EE273 Lecture 9
Advanced Signaling
October 21, 1998

William J. Dally
Computer Systems Laboratory
Stanford University
billd@csl.stanford.edu

Today's Assignment

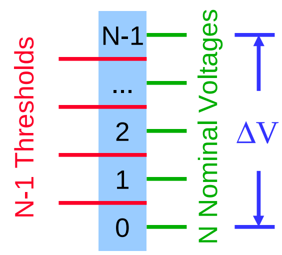
- No Homework This Week
- Prepare for Midterm
  - 10/26 from 7:00PM to 9:00PM
  - Room 320-105
- Reading
  - Sections 9.1 through 9.5
  - Complete before class on Wednesday 10/28

A Quick Overview

- Multi-level signaling
  - left over from last time
- Driving long RC wires
  - on chip wires are like wet noodles
  - delay and rise time are quadratic with length
    - 20ps/mm^2 today (0.35µm)
    - 80ps/mm^2 soon (0.18µm)
  - can make delay linear with repeaters
  - wider wires help a little
    - fringing fields
  - fatter 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

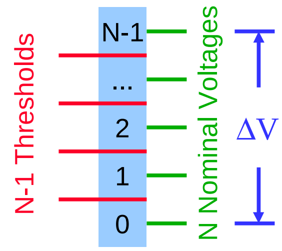
Number of Signal Levels

- There is nothing magical about 2-level or *binary* signaling
- Could use N-levels
  - N symbols
  - N nominal symbol voltages
  - N-1 thresholds
  - Nominal voltage separated from threshold by ΔV/2(N-1)



Multi-Level Signals and Noise

- In the worst case, signal can swing through ΔV, from 0 to N-1
  - proportional noise is proportional to full swing
- Gross margin is distance from nominal voltage to threshold
- Proportional noise constant, K_N must be kept very small to allow more signaling levels
- Number of bits per symbol is $\log_2(N)$



$$V_{GM} = \frac{\Delta V}{2(N-1)}$$

$$K_N \le \frac{1}{2(N-1)}$$

Multi-Level Signals and Power

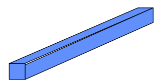
- Power per symbol (worst case) is proportional to ΔV^2
- With fixed noise sources this grows as N^2.
- So power per bit grows as

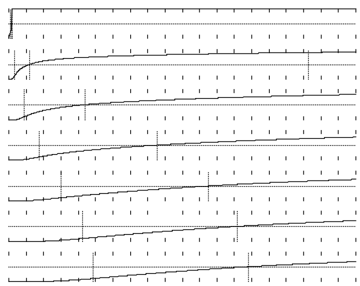
$$\frac{N^2}{\log_2 N}$$

- So why use multilevel signaling?
  - when channel is band-limited
    - it may be the *only* way to get more bits over a channel
  - when there is a very large SNR
    - so proportional noise doesn't swamp the multi-level signal.

Long On-Chip Wires are Diffusive RC Lines

- Typical wire 0.5µm x 0.5µm Aluminum
  - R = 120Ω/mm
  - C = 160fF/mm
  - τ = RC = 19ps/mm²
- 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

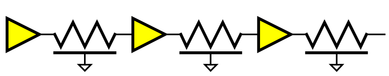




Response of 30mm wire at 5mm intervals

Optimal Repeater Spacing

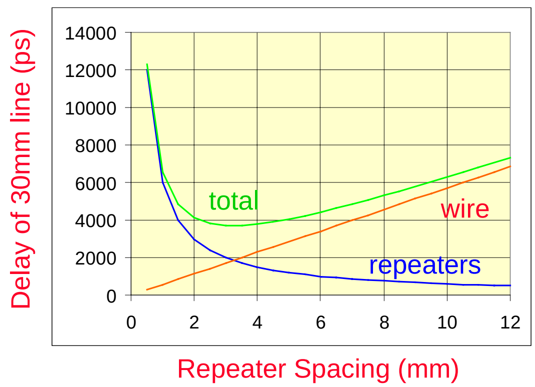
- Repeaters convert quadratic delay to linear delay
- Optimal repeater spacing is when the delay of the **repeater** equals the delay of the **wire**
  - about 3mm for an 0.35µm process
  - about 1mm for a 0.18µm process
- Results in a maximum signal propagation velocity that goes as the inverse root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

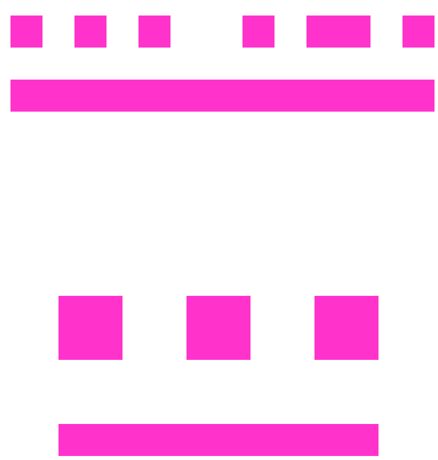


EE273, L9, Oct 21, 1998

9

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

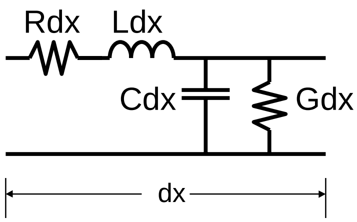


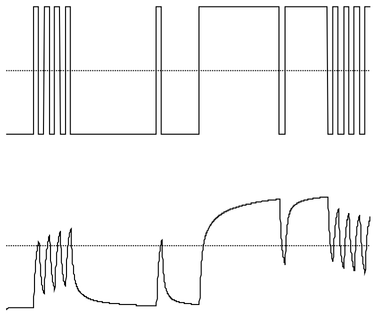
EE273, L9, Oct 21, 1998

10

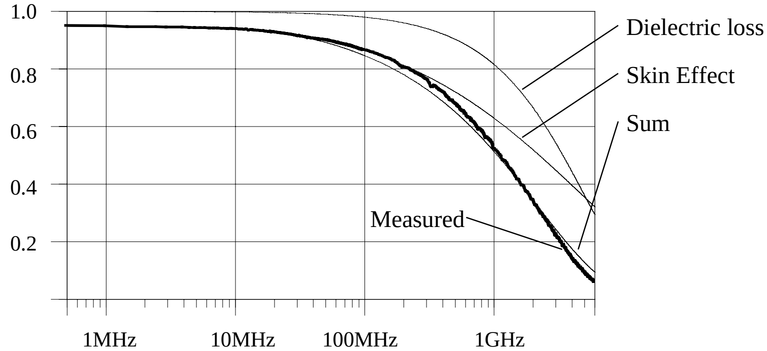
Long Off-Chip Wires are Lossy LRC Lines

- 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





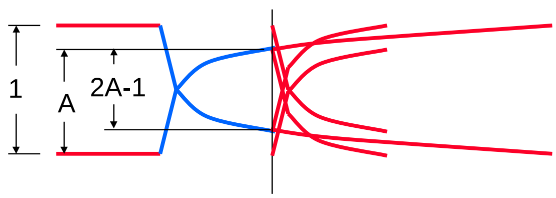
Skin effect resistance and dielectric absorption



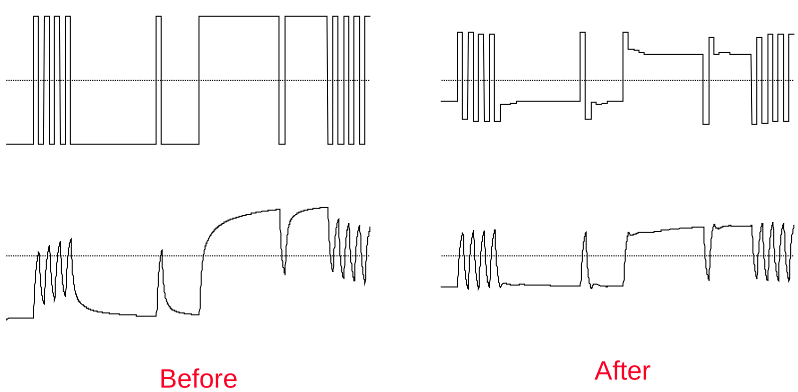
1m 8mil 50Ω stripguide with GETEK dielectric

The problem of the '*Lone Pulse*'

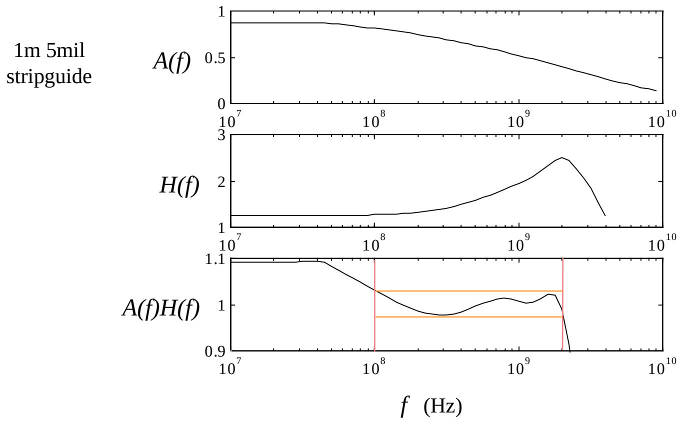
- Critical parameter is what fraction of swing, A is achieved in one bit time
- Eye opening is reduced to B = 2A-1
- No eye opening at 50% attenuation
- Also results in data-dependent jitter



With Transmitter Equalization

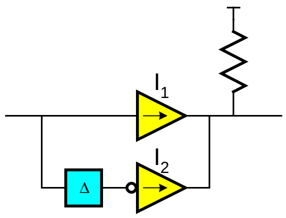


Solution - Equalization

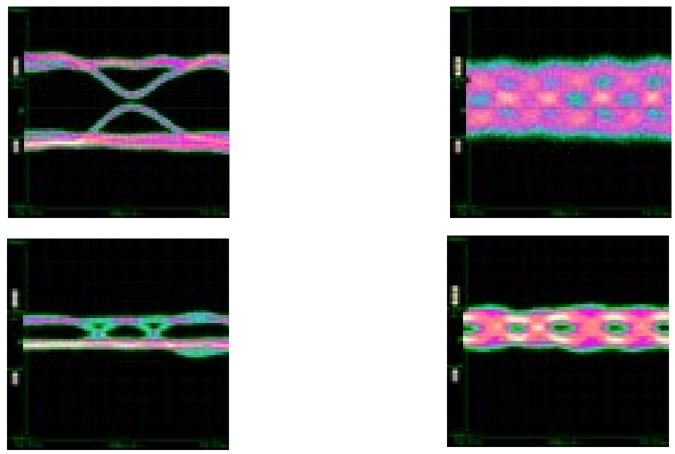


Equalization - A Simple Implementation

- 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



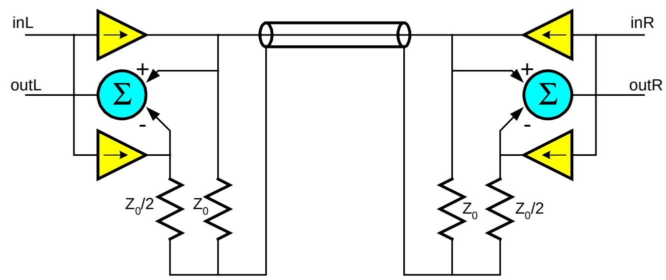
Equalization
Some Photos



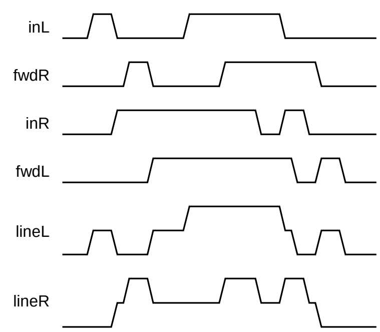
Simultaneous Bidirectional Signaling

- 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

Simultaneous Bidirectional Signaling
The Circuit



Simultaneous Bidirectional Signaling
Waveforms



Next Time (after midterm)

- Timing