Measurement Uncertainty at SAR Determination for Mobile Phones

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The Specific Absorption Rate (SAR) of the electromagnetic radiation generated by mobile phones is one of the important characteristics of these wireless terminals with a major influence on the health condition of any age user, especially children.
The first Romanian SAR dosimetry laboratory is being achieved at ICMET Craiova following to be put in operation next year.
It will enable ANC (National Authority for Communications) to organize market surveillance for new equipments as well as for the second hand ones traded in Romania.
The paper presents the SAR measurement system used, the existing uncertainty sources and the contribution to the global system uncertainty which shall not exceed 3 dB when the in force standards (IEC series 62209) are applied.

Index Terms—**SAR.**

I. Introduction

Mobile phones certification with a view to trading imposes, according to the present standards, the experimental determination of SAR factor (Specific Absorption Rate of electromagnetic field measured in W/kg of user's body weight) and its value limitation to the nationally and internationally regulated values considered non-dangerous (at the present knowledge level).

As regarding the domestic market of mobile phones, the state has the role of protecting the citizens in their position of consumers and of performing or financing studies and comparative tests according to EU Recommendation 1999/519/CE transposed in the Romanian legislation by Order. No. 1193/29/09/2006, issued by the Ministry of Public Health, Official Journal No. 895/3.11.2006 [1].

Unfortunately, in Romania there is no facility for SAR determination and the values written on terminals, according to the law, originate from the manufacturers and not from independent accredited laboratories. Other important functional characteristics like energy consumption, audio and emission/ reception properties are not checked in authorised laboratories either.

In EU countries and even in the countries that recently joined EU excepting Romania and Bulgaria, there are tens of independent laboratories specialised in SAR evaluation and full characterisation of the said terminals.

In this context, the existence of a laboratory specialised in SAR evaluation independently of the mobile phone operators becomes absolutely necessary.

This laboratory should be nationally accredited and internationally recognised and intended to:

- conformity evaluation and validation according to the in force European and international standards for the traded products, the second-hand ones inclusively;
- performing comparative studies and tests at international level (including participation in intercomparison circuits);
- creating conditions for the participation of Romanian scientific community in the development of modern communication systems with reduced electromagnetic pollution within the frame of some European projects.

This specialised laboratory -Project SAREMF (program "Capacities 2007", project No. 79) – financed by ANCS aims to solving the above related problems.

In this paper we discuss the uncertainty questions related to this matter.

II. Methods For Experimental Evaluation Of The Exposure To Electromagnetic Field Generated By Mobile Phones

The evaluation of the radiofrequency field exposure levels is a fundamental issue at present. The effects are different depending on frequency [2].

This measurement is performed exclusively in near field in completely different conditions than the far field measurement.

According to EC Recommendation 1999/519/CE, the restrictions regarding people exposure to time varying electric, magnetic and electromagnetic fields, based directly on the effects observed on health and for biological reasons are defined as "basic restrictions".

In the frequency range used by mobile phones, with a view to preventing a generalised thermal stress at body level and an excess local heating of the tissues, there are provided basic restrictions regarding SAR.

The Specific Absorption Rate (SAR) is the main dosimetric quantity for the evaluation of the human exposure both in near field (mobile terminals) as well as in far field (base stations). It is the power absorbed by the unit mass of the tissue defined as the time derivative of the incremental energy (dW) absorbed by an incremental mass (dm) contained in a volume element (dV) of given mass density (ρ) and has the general expression:

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho\, dV}\right) \ \text{[W/kg]} \tag{1}$$

SAR evaluation in near field can be made either by means of the local electric/magnetic field or by means of the local temperature measured in a given volume [3]

SAR expressions become:

$$SAR = \frac{\sigma |E|^2}{\rho} \qquad (2)$$

respectively:

$$SAR = \frac{cdT}{dt} \qquad (3)$$

where: - E is electric field strength (peak value);
- σ is the electrical conductivity of the sample (tissue);
- ρ is sample density;
- T is the absolute temperature of the sample.

However, electric field measurement is the favourite method for the industrial tests.

To be noticed that the measurement of the so called Maximum Permissible Exposure (MPE), determined by the power density [W/m2], is accepted in the far field by the same recommendations instead of SAR measurement.

SAR limits applicable for mobile phones and other similar systems are prescribed in the source documents from USA (ANSI/IEEE C95.1) and Europe (ICNIRP).

There are used two limit values: a lower value for the exposure averaged on the entire human body(0,08W/kg) and a higher value applicable for the local exposure of a particular area of the body -the head or the trunk-(2 W/kg in Europe and 1,6 W/kg in USA). This SAR for a body area is averaged over any 10 g of tissue and 6 min in Europe and 1 g and 30min in USA defined as a tissue volume in the shape of a cube.

Since it is difficult to measure SAR directly in the human body, the standard procedure is based on phantoms use. In this case, a series of elements affecting the measured value appear, for ex.: the shape and electrical characteristics of the phantom, the shape and radiation characteristics of the field source especially the cell phone antenna and phantom relative position towards the source.

A high measuring accuracy is obtained by an as accurate as possible physical simulation of the real exposure.

Since, the most important mobile phones manufacturers are in USA (Motorola) respectively in Europe (Nokia), the new American [4] and European [5] standards are structured similarly, respectively harmonised, with minor variations one with respect to another.

The most important aspects are the requirements on the measurement accuracy achieved by the test system and on the measuring method. A special characteristic of both standards consists in the explicit and detailed provision of the requirements for the evaluation of the measurement uncertainty budget and a limit for the maximum permissible uncertainty (about 3dB or 30%).

In this way, the requirements involve both the measuring equipment and the laboratory technical procedures.

In brief, the SAR measurement procedure is according to IEC 62209-1 cl.5.1:

"The test shall be performed using a miniature probe that is automatically positioned to measure the internal E-field distribution in a phantom model representing the human head exposed to the electromagnetic fields produced by wireless devices. From the measured E-field values, the SAR distribution and the maximum mass averaged SAR value shall be calculated."

The test equipment presented in Fig.1 includes components for mobile phone (Device Under Test - DUT) positioning and scanning system alignment, dielectric properties measurement for the liquid simulating the human tissues, check and validation of the measurement accuracy.

Two types of phantoms are used:

- specific anthropomorphic phantom (SAM) for mobile phones testing;
- flat phantom for the validation and testing of the wireless devices that are not held close to the ear (laptop & desktop, limb mounted device, front of face device or clothing integrated device)

Phantom enclosure and the liquids simulating the head tissue or other human body part tissues are subjected to some strict requirements and when the frequency band of the mobile phone is changed the liquid will be changed accordingly due to the working frequency influence on its complex permittivity.

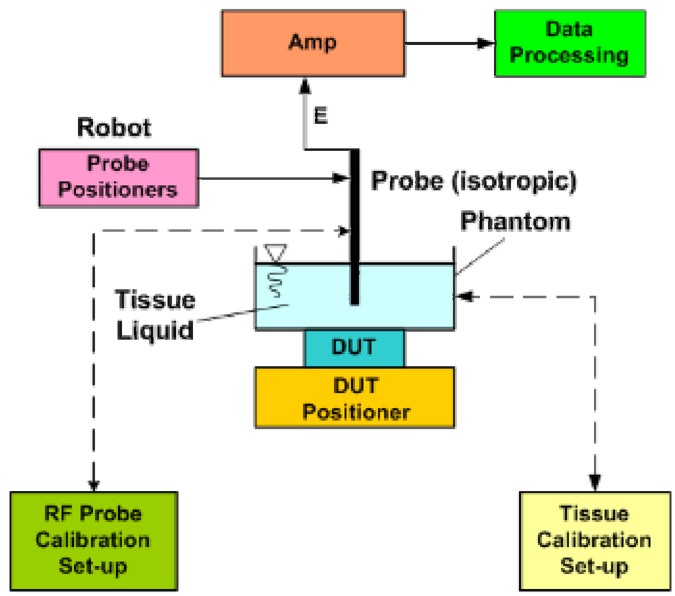

Fig. 1. Block diagram of SAR dosimetry equipment

The robot for field probe positioning must be capable to scan the whole volume subjected to exposure with a view to achieving a three-dimensional measurement of SAR with a remarkable positioning accuracy of ±0,2 mm.

The miniature field probes have a special construction and very high linearity.

All mentioned measuring system characteristics and many others make the acquisition of such a system to be expensive.

More than that, the whole measuring system must be introduced in an electromagnetically screened room.

III. SAR Dosimetry Uncertainty Budget

A measurement result is never exact and the doubt is always associated to it. Therefore, a measurement result is complete only when it is associated to a certain uncertainty. It is only on this basis that a measurement result can be decided whether the result is satisfactory for the proposed aim.

The SAR measurement system, purchased within the project frame which will be operational in 2009 is a complete computer-controlled assessment system but measurement result determination still remains the test engineer task and depends on an important number of system specific factors but also on the system specific mounting and exploitation conditions of the said location (operator inconsistency is excluded by construction).

At present, there are four measurement uncertainty evaluation methods: model method, single laboratory validation method, inter-laboratory validation method and the one using proficiency testing data.

The model method uses a model which takes into account all quantities that could significantly influence the measured quantity. The model covers corrections for all effects considered significant for the measuring process. The application of the uncertainty propagation law enables the evaluation of the combined result uncertainty. The method depends on the partial derivatives of each influence quantity. If the method is difficult to achieve any of the alternating methods can be used.

3.1 Conditions for correct SAR measurement

The following conditions shall be fulfilled when the uncertainty budget for a SAR dosimetry system is determined [6,7]:

- The system shall be used by a skilled engineer trained in an operational SAR laboratory;
- The field probe shall be calibrated with an uncertainty not exceeding 6% (k=1);
- The validation dipole shall be calibrated within the frame of the periodical system performance check;
- The electronic acquisition and processing unit shall be calibrated at the time intervals provided in the documentation of the measuring system;
- The minimum distance between the sensor and internal wall of the phantom shall be within 4 and 5 mm;
- The operation duty of the device under test (DUT) is - CW, CDMA, FDMA or TDMA (GSM, DCS, PCS, IS136, PDC) and the measuring/ integration time per point shall be >500ms;
- The dielectric parameters of the simulation liquid shall be determined with calibrated equipments before each test and the measured values shall not be different from the specified values with more than ±5%;
- DUT shall be positioned in compliance with manufacturer's indications.

The calibration certificates of all components shall be compliant with the specific international standards [8,9] corroborated with the requirements of ISO/IEC 17025 and shall contain the expanded measurement uncertainty.

3.2 Uncertainty Components Assessment

When the evaluation is performed the factors affecting SAR value (Fig.2) shall be had in view.

The component of uncertainty may generally be splited according to the methods used to evaluate them [10] in Type A or type B.

A type A evaluation may be based on any valid statistical method for data treating. A type B evaluation is typically based on scientific judgement using all the relevant information available.

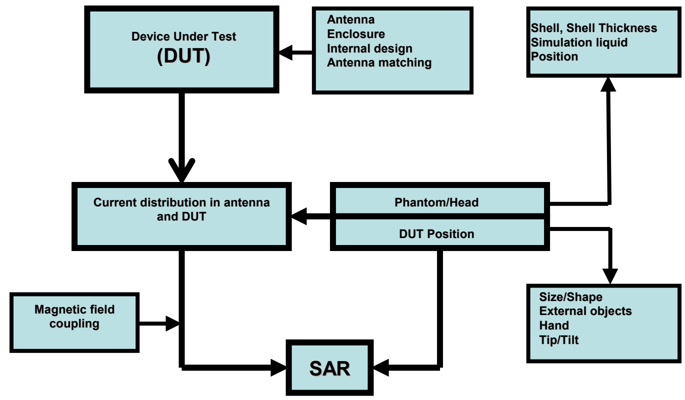

Fig. 2. Factors affecting SAR

Generally speaking, the uncertainty is either obtained from an external information source or from an assumed distribution (normal, rectangular, triangular, U/shaped, etc.). The main components of the uncertainty budget leading to the final result are given in Fig.3.

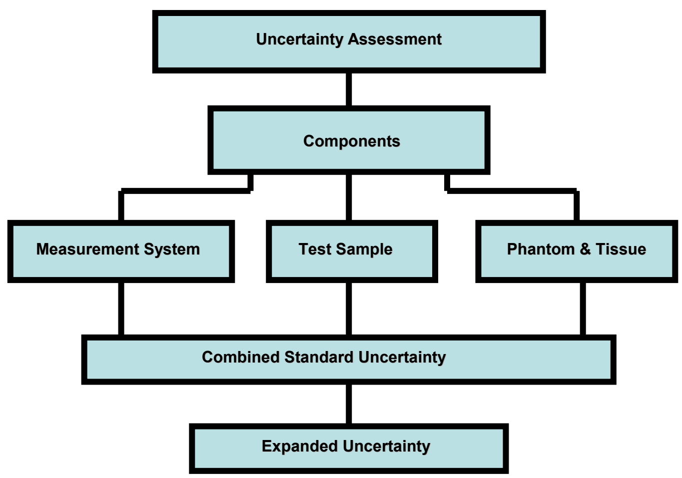

Fig. 3. Uncertainty at SAR Measurement

The concept of uncertainty estimation in the measurement of SAR values produced by wireless devices is not different from the general rules provided by [10, 11, 12,13, 14].

Hereinafter, the above components will be mentioned:

3.2.1 Measurement system

- Field probe calibration uncertainty depending on frequency, a usual value is ±6% (Normal distribution, N);
- Field probe isotropy determination uncertainty. Usually, an axial anisotropy of ±0,2dB (±4,7%) and a semi-spherical

anisotropy of about ±0,4dB (±9,6%) are determined (Rectangular Distribution, R);

- Uncertainty given by the boundary effect of the field probe, in the worst case scenario under ±0,8% (R);
- Uncertainty given by the field probe linearity at un-modulated signals (CW) and impulses – about ±0,2dB(±4,7%) (R);
- Uncertainty given by the system sensitivity (about 1mW/kg) which for the range 0,4W/kg – 10W/kg may be <0,25% (N);
- Uncertainty of the field probe readout electronics, usually ±0,3% resulted from the periodic calibration (N);
- Uncertainty given by the response time of the field probe may be considered negligible (R);
- Uncertainty given by the integration time appearing at pulse emission of DUT. Its value depends on the standard according to which DUT works. For ex. the systems operating in CDMA do not introduce significant uncertainties but GSM/DCS/DECT systems introduce uncertainties around 2%. Usually, the worst case value of ±2,6% will be taken (R);
- Uncertainty related to the conditions of the RF field where the measurements are performed (R);

When RF spurious signals appear during SAR measurement, their level is evaluated in the following way: SAR measurements are performed using the same measuring structure but with disconnected base station simulator.

Taking into account that DUT is tested in near field conditions, even the strong reflections generated by the laboratory walls (metallic surfaces – shield) will generate relatively small errors.

According to the standard [4] the environmental fields and their reflections shall be lower than 3% of minimum system sensitivity.

- Contribution given by the mechanical tolerances introduced by the used robot arm.

