7.1

Twisted pairs are useful for minimizing incoming and outgoing radiated EM noise to/from a signal carrying wire.

Current flowing out the V+ wire and back in the V- wire will generate a magnetic field with opposite curls, according to the right hand rule. If we could place these wires directly co-axial or within one another, these fields would cancel each other, and twisted pairs are a less expensive means to get a similar effect.

Similarly if an external changing magnetic field is applied to a twisted pair, because the wires are in close alternating contact, this magnetic field will have a more or less equal effect on both, and therefore not change the potential between them.

Shielding is used to create essentially a faraday cage around our wires, thereby minimizing the effects of electric fields. Because in static conditions, the electric field (and therefore potential) inside a conductor must be zero, which is to say that free electrons inside the conductor will generate an equal and opposite electric field to oppose an external one.

7.2 salt water:

using 7.33 : $\delta = \dfrac{1}{(\pi \nu \mu \sigma)^{1/2}}$

where:
$\nu$ = frequency
$\mu$ = permability
$\sigma$ = conductivity

at $10^4$ Hz

$$\delta_{sw} = \frac{1}{(\pi \cdot 10^4 \cdot 1.3e\text{-}6 \cdot 4)^{1/2}} = 2.5\,m$$

compared to copper

$$\delta_{cu} = (\pi \cdot 10^4 \cdot 1.2e^{-6} \cdot 58.7)^{-1/2} = 0.672\ m$$

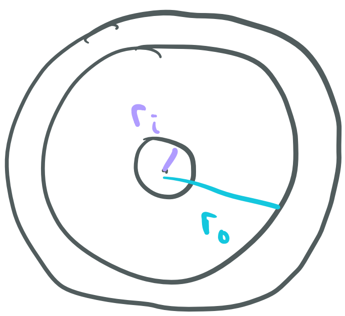
doesn't matter much at low frequencies

(7.3) $P = E \times H$

$$\|\vec{H}\| = \frac{I}{2\pi r} \qquad \|\vec{E}\| = \frac{Q}{2\pi \epsilon r}$$

$$\|\vec{P}\| = \|\vec{H}\| \cdot \|\vec{E}\| \sin(\theta)$$

$$\|P\| = IQ / 4\pi^2 r^2 \epsilon$$




we will integrate radially + around 360 deg

$$P = \int_0^{2\pi} \int_{r_i}^{r_o} \|\vec{P}\| \cdot r \cdot dr \cdot d\theta$$

$$P = \frac{IQ}{4\pi^2 \epsilon} \int_0^{2\pi} \int_{r_i}^{r_o} r^{-1} \, dr \, d\theta$$

$\int x^{-1} = \ln\left(\left|\frac{1}{x}\right|\right)$

$$= \frac{IQ}{2\pi \epsilon} \int_{r_i}^{r_o} r^{-1} \, dr$$

$$= \frac{IQ}{2\pi \epsilon} \left( \ln \frac{1}{r_o} - \ln\left(\frac{1}{r_i}\right) \right)$$

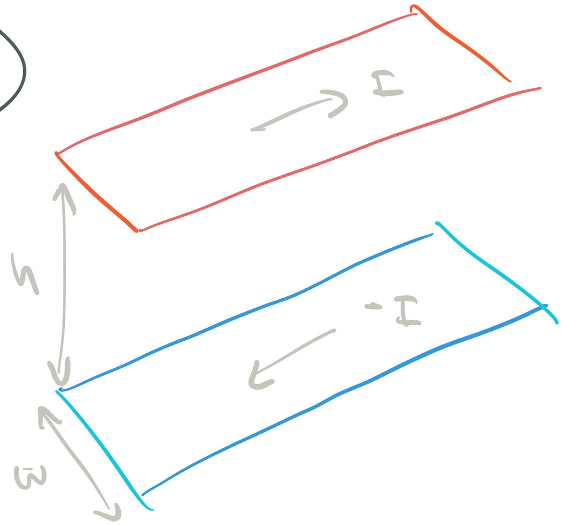
$$\Downarrow$$

$$= \frac{IQ}{2\pi \epsilon} \cdot \ln\left(\frac{r_i}{r_o}\right)$$

defined as $V$ in (7.45)

$\therefore = VI$

7.4




Find Impedance, ignore fringing

L = inductance / unit length

C = capacitance / unit length

$$Z = \sqrt{\frac{L}{C}}$$ "characteristic impedance"

$$v = \frac{1}{\sqrt{LC}}$$ "signal velocity"

