

MEASUREMENT UNCERTAINTY IN BROADBAND RADIOFREQUENCY RADIATION LEVEL MEASUREMENTS

by

Branislav D. VULEVIĆ^{*}, Čedomir I. BELIĆ, and Luka S. PERAZIĆ

Public Company Nuclear Facilities of Serbia, Belgrade, Serbia

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For the evaluation of measurement uncertainty in the measurement of broadband radio frequency radiation, in this paper we propose a new approach based on the experience of the authors of the paper with measurements of radiofrequency electric field levels conducted in residential areas of Belgrade and over 35 municipalities in Serbia. The main objective of the paper is to present practical solutions in the evaluation of broadband measurement uncertainty for the *in-situ* RF radiation levels.

Key words: non-ionizing radiation, RF radiation, measurement uncertainty

INTRODUCTION

The presence of man-made electric, magnetic, and electromagnetic fields (EMF) in the environment have become omnipresent. In this sense, levels of exposure to time-varying electric and magnetic fields in living spaces have become a topic of concern for many people. Until now, the main sources of the high frequency range (100 kHz to 300 GHz) have been radio and TV transmitters and the cellular mobile communication systems. Their functions are to be enlarged by additional services (mobile video and television) in the future. Significant public and media concern is expressed about increases in EMF exposure of people and its potentially adverse effects on health. These associations are not explained by any confirmed biological mechanism and there are doubts as to their causal nature. Besides, the available evidence is inadequate to make sound scientific conclusions. The International Agency for Research on Cancer (IARC) has released its detailed evaluation of the cancer risks associated with radiofrequency (RF) radiation, which serves as the rationale for designating RF as a possible human carcinogen [1].

In order to evaluate the population exposure, knowledge of the field levels is very important. Measurements are a basic element both for the verification of the results obtained through the use of numerical models and for the evaluation of the field levels when the sources, because of their number, working conditions and complex distribution, are unlikely to be sim-

ulated. The result of a measurement, given by the indication of the instrument, is only an estimate of the measurand (subject to measurement) and thus it is complete only if associated to a statement of uncertainty parameter that characterizes the dispersion of the values that could be reasonably attributed to the measurand. Besides the uncertainty associated with the use of a field meter, other contributions also have to be considered when evaluating uncertainty of a field measurement. These contributions depend both on the measurement procedures and conditions as well as on the characteristics of the field source [2, 3].

The following consideration in this paper are to be related to the observation of measurement uncertainty for the case of broadband measurements of RF electric field strength in the area of GSM base stations (GSM BS). In order to minimize the influence of other sources of RF radiation, GSM BS were selected as the sole source of RF radiation located within the area of 150 m. The purpose of this paper is to present a simplified approach to solving the problem of assessment of uncertainty which should be applied in case of a quick review of the situation on the field.

THE SUBJECT OF OBSERVATION

The European Committee for Electrotechnical Standardization (CENELEC) issued the standard EN 50413 [4], where useful information can be found about identification of the uncertainty components. Different scientific or technical approaches have produced different philosophies of the concept of evalua-

^{*} Corresponding author; e-mail: banevul@gmail.com

tion of measurement uncertainty [5]. CENELEC standard EN 50413 emphasizes typical examples of measurement uncertainties which are:

- size and shape of the measurement probe,
- the actual position of the probe in relation to the planned measurement point,
- calibration or stated accuracy of the measurement instrument,
- interaction between the equipment under evaluation and the measurement system,
- repeatability, and
- effects of the environment during the measurement.

In the case when looking at a high frequency range (100 kHz to 300 GHz), several field types exist which should be assessed differently depending on the distance r from and the biggest dimension (D) of the radiating source. Table 1 indicates whether to measure electric (E) or magnetic (H) field strength, or both, at different distances from the field source.

Reliable assessment procedures have to be able to distinguish between the contributions from different RF sources and also to estimate individual exposure. Possible dosimetric approaches are the use of frequency selective monitoring equipment to assess variation vs. time, and of frequency selective equipment like dosimeters to assess individual exposure. Procedures based on the use of broadband measurements equipment are suitable for epidemiological studies if one source is dominant or if other reliable procedures, such as analytical calculations, are applied, that makes it possible to distinguish between the contributions from different sources [6].

