CEPT ECC
Electronic Communications Committee

ECC Recommendation (02)04

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

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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/SG5, and EBU.

It is intended that this Recommendation will assist other competent bodies in their work and interchange of information.

ECC RECOMMENDATION (02)04 OF 30 SEPTEMBER 2002 ON MEASURING NON-IONISING ELECTROMAGNETIC RADIATION (9 KHZ – 300 GHZ), REVISED OCTOBER 2003, AMENDED 6 FEBURARY 2007 AND AMENDED 17 OCTOBER 2025

"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;

d) that European Standard EN 50413 "Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz - 300 GHz)" provides general methods for measurement of quantities associated with human exposure to electromagnetic fields;

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 Annex 2, Annex 3, Annex 4 and Annex 5,

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

Note:

Please check the ECO Documentation Database https://docdb.cept.org/ for the up to date position on the implementation of this and other ECC Recommendations.

ANNEX 1: GENERAL INFORMATION

A1.1 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 providing confidence in the results.

The methods are not suitable for situations where 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 are not within scope of this measurement process.

A1.2 NORMATIVE REFERENCES

ISO/IEC Guide 98-1:2024 “Guide to the expression of uncertainty in measurement”

A1.3 PHYSICAL QUANTITIES AND UNITS

SI-units are used throughout the present recommendation:

Table 1: Physical quantities and units

Quantity	Symbol	Unit	Symbol
Frequency	f	Hertz	Hz
Wavelength	λ	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/m²
Intrinsic impedance	Z	Ohm	Ω
Largest dimension of the antenna	D	metre	m

A1.4 TERMS AND DEFINITIONS

A1.4.1 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).

A1.4.2 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).

A1.4.3 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/m²), milliwatts per square centimetre (mW/cm²), or microwatts per square centimetre (μW/cm²).

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,

$$S = \frac{E^2}{377} \text{ or } S = 377 \times H^2 \quad (1)$$

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

A1.4.4 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.

A1.4.5 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 are large compared to the wavelength, the radiating near-field region is sometimes referred to as the Fresnel region – by way of analogy to optical terminology.

A1.4.6 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:

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

where:

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

A1.4.7 Peak Value

It corresponds to the maximum absolute value of the function.

A1.4.8 Mean Value

Mathematically, the mean value can be defined as:

$$\bar{x} = \lim_{T\to\infty} \frac{1}{T} \int_0^T x(t)dt \tag{3}$$

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.

A1.4.9 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.

A1.4.10 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);
- to decide whether a spatial average according to A1.6.2 has to be established.

A1.4.11 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.

A1.4.12 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).

A1.5 EXAMPLES OF EMISSIONS IN THE FREQUENCY BAND FROM 9 KHZ TO 300 GHZ

Table 2: Examples of emissions in the frequency band from 9 kHz to 300 GHz

Symbols	Frequency range (lower limit exclusive, upper limit inclusive	Services and applications
VLF	9 to 30 kHz	Induction heating
LF	30 to 300 kHz	Industrial induction heating, AM broadcasting, clock transmitters, wireless power transmission
MF	300 to 3 000 kHz	AM radio, industrial induction heating, wireless power transmission
HF	3 to 30 MHz	Broadcasting, Radio-amateurs, Armed Force, wireless power transmission
VHF	30 to 300 MHz	PMR, TV, Armed Forces, Radio-amateurs, FM broadcasting, Aeronautical services
UHF	300 MHz to 3 000 MHz	TV, Public Mobile Networks, DCS, DECT, Bluetooth, earth station, Radar
SHF	3 to 30 GHz	Public Mobile Networks, Radar, Earth stations, Microwave links, Ultrawideband systems, Safety scanners
EHF	30 to 300 GHz	Radar, microwave links, Safety scanners, Industrial radiolocation

A1.6 GENERAL CONSIDERATIONS FOR MEASUREMENT OPERATION

A1.6.1 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]:

$$E = H \times Z_0 \ , \ S = H^2 \times Z_0 \quad \text{knowing } Z_0 = 377\Omega \tag{4}$$

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

If there is any doubt about sensor performance in the far field due to, for example, environmental conditions, both E and H fields may be measured separately and the free space impedance calculated. This is usually only done at low frequencies (VLF, LF, MF and HF).

