Today’s Assignment

• Problem set 3
  – Dally and Poulton, Exercises 6-3, 6-6, 6-7, 6-13, and 6-16
  – Due at start of class next Wednesday 10/14

• 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

Transmitter offsets
Transmitter PS noise

Crosstalk

Inter-Symbol Interference

Signal return noise

Receiver offsets
Receiver PS noise
Reference offset and noise
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 cancel this noise, not overpower it!

- Some noise is independent of signal swing
  - receiver sensitivity
  - receiver offset
  - unrelated power supply noise
  - reference offsets

\[
V_N = K_N V_S + V_{NI}
\]
\[
\frac{V_S}{2} \geq K_N V_S + V_{NI}
\]
\[
V_S \geq \frac{2V_{NI}}{1 - 2K_N}
\]
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
  - \( R_i + L \frac{di}{dt} \)
- 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 disturbed
  - capacitive voltage divider
  - signal is not restored

\[ k_{2C} = \frac{2C_c}{2C_c + C_o} \]

x wires
y wires
tax wires b.a.c
y wires

a is victim, b and c are aggressors

To y wires
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 aggressor, b, is slow compared to \( \tau \), magnitude of disturbance is reduced

\[
\left( \frac{\tau}{t_r} \right) \left( 1 - \exp\left( -\frac{t_r}{\tau} \right) \right)
\]

Cross Talk and Delay

- Capacitive cross talk can affect delay of RC signals
- If aggressor(s) switch in opposite direction, effective capacitance of \( C_c \) is doubled
- If aggressor(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

A diagram showing the setup of the experiment with labeled lines and ports.
Experimental Cross Talk Measurements

Inductive and Capacitive Coupling

- Consider a positive transient on aggressor 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

\[ k_{I_x} = \frac{M}{L} \]
\[ k_{C_x} = \frac{C_d}{C} \]
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 aggressor

**The Equations**

\[
k_{rx} = \frac{k_{cx} + k_{fx}}{4} \\
k_{fx} = \frac{k_{cx} - k_{fx}}{2}
\]
Next Time

- Signal return crosstalk
- Intersymbol interference
- Managing noise