Characterization of a GTEM Cell Designed for the SAR Evaluation in *in vitro* Experiments

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Abstract

In this paper we propose a new version of the GTEM cell suitable for *in vitro* experiments. It is a valid dosimetric site because the cell can assume properly reduced sizes in order to be included in a commercial incubator necessary to allow the survivor of the biological sample under test. Moreover, the electromagnetic field inside the GTEM cell can be accurately monitored and controlled in order to guarantee a uniform distribution near to the sample under test. We have experimentally verified the feasibility of the first preliminary GTEM cell prototype as dosimetric site by measuring the SAR of a distillate water sample and the experiment result has been validated by the corresponding value numerically calculated by a dedicated homemade computer code based on the method of moments and on the resonance transverse diffraction method. Finally, the SAR calculation of a brain cell sample in the GTEM cell is reported.

Introduction

Owing to the recent explosive growth in the area of wireless communication such as the diffusion of cellular phones and wireless local area networks, international and national commissions have recommended limits for the protection of mobile phone users and standards are going to be established to certify the compliance of mobile phones within these limits. The first step necessary for an assessment of the potential risks is to analyze and to quantify the contribution of electromagnetic (e.m.) field strength induced in the human body or, generally, in exposed biological systems. In particular, the two fundamental problems regard the exposure of the user head to the portable phone and the general population exposure in the field radiated by the base-station antennas. At the present time, there are well over 20000 papers in the scientific literature that report the results of laboratory studies of exposed animals, humans and in vitro preparations. However, even though a lot of work has been done, there is still no complete assessed knowledge about the radiofrequency and microwave radiation effects on the biological tissues. Fundamental step in order to interpret a biological effect, consists in determining the internal field strength or the energy dose that can cause such an effect. The problem can be approached by means of both the experimental and the numerical techniques. The most used numerical method to solve this e.m. problem is the finite difference time domain technique [1], while the bio-physical measurement experiments, based on electromagnetic exposure techniques, are essentially subdivided in *in vitro* [2] and *in vivo* [3] systems [4]. A critical measure to classify the biological effect entity is the Specific Absorption Rate (SAR) defined as the rate at which energy is absorbed per unit of mass.

In the case of *in vitro* experiments, SAR measurement of the sample under test, must be carried out in a region having a uniform electromagnetic field distribution. In order to analyze the effects of the
exposure to e.m. fields in the ranges around the typical operating frequencies of the mobile phone system, we propose a new version of the GTEM cell suitably designed in order to be included inside a conventional incubator, useful to allow the survival of the biological sample during the experiments. The 50 Ω impedance matching of the terminal section is obtained by using a lumped resistance network. The electromagnetic field inside the GTEM cell has been evaluated by implementing a computer code based on the Resonance Transverse Diffraction (TRD) and generalized telegraphist equations. The knowledge of the e.m. field distribution inside the GTEM cell allows to determine the optimal section where to put the Petri dishes and to calculate the SAR by means of the Method of Moments (MoM).

Design of the GTEM Cell

The design of the proposed GTEM cell, useful for SAR evaluation of biological in vitro experiments, must satisfy some technological constraints. In fact, contrary to the conventional applications, our designed and fabricated GTEM cell, as in Fig.1, is characterized by reduced geometrical sizes in order to allow its inclusion in a commercial incubator having sizes 50x50x70 cm, necessary to achieve the best environmental conditions for the survival of the cellular cultures under test. Further requirements regard the electromagnetic field uniformity in the test region and the impedance matching of the termination of the GTEM cell. Thus, in order to optimize the test volume and to have a matched characteristic impedance $z_0=50 \, \Omega$ in all the sections along the longitudinal $z$ direction of the GTEM cell, the following geometrical parameters have been chosen: cell length $L=45$ cm (pyramid height), aspect ratio $(b+d)/a=2/3$ (in the terminal section we have $a=24$ cm, $b=4$ cm and $d=12$ cm), angles $\theta=5^\circ$, $\gamma=10^\circ$ and $\alpha=15^\circ$. Fig.2 shows the pattern of the characteristic impedance of the GTEM cell, normalized to the value of the vacuum intrinsic impedance $\mathcal{Z}$, as a function of the $w/a$ ratio, calculated by applying the singular integral technique [5]: we notice that the 50 Ω impedance value occurs for $w/a=0.7$.

