THE LONGITUDINAL FIELD IN THE GTEM 1750 AND THE NATURE OF THE TERMINATION.

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Abstract The GTEM 1750 cell is widely used for generating fields for EMC testing. The cell performs well, except at 127 MHz, where a large longitudinal field component is observed. Field measurements show the problem is due to a transverse magnetic mode (TM_{111}) resonance. A simple model is used to predict the frequency of the resonance for different sizes of GTEM. Placing 64 ferrite tiles on the floor of the cell was found to improve the cross-polar performance of the GTEM by 7 dB.

I. INTRODUCTION

The Gigahertz Transverse Electric and Magnetic (GTEM) cell [1] is a widely used variation of the TEM cell designed to operate up to frequencies of several gigahertz. It is a tapered coaxial transmission line that is terminated at the broad end by a hybrid absorber (see figure 1). At low frequencies, the septum is terminated to the end wall of the cell via a network of resistors that provide a distributed 50 Ω load. At higher frequencies, it is effectively terminated by pyramidal radio-frequency absorbing material (RAM) that is placed near to the end wall.

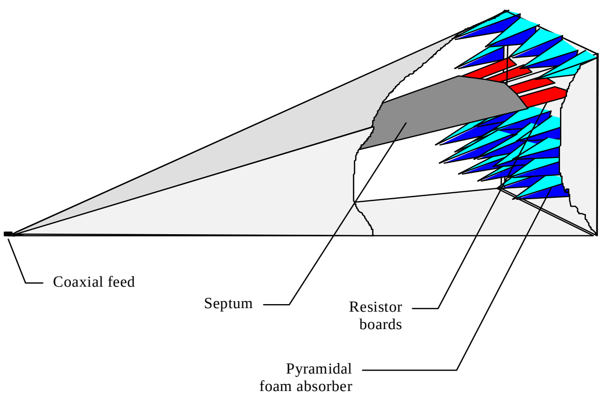


Figure 1: Schematic diagram of the GTEM cell.

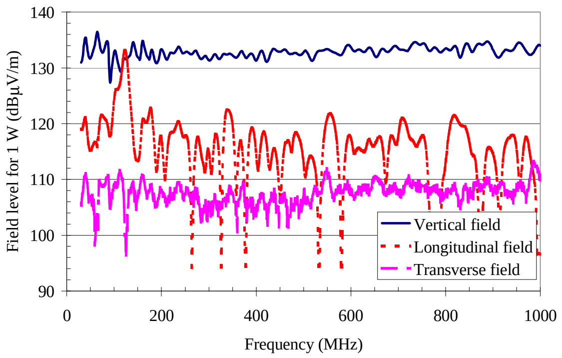
The cells generally have good cross-polar performance, typically better than 10 dB, except at a few frequencies where a large axial (longitudinal) field component exists. These axial fields may be greater than the vertical field in the cell. In the case of the GTEM 1750 this occurs around 127 MHz.

Poor cross-polar performance limits the accuracy of the GTEM for EMC testing and also as a field standard at these frequencies. The draft CISPR standard for EMC testing in TEM waveguide devices [2] places a requirement for a well-polarised field. Whether the presence of a longitudinal component will result in over or under testing of a device depends on the relative phases of the field components. For these reasons it is highly desirable to improve the cross-polar performance of the large GTEM cells.

This paper investigates the nature of the longitudinal field component through measurement, and a simplified cavity resonance model. The extent to which resonance is damped depends on the performance of the resistor board and RAM used to terminate the GTEM cell. The performance of the termination is therefore determined to see if improvements can be made. A cost effect method of improving the cross-polar performance by using a small number of ferrite tiles on the floor of the GTEM is investigated. Suggestions for future improvements to the GTEM cell termination are made.

