Electric field uniformity in a GTEM cell for in-vitro exposure studies: simulations and measurements

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ABSTRACT

In this paper we present field uniformity measurements inside a GTEM cell at mobile communication frequencies for different modulation types and stress levels. In addition, a numerical GTEM model is developed and simulations of the electric field are carried out. Measured and simulated field values are in satisfactory agreement with a maximum difference lower than 3 dB.

1. INTRODUCTION

Several *in vitro* studies have been carried out in the past evaluating the biological effects of electromagnetic fields at mobile communication frequencies. In these studies, different types of exposure systems have been employed, but only few experiments were conducted utilizing a GTEM (Gigahertz Transverse Electro Magnetic) cell [1]-[3]. The present work targets to lay the foundation for the proper design of biological experiments using a GTEM cell, aiming at assessing cytogenetic, molecular, and biochemical indicators of biological effects of electromagnetic fields (EMF) on human peripheral blood.

The aim of this paper is twofold. Firstly, to examine the field homogeneity inside a GTEM cell (Teseq GTEM750) at a predefined frequency and different stress levels as an important step towards designing exposure experiments to assess EMF effects on peripheral blood samples. Secondly, to develop an accurate numerical model of the GTEM cell and perform field uniformity simulations using the finite element method (FEM). Preliminary uniformity measurements in a GTEM cell have been reported in [4], for an empty chamber and for a chamber containing ten dielectric tubes filled with blood simulating liquid. Additional tests have been reported in [2], concerning *in vitro* biological experiments, as well as in [5] and [6], regarding non-biological tests. GTEM cell models and simulations based on the FEM technique have been reported in [7]-[9], regarding non-biological experiments, whereas in [10] simulations are compared with electric field measurements.

The rest of the paper is organized as follows. Field uniformity measurements, performed in a GTEM cell at 1.966 GHz for three predefined stress levels, following the methodology presented in [4], are presented in Section 2. Both modulated and unmodulated radiated signals are considered. Field simulations in a GTEM model, utilizing the FEM technique are presented in Section 3 and validated through comparison with measurements. The ultimate goal is to utilize the GTEM numerical model to perform simulations and assess the electric field, the specific absorption rate (SAR) and the temperature of the irradiated blood samples contained in tubes placed inside the GTEM cell. Such assessment is impossible through measurements in a real GTEM cell.

2. FIELD UNIFORMITY MEASUREMENTS

In order to ensure that all the samples positioned inside a GTEM cell are evenly irradiated and the variance of the targeted stress level is within specified limits, electric field uniformity measurements inside the GTEM cell are of utmost importance. Our aim is to investigate the field homogeneity in the volume (see Fig. 1) where the dielectric tubes with the peripheral blood samples are going to be exposed [4]. According to the field uniformity requirements, at least 75% of the considered points in the defined cubic grid should be within ±3 dB of the nominal target electric field level [11]. The measurements were conducted at 1.966 GHz, for three different reference electric field levels (stress levels), namely 3 V/m, 10 V/m and 76 V/m (maximum achievable by the available measurement equipment). The measurements were initially carried out transmitting an unmodulated carrier (CW), and then, were repeated producing a generic wideband UMTS signal (5 MHz bandwidth) [12]. The measurement methodology is described in [4]. The typical setup, the utilized equipment and the measurement points are presented in Fig. 1. The upper right photo in Fig. 1 shows the grid of the measured points, above the wooden holder in the real GTEM cell, whereas the lower right photo indicates the position of the tubes during the final irradiation experiment. The blood tubes are positioned in the central vertical grid (blue dots plane) above the wooden holder as shown in Fig. 1.

