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Comparison of NRZ, PR-2, and PR-4 signaling

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Scope and Purpose

- Operation over electrical backplanes at 10.3125Gb/s is investigated using NRZ, PR2, and PR4 signaling.
- A common equalizer architecture is used in all cases.
- Estimated BER, as well as voltage and timing margin at 1E-12, is reported.

Agenda

- Simulator Overview
  - Link Model
  - Transmitter Model
  - Receiver Model
  - Equalization Strategy
- Test Cases
- Sample Results
- Results Summary

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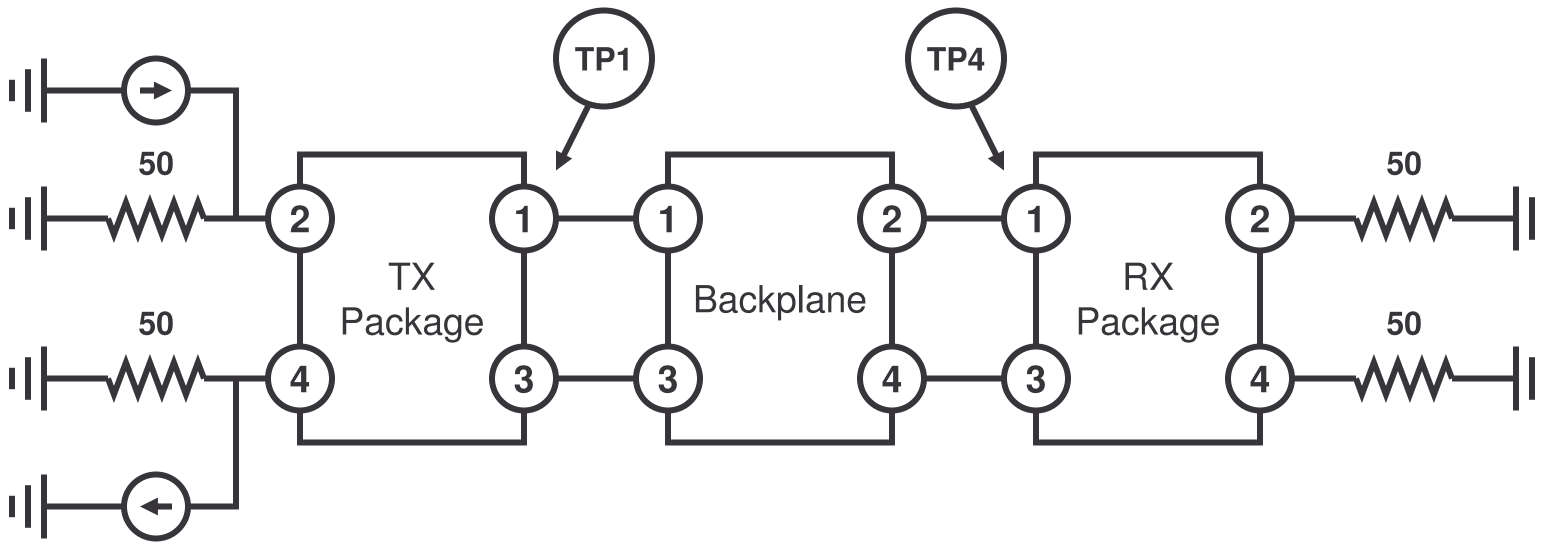
Simulator Overview

Link Model



TX Package Model	Mellitz "Capacitor-Like" Model
Backplane Model	As described in "Test Cases" section…
RX Package Model	Mellitz "Capacitor-Like" Model

Crosstalk (1/2)

- For each crosstalk aggressor…
  - The response to a PRBS-15 pattern (with an additional trailing “0”) is computed.
  - This response is sampled at baud-spaced intervals at 16 offsets from 0 to (15/16)T in T/16 steps.
  - At each offset, the amplitude distribution of sampled response is computed.
  - The aggressor amplitude distribution is defined as the average of the amplitude distributions computed at each sample offset.

Crosstalk (2/2)

- The overall crosstalk distribution is defined as the convolution of the individual aggressor distributions.
- The effect of crosstalk on the eye is modeled as the convolution of the overall crosstalk distribution and amplitude distribution of the “thru” path at each sample phase.
- This methodology is has been previously described by Moore:
  - http://ieee802.org/3/ap/public/channel_adhoc/moore_c1_0305.pdf
- Computed RMS and peak-peak crosstalk will be reported.

Transmitter Model

- Transmitter differential output voltage fixed at $800mV_{p-p}$.
- Transmit filter is Gaussian.
  - Rise Time (20-80%): 24 ps
- Transmitter output jitter
  - Duty Cycle Distortion: $0.05\ UI_{p-p}$ (even-odd)
  - Deterministic Jitter: $0.10\ UI_{p-p}$ (sinusoidal)
  - Random Jitter: $0.15\ UI_{p-p}$ (at 1E-15), $9.4mUI_{rms}$
- Parameters defined at package model input and <u>do not</u> include package parasitics.
  - The impact of the package model is investigated in the next slide.

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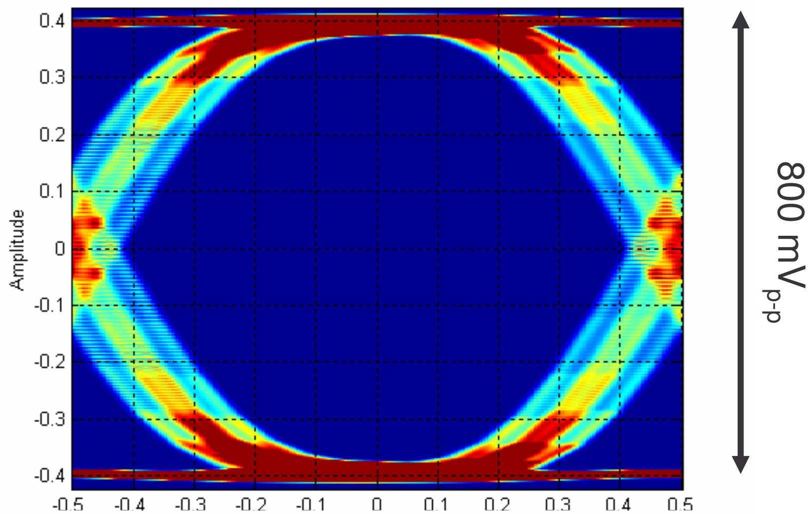
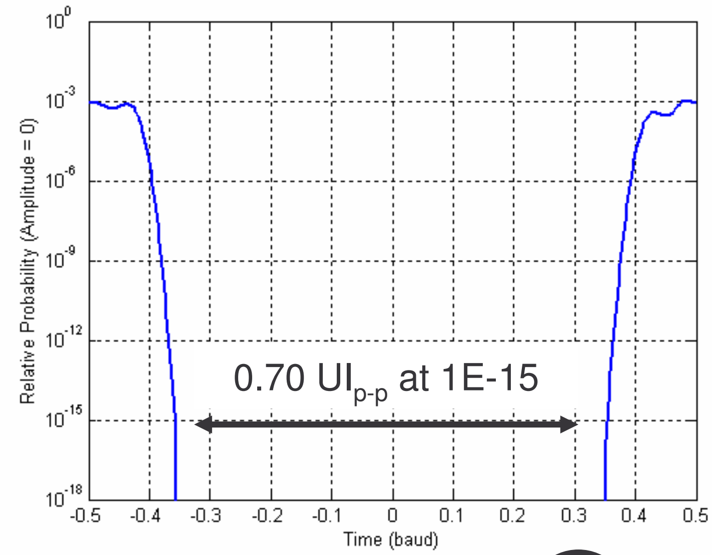
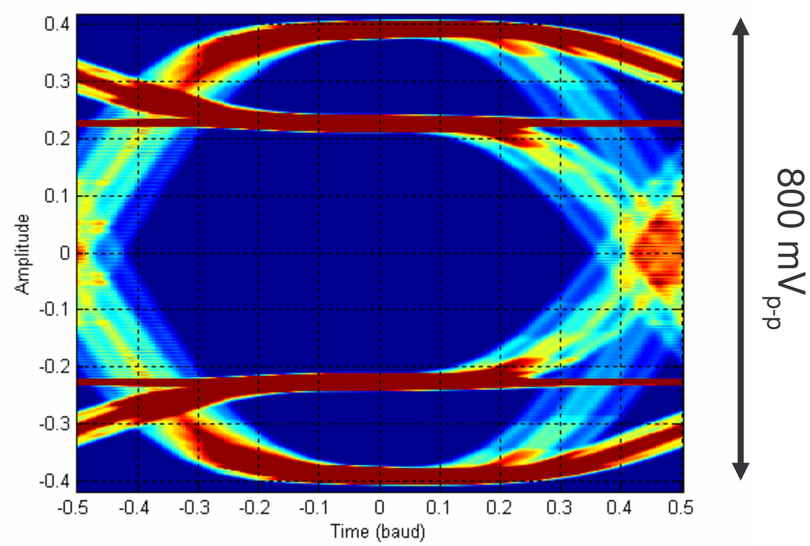
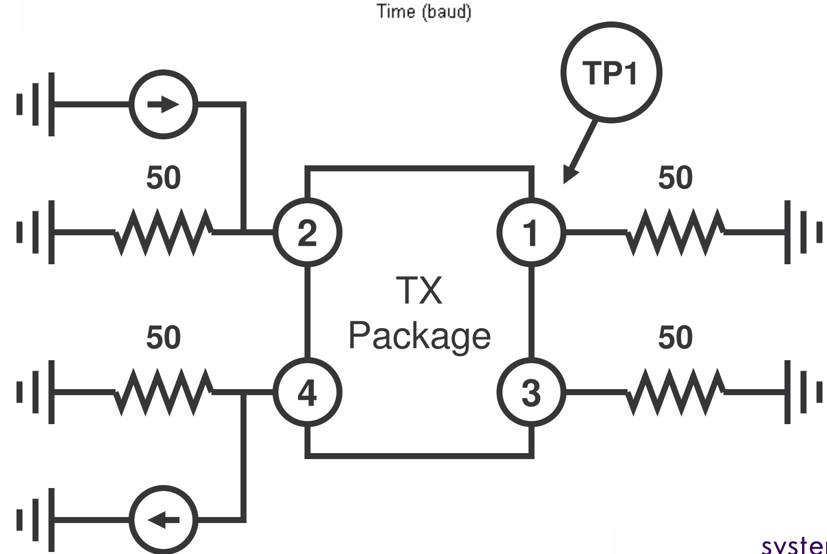
Transmitter Output at TP1









Receiver Model

- Receiver modeled as a single pole at 75% fbaud.
  - Noise Bandwidth (B_n): 11.4 GHz $$B_n = \int_0^\infty |H(f)|^2 df$$
  - Noise Figure: 18 dB
  - sqrt($4kTRB_n$): 1.08 mV_{rms}
- Receiver jitter:
  - Random Jitter: 0.15 $UI_{p\text{-}p}$ (at 1E-15), 9.4 mUI_{rms}
- No gain stages have been included in the receive path.

Equalization Strategy

- Transmitter Finite Impulse Response filter.
  - 3 taps, T-spaced with “infinite” tap weight resolution.
- Receiver Decision Feedback Equalizer
  - 5 taps, unconstrained with “infinite” tap weight resolution.
- Sequential adaptation
  - Transmit FIR is adapted first, then the DFE.
- Sample phase chosen to minimize mean-squared error.
  - T/32 resolution

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Test Cases

Test Patterns

- Equalizer trained with PN-11 pattern with a trailing “0”.
- Equalizer settings are then frozen.
- Voltage and timing margin is estimated based on PN-15 pattern with a trailing “0”.
  - Thru, NEXT, and FEXT channels share the same output amplitude (800 mV_{ppd}) and transmit FIR settings.
- Decision threshold set at the mid-point between nominal signal levels, as determined by the 1E-4 contour.
  - Reported margins are twice the minimum distance from the sample phase (or threshold) to the BER contour of interest.

Channels Studied

- All Tyco Electronics channels
  - Test Cases 1 through 7
  - Note that the FEXT channels were included twice due to connector symmetry.
- Recommended subset of Intel channels
  - Test Cases 8, 11, and 12 map to T1, T12, T20
  - Test Cases 14, 17, and 18 map to B1, B12, B20
  - Test Cases 20 and 24 map to M1, and M20
- Other channels not simulated due to a lack of time…

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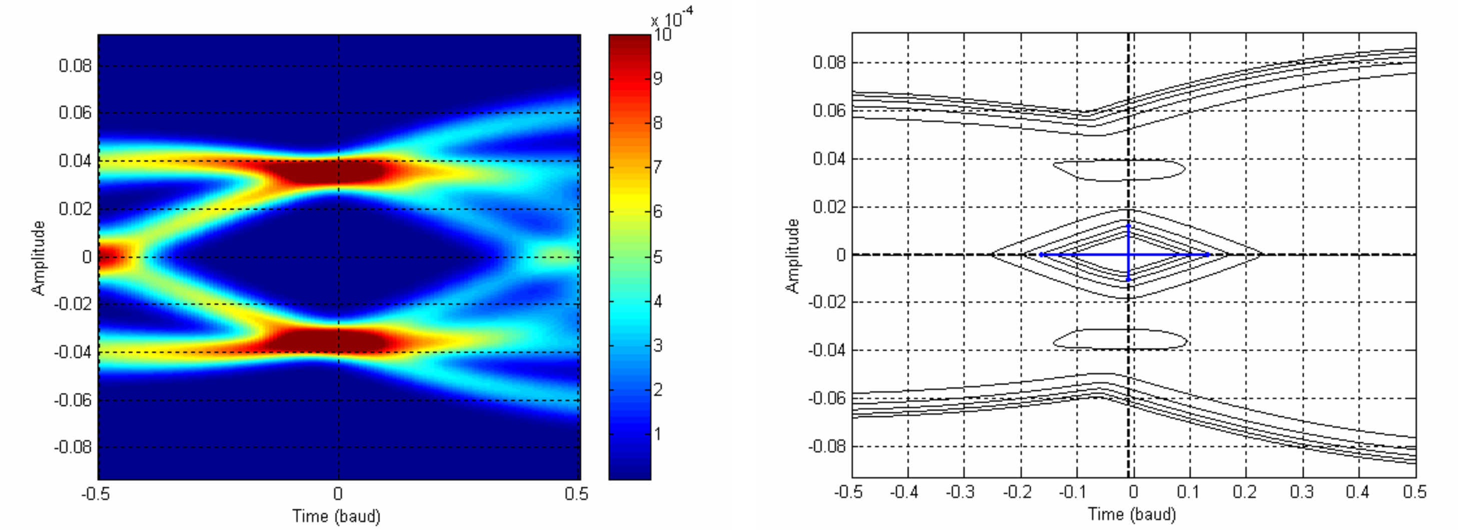
Sample Results

Disclaimer

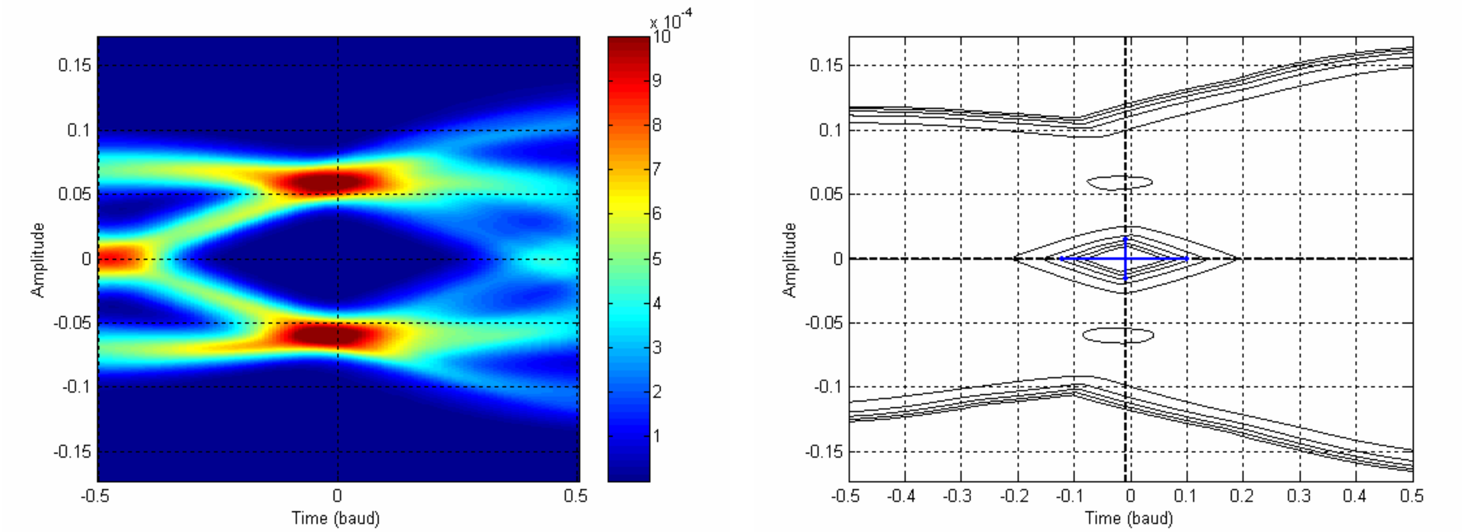
- The following results are based on PRBS-11 pattern and are included for illustrative purposes.