Table 3: Method to be applied at different distances from transmitters

	Reactive near-field region	Radiating near-field region	Far-field region
Lateral edge of the region, measured from antenna	0 to λ	λ to $\lambda+2D^2/\lambda$	$\lambda+2D^2/\lambda$ to ∞
E $\perp$ H	No	Quite Yes	Yes
Z = E / H	$\neq$ Zo	$\approx$ Zo	= Zo
Component to be measured	E & H	E or H	E or H

As measurements are usually made in the far-field region, only one field component E or H needs to be measured. In case measurements of E or H have to be done in the radiating near-field, several measurement points should be chosen, or the measurement shall be performed in accordance with the instructions of the measurement equipment. For certain antenna types, the distances can be alternatively defined based on international standards (e.g. IEC 62232).

A1.6.2 Measurement point (s)

A1.6.2.1 Location of measurement points:

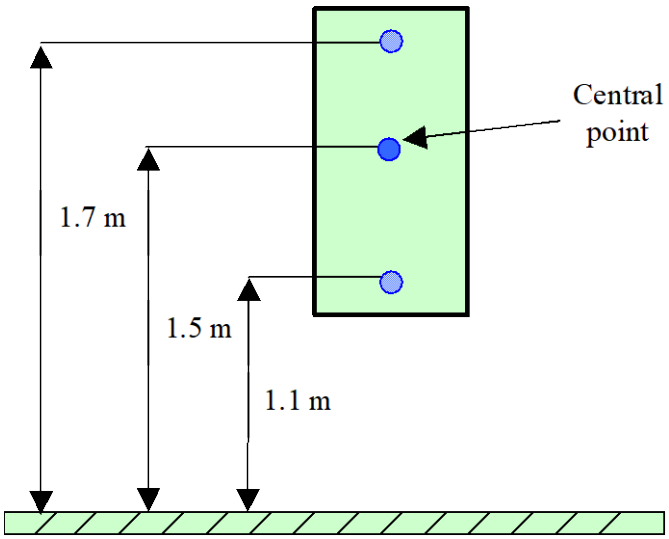
Measurement point(s) should be chosen to represent the highest levels of exposure to which a person might be subjected, considering the positions of neighbouring antennas. These locations can either be found by a quick check using measuring equipment (see case 1 and case 2), or, if that doesn't succeed,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

The measurement antenna shall not be positioned too close to conducting objects.

A1.6.2.2 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 root mean squared value of the three values, obtained for each spatial point:

$$E_{spatial_average} = \sqrt{\frac{\sum_{i=1}^{3} E_i^2}{3}}, \quad H_{spatial_average} = \sqrt{\frac{\sum_{i=1}^{3} H_i^2}{3}} \tag{5}$$

A1.6.3 PRE PROCESSING

A1.6.3.1 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.

ANNEX 2: APPLICABILITY OF NON-IONISING RADIATION MEASUREMENT METHODS

A2.1 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 A1.6.2 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;
e) If the measurement location is not in the far field region of the transmitter.

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

A2.2 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 wideband 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.

A2.3 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 wideband emissions).

ANNEX 3: MEASUREMENT METHOD APPLICABLE TO CASE 1

A3.1 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.

A3.2 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 RMS value (Peak detectors will give an artificially high result for elliptically polarised signals or signals with a peak-to-average power ratio larger than unity). A RF radiation meter with RMS detector will provide the most accurate result for the existing EMF.

A3.3 MEASUREMENT PROCEDURE

The procedure should follow these steps:

A3.3.1 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 equation:

$$E = \sqrt{\sum_{i=1}^{n} E_i^2} \quad \text{or} \quad H = \sqrt{\sum_{i=1}^{n} H_i^2} \tag{6}$$

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 in practice the probe frequency bands overlap each other, and the equation does not correct this.

Preferably, 3-axis probes shall be used, capable of measuring each polarisation of the signal. If not possible or available, a single polarisation antenna can be used to measure each polarisation individually.

A3.3.2 Measurement:

The choice of measurement point (location and number of points) will be in accordance with the general considerations (A1.6.2).

