EE273 Lecture 4
Noise in Digital Systems

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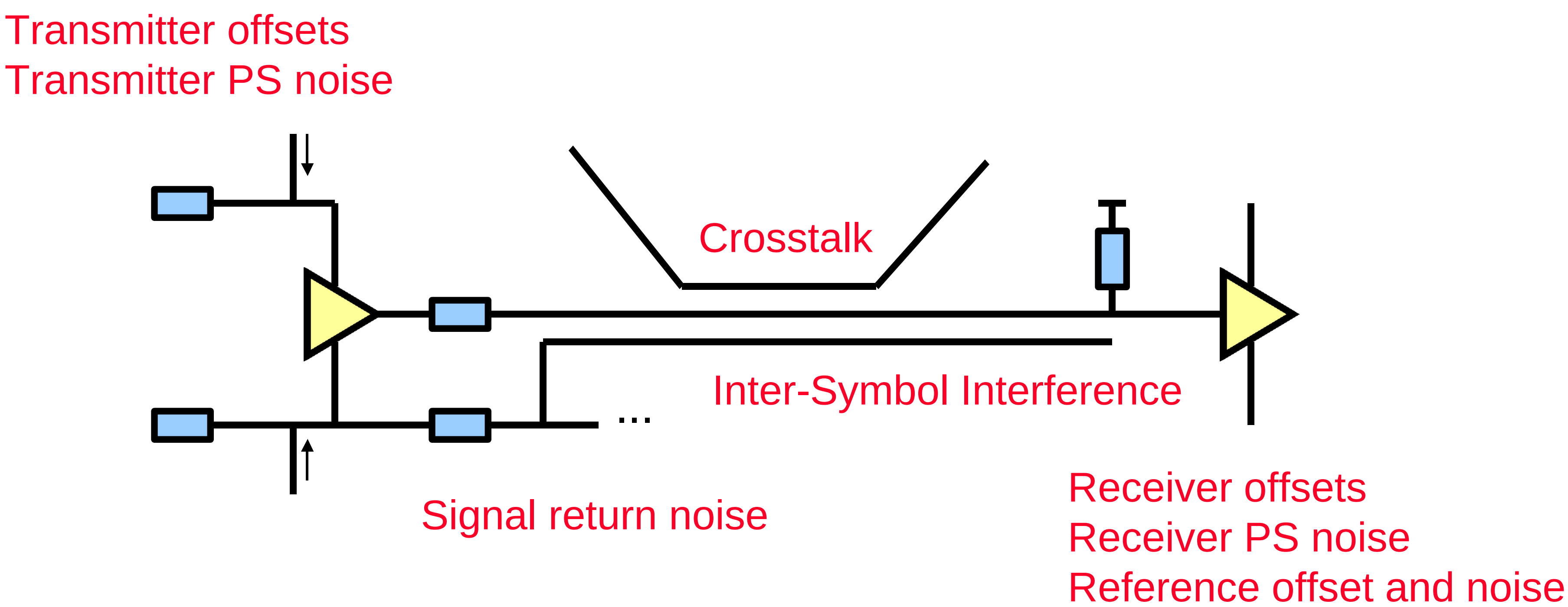
Today's Assignment

- Problem set 3
  - Dally and Poulton, 6-3, 6-6, 6-9, 6-16, new problem (see web)
  - Due at start of class next Wednesday January 31
- Reading
  - Sections 6.4 through 6.6
  - Complete before class on Monday

A Quick Overview

- Noise
  - Signals may be corrupted from many sources
    - power supply noise
    - cross talk
    - inter-symbol interference
    - *real* noise (thermal and shot)
    - parameter variation
  - Proportional and independent
- Power Supply Noise
  - Inductance and resistance of supply network cause voltage drops
  - Variation in space on one supply voltage
  - Variation in time on voltage between supplies
- Cross Talk
  - One signal interfering with another signal
  - Capacitive crosstalk between RC lines on a chip
    - floating
    - driven
  - Coupling between LC transmission lines
    - near end
    - far end

Noise in Digital Systems



Proportional and Independent Noise Sources

- Some noise is *proportional* to signal swing
  - crosstalk
  - inter-symbol interference
  - signal return noise
  - signaling power supply noise
  - if you increase the signal swing, you increase the noise
- Need to eliminate or cancel this noise
  - You can't overpower it!

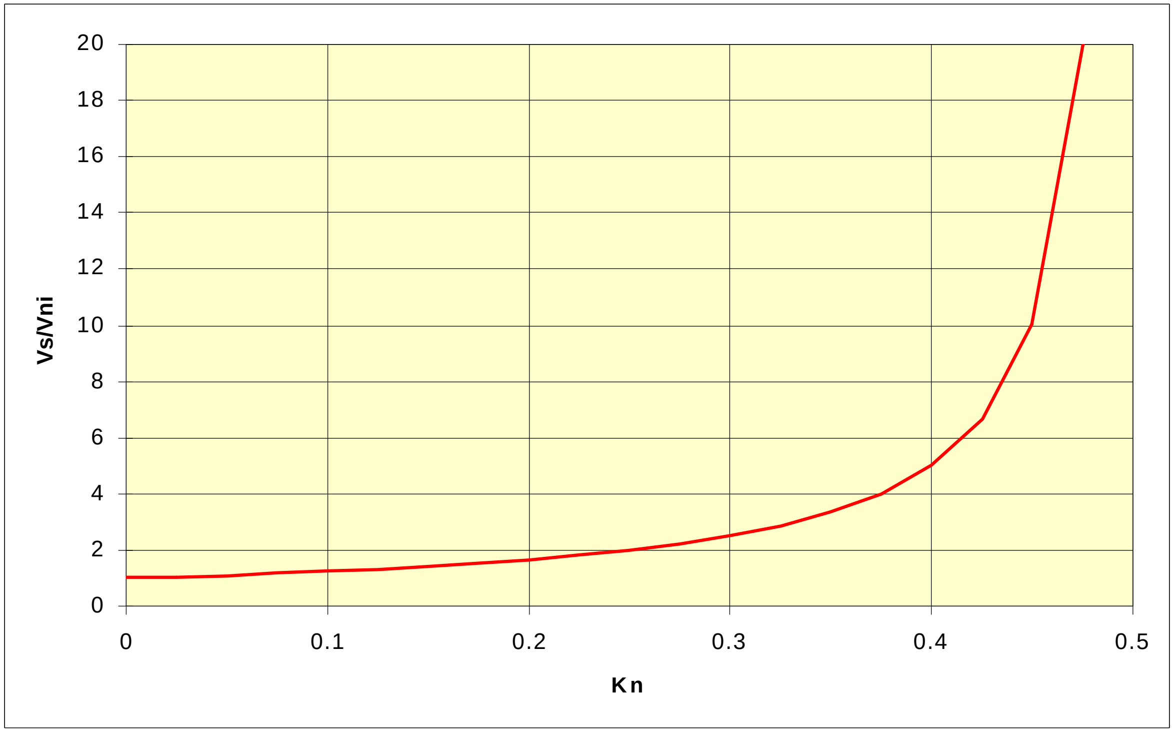
- Some noise is independent of signal swing
  - receiver sensitivity
  - receiver offset
  - unrelated power supply noise
  - reference offsets
- Can eliminate or overpower this noise

Proportional and Independent Noise Sources

$$V_N = K_N V_S + V_{NI}$$

$$\frac{V_S}{2} \geq K_N V_S + V_{NI}$$

$$V_S \geq \frac{2V_{NI}}{(1-2K_N)}$$

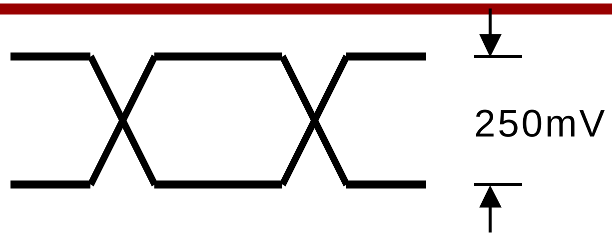


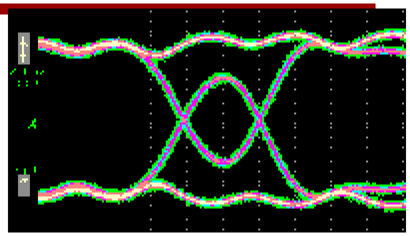
Bounded and Statistical Noise Sources

- Bounded noise sources
  - Bound total amplitude of noise via worst-case analysis
  - Noise guaranteed not to exceed this amount
  - Pessimistic but simple analysis
  - Examples
    - Crosstalk to adjacent lines (prop)
    - ISI (prop)
    - Receiver offset (fixed)
- Statistical noise sources
  - Approximate noise by a random process
    - Actual noise may really be random or may be deterministic
  - Noise amplitude characterized by RMS value
  - Can compute probability that noise will be less than margin
  - Examples
    - Johnson (thermal) noise (fixed)
    - Shot (quantization) noise
    - Crosstalk to large number of lines (prop)

Which sources are Proportional? Fixed? Which are Bounded? Statistical?

- 250mV differential signal
- 15% high-frequency attenuation
- 5% crosstalk from adjacent lines
- 5% ISI from reflections
- 20mV receiver offset+sensitivity
- 10mV RMS Gaussian noise
- What is the Bit Error Rate?

