Edge-Equalized NRZ

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NOTICE:

Xilinx has not conducted a search of its patent portfolio with respect to EE-NRZ. However, to the personal knowledge of the presenter, Xilinx may own Intellectual Property Rights (IPR) in the form or patents and/or patent applications that may be essential to the implementation of the EE-NRZ.

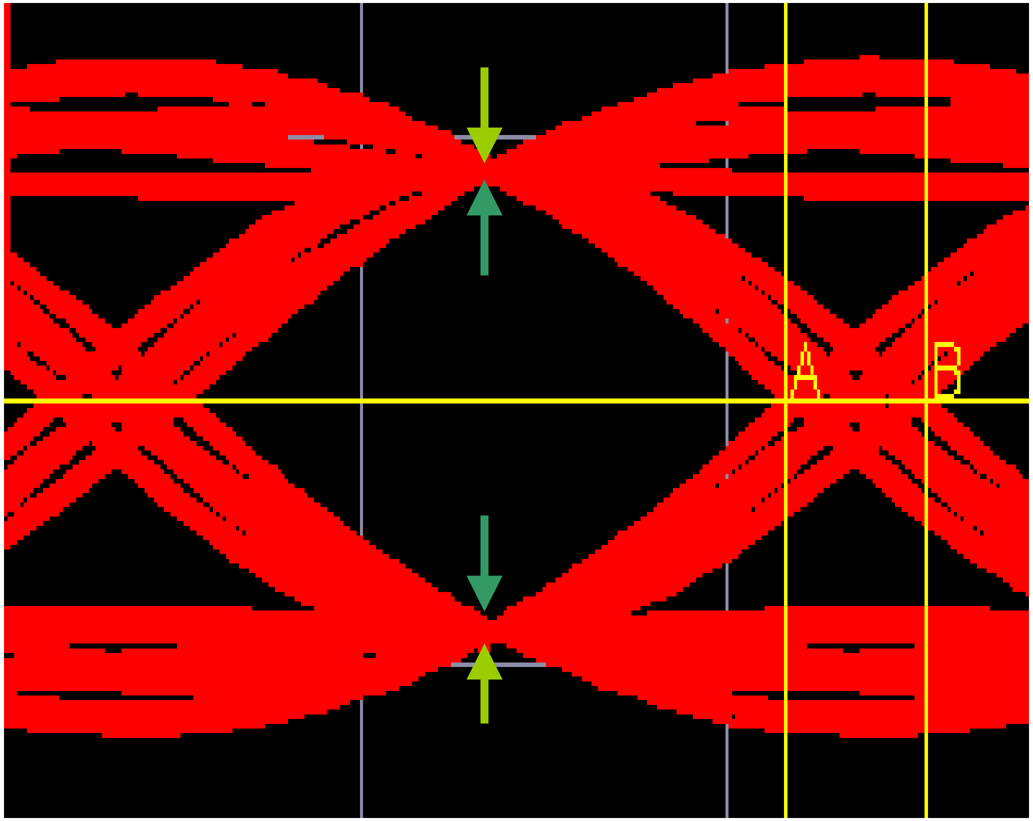
Purpose of Presentation

- Our links of interest are often jitter limited. If we reduce jitter, performance improves. $14*(kTBR)^{0.5}$ < 1mV, we use bathtub curves, …
- Jitter-optimized equalization to minimize channel-induced jitter is unconventional.
- We use a jitter-optimized equalization technique for NRZ termed Edge-Equalized NRZ (EE-NRZ).
- We are sharing this technique to achieve broader exposure, generate further technical discussions and have others validate its effectiveness through simulation and measurement.

Classic Equalization

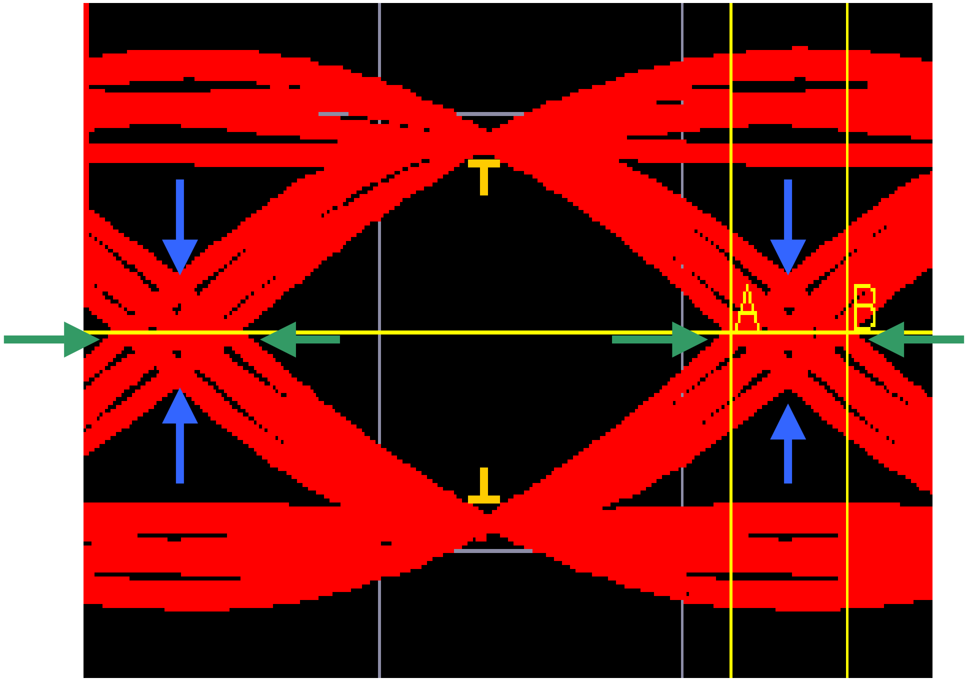
- General goal is to invert the channel.
  - Can work in frequency or time domain (can be mapped back and forth)
- In this discussion, we use a symbol-spaced time domain approach.
- The classic technique is a zero-forcing-equalizer (ZFE) on a sampled pulse response where the samples correspond in time to bit centers. We term this Center-Equalized NRZ (CE-NRZ).
- CE-NRZ results in a composite pulse response that has zero-crossings at all the adjacent bit centers. The zero-crossing pulse width is 2UI.
- Contrary to common belief, CE-NRZ does not maximize the eye-height. It minimizes the the “error” at the bit center and thus it maximizes the SNR at the bit center where noise is due to ISI.
- Unique to NRZ, this “error” could have alternatively been eliminated simply in the NRZ decision process. NRZ does not have other symbols above or below to be encroached upon.

Center Equalized - NRZ



- FIR tap polarity typically alternates so the eye height is determined by max transmitter swing less channel loss at Fdata/2.
- Equalizer only pushes wide excursions inward (light green).

The goal



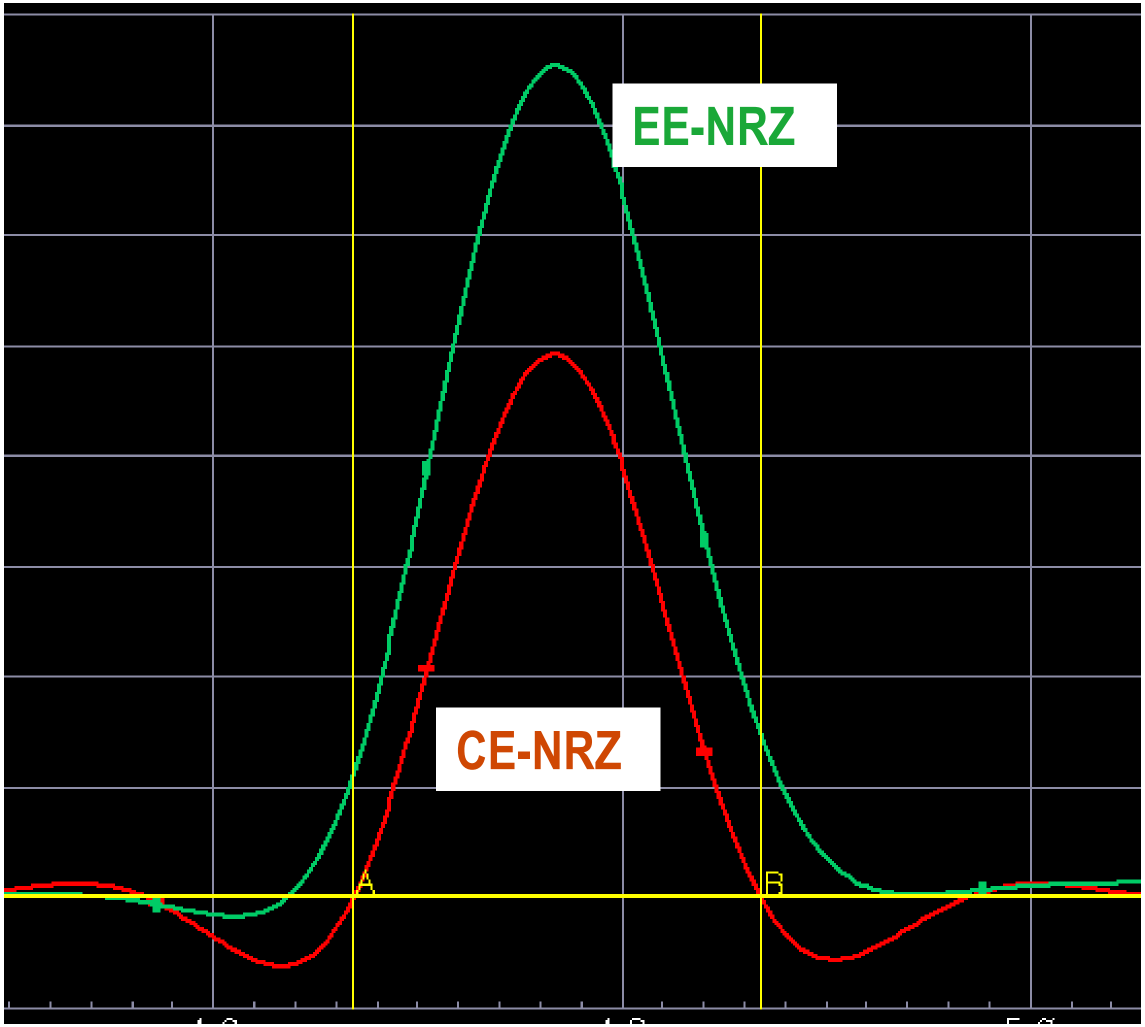
- The goal is to drive the jitter to zero (green). This is done by driving the error at the zero crossings to zero (blue). Maintaining eye-height (orange) is also beneficial.

Edge Equalized - NRZ

- With EE-NRZ the tap weights are adjusted such that the composite pulse response has zero crossings at all adjacent bit *edges* beyond the most immediate edges. The zero-crossing pulse width is 3UI (vs 2UI for CE).

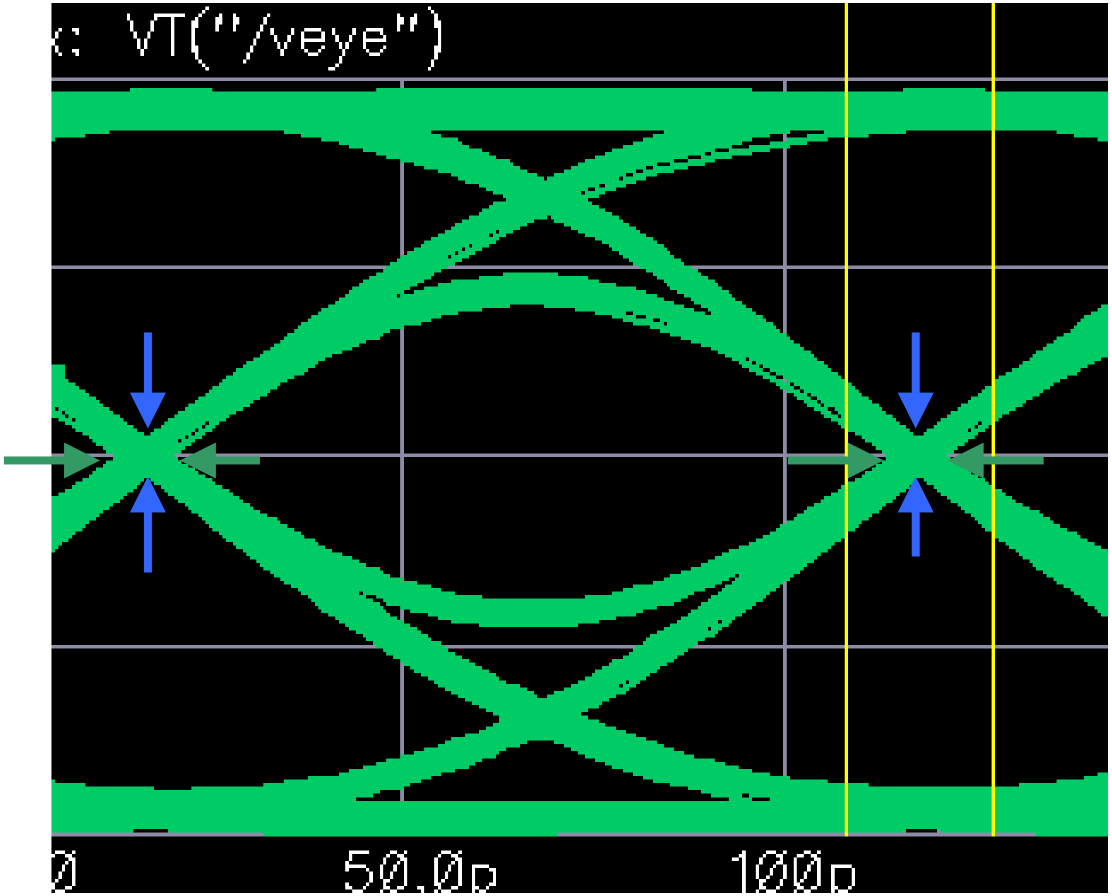
- With symbol-spaced corrections, only one point per bit period can be controlled so the bit-centers are "let go". This is OK because the natural NRZ detection process will eliminate bit-center error.

