Development and test analysis of Symmetric Open TEM cell

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Abstract:
Electrical and electronic devices are constantly present in human lives, as providing communication, entertainment or transportation. Ever increasing use of power electronics equipment and communication equipment in everyday life is increasing electromagnetic pollution day by day. This pollution may degrade the performance of electronic and electrical equipment. Any RF radiation emitting devices emit Electro Magnetic (EM) radiation and without proper shielding, the radiation could be harmful to humans and other biological elements. Modernization in new generation of mobile telecommunication system, with enhanced bandwidth and power, the biological effects of electromagnetic radiation from these gadgets is a real concern to many It is necessary that all electronics equipment or systems must be constructed to ensure that any electromagnetic disturbance it generates must be constructed with inherent level of immunity to externally generated Electromagnetic disturbances. These needs to design the equipment known as TEM cell with symmetric open structure geometry to limit the amount of unwanted radiation, the shielding of critical parts, making equipment less immune to external interference.

Key words: EMI, EMC, Higher Order Mode, Return loss, Symmetric Open TEM, TEM cell

Introduction:

In 1974 M.L. Crawford described the TEM (Transverse Electromagnetic Mode) cell [1-4]. It is an expanded planar transmission line operated in the TEM mode to simulate a free space plane wave. As it is a mobile shielded enclosure, it can be handled much easier than any of the previous test setups. It can be used for radiated susceptibility tests and emission measurements up to a frequency of about 500 MHz depending on the mechanical dimensions of the cell.

These open TEM cells are well suited for immunity testing of small objects per European (CE) and automotive standards (SAE J1113-25) or for biological experiments. The advantage of these TEM cells is that they are open and it is very easy to control the functions of the EUT (Equipment under Test).

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The applications are for instance the immunity testing of watches, pagers, telephone or PCB's. In comparison with other closed TEM cells, the price is low. Other interesting application is the calibration of field probes as the generated field inside the TEM cell is very exact. TEM cells are the most precise structures for field calibrations.

Dimension of the transmission line depends on the dimension of the equipment under test. The criterion of selecting the terminating resistance gets decided from the transmission lines transverse dimension that in turn depends upon the transmission line openings required for the uniform illumination of the equipment under test. The more volume the equipment under test occupies the more influence it induces on the field. In addition, its physical dimensions that constrain the size of equipment under test bind the upper operating frequency of the transmission line. Low distortion illumination of equipment under test within the test volume is achieved if, the equipment under test height and width are less than one third the corresponding line openings. The equipment under test should occupy a length not exceeding two third the length of the parallel region of the opening of the transmission line.

Electromagnetic characteristics of the transmission line i.e.: line parameters, capacitance per unit length, inductance per unit length and characteristic impedance is very important in estimating the accuracy of the charge distribution, form of the fields, field strength, study of higher order mode and study of singularity in field. In addition, to evaluate the distortion caused by the interacting of the equipment under test and transmission line, key is to define and compare the differences of the field distributions between the distributions of ideal field and simulating field around equipment under test. Knowing the characteristic impedance of the line helps in suitable termination of open area test site. A good termination reduces reflection toward the pulsed power source and absorbs the lower frequencies.

At either end, the transmission line is tapered down for connecting the generator at the sending end and to the terminating load impedance at the receiving end. The cell working volume is of same order as the parallel plate width and the width to height ratio is kept constant.

WORKING PRINCIPLE AND THEORY

The TEM cell design is based on the concept of an expanded planar transmission line operated in a TEM mode to simulate a free space planar wave for testing. Basic principle is to convert spherical waves from a tapered section to planar waves & vice versa.

The TEM cell is mainly a section of a rectangular coaxial transmission line with a wide center conductor and tapered ends acting as transitions to adapt standard 50Ω coaxial connectors. The cell usually has a Characteristic Impedance of 50Ω along its length to minimize electromagnetic reactions in the transaction section and the standing wave ratio. The size of a EUT is typically restricted to one third of the height 'h' because the EM field is uniform only within that region. For larger equipment, the effect of the equipment itself on the field strength is too large impedance and usable frequency range (first resonance frequency).The line characteristic impedance of the TEM cell is given by [5-8];

$$z_0 = \frac{\varepsilon_0 \eta_0}{c_0}$$ -------------------------→ 1.1

$$z_0 = \frac{94.15}{\sqrt{\varepsilon_r}\left[\frac{w}{b\left(1-\frac{t}{b}\right)} + \frac{c_{f'}}{0.0885\varepsilon_r}\right]}$$ ---------------->1.2

Where,

ε_r - is the relative dielectric constant of the medium between the conductors

c_f ' - is the fringing capacitance in Pico

farads per cm a- Length of TEM cell

b- Breadth of TEM cell

t- Thickness of material used for TEM cell

g- Gap between the outer conductor and septum.

z_0 -is the intrinsic impedance dependent on the dielectric permittivity and magnetic permeability of the material spacing the inner and outer conductor.

