Analysis of Crosstalk on Non Uniform Transmission Lines by Means of the FDTD Algorithm in a Random Multisource Context

Loubna Tani, Nabih El ouazzani

Abstract— In high speed communication systems, crosstalk between closely spaced signal lines limits interconnect performance and becomes an important aspect of circuit design .This paper deals with a computational approach, based upon centred points finite difference time domain (FDTD) technique, to evaluate crosstalk between non uniform transmission lines interconnection. The approach is based on the subdivision of the non uniform line to a large number of thin lines having different widths. Thus, the non uniform lines can be analysed as a coupled multiconductor transmission line. Moreover, the paper presents a statistical analysis of near end and far ends crosstalk voltages, the non uniform transmission line circuit has been excited under random circumstances depending on the timing and the probability density function PDF normal (or Gaussian) distribution and uniform distribution. The results are obtained has been yielded great deal of useful knowledge.

Index Terms— Crosstalk, finite difference time domain (FDTD), printed-circuit board (PCB), non uniforme transmission lines, random multisource.

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1 INTRODUCTION

In recent years, the non uniform interconnections structures are quite are quite often used in microwave systems and in high-speed electronics. In chip carriers for example, the interconnections are usually non uniform because of the high circuit density, the complex geometry, and the geometrical constraints at the edges of the chip. Non uniform transmission lines are also used in RF and microwave circuits as resonators , impedance matching , delay equalizers, filters, wave shaping , analogue signal processing , VLSI interconnect [1] and etc. Some non uniform transmission lines show good transmission responses and they are used to realize specific time-domain waveforms in various measurement systems [2].

In high-speed digital circuits, the electromagnetic interference related problems in such circuits become critical for the success of the overall system performance. One of the main sources for the EMI is crosstalk between the electrical interconnects. Crosstalk affects mainly and in a straight forward way the voltage of the victim signal, depending on the nature of the coupling between the aggressors and the victim. In this paper, we deal with non uniform transmission lines (NTLs) that are encountered in many interconnects and electronic systems to transfer data from one device to another or to multiple devices with a good level of precision. In industrial applications, such as embedded systems and motherboard of sophisticated devices, the NTLs can be excited with different voltage sources and also have different loads. The wave propagation on the structure is governed by the multiconductor transmission line (MTL) equation in the time domain. The per-unit-length parameters are expressed with respect to the position along the non uniform line. Using a time-domain method enables the propagation of a pulse to be seen clearly without the need for any frequency-time transformations [3]. In this paper, a method is proposed and detailed to analyse crosstalk problems for non uniform transmission lines NTLs. One such widely used method is the finite-difference time-domain or FDTD method. The technique is flexible and can be applied to many basic EM scattering and radiation problems. In this method, the non uniform line is subdivided to a large number of narrow lines having different widths. Thus, the non uniform line can be analysed as a coupled multiconductor transmission line.

This paper is structured as follows: In section 2 a non uniform transmission line is analysed in the time domain using finite difference time-domain (FDTD) technique. In section 3 a non uniform transmission line excited with multiple sources is handled to determine the crosstalk variation in the case of more than one aggressor. The study is carried out in a deterministic context. In section 4 the paper presents a statistical analysis of near end and far ends crosstalk voltages, the non uniform transmission line circuit has been excited randomly with two pulses according to two statistical laws normal (or Gaussian) distribution and uniform distribution. In section 5 comparison and discussion of the Results and finally conclusions are drawn in section 6.

2 FDTD-BASED SIMULATION OF NON UNIFORM TRANSMISSION LINE

In order to illustrate the method, we consider a non-uniform transmission line whose per unit length parameters vary depending on the position (x) along the propagation axis. The MTL equations of a lossless non uniform line become [4]:

$$\frac{\partial}{\partial x}\boldsymbol{V}(x,t)+\boldsymbol{L}(\boldsymbol{x})\frac{\partial}{\partial t}\boldsymbol{I}(x,t)=0$$

$$\frac{\partial}{\partial x}\boldsymbol{I}(x,t)+\boldsymbol{C}(\boldsymbol{x})\frac{\partial}{\partial t}\boldsymbol{V}(x,t)=0$$

Where V and I are the voltage and current vectors of the line, and the line cross-sectional dimensions are contained in the (n x n) per-unit-length parameter matrices of L (inductance) and C (capacitance). The application of the FDTD technique is mainly based on the division of the non uniform line

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into several uniform sections of different cross sections as shown in Fig.1.