NRZ Sample Results: Eye at Slicer Input

Test Case #1



Test Case #6



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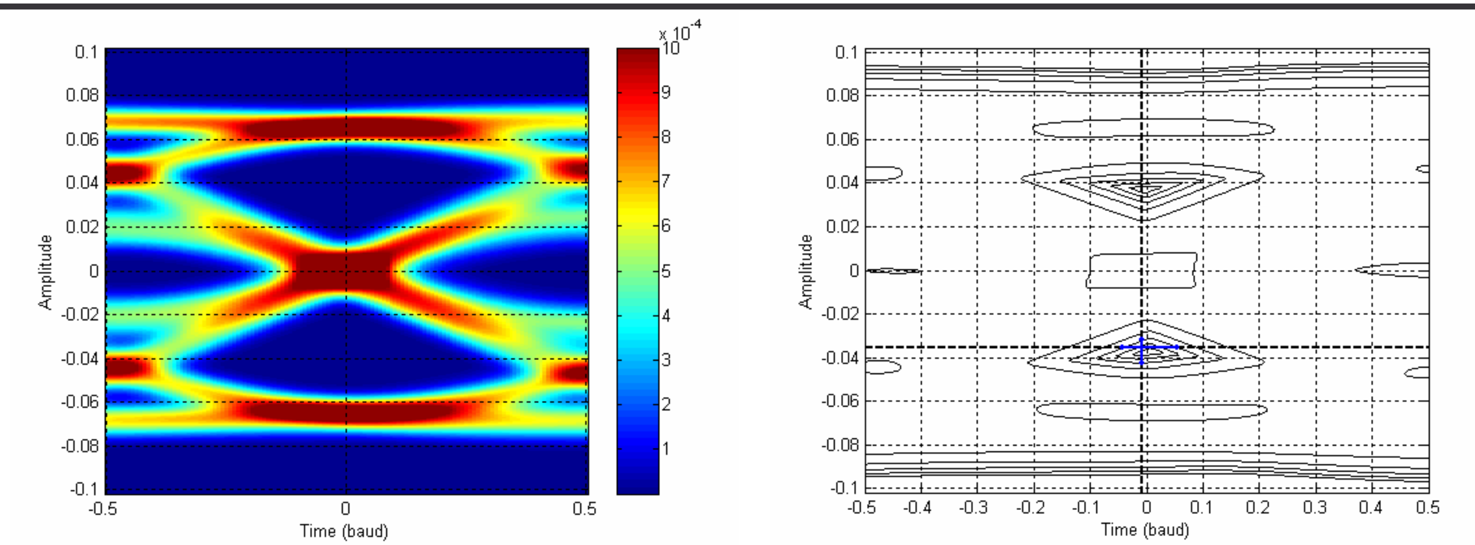
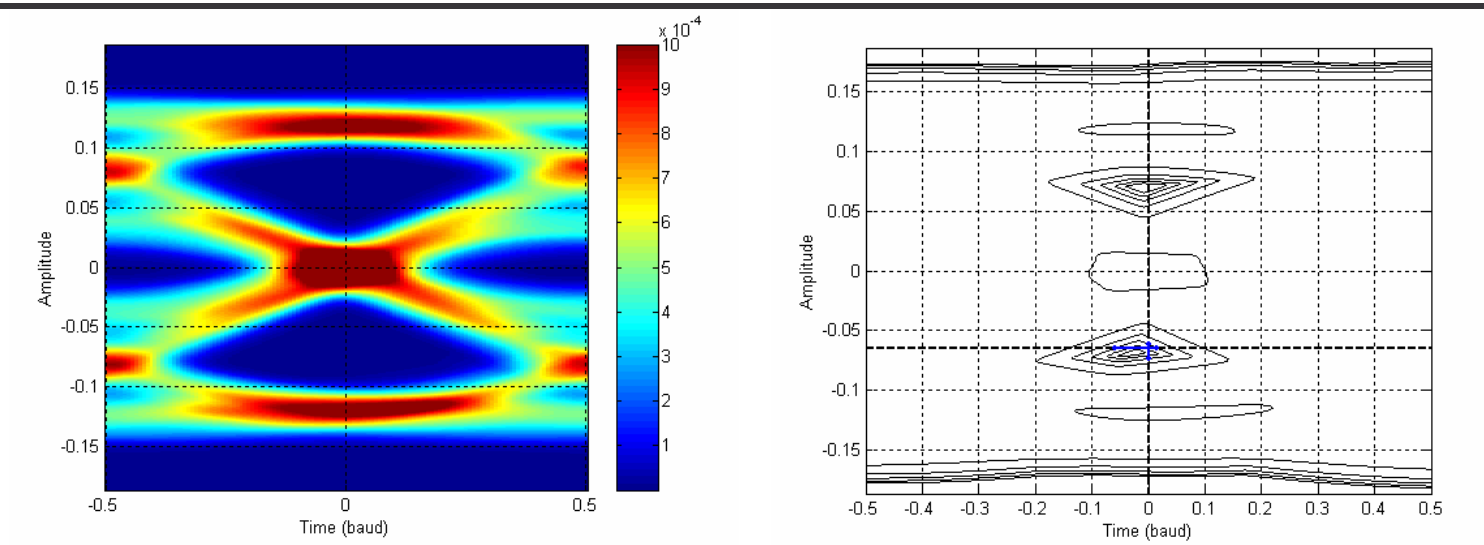
PR2 Sample Results: Eye at Slicer Input