CENELEC standard EN 50492 [7] defines the process to be followed for selection of the methods, the measurement systems and the post processing used to estimate *in-situ* the electromagnetic field for human exposure assessment.

MEASUREMENT METHOD

The European Conference of Postal and Telecommunication Administrations (CEPT) produced the ECC Recommendation (02)04 covering RF radiation [8]. The latter defines generally applicable measurement methods without mentioning any limit values. For such values, it refers to the EU Council Recommendation 1999/519/EC on protection of the

general public [9] and to corresponding national regulations.

The ECC Recommendation envisages three cases for evaluating situations involving exposure to RF radiation:

- case 1: quick overview,
- case 2: variable frequency band, and
- case 3: detailed investigation.

Case 1, quick overview, is sufficient as all the measured values remain below the Decision Level (the thresholds below the reference level on the international or nationally-determined limit values). A broadband measuring equipment is ideal for case 1. The following property is essential – a measuring instrument and isotropic (non-directional) field probes must be capable of measuring the root mean square (RMS) value [10]. In our case, the measured RMS values of RF electric field strength obtained from 10 seconds samples for a total time of 6 minutes. The height of the field sensor was 1.5 m above the ground.

THE BROADBAND MEASUREMENT SYSTEM

The basic technical specifications, guaranteed by the manufacturer of the Narda Broadband Field Meter NBM-550 [11], with the corresponding isotropic E-field probe EF1891 [12], are shown in tab. 2. The probe is calibrated at several frequencies. The correction values are stored in an EPROM in the probe and are automatically taken into account by the NBM instrument. Calibrated accuracy is thus obtained regardless of the combination of a probe and instrument. Information on the uncertainty in the following table are the basis for the measurement uncertainty (type B) guaranteed by the manufacturer (Manufacturer data sheet). Also, conditions apply to a relative humidity less than 95%, and the ambient temperature in the range 0 °C to 50 °C.

UNCERTAINTY IN MEASUREMENTS OF RF ELECTRIC FIELD STRENGTH

A measurement of the RF electric field strength requires a considerable amount of care as the result is influenced by many parameters. These are some of the uncertainty contributions [2]:

Table 1. Evaluation parameters for high frequency range [4]

	Reactive near field	Radiating near field	Far field
Distance (r)	$r < \lambda$	$\lambda < r < D < \lambda$	$r > 2D^2/\lambda$
E, H	1/r	No	Yes
$Z_0 = E/H$	Z_0	Z_0	$=Z_0$
To measure	E and H	E or H	E or H

NOTE: D – biggest dimension of the radiating structure; *i. e.* diameter of a parabolic antenna

- (a) probe calibration, which should be carried out in an accredited laboratory,
- (b) frequency interpolation, due to the fact that the probe calibration curve is determined for discrete frequencies of the reference EMF,
- (c) the measuring procedure followed to estimate the measured quantity and differences due to different staff carrying out the same type of measurement, and
- (d) the effects of environmental conditions (*i. e.* temperature, humidity) in the measurement set-up.

In addition to these uncertainty contributions, according to the analysis from the literature [2], one of the important factors that could significantly contribute to the total uncertainty is the short-term repeatability

of the measurements (uncertainty type A). Repeatability is the variability of the measurements obtained by one person while measuring the same quantity repeatedly. The repeatability of measurement is expressed as a percentage based on the ratio of the standard deviation and the mean of the results of measurements [13,14]. Based on our practical experience in so far, the value of the repeatability of measurement is less than 15% for the survey of RF electric field levels on roofs where GSM BS are mounted.

