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**THE INFORMATION AND COMMUNICATION TECHNOLOGIES
AUTHORITY IN-SITU MEASUREMENT PROTOCOL FOR
DETERMINATION OF RF FIELDS (300 MHz – 6 GHz) IN THE VICINITY
OF RADIO COMMUNICATION BASE STATIONS FOR THE PURPOSE OF
EVALUATING GENERAL PUBLIC EXPOSURE TO ELECTROMAGNETIC
FIELDS (EMF)**

REVISIONS

Revision no.	Date	Nature of Revision
V 1	30 April 2009	Creation of document

1 INTRODUCTION

Under section 18(1)(n) of the ICT Act 2001 (as amended), the ICT Authority has the function to “ensure the safety and quality of every information and communication services including telecommunication service and, for that purpose, determine technical standards for telecommunication network, the connection of customer equipment to telecommunication networks”

The aim of this document is to describe the measurement method that has been adopted by the ICT Authority for the determination of RF fields between 300 MHz and 6 GHz in the vicinity of radio communication base stations for the purpose of evaluating general public exposure to non-ionising electromagnetic fields (EMF).

The applicability of this measurement protocol is limited to Radio Communication Base Stations (RBS) and may not be used to evaluate radiations from portable or mobile stations.

This document has mainly been based on:-

1. The Electronic Communications Committee (ECC) Recommendation (02)04 on “Measuring Non-Ionising Electromagnetic Radiation (9kHz – 300 GHz)”;
2. The International Electrotechnical Commission, IEC Standard 62232 on “Determination of RF fields and SAR in the vicinity of radio communication base stations for the purpose of evaluating human exposure”

2 PHYSICAL QUANTITIES AND UNITS

SI-units are used throughout the present recommendation:

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/m ²
Intrinsic impedance	Z	Ohm	Ω
Largest dimension of the antenna	D	metre	m

3 TERMS AND DEFINITIONS

3.1 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).

3.2 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).

3.3 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).

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

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. Z₀=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.

3.4 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.

3.5 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.

3.6 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.

3.7 Peak Value

It corresponds to the maximum absolute value of the function.

3.8 Mean Value

Mathematically, the mean value can be defined as:

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

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.

3.9 Reference level

The reference levels are derived from the International Commission on Non-Ionizing Radiation Protection (ICNIRP) basic limits of exposure of human beings to electromagnetic fields 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. These limits are adopted by the ICT Authority pursuant to section 18(1)(n) of the ICT Act 2001 (as amended) and in accordance with the ITU-T Rec. K.52.

3.10 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.

3.11 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).

3.12 Radio Communication Base Station (RBS)

Fixed equipment including the radio transmitter and associated antenna(s) as used in wireless telecommunications networks, such as those used in cellular communication, Wireless Local Area Networks, point-to-point communication and point-to-multipoint communication according to ITU-R F.592-3. Examples include rooftop, standalone masts, access point installations, etc. but do not include TV and radio broadcast services

4 ICNIRP BASIC LIMITS FOR GENERAL PUBLIC EXPOSURE

Table 1 shows the basic limits.

Table 1 – ICNIRP basic limits

Type of exposure	Frequency range	Current density for head and trunk (mA/m ²) (rms)	Whole-body average SAR (W/kg)	Localized SAR (head and trunk) (W/kg)	Localized SAR (limbs) (W/kg)
General public	Up to 1 Hz	8			
	1-4 Hz	$8/f$			
	4 Hz-1 kHz	2			
	1-100 kHz	$f/500$			
	100 kHz-10 MHz	$f/500$	0.08	2	4
	10 MHz-10 GHz		0.08	2	4

NOTE 1 – f is the frequency in Hertz.

NOTE 2 – Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm² perpendicular to the current direction.

NOTE 3 – All SAR values are to be averaged over any 6-minute period.

NOTE 4 – The localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.

5 ICNIRP REFERENCE LEVELS FOR GENERAL PUBLIC EXPOSURE

The reference levels in table 2 are derived from the International Commission on Non-Ionizing Radiation Protection (ICNIRP) basic limits of exposure of human beings to electromagnetic fields in table 1.

These reference levels have been adopted by the ICT Authority pursuant to section 18(1)(n) of the ICT Act 2001 (as amended) and in accordance with ITU-T Rec. K.52 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.

Table 2 – ICNIRP reference levels (unperturbed rms values)

Type of exposure	Frequency range	Electric field strength (V/m)	Magnetic field strength (A/m)	Equivalent plane wave power density S_{eq} (W/m ²)
General public	Up to 1 Hz	–	2×10^4	–
	1-8 Hz	10 000	$2 \times 10^4/f^2$	–
	8-25 Hz	10 000	$5\,000/f$	–
	0.025-0.8 kHz	$250/f$	$4/f$	–
	0.8-3 kHz	$250/f$	5	–
	3-150 kHz	87	5	–
	0.15-1 MHz	87	$0.73/f$	–
	1-10 MHz	$87/f^{1/2}$	$0.73/f$	–
	10-400 MHz	28	0.073	2
	400-2000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$f/200$
2-300 GHz	61	0.16	10	

NOTE 1 – f is as indicated in the frequency range column.

NOTE 2 – For frequencies between 100 kHz and 10 GHz, the averaging time is 6 minutes.

NOTE 3 – For frequencies up to 100 kHz, the peak values can be obtained by multiplying the rms value by $\sqrt{2}$ (≈ 1.414). For pulses of duration t_p , the equivalent frequency to apply should be calculated as $f = 1/(2t_p)$.

NOTE 4 – Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 MHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz, it is suggested that the peak equivalent plane-wave power density, as averaged over the pulse width, does not exceed 1000 times the S_{eq} limit, or that the field strength does not exceed the field strength exposure levels given in the table.

NOTE 5 – For frequencies exceeding 10 GHz, the averaging time is $68/f^{1.05}$ minutes (f in GHz).

6 GENERAL PROCESS

Prior to carrying out the process below, it must be ascertained from the operators having their RBS in the vicinity of the measurement site that their installations will be operating normally for a period of at least two weeks during which site measurement may be carried out at any time. The operators may also be requested to submit any additional information (e.g. BCCH frequencies) that will be required in the evaluation.

