Links are everywhere...

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 $c$:

  - Properties:
    - Delay
    - Characteristic impedance
    - Energy stored in E, B fields

Termination and Reflection

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

Basic Link Issues

- Signaling: getting bits from the TX to the RX

- Timing: determining which bit is which
• Real T-lines have loss too:
  • Skin loss $\alpha \sqrt{f}$ (in dB)
  • Dielectric loss $\alpha f$ (in dB)

Not Just Material Issues…

• Energy splits at via
• Via stub looks like a capacitor – 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 transmitted bits

Min. Signal Amplitude

• Min. signal set by noise $\sigma$ and residual offset:

$$BER = \frac{1}{2} \text{erfc} \left( \frac{V_{in,ampl} - V_{off}}{\sqrt{2} \sigma_n} \right)$$

• 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 (~50Ω)
    • 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: