Uncertainty Assessment of Electric Probe in Electromagnetic Field Monitoring System

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Abstract –**Development of the electromagnetic field monitoring and control systems represents one of the major innovations in the range of methodologies for evaluating, through the measurements, the so-called environmental electromagnetic pollution. This phenomenon have caused the alerting of the public and the agencies for non-ionizing radiation protection, and therefore there is a need for constant and accurate surveillance of electromagnetic fields. This paper presents initial consideration of uncertainty assessment of theelectric probe, which used in the electromagnetic pollution monitoring system. This system is based on the wireless sensor networkand our team develops it within the program of technological development of the Republicof Serbia, for period of 2011–2014.**

Keywords – **EM pollution, monitoring network, uncertainty.**

I. Introduction

The fast growing penetration of radiofrequency and microwave radiating devices into everyday and occupational life of population emerges the public theme of the so-called electromagnetic pollution of the environment. Electromagnetic pollution has become sensitive and highly important scientific and research subject at an international level requiring analysisof the electromagnetic radiation on biological systems[1]-[2].

As support for those research efforts various methodologies for evaluating, through the measurements, have been considered. In addition, several agencies and standardization bodies [4]-[7]established guidelines for limiting the electromagnetic fields (EMFs) exposure that provide protection against known adverse health effects[8].

In this paper we consider a monitoring system based on a wireless sensor network [9]-[11], for automated, remote and selective monitoring of the overall level of EMFs. The proposed system collects measurement data and compares them with national prescribed limits on the daily basis[12]-[19].Moreover,the results of measurements are instantly available through Internet, providing information to the relevant institutions in the area of environmental protection against the electromagnetic pollution [12], [20], caused by a number of sources of EMFs.

The proposed system is an advanced solution available to meet the growing demands for monitoring the EMFs and continuous informing about the EMF distribution in the areas connected with human activities and their exposure to EMF radiation. The system has been supportedby Ministry of Sciences and Technological Developments of the Republicof Serbia[21]in period of 2011–2014.

This system is intended to be used in the various aspects, especially for EMF exposure evaluation in the zones of increased sensitivity, that are defined in legaldocument"*Rules for non-ionizing radiation sources of interest, types of sources, the manner and period of their investigation*" [16], as shown in Fig. 1.

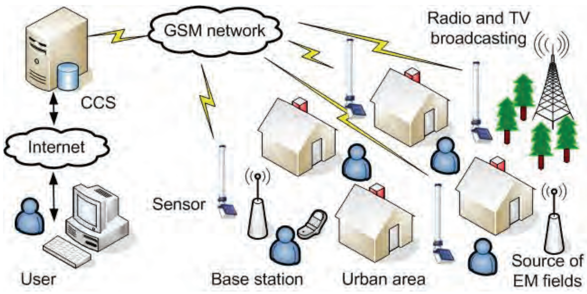

Fig. 1 Example of monitoring system utilization

The zones of the increased sensitivity are residential areas where people can spend 24 hours a day, i.e. schools, homes, pre-schools, maternity hospitals, hospitals, tourist facilities, play-grounds and areas of un-built land intended for specified purposes [16].

The monitoring system will perform measurements in real environment, containing the fixed and movable reflective structure and will be exposed to different weather conditions, as show in Fig. 2.

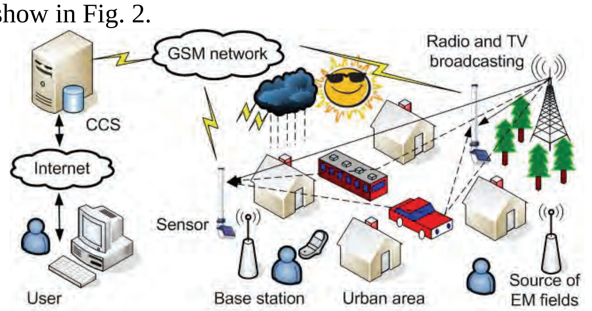

Fig. 2 Example of the area conditions

Generally, the measurements have to meetseveral requirements proposed by specific guidelines or standards[22]. On the other hand, performing non-ionizing exposureassessment using real measurement data requires consideration of the uncertainty of measurement[23].

In this paper, a methodology forestimating the overall uncertainty ofthe electric field probe in the monitoring system is proposed. Estimating and reporting measurement uncertainty are of great importance,especially when the measured values are very close to the established limits of human exposure to non-ionizingEMFs.

