ECEN689: Special Topics in High-Speed Links Circuits and Systems Spring 2010

Lecture 16: Equalization Introduction

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Announcements

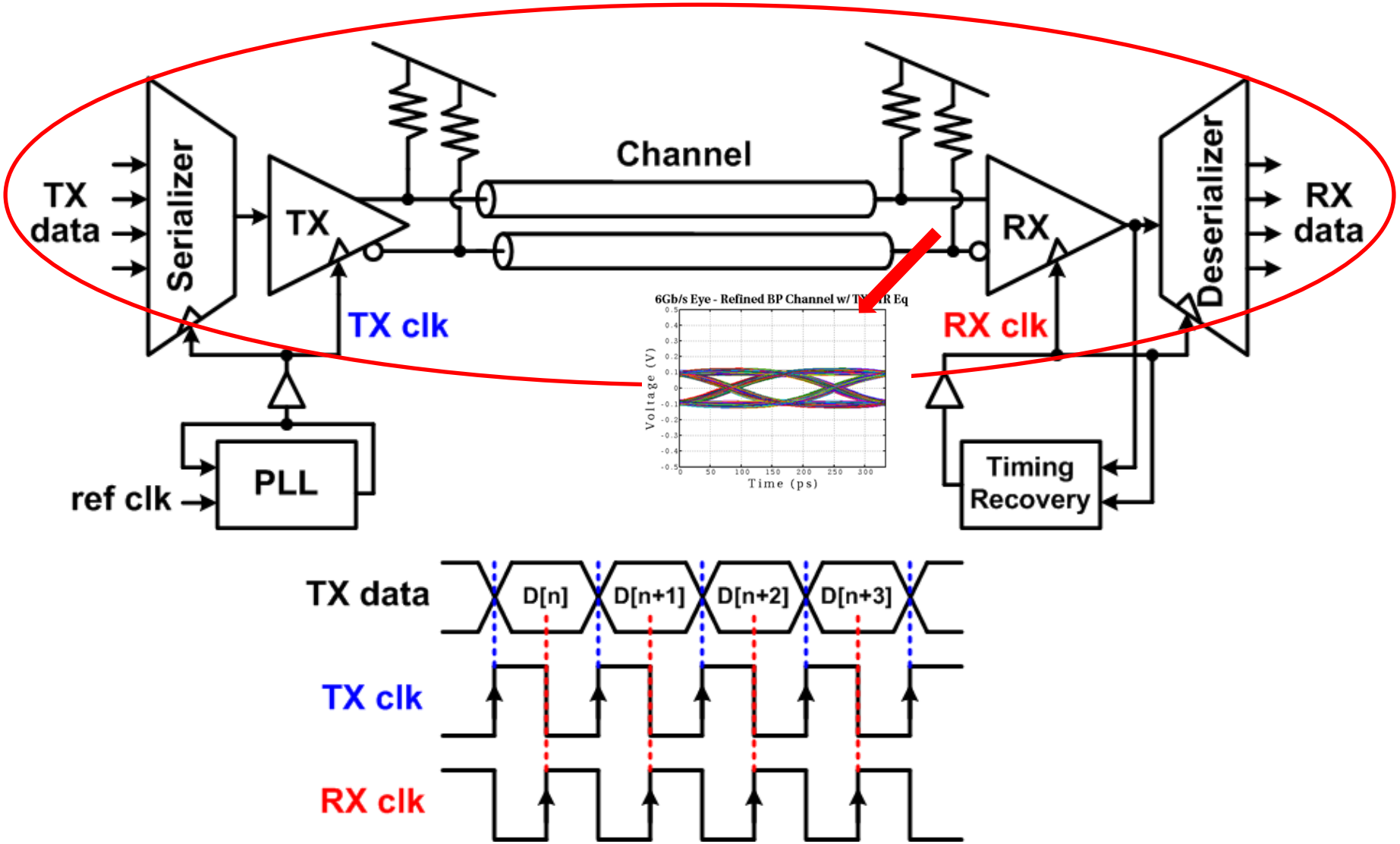
- HW4 due Wednesday 5PM
  - Any issues?

- Exam 1 is March 12
  - 9:10-10:10AM (10 extra minutes)
  - Closed book w/ one standard note sheet
    - 8.5”x11” front & back
  - Bring your calculator

