EXPERIMENTAL STUDY OF COUPLING BETWEEN AN ELECTROMAGNETIC WAVE AND TRANSMISSION LINES IN A GTEM CELL

H. SLIMANI, A. BENDAOUD, A. REGUIG, B. BENAZZA
Laboratory of Applications of Plasma, Electrostatics and Electromagnetic Compatibility (APELEC)
Djillali Liabes University of Sidi Bel-Abbes, e-mail: babdelber22@yahoo.fr

A. REINEIX, O. DAFIF
Research Institute XLIM UMR CNRS 7252 – Laboratory of OSA department – University of Limoges, France

Abstract: *In installation or electronic equipment, transmission lines are usually located in proximity of a ground plane. Also an interference electromagnetic field can cause on the lines a parasitic current and voltage. As the security of such equipment depends on the amplitude of these parasites, the evaluation of the electromagnetic risk requires a measurement of this amplitude.*
To identify the coupling between the electromagnetic waves and transmission lines and proposing solutions allows reducing perturbations in EMC; an experimental study was performed using a GTEM cell and a vector network analyzer which gives the results of the induced voltage at the extremity of various transmission lines.

Key words: *EMC, electromagnetic wave, transmission line, electromagnetic perturbations, coupling, GTEM cell.*

1. Introduction.

The EMC requirements are increasingly becoming severe and must be taken into account during the design phase of electrical or electronic devices. For this, it is necessary to have models reflecting the electromagnetic behavior of the transmission lines either in emission or in immunity. Currently, conducted studies concern mainly the characterization of components in conducted and radiated emissions and conducted immunity.

To complete this works, radiated immunity studies should be performed. This work aims to estimate the induced perturbations in the transmission lines when they are subjected to an electromagnetic aggression [1, 2].

From the literature review on the experimental methods allows the studying of the radiation coupling between electromagnetic waves and transmission lines we performed experiments using an adequate measures bench contains a GTEM cell and a vector network analyzer, which allowed us to measure the amplitude of the parasitic voltages at the extremity of lines according to different parameters.

2. Reminder of the transmission lines theory

The principle of the transmission lines theory based on the modeling of the coupling or the interaction of electromagnetic waves with the transmission lines by the equivalent voltage and current sources distributed along this line. These sources calculated from the electromagnetic field that excites the line, reflect the effect of coupling of electromagnetic perturbation generated at the line (Fig. 1) [3-6].

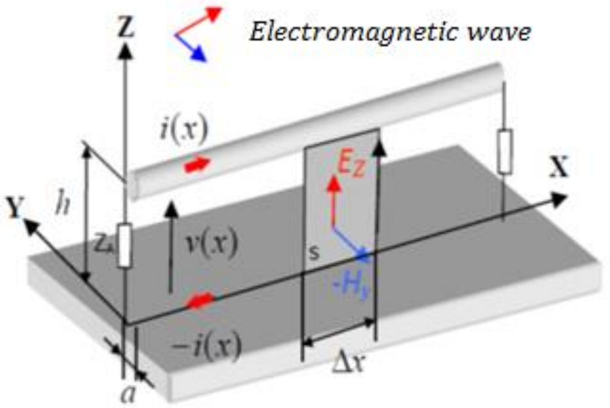

Fig. 1. Transmission line excited by an electromagnetic wave [1].

A. Model of a transmission line.

A transmission line is generally constituted by two parallel conductors which present a geometric uniformity. The main lines used currently are the lines: coaxial, symmetrical two-wires, twisted two-wires and printed circuits lines.

A transmission line can be likened to a succession of elementary sections «*localized elements*» with infinitesimal length dx (Fig. 2) [7-9].

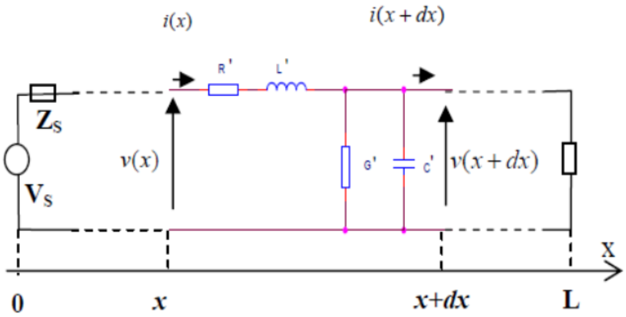

Fig. 2. Model of a transmission line.