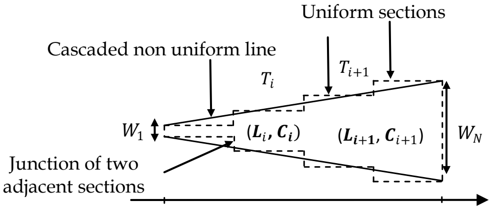

Fig1 .Model of cascaded non uniform line. L_i inductance matrix, $C_i$capacitance matrix, W width of the current line.

The per-unit-length parameters of the line vary from one section to another. The application of the general algorithm must take into account the junction between two adjacent sections Fig.2 [5].

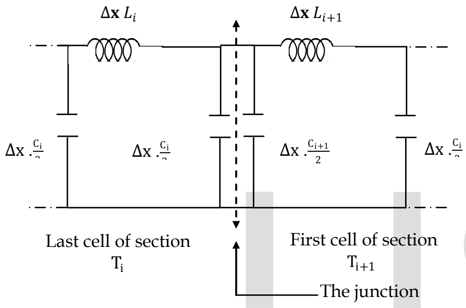

Fig2 . Junction of two adjacent sections.

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In the FDTD method, the line axis x is discretized in Δx increments or spatial cells, the time variable t is discretized in Δt increments or temporal cells. To insure second-order accuracy of the discretization, we interlace the NDX+1 voltage points, V_1, V_2, , … , V_{NDX}, V_{NDX+1}, and the NDX current points, $I_1, I_2,…, I_{NDX}$ [6]. Each voltage and adjacent current solution points are separated by Δx /2. In addition, the time points are also interlaced, and each voltage time point and adjacent current time point are separated by Δt /2 [6].

The modelling technique, presented in the previous paragraph, can deal with non-uniform lines with great flexibility and more precision. However, we insist on the importance of the discretization in time Δt and space Δx and their influence on numerical calculation results. So, the following relation must be verified:

$$\Delta t \leq \frac{\Delta x}{Vp} \tag{3}$$

Vp is the phase velocity of propagation of the waves.

Based on this model and by discretizing the equations of the line in time and in space, we obtain the following recurrence relations taking into account the boundary conditions:

$$\mathbf{I}_K^{n+3/2} = \mathbf{I}_K^{n+1/2} - \frac{\Delta x}{\Delta t} L_i^{-1}(\mathbf{V}_{k+1}^{n+1} - \mathbf{V}_k^{n+1}) \tag{4}$$

k = 1… NDX

$$\boldsymbol{V}_k^{n+1} = \boldsymbol{V}_k^n - \frac{2\Delta t}{\Delta x}(C_i + C_{i+1})^{-1}(\boldsymbol{I}_K^{n+\frac{1}{2}} - \boldsymbol{I}_{K-1}^{n+\frac{1}{2}}) \tag{5}$$

At the junction $T_i - T_i + 1$

$$\mathbf{V}_k^{n+1} = \mathbf{V}_k^n - \frac{\Delta t}{\Delta x} C^{-1}(\mathbf{I}_K^{n+\frac{1}{2}} - \mathbf{I}_{K-1}^{n+\frac{1}{2}}) \tag{6}$$

k = 2… NDX

$$\boldsymbol{V}_1^{n+1} = (\frac{\Delta x}{\Delta t} R_s C + 1)^{-1} \times [\left(\frac{\Delta x}{\Delta t} R_s C - 1\right) \boldsymbol{V}_1^n - 2R_s \boldsymbol{I}_1^{n+\frac{1}{2}} + (\boldsymbol{V}_s^{n+1} + \boldsymbol{V}_s^n)] \tag{7}$$

$$\boldsymbol{V}_{NDZ+1}^{n+1} = \frac{\Delta x}{\Delta t} R_L C + 1)^{-1} \times [\left(\frac{\Delta x}{\Delta t} R_L C - 1\right) \boldsymbol{V}_{NDX+1}^n - 2R_L \boldsymbol{I}_{NDX}^{n+\frac{1}{2}} + (\boldsymbol{V}_L^{n+1} + \boldsymbol{V}_L^n)] \tag{8}$$

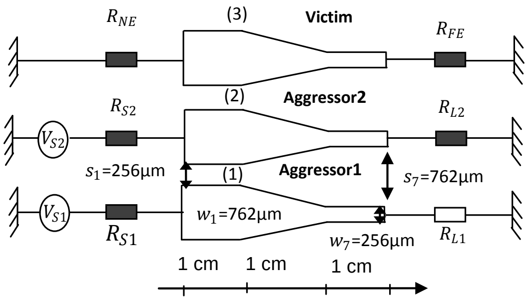
The index (i) is relative to the section T_i.

