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

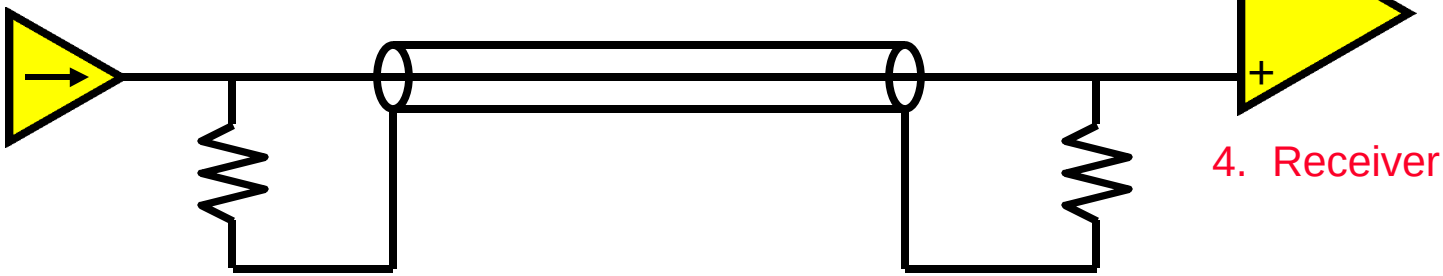
- Introduction to Signaling
- transmission method
  - current vs. voltage
  - bipolar vs. unipolar
- termination scheme
  - parallel, source, both, underterminated
- references
  - 0 reference, transmitter reference, receiver reference
- source termination
  - use reflection to double signal amplitude
- differential signaling
  - 1.3-1.8x as many pins but many nice properties

Main Idea

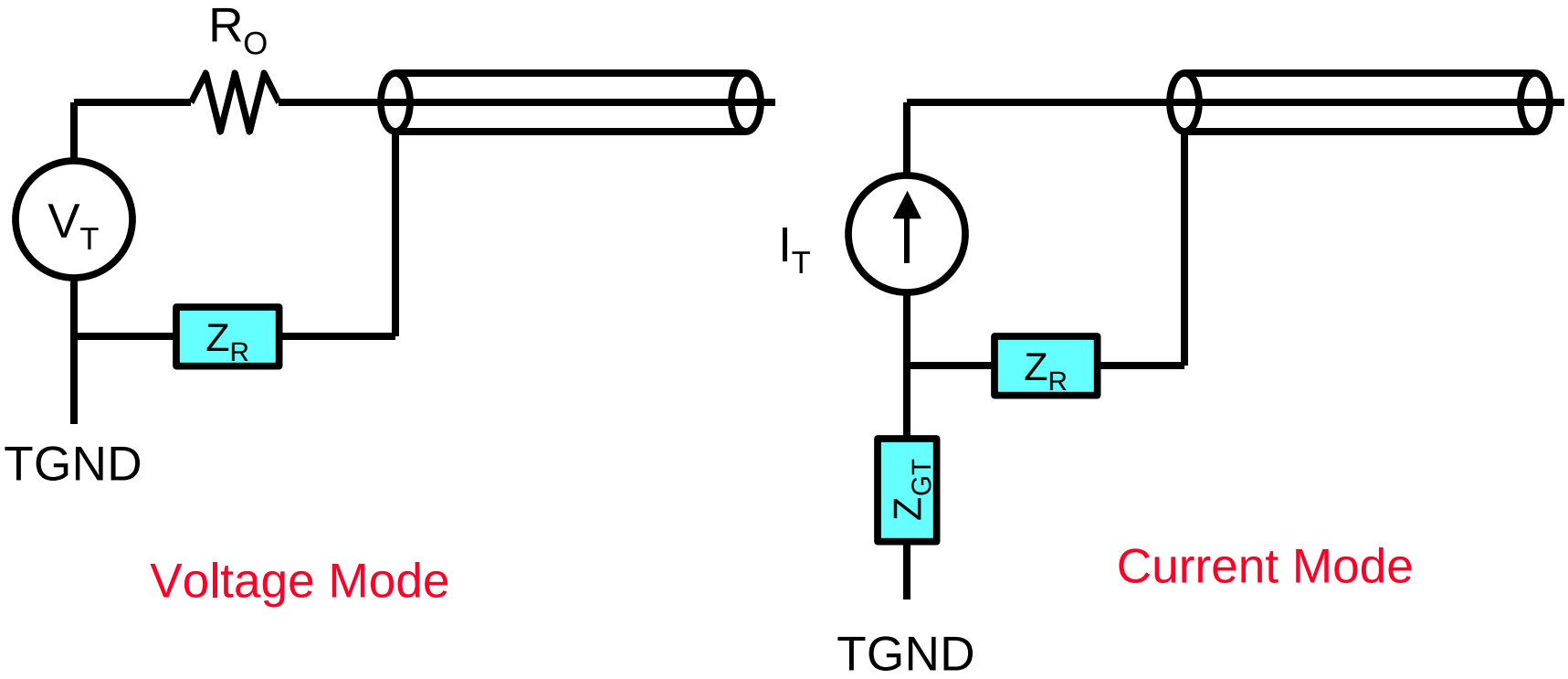
- A good signaling system isolates the signal from noise rather than trying to overpower the noise
  - crosstalk - terminate both ends
  - ISI - matched terminations, no resonators, rise-time control
  - Power supply noise - current mode, stable reference, differential signaling
  - Reference noise -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