With: R': the linear resistance (Ω/m) which represents the ohmic losses in the conductor.
G': the linear conductance (S/m) which represents the dielectric losses in the insulation between the two lines.
C': the linear capacitance (F/m) between the line and their ground plane.
L': the linear inductance (H/m) of the line.

B. Coupling models

Several approaches have been proposed to study the coupling of an electromagnetic field with the transmission lines. According to the electromagnetic field formula adopted to describe coupling, there are three approaches for modeling the action of interference field by a distribution of voltage and current sources along the line [10, 11].

B1. Taylor approach

This approach models the influence of the electromagnetic field by voltage and current sources distributed along the line. The relationship between the voltage and the total current on the one hand and the exciter electromagnetic field on the other hand is given by the following two equations: [2, 12]

$$\frac{dV(x)}{dx} + j\omega L' I(x) = V_{S1}(x) = -j\omega\mu_0 \int_0^h H_y^e(x,z)\,dz \quad (1)$$

$$\frac{dI(x)}{dx} + j\omega C' V(x) = I_{S1}(x) = -j\omega \acute{C} \int_0^h E_z^e(x,z)\,dz \quad (2)$$

The equivalent circuit diagram is shown in Figure 3:

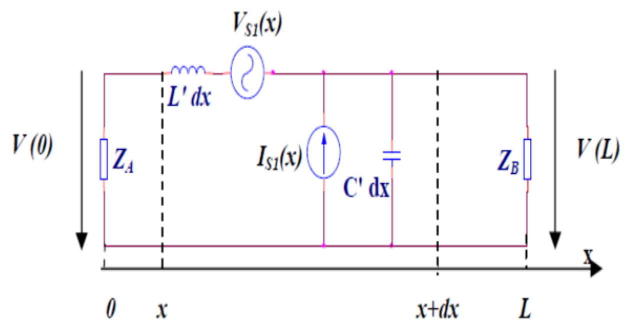

Fig. 3. Equivalent diagram of Taylor model.

B2. Agrawal approach

This approach describes the coupling of the electric field by the voltage sources distributed along the line and two voltage sources localized at the loads [2, 13]. The relationship between the diffused voltage by the line V_s(x) and the total current *I* (x) in one part and the exciter electric field is given by:

$$\frac{dV^s(x)}{dx} + j\omega L' I(x) = V_{S2}(x) = E_x^e(x,h) \quad (3)$$

$$\frac{dI(x)}{dx} + j\omega C' V^s(x) = 0 \quad (4)$$

The equivalent circuit diagram of the model is given by Figure 4 :

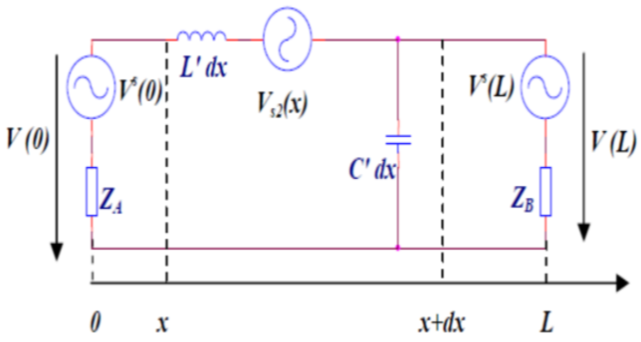

Fig. 4. Equivalent diagram of Agrawal model.

B3. Rachidi approach

This approach only describes the coupling of the magnetic field in terms of current sources distributed along the line and by two current sources localized at the loads [14].
The relationship between the total voltage *V*(x) and diffused current I_s(x) on the one hand and the exciting magnetic field on the other hand is given by the following equation system :

$$\frac{dV(x)}{dx} + j\omega L' I^s(x) = 0 \quad (5)$$

$$\frac{dI^s(x)}{dx} + j\omega C' V(x) = I_{S2}(x) = +\frac{\mu_0}{L}\int_0^H \frac{\partial H_x^e(x,z)}{\partial y}\,dz \quad (6)$$

The equivalent circuit diagram of the model is given by Figure 5.