Finally, we have all necessary data to the algorithm for developing a simple approach to analyze non uniform transmission lines in the time domain.

3 NON UNIFORM TRANSMISSION LINE WITH MULTIPLE SOURCES

In a deterministic context, we consider a non uniform three-conductor transmission line system with two aggressors and one victim, the top view and the cross section are shown in Fig. 3.

A three conductor micro strip transmission line of width varies from w_1=762µm to w_7=256µm and separation varies from s_1=256µm to s_7=762µm is excited by multiple voltage sources in order to determine the crosstalk level variation at both the near and the far ends of the victim conductor. The substrate has relative permittivity εr=4.7 and thickness h=203µm. The input voltage sources are a 1V pulse with a 50 ps rise/fall time and a width of 50 ps. The length of the coupled line is 3 cm and is terminated at the near and far ends in 50 Ω resistors. The three non uniform conductors are divided into 7 sections with different lengths.



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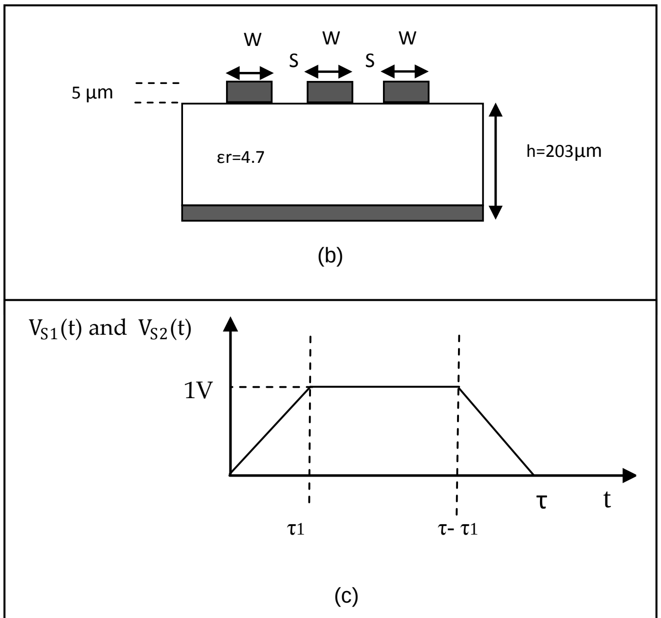

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Fig3 . The non uniform line under study. (a) The line dimensions and terminations. (b) The cross-sectional dimensions. (c) The source voltage wave shape.

In order to evaluate the far end and near end crosstalk voltages between non uniform conductors, we performed several simulations according to the following parameters, $\Delta x = 0.11667$mm, $\Delta t = 6.1608.10^{-13}$s and $V_p=1.8937.10^{8}$ m/s. First, we connect only one voltage source at a time. Secondly, the complete circuit is examined in terms of the victim trace response as both sources are connected to the line and work in a synchronized way. Fig.4 presents the near and far ends crosstalk (V_{NEXT} and V_{FEXT}) for the cases previously described

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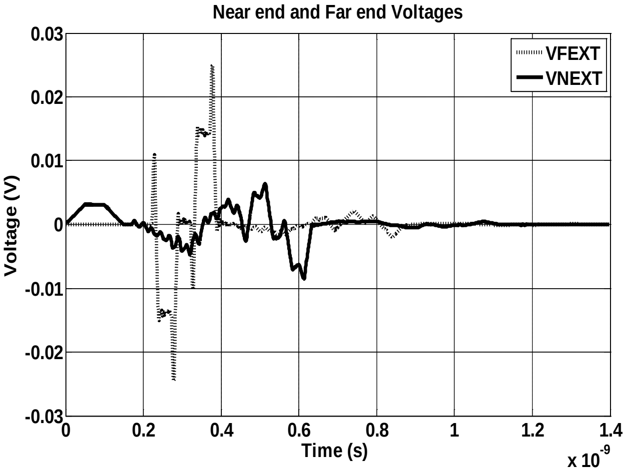

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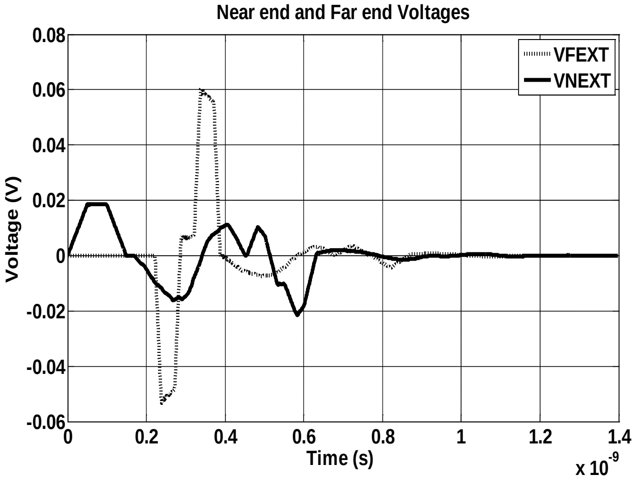

