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Numerical Analysis and Measurement of Electric-field Strength inside GTEM Cell at GSM Frequencies

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ABSTRACT

A miniaturised gigahertz transverse electromagnetic (GTEM) cell is designed and fabricated to generate uniform electric (E-) field, essential for studying the radio frequency exposure effect on tissue equivalent liquids at global system for mobile (GSM) communication frequencies (914 MHz and 2.10 GHz). The simulation procedure is discussed and its results are compared with measurement data. The E-field strength inside the GTEM cell is scanned using a microstrip based E-field probe and complete uncertainty evaluation procedure is discussed. Theoretically, simulated and measured E-field strength is reported with expanded uncertainty.

Keywords: E-field probe; GTEM cell; Microstrip; RF exposure; Uncertainty

1. INTRODUCTION

A gigahertz transverse electromagnetic (GTEM) cell is an alternative of the anechoic chamber for EMI and EMC testing of small devices while doing high frequency measurements[1-3]. This paper reports the fabrication of a miniature GTEM cell for generating known and uniform electric (E-) field strength to study the effect of radio frequency (RF) exposure on sample under test[4]. The design of the GTEM cell is optimised for 914 MHz and 2.10 GHz, two most commonly used frequencies of communication in India. The GTEM cell design[5] is simulated on HFSS [6], which is based on well known numerical method for electromagnetic problems - finite element method (FEM). A microstrip E-field probe working on the above mentioned frequencies is used to scan the E-field strength inside the cell. A novel approach to suppress higher order modes at 914 MHz and 2.10 GHz is explained for the design of GTEM cell[5]. The performance of the probe is exhaustively characterised; details are Narang[7]. The matching condition and E-field strength inside the GTEM cell at different positions with varied input power is given and discussed. The E-field strength measurement results obtained using indigenous probe are compared with the results of another commercial isotropic E-field probe. The analytical and simulated analysis of E-field strength is also presented.

2. DESIGN OF GTEM CELL

The designed prototype of the GTEM cell as is shown in Fig. 1. Aluminum is used to fabricate the GTEM cell casing and copper is used for the inner conductor i.e., septum which is backed by Teflon coating. An N-type connector is used to provide the feeding to the cell. The connector pin is connected to the septum and the cell housing is grounded with the connector. The septum is supported with the upper sheet with microwave-transparent Teflon rods to avoid sagging with the running length in the *z*-direction. Commercially available 4cm pyramidal microwave absorber is used for matching of the impedance and termination of the cell. The design parameters of the cell are shown in Fig. 2(a-b).

The use of copper backed by Teflon coating is suggested to suppress the generation of higher order modes due to the direct multiple reflections from the septum itself. The effect of the septum is studied using the simulated results. The tapered shape of the GTEM cell ensures 50 Ω characteristic impedance along the direction of propagation. It was understood from[4]

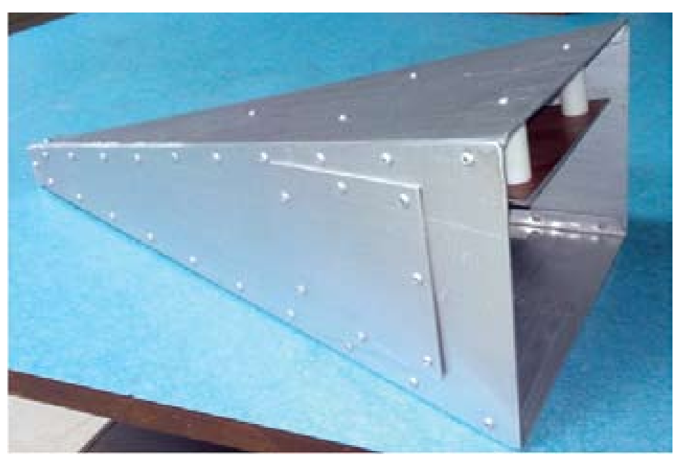

Figure 1. GTEM cell prototype fabricated at National Physical Laboratory, India.

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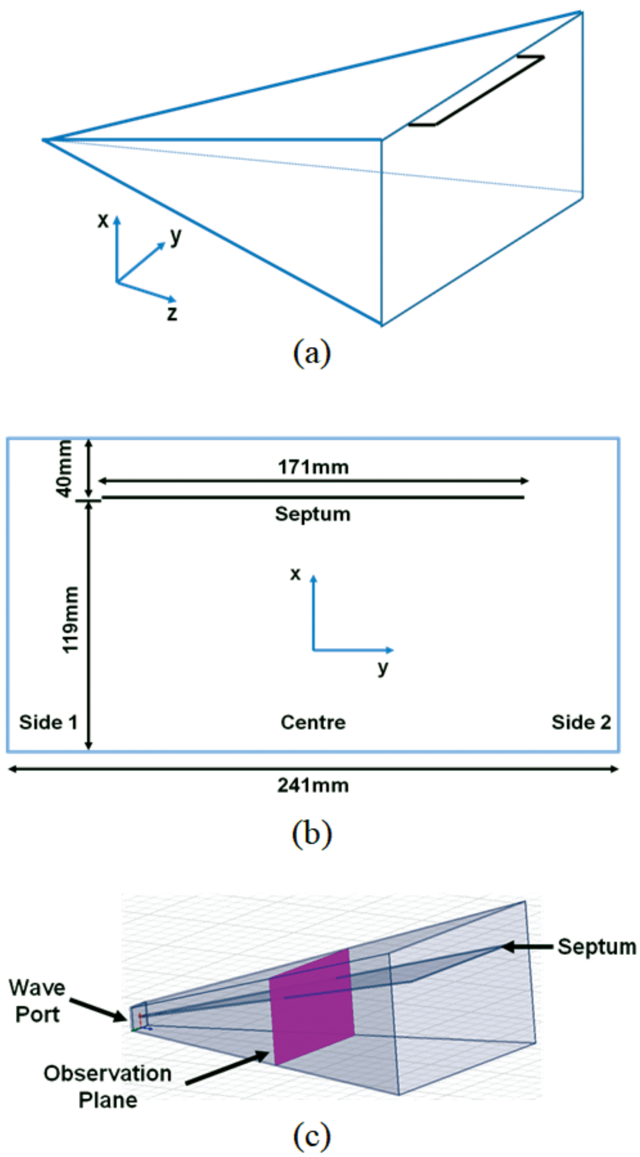

Figure 2. (a) Full view of the GTEM cell, (b) Transverse section of the GTEM cell, and (c) Observation plane simulated in HFSS.

that the design parameters are theoretically optimised for GSM band frequency ranges. Hence, it is found suitable for our purpose and the design is used to fabricate the cell for GSM and additionally Universal Mobile Telecommunications Systems (UMTS) band studies. As part of the electromagnetic characterisation of the GTEM cell, Voltage Standing Wave Ratio (VSWR) of the cell is measured at the frequencies of interest. The simulation of the design, Fig. 2(c), is carried out beforehand on EM software-HFSS[5] to ensure the GTEM cell capabilities.

3. THEORETICAL CONSIDERATIONS

3.1 Analytical Approach

The E-field strength E inside the GTEM cell is given as

$$E = \frac{\sqrt{P/(M \times F) \times Z}}{h} \tag{1}$$

where, h is the height of the septum, P is input power, Z is characteristic impedance, M is the modulation and F is the flatness[8, 9].

However, the estimation of h can be made using the fact that E-field in the x-direction can be given by

$$E = \frac{V}{h}, \tag{2}$$

where, V is the input voltage. It can hence be estimated that at h=0.119 m and input power of 0 dBm in 50 Ω system, the E-field strength will be

$$E = \frac{0.2236\ (V_{rms})}{0.119\ m} = 1.8\ V/m \tag{3}$$

3.2 Finite Element Method based Mathematical Model

The septum conductor when coated with material, such as Teflon, the potential and E-field strength changes due to the change in the effective relative permittivity inside the GTEM cell. The frequency dependence and effect of Teflon is studied using HFSS. An observation plane is created at z = 240 mm from the input port. The simulated results on this plane are as discussed in the following section.