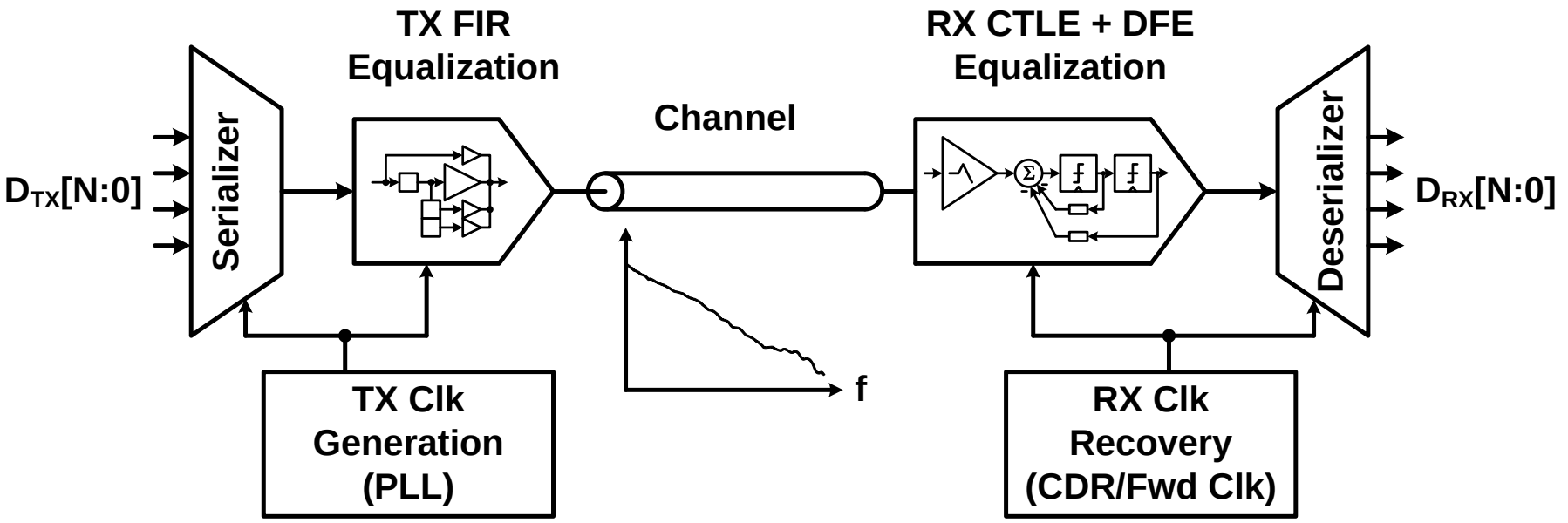
Agenda

- Equalization theory and circuits
  - Equalization overview
  - Equalization implementations
    - TX FIR
    - RX FIR
    - RX CTLE
    - RX DFE
  - Setting coefficients
  - Equalization effectiveness
  - Alternate/future approaches

