will be in accordance with the general considerations (Annex 1 - § 6.2).

2. *Frequency band:*
The method is appropriate to frequencies between 9 kHz and 3 GHz. Within this frequency range, measurement process and settings of Case 2 provide confident results. But for frequencies above 3 GHz (e.g., radar, microwave links), either Case 1 or recommendations of Case 3 (and especially §4) must be applied.

3. *Settings of receiver or spectrum analyser.*
Bandwidth and Stepping
The measurement bandwidth will be a compromise for the various RF sources in the radio spectrum. Throughout the spectrum there is a mixture of wide / narrow, analogue / digital and continuous / discontinuous sources. In addition, although there are many single-service bands there are also many shared bands where services exist with widely different signal characteristics.

For receivers it is recommended that:

The following bandwidth / step size are used :

9 kHz - 30 MHz	BW = 9 or 10kHz	with a step size of 10 kHz
30 MHz - 3GHz	BW = 100 kHz	with a step size of 100 kHz

Receiver dwell time :
0,1 seconds minimum

For spectrum analysers it is recommended that the following bandwidth/sweep settings are used :

9 kHz - 30 MHz	BW = 10 kHz	with a sweep time of 50 - 100 ms
30 MHz - 300 MHz	BW = 100 kHz	with a sweep time of 100 ms
300 MHz - 3 GHz	BW = 100 kHz	with a sweep time of 700 ms – 1 sec

Threshold level :
The threshold level is chosen 40 dB below the reference level. If no emission exceeds the threshold level within a frequency band the 2 highest emissions may be reported.

Antenna Polarisation :
Measurements shall be made with the measurement antenna in both horizontal and vertical planes.

Mode :
Max-hold techniques and peak mode detector should be used.

5 POST-PROCESSING

Calculation of Magnetic field H / Power density

Under far field conditions, unmeasured quantities can be calculated using the following formulae:

$$S = EH \ or \ S = \frac{E^2}{Z_0} \ or \ S = H^2 Z_0$$

where E and H are expressed in units of V/m and A/m, respectively, and S in units of W/m².

6 UNERCTAINTY ESTIMATION

The measurement uncertainty should be evaluated for those measurements addressed in the following sub-clauses, taking into consideration each of the quantities listed there. The standard uncertainty $\mathbf{u_{(xi)}}$ and the sensitivity coefficient $\mathbf{c_i}$ shall be evaluated for the estimate $\mathbf{x_i}$ of each quantity. The combined standard uncertainty $\mathbf{u_c(y)}$ of the estimate y of the measurand is calculated as a weighted root sum square (r.s.s.) :

$$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i * u_{(x_i)})^2}$$

The expanded measurement uncertainty u_e is calculated as :

$$u_e = 1{,}96\, u_c$$ [2]

and should be stated in the measurement report.

Input Quantity	Uncertainty of x_i		$u(x_i)$	c_i	$(c_i\, u_{(xi)})^2$ %
	Value %	Probability distribution ; Divisor k			
Measurement device (receiver, spectrum analyser) including cable loss		normal; k=1		1	
Antenna factor		normal; k=1		1	
…..	….	…..	….	...	…….
Combined standard uncertainty	$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i * u_{(x_i)})^2}$				
Expanded uncertainty (confidence interval of 95%)	$u_e = 1{,}96\, u_c =$				

In most cases, figures above are given for a high level of confidence (of 95%). Typically values for a spectrum analyser associated with a calibrated antenna are as follows:

Input quantity	Uncertainty (confidence interval of 95%)	Uncertainty (num.) (confidence interval of 95%)	$u(x_i)$ Standard uncertainty (num) (confidence interval of 66%)
Antenna factor	1.0 dB	0.12	0.06
Cable	0.2 dB	0.02	0.01
Receiver	2.0 dB	0.26	0.13

The following combined standard and expanded uncertainty result from standard uncertainties above

Combined standard uncertainty	$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i * u_{(x_i)})^2}$	1.165 dB
Expanded uncertainty (confidence interval of 95%)	$u_e = 1.96\, u_c$	2.15 dB

[2] The coverage factor of 1.96 yields a 95% level of confidence for the near-normal distribution typical of most measurement results

7 REPORT

The measurement report shall follow the structure defined in Annex 6. For Case 2 the following particularities have to be taken into account.

Measurement data should be presented in tabular form (graphical form optional) for each measurement location against the recommended levels.

Measured component E

The table below is used for reporting the significant emissions.