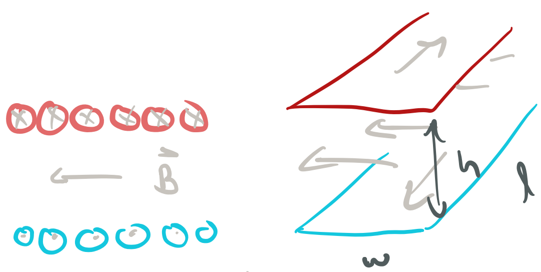
so we need to solve for L & C

$$C = \frac{\varepsilon w \cdot l}{h}$$

This is essentially a parallel plate capacitor, so from last week

Now L

find B field similar to solenoid from last week

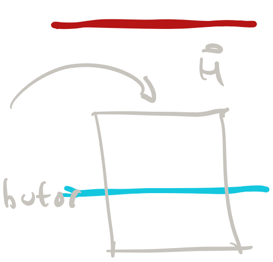



similar

$$\oint \vec{H}\cdot d\vec{l} = \int_A^B \vec{H}\cdot d\vec{l} + \int_B^C \overset{0}{\cancel{\vec{H}\cdot d\vec{l}}} + \int_C^D \overset{0}{\cancel{\vec{H}\cdot d\vec{l}}} + \int_D^A \overset{0}{\cancel{\vec{H}\cdot d\vec{l}}}$$

$$= H \cdot w$$

using stokes again




only contributor

$$\int_S \nabla\times\vec{H}\cdot d\vec{A} = \int_S \vec{J}\cdot d\vec{A} = I$$

curl of H field is current $\vec{J}$

$$Hw = I$$

$$H = \frac{I}{w}$$

$$B = \frac{I\mu_0}{w}$$

$$L = \frac{\Phi}{I} \quad \text{where} \quad \Phi = \int B \cdot dA \quad \text{so} \quad \Phi = \frac{I \mu_0}{w} h \cdot l$$

$$\text{so} \quad L = \frac{\cancel{I} \mu_0 h \cdot l}{w \cancel{I}} = \frac{\mu_0 h}{w} l$$

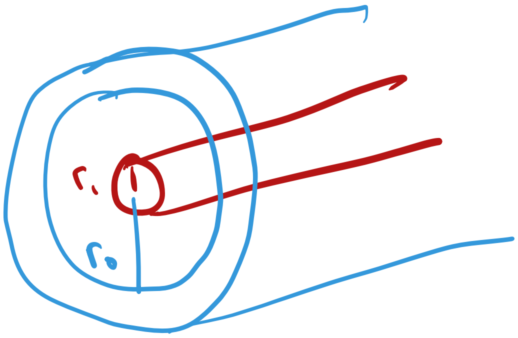
defined as per unit length so we will drop $l$ here & in $C$

$$v = \left( \frac{\mu_0 \cancel{h}}{\cancel{w}} \cdot \frac{\varepsilon \cancel{w}}{\cancel{h}} \right)^{-1/2}$$

$$\therefore \quad v = \frac{1}{\sqrt{\mu_0 \varepsilon}} \quad \& \quad Z = \sqrt{\frac{L}{C}} = \left( \frac{\mu_0 h}{w} \cdot \frac{h}{\varepsilon w} \right)^{1/2}$$

$$Z = \left( \frac{\mu_0 h^2}{\varepsilon w^2} \right)^{1/2}$$

7.5




RG58/U

$r_i = 0.406$ mm

$r_o = 1.48$ mm

$\epsilon = 2.26$

a. $$Z = \sqrt{L/C}$$

for coax $$L = \frac{\mu_0}{2\pi} \ln\left(\frac{r_o}{r_i}\right)$$ (7.43)

$$C = \frac{2\pi \underbrace{\epsilon_0}_{\text{free space}} \cdot \underbrace{\epsilon_r}_{\text{relative}}}{\ln(r_o/r_i)}$$ (7.46)

$Z = 51.6\ \Omega$ (wolfram)

b. $$V = \frac{1}{\sqrt{LC}} = 2 \cdot 10^8 \text{ m/s}$$ (where light is $3 \cdot 10^8$ m/s)

c. 1ns clock speed.

$$d = v \cdot t = 2 \cdot 10^8 \cdot 10^{-9} = 0.2 \text{ m}$$

d. we resolve impedance for $r_i$ where $Z = 51.6$

$r_i = 0.202$ mm & $r_o = 0.742$ mm

e. $$V = \frac{c}{\lambda} = \frac{2 \cdot 10^8}{2(1.48\text{mm})(10^{-3})} = 67.6 \text{ GHz}$$

7.6 CAT 6 $Z = 100\ \Omega$

- twisted pair prop. delay = 4.6 ns/m

a. $v = \frac{1}{4.6 \cdot 10^{-9}}$ m/s

assuming clockspeed is 1ns/bit

64 bytes $\cdot$ 8bits/byte = 512 bits

@ $\frac{1\text{ns}}{\text{bit}}$ we take 512 ns

& travel $\frac{512}{4.6} = 111$ m

b. reflection coefficient

$$R = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (7.66)$$

$Z_L$ would be the impedance of the two cables forming the T, so $\frac{1}{1/100 + 1/100} = 50\ \Omega$

$$\therefore R = \frac{50 - 100}{50 + 100} = -\frac{1}{3}$$