Investigation of Electronic Stirring Chamber Phase-shifting Excitation and Load Effects

Mario Alves dos Santos Junior, Damien Voyer, Carlos Sartori, Djonny Weinzierl, Ronan Perrussel, Christian Vollaire, Laurent Krähenbühl, José Cardoso

Investigation of Electronic Stirring Chamber Phase-shifting Excitation and Load Effects

M.A. Santos Jr.[1,4], D. Voyer [2], C. A. F. Sartori[1], D. Weinzierl[3],
R. Perrussel[2], C. Vollaire[2], L Krähenbühl[2], J.R. Cardoso[1]
[1] Laboratório de Eletromagnetismo Aplicado LMAG/PEA/EPUSP. 05508-900. São Paulo-SP, Brazil
[2] Ampère (CNRS UMR5005), Université de Lyon, Ecole Centrale de Lyon, 69134, Ecully Cedex - France
[3] Centro Universitário de Jaraguá do Sul – Rua dos Imigrantes 500, 89254-430, - Jaraguá do Sul/SC - Brazil
[4] Centro Tecnológico da Marinha em São Paulo – 05508-000 - São Paulo/SP – Brazil

mario_alves@pea.usp.br, Damien.Voyer@ec-lyon.fr, sartori@pea.usp.br, Laurent.Krahenbuhl@ec-lyon.fr

***Abstract* — This paper presents a theoretical evaluation of the phase-shifting excitation and load effects in a Transmission Line Excitation Chamber. It is suggested as an alternative for immunity tests because of the restrictions related to canonical chambers. Here, two methods are used to calculate the E-field: a semi-analytic approach and a numerical one. The semi-analytic method is based on the well-known modal expansion while a commercial software is used for numerical simulations. The results regarding the field profile and the related statistical indexes of merit are presented and used to evaluate the chamber performance.**

I. Introduction

Canonical chambers - that is Reverberation Chambers (RC) and TEM Chambers - are generally used for electromagnetic immunity testing despite their particular operational restrictions. RCs using mechanical paddles or frequency stirring provide a statistical E-field uniformity in all the directions inside the work volume [1]-[2]. Nevertheless, the frequency operation of RCs is inversely proportional to the chamber dimensions and it is a constraint for low frequencies tests. The International standards recommend the RC configuration for immunity tests over 80 MHz frequencies [2]. TEM Chambers present for low frequencies a deterministic E-field uniform over a work area parallel to the septum, but not in all directions in the chamber volume [3]. Recently, a concept called Transmission Line Excitation Chamber (TLEC) has been proposed, based on a phase-shifting excitation of several transmission lines (TL). For a sake of illustration, a configuration constituted of three-conductor phase-shifting excitation has been investigated in [4].

In this work, we present semi-analytical and numerical approaches for evaluating the performance of a TLEC. Basically, a chamber excited by several TL presents several TEM modes inside the closed metallic cavity. The resulting standing waves depend on the position of the TL as well as the phase-shifting excitation and the loading. Those parameters are important in the search for a suitable chamber working volume; they can be modified electronically, resulting in a random standing wave profile. Based on this, a set of parameters combination can be chosen to improve and satisfy the pre-defined uniformity criteria within a wide frequency range, even at frequencies lower than 80 MHz.

II. Semi-analytic and numerical approaches

A. Analytic expression of a single TL

Considering the TL geometry given by Fig.1, the E-field of a TEM mode inside the chamber can be evaluated by the following analytical expressions:

$$E_{TEM\,X}(x,y)=\eta_0\sqrt{\frac{2}{a}}\sum_{m=1}^{+\infty}\cos\left(\frac{m\pi}{a}x\right)\times\begin{cases}\alpha_{1m}\,sh\left(\frac{m\pi}{a}(y-l_1)\right) & y>0\\ \alpha_{2m}\,sh\left(\frac{m\pi}{a}(y+l_2)\right) & y<0\end{cases}\qquad(1)$$