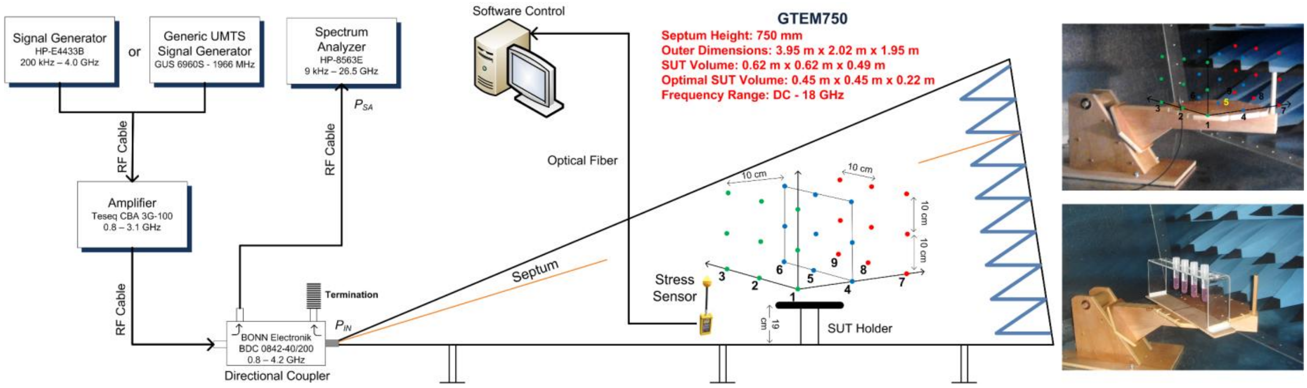

Figure 1. Field uniformity measurement setup and equipment. The photos on the right side indicate the measurement points in the GTEM cell and the location where the blood samples are positioned during the final irradiation experiment.

The generated signal (either unmodulated or UMTS) was fed to a broadband high power amplifier through a low loss cable and after amplification it was forwarded to the GTEM cell through a directional coupler. The latter was used for continuous monitoring of the input power with the help of a spectrum analyzer. At each point of the cubic grid of Fig. 1, the field intensity was recorded, and 27 spatially separated field values were produced. The normalized values of the measured field with respect to the reference levels are presented in Fig. 2 for both modulation types. The selected reference values of 3, 10 and 76 V/m were measured at Point 5 (see Fig. 1). As it is evident from Fig. 2, the normalized field values are within the ±3 dB range for more than 25 measured points and field uniformity between 93% and 96% is achieved in the defined cubic area for all the selected stress levels and modulation types.