Test Case #1



Test Case #6



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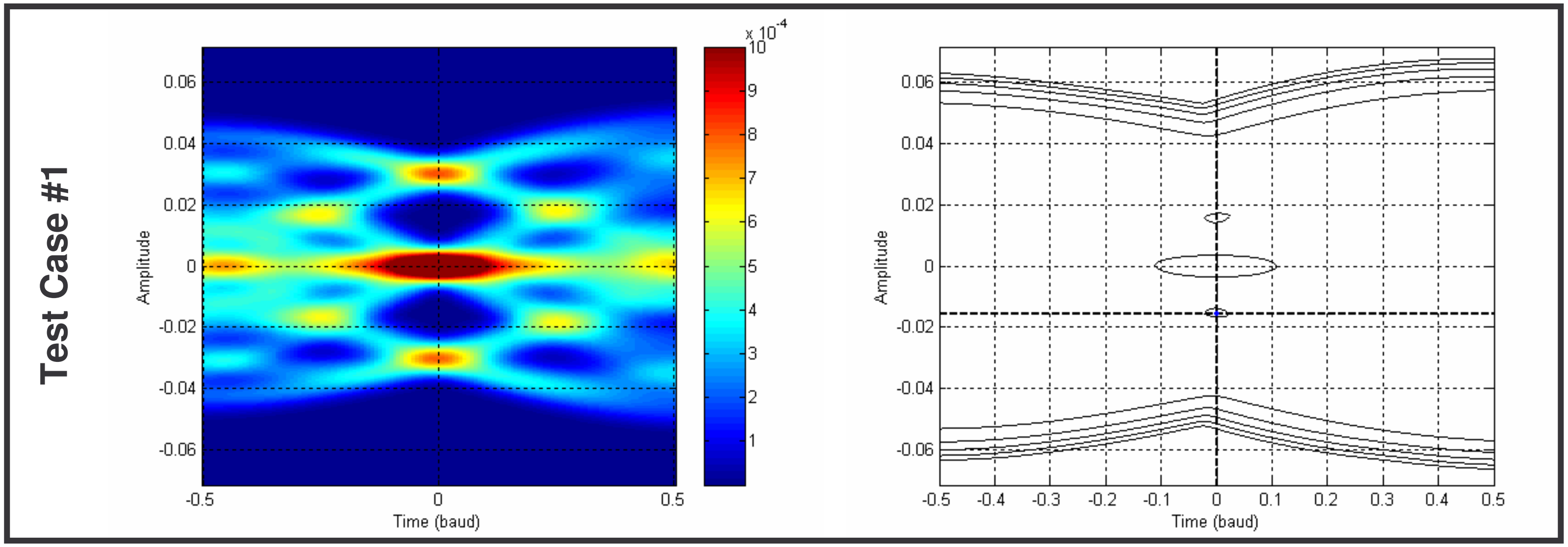
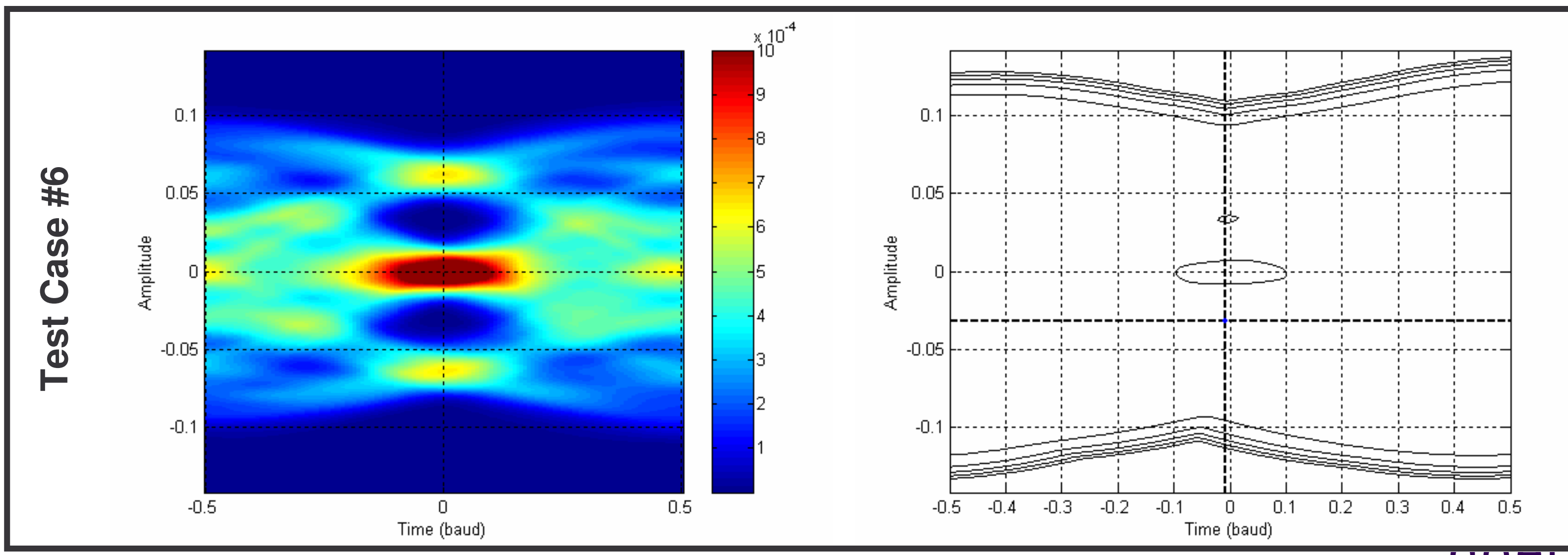
PR4 Sample Results: Eye at Slicer Input