Frequency	Value	Results	Unit	Equipment

Calculated component(s)

H, S can be calculated taking into account the remarks in § 5 Post processing "*Calculation of Magnetic field H / Power density"*

Application of recommendation/guidelines

Measured and calculated quantities shall be used to check the compliance of RF exposure with the legislation in force. This is done in the following two steps:

- E, H and S shall be compared to reference levels,
- E, H and S are used to calculate the eventual total exposure quotients.

Some examples for the calculation of the total exposure quotients can be found below

- Total exposure quotient based on power flux density:

$$\sum_{i=1}^{N} \frac{S_i^{meas}}{S_i^{guid}} = \frac{S_1^{meas}}{S_1^{guid}} + \frac{S_2^{meas}}{S_2^{guid}} + \frac{S_3^{meas}}{S_3^{guid}} + ... + \frac{S_N^{meas}}{S_N^{guid}} < 1$$

- Total exposure quotient referred to electrical stimulation effects (a=87 V/m, b=5 A/m; E_l and H_l are frequency depended limits) :

$$\sum_{i=1Hz}^{1MHz} \frac{Ei}{El,i} + \sum_{i>1MHz}^{10MHz} \frac{Ei}{a} \leq 1 \qquad \sum_{j=1Hz}^{150kHz} \frac{Hi}{Hl,j} + \sum_{j>150kHz}^{10MHz} \frac{Hj}{b} \leq 1$$

(Source : European recommendation of 12 July 1999; (1999/519/EC))

- Total exposure quotient referred tothermal effect circumstances (c=87/$f^{1/2}$ V/m, d=0.73/f A/m ; E_l and H_l are frequency depended limits):

$$\sum_{i=100kHz}^{1MHz} (\frac{Ei}{c})^2 + \sum_{i>1MHz}^{300GHz} (\frac{Ei}{El,i})^2 \leq 1 \qquad \sum_{j=100kHz}^{150kHz} (\frac{Hi}{d})^2 + \sum_{j>150kHz}^{300GHz} (\frac{Hi}{Hl,i})^2 \leq 1$$

(Source : European recommendation of 12 July 1999; (1999/519/EC))

Taking into account the measured and calculated values and their uncertainty, the CASE 3 method should be applied if the results reach or exceed the decision level (or the limits).

Annex 5

MEASUREMENT METHOD APPLICABLE TO CASE 3

1 SCOPE & SPECIFIC REQUIREMENTS

The present method should be applied where Case 1 & 2 are not suitable and especially

- Where near-field measurements are required,
- Where strong Electric or Magnetic field measurements are required,
- To non classic services measurement (for example, pulsed, discontinuous or wide-band emissions).

2 MEASUREMENT EQUIPMENT

The equipment used is the same as used for Cases 1 & 2. Additionally it should be noted that for a near-field situation both electric and magnetic measurement are required (use of E and H sensors). And, for some types of signals, especially pulsed or UWB[3], the use of a time domain receiver / analyser is strongly recommended to pre-analyse signals (for example detection and characterisation of bursts) and ensure that measurement settings are adapted accordingly.

3 PRE PROCESSING

Pre processing operation is identical to Case 2. Additionally it could be helpful to ask the operators for more details concerning the station (number of transmitters, temporal operation mode and antenna system/pattern).

4 MEASUREMENT PROCEDURE

The procedure should be according to the following steps:

1. **Measurement point**
The choice of measurement points (location and number of points) will be done according to the general considerations (Annex 1 - § 6.2). Personnel should retreat from the antenna during measurements, which should be mounted on non conductive tripods in order not to perturb electromagnetic field.

2. **Frequency band**
Measurement operation is appropriate for frequencies between 9 kHz and 3 GHz. If in a measurement location, there are antennas using frequencies above 3 GHz (for example: radar), the associated emissions have to be measured considering the remarks below (§ 4 - specific configurations).

3. **Settings of the equipment**
They have to be identical to CaseC 2 except for the emissions reaching the limits (strong emissions measurements), pulsed, discontinuous and wide-band emissions. For these types of emissions, you have to take into account the following paragraph § 4 (specific configurations).

4. **Specific configurations**

4.1 Reactive near-field measurement

In contrast to the radiating near-field and the far-field region, in the reactive near-field region, the H-field and E-field must be measured separately;; this could be done by using distinct sensors. The electric component (E) of the electromagnetic field can be easily measured using suitable antennas, e.g. dipole, bi-conical, log-periodic etc, and the magnetic component (H) of the electromagnetic field is usually measured with loop sensors (as the current induced in the loop is proportional to the magnetic field strength crossing the loop).

[3] Ultra Wide Band

4.2 Strong Electric or Magnetic field measurement
Immunity of equipment, especially for receivers or spectrum analysers, has to be checked, and if necessary, probes, having better immunity against strong signals should be used.

