EE273 Lecture 8
Advanced Signaling
February 7, 2001

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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/mm² 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 0.5\(\mu\)m x 0.5\(\mu\)m
  - \(R = 120\Omega/mm\)
  - \(C = 160fF/mm\)
  - \(\tau = RC = 19ps/mm^2\)

- 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 0.18\(\mu\)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 0.35µm 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)

\[
\begin{align*}
\text{Result:} \\
\frac{l}{l_s} 
\end{align*}
\]

\[
\begin{align*}
\frac{l}{l_s} & = \left( \frac{t_d}{t_b + 0.4l^2_s RC} \right) \quad \text{for repeaters} \\
\frac{l}{l_s} & = \left( \frac{1}{t_b RC} \right) \quad \text{for wires}
\end{align*}
\]

\[
v = \frac{1.3}{\sqrt{t_b RC}}
\]
Optimal Repeater Spacing

The Graph

0.35\textmu m 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

\[
\begin{align*}
\text{inL} & \quad \text{outL} \\
\Sigma & \quad Z_0/2 \quad Z_0 \quad \Sigma \\
\text{outR} & \quad \text{inR}
\end{align*}
\]
Simultaneous Bidirectional Signaling Waveforms
Next Time

- Timing