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 RMS value of E (or H). Personnel should be retreat from the antenna during measurements. Personnel should switch off close-in radiating equipment that could influence the measurement.

A3.4 POST-PROCESSING

A3.4.1 According to the value obtained:

- If the value is below the usable 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.

A3.4.2 Calculation of Electric field (E) / Magnetic field (H) / Power density (S)

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

$$S = EH \ or \ S = \frac{E^2}{Z_0} \ or \ S = H^2 Z_0 \tag{7}$$

where:

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

A3.4.3 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:

$$\mathrm{E}_{\mathrm{sum}} = \sqrt{\sum_{i=1}^{n} \mathrm{E}_{\mathrm{i}}^2} \tag{8}$$

where:

- E_{sum} is the display value of the RF meter (probe);
- n, the number of emissions.

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

A3.5 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 (RSS)[1]:

$$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i * u_{(x_i)})^2} \tag{9}$$

[1] ECC/REC/(17)01: Measurement uncertainty assessment for field measurements; Calculation of the combined measurement uncertainty (STEP 4), page 9.

The expanded measurement uncertainty u_e is calculated as:

$$u_e = 1{,}96\, u_c \quad [2] \tag{10}$$

and should be stated in the measurement report.

Table 4: Uncertainty calculation

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%)	$u_e = 1.96\, u_c$				

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:

Table 5: Typical Uncertainty Values

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

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

Table 6: Uncertainty calculation result

Quantity	Equation	Resulting value
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%)	$u_e = 1.96\, u_c$	2.05 dB

It needs to be noted that for common EMF measurement equipment the uncertainty of the separate factors such as anisotropy are taken into account during calibration, so measurement uncertainty is usually expressed as a single value. For more information on measurement uncertainty in field strength measurements see ECC/REC/(17)01 of 3 February 2017 on measurement uncertainty assessment for field measurements.

A3.6 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.

Table 7: Measurement Report Structure

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			

A3.6.1 Calculated component(s)

H (or E), S can be calculated taking into account the remarks in A3.4.2 Post processing "*Calculation of Electric field / Magnetic field H / Power density*"

A3.6.2 Application of recommendation / guidelines

When assessing human radiation exposure, linear units V/m are used. Measuring instruments may display values in logarithmic units (e.g. dBµV/m) therefore in that case, it is appropriate to convert logarithmic units to linear units in the report. Conversion procedures are given in ETSI TR 100-028 -1.

Unless the probe provides an immediate assessment of the result in terms of exposure ratio, measured and calculated quantities have to be compared to the lowest reference level (see A1.4.9) 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

A4.1 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.

A4.2 MEASUREMENT EQUIPMENT

This type of survey is best carried out using a 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 intermodulation 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. All electronic devices of personnel, that could influence the measurements, should be switched off.

A4.3 MEASUREMENT PROCEDURE

The procedure should be conducted according to the following steps:

A4.3.1 Measurement point

The choice of measurement point (location and number of points) will be in accordance with the general considerations (A1.6.2).

A4.3.2 Frequency band

The method is appropriate to frequencies between 9 kHz and 6 GHz. Within this frequency range, measurement process and settings of Case 2 provide confident results. But for frequencies above 6 GHz (e.g. radar, microwave links), either Case 1 or recommendations of Case 3 (and especially A5.4) must be applied.

A4.3.3 Settings of receiver or spectrum analyser

A4.3.3.1 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 - 6GHz	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 - 6 GHz	BW = 100 kHz	with a sweep time of 700 ms – 1000 ms

For analysers employing FFT techniques, appropriate settings considering resolution and time behaviour should be chosen.

A4.3.4 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.

A4.3.5 Antenna Polarisation:

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

A4.3.6 Mode:

Max-hold techniques and RMS detector shall be used.

A4.4 POST-PROCESSING

A4.4.1.1 Calculation of Magnetic field H / Power density

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

$$S = EH \ or \ S = \frac{E^2}{Z_0} \ or \ S = H^2 Z_0 \tag{11}$$

where:

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

A4.5 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 (RSS):

$$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i * u_{(x_i)})^2} \quad (12)$$

The expanded measurement uncertainty u_e is calculated as:

$$u_e = 1{,}96\, u_c \quad [3] \quad (13)$$

and should be stated in the measurement report.