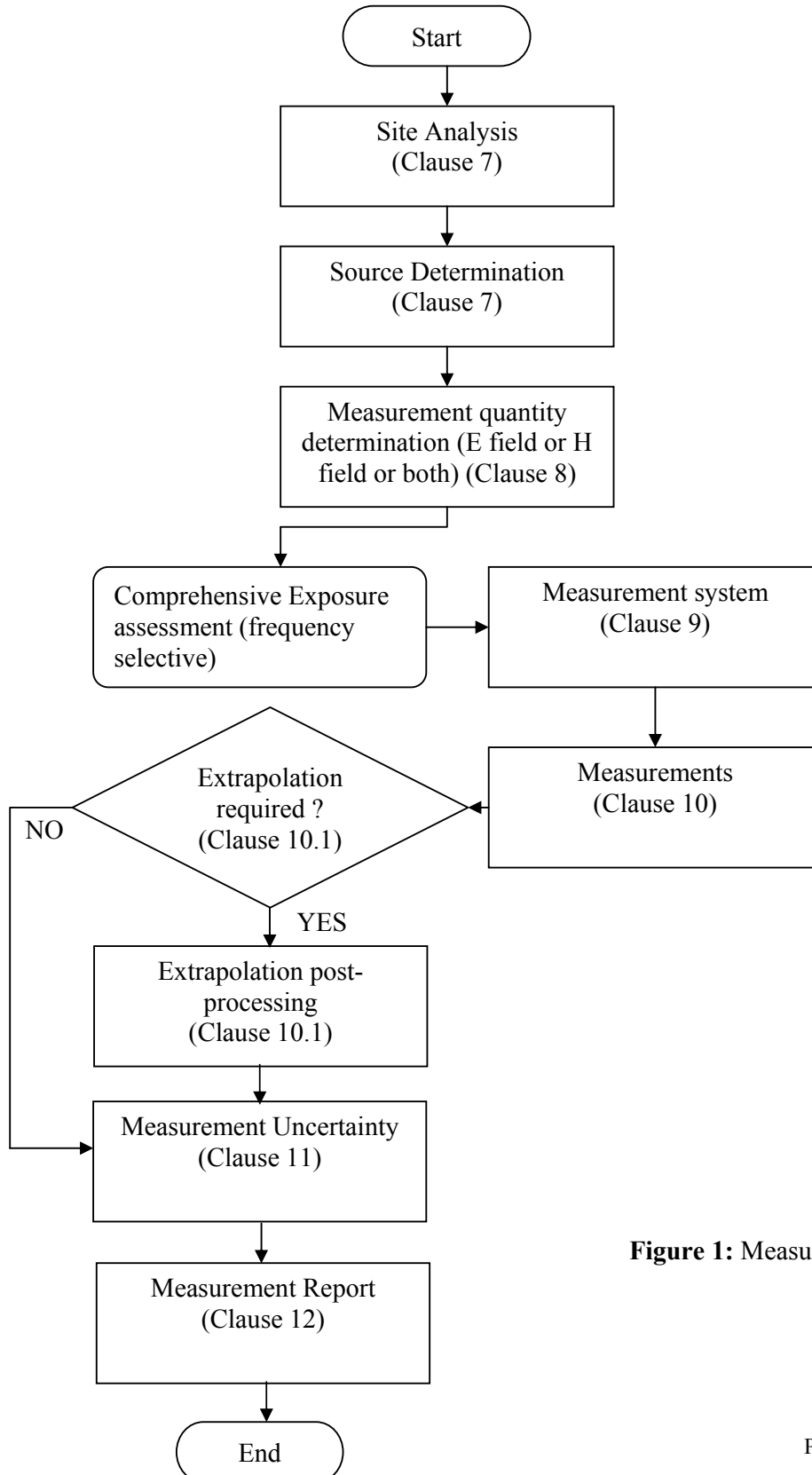


Figure 1: Measurement Process

7 SITE ANALYSIS AND SOURCE DETERMINATION (Source: IEC 62 232)

Where there is a requirement to establish the potential exposure from RF Fields at a given location ambient fields must be evaluated.

Reasonable endeavours should be applied to identify all RF emissions between 100 kHz and 300 GHz. Such sources can be identified through visual inspection, consulting databases and using frequency selective measurements. The ambient fields identified from fixed permanent sources operating between 100 kHz and 6 GHz shall be considered.

Ambient fields need not be evaluated in the following cases:-

1. When the requirement is to establish only exposure from a particular Radio communication Base Station (RBS) RF fields;
2. When the critical exposure condition from the RBS is localized specific absorption rate (SAR). For example a microcell with localized exposure. E.g. a person standing in close proximity to the antenna;
3. for situations where the antennas are operating above 6 GHz, (which are typically point to point sources) and the evaluation locations are beyond the main beam.

8 MEASUREMENT QUANTITY DETERMINATION (Source: ECC(02)04)

This clause explains how to determine the quantity to be measured for evaluating human exposure to EMF.

8.1 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/m²]:

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

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 ($Z_0=377\Omega$). 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 3 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 $\lambda+2D^2/\lambda$	$\lambda+2D^2/\lambda$ to ∞
$E \perp H$	No	Quite Yes	Yes
$Z = E / H$	$\neq Z_0$	$\approx Z_0$	$= Z_0$
Component to be measured	E & H	E or H	E or H

Table 3: Component to be measured at different distances from radio stations

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:

- GSM base station at a distance of 30 cm (λ for 935 MHz) and 15 cm (λ for 1800 MHz),
- UMTS base station at a distance of 14 cm (λ for 2140 MHz)

9 MEASUREMENT SYSTEM (Source: IEC 62 232)

The measurement technique used by the Authority to evaluate human exposure to EMF is Frequency selective field measurement.

This technique employs spectrum analysis or channel decoding to isolate and identify RBS source and ambient frequencies. The method is used:

- To discriminate signals from different sources
- When ambient fields are comparable to, or may exceed, the level of the RBS source;
- When information is needed to enable extrapolation for the purpose of demonstrating compliance with a limit or exceedance of a limit;
- For measurements in low field strength environments (e.g. public areas) where the higher sensitivity of spectrum analysers/receivers compared with broadband probes makes this method especially suitable.

The measurement system used by the Authority to carry out human exposure to EMF measurements consists of the following:-

1. Agilent E4407B (ESA Series) spectrum analyzer, 9 kHz – 26.5 GHz;
2. Broadband logarithmic periodic (log-per) antennas
3. 10 m low loss calibrated coaxial cable

10 MEASUREMENT PROCEDURES – THE SWEEPING METHOD (Source: IEC 62 232)

The sweeping method may be used to find maximum field values within a volume such as a room. With a view to ensuring reproducible measurements, only emitted time invariant signals or parts thereof are suitable to be measured (e.g. The BCCH for GSM).

- To effect the measurement, the antenna shall be moved smoothly throughout the region without touching objects; a distance of at least 20cm shall be maintained between walls, floor, ceiling, furniture and other objects, and the antenna;
- Measurements up to a height of 2 m above the floor are sufficient;
- The antenna shall be moved vertically and horizontally throughout the region under test while observing the instrument display;
- The directional antenna shall be rotated or oriented appropriately to measure orthogonal components of the electric field;
- Careful sweeping is necessary around the location where the value of interest is expected;
- The r.m.s. detector shall be selected except when indicated otherwise in clause 10.1;
- When searching for a peak in a region the displayed/recorded signal trace shall be set to capture the maximum level (e.g. “max. hold”);
- The sweep time of the analyzer should be at least 10 sweeps per second; otherwise the antenna needs to be moved very slowly. The number of sweeps per second of the analyzer should not be too high and the frequency bands should be sufficiently small;
- The antenna shall be swept slowly over the region ensuring that sufficient time has been allowed to enable an accurate evaluation of the r.m.s. value of the signal;
- Sufficient time should be taken such that the probability of having a higher level recorded is small;
- In a multi-frequency environment where there is more than one signal of interest, a scan shall be made of the entire frequency range of interest to identify frequency peaks and their respective levels.
- It may be necessary to separate the frequencies into various groups (bands) to identify the levels of emissions from these individual bands.

10.1 Relevant Services in the 300 MHz – 6GHz band and Spectrum Analyzer Measurement Parameters

Services	Measurement Frequency	Signal BW	Measurement Parameters	ICNIRP Reference Level (V/m)
CDMA2000	869 – 890 MHz	1.25 MHz	RBW: 2 MHz Detector: r.m.s Sweep time: max. \approx 200ms Worst case approach: Assume that measured signal is contributed by power control/pilot channel (imbedded in the carrier) which has a fixed power relationship to maximum allocated power and extrapolate.	$1.375f^{1/2}$
GSM 900	935 – 960 MHz	200 kHz	RBW: 200 (300) kHz Detector: r.m.s or peak Sweep time: max. \approx 200ms Worst case approach: Measure BCCH-signals and multiply by number of installed or licensed channels $E_{\max} = E_{BCCH} \times \sqrt{n_{Transmitters}}$	$1.375f^{1/2}$
DECT	1880 – 1900 MHz	1.728 MHz	RBW: 2MHz Detector: Peak Sweep time: max. \approx 200ms Span: 0 Hz To get r.m.s exposure, the measured peak fieldstrength [dB μ V/m] must be <u>reduced</u> by the correction factor K [dB] $K = 10\log(\text{Pulse duration/Pulse Period})$ Pulse period: 10ms (fixed) Pulse duration (BTS) - One voice connection: 368 μ s - n voice connection: n. 368 μ s - Standby mode: 83 μ s - Max downlink data transfer: 8.46 ms	$1.375f^{1/2}$
GSM 1800	1805 – 1880 MHz	200 kHz	RBW: 200 (300) kHz Detector: r.m.s or peak Sweep time: max. \approx 200ms Worst case approach: Measure BCCH-signals and multiply by number of installed or licensed channels as for GSM900	$1.375f^{1/2}$

WCDMA	2110 – 2170 MHz	5 MHz	<p>RBW: 5 MHz or apply correction factor, $K=10\log(B_{\text{signal}}/B_n)$ if not available. $B_n \approx 1.1B_{3\text{dB}}$</p> <p>Detector: r.m.s Sweep time: max. $\approx 200\text{ms}$ Worst case approach: Assume that measured signal is contributed by signaling only (i.e. P-CPICH) and extrapolate by $P_{\text{max}}/P_{\text{p-cpich}}$ as follows:-</p> $E_{\text{max}} = E_{\text{PCPICH}} \sqrt{P_{\text{max}}/P_{\text{PCPICH}}}$ <p>It is to be noted that we assume ‘no traffic load’ in this measurement. This overestimates real exposure especially when traffic is present.</p>	61
WLAN (WiFi) IEEE802.11b IEEE802.11g IEEE802.11h	2.4 – 2.4835 GHz	20 MHz	<p>RBW: \geq signal bandwidth or apply correction factor, $K=10\log(B_{\text{signal}}/B_n)$ if not available. $B_n \approx 1.1B_{3\text{dB}}$ Detector: r.m.s Sweep time: max. $\approx 200\text{ms}$ Span: 0 Hz</p> <p>Measure beacon signal level in time domain. The beacon signal has a period of 100ms. Apply load correction factor, L as follows: Min exposure: $L=-26\text{dB}$ Mean exposure: $L=-3\text{dB}$ Max exposure: $L=-0.5\text{dB}$</p>	61
	5.15 – 5.35 GHz	16.6 MHz		
	5.47 – 5.725 GHz	16.6 MHz		

Table 4: Spectrum measurement parameters for sweeping method

11 MEASUREMENT UNCERTAINTY (Source: ECC(02)04)

The measurement uncertainty should be evaluated taking into consideration each of the quantities listed in this clause. 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 (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: $u_e = 1,96 u_c$ [*] and should be stated in the measurement report.

Table 5 gives quantities that contribute to the determination of the measurement uncertainty.

Component	Influence factor	Specified uncertainty [dB]	Distribution	Division factor	Standard uncertainty $u(x_i)$ [dB]
Spectrum Analyzer	Frequency Response	[as specified in calibration report]	Normal (K=2)	2	
Spectrum Analyzer	Overall Amplitude Accuracy	[as specified in calibration report]	Normal (K=2)	2	
Spectrum Analyzer	Input Attenuator Switching Uncertainty	[as specified in calibration report]	Normal (K=2)	2	
Spectrum Analyzer	Resolution Bandwidth Accuracy	[as specified in calibration report]	Normal (K=2)	2	
Spectrum Analyzer	Gain Compression	[as specified in calibration report]	Normal (K=2)	2	
Spectrum Analyzer	Resolution Bandwidth Switching Uncertainty	[as specified in calibration report]	Normal (K=2)	2	
Antenna cable	Calibration uncertainty	[as specified in calibration report]	Normal (K=2)	2	

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

Antenna	Calibration uncertainty	[as specified in calibration report]	Normal (K=2)	2	
Repeatability	Limited Repeatability	2.3	Normal (k=2)	2	
Combined standard uncertainty, $u_c(y) = \sqrt{\sum_{i=1}^n (c_i * u_{(x_i)})^2}$ where $c_i = 1$					
Expansion factor					1.96
Expanded uncertainty [dB] = $u_e = 1,96 u_c$					

Table 5: Uncertainty budget

12 MEASUREMENT REPORT

The measurement report shall follow the structure defined in Annex 1.

12.1 APPLICATION OF ICNIRP REFERENCE LEVELS

Measured and calculated quantities shall be used to check the compliance of RF exposure with the adopted ICNIRP reference levels. 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.

The total exposure quotient will be calculated based on power flux density as follows:-

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

ANNEX 1 (Adapted from ECC(02)04)

REPORT

The main elements of the report structure are as follows:

1 EXECUTIVE SUMMARY

2 OBJECTIVES AND LIMITATIONS

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

3 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,

4 DESCRIPTION OF EQUIPMENT

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	

- For a Spectrum Analyser or receiver :

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

5 UNCERTAINTY

In order to be complete, each measurement should be accompanied by a statement of uncertainty in accordance with Clause 11 of the procedure. 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.

7 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.

8 CONCLUSION

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