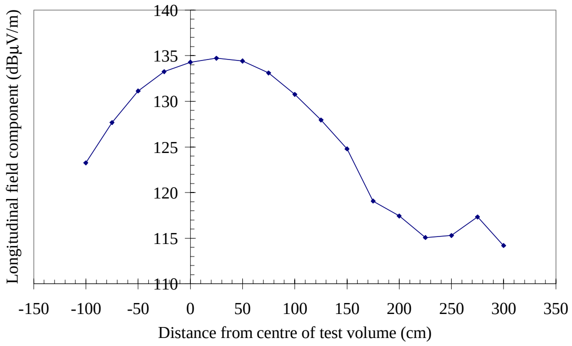
II. MEASUREMENT OF THE LONGITUDINAL FIELD IN THE GTEM 1750

The field components at the centre of the test volume in the GTEM 1750 are shown in Graph 1. The poorest cross-polar performance for the cell occurs at 125.5 MHz, where the ratio of the longitudinal to vertical field components is 1 dB. The maximum longitudinal field occurs at 127.25 MHz.



Graph 1: Field components in the GTEM 1750.

Measurements of the spatial distribution of the longitudinal field were made using the Tokin Robust Optical Electric Field Sensor (ROEFS) system, which does not perturb the fields being measured [3]. Graph 2 shows the variation in the longitudinal field along the axis of the GTEM cell at 127.275 MHz. The tips of the absorbers correspond to a displacement of –100 cm, 0 is the centre of the test volume and + 300 cm is the measurement position nearest to the apex of the cell. Transverse and vertical scans show that there is a single maximum at the centre, and this confirms that there is a TM_{111} resonance in the cell at this frequency. Measurements showed that no significant longitudinal field is present above the septum, or in the gap between the edge of the septum and the sidewalls of the GTEM.



Graph 2: Variation of longitudinal field component along the axis of the cell, 1W input power.

III. CALCULATION OF APPROXIMATE RESONANT FREQUENCIES IN THE GTEM CELL

The size of the GTEM 1750 cell means that it is able to support waveguide modes at frequencies around 40 MHz and above. Because the GTEM is a tapered transmission line, the distance from the apex of the cell at which a particular waveguide mode can propagate is frequency dependent. At the termination, some energy is reflected and propagates towards the apex until it reaches the cut-off point for the mode. At this point, most of the energy is reflected again. In this way the volume between the septum and the floor forms a cavity resonator at the wide end of the GTEM. Because the higher order modes cannot propagate to the apex of the cell, resonance may not be apparent from return loss measurements at the input port to the GTEM cell. Absorber on the end wall of the GTEM is used to damp the resonance. A detailed analysis of the higher order field distributions in this system is given in [4].

Consider the geometry shown in Figures 2 and 3, which represent the tapered cavity formed between the septum and the floor of the GTEM.

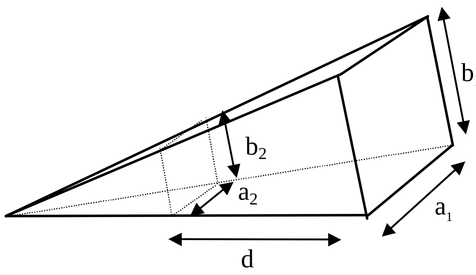
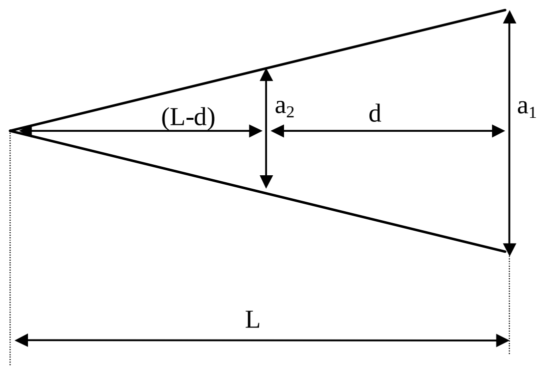


