ECEN689: Special Topics in High-Speed Links Circuits and Systems
Spring 2010

Lecture 20: Noise Sources

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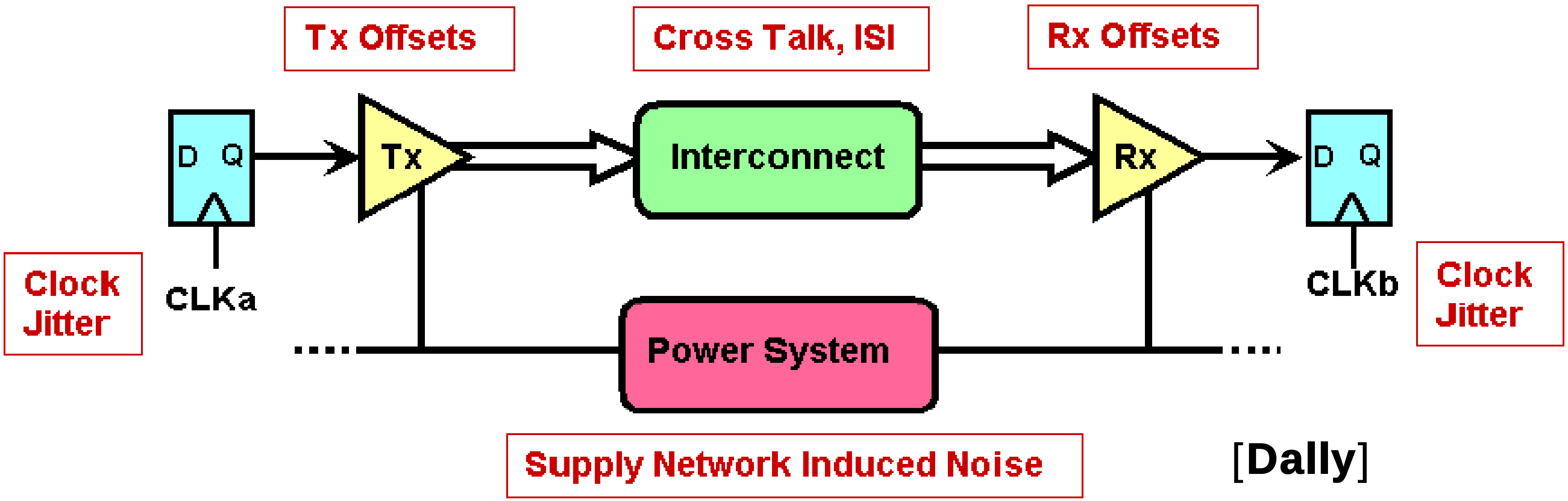
Announcements

- HW5 now due now
- HW6 will be posted this weekend and due Monday April 5
- Reading
  - DFE papers posted
  - Advanced signaling paper posted (reference only)
  - Dally 6.1-6.3

Agenda

- Noise source overview
- Common noise sources

Noise in High-Speed Link Systems



[Dally]

- Multiple noise sources can degrade link timing and amplitude margin

Noise Source Overview

- Common "noise" sources
  - Power supply noise
  - Receiver offset
  - Crosstalk
  - Inter-symbol interference
  - Random noise
- Power supply noise
  - Switching current through finite supply impedance causes supply voltage drops that vary with time and physical location
- Receiver offset
  - Caused by random device mismatches
- Crosstalk
  - One signal (aggressor) interfering with another signal (victim)
  - On-chip coupling (capacitive)
  - Off-chip coupling (t-line)
    - Near-end
    - Far-end
- Inter-symbol interference
  - Signal dispersion causes signal to interfere with itself
- Random noise
  - Thermal & shot noise
  - Clock jitter components

Bounded and Statistical Noise Sources

- Bounded or *deterministic* noise sources
  - Have theoretically predictable values with defined worst-case bounds
  - Allows for simple (but pessimistic) worst-case analysis
  - Examples
    - Crosstalk to small channel count
    - ISI
    - Receiver offset
- Statistical or *random* noise sources
  - Treat noise as a random process
    - Source may be psuedo-random
  - Often characterized w/ Gaussian stats
    - RMS value
    - Probability density function (PDF) yields probability noise will exceed a certain value
  - Examples
    - Thermal noise
    - Clock jitter components
    - Crosstalk to large channel count
- Understanding whether noise source is bounded or random is critical to accurate link performance estimation