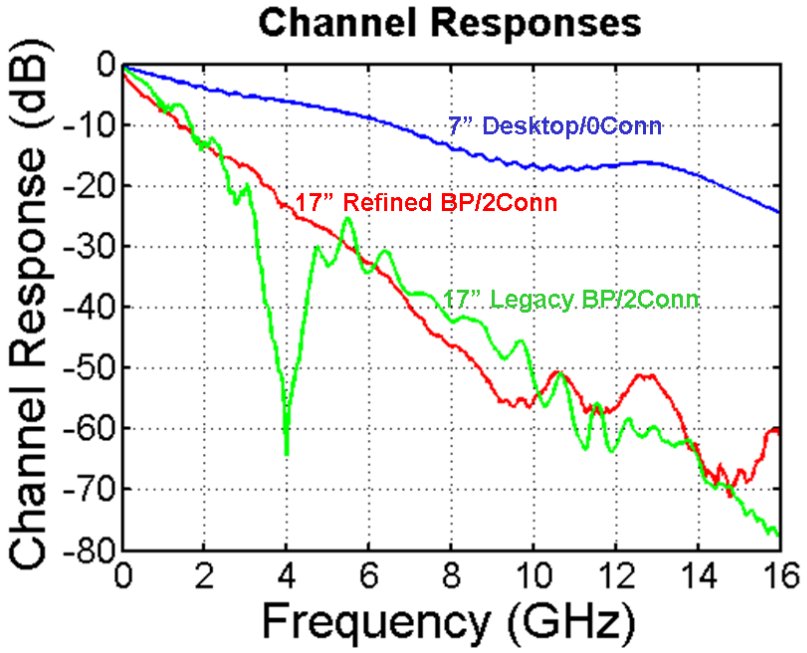
High-Speed Electrical Link System

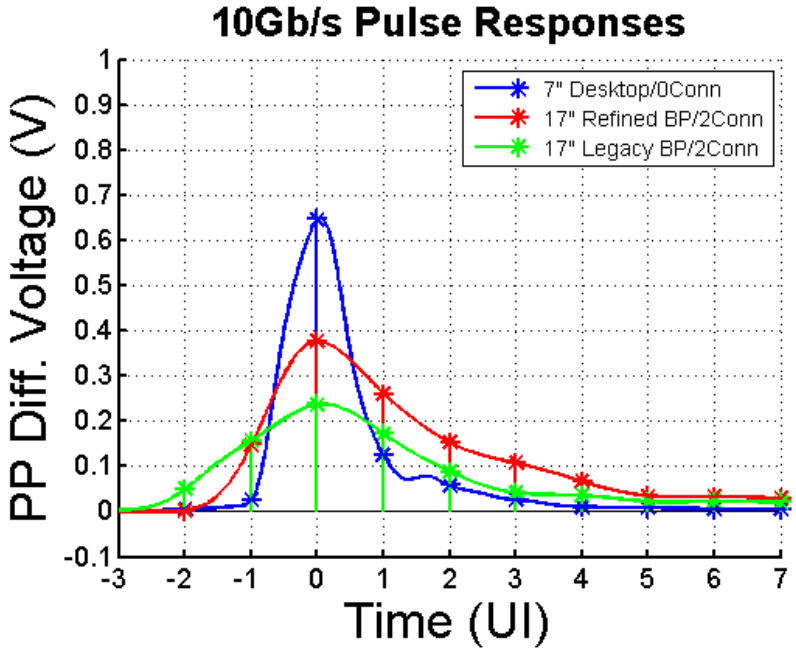


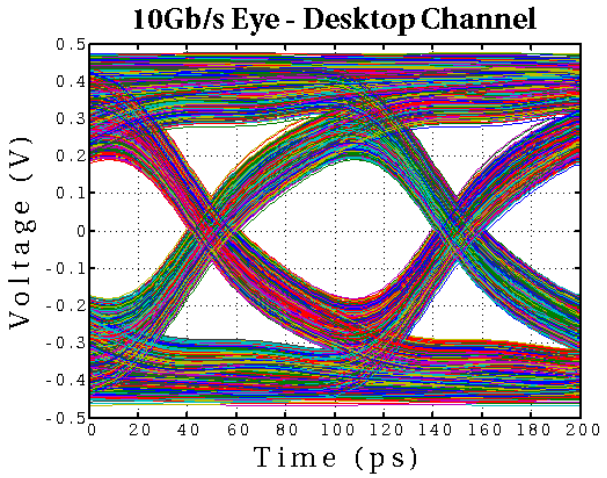
Link with Equalization

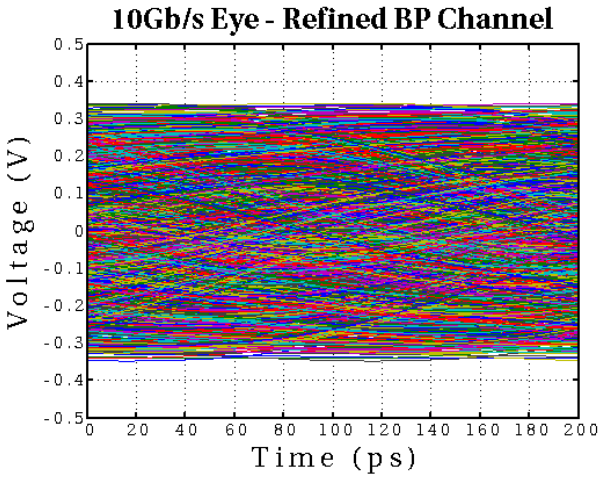


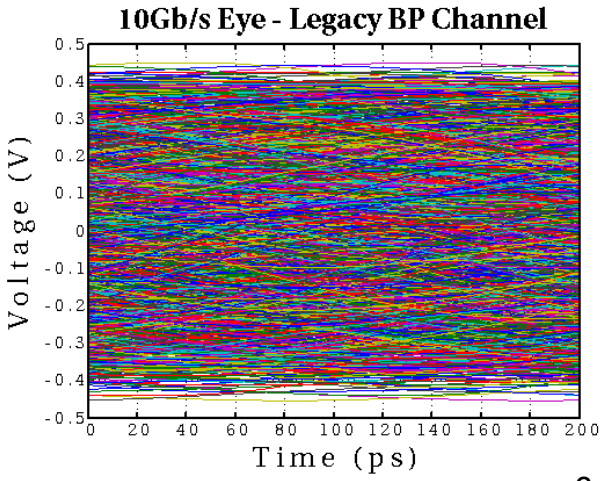
Channel Performance Impact



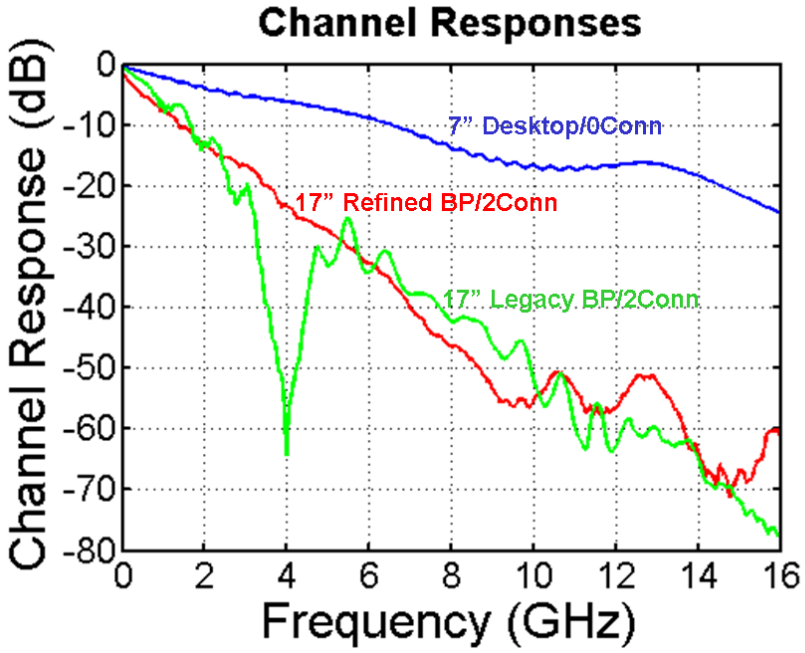


