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 proportional to its cross-sectional area.

area $= \pi r^2$

gauge increases by	6	3	12
diameter decreases by	2 $(\times \frac{1}{2})$	$\frac{1}{\sqrt{2}}$	4 $(\times \frac{1}{4})$
area decrease by	4 $(\times \frac{1}{4})$	$\frac{1}{2}$	
resistance increases by	4 $(\times 4)$	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?

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

$L = 94\,nH \quad 94 \times 10^{-9}$

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

74.36 Ω

$$Z_0 = \sqrt{\frac{94}{17} \frac{\times 10^{-9}}{\times 10^{-12}}} \approx \sqrt{\frac{100}{20} \cdot 1000}$$

$$\approx \sqrt{5000} \approx \underline{70}\ \Omega$$

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?

AWG24

24ga : D=0.5mm

S = 0.5+0.5

= 1mm

2s = 2mm

$$Z_0 = \frac{120}{\sqrt{\varepsilon_r}} \ln\left(\frac{2s}{D}\right)$$

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

$$\approx 100 \cdot \ln(4)$$

$$100 \cdot 1.1$$

$$\approx \underline{\underline{110}}\ \Omega\ (112)$$

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?

$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{D}{d}\right) = \frac{60}{\sqrt{1.5}} \ln\left(\frac{3.5}{0.8}\right)$$

$$\approx 50 \times 1.1$$

$$\approx 55\ \Omega$$

$$\underline{\underline{72\ \Omega}}$$

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?

← 75m →

10dBm →  ?

f = 800 MHz

Loss = 24 dB / 100m @ 800 MHz

$10\,dBm - 75 \cdot \frac{24}{100}$

1mW → [½] [½] → ¼ mW

−3 −3 → −6dBm

0 dBm −6

e.g. with linear loss units

loss = 0.005 / 100m

for 75m loss = $(.005)^{\frac{75}{100}}$

10mW ≐ 10dBm

0dB = 1X (power)

−3dB = { $\frac{1}{\sqrt{2}}$ (voltage); $\frac{1}{2}$ (power) }

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

$= 20 \log\left(\frac{V_1}{V_2}\right)$

power

$\frac{1}{2} \to 10\log(0.5)$

−3dB.

Why dB units? Why not Bels?

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

$dB : 10\log_{10}\left(\frac{P_1}{P_2}\right)$

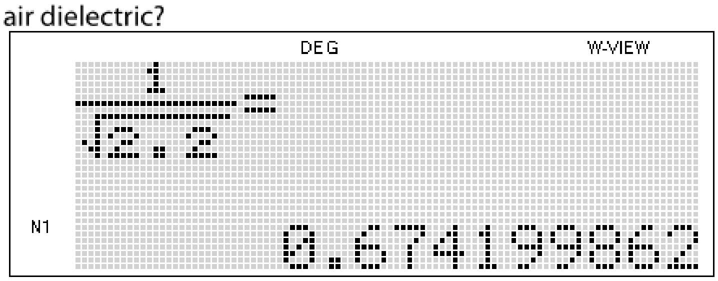
2mW → ▷ (20) → 40mW

3 dB → ▷ (13 dB) → 16dBm

− ▷ − ▷ −6 —

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?

$VF = \frac{1}{\sqrt{\epsilon_r}} =$



$\frac{m/s}{m} = 1/s$

490 ns

$0.67 \times 3\times10^8$

$v = VF \cdot c$

$t = \frac{d}{v} = \frac{100}{3\times10^8 \cdot 0.66} = \frac{1\times10^2}{2\times10^8} = 0.5\times10^{-6}$

$= 500\,ns.$

for air $\epsilon_r = 1$ VF = 1

$$t = \frac{100}{3\times10^8} = 0.3\times10^{-6} \simeq 300ns$$

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

$\lambda = 1.3\times10\ \mu m$

$f =$

$v =$

assume glass $\epsilon_r = 4$

$$VF = \frac{1}{\sqrt{4}} = \frac{1}{2}$$

$\therefore v = 1.5\times10^8$ m/s.

$v = \lambda \cdot f \quad \left(m \cdot \frac{1}{s}\right)$

$10^9 = G$

$$f = \frac{v}{\lambda} = \frac{1.5\times10^8}{1.3\times10^{-6}} \approx 1\times10^{14} = 100\times10^{12}$$

$10^{12} = T$

100 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?

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

$P = 1W$

$G_T = G_R = 20$ dB

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

$$2 = \log\left(\frac{P_1}{P_2}\right)$$

$f = 3\times10^9 \qquad d = 300$

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{3\times10^9} = 0.1m$$

$$G_R = G_T = \frac{P_1}{P_2} = 10^2 = \underline{100}$$

$$P_R = 1\times100\times100\left(\frac{0.1}{4\pi\cdot300}\right)^2 \approx 10^4\left(\frac{1\times10^{-1}}{3\times10^3}\right)^2$$

$$\approx 10^4\times\frac{1}{9}\times10^{-8} \approx 1\times10^{-5} \approx 10\mu W$$

1×10^{-5}

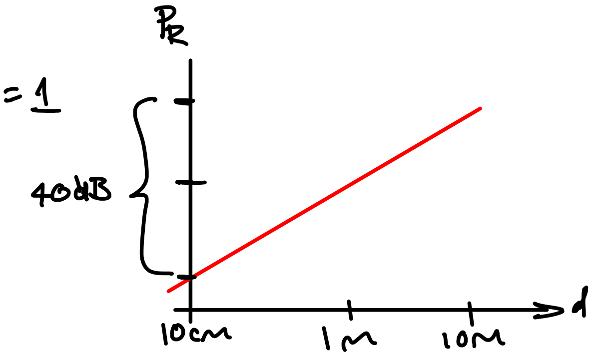
10×10^{-5}

Bluetooth example

frequency $f = 2.4 \times 10^9$

assume P_T = 50mW (17dBm)

assume $G_T G_R = 1$



assume range varies from

10cm → 10m

distance ratio is 100x → 10^4 → 40dB ← ratio of received power levels

d ratio → P_R ratio

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 thickness	interference
twisted pair (UTP)	$	$	thinner	L → M
co-ax	$$	$$	thicker	M
fiber	$$$	$$$	125μm (small)	H
free space	0 (¢)	$$$$	?	L