PREDICTION AND ANALYSIS OF CROSSTALK IN ELECTRONIC SYSTEM DESIGN FOR INTRA-SYSTEM EMC COMPLAINCE

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ABSTRACT*:* The functional characteristics of the one module within an electronic equipment or system is disturbed due to EMI from another module is called intra system EMI. Crosstalk refers to the unintended electromagnetic coupling between the PCB lands and wires that are in close proximity. Crosstalk concerns the intra system interference. In modern digital circuits, clock speeds and data transfer rates in digital computers steadily increasing, crosstalk between lands and wires become significant mechanism for interference in digital systems. Crosstalk between two cables can induce signals on the peripheral cable that may radiate externally to the product, causing the product to be out of compliance with radiated emission regulatory limits. If this internal coupling occurs to the power cord of the product, the coupled signals may cause it to fail the conducted emission regulatory requirements. In this paper, coupled microstrip printed circuit board (PCB) crosstalk prediction model is designed and simulated by using 3D EM simulation tool, CST tool. Simulations are carried out for analyzing coupling of traces with different distance and different input pulses with different rise time. The simulated crosstalk between the PCB traces are verified using MATLAB tool.

Keywords: EMI, EMC, Crosstalk, Intra system EMI, Printed circuit board (PCB), signal integrity.

I. INTRODUCTION

When operating any electronic devices, it will emit electromagnetic radiations. These radiations are called crosstalk. Due to this crosstalk the devices do not function well and sometimes they can stop it from their work. Recent technology developments, the requirements of the customers also enhance. Customers always lookup for the devices which are in small size and having the capability of handling higher data rates. Therefore, the manufactures will focus on this development, thereby they integrate more components on less area of PCB that are in close in contact. At the same time, they are trying to operate at very high speeds, it leads to frequency increases up to GHz range. By these developments, the problems associated with EMI has also grown by giving these developments. So, it will create the electromagnetic coupling from one trace to other trace, it is called crosstalk. Crosstalk creates some issues like reflection, ringing, overshoot problems and also debase the signal integrity.

Crosstalk refers to the unwanted electromagnetic coupling between the lands of the PCB and wires that are in close proximity [1]. If this coupling is generated due to the stray capacitance then it is called capacitive coupling or if the coupling produced due to the inductance called inductive coupling. Capacitive coupling weaker than the inductive coupling [2]. Crosstalk occurs between the two parallel traces. The space between the two traces are low, then the probability of occurrence of crosstalk is high. In the same way, the space between the two traces are high then the possibility of generation of crosstalk is low. The geometry of PCB as shown in fig.1

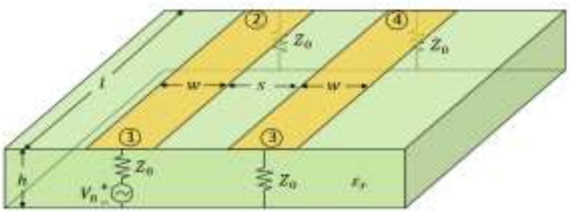


Fig.1: Geometry of Coupled microstrip PCB

Width has significant effect on crosstalk as crosstalk changes inversely proportional to the width. In contrast, crosstalk proportional to length.

II. EQUIVALENT MODEL FOR THREE CONDUCTOR TRANSMISSION LINE

A. Illustrating crosstalk using Three conductor transmission line

In order to understand the crosstalk, consider three conductor transmission line of length 'l '