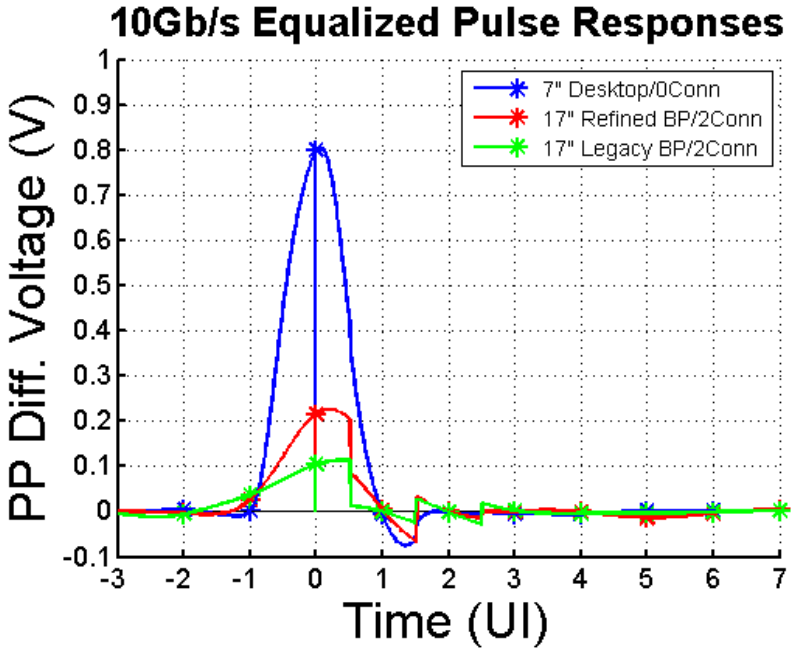


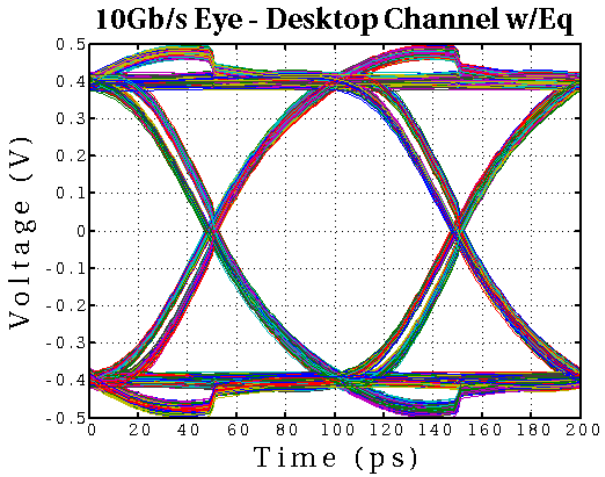


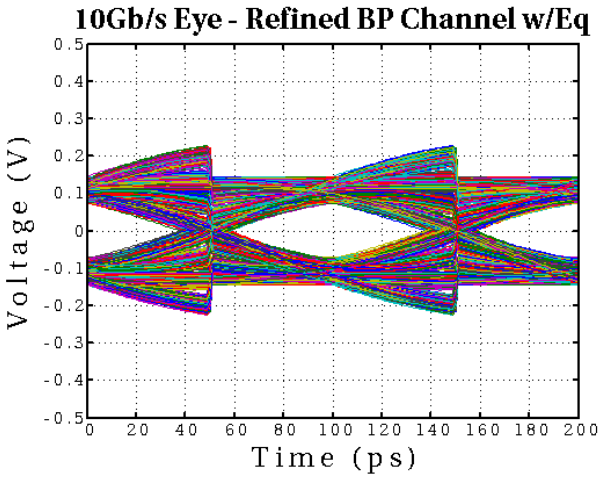


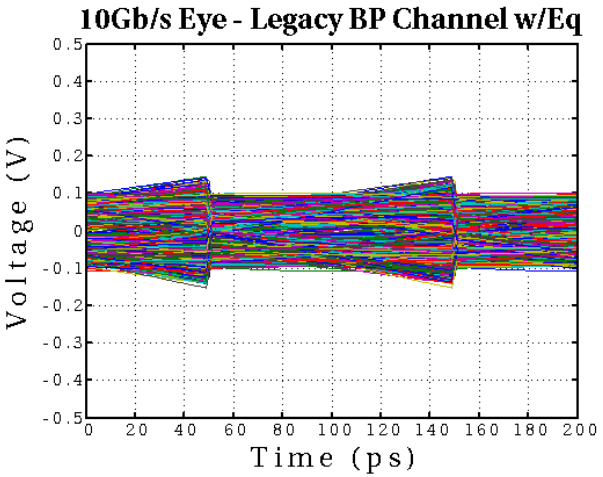
Channel Performance Impact







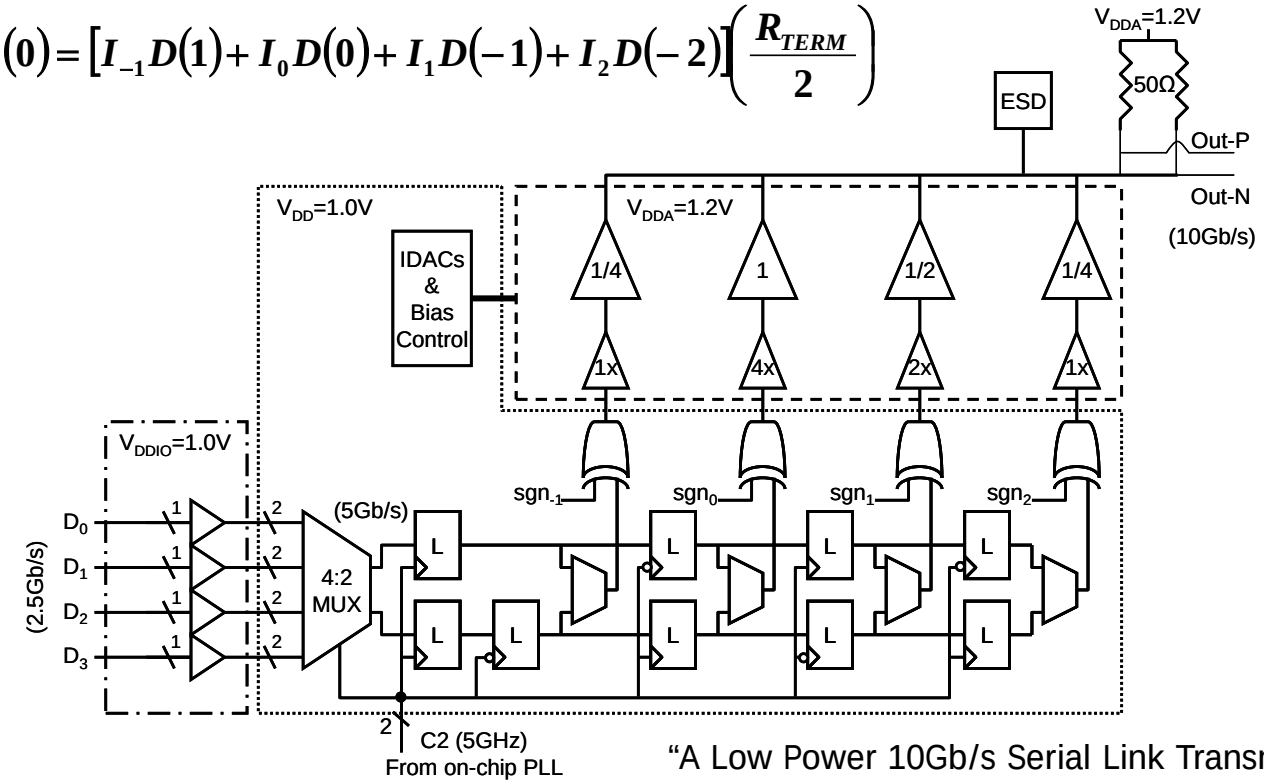




TX FIR Equalization

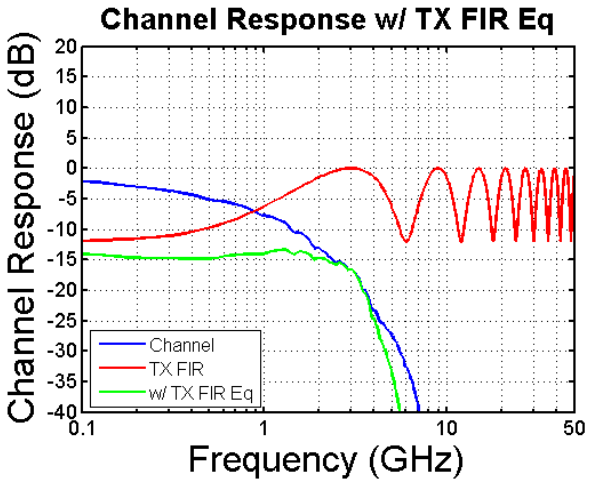
- TX FIR filter pre-distorts transmitted pulse in order to invert channel distortion at the cost of attenuated transmit signal (de-emphasis)

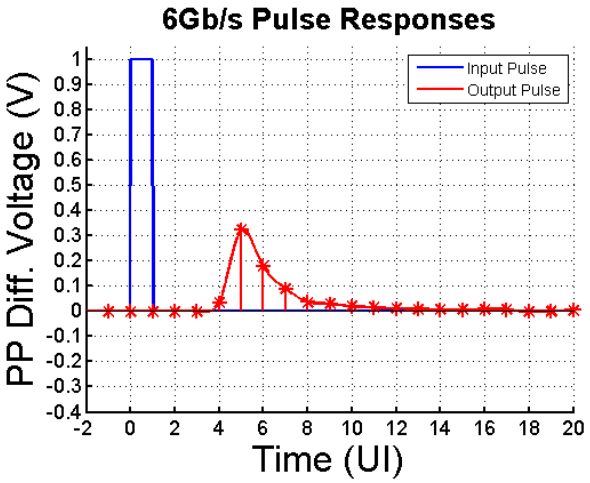
$$V_{out}(0) = \left[I_{-1}D(1) + I_0 D(0) + I_1 D(-1) + I_2 D(-2)\right]\left(\frac{R_{TERM}}{2}\right)$$

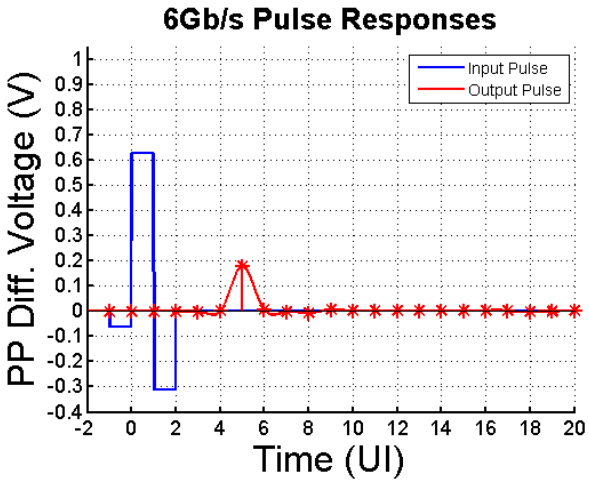


"A Low Power 10Gb/s Serial Link Transmitter in 90-nm CMOS," A. Rylyakov et al., CSICS 2005