Figure 2: Geometry of tapered resonant cavity in GTEM

Figure 3: Plan view of tapered cavity



The cut-off point for the higher order mode determines the effective length of the cavity. For a rectangular waveguide, the cut off frequency (fc) of a mode is given by

$$f_c = f_{m,n} = \frac{c}{2}\sqrt{\left(\frac{n}{a_2}\right)^2 + \left(\frac{m}{b_2}\right)^2} \qquad (1)$$

where n and m are the mode indices, and a_2 and b_2 are the cross sectional dimensions. For the GTEM, the ratio of the width and height are constant so that

$$r = \frac{a}{b} = const. \tag{2}$$

so

$$f_c = \frac{c}{2a_2}\sqrt{n^2 + (rm)^2} \tag{3}$$

Now by similar triangles (see Figure 3)

$$a_2 = \frac{a_1(L-d)}{L} \tag{4}$$

Therefore for a given mode with indices m,n, the cut-off frequency (f_c) as a function of distance (d) from the back-wall of the GTEM is given by

$$f_c = \frac{cL}{2a_1(L-d)}\sqrt{n^2 + (rm)^2} \tag{5}$$

This gives the effective length (d) of the cavity at a given frequency.

The tapered cavity can be approximated by a rectangular cavity with the average dimensions of the tapered cavity. Then resonant frequency (f_r) of the m, n, p resonant mode is given by

$$f_r = f_{m,n,p} = \frac{c}{2}\sqrt{\left(\frac{n}{w}\right)^2 + \left(\frac{m}{h}\right)^2 + \left(\frac{p}{d}\right)^2} \tag{6}$$

where

$$w = \frac{(a_1 + a_2)}{2} \text{ and } h = \frac{(b_1 + b_2)}{2} \tag{7}$$

Now

$$r = \frac{a}{b} = const. \tag{8}$$

so

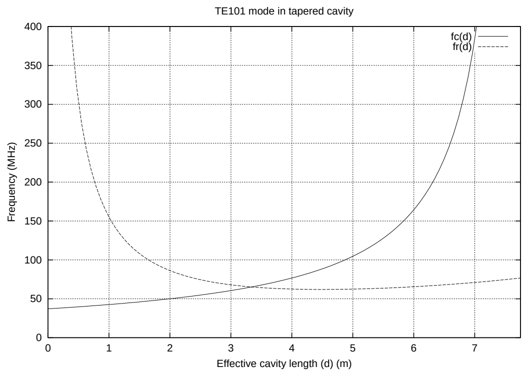
$$h = \frac{1}{2r}(a_1 + a_2) \tag{9}$$

It follows that the resonant frequency of the tapered cavity as a function of the effective length (d) of the cavity is

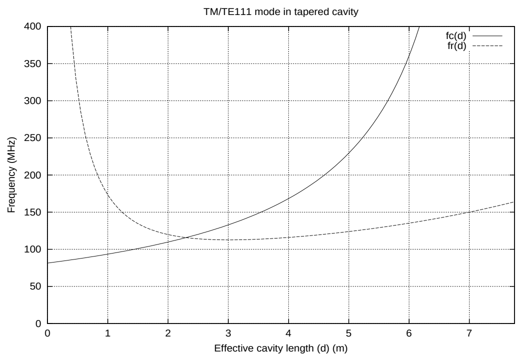
$$f_r = \frac{c}{2}\left(\left(\frac{2}{a_1 + a_1\left(1 - \frac{d}{L}\right)}\right)^2 \left(n^2 + (mr)^2\right) + \left(\frac{p}{d}\right)^2\right)^{\frac{1}{2}} \tag{10}$$

The resonant frequency for a mode can be determined by plotting f_c and f_r against the effective length of the cavity and determining the point of intersection. This method only gives an approximation for the frequency of different resonant modes in the cavity. It does allow the nature of the resonant mode at a given frequency to be determined, and this is very helpful in understanding the causes of the unwanted field components in the GTEM.

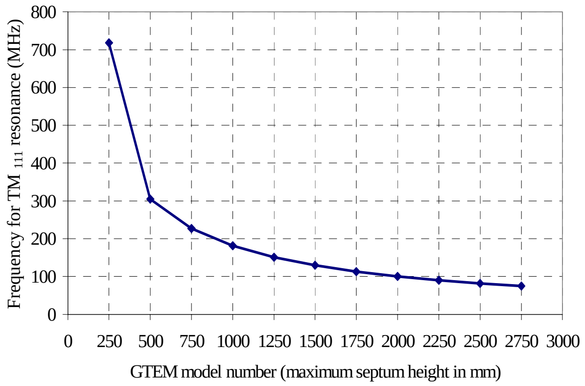
Graph 3 shows the TE_{101} resonance occurs at 66 MHz in the GTEM 1750. Graph 4 shows that the resonant frequency for the TM_{111} mode is at 120 MHz, and this closely corresponds to the measured results (Graph 1). The resonant frequencies of the TM_{111} mode for different sizes of GTEM cell are shown in Graph 5. For the smaller cells, the resonance occurs at higher frequencies, as would be expected.



Graph 3: Frequency for TE_{101} mode resonance.



Graph 4: Frequency for TM_{111} and TE_{111} mode resonance



Graph 5: Frequency of TM_{111} mode resonance for different sizes of GTEM cell.

IV. PERFORMANCE OF THE GTEM TERMINATION.

The extent to which resonance is damped depends on the performance of the GTEM termination, so this is analysed. The GTEM cell is terminated with a hybrid absorber consisting of pyramidal carbon loaded foam absorber (RAM), and resistor boards.

Four resistor boards connect the broad end of the GTEM cell's inner conductor (septum) to the end wall, and these provide correct termination down to DC. The arrangement of these boards is shown in Figure 4. Individual resistors are arranged in chains to provide a total distributed resistance of 50 Ω measured between the septum and the end wall.

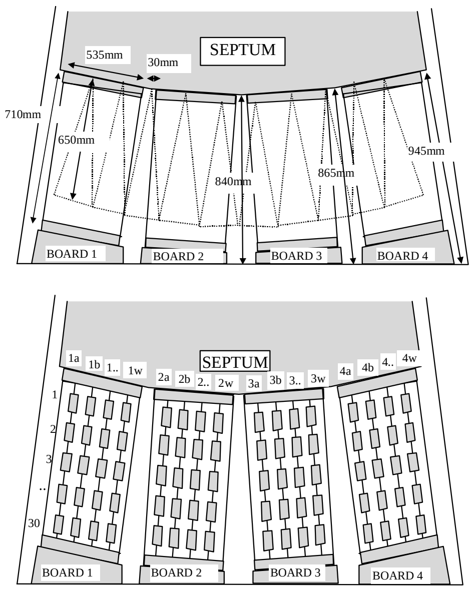
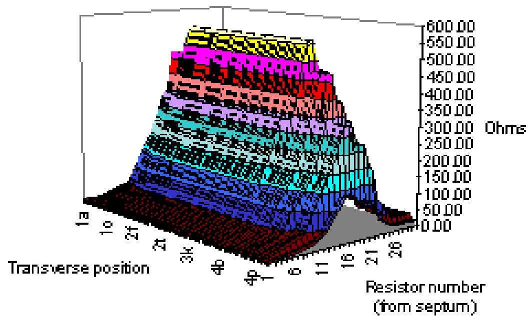


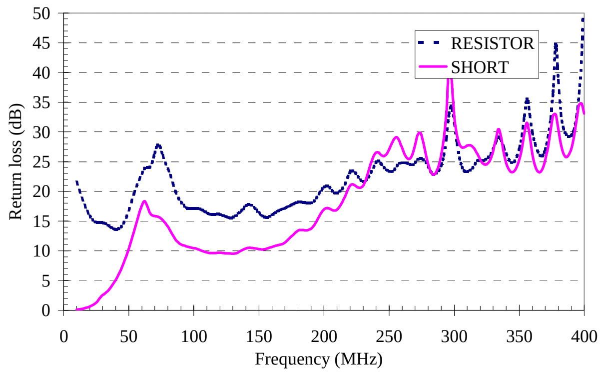
Figure 4: Resister boards (plan view)

The boards were removed from the GTEM, and the values of the individual resistors and their locations on the board were determined. To minimise reflections from the termination, the values of the resistors ramp up gradually from the end of the septum, as shown in Graph 6. The transverse profile of the power absorption matches the field distribution in the cross section of the cell for the TEM mode, which again minimises reflections.