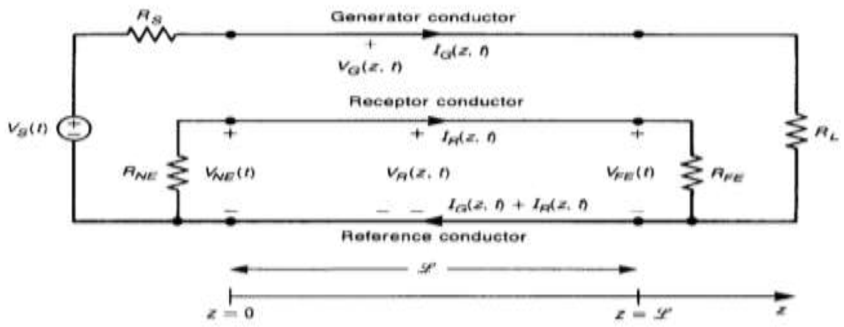


Fig.2: three conductor transmission line

The voltage source $V_S(t)$ is applied in between the generator conductor and reference conductor and generator conductor has source resistance R_S and it is terminated with load resistance R_L. Reference conductor has two termination resistances R_{NE} and R_{FE}, those are nearend and farend resistances. The generator conductor consists of generator current represented as $I_G(z,t)$ passing through generator and reference conductor and $V_G(z,t)$ is the voltage between the generator and reference conductor. The voltage and current in the generator circuit will create the EM fields. These fields will interact with the receptor circuit, due to this interaction, receptor voltage and receptor current has generated. They are represented as $V_R(z,t)$& $I_R(z,t)$. The receptor voltage and receptor current are further responsible for producing nearend crosstalk voltage $V_{NE}(t)$ and farend crosstalk voltage $V_{FE}(t)$.

B. Theoritical analysis of crosstalk

Crosstalk is mainly generated by inductive and capacitive coupling. fig.2 is replaced with its equivalent inductive and capacitive coupling sources. Super position theorem has applied to the resultant circuit (fig.3); thereby, the nearend crosstalk voltage and farend crosstalk voltages are obtained.

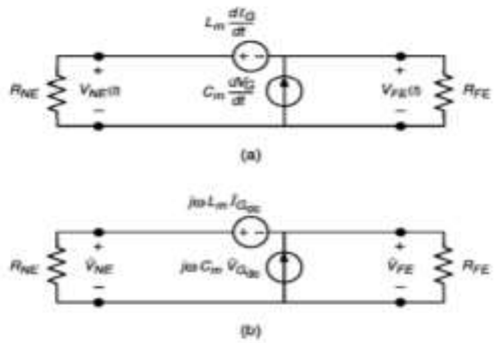


Fig.3. equivalent inductive – capacitive coupling model a) time domain b)frequency domain.

Nearend crosstalk is

$$\frac{V_{NE}}{V_S} = j\omega\,(M_{NE}^{IND} + M_{NE}^{CAP}) + M_{NE}^{CI} \qquad (1)$$

Where $\omega = 2\pi f$ (2)

From the equation (1), nearend crosstalk voltage is expressed as the ratio of voltage at near end of the victim line to the voltage at the source. Similarly, the farend crosstalk voltage is given by

$$\frac{V_{FE}}{V_S} = j\omega\,(M_{FE}^{IND} + M_{FE}^{CAP}) + M_{FE}^{CI} \qquad (3)$$

From the equation (3), farend crosstalk is the ratio of far end of the victim line to the voltage at the source. The inductive coupling in the nearend crosstalk is given below

$$M_{NE}^{IND} = \frac{R_{NE}}{R_{NE}+R_{FE}} L_M \left\{\frac{1}{R_L+R_S}\right\} \qquad (4)$$

the capacitive coupling in the nearend crosstalk and farend crosstalk is given below

$$M_{FE}^{CAP} \;\&\; M_{NE}^{CAP} = \frac{R_{NE}\,R_{FE}}{R_{NE}+R_{FE}} C_M \left\{\frac{R_L}{R_L+R_S}\right\} \qquad (5)$$

the common impedance coupling in the nearend crosstalk is determined by

$$M_{NE}^{CI} = \frac{R_{NE}}{R_{NE}+R_{FE}} \left\{\frac{R_0}{R_L+R_S}\right\} \qquad (6)$$

the inductive coupling in the farend crosstalk is given below

$$M_{FE}^{IND} = \frac{-R_{FE}}{R_{NE}+R_{FE}} L_M \left\{\frac{1}{R_L+R_S}\right\} \quad (7)$$

Finally, the common impedance coupling for farend is given below

$$M_{FE}^{CI} = \frac{-R_{FE}}{R_{FE}+R_{NE}} \left\{\frac{R_0}{R_L+R_S}\right\} \quad (8)$$

Where L_M is the mutual inductance and C_M is the mutual capacitance between traces of PCB.R_0 is the resistance of reference conductor (ground).

