19. ELECTROMAGNETIC RELATIONS

19.1. Impedances (SI units)

ρ = resistivity at room temperature in $10^{-8}\,\Omega$ m:

$\sim$ 1.7 for Cu	$\sim$ 5.5 for W
$\sim$ 2.4 for Au	$\sim$ 73 for SS 304
$\sim$ 2.8 for Al	$\sim$ 100 for Nichrome

(Al alloys may have double the Al value.)

For alternating currents, instantaneous current I, voltage V, angular frequency ω:

$$V = V_0\, e^{j\omega t} = ZI \ . \tag{19.1}$$

Impedance of self-inductance L: $Z = j\omega L$.

Impedance of capacitance C: $Z = 1/j\omega C$.

Impedance of free space: $Z = \sqrt{\mu_0/\epsilon_0} = 376.7\ \ \Omega$.

Impedance per unit length of a flat conductor of width w (high frequency, ν):

$$Z = \frac{(1+j)\ \rho}{w\,\delta} \ , \qquad \text{where } \delta = \text{effective skin depth} \ ; \tag{19.2}$$

$$\delta = \sqrt{\frac{\rho}{\pi\nu\mu}} \approx \frac{6.6 \text{ cm}}{\sqrt{\nu\,(\text{Hz})}} \quad \text{for Cu} \ . \tag{19.3}$$

19.2. Capacitance $\widehat{C}$ and inductance $\widehat{L}$ per unit length (SI units)

Flat rectangular plates of width w, separated by $d \ll w$:

$$\widehat{C} = \epsilon\, \frac{w}{d} \ ; \qquad \widehat{L} = \mu\, \frac{d}{w} \ ; \tag{19.4}$$

$$\frac{\epsilon}{\epsilon_0} = 2 \text{ to } 6 \text{ for plastics; } 4 \text{ to } 8 \text{ for porcelain, glasses.} \tag{19.5}$$

Coaxial cable of inner radius r_1, outer radius r_2:

$$\widehat{C} = \frac{2\pi\ \epsilon}{\ln\ (r_2/r_1)} \ ; \qquad \widehat{L} = \frac{\mu}{2\pi}\ \ln\ (r_2/r_1) \ . \tag{19.6}$$

Transmission lines (no loss):

$$\text{Impedance: } Z = \sqrt{\widehat{L}/\widehat{C}} \ . \tag{19.7}$$

$$\text{Velocity: } v = 1/\sqrt{\widehat{L}\,\widehat{C}} = 1/\sqrt{\mu\,\epsilon} \ . \tag{19.8}$$

See the full *Review of Particle Properties* for Maxwell's Equations and for further discussion.