An asymmetrical microstrip SPICE model for crosstalk evolution

N. Tidjani, J. C. Le Bunetel, A. Ouchar

Abstract—In this work, an asymmetrical microstrip SPICE model for crosstalk evolution used in telecommunication sectors is presented. In a first part, we evaluate the per unit length parameters in coupled microstrip lines by mathematical model based on the method of moments. In a second part, predicting near-crosstalk and far-crosstalk are realized by a SPICE model. The model allows the study of the crosstalk evolution in function of physical parameters, and the electrical signal dynamic. Some curves are proposed in function of strip width, spacing, and electrical stress, which can help the designer in the conception for limiting the adverse effects of crosstalk.

Keywords—Crosstalk, NEXT, FEXT, method of moment, per unit length parameters.

I. Introduction

The industrial constraints evolution causes a break in the electronic cards design. Today, it is necessary that all of analog and digital functions are integrated on supports increasingly small and they have increased speed. However, these changes also lead to a degradation of signal quality and increased electromagnetic interference especially in PCB cards used in telecommunication sectors [1]-[3]. The electromagnetic interference such as crosstalk is a coupling between an aggressor line, and an adjacent line (victim). This could cause a failure or a degradation of the electrical system. The near-crosstalk (*NEXT)* is the voltage on the victim line next to the source, and the voltage at the other end is the far-crosstalk (*FEXT).* In this paper, an asymmetrical microstrip spice model for crosstalk evolution used in telecommunication sectors is presented. First of all, we need the knowledge of per unit length parameters for asymmetrical transmission lines. The extraction of per unit length parameters is performed by a mathematical model based on the method of moment (MoM) in *MATALB* routines. In second part to modeling the crosstalk between asymmetrical transmission lines, we developed a SPICE model based on per unit length parameters. The electrical model allows the estimation of the *NEXT* and the *FEXT*, between asymmetrical coupled transmission lines. The model allows the study of the crosstalk evolution in function of physical parameters, and the electrical signal dynamic. Some curves are proposed in function of strip width, spacing, and electrical stress, which can help the designer in the conception.

II. Extraction principal

We used the method of moment for the extraction of per unit length parameters, in the case of asymmetrical coupled transmission lines [4]-[7]. In the method of moments we use the pulse basic function, and divide each strip width in N section. We consider the charge distribution constant in each strip division, for estimating the total charge distribution on coupled transmission lines. The different steps of the extraction are resumed as follows [8]-[9]:

- First of all, we calculate the total charge distribution Q_0 in the absence of the substrate. For a unitary voltage, the expression of the capacitance matrix C_0 is given by (1) [10]-[12].
- From the propagation velocity expression we can find the inductance matrix expression by (2).
- Finally, we calculate the total charge distribution Q in the presence of the substrate. For a unitary voltage, the expression of the capacity matrix C is given by (3).
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$$Q_0 = C_0 V_0 \tag{1}$$

$$L = \mu_0 \varepsilon_0 {C_0}^{-1} \tag{2}$$

$$Q = C V_0 \tag{3}$$

III. Extraction validation

To validate the extraction model previously defined, a series of measurement were performed by the impedance analyzer 4294A. Fig 1 and Fig 2 illustrate a PCB card (PCB1), with two asymmetrical coupled transmission lines of length *l*, and a ground plane on the other side.

Table 1 summarizes the characteristics of PCB 1. In the case of asymmetrical coupled transmission lines, two scenarios facing us: scenario 1 and 2. In scenario 1, we consider the line 1 as the aggressor line, and line 2 as a victim line. In scenario 2 we consider the line 2 as the aggressor line, and line 1 as a victim line.

Fig 3 illustrates the electrical model of asymmetrical coupled transmission lines with the assumption of weak coupling [13]. That means in scenario 1, line 1 have effect on line 2, and the effect of line 2 on line 1 is negligible. Reciprocally we have the same effect when line 2 is the aggressor [14]-[17]. With C_{11} is the capacity of the line 1, C_{12} is the mutual capacitance

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from line 1 to line2. L_{11} is, the inductance of the line 1, L_{12} is the mutual inductance from line 1 to line 2.

