CHAPTER 2
BACKGROUND INFORMATION

2.1 DEFINITION OF EMC

EMC (Electromagnetic Compatibility) means the system’s ability to operate effectively in electromagnetic field without causing any undesirable interference. It is always essential to ensure that there are certain allowed amount of EMC existing in the designed device.

![EMC Diagram]

Figure 2.1 EMC elements

Poor performance of EMC may then affect eminence and client satisfaction and therefore the designers should examine the products by exposing them to ambient noise situations prior to introduction of the product in the field. The regulation of EMC may then categorize into two parts such as emission and susceptibility.

Emission

The purpose of EMC existing in the emission part is to protect the device from other devices with the noises produced in the range of higher to
lower frequency. Higher frequency emitting devices are the IGBTs (faster switching device) and the digital circuits in which they could be transmitted by employing radiation and conduction process and the lesser frequency emitting device are the radiations emitted from transformers and the harmonics existing in the input current. Hence, several EMC principles are setting limit for noise range produced based on the application.

**Susceptibility**

Immunity or Susceptibility is the capability of the receptor to perform accurately with the existence of EMI. However, the immunity and the susceptibility are contrary in behavior so that the higher immunity systems have reduced susceptibility. Then, the purpose of EMI existing in the immunity part is to ensure that the system does not get disturbed with the noise of the neighbor equipment and maintain immunity against higher and lower frequency noises, which may affect the system.

### 2.2 DEFINITION OF EMI

EMI is defined as the electromagnetic interference that causes disturbances to working of electrical systems in such a way that these undesirable interferences occurred due to existence of electromagnetic radiation or conduction. Based on propagation of the electromagnetic field, electromagnetic radiation and conduction differ. In the conducted EMI, there should be an external electrical link that connects the source of noise signal and the affected system are needed whereas in the radiated EMI, the propagation occurs through air medium so that external links are not needed.

EMI conduction causes proximity effect, hysteresis losses, harmonic distortion and eddy current losses. The electromagnetic (EM) waves propagated through the radio frequency (RF) energy stream which often caused EMI that exists in the range of KHz to GHz so that the conducted EMI ranging from
certain KHz to 30 MHz and the radiated EMI ranging is within 30 MHz to 1 GHz. Several Radio frequency (RF) generating sources including human-made sources such as refrigerator, phones, air craft navigation, arc welding machine and also sources from nature like lightning and solar flares.

EMI types
- CE (Conducted Emission)
- RE (Radiated Emission)
- CS (Conducted Immunity/Susceptibility)
- RS (Radiated Immunity/Susceptibility)

![Diagram](image)

**Figure 2.2 Fundamental electromagnetic propagation procedures**

Every EMI problem consists of three elements i.e., coupling path, receptor and source. A Source may have described as a device, which performs operation of transmission, distribution, and utilization of energy (electrical)
whereas certain features produce radiated or conducted signals that may affect the system’s operation. A receptor is a device that affected while exposing the EM energy (radiated or conducted) originated from the source. A coupling path is a medium through which EMI propagates from source towards the receptor. Generally, the EMI propagation happens in the range less than 30 MHz through conducted emission and beyond 30 MHz through radiated emission and no accurate boundary exists for frequency transition. Advance Design System (ADS) 2011.05 is one of the real time numerical solver for designing various structures and to study about the EMI and EMC effects in terms of Advanced features designed to solve high frequency challenges like signal integrity and power integrity. Following are the features of ADS 2011.05

- Improved EM Port View includes port editing capabilities
- Momentum dataset stores port, pin, and net names for easier interpretation of the S-parameters
- New mesher (quadrangular cells) provides better convergence and speed
- $N \log N$ matrix load algorithm
- Advanced Model Composer can now generate a scalable EM model based on FEM simulations