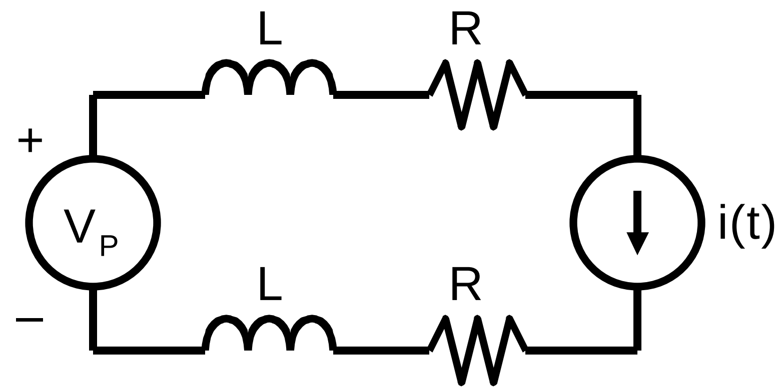


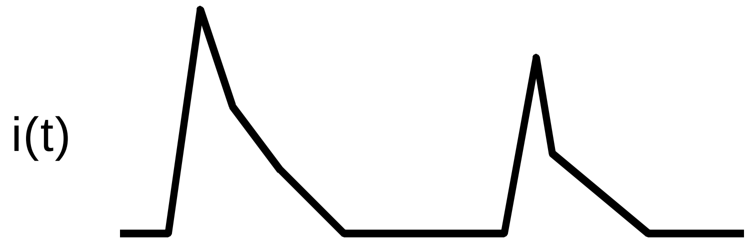


Signal Swing (dp-dn)		500
Gross Margin		250
Crosstalk	0.05	25
Reflections	0.05	25
Attenuation	0.15	75
KN	0.25	125
Receiver offset+sensitivity		20
Bounded noise		145
Net Margin		105
Gaussian Noise		10
VSNR		10.5
BER		1.15E-24

Power Supply Noise

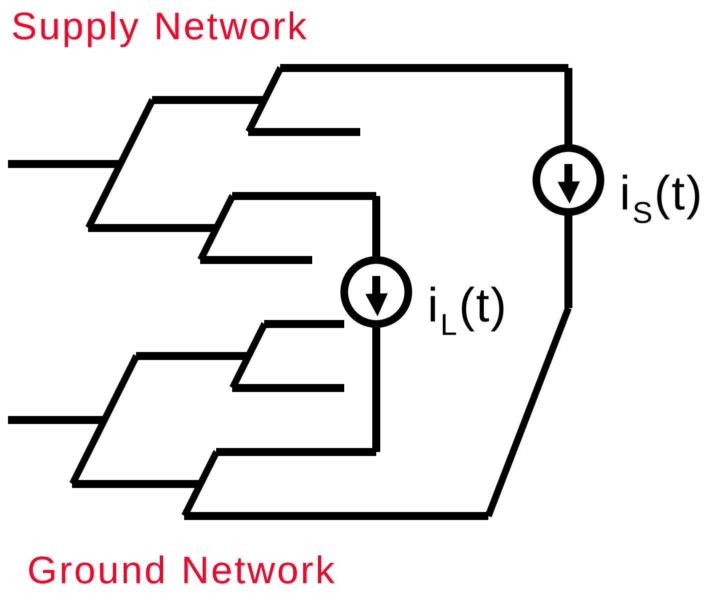
- The power supply network has parasitic elements
  - on-chip: resistive
  - off-chip: inductive
- Current draw across these elements induces a noise voltage
  - Ri + Ldi/dt
- Instantaneous current is what matters
  - may be many times the DC current
    - 10W chip draws 4A at 2.5V
    - peak current may be 10-20A.





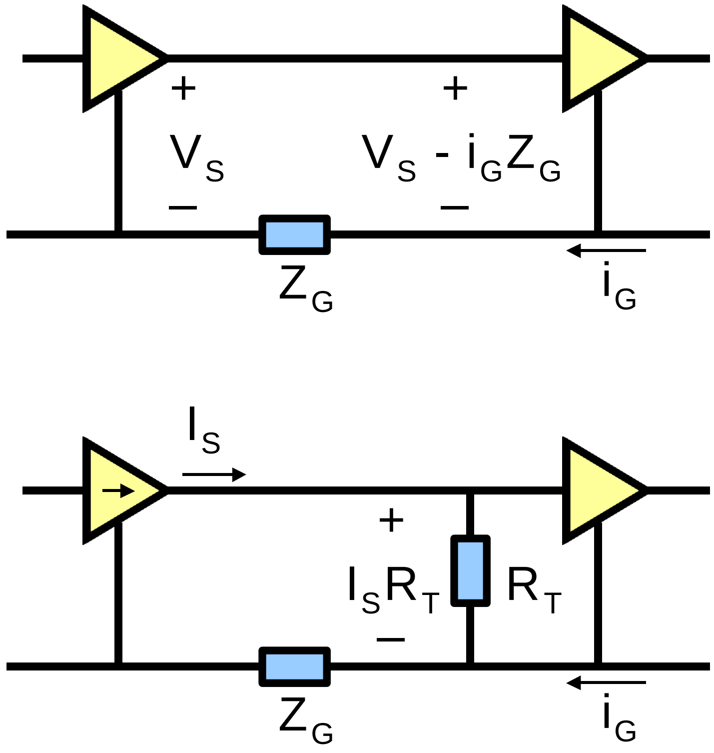
Types of Supply Noise

- Two types of loads
  - logic loads
  - signal loads
- Two types of noise
  - single-supply noise
  - differential-supply noise