An Example Signaling System

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



Transmission Mode (Output Impedance)



Voltage Mode vs. Current Mode

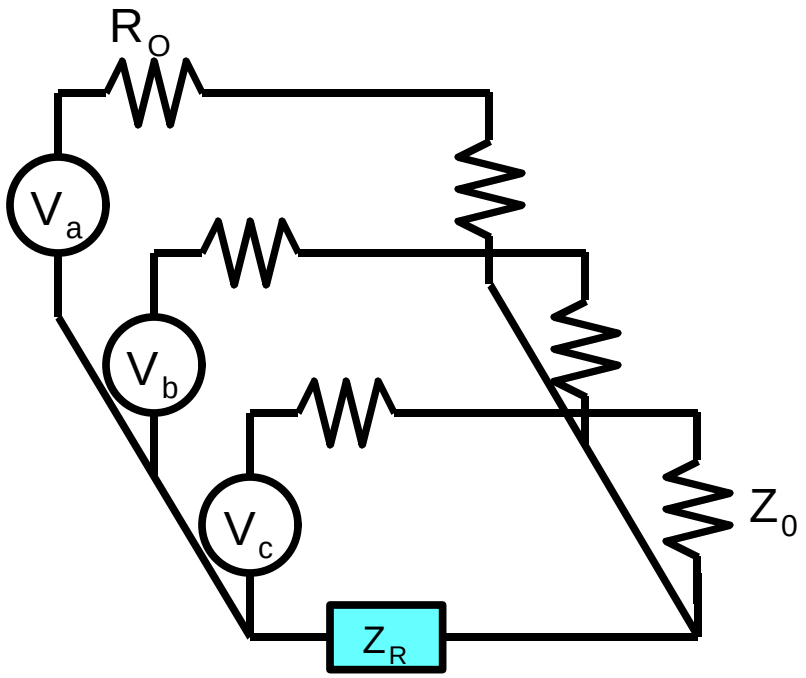
- In reality a continuum as R_O varies from 0 to ∞.
- Both launch the same signal into the line

