EE273 Lecture 6
Introduction to Signaling
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Today’s Assignment

• Problem Set 4
  – 7-2, 7-5, 7-8, and new problem (see web)

• Reading
  – Sections 7.4 and 7.5
  – Complete before class on Monday

• Demonstration
  – Next Friday 2/9

• Midterm
  – evening of 2/12
  – local SITN students must come to Stanford for the exam
  – we will have class on 2/12
A Quick Overview

- Introduction to Signaling
- transmission method
  - current vs. voltage
  - bipolar vs. unipolar
- termination scheme
  - parallel, source, both, underterminated
- references
  - 0 reference, transmitter reference, receiver reference

- source termination
  - use reflection to double signal amplitude
- differential signaling
  - 1.3-1.8x as many pins but many nice properties
Main Idea

- A good signaling system isolates the signal from noise rather than trying to overpower the noise
  - crosstalk - terminate both ends
  - ISI - matched terminations, no resonators, rise-time control
  - Power supply noise - current mode, stable reference, differential signaling
  - Reference noise - bipolar signaling, differential signaling
An Example Signaling System

1. Transmitter:
   - output impedance
   - bipolar vs. unipolar
   - amplitude
   - rise time

2. Termination method

3. Reference

4. Receiver

2. Termination method
Transmission Mode
(Output Impedance)

Voltage Mode

Current Mode
Voltage Mode vs. Current Mode

• In reality a continuum as $R_O$ varies from 0 to $\infty$.
• Both launch the same signal into the line

\[ V_i = I_i Z_0 \]

• Main differences are
  – ease of generation
    • much easier to generate a small current than a small voltage
    • especially with bipolar signaling
  – coupling of supply noise
  – coupling of return noise
Output Resistance and Signal Return Crosstalk

- Solve for signal return crosstalk using superposition
  - voltage source $V_a$ active, all others shorted
  - How much current goes down other lines?
  - Other lines are in parallel with $Z_R$
    - form a current divider

\[
Z_x = Z_R \left[ \frac{R_O + Z_0}{N - 1} \right] = \frac{Z_R (R_O + Z_0)}{(N - 1)Z_R + R_O + Z_0}
\]
Signal Return Crosstalk (continued)

\[
Z_X = Z_R \left( \frac{R_O + Z_0}{N - 1} \right) \\
= \frac{Z_R (R_O + Z_0)}{(N - 1)Z_R + R_O + Z_0}
\]

\[
I_X = I_a \left( \frac{Z_X}{R_O + Z_0} \right) \\
= I_a \left( \frac{Z_R}{(N - 1)Z_R + R_O + Z_0} \right)
\]

\[
k_{RX} = \left( \frac{Z_R}{(N - 1)Z_R + R_O + Z_0} \right)
\]
Signal Return Crosstalk (concluded)

- Since $Z_R$ is usually $<< R_O + Z_0$, we can approximate the formula with a simple ratio.
- High output impedance reduces return crosstalk:
  - $Z_R/Z_0$ for voltage mode $R=0$
  - $Z_R/2Z_0$ for matched $R=Z$
  - $\infty$ for current mode $R=\infty$
- Even with current mode signaling, however, it is advantageous to have a source termination: $R_O=Z_0$

\[ k_{RX} \leq \left( \frac{Z_R}{R_O + Z_0} \right) \]
Source Terminated Current Mode

What is $k_{RX}$ for this configuration?
Bipolar vs. Unipolar Signaling

- **Unipolar signaling**
  - logic 0 is 0 mA
  - logic 1 is 2x mA

- **Bipolar signaling**
  - logic 0 is -x mA
  - logic 1 is x mA
  - gives balanced transmitter offsets
    - same for 0 and 1
  - allows the use of 0 as a receiver reference

- Same applies to voltage-mode x V rather than x mA

- Can use offset threshold for unipolar signaling - complicated
A Typical Bipolar Current-Mode Driver

- Steers 5mA current between out+ and out-
  - constant draw from both current sources
- Relatively small devices
  - about 8\mu m/0.18\mu m
  - termination is much bigger
- Use directly for differential signaling
- Tie out- to return for single-ended signaling
- Half the supply power of a unipolar driver with the same signal swing
References

- Receiver compares received voltage or current to a *reference* to discriminate between symbols
- Errors in reference add directly to independent noise
- Several ways to generate a reference
  - use 0 (bipolar signaling)
  - derive from receiver power supply
  - send from transmitter
Source Termination
(Without receiver termination)

- What is response at S and R to 10mA current step on source?
  - assume line and termination are both 50Ω
- What about a narrow current pulse?
Source Termination
Advantages and Disadvantages

• Power
  – current driver
    • half the power as terminating at both ends
  – voltage driver
    • half the power as parallel termination
    • no static power

• Cross talk
  – rejects near-end cross talk
  – but creates near-end cross talk at the far end of the line

• Proper waveform is observed only at receiver

• More sensitive to inter-symbol interference
  – one bounce vs. Two
Source Termination
The Bottom Line

- Little difference between terminating just at the source and just at the receiver
- Much better to terminate both ends of the line
A Voltage-Mode Source Terminated Driver

- Looks like a simple driver, but...
  - Must digitally trim FETs to get $R_T = Z_0$ to an acceptable tolerance
  - Need a very low transmitter supply (250mV) to get an appropriate signal level
    - $\pm 125$ mV would be better
    - If transmit supply is generated with a switching regulator, very low power is possible
Underterminated Sources

• Conventional inverter drivers
  – have too high an output resistance (400\,\Omega \text{ typical})
  – operate off of too high a supply voltage (3.3\,V typical)
• If the inverter tries to drive a line to full swing, it must ring-up the line resulting in large delay
• These inverters can be used as underterminated sources (high output impedance) to directly drive a 50\,\Omega line with a low swing

• Line is parallel terminated to mid-rail supply, \( V_T \).
• What are the signal levels on the line?
• Why mid-rail terminate?
Differential Signaling

- A differential signal is sent as a difference in voltage or current between two lines.
- Typically a positive signal is sent on one line and its complement on the other line.
- This uses twice as many pins as single-ended signaling right?
  - wrong! 1.3-1.8x
  - differential signaling has a separate return for each signal
  - typically have 1 return for 2-8 signals
Advantages of Differential Signaling

- Signal serves as its own reference
  - compare positive signal to complement to detect
- Twice the signal swing
  - effective swing is A - B
- Noise immunity
  - many noise source become common mode
- Return current
  - becomes strictly DC
  - can be 0 for bipolar signaling
Differential Signaling and Balanced Transmission Lines
Next Time

• Signaling over lumped media
  – on-chip capacitive lines
  – off-chip LC circuits
• Signal encoding and Signal Amplitude
• Driving RC lines