Serial Data Transmission

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Outline

- Baseband serial transmission
- Line Codes
- Bandwidth of serial data streams
- Block codes
- Serialization
- Intersymbol Interference (ISI)
- Jitter
- Eye Diagrams
- Equalization and Pre-emphasis

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Baseband Serial Transmission

- Baseband serial transmission refers to serial data streams transmitted without modulation
- It is the most popular signaling technique for multigigabit-per-second data rates
- It is widely used for signaling across long interconnects (including backplanes)

Line Codes

- They are standard ways to electrically represent logic data
- The two most popular line codes are:
  - NRZ format (unipolar and bipolar)
  - RZ format (unipolar and bipolar)

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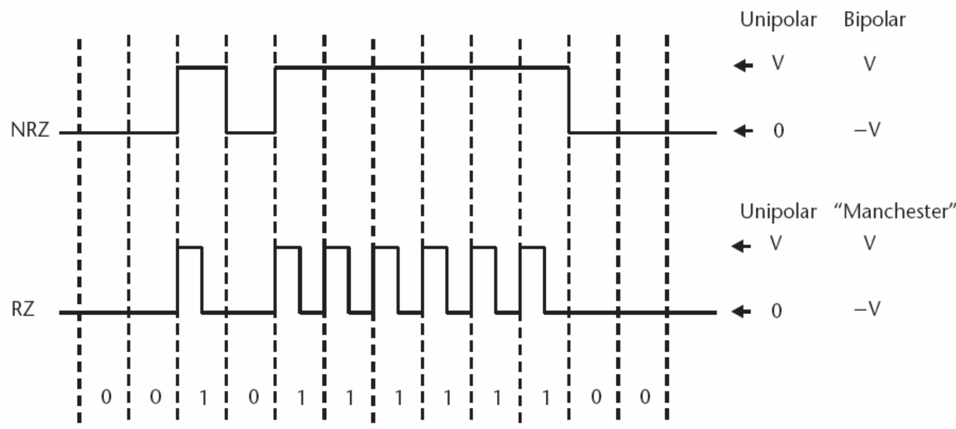
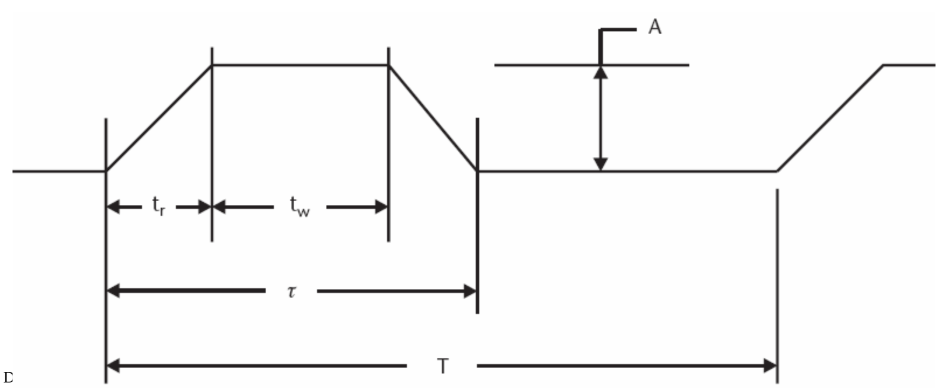
NRZ and RZ Line Codes



(S. C. Thierauf, High-Speed Circuit Board Signal Integrity, Artech, 2004)

Duty Cycle, Unit Interval and Bit Rate

- Duty cycle (δ), $\delta = \dfrac{\tau}{T}$
- Bit time, cell time, or unit interval (UI), $UI = \tau\big|_{RZ} = T\big|_{NRZ}$
- $\text{bit rate} = \text{data rate} = \dfrac{\text{number of bits transmitted}}{\text{time interval}} = \dfrac{1}{UI}$ (bps)



