TEM CELL AS EXPOSURE SYSTEM FOR BIOLOGICAL EXPERIMENTS

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Abstract. The experimental study of the biological effects of electromagnetic fields requires a well-defined exposure field inside the volume occupied by exposed objects. A good exposure system has to generate a controlled electromagnetic field having the same magnitude for all biological samples. A shielded exposure system of TEM cell type was built, according to the requirements for biological exposure experiments. To allow long-term exposure of vegetal organisms and animals, illumination and natural ventilation were provided inside the exposure system. In the case of animal exposure, the perturbation of the electromagnetic field in the location of a specific animal due to the presence of neighbor animals was eliminated by using plexiglas holders. Restraining animals in specific locations inside the TEM cell, planewave exposure conditions are achieved for all exposed animals. The wide band of frequencies that can be coupled to the TEM cell, up to about 400 MHz, makes it versatile and suitable for various types of experiments concerning biological exposure to RF fields.

Key words: biological exposure, electromagnetic fields, exposure system, planewave.

INTRODUCTION

The role of biological exposure experiments is to emphasize bioeffects of electromagnetic fields (EMF) and to correlate the effects with exposure parameters. Given that the EMF exposure has to be well defined, a key element in designing biological exposure experiments is the exposure system. A great diversity of exposure systems have been used in biological experiments on cell cultures, vegetal organisms and animals [2, 3, 5, 10]. The resulting diversity of exposure conditions has created difficulties in comparing the output of various exposure experiments even when the same biological species, frequency and level of exposure field were used.

To allow comparisons with the results of other studies and interspecies extrapolations, some requirements have to be fulfilled [6]. One of the most important criteria is that the exposure system has to generate a uniform field or a

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homogenous plane wave. The usable volume of the exposure system where the same exposure is achieved for all objects placed inside has to be big enough to allow simultaneous exposure of many samples. The exposure system should allow long-term hosting of exposed biological species in good environmental conditions. Another important requirement is the shielding of EMF, both generated inside – to protect operators – and generated outside the system – to eliminate parasitical radiation.

A transverse electromagnetic (TEM) cell is an exposure system that combines the above mentioned qualities with some other characteristics: operates over a wide frequency band, generates a planewave, field strength can be computed from the radiofrequency (RF) power travelling the cell. TEM cells had been used to expose biological samples [4, 5] or animals [4, 10], authors focusing mainly on upper frequency limit, but little attention was paid to reciprocal field perturbation due to neighbour biological objects that complicates dosimetric analysis [1]. We designed a TEM cell having an elongated and quite flattened structure that allows exposure of a sufficient number of animals, the exposure field over all biological bodies being similar and the quantifiable.

MATERIALS AND METHODS

We decided to build a shielded exposure system that do not radiate fields outside and it is immune to external electromagnetic radiation so that biological exposure is not perturbed by other factors. Shielding of the electromagnetic field generated by the exposure system itself (metallic walls) is important, not only for personnel protection, but also allows keeping all biological samples or lots of animals, the control ones and the exposed ones, in the same room. We calculated a structure that optimizes the compromise to be done between upper frequency limit and the volume of the uniform exposure field.

TEM cell derives from a stripline type structure and consists of a rectangular coaxial transmission line with large cross section, continued at both ends with pyramidal sections that make transition to 50 ohms coaxial standard connectors (Fig. 1). The dimensions of component elements of the TEM cell were calculated having in mind two endpoints: desired frequency of operation and the needed volume to expose small animals. To obtain a 50 ohms impedance along the whole structure and to get a large enough volume for rat exposure (especially the distance between inner and outer conductor), the dimensions of the TEM cell components were computed starting from the rectangular section (Fig. 2). The width a, of the outer conductor and the width w of the inner conductor (septum) were calculated as a compromise between the value of height b needed to place biological recipients and the upper limit frequency of operation of the TEM cell in the quasi-TEM mode. Longitudinal dimension of the cell was calculated such as to get an enlarged septum length without limiting too much the upper frequency.