Fig 1. PCB1's photography

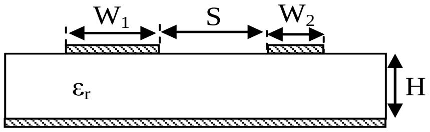

Fig 2. Asymmetrical microstrip

Table .1. The PCB1's characteristics

Line 1 width W_1	3 mm
Line 2 width W_2	1.5 mm
S	4 mm
H	1.5 mm
l	25 cm
ε_r	4.3

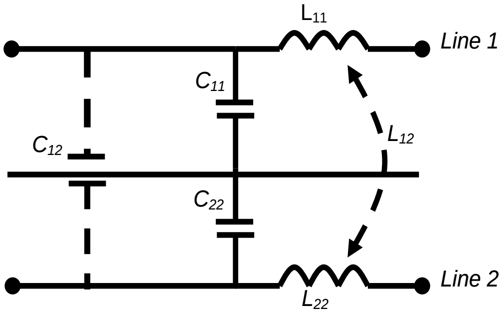

Fig 3. Electrical model of asymmetrical microstrip

A. Capacitance measurement

For the capacitance measurement C_{11}, the impedance analyzer probe is connected at the first connector of the line 1 via an adapter, and the other connector is open. Also for the capacitance measurement C_{22}, the impedance analyzer probe is connected at the connector of line 2 via an adapter, and the other connector is open.

B. Inductance measurement

For the inductance measurement L_{11}, the impedance analyzer probe is connected at the first connector of line 1 via an adapter, and the other connector is in short circuit. The expression of the inductance measurement L_{meas} is given by (4).

$$L_{meas} = L_{11} + L_{GND} \tag{4}$$

L_{GND}, is the ground plane inductance, which is measured by the impedance analyzer. Also for the inductance measurement L_{22}, the impedance analyzer probe is connected at the first connector of line 2 via an adapter, and the other connector is in short circuit.

C. Mutual inductance measurement

To measure the mutual inductance L_{12}, we proceeded at two measurements in PCB 1. At first we put the analyzer probe in port 1, connect port 2 to port 3 with a cable, and port 4 in short circuit. The expression of inductance measurement L_{meas1} is given by (5). L_{cable} is the cable inductance. In the second step we connect port 2 to port 4, with the same cable used in the first measure, and port 3 in short circuit. The expression of inductance measurement L_{meas2} is given by (6). Finally, the mutual inductance expression is given by (7).

$$L_{meas1} = L_{11} + L_{22} - 2\,L_{12} + L_{GND} + L_{cable} \tag{5}$$

$$L_{meas2} = L_{11} + L_{22} + 2\,L_{12} + L_{GND} + L_{cable} \tag{6}$$

$$L_{12} = \left(L_{meas2} - L_{meas1}\right)\big/4l \tag{7}$$

D. Mutual capacitance measurement

The mutual capacitance C_{12} measurement requires using a special probe in point. We put the probe directly on the coupled asymmetrical microstrip, with all connectors open. The mutual capacitance expression is given by (8).

$$C_{12} = \left(C_{meas} - \frac{C_{11}C_{22}}{C_{11}+C_{22}}\right)\Big/l \tag{8}$$

E. Results

We have proceeded at measurements, for the total evaluation of parameters per unit length, of asymmetrical coupled microstrip. Table 2 and table 3 illustrate the results obtained from a mathematical model, and the measurement for both scenarios. The obtained results show a good agreement, with an error from 0.21% to 4.5%.

