EE273 Lecture 8
Advanced Signaling

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Logistics

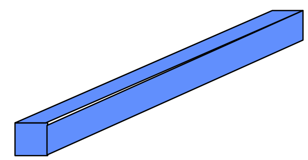
- No homework this week
- Demo
  - Friday 2/9/01 12Noon to 12:50PM
  - Gates B03 (Channel E3)
- Midterm
  - Monday 2/12/01 from 7:00PM to 9:00PM
  - Room 200-2
  - We will be having class on Monday
- Reading
  - Sections 9.1 through 9.5
  - Complete before class on Monday 2/12

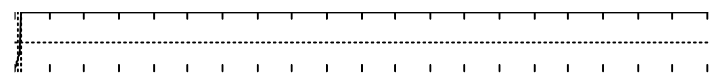
A Quick Overview

- Driving long RC wires
  - on chip wires are like wet noodles
  - delay and rise time are quadratic with length
    - 80ps/mm^2 in 0.18μm
  - can make delay linear with repeaters
  - wider wires help a little
    - fringing fields
  - fatter (taller) wires help a lot
- Driving lossy LC lines
  - frequency dependent loss closes the eye diagram
  - a lone pulse is affected the most
  - equalization can cancel the frequency dependent loss
- Simultaneous bidirectional signaling
  - use both forward and reverse traveling wave at the same time

Long On-Chip Wires are Diffusive RC Lines

- Typical wire 0.5µm x 0.5µm Aluminum (0.35µm technology)
  - R = 120Ω/mm
  - C = 160fF/mm
  - τ = RC = 19ps/mm^2
- Delay *and* Rise Time are ***quadratic*** with distance
- Complicated by R of wire and C of load
- Large drivers don't help - R of wire dominates
- Problem is getting worse with time
  - 80ps/mm^2 in 0.18µm technology

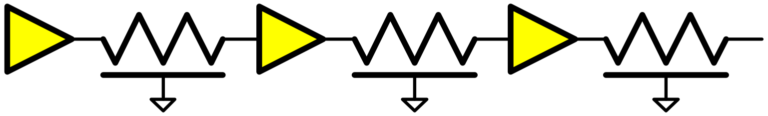




Response of 30mm wire at 5mm intervals

Optimal Repeater Spacing

- Repeaters convert quadratic delay to linear delay
- Optimal repeater spacing is when the delay of the **repeater** equals the delay of the **wire**
  - about 3mm for an 0.35µm process
  - about 1mm for a 0.18µm process
- Results in a maximum signal propagation velocity that goes as the inverse root of RC (nearly linear with line width)