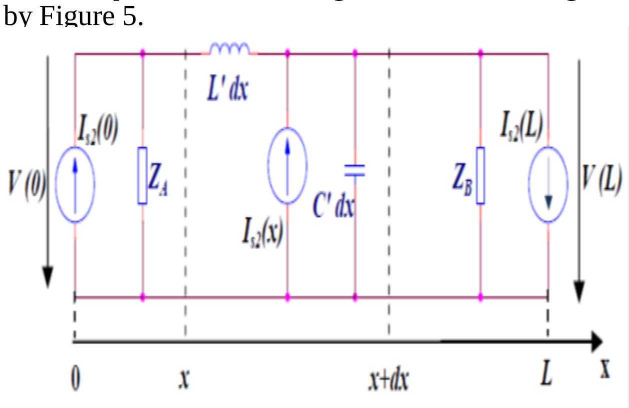

Fig. 5. Equivalent diagram of Rachidi model.

3. Experimental study

To properly study the coupling between an electromagnetic wave and a transmission line (wire above a ground plane) and to test the immunity of the line we used the GTEM cell (Figs 6 and 7) as an experimental test means connected to a vector network analyzer of type « *magnitude and phase* » (Fig. 8) by measuring as a function of the frequency the induced voltage at the extremity of the transmission line, by a radiated electromagnetic EM wave.

A. GTEM Cell (Gigahertz transverse electromagnetic)

This test method can be used for testing the radiated immunity of components. Measurements are carried out by placing the element or the line to be tested within the cell where we find an internal median conductor « *septum* » completed by adapted impedances. This last allows either the collection of transmitted signals «*emission test*» or the aggression of the line with an almost uniform transverse electromagnetic wave «*immunity test*». The GTEM has a pyramidal shape it comprises absorbents to prevent waves reflection [15-17].

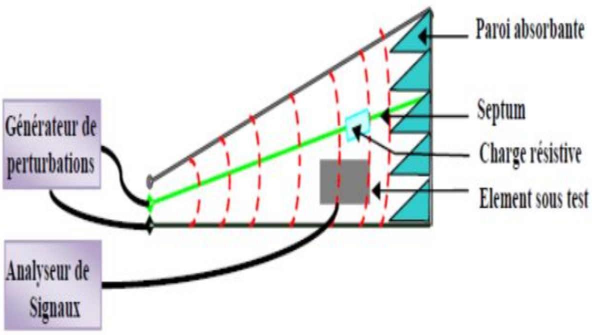

Fig. 6. GTEM cell in immunity test

Fig. 7. Photography of the GTEM cell used in the experiment

The vector network analyzer has two functions :
- Feeding the GTEM cell by power to create an electromagnetic wave inside the cell.
- Measuring the induced voltages at the output of the victim line.

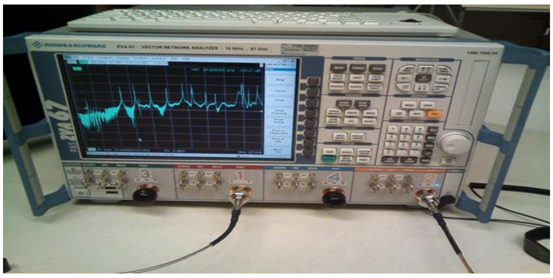

Fig. 8. Photography of vector network analyzer.

The studied structure is placed inside the GTEM cell. The coupling of the guided wave in the GTEM cell will be made by looking the influence of different parameters of the line situated in the test zone namely: value of the load at the extremity, height of the line from the ground plane, and connecting one extremity to the ground as shown in Figure 9.

