Technique of High Power Microwave Pulses Dosimetry of Living Systems

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Abstract— In order to investigate the biological effects evoked in the high power microwave fields, the numerical calculation of dosimetry for *in vitro* study has been carried out. The widely used 90 mm Petri dishes filled with human blood was planned to be exposed to high power microwave pulses. Electric and magnetic vectors of the incident field were parallel to the surface of Petri dishes. Taking into account that according to the actual safety standards the specific absorption rate (SAR) is a basic restriction parameter for protecting against thermal effects in the risk assessment study the numerical calculation has been performed to maintain the SAR distribution in the specimen. The novel attempt of the dosimetry takes into account the calculation of SAR of all frequency harmonics of the spectrum taking into consideration the function of permittivity of the medium (human blood) in the analyzed frequency range.

1. INTRODUCTION

Electromagnetic radiation emitted from HPM (High Power Microwaves) generators can be characterized by extremely high power in peak (mega or giga watts) and pulse duration less than 50 ns and they are called as e-bomb. Many reports demonstrated the destructive effects of e-bombs to electronics exposed to HPM's. Despite the fact that potential health hazard from HPM pulses is not broadly investigated, the generators emitting such HPM pulses have been called as non-lethal weapon. Electromagnetic radiation emitted from HPM generators can also be treated as ultra-wideband (UWB) signals. Such frequency range of radiation can be obtained with contemporary antennas [3, 4, 7, 8, 16–19] or microstrip antennas [5, 9, 20–22]. In addition, ultra-wideband (UWB) wireless communication became the subject of intensive investigation due to its potential applications in high rate transmission [2, 11–14].

The ultra-wideband signals have different forms of interaction with biological structures comparing with continuous signals because the frequency spectrum of harmonics of such radiation sometimes exceeds 500 MHz. This is why, for such signals the efficiency of electromagnetic absorption inside biological tissues cannot be investigated with the same methods as it was presented for monochromatic signals or for narrowband signals. The main parameter which differentiates the level of absorption in function of frequency is permittivity. However, the real and imaginary part of permittivity of biological tissues significantly changes in such broad frequency band [1, 7, 10]. From this point of view the level of absorbed electromagnetic energy by tissues depends on frequency.

According to the actual safety standards the specific absorption rate (SAR) is a basic restriction parameter for protecting against thermal effects in the risk assessment study. This parameter should be treated as a basic restriction for protecting against thermal effects from exposure to radiofrequency fields. The SAR is expressed by watt per kg of tissue mass, according to the following equation

$$\mathrm{SAR} = \frac{\sigma |E_{int}|^2}{\rho} \tag{1}$$

where: σ is the conductivity of the tissue in S/m, ρ is the mass density in kg/m^3, $|E_{int}|$ is the root-mean-square of the induced electric field in the medium in V/m.

Nevertheless, there is still an open question if specific absorption rate (SAR) is a suitable parameter to characterize the dose-effect dependence. The SAR has been effective parameter for continuous wave (CW) due to thermal effect. In case of HPM/UWB pulsed radiation, the value of SAR can be determined only for time duration of single pulse or for train of pulses. Between pulses the field does not affect the biological structures. For such radiation bioeffects of HPM/UWB signals could be different from CW.

The Petri dishes of different types are widely used in biological investigation to assess the microwave exposure level of cell cultures. An important requirement of the biological research is accurate field and/or dosimetry assessment. Biological effects should be related to the induced internal electromagnetic field or energy rate absorbed by the biological specimen. At microwaves the dosimetry of exposure to very high power pulses of cells in a solid nutrient medium (agarose gel) was presented by Pakhomov et al. [15]. The carrier frequency was 9.3 GHz and the radiation was modulated by pulses of 0.5 μs duration and 10 Hz repetition. The simulation was made for setup based on waveguide and electric field strength of 1.57 MV/m. For this configuration the radiation was treated as a narrowband signal and the SAR of 650 MW/kg was obtained.