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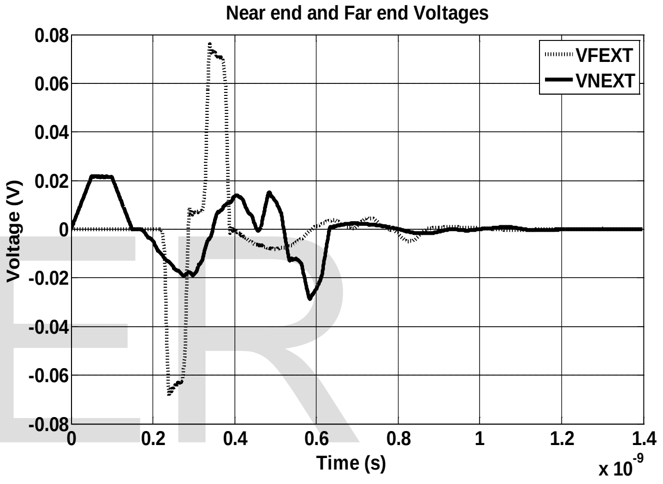

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Fig4 .The V_{NEXT} and V_{FEXT} voltages of the victim trace. (a) V_{NEXT} and V_{FEXT} voltages with V_{s1} disabled (V_{s1} =0). (b) V_{NEXT} and V_{FEXT} voltages with V_{s2} disabled (V_{s2} =0). (c) V_{NEXT} and V_{FEXT} voltages with the two excitations enabled (V_{s2}=1V and V_{s1}=1V).

Fig.4 presents the first simulation resalts obtained with one excitation source (Vs_2=0 or Vs_1=0) and two excitation sources (Vs_2=1V and Vs_1=1V) cases. It can be shown, that there is a close relationship between the two cases under study. In fact, the near end and the far end crosstalk voltages when considering two pulses simultaneously are increased. That is, the overall crosstalk level represents obviously the sum of the individual crosstalk voltage levels. The crosstalk magnitude is decreased by eliminating the pulse applied to the trace1 or trace2 (Vs_2=0 or Vs_1=0). Thus, by analysing the computed results, we prove that the reduction of the crosstalk magnitude is mainly caused by the variation of the distance between the victim and aggressor traces.

4 NON UNIFORM TRANSMISSION LINE UNDER RANDOM EXCITATION WITH MULTIPLE PULSES

For high-speed electronics, crosstalk is one of the main concerns for reduction of electromagnetic interference. Along a

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multiconductor transmission line system, the transfer of data causes inevitably electromagnetic coupling between conductors leading to crosstalk voltages. The transfer is generally performed by a code according to a random law.

In order to address this issue, we consider a non uniform three-conductor transmission line system excited randomly by multiple pulses. We are limited to the case of transmitting two bits, each on different trace. For better understanding of the phenomenon, we choose two probability density functions PDF, normal and uniform. The circuit under study is the same as that in section 3 with two aggressors and one victim (Fig.3). The crosstalk level depends strongly on the random occurrence and the amplitude of the two pulses. The two bits have random occurrences governed by normal (Gaussian) and uniform distributions. The corresponding pulses can be both synchronized and unsynchronized.

4.1 Normal Distribution

Normal distribution is by far the most important and fascinating continuous two parameter probability distribution. The bell shaped curve of Fig.5, called the normal curve, is a graph of the probability density function of the normal distribution. We first consider two pulses with random occurrences governed by the normal distribution. We also use the same simulation parameters as those of the deterministic case. Next, we assume that the mean of the normal distribution, μ is set equal to 0.5 and the standard deviation,σ is 0.128. Therefore, the Gaussian density function will have its peak at 0.513; the normal curve is illustrated by Fig.5. The probabilities of pulses occurrence cover all the area under the PDF curve. That is, the probability of a sources couple (V_{S1}, V_{S2}) happening depends on the corresponding interval of the PDF as defined in Fig.5.

Excitation couples (V_{S1}, V_{S2}) are chosen with respect the peak of the Gaussian density function. Knowing the practical aspect, the unsynchronized pulses occurrences are the most probable cases to take place. The combinations of the synchronized and unsynchronized pulses possibilities, representing logic "1" and logic "0", are also illustrated by Fig.5.

