Links are everywhere…
Basic Link Issues

- Signaling: getting bits from the TX to the RX
- Timing: determining which bit is which

Speed of Light

- Why is a link (i.e., off-chip I/O) different than on-chip wires?
  - Both send info back and forth
- Usually model on-chip wires with capacitor
  - Sometimes with resistance too
- On-chip model works because dimensions $\ll \lambda$
  - Not true for off-chip wires...
Transmission Lines

• Wire model when can’t ignore $c$:

• Characteristics:
  • Delay
  • Characteristic impedance
  • Energy stored in E, B fields

Termination and Reflection

• Two constraints at any junction:
  • Voltage are equal
  • Power is conserved
Loss

- Real T-lines have loss too:
  - Skin loss $\alpha \sqrt{f}$
  - Dielectric loss $\alpha f$

Not Just Material Issues...

- Energy splits at via

- Short vias look like capacitive load → reflections...
Example Channels

- 20-30dB loss at 3GHz
- How bad is that?
- Two related issues:
  - (1) Noise and min. signal amplitude
  - (2) Intersymbol interference

Noise and BER

- RX circuits always have noise
  - If noise is ever larger than the input signal (at sampling point), RX will decode the bit incorrectly
- BER = Bit Error Rate
  - I.e., average # of incorrectly received bits / total transmitter bits
Min. Signal Amplitude

- Min. signal set by noise $\sigma$ and residual offset:
  \[
  BER = \frac{1}{2} \text{erfc} \left( \frac{V_{in,ampl} - V_{off}}{\sqrt{2} \sigma_{noise}} \right)
  \]
  - $BER = 10^{-12}$: $(V_{in,ampl} - V_{off}) = 7\sigma_n$
  - $BER = 10^{-20}$: $(V_{in,ampl} - V_{off}) = 9.25\sigma_n$

So What?

- Why not just hit the RX with a larger signal?
  - (Not a stupid question – this is often what people do)

- Simple (hand-wavy) answers:
  - Transmission line $Z$ usually low (~50$\Omega$)
    - 1V swing $\rightarrow$ 20mW
  - Larger swing doesn’t help with ISI...
    - More next lecture

- Bottom line:
  - If can use lower swing, can get lower power
  - Good application of EE240 material!
Link Circuits: “Current-Mode” TX

- Often use differential signaling/circuits to reject supply/CM noise:

“Voltage-Mode” TX
Receiver Termination Options

Basic Receiver