Chapter 21: Plane Wave Shielding

21.1 Why does insulating material not generally act as a good shield to plane waves? What if the insulator has a very large permeability? At high frequencies, it is stated that most materials act like dielectrics in terms of their reflective properties. Determine whether this is true.

21.2 In reference to the impedance of a wave discussion, explain in simpler terms why the "*R* term" is not included in the wave impedance equation? Under what circumstances would this term be included?

21.3 The intrinsic impedance of a good conductor was given in this chapter as

$$\eta \approx \sqrt{\frac{\omega