$$E_{TEM\,Y}(x,y)=\eta_0\sqrt{\frac{2}{a}}\sum_{m=1}^{+\infty}\sin\left(\frac{m\pi}{a}x\right)\times\begin{cases}\alpha_{1m}\,ch\left(\frac{m\pi}{a}(y-l_1)\right) & y>0\\ \alpha_{2m}\,ch\left(\frac{m\pi}{a}(y+l_2)\right) & y<0\end{cases}\qquad(2)$$

with

$$\alpha_{1m}=\frac{J_m\,th\left(\frac{m\pi}{a}l_2\right)\Big/ch\left(\frac{m\pi}{a}l_1\right)}{th\left(\frac{m\pi}{a}l_1\right)+th\left(\frac{m\pi}{a}l_2\right)};\quad \alpha_{2m}=-\frac{J_m\,th\left(\frac{m\pi}{a}l_1\right)\Big/ch\left(\frac{m\pi}{a}l_2\right)}{th\left(\frac{m\pi}{a}l_1\right)+th\left(\frac{m\pi}{a}l_2\right)}\qquad(3)$$

where η_0 is the vacuum wave impedance and J_m the harmonic coefficients related to the current density on the central conductor. Assuming the conductor as an infinitely thin wire along z axis, one finds:

$$J_m=I_0\sqrt{\frac{2}{a}}\sin\left(\frac{m\pi}{a}x_0\right)\qquad(4)$$

The dependence with z direction is decoupled and equal to e^{-jk_0z}, when an incident wave is considered.

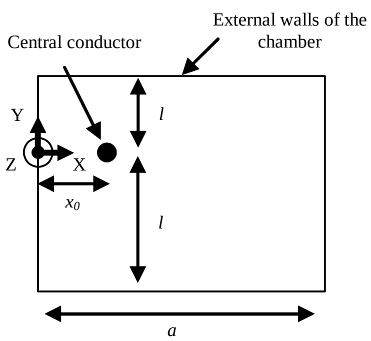


Fig. 1: geometry of a TL in the transverse plane

4. Electromagnetic Compatibility.

B. Phase Shifting and Load Effects Modeling

Several TL can be treated by superposition. When the TLs are ended with the same load, the E-field can be written using the separation of variables in the transverse plane and in the longitudinal direction. The phase shifting between the TLs has then an effect on the repartition of the fields in the transverse plane:

$$\vec{E}_{TOT}(x,y) = \sum_i \vec{E}_{i\,TEM}(x,y)\, e^{j\varphi_i} \qquad (5)$$

where $E_{i\ TEM}$ is the E-field due to the i^{th} TL and φ_i represents the applied excitation phase.

The load introduces a reflection coefficient Γ that affects the longitudinal repartition of the field:

$$\vec{E}_{TOT}(x,y,z) = \vec{E}_{TOT}(x,y) \times \left(e^{-jk_0 z} + \Gamma e^{+jk_0 z}\right) \qquad (6)$$

If we consider when $|\Gamma| = 1$, a stationary wave is expected but the maximum of E-field can be moved changing the phase of Γ. Thus, it is possible to homogenize the field in *z* direction even if the TL is unmatched.

C. Numerical Approach

Numerical evaluation was performed using FIT [5]. The loads are imposed by boundary conditions while the phase-shifting excitation is implemented by a post-processing approach.

D. Indexes of Merit calculation

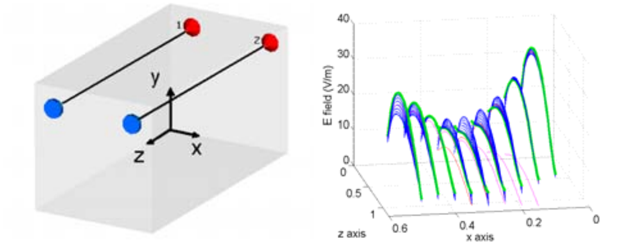
Standard deviation for the distribution of E-field in the chamber can be calculated from the definitions in [1] [4] and [6]. Due to the phase and load shifting, the E-field considered at any point of the chamber is the average field.

