Designing Transverse Electromagnetic (TEM) Cell

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***Abstract*—Transverse electromagnetic (TEM) Cell generates accurate electromagnetic waves from 0 Hz to several MHz. Using this device, Electromagnetic Interference/Compatibility (EMI/EMC) tests of small RF devices can be performed in regular laboratory environment. Before invention of TEM Cell, anechoic chamber environment is needed to perform EMI/EMC tests. However, this way is too costly and restricted and using TEM Cell, it is much cheaper and less time consuming. During this project, TEM Cell is designed, manufactured and tested.**

Index Terms—**Transverse Electromagnetic (TEM) Cell, TEM Cell design, Manufacturing TEM Cell, EMI/EMC tests.**

I. Introduction

Crawford introduced first Transverse Electromagnetic (TEM) Cell in 1974 [1]. Nowadays, it is widely used during EMI/EMC tests of small RF devices and radiofrequency radiation tests of biological samples [2, 3]. TEM Cell can be designed as open or closed model. One of the closed models can be used to test larger units or objects and it is called Gigahertz Transverse Electromagnetic (GTEM) Cell. GTEM Cells have absorbers inside the chamber and it is not only composed of metal. If the object is large to fit into TEM Cell or GTEM Cell, anechoic chamber is needed to accomplish EMI/EMC tests.

Because of TEM Cell's advantages (quasi-uniform electric field inside the cell, cost and easy to simulate, design and build), it started to get attention and EMI/EMC companies started to sell these devices [4].

In this project, it is preferred to manufacture open model since closed model doesn't have any advantages when simulation results are compared and open model is also cheaper than closed model. It is seen that either copper sheet or printed circuit board (PCB) is used as a material [2, 3]. Aluminum is used as a metal type in this work since it is easy to work on.

The purpose of this project is to teach students to use an electromagnetic simulation program, to learn the design process of a device and to measure return loss (S_{11}). In the following section, design steps of TEM Cell are shown and return loss and voltage standing wave ratio (VSWR) results are given.

II. Design of a TEM Cell

Firstly, this project started with learning ANSYS High Frequency Software Simulator (HFSS) program to model antennas to be ready for final aim (to design a TEM Cell) as a part of undergraduate research project. While drawing prototype of TEM Cell in HFSS, CATIA program was also used because drawing in HFSS is troublesome for beginners. Fig. 1 shows an actual TEM Cell [4].

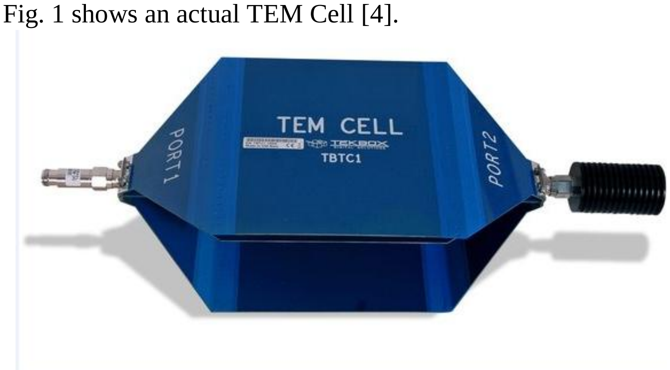

Fig. 1. Open TEM Cell [4]

Using reference [3], most of the TEM Cell dimensions were already known and some of them had to be assumed. Next step is to draw TEM Cell, finish simulations in HFSS and look at return loss (S_{11}) and voltage standing wave ratio (VSWR) results. TEM Cell drawing in ANSYS HFSS is given in Fig. 2. Figures 3-6 show technical drawings of TEM Cell and the dimensions used in HFSS. Fig. 7 and Fig. 8 show return loss and VSWR results obtained from HFSS for Fig. 2. Inside the simulation program, perfect electric conductor's thickness is assumed as 1.6 mm as seen in Fig. 6. All dimensions are in mm.

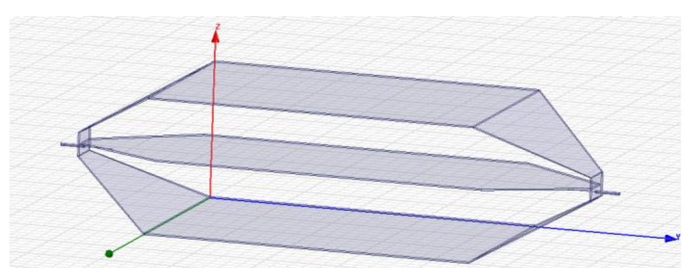

Fig. 2. TEM Cell in HFSS (isometric view)