Table .2. Parameters per unit length of two asymmetrical microstrip lines for scenario 1

	MoM	Measure
L_{11} (nH/m)	75.87	76.26
L_{12} (nH/m)	4.41	4.47
L_{22} (nH/m)	107.7	110.56
C_{11} (pF/m)	34.3	34.2
C_{12} (pF/m)	0.46	0.44
C_{22} (pF/m)	23.05	23.1

Table .3. Parameters per unit length of two asymmetrical microstrip lines for scenario 2

	MoM	Measure
L_{11} (nH/m)	107.7	110.56
L_{12} (nH/m)	7.9549	7.11
L_{22} (nH/m)	75.87	76.26
C_{11} (pF/m)	23.05	23.1
C_{12} (pF/m)	0.58016	0.65
C_{22} (pF/m)	34.3	34.2

IV. ELECTRICAL MODEL OF ASYMMETRICAL COUPLED TRANSMISSION LINES

The extracted parameters based on the method of moments are introduced into an SPICE model, illustrated in Fig 2.
A *Matlab* routine was developed for the determination of parameters per unit length in function of physical parameters (strip width, spacing, and substrate).
This model will be used to study the crosstalk by calculating the *NEXT* and the *FEXT* in function of physical parameters, and also the rise time of the input signal.
This study will allow us to find the optimal distance of tolerance, for limiting the crosstalk effects.

A. Electrical model validation

To validate the electrical model, a series of measurement were performed for the *NEXT* (Fig 4), and the *FEXT* (Fig 5) in *PCB1*, and compared at the model results. We applied a pulse input signal at port 1 of *PCB1*. Port 2 is loaded with a matched load. The measurement of the *NEXT* and the *FEXT* are made from port 3 and port 4.
Fig 6 and Fig 7 show a good reproduction of the phenomenon of electromagnetic coupling by the electric model. This model will allow studying the crosstalk by reducing the number of experimental measurements.

B. Spacing influence on crosstalk

As a function of the spacing between asymmetrical microstrip, we studied the influence of the strip width on the crosstalk. The calculation of per unit length parameters was performed for 12 spacing values, and for three cases of strip widths:

- Case 1: $W_1=1mm$, $W_2=1.5mm$
- Case 2: $W_1=1.5mm$, $W_2=2mm$
- Case 3: $W_1=2.5mm$, $W_2=3mm$

Fig. 8, and Fig. 9, show respectively the *NEXT* and the *FEXT* depending on the spacing between asymmetrical microstrip lines, for three fixed strip widths. We observe that the *NEXT* and the *FEXT* decreases exponentially with the increase of the spacing between the coupled transmission lines. Also increasing the width of the strip reduces the crosstalk

