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Minimization of Crosstalk in PCB

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***Abstract*: This paper describes the cross-talk problems in printed circuit board design. Some models consisting of multi-conductor PCB traces above a ground plane are taken. Theoretical analysis in time and frequency domains is carried out to obtain results for near-end and far-end cross-talks by using MATLAB. These results are compared with those obtained from modeling and simulation using Ansoft HFSS-12 software and experimental results. All the results are found in good agreement. The reduction techniques of cross-talk are highlighted.**
***Keywords:* Crosstalk, Multi-conductor PCB traces, near - end crosstalk, Far - end crosstalk, Micro-strip.**

I. INTRODUCTION

Crosstalk is an unwanted electromagnetic coupling from source trace to the victim trace in the printed circuit board. It occurs due to near-field / reactive field electromagnetic coupling between signal traces through mutual inductance and stray/mutual capacitance between two or more conducting traces. The cross-talk at a given terminal is calculated by the ratio of voltages between the said terminal and the input terminal, viz., V_i/V_1 , where i is the terminal at which the cross-talk is measured for input at terminal 1.

II. CROSSTALK ANALYSIS IN FREQUENCY AND TIME DOMAIN

For crosstalk analysis a microstrip configuration having two traces with equal widths w and separated by s are placed on a lossless dielectric substrate of thickness h, is considered as shown in Fig. 1. The substrate has a dielectric constant ε_r=4.4 and permeability μ_0. The ground plane and the traces are assumed to be perfectly conducting. All the traces are 50 ohm and matched terminated.

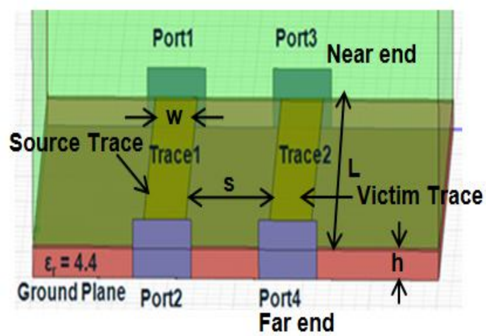

Fig. 1 PCB design describing Crosstalk

An electrically short length of PCB (i.e. line length much shorter than the minimum wavelength of interest, $l<\lambda/10$), can be modeled by the lumped equivalent circuit as shown in Figure 2.

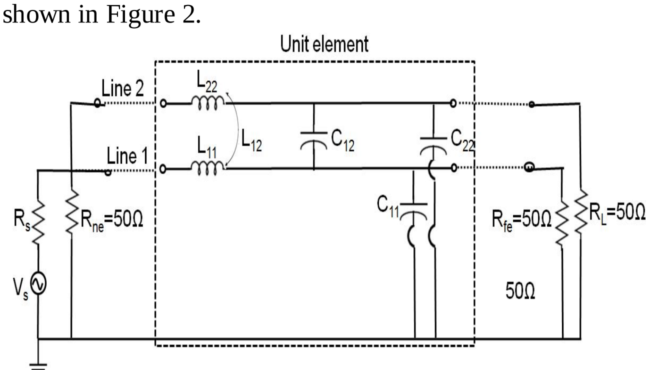

Fig. 2 Equivalent circuit of Crosstalk Model of PCB

In a homogeneous medium, if the traces or lines are weakly coupled and $l \ll \lambda$, the near and far end voltages are obtained from equations as [1]

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$$\frac{V_{ne}}{V_S} = j\omega\left(\frac{R_{ne}}{R_{ne}+R_{fe}} * \frac{L_{12}}{R_S+R_L} + \frac{R_{ne}R_{fe}}{R_{ne}+R_{fe}} * \frac{R_L C_{12}}{R_S+R_L}\right) \quad (1)$$

$$\frac{V_{ne}}{V_S} = j\omega\left(-\frac{R_{fe}}{R_{ne}+R_{fe}} * \frac{L_{12}}{R_S+R_L} + \frac{R_{ne}R_{fe}}{R_{ne}+R_{fe}} * \frac{R_L C_{12}}{R_S+R_L}\right) \quad (2)$$

Approximate solutions for electrically short, weak coupling, and at low frequencies, frequency domain solution can be used for time domain analysis by translating $j\omega$ term to $\frac{d}{dt}$