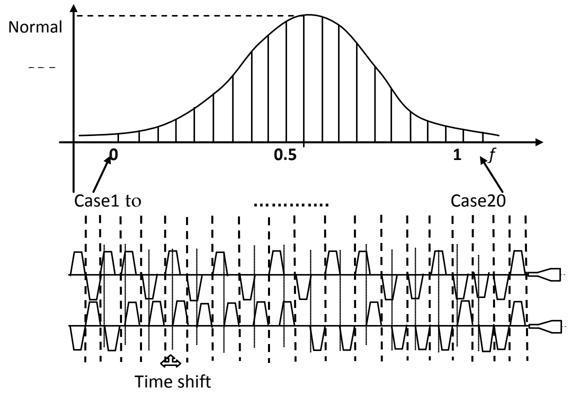

Fig5 . The.The normal curve and synchronized and unsynchronized pulses possibilities

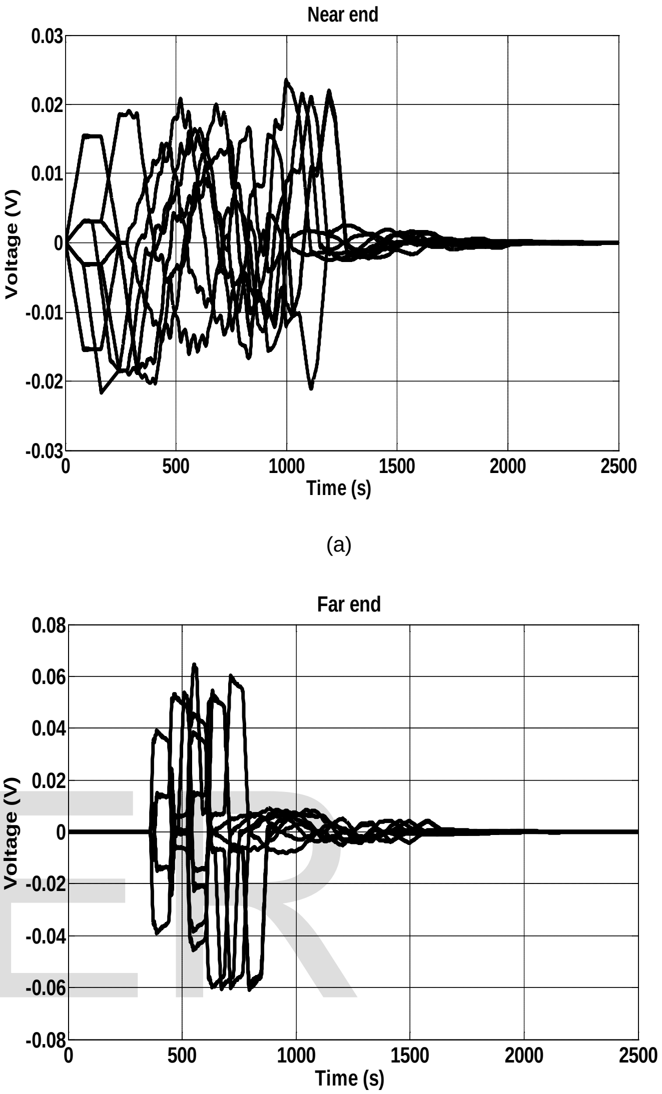

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Fig6 . The near end and the far end crosstalk voltages. (a) Near end crosstalk voltage for 3000 simulations. (b) Far end crosstalk voltage for 3000 simulations.

It can be shown, after running a set of simulations, that there are several responses depending on the injection of excitation sources. Thus, it is of interest to note that both near end and far end crosstalk voltages reach maximum and minimum levels at different instants. That is, the near end and far end crosstalk levels present maximum values at 1000 ns and 552 ns, and minimum values at 1658 ns and 1577 ns respectively. Fig.7 and Fig.8 show the histograms illustrating the number of occurrences of the maximum and the minimum values of the near end and the far end crosstalk voltages at the relevant times.