If receivers or spectrum analysers are necessary, you have to:

- Use passive antennas and protected equipment,
- Or reduce one or several transmitter's power and simultaneously record the reduction factor(s).

For these types of equipment, the procedure should be according to the following steps:

- Set the centre frequency on each channel of the emission with a resolution equal (if possible, otherwise larger) to the bandwidth of the channel,
- Select "Average mode" during adequate time (the measurement duration should be referenced to the exposure guidelines used (for example, 6 minutes in EU 1999/519/EC)),
- Select "rms detector"
- If a single dipole or single loop is used, 3 measurements should be performed in 3 orthogonal directions to obtain the different components of the field. The total field is given by the following formula :

$$|E| = \sqrt{|Ex|^2 + |Ey|^2 + |Ez|^2} \text{ , } |H| = \sqrt{|Hx|^2 + |Hy|^2 + |Hz|^2}$$

Precautions for measurement staff:
When strong electromagnetic fields have to be measured, safety measures against radiation exposure of the staff have to be taken. Field strength predictions, the use of radiation protection gauges and explicit work instructions may be appropriate tools to ensure safe working conditions.

4.3 Signals above 3 GHz
In these frequency bands there are only a few omni-directional antennas available. Therefore, directive survey antennas (horn, dish, lens, log-periodic…) are used.

The procedure should be according to the following steps:

- Set the centre frequency on each channel of the emission with a resolution equal (if possible, otherwise larger) to the bandwidth of the channel,
- Select "Average mode" during adequate time (the measurement duration should be referenced to the exposure guidelines used (For example 6 minutes in EU 1999/519/EC)),
- Select "rms detector",
- The antenna should be used in one position of the antenna (maximum signal) with the appropriate polarisation. In that measurement procedure, the reflections are negligible.

4.4 Pulsed / Radar emission measurements
For this type of signals, the microwave energy is carried in short bursts. The pulse is usually short compared to the interval between pulses. There is a great diversity of radar, in particular for aeronautical applications, but also in other fields such as, for example, monitoring and control activities. These applications have very varied characteristics, typically in frequency between 100 MHz and 95 GHz and in peak power between 1 W and 50 MW. The values to be assessed (for the electric and magnetic field) are the peak value and "rms" value of the pulsed field.

For the assessment of the peak value, the procedure should be in accordance with the following steps:

- Choose a sufficiently broadband filter to take measurements over one duration lower than the impulse (in the case of an unmodulated impulse, a filter of width $4/\tau$, with τ duration of the impulse makes it possible to obtain 99% of the power of the signal),
- Select " max hold " mode for 1 or several rotations of the radar (until stabilisation of the signal),
- Select "positive peak detection" mode,

- With a span “0” centred on the frequency of the emission.

The peak power should not exceed the reference level by a factor of:

- 1000 if you deal with the power density,
- 32 if you deal with the field strength.

The figures above have to be in accordance with the adopted guideline[4], and do not directly relate to the pulse characteristics of the radar.

For the assessment of the “rms” field-strength, it is necessary either:

- To know the temporal characteristics of the signal in order to determine the average value, knowing the peak value,
- Or, to carry out the average of the instantaneous signal in “rms” mode.

The “rms” value averaged over the measurement period should not exceed the reference level. Many radar antennas have a narrow beam with agility in direction obtained by mechanical or electronic means. In general in these cases it is not useful to assess the average value.

4.5 Discontinuous signals

For this type of signal, 2 different cases should be considered:

1 - The technical parameters of the signal are known (duty cycle, modulation…), it is recommended to:

- Set the centre frequency on each channel of the emission with a resolution equal (if possible, otherwise larger) to the bandwidth of the channel,
- Select “max hold mode”,
- Select “peak” detector.

The “rms” value is then assessed by calculation:

- If a single dipole or single loop is used, 3 measurements should be performed in 3 orthogonal directions to obtain the different components of the field. The total field would be given by the following formula :

$$|E| = \sqrt{|Ex|^2 + |Ey|^2 + |Ez|^2}\ ,\ |H| = \sqrt{|Hx|^2 + |Hy|^2 + |Hz|^2}$$

2 - The technical parameters of the signal are unknown, it is recommend to:

- Set the centre frequency on each channel of the emission with a resolution equal (if possible, otherwise larger) to the bandwidth of the channel,
- Select “Average mode” during adequate time (the measurement duration should be referenced to the exposure guidelines used (For example 6 minutes in EU 1999/519/EC)),
- Select “rms” detector,
- If a single dipole or single loop is used, 3 measurements should be performed in 3 orthogonal directions to obtain the different components of the field. The total field would be given by the following formula :

$$|E| = \sqrt{|Ex|^2 + |Ey|^2 + |Ez|^2}\ ,\ |H| = \sqrt{|Hx|^2 + |Hy|^2 + |Hz|^2}$$

The operator should be requested to activate the station so as to avoid a long period of observation.