2.3 HIGH SPEED PCB’s

PCBs (Printed circuit boards) are most general approaches in assembling electronic components (Xu Chen et al. 2013). PCBs are sandwich of the copper and insulating layers, which has the signal path, grounding, supply that made the PCB layout model as significant as the electric circuit model. Conduction track, pad and others obtained from copper sheet etching and laminated to substrate of non-conduction made the electrical connection with PCB components and provided the mechanical support to the PCB components. Conductors on different layers connected with plated-through holes. PCB design
in an advanced level include the resistor, capacitor and active devices which are placed in the substrate (Toshiki Kanamoto et al. 2016). All electronic devices whether smaller or larger include the PCB in such a way that the point-to-point connection and the wire wrap are the alternates for PCB in certain areas. Alternatives to PCBs include wire wrap and point-to-point construction. PCB needs additional design procedure for layout whereas the assembling and manufacturing process done in an automated manner.

Hence, circuit manufacture using PCB is inexpensive and rapid than several other components wiring that wired and mounted in a single manner. Designer of PCB could lessen the following concerns.

- Higher frequency and faster rise time of the device.
- What are the Electrical provisions on the output and the input side of the source and sink?
- Are there any signals that are sensitive to the route?
- Is the micro-strip acceptable for sensitive signals or strip-line needed?
- Do more number of supply voltages needed?
- Does every supply voltage require individual power plane?
- Is the splitting of the power plane possible?
- Designing diagram with operational groups.
- Are there interconnections existing between any of the two liberated operational groups?
- Distinctive care taken on the estimation of return current and crosstalk among traces.
- Adaptation of least height, width and separation of the trace from the PCB creator.
- What will be the least distance within the two layers?
- Is there a possibility of applying buried and blind via?
2.4 TRANSMISSION LINE

The energy can be transferred from source to load port by using Transmission lines (TL) in such away that it has certain lower frequency applications such as distribution of power and higher frequency communications (Xu Chen et al. 2013). Several TL examples specified are two wires, coaxial cable, Planar Line (PL), Strip-Line (SL), Microstrip Line (MSL) with the application of Electric Circuit Theory (ECT) or Electromagnetic Field Theory (EMFT), problems existing in the TL could be resolved.

2.4.1 Transmission Line Parameter

There are three factors that categorise the TL in which the initial factor includes line length and its dimensions, spacing and substrate’s thickness i.e., physical factor. Next is the Material factors such as dielectrics and conductors which include sub factors such as Permittivity (ε), Conductivity (σ) and Permeability (μ) that affect the TL operation. And, lastly the electrical factors are then considered which include the Resistance (R) that exists based on the conducting behaviour of the materials, Capacitance (C) existing due to the dielectric spacing in between the two plates, Inductance (L) and Conductance (G) based on inductance of conducting materials and its dielectric losses respectively.

2.4.2 Transmission Line Equation

TL supports TEM (Transverse Electromagnetic) waves in which both magnetic fields and electric fields, which are orthogonal within each other, are directing transverse to the propagation waves. The relations between I, V, H and E in TEM waves are then mentioned in an equation below

\[ V = \int E \cdot dl \]  

(2.1)
The flow of current through any conductor is denoted as I, E and H which are the electric and magnetic field respectively (Note: I and V are circuit quantities where as E and H are field quantities).

The propagation constant $\gamma$ and wave velocity $\mu$ defined in the following equations respectively

$$\gamma = \alpha + j\beta$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$$

$$\mu = \frac{\omega}{\beta} = f\lambda$$

Attenuation constant is denoted as $\alpha$, phase constant as $\beta$ and wave frequency as $f$.

2.5 MICROSTRIP LINE

Microstrip line is a parallel plate transmission line, which is widely used nowadays. Used for microwave integrated circuits such as filters, coupler, resonators and antennas as a circuit component. When compared microstrip line with other transmission lines, its simple geometry, small size and easy integration to the circuit they are desirable properties in recent technologies in microwaves and communication (Tian Hong et al. 2011).
A microstrip line is composed of two parallel conductors the reference plane and open metal conductor separated by a substrate as shown in Figure 2.3.