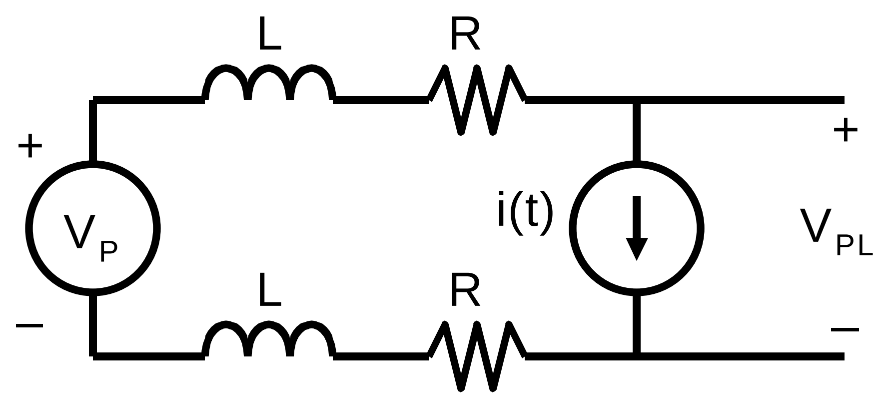
Single Supply Noise

- Voltage drops across parasitics cause variation in the voltage of a single supply (V_{DD} or GND) from one point in the system to another
- If a signal is referenced to the local supply, this variation is additive voltage noise
- The problem can be reduced by using an appropriate reference
  - reference to receiver supply
  - send an explicit reference



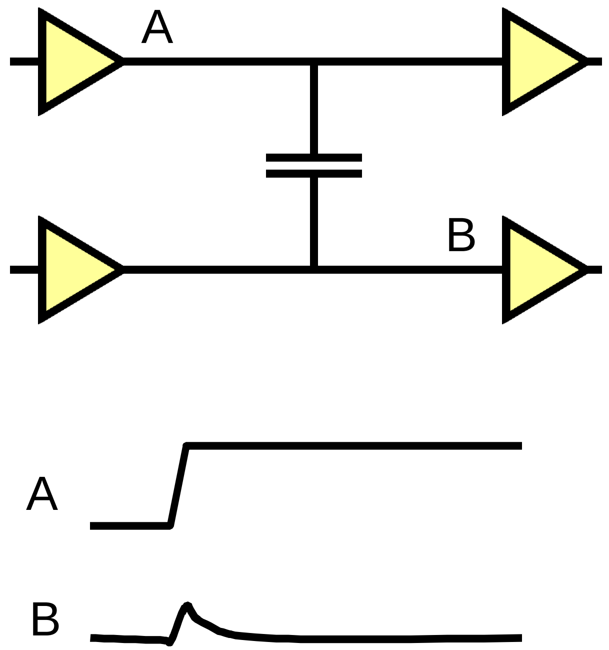
Differential Supply Noise

- Drops across supply parasitics cause the local supply voltage, V_{PL}, to vary over time
  - affects the delay of many elements
    - systems may not meet timing specifications
    - causes jitter in timing circuits



Cross Talk

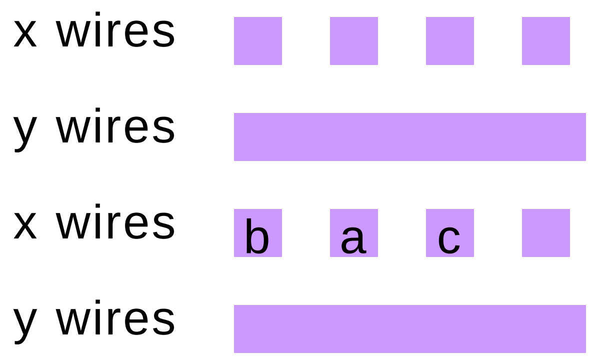
- Noise induced by one signal that interferes with another signal
- Capacitive coupling between on-chip lines
- Capacitive *and* Inductive coupling between off-chip lines
- Coupling over shared signal returns



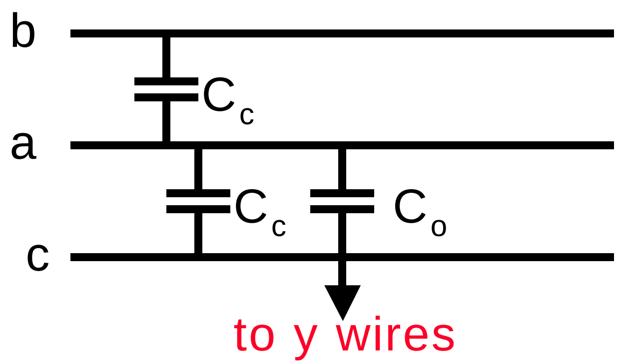
Cross Talk Between Capacitive Lines

- On-chip wires have significant capacitance to adjacent wires
  - on same layer
  - on adjacent layers
- When adjacent signals change, voltage on a floating line is disurbed
  - capacitive voltage divider
  - signal is not restored