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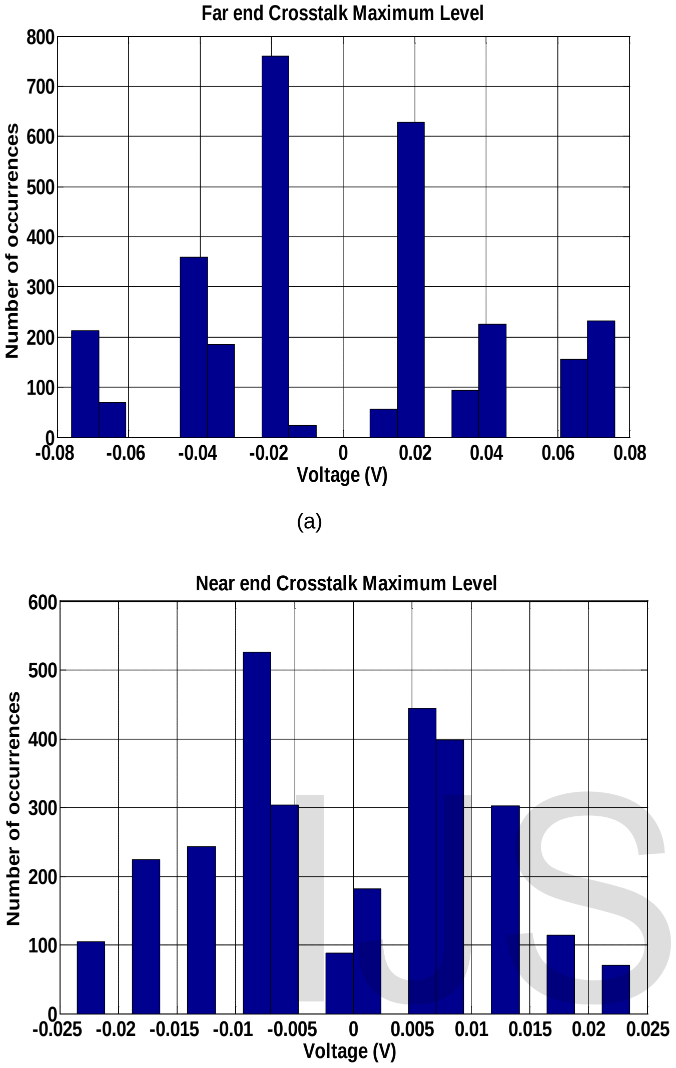

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Fig7 . The histograms of the maximum values of the near end and the far end crosstalk voltages. (a) Histogram of V_{FEXT} crosstalk for 3000 simulations at t = 552ns. (b) Histogram of V_{NEXT} crosstalk for 3000 simulations at t = 1000ns.

According to the two histograms shown in Fig.7, we can see that the number of occurrences of the maximum level follows a bell-shaped curve closely, but not perfectly with the highest number of occurrences of the crosstalk voltages happening in the middle and gradually tapering toward the extremes.

As illustrated by Fig.8, the graphical distribution of the number of occurrences related to the far end crosstalk voltage is described as bell-shaped curve, the highest point in the curve, which is the most probable event stands for the favorite case of crosstalk voltage values. On the other hand we see that the worst case values of the near end and the far end crosstalk are far less likely than the favorite case.

