IEEE CX4: Serial Transceivers over 15-m InfiniBand Cables

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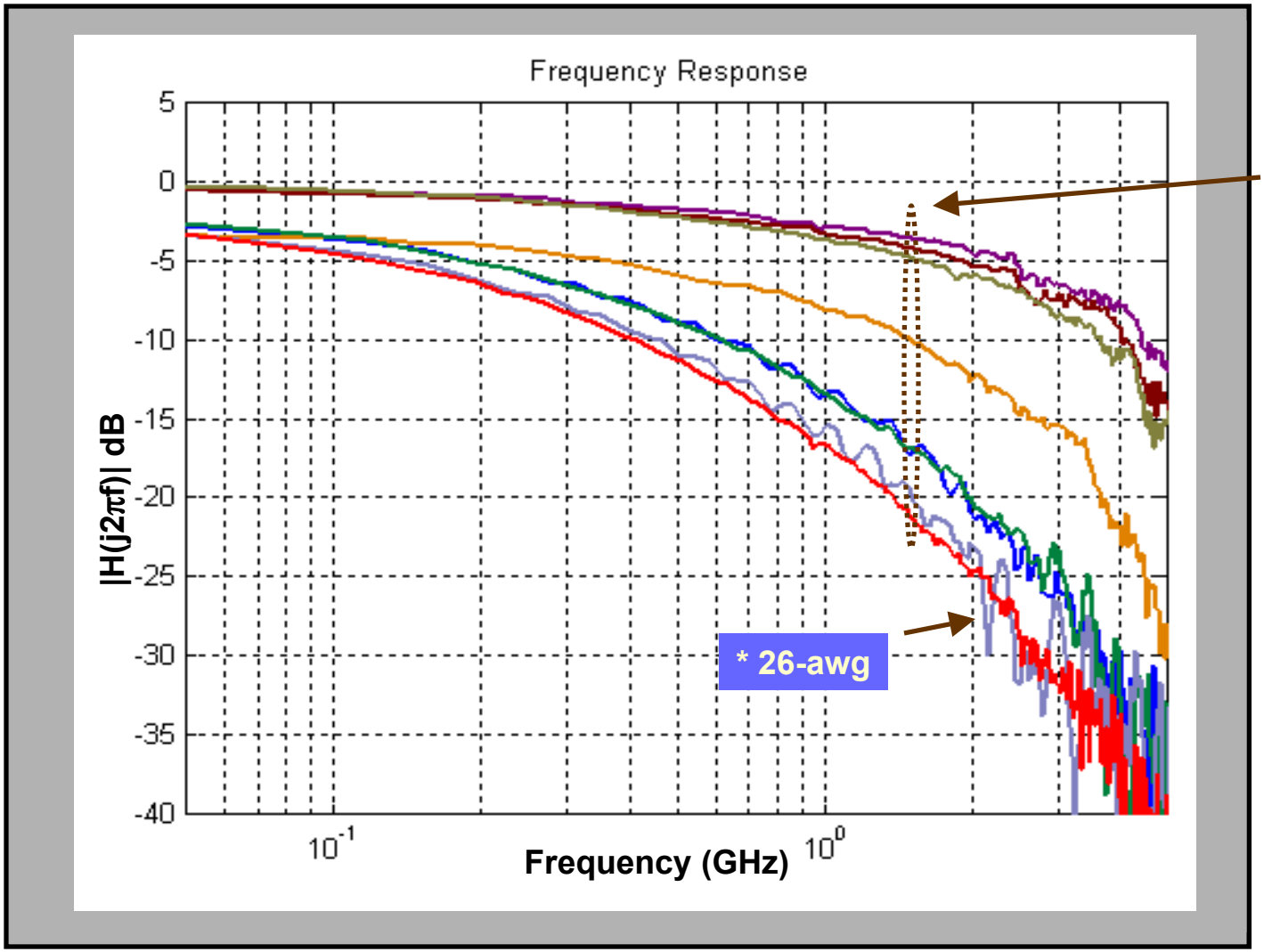
Time to Market: Leverage of XAUI TXVRs

- 2 approaches:
  - totally new spec
  - retrofit XAUI
- Leverage known solutions and existing silicon
  - 3.125-Gb/s solution exist with simple equalizers
  - Multiple silicon vendors have demonstrated samples
- Simulations & Measurements to determine limitations of 2-tap de-emphasis equalizer
  - Channel model & packages
  - Xtalk
  - Jitter

2-Tap Equalizer

Frequency Response: 24-awg InfiniBand Cables



Loss @ 1.5625-GHz

- 0.5m: -3.72 dB
- 1m: -4.40 dB
- 3m: -5.00 dB
- 10m: -10.26 dB
- 15m: -16.66 dB
- 15m: -17.15 dB
- 15m: -18.65 dB*
- 20m: -21.80 dB

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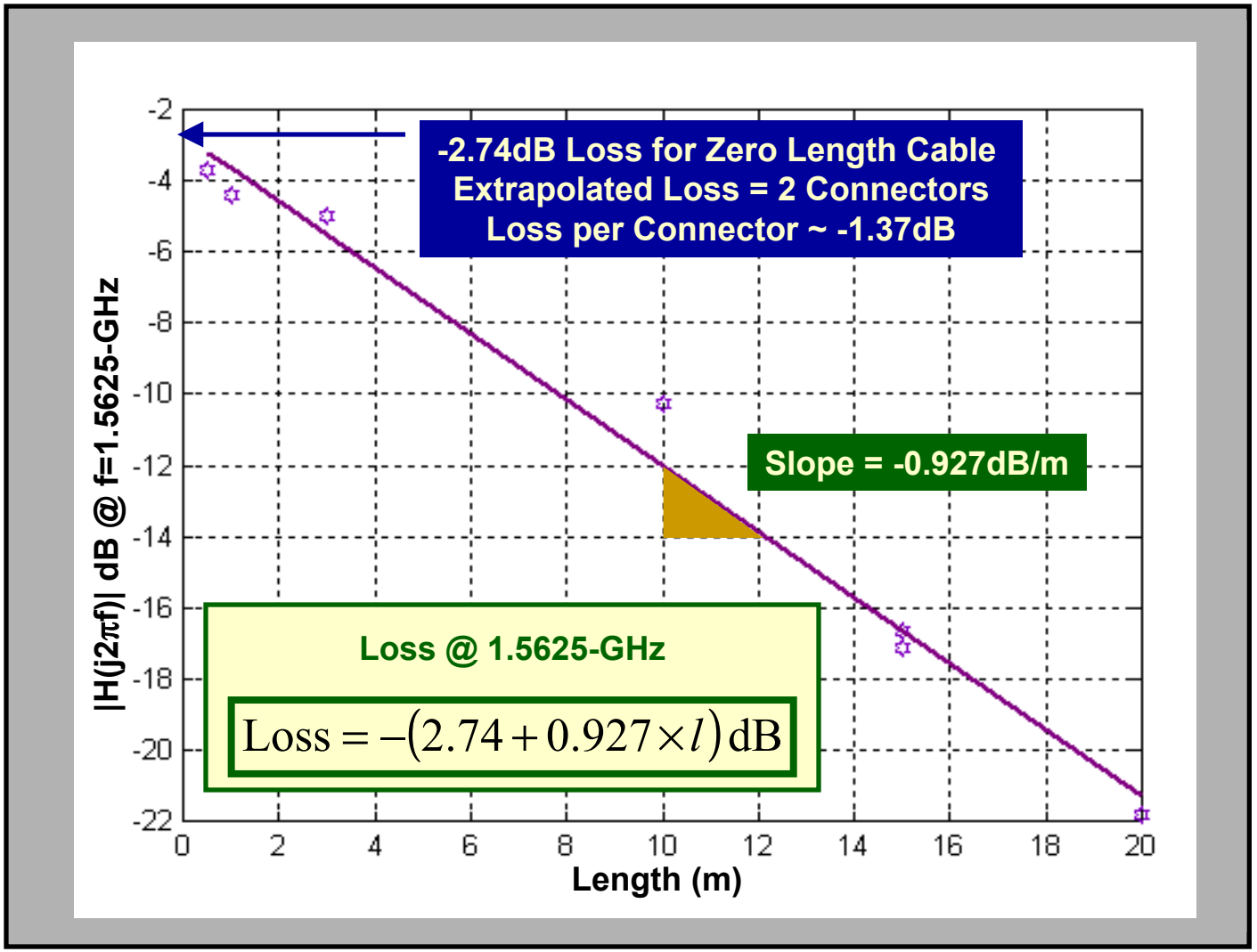
Attenuation vs. Length: 24-awg Cables



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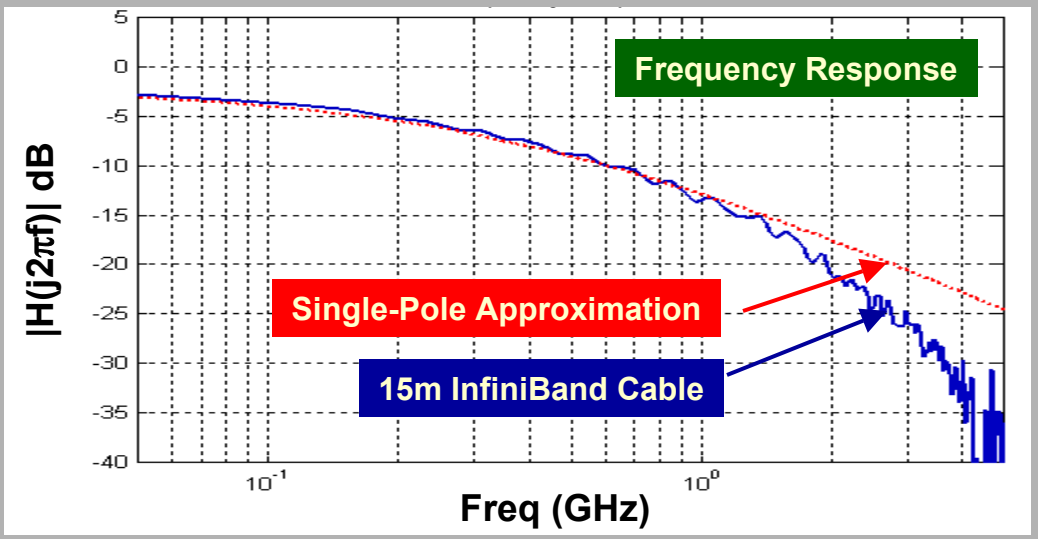
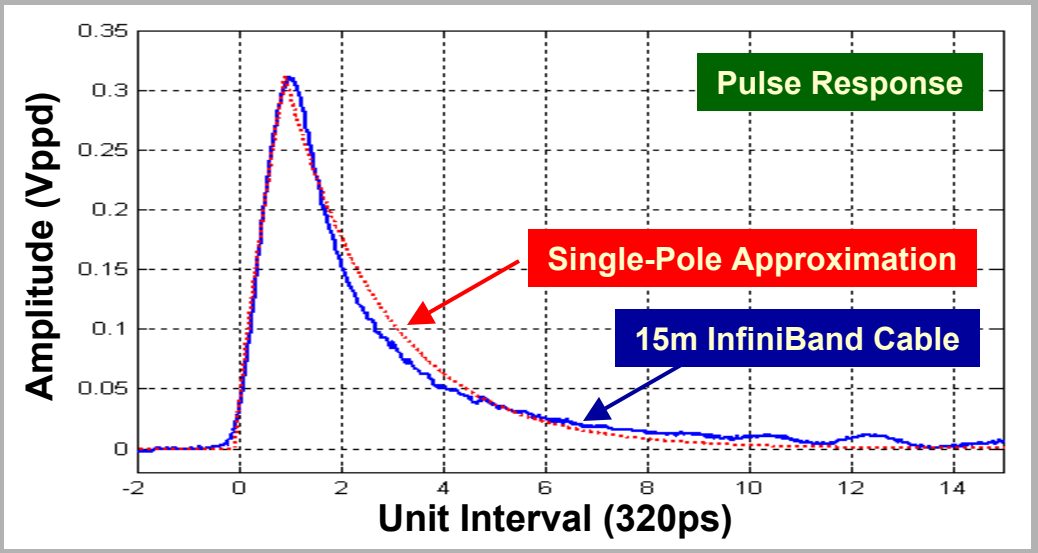
15m Cable: Approximation as 1-Pole Channel

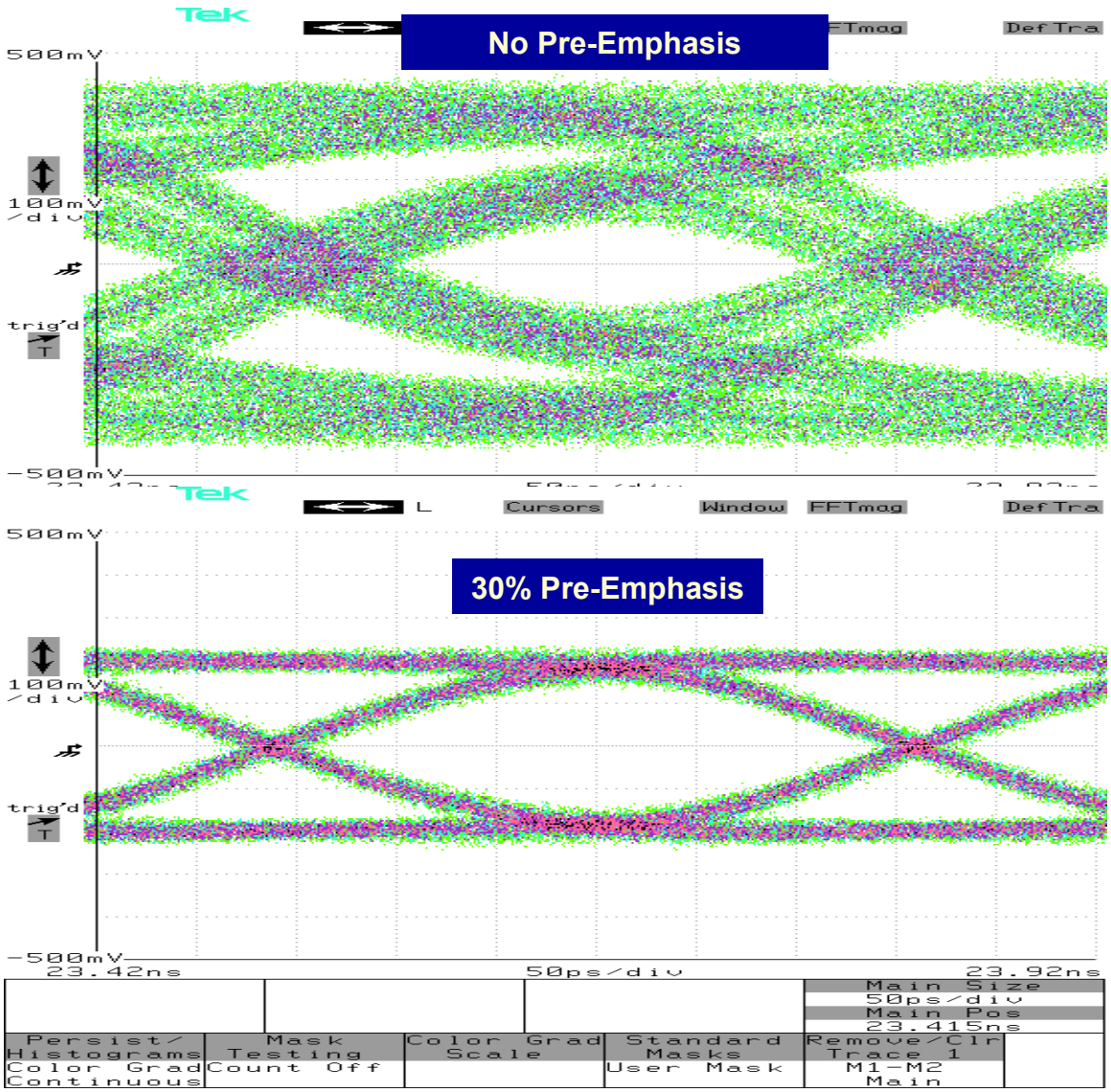


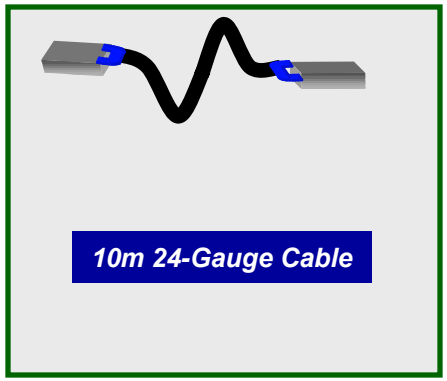


InfiniBand Cables can be approximated by a 1st-order (single-pole) roll-off for frequencies below 1.5625-GHz

Channel can be accurately equalized for frequencies up to 1.5625-GHz using a simple first-order equalizer. (2-Tap FIR)

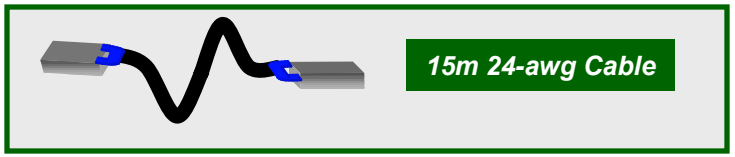
10-m Infiniband: 3.125-Gb/s Eye Diagrams

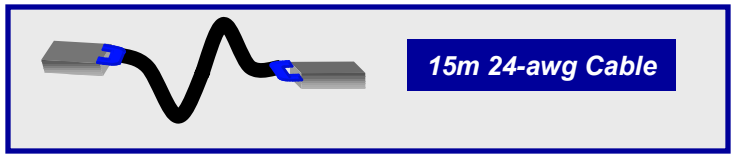


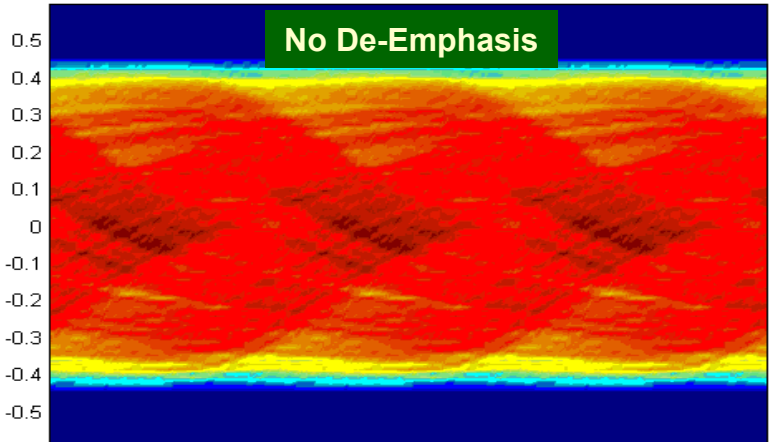


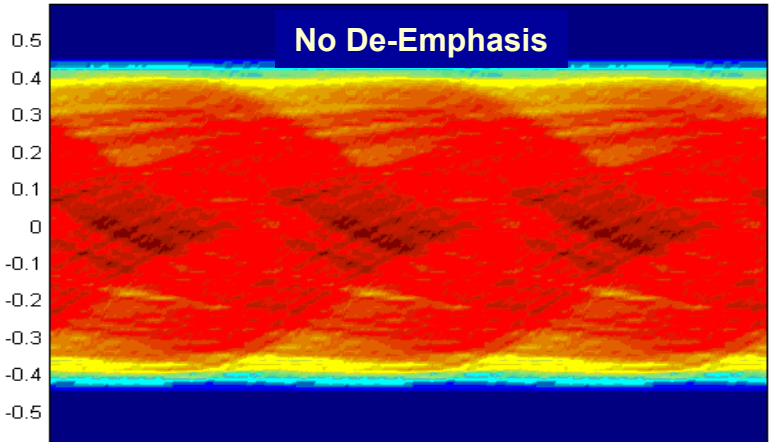
IEEE

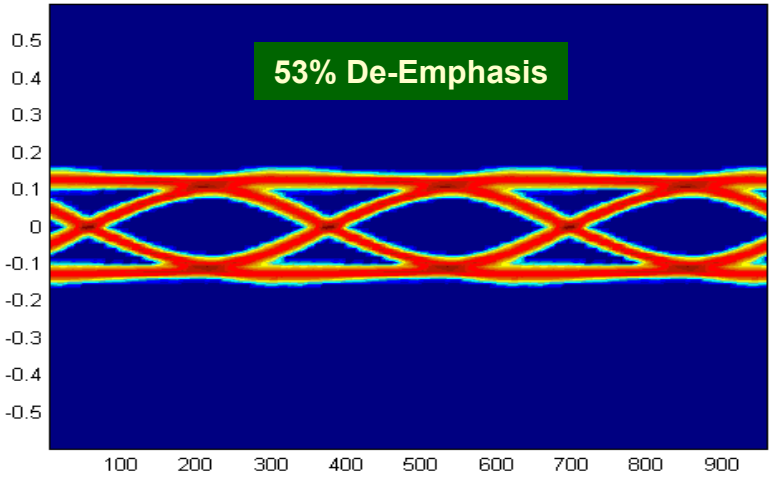
15-m Infiniband: 3.125-Gb/s Eye Diagrams

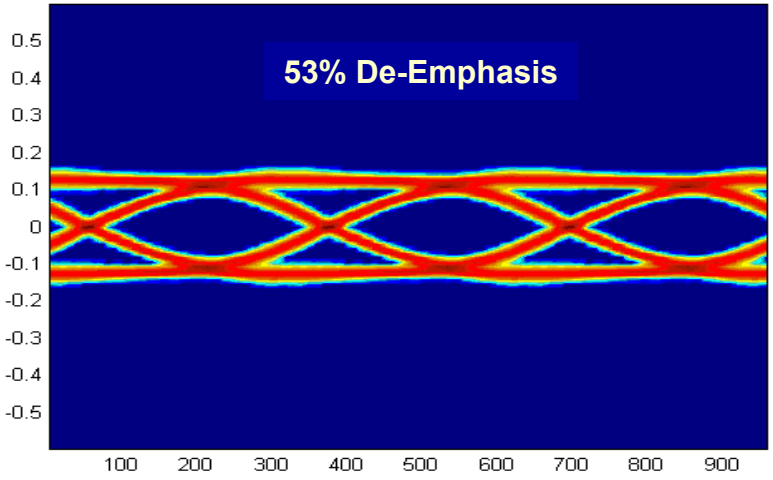




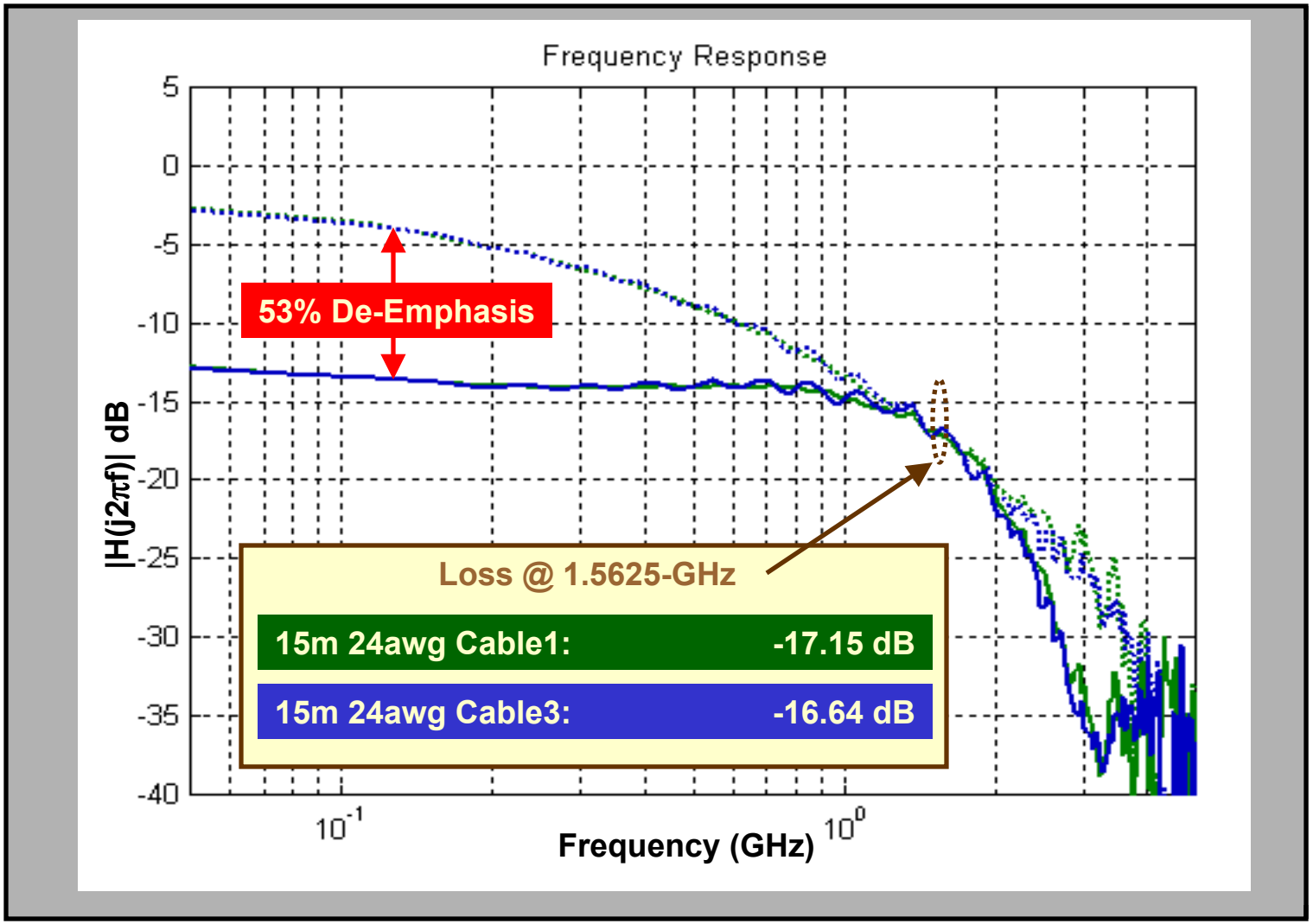








Frequency Response with 53% De-Emphasis



2-Tap De-Emphasis Equalizes Channel to 1.5625-GHz

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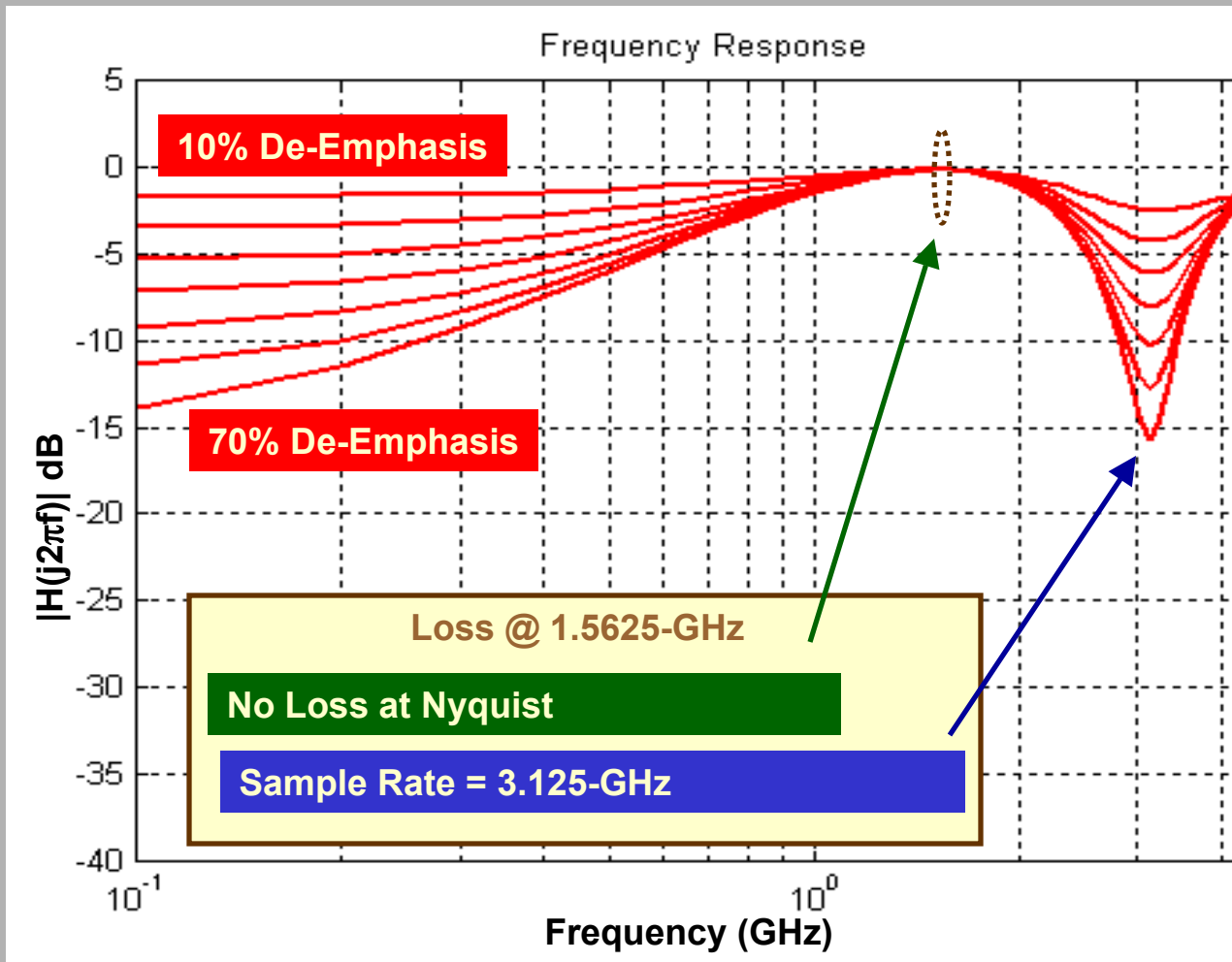
2-Tap De-Emphasis Frequency Response



2-Tap De-Emphasis Frequency Response for

- 10%
- 20%
- 30%
- 40%
- 50%
- 60%
- 70%

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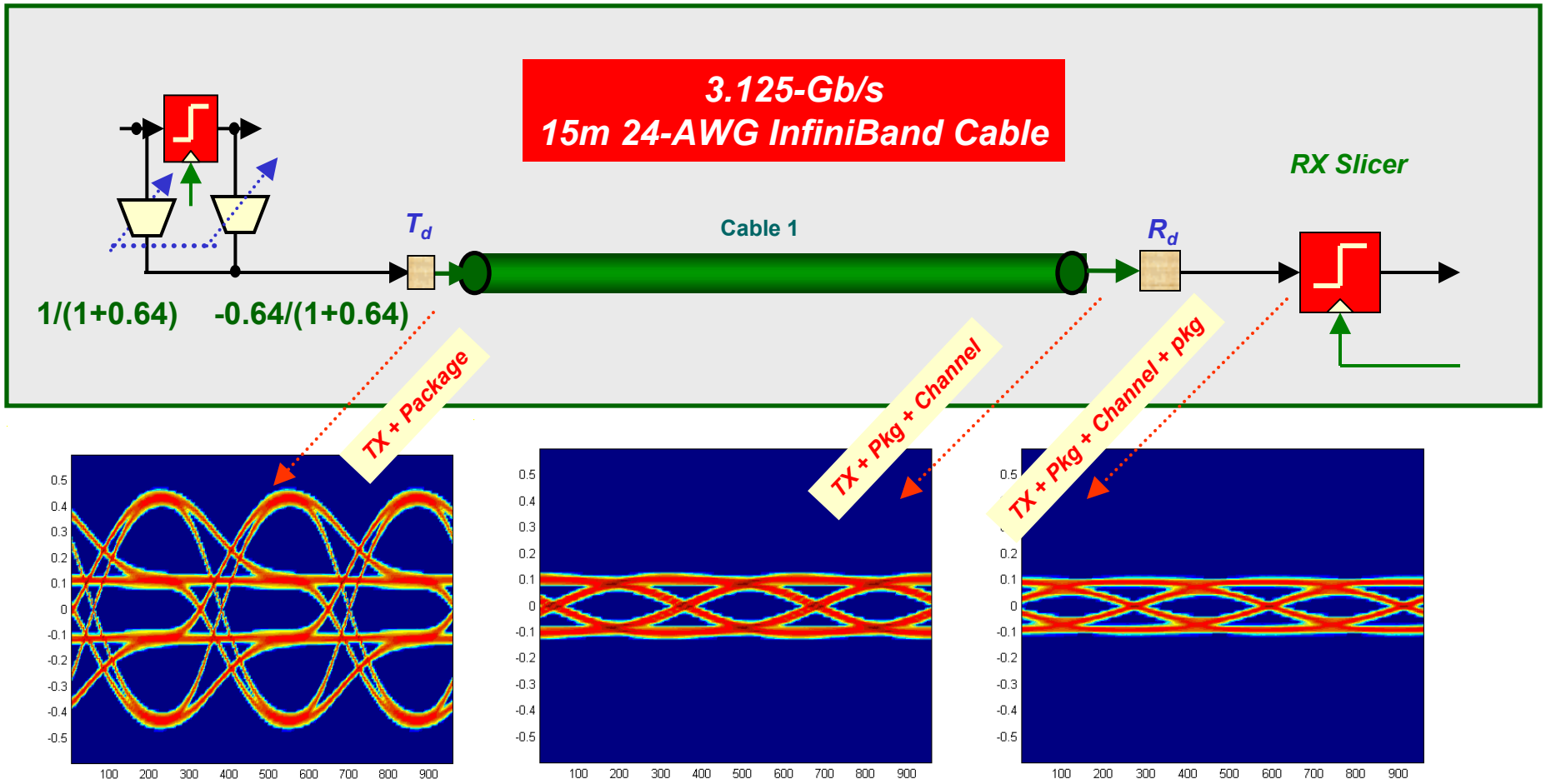
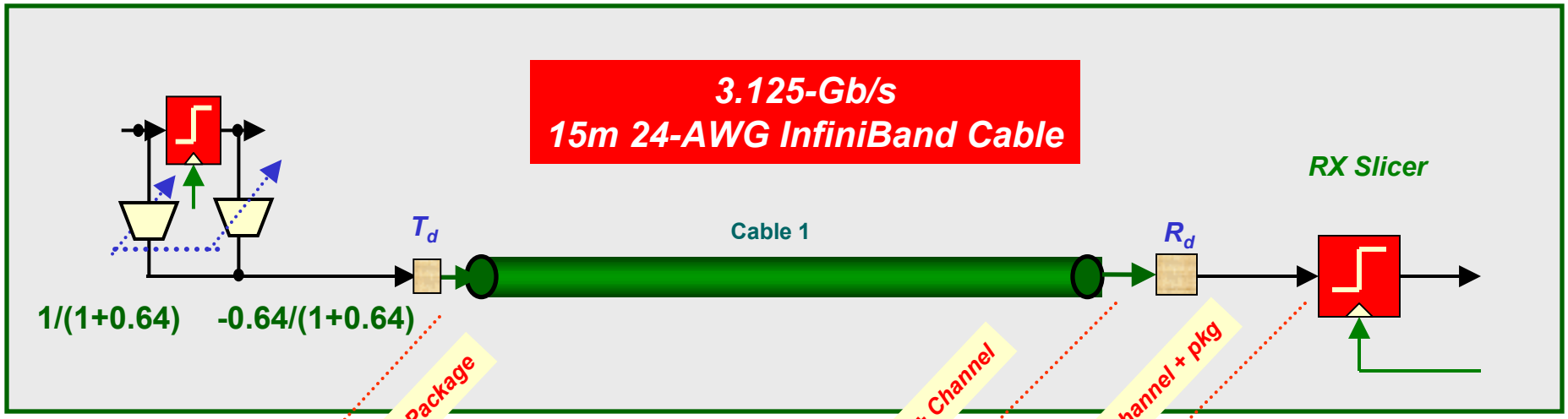
Accumulated ISI

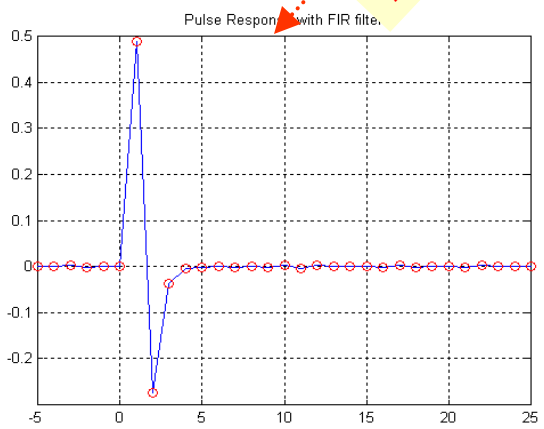
2-Tap De-Emphasis Transmitter: Eye Diagrams

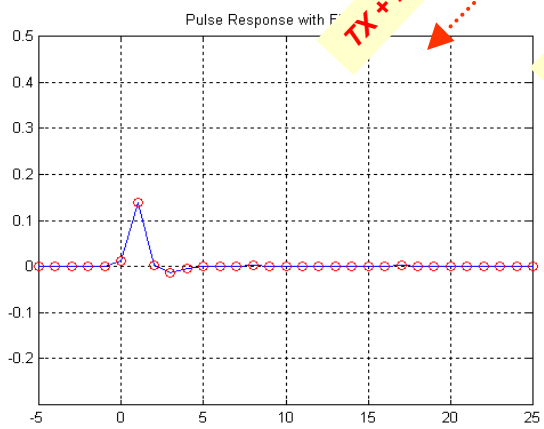


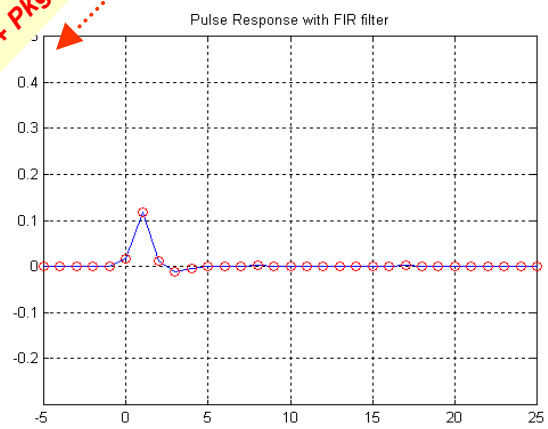
• Typical Eye Diagrams for 2-Tap De-Emphasis Transmitter