2.6 TRANSMISSION LINE LOSSES

Transmission lines losses classified as conductor loss, dielectric loss and radiation loss.

2.6.1 Conductor Loss

Conductor loss or copper loss is due to resistance level of conductors, which are certainly not equivalent to zero, except for superconductor. When there is a flow of current in any of the conductors, there should be certain energy dissipation occurring in a heat form or certain other losses existing due to the skin effect. Current in the center of the wire becomes smaller and most of the electrons flow on the wire surface. Mostly, the flow of electrons is over the surface of the wire so that the wire’s center part has lesser current flow. When the frequency applied is in GHz range, the electron movement in the center is so small that the center of the wire removed without any noticeable effect on the current. If the applied frequency is in the range of GHz, then the wire’s center part has reduced current flow and if the wire’s center part removed also, it will
not cause any effect with the electron flow. The effective cross-sectional area decreases as the frequency increases. Resistance will increase as the frequency is increased. Also power loss increases as the resistance increases. Resistance and frequency directly related to each other when the frequency increase the resistance also increase, which increased the loss of power too. On the contrary, when the frequency rises, cross-sectional area reduced.

2.6.2 Dielectric Loss

The dielectric loss based on the voltage, which passes through the dielectric material. The dielectric loss is not directly proportionate with the line impedance so that if the frequency increased, then also the losses increased. However, if the dielectric medium used is air, loss occurred is nearly zero.

2.6.3 Radiation Loss

If the distance that separates the conductors is lesser than its wavelengths, then the TL operates as an antenna and hence the conductors initiated the energy radiation process (Petrosyants et al. 2013). Additionally, if the frequency rises, it caused more loss of radiation.

When the cycle gets alternated, there are certain lines of forces (magnetic) that do not turn back to conduct material which then caused radiation loss. These unturned lines of force reached the atmosphere in radiation form and caused loss of power. In another term, it is described as the power transmitted from the source, which did not reach its load destination. The radiation losses occurred in the circuit operating at high frequencies (e.g., microwave frequencies). Mostly, the performance depends on the design of circuit. However, the material had an impact too. Hence, the designer should concentrate on vital connections in between the materials of the circuit and its designing method. The Radiation loss definition is the energy loss with in the circuit-taking place due to radiation of energy to the atmosphere (i.e., surrounding far from the
circuit). The energy radiated could be the cause of the EMI problems. The occurrence of radiation loss is then based on designing of the circuit, its configuration, frequency, dielectric constant and thickness of the material.

One of the major sources of radiation loss is impedance mismatching. Generally, the designer attempted to match the impedance, but in some cases, designing of microwave needs various levels of impedance. Another issue, which is sometimes related to impedance mismatch, is radiation loss due to signal launch, which happens where the connector meets the circuit board. In common, the circuit, which is thick, undergoes radiation losses more than the circuit, which is thin. Lesser dielectric constant circuit undergoes radiation loss larger than the circuit that has higher dielectric constant. Higher frequency applications are radiating more than the lower frequency applications. Consequently, there was the connections in all the above-discussed statements, which made radiation loss process to be challenging to understand.

2.7 **INSERTION LOSS**

Insertion Loss (dB) described as the power loss that occurs when the signal goes into the RF system. These losses including both systems attenuation and incoming signal are reflected back. In other terms, the proportion of the transmitted power to the incident power, in dB terminology, is insertion loss so that the transmission of power from source is earlier than the insertion process and the same is denoted as $P_T$ and $P_R$ is the power obtained by load next to the insertion process. Based on that, the insertion loss is then calculated as follows

\[
InsertionLoss(dB) = 10 \times \log_{10} \left( \frac{P_R}{P_T} \right) 
\]

(2.5)

Where,

$P_R$ - Received Power; $P_T$ - Transmitted Power

\[
\text{Where,} \\
P_R \text{ - Received Power; } P_T \text{ - Transmitted Power}
\]
Insertion Loss has three major bases,

- Dielectric losses
- Copper losses
- Reflected losses

Figure 2.4 Insertion losses in a transmission line

Figure 2.4 shows a proportion of the existence of dispersed signal wave to the entrance of the incident wave with the port. With the dual port interconnect like PCB cable, port 1 is allocated on the one part and another part gets allocated with the port 2. The insertion loss $S_{21}$ represents the S-parameter in which the wave is entering through port 1 and is leaving through the port 2.

