# Lecture 2 - Transmission Lines

**Exercise 1**: How much does a cable's resistance increase when the gauge size increases by 6? By 3? Hint: a wire's resistance is inversely proportional to its cross-sectional area.

$A = \pi r^2$

+3 +3

| gauge | diameter | area | resistance |
|---|---|---|---|
| + 6 | $\div 2$ | $\div 4$ | $\div \frac{1}{4}$ |
| | $\times \frac{1}{2}$ | $\times \frac{1}{4}$ | $\times 4$ |
| + 3 | $\div \sqrt{2}$ | $\div 2$ | $\div \frac{1}{2}$ |
| | $\times \frac{1}{\sqrt{2}}$ | $\times \frac{1}{2}$ | $\times 2$ |

**Exercise 2**: What is the characteristic impedance of a lossless cable with an inductance of 94 nH per foot and capacitance of 17pF/ft?

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

$L = 94 \text{ nH/ft} \quad 94 \times 10^{-9}$

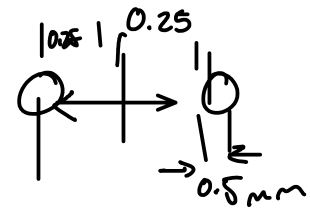
$C = 17 \text{ pF/ft} \quad 17 \times 10^{-12}$

$$= \sqrt{\frac{94 \times 10^{-9}}{17 \times 10^{-12}}} \approx \sqrt{\frac{100}{20} \times 10^{3}} = \sqrt{5000}$$

$$\approx 70\ \Omega$$

74

**Exercise 3**: What is the characteristic impedance of UTP made from 24-gauge wire with polyethylene insulation ($\epsilon_r = 2.2$) of 0.25mm thickness?




$$Z_0 \approx \frac{120}{\sqrt{\epsilon_r}} \ln\left(\frac{2S}{D}\right)$$

$$= \frac{120}{\sqrt{2.2}} \ln\left(\frac{2S}{D}\right)$$

$0.5 + 2 \times (0.25)$

1 mm

$$= \frac{120}{\sqrt{2.2}} \ln\left(\frac{2}{0.5}\right)$$

$= 100 \ln(4)$

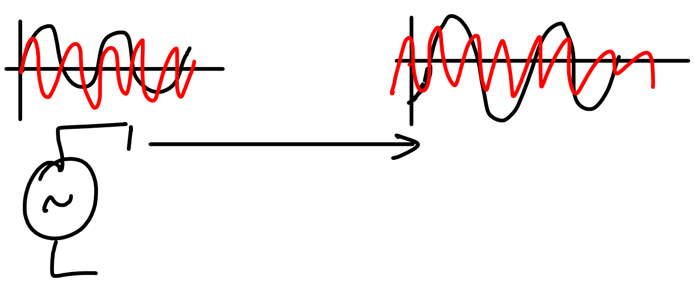
$\approx 100$ (112)

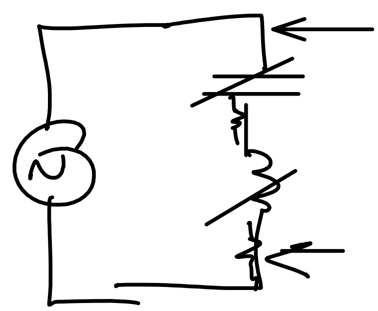
D = 0.5 mm

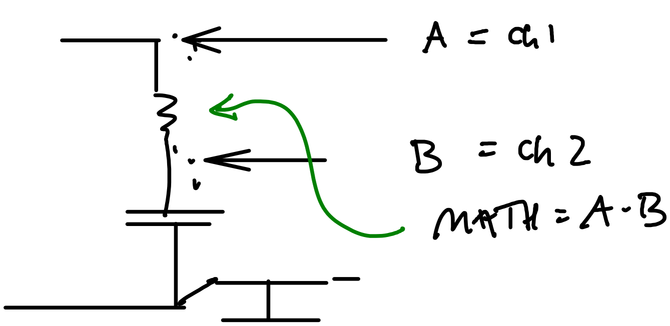
S = 1 mm

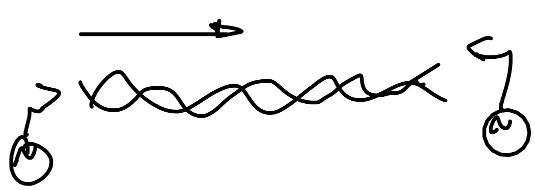
2S = 2 mm

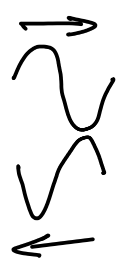
**Exercise 4**: What is the characteristic impedance of a co-ax cable with a 0.8mm diameter center conductor, 3.5mm diameter shield and foamed polyethylene between them that has a dielectric constant of 1.5?