Graph 6: Resistance profile of termination.

So that the performance of the RAM and resistor boards could be determined separately, the resistor boards were replaced with metal plates which short circuit the septum to the end wall. In this configuration, the RAM alone then provides the termination of the transmission line, and the effect of the resistor boards is removed. The return loss at the input port to the GTEM, with and without the resistor board is shown in graph 7. Note that only the TEM mode can propagate to the apex of the cell, so the return loss at the inpt port may not represent the performance of the absorber for other modes.

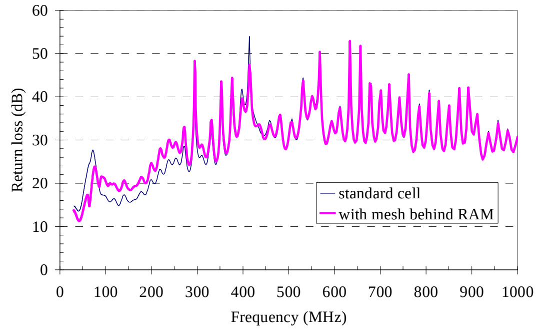


Graph 7: Return loss of GTEM 1750.

The RAM provides only 10 dB return loss at 120 MHz. There is a sharp increase in the return loss at about 60 MHz. This dip is not a characteristic of the RAM. The resistor board produces a marked improvement in the return loss below 220 MHz.

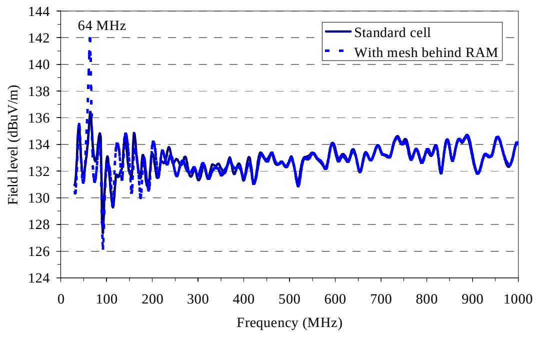
V. TE_{101} MODE AND THE EFFECT OF THE AIR GAP BEHIND THE ABSORBER

There is an air gap between the back of the RAM and the end wall of the GTEM 1750. This gap is 17 cm at the centre, and increases to 41 cm at the sidewall of the cell. It is likely that this air gap changes the performance of the RAM. To investigate this, a 2.5 cm wire mesh was placed on the back surface of the RAM to effectively remove the air gap. The return loss at the input to the GTEM cell with and without the mesh is shown in graph 8. The results shown that the air gap improves the return loss of the termination at 65 MHz from 15 dB to 25 dB. However, the air gap reduces the return loss for frequencies between 100 to 250 MHz by 4 dB.



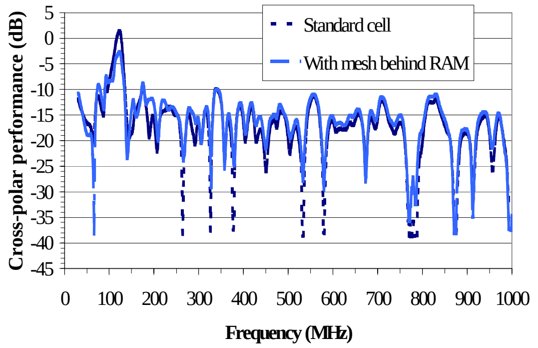
Graph 8: Return loss with resistor boards and short circuit termination.

The vertical field at the center of the test volume, shown in Graph 9, shows a sharp resonance at 64 MHz with the mesh fitted. This corresponds to the TE_{101} mode that is predicted at this frequency in section 3. Note that the TE_{101} has a vertically polarized electric field. The gap behind the RAM results in better absorption at this frequency, thus eliminating this resonance.



Graph 9: Effect of mesh behind RAM on vertical field component of GTEM 1750.

