ON THE CHARACTERIZATION AND MEASUREMENT OF INDUCED CROSSTALK IN MICROSTRIP LINES: A TWO LINE, 50 Ω, 1 m CASE OF STUDY

V. González, J. Martos, E. Sanchis, J. Soret, G. Torralba, J. Torres, A. Valero
Department of Electronic Engineering, University of Valencia
E-mail: vicente.gonzalez@uv.es

Abstract: This paper presents the characterization, simulation and measurement of crosstalk in microstrip lines. In particular we have studied a case where two 50 Ω microstrip lines run in parallel for 1 m. We are particularly interested in observing the effect of mismatching in the near and far end crosstalk.
Key words: Microstrip line, near-end crosstalk, far-end crosstalk, mismatched loads, mismatched reflection crosstalk.

1. Introduction

Crosstalk appears in a circuit whenever two or more lines are sufficiently close to each other so the electromagnetic field of one line induces currents and voltages in the other due to Faraday and Ampere laws.

This coupling depends on the signal on the aggressor line, the running length, the rise time and the geometry of the lines.

As it is well known, there are two types of coupling, capacitive and inductive, which lead to two types of crosstalk depending on where it is observed. The signal seen on the victim line close to the driver is the near-end crosstalk while the one observed on the opposite point on the victim line is the far-end crosstalk.

In this paper we are especially interested in observing the effects on the near and far end crosstalk caused by the mismatching of the aggressor or victim line. As a case of study we have prepared a setup consisting of two 50 Ω microstrip lines running 1 m in parallel, terminated with variable resistors. This setup allowed us to measure the near-end and far-end crosstalk under different situations of rise time, voltage level and mismatching degree. The results could be used in high speed digital design where these effects could lead to the violation of the logic noise margins.

2. Principles

Near and far end crosstalk are due to inductive and capacitive coupling which inject current and voltages from an aggressor line to a victim line. Figure 1 shows this basic mechanism.

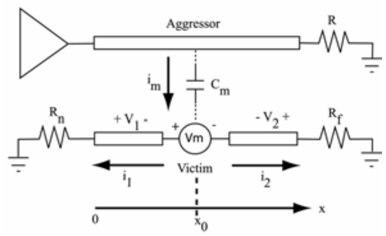

Figure 1. Near-end and far-end coupling mechanism.

The near and far end crosstalk voltage and coupling factors, K_n and K_f, are expressed in the following equations [1][2]:

$$V_f^{(0)}(x,t) = K_f \cdot x \cdot \frac{dV(x,t)}{dt}$$
$$V_n^{(0)}(x,t) = K_n \cdot \left(V(x,t) - V(2l - x,t)\right)$$
$$K_f = -\frac{1}{2}\left(\frac{L_m}{Z_0} - C_m \cdot Z_0\right) \qquad (1)$$
$$K_n = \frac{1}{4t_p}\left(\frac{L_m}{Z_0} + C_m \cdot Z_0\right)$$

The far-end crosstalk appears as a pulse of duration equal to the rise time of the signal applied to the aggressor line. The near-end crosstalk, on the other hand, has a square pulse like shape of duration twice the propagation delay if the rise time of the signal is less than this propagation delay (saturated case). If this last condition is not met, the shape of the near-end pulse approaches a pulse similar to the far-end crosstalk one.

3. Crosstalk in mismatched lines

The well known equations showed above need to be readjusted in case mismatching is present in one or both of the lines. In this sense we may consider the following situations:

- Mismatched aggressor and matched victim
- Matched aggressor and mismatched victim
- Mismatched aggressor and victim

Qualitatively we may explain what we expect the system to behave in each one of the previous situations.

3.1. Mismatched aggressor and matched victim

In this case the basic coupling mechanism applies until reflection occurs at the end of the aggressor line. This reflection will couple again onto the victim line, increasing or decreasing the coupling depending on the reflection coefficient (Γ).

The equations for this second coupling are:

$$V_f^{(2)}(x,t) = K_f \cdot x \cdot \frac{dV_R(x,t)}{dt}$$
$$V_n^{(2)}(x,t) = K_n \cdot \left(V_R(x,t) - V_R(2l - x,t)\right) \quad (2)$$

where $V_R = \Gamma \cdot V$.

3.2. Matched aggressor and mismatched victim

This is a, somehow, more complicated case because now we have to take into account the reflections at both ends of the victim line. These reflections translate a far-end signal into a near-end signal perturbation and vice-versa. Besides, the reflection modifies the amplitude of the near-end and far-end pulses before the effects of the reflection at the other end appear.