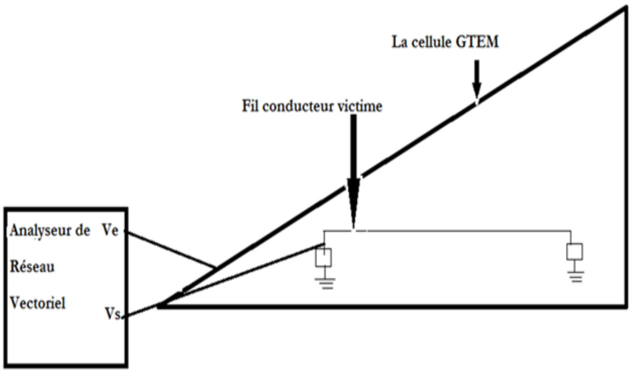

Fig. 9. Test bench for immunity test of the conductor wire in the GTEM cell

B. Test on a simple conductor wire with three different loads

We conducted a test on a simple conductor wire with length L = 75 cm and radius R = 0.32 mm situated at a height of h = 2 cm from the ground plane (Fig. 10). This conductor wire was aggressed by an EM wave in three cases separately according to the load at his extremity: line loaded on 50 ohms (the other extremity is closed on the internal impedance equal to 50 ohms of the network analyzer) short-circuit and open circuit.

Fig. 10. Photography for experiment of a simple conductor wire inside the GTEM cell at the test zone

C. Test on a simple wire and a twisted cable with two different heights from the ground plane

In this case, we placed separately two types of cables the first a simple conductor cable and the second twisted, both are closed at the other extremity on a resistive load of 50 ohms, with the same length L = 75 cm and each one of them has two different heights from the ground plane (2 cm and 9 cm) (Fig. 11), these cables are attacked by an EM wave in a frequency band of 300 kHz to 1 GHz.

Fig. 11. Photography for the experiment of a twisted cable with height h=9cm

D. Coupling with a simple conductor cable with and without grounding the other extremity

To see the importance of grounding an aggressed line, we made two experiments with two simple lines as previously charged. The first consists on a grounded wire and the second without ground (Fig. 12).

Fig. 12. Photography for experiment of a simple cable without ground

4. Results and interpretations

A. Coupling on a simple conductor wire with three different loads

From the results of Figure 13a, we can see that:
In low frequency before the resonance phenomenon related to the length of the lines, the coupling of the EM wave with the wire conductor increases in the three cases by increasing the frequency and we note that we have:

1- Case of short-circuit: there is an inductive coupling due to the current flow in a closed loop.

2- Case of open circuit : there is a difference of potential between the wire and the ground plane that will create an electric field which generates a capacitive coupling and will causes in high frequency an important resonances (maximum coupling or resonance in a quarter-wave of the line). It's for this reason that we should never put a cable in open circuit.

3- Case of the line loaded at 50 ohms : in this case, we have the twice types of coupling at the same time inductive and capacitive but both are minimized by the impedance which is situated at the extremity.

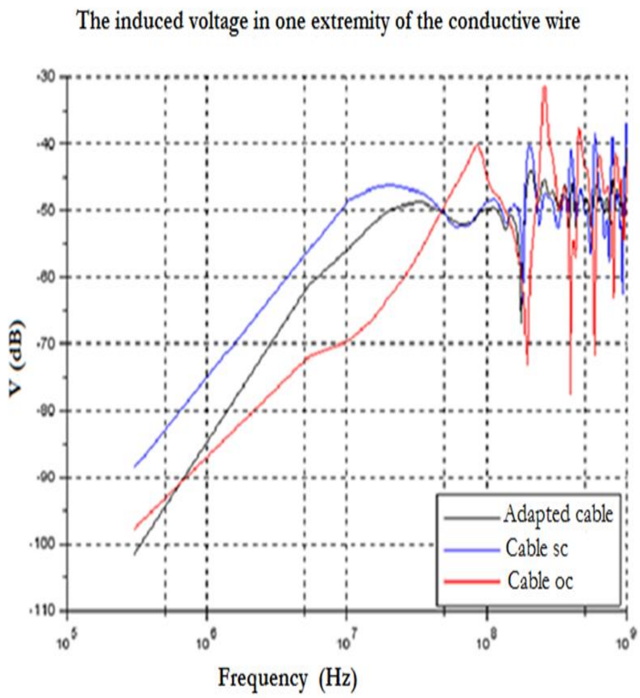

Fig. 13. Experimental variation of the induced voltage in one extremity of the conductive wire in dB as a function of the frequency.

