
EE273 Lecture 8 Advanced Signaling

February 4, 2004

Heinz Blennemann
Stanford University
heinzb@stanford.edu

Logistics

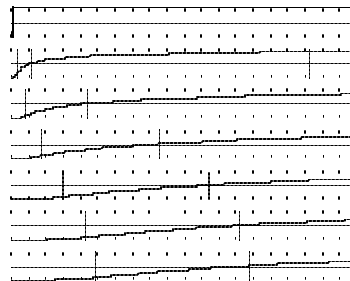
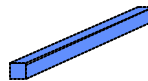
- No homework assignment this week
- Midterm review Fri. 11AM
- Lectures as usual next week, Mon & *Wed*
- Midterm
 - Wed 2/11/02 from 7:00PM to 9:00PM
 - Room: in the Quad, Bldg. 420, Room 041
 - parking: come early, campus map on-line, any A/C permit space (not enforced in the evenings)
- Reading
 - Sections 5
 - Complete before class on Monday 2/9

A Quick Overview

- Driving long RC wires
 - on chip wires are like wet noodles
 - delay and rise time are quadratic with length
 - 80ps/mm² in 0.18 μ m
 - 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 0.5 μ m x 0.5 μ m Aluminum (0.35 μ m technology)
 - $R = 120\Omega/\text{mm}$
 - $C = 160\text{fF}/\text{mm}$
 - $\tau = RC = 19\text{ps}/\text{mm}^2$
- 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/mm² in 0.18 μ m 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 0.35 μm process
 - about 1mm for a 0.18 μm process
- Results in a maximum signal propagation velocity that goes as the inverse root of RC (nearly linear with line width)

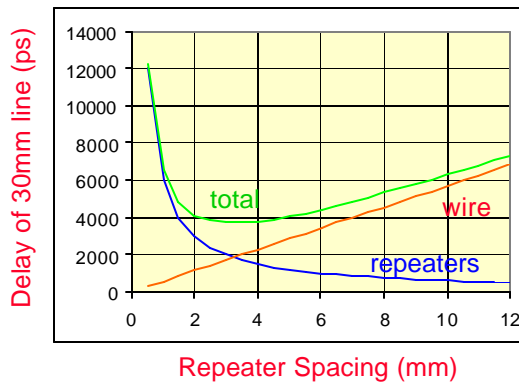


$$t_d = \left(\frac{l}{l_s} \right) (t_b + 0.4l_s^2 RC)$$

$$v = \frac{13}{\sqrt{t_b RC}}$$

Optimal Repeater Spacing The Graph

0.35 μm technology



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

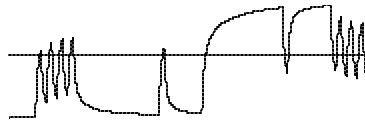
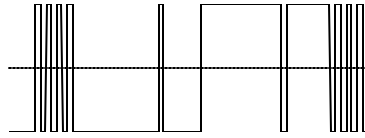
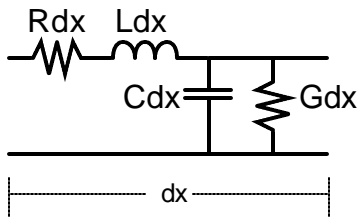
- Making wires wider than minimum width doesn't help much
 - R decreases
 - C parallel plate increases
 - C fringing stays the same
- Making wide wires on thick metal layers helps **a lot**
 - R decreases
 - C stays the same
- Can have a few fast wires or lots of slow wires



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

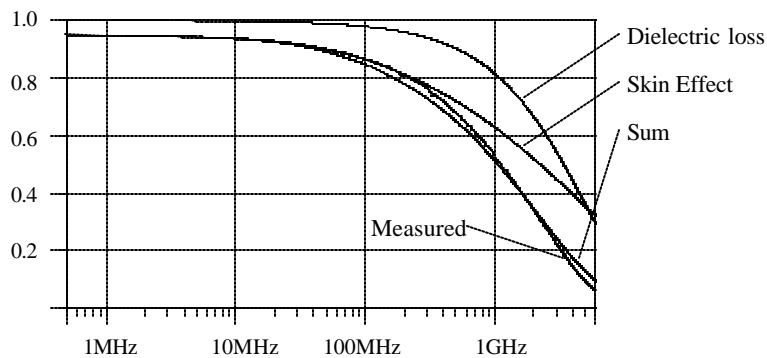


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Skin effect resistance and dielectric absorption



1m 8mil 50Ω stripguide with GETEK dielectric

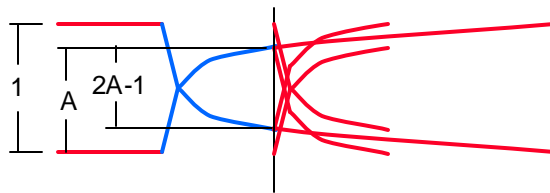
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The problem of the 'Lone Pulse'

- 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

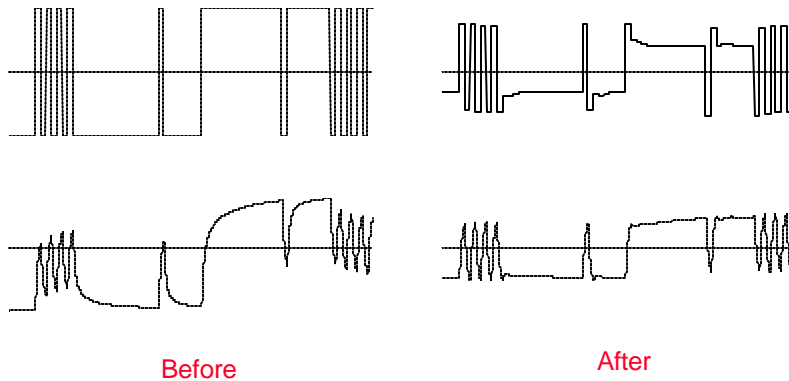


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With Transmitter Equalization