Where, $L_M = l_m * L$ and $C_M = c_m * L$. L is the length of the wire. The crosstalk is the sum of total couplings i.e. inductive, capacitive and common impedance couplings. These couplings are occurred due to the high integration of current PCB designs. It implies that clock signal traces are routed in the vicinity of the other signal traces. Thereby, the high hormonic content of clock signal can easily be coupled to the nearby traces, causing crosstalk problems [4]. These equations are implemented with MATLAB.

C. MATLAB Simulation analysis

The simulation analysis of Nearend crosstalk was performed by the MATLAB software. It develops the computational codes easily and debugging is also easy [7]. crosstalk voltage is analysed by this software.

All the crosstalk equations are implemented using matlab software and the resultant graph magnitude versus frequency in the powers of 10 as shown in fig.4 for the values of $R_L = R_{NE} = R_{FE} = 50\Omega$ and R_S =0 ohms.

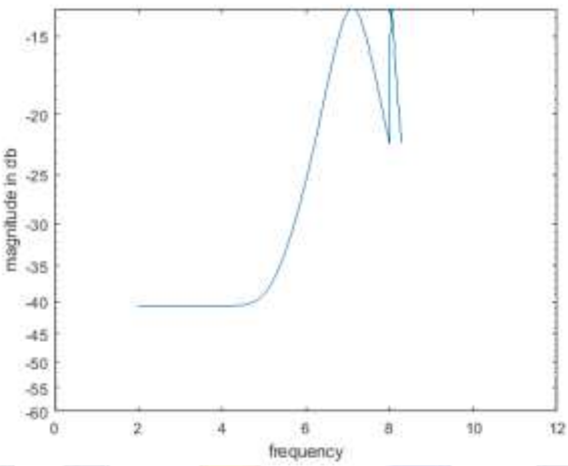


Fig.4. Nearend crosstalk waveform by MATLAB

The crosstalk is calculated up to 10MHZ. from the common impedance coupling, the obtained crosstalk in dB is -40.7dB and it is occurred at low frequencies. From inductive and capacitive coupling, the obtained crosstalk in dB is -22.4dB.

From the fig.11, +20dB/decade region present between the 100KHZ to 1MHZ. after 1MHZ resonance is present.

III. MODELLING OF PRINTED CIRCUIT BOARD (PCB)

A. Modelling of coupled Printed Circuit Board

The modelled coupled microstrip printed circuit board is utilised up to 1GHz. The problems regarding nearend crosstalk,farend crosstalk, characteristic impedance and dimensions are the main problems of concern.

The geometry and dimensions were chosen in a way to obtain a characteristic impedance of 50Ω, dimensions are specified in Table1 , as per the formula

$$Z_0 = \frac{87}{\left(\sqrt[2]{\epsilon_r+1.41}\right)} \ln\left[\frac{5.98\,h}{0.8\,w+t}\right] \quad (9)$$

Here , ϵ_r is the substrate dielectric constanst, h is the height of the board, w is the width and t is the thickness. As per MIL-STD-461E, in CS115 testing procedure, the characteristics of rectangular pulse has amplitude of 5A and rise time and fall time are ≤ 2ns and the pulse width has ≥ 30ns at the repetition rate of 30Hz [6] has consider as one of the input signals ,as shown in below.

Fig.5 characterstics of rectangular signal

Table.1. dimensions of PCB

S. no	Name	Dimensions(mm)
1	Length of board	200mm
2	Width of traces	2.5mm
3	Separation between traces	2.5mm
4	Thickness	0.035mm
5	Height of the board	1.5mm

The printed circuit board is modelled by using dimensions in Table 1. The proposed coupled microstrip printed circuit board is modelled by CST software. The nearend and farend crosstalk voltages and source termination voltages are observed and compared with theoretical results.

