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

Basic Link Issues
- Signaling: getting bits from the TX to the RX
  
  ![Diagram of signaling](image1)

- Timing: determining which bit is which

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

![Diagram of transmission lines](image2)
• Real T-lines have loss too:
  • Skin loss $\alpha \sqrt{f}$
  • Dielectric loss $\alpha f$

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

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

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

• 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:

Front-end Amp Gain

Receiver Termination Options

Front-end Amp Bandwidth

Basic Receiver