Composite Pulse Responses



Pulses scaled for same peak transmit power

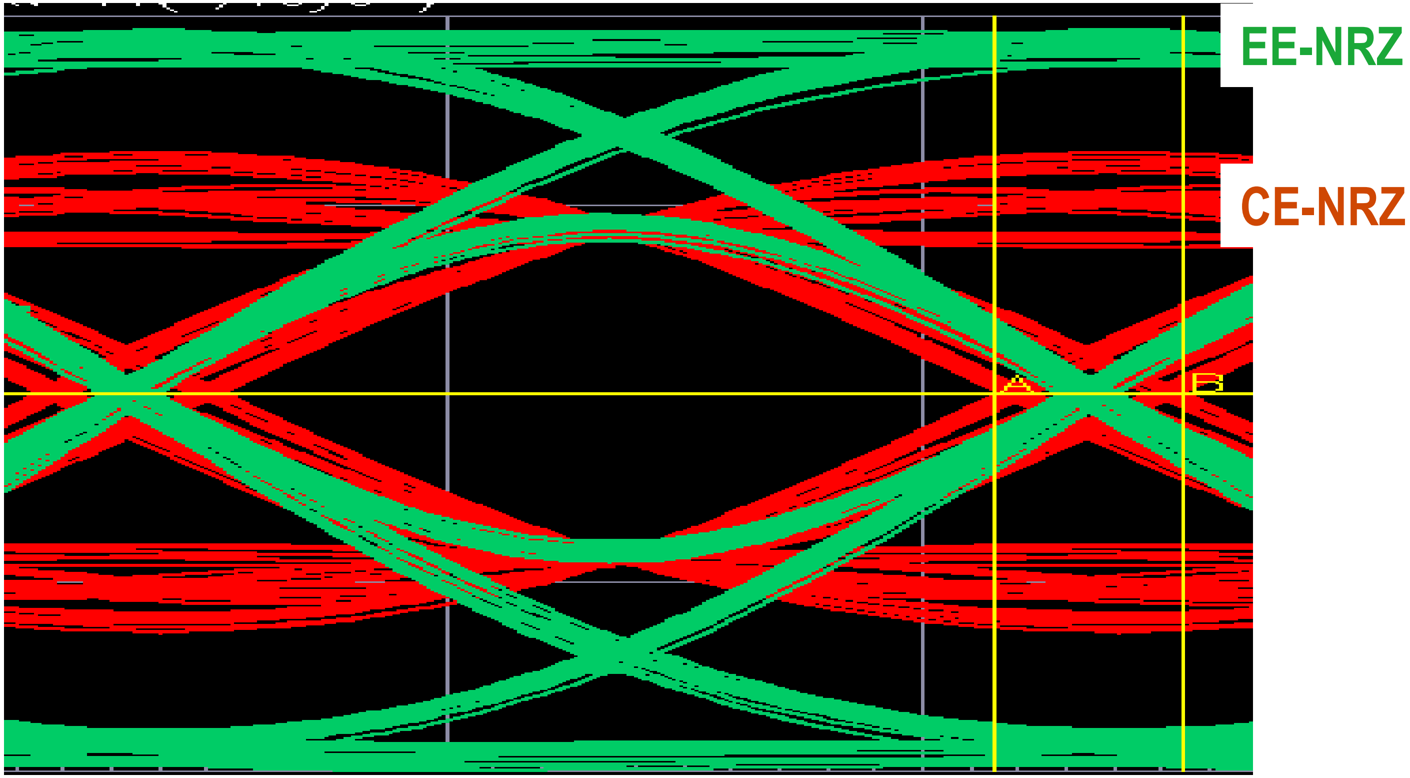
Edge Equalized - NRZ



- The error at the bit edges has been reduced and thus the channel-induced jitter has been reduced.

EE-NRZ vs CE-NRZ

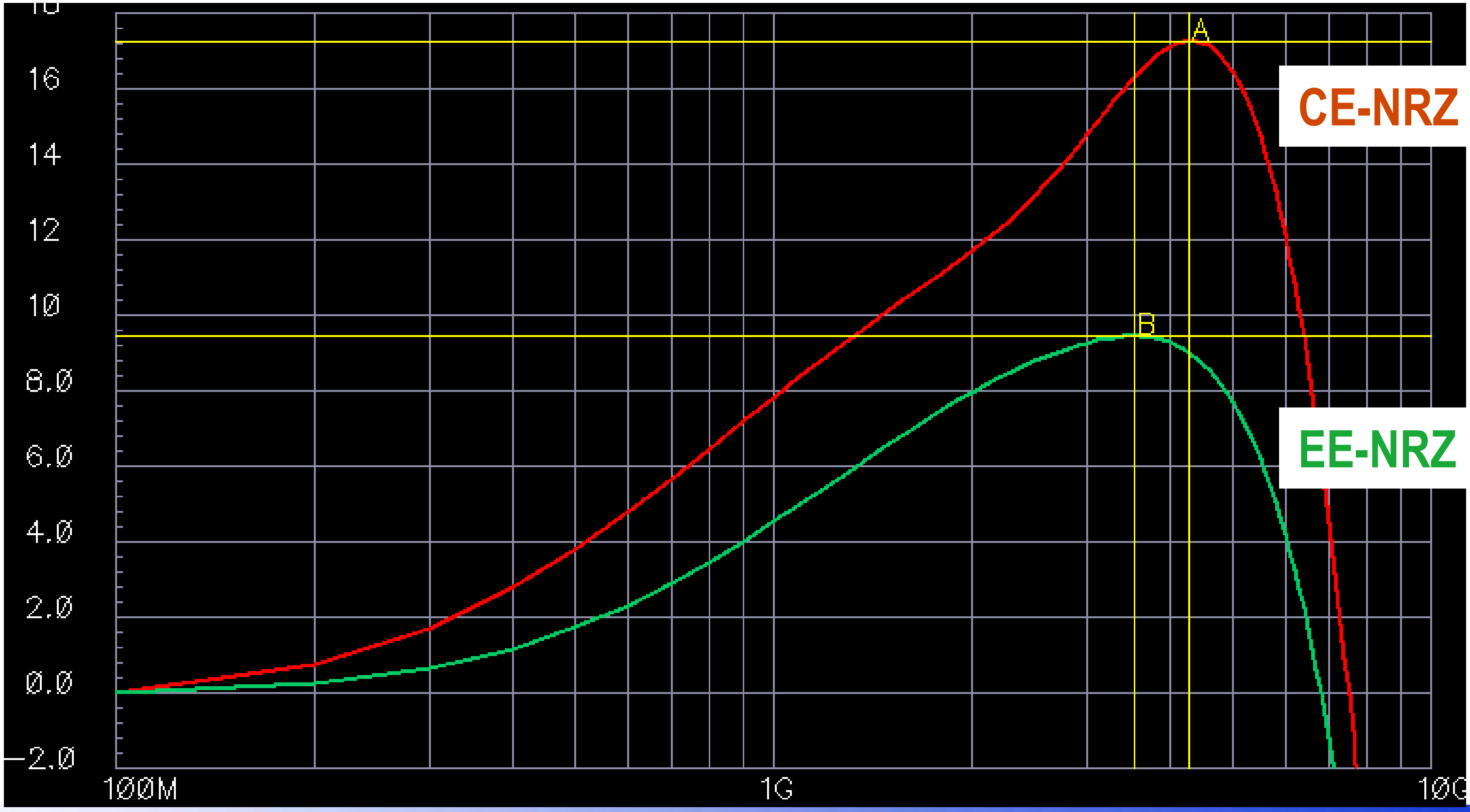
- When scaled for equivalent maximum TX swing, EE-NRZ reduced the jitter and maintained the same eye height.



- The number of significant taps are less for EE-NRZ, leaving more taps for addressing reflections.

EE-NRZ using Receiver CT Equalizer

- Comparing the frequency response of the equalizers, EE-NRZ, requires a less aggressive frequency boost. 9dB (vs 17dB) boost for a 24" FR4 (-18dB) channel. *We do not need N dB of boost to equalize a -N dB channel.*



Summary

- EE-NRZ drives the channel-induced jitter to zero.
- EE-NRZ utilizes the simple structures we already use today.
- Spectral content of EE-NRZ is lower than CE-NRZ. Less susceptible to cross-talk.
- For a given distance (or bandwidth) channel, EE-NRZ lowers the jitter and cross-talk induced BER.
- For a given jitter and cross-talk induced BER, EE-NRZ allows greater distance (or lower bandwidth) channels.