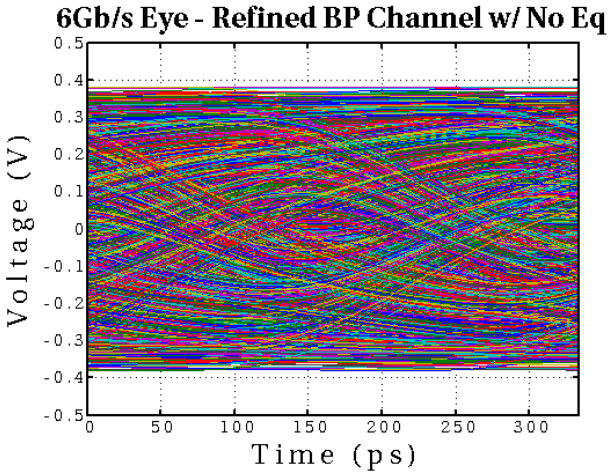
6Gb/s TX FIR Equalization Example

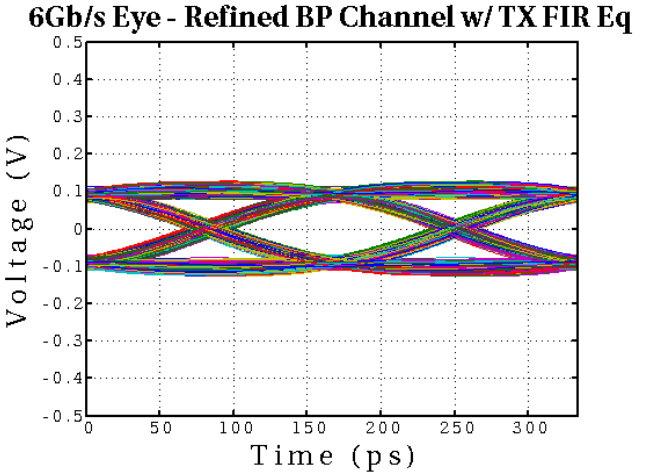




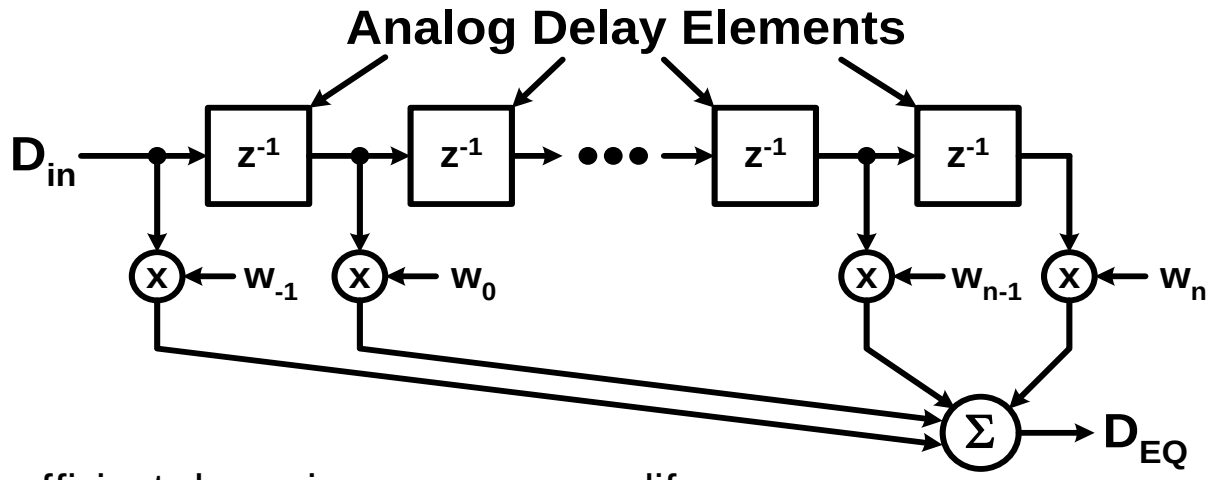


- Pros
  - Simple to implement
  - Can cancel ISI in pre-cursor and beyond filter span
  - Doesn't amplify noise
  - Can achieve 5-6bit resolution
- Cons
  - Attenuates low frequency content due to peak-power limitatior
  - Need a "back-channel" to tune filter taps



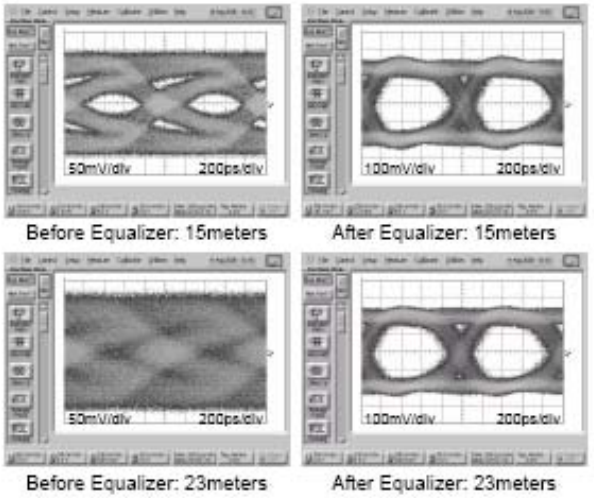


RX Equalization #1: RX FIR



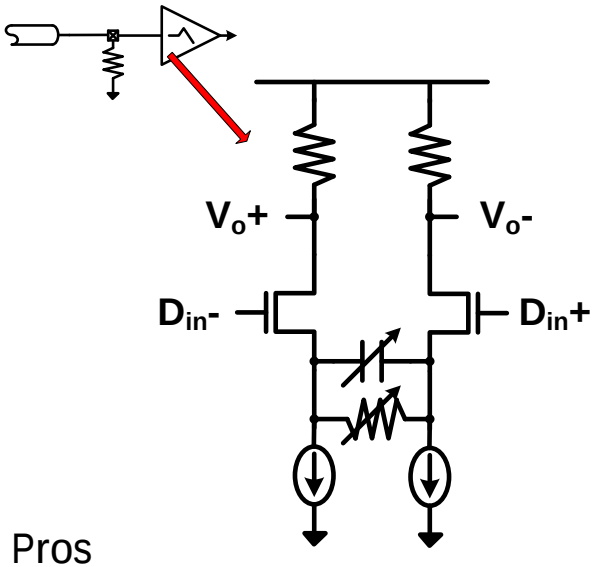
- Pros
  - With sufficient dynamic range, can amplify high frequency content (rather than attenuate low frequencies)
  - Can cancel ISI in pre-cursor and beyond filter span
  - Filter tap coefficients can be adaptively tuned without any back-channel
- Cons
  - Amplifies noise/crosstalk
  - Implementation of analog delays
  - Tap precision

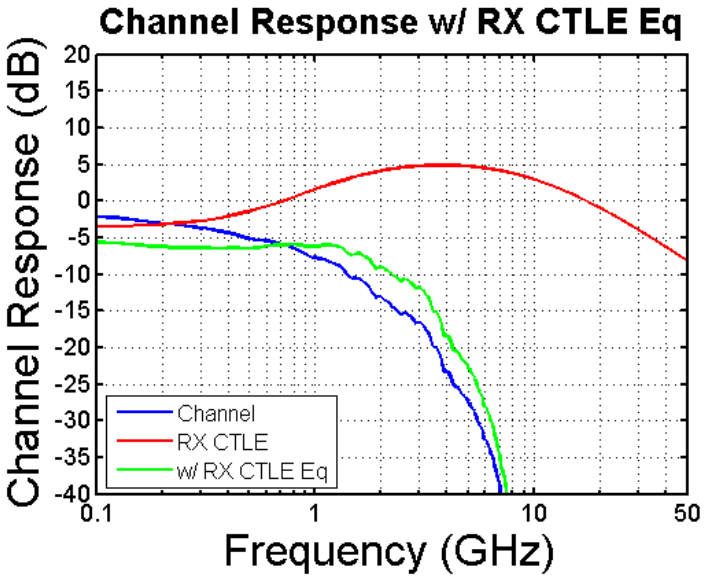
Eye-Pattern Diagrams at 1Gb/s on CAT5e*



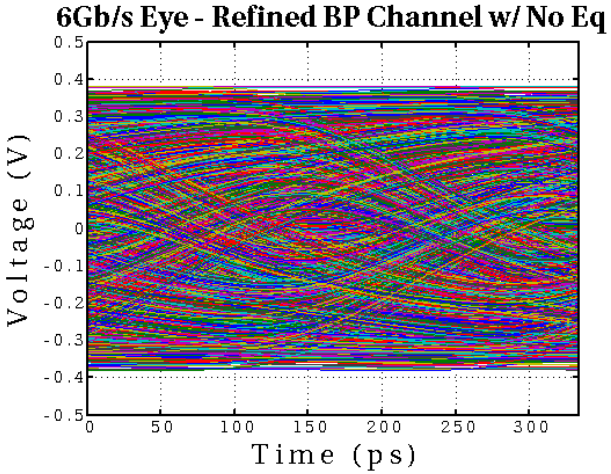
*D. Hernandez-Garduno and J. Silva-Martinez, “A CMOS 1Gb/s 5-Tap Transversal Equalizer based on 3rd-Order Delay Cells," ISSCC, 2007.

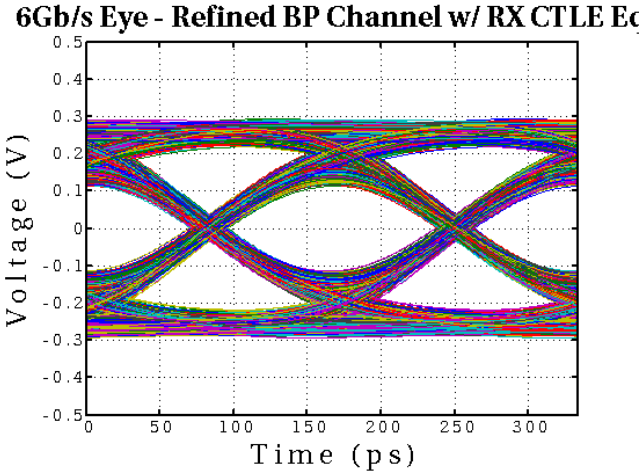
RX Equalization #2: RX CTLE



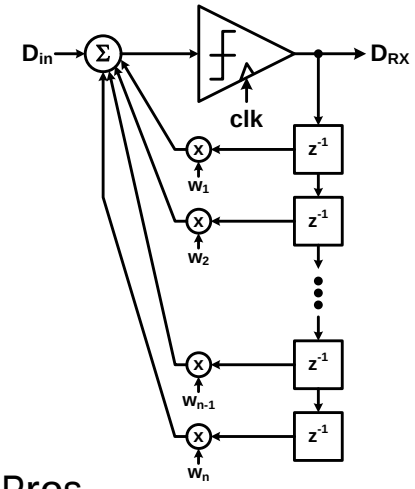


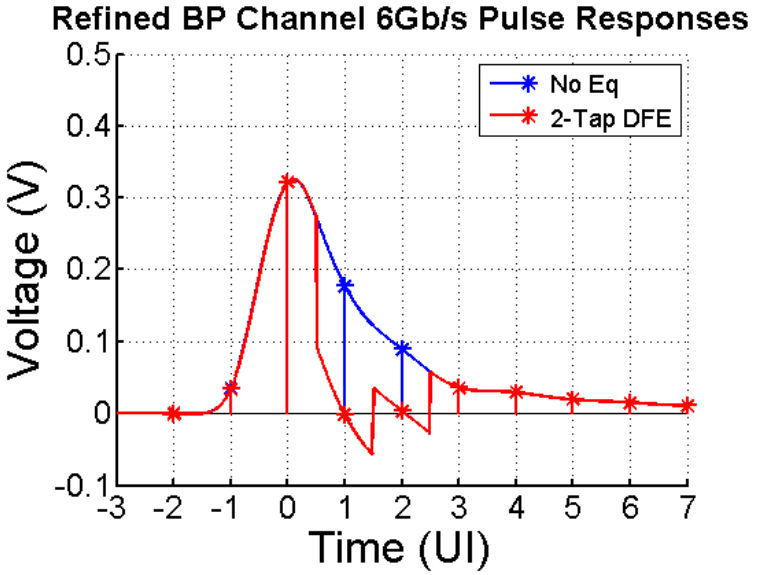
- Pros
  - Provides gain and equalization with low power and area overhead
  - Can cancel both pre-cursor and long-tail ISI
- Cons
  - Generally limited to 1st order compensation
  - Amplifies noise/crosstalk
  - PVT sensitivity
  - Can be hard to tune



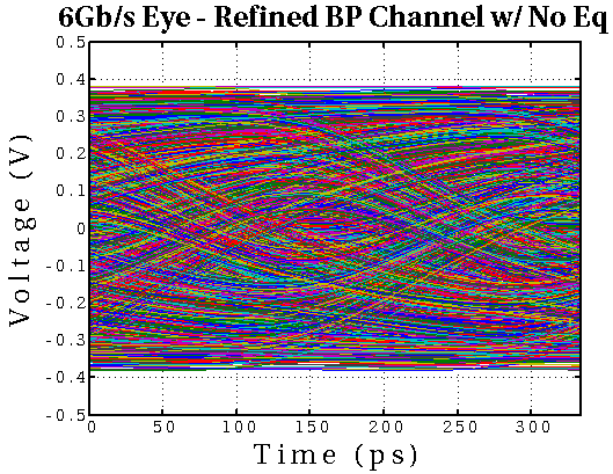


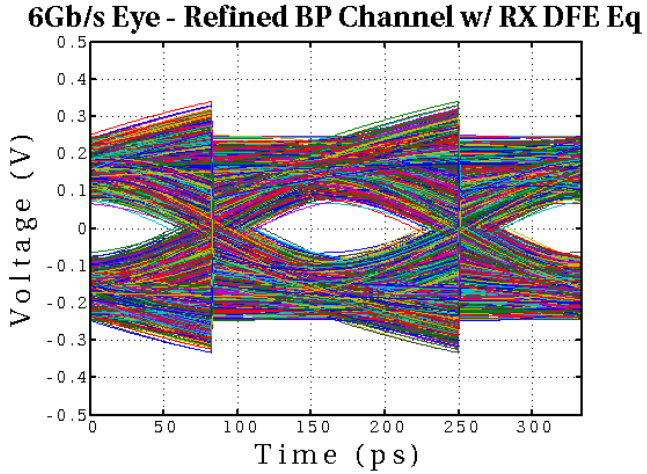
RX Equalization #3: RX DFE



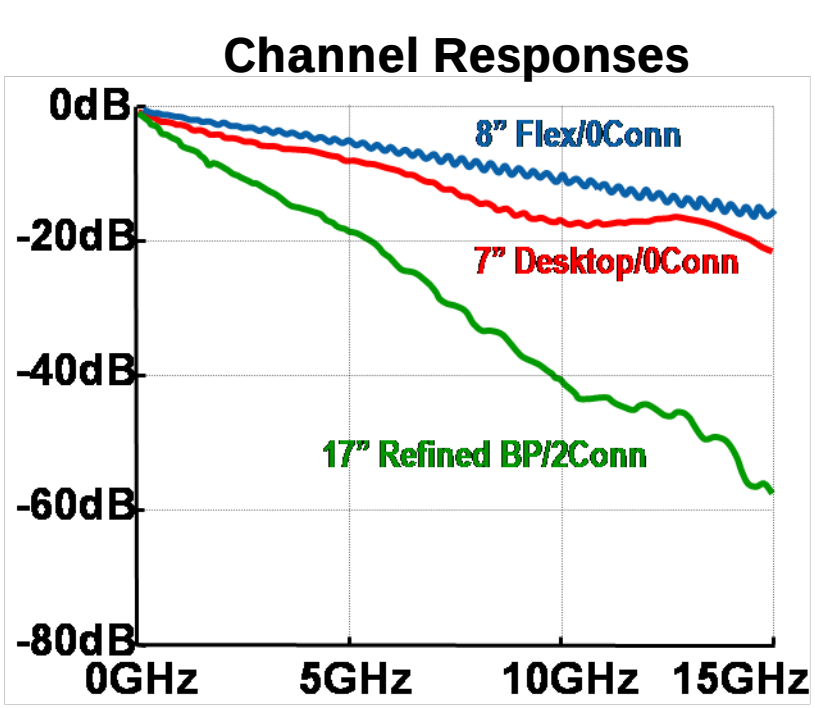


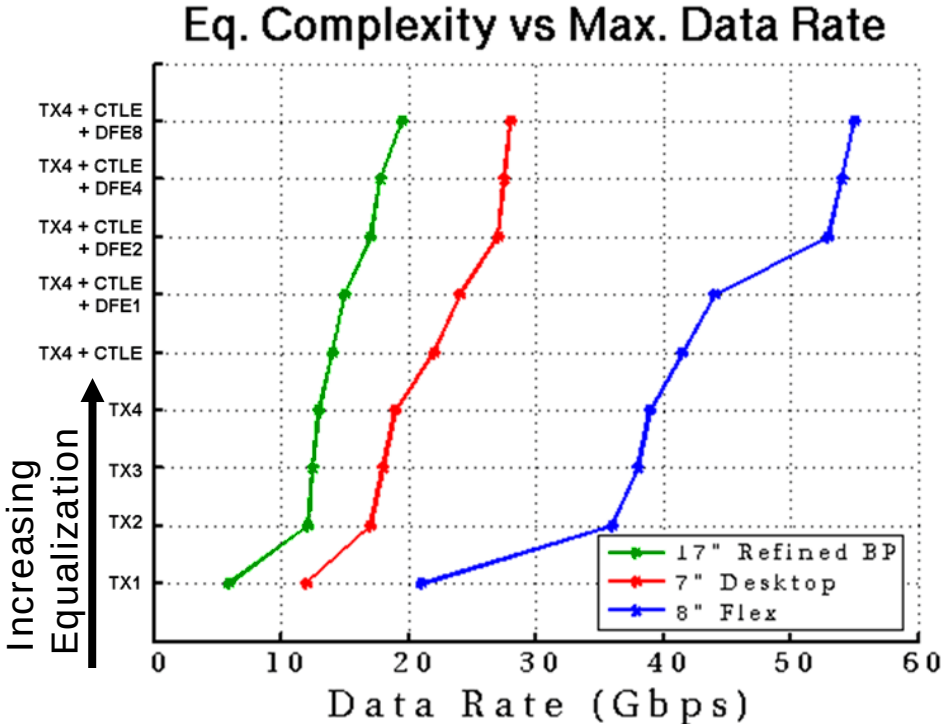
- Pros
  - No noise and crosstalk amplification
  - Filter tap coefficients can be adaptively tuned without any back-channel
- Cons
  - Cannot cancel pre-cursor ISI
  - Critical feedback timing path
  - Timing of ISI subtraction complicates CDR phase detection





Equalization Effectiveness





- Some observations:
  - Big initial performance boost with 2-tap TX eq.
  - With only TX eq., not much difference between 2 to 4-tap
  - RX equalization, particularly DFE, allows for further performance improvement
    - Caution – hard to build fast DFEs due to critical timing path

Next Time

- Equalization theory and circuits
  - Equalization implementations
    - TX FIR
    - RX FIR
    - RX CTLE
    - RX DFE
  - Setting coefficients
  - Equalization effectiveness
  - Alternate/future approaches