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II. GENERALLY ABOUT UNCERTAINTY

Metrology suggests that each measurement result should be stated with accompanied uncertainty. Only than result is complete and acceptable, and can be compared with other results of same quantity or with reference values.

Uncertainty of measurement represents quantitative indication of the quality of measurement result. It defines range of values that could be attributed to the measured quantity.

General approach for uncertainty evaluation are imposed by *Evaluation of measurement data — Guide to the expression of uncertainty in measurement* (GUM) [24], where two types of uncertainty assessment are introduced

- Type A – determined using statistical methods on a series of repeated readings and
- Type B – determined using non-statistical methods, i.e. information from past experience of the measurements, from calibration certificates, from manufacturer specifications, from calculations, from published information, etc.

In order to evaluate measurement uncertainty, all the possible contributors of uncertainty have to be considered[25]. It has to be pointed out that uncertainty is a result both of incomplete knowledge of the value of the measurand and of the factors influencing it [26].

Some of the possible sources of uncertainty are:

- The uncertainty of the equipment used for calibration of a specific measuring instrument,
- Uncertainties resulting from measuring equipment determined with accredited calibration procedure, together with any drift or instability in their values,
- The uncertainties due to the instabilities of the measuring equipment during the measurement,
- The measuring procedure followed to estimate the measured quantity,
- Differences due to different staff carrying out the same type of measurement,
- The effects of environmental conditions (i.e. temperature, humidity) in the measurement setup [27].

GUM assumes that the uncertainty of a measurement result can be evaluated based on a mathematical model of the measurement, which describes afunctional relationship between the measurand $y$and the input (influence) quantities x_i.If the input quantities are designated as x_1, x_2, … x_n, then the mathematical modelcan be written as

$$y = f(x_1, x_2, ..., x_n)\ . \tag{1}$$

In some cases, this relation is complicated and it is not possible to explicitly write it down.Besides, a functional relationship $f$can be determined experimentally or exist only as a numerically evaluated algorithm.

Contribution of all the possible sources of uncertainty have to be expressed in terms of standard uncertainties $u(x_i)$ (standard deviation) based on the associated probability distributions (extended consideration on calculating uncertainties depending on respective distribution is presented in [24]).

Moreover, uncertainty must be expressed in the same units as measurand before they are combined. It is achieved by multiplying standard uncertainty by sensitivity coefficients, denoted asc_i. Mathematically, sensitivity coefficients are obtained from partial derivatives of the model function f with respect to the input quantities[24], or they can be estimated experimentally. Sensitivity coefficients describe how change in the estimation of input quantities influences the estimate of measurand[27].

If all input quantities areindependent combined uncertainty is calculated according to

$$u(y) = \sqrt{\sum c_i^2 u(x_i)^2} \tag{2}$$

Expanded uncertainty, usually denoted as$U$,is the combined uncertainty multiplied by a coverage factor$k$. A particular value of coverage factor gives a particular confidence level for the expanded uncertainty.

Commonly, the overall uncertainty is scaled by the coverage factor k = 2, giving a level of confidence of approximately 95 %. (k = 2 is correct if the combined standard uncertainty is normally distributed, which is usually a fair assumption.The detail reasoning behind this is explained in [24]).

III. UNCERTAINTY OF THE PROBE

The proposed monitoring system is designed to investigate the overall level of the EM field and population exposure to the EM field at the particular location on the daily basis. In order to determine electric field strength,the electric field quad-band probe is used[28]-[29].

Calibration certificate data and manufacturer specification of field probe are stated in Table I.

TABLE I
MANUFACTURER SPECIFICATION AND CALIBRATION DATA OF PROBE

Quantity	Wide Band 0.1 to 3000 MHz	EGSM 900, 1800 and UMTS Bandpass
Meas.Range	(0.2 to 200) V/m	(0.03 to 30) V/m
Meas. Resolution	0.01 V/m	
Flatness @ 6 V/m	(1 - 200 MHz) ±0.8 dB (150 kHz - 3 GHz) ±1.5 dB	+0.5/-2.5 dB
Anisotropy	±0.8 dB (typical ±0.6 dB) @ 50 MHz, 3 V/m	±0.8 dB (typical ±0.6 dB)
Temperature Error	0 – 50ºC = ±0.3 dB -20 – 0ºC = -0.1 dB/ ºC	
Calibration Uncertainty	1 dB	1 dB