Table 8: Uncertainty calculation

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:

Table 9: Uncertainty values

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

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

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

Table 10: Uncertainty calculation result

Quantity	Equation	Resulting value
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%)	$u_e = 1.96\, u_c$	2.28 dB

A4.6 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.

A4.6.1 Measured component E

Table 11: Reporting of the significant emissions

Frequency	Value	Results	Unit	Equipment

A4.6.2 Calculated component(s)

H, S can be calculated taking into account the remarks in A4.4.1.1

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 (see A1.4.9);
- 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:

$$\sum_{i=1}^{N} \frac{S_i^{meas}}{S_i^{guid}} = \frac{S_1^{meas}}{S_1^{guid}} + \frac{S_2^{meas}}{S_2^{guid}} + \frac{S_3^{meas}}{S_3^{guid}} + ... + \frac{S_N^{meas}}{S_N^{guid}} < 1 \quad (14)$$

- 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):

$$\sum_{i=1Hz}^{1MHz} \frac{Ei}{El,i} + \sum_{i>1MHz}^{10MHz} \frac{Ei}{a} \leq 1 \qquad \sum_{j=1Hz}^{150kHz} \frac{Hi}{Hl,j} + \sum_{j>150kHz}^{10MHz} \frac{Hj}{b} \leq 1 \tag{15}$$

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

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

$$\sum_{i=100kHz}^{1MHz} \left(\frac{Ei}{c}\right)^2 + \sum_{i>1MHz}^{300GHz} \left(\frac{Ei}{El,i}\right)^2 \leq 1 \qquad \sum_{j=100kHz}^{150kHz} \left(\frac{Hi}{d}\right)^2 + \sum_{j>150kHz}^{300GHz} \left(\frac{Hi}{Hl,i}\right)^2 \leq 1 \tag{16}$$

(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

A5.1 SCOPE & SPECIFIC REQUIREMENTS

The present method should be applied where Case 1 and 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 wideband emissions).

A5.2 MEASUREMENT EQUIPMENT

The equipment used is the same as used for Cases 1 and 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[4], 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.

A5.3 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).

A5.4 MEASUREMENT PROCEDURE

The procedure should be according to the following steps:

A5.4.1 Measurement point

The choice of measurement points (location and number of points) will be done according to the general considerations (A1.6.2). Personnel should retreat from the antenna during measurements, which should be mounted on non-conductive tripods in order not to perturb electromagnetic field. All electronic devices of personnel, that could influence the measurements, should be switched off.

A5.4.2 Frequency band

Measurement operation is appropriate for frequencies between 9 kHz and 6 GHz. If in a measurement location, there are antennas using frequencies above 6 GHz (for example: radar), the associated emissions have to be measured considering the remarks below (A5.4.4).

A5.4.3 Settings of the equipment

They have to be identical to Case 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 in A5.4.4.

[4] Ultra Wide Band

A5.4.4 Specific configurations

A5.4.4.1 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).

A5.4.4.2 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, attenuators 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 equation:

$$|E| = \sqrt{|Ex|^2 + |Ey|^2 + |Ez|^2} \quad , \quad |H| = \sqrt{|Hx|^2 + |Hy|^2 + |Hz|^2} \tag{17}$$

A5.4.4.3 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.

A5.4.4.4 Signals above 6 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.

A5.4.4.6 Pulsed / Radar emission measurements

For this type of signals, the microwave energy is carried in short pulses. These pulses are usually short compared to the interval between pulses. Other radar characteristics may also vary, 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 radar emission.

For the assessment of the peak value, the procedure should be according to 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 “zero span” mode centred on the frequency of the emission;
- Select “positive peak” detection mode;
- Apply “video trigger” to obtain a stationary readout;
- Select "max hold" mode for 1 or several rotations of the radar (until stabilisation of the signal).

From the measurement result the received peak power density can be calculated by taking into account the antenna factor and the attenuation of the cable.