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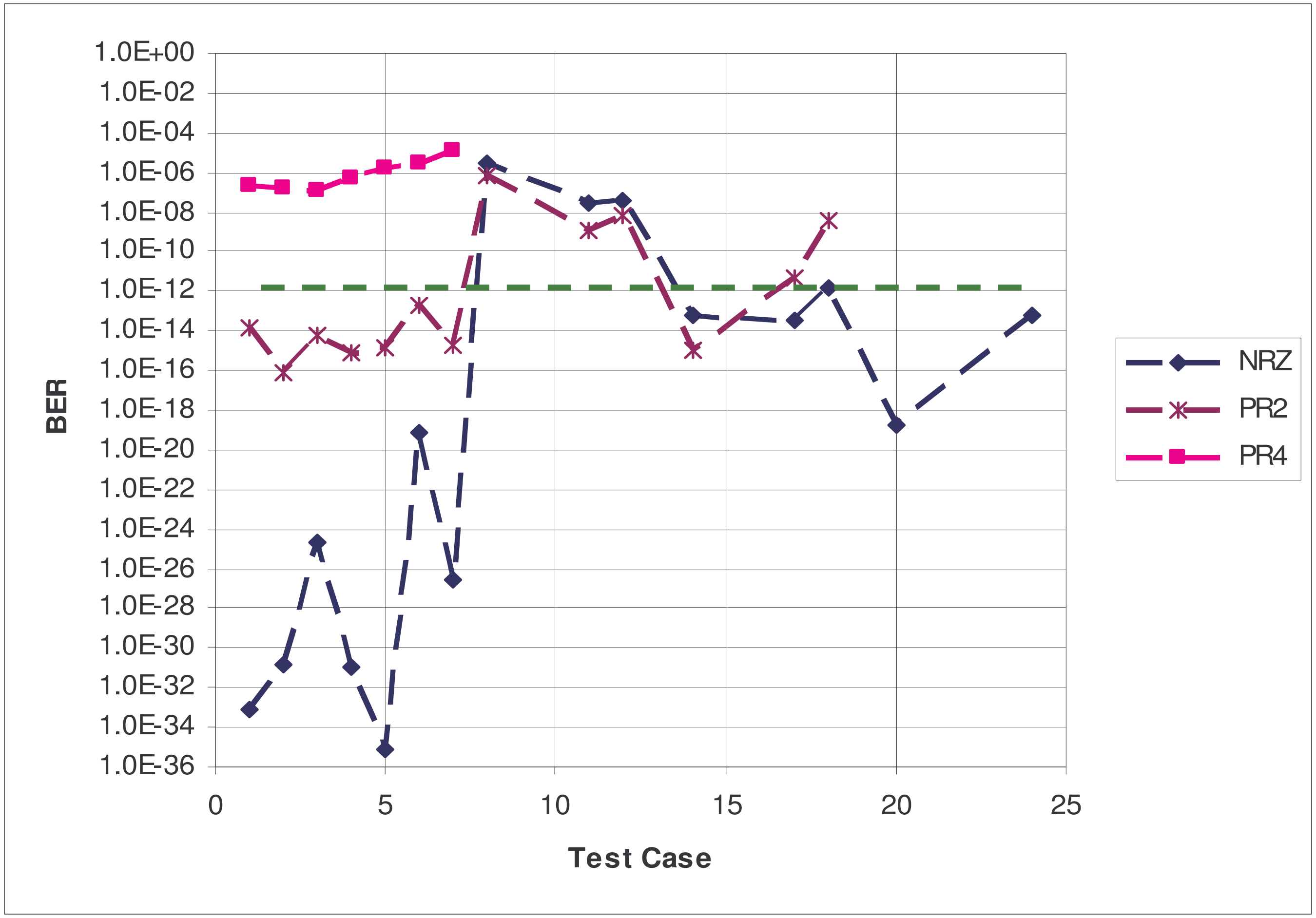
Results Summary