$$k_{2C} = \frac{2C_C}{2C_C + C_O}$$

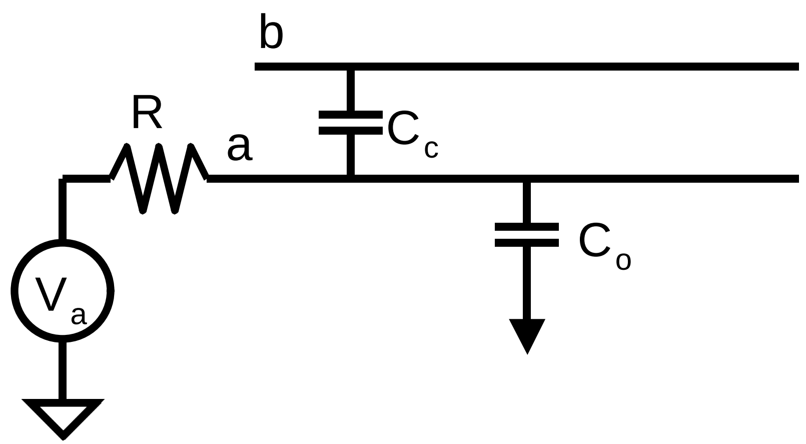


a is *victim*, b and c are *agressors*

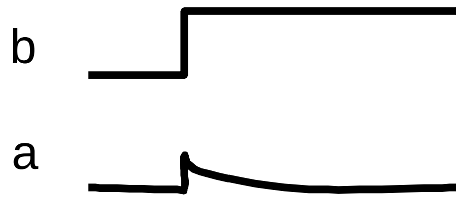


Capacitive Lines with Drive

- If victim line, a, is driven, a will be disturbed but then restored with time constant $\tau=R(C_c+C_o)$
- If rise on agressor, b, is slow compared to τ, magnitude of disturbance is reduced



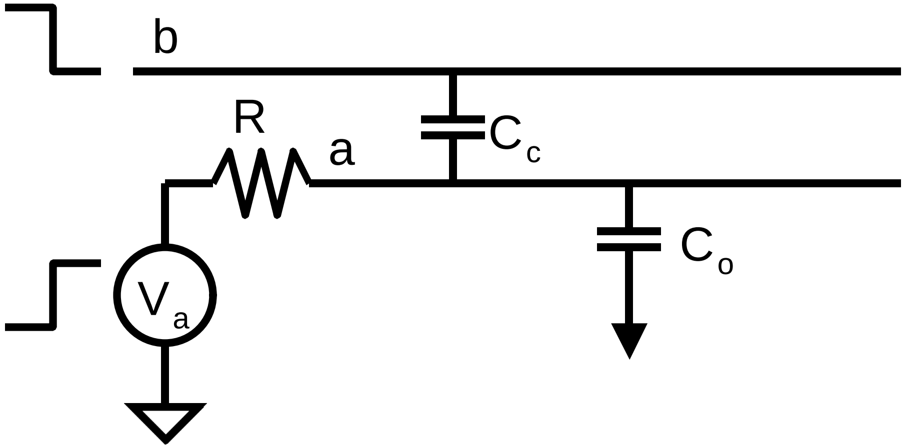
$$\left(\frac{t}{t_r}\right)\left(1-\exp\left(-\frac{t_r}{t}\right)\right)$$



$\tau=R(C_c+C_o)$

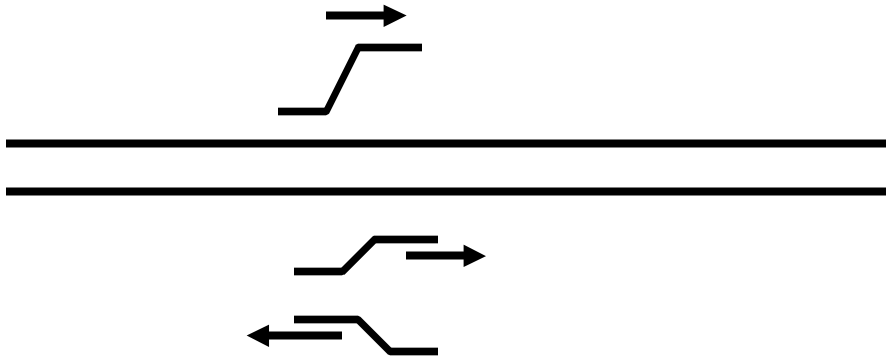
Cross Talk and Delay

- Capacitive cross talk can affect delay of RC signals
- If agressor(s) switch in opposite direction, effective capacitance of C_c is doubled
- If agressor(s) switch in the same direction, C_c is effectively eliminated
- Can cause 2:1 variation in delay in some cases
- Significant cause of jitter if timing is critical