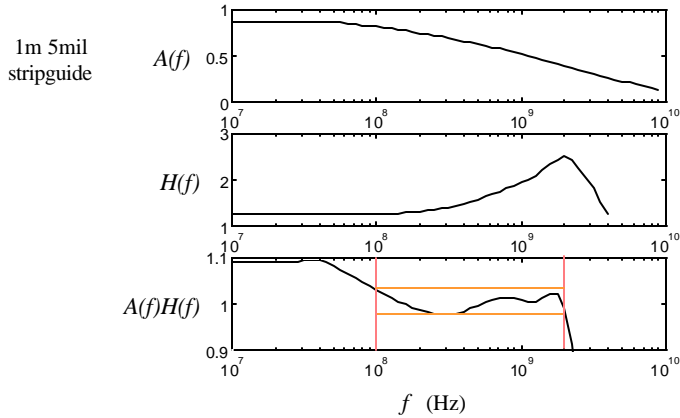


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Solution - Equalization



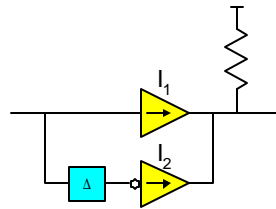
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Equalization - A Simple Implementation

- 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

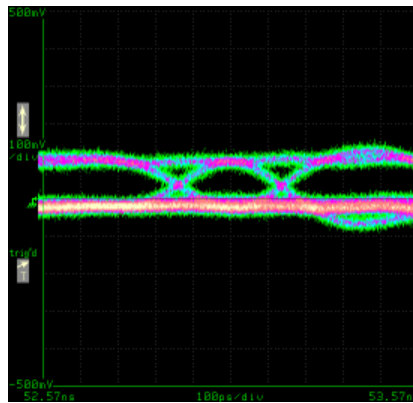
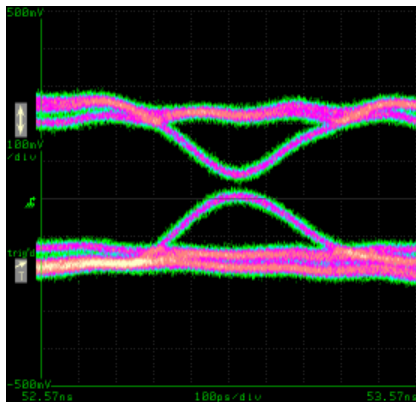


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Equalization Some Photos



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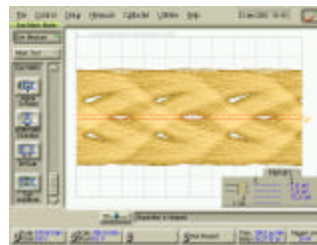
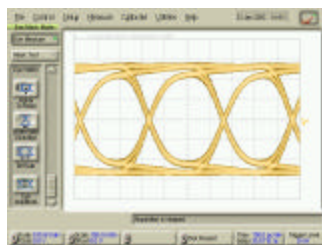
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More Pictures VC1003 driving 1m FR4 + 2 Connectors

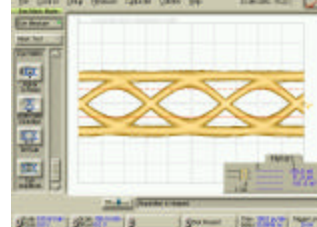
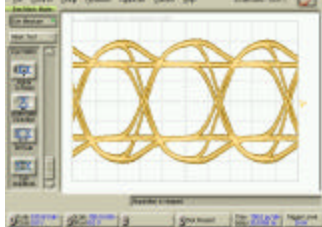
Tx

Rx

Eq off



Eq on

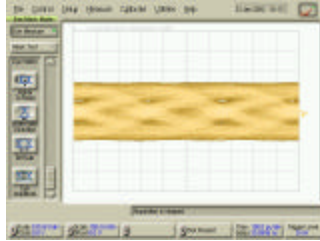


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Can you receive this signal without errors?

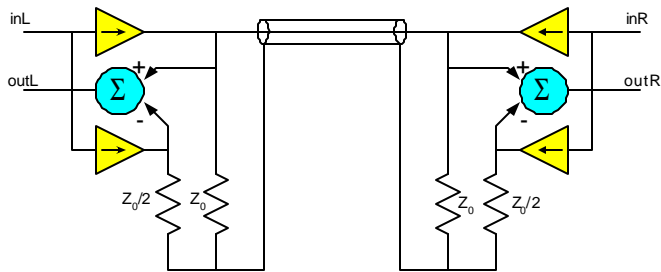


VC1003 driving 2m FR4 and 2 connectors

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 one end of the line were terminated)

Simultaneous Bidirectional Signaling The Circuit

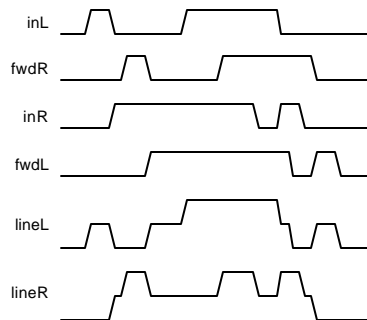


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Simultaneous Bidirectional Signaling Waveforms



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Next Time

- Timing