Proportional and Independent Noise Sources

- Some noise is *proportional* to signal swing
  - Crosstalk
  - Simultaneous switching power supply noise
  - ISI
- Can't overpower this noise
  - Larger signal = more noise

- Some noise is *independent* to signal swing
  - RX offset
  - Non-IO power supply noise
- Can overpower this noise

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

Total noise

Proportional noise constant

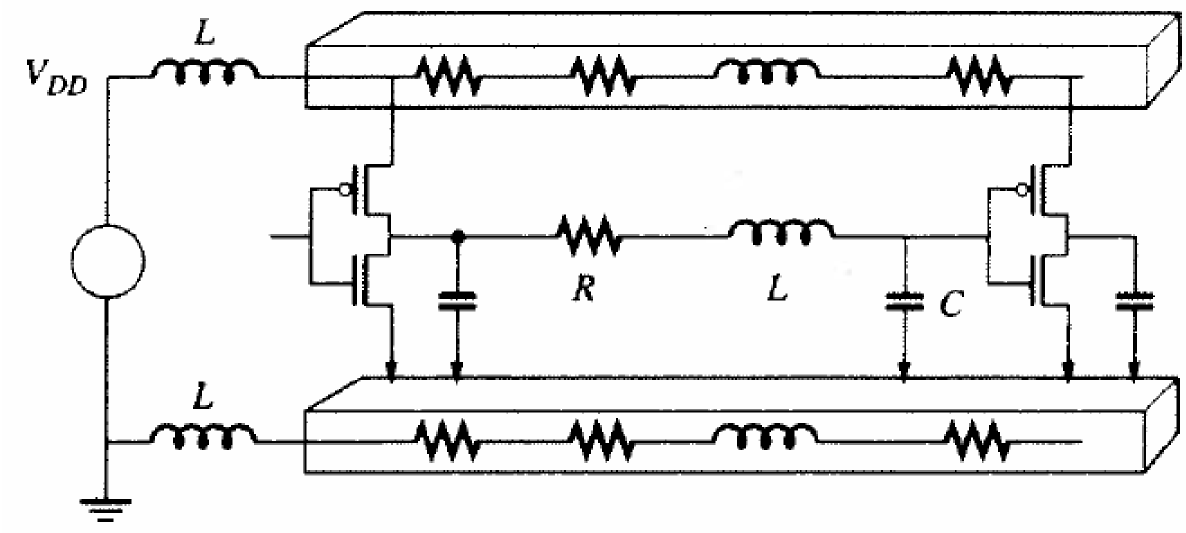
Signal swing

Independent noise

Common Noise Sources

- Power supply noise
- Receiver offset
- Crosstalk
- Inter-symbol interference
- Random noise

Power Supply Noise

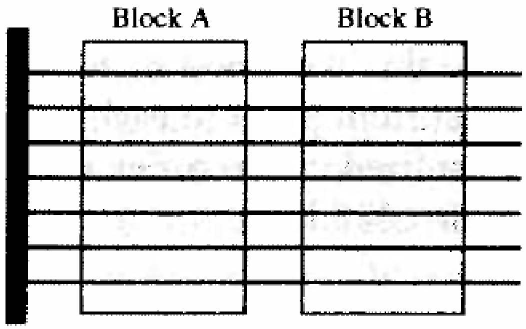


[**Hodges**]

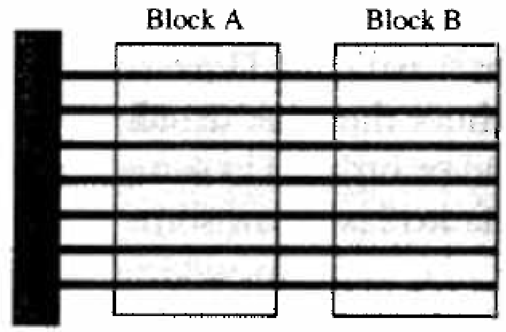
- Circuits draw current from the VDD supply nets and return current to the GND nets
- Supply networks have finite impedance
- Time-varying (switching) currents induce variations on the supply voltage
- Supply noise a circuit sees depends on its location in supply distribution network