At the far-end we will have a first coupled signal equal to the matched cases plus the reflection.

$$V_f^{(1)}(l,t) = V_f^{(0)}(l,t) \cdot (1 + \Gamma_{far-end}) \quad (3)$$

The reflection from the near-end also arrives at the far-end at the same time but with duration (if saturated) of twice the propagation delay (t_d).

$$V_f^{(1)}(l,t) = V_f^{(0)}(l,t) \cdot (1 + \Gamma_{far-end}) + V_n^{(0)}(0,t) \cdot \Gamma_{near-end} \quad (4)$$

At the near-end the situation is similar. In case of saturation the near-end pulse amplitude is affected by the reflection coefficient. This pulse is modified after two propagation delays by the reflected wave of the far-end crosstalk.

$$V_n^{(1)}(0,t) = V_n^{(0)}(0,t) \cdot \left(1 + \Gamma_{near-end}\right) \quad t < 2t_d \quad (5)$$
$$V_n^{(1)}(0,t) = V_n^{(0)}(0,t) \cdot \left(1 + \Gamma_{near-end}\right) + V_f^{(0)}(l,t) \cdot \Gamma_{far-end} \quad t > 2t_d$$

3.3. Mismatched aggressor and victim line

This is the most complicated situation as one may expect. The near-end and far-end crosstalk are affected by the reflection at their end, the second coupling due to reflection in the aggressor line and the near-end/far-end, reflections at the opposite ends.

We may distinguish the following phases:

- For $t < t_d$, there has been no reflection on the aggressor line yet, so the coupling follows the normal equations (1).
- For $t_d < t < 2t_d$, the far-end crosstalk in the victim line appears as a sum of the initial far-end pulse, its reflection at the far-end and the near-end effect of the reflection of the incident wave of the aggressor line; the near-end crosstalk in the victim line is only affected by the reflection coefficient at this end as expressed in equation (5a).

$$V_f^{(1)}(l,t) = V_f^{(0)}(l,t) \cdot \left(1 + \Gamma_{far-end}\right) + V_n^{(2)}(0,t) \cdot \left(1 + \Gamma_{far-end}\right) \quad (6)$$

- For $t>2t_d$, the near-end crosstalk on the victim line is modified by the effect of the reflection of the far-end crosstalk in the victim line and the arrival of the far-end crosstalk of the reflection on the aggressor line.

$$V_n^{(1)}(0,t) = V_n^{(0)}(0,t) \cdot \left(1 + \Gamma_{near-end}\right) + \left(V_f^{(0)}(l,t) + V_n^{(2)}(0,t)\right) \cdot \Gamma_{far-end} + V_f^{(2)}(l,t) \quad (7)$$

- For t>3td, the reflected near-end crosstalk in the victim line arrives at the far-end point affecting the far-end crosstalk.

The matching at the source in the aggressor line ends up with the reflection on this line. However, in the victim line, successive reflection will still occur, with less and less amplitude arriving each $2t_d$ at both ends.

4. Experimental setup

To measure the effect of mismatching in near and far end crosstalk we have built an experimental setup consisting of two parallel 1 m microstrip lines separated 3 mm center to center and 2 mm wide on a 1 mm thick PCB above a ground plane. Figure 2 show an image of the setup.

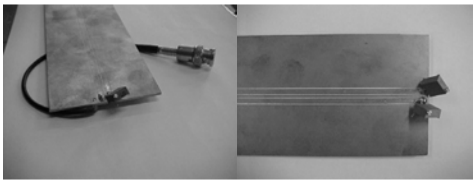

Figure 2. Source and load sides of the experimental setup.

We have used an Agilent 33250A signal generator and a Tektronics TDS 5104 1 GHz oscilloscope with 1 GHz probes to perform the measurements.

4.1. Microstrip characterization

The first measurements carried out where aimed to characterize the microstrip lines built. We measured the propagation delay getting 5.8 ns. The exact length of the PCB lines was 91.5 cm so we get a propagation delay of 63.4 ps/cm.

Using the relation between propagation delay in vacuum and in other media, we get the effective dielectric constant of our traces.

$$t_p = 33.3\sqrt{\varepsilon_{eff}} = 63.4 ps/cm \Rightarrow \varepsilon_{eff} = 3.62 \quad (8)$$

Because the trace width is bigger than the height above the ground plane, the effective dielectric constant is related to the relative one by the following equation[2]:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{12h}{w}}}\right) \quad (9)$$

Substituting, we get a dielectric constant of 4.809. This value allowed us to calculate the characteristic impedance of the traces:

$$Z_0 = \frac{87}{\sqrt{\varepsilon_r + 1.41}} \ln\left(\frac{5.98h}{0.8w + t}\right) = 45.99\Omega \quad (10)$$

We wanted to check this number with another procedure and we used the one suggested in [3]. With the expression proposed there for the effective dielectric constant and the characteristic impedance of microstrip lines we get $\varepsilon_{eff} = 3.68$ and $Z_0 = 46.5\Omega$, very close to what we have obtained.

