(7.1) Cables designed to carry a low-frequency signal with minimum pickup of interference often consist of a twisted pair of conductors surrounded by a grounded shield. Why the twist? Why the shield?

The twist reduces nearfield coupling two ways. It makes it easier to maintain a small distance between the wires, minimizing pickup loop area. Additionally, each half twist "flips the sign" of the interference, cancelling out the effects of interference that is constant over the cable length (for at least a full twist length).

The shield reflects EM radiation and acts as a faraday cage. It can also protect against ESD events by shunting the energy to ground.

(7.2) Salt water has a conductivity ~ 4 S/m. What is the skin depth at 10^4 Hz?

$$\delta = 1/\sqrt{\pi v \mu \sigma}$$

$$\delta = 1/\sqrt{\pi(10^4 Hz)(\mu_0 * 1)(4\,S/m)}$$

$$\delta \approx 2.5m$$

(7.3) Integrate Poynting's vector P~ = E~ × H~ to find the power flowing across a crosssectional slice of a coaxial cable, and relate the answer to the current and voltage in the cable.

$$E = Q/2\pi\epsilon r$$

$$H = \frac{I}{2\pi r}$$

$$P = \frac{QI}{(2\pi r)^2 \epsilon}$$

$$\int_{r_i}^{r_o} \frac{QI}{(2\pi r)^2 \epsilon}\,(2\pi r\,dr)$$

$$\int_{r_i}^{r_o} \frac{QI}{2\pi r \epsilon}\,dr$$

$$W = \frac{QI}{2\pi\epsilon} \ln\left(\frac{r_0}{r_i}\right)$$

$$W = I\frac{(V/\mathcal{C})}{2\pi\epsilon}\ln\left(\frac{r_0}{r_i}\right) = I\frac{\left(V/\frac{2\pi\epsilon_0\epsilon}{\ln\, r_0/r_i}\right)}{2\pi\epsilon}\ln\left(\frac{r_0}{r_i}\right) = IV$$

(7.5) The most common coaxial cable, RG58/U, has a dielectric with a relative permittivity of 2.26, an inner radius of 0.406 mm, and an outer radius of 1.48 mm.

(a) What is the characteristic impedance?

$\mathcal{L} = \frac{\mu_0}{2\pi}\ln\frac{r_0}{r_i}$

$\mathcal{C} = \frac{2\pi\epsilon_0\epsilon}{\ln\, r_0/r_i}$

$Z = \sqrt{\mathcal{L}/\mathcal{C}} = \frac{1}{2\pi}\ln\frac{r_0}{r_i}\sqrt{\mu_0/\epsilon_0\epsilon} \approx \frac{377\Omega}{2\pi}\ln\frac{r_0}{r_i}\sqrt{1/\epsilon} \approx 51.6\Omega$

(b) What is the transmission velocity?

$v = \frac{1}{\sqrt{\mathcal{LC}}} = 1/\sqrt{\left(\frac{\mu_0}{2\pi}\ln\frac{r_0}{r_i}\right)\left(\frac{2\pi\epsilon_0\epsilon}{\ln\frac{r_0}{r_i}}\right)} = 1/\sqrt{\mu_0\epsilon_0\epsilon} \approx 2E^8 m/s$

(c) If a computer has a clock speed of 1 ns, how long can a length of RG58/U be and still deliver a pulse within one clock cycle?

0.2 meters

(d) It is often desirable to use thinner coaxial cable to minimize size or weight but still match the impedance of RG58/U (to minimize reflections). If such a cable has an outer diameter of 30 mils (a mil is a thousandth of an inch), what is the inner diameter?

$$\frac{1.48}{.406} = \frac{30}{r}$$

$$r = 8.23\, mil$$

(e) For RG58/U, at what frequency does the wavelength become comparable to the diameter?

$$\lambda = fv$$

$$1.48mm = f(2E^8 m/s)$$

$$f = 134GHz$$

(7.6) Consider a 10 Mbit/s ethernet signal traveling in a RG58/U cable.

(a) What is the physical length of a bit?

$\left(2E^{8}\frac{m}{s}\right)$ / $(10MHz) = 20m$

(b) Now consider what would happen if a “T” connector was used to connect one ethernet coaxial cable to two other ones. Estimate the reflection coefficient for a signal arriving at the T.

The 50Ω source impedence would mismatch into an effective 25Ω Load impedance, assuming the double terminated load is otherwise matched.

$$R = \frac{25\Omega - 50\Omega}{25\Omega + 50\Omega} = -\frac{1}{3}$$