B. Nearend crosstalk voltage and Farend crosstalk voltage of PCB

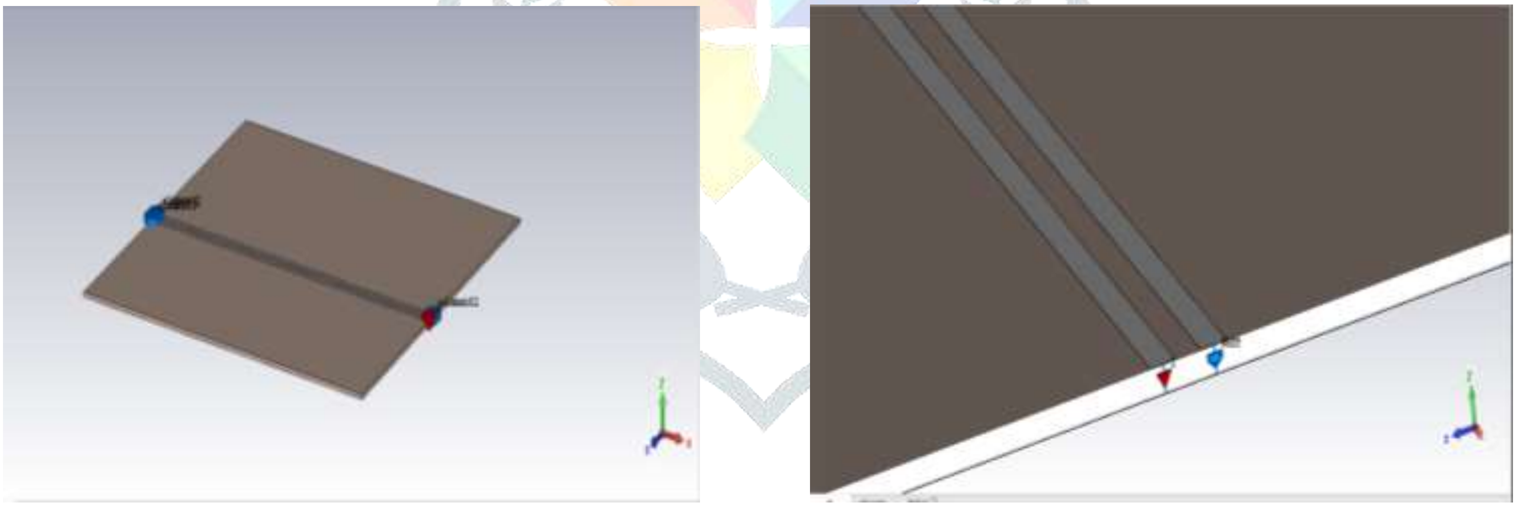
Nearend crosstalk (NEXT) and farend crosstalk (FEXT) are the two types of crosstalk voltages. The operating frequency of any digital systems increases then interference occurs. This may be due to the less spacing between the routings of PCB. So, always keep the clock frequencies as small as possible and routing them initially to provide optimum placement [3]. In nearend crosstalk, the signal from the source at one end can interfere with victim at the same end of the trace, here we can observe nearend crosstalk. The equation for nearend crosstalk is

$$\frac{V_{NE}}{V_S} = j\omega \frac{R_{NE}}{R_{NE}+R_{FE}} L_M \left\{\frac{1}{R_L+R_S}\right\} + j\omega \frac{R_{NE}\,R_{FE}}{R_{NE}+R_{FE}} C_M \left\{\frac{R_L}{R_L+R_S}\right\} \quad (10)$$

farend crosstalk is observed at the signal from the source can interfere with the trace at the opposite end of the victim trace. The farend crosstalk voltage equation is

$$\frac{V_{FE}}{V_S} = j\omega \frac{-R_{FE}}{R_{FE}+R_{NE}} L_M \left\{\frac{1}{R_L+R_S}\right\} + j\omega \frac{R_{FE}R_{NE}}{R_{FE}+R_{NE}} C_M \left\{\frac{R_L}{R_L+R_S}\right\} \quad (11)$$

Fig.6 is modelled by using CST Microwave studio. This code based on finite integration method, depend on a discretization of Maxwell's equations in an integral form. The feeding source is given by using discrete port and aggressor trace is terminated with 50 Ω. Victim trace are terminated with lumped ports of having equal value of resistance 50Ω. Source termination blocks the waves at the travelling source from reflecting back at the receiver by adding series resistor. So, here the source amplitude also observed as from this, how much amount of crosstalk added is determined.



(a) (b)

Fig.6. modelled PCB a) top view b) traces with ports.