2-Tap De-Emphasis Transmitter: Pulse Response



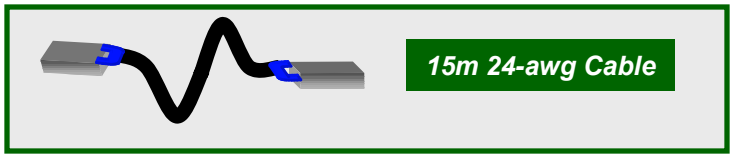


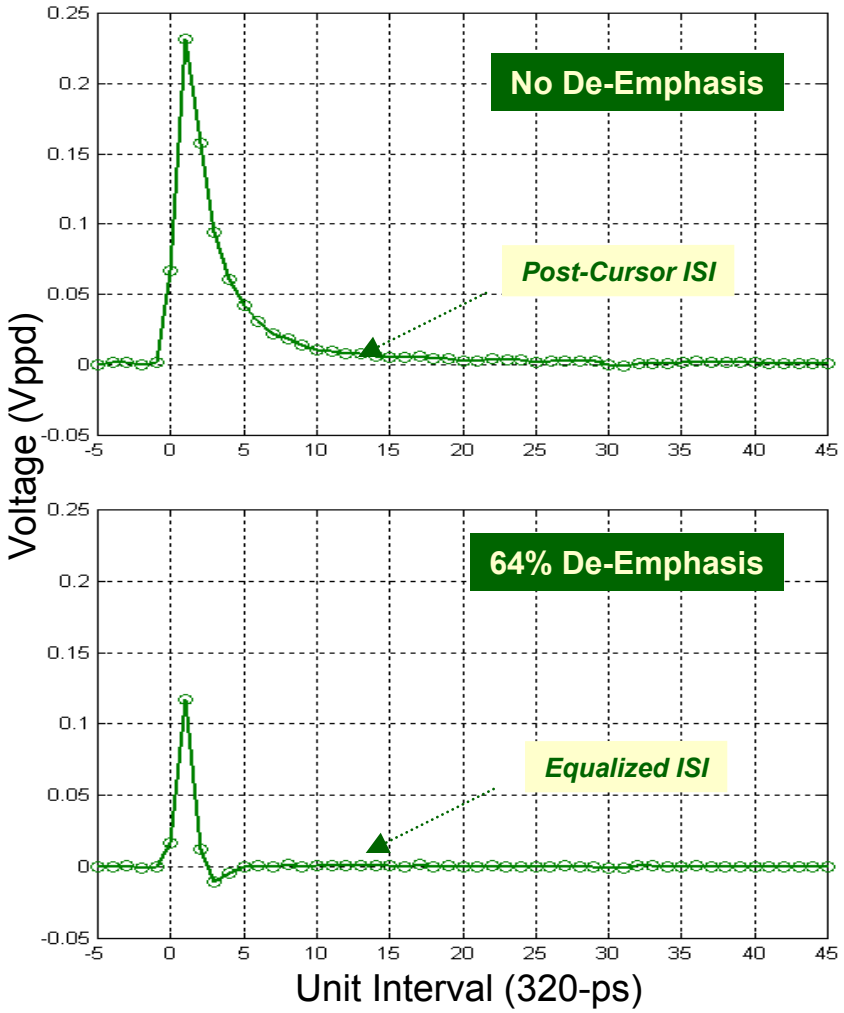


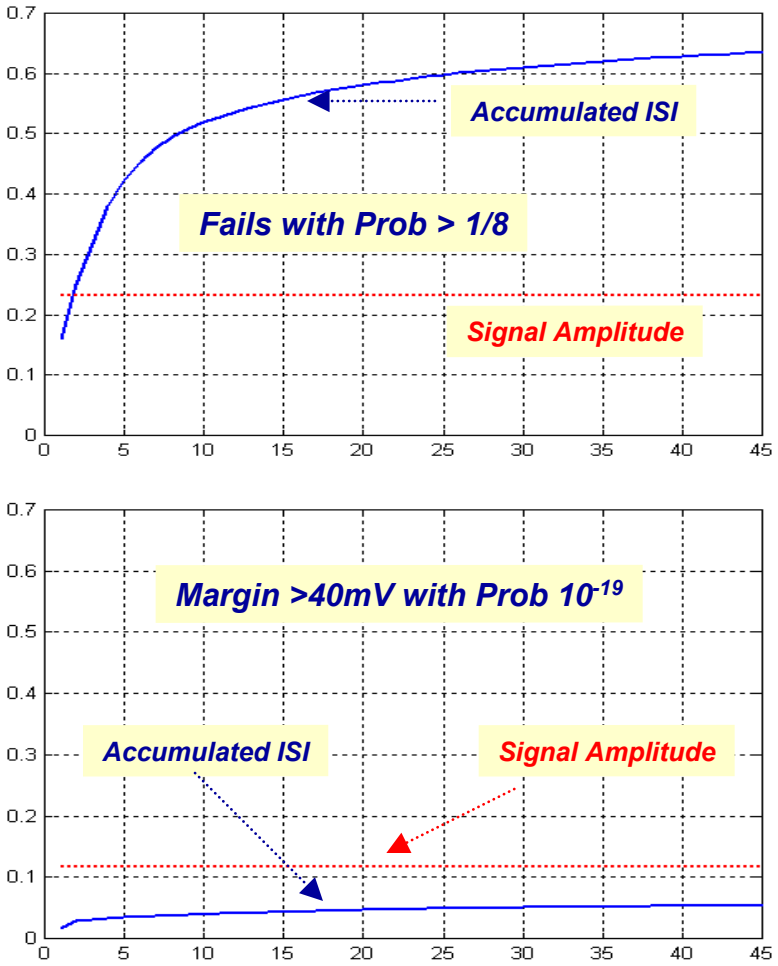


- Pulse Response at various points in the channel for 2-tap De-Emphasis

ISI Accumulation from Pulse Response

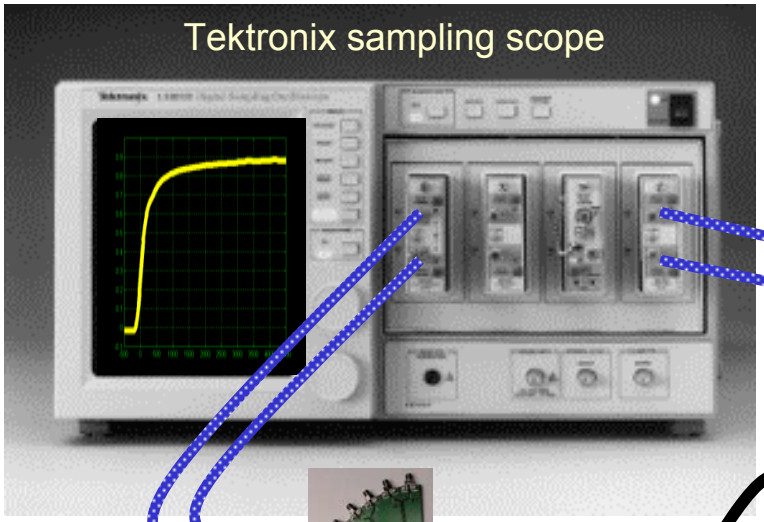






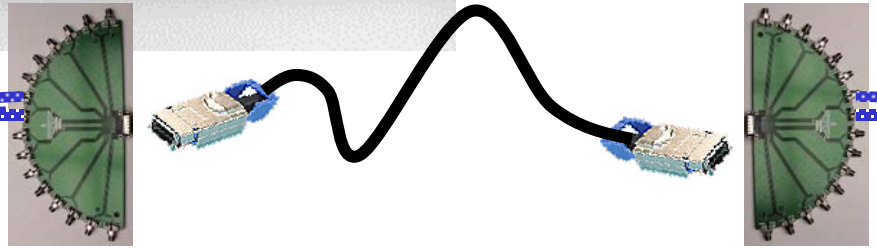
Xtalk

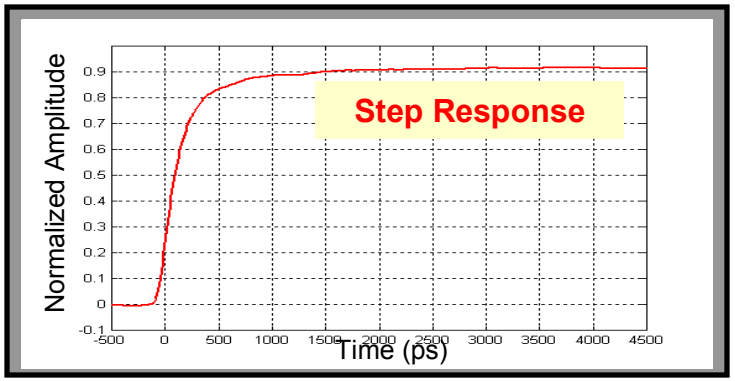
TDT Step Response & Impulse Response



TDT Measures step response directly

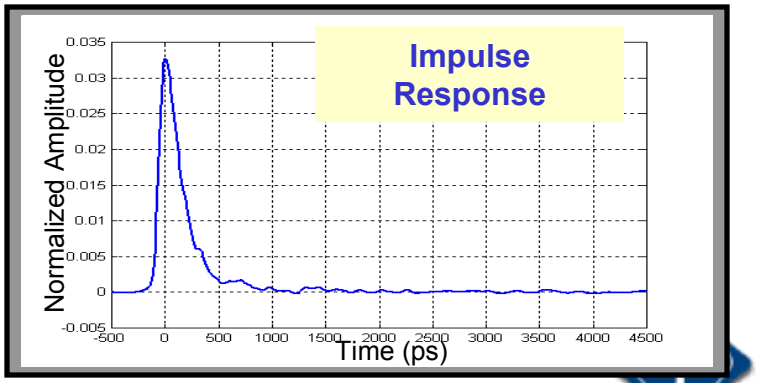
Impulse response obtained by differentiation