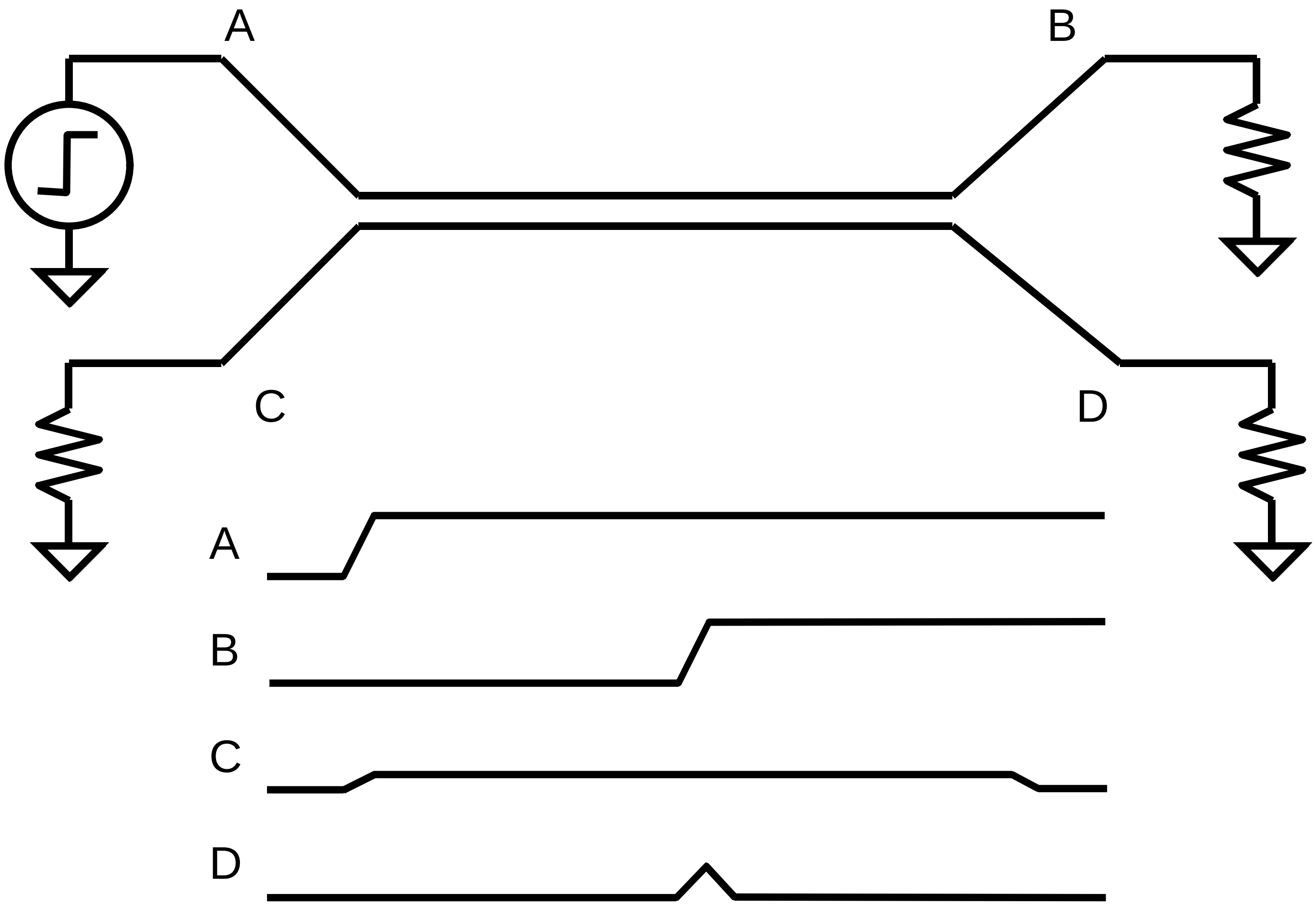


Transmission Line Cross Talk

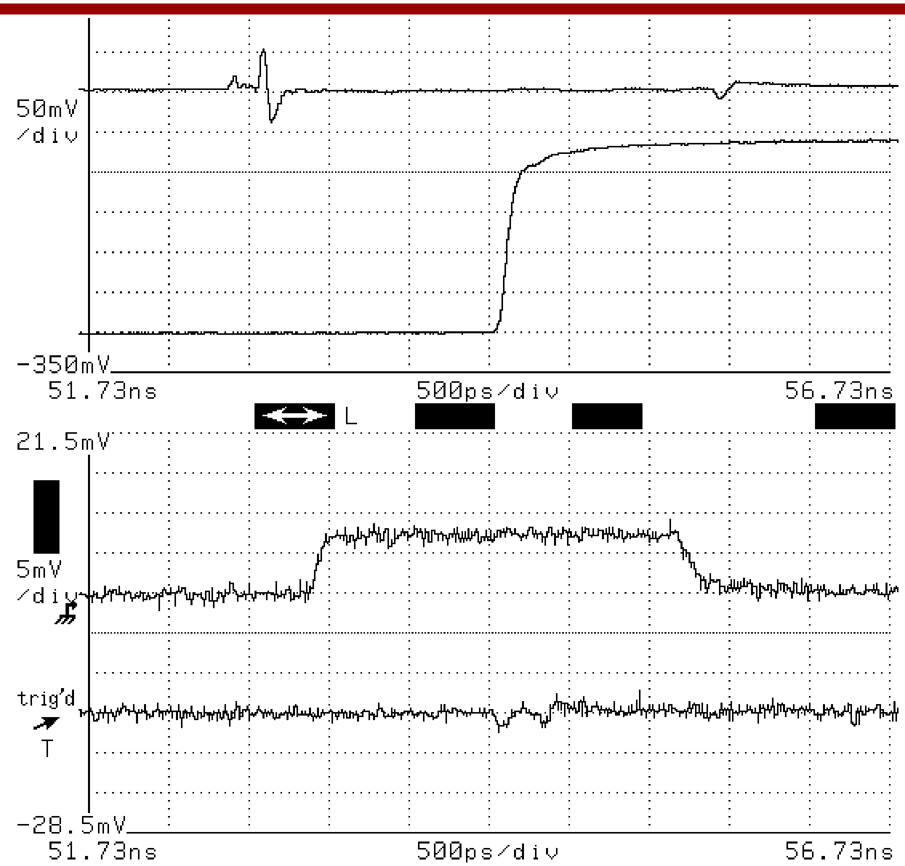
- A signal transition on one transmission line induces forward and reverse traveling waves on adjacent transmission lines



Transmission Line Cross Talk Experiment

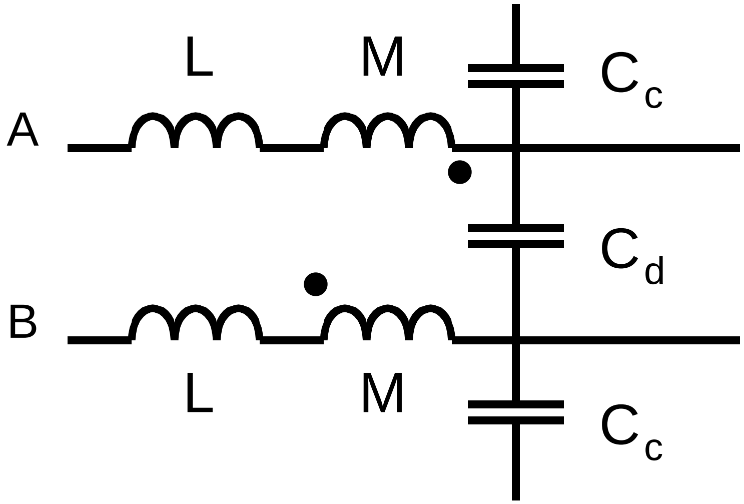


Experimental Cross Talk Measurements



Inductive and Capacitive Coupling

- Consider a positive transient on agressor line, A
- Capacitive coupling induces a *voltage* on victim line B
  - positive waves in both forward and reverse directions
- Inductive coupling induces a *current* in line B
  - positive wave in the reverse direction
  - negative wave in the forward direction

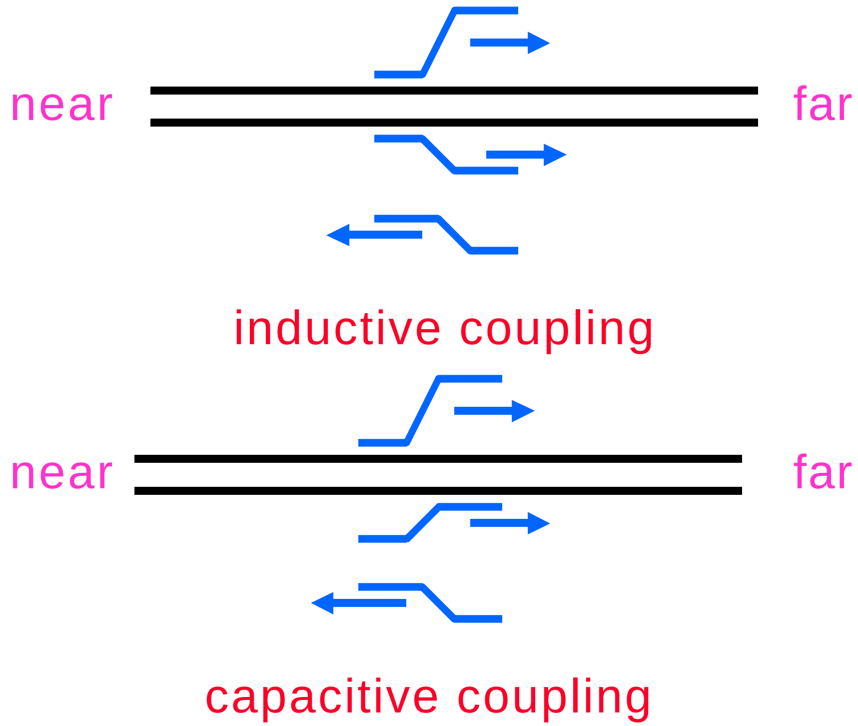


$$k_{lx} = \frac{M}{L}$$

$$k_{cx} = \frac{C_d}{C}$$

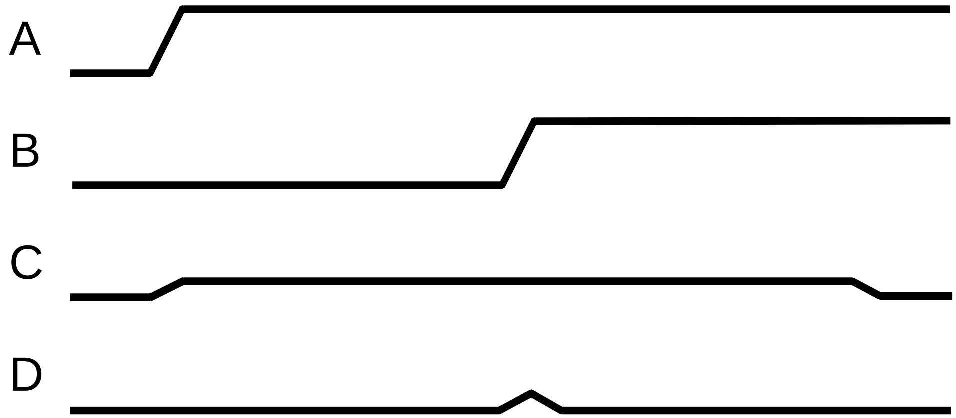
Near-end and Far-end Crosstalk

- Inductive and capacitive coupling *add* at the near end of the line
  - both waves are positive
  - pulse begins at beginning of coupled section
  - pulse width equals length of coupled section
- Inductive and capacitive coupling *subtract* at the far end of the line
  - in a homogeneous medium cancellation is exact
  - narrow pulse coincident with wave on agressor



Near End and Far End Crosstalk
The Equations

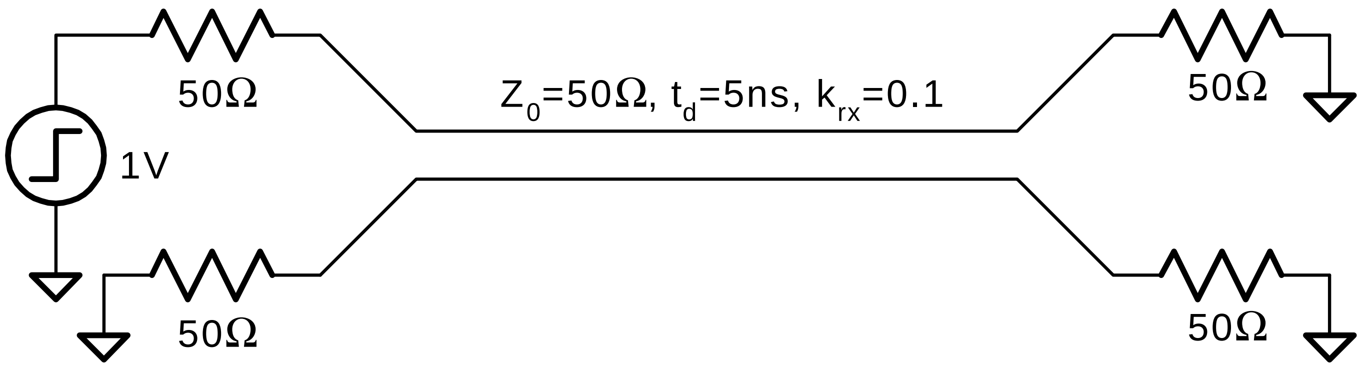
$$k_{rx} = \frac{k_{cx} + k_{lx}}{4} \qquad k_{fx} = \frac{k_{cx} - k_{lx}}{2}$$

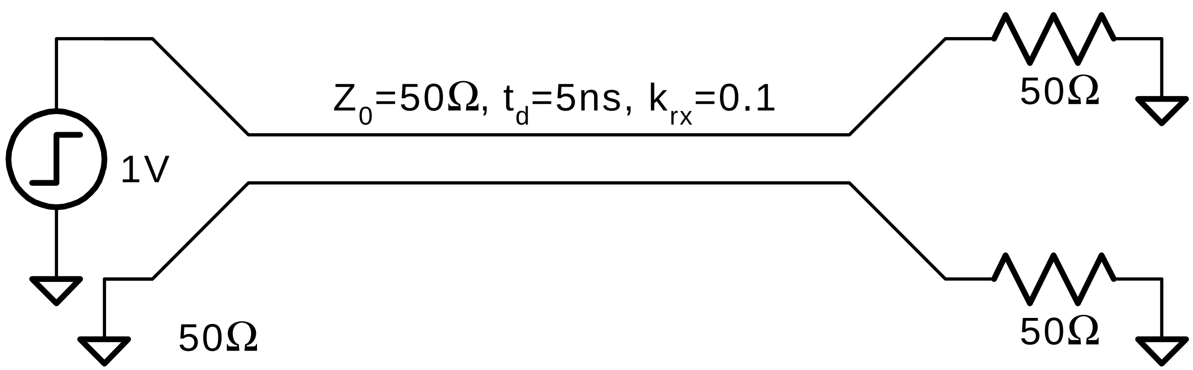


Crosstalk and Termination

- The noise resulting from crosstalk depends on the termination
- E.g., if $k_{fx} = 0$ and $k_{rx} = 0.1$ compare termination at both ends to termination at receiver only
  - Both ends: near end crosstalk absorbed by source termination, little or no contribution to noise at destination
    - $k_{Nrx} = k_{rx} k_r$
  - Receiver only: near end crosstalk reflects from source and adds directly to noise at receiver
    - $k_{Nrx} = k_{rx}$
- What happens with termination only at source?

Crosstalk and Termination





Next Time

- Signal return crosstalk
- Intersymbol interference
- Managing noise