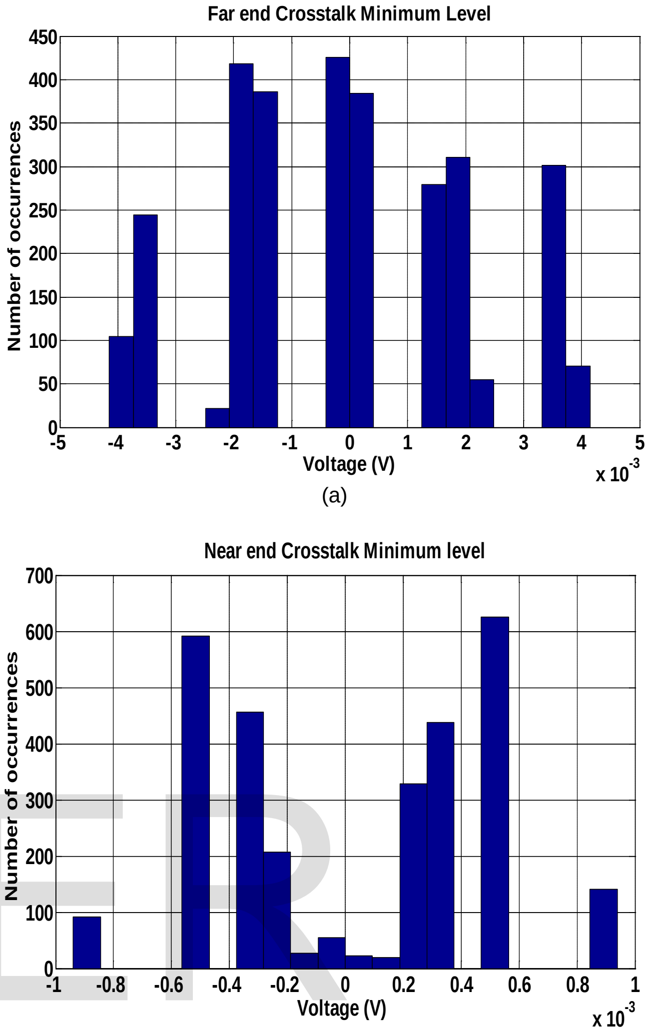

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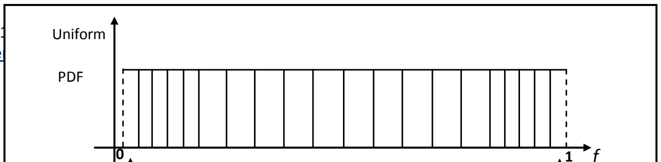
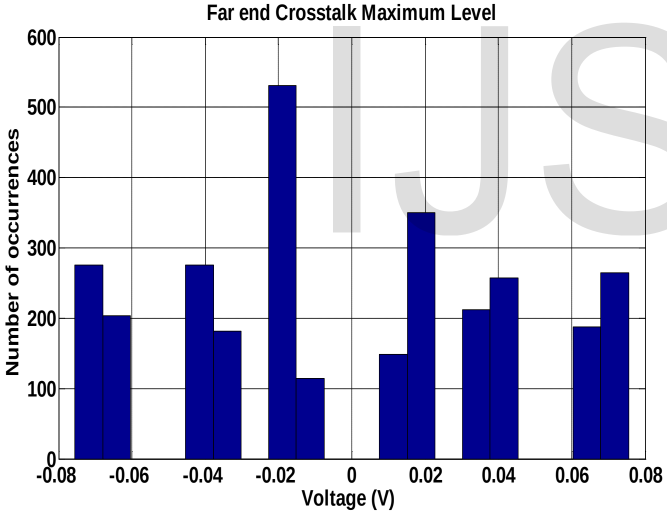
Fig8 . The histograms of the minimum values of the near end and the far end crosstalk voltages. (a) Histogram of V_{FEXT} crosstalk for 3000 simulations at t=1577ns. (b) Histogram of V_{NEXT} crosstalk for 3000 simulations at t = 1658ns.

4.1 Normal Distribution

As well known, the uniform distribution is sometimes referred to as the distribution of little information, due to the fact that identical intervals of the uniform PDF lead to equiprobable events. So, for more uncertainties we consider the same transmission line excited with time shifted pulses according to non equiprobable occurrences. That is, the curve is divided in to several intervals with different lengths Fig.9. This fact can be achieved by considering different source couples having synchronized and unsynchronized pulses as shown in Fig.9. In addition, the excitation couples (V_{S1}, V_{S2}) are randomly and independently chosen with non equiprobable occurrences according to the uniform distribution (case1 to case 20 Fig.9). The unsynchronized pulses occurrences are most probable.



As well expected, the time domain responses with respect to the far and near ends crosstalk are the same as those presented in Fig.6. The near end and far end crosstalk amplitudes present maximum levels at 1000 ns and 552 ns, and minimum level at 1658 ns and 1577 ns respectively. We carried out 3000 time domain simulations to achieve another statistical study based on the maximum and minimum level histograms at the mentioned instants.



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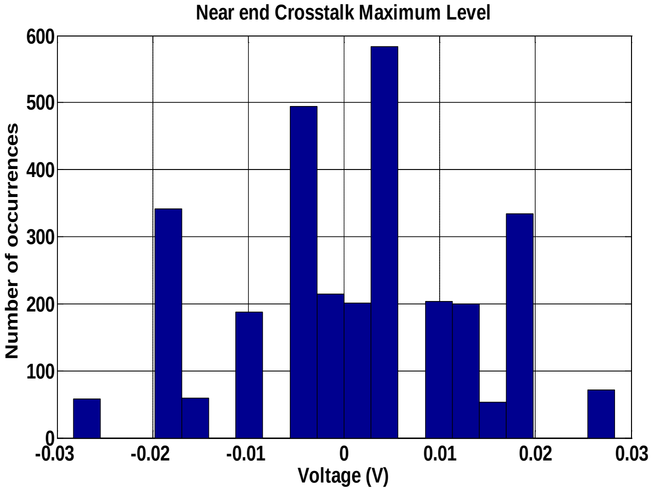

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Fig10 . The histograms of the maximum values of the near end and the far end crosstalk voltages. (a) Histogram of V_{FEXT} crosstalk for 3000 simulations at t=552ns. (b) Histogram of V_{NEXT} crosstalk for 3000 simulations at t = 1000ns.