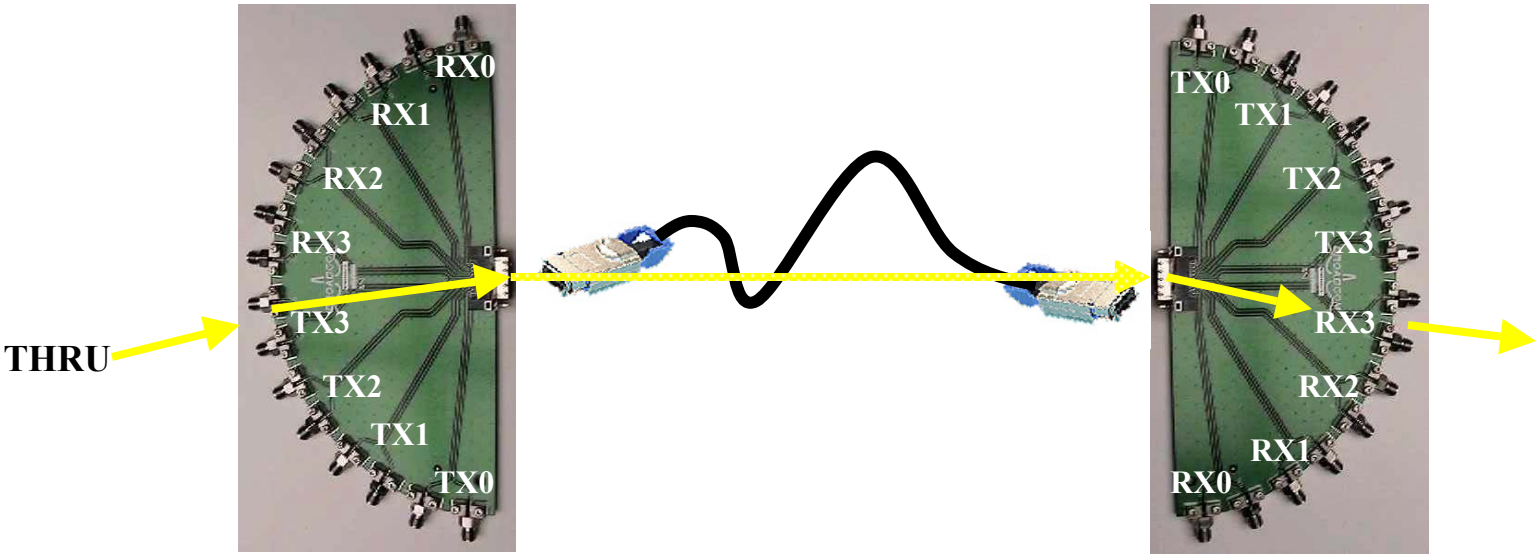


MATLAB

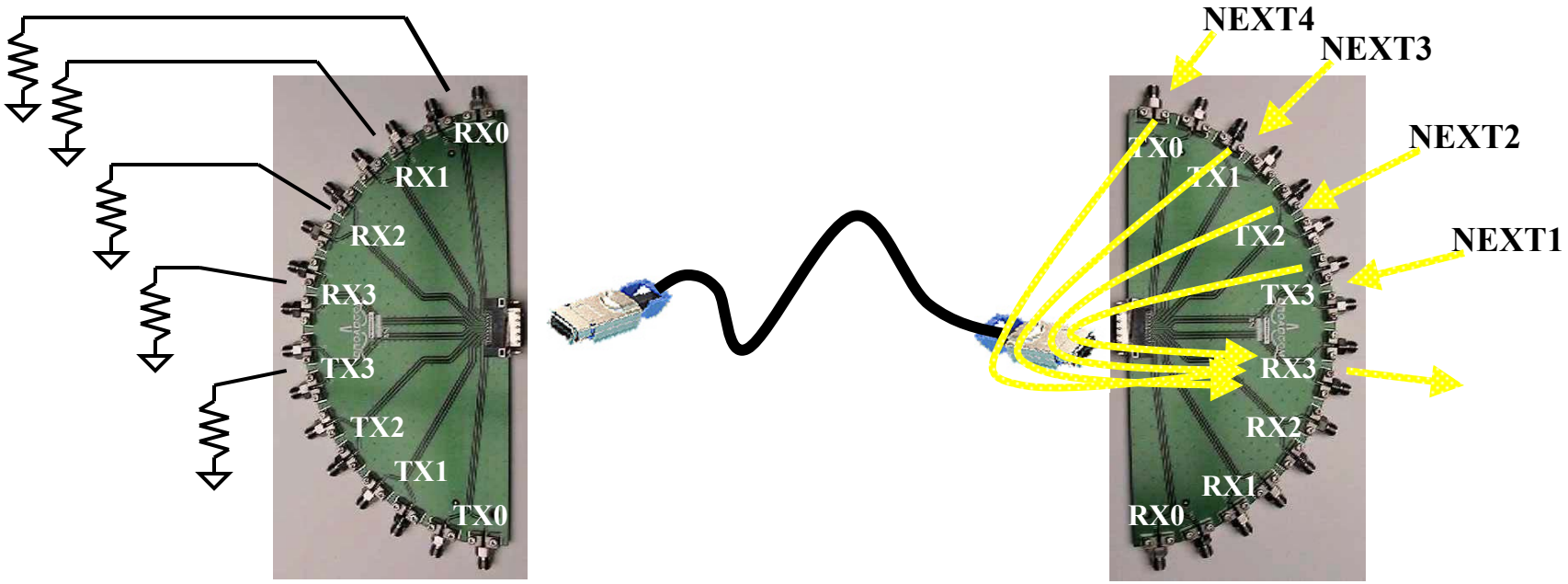
Differentiation



Thru Channel

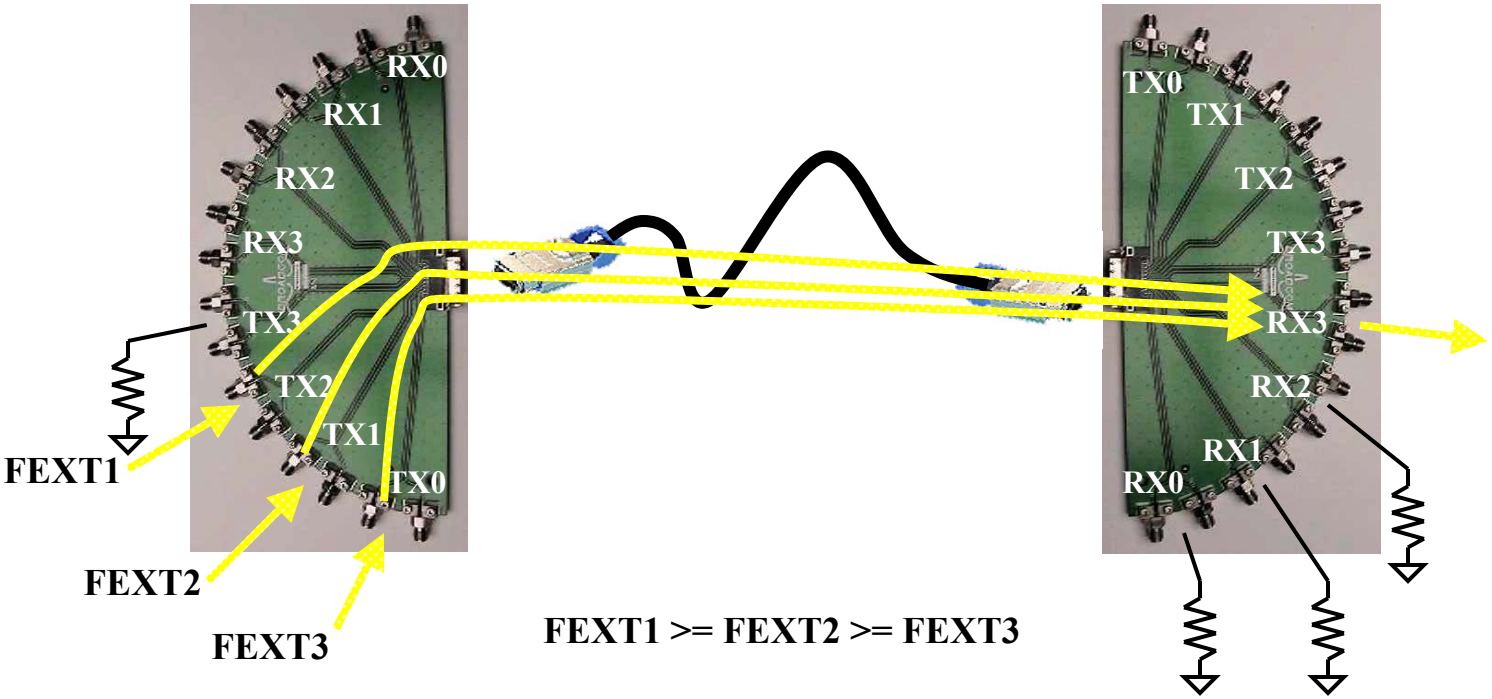


NeXT: Near-End Cross-Talk Definition

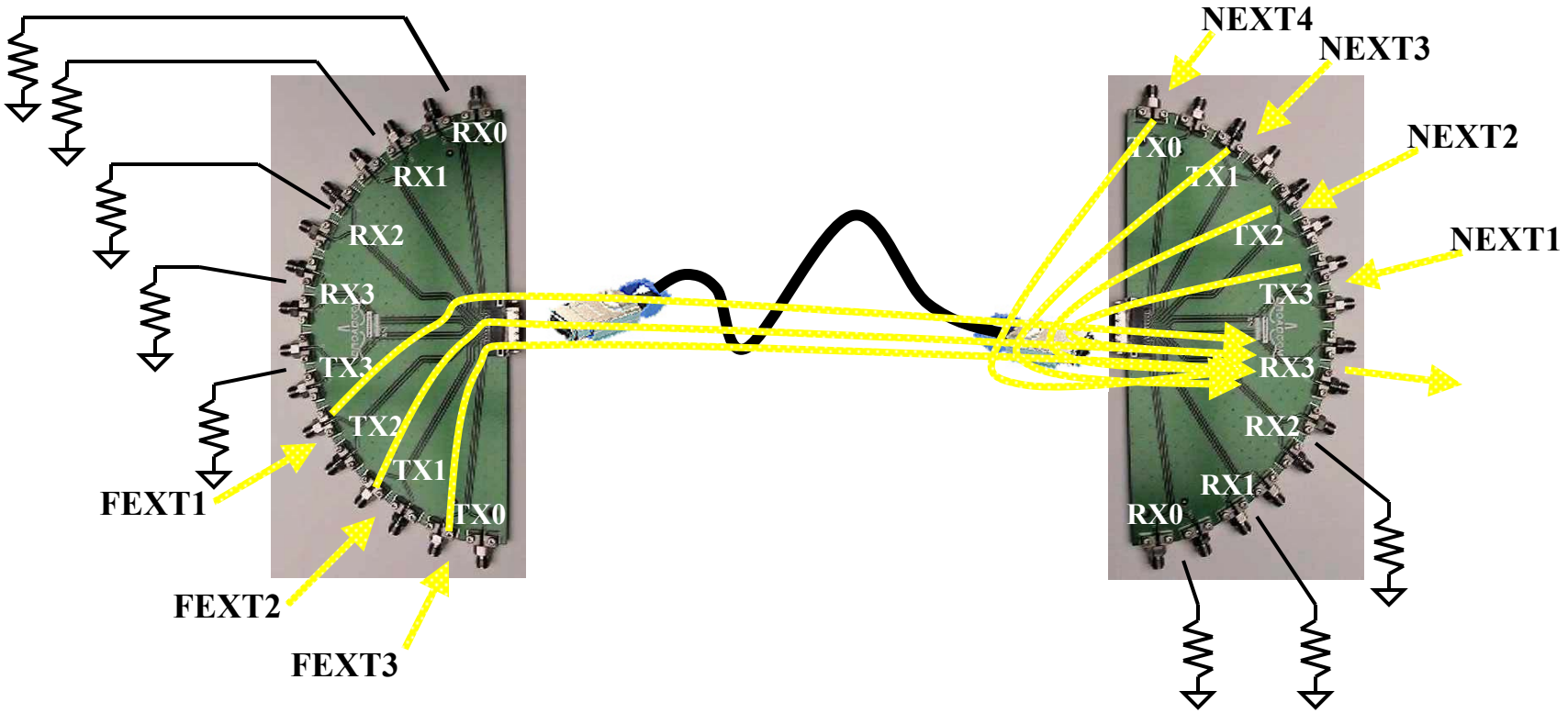


NEXT1 >= NEXT2 >= NEXT3 >= NEXT4

FeXT: Far-End Cross-Talk Definition



FCT: Full Cross-Talk Definition



FCT Equations for Each Trace

FCT3 = NEXT1+NEXT2+NEXT3+NEXT4+FEXT1+FEXT2+FEXT3

FCT2 = NEXT2+NEXT3+NEXT4+NEXT5+FEXT1+FEXT1+FEXT2

FCT1 = NEXT3+NEXT4+NEXT5+NEXT6+FEXT1+FEXT1+FEXT2

FCT0 = NEXT4+NEXT5+NEXT6+NEXT7+FEXT1+FEXT2+FEXT3

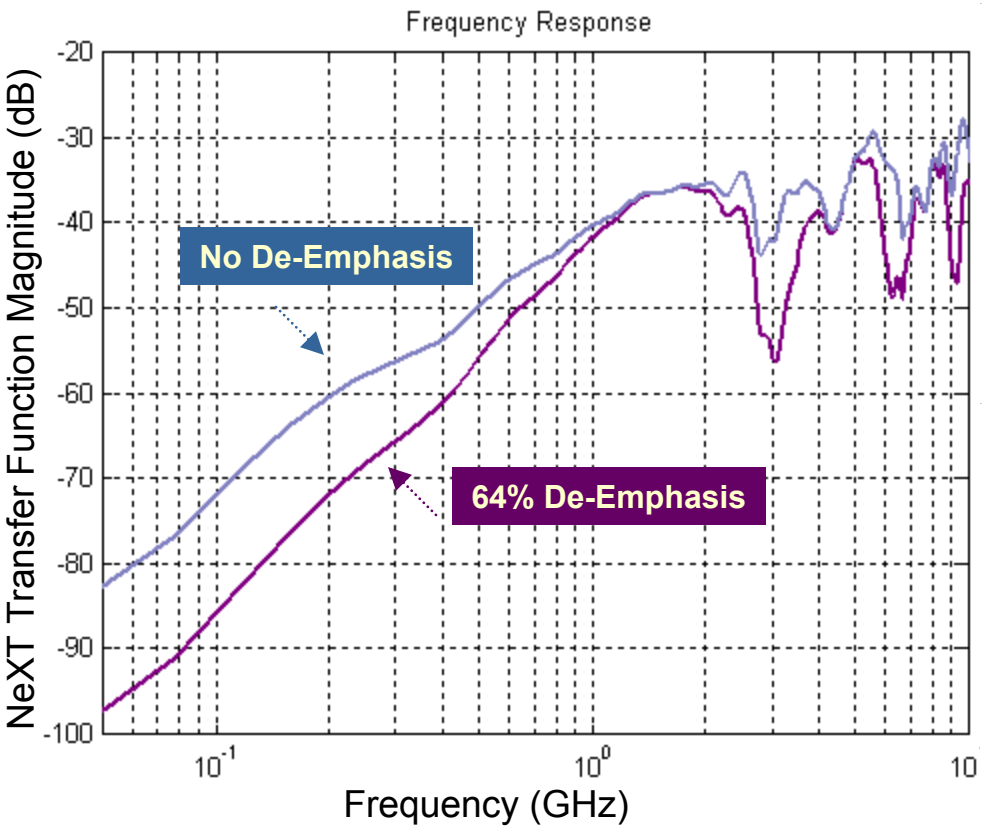
Worst Case: FCT3

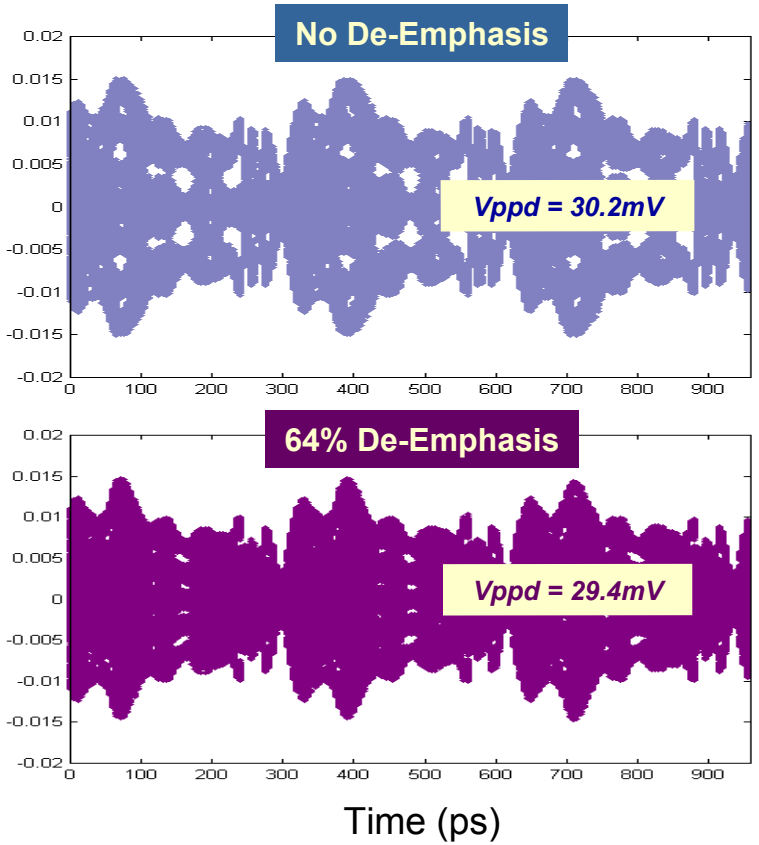
Best Case: FCT0

Cross-Talk: NeXT1 vs. De-Emphasis

15m 24-awg Cable1

1-Vppd Launch





De-emphasis reduces signal amplitude, but has almost no effect on Xtalk amplitude. De-emphasis reduces low-frequency content but leaves attenuation at Nyquist unchanged

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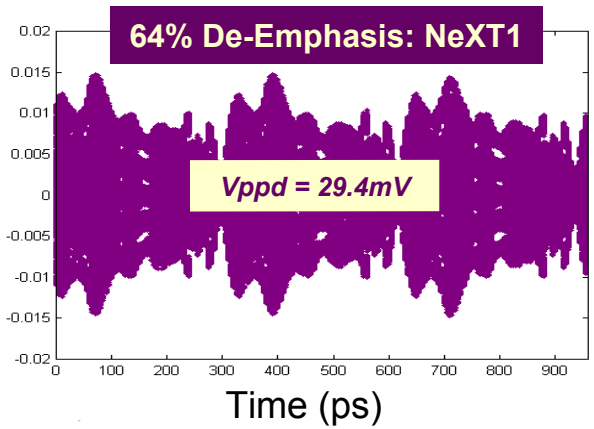
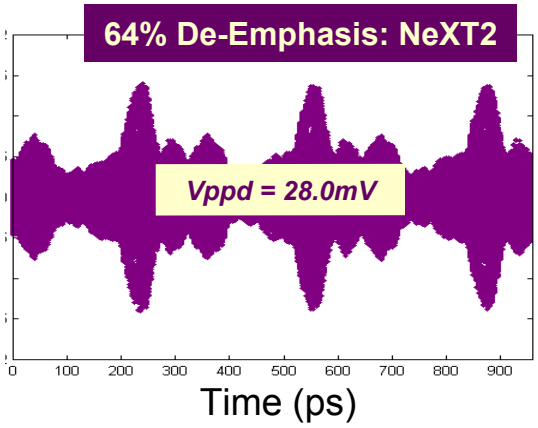
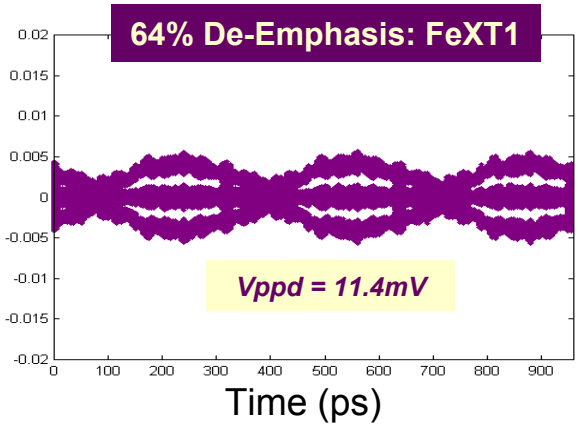
Cross-Talk: NeXT1, NeXT2, FeXT1

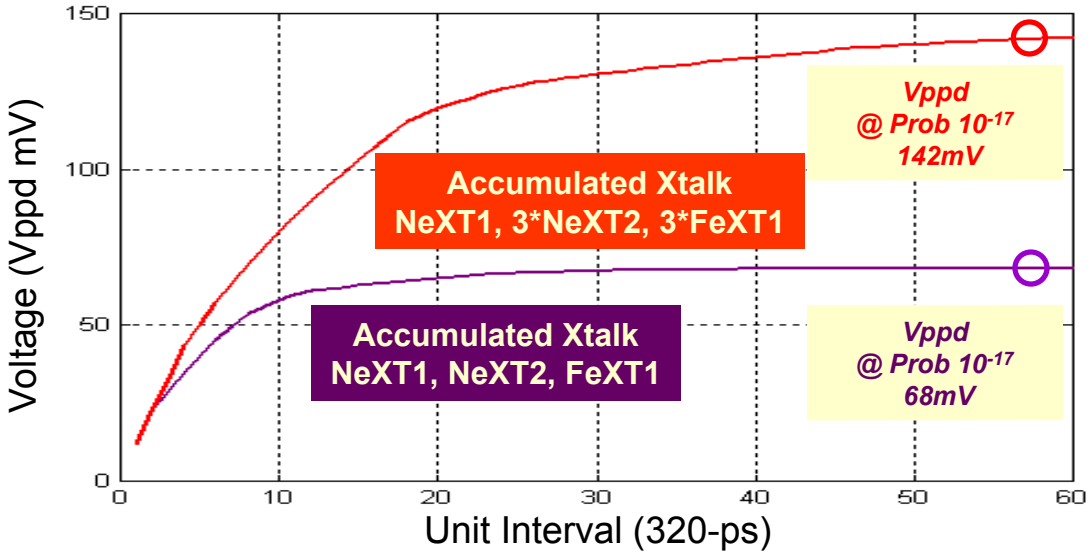
15m 24-awg Cable1

1-Vppd Launch









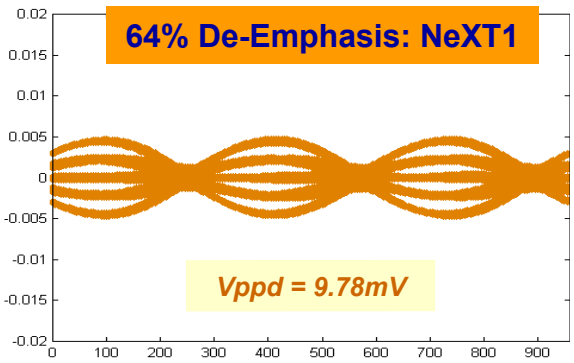
Accumulated Xtalk > 100mV for full MDNeXT with a 1-Vppd launch

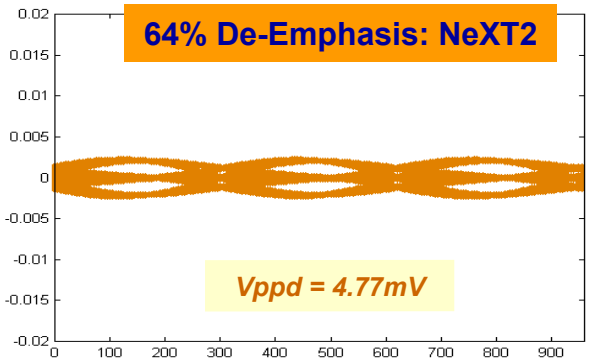
Still need full characterization of all NeXT and FeXT for complete modeling effort

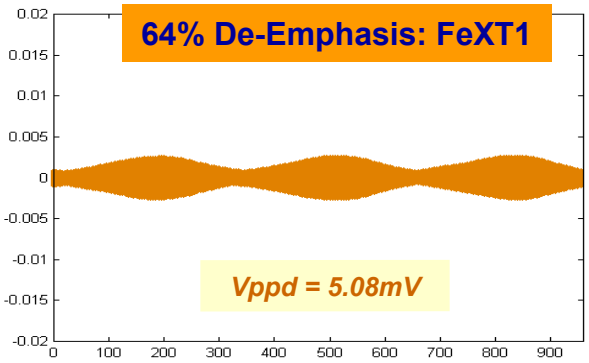
Cross-Talk with Package: NeXT1, NeXT2, FeXT1