In order to limit the maximum allowed peak value of exposure, a guideline[5] provides reference values for local short-term exposure, given by levels for incident energy density. The measured peak power density can be expressed in incident energy density by multiplication with the actual exposure time (one or more pulse duration times), according to:

$$U_{inc} = S_{pk} * N * \tau \tag{18}$$

where:

- U_{inc} is the incident energy density in J/m^2;
- S_{pk} is the measured peak power density in W/m^2;
- τ is the pulse length in s;
- N is the number of pulses during the integration time.

For a rotating radar system an integration time of 360 s can be chosen. In that case, the number of pulses that contribute to the exposure during that time can be calculated by the following expression:

$$N = \varphi * prf \tag{19}$$

where:

- φ is the -3 dB beamwidth of the antenna in degrees;
- prf is the pulse repetition frequency in Hz.

Incident energy density derived from the measurement shall be lower than the reference level.

For the assessment of the “RMS” power density , 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.[6]

[5] ICNIRP2020, Table 7

[6] ICNIRP2020, Table 5

A5.4.4.7 Discontinuous signals

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

1 If the technical parameters of the signal are known (e.g. 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 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 equation:

$$|E| = \sqrt{|Ex|^2 + |Ey|^2 + |Ez|^2} \quad , \quad |H| = \sqrt{|Hx|^2 + |Hy|^2 + |Hz|^2} \tag{20}$$

2 The technical parameters of the signal are unknown, 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 “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 equation:

$$|E| = \sqrt{|Ex|^2 + |Ey|^2 + |Ez|^2} \quad , \quad |H| = \sqrt{|Hx|^2 + |Hy|^2 + |Hz|^2} \tag{21}$$

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

A5.4.4.8 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).

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 equation:

$$|E| = \sqrt{|Ex|^2 + |Ey|^2 + |Ez|^2} \quad , \quad |H| = \sqrt{|Hx|^2 + |Hy|^2 + |Hz|^2} \tag{22}$$

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

- Investigate the number of transmitters of the base station (traffic channels and 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 equation:

$$E_{\max} = E_{Control\ \ Channel} \times \sqrt{n_{Transmitters}} \tag{23}$$

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

$$E_{\max} = E_{Control\ \ Channel} \times \sqrt{\frac{P_{total}}{P_{Control-Channel}}} \tag{24}$$

P_{total} is the maximum possible power.

A5.4.4.9 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 equation:

$$|E| = \sqrt{|Ex|^2 + |Ey|^2 + |Ez|^2}\ ,\ |H| = \sqrt{|Hx|^2 + |Hy|^2 + |Hz|^2} \tag{25}$$

A5.4.4.10WCDMA technology

An extrapolation of maximum traffic could 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 $P_{P-CPICH}$. The UMTS maximum power associated with this channel will be deducted from $P_{P-CPICH}$ using a coefficient shown below.

The principle of measurement and calculation is thus as follows:

- Using a spectrum analyser, identify all UMTS emissions "UMTS" and store their centre frequency (called $freq_0$ below). For each emission, using a "UMTS" scanner, obtain the P-CPICH$_i$ power of the various detected channels "CPICH$_i$"" and then sum the power for all the CPICH$_i$ channels associated with a given frequency:

$$P_{P-CPICH}(freq_0) = \sum_{i=1}^{n} P_{P-CPICH_i}(freq_0) \tag{26}$$

- The equivalent $E_{P-CPICH}$ ($freq_0$) will be calculated starting from the value of P-CPICH ($freq_0$) by integrating the antenna factor and the cable losses. The following equation makes it possible to calculate the E field for the maximum traffic at the frequency $freq_0$ by using the $R_{P-CPICH}$ coefficient:

$$E_{Max}(freq_0) = E_{P-CPICH}(freq_0) \times \sqrt{R_{P-CPICH}} \quad (27)$$

with

$$R_{P-CPICH} = \frac{P_{\max}}{P_{P-CPICH}} \quad (28)$$

A5.4.4.11 4G LTE technology

The 4G LTE has two duplex communication methods that are used to separate the uplink from the downlink that should be considered in the measurements:

- The frequency division duplex mode (FDD) uses separate frequency bands for uplink and downlink communications. This frequency separation allows simultaneous transmission and reception, reducing interference between the uplink and downlink signals. FDD is well-suited for symmetric traffic, where the data rates for uplink and downlink are similar;
- The time division duplex mode (TDD) uses a single frequency band for both uplink and downlink communications but separates them in time. The transmission and reception occur in different time slots, allowing the same frequency to be used for both directions. TDD is more flexible in handling asymmetric traffic, where the data rates for uplink and downlink can vary significantly.