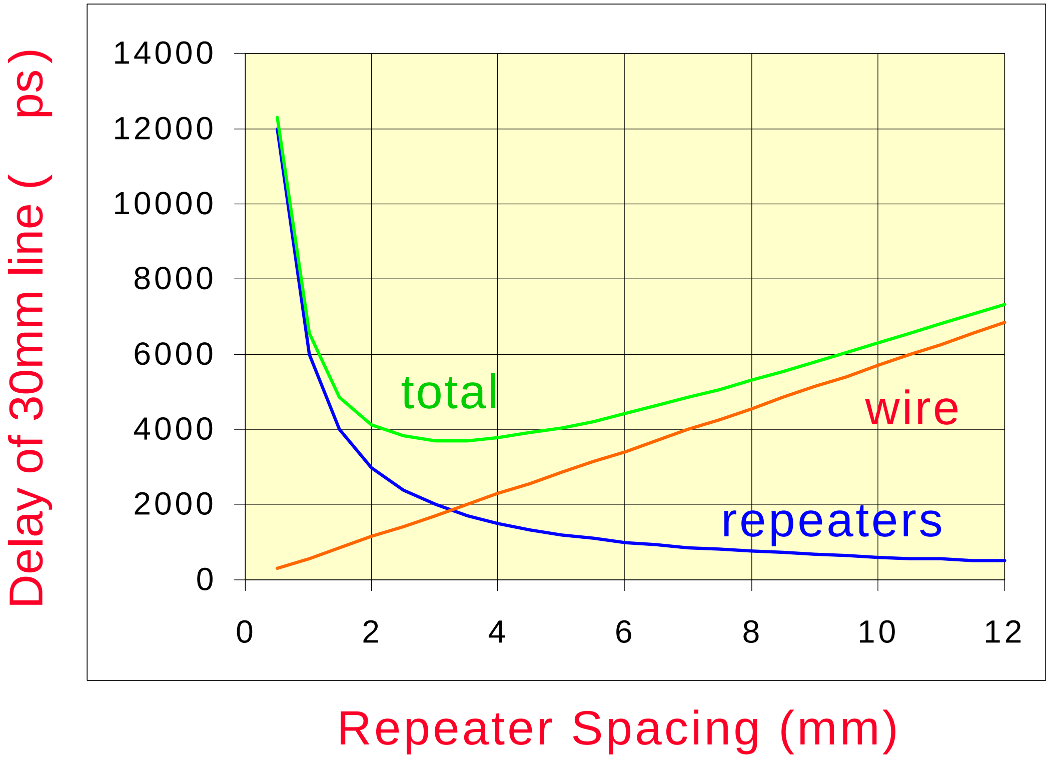


$$t_d = \left(\frac{l}{l_s}\right)\left(t_b + 0.4 l_s^2 RC\right)$$

$$v = \frac{1.3}{\sqrt{t_b RC}}$$

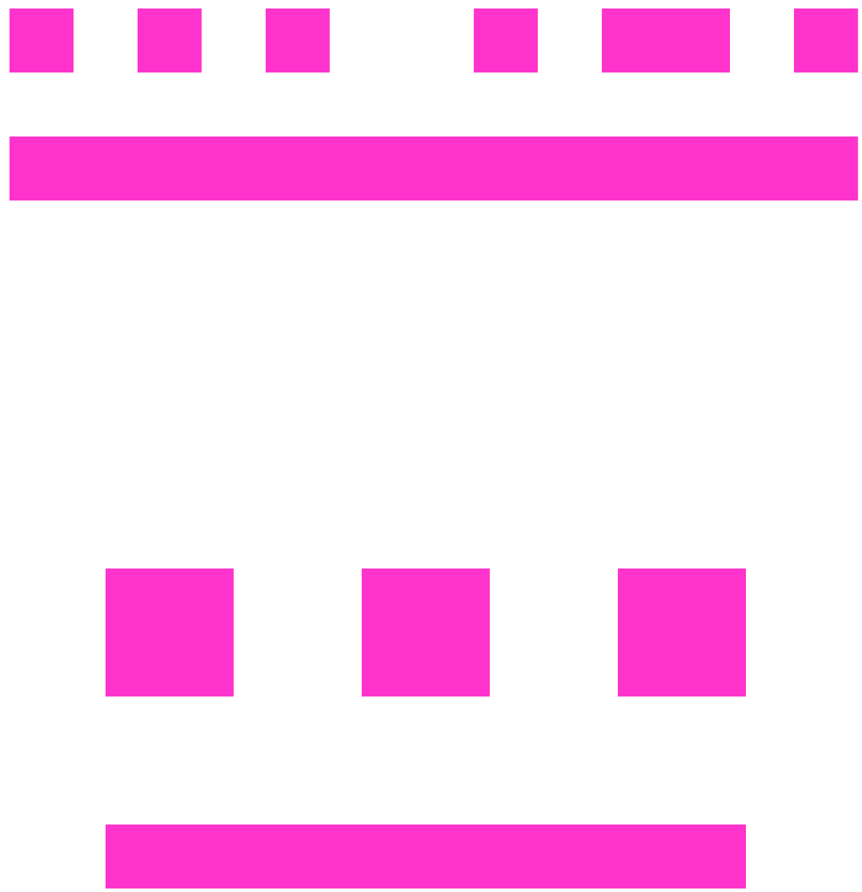
Optimal Repeater Spacing
The Graph

0.35µm technology

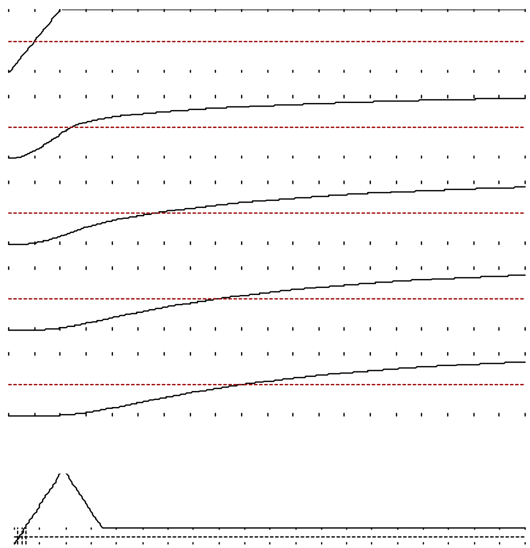


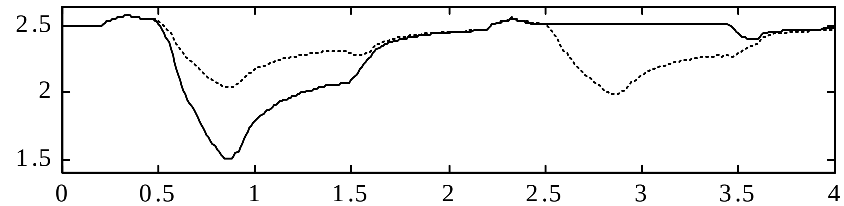
Fat Wires Help (a little)
Thick, Fat Wires Help a lot

- Making wires wider than minimum width doesn't help much
  - R decreases
  - C parallel plate increases
  - C fringing stays the same
- Making wide wires on thick metal layers helps **a lot**
  - R decreases
  - C stays the same
- Can have a few fast wires or lots of slow wires



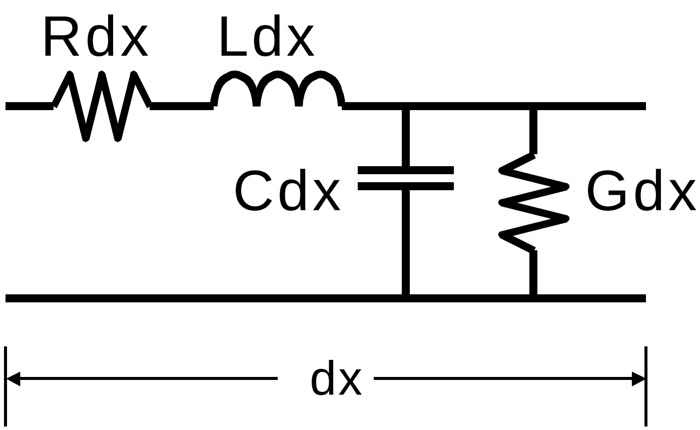
Overdrive increases signal velocity by 3x

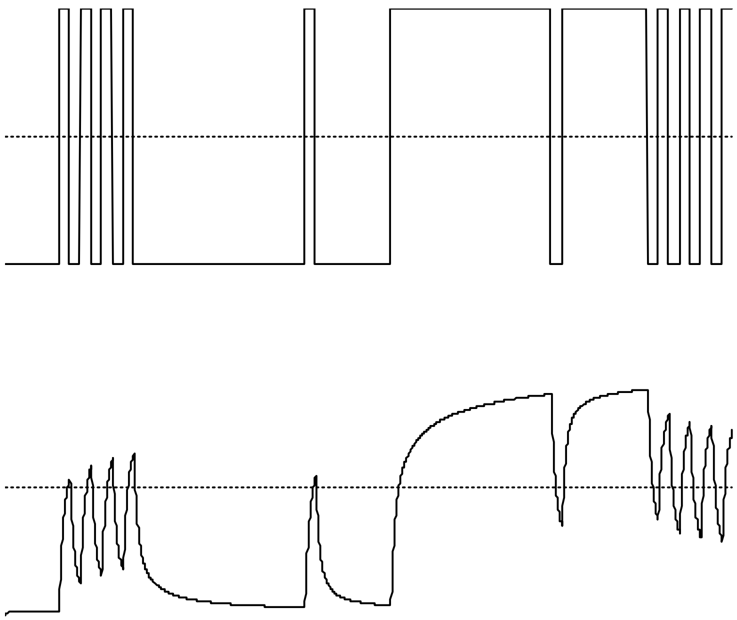




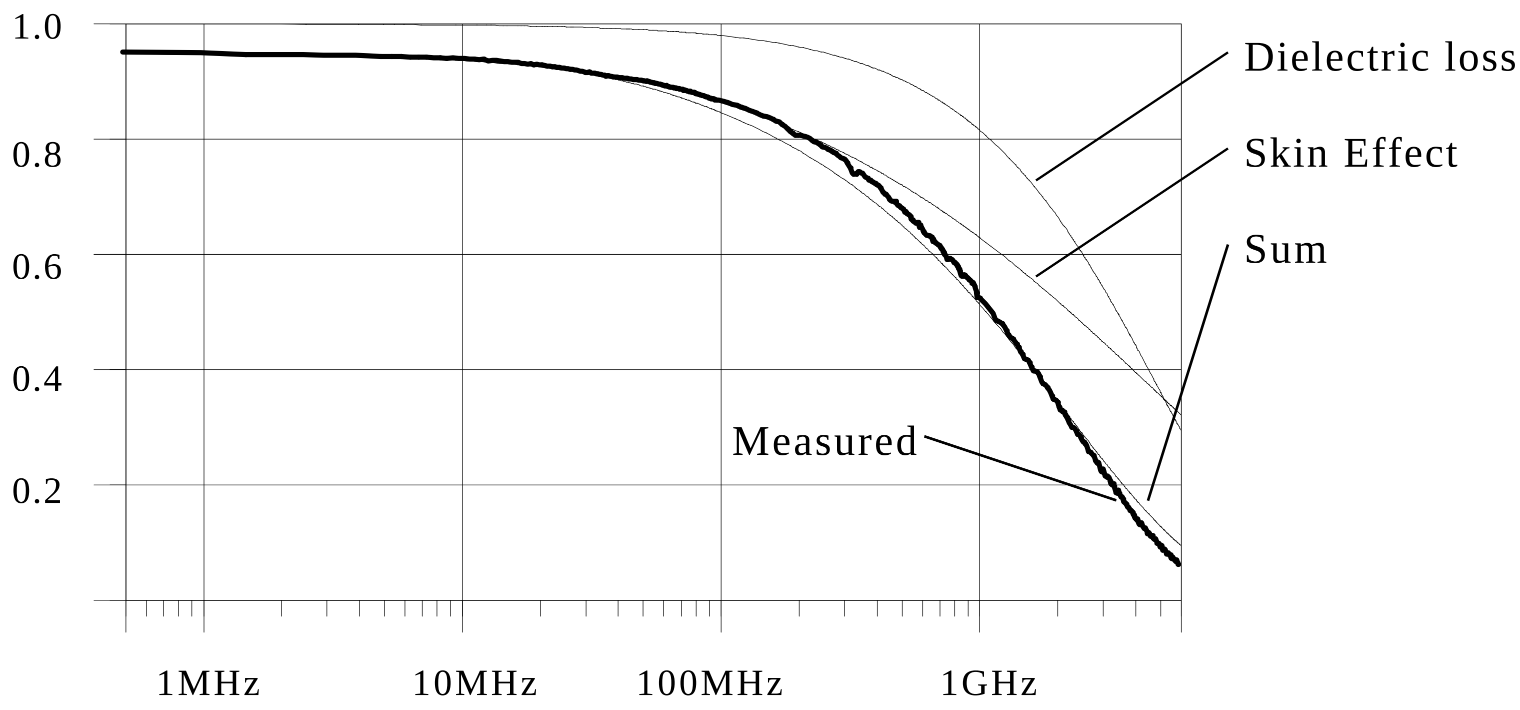
Long Off-Chip Wires are Lossy LRC Lines

- Long off-chip wires are LRC transmission lines
  - fast rise to AC attenuation
  - long diffusive tail
  - complicated by frequency-dependent attenuation due to skin effect





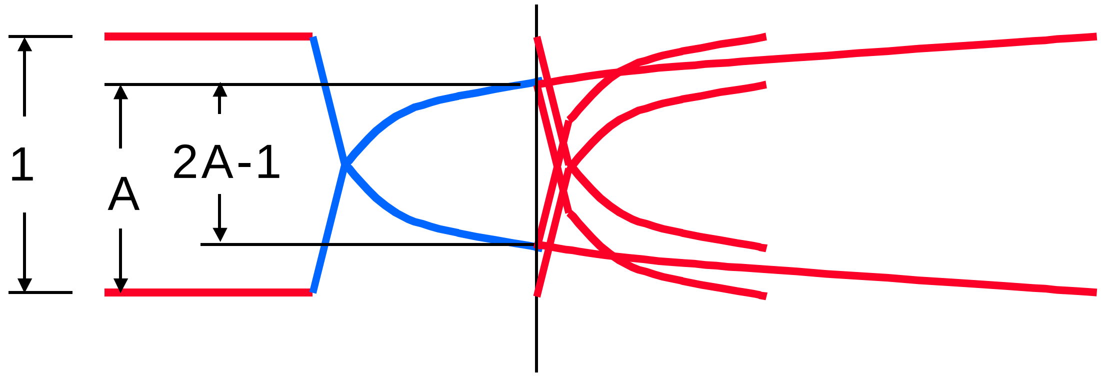
Skin effect resistance and dielectric absorption



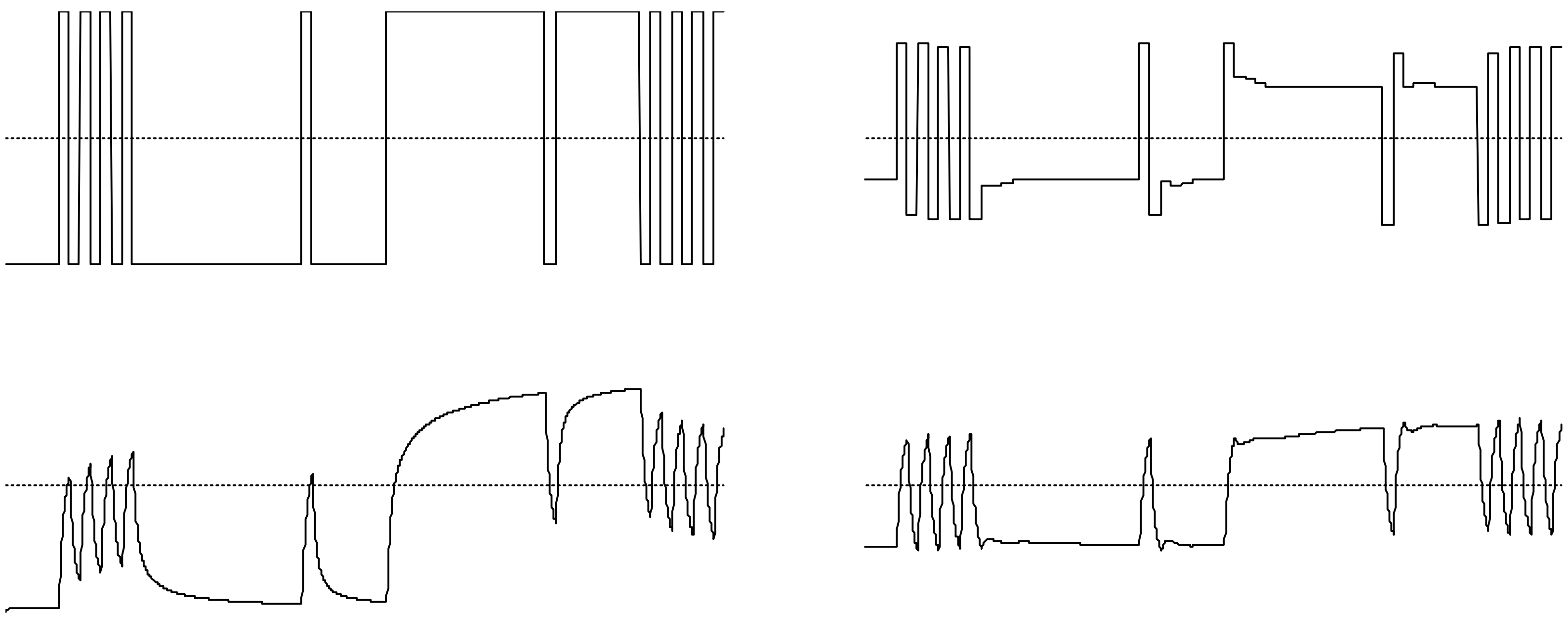
1m 8mil 50Ω stripguide with GETEK dielectric

The problem of the '*Lone Pulse*'

- Critical parameter is what fraction of swing, A is achieved in one bit time
- Eye opening is reduced to B = 2A-1
- No eye opening at 50% attenuation
- Also results in data-dependent jitter



With Transmitter Equalization



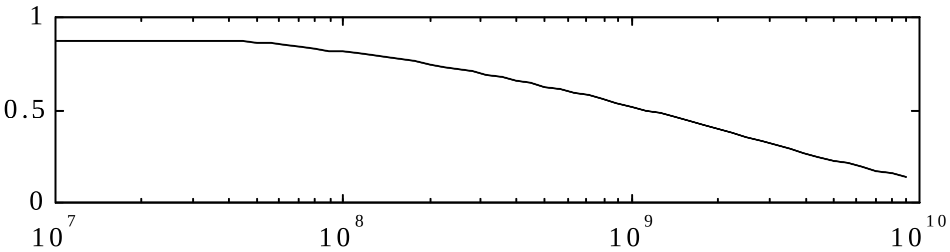
Before

After

Solution - Equalization

1m 5mil
stripguide

$A(f)$



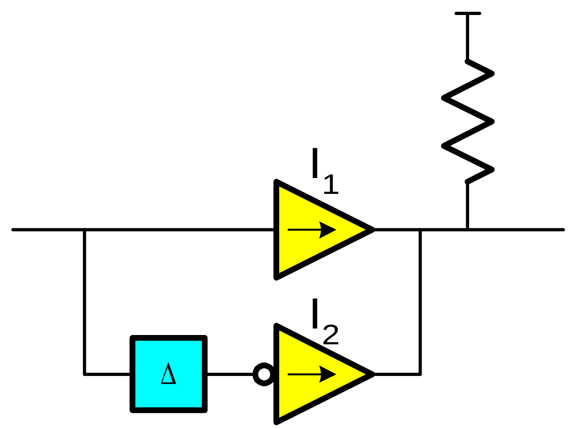
$H(f)$

$A(f)H(f)$

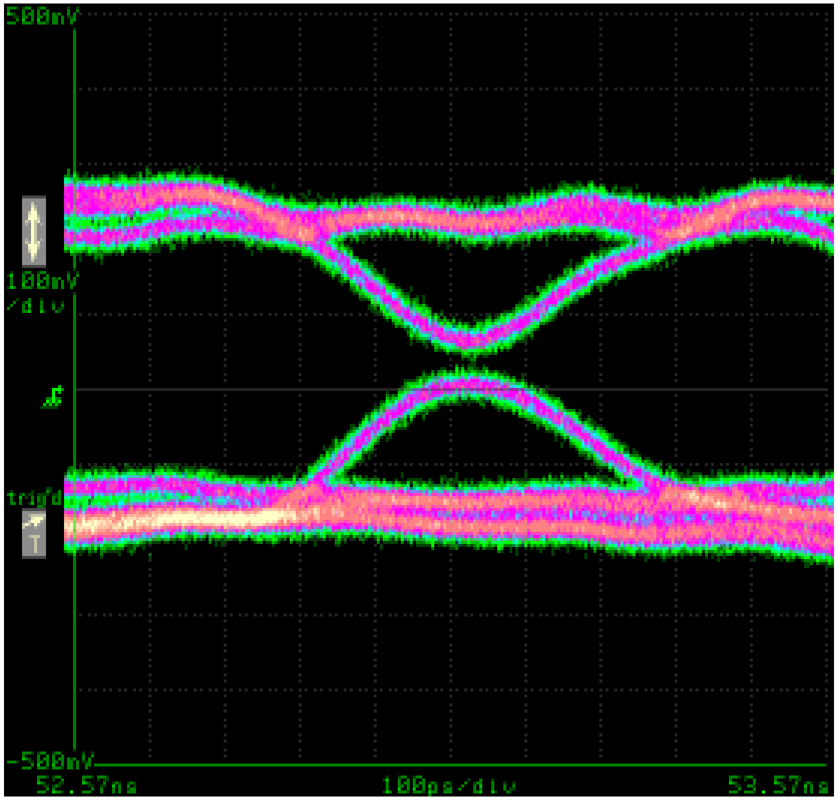
f (Hz)

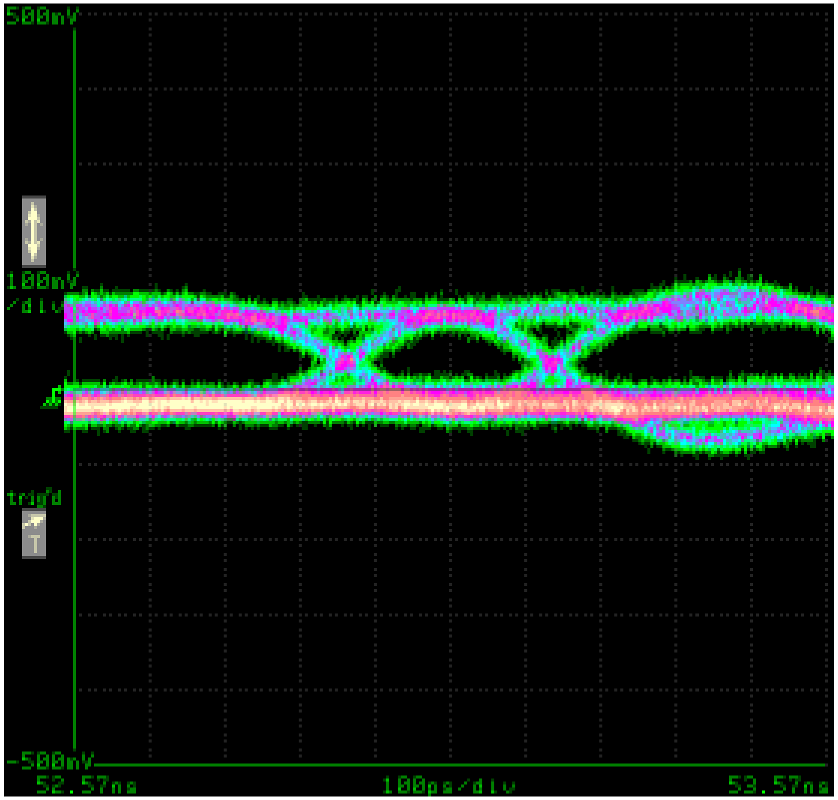
Equalization - A Simple Implementation

- Two-tap FIR filter
  - send AC component (adjacent bits different) at full magnitude
  - send DC component (adjacent bits the same) at reduced magnitude
- Implement with two transmitters
  - one lags the other by one bit and drives in the opposite direction

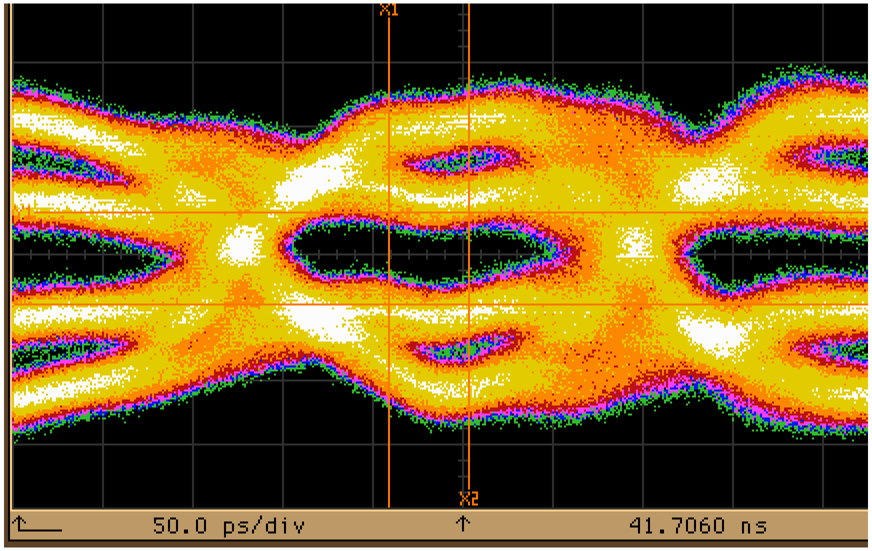


Equalization
Some Photos

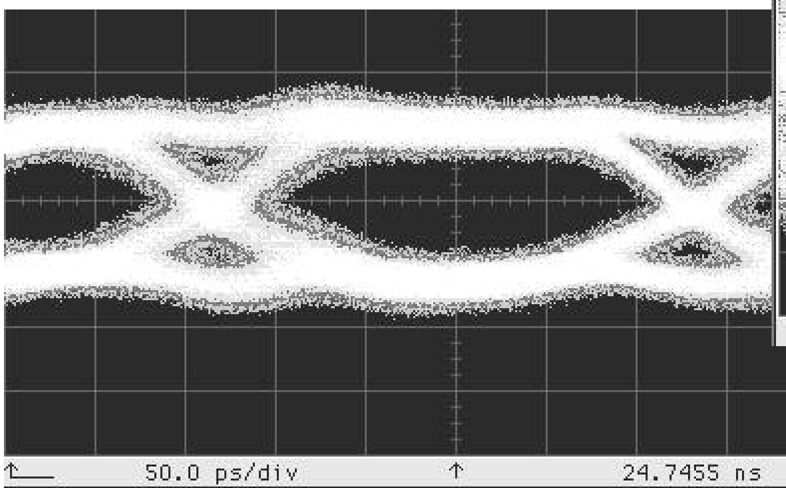


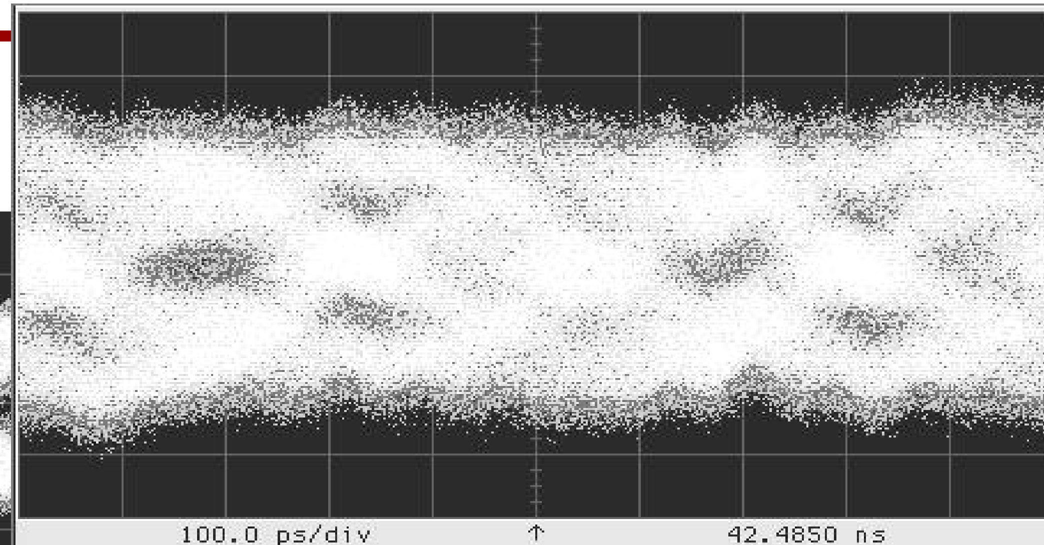


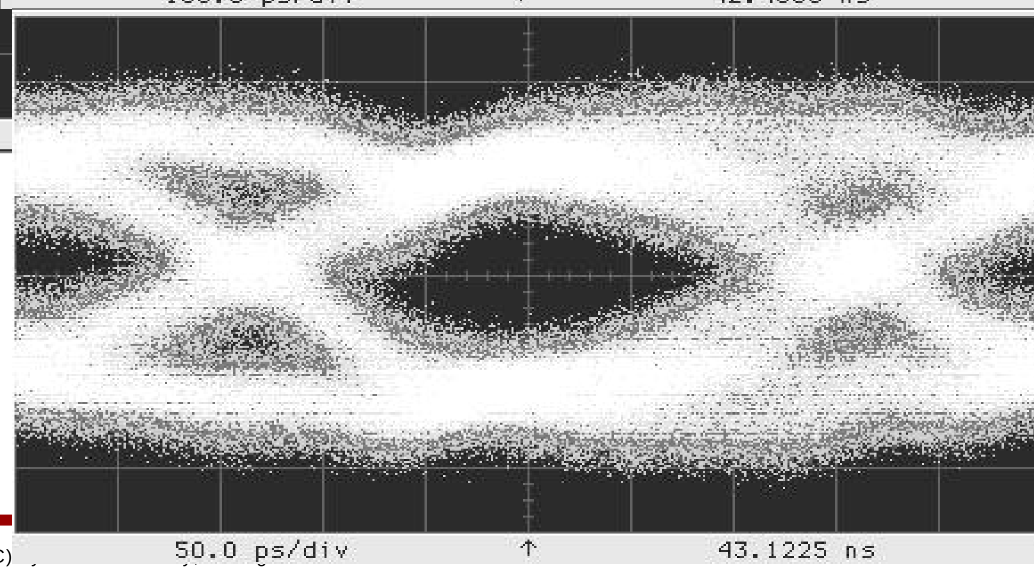
More Pictures



Still More Pictures



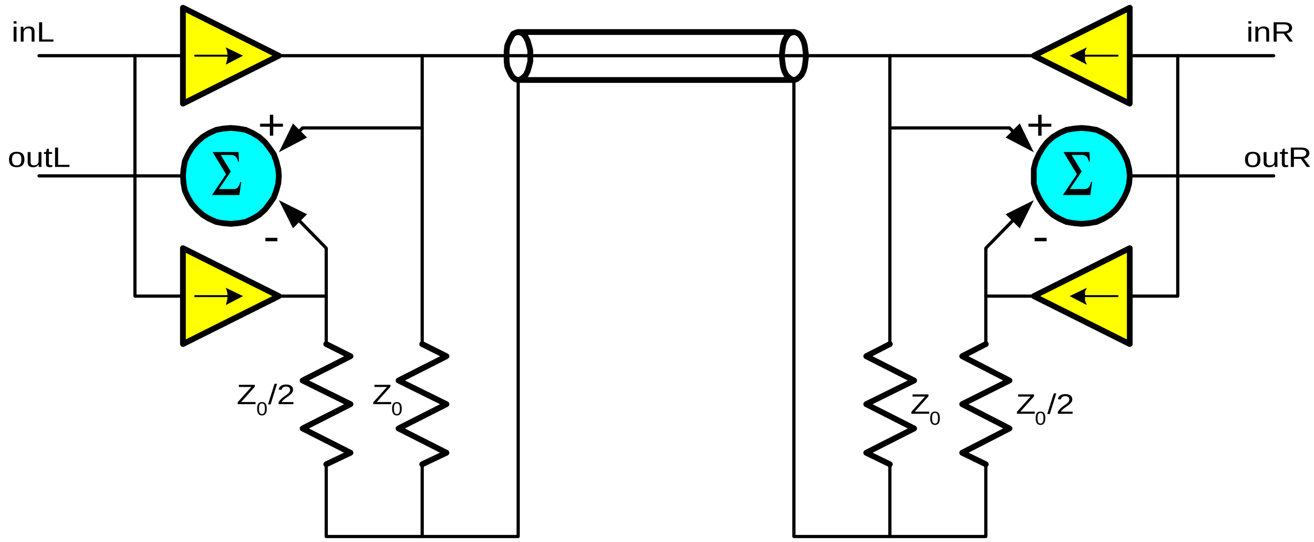




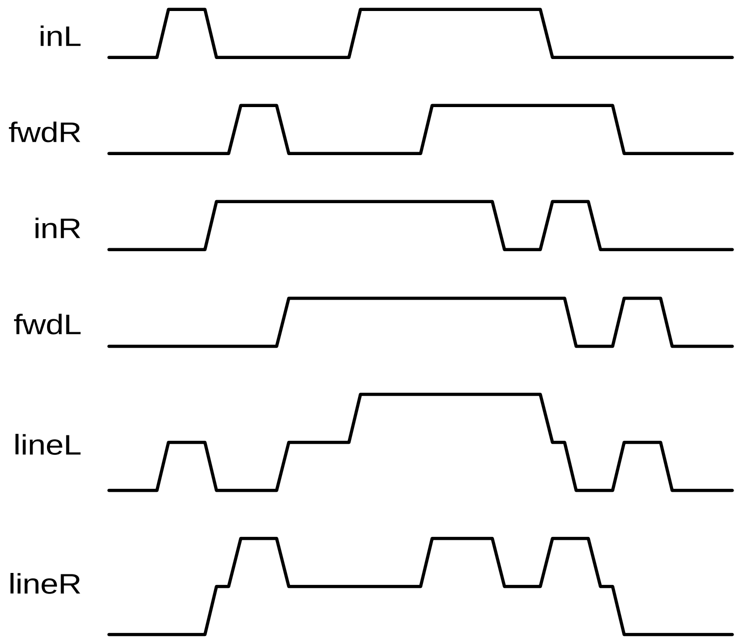
Simultaneous Bidirectional Signaling

- Wires can transmit waves in both directions
- It seems a shame to only use one direction at a time
- Simultaneous bidirectional signaling
  - transmit waves in both directions at the same time
  - waveform on wire is superposition of forward and reverse traveling wave
  - subtract transmitted wave at each end to recover received wave
- There are 3-levels on the line but its still 2-level signaling
- Much more sensitive to reflections and crosstalk (as if only one end of the line were terminated)

Simultaneous Bidirectional Signaling
The Circuit



Simultaneous Bidirectional Signaling Waveforms



Next Time

- Timing