Then the time domain crosstalk voltages in the victim are expressed by

$$V_{ne}(t) = \left(\frac{R_{ne}}{R_{ne}+R_{fe}} * \frac{L_{12}}{R_S+R_L} + \frac{R_{ne}R_{fe}}{R_{ne}+R_{fe}} * \frac{R_L C_{12}}{R_S+R_L}\right)\frac{dV_S(t)}{dt} \quad (3)$$

$$V_{fe}(t) = \left(-\frac{R_{fe}}{R_{ne}+R_{fe}} * \frac{L_{12}}{R_S+R_L} + \frac{R_{ne}R_{fe}}{R_{ne}+R_{fe}} * \frac{R_L C_{12}}{R_S+R_L}\right)\frac{dV_S(t)}{dt} \quad (4)$$

Under the weak coupling assumption, the near-end crosstalk and the far-end crosstalk are obtained from above equations as [5]

$$V_{NE} = \frac{1}{4}\left(\frac{C_m}{C} + \frac{L_m}{L_S}\right)V_O \quad (5)$$

$$V_{FE} = \frac{\left(Z_O C_m - \frac{L_m}{Z_O}\right)l}{2t_r}V_O \quad (6)$$

From equations (3-6), the crosstalk voltages can be calculated from the knowledge of line parameters at a given frequency or at a given rise time of the pulse.

III.RESULTS

To determine the crosstalk due to RF pulses, a simple PCB structure is considered having copper plane on the bottom of the FR4 epoxy dielectric substrate having substrate height h = 1.6mm and two parallel traces are on the top of the substrate. The traces are 50 ohm and matched terminated. Therefore, $R_s, R_L, R_{ne}, R_{fe} = 50\Omega$. The thickness of the copper trace is assumed negligible(t = 0.001mm) and trace width w = 3.1mm. The spacing between two traces is considered as 6.2mm. Theoretical results of crosstalk in time domain are obtained by using MATLAB as shown in Fig. 3. Theoretical results of crosstalk in frequency domain are compared with those obtained from modeling and simulation using Ansoft HFFS-12 software agree well as shown in Fig 4 (a) and Fig. 4 (b). The experimental results are shown in Fig. 5 (a) and 5 (b). Some discrepancy observed in these results is because of various assumptions made in the theory and also due to non ideal situations in the experimental setups.

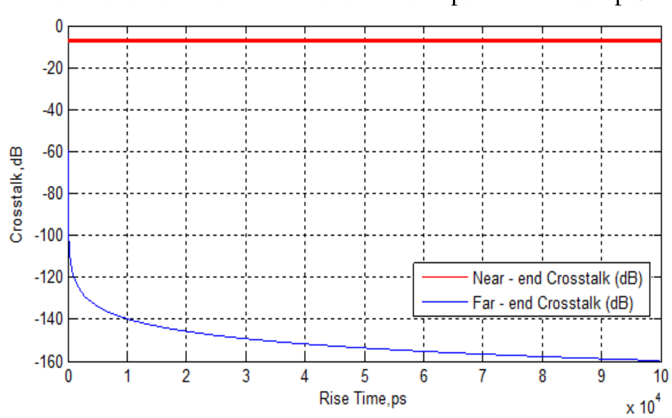

Fig. 3 Crosstalk in time domain obtained by using MATLAB

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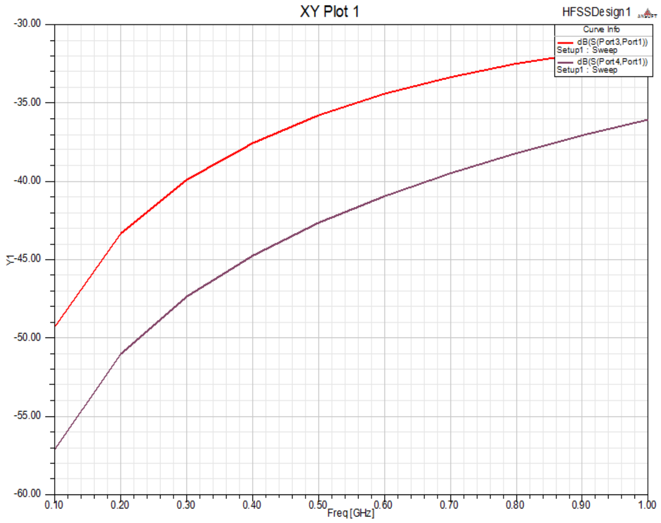