ε0 is the dielectric constant of the medium

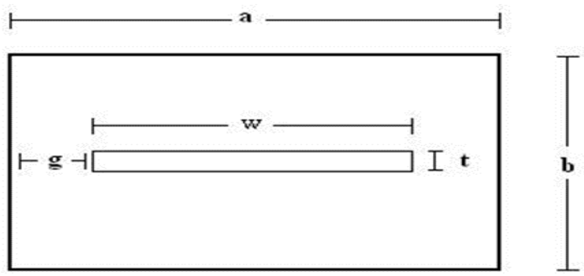

Fig. 1 Dimensions of TEM cell

Due to non-uniform structure of the cell the unperturbed electric field will confined within the central portion of the cell [9-11]. When P watts is transmitted through the cell, the absolute electric field (volts per meter) at the center of the cell test volume is computed from equation (1.3)

$$E = \frac{\sqrt{PR}}{d}$$ ---------------------→ (1.3)

Where,

R is the real part of the cell characteristic impedance in ohms

d is the distance in meters between the septum and side wall that bound the test volume (e.g. d=b).

Higher order modes are studied to know the effect of singularities on the field distribution, which may be due to:

1. Discretization of boundary condition
2. Sharp edges of conductors
3. Geometry of the conductor
4. Open waveguide like structure

As the frequency is increased and some of the power entering the cell couples into higher order modes, those modes are superimposed upon and thus degrade the field configuration of the pure TEM mode.

The TEM mode propagates through the tapered ends of the cell without significant alteration. Each higher-order mode, is always reflected at some point within the taper where it becomes too small to propagate the mode. The propagating energy in the higher-order mode undergoes multiple reflections, end to end, within the cell, until it is dissipated.

The Open TEM cell 1 dimensions has designed from equation (1.1) and (1.2) are listed in the following table. While cell 2 has double the dimensions than cell 1. Open TEM cell 1 is fabricated with copper material while Open TEM cell 2 is fabricated with aluminum material.

Table.1 Dimensions of Open TEM cell of Small Size

View	Dimensions(mm)
Top Length (un-tapered)	450mm
Top Length (tapered)	156mm
Cross section Width (outer shield)	300mm
Cross-section Width (septum)	214mm
outer shield	90 mm × 2
Side Tapering angle	≈30◦

Methodology for fabrication of open TEM cell

The characteristic impedance of the cell structure seen by the source and load mainly governs the constructional dimensions of the TEM cell. For a 50 Ω source and load impedance, it is easy to design the TEM cell with 50 Ω characteristic impedance. As mentioned before, an important limitation of the TEM cell is that its upper frequency limit is reduced, as its overall dimensions are made larger. For the presented design, an upper frequency limit of 1 GHz is chosen for the fabrication as it fulfills radiated emission frequency band requirements.

Mostly two numerical methods are used for TEM cell design Finite Element Method (FEM) and Finite Integration Technique (FIT). FEM was used for the electric and magnetic field calculation inside the TEM cell and FIT was used for the calculation of the higher order mode frequencies. The corresponding resonant frequencies of those TE modes disturb the field TEM mode field distribution inside the TEM cell. The resonances of those TE modes determine the bandwidth of a TEM cell.

Fabricated Design with Test Data

To fabricate the Open TEM cell 1 of copper material, all the design dimensions of the cell 1 height, width, length and tapering angle must be known. Thickness of the copper sheet is 1.5 mm. Both the input and output ends relate to N-type connector. Open TEM cell 1of small size designed under testing for Insertion loss is shown in Fig. 2.

Fig. 2 Insertion loss test set up for Open TEM cell 1

After calibrating the port 1 of Open TEM cell 1of Vector Network analyzer for reflection coefficient measurement and port 2 for Insertion loss following results are obtained as shown in Table 2.