Power Routing

Bad – Block B will experience excessive supply noise

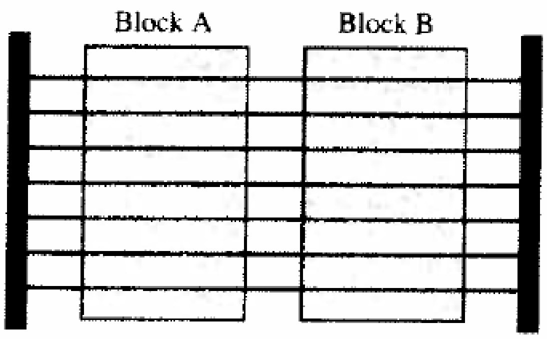


Better – Block B will experience 1/2 supply noise, but at the cost of double the power routing through blocks

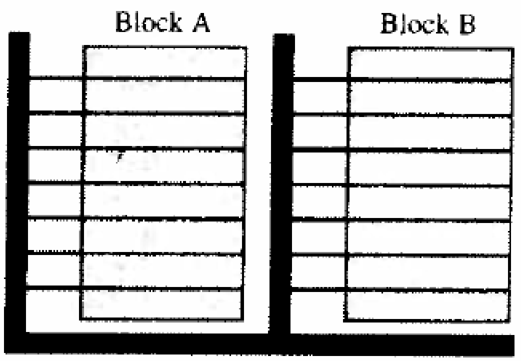


[**Hodges**]

Even Better – Block A & B will experience similar supply noise



Best – Block A & B are more isolated



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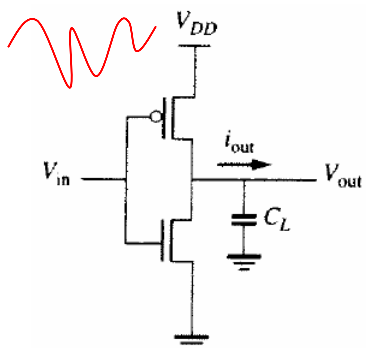
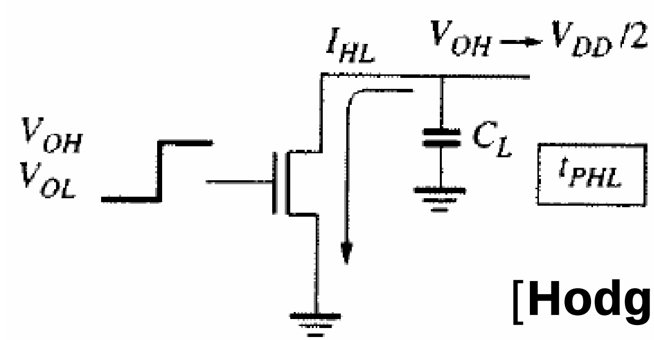
Supply Induced Delay Variation

- Supply noise can induce variations in circuit delay
  - Results in deterministic jitter on clocks & data signals





[**Hodges**]

$$t_{PHL} = \frac{C_L (VDD/2)}{I_{DSATN}} = \frac{C_L (VDD/2)}{\left(\frac{W_N v_{sat} C_{ox} (VDD - V_{TN})^2}{VDD - V_{TN} + E_{CN} L_N} \right)} \approx \frac{C_L VDD}{2 W_N v_{sat} C_{ox} (VDD - V_{TN})}$$