In the work, the novel technique was proposed to improve the dosimetry of living tissues exposed to high power microwaves radiation. In this method the incident signal has been presented as a series of frequency harmonics. Harmonic amplitudes were calculated using the Fourier transform. The SAR has been calculated for each harmonic taking into account value of blood permittivity, suitable for analyzed frequency.

In the exposure of cell cultures with Petri dishes an important task is polarization. Generally speaking, three polarizations can be used, yielding to a different coupling to the electromagnetic field and different SAR distribution inside the medium. The k polarization, used in this work, refers to the exposure in the free space when electric and magnetic vectors of incident field are parallel to the bottom surface of the specimen.

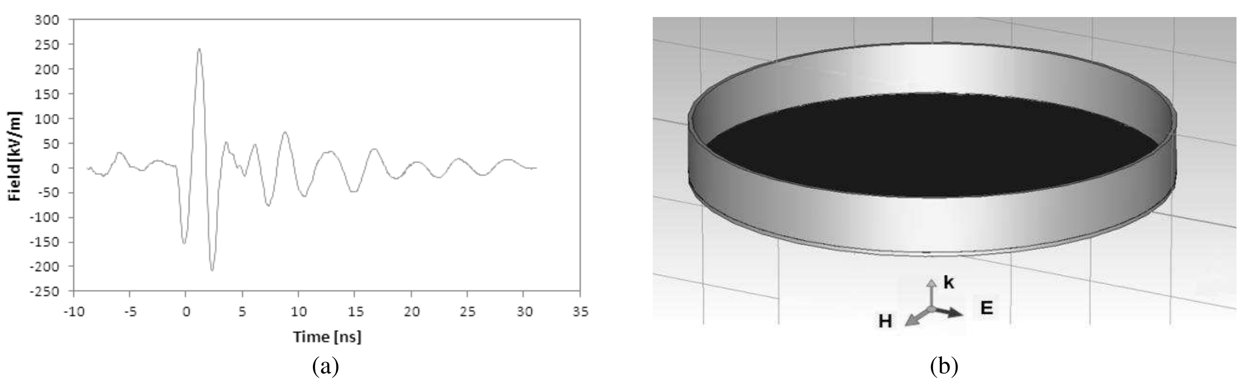
2. MATERIALS AND METHODS

The generation system has been based on DS110 RF Source (Diehl BGT Defence, Germany) [6]. The setup consists of a generator of HPM pulses equipped with reflector. Generated signal (pulses) consists of the main part of the pulse of 4 ns time duration and 30 ns of the remaining part as presented in Figure 1(a). Maximum value of the pulse is 240 kV/m. The remaining part of the pulse reaches value of 70 kV/m.

Using DS110 RF Source (Diehl BGT Defence, Germany) it is possible to emit single pulse or a train of pulses with 5 Hz repetition. Signal, as presented in Figure 1(a), has a broadband spectrum frequency of harmonics.The frequency spectrum of signal presented in Figure 1(a) covers the frequency bandwidth of 500 MHz, from 150 MHz to 650 MHz. Such a RF source can be useful to investigate the biological effects of exposure to high power pulses as well as UWB signals.

The Petri dishes are intended to place 0.5 m above the DS110 RF Source (Diehl BGT Defence, Germany). All elements will be installed in an anechoic chamber providing the free space condition of exposure. For such case the electromagnetic field incidents on the bottom of Petri dish surface. This configuration provides the TEM type field with k polarization — vectors E and H are parallel to the surface of specimen (Figure 1(b)). In the investigation the standard 90 mm Petri dishes have been performed with the internal diameter of 86.5 mm (radius of 43.25 mm). Dishes were filled with 4 ml of human blood as specimen. This corresponds to medium height of 0.68 mm of the medium.

