12th IMEKO TC4 International Symposium
Electrical Measurements and Instrumentation
September 25−27, 2002, Zagreb, Croatia

SAR MEASUREMENTS OF DIFFERENT MIXTURES AT 900 MHz

Dina Šimunić and Zvonko Glavaš

University of Zagreb, Faculty of Electrical Engineering and Computing,Unska 3, HR-10000 Zagreb, Croatia

Abstract – The paper discusses measurements of Specific Absorption Rate at mobile telephone frequencies. More specifically, measurements are performed at frequency of GSM system, i.e. 900 MHz. Recently issued CENELEC standard in this field, as well as requirements of European Commission for SAR labeling of every phone are calling for creating and testing different measurement set-ups for this purpose. For this kind of testing, a mixture with required complex dielectric properties is necessary. One of the contributions presented in this paper is creating an adequate liquid with measuring its properties. Measurement system uncertainty has been assessed according to CENELEC EN 50361.

Keywords: SAR Measurements, Dielectric Properties, Mobile Telephone Systems

1. INTRODUCTION

Various national regulatory agencies, as well as European Commission initiated labeling of Specific Absorption Rate (SAR) value at every phone. The labeling is being performed by independent laboratories with special measuring methods according to several standards. In Europe CENELEC EN 50361, published in 2001 is one of the most important.

Specific Absorption rate (SAR) value evaluates the maximum heating effect in the body resulting from electromagnetic fields generated by a high frequency source. In the case of mobile phones, a high frequency source is a mobile phone, and an evaluated part of the body is head, exposed directly to the electromagnetic field of the mobile phone. For SAR measurement, the mobile phone is operating at maximum output. SAR value is measured in the frequency range of 300 MHz to 3 GHz and in a dynamic range of 10 mW/kg to 100 W/kg. SAR can be defined as a measure of maximum energy *(dW)* absorbed by a unit of mass of exposed tissue *(dm)* of a person using a mobile phone, over a given time:

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) \tag{1}$$

SAR is expressed in units of watts per kilogram *(W/kg)* in either 1g or 10g of tissue. The measured reference value is electric field and SAR is from it calculated by:

$$SAR = \frac{\sigma}{\rho} E_i^2 \tag{2}$$

where E_i is a rms value of the electric field strength in tissue in *V/m;* σ a conductivity of body tissue in *S/m* and ρ a density of body tissue in *kg/m³*.

SAR is also defined as an initial slope of temporal temperature rise (ΔT/Δt), ie:

$$SAR = c\left.\frac{\Delta T}{\Delta t}\right|_{t=0} \tag{3}$$

In equation (3) *c* is a specific heat capacity.

The importance of the last definition of SAR is that it shows that it is used for assessing thermal effects only.

2. MEASUREMENT TECHNIQUE

SAR measurements will be performed in a tank with tissue equivalent liquid (so-called flat phantom) [1] at 900 MHz. The fact that SAR is measured in a tissue equivalent liquid is a consequence of the following equation:

$$SAR_{head} = SAR_{solution} \frac{\rho_{solution}}{\rho_{head}} \tag{4}$$

which clearly shows that SAR in the real head can be easily calculated once when the measured SAR in a solution is known. Of course, the ratio of mass densities of solution and head should be known, as well.

Measurement system is shown in Fig. 1. Measuring all three components of E-field by an isotropic electric field probe, SAR can be calculated using (2). In this case, a mass density of ρ = 1000 kg/m^3 is used.

SAR measurement system comprises of four important components: phantom human head, robot, isotropic measurement probe and a mobile phone.

There is a choice of using three different phantoms: an anthropomorphic, flat/rectangular and spherical phantom.

Antropomorphic phantom has the important property that the measured peak spatial-average SAR shall be always higher than the actual value expected in to occur in the heads of a significant majority of persons during normal use of wireless handsets. On the basis of published literature in this field, the design of a phantom is a function of head size, shape, and homogeneity of the shell and liquid; electrical parameters of head tissue simulating liquid and phantom shell and ear pinna/auricle size, shape, and its material properties.

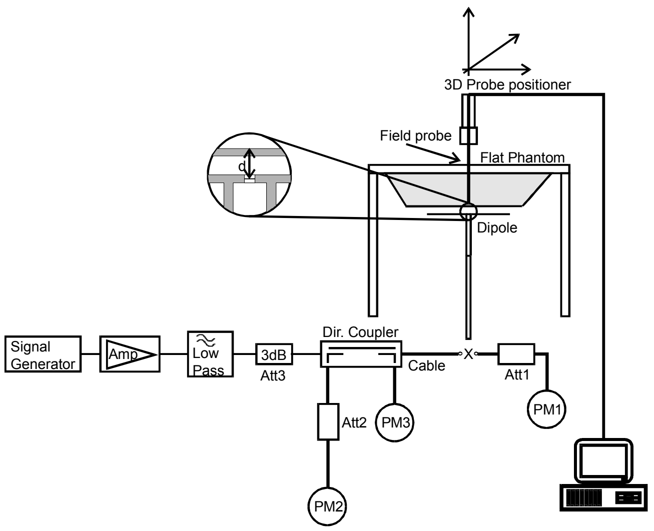

Fig. 1 Simplified system for E-field measurements

Flat phantom has an important property that it allows a closest-spacing condition. Of course, one has to be aware that by using flat phantom considerable changes in antenna loading and impedance can be made due to improper antenna spacing near the skull behind and above the pinna. As mentioned before, it is possible to use spherical phantoms of appropriate diameter. The spherical phantoms better resemble the proper antenna spacing in the head posterior region [2]. However, compared with real heads, the greater relative spacing below the pinna reference point may lead to an underestimation of SAR. Moreover, spherical shapes have other repeatability and volume scanning challenges.