From Fig.10, the far end crosstalk voltage presents almost the same number of occurrences of the maximum level with different values, ranging from -0.08 V to 0.08 V. On the other hand, the favourite case values of the near end crosstalk are likely to take place more repeatedly than the worst case values.

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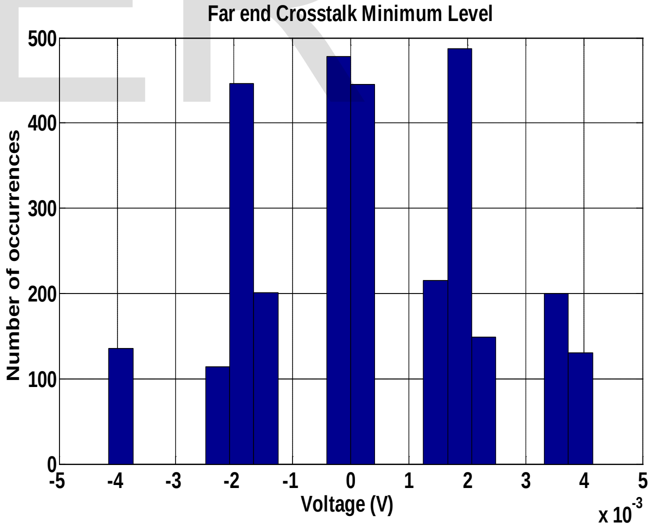

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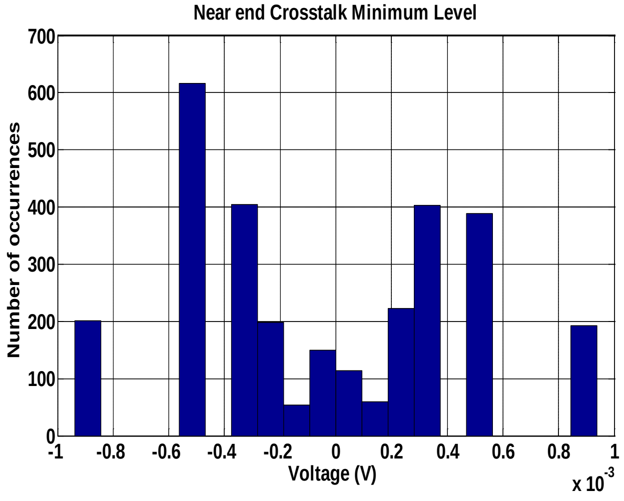

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Fig11 . The histograms of the minimum values of the near end and the far end crosstalk voltages. (a) Histogram of V_{FEXT} crosstalk for 3000 simulations at t=1577ns. (b) Histogram of V_{NEXT} crosstalk for 3000 simulations at t = 1658s.

As can be seen in Fig.11 the favourite case of the far end crosstalk occurrences represent the most probable event. On the other hand, there is an increase in the number of occurrences of the worst cases. Contrary to the maximum level of near end crosstalk, the favourite case values are likely to take place more often than the others.

5 COMPARISON AND DISCUSSION

The comparisons were performed in all of the previous cases, indicate major differences and similarities. The maximum and the minimum levels of crosstalk voltages are compared with respect to the number of occurrences in order to illustrate the influence of random multi excitations.

We can now draw some conclusions from the probability density functions (PDF) uniform and normal distribution. The number of occurrences of the worst case values of the near end and the far end crosstalk are far less likely to happen than the favorite case ones. This aspect illustrates the advantages of non uniform lines.

6 CONCLUSION

MTL equations using the finite difference time domain FDTD algorithm have been developed to perform a statistical evaluation of crosstalk between non uniform interconnection structures with multiple pulses. A non uniform three-conductor transmission line system with two aggressors and one victim has been analyzed by dealing with several cases related to the occurrences of injected sources in order to simulate real behaviour. The non uniform transmission line has been divided into several uniform sections of different cross sections. So, non uniform lines can be considered as a coupled multi-conductor transmission line. However, the non uniform transmission line circuit has been excited randomly with two pulses according to two statistical laws normal (or Gaussian) distribution and uniform distribution. The excitations can be both synchronized and unsynchronized and it has been injected with non equiprobable occurrences for the uniform law. The statistical analysis has led to several histograms representing the number of occurrences of the crosstalk maximum and minimum level at both near and far ends of the victim trace. The crosstalk variation in the case of more than one aggressor for the non uniform interconnection structures has been yielded great deal of useful knowledge.

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