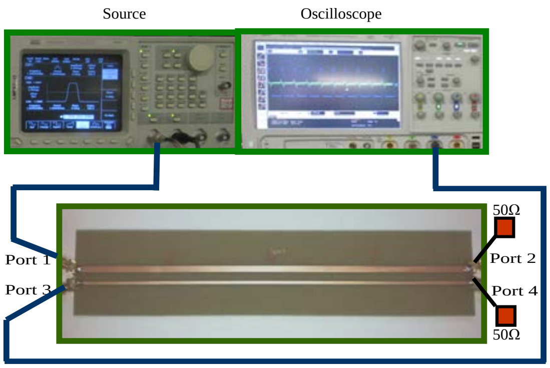

Fig 4.NEXT measurement

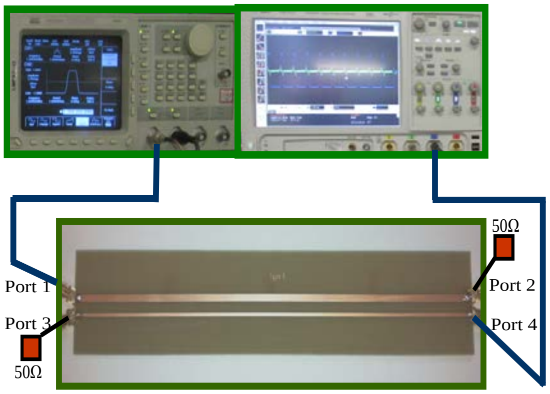

Fig 5. FEXT measurement

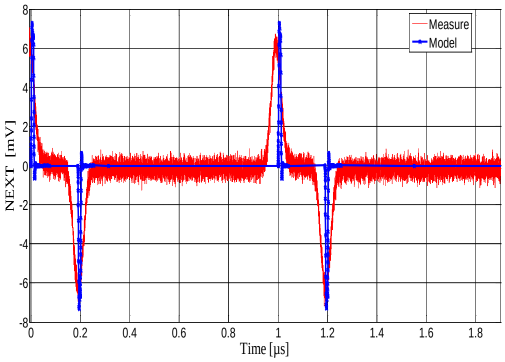

Fig 6. NEXT by model and measurement

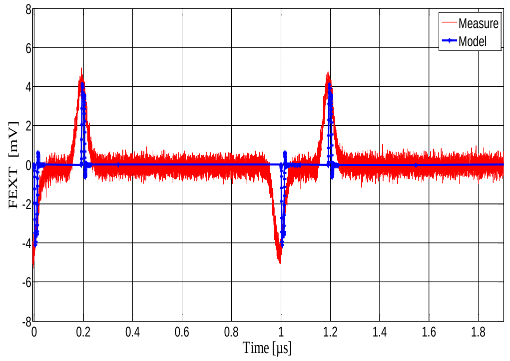

Fig 7. FEXT by model and measurement

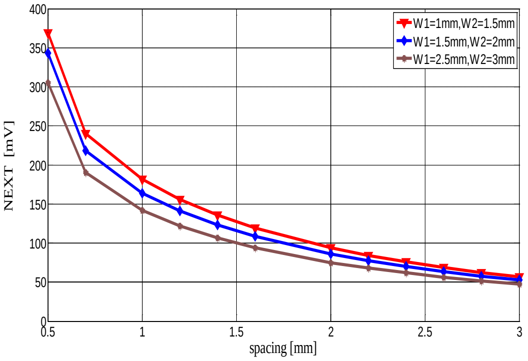

Fig 8. NEXT as a function of the spacing for different strips width

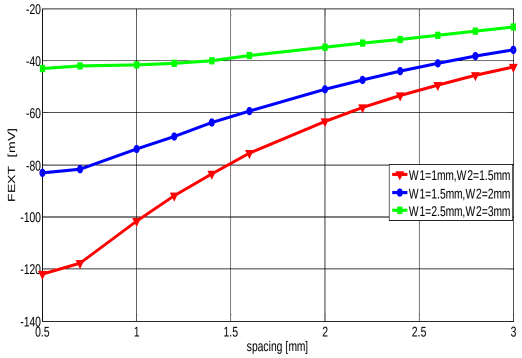

Fig 9. FEXT as a function of the spacing for different strips width

C. Influence of lines length on crosstalk

We studied the influence of the length of coupled transmission lines onto the crosstalk. The calculation per unit length parameters was applied for 12 spacing values, and for three configurations of lines length (*l=5 cm, l= 20 cm, l=50 cm*). For each model, we have taken the peaks of voltages for the *NEXT* and the *FEXT*. Fig. 10, and Fig. 11, illustrate the variation of the peaks of the *NEXT* and the *FEXT* in function of the spacing for different line length. We observe that the *NEXT* and the *FEXT* decreases exponentially with the increase of the spacing between the coupled transmission lines.