To estimate the maximum EMF levels, two methods can be used, using a dedicated decoder for the code selective method or using a spectrum analyser for the frequency selective method, which are both supported by IEC62232. It is also important that the signal level of the received signal isn't traffic dependent. In 4G LTE technology there are reference signals that are time invariant and traffic independent with maximum level, such as the Reference Signal (RS), the Primary Synchronization Signal (PSS), the Secondary Synchronization Signal (SSS) or the Physical Broadcast Channel (PBCH), which can be used for the code selective method. In the frequency selective measurement, the power of the RS signal cannot be measured accurately, because it is transmitted spread in frequency and time. Instead, the PBCH signal is measured. Both methods are acceptable, but the code selective measurement guarantees a better estimation of the EMF levels.

Method 1 – Code selective

In this method dedicated equipment is used that is able to decode LTE signals and measure the level of each of the different components. Normally the received signal reference power (RSRP) is measured, because it is uniformly distributed over the bandwidth of the signal.

Extrapolation to a full traffic situation can be calculated with the following equation:

$$P_{tot} = 10log\left(\sum_{i=0}^{k} 10^{\frac{RSRP_i}{10}}\right) + 10\log(n) - P_B \quad (29)$$

where:

- P_{tot} is the total mean level for all antennas in a full traffic load situation in dBm;
- $RSRP_i$ is the reference signal power produced by i^{th} transmitting antenna in dBm;
- k is the number of antennas;
- n is the number of subcarriers in the relevant LTE signal as provided in the following table;
- P_B is the reference signal power boosting value in dB (usually equal to 0 dB unless other information from the provider is available).

Table 12 indicates the number of active subcarriers in the LTE signal depending on the bandwidth of the LTE signal:

Table 12: Number of active subcarriers in the LTE signal depending on the bandwidth of the LTE signal

LTE signal bandwidth, in MHz	Number of subcarriers in LTE downlink signal
1.4	72
3	180
5	300
10	600
15	900
20	1200

To determine the field strength or power density from the extrapolated power by considering the antenna factor and cable loss in the measurement setup, the following equation can be applied for electric field strength:

$$E_{ext} = P_{tot} + K_a + L_c + 107 \quad (30)$$

where:

- E_{ext} is the extrapolated electric field strength in dBµV/m;
- P_{tot} is the maximum (extrapolated) received level in dBm;
- K_a is the antenna factor of the measurement antenna in dB/m;
- L_c is the loss of the cable between measurement antenna and receiver in dB.

Method 2 – Frequency selective

For the frequency selective method the PBCH signal can be used, which is transmitted at the centre frequency of the OFDM signal.

For the measurement using a SA is recommended that:

- set the centre frequency on the SA to centre frequency of the 4G LTE signal;
- set the span to “Zero span”;
- use a resolution bandwidth (RBW) of 1 MHz;
- the trace should be set to maximum hold, using a sweep time of 2 ms and a trigger fixed every 10 ms for a holding time of 20 s. The offset should be adjusted to guarantee that the PBCH signal is in the display window;
- select “RMS” detector.

Assuming that in a full traffic situation all subcarriers are transmitted with same power as the PBCH, the total mean power can be calculated by:

$$P_{tot} = P_{meas} + 10log\left(\frac{B_{LTE}}{RBW}\right) \quad (31)$$

where:

- P_{tot} is the total mean level in a full traffic load situation in dBm;
- P_{meas} is the measured PBCH level in dBm;
- B_{LTE} is the bandwidth of the LTE channel in MHz;
- RBW is the resolution bandwidth of the spectrum analyser in MHz.

The equation (30) can be used as in the previous method to determine the field strength or power density from the extrapolated power by considering the antenna factor and cable loss of the measurement setup.