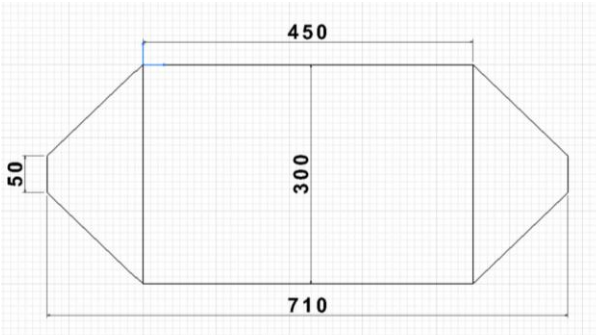

Fig. 3. Technical drawing of TEM Cell – top view (top and bottom plate dimensions)

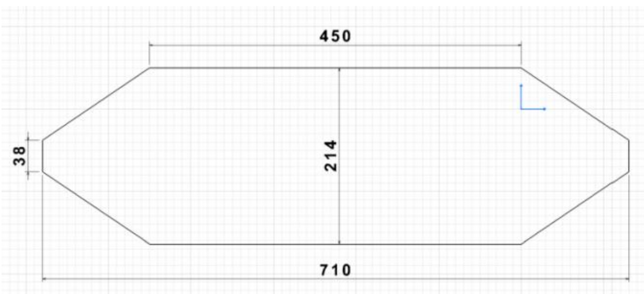

Fig. 4. Technical drawing of TEM Cell – top view (middle plate dimensions)

Fig. 5. Technical drawing of TEM Cell – left side view

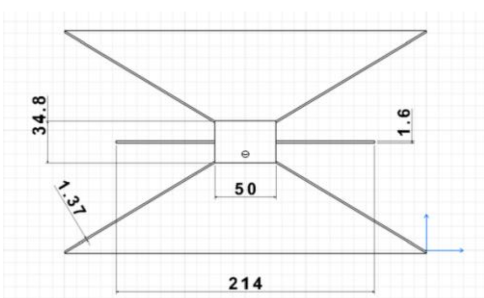

Fig. 6. Technical drawing of TEM Cell – back view (probe side)

While designing TEM Cell, some assumptions are done about the dimensions (Figures 3-6). As a conclusion, return loss and voltage standing wave ratio results are not matching with reference [3]. The reference is using another simulation program and lack of the dimensions is another difference between the reference and this paper. The troubling part is that return loss value is supposed to be less than -10 dB for TEM Cell's operating frequency range (400-1000 MHz for this TEM Cell design) and it cannot be reached to -10 dB level at some frequencies.

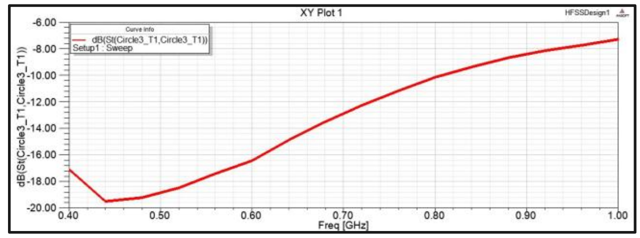

Fig. 7. Return loss (S_{11}) of TEM Cell – metal thickness 1.6 mm

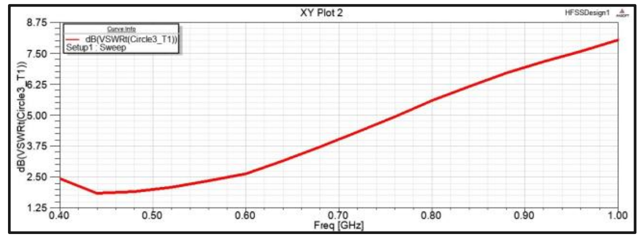

Fig. 8. Voltage standing wave ratio (VSWR) of TEM Cell – metal thickness 1.6 mm

Since the important dimensions between the reference and this paper are the same [3], TEM Cell was decided to be manufactured using aluminum as a material. During the simulation, perfect electric conductor's thickness is taken as 1.6 mm but because of the manufacturing difficulties, the thickness had to be changed to 2 mm. When this change is added to HFSS, as expected, it is seen that there are small differences in results (Figures 9 and 10) when they are compared with 1.6 mm thickness results (Figures 7 and 8).

