

Chapter 1: Introduction: Waves and Phasors

Lesson #1

Chapter — Section: Chapter 1

Topics: EM history and how it relates to other fields

Highlights:

- EM in Classical era: 1000 BC to 1900
- Examples of Modern Era Technology timelines
- Concept of “fields” (gravitational, electric, magnetic)
- Static vs. dynamic fields
- The EM Spectrum

Special Illustrations:

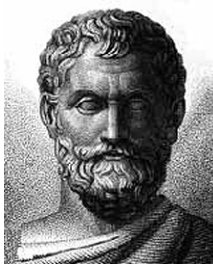
- Timelines from CD-ROM

Timeline for Electromagnetics in the Classical Era

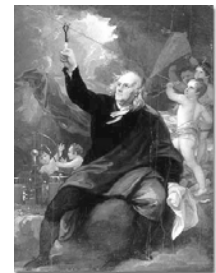
ca. 900 BC Legend has it that while walking across a field in northern Greece, a shepherd named Magnus experiences a pull on the iron nails in his sandals by the black rock he was standing on. The region was later named **Magnesia** and the rock became known as **magnetite** [a form of iron with permanent magnetism].

ca. 600 BC Greek philosopher **Thales** describes how amber, after being rubbed with cat fur, can pick up feathers [static electricity].

ca. 1000 Magnetic compass used as a navigational device.



1752 **Benjamin Franklin** (American) invents the **lightning rod** and demonstrates that lightning is electricity.



1785 **Charles-Augustin de Coulomb** (French) demonstrates that the **electrical force** between charges is proportional to the inverse of the square of the distance between them.

1800 **Alessandro Volta** (Italian) develops the first **electric battery**.



1820 **Hans Christian Oersted** (Danish) demonstrates the **interconnection** between electricity and magnetism through his discovery that an electric current in a wire causes a compass needle to orient itself perpendicular to the wire.

Lessons #2 and 3

Chapter — Sections: 1-1 to 1-6

Topics: Waves

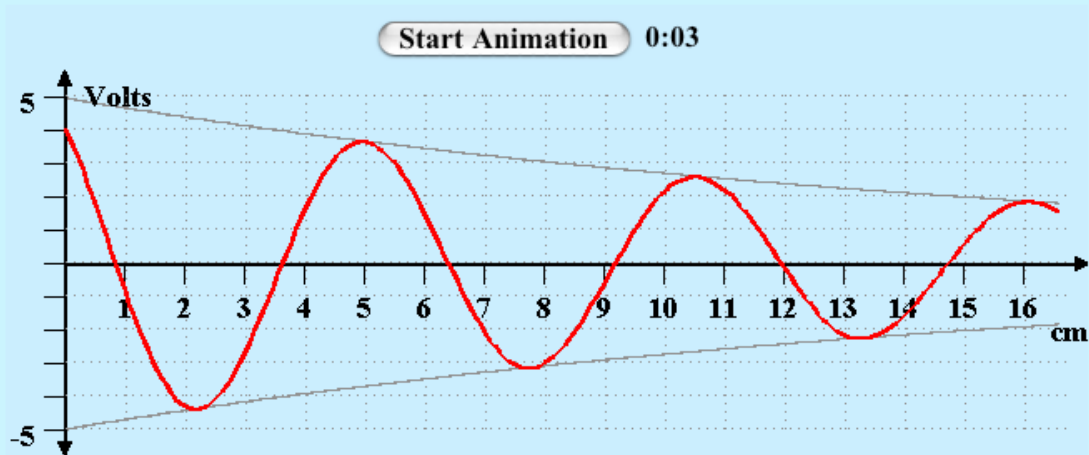
Highlights:

- Wave properties
- Complex numbers
- Phasors

Special Illustrations:

- CD-ROM Modules 1.1-1.9
- CD-ROM Demos 1.1-1.3

Module 1.6: Red Wave in a Lossy Medium



Q1. What is the wave amplitude?

$A =$ V

Q2. What is the wave frequency? [Use the digital clock to estimate it]

$f =$ Hz

Q3. What is the wavelength?