The photo of the first GTEM cell prototype, having the aforesaid geometrical parameters, is shown in Fig.3. In particular, the cell walls are made of aluminum, whereas the metallic septum consists of a printed circuit board linked to the terminal section by means of a 50 Ω resistive network. Moreover, in order to obtain inside the cell the conditioning thermodynamic parameters obtained by the incubator, on the lateral walls of the GTEM cell, circular apertures of diameter $s=5$ mm suitably, designed to be under cutoff for the electromagnetic propagation at the operating frequency $f=1.8$ GHz, have been made.

Experimental and Numerical Results

Before using the fabricated GTEM cell for the investigation of the biological effects of in vitro exposure, we have experimentally verified its applicability and feasibility as dosimetric site. First of
all, by using the measurement set-up of Fig.4 with GTEM cell inserted in a shielded test chamber, we have verified that the radiated electric field evaluated near the circular apertures is attenuated over 70 dB with respect to the input generator signal power at the operating frequency $f=1.8$ GHz. By using the fault location measurement option of the network analyzer, we have found that the cell exhibits a not negligible power reflection at the input port due to a mismatch of the abrupt transition from $50 \, \Omega$ SMA coaxial connector to the metallic septum at the input port. On the other hand all sections of the GTEM cell show characteristic impedance practically constant and equal to $50 \, \Omega$. Moreover, because the measured Standing Wave Ratio (SWR) reaches a minimum value around the frequency $f=1.82$ GHz, we have carried out the preliminary experiments in the frequency range from 1.75 GHz to 1.85 GHz. Fig.5 sketches the SWR measured around to the frequency $f=1.8$ GHz for the GTEM cell without (solid line) and with (dashed line) the Petri dish filled with distilled water. We can see that for $f=1.8$ GHz the SWR assumes a value equal to about 2.5 which reduces to about 2 by inserting the sample, owing to the water power absorption.

**Figure 3.** Photo of the first GTEM cell prototype.  

**Figure 4.** Set-up configuration for the radiated emission measurement

In order to evaluate the Specific Absorption Rate (SAR) we have measured, at the operating frequency $f=1.8$ GHz, the temperature variation induced in a distilled water sample after different intervals of exposure time by using the expression [6]:

$$\text{SAR} = \frac{C \, \Delta T}{\Delta t},$$

where $C=4.184 \, \text{J/(kg} \cdot \text{K)}$ is the specific heat of the sample, $\Delta T$ is the temperature change induced in the sample and $\Delta t$ is the exposure time. The section inside the GTEM cell, where to place the sample, must be suitably chosen in order to include multiple Petri dishes or a multi-well plate and to obtain a uniform distribution of the electromagnetic field, that is the presence of the only dominant TEM mode. We have evaluated by means of the TRD method together with the generalized telegraphist equations [7], that for $f=1.8$ GHz in the section $z=23$ cm distant from the input port, besides the dominant TEM mode, only the first TE mode propagates, but without significantly perturbing the field distribution. Moreover, in correspondence of $z=23$ cm, the GTEM cell exhibits suitable sizes to include the Petri dishes. The time mean value of the SAR, measured inside the GTEM cell around the $z=23$ cm, has been compared with the corresponding numerical value calculated by means of the TRD method together with the Method of Moments (MoM) [8]. The measured averaged SAR value, corresponding to a temperature increase $\Delta T=0.2 \, \text{K}$ every five minutes of exposure, is equal to 1.4 mW/kg for an input power $P_{in}=1 \, \text{W}$ and $f=1.8$ GHz, and slightly underestimates the calculated one equal to 2.04 mW/kg.

Finally, Fig.6 shows the mean SAR values, numerically evaluated by means of the TRD method and the MoM, for a biological brain sample characterized by a relative dielectric constant $\varepsilon_r=43.3$, volumetric density $\rho=1040 \, \text{kg/m}^3$, electric conductivity $\sigma=1.29 \, \text{S/m}$, as a function of the location $g$ of the Petri dish, along the x direction at the section $z=23$ cm, with respect to the centre. As expected, the maximum mean SAR value occurs for $g=0$ cm.
Conclusion

We have demonstrated the feasibility of a new dosimetric site by using a properly designed GTEM cell. The safety of the user has been verified by testing in a shielded chamber the surrounding of the GTEM cell: the radiated e.m. power is attenuated of about 70 dB with respect to the input generator signal power at the operating frequency $f=1.8$ GHz. A simple sample of distillate water has been used to validate the GTEM cell as a dosimetric site at the frequency $f=1.8$ MHz. The measured SAR value, equal to 1.4 mW/kg, exhibits a good result compared with that numerically evaluated, equal to 2.04 mW/kg. An optimized version of the GTEM cell will be realized with the aim to have a better impedance matching at the input port and an improved termination load by means of a combination of resistor network and ferrite absorbers.

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