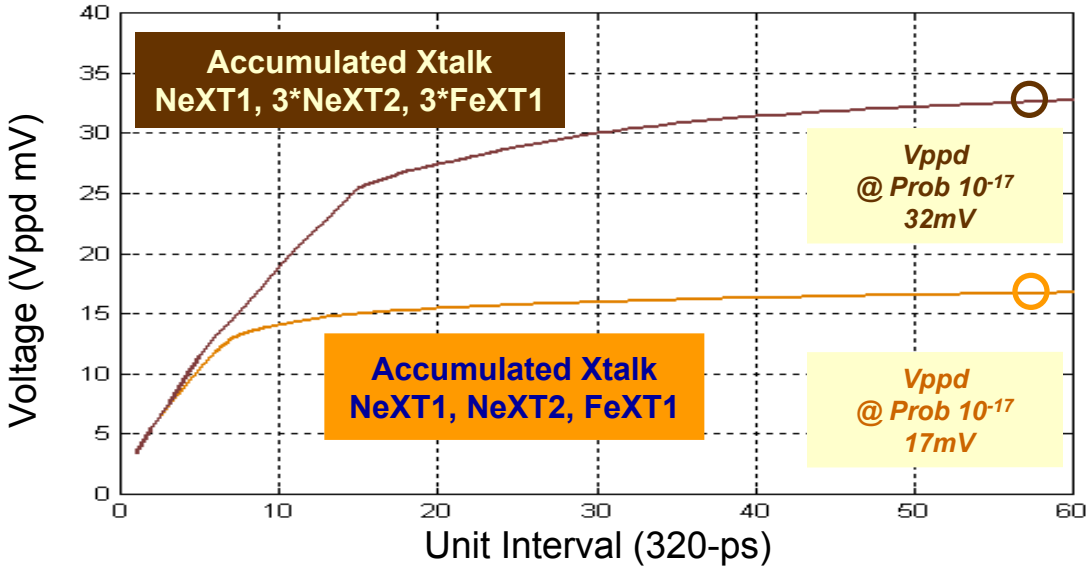
15m 24-awg Cable1

1-Vppd Launch





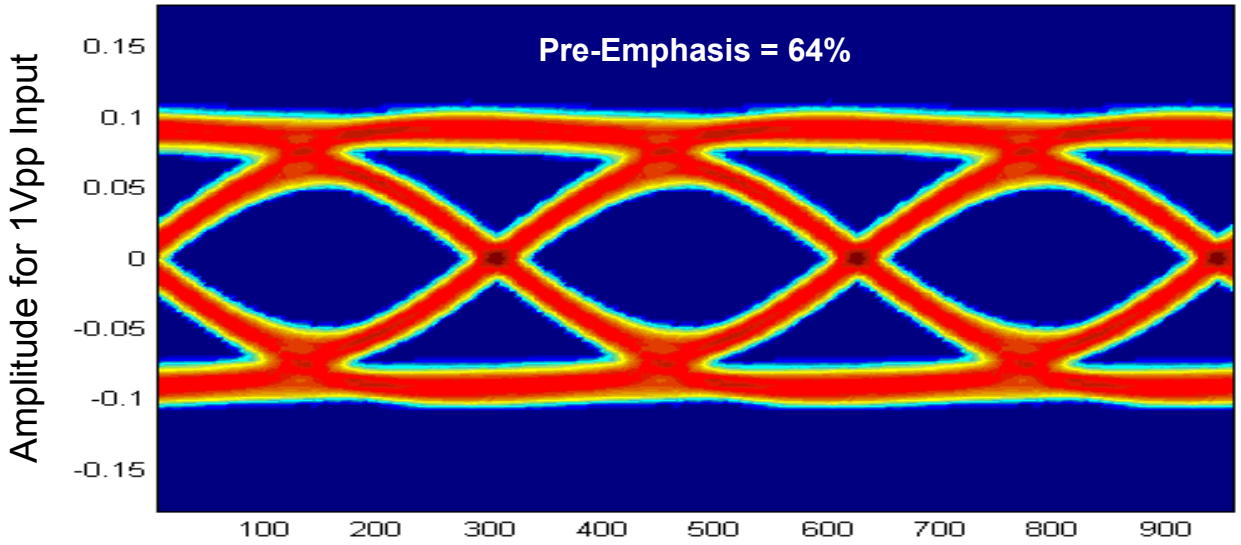


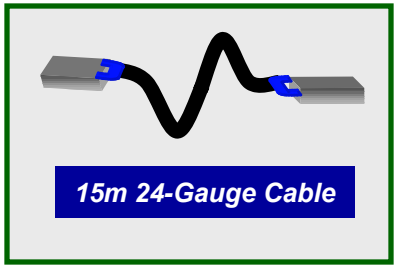


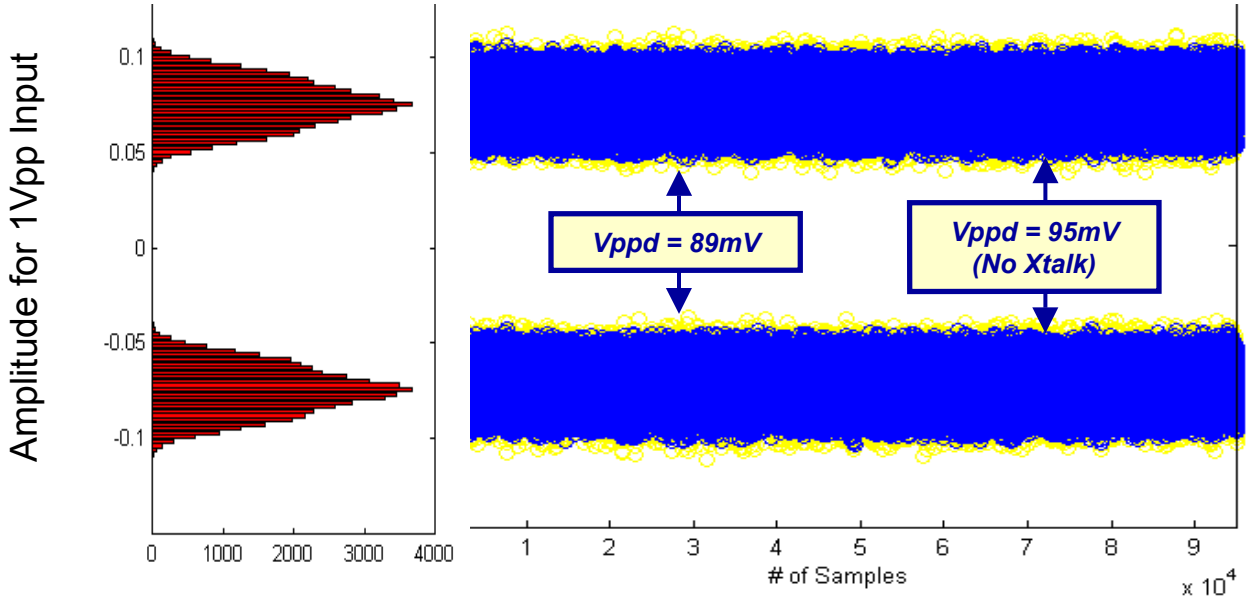
Cross-Talk is substantially reduced with Low-pass filter.

Package & ESD provides low frequency roll-off that reduces cross-talk by about 4x

15-m Infiniband: 3.125-Gb/s Eye Diagrams







A single simulations may not stimulate absolute worst-case cross-talk.

Worst-case requires worst-case pattern
and worst-case phase relationship between data channels

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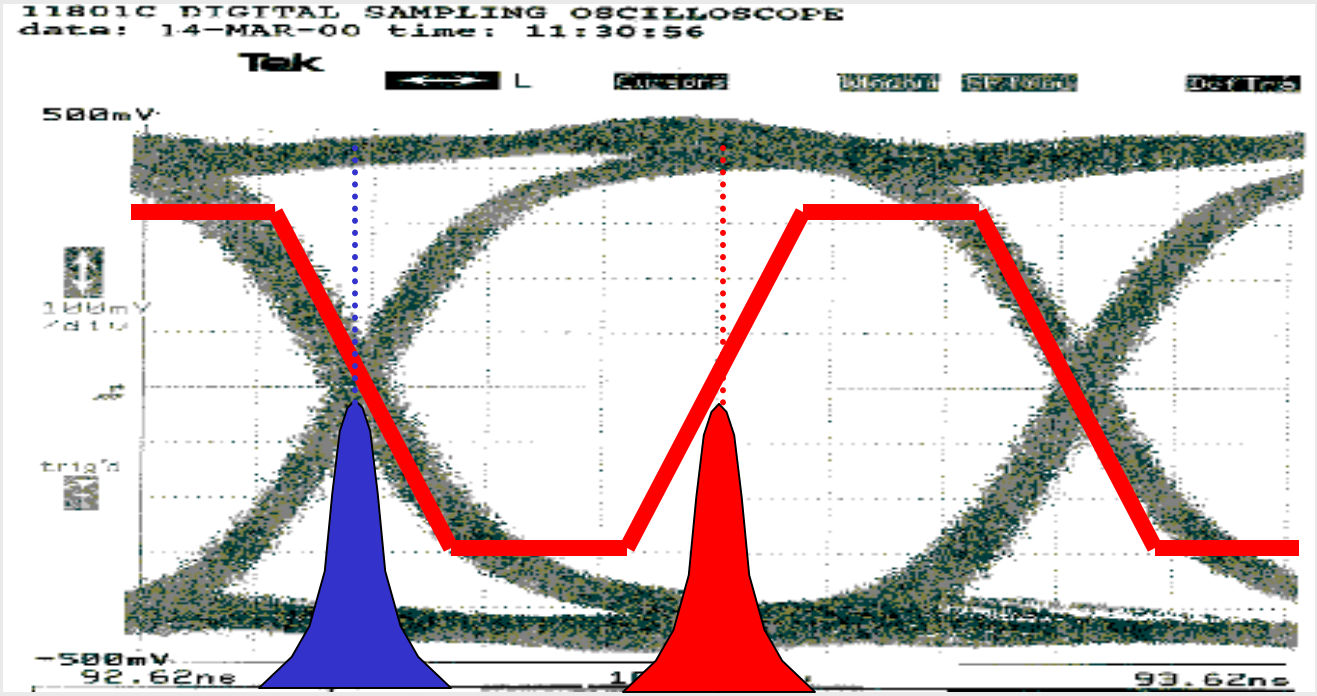
Jitter