The TEM cell we built was designed to allow long-term exposure to RF fields of cell cultures, vegetal organisms and small animals like mice and rats. The cell was made from aluminium and it was provided with small holes for illumination and ventilation regularly distributed on side walls. The central conductor – septum – was mounted on plexiglas insulating rods.

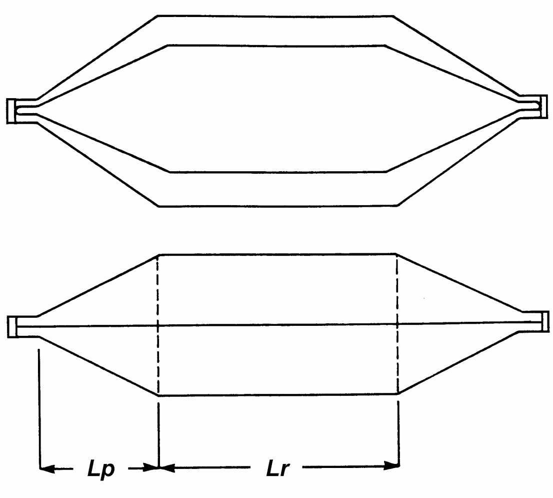

Fig. 1. Longitudinal sections of TEM cell: top view and side view.

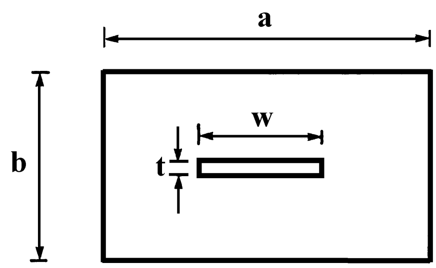

Fig.2. Rectangular part of the TEM cell: transversal section.

RESULTS AND DISCUSSIONS

The TEM cell we built [4] has quite large dimensions that allow exposure of various vegetal organisms and small size animals that can be introduced inside through two access doors (Fig. 3). The transversal dimensions of the rectangular section are a = 715 mm, b = 340 mm, w = 450 mm. The length of any pyramidal section is L_p = 380 mm. The length of the rectangular section L_r is higher than the one of standard structure TEM cell that is double the length of the pyramidal section ($L_r > 2L_p$). To achieve the desired volume and minimize the resonance effect the optimum length of the rectangular section is L_r = 1524 mm. The total length of the cell is about 2.3 m.

The maximum frequency of operation in pure TEM mode is given by the cutoff frequency of the first transverse electric (TE) mode TE_{10}:

$$(f_C)_{1,0} = \frac{c_0}{2a} \tag{1}$$

For the dimenssions mentioned above the cutoff frequency of the TE_{10} mode is 209 MHz. The cutoff frequencies of higher order TE modes, $TE_{m,n}$ are determined by the formula:

$$f_C = \frac{c_0}{2ab}\left[n^2a^2 + m^2b^2\right]^{1/2} \tag{2}$$

The TE_{20} , TE_{01} şi TE_{11} modes have the following cutoff frequencies: 418 MHz, 439 MHz and 487 MHz, respectively.

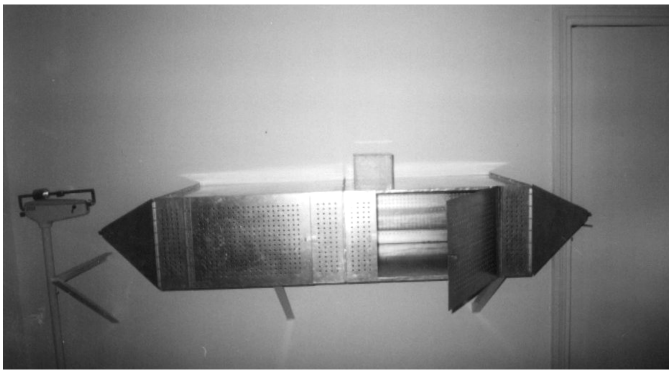

Fig. 3. TEM cell.