A5.4.4.12 5G NR technology

5G NR is a spread spectrum technique that uses massive MIMO and can be used with various signal bandwidths in FDD, but usually in TDD application. The 5G NR signal is digitally modulated with OFDMA, consisting of a number of subcarriers that are assigned to different users.

The main difference between 5G NR technology and earlier technologies is that almost no power is transmitted when there is no traffic demand. The only signals that are always emitted with maximum power are synchronisation signals, which contribute only marginally to the maximum power capability of the base station. However, synchronisation signals can be used as a starting point for extrapolation to maximum exposure at highest traffic load.

Another difference with previous technologies is that 5G NR supports the use of Active Antenna Systems (AAS), which enables beamforming in order to address individual UEs.

Broadcast beams are transmitted relatively wide to identify subscribers. For the purpose of data traffic to a specific UE, a narrower traffic beam is applied. Hence, maximum exposure can only occur when a traffic beam is pointed towards a subscriber.

These advancements complicate the task of doing EMF measurements. This is because during the time of measurement the base station is expected to provide the maximum possible power and, at the same time, the antenna beam should be pointed towards the measurement position. Basically, two methods can be applied to estimate the situation of maximum exposure.

Method 1 – Traffic based

Maximum power can be simulated by generating full traffic[7] and attracting the antenna beam by a UE (e.g. smartphone or CPE). However, some precautions shall be taken into account:

- all available resource blocks shall be operative and dedicated to the UE, or the measurement equipment must be able to determine the resource blocks dedicated to the UE;
- the entire instantaneous signal bandwidth of the 5G NR signal shall be assessed;
- avoid influence due to the presence of a nearby UE (TDD uplink);
- risk of underestimation due to power control backoff by the base station.

The measurement can be done using dedicated frequency selective EMF equipment, or by using a real-time spectrum analyser. Preferably, a 3-axis antenna is used. In case a 3-axis antenna is not used, separate measurements for each polarisation shall be performed, after which the results have to be combined.

In case it cannot be guaranteed that all available resource blocks are dedicated to the UE during the measurement, the equipment has to be able to display the frame used for the measurement, including the level of each RB. The average power of those resource blocks assigned to the UE is then extrapolated to full bandwidth using:

$$Pext = PRB,avg + 10log(NRB) \quad (32)$$

where:

- P_{ext} is the extrapolated power;
- $P_{RB,\ avg}$ is the average measured power of the resource blocks;
- N_{RB} is the total number of resource blocks.

[7] For this purpose a UE with a data download tool can be used (e.g. Iperf).

In the case where multiple operators are present at a single site, the measurement must be done separately for each operator.

Method 2 – Broadcast based

Maximum field strength shall be calculated based on the measurement and extrapolation of the measured power of the synchronisation signals, which method is supported by IEC62232. The following steps shall be taken.

1 Initially, determination of the power of the synchronisation signal block (SSB) per resource element (SS-RSRP) shall be done, either from the primary synchronisation signal (PSS) or secondary synchronisation signal (SSS). The measurement device can either be a NR decoder or a spectrum analyser. An NR decoder is desirable, because SS-RSRP power is provided instantly. When using a spectrum analyser, first the highest SSB has to be traced and measured in zero-span mode, using a sweep time of 20 ms[8], a resolution bandwidth (RBW) smaller than 127 subcarriers (e.g. 1 MHz) and an RMS detector. Subsequently, SS-RSRP power can be determined after correction by the ratio of the subcarrier spacing (SCS) and the applied RBW, according to:

$$P_{SS\text{-}RSRP} = P_{meas} + 10log(SCS / RBW) \quad (33)$$

where:

- $P_{SS\text{-}RSRP}$ is the power per resource element;
- P_{meas} is the measured power of the strongest SSB;
- SCS is the subcarrier spacing;
- RBW is the resolution bandwidth of the spectrum analyser.

2 Once SS-RSRP is known, the extrapolation is done using the following expression:

$$P_{ext} = P_{SS\text{-}RSRP} + 10log(F_{BW} * F_{PR} * F_{TDC} * F^{-1}_{B} * F_{extBeam}) \quad (34)$$

where:

- P_{ext} is the extrapolated power;
- F_{BW} is the ratio of the total carrier bandwidth and the SCS, as given in Table 13;
- F_{PR} is the power reduction factor, if applicable[9], otherwise it is set to 1;
- F_{TDC} is the technology duty cycle;
- F_B is the reference signal power boosting value;
- $F_{extBeam}$ is the radiation pattern envelope ratio of broadcast beam and traffic beam[10].