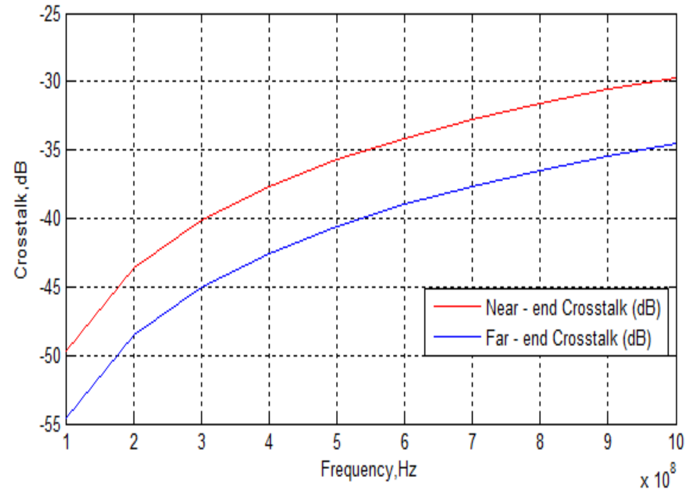
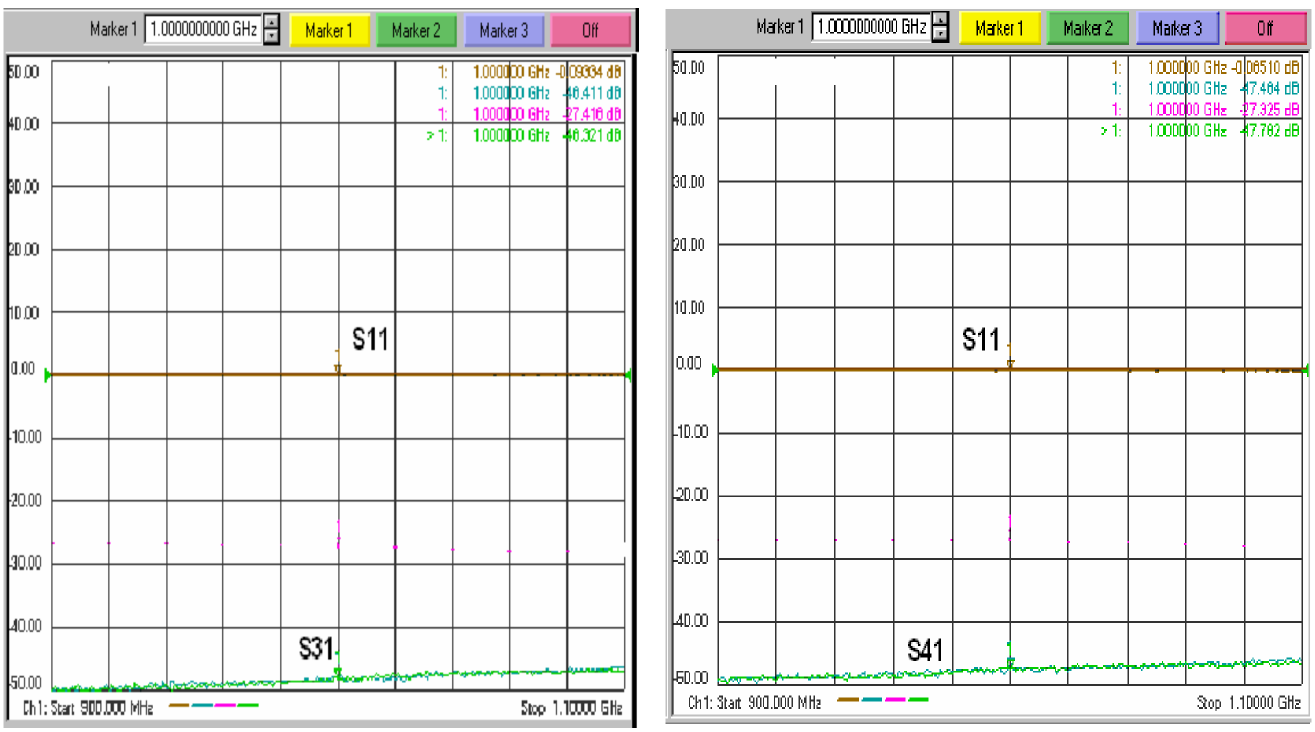