Presented in this paper, the HPM pulses as a ultra wideband signal covers a broad frequency range from 150 MHz to 650 MHz. For such a broad frequency range relative complex permittivity of investigated medium changes significantly. For further study the SAR for each harmonic was numerically calculated taking into account suitable amplitude of harmonic and permittivity for its frequency. To model the SAR distribution in the specimen, the three-dimensional model accounting both dielectric materials, i.e., human blood as a medium and supporting plastic part (Petri dish) has been developed. The coordinate system has been placed in the dish bottom with the origin



(a) (b)

Figure 1: (a) HPM pulse in function of time, (b) 90 mm Petri dish filled with blood and electromagnetic field configuration showing the k, E, H directions.

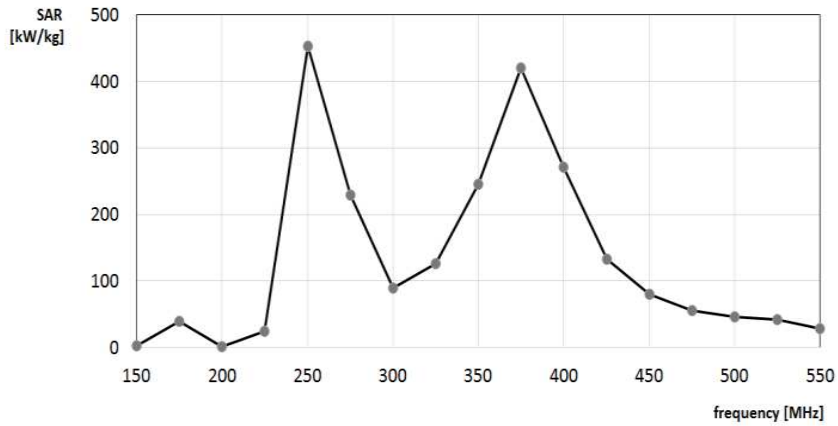


Figure 2: Function of maximum values of SAR in function of harmonic frequencies.

of coordinate centered in the middle of circular layer of dish bottom. The dish thickness of the side and the bottom of 1 mm and relative permittivity of 2.5 and conductivity of 0.02 S/m were considered in the calculation. The maximum values of SAR of all harmonics were presented in Figure 2. Presented values have been determined at the middle point of horizontal layer located 0.3 mm above the specimen bottom.

In the Figure 2 the SAR values for all harmonics within analyzed frequency range have been determined. The discussed exposure to HPM/UWB can also be treated as 17 plane waves having SARs as presented in the picture. It is easy to notice that assessing such exposure, according existing methods, using only one value of SAR is too large simplification of the problem. Figure 2 shows that for incident pulsed field used in this investigation two SAR maxima appear in function of frequency — 250 and 375 MHz, achieving values of 450 and 420 kW/kg. For other frequencies SAR have significantly lower values.

Presented data for HPM/UWB signals open the question if the SAR as the basic restriction factor should be predicted only for one frequency as is defined in guidelines or for all representative harmonics as is underlined in this work. According to the general statement on safety factors limitations the establishing data should be provided for the whole frequency range, thus the assessing of SAR for only one frequency, for example for carrying frequency, is insufficient. As the minimum approach the SAR should be assessed at specific frequencies where they reach maximum values.

3. CONCLUSIONS

In the paper the study describing the exposure system and dosimetry evaluation have been proposed for high power microwave pulses (HPM) as well as for ultra-wideband (UWB) signals. In order to investigate the biological effects the numerical simulation for in vitro has been carried out for the widely used 90 mm Petri dish filled with human blood exposed to high power microwaves (HPM) with the free space condition. The incident electromagnetic field was with the k polarization. The simulation has been performed to maintain uniformity of the specific absorption rate (SAR) distribution in the specimen. According to the actual safety standards the SAR is a basic restriction parameter for protecting against thermal effect in the risk assessment study. The novel attempt at the dosimetry takes into account calculation of SAR of all frequency harmonics of the spectrum of incident signal with regard to permittivity of the medium in the analyzed frequency range.

ACKNOWLEDGMENT

The project was financed from NCBiR means within the Agreement No. DOBR-BIO4/016/13071-/2013 in the years 2013–2015.

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