IV. SIMULATION RESULTS

A. Simulation analysis

The simulation analysis of coupled microstrip Printed Circuit Board (PCB) has modelled by using Computer Simulation Technology (CST). It is 3D EM simulation software [5]. This CST software mostly high-performance software package for electromagnetic design and analysis in the micro frequency range. The materials types and properties used for PCB were glass epoxy material (G-10) for PCB board, copper for traces of PCB and perfect Electric Conductor (PEC) is used for reference conductor. The input signal is applied to one of the two traces, other trace is terminated.

This simulation setup made to analyse the neared crosstalk and farend crosstalk at different separation between traces of PCB, and also analysed at various rise times of different input signals. The following sections will show the crosstalk waveforms.

B. Square pulse analysis

Square pulse with characteristics of MIL-STD 461E, CS115, the rise time ≤2ns and fall time is ≤ 2ns and pulse width is ≥ 30ns at a repetition period of 30Hz and amplitude of 5A as shown in fig.7, applied to one of the traces and other end of this trace is terminated.

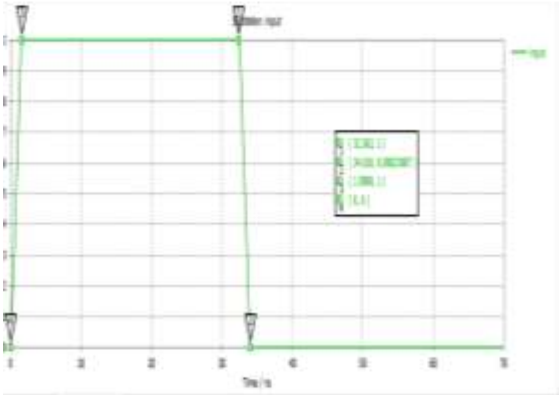


Fig.7. Square input pulse

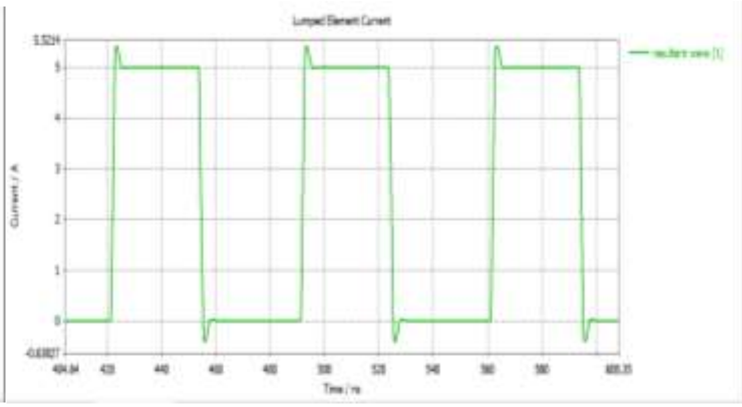


Fig.8. Result of square wave

C. Analysis of crosstalk at different spaces between the traces

In this section, how much amount of crosstalk is coupled to its nearest traces is notified. The crosstalk is observed at different spaces (separation) between the traces. Crosstalk is mainly generated due to electromagnetic coupling. this coupling is due to less space between the traces. So, the distance between traces will have a significant effect on crosstalk. The nearend crosstalk (NEXT) and farend crosstalk (FEXT) is observed at different separation between traces. This simulation done to individual separations at 1mm, 2.5mm, 3.5mm respectively.