Fig. 4 (a) Crosstalk obtained by using HFSS   Fig. 4 (b) Crosstalk in frequency domain obtained by using MATLAB



(a) (b)

Fig. 5 Experimental results of Crosstalk Vs Frequencymm, h=1.6mm, εr=4.4)
(a) NEXT (b) FEXT

A PCB model was made with FR4 material having h = 1.6mm, trace width w = 3.1mm, , ground plane and trace thickness t = 0.001mm. The coupling length of the trace is considered as λ/10 with respect to 1GHz frequency. The spacing between the adjacent lines is varied as s = 6.2mm, 9.3mm and 12.4mm to determine the variation of the crosstalk. The theoretical results of crosstalk in time domain is obtained by using MATLAB as shown in Fig. 6. The results obtained by modeling and simulation using HFSS are given in Fig. 7 (a) and Fig. 7 (b). From the results it is concluded that increasing the spacing between traces causes reduced capacitive and inductive coupling and thus cross-talk.

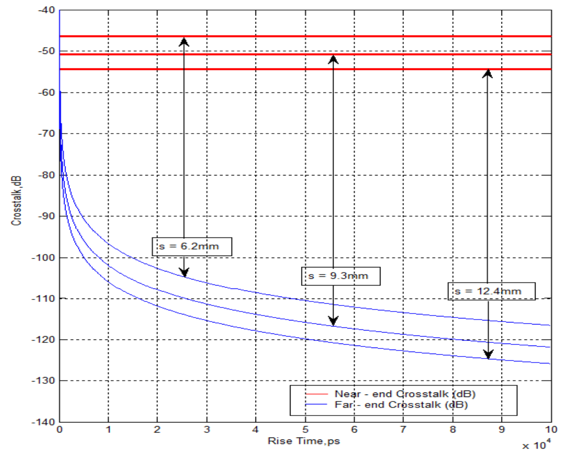
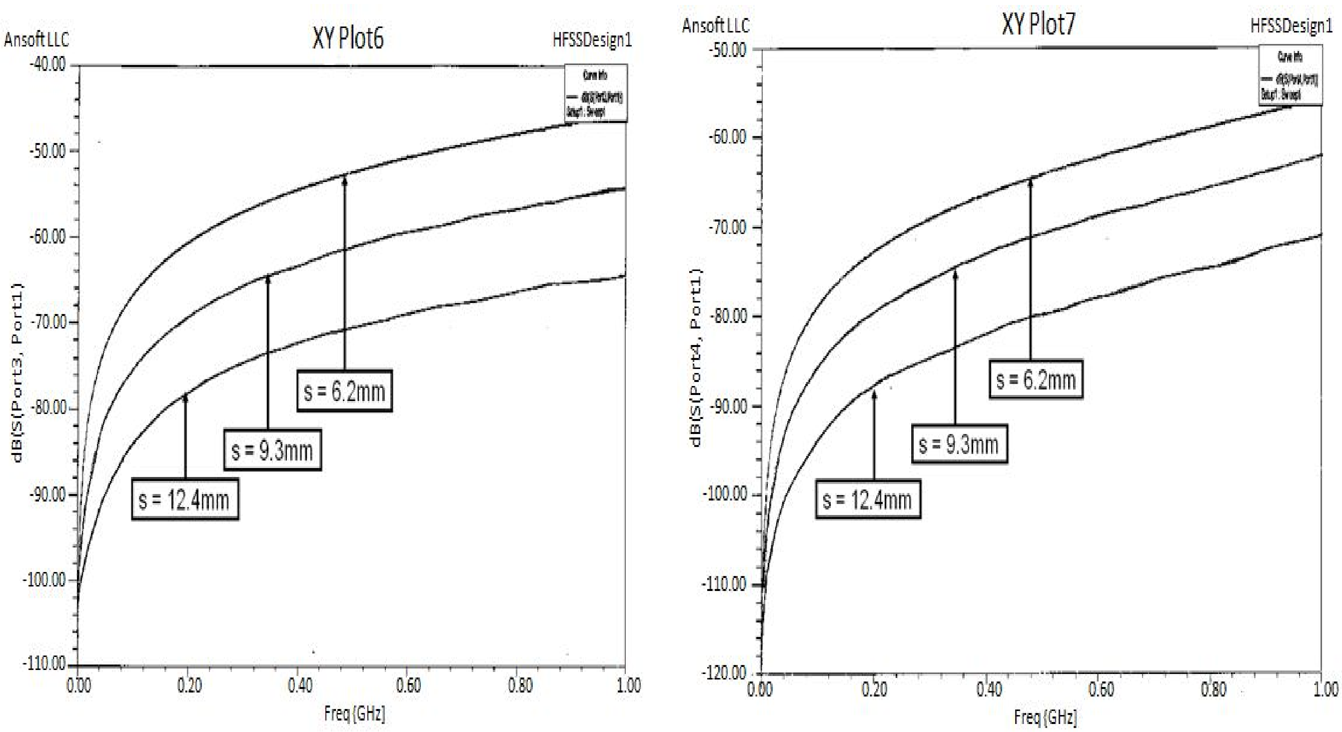