Solution:

(a)

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{50 + j100 - 100}{50 + j100 + 100} = \frac{-50 + j100}{150 + j100} = 0.62e^{j82.9^\circ}.$$

The time average power dissipated in the load is:

$$\begin{aligned} P_{av} &= \frac{1}{2} \tilde{I}_L^2 R_L \\ &= \frac{1}{2} \left| \frac{\tilde{V}_L}{Z_L} \right|^2 R_L \\ &= \frac{1}{2} \frac{\tilde{V}_L^2}{Z_L^2} R_L = \frac{1}{2} \times 12^2 \times \frac{50}{50^2 + 100^2} = 0.29 \text{ W} \end{aligned}$$

(b)

$$P_{av} = P_{av}^i (1 - |\Gamma|^2)$$

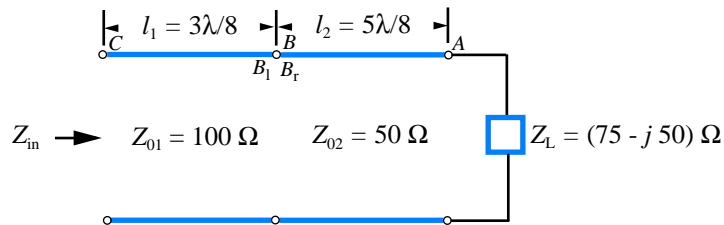
Hence,

$$P_{av}^i = \frac{P_{av}}{1 - |\Gamma|^2} = \frac{0.29}{1 - 0.62^2} = 0.47 \text{ W}$$

(c)

$$P_{av}^r = -|\Gamma|^2 P_{av}^i = -(0.62)^2 \times 0.47 = -0.18 \text{ W}$$

Problem 2.63



Use the Smith chart to determine the input impedance Z_{in} of the two-line configuration shown in the figure.

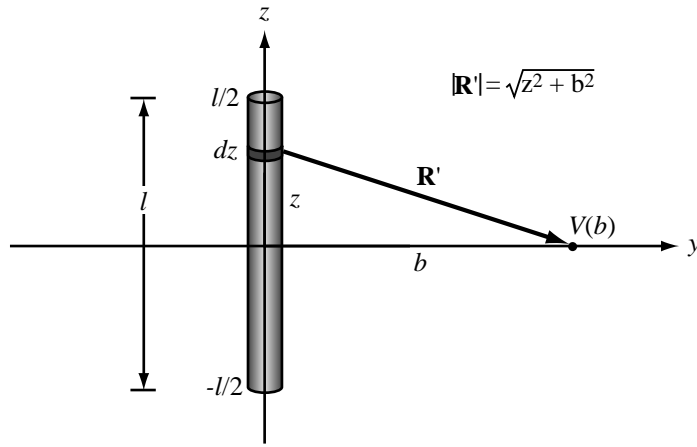


Figure P4.31: Line of charge of length ℓ .

Solution: From Eq. (4.48c), we can find the voltage at a distance b away from a line of charge [Fig. P4.31]:

$$V(b) = \frac{1}{4\pi\epsilon} \int_{-l/2}^{l/2} \frac{\rho_l}{R'} dz = \frac{\rho_l}{4\pi\epsilon} \int_{-l/2}^{l/2} \frac{dz}{\sqrt{z^2 + b^2}} = \frac{\rho_l}{4\pi\epsilon} \ln \left(\frac{l + \sqrt{l^2 + 4b^2}}{-l + \sqrt{l^2 + 4b^2}} \right).$$

Problem 4.32 For the electric dipole shown in Fig. 4-13, $d = 1$ cm and $|\mathbf{E}| = 4$ (mV/m) at $R = 1$ m and $\theta = 0^\circ$. Find \mathbf{E} at $R = 2$ m and $\theta = 90^\circ$.

Solution: For $R = 1$ m and $\theta = 0^\circ$, $|\mathbf{E}| = 4$ mV/m, we can solve for q using Eq. (4.56):

$$\mathbf{E} = \frac{qd}{4\pi\epsilon_0 R^3} (\hat{\mathbf{R}} 2 \cos \theta + \hat{\boldsymbol{\theta}} \sin \theta).$$

Hence,

$$|\mathbf{E}| = \left(\frac{qd}{4\pi\epsilon_0} \right) 2 = 4 \text{ mV/m} \quad \text{at } \theta = 0^\circ,$$

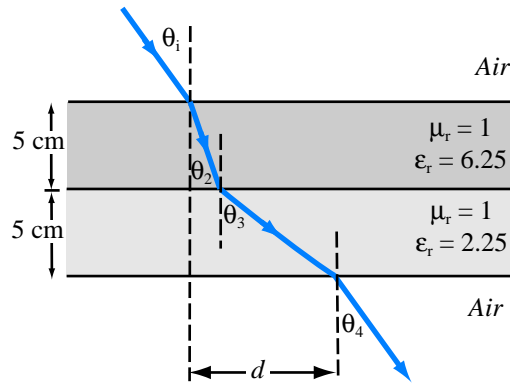
$$q = \frac{10^{-3} \times 8\pi\epsilon_0}{d} = \frac{10^{-3} \times 8\pi\epsilon_0}{10^{-2}} = 0.8\pi\epsilon_0 \quad (\text{C}).$$