With the mesh behind the RAM, the magnitude of longitudinal field has been reduced, and this is shown in Graph 10. The cross-polar performance of the cell at this frequency is improved by 4 dB, and this results from the improved absorber performance without the air gap at this frequency.

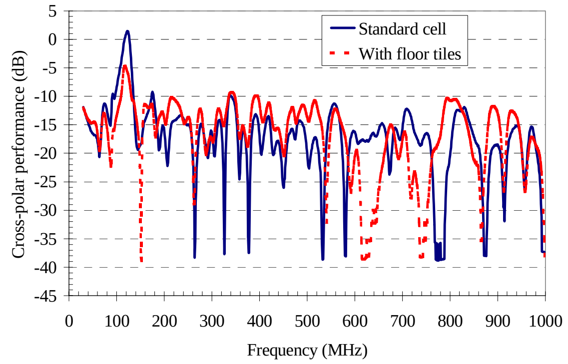


Graph 10: Effect of mesh on cross-polar performance of GTEM 1750.

By decreasing the air gap behind the RAM, it should be possible to improve the performance of the absorber at 125 MHz, but this degrades performance at 64 MHz, so is not a viable solution to the longitudinal field problem. By using multi-layer absorber structures, it should be possible to obtain improved absorption at 66 MHz and 127 MHz. This is the subject of current work.

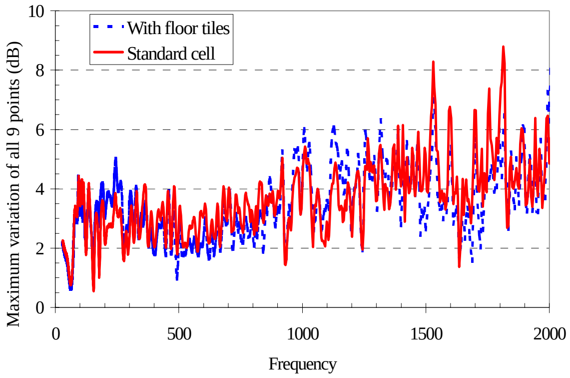
VI. DAMPING THE TM_{111} RESONANCE USING FERRITE TILES

The TM_{111} resonance can be damped by placing ferrite tiles on the floor of the GTEM under the region where the maximum longitudinal E-field occurs. Sixty-four ferrite tiles, with dimensions 100 mm by 100 mm by 6.5 mm, were placed on the floor in a square beneath the test volume of the GTEM cell. The cross-polar performance of the cell at the center of the test volume is shown in Graph 11. The results show that the tiles have improved the cross-polar performance for the cell by 7 dB at 125 MHz.



Graph 11: Effect of ferrite tiles on cross-polar performance of GTEM 1750.

Graph 12 shows the field uniformity in the cell on a 9-point grid, covering an area of 583 mm by 583 mm. The tiles have reduced the field at the points nearest the floor, and this reduces the field uniformity slightly at around 250 MHz. There was no significant change in the input impedance to the cell. Using a small number of ferrite tiles on the floor provides a simple way of improving the cross-polar performance the GTEM 1750.



Graph 12. Field uniformity for 9-point grid

VII. CONCLUSIONS.

Electric field measurements and analysis of the GTEM 1750 cell show that the large longitudinal field that occurs at 127 MHz corresponds to the TM_{111} mode resonance. The analysis predicts a TE_{101} mode resonance at 66 MHz. There is a 17 cm air gap behind the RAM and this improves its performance at this frequency, effectively damping this resonance. The resonance is apparent if the air gap is removed (by placing a wire mesh on the back surface of the RAM).

Placing 64 ferrite tiles on the floor beneath the test volume has been found to damp the TM_{111} resonance in the GTEM 1750, and improves the cross-polar performance of the cell by 7 dB. The ferrite tiles have only a slight effect on the vertical electric field in the GTEM. This provides a simple and cost-effective solution way to improve the cross-polar performance of the GTEM cell. Current work is looking at improving the termination at 127 MHz by the use of multiple layer absorber structures.

VIII. REFERENCES

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