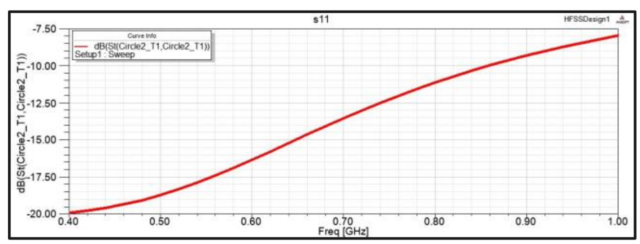

Fig. 9. Return loss of TEM Cell – metal thickness 2 mm

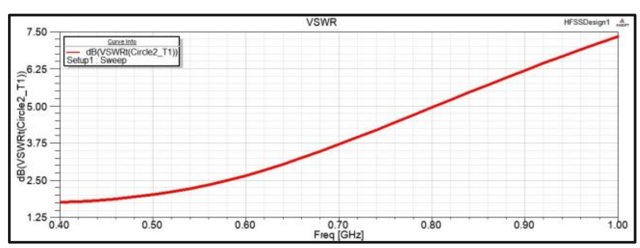

Fig. 10. VSWR of TEM Cell – metal thickness 2 mm

During simulation process, it is seen that using different connector dimensions is affecting the simulation results dramatically and after the connector is chosen; actual connector's dimensions are used to obtain Figures 7-10. There are two probes on TEM Cell and each of them are placed at back side and across from each other (Fig. 6). During the simulation, one side is chosen as active side (or where power is connected) and the other is terminated (or it is connected to 50 Ω load). When both probes are chosen as active, S_{11} and S_{12} results are shown in Figures 11 and 12. It can be seen that S_{11} is almost the same as Fig. 9 and S_{12} values are less than -40 dB. This shows that if this device will be used for actual tests, power value, connected to active side, has to be chosen carefully since there is too much loss between the probes. Fig. 13 shows VSWR result and again it is almost the same as Fig. 10.

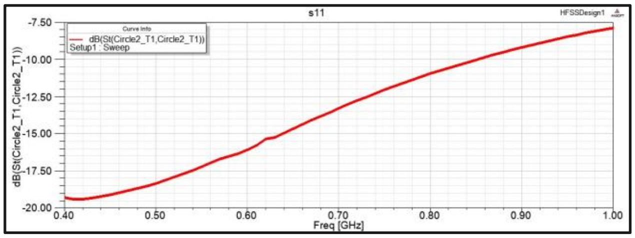

Fig. 11. S_{11} of TEM Cell without termination – metal thickness 2 mm

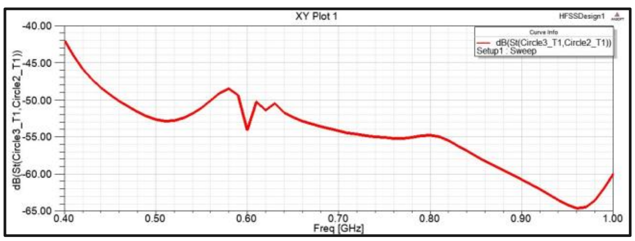

Fig. 12. S_{12} of TEM Cell without termination – metal thickness 2 mm

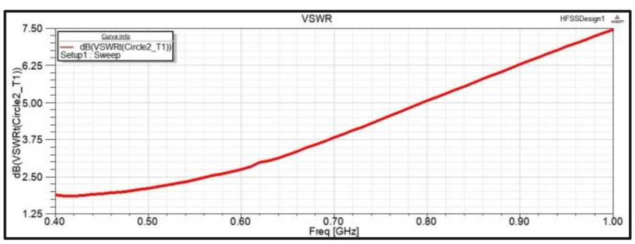

Fig. 13. VSWR of TEM Cell without termination – metal thickness 2 mm

Results shown in Figures 8-13 are for open model TEM Cell. Figures 14 and 15 show return loss and VSWR results for closed model of TEM Cell where conductor thickness is 2 mm.

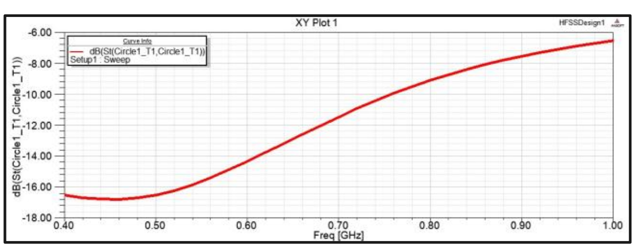

Fig. 14. S_{11} of closed TEM Cell model – metal thickness 2 mm

Fig. 15. VSWR of closed TEM Cell model – metal thickness 2 mm

When Figures 9 and 10 are compared with Figures 14 and 15, it can be seen that open model results are better than closed model results and reflections from side walls must be causing this problem.

Different sizes of TEM Cells can be found easily with simple searches on internet. However, most of them are working at similar frequency bands [2, 3]. Using dimensions from [2], new TEM Cell is created and return loss and voltage standing wave ratio results are given in Figures 16 and 17. Conductor thickness is given as 0.8 mm. When these results are compared with Figures 9 and 10, it can be observed that these results are worse than previous results and because of this reason, the dimensions from [3] are preferred to be used to manufacture.