Table 2. Insertion loss and VSWR readings for Open TEM cell 1

Frequency in MHz	S21 in dB (Insertion loss)	VSWR
0.3	-1.828	0.0137
1	-0.0087	1.3613
100	-0.1671	1.3614
200	-0.0619	1.0108
300	-0.1508	1.3946
400	-0.1620	1.0620
500	-0.3752	1.5473
600	-0.6281	1.0407
700	-1.0680	1.6031
800	-0.9082	1.1064
900	-0.9083	1.5513
1000	-1.7977	1.2298

To test EUT of larger size Open TEM cell 2 is designed with double the dimensions than OPEN TEM cell 1 as shown in Figure 3. It is of Aluminum material and bulky compare to Open TEM cell 1. Thickness of aluminum sheet is 1.5 mm. Fiber rods are inserted to support the structure.

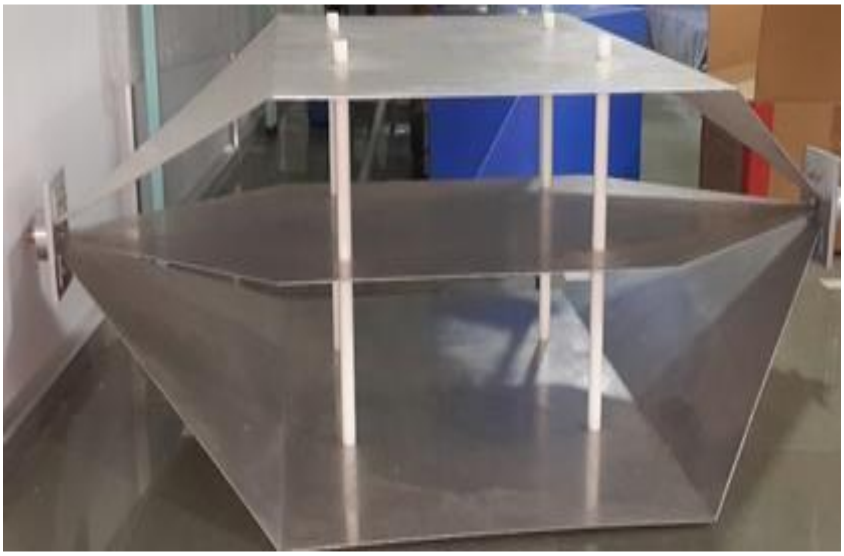

Fig. 3 Designed model of large size Open TEM cell 2

All the dimensions are calculated manually using (1.1) and (1.2). It is done intentionally to avoid the use of any software. It was observed that copper inner conductor material is much preferable than aluminum [].

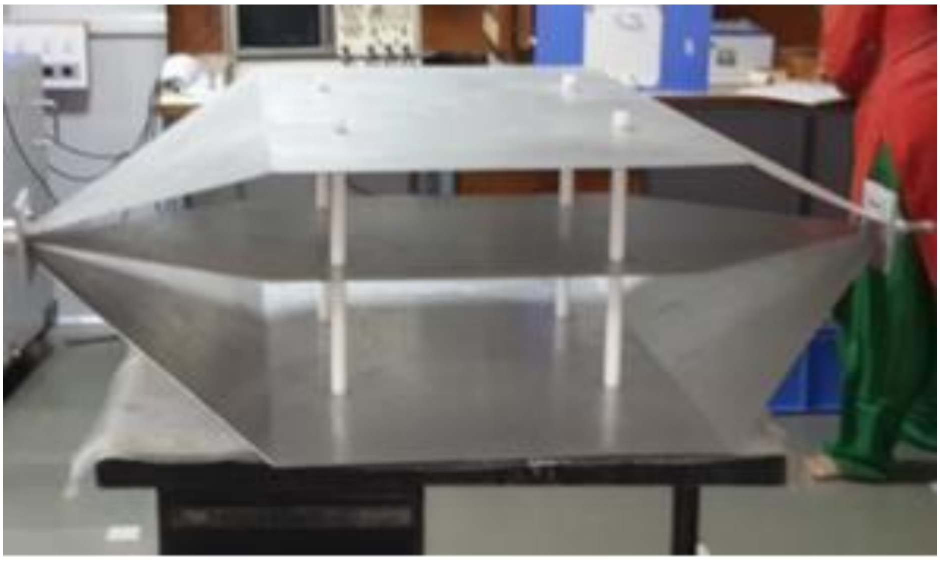

Fig. 4 Fabricated Open TEM cell 2 for testing

After calibrating the port 1 of Open TEM cell 2 (Bigger size) of Vector Network analyzer for reflection coefficient measurement and port 2 for Insertion loss following results are obtained as shown in Table 3.