A theoretical study on the coupling of the electric field generated inside the GTEM cell at one extremity of the simple conductor wire situated above an infinite conductor ground plane, was also carried out by applying the Agrawal approach and this is according to the three types of load at the other extremity of this wire:

- 50 ohms load
- Short circuit
- Open circuit

It is found in the theoretical curves of Figure 14, a similar results of those obtained experimentally (Figure 13), and in the three cases of configurations of the load at the other extremity of the line.
In low frequency before the resonance phenomenon related to the length of the lines, the coupling of the EM wave with the conductor wire increases in the three cases by increasing the frequency.

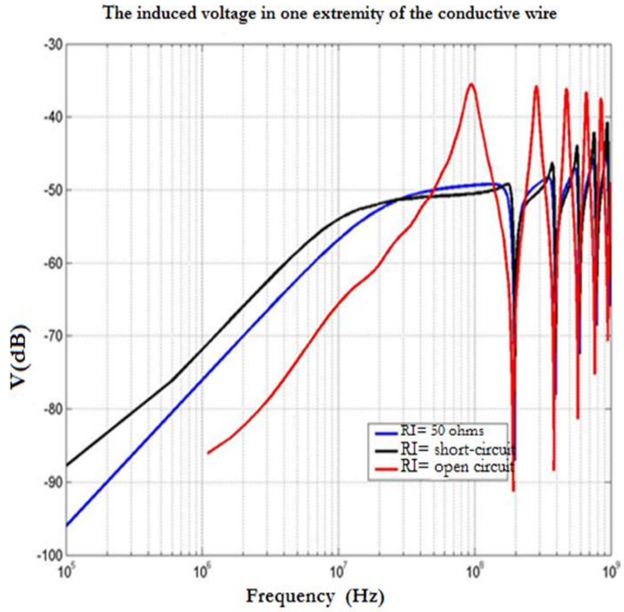

Fig. 14. Theorical variation of the induced voltage in one extremity of the conductive wire in dB as a function of the frequency.

B. Coupling with a simple conductor wire and with a twisted cable for two different heights from the grounded plane

Both Figures 15 and 16 shows the coupling of the electromagnetic wave with the twice cables for two heights: 2 cm and 9 cm, it's found in the both cases that the increase of height causes an augmentation of the loop surface between the cable and the ground plane, which increase the coupling between 12 to14 dB for both cases.

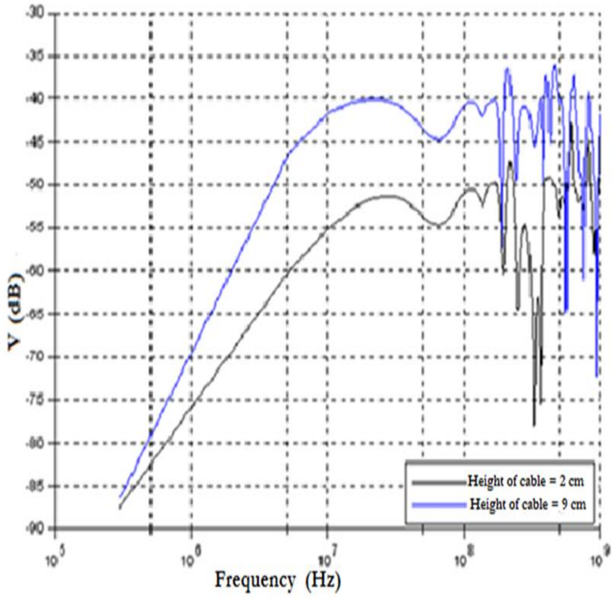

Fig. 15. Experimental variation of the induced voltage at the extremity of a twisted cable in dB as a function of the frequency for two heights h = 2 cm, h = 9 cm.