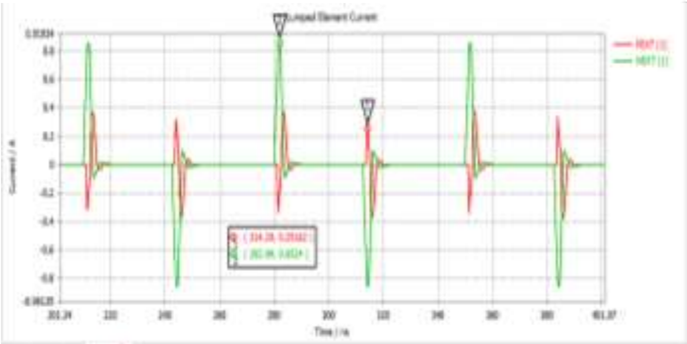


Fig.9. NEXT & FEXT waveforms at S = 1mm

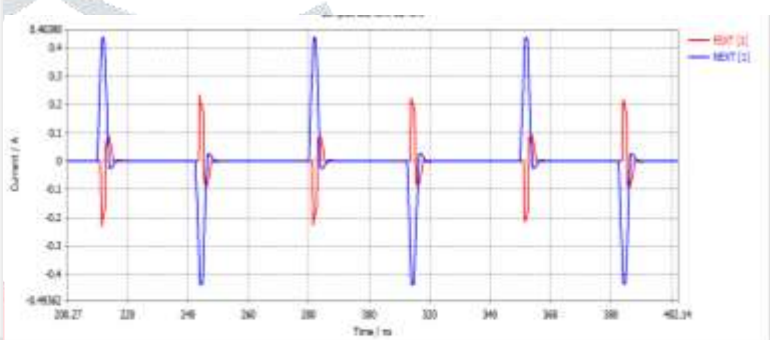


Fig. 10. NEXT & FEXT waveform at S = 2.5mm

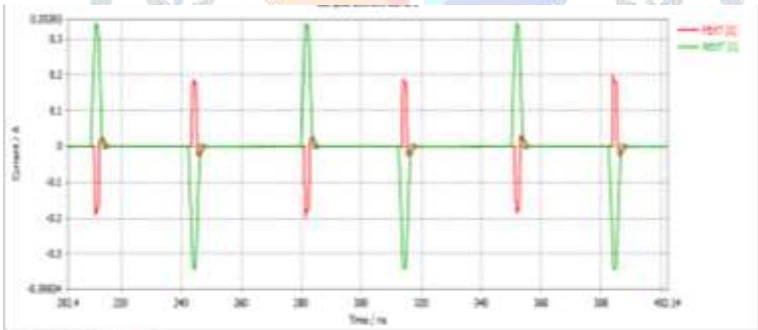


Fig.11. NEXT & FEXT waveform at S = 3.5mm

In fig.9 the coupled crosstalk magnitude of NEXT is 0.89A & the coupled FEXT is 0.32A, obtained at S = 1mm. Now the separation between two traces are 2.5mm then the simulation results are in the fig.10,the magnitude of NEXT is 0.46A, the magnitude of FEXT is 0.2A, these are obtained at S = 2.5mm. Now the distance between the traces increased up to 3.5mm ,Above fig.11 the magnitude of NEXT is 0.33A, magnitude of FEXT is 0.18A. From this analysis, we can conclude that if the distance between the two traces enhances, then the corresponding crosstalk values are reducing or vice versa. The parameter distance (S) plays a major role on crosstalk.

D. Analysis of crosstalk at different rise times of input signal

The input signal (square) is applied one of the ports according to CS115 characteristics with different rise times. The crosstalk waveforms are observed at various risetimes

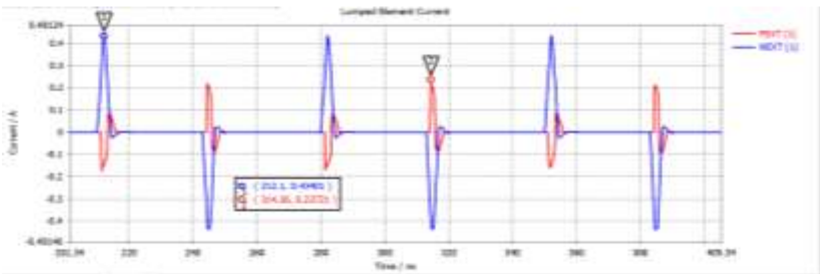


Fig.12. NEXT & FEXT waveform at rise time = 2ns

From the fig.12,the magnitude of NEXT and FEXT are 0.43A & 0.23A respectively. These values are obtained at t_r = 2ns.