Table 3. Insertion loss and VSWR readings for Open TEM cell2

Frequency in MHz	S21 in dB (Insertion	VSWR
0.3	-0.0107	1.327
1	-0.0046	1.011
100	-0.0942	1.138
200	-0.1275	1.209
300	-0.6535	1.424
400	-0.0459	1.097
500	-2.0293	1.051
600	-5.71726	2.094
700	-9.7219	2.320
800	-20.189	1.510
900	-20.2	1.992
1000	-20.2	2.332

Conclusion

The presented work shows that the two Open TEM cell of different size work satisfactory for frequency up to 500 MHz Even it was observed that smaller size cell has good VSWR than bigger size Open cell. The Bigger Open TEM cell 2 is bulky compared to cell 1. However, we can test large size EUT in Open cell 2. In addition, Insertion loss is very less for design 1 compare to open cell 2.

References:

1. M.L. Crawford "Generation of standard EM fields using TEM trans-mission cells," IEEE Transactions on Electromagnetic Compatibility,Vol. EMC-16, No.4,pp.189-195, November 1974.
2. Rahul Prakash, Thesis submitted on “Analysis of Electromagnetic pulse simulator” in Faculty of Engineering by Supercomputer Education and Research Centre Indian Institute of Science Bangalore -560 012 (India) September 2007.
3. Turk J Elec Engin,” FEM Journals”, Volume.11, No.2, 2003.
4. Kresimir Malaric , Iva Bacic ,”Efficiency of the Materials used in Building TEM-Cell,” Dept. of Wireless Communications, Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb, Croatia in 2008.
5. Karthick, R., and M. Sundararajan. "PSO based out-of-order (OoO) execution scheme for HT-MPSOC." Journal of Advanced Research in Dynamical and Control Systems 9 (2017): 1969.
6. Karthick, R., and M. Sundararajan. "Design and Implementation of Low Power Testing Using Advanced Razor Based Processor." International Journal of Applied Engineering Research 12, no. 17 (2017): 6384-6390.
7. Karthick, R., and M. Sundararajan. "A reconfigurable method for time-correlated MIMO channels with a decision feedback receiver." International Journal of Applied Engineering Research 12, no. 15 (2017): 5234-5241.
8. Sabarish, P., Karthick, R., Sindhu, A. and Sathiyanathan, N., 2020. Investigation on performance of solar photovoltaic fed hybrid semi impedance source converters. Materials Today: Proceedings., https://doi.org/10.1016/j.matpr.2020.08.390

9. R. Karthick, R. Ramkumar, M. Akram et al., Overcome the challenges in bio-medical instruments using IOT – A review, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.08.420
10. Sabarish, P., Raj, L.H.T., Ramprakash, G. and Karthick, R., 2020, September. An Energy Efficient Microwave Based Wireless Solar Power Transmission System. In IOP Conference Series: Materials Science and Engineering (Vol. 937, No. 1, p. 012013). IOP Publishing.
11. Vijayalakshmi, S., Sivaraman, P.R., Karthick, R. and Ali, A.N., 2020, September. Implementation of a new Bi-Directional Switch multilevel Inverter for the reduction of harmonics. In IOP Conference Series: Materials Science and Engineering (Vol. 937, No. 1, p. 012026). IOP Publishing.
12. Subramanian, AT Sankara, P. Meenalochini, S. Suba Bala Sathiya, and G. Ram Prakash. "A review on selection of soft magnetic materials for industrial drives." Materials Today: Proceedings (2020). https://doi.org/10.1016/j.matpr.2020.08.389
13. Kalavalli, C., P. Meenalochini, P. Selvaprasanth, and S. Syed Abdul Haq. "Dual loop control for single phase PWM inverter for distributed generation." Materials Today: Proceedings (2020). https://doi.org/10.1016/j.matpr.2020.10.116