BER Estimates



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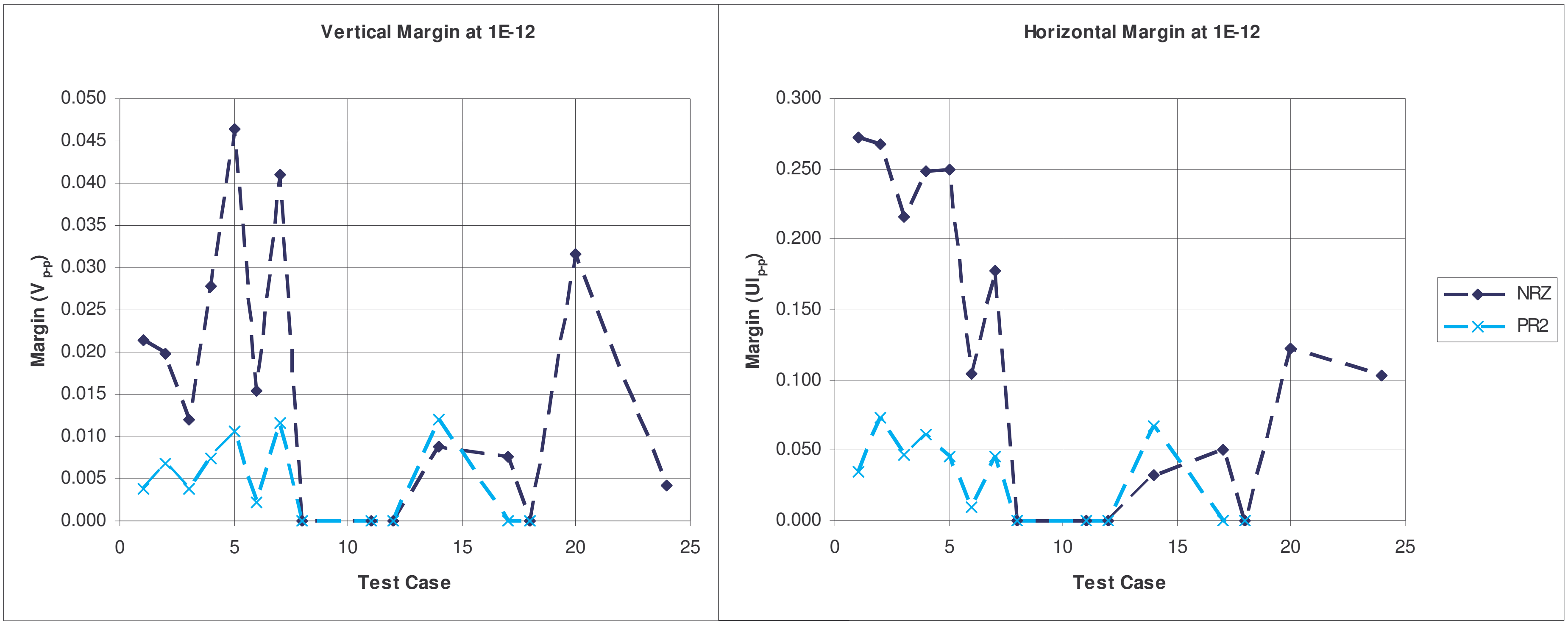
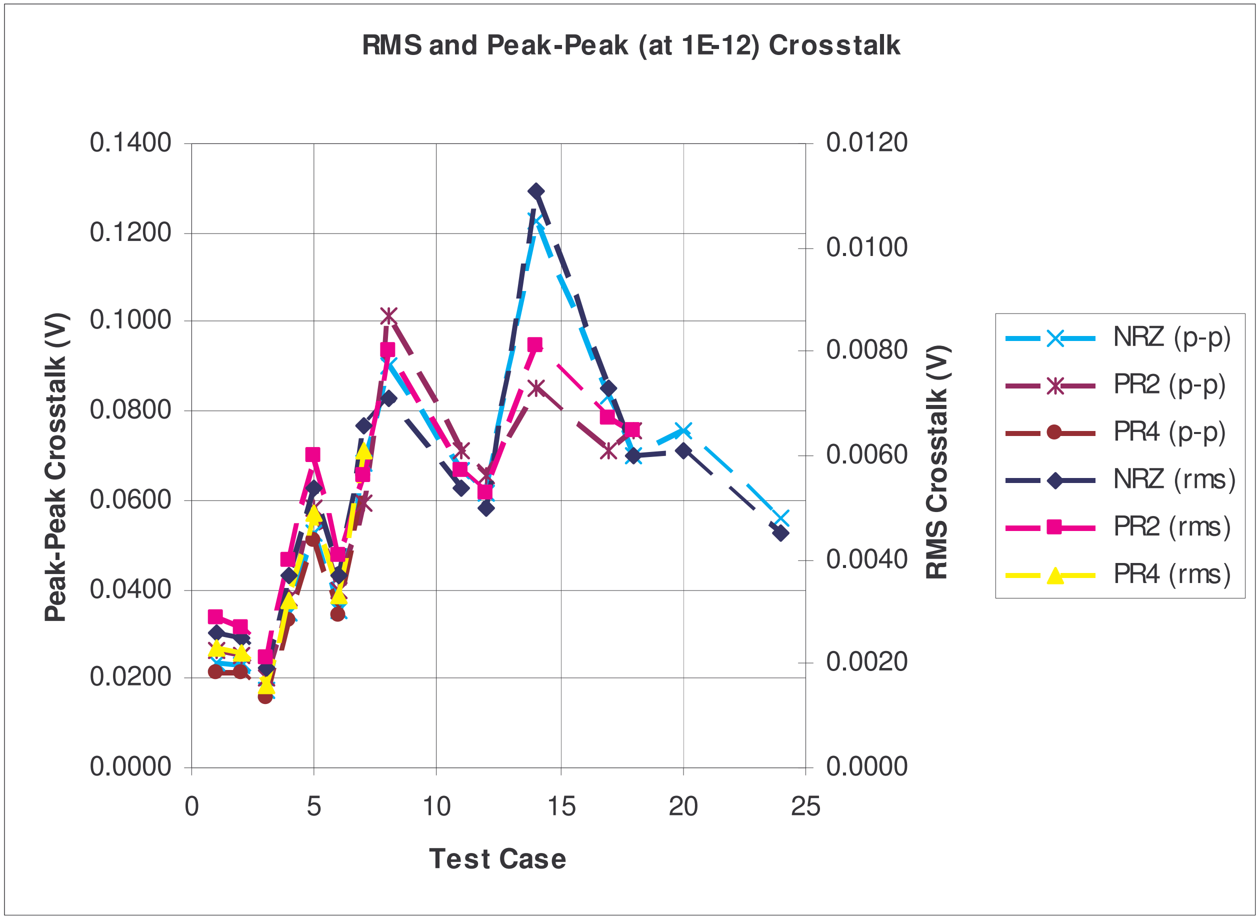
Voltage and Timing Margin at 1E-12



Crosstalk Environment



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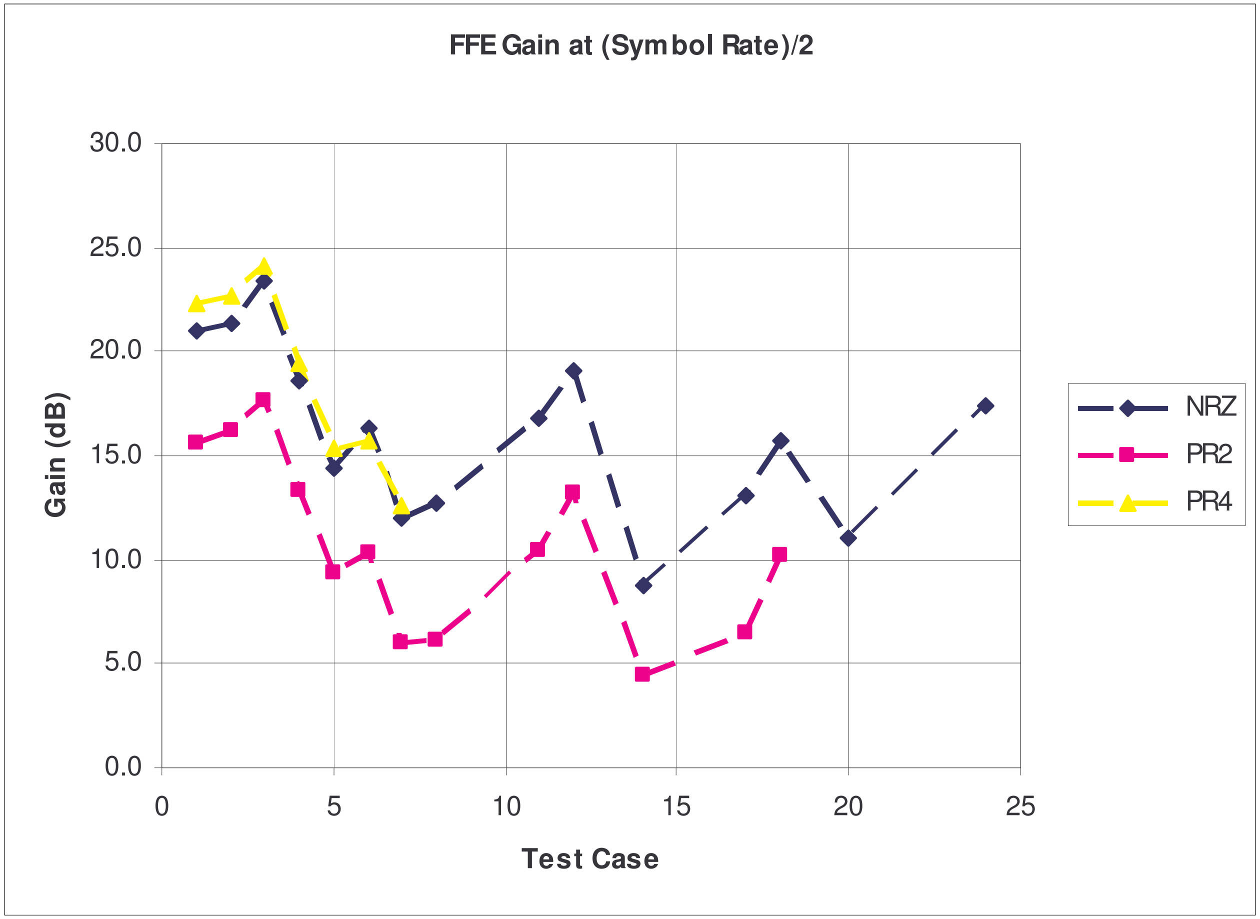
Required FFE Boost