With the values of t_p and Z_0, we deduced the distributed capacitance and inductance values of the line: C=1.38 pF/cm and L = 2.92 nH/cm.

The next step was the measurement of the coupling factors K_f and K_b. For this purpose we matched the aggressor and the victim line and measured the near-end and far-end crosstalk. We adjusted the signal generator for a pulse of 5 ns rise time (7.76 measured in the near-end of the aggressor line) and set different amplitude values, measuring the coupled voltages. The results where averaged getting K_b = 0,047 and K_f = -4.33 ps/cm.

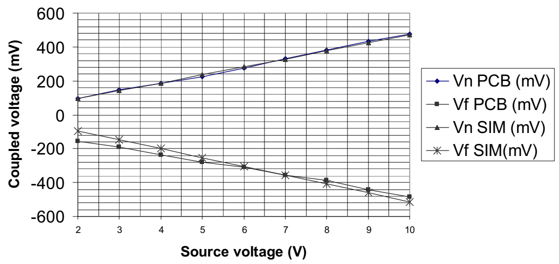

Figure 3. Simulated (SIM) and measured (PCB) near-end and far-end voltages with all lines matched.

From the values of K_b and K_f we deduced the mutual capacitance and inductance of our setup getting C_m = 35.4 fF/cm and L_m = 0.473 nH/cm.

The values of L, C, L_m and C_m let us model our setup for simulations in SPICE using the LC segment approach. In our case we used a 250 LC segments circuit for the simulation. Figure 3 shows the good agreement between the measured crosstalk voltages and the simulated ones.

4.2. Mismatched loads crosstalk measurements

All the situations studied were done for three voltage levels: 1.8 V, 3.3 V and 5V. The first situation studied was the effect of a mismatched aggressor line on the coupled near and far end voltages with a matched victim line. Figure 4 shows the results of voltage deviation in percent relative to the all-matched case in function of the aggressor load mismatch relative to Z_0

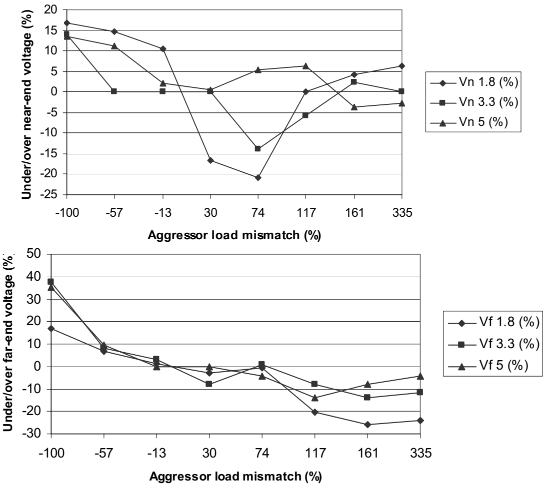

Figure 4. Over/under far-end and near-end voltages versus aggressor load mismatch with victim line matched.

The next studies comprised the mismatching of the aggressor line (25 Ω load) and the study of the variations in the near-end and far-end crosstalk. The first case was the study of effects of a mismatched near-end on the near-end and far-end crosstalk with the far end of the victim line matched. Figure 5 shows the results measured.

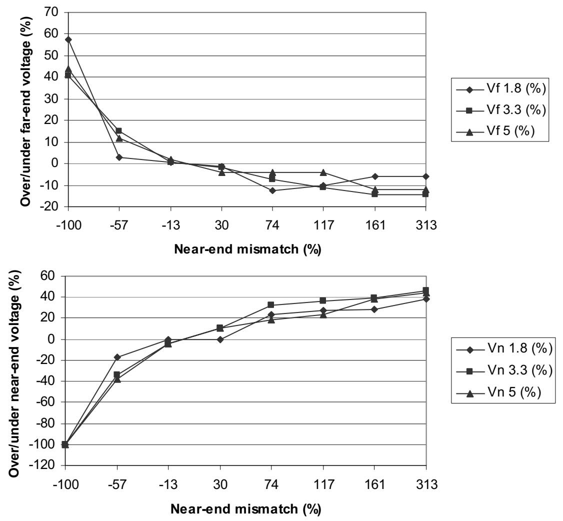

Figure 5. Voltage variation versus near-end mismatch in the victim line. Aggressor line mismatched (25 Ω).

The following graphics show the percentage voltage variation in the near-end and far-end crosstalk due to a mismatched far end termination in the victim line. As in the previous situation, the aggressor line was also mismatched.