2.8 RETURN LOSS

The proportion of the signal that entered to device that gets reflected immediately entering into device is called return loss. In other terms, it is described as the quantity of signal that gets returned to source due to impedance mismatch happening with in the path of transmission. The factor that affects the return loss is the device impedance matching, path allocation for signals, bandwidth of the signals transmitted.

$$\text{Return Loss} (dB) = 10 \log_{10} \left( \frac{P_I}{P_R} \right)$$

(2.6)

where,
- $P_I$ - Incident Power
- $P_R$ - Reflected power
The power gets returned to the TL due to variations within the configurations of microwave in TL and its components. The unreflected power may then enter in to a component in which certain powers get absorbed and the rest of the power are transmitted to the TL on the another part via the component. The power then exists from the component is known as transmitted power.

Return loss linked to reflection coefficient (Γ) and Standing wave ratio (SWR). Rising of the return loss may lessen the SWR. It measures the lines matching quality in such away that there is a higher return loss if the matching is better. However, the higher return loss causes lesser insertion loss. Compared to SWR, the return loss shows most priority due to its superior perseverance for reflected waves having lesser values. The return loss $S_{11}$ represents S-parameter in which wave that enters and gets back from same port.

2.9 SCATTERING PARAMETER

The other approach for stating insertion and return loss is the S-parameter described in Figure 2.6 that displays microwave signal when the signals are going and leaving in both ways. When the signals of the microwave are existing in the device is entering part, certain signals are returned (reflected) and others are transmitted via the device.

\[
\text{Reflection Coefficient} = \frac{\text{Reflected electric field at port } n}{\text{incident electric field at port } n} \quad (2.7)
\]

\[
\text{Transmission Coefficient} = \frac{\text{Reflected electric field at port } m}{\text{incident electric field at port } n} \quad (2.8)
\]

To characterize the component completely, the transmission and the reflection coefficients should be indicated in either direction. S-parameters designed as follows. The entering and the leaving of microwave signals from input side port are then represented with the subscript.
Figure 2.5 Two port network

\[ S_{11} = \text{Input Reflection Coefficient} \]
\[ S_{12} = \text{Isolation} \]
\[ S_{21} = \text{Forward Transfer Coefficient or Gain /Loss} \]
\[ S_{22} = \text{Output Reflection Coefficient} \]

The electric field of the microwave signal going into the component port designated as “M” leaving the ports are designated as “N”.

Therefore, M1 is the electric field of the microwave signal entering the component port 1. M2 is the electric field of the microwave signal entering the component port 2. N1 is the electric field of the microwave signal leaving the component port 1. N2 is the electric field of the microwave signal leaving the component port 2.

By definition then,

\[ S_{11} = \frac{N1}{M1} \mid M2=0 \]
\[ S_{21} = \frac{N2}{M1} \mid M2=0 \]
\[ S_{12} = \frac{N1}{M2} \mid M2=0 \]
\[ S_{22} = \frac{N2}{M2} \mid M1=0 \]

Therefore, \( S_{11} \) is electric field, exiting from input that gets divided by incoming electric field to the input, in the case of no signal entry in the output side. Then N1 and M1 are electric fields and its proportion are the reflection coefficients. Likewise, \( S_{21} \) is the ratio of the exiting electric field from the output.
and the entering electric field from input, while there is no entry of the signal from the output. Hence, \( S_{21} \) is the coefficient of transmission, which is linked to the component’s gain or insertion loss.

