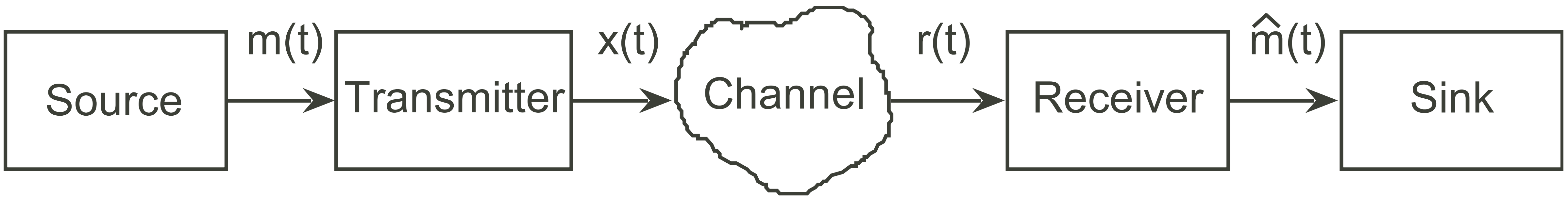
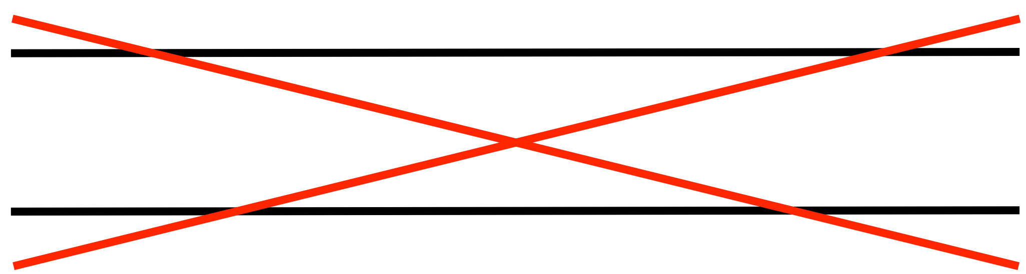
Fundamentals of Electrical Engineering

Wireline Communication Channels

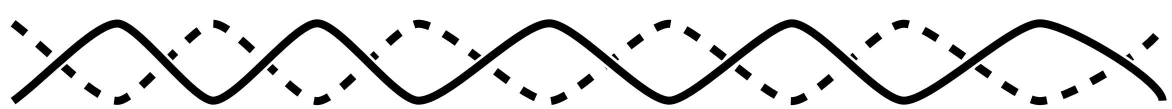


Wireline Channels

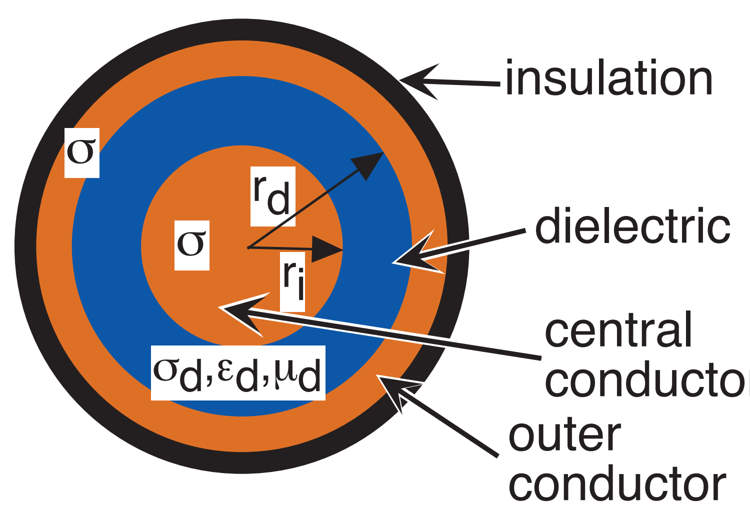
- Transmitter and receiver communicate over special wired channels
- Care must be taken to minimize *crosstalk*