4. RESULTS AND DISCUSSION

The GTEM cell is characterised based on VSWR measurement along with the simulation and measurement results of E-field strength. The measured VSWR of the GTEM cell loaded with absorbing dielectric foam at 914 MHz is 1.34±0.02 and at 2.10 GHz the value is 1.14±0.02. The simulation gave the VSWR of the order of 1.15. The difference is accounted for the higher mismatch in the real structure than that of the ideal simulated one. The detailed measurement results of VSWR and reflection coefficient (Γ) are given in Table 1.

Table 1. Impedance matching of GTEM cell

	914 MHz		2.10 GHz	
	VSWR	Γ	VSWR	Γ
GTEM cell terminated by microwave absorber	1.32	0.138	1.14	0.065
Microstrip E-field probe inserted	1.33	0.142	1.14	0.065
Standard Isotropic E-field probe inserted	1.34	0.145	1.16	0.074

The E-field strength is measured inside the GTEM cell for fed power ranging from P=-10 to 10 dBm in the test area where h=98 mm and distance from the input port is 240 mm. For a 50 Ω system, the measured values of the E-field strength are compared with the theoretical value calculated using (1), taking M=3.24 and F=2. The results are also compared with the measurement carried out using an isotropic E-field probe, R&S TSEMF-B2, as shown in Fig. 3.

Figure 4 shows the simulated results of HFSS in form of contour plot for E-field strength at a plane on z=240 mm. It is found that instead of a copper septum, if the sheet of copper is backed by Teflon, then a larger area of uniform electric field

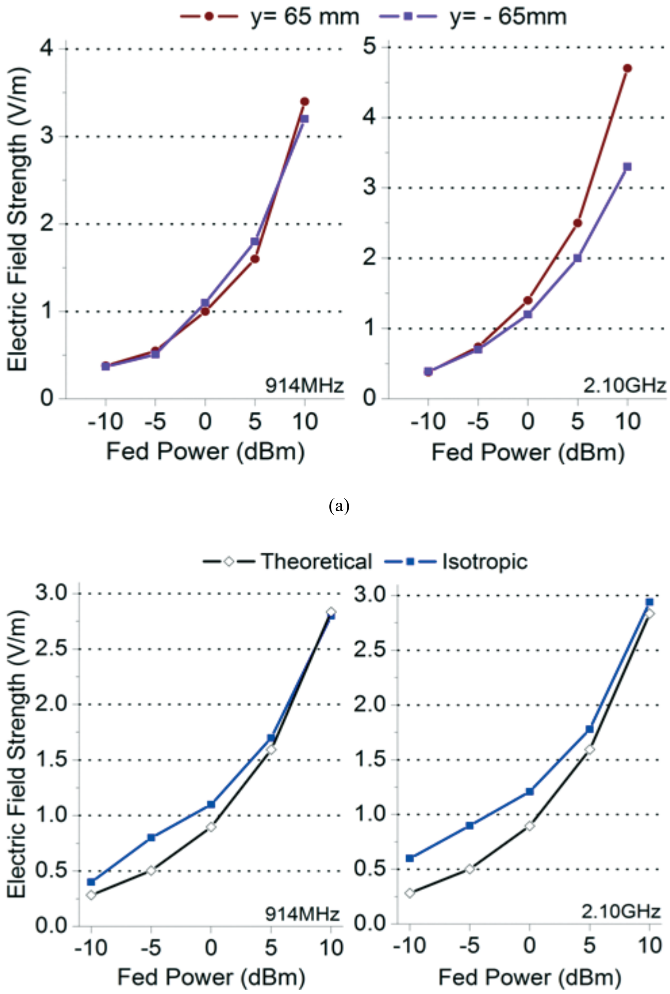

Figure 3. E-field inside the GTEM cell at three different positions at *h*=98 mm (a) *y*=-65 mm and *y*=65 mm and (b) *y*=0 mm.

can be generated. The simulations agree well with experimental measurements of E-field strength envisage a highly uniform field distribution that closely approximates a TEM wave. The uniform distribution also justifies the recommendation of one-third area given in[10]. The results are also in agreement with analytical values in (2) and (3).