Dielectric properties of the phantom are measured using open-ended coaxial line sensor and reference liquid (de-ionised water) by measuring input reflection coefficient s_{11}. Measurement calibration is performed in a classic way, but the measuring in a reference liquid is added in a calibration process. Complex permittivity is calculated from a reflection coefficient by a computer program where Mosig technique was implemented [3][4].

Half-wave dipole is used as a source of electromagnetic field, and it is placed at a certain distance from the bottom of the flat phantom [5].

A three dimensional probe positioner is controlled by a computer and it is able to move the probe to any position in the flat phantom. Also, computer can read all three E-field components and probe position coordinates and store them in a file for further use in post-processing [6].

The first measurement is performed in a plane closest to the bottom (less than 8 mm) of the flat phantom covering a region of the dipole projection to the flat phantom with grid spacing less than 20 mm. Using interpolation algorithms SAR peak values can be determined. After this measurement, spatial E-field distribution is measured in the cubic area, centered with the peak SAR location, with the dimensions at least 1,5 times the length of a 1-g or 10-g cube edge, or 15 mm and 32 mm respectively. For a sufficient interpolation and extrapolation accuracy, horizontal grid spacing should be less than 8 mm and vertical less than 5 mm.

The required 1-g and 10-g averaged SAR values can be calculated using interpolation and extrapolation. Also, using reference data and reference SAR distribution functions, the relative uncertainty in SAR due to post-processing methods can be determined [1].

3. EXPERIMENTS

3.1. Equipment and software

The measurements have been performed using Motorola Boynton Cellular Design Center ScanProfiler system [6], which consists of a three-dimensional positioning system and data acquisition/switch unit HP 34970A. The measurement set-up encompasses except the mentioned units also signal generator HP 83260A (10 MHz – 20 GHz) and isotropic E-field probe ET3DV6R by Schmidt and Partner [8], [9]. Electromagnetic field has a sharp spatial variation in both magnitude and polarization in the near field of an antenna of a wireless handset. Therefore, the electric field sensor must be isotropic and have much smaller dimensions than the wavelength in the tissue medium. Also, an ideal probe should exhibit a linear response to the intensity of the square of the incident electric field. An isotropic electric field probe consists of three mutually orthogonal center-fed short dipole antennas. The total electric field vector magnitude is the root sum square of the three orthogonal components measured by the sensors:

$$|E|_{RSS} = \sqrt{|E_1|^2 + |E_2|^2 + |E_3|^2} \tag{5}$$

Each sensor consists of an electrically short dipole antenna, a diode detector and a highly resistive transmission line to extract the signal detected by the diode while maintaining the high-frequency transparency of the line. As in other implementations, ideal detector diode acts as an electric field RMS detector for small high frequency signal, whereas at higher levels it acts in the different way. After detection, the low frequency DC voltage is transferred to an amplifier. Taking V_i as the open circuit voltage and γ_i in $\mu V/(V/m)^2$ as the sensitivity at port *i*, (i = 1, 2, 3) the magnitude of the total electric field is:

$$|E| = \sqrt{\frac{V_1}{\gamma_1} + \frac{V_2}{\gamma_2} + \frac{V_3}{\gamma_3}} \tag{6}$$

From the gathered results the SAR values are calculated by a home-made MathCad program.

3.2. Phantom–tissue equivalent liquid

Dielectric properties of the phantom at given frequency of 900 MHz are given in [1]. Relative permittivity and conductivity should be ε_r=42 and σ=0,99 S/m, respectively. After performing experiments with different recipes [7], it is concluded that the recipe that satisfied the requirements is given in Table I. Two columns table gives the details: in the first is the material, and in the second is percentage by weight.

Measurement results are dielectric properties as follows: relative permittivity, ε_r is 41.7, and the conductivity, σ is exactly 1.00 S/m.

TABLE I. Phantom specifications and dielectric properties

material	percentage
saccharose	57.00%
NaCl salt	1.72%
de-ionised water	41.28%

3.3. Peak SAR

According to [1], the measurement process starts with a coarse measurement grid, in order to find the locations of the peak SAR or possible peak SARs (so-called “area scan”). The SAR distribution is scanned along the inside surface of typically half of the head, or in our case, along the inside surface of the flat phantom. In the both cases, the area scan encompasses larger area than the projected area of the both handset and the head. The distance between the measured points and phantom surface should be less than 8 mm, and should remain constant (variation less than ± 1 mm) during the entire scan in order to determine the locations of the local peak SAR with sufficient precision. In our case, area scan is performed at distance of 4 mm from the bottom of the flat phantom with 5 mm grid spacing. The distance *d* from the liquid surface to the dipole’s central axes at location of the feed-point was 15 mm. This grid spacing should enable the detection of the location of local maximum with an accuracy of better than half the linear dimension of the tissue cube after interpolation. If the peak is closer than one-half of the linear dimension of the 1 g or 10 g tissue cube to the scan border, the measurement area should be enlarged if possible by tilting the probe.