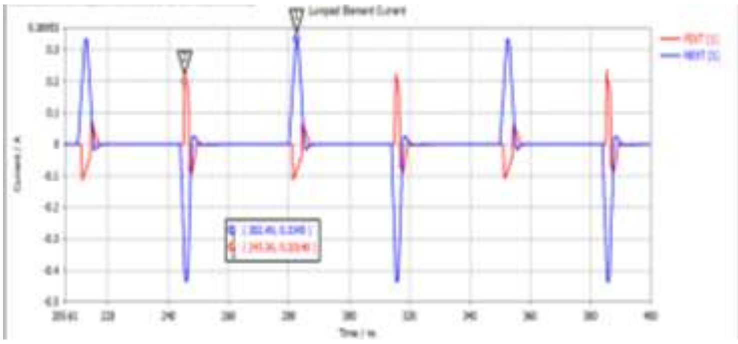


Fig.13. NEXT & FEXT wave form at t_r = 3ns

From the fig.13, the magnitude of NEXT & FEXT are 0.33A and 0.2A respectively. This crosstalk analysis is carried out at different rise times (2ns & 3ns). Form this analysis, we can say that the crosstalk is inversely proportional to t_r.

E. Double Exponential Pulse analysis

Double Exponential pulse with characteristics of MIL-STD-461E, RS105, with 2.1ns rise time and FWHM of 23ns and magnitude of 50kV as shown in fig.14, applied to one port of PCB and another port is terminated.

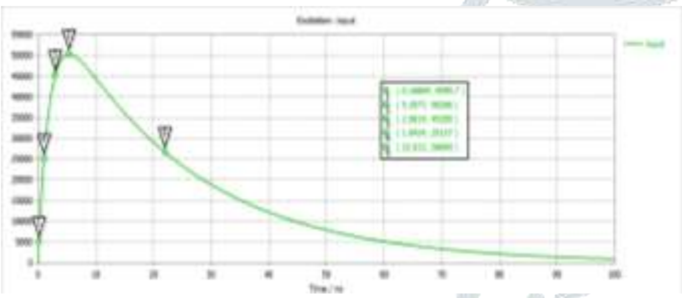


Fig.14. double exponential signal

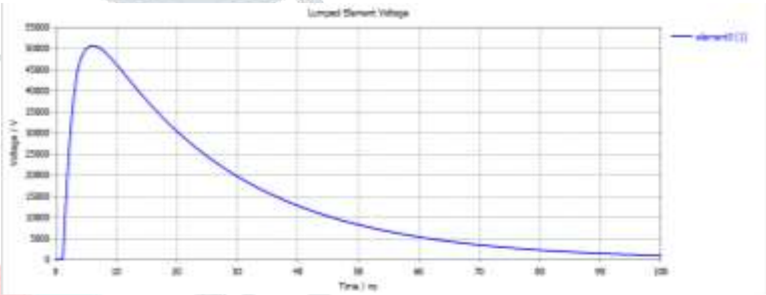


Fig.15. resultant waveform

These analyses are carried out at different separations between traces and also done at various rise times. Now the separation is 1mm.