$$V_i = I_i Z_0$$

- 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

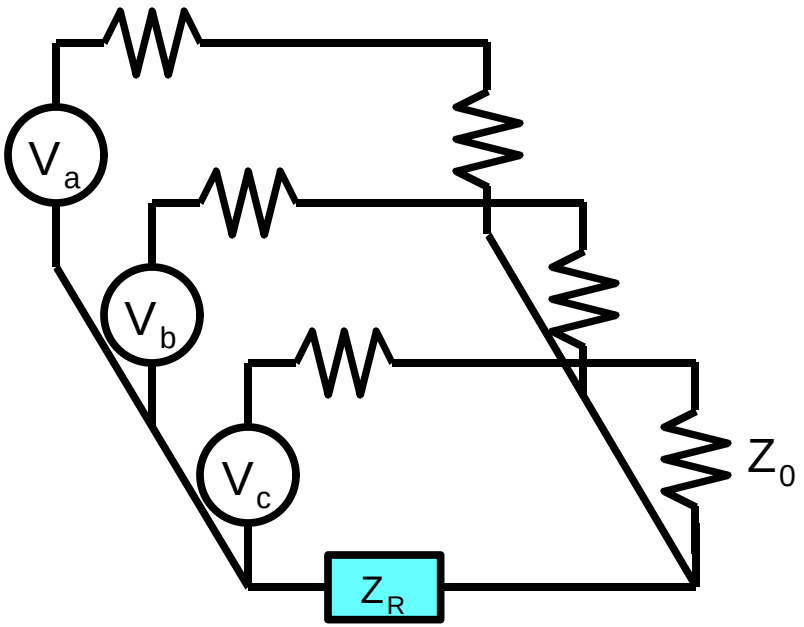
- Solve for signal return crosstalk using superposition
  - voltage source V_a active, all others shorted
  - How much current goes down other lines?
  - Other lines are in parallel with Z_R
    - form a current divider



$$Z_X = Z_R \left\| \left(\frac{R_O + Z_0}{N-1} \right) \right.$$

$$= \frac{Z_R (R_O + Z_0)}{(N-1)Z_R + R_O + Z_0}$$

Signal Return Crosstalk (continued)



$$Z_X = Z_R \left\| \left(\frac{R_O + Z_0}{N-1} \right) \right.$$

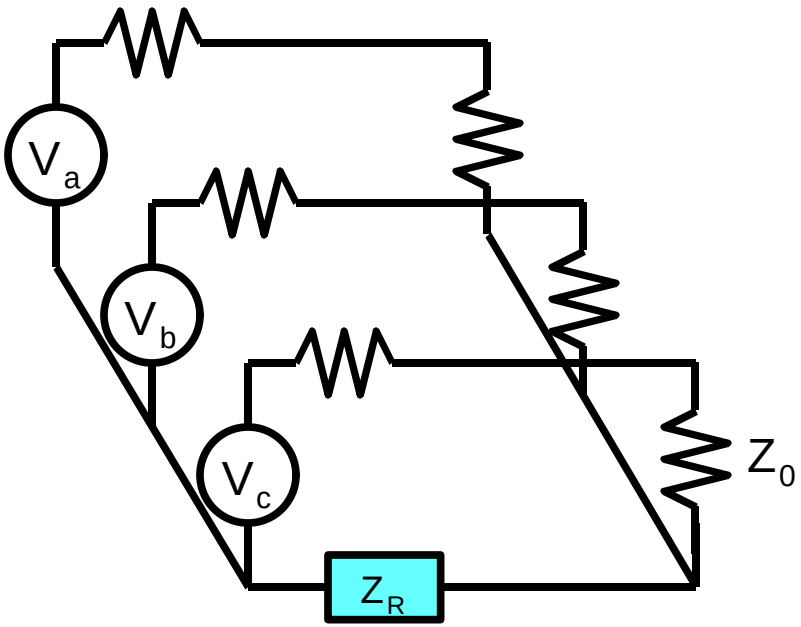
$$= \frac{Z_R (R_O + Z_0)}{(N-1)Z_R + R_O + Z_0}$$

$$I_X = I_a \left(\frac{Z_X}{R_O + Z_0} \right)$$

$$= I_a \left(\frac{Z_R}{(N-1)Z_R + R_O + Z_0} \right)$$

$$k_{RX} = \left(\frac{Z_R}{(N-1)Z_R + R_O + Z_0} \right)$$

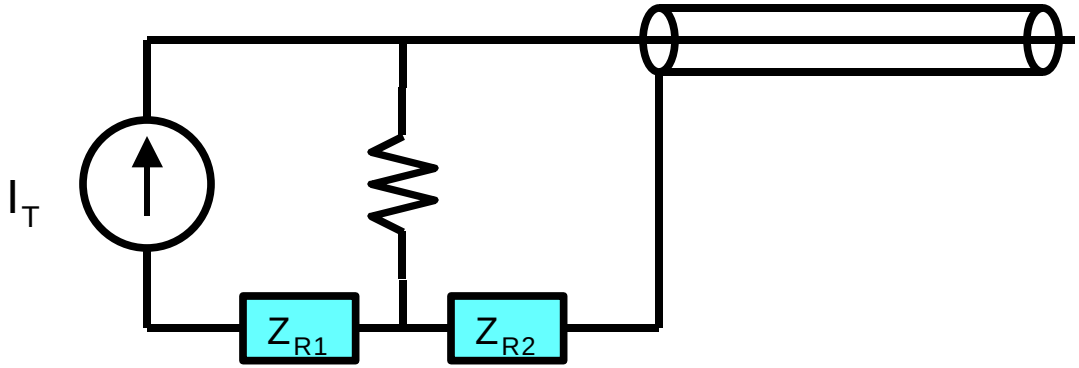
Signal Return Crosstalk (concluded)



$$k_{RX} \leq \left(\frac{Z_R}{R_O + Z_0} \right)$$

- 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
  - ∞ for current mode R= ∞
- Even with current mode signaling, however, it is advantageous to have a source termination: $R_O=Z_0$

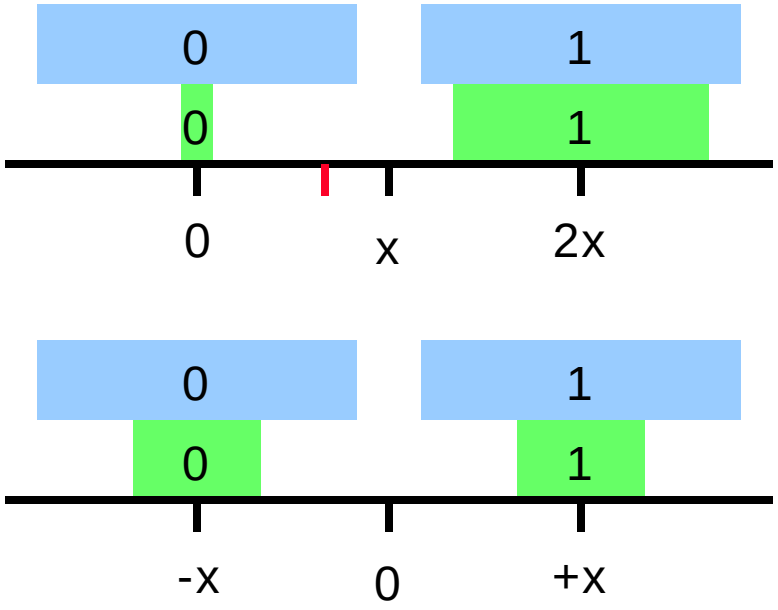
Source Terminated Current Mode



What is k_{RX} for this configuration?

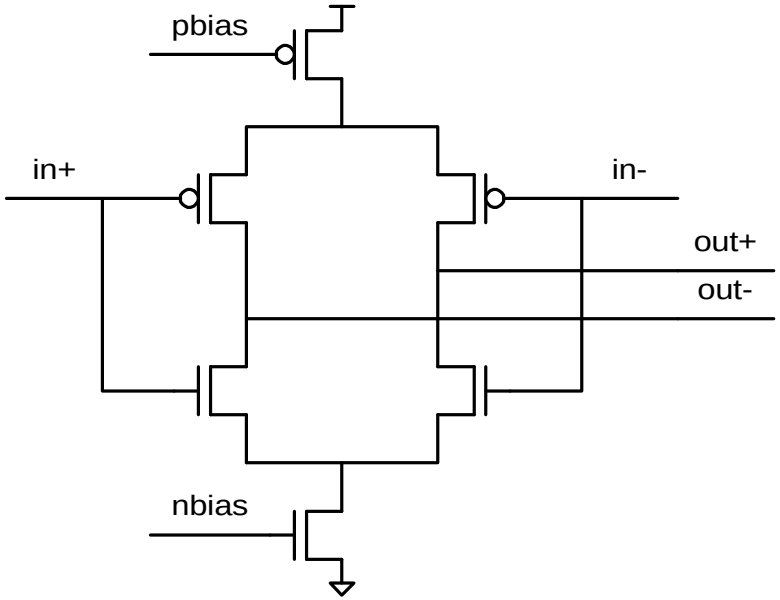
Bipolar vs. Unipolar Signaling

- 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



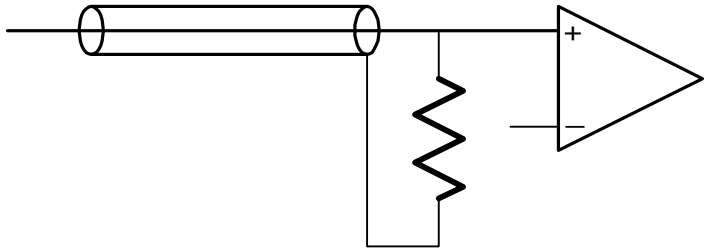
A Typical Bipolar Current-Mode Driver

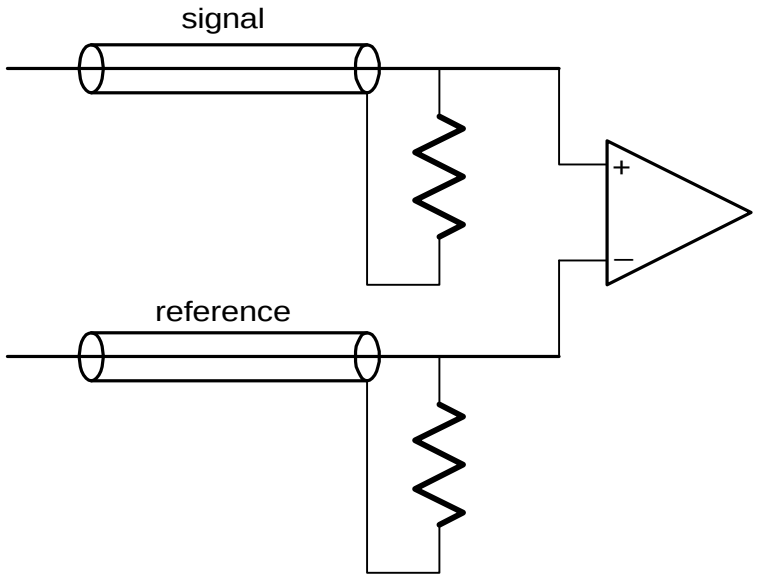
- Steers 5mA current between out+ and out-
  - constant draw from both current sources
- Relatively small devices
  - about 8µm/0.18µm
  - termination is much bigger
- Use directly for differential signaling
- Tie out- to return for single-ended signaling
- Half the supply power of a unipolar driver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



References

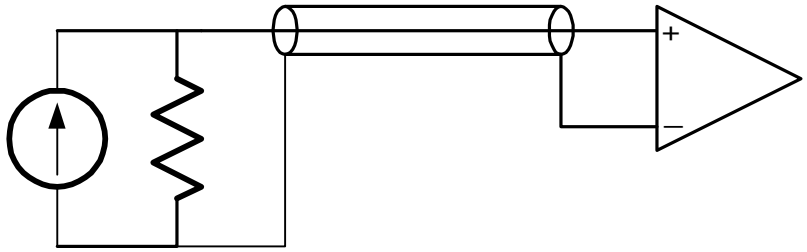
- Receiver compares received voltage or current to a *reference* to discriminate between symbols
- Errors in reference add directly to independent noise
- Several ways to generate a reference
  - use 0 (bipolar signaling)
  - derive from receiver power supply
  - send from transmitter





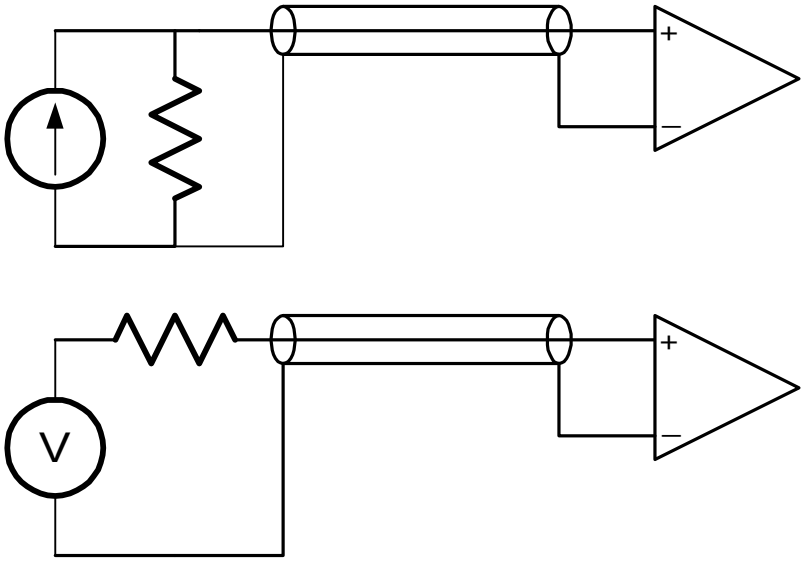
Source Termination
(Without receiver termination)

- 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

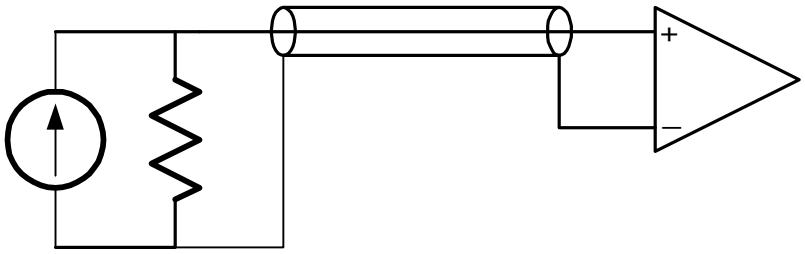
- Power
  - current driver
    - half the power as terminating at both ends
  - voltage driver
    - half the power as parallel termination
    - no static power
- Cross talk
  - rejects near-end cross talk
  - but creates near-end cross talk at the far end of the line
- Proper waveform is observed only at receiver

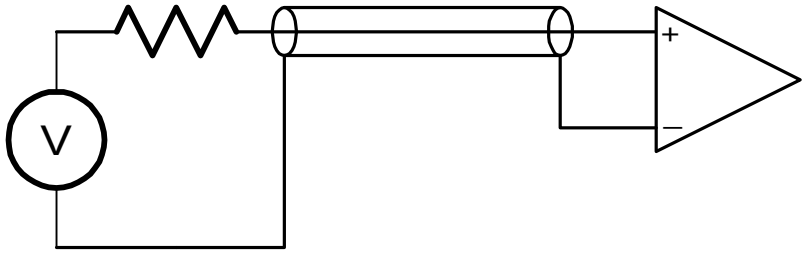


- More sensitive to inter-symbol interference
  - one bounce vs. Two

Source Termination
The Bottom Line

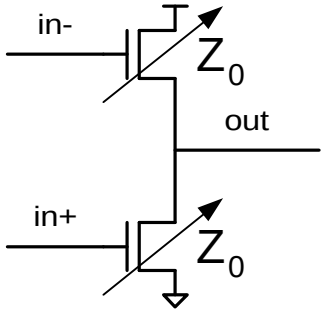
- Little difference between terminating just at the source and just at the receiver
- Much better to terminate both ends of the line

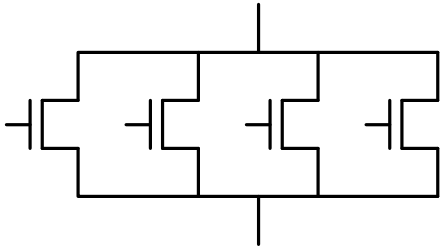




A Voltage-Mode Source Terminated Driver

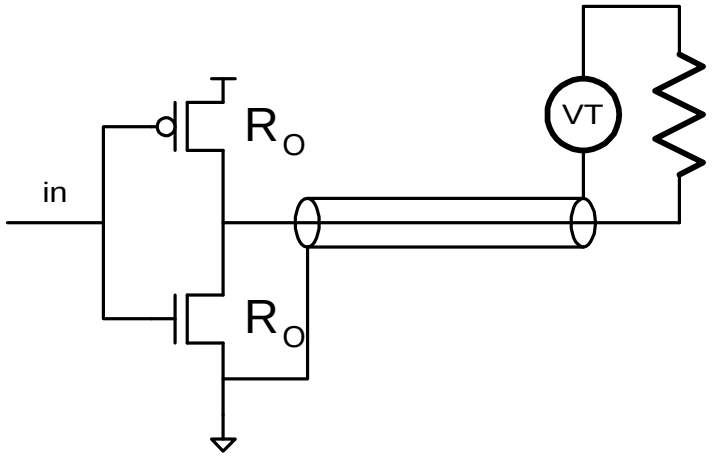
- Looks like an simple driver, but…
  - Must digitally *trim* FETs to get $R_T = Z_0$ to an acceptable tolerance
  - Need a very low transmitter supply (250mV) to get an appropriate signal level
    - ±125mV would be better
    - if transmit supply is generated with a switching regulator, very low power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





Underterminated Sources

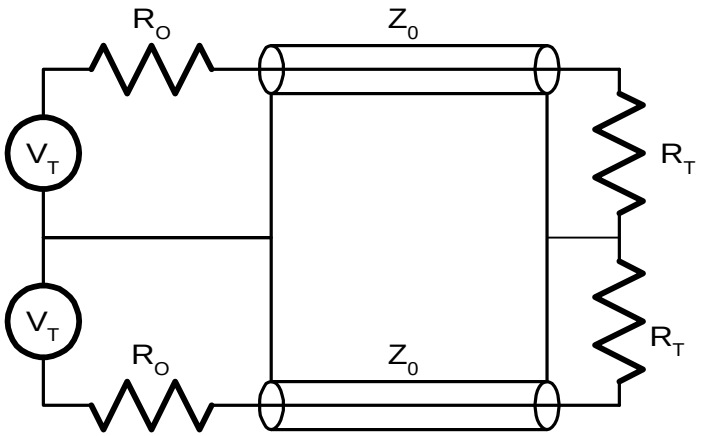
- Conventional inverter drivers
  - have too high an output resistance (400Ω typical)
  - operate off of too high a supply voltage (3.3V typical)
- If the inverter tries to drive a line to full swing, it must *ring-up* the line resulting in large delay
- These inverters can be used as *underterminated*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

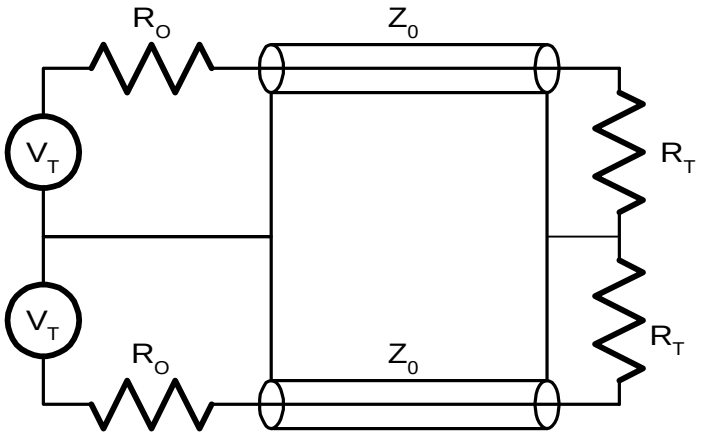
Differential Signaling

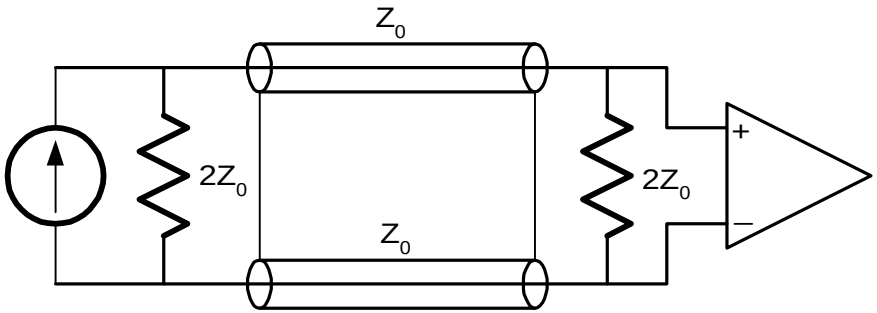
- A *differential* signal is sent as a difference in voltage or current between two lines
- Typically a positive signal is sent on one line and its complement on the other line
- This uses twice as many pins as *single-ended* signaling right?
  - wrong! 1.3-1.8x
  - differential signaling has a separate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



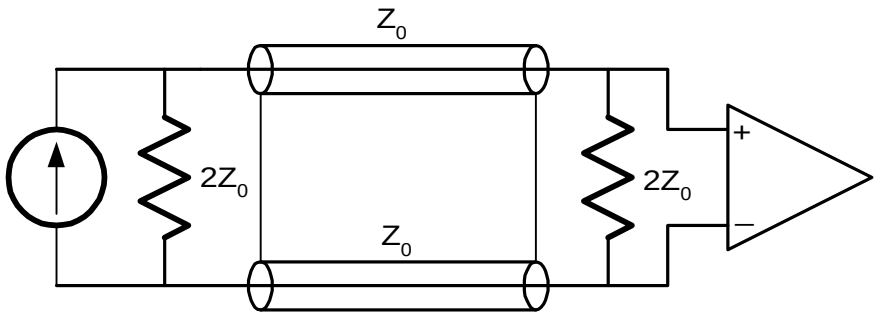
Advantages of Differential Signaling

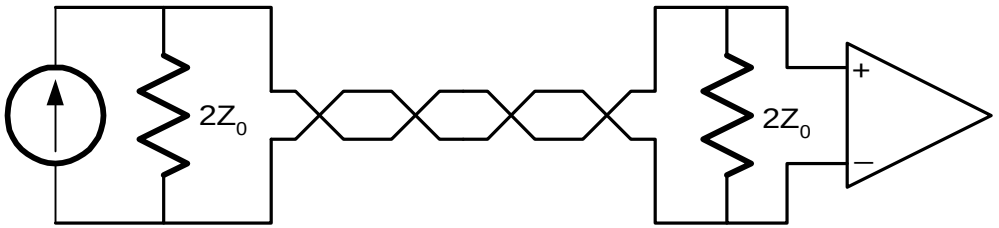
- Signal serves as its own reference
  - compare positive signal to complement to detect
- Twice the signal swing
  - effective swing is A-B
- Noise immunity
  - many noise source become common mode
- Return current
  - becomes strictly DC
  - can be 0 for bipolar signaling





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