Abstract:- In this paper characterization of TEM and GTEM cells are presented which are widely used in E.M.C (Electromagnetic Compatibility). The models having a metallic wire over a perfectly conducting ground plane are developed with different heights based on coupled transmission line theory. The comparison with theory, in some cases may deduce the uncertainty of measurements. Actually, in most cases of EM coupling to transmission line, hypothesis of infinite ground plane and TEM approximation is considered. Initially the experimental results were obtained for different polarizations of the incident electromagnetic waves. Secondly the theoretical prediction is done using transmission line theory. Finally the experimental and analytical results are further verified by using piece-wise cubic spline interpolation technique and PCHIP (Piecewise Cubic Hermite Interpolating Polynomial) to find the data points at some intervals.

Keywords:- Transverse Electromagnetic Cell, Gigahertz- TEM, EMC.

1 Introduction
The objective of the study is to observe the behavior of TEM and GTEM cells which are used for immunity and radiation measurements of the electronic equipment. For the study we develop two models [transmission lines over a perfectly conducting ground plane with different heights: 65mm and 5mm(Fig-1)]. Here only the experimental results of one model have been discussed. For which the characteristic impedance is $292\,\Omega$. The dimensions of the models are selected arbitrarily. Plane wave is generated which is characterized by the electric and magnetic field components. The EM field will induce the voltage at the extremities of the conductor of the model. This induced voltage is then measured using a semi-rigid coaxial cable and spectrum analyzer. Theoretical simulation by transmission line theory and the obtained experimental data is compared and analyzed further using a piece-wise cubic spline interpolation technique to interpolate on the set of the experimental data.

2 Transverse EM Cell
The experiments are carried out by connecting a radio-frequency source and an amplifier. A spectrum analyzer is used to measure the induced voltage. Both these equipments are placed outside the cell and connected to the DUT [Device Under Test] with high immunity shielded cables. Due to the size of the cell, the frequency range of the study is selected from 100kHz to 200MHz. The characteristic impedance of the cell is $Z_{\text{TEM}}\approx50\,\Omega$. The wavelength must be large enough compared to $L_0$ and $h$ so that the equivalent model remains valid. Otherwise the simulation has to be carried out by
using coupled transmission line theory [1]. The separating distance between the septum and the reference plan of TEM cell is 60cm, which justifies the approximation of plane wave for each prototype. Components of Electric and Magnetic fields are deduced from the Voltage, V applied at the end of TEM cell:

\[
E_x^i = \frac{V}{H'} \quad \text{And} \quad H_y^i = \frac{E_x^i}{\eta}
\]

(1)

Where:
\(V\)=Source voltage, Volt.
\(\eta\)=Wave impedance, 377Ω.
\(H'\)=Separating distance between the septum and the reference plan of the cell, meter.

2. 1 Results

![Fig.2: Induced voltage vs. frequency for Hybrid coupling.](image1)

![Fig.3: Induced voltage vs. frequency for Electric coupling.](image2)

2. 2 Discussion

The concept of equivalent circuits can be employed, as the dimensions of \(L_0\) and \(h\) are small enough w.r.t. the wavelengths.

\[
\xi = j \omega \mu_0 H_y^i h L_0
\]

(2)

\[
I = j \omega \mu_0 E_x^i C_0 h L_0
\]

(3)

\[
C_0 = \frac{2 \pi \varepsilon_0}{\ln(\frac{4h}{d})} L_0
\]

(4)

where;
\(h\)=height the conductor above the ground plane, m.
\(L_0\)=length of the conductor, m.
\(C_0\)=capacitance between the conductor and the models reference plan, F/m.
\(d\)=diameter of the conductor, m.
\(I\)=equivalent current source, A.
\(\xi\)=equivalent voltage source, V.
\(E_x^i=1/0.6=1.66\) V/m.
\(H_y^i=0.00442\) A/m.

Theoretical simulation based on the equivalent circuit is achieved by the exact solution taking into account the propagation phenomenon in order to point out the resonance occurring at high frequencies. A relative good agreement is achieved in the measurements performed in TEM cell.