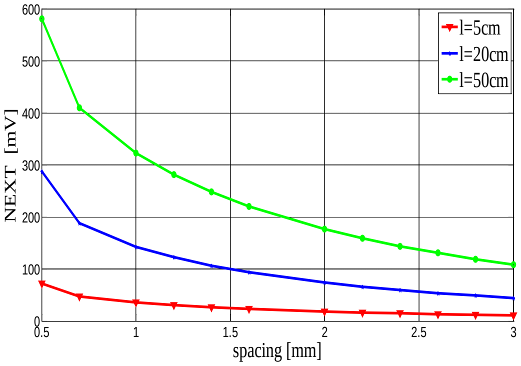

Fig 10. NEXT as a function of the spacing for different line length

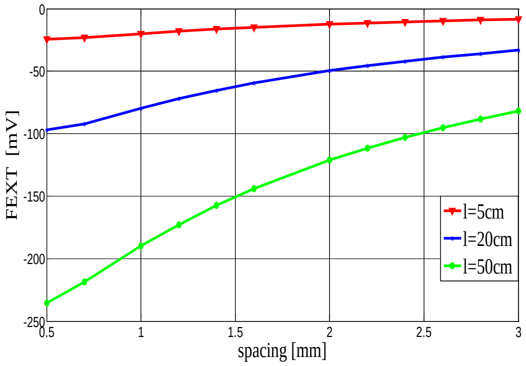

Fig 11. FEXT as a function of the spacing for different line length

D. The electrical signal dynamic influence

Another important factor to take into account is the dynamic of the electrical signal. We studied the influence of the time variation of an input signal depending on the spacing between two microstrips. The calculation per unit length parameters was applied for 12 spacing values, and for three configurations:

- Case 1: $W_1=1mm$, $W_2=1.5mm$, $t_r=5ns$
- Case 2: $W_1=1mm$, $W_2=1.5mm$, $t_r=10ns$
- Case 3: $W_1=1mm$, $W_2=1.5mm$, $t_r=15ns$

For each model, we have taken the peaks of voltages for the *NEXT* and the *FEXT*. Fig. 12, and Fig. 13, illustrate the variation of the peaks of the *NEXT* and the *FEXT* in function of the spacing for different rise time. We can see that the influence of the rise time is not linear. For example, for a spacing of *0.5mm* the *NEXT* changes from *587 mV* at t_r=5ns to *368 mV* at t_r=10ns. This amplitude is not negligible and can seriously disrupt the functioning of the victim line. The knowledge of this parameter is important at the moment of conception.

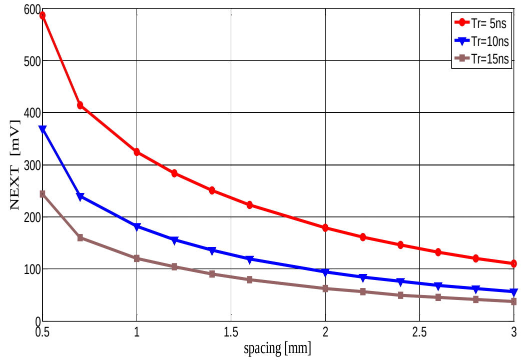

Fig 12. NEXT in function of the spacing for different rise time

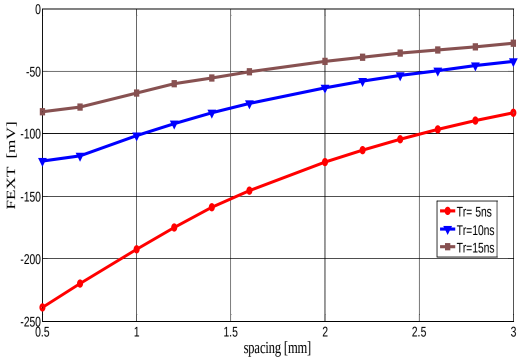

Fig 13. FEXT in function of the spacing for different rise time

V. CONCLUSION

In this work an asymmetrical coupled microstrip transmission lines SPICE model for crosstalk evolution used in telecommunication sectors is presented. The study of the crosstalk requires knowledge of per unit length parameters and coupling coefficients between coupled transmission lines, the extraction of per unit length parameters is performed by the method of moments. To model the electromagnetic couplings between coupled transmission lines, we developed a model based on electrical parameters of the per unit length extracted by the method of moments. This model allowed us the estimation of the *NEXT* and the *FEXT* between asymmetrical transmission lines used in telecommunication systems and show the influence of physical parameters. The crosstalk collected can be very harmful, in our application; by increasing the spacing of *0.5mm* we can divide by two the crosstalk. By adjusting the physical parameters, and the dynamic of the input signal we can reduce the influence of the crosstalk by more than 90%, and it becomes less problematic for components and systems close to telecommunication systems. This work will create curves that will help the designer in the choice of strip width and spacing as a function of electrical stress in the accepted specifications.

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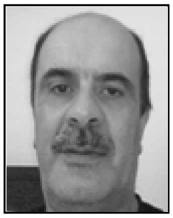

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