III. Application and Results

A TLEC with dimensions of *0.6m×0.6m×1.2m* has been considered. The semi-analytical approach has been applied in the transverse plane *{x, y}* since the variation of E-field in z direction can be canceled using a suitable load-shifting. The area under evaluation is a rectangular *0.3m×0.3m* centered at the middle of the chamber. The study concerns the influence of the phase-shifting when several TL are considered. Results are reported in Table I. It appears that the number of TL is important: the standard deviation decreases of *3 dB* when 4 TL are introduced instead of 2 TL. Moreover, the phase-shifting improves of *0.5 dB* the performance. A TEM stripline like the one used in TEM Chambers has also been simulated and the E-field uniformity is presented.

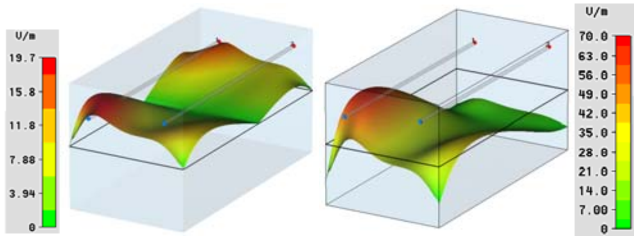
TABLE I
STANDARD DEVIATIONS FOR SEMI-ANALYTICAL APPROACH

Chamber Configuration		Standard Deviation (dB)		
Number of TL	Phase-shifting	$\hat{\sigma}_x$	$\hat{\sigma}_y$	$\hat{\sigma}_{x,y}$
1	-------	5.7	6.0	5.9
2	No	6.5	3.3	5.3
2	Yes	6.4	2.0	5.0
4	No	3.2	3.2	3.3
4	Yes, random	2.8	2.6	2.8
TEM Chamber	-------	5.1	3.1	4.6



(a) (b)

Fig. 2 (a) Position of two TL in the chamber (b) E-field distribution in the horizontal plane at the middle of the chamber (load 50 Ω).



(a) (b)

Fig. 3 E-field distribution with different loads (a) –j500Ω (b) j500 Ω.

3D simulations using commercial software have also been carried out. The interest is that this approach is more realistic since it takes into account the connection of the TLs outside the chamber, which introduces a discontinuity. Table II presents the statistical E-field indexes calculated when the TLs are terminated by a 50 Ω load. The volume is defined with the same cross section as previously, and a *0.6m* length in the *z* direction. The influence of the phase-shifting on E-Field profile is also given at Fig. 2 in a 2 TL configuration.

TABLE II
STANDARD DEVIATIONS FOR NUMERICAL APPROACH (LOAD 50Ω)

Configuration		Standard Deviation (dB)		
Number of TL	Phase-shifting	$\hat{\sigma}_x$	$\hat{\sigma}_y$	$\hat{\sigma}_{x,y}$
1	-----	7.7	6.6	7.3
2	No	9.0	4.4	6.4
2	Yes, random	7.0	5.1	6.2
4	No	7.1	7.1	7.1
4	Yes, random	5.0	6.3	5.6

The effect of the load is presented in Fig. 3: the maximum of E-field moves between a –j500*Ω* and j*500 Ω* load.

Acknowledgment

This work was partially supported by Capes-Cofecub (07/0568), and FAPESP (2007/51192-6).

IV. References

[1] IEC61.000-4-21, Electromagnetic Compatibility (EMC), Part 4, Testing and Measurement Techniques – Section 21: Reverberation Chamber Test Methods.

[2] M. Klingler, S. Egot, J. GHYS, J. Rioult, "On the use of 3D TEM Cells for Total Radiated Power Measurements", *IEEE Transactions on EMC*, 44 (3): 364-372, 2002.

[3] J. Perini and L. S. Cohen, "*Extending the frequency of mode stir chambers to low frequencies*", IEEE International Symposium on Electromagnetic Compatibility, v. 2, 2000, pp. 633-637.

[4] D. Hill, "Electronic mode stirring for reverberation chambers", *IEEE Transactions on Electromagnetic Compatibility*, 36 (4): 294-299, 1994.

[5] [Online]. Available: http://www.cst.com/

[6] D. Weinzierl, C. A. F. Sartori, M. B. Perotoni, J. R. Cardoso, A. Kost, E. F. Heleno, "Numerical evaluation of non-canonical reverberation chamber configurations", *IEEE Transactions on Magnetics*, v. 44, n. 6, p. 1458-1461, JUN2008.