When once the peak SAR locations are known (and if they are less than –2dB of the local maximum), additional volume scans are carried out to determine not only localized peak SAR, but the so-called spatial-average SAR value. From the nature of the problem (source of electromagnetic field close to the phantom), it is clear that the local peak SAR value occurs at the surface of the phantom. But exactly at the surface, an increased measurement uncertainty is a consequence of a boundary effect, that takes place due to interactions and capacitive coupling between the media boundary and the probe. Therefore, probe usually does not have the sensors directly at its end, but with an offset from 2 to 4 mm from the housing tip. Even with this offset, it is still possible to get accurate field strength values by carrying out the compensation, as it is done in [8]. The SAR values are calculated by extrapolation algorithms.

The peak spatial SAR values averaged over a 1 g and 10 g cube, as required in [1] are performed during fine resolution volume scans, called "zoom scans". The zoom scan volume should have at least 1.5 times the linear dimension of either a 1 g or a 10 g tissue cube for whichever peak spatial-average SAR is being evaluated.

The peak spatial-average SAR is calculated by a numerical interpolation between measured points and extrapolation between surface and closest measured points.

3.4. Measurement uncertainty

TABLE II. SAR measurement uncertainty assessment for system performance check

Uncertainty Component	u_i**(±%)**
Measurement System	
Probe Calibration	7.0
Axial Isotropy	2.3
Hemispherical Isotropy	4.2
Boundary Effect	0.3
Linearity	2.3
System Detection Limits	0.8
Readout Electronics	–
Response Time	0.0
Integration Time	–
RF Ambient Conditions	–
Probe Position Mechanical Tolerance	0.0
Extrapolation, Interpolation and Integration Algorithms for Max. SAR Evaluation	1.4
Dipole	
Dipole Axis to Liquid Distance	1.3
Input Power and SAR Drift Measurement	2.9
Phantom and Tissue Parameters	
Phantom Uncertainty-Shell tickness tolerance	0.0
Liquid Conductivity-deviation from target values	0.8
Liquid Conductivity-measurement uncertainty	2.9
Liquid Permittivity-deviation from target values	0.9
Liquid Permittivity-measurement uncertainty	1.5
Combined Standard Uncertainty	9.65
Expanded Uncertainty (95% CONFIDENCE LEVEL)	**19.3**

At this time, uncertainty for some components could not be determined. Expanded uncertainty is less than 30% which means that this system can be used for SAR measurements.

4. CONCLUSION

The measurements of SAR have been performed at frequency of 900 MHz with the flat phantom. In the paper, the measurement set-up and technique have been explained. The values of required permittivity and conductivity, defined on a European level are measured in a originally mixed phantom-tissue equivalent liquid. Finally, a measurement uncertainty of the whole measurement set-up has been assessed.

Acknowledgement

Authors are grateful to Croatian Ministry of Science and Technology for support (project: MZT 036039), to "Motorola Inc" for their donation of ScanPro system and to Schmid & Partner Engineering AG who donated E-field probe.

REFERENCES

[1] CENELEC, EN 50361, "Basic standard for the measurement of Specific Absorption Rate related to human exposure to electromagneticfields from mobile phones (300MHz-3GHz)", Brussels, 2001.

[2] A. Faraone, Q. Balzano, D. Šimunić, "Experimental Dosimetry in a Sphere of Simulated Brain Tissue near a Half-Wave Dipole Antenna", IEEE AP, Colorado, SAD, 1998.

[3] S. Škokić, "Mjerenje dielektričnih svojstava materijala u mikrovalnom području", *Diplomski rad, Fakultet elektrotehnike i računarstva*, Zagreb, 2001.

[4] J. R. Mosig, J. E. Besson, M. G. Fabry, F. E. Gardiol, "Reflection of an Open-Ended Coaxial Line and Application to Nondestructive Measurement of materials", *IEEE Trans. Instrum. Meas, vol. IM-30, pp. 46-51*, March 1981.

[5] Motorola balanced dipole at 900 MHz, 2000.

[6] Motorola Boynton Cellular Design Center ScanProfiler system, 2001.

[7] Z. Glavaš, "Izrada otopine ekvivalentnog ljudskog tkiva na frekvencijama pokretne telefonije", *Diplomski rad, Fakultet elektrotehnike i računarstva*, Zagreb, 2002.

[8] K. Poković, "Advanced Electromagnetic Probes for Near Field Evaluations", *Dissertation at Swiss Federal Institute of Technology for a degree of doctor of technical sciences, DISS.ETH No. 13334,* Zurich, 1999.

[9] Schmidt and Partner isotropic E-field probe ET3DV6R, 2000.