Again using Eq. (4.56) to find \mathbf{E} at $R = 2$ m and $\theta = 90^\circ$, we have

$$\mathbf{E} = \frac{0.8\pi\epsilon_0 \times 10^{-2}}{4\pi\epsilon_0 \times 2^3} (\hat{\mathbf{R}}(0) + \hat{\boldsymbol{\theta}}) = \hat{\boldsymbol{\theta}} \frac{1}{4} \quad (\text{mV/m}).$$

Problem 8.46 A parallel-polarized plane wave is incident from air at an angle $\theta_i = 30^\circ$ onto a pair of dielectric layers as shown in the figure.

- (a) Determine the angles of transmission θ_2 , θ_3 , and θ_4 .
 (b) Determine the lateral distance d .



Solution:

- (a) Application of Snell's law of refraction given by (8.31) leads to:

$$\sin \theta_2 = \sin \theta_i \sqrt{\frac{\epsilon_{r1}}{\epsilon_{r2}}} = \sin 30^\circ \sqrt{\frac{1}{6.25}} = 0.2$$

$$\theta_2 = 11.54^\circ.$$

Similarly,

$$\sin \theta_3 = \sin \theta_2 \sqrt{\frac{\epsilon_{r2}}{\epsilon_{r3}}} = \sin 11.54^\circ \sqrt{\frac{6.25}{2.25}} = 0.33$$

$$\theta_3 = 19.48^\circ.$$

And,

$$\sin \theta_4 = \sin \theta_3 \sqrt{\frac{\epsilon_{r3}}{\epsilon_{r4}}} = \sin 19.48^\circ \sqrt{\frac{2.25}{1}} = 0.5$$

$$\theta_4 = 30^\circ.$$

As expected, the exit ray back into air will be at the same angle as θ_i .

At $f = 12$ GHz, $\lambda = c/f = 3 \times 10^8 / 12 \times 10^9 = 2.5 \times 10^{-2}$ m. With $\xi_t = \xi_r = 1$,

$$G_t = D_t = \frac{4\pi A_t}{\lambda^2} = \frac{4\pi(\pi d_t^2/4)}{\lambda^2} = \frac{4\pi \times \pi \times 1}{4 \times (2.5 \times 10^{-2})^2} = 15,791.37,$$

$$G_r = D_r = \frac{4\pi A_r}{\lambda^2} = \frac{4\pi(\pi d_r^2/4)}{\lambda^2} = \frac{4\pi \times \pi (0.2)^2}{4 \times (2.5 \times 10^{-2})^2} = 631.65.$$

Applying Eq. (10.11) with $\Upsilon(\theta) = 1$ gives:

$$S_n = \frac{P_t G_t G_r}{k T_{\text{sys}} B} \left(\frac{\lambda}{4\pi R} \right)^2 = \frac{10^3 \times 15,791.37 \times 631.65}{1.38 \times 10^{-23} \times 10^3 \times 6 \times 10^6} \left(\frac{2.5 \times 10^{-2}}{4\pi \times 4 \times 10^7} \right)^2 = 298.$$

Sections 10-5 to 10-8: Radar Sensors

Problem 10.5 A collision avoidance automotive radar is designed to detect the presence of vehicles up to a range of 0.5 km. What is the maximum usable PRF?

Solution: From Eq. (10.14),

$$f_p = \frac{c}{2R_u} = \frac{3 \times 10^8}{2 \times 0.5 \times 10^3} = 3 \times 10^5 \text{ Hz.}$$

Problem 10.6 A 10-GHz weather radar uses a 15-cm-diameter lossless antenna. At a distance of 1 km, what are the dimensions of the volume resolvable by the radar if the pulse length is 1 μ s?

Solution: Resolvable volume has dimensions Δx , Δy , and ΔR .

$$\Delta x = \Delta y = \beta R = \frac{\lambda}{d} R = \frac{3 \times 10^{-2}}{0.15} \times 10^3 = 200 \text{ m,}$$

$$\Delta R = \frac{c\tau}{2} = \frac{3 \times 10^8}{2} \times 10^{-6} = 150 \text{ m.}$$

Problem 10.7 A radar system is characterized by the following parameters: $P_t = 1$ kW, $\tau = 0.1$ μ s, $G = 30$ dB, $\lambda = 3$ cm, and $T_{\text{sys}} = 1,500$ K. The radar cross section of a car is typically 5 m². How far can the car be and remain detectable by the radar with a minimum signal-to-noise ratio of 13 dB?