Usual values of the 6 axle robots used in SAR dosimetry are around ±(25-50)μm, the absolute accuracy at small distance displacements is lower than ±0,1mm so that the uncertainty introduced by SAR measurement is lower than ±1,5% (Rectangular distribution) [8];

- Contribution given by the tolerances introduced by the distance from the probe to the phantom that is usually around 0,2 mm that leads to an uncertainty lower than ±3% (R distribution);
- Uncertainty given by post-processing the field probe signal (interpolation, extrapolation, volume averaging and finding SAR maximum).

This contribution characterises the calculation algorithm on which it is based the SAR maximum value evaluation depending on the resolution chosen for the measurement.

This component of the global uncertainty is assessed at a level around 1,5% (R distribution), that can be monitored only by numerical simulation [15].

3.2.2 Test Sample (DUT)

- Uncertainty given by DUT position

Due to the fact that the mobile phones have smaller and smaller dimensions, SAR distribution is also concentrated on an increasingly smaller area.

The tests performed by great companies (Sony Ericsson, Nokia and Motorola) [6] lead to a SAR tolerance below ±3% for the normal distribution.

- Uncertainty given by DUT holder that can be moved on the three coordinates.

A tolerance of ±(3-4)% (N distribution) was also found based on the tests[6].

- Uncertainty given by DUT emitted power variation, it is a common phenomenon. On the basis of the experimental determinations it was established that this uncertainty is smaller than ±5% (R distribution).

3.2.3 Phantom and tissue simulation liquid parameters

- Uncertainty given by phantom construction (shape and wall thickness).

It is assessed according to the relationship [6]:

$$SAR\ [\%] \sim (2d/a)100 \qquad d \ll a$$

where d is the tolerance admitted for phantom wall thickness (±0,2mm) and a is the distance from the RF source to the simulation liquid, usually 10mm.

The resulted uncertainty is ±4% (R distribution).

- Uncertainty of simulation liquid conductivity value, according to [6] it shall not be greater than ±5% (R distribution).
- Uncertainty introduced by conductivity measuring instruments, appreciated ±2,5% (N distribution);
- Uncertainty of measuring liquid dielectric permittivity value compared to the imposed value [6], it shall not be greater than ±3% (R distribution).
- Uncertainty introduced by the dielectric permittivity measuring instruments, appreciated also to ±2,5% (N distribution).

3.3 Expanded uncertainty calculation

First, the standards uncertainties u_i are determined taking into consideration the probability distribution type.

The combined standard uncertainty of the measurement result represents the estimated deviation of the result. It is obtained by combining the individual standard uncertainty of both Type A and Type B evaluation using the usual root-sum-squares (RSS) method [10]:

$$u_c = \sqrt{\sum_{i=1}^{n} c_i^2 \cdot u_i^2} \tag{4}$$

where c_i is the weighing coefficient and its value is about 10%.

The expanded uncertainty is evaluated for a confidence level of 95% (k=2).

$$U_e = ku_c = 2u_c \tag{5}$$

This approximately 20% value is smaller than the expanded uncertainty allowed by the standards [6,8] namely 30% or 3dB.

IV. Conclusions

1. Achievement for the first time in Romania of a laboratory for SAR evaluation and certification at mobile phone terminals. Its putting into operation is provided for 2009.

2. The laboratory will provide tests compliant with the in force international regulations and will have secured customers and benefits accordingly taking into account the development and rapid innovation of the wireless technology.

3. Due mainly to the great number of components of the SAR dosimetry system, the measurement uncertainty matter is much more complicated than in the case of EMC tests for industrial products.

4. A review of different uncertainty sources enables the drawing of the conclusion that the expanded uncertainty of such a system reaches to about 20% and that there is a reserve compared to the value provided by the in force standards for the maximum limit: 30% (6dB).

5. In these conditions, it will be possible to accredit the SAR Dosimetry Laboratory that will serve to certify the mobile phones manufactured or imported in Romania as well as to ensure market surveillance in compliance with European norms requirements.

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