Above 209 MHz, higher order modes could distort the field distribution inside the cell. However, given that the inner conductor of the cell is connected directly to the inner conductor of the coaxial cable, the dominant mode excited is transverse electromagnetic [7, 8]. The mode TE_{10} cannot be efficiently excited: only a very small fraction of the power may be carried out by the parasitical TE_{10} mode. Moreover, the presence of TE_{10} mode does not significantly alter the field structure inside the cell, especially in its central zone where the field lines are still upright as in the case of operating in pure TEM mode. Consequently, the cell can operate in quasi-TEM mode up to the cutoff frequency of the next higher order mode, TE_{20}, that is 418 MHz.

Above 418 MHz, a superposition of higher order TE modes with more complicate distribution is present and the total power of the parasitical modes increases. The field distribution inside the TEM cell is distorted and field levels vary significantly across septum surface. Consequently, the exposure of biological samples inside the cell is neither the same for all samples, nor simple to quantify.

To excite the RF travelling wave, at one end a RF power generator, via a bidirectional coupler supplies the TEM cell, and the other end is terminated on a matched load (Fig. 4). The forward P_f and reflected P_r powers are measured by means of powermeters connected to the bidirectional coupler. Considering that almost the entire RF power coupled to the cell is propagating through it by means of TEM mode, the electric field strength E along septum axis is [9]:

$$E = \frac{\sqrt{P\,Z_0}}{d} \tag{3}$$

where P is the transmitted power, Z_0 is the characteristic impedance of TEM cell and $d = b/2$ is the distance between the septum and the outer conductor of the cell. The transmitted power through the TEM cell is the difference between the forward RF power P_f and reflected power P_r measured at the input of the cell.

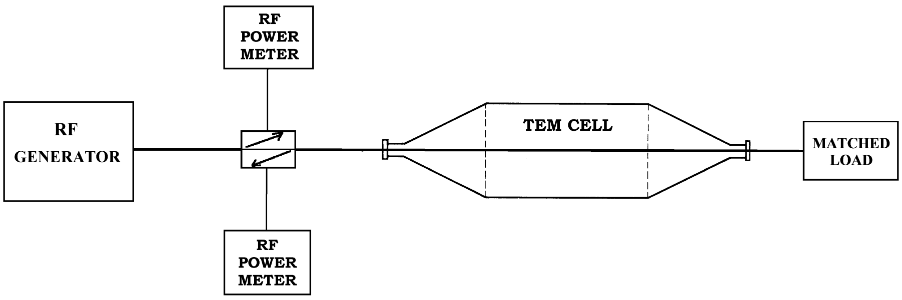

Fig. 4. Experimental setup.

When TEM mode is propagating through the cell, the wave impedance inside the cell is, actually, the impedance of free space Z_{00} = E / H = 377 Ω. The magnetic field strength H and the power density S have the following expressions:

$$H = \frac{\sqrt{P\,Z_0}}{d\,Z_{00}} \tag{4}$$

$$S = E \cdot H = \frac{E^2}{Z_{00}} = Z_{00}\,H^2 = \frac{P\,Z_0}{d^2\,Z_{00}} \tag{5}$$

Measurement of the reflection coefficient was carried out at the input and the output of the TEM cell. The values of the reflection coefficient were lower than 4%, proving a good impedance matching between the components of the experimental setup. Therefore, the TEM cell impedance is close to the calculated value and the field level inside it can be estimated starting from the value of generated RF power. For the elongated ($L_r > 2L_p$) and quite flattened ($a/b = 2.1$) calculated structure, an increased exposure volume and a good RF illumination of all exposed animals was obtained.

CONCLUSIONS

The TEM cell we built can be used for electromagnetic treatment of various biological objects: cell cultures, vegetal organisms and small animals up to rat size. The large enlarged usable volume of the calculated TEM structure allows unperturbed and similar exposure for a sufficient number of samples or animals. External illumination and natural ventilation allows long-term hosting of vegetal organisms and animals inside the cell. Moreover, the homogeneity of the travelling wave and the wide range of frequencies that can be coupled to the cell make it versatile and suitable for various types of experiments concerning biological exposure to RF and microwave fields.

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