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Conclusions (1/2)

- The target response for PR4 is a poor fit to the channel and therefore higher equalizer complexity is required to achieve acceptable performance.
- NRZ and PR2 both support 1E-12 operation over the Tyco channels.
  - In general, PR2 requires considerably less boost to achieve this objective.
  - In the majority of test cases studied, NRZ offered superior voltage and timing margin.

Conclusions (2/2)

- The Intel “T” channels were not supported by any of the signaling schemes studied with the chosen equalizer architecture.
- NRZ signaling may be feasible for select Intel “B” and “M” channels.
  - Crosstalk is a significant impairment on these channels.

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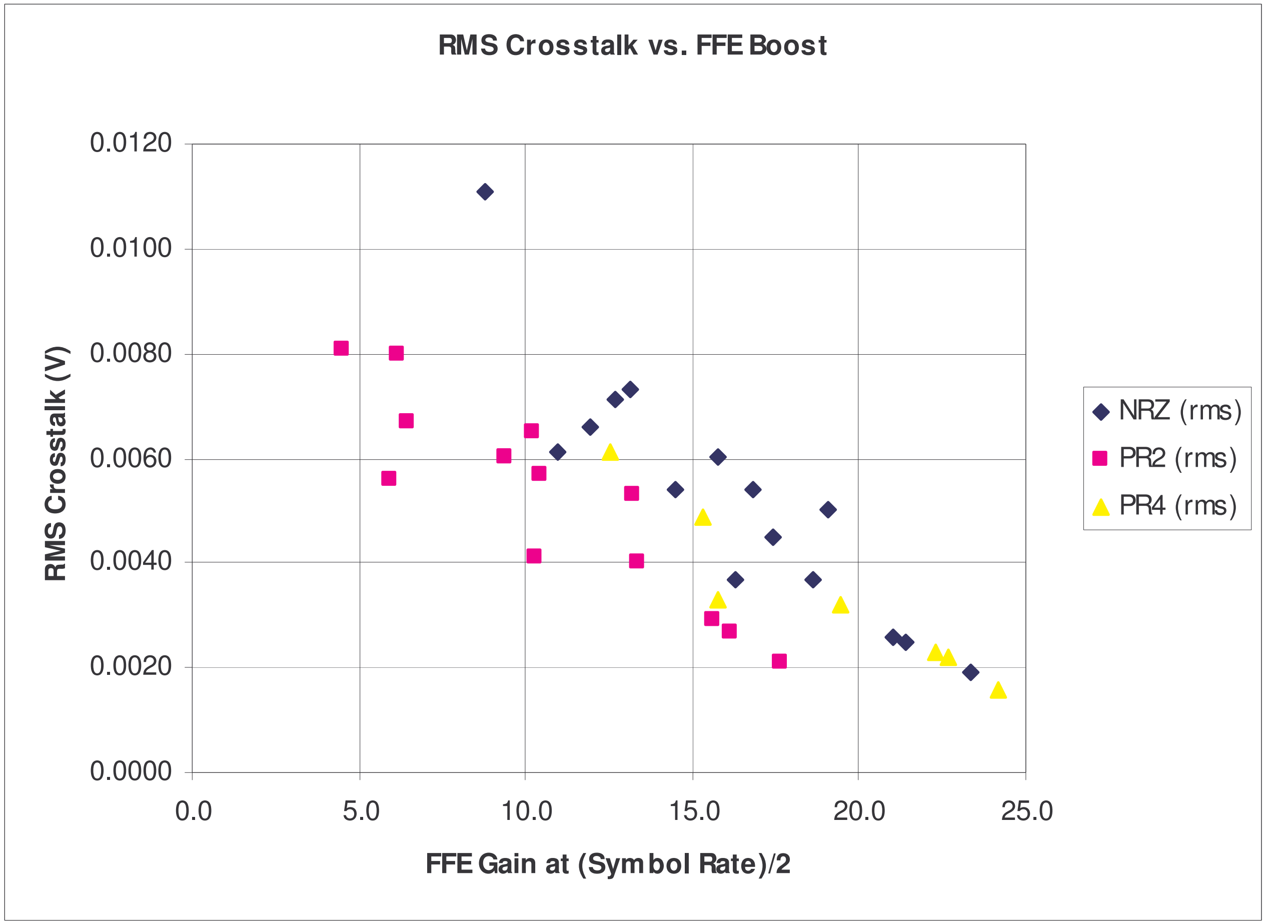
Backup

Relationship Between Crosstalk and Boost



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