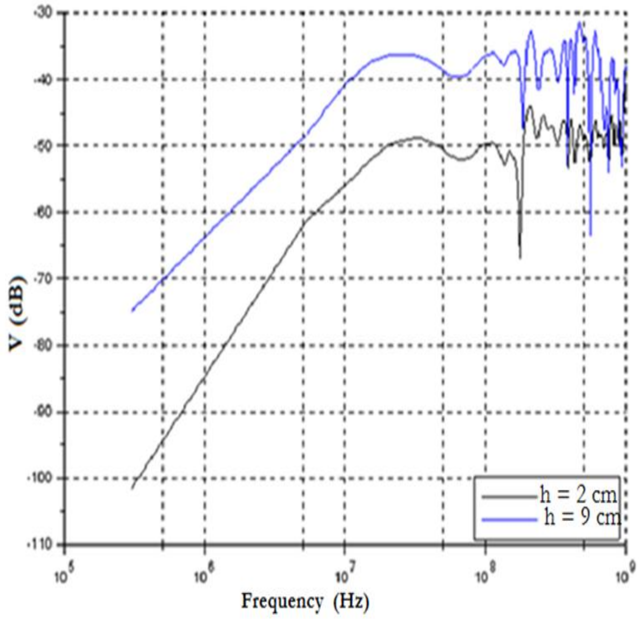

Fig. 16. Experimental variation of the induced voltage at the extremity of a simple conductor wire in dB as a function of the frequency for two heights h = 2 cm, h = 9 cm.

C. Coupling with a simple conductor cable with and without grounding one extremity

According to the measurement results of figure 17, where we measure the coupling between the EM wave and the conductor, we can said that in LF there is an augmentation of coupling of 10 dB with the frequency. But in high frequency, this coupling causes a resonance (maximum coupling or resonance in quarter-wave of the length of the line) or the line transforms as a form of a receiving antenna.

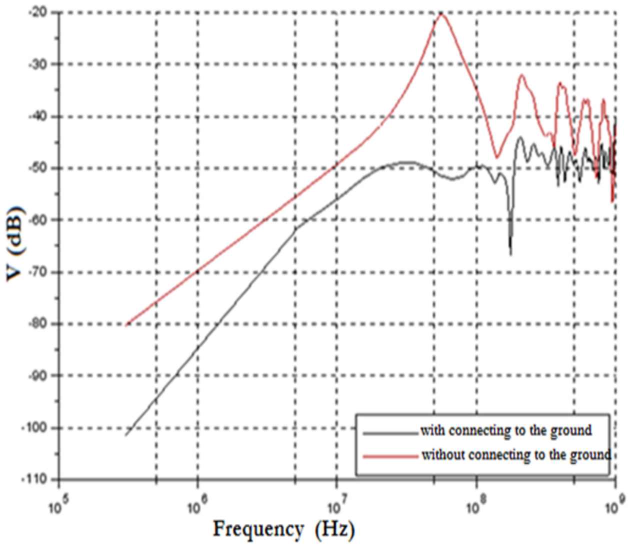

Fig. 17. Experimental variation of the induced voltage at the extremity of a simple conductor wire loaded at 50 ohms (in dB) as a function of the frequency with and without connecting to the ground.

5. Conclusion

In this work, we focused particularly on the study of the coupling between the electromagnetic waves and the transmission lines to predict the induced perturbations in this line. After describing the transmission lines theory and exposing the different coupling models, we measured the frequency evolution of the induced voltages at the extremity of the aggressed line by an electromagnetic EM wave using an adequate measures bench involving a vector networks analyzer connected with a GTEM cell.
This study allowed us to describe this coupling phenomenon by: the load at the extremity, the height from the ground plane and the importance of connecting to the ground.

References

[1] Razafferson, Analyse du rayonnement et des couplages électromagnétiques provoqués par des signaux hautes fréquences interférant avec des câbles d'énergie basse tension. Thèse de doctorat de l'Université des Sciences et Technologies de Lille, octobre 2002,

[2] Sofiane Atrous, « Mise en place d'une méthodologie de caractérisation en immunité champ proche de dispositifs électroniques » thèse de doctorat de université de Rouen Janvier 2009

[3] P. Degauque, J. Hamelin « Compatibilité Électromagnétique 'bruits et perturbations radioélectriques' », Dunod, Inc, 1990.