In case of EMFs measurement, the employed instrumentation and the measurement technique, as well as environmental conditions, contribute to measurement uncertainty. To evaluate uncertainty ofelectric field strength measurement, only standard uncertainty type B is taken into account. In order to determine standard uncertainty of type A, series of measurements should be provided. As our system is still in the developing phase, we are not able to give concrete results of measurement and to calculate the type A of uncertainty, therefore it will be omitted. The most important uncertainty sources,

TABLE II

UNCERTAINTY BUDGET OF MEASUREMENTS OF ELECTRIC FIELD STRENGTH MEASURED IN EGSM 900, EGSM 1800 AND UMTS BANDPASS MODE USING ELECTRIC PROBE

No		Source of uncertainty	Partial uncertainty [dB]	Type	Probability distribution	Divisor	Sensitivity coefficients	Standard uncertainty [%]
1.	Measurement Equipment	Calibration	1	B	normal	2	1	5.93
2.		Resolution of measurement	1.34	B	rectangular	1.73	1	9.32
3.		Flatness	2.5	B	rectangular	1.73	1	18.10
4.		Anisotropy	0.8	B	rectangular	1.73	1	5.47
5.		Temperature variation	0.3	B	rectangular	1.73	1	2.02
6.	Meas. Method	Antenna position in the field with high spatial variation	0	B	rectangular	1.73	1	0
7.		Spatial averaging	-	B	rectangular	1.73	1	-
8.	Environmental Parameters	Perturbation by the environment	1.5	B	rectangular	1.73	1	10.5
9.		Variations in the emitted power sources	1	B	rectangular	1.73	1	6.88
10.		Reflection of the major mobile sources close to sources of radiation	0	B	rectangular	1.73	1	0
Combined standard uncertainty [%]								25.32
Coverage factor								2
Expanded uncertainty [%]								50.64

their type and probability distributions are shown in Table II.

As all units of standard uncertainty are expressed in terms of the measurand and the functional relationship between the input quantities and measurand is given as linear summation, then all sensitivity coefficients are unity value (c_i=1), otherwise partial derivatives should be calculated [30].

Since all input contributors can be considered unrelated, the combined uncertainty is obtained as summation in squares of the individual uncertainty contributors.

Finally, the expanded uncertainty is obtained by multiplying the combined uncertainty by coverage factor k=2 which corresponds to the confidence level of 95 % as recommended by standard [25].

In this paper the worst case scenario is considered, therefore the maximum errors are taken into account when estimating uncertainty, using the parameters for EGSM 900, EGSM 1800 and UMTS bandpass mode.

As it can be seen from Table IIthe relative standard uncertainty due to resolution is significant. This value is calculated atelectric field strength of 0.03 V/m, at the detection threshold of the probe. At upper measurement range limit, 30 V/m, relative standard uncertainty due to resolution is less than 0.01 %. Therefore, knowing the exact measuredvalue of electrical field strength, the uncertainty contribution due to resolution will be significantly reduced,so that it can even be neglected.

The relative standard uncertainty due to flatness is dominant. When calculating uncertainty due to temperature variations, it is assumed that temperature is higher than 0 ºCin a real environment, therefore temperature error of ±0.3 dB is used.

Considering the measurements method, in this initial investigation the antenna position in the field with high spatial variation was omitted as a sources of uncertainty. This was done because in some first implementations the sensors will be positioned in a same plane. In addition, for the same reason the spatial averaging was not taken into account.

These two parameters are accounted as a possible source of the uncertainty and will be considered in applications where sensors are place on different heights (for example in case of monitoring electric field from the base station for mobile communication [11], [31]).

Furthermore, considering the environmental parameters as sources of uncertainty, reflection of the major mobile sources close to the sources of radiation, was omitted as influential source because we assumed that our system will be implemented in area where reflection can be neglected. We are fully aware of this assumption, but without precise description of the site where sensors are positioned, this source can not be properly estimated.

IV. Conclusion

This paper presents an information network, as support for automatic and continuous monitoring of the overall level of EMFs. To ensure the EMF measurement validity, it has to be conducted according to the standards and uncertainty estimation has to be associated.This is important for data interpretation, especially when a compliance statement with a specification or a legal exposure limit is needed.

In order to determine uncertainty, all sources of uncertainty have to be identified and their contribution to overall uncertainty has to be estimated.

In this paper, a concept for estimating uncertainty, when EMF measurements are performed using electric field sensor, is presented.

In a process of evaluation of measurement uncertainty we consider different contributors divide in a three main categories:

- uncertainties which derive measuring equipment,
- method and
- environmental parameters.

The contribution of each source of uncertainty of measurement is registered by the name, probability distribution, and sensitivity coefficient and uncertainty value.

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