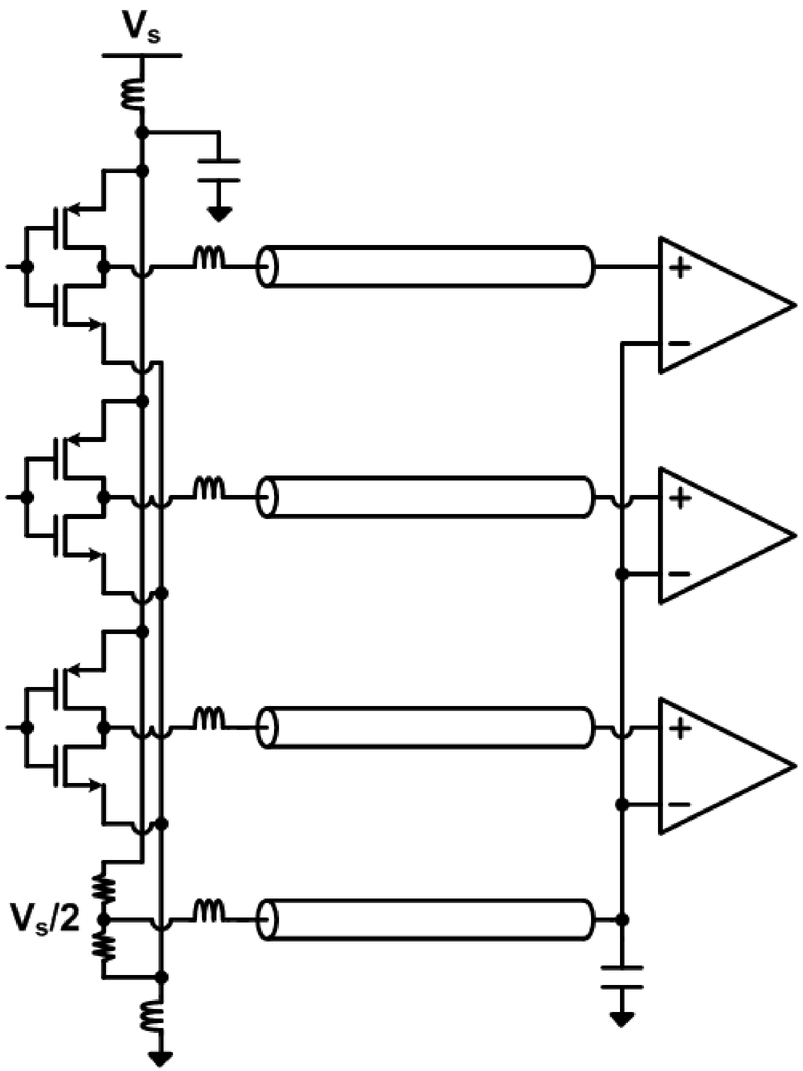
$$\textbf{Delay} \propto \frac{VDD}{VDD - V_{TN}} \approx \propto VDD$$

- CMOS delay is approximately directly proportional to VDD
  - More delay results in more deterministic jitter

Simultaneous Switching Noise

- Finite supply impedance causes significant Simultaneous Switching Output (SSO) noise (xtalk)
- SSO noise is proportional to number of outputs switching, n, and inversely proportional to signal transition time, t_r

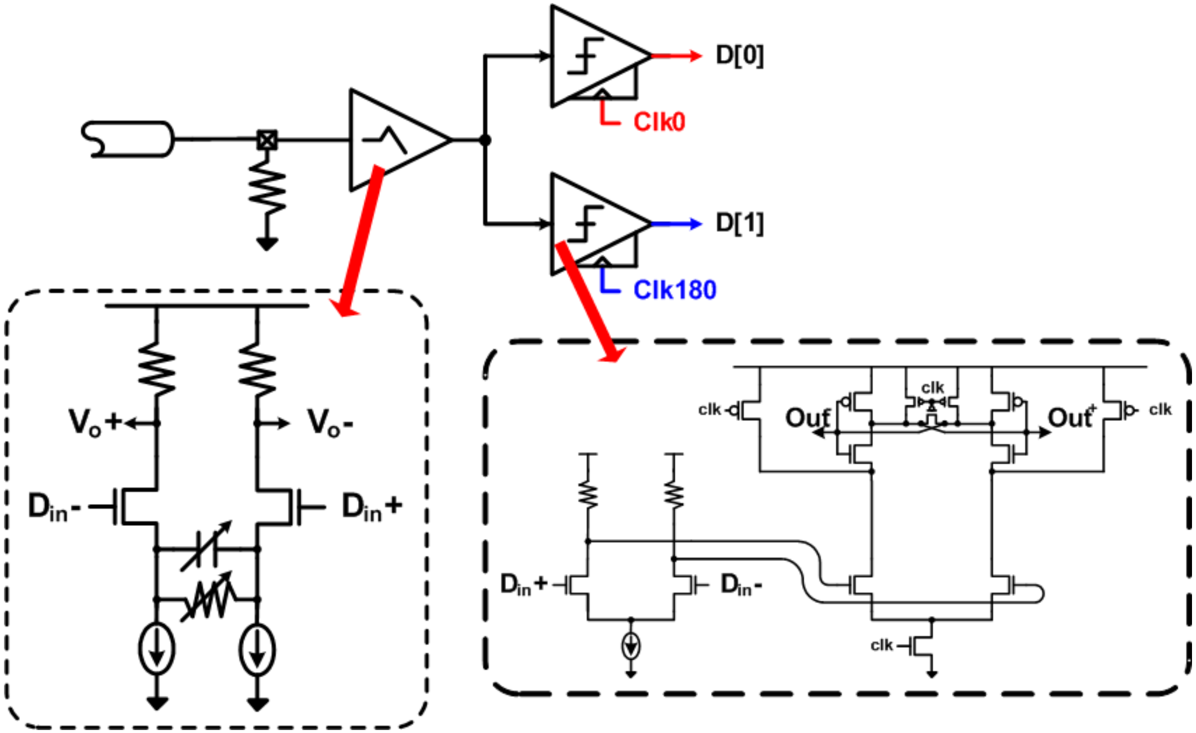
$$V_N = L\frac{i}{t_r} = n\frac{LV_s}{Z_0 t_r}$$