[4] J.-P. Perez, R.Carless, R.Fleckinger, « Électromagnétisme Fondements et Applications », Masson, 1996.

[5] A. Bendaoud, H. Slimani, F. Benhamida, Z. ayache, H. Miloudi, K. Medles, " Perturbations électromagnetiques à proximite des lignes d'energie transportant des signaux HF", TELECOM2011 & 7ème JFMMA, Mars 16-18, 2011 – Tanger MAROC

[6] Weens Yannick, "Modélisation des câbles d'énergie soumis aux contraintes générées par les convertisseurs électroniques de puissance", thèse de doctorat de l'Université des Sciences et Technologies de Lille génie électrique, décembre 2006

[7] H. Slimani, A. Bendaoud, M. Bensetti, H. Miloudi, B. Benazza, F. Benhamida, « Comportement et Calcul du Champ Electromagnétique Engendré à Proximité de Lignes d'Energie Transportant des Signaux HF » pp: 182-187, ICEN'10 – International Conference on Electrical Networks. Sidi Bel-Abbès, September 28-29,2010

[8] H. Slimani, A. Bendaoud, F. Benhamida, H. Miloudi, A. Timatine, K. Medles, « Propagation des perturbations electromagnetiques dans un cable alimentant un moteur asynchrone », TELECOM2011 & 7ème JFMMA, Mars 16-18, 2011 – Tanger MAROC.

[9]H. Slimani, A. Bendaoud, F. Benhamida, A. Dahak, K. Medles, A. Tilmatine, « Calcul du rayonnement électromagnetique provoqué par des signaux HF à proximité d'un câble électrique domestique », Cinquième Conférence Internationale sur l'Electrotechnique, ICEL'13,USTO-Oran, 03-04 décembre 2013

[10] Z. Nadir "Caractérisation de plusieurs méthodes d'essais utilisées en compatibilité électromagnétique à partir de mesures pratiquées sur des objets respectant les propriétés des lignes de transmission", thèse dedoctorat en électronique - Lille, Nov, 99.

[11] A.Guerrab, "Validation expérimentale de la théorie des lignes couplées appliquées à des faisceaux de câbles simulant un site industriel", Thèse de doctorat en électronique -Lille, Jul, 00

[12] C. D. Taylor, R. S. Sattewhite, and C. W. Harrison, « The Response of a Terminated Two-Wire Transmission Line Excited by a Nonuniform Electromagnetic Field », IEEE Transactions on Antenna Propagation, P. 987-989, Vol. E, November 1965.

[13] A. K. Agrawal, H.J. Price, « Transient Reponce of Multiconductor Transmission Lines Excited By a Nonuniform Electromagnetic Field », IEEE Transactions on Antenna and propagation, P. 432-435, Vol. 18, Jun 1980.

[14] F. Rachidi, « Formulation of the Field to Transmission Line Coupling Equations In Terms of Magnetic Excitation Field », IEEE Transactions on, Electromagnetic Compatibility, P. 404-407 ,Vol. 35, No. 3, Aug. 1993

[15] M. L. Crawford: « Generating of Standard EM Fields Using TEM transmission cells », IEEE Trans. On Electromagnetic Compatibility, P. 189-195, Vol. 16, No.4, Nov. 1974.

[16] A. Picard, F. Fouquet, V. Deniau, A. Louis, B. Mazari, B. Demoulin, « Perturbations Induites par un Câble de Servitude Lors de la Mesure en Cellule TEM 3D » EMC 06, Saint Malo, P. 293– 294, 4- 6 April 2006.

[17] R. De Leo, T. Rozzi, Carlo Svara, and L. Zappelli, « Rigorous Analysis of the GTEM Cell Transactions on Microwave Theory and Techniques, P.488 - 500, Vol. 39, No. 3, Mar 1991.