two-wire pair

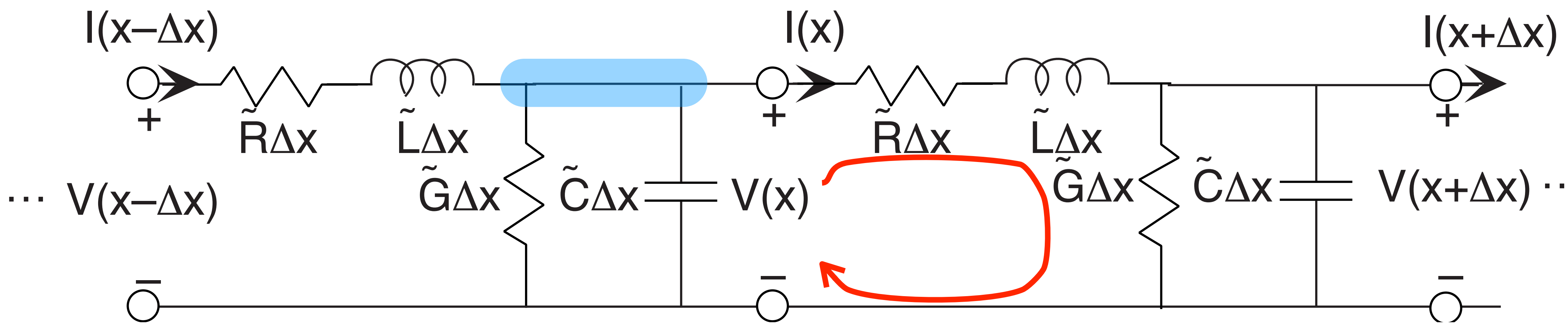


twisted pair



coaxial cable

Circuit Model for Wired Channels



KCL: $I(x) = I(x-\Delta x) - V(x)\left(\widetilde{G} + j2\pi f\widetilde{C}\right)\Delta x$

KVL: $V(x) = I(x)\left(\widetilde{R} + j2\pi f\widetilde{L}\right)\Delta x + V(x+\Delta x)$

$$\frac{d}{dx}I(x) = -\left(\widetilde{G} + j2\pi f\widetilde{C}\right)V(x)$$

$$\frac{d}{dx}V(x) = -\left(\widetilde{R} + j2\pi f\widetilde{L}\right)I(x)$$

$$\boxed{\frac{d^2}{dx^2}V(x) = \left(\widetilde{G} + j2\pi f\widetilde{C}\right)\left(\widetilde{R} + j2\pi f\widetilde{L}\right)V(x)}$$

RICE

Voltage Propagates!

$$\frac{d^2}{dx^2}V(x) = \left(\widetilde{G} + j2\pi f\widetilde{C}\right)\left(\widetilde{R} + j2\pi f\widetilde{L}\right)V(x)$$

$$V(x) = V_+ e^{-\gamma x} + V_- e^{+\gamma x}$$

As $\frac{d^2}{dx^2}V(x) = \gamma^2 V(x),\ \gamma = \pm\sqrt{\left(\widetilde{G} + j2\pi f\widetilde{C}\right)\left(\widetilde{R} + j2\pi f\widetilde{L}\right)}$

$$= \pm\left(a(f) + jb(f)\right)$$

$$V(x) = \begin{cases} V_+ e^{-(a+jb)x} & x > 0 \\ V_- e^{+(a+jb)x} & x < 0 \end{cases}$$

$$v(x,t) = \mathrm{Re}\left[V_+ e^{-ax} e^{j(2\pi f t - bx)}\right], \quad x > 0$$

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Voltage Propagates!

$$v(x,t) = \mathrm{Re}\left[V_+ e^{-ax} e^{j(2\pi f t - bx)}\right], \quad x > 0$$

$$\begin{aligned} 2\pi f t_2 - bx &= 2\pi f (t_1 + t_2 - t_1) - bx \\ &= 2\pi f t_1 - b\left(x - \frac{2\pi f}{b}(t_2 - t_1)\right) \end{aligned}$$

Speed of propagation: $c = \dfrac{2\pi f}{b}$ Since $\lambda \cdot f = c,\ \lambda = \dfrac{2\pi}{b}$

$$c = \frac{2\pi f}{\mathrm{Im}\left[\sqrt{(\widetilde{G} + j2\pi f \widetilde{C})(\widetilde{R} + j2\pi f \widetilde{L})}\right]} \xrightarrow{f\to\infty} \frac{1}{\sqrt{\widetilde{L}\widetilde{C}}}$$

and $a = \mathrm{Re}\left[\sqrt{(\widetilde{G} + j2\pi f \widetilde{C})(\widetilde{R} + j2\pi f \widetilde{L})}\right] \xrightarrow{f\to\infty} \dfrac{1}{2}\left(\dfrac{\widetilde{R}}{Z_0} + \widetilde{G} Z_0\right)$

Current Propagates, too!

$$V(x) = V_+ e^{-\gamma x} + V_- e^{+\gamma x}$$

As $\frac{d}{dx} V(x) = -\left(\widetilde{R} + j2\pi f \widetilde{L}\right) I(x)$

and $\gamma = \sqrt{\left(\widetilde{G} + j2\pi f \widetilde{C}\right)\left(\widetilde{R} + j2\pi f \widetilde{L}\right)}$

$$I(x) = \sqrt{\frac{\widetilde{G} + j2\pi f \widetilde{C}}{\widetilde{R} + j2\pi f \widetilde{L}}} V_+ e^{-\gamma x} - \sqrt{\frac{\widetilde{G} + j2\pi f \widetilde{C}}{\widetilde{R} + j2\pi f \widetilde{L}}} V_- e^{+\gamma x}$$

$$v(x,t) = \mathrm{Re}\left[V_+ e^{-ax} e^{j(2\pi f t - bx)}\right],\ x > 0$$

$$i(x,t) = \mathrm{Re}\left[I_+ e^{-ax} e^{j(2\pi f t - bx)}\right],\ x > 0$$

$$I_+ = \sqrt{\frac{\widetilde{G} + j2\pi f \widetilde{C}}{\widetilde{R} + j2\pi f \widetilde{L}}} V_+$$

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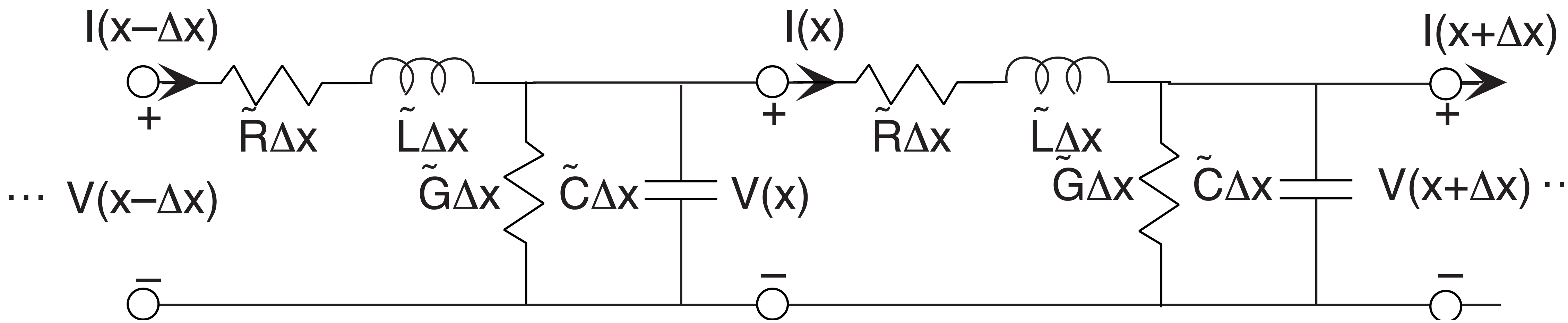
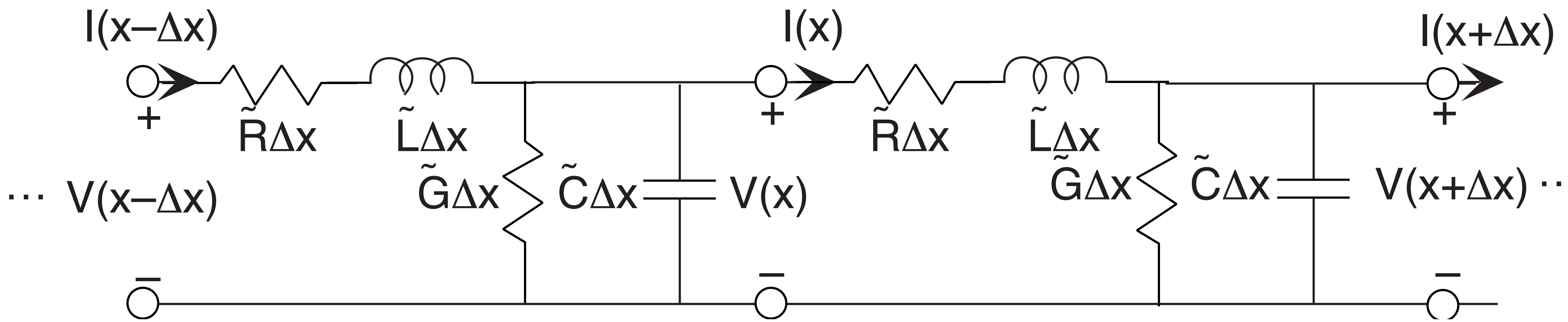
Wireline Channels



$$v(x,t) = \mathrm{Re}\left[V_+ e^{-ax} e^{j(2\pi f t - bx)}\right], \quad x > 0$$

At sufficiently high frequencies, signals propagate with very little loss at speed $\frac{1}{\sqrt{\widetilde{L}\widetilde{C}}}$

Wireline Channels



$$\frac{V(x)}{I(x)} = \sqrt{\frac{\widetilde{R} + j2\pi f \widetilde{L}}{\widetilde{G} + j2\pi f \widetilde{C}}}$$

$$\equiv Z_0 \text{ (characteristic impedance)}$$

$$\lim_{f \to \infty} Z_0 = \sqrt{\frac{\widetilde{L}}{\widetilde{C}}}$$

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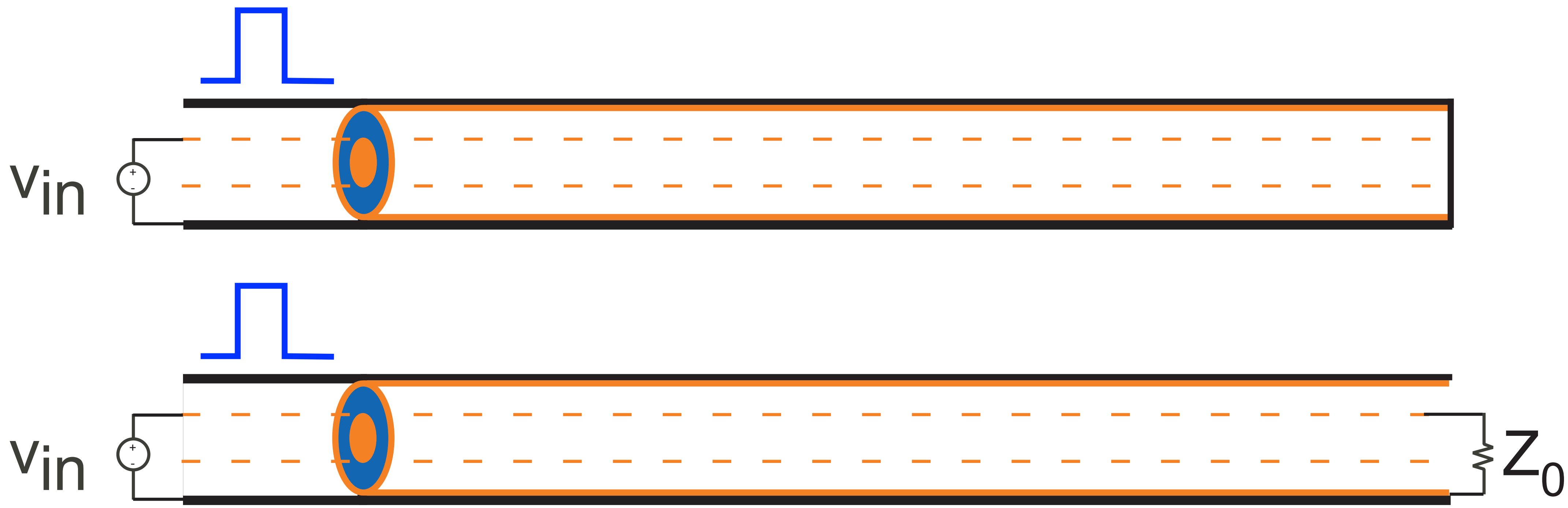
Wireline Channels

- An important detail is that the circuit model assumed an *infinitely* long cable
- Unless you *terminate* a cable properly, reflections will occur



$$Z_0 = 50 - 75\ \Omega$$

Wireline Channels

- Designed to minimize interference
- Receiver and transmitter must be connected to the cable
- Well-designed cable has little attenuation at high frequencies
- At low frequencies, amplitude decreases *exponentially* with distance

Wireless vs. Wireline

- Flexible connections via wireless, but communication distance limited by power and "natural" considerations
- Wireline requires a direct connection between transmitter and receiver
- Wireless prone to much more noise and interference

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