In a similar manner, \( S_{12} \) is a transmission coefficient related to the insertion loss or the gain of the component. Likewise, \( S_{21} \) is a transmission coefficient related to isolation of component in the wrong direction. \( S_{22} \) is similar to \( S_{11} \), but it looks in other direction into the component. It is better, known as S-Parameters, these 4 values help in defining the performance of several variables at various frequencies.

2.9.1 Two-Port S-Parameters

For port label assignment to TL, there are two existing approaches. The first case is the suggested one whereas the second one is not suggested even though it is generally used. when, there are many interconnects like two TL (adjacently) in the circuit board, estimation of return loss \( S_{11} \), Insertion loss \( S_{21} \), near end cross talk \( S_{31} \) and far end cross talk \( S_{41} \) are defined based on the port labeling. Near end crosstalk is a new parameter that results due to the coupling of energy from source line (excited with source) to victim line at the vicinity of the source port. For example in figure 2.6 case 1, if source is connected to the port 1 and terminated at port 2, there will a signal coupling at port 3 which is near end crosstalk. Port 3 is the line near to port 1 where source is excited at port1. Far end crosstalk is another parameter results due to the coupling of energy from source line to victim line at the vicinity of the terminating port.
Port labeling is done by two methods such as in the first approach, one line’s both opposing ends are marked as port 1,2 and the another line’s opposing end are marked as port 3,4. Moreover, within this labeling method, one line’s insertion loss mentioned as $S_{21}$, which is the element of S matrix. Thus, the first method for labeling suggested. Because it is reliable in linking $S_{21}$ with the insertion loss, which also scales to numerous ports in an easy manner.

In the second approach, with the lines pair port 1, 2 are the left part labels and port 3, 4 are the right part labels. Within this labeling method, the first line has insertion loss that is $S_{31}$ and $S_{21}$ is its near-end crosstalk. Then the two labeling method are implemented in the industrial environment. The S-parameter i.e., the matrix element with same label differed based on the assignment of the utilised port.

With port assignment as in first approach, $S_{21}$ the insertion loss, is almost near to 0 dB for lower frequency. $S_{31}$ representing the near-end crosstalk between two lines should be less than or equal to 0 dB in lower frequency. Similarly, within the assignment in second approach, $S_{31}$ is the insertion loss, near-end crosstalk is the S21, and these labeling is legal just as the first labeling.
approach. However, when the S-parameter approach done with single labeling method, which has varied port assignment. In such cases, even though it has the worst approach, the outcome will not be affected.

By viewing $S_{21}$, it is possible to denote that port assignment utilized in such away that if the $S_{21}$ appears as an insertion loss with the value nearer to 0 dB at low frequency, then it could be concluded that the labeling of the port is done based on the first method. If $S_{31}$ looks like an insertion loss and has a nearly 0 dB value at low frequency, then it could be concluded that the labeling of the ports was done on second method. In this work, case 1 type of numbering is adopted. $S_{41}$ is considered as far end crosstalk of the proposed system.

### 2.10 SIGNAL INTEGRITY ISSUES

The various signal integrity issues are

1. Discontinuities
2. Propagation Delay
3. Crosstalk
4. Ringing
5. Ground bounce
6. Distortion
7. Signal loss
8. Power supply noise.

#### 2.10.1 Discontinuities

Every distributed circuit having propagation in coaxial lines, waveguides or several other forms should intrinsically include discontinuities. The straight path of transmission with no interruption had lesser usage. However, the junction origins the discontinuity with the PCB path (Ihsan Erdin et al. 2016). The discontinuities causing reduced inductance and capacitance then affect frequencies at the range of millimeter and microwave. Several
circuits like mixers, filters, oscillators also include certain discontinuities (Fangxu Yang et al. 2016). Transmission discontinuities existing in almost every technology either on the hybrid MMIC or MIC based. The modeling of discontinuities is then designed on the basis of equivalent inductances and capacitances. The following are some examples of discontinuities in PCBs.

a) Short circuits over the ground plane
b) T & Cross junctions
c) Open circuits
d) Series coupling gaps.
e) Changes in Step width.

2.10.1.1 Microstrip bends

The two lines having even or uneven impedances used to form microstrip bend, which provides flexibility in circuit layout. It has equivalent circuit that consists of lines having impedance that are equal and used to compensate the surplus capacitance.

2.10.1.2 T-junctions

Many circuits like stub filters, branch line couplers and networks of impedance are having T-junction, which is the major discontinuity that exists in microstrip. Repairing of T-junction discontinuity is more complex than the repairing method of steps of steps in width and bends in right angle format.

Figure 2.7 Open end discontinuities
2.10.1.3 Steps in width of the Microstrip trace lines MTL

There is a microstrip junction formed by two lines that contain varied impedances caused by step discontinuity, which mostly occurs in the designing process of identical transformers, filters and couplers. Width of these step discontinuities give rises to change in length in accountable manner.

2.10.2 Analysis of Discontinuities

Discontinuity calculated by open-end transmission line. It can be analysed using the following equation [2.9],

\[
\frac{\Delta l}{h} = \frac{\varepsilon_1 \varepsilon_{35}}{\varepsilon_4}
\]

(2.9)

![Figure 2.8 Discontinuities due to change in length](image)

where,

\(\Delta l\) - Change in length

h - Substrate thickness

\[
\varepsilon_1 = 0.434907 \left( \frac{\varepsilon_{r0.81} + 0.26 \left( \frac{W}{H} \right) 0.8544 + 0.236}{\varepsilon_{r0.81} - 0.189 \left( \frac{W}{H} \right) 0.8544 + 0.87} \right)
\]

(2.10)

By substituting the value of width and height of the conductor of the PCB traces, the permittivity of first discontinuities are measured.

\[
\varepsilon_2 = 1 + \left( \frac{\left( \frac{W}{H} \right) 0.371}{2.35 \varepsilon_r} + 1 \right)
\]

(2.11)
\[ \varepsilon_3 = 1 + \left( \frac{0.5274 \tan^{-1} \left( \frac{0.084 \left( \frac{W}{H} \right)^{1.9413}}{\varepsilon_2} \right)}{ \varepsilon_{re0.9236} } \right) \] 

(2.12)

\[ \varepsilon_4 = 1 + 0.037 \tan^{-1} \left[ 0.067 \left( \frac{W}{H} \right)^{1.456} \right] \left[ 6 - 5 e^{(0.036(1-\varepsilon_r))} \right] \] 

(2.13)

\[ \varepsilon_5 = 1 - 0.218 e^{(-7.5 \left( \frac{W}{H} \right))} \] 

(2.14)

From the equations 2.11-2.14, relative permittivity of the corresponding discontinuities derived.

### 2.10.3 Propagation Delay

The signal rise time determines if a line will behave as a transmission line or as a lumped circuit. A line will act as a transmission line if its electrical length is greater than half the signal rise time. In some critical situations, even shorter lines will act as transmission lines. The impedance and the propagation delay time should depend on the line’s length, but, in fact, the impedance does not depend on the length of line, while the propagation delay depends on material of the trace.

Delay constant of ns/ft is the parameter of the dielectric constant alone i.e. without dimension of trace. Hence, this is the appropriate condition for the PCB layout. \( \varepsilon_r \) constant of propagation delay is stable for numerous line impedances.

\[ T_{pd} \left( \frac{\text{ns}}{\text{ft}} \right) = 1.017 \sqrt{0.475 \varepsilon_r} + 0.67 \] 

(2.15)

In other terms, the delay constant is mentioned by the ps/inch form which then is most applicable in the PCBs of smaller size.
\[ T_{pd} \left( \frac{ps}{\text{inch}} \right) = 85\sqrt{0.475\varepsilon r + 0.67} \]  
(2.16)

2.10.4 Analysis of Propagation Delay

The delay expressed in ns/ft as a function only of the dielectric constant (Keisuke Ikemiya et al. 2012). The dielectric constant for substrate [\( \varepsilon r \)] is 4.6.

\[ T_{pd} \left( \frac{ns}{ft} \right) = 1.017\sqrt{0.475\varepsilon r + 0.67} \]  
(2.17)

2.10.5 Crosstalk

Crosstalk will become an issue for printed circuit board designers as the packaging densities keep on increasing.