[8] Typical periodicity of SSB(SS+PBCH) in NR is 20 ms, but the periodicity can vary according to 3GPP specification.

[9] When the 'actual maximum approach' is applied, the output power of the base station will be limited when a particular number of subscribers is reached.

[10] $F_{extBeam}$ can be determined from information from the mobile operator, or by time domain measurement and comparison of SS/PBCH (SSB) and PDSCH (traffic data) frames.

Table 13: Number of active subcarriers in the NR signal depending on the bandwidth and the SCS for FR1

	SCS [kHz]		
Bandwidth [MHz]	15	30	60
5	300	132	n/a
10	624	288	132
15	948	456	216
20	1272	612	288
25	1596	780	372
30	1920	936	456
35	2256	1144	528
40	2592	1272	612
45	2904	1428	696
50	3240	1596	780
60	n/a	1944	948
70	n/a	2268	1116
80	n/a	2604	1284
90	n/a	2940	1452
100	n/a	3276	1620

3 Finally, the field strength or power density can be calculated from the extrapolated power by taking into account the antenna factor and cable loss of the measurement setup. For electric field strength the following expression can be used:

$$E_{ext} = P_{ext} + K_a + L_c + 107 \quad (35)$$

where:

- E_{ext} is the extrapolated electric field strength in dBµV/m;
- K_a is the antenna factor of the measurement antenna in dB/m;
- L_c is the loss of the cable between measurement antenna and receiver in dB.

It should be noted that Method 2 is only applicable if it can be assured that the measurement location is within the vertical and horizontal main lobe of the SSB. Furthermore, this method requires a-priori knowledge of the antenna gains of SSB and traffic beams.

Preferably, both methods 1 and 2 shall be applied. The highest result of the two shall be used.

A5.5 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 **$u(x_i)$** and the sensitivity coefficient **c_i** shall be evaluated for the estimate **x_i** of each quantity. The combined standard uncertainty **$u_c(y)$** of the estimate y of the measurand is calculated as a weighted root sum square (RSS):

$$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i * u_{(x_i)})^2} \quad (36)$$

The expanded measurement uncertainty u_e is calculated as:

$$u_e = 1{,}96\, u_c \quad [11] \quad (37)$$

and should be stated in the measurement report:

- For RF radiation meters with isotropic field probes:

Table 14: Uncertainty calculation

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):

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

Table 15: Uncertainty calculation

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%)	$u_e = 1{,}96\ u_c =$				

A5.6 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.

A5.6.1 Measured component E (or H)

Table 16: Report of measurement results

Frequency	Value	Results	Unit	Equipment

A5.6.2 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 (see A1.4.9),
- 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:

A6.1 OBJECTIVES AND LIMITATIONS

The objectives and the operation should be described (site of measurement, choice of the points of measurement, mode of operation of transmitter under test, measurement method applied).

A6.2 DESCRIPTION OF THE SITE OF MEASUREMENT

Information below should be provided:

- Date, start and stop time;
- Geographic coordinates (based on WGS84): Latitude – Longitude (GPS);
- Height of the measurement above ground level (a.g.l) (e.g. high story building balcony, roof);
- Address (where applicable);
- 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 transmitters, impacting the measured result;
- Temperature in °C.

A6.3 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 in Table 17, Table 18 and Table 19.

- For an antenna:

Table 17: Antenna specification

Antenna n°....	
Manufacturer	Gain (F_{min} and F_{max} –Gain in the axis)
Type	Antenna factor uncertainty
Frequency band	Check / update date

- For a Spectrum Analyser or receiver:

Table 18: Receiver specification

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

- For a probe:

Table 19: Probe specification

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

A6.4 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.

A6.5 REPORT OF MEASUREMENTS

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

A6.6 APPLIED LIMITS AND EQUATIONS 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.

A6.7 CONCLUSION

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