Fig. 6 Crosstalk for two traces having different spacing in between obtained by using MATLAB



(a) (b)

Fig. 7 Crosstalk two traces having different spacing in between obtained by using HFSS (source: presented by authors in National Conference------)

(a) NEXT (b) FEXT

To determine the variation of crosstalk with substrate thickness, another PCB model was made with all the parameters mentioned above except substrate height and spacing is considered as 6.2mm. The height h is varied as h = 1.6mm, 1.0mm and 0.5mm. The results of crosstalk in time domain are obtained by using MATLAB as shown in Fig. 8. The modeling and simulation results obtained by HFSS are given in Fig. 9 (a) and Fig. 9 (b). It is observed from the results that by decreasing the height of the dielectric material reduce fringing field coupling and thus cross-talk.

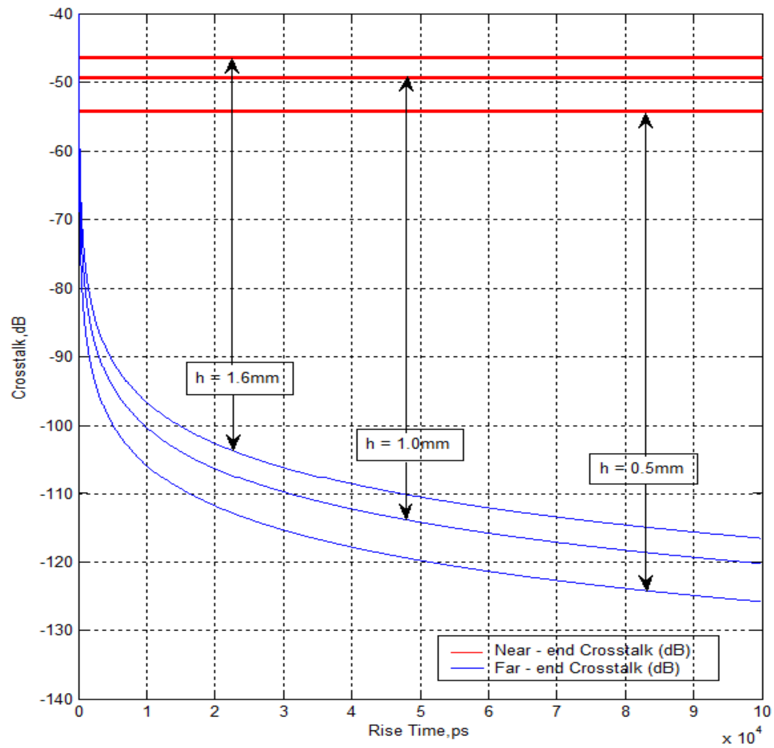
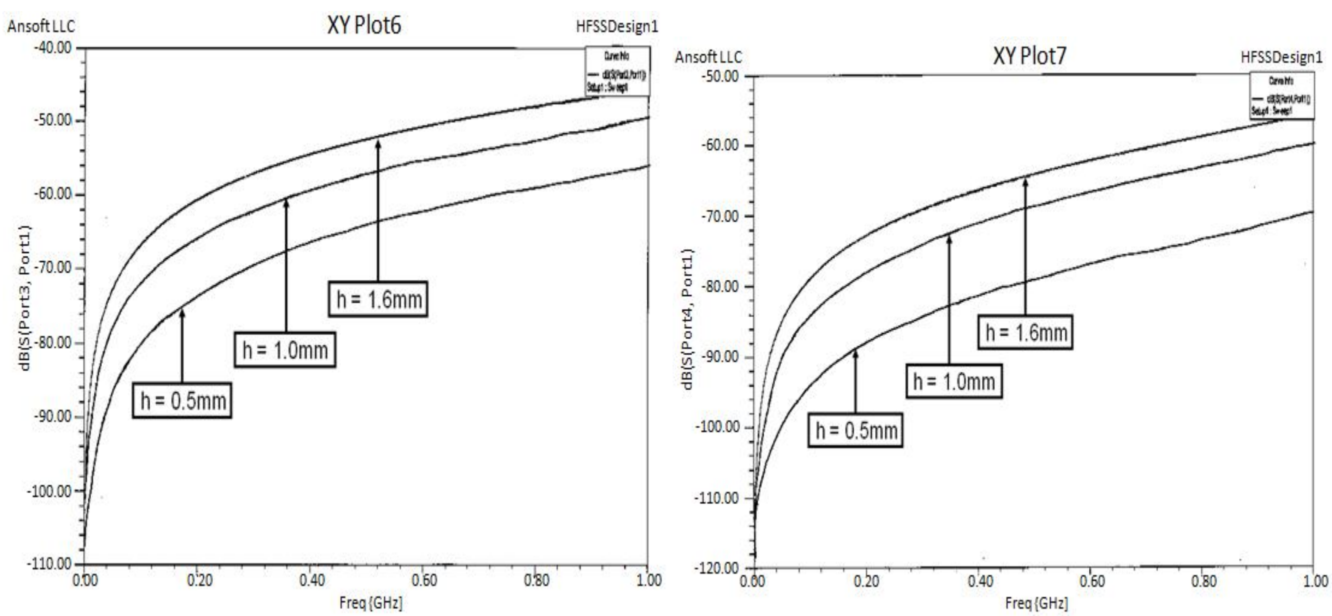