Crosstalk is the coupling of EM energy from one transmission line to another transmission line (Jiangwei Wang et al. 2011). Undesirable signals are from a neighboring transmission circuit, which happen due to unwanted coupling of capacitance, conductance or inductance existing in the circuit’s part, or within the channel.

2.10.5.1 Types of Crosstalk

- **Near End Crosstalk** - Victim line’s voltage that exists besides the source.
- **Far End Crosstalk** – voltage existing at another end

Interference occurred due to two signals, which are partly super imposed owing to capacitive or inductive coupling among the signaling conductors. Crosstalk experienced as magnetic field of single wire that exists due to varying flow of current that may then induce the current flow to the other wire, which placed parallel to the first one.
When a PCB (Andreas Mantzke et al. 2016) track carrying control or logic levels is in close proximity with a second track, which used for low-level signals, over a distance of 10 cm or more, crosstalk expected. Crosstalk in between the conductors could be instigated by coupling of electric field through mutual capacitance or by magnetic field through mutual inductance. When considering crosstalk between PCB tracks, conductors in a cable, over wires and cables in close proximity, it is important to determine if it is inductive or capacitive coupling. Predominantly couplings are electric field (capacitive) or magnetic field (inductive) coupling. If neither mode predominates, then both should be examined separately. More conveniently, the characteristic impedance between the source and the receptor circuit and the receptor circuit and the ground may be used in a crosstalk prediction. If the spaces in between the conductors are more, then there is a reduced crosstalk.

2.10.5.2 Estimation of Crosstalk

Signals transmitted from the transmitter to the receiver undergo interferences. Certain devices such as transmitters, connectors, receivers, cables, PCB traces may cause disturbance to the signal’s timing and amplitude. Signal may then be affected from inner sources such as PCB trace pair and toggle of IC pins. Moreover, the crosstalk with in these signals could inhibit with certain other signals, which then reduced the signal’s quality.

General quality analyser of high-speed transmission signals is the eye diagram produced by using oscilloscope due to overlapping of the extensive data stream’s sweep that are determined from the main clock. While multiple transitions are overlapped, the superimposition of positive and negative pulses then occurred. By overlapping the multiple bits generating the eye diagram (image as an eye opening view). Hence the eye diagram having vast parametric data of the signal afford prompt vision of the interference signal which are then
used by the designers for checking the signal integrity and solving the issues in an initial stage of the designing.

Figure 2.9 Simulated eye patterns of a PCB trace

Figure 2.9 shows the obtained eye pattern of a PCB trace, which shows best timing of sampling and eye opening. Eye pattern is a perfect estimator of crosstalk.

2.10.6 Analysis of Crosstalk

Crosstalk calculated by odd mode impedance and even mode impedance as shown in equation 2.18

\[
\text{CROSSTALK} = \left( \frac{Z_{oe}}{Z_{od}} \right) \left( \frac{Z_{od}}{Z_{oe}} \right)\]  

Where,

\[
Z_{oe} = 276 \log \left( \frac{2D}{W} \right) \sqrt{\frac{1}{1 + \left( \frac{B}{2R} \right)^2}}
\]
$Z_{oe}$ = Even mode Impedance

$$Z_{od} = 69 \log \left( \frac{4h}{W} \right) \sqrt{\frac{1}{1 + \left( \frac{2h}{D} \right)^2}}$$

where,

$Z_{od}$ = Odd mode impedance

Crosstalk depends on various parameters such as height of the substrate (h), distance between two transmission lines (D) and width of the conductor (w).