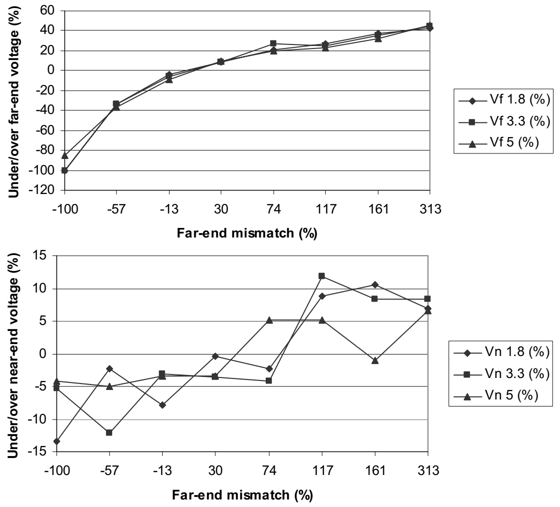

Figure 6. Voltage variation versus far-end mismatch in the victim line. Aggressor line mismatched (25 Ω).

Finally, it was also interesting observing the second peak in the near-end and far-end crosstalk produced by the coupling of the reflection of the signal in the aggressor line. Figure 7 shows the amplitude of this second peak relatively to the firs peak. In some cases, the voltage drop to zero but in other we have an over or under voltage with may cause problems.

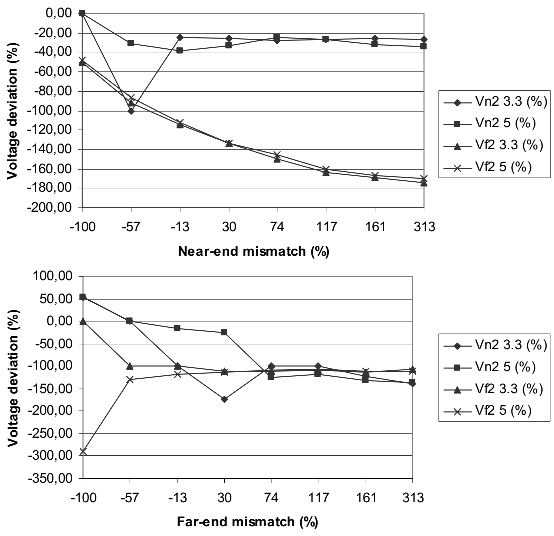

Figure 7. Second peak amplitude relative to first in near-end and far-end crosstalk

5. Discussion

As seen in figure 4, aggressor load mismatch produces a bigger dispersion in near-end crosstalk than in far-end crosstalk in a matched victim line. This could be explained by the arrival of the coupling of the reflected wave to the near end of the victim. On the other hand, the effect in the far-end crosstalk is clearly due to the near-end coupling of the reflected wave, observing the relation between the aggressor mismatch (sign of the reflection coefficient) and the sign of the far end crosstalk which is negative in absence of reflection. For a ±10% mismatch a variation of +2% to -20% in the near-end crosstalk and of 0% to -3% in far-end crosstalk is observed.

For figures 5 and 6 the explanation is more complicated as there is a mixture of effects: the aggressor signal reflected and the reflection on the near end or far end of the victim line. For near-end mismatch the voltage deviation is clearly linear with the mismatch for both near-end and far-end crosstalk. For far-end mismatch, this dependence is clearly seen for far-end crosstalk but not for near-end where a bigger dispersion appears. For a ±10% mismatch in the near-end termination, the far-end crosstalk varies between 0% and -10% while the near-end does it between 0% and +30%. For far-end mismatch of ±10% the far-end crosstalk varies between +10 and +30% and the near-end between ±5%.

For the second peak the ranges are bigger. For near-end mismatch they stay between -20% to -40% for near-end crosstalk and between -130% to -150% for far-end crosstalk. For far-end mismatch the ranges are: -70% to -120% for near-end crosstalk and -114% for far-end crosstalk. These values suggest looking carefully to second peaks for possible logic threshold violations.

6. Conclusions

A case of study for microstrip crosstalk measurements in mismatched situation has been presented. Simple equations have been derived for different cases and an experimental setup has been build to make real measurements.

Considering violation of noise margins at inputs, aggressor mismatch is not an issue as the variation is limited to -3%. This same mismatch added to a victim line mismatch rise the percentage to 30% in the worst case. This implies a reduction in the same amount of the noise margin of the system. For the second peak the situation is more unpredictable as its amplitude could be of opposite sign that the first peak. For far-end crosstalk the values are negative and bigger than 100 (-150% worst case) which implies a polarity change in the coupled signal.

These results show that care should be taken to analyze in detail termination mismatches for possible crosstalk increasing or even logic threshold violations.

References

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