TX & RX Jitter

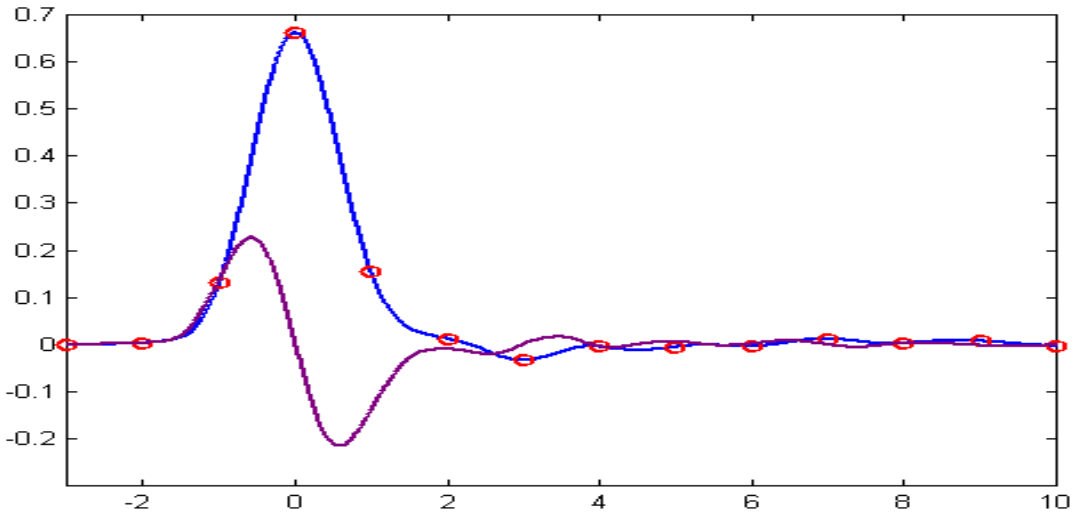


σ_{TX} = 4ps σ_{RX} = 4ps

Lumped total jitter is Gaussian with standard deviation σ_j

$$\sigma_J = \frac{4 \cdot \sqrt{2}}{320} \quad \text{UI}$$

Jitter Transfer Function



$$\sigma_e^2 = \sigma_J^2 \cdot \sigma_X^2 \cdot \sum_k h'(k)^2$$

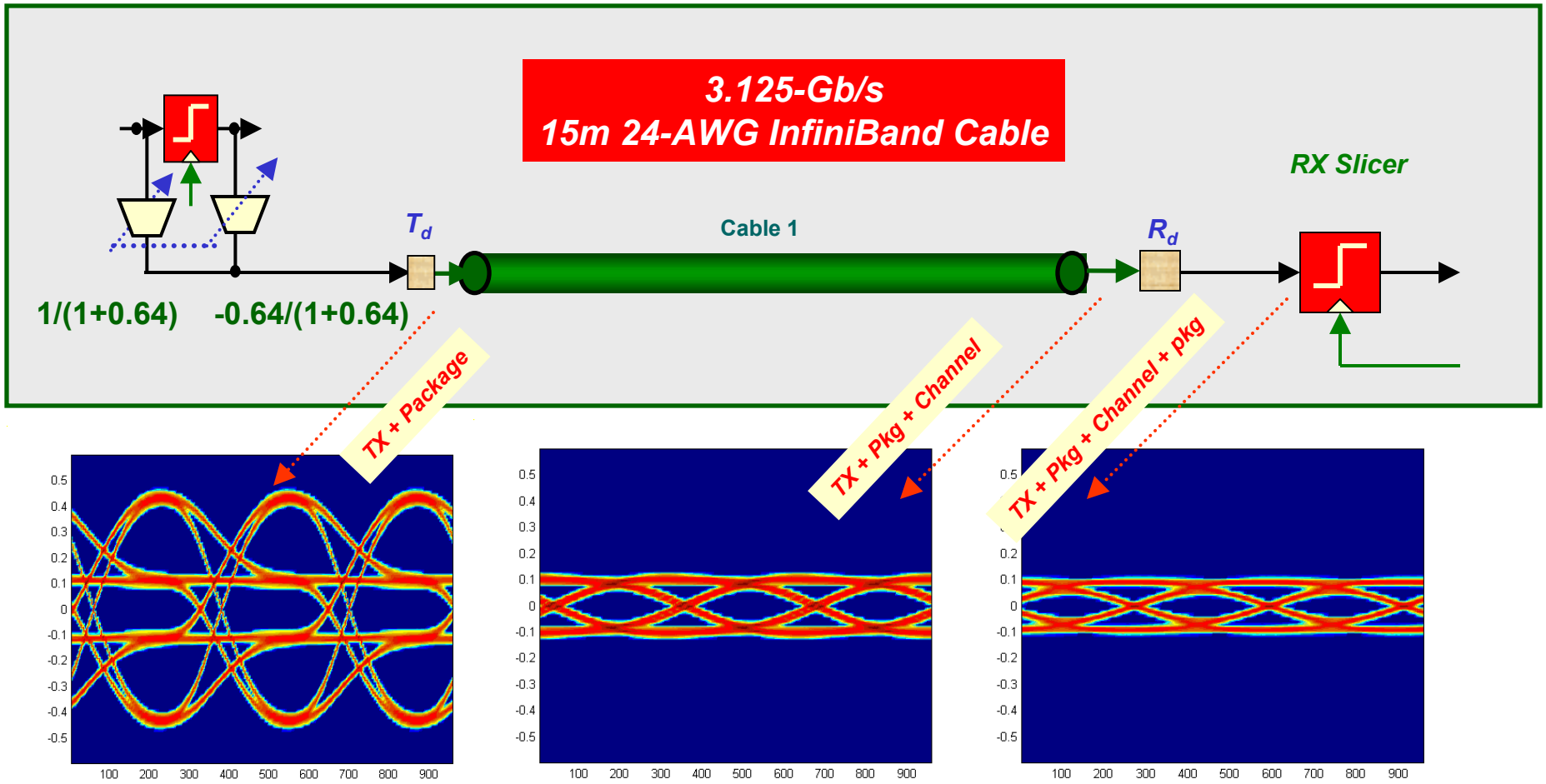
$$\sigma_X = 1$$

$$h'(k) = h(k+1) - h(k)$$

$$\sigma_J = \frac{4 \cdot \sqrt{2}}{320} \text{ UI}$$

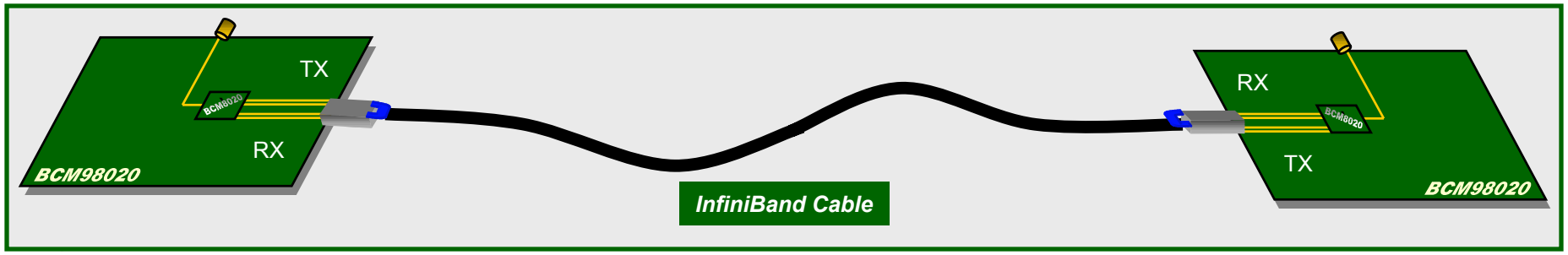
BER vs. Cable

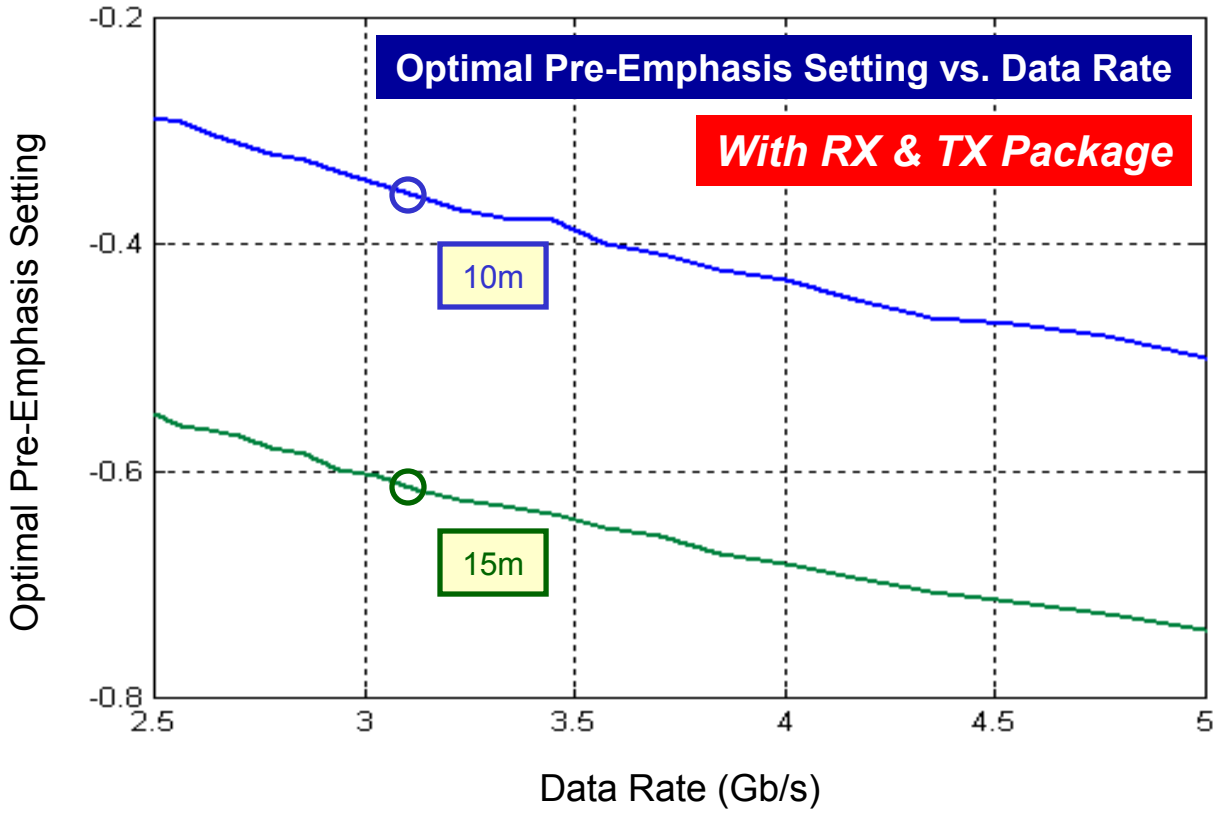
2-Tap De-Emphasis Transmitter: Eye Diagrams



• Typical Eye Diagrams for 2-Tap De-Emphasis Transmitter

2-Tap Optimal Pre-Emphasis: 10m &15m Cable

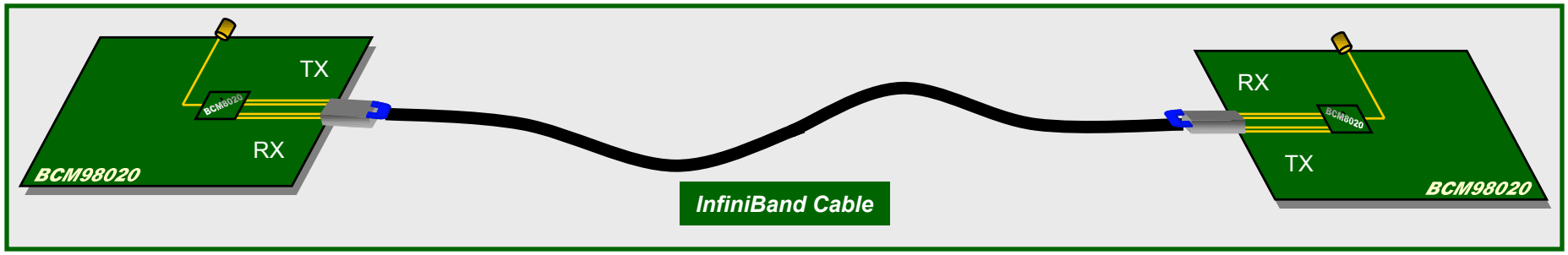


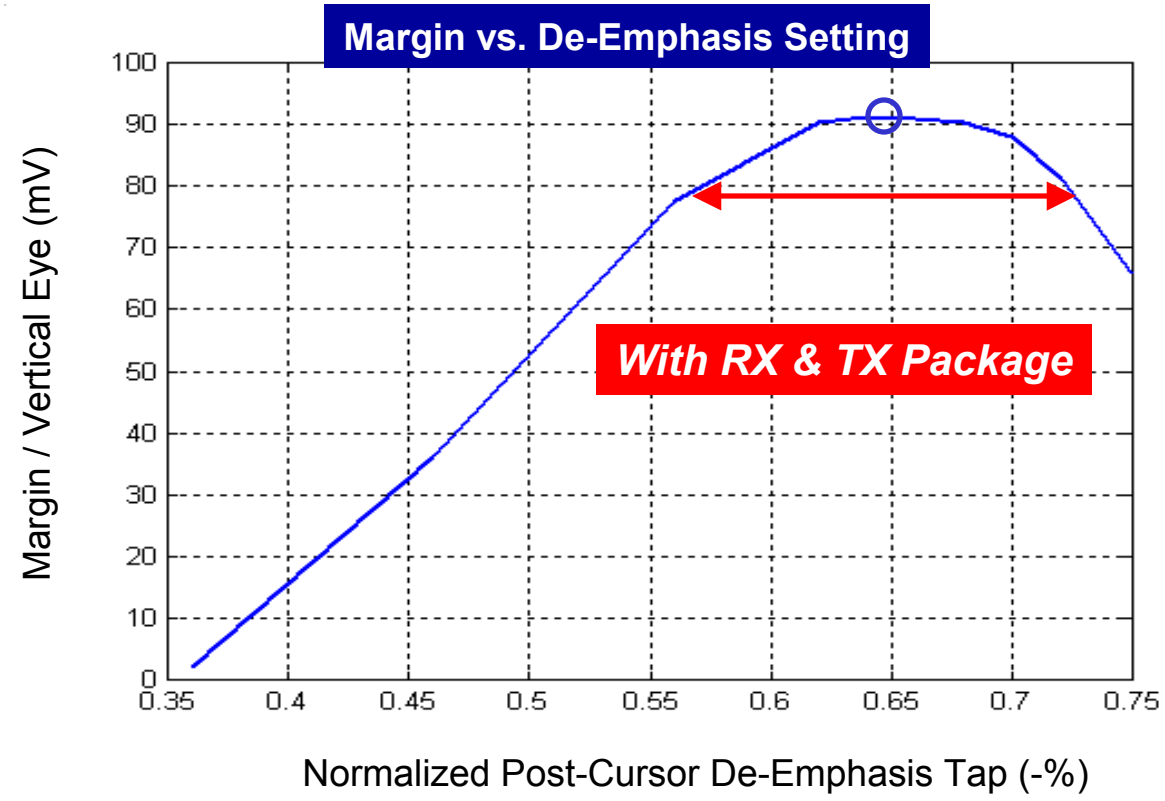


Optimal Pre-Emphasis @ 3.125-Gb/s over 10m & 15-m InfiniBand Cable

- 10m 24-AWG => -0.36
- 15m 24-AWG => -0.64

2-Tap De-Emphasis: 15m Cable



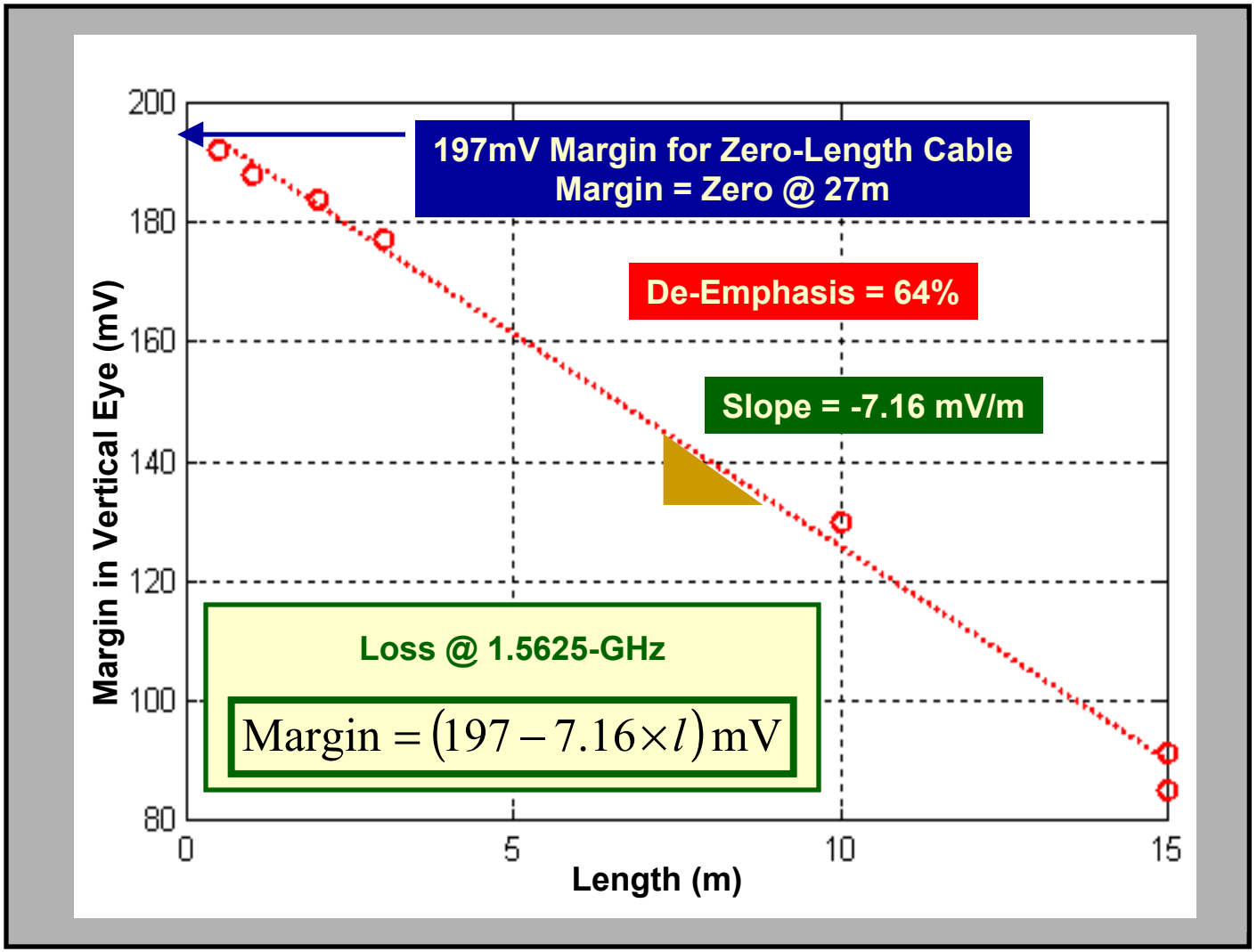


2-Tap De-Emphasis show soft maximum vs. tap value

Allows single value to be used for large range of cables. Value can range +/- 12.5% with only a 10mV reduction in margin.

- Low Value = -0.56
- Mid Value = -0.64
- High Value = -0.72

Margin vs. Length: 24-awg Cables

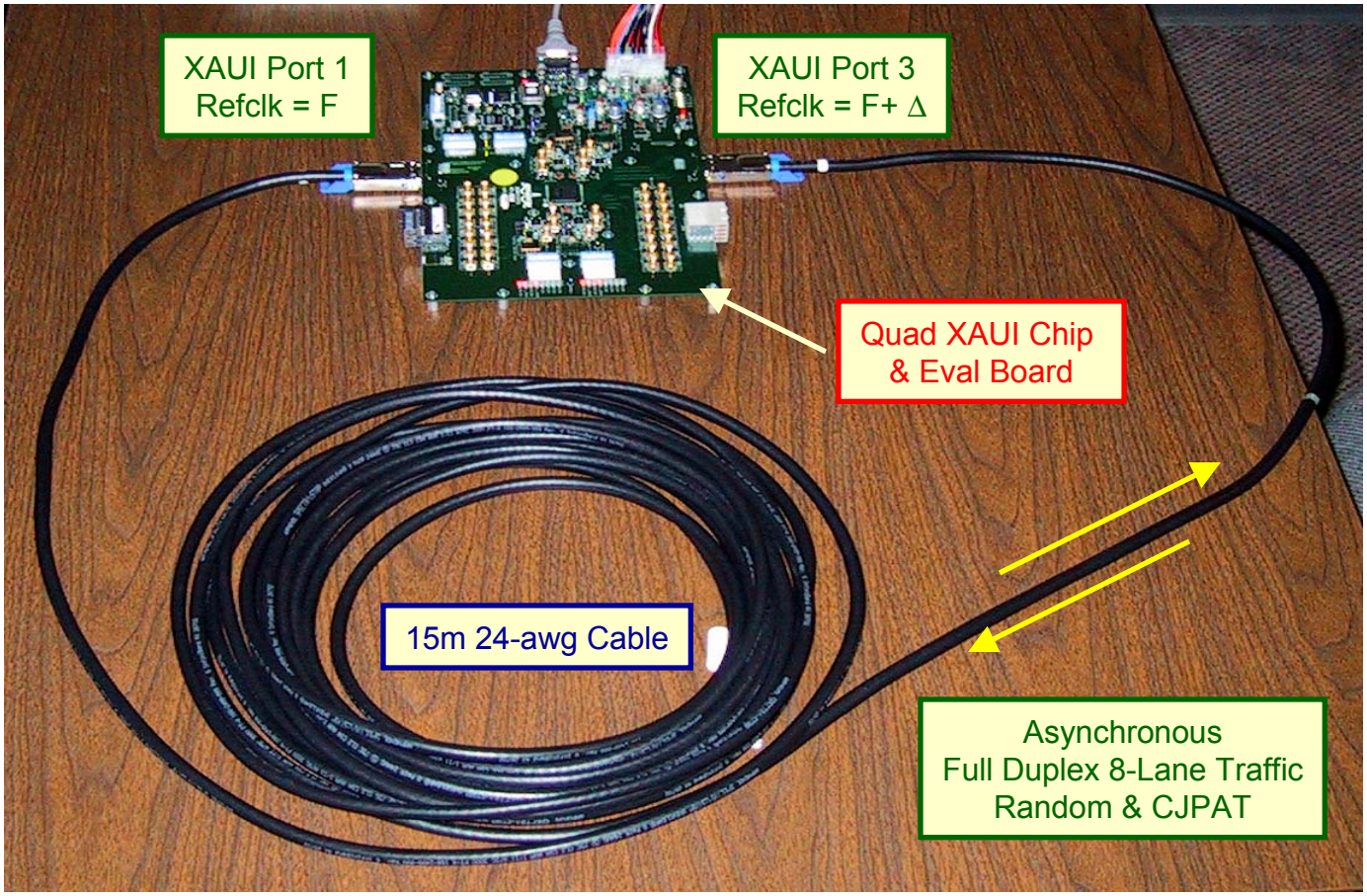


A fixed setting of 64% for De-Emphasis tap give optimal performance @ 15m.