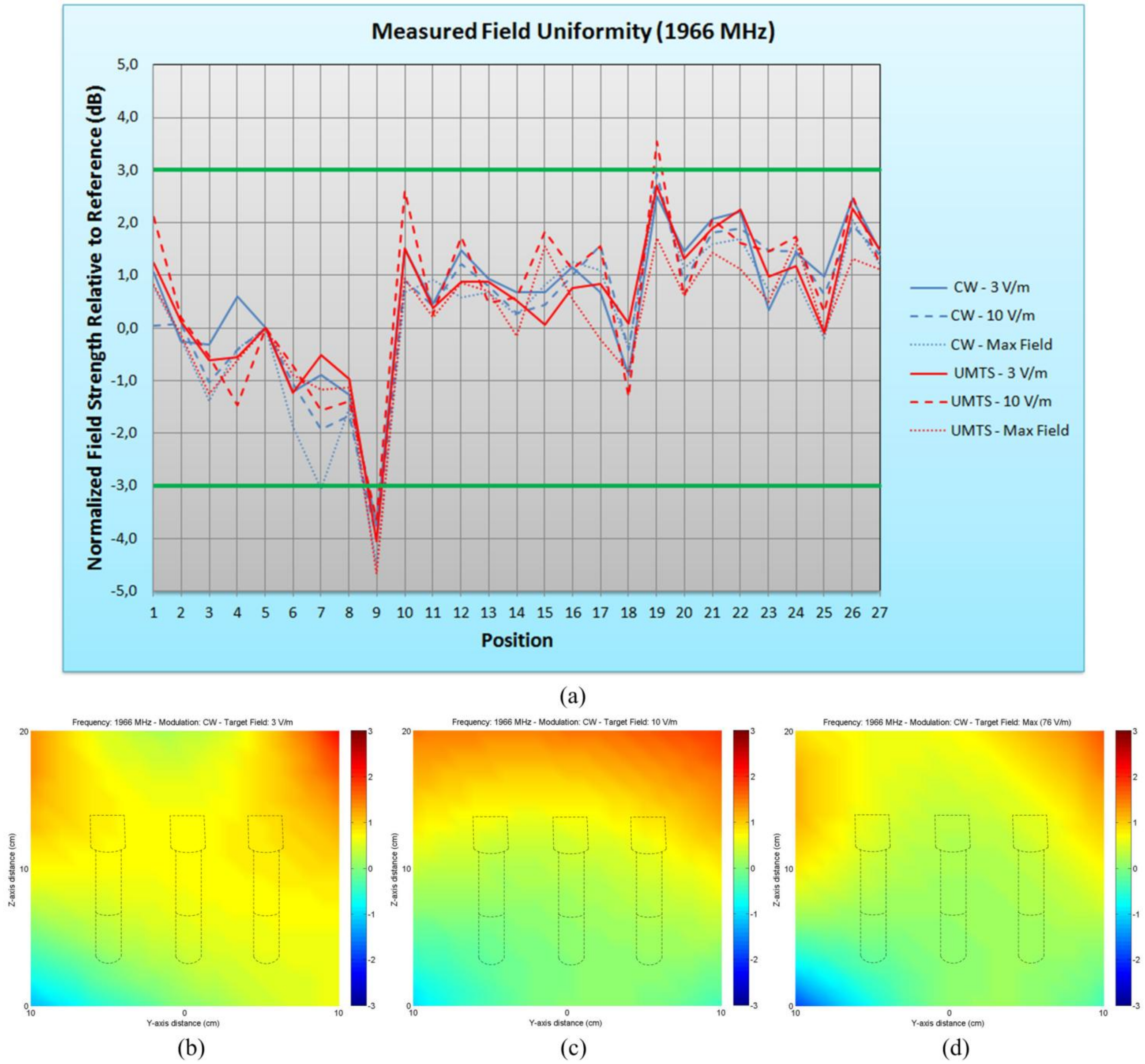

Figure 2. (a) Field uniformity measurement results. Normalized electric field distribution in [dB] on the central vertical plance of the considered volume (Fig. 1), for an unmodulated carrier (CW), and stress levels (b) 3 V/m, (c) 10 V/m, and (d) 76 V/m.

At the bottom of Fig. 2, spatial distributions of the normalized field derived from measurements, on the central vertical grid of the cubic volume (see blue dot plane in Fig. 1) are shown, for 3, 10 and 76 V/m reference electric field intensity, respectively. The distributions were produced from the measurement points using cubic interpolation. The position of the blood tubes during the final experiment is superimposed. The results of Fig. 2 refer to an unmodulated carrier (CW) but similar results were obtained in the case of a UMTS signal. Finally, it is evident that the field homogeneity in the area of the blood sample is even better with the normalized field being within ±1 dB from the selected reference stress levels.

3. Field Uniformity Simulations

In this section we present a full scale detailed model of the GTEM cell developed using the HFSS software, a commercial, high-performance, full-wave, finite element method solver for electromagnetic structures [13]. Special care is taken to include the different sectors of the chamber, material attributes and connections in the developed model. Fig. 3 shows the detailed GTEM model with the wooden holder (see photos in Fig. 1). The green box denotes the optimal sample under test (SUT) volume, according to GTEM specifications (see Fig. 1), where field uniformity results will be obtained through simulations. The connection of the coaxial feeder to the septum is illustrated in detail. The main body, the apex, the septum and the outer back cap of the chamber are modeled as perfect electric conductors (PEC). The depicted holder material is modeled as fir plywood ($\varepsilon_r = 1.87$), whereas the RF absorbers (inner part of the back cap) are modeled as a perfect matched layer (PML) with quarter wavelength thickness. A total number of 417849 mesh elements and a wave port excitation source are used.

Simulated field distributions on the central vertical plane (blue dots plane in Fig. 1) for an unmodulated carrier at 3 V/m stress level, are shown in Fig. 3. For comparison purposes, the corresponding measured distributions are also shown. In both measured and simulated field distributions, electric field intensity remains within the ±3 dB range (2.1-4.2 V/m) of the nominal stress value. Considering the numerical values from the nine points of the central vertical grid plane (Fig. 1), the difference between measured and simulated field values vary in the range 0.4-0.8 V/m (1.2-2.5 dB). Similar findings were derived for the rest of stress levels and modulation types.

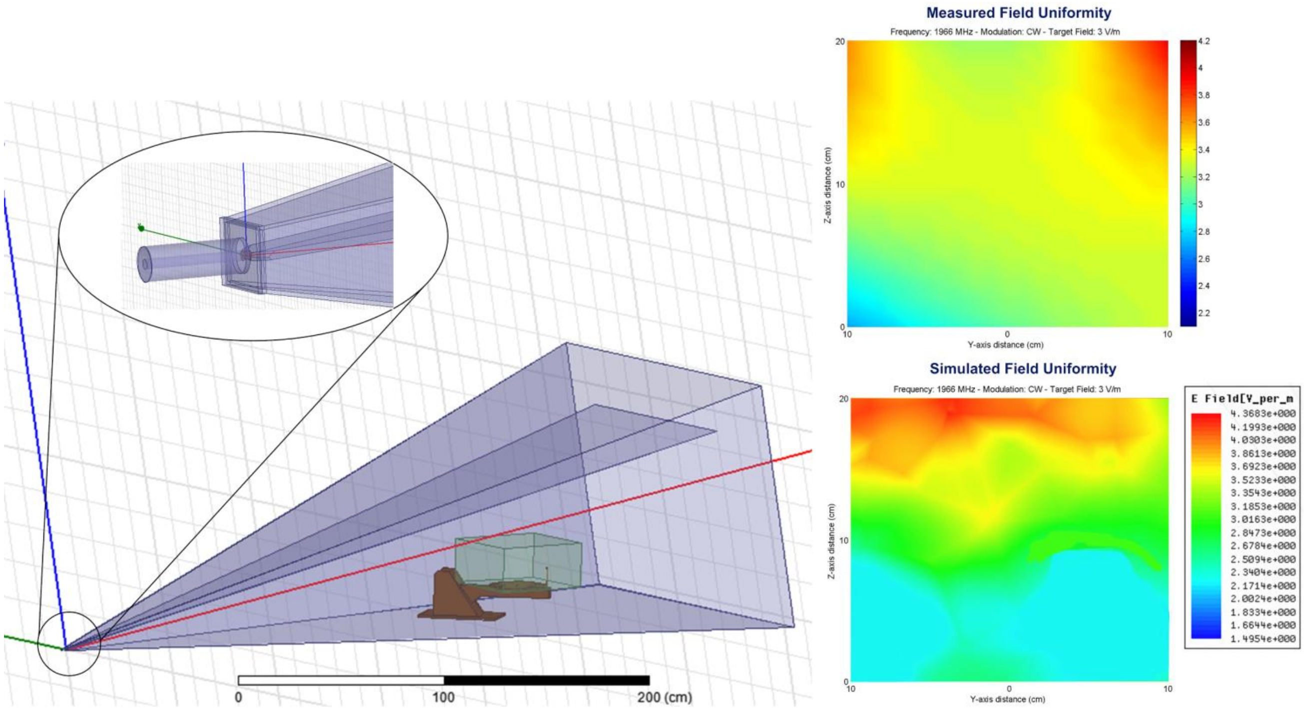

Figure 3. GTEM cell model in HFSS software. Mesaured and simulated electric field distributions on the central vertical plane of the considered volume (Fig. 1) for a stress level of 3 V/m and an unmodulated carrier.

4. CONCLUSIONS

The results from field uniformity measurements and simulations within a GTEM cell, at 1.966 GHz, for different modulation types and stress levels were presented. According to measurements, ideal field homogeneity (93-96%) was observed for all the examined stress levels and modulation types. An even better uniformity was observed in the area where the blood samples will be positioned during the final irradiation experiment. An excellent agreement between measured and simulated field values was observed. Their difference varies in the range 1.2 and 2.5 dB. Thus, the developed GTEM numerical model is able to provide accurate field predictions and can be used as a reliable dosimetric tool for biological experiments design.

ACKNOWLEDGMENTS

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