Taking into account all of the relevant factors, the assessment of an uncertainty budget can be made. In accordance with the standard EN 50413 [4], tab. 3 shows a typical example of uncertainty budget for RF electric field strength measurement by using the iso-

Table 2. Basic characteristics of the measuring system NBM-550 with E-field probe EF1891 [12]

Frequency range	3 MHz – 18 GHz
Type of frequency response	Flat
Measurement range	0.6-1000 V/m (CW) 0.6-35 V/m (true RMS)
Dynamic range	64 dB
CW damage level	1600 V/m
Peak damage level	16 kV/m
Sensor type	Diode based system
Directivity	Isotropic (tri-axial)
Readout mode/spatial assessment	3 separate axes
Uncertainty	
Flatness of frequency response (calibration uncertainty not included)	1 dB (10 MHz to 1.8 GHz) ±2 dB (1.8 to 6 GHz) 3 dB (>6 GHz)
Calibration uncertainty (referred to 27.5 V/m)	1 dB (<400 MHz) ±1.5 dB (400 MHz to 1.8 GHz) 1 dB (1.8 GHz)
Linearity (referred to 27.5 V/m)	3 dB (0.8 to 1.65 V/m) ±1 dB (1.65 to 3.3 V/m) 0.5 dB (3.3 to 300 V/m) ±0.8 dB (300 to 1000 V/m)
Isotropic response	1 dB (27 MHz to 1 GHz) ±2 dB (1 GHz to 18 GHz)
Temperature response	+0.2/ -1.5 dB (0.025 dB/K at 10 to 50 °C)

Note/conversion: $x [\%] = [10 \exp (X_{dB}/20) - 1] 100$

Table 3. Example of an uncertainty budget for field strength measurement using a broadband field meter NBM-550 with isotropic E-field probe (EF1891)

Influence factor	Reference	Specified uncertainty [%]	Distribution	Division factor	Standard uncertainty $u(x_i)$ [%]
Frequency response	Calibration report	11.6	Rectangular	1.73	6.7
Uncertainty of frequency response	Calibration report	20	Normal ($k = 2$)	2	10
Linearity deviation	Calibration report	3	Rectangular	1.73	1.7
Uncertainty of linear deviation	Calibration report	15	Normal ($k = 2$)	2	7.5
Isotropic deviation	Data sheet	12.2	Rectangular	1.73	7.1
Modulation response	Data sheet	–	Rectangular	1.73	–
Temperature response	Data sheet	2.3	Rectangular	1.73	1.3
Repeatability	Measuring series	15	Normal ($k = 1$)	1	15
Combined standard uncertainty (u_c [%])					21.9
Expansion factor (k)					1.96
Expanded uncertainty (U [5%])					43

tropic electric field probe (EF1891) of Narda Broadband Field Meter – NBM-550.

CONCLUSIONS

The values of measurement uncertainty in tab. 3 are higher in comparison to the appropriate data given in [5]. It is a common fact when it comes to the estimation of measurement uncertainty under the same/different conditions using a variety of measuring instruments. In the area of RF hazard exposure assessments, uncertainty estimates for electric field evaluations is something that is generally seen as a good idea, but daunting in the execution [15]. Certainly, the quantities that can influence the measurement result, such as those listed in the previous analysis, have to be identified, and, whenever possible, their effect has to be made negligible.

This paper is not intended to be a definite and final guide to assessment of uncertainty in measurements for RF human exposure evaluations, but is hoped to provide a reasonable starting framework for doing so.

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AUTHOR CONTRIBUTIONS

All authors are worked on the proposed idea and discussed its applicability. The manuscript was written by B. D. Vulević, however, the co-authors are contributed to the proofreading.

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Бранислав Д. ВУЛЕВИЋ, Чедомир И. БЕЛИЋ, Лука С. ПЕРАЗИЋ

**МЕРНА НЕСИГУРНОСТ КОД ШИРОКОПОЈАСНИХ МЕРЕЊА НИВОА
РАДИОФРЕКВЕНЦИЈСКОГ ЗРАЧЕЊА**

У овом раду предлажемо нови приступ за процену мерне несигурности код широкопојасних мерења радиофреквенцијског зрачења који се заснива на искуству аутора овог рада стеченог вишегодишњим мерењима нивоа електричног поља радиофреквенција у стамбеним областима у Београду и 35 општина у Србији. Основна сврха рада је приказ практичног решења у процени мерне несигурности код широкопојасних мерења нивоа радиофреквенцијског зрачења “на лицу места”.

Кључне речи: нејонизујуће зрачење, радиофреквенцијско зрачење, мерна несигурности