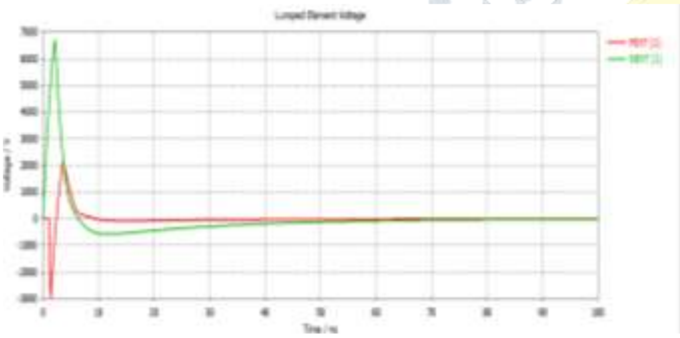


Fig.16. NEXT & FEXT At S = 1mm

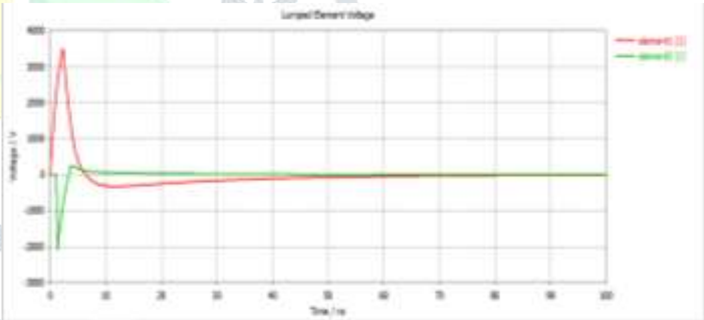


Fig.17. NEXT & FEXT at S = 2.5mm

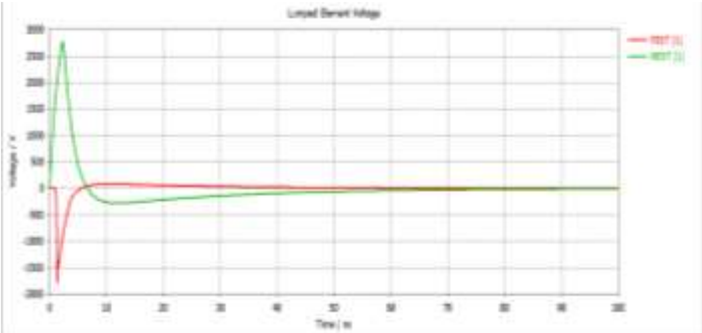


Fig.18. NEXT & FEXT at S = 3.5mm

From the fig.16,the magnitudes of NEXT and FEXT are 6448V and -2845V respectively. Due to less spacing of traces, the amount of coupling is high. Now, distance between traces are 2.5mm, from the fig.17, the magnitude of NEXT is 3750V and FEXT is -2100V respectively. Now the distance is 3.5mm in fig.18, the amplitude of NEXT and FEXT is 2760V and -1800V respectively. This simulation analysis proves that, when increasing the distance between traces the amount of coupling is gradually decreases. Now coupling is observed at different risetime of input signals.

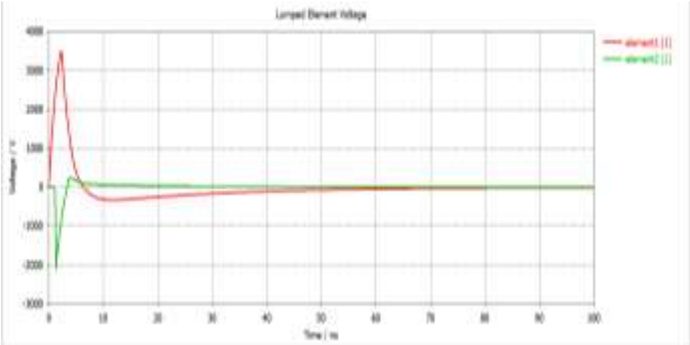


Fig. 19. NEXT & FEXT at t_r = 2ns

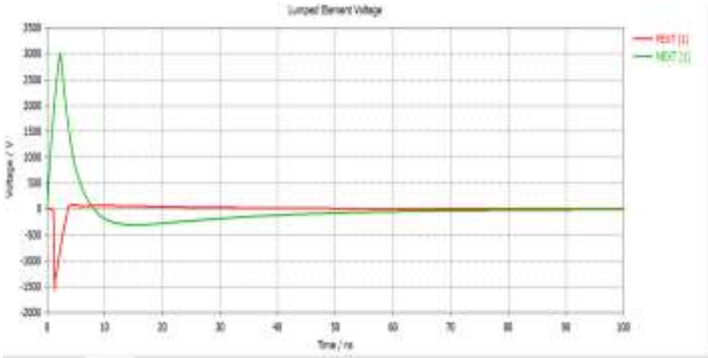


Fig.20. NEXT & FEXT at t_r = 3ns

From the fig.19, the magnitude of NEXT and FEXT are 3680V and -2025V are coupled at rise time 2ns. At rise time 3ns, the NEXT and FEXT are 2993V and -1549.7V are observed in fig.20. This simulation analysis is carried out for rise times 2ns and 3ns respectively. From this analysis, crosstalk is reduced if the risetime of signal increased. So risetime also plays vital role for reducing crosstalk.

V. CONCLUSION

In this paper, the PCB was modelled by using CST software for measurement of crosstalk. The material used for PCB is glass epoxy. The source is driven by the square wave with the characteristics of MIL-STD-461E, CS115 and double exponential signal. Simulation analysis for both nearend crosstalk and farend crosstalk is carried out at various distance between the two traces and different rise times of different input signals. From this simulation analysis, it is observed that how crosstalk will be affected, when the distance between the trace's changes and also at different risetimes is observed. Finally, the crosstalk between the PCB traces theoretically calculated by using MATLAB tool.

VI. ACKNOWLEDGEMENT

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