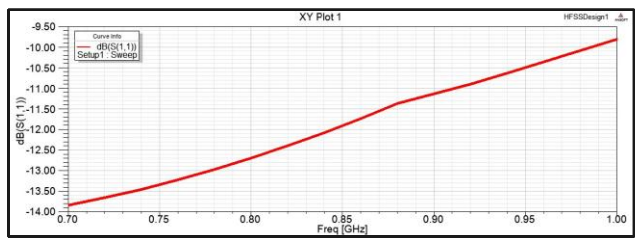

Fig. 16. Return loss of TEM Cell created using [2]

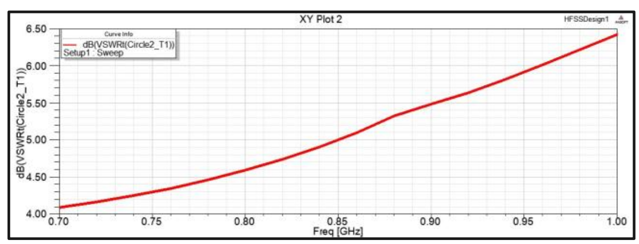

Fig. 17. VSWR of TEM Cell created using [2]

Next step of the project is to obtain different TEM Cell dimensions so that it will be operating at different operating frequency ranges. For this purpose, TEM Cells lengths are modified to have half of the all TEM Cell dimensions. Conductor thickness is again chosen as 2 mm. TE mode cutoff frequencies can be calculated easily [2, 3, 5] and new operating frequency range will be between 1-2 GHz with new TEM Cell dimensions. When all these modifications are applied to draw all half TEM Cell, simulation results are shown in Figures 18 and 19. The results are worse than it is expected. More simulations will be done to see the effect of dimension changes on the performance of TEM Cell.

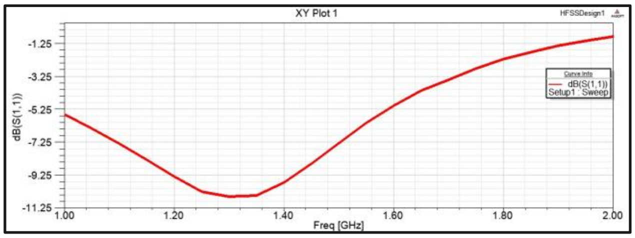

Fig. 18. S_{11} of all half TEM Cell

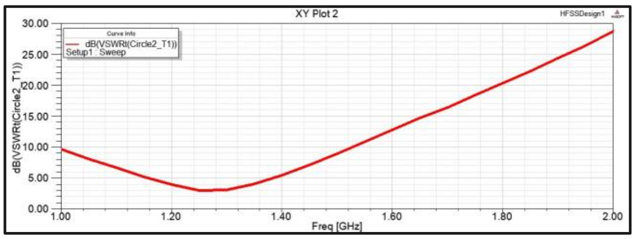

Fig. 19. VSWR of all half TEM Cell

When TEM Cell manufacturing process is finished (Fig. 20), first measurements are done for without termination case (Figures 21 and 22). Later 50 Ω load is connected and return loss measurement is repeated (Fig. 23). It can be seen that there are differences between simulation and actual measurement results. This will be investigated.

Fig. 20. Manufactured TEM Cell

Fig. 21. S_{11} of manufactured TEM Cell without termination

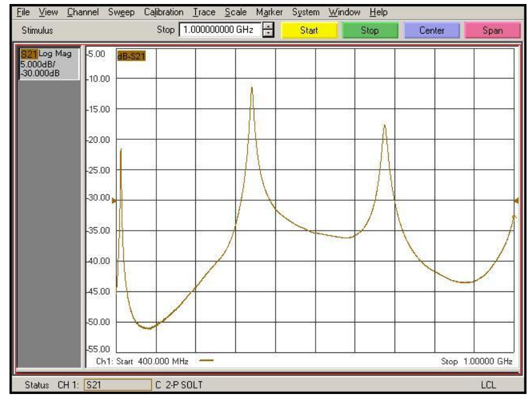

Fig. 22. S_{12} of manufactured TEM Cell without termination

Fig. 23. S_{11} of manufactured TEM Cell

III. CONCLUSION

This project is studied within the scope of Atılım University’s undergraduate research project (ATÜ-LAP-C-1415-04) program. Students learnt ANSYS HFSS program to draw and simulate TEM Cell. They had a chance to observe overall design process (from modeling to testing).

During the project, different sizes of TEM Cells are designed to see the effect of dimensions on the results and they are compared with references. Due to lack of some of the dimensions and different simulation programs, results are not matching. Manufactured and simulated TEM Cell results are also different. We have a future investigation plan to search for the possible reason/s that lie behind these inconsistencies.

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