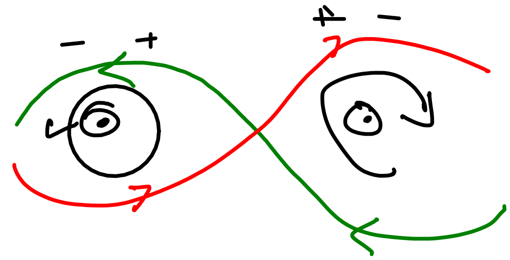





$$v = \frac{c}{\sqrt{\epsilon_r}}$$

$$t = \frac{d}{v}$$

**Exercise 5**: An 800 MHz signal is output from a CATV amplifier at a power level of 10dBm. What power level would you expect at the other end of a 75m run of co-ax whose loss is specified as 24dB/100m at 800 MHz?

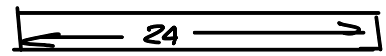


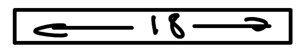

$$10\,dBm = 10\log\left(\frac{P}{1mW}\right)$$

$$1 = \log\left(\frac{P}{1mW}\right)$$

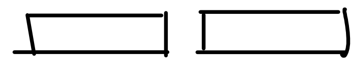
$$10^1 = \frac{P}{1mW} \qquad P = 10\,mW$$

100m → 24dB




$$= \frac{75}{100} \times 24$$



$$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

$$-3dB + -3dB = -6dB$$

$$B = \log_{10}\left(\frac{P_1}{P_2}\right)$$

0.3

−10 dBm

$$-10 = 10\log\left(\frac{P_1}{1}\right)$$

$$-1 = \log\left(\frac{P_1}{1}\right)$$

$$P_1 = 10^{-1} = 0.1\,mW$$

loss = 18dB

power level = 10dBm − 18 dB

= −8 dBm

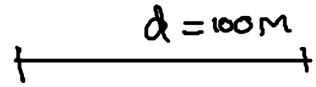
$$= 10^{\left(\frac{-8}{10}\right)} \Rightarrow \approx 0.1\,mW$$

10dBm + 6dBm.

10mW × 4mW.

**Exercise 6**: What is the velocity factor for a cable with polyethylene insulation ($\epsilon_r = 2.2$)? How long would it take for a signal to propagate 100m? For a cable with air dielectric?

$$VF = \frac{1}{\sqrt{\varepsilon_r}} = \frac{1}{\sqrt{2.2}} = 0.66$$




$$v = \frac{d}{t} \qquad t = \frac{d}{v}$$

$$v = c \cdot VF = 3\times10^8 \times 0.66\ m/s.$$

$$= 2\times10^8\ m/s$$

$$t = \frac{100}{2\times10^8} = 50\times10^{-8}\,s = 500\times10^{-9} = 500\,ns.$$

**Exercise 7**: If the optical signal wavelength is 1330nm what is the frequency?

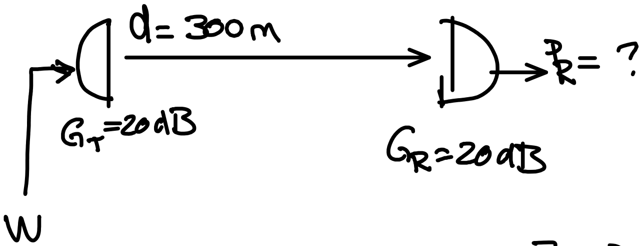
$$\lambda = 1330 \times 10^{-9}$$
$$1.33 \times 10^{-6}$$

$$c = \lambda \cdot f$$

$$f = \frac{c}{\lambda} = \frac{3 \times 10^{8}}{1.3 \times 10^{-6}} = 2.3 \times 10^{14}$$

$$226 \times 10^{12} \text{ Hz}$$
$$222 \text{ THz}$$

**Exercise 8**: A point-to-point link uses a transmit power of 1 Watt, transmit and receive antennas with gains of 20dB and operates at 3 GHz. How much power is received by a receiver 300m away?




$$P_R = P_T \, G_T \, G_R \left(\frac{\lambda}{4\pi d}\right)^2$$ (d: dist.)

$$= 1 \times 10^{2} \times 10^{2} \left(\frac{0.1}{4\pi \cdot 300}\right)^2$$

$$= 10^{4} \left(\frac{10^{-1}}{3 \times 10^{3}}\right)^2$$

$$= 10^{4} \frac{10^{-2}}{10^{7}} = 10^{-5} \approx 10 \mu W$$

$$(7 \mu W)$$

$$7 \mu W$$

$$f = 3 \text{ GHz}$$
$$\lambda = c / f$$
$$\lambda = \frac{3 \times 10^{8}}{3 \times 10^{9}} = 0.1 \text{ m}$$

$$20 \text{ dB} = 10 \log\left(\frac{P_1}{P_2}\right)$$
$$\frac{P_1}{P_2} = 100$$

$$P_{R_{dBm}} = P_{T_{dBm}} + G_{T_{dB}} + G_{R_{dB}} + 20 \log\left(\frac{\lambda}{4\pi d}\right)$$

**Exercise 9**: Rank each of twisted-pair, co-ax, optical fiber and free space media according to cost of the medium, cost of the interface, media size and immunity to interference.

| | cost of medium | cost of interface | media size | immunity to interference | capacity. throughput bandwidth |
|---|---|---|---|---|---|
| twisted pair | $ | $ | medium | L | L |
| co-ax | $$ | $$ | thickest | M | M |
| optical fiber | $$$ | $$$ | smallest | H | H |
| wireless | 0 | $$$$ | 0 | very L | M ? |