Fig. 8 Crosstalk for different dielectric height obtained by using MATLAB



(a) (b)

Fig. 9 Crosstalk for different dielectric height obtained by using HFSS
(a) NEXT (b) FEXT

Another PCB model was made with trace width w = 3.1mm, h = 1.6mm, t = 0.001mm, s = 6.2mm. The ε_r is varied as 2.2, 4.4 and 12. The results of crosstalk in time domain is obtained by using MATLAB and simulation results obtained by HFSS are shown in Fig. 10, Fig. 11 (a) and Fig. 11 (b). From the results it is found that by increasing the dielectric constant cross-talk reduces due to tightly binding of electric field between the trace and ground.

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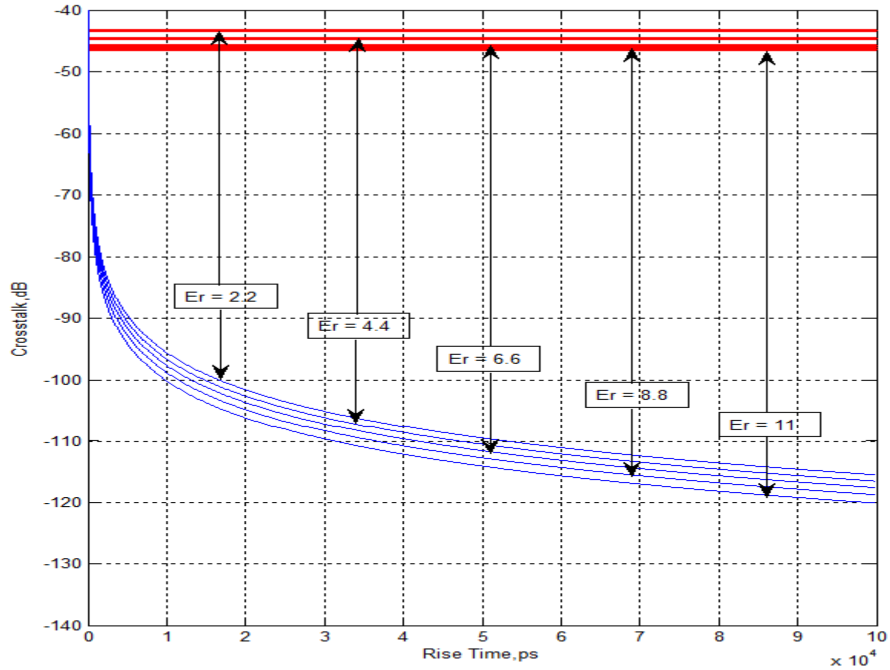
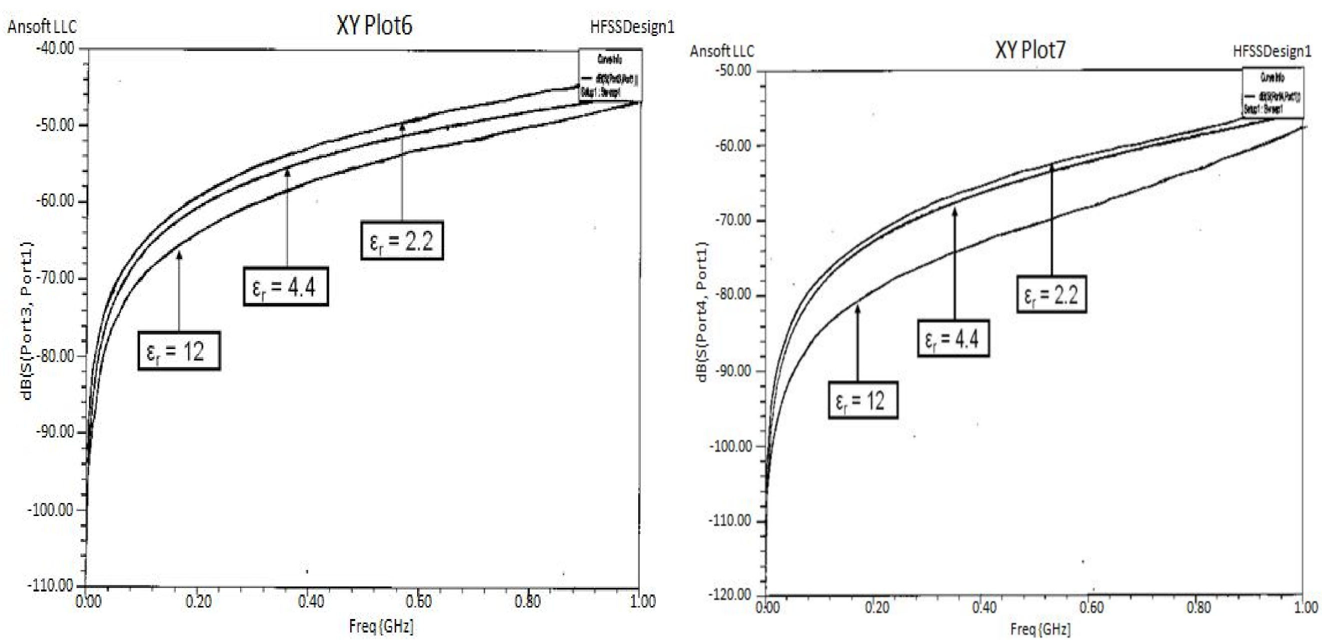


Fig.10 Crosstalk for different dielectric constant obtained by using MATLAB



(a) (b)

Fig. 11 (a) Near End Crosstalk for different dielectric constant obtained by using HFSS

(a) NEXT (b) FEXT

The effect of terminating loads in crosstalk is observed in a PCB model with FR4 material, trace width w = 3.1mm, h = 1.6mm, t = 0.001mm, s = 6.2mm is considered. From the results as shown in Fig. 12, Fig. 13 (a) and Fig. 13 (b), it is concluded that by matching the line terminations reduces reflection and hence cross-talk.

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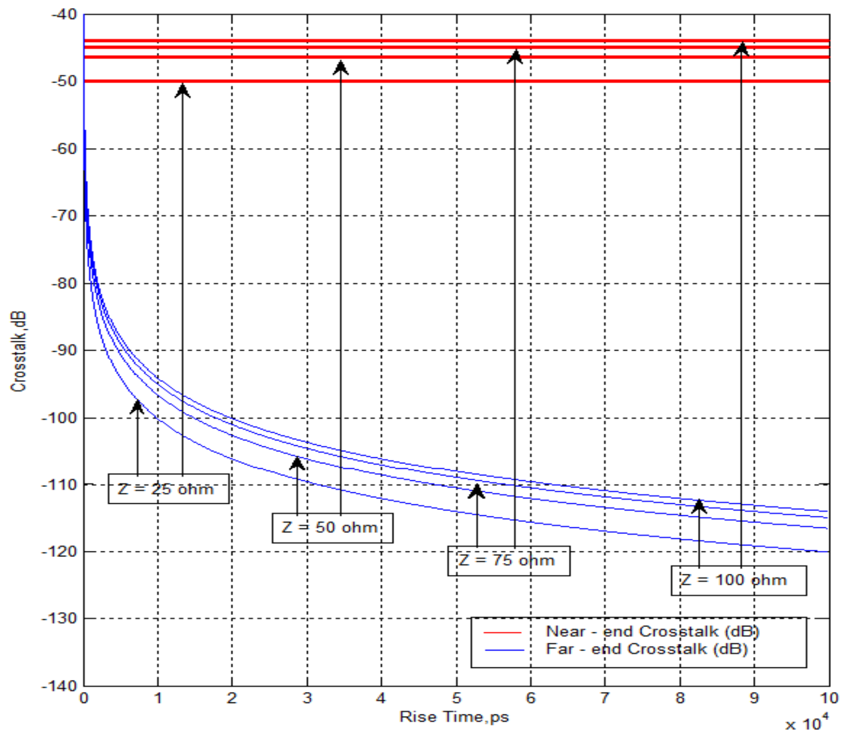
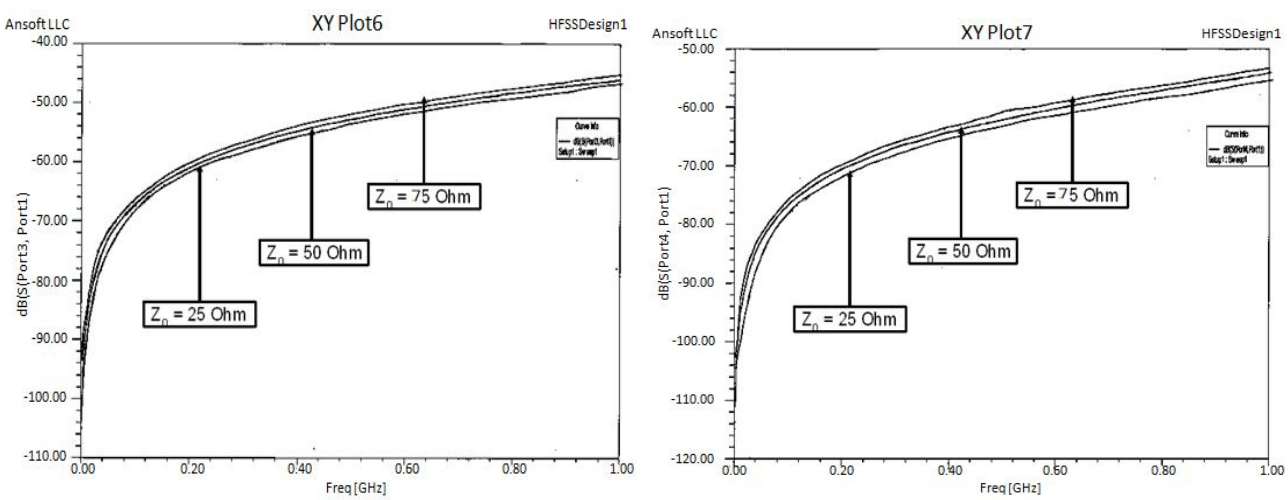


Fig.12 Crosstalk for different terminating loads obtained by using MATLAB



(a) (b)

Fig. 13 Crosstalk for different terminating loads obtained by using HFSS
(a) NEXT (b) FEXT

IV. CONCLUSIONS

Signal integrity issues in high speed and high frequency PCB designs are described in this paper. Crosstalk analysis is shown in the microstrip configuration having two traces above a ground plane. Theoretical results of crosstalk in time and frequency domain are calculated using MATLAB and are compared with those obtained from modeling and simulation using Ansoft HFFS-12. It is seen that both these results agree well. Theoretical and simulation results are also compared with the experimental results and found in agreement. There are some discrepancies observed due to various theoretical assumptions and in experimental limitations. Different techniques for crosstalk reduction in PCB are also highlighted. Placing traces close to the reference plane and also increasing the dielectric constant reduces fringing fields and thus coupling. Crosstalk is reduced by increasing the spaces between the traces which reduces capacitive and inductive coupling. Matching the line terminations reduces reflection and in turn cross-talk.

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