The uncertainty evaluation is carried out considering all the parameters as given in IEEE standard 1309-2013[11] and CCEM.RF-K20[12]. The computed expanded uncertainty for the reported measurement is ±0.80 V/m. The major uncertainty contributor is the Type-A component, i..e. the standard deviation in the independent repeated measurements of E-field strength, contributing ±0.483 and ±0.410 V/m at 914 MHz and 2.10 GHz, respectively.

5. CONCLUSIONS

A miniature GTEM cell is fabricated having a length of 450 mm. The variation in E-field strength due to the effect of Teflon coated septum conductor is analysed in detail. A comprehensive numerical analysis and simulation is carried out for the construction of GTEM cell. The E-field strength inside the GTEM cell, at a distance of 240 mm from the input port, is scanned using a microstrip E-field probe with an expanded uncertainty of ±0.80 V/m at 914 MHz and 2.10 GHz. For the validation of the measurement, results are compared with commercial isotropic E-field probe. A uniform E-field strength is found with the maximum strength of E_{max}=2.94 V/m against the analytical value of E=2.86 V/m at the center of the GTEM cell for a fed power of +10 dBm. The GTEM cell is hence a suitable exposure system for studying the effect of RF radiation on different samples. The uniform electric field strength generated in the calibrated GTEM cell ensures effective studies of exposure.

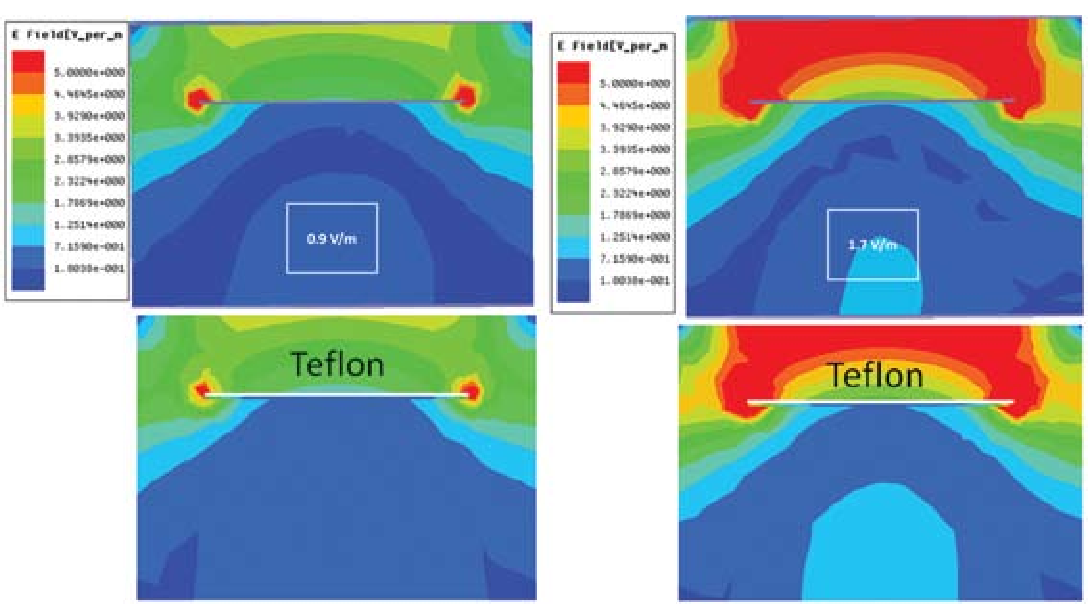

Figure 4. Simulation results of E-field strength at *z*=240 mm, *h*=98 mm, 0 dBm power for (a) *f*=914 MHz and (b) *f*=2.10 GHz. The white boundary shows the measured results in that area. Teflon backed conductor is used as the septum for suppressing the higher order modes required to increase the area of uniform electric field.

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In the present work, she developed the prototype GTEM cell and evaluated its performance.

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In the present work, he guided for E-field evaluation inside GTEM cell.