4.6 Trunked Systems (GSM, TETRA,…)

Transmissions by these systems consist of a permanent control channel and additional traffic channels. A base station could be regarded as n transmitters:

- 1 transmitter (for example in GSM 900/1800, BCCH channel) with a constant power level $P_{\text{control channel}}$,
- (n-1) transmitters of a power level equal to $P_{\text{control channel}}$ (n numbers total transmitters or " TRX " of the base station).

[4] e.g. EU 1999/519/EC

In order to take into account the maximum possible traffic, it is recommended to proceed as follows:

- Identify the permanent control channel. This can be done (using a spectrum analyser the permanent control channel is identified by its permanence and its stable level),
- Set the centre frequency on the permanent control channel with a resolution equal (if possible, otherwise larger) to the bandwidth of the channel,
- Select “max hold mode”,
- Select “peak” detector,
- If a single dipole or single loop is used, 3 measurements should be performed in 3 orthogonal directions to obtain the different components of the field. The total field would be given by the following formula :

$$|E| = \sqrt{|Ex|^2 + |Ey|^2 + |Ez|^2}\ ,\ |H| = \sqrt{|Hx|^2 + |Hy|^2 + |Hz|^2}$$

$E_{\text{control channel}}$ is then assessed

- Investigate the number of transmitters of the base station (traffic channels & control channel). Using a spectrum analyser, one can also note the numbers of channels except in some cases of frequency hopping.

The extrapolation to the maximum traffic is then calculated by the following formula :

$$E_{\max} = E_{Control\ \ Channel} \times \sqrt{n_{Transmitters}}$$

If the transmitting channels belonging to the same cell are using different power levels, the following formula should be used:

$$E_{\max} = E_{Control\ \ Channel} \times \sqrt{\frac{P_{total}}{P_{Control-Channel}}}$$

P_{total} is the maximum possible power.

4.7 Analog /Digital wide-band emissions (TV, T-DAB, DVB-T, …)

For these types of emissions, it could be difficult to get a resolution equal to the bandwidth of the emissions, so the procedure should be according to the following steps :

- Select a lower resolution filter and carry out a cumulative calculation taking into account the shape of the resolution filter. This type of process is known as the " Channel Power " mode,
- The measurement duration should be referenced to the exposure guidelines used (For example 6 minutes in EU 1999/519/EC)),
- If a single dipole or single loop is used, 3 measurements should be performed in 3 orthogonal directions to obtain the different components of the field. The total field would be given by the following formula :

$$|E| = \sqrt{|Ex|^2 + |Ey|^2 + |Ez|^2}\ ,\ |H| = \sqrt{|Hx|^2 + |Hy|^2 + |Hz|^2}$$

4.8 W-CDMA technology

An extrapolation of maximum traffic could be also be done for UMTS networks, however, the methodology is different compared to that for GSM. For UMTS networks using a CDMA (Code Division Multiple Access) technology measurements of power in the code domain should be done. The first step is to identify a particular common channel, the "P-CPICH" (Common Pilot Channel) and then to measure the power of this channel $P_{P\text{-}CPICH}$. The UMTS maximum power associated with this channel will be deduced from $P_{P\text{-}CPICH}$ using a coefficient shown below.

The principle of measurement and calculation is thus as follows:

Using aa spectrum analyser, identify all UMTS emissions "UMTS" and store their centre frequency (called $freq_O$ below).). For each emission, using a "UMTS" scanner, obtain the P-CIPCH$_i$ power of the various detected channels "CPICH$_i$"" and then sum sum the power for all the CPICH$_i$ channels associated with a given frequency:

$$P_{P-CPICH}(freq_0) = \sum_{i=1}^{n} P_{P-CPICH_i}(freq_0)$$

The equivalent $E_{P\text{-}CPICH}$ ($freq_O$) will be calculated starting from the value of P-CPICH ($freq_O$) by integrating the antenna factor and the cable losses.. The following formula makes it possible to calculate the E field for the maximum traffic at the frequency $freq_O$ by using the $R_{P\text{-}CPICH}$ coefficient:

$$E_{Max}(freq_0) = E_{P-CPICH}(freq_0) \times \sqrt{R_{P-CPICH}}$$

with

$$R_{P-CPICH} = \frac{P_{\max}}{P_{P-CPICH}}$$

5 UNCERTAINTY ESTIMATION

The measurement uncertainty should be evaluated for those measurements addressed in the following sub-clauses, taking into consideration each of the quantities listed there. The standard uncertainty $\mathbf{u(x_i)}$ and the sensitivity coefficient $\mathbf{c_i}$ shall be evaluated for the estimate $\mathbf{x_i}$ of each quantity. The combined standard uncertainty $\mathbf{u_c(y)}$ of the estimate y of the measurand is calculated as a weighted root sum square (r.s.s.):

$$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i * u_{(x_i)})^2}$$

The expanded measurement uncertainty u_e is calculated as:

$$u_e = 1{,}96\, u_c$$ [5]

and should be stated in the measurement report :

- For RF radiation meters with isotropic field probes :

Input Quantity	Uncertainty of x_i		$u(x_i)$	c_i	$(c_i\, u_{(xi)})^2$ %
	Value %	Probability distribution ; Divisor k			
Isotropy		rectangular; $\sqrt{3}$		1	
Linearity		rectangular; $\sqrt{3}$		1	
Flatness		normal; k=1		1	
Temperature		rectangular; $\sqrt{3}$		1	
…..	….	…..	….	...	…….
Combined standard uncertainty	$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i * u_{(x_i)})^2}$				
Expanded uncertainty (confidence interval of 95%)	$u_e = 1.96\, u_c =$				

- For a receiver or spectrum analyser (associated with a calibrated antenna) :

Input Quantity	Uncertainty of x_i		$u(x_i)$	c_i	$(c_i\, u_{(xi)})^2$ %
	Value %	Probability distribution ; Divisor k			
Measurement device (receiver, spectrum analyser) including cable loss		normal; k=1		1	
Antenna factor		normal; k=1		1	
…..	….	…..	….	...	…….
Combined standard uncertainty	$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i * u_{(x_i)})^2}$				
Expanded uncertainty (confidence interval of 95%)	$u_e = 1{,}96\, u_c =$				

[5] The coverage factor of 1.96 yields a 95% level of confidence for the near-normal distribution typical of most measurement results.

6 REPORT

The measurement report shall follow the structure defined in Annex 6. For Case 3 the following particularities have to be taken into account.

Measurement data should be presented in tabular form (graphical form optional) for each measurement location against the recommended levels.

Measured component E (or H)

Frequency	Value	Results	Unit	Equipment

Application of recommendation/guidelines

Measured and calculated quantities have to be used to check the compliance of RF exposure with the legislation in force, i.e.:

- E, H and S have to be compared to reference levels,
- E, H and S are used to calculate the eventual quotients (see Case 2 for examples).

Annex 6

REPORT

The main elements of the report structure are as follows:

1 OBJECTIVES AND LIMITATIONS

The objectives and the operation should be described (site of measurement, choice of the points of measurement).

2 DESCRIPTION OF THE SITE OF MEASUREMENT

Information below should be provided:

- Date, start & stop time,
- Geographic co-ordinates (based on WGS84): Latitude – Longitude (GPS),
- Address,
- Description and particular characteristics of the site of measurement (In the case of an operation in a complex area (in an urban area for example), the exact site of measurement has to be described),
- List of visible identified transmitters,
- Temperature in °C.

3 DESCRIPTION OF EQUIPMENT'S

The used equipment and its relevant characteristics will be noted in the report. Examples for some categories of equipment categories are described below.

- For an antenna:

Antenna n°....	
Manufacturer	Gain (Fmin and Fmax –Gain in the axis)
Type	Antenna factor uncertainty
Frequency band	Check / update date

- For a Spectrum Analyser or receiver :

Equipment n°	
Manufacturer	Frequency Band
Type	Check / update date
Measurement Uncertainty	

- For a probe

Equipment n°	
Frequency Band	Dynamic range
Measurement uncertainty	Check / update date

4 UNCERTAINTY

In order to be complete, each measurement should be accompanied by a statement of uncertainty in accordance with the specifications introduced in Case 1, Case 2 or Case 3. However, due to the in-situ nature of the measurement site, it may not be practical to include all the uncertainties associated with the measurement location.

5 REPORT OF MEASUREMENTS

The Report of measurements should be in accordance with the specifications introduced in Case 1, Case 2 or Case 3.

6 APPLIED LIMITS AND FORMULAS FOR TOTAL EXPOSURE QUOTIENTS

The value of limits in the observed frequency band and the method to obtain the total exposure quotients should be described. Alternatively the method could be referred to.

7 CONCLUSION

A conclusion on the conformity of the RF exposure with respect to the guidelines will be specified.