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# Transmission Lines

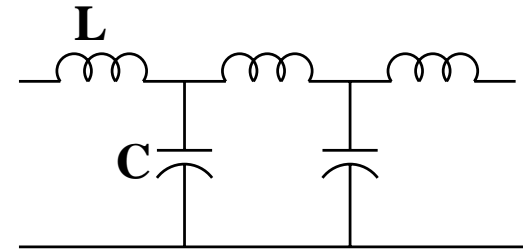
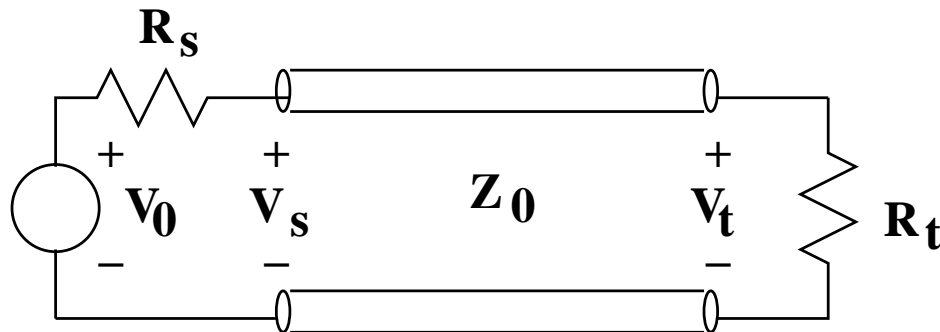




# Transmission Lines



- Signals travel on wires.
  - Attenuation – losses due to resistance of wires
  - Reflections – affected by terminations



Transmission line has characteristic parameters:

**L**: Inductance per unit length

**C**: Capacitance per unit length

**Z<sub>0</sub>** : Characteristic Impedance

**U<sub>0</sub>** : Phase Velocity

$$Z_0 = \sqrt{\frac{L}{C}}$$

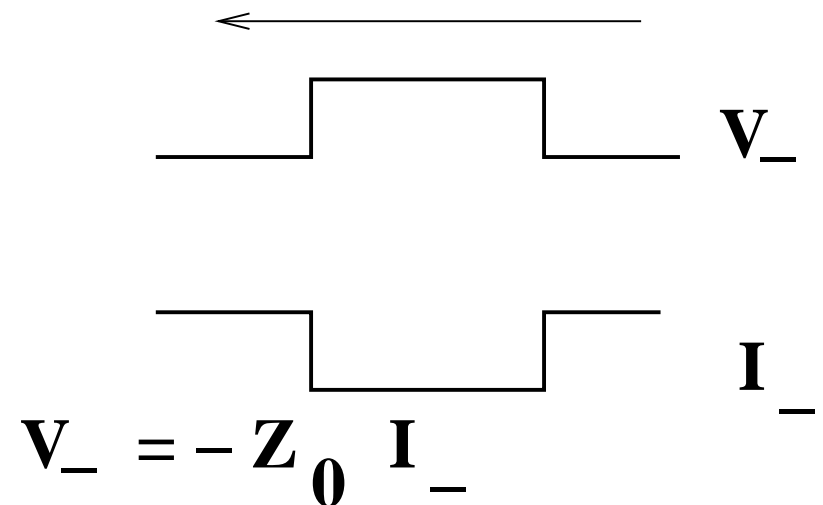
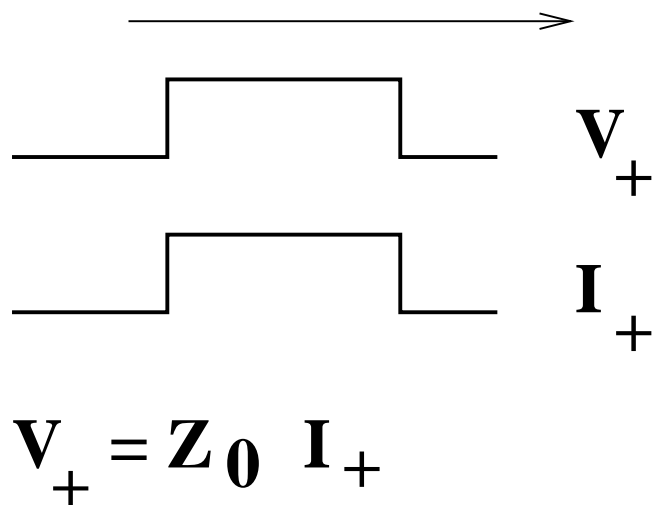
$$U_0 = \sqrt{\frac{1}{LC}}$$



# Signal Propagation



- Pulses travel along the line.
  - Ratio of voltage to current is the “characteristic impedance”.
  - Sign of that ratio is the direction of propagation.
  - Pulses propagate at a velocity  $< c$  (speed of light).

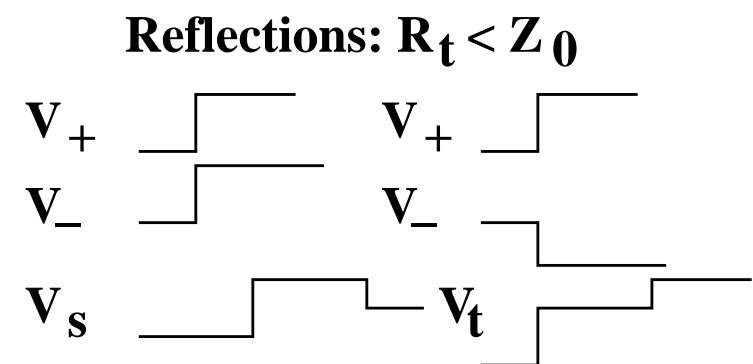
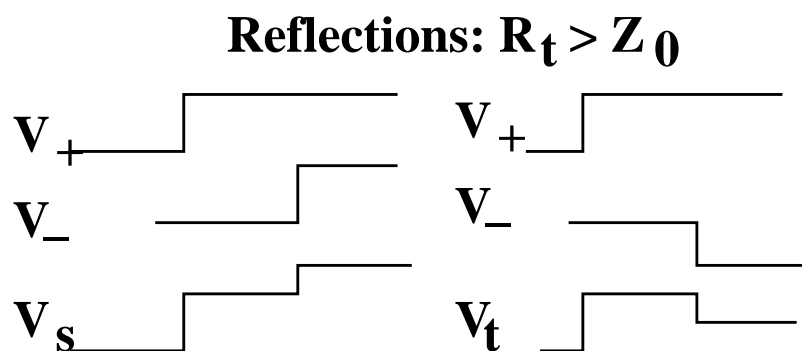




# Reflections



- Pulses are absorbed if the receiving end is matched to the characteristic impedance.
  - If the receiving end is not matched then a pulse “reflects”.
  - The sign of the reflection depends on the impedance value relative to the characteristic impedance.

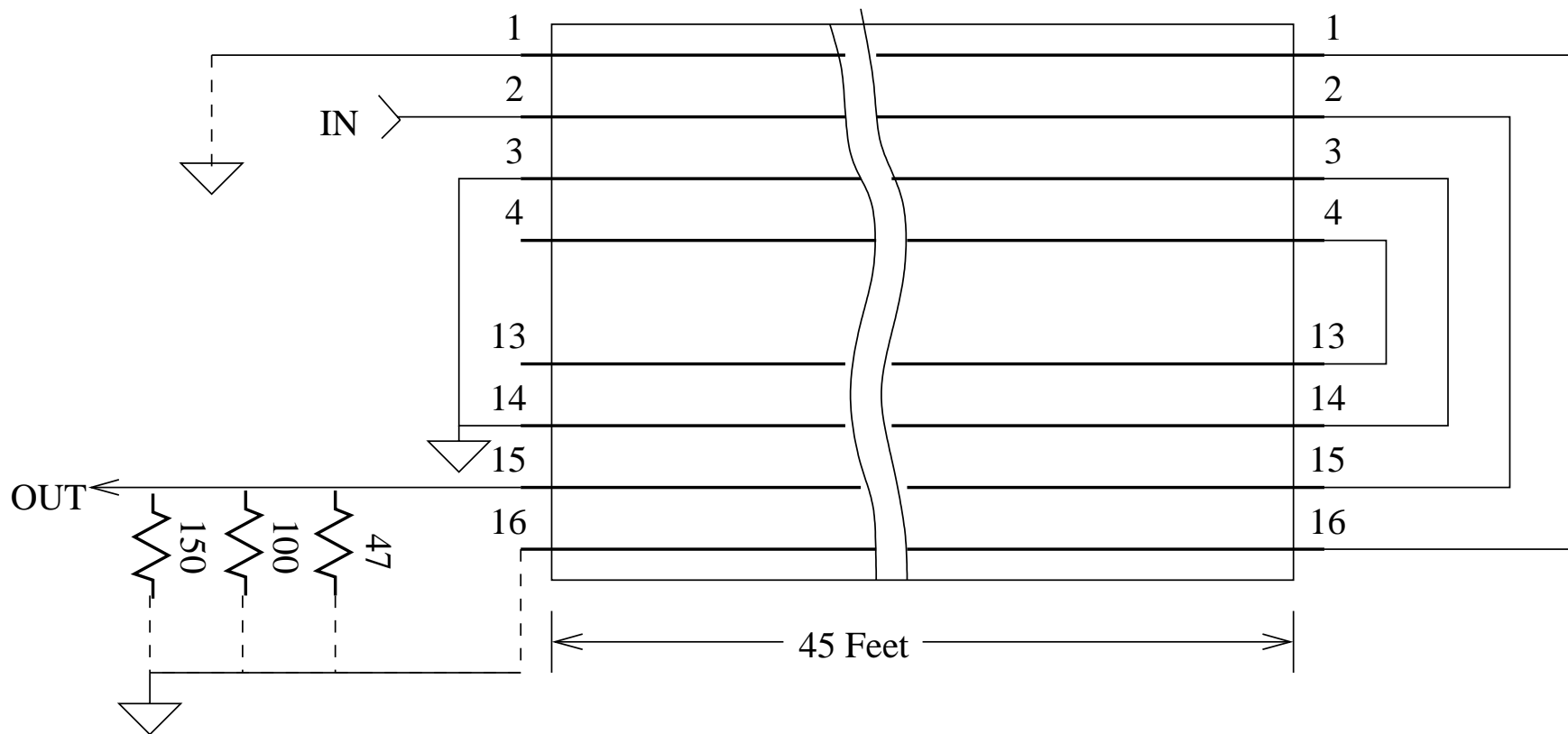




# Characteristic Impedance Demo



- Reflections depend on the terminating impedance.
  - They can be minimized by terminating correctly, i.e., with the characteristic impedance?
  - Why can't they be eliminated?



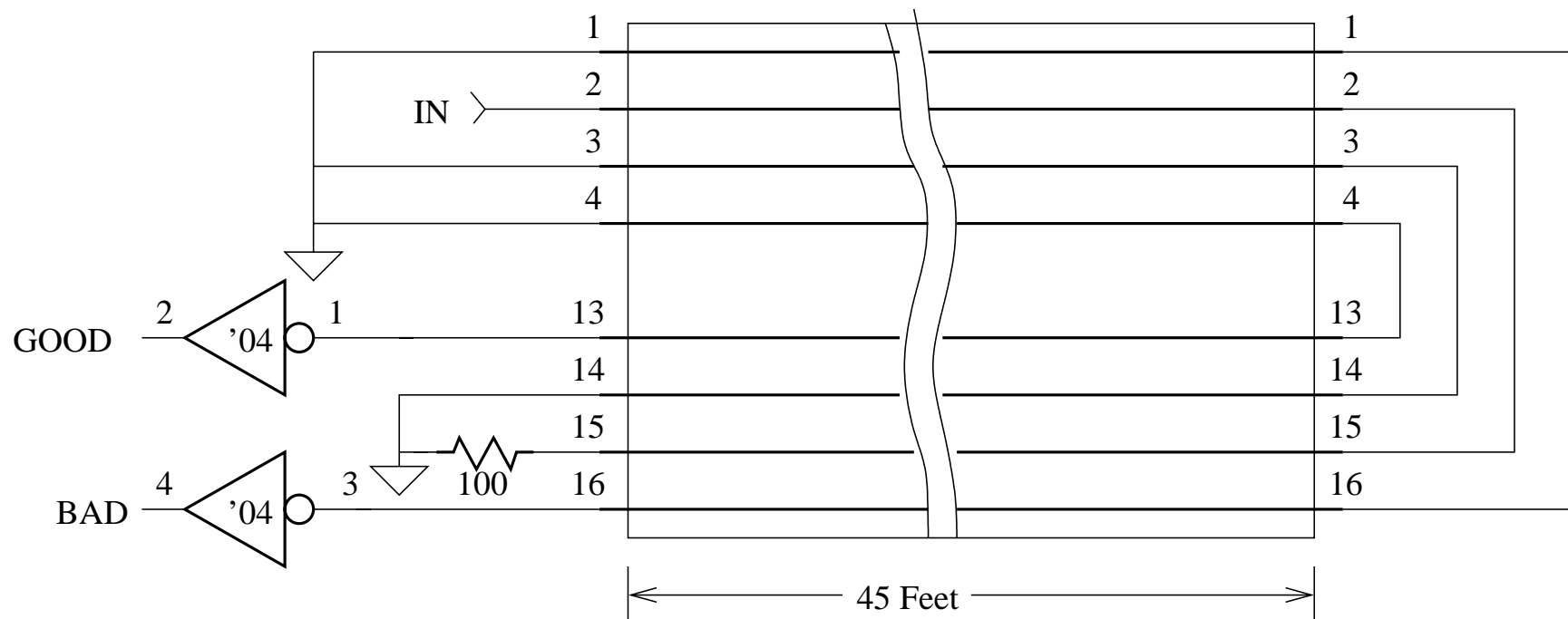
**Moral: Terminate Wires in Characteristic Impedance**



# Crosstalk Demo



- **Flat ribbon cable – similar to kit interconnect cables**
  - The wires are situated right next to each other.
  - They have capacitive and inductive coupling.
- **Crosstalk is minimized by alternating signals and grounds.**
  - **Ground – Signal – Ground – Signal .....**



**Moral: Alternate Ground and Signal Wires in Cables**