Common Noise Sources

- Power supply noise
- Receiver offset
- Crosstalk
- Inter-symbol interference
- Random noise

Receiver Input Referred Offset



- The input referred offset is primarily a function of V_{th} mismatch and a weaker function of β (mobility) mismatch

$$\sigma_{V_t} = \frac{A_{V_t}}{\sqrt{WL}}, \quad \sigma_{\Delta\beta/\beta} = \frac{A_\beta}{\sqrt{WL}}$$

Receiver Input Referred Offset

$$\sigma_{V_t} = \frac{A_{V_t}}{\sqrt{WL}}, \quad \sigma_{\Delta\beta/\beta} = \frac{A_\beta}{\sqrt{WL}}$$

- To reduce input offset 2x, we need to increase area 4x
  - Not practical due to excessive area and power consumption
  - Offset correction necessary to efficiently achieve good sensitivity

- Ideally the offset "A" coefficients are given by the design kit and Monte Carlo is performed to extract offset sigma

- If not, here are some common values:
  - A_{Vt} = 1mVμm per nm of t_{ox}
    - For our default 90nm technology, t_{ox}=2.8nm $\rightarrow$ A_{Vt} ~2.8mVμm
  - A_β is generally near 2%μm

Common Noise Sources

- Power supply noise
- Receiver offset
- Crosstalk
- Inter-symbol interference
- Random noise

Crosstalk

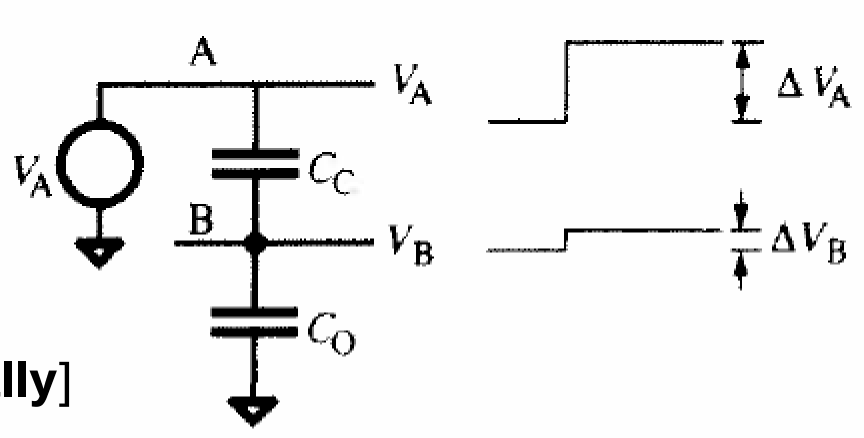
- Crosstalk is noise induced by one signal (aggressor) that interferes with another signal (victim)