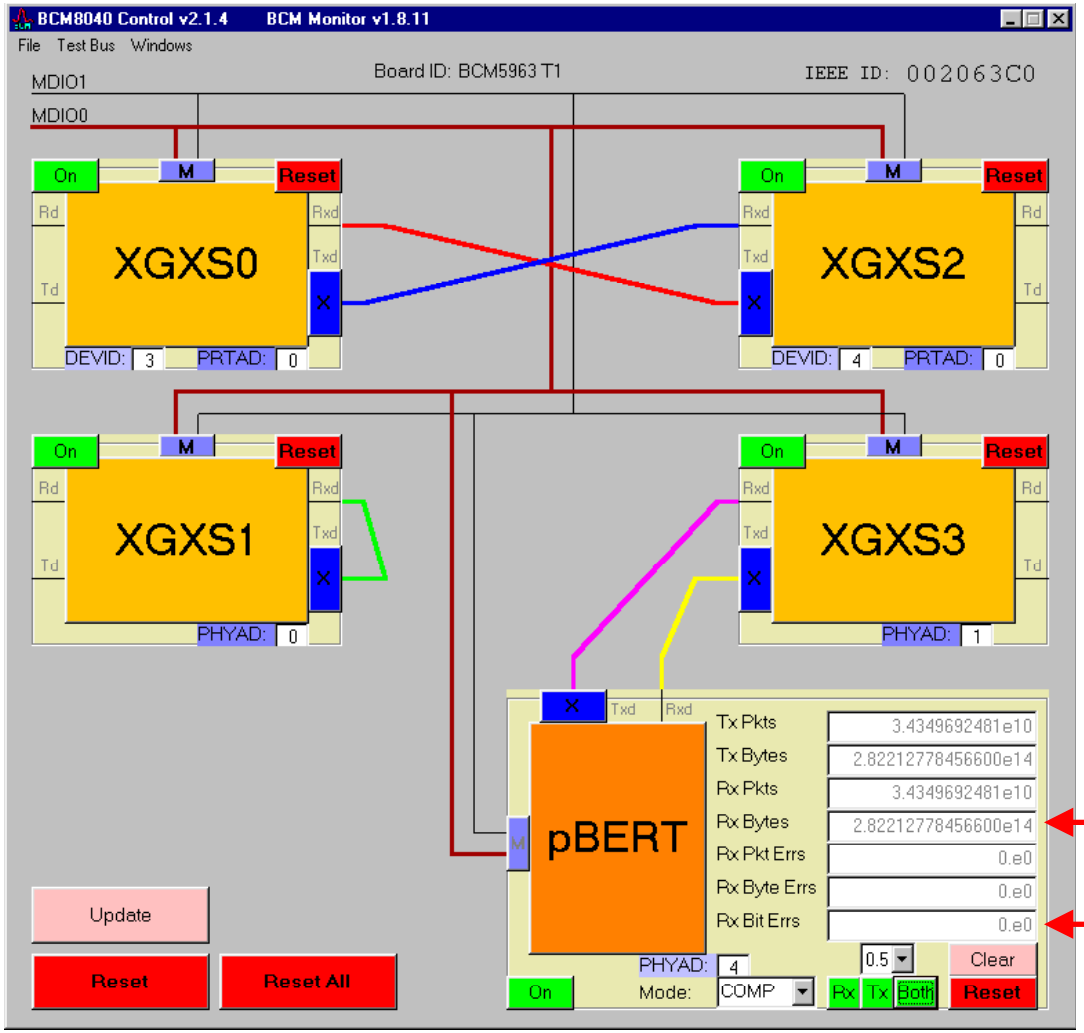
- Performance improves as cable is reduced in length
- Although non-optimal at shorter lengths, margin is always better as cable gets shorter

Measured BER

BERT Bench Setup



BERT Results: 15m Infiniband Cable



15m 24-awg Cable

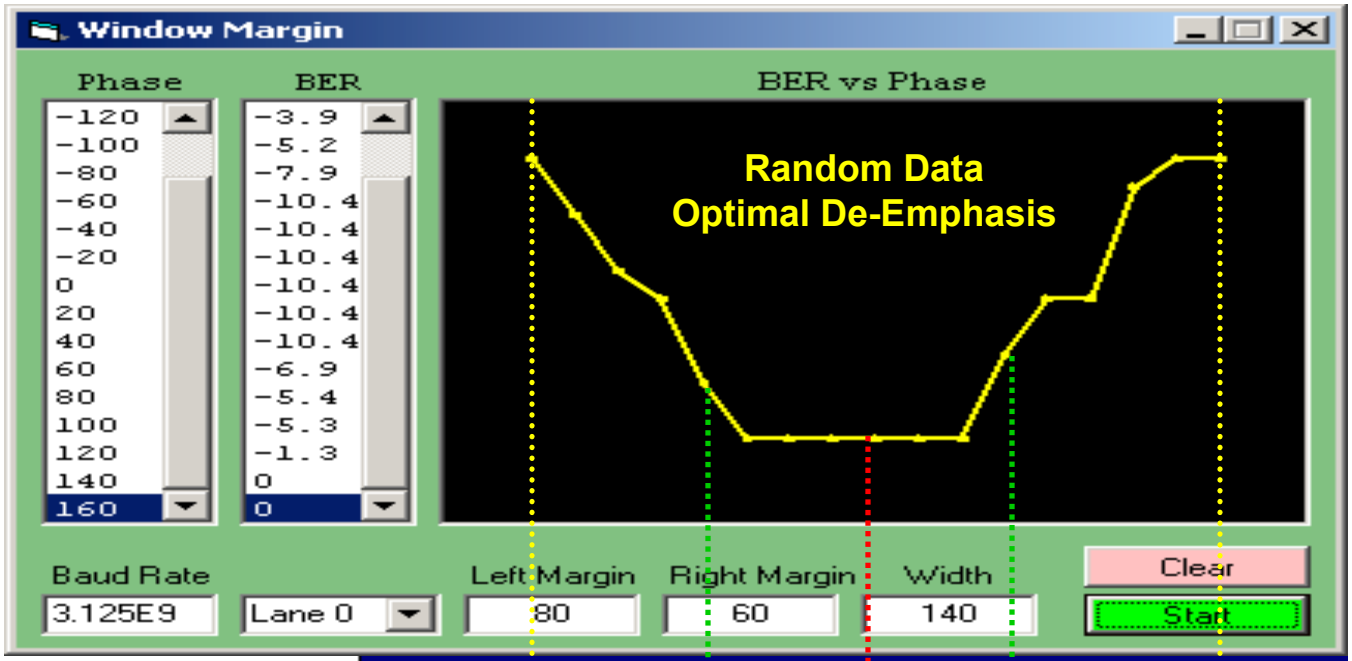
- Asynchronous
- Full Duplex 8-Lane Traffic
- Random Data

# of Bits Received = 2.8×10^{15}

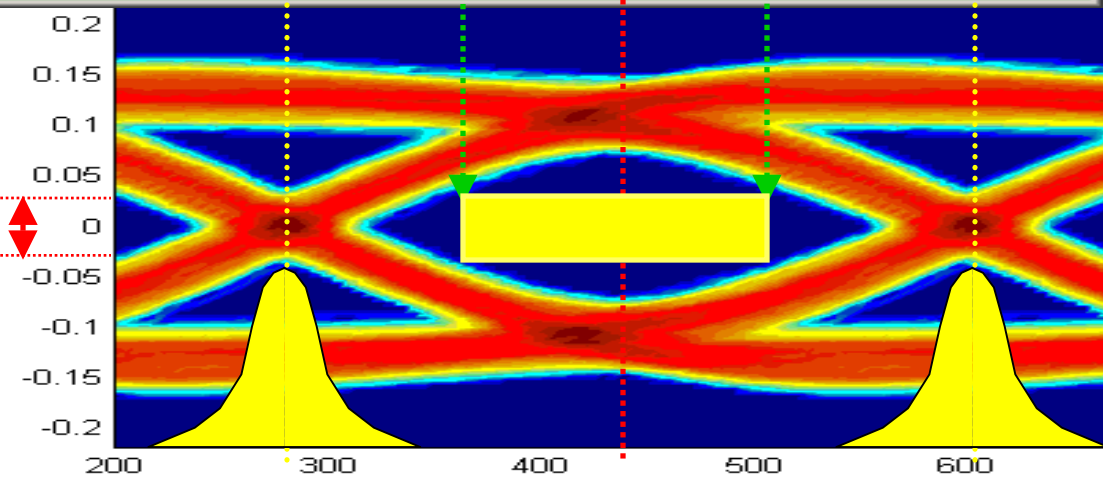
# of Bits Errors = 0

IEEE

BER vs. CLK Skew: 15m Cable



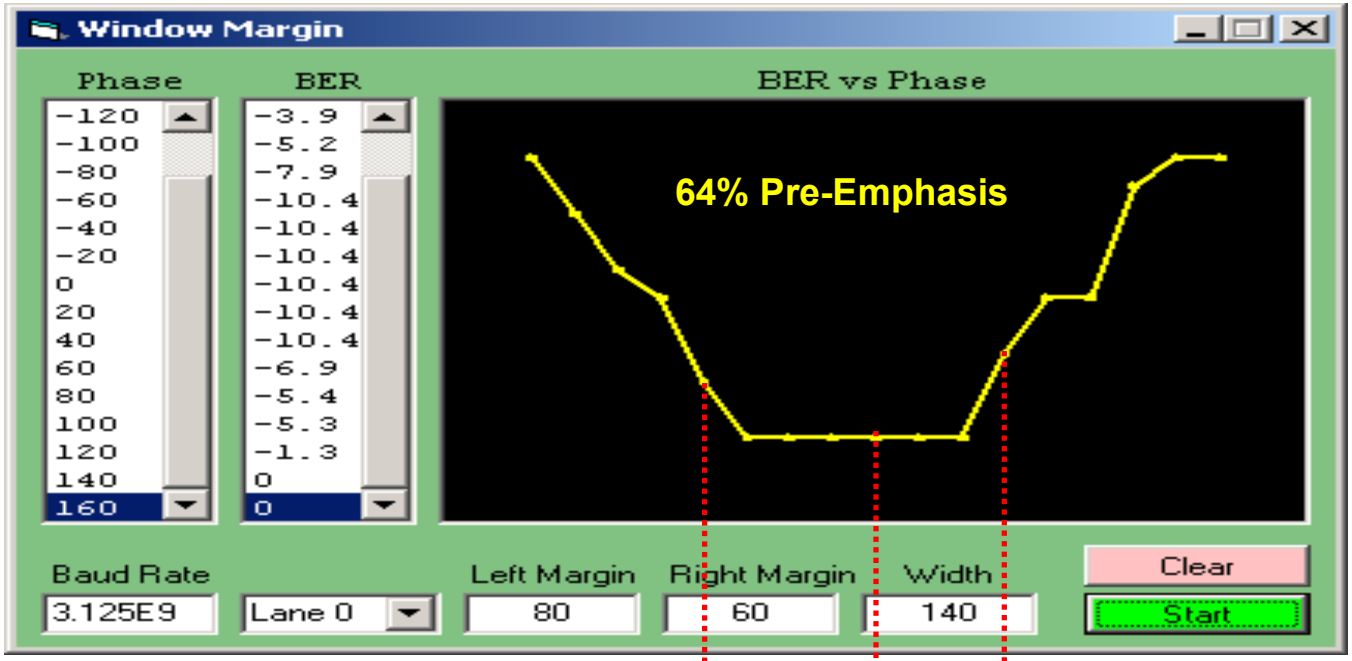
Measured
BER vs. RX CLK Offset



60mV Vppd for
RX Eye
No Xtalk
Jitter Tolarance
= 0.375-UI

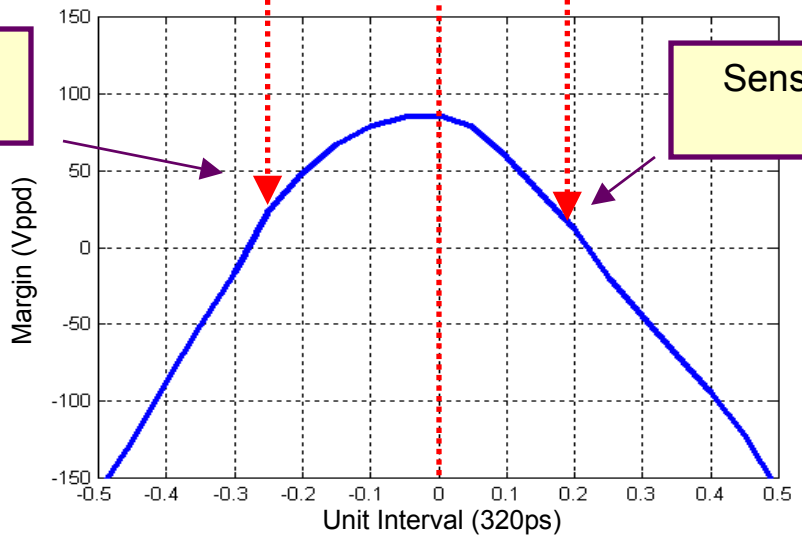
Eye Diagram at RX
for Random Pattern
No Xtalk

15m Simulated & Measured Margin vs. Skew



Sensitivity @ BER = 10^{-8}
23mVppd

Sensitivity @ BER = 10^{-7}
18mVppd



Conclusions: 2-tap De-emphasis

- 2-tap de-emphasis proven to meet BER @ 15m
  - Multiple cables
  - Significant jitter tolerance
- Single tap setting of ~ 64% is adequate for all cables
  - Soft optimum means all 15m cables will show near optimum performance
  - Shorter cables perform better than longer cables for same de-emphasis setting
- Need clear specification to eliminate non compliant cables

Thoughts on Specification Templates

- Specifications goals
  - Sufficient to fully characterize performance
  - Observable in full assembly
  - Consistent & unambiguous
- Channel characteristics
  - Step response template
  - Frequency response
- De-emphasis setting
  - Step response template
- Jitter generation
  - Sampling scope, Fixed pattern, Self-triggered, Specified trigger delay