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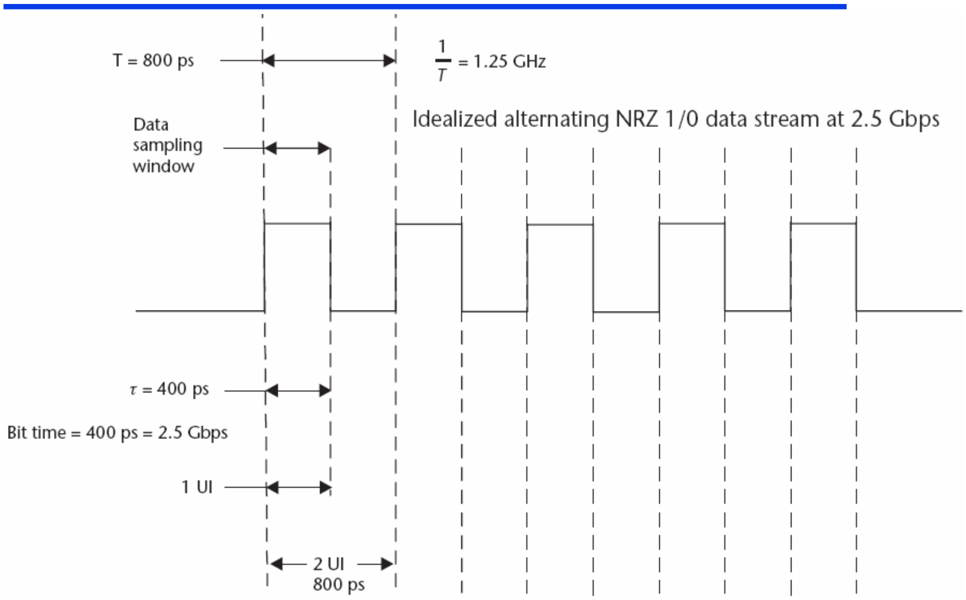
Example



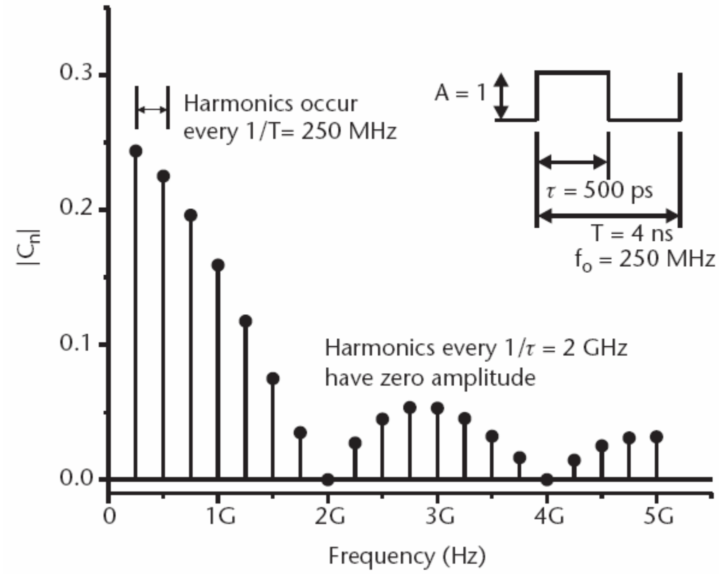
 (S. C. Thierauf, High-Speed Circuit Board Signal Integrity, Artech, 2004)

Bandwidth of Serial Data Streams

- The frequency contents of a NRZ serial data signal can vary from 0 Hz up to very high frequencies if no restrictions are imposed in the code sequence
- Standard block codes are used to place a lower limit on the frequency content
- The upper limit depends the maximum data rate. The maximum fundamental frequency of a binary NRZ data stream is

$$f_{0\max} = \frac{1}{2UI}$$

Spectrum of Periodic Rectangular Pulses



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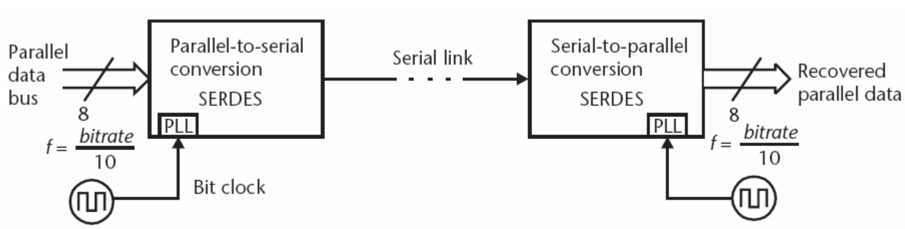
Serializers/Deserializers (SERDES)

- They transform parallel data into serial data streams, and vice-versa
- The transmitting and receiving SERDES have separate reference clocks
- The clock frequency is multiplied in the SERDES using a PLL (with variable multiplication factor)



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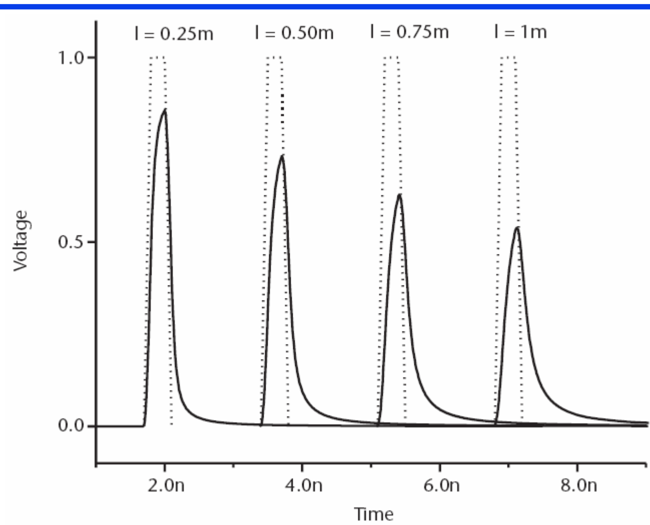
8b/10b Block Code

- It is the most popular block code for serially transmitting binary data over copper and fiber optic cables
- In this code, an 8-bit parallel word is encoded into 10 serial bits

Table 7.1 8b/10b Coding Table Fragment

Input Word Value (Hexadecimal)	*Input Word Binary Value (MSB/LSB)*	*Byte Name*	*Encoding Disparity–*	*Encoding Disparity+*
00	000 00000	D0.0	100111 0100	011000 1011
01	000 00001	D0.1	011101 0100	100010 1011
F5	111 10101	D21.7	101010 1110	101010 0001
1C	000 11100	D28.0	001110 1011	001110 0100
4A	010 01010	D10.2	010101 0101	010101 0101
FC	111 11100	D28.7	001110 1110	001110 0001
BC	000 11100	K28.5	001111 1010	110000 0101
FC	111 11100	K28.7	001111 1000	110000 0111

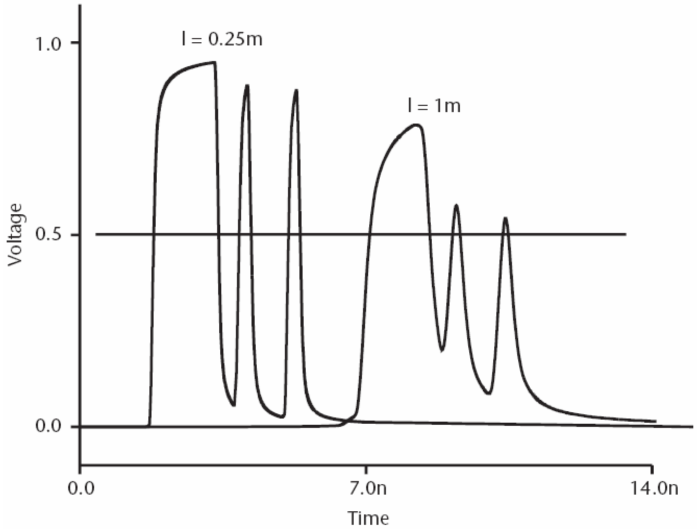
Transmitting 1-Bit on a Dispersive Interconnect



400-ps, 1-V pulse propagating down a 1m-long, 5-mil-wide lossy stripline on FR4

(S. C. Thierauf, High-Speed Circuit Board Signal Integrity, Artech, 2004)

Transmitting a Data Stream on a Dispersive Line



Bit stream traveling down a lossy line

(S. C. Thierauf, High-Speed Circuit Board Signal Integrity, Artech, 2004)

Intersymbol Interference (ISI)

- It is the distorsion of a data bit within a symbol (group of bits) caused by interference with one or more earlier data bits due to bandwidth limitations
- ISI can also be caused by residual energy left on the line due to reflections from an impedance discontinuity or improper matching loads

ISI due to Bandwidth Limitations

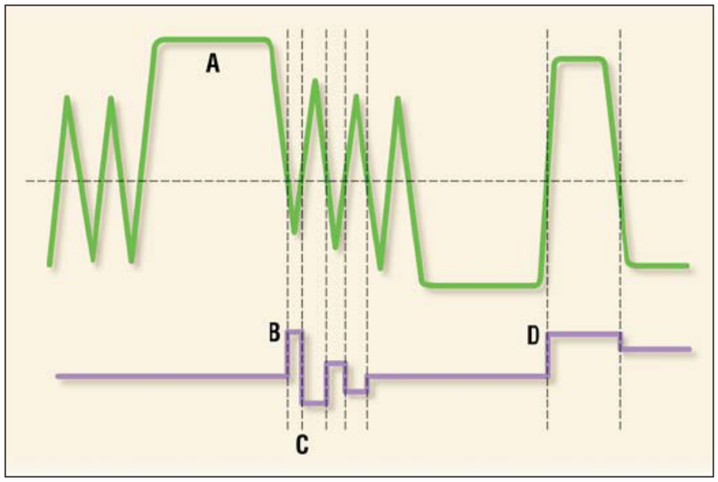


Figure 3 · Inter-symbol interference (ISI) due to bandwidth limitation problems.

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ISI due to Reflections on the Line

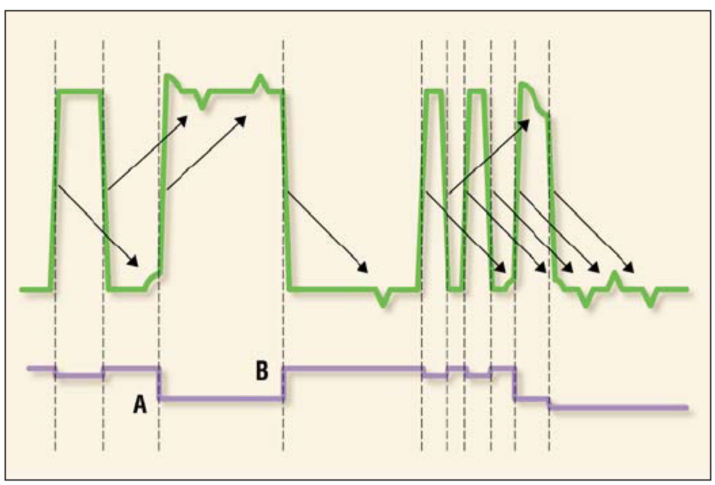

Figure 4 · Intersymbol Interference (ISI) due to signal reflections.

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Jitter

- It is the uncertainty in the pulses timing
- It is caused by many factors (many different types of jitter)
- ISI = data-dependent jitter

Periodic Jitter due to Capacitive Coupling

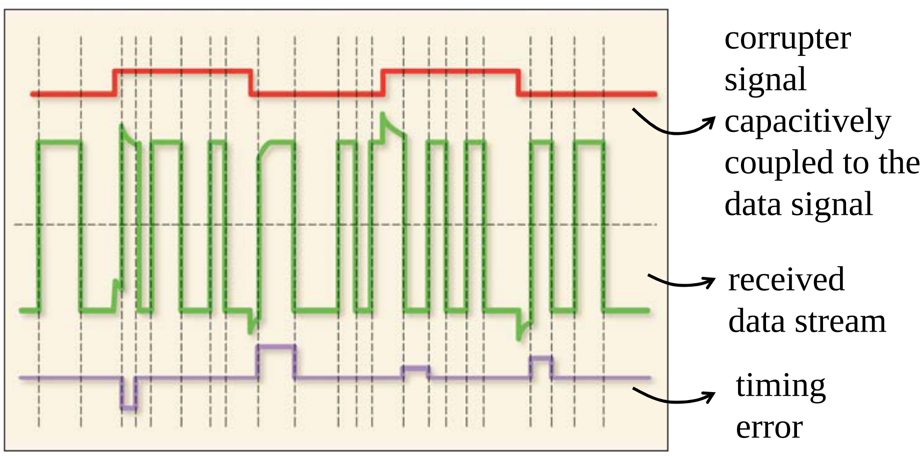

Figure 5 · Periodic Jitter (PJ) caused by capacitive coupling.

(J. Hancock - Agilent, High-Frequency Electronics Journal, June 2004)

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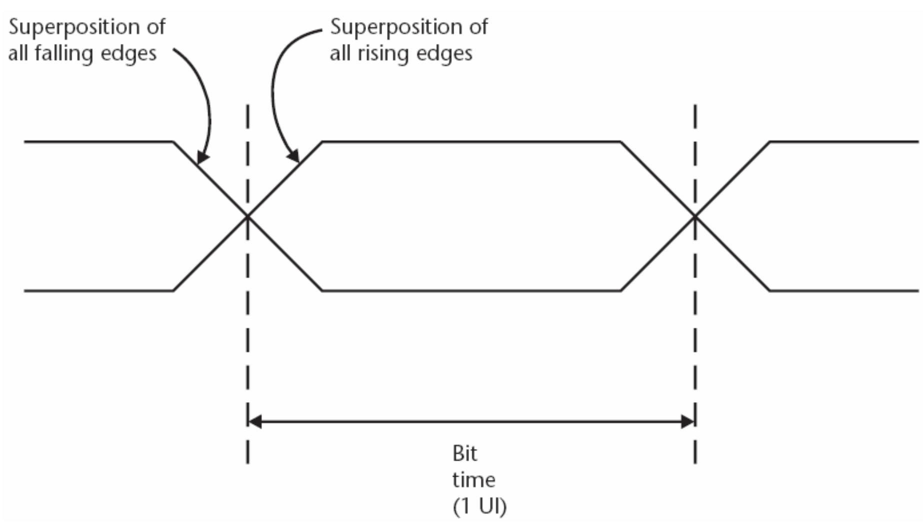
Eye Diagrams

- It is a visual aid to quickly evaluate the signal integrity of a data stream on an interconnect
- Eye diagrams are created by overlaying the positive and negative pulses in a data stream on a fixed unit interval
- They can be displayed on an oscilloscope by sincronizing the horizontal sweep with the data pattern
- They can also be simulated using CAD tools

An Ideal Eye Diagram



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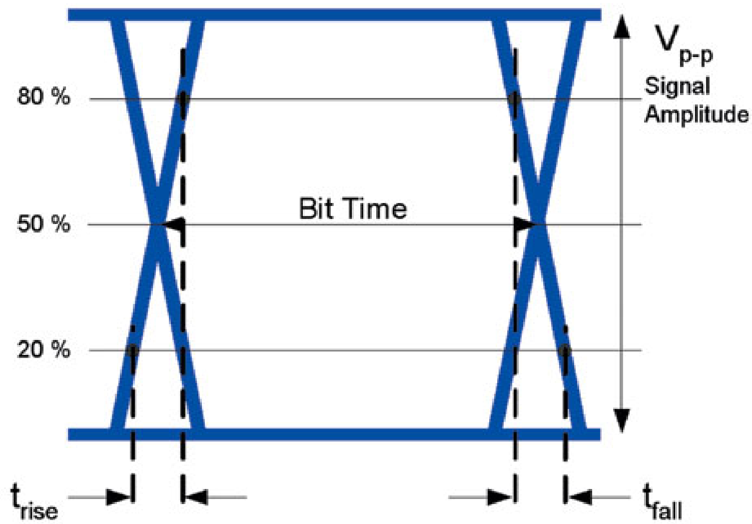
An Ideal Eye Diagram (cont)



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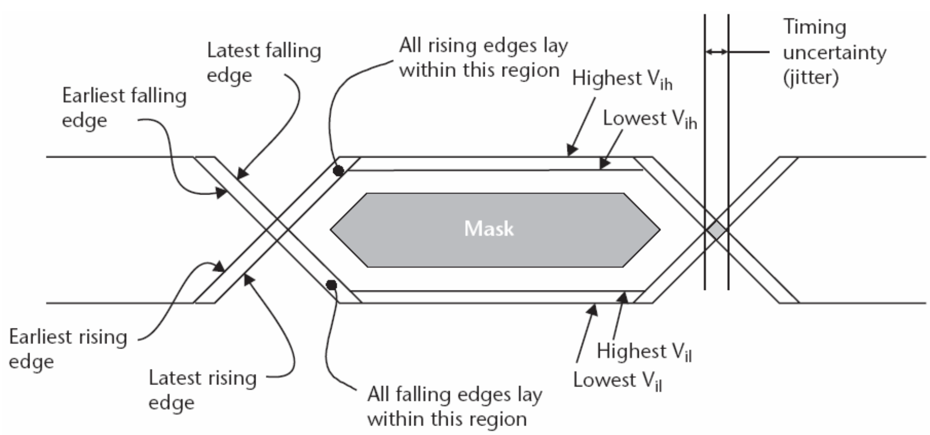
Mask of an Eye Diagram



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A Measured Eye Diagram

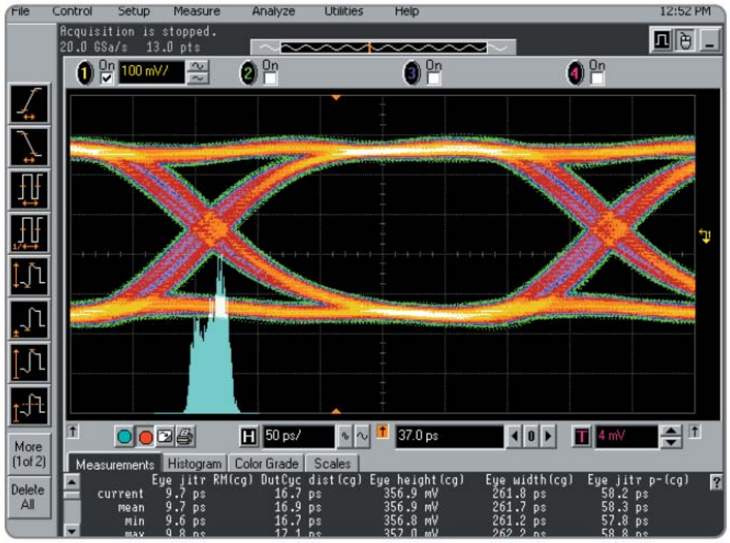
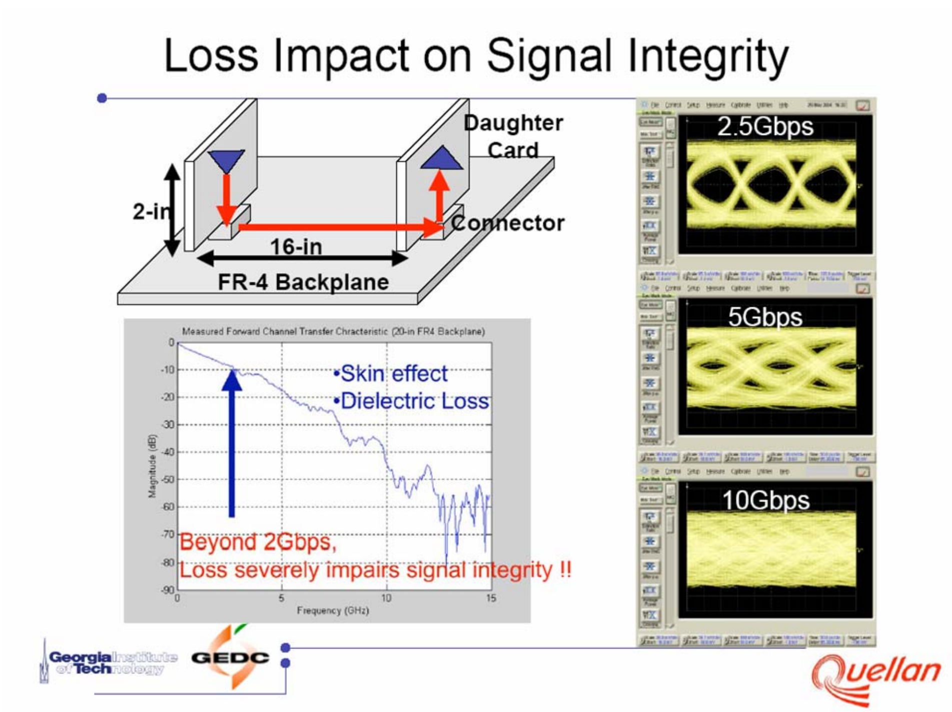


Figure 5: Eye diagram with the 54850 Infiniium oscilloscope



Figures of Merit of an Eye Diagram

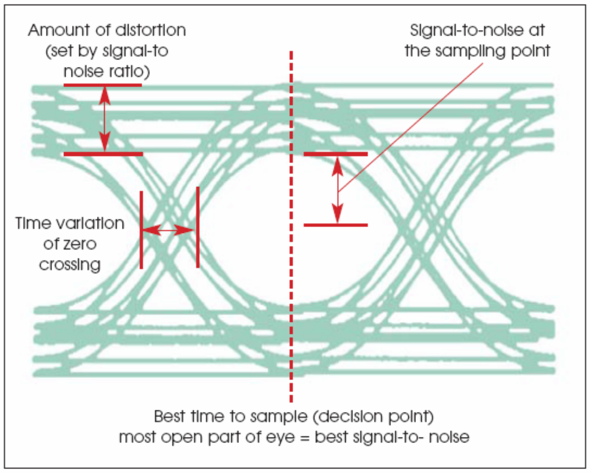


Figure 3 · Basic information contained in the eye diagram. The most important are size of the eye opening (signal-to-noise during sampling), plus the magnitude of the amplitude and timing errors.

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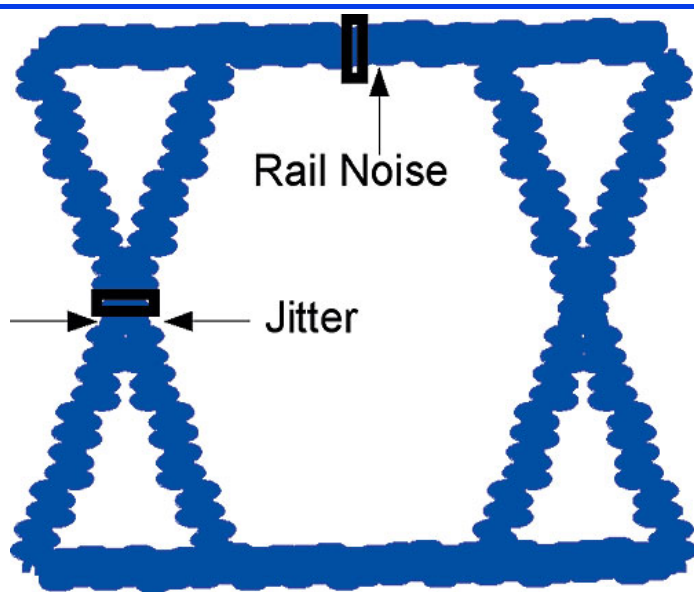
Figures of Merit of an Eye Diagram (cont)



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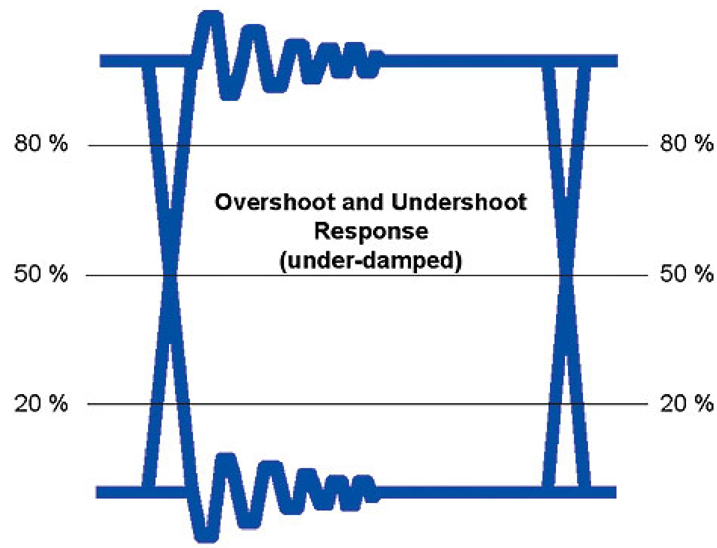
Figures of Merit of an Eye Diagram (cont)



(Z. Matni, Inphi Corp., Microwave Journal, Aug. 2003)

Equalization and Pre-emphasis

- These are techniques to open an eye diagram without changing the main interconnect
- Pre-emphasis essentially consists of transmitting the high-frequency portions of a waveform with more energy than those with low-frequency contents
- Pre-emphasis is usually realized internally in most gigabit SERDES

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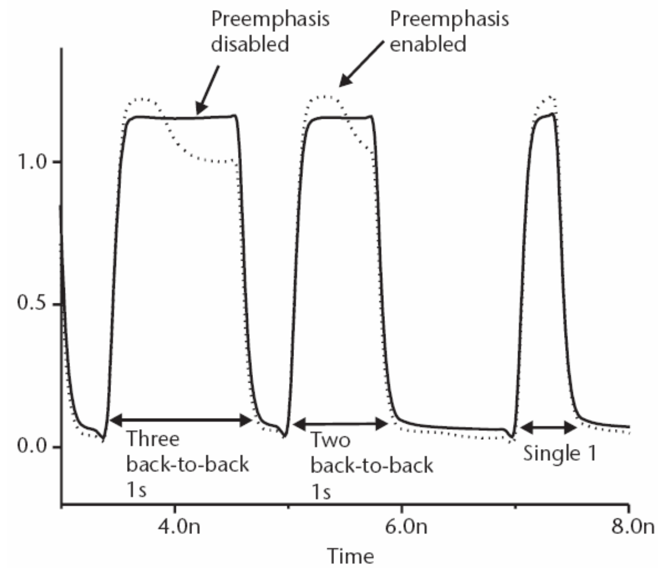
Example of Pre-emphasis

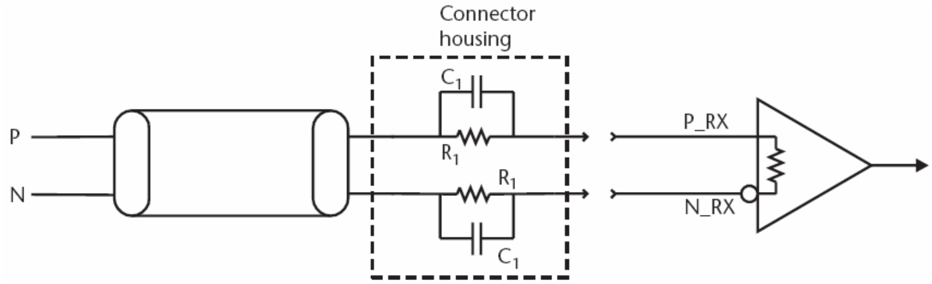


(S. C. Thierauf, High-Speed Circuit Board Signal Integrity, Artech, 2004)

Equalization

- Equalization is essentially a filtering technique to compensate for frequency-dependent amplitude and phase distortion
- Equalization can be implemented using analog or digital techniques
- The simplest equalizer consists of a high-pass filter in series with the transmission line
- Some buffers (receivers) internally incorporate an equalizer

An RC Passive Equalizer



$$R_1 = Z_o(K-1)$$

$$C_1 = \frac{1}{2\pi f_c Z_o}\frac{\sqrt{K}}{(K-1)}$$

$$IL(f) = 10\log\left(1+\frac{K^2-1}{1+K(f/f_c)^2}\right)\ \text{dB}$$

- f_c is the desired cut-off high-frequency
- IL is the insertion loss produced by the filter

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