- Main crosstalk sources
  - Coupling between on-chip (capacitive) wires
  - Coupling between off-chip (t-line/channel) wires
  - Signal return coupling

- Crosstalk is a proportional noise source
  - Cannot be reduced by scaling signal levels
  - Addressed by using proper signal conventions, improving channel and supply network, and using good circuit design and layout techniques

Crosstalk to Capacitive Lines

- **On-chip wires** have significant capacitance to adjacent wires both on same metal layer and adjacent vertical layers
- Floating victim
  - Examples: Sample-nodes, domino logic
  - When aggressor switches
    - Signal gets coupled to victim via a capacitive voltage divider
    - Signal is not restored



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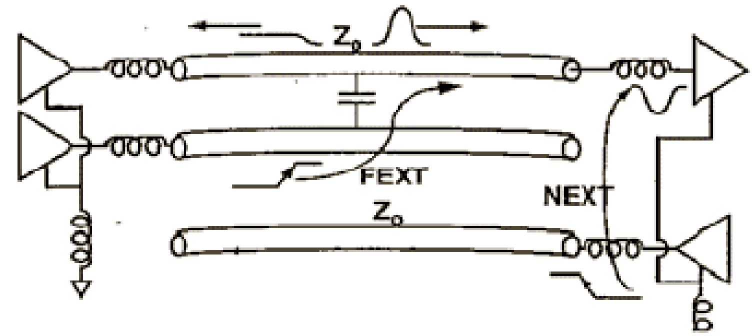
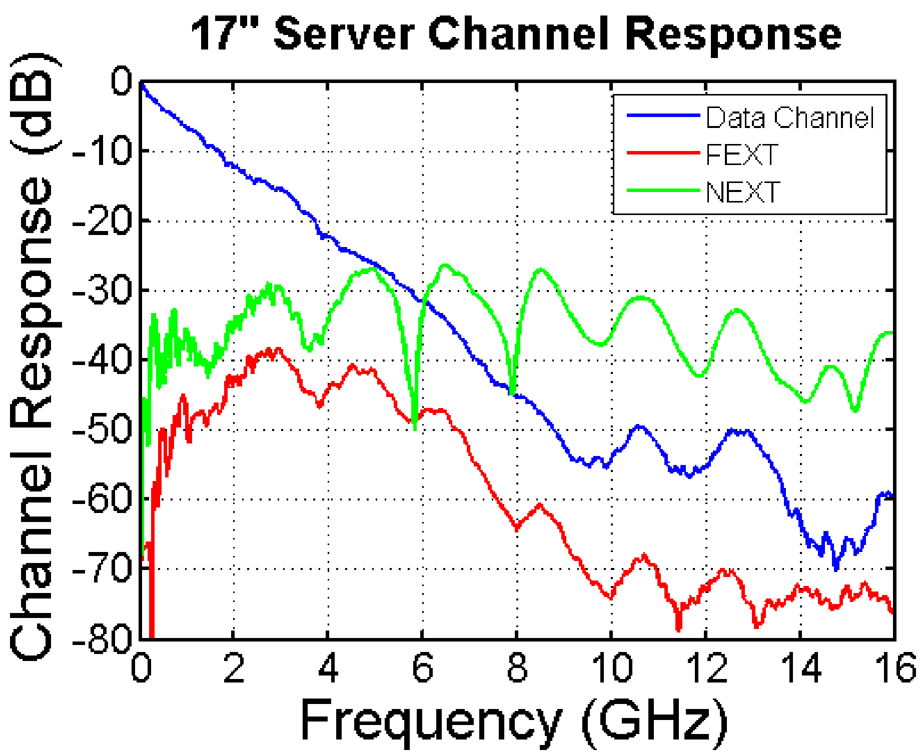
$$\Delta V_B = k_c \Delta V_A$$

$$k_c = \frac{C_C}{C_C + C_O}$$

Off-Chip Crosstalk

- Occurs mostly in package and board-to-board connectors
- FEXT is attenuated by channel response and has band-pass characteristic
- NEXT directly couples into victim and has high-pass characteristic





Next Time

- Noise Sources
- Timing Noise
- BER Analysis Techniques