Above figures (Fig. 2 to Fig. 3) show the relationship between induced voltage and frequency for hybrid excitation and electric excitation, respectively, which show good agreement with the theory up to a frequency of 100MHz. This limitation is due to the dimensions
of the cell being used. The dimensions of $L_0$ and $h$ are small enough with respect to the wavelengths so the concept of equivalent circuits can be employed. For the equivalent excitation the equivalent circuit employed is as following:

![Equivalent Circuit](image)

**Fig.5: Equivalent circuit for Electric excitation**

Theoretical simulation based on the equivalent circuit is achieved by the exact solutions taking into account the propagation phenomenon in order to point out the resonance occurring at high frequencies [1]. A relative good agreement is achieved between theoretical and experimental results of TEM cell.

### 3 GTEM Cell and statistical analysis

The GTEM cell used for experiments has the dimensions as $W=2m$, $H=2m$ and $L=4.5m$[1]. The average distance was taken from the middle of the reference plane of the model to the septum for the deduction of electric field component.

#### 3.1 Results

![Graph](image)

**Fig.6: Induced voltage vs. frequency for Hybrid coupling.**

![Graph](image)

**Fig.7: Induced voltage vs. frequency for Electric coupling.**

#### 3.2 Discussion

For the frequencies less than 10MHz, the Fig. 6 and Fig. 7 show the deviation in amplitude of induced voltage with respect to the voltage calculated by simulation. This was due to the sensibility of the measuring device, the network analyzer. Above the frequency of 10MHz, a reasonably good correlation is observed. Precise estimation gives around $1.53V/m$ as the electric field component and $4.08mA/m$ as the magnetic field component. Theoretical simulation is based on the equivalent circuit by taking into account the propagation phenomena in order to point out the resonance occurring at high frequencies. In case of electric coupling the resonance occurring above 100MHz are very well described by the theoretical simulation, while for hybrid coupling some deviation occurs which may be due to the EM field distribution inside the GTEM cell.

Theoretical simulation by transmission line theory and the obtained experimental data is compared and analyzed further using a piecewise cubic spline interpolation and PCHIP to interpolate on the set of the experimental data. Piece-wise polynomial interpolation provides more flexibility than a typical inflexible higher-order polynomials [2]. Piece-wise cubic spline interpolation also provides a fairly smooth and efficient approximation without increasing the computational complexities required for higher-order polynomial approximation. In our effort, we take the sequence $\Delta = \{t_i\}_{i=1}^n$ of strictly increasing data nodes on the interval $I = [a, b]$, and a
cubic spline \( u(x) \) to coincide with cubic polynomials \( u_i(x) \) on every interval \([t_i, t_{i+1}]\) for \( i = 0, 2, ..., n \) of experimental data. We obtain a complete spline interpolation of data, which are given at the knots \( \{t_i\} \).

After comparing PCHIP and spline, we find a good agreement as the function \( S(x) \) supplied by SPLINE is constructed in exactly the same way, except that the slopes at the \( x(j) \) are chosen differently, namely to make even \( S''(x) \) continuous. Spline is smoother, i.e., \( S''(x) \) is continuous. Spline is also more accurate if the data are values of a smooth function. Pchip has no overshoots and less oscillation if the data is not smooth.

A good correlation is observed for the frequency range from 200MHz to 1GHz. The good agreement of the characteristics show that experimentally reproduced coupling is a good representation of that described by plane wave as assumed by transmission line theory.

4 Conclusion
Taking into consideration the size of the chambers and the models developed for experimental work, we observe a good agreement of experimental and theoretical values while using TEM cell for a frequency range of 300kHz to 100MHz. This limitation is due to the dimensions of the cell being used. For the higher frequencies up to 1GHz, GTEM cell is used which shows again a good agreement between experimental and theoretical values for the frequency range of 10MHz to 1GHz. For the frequencies less than 10MHz the sensitivity of the measuring device causes the difference between experimental and theoretical data [3]. Spline interpolation technique is adopted to estimate the missing experimental data.

In future work, the analysis of the data for higher frequencies e.g. up to 10GHz will be proposed using Semi Anechoic chamber and Mode Stirrer Reverberating Chamber. Theory of antennas will be exploited and the limits of the use of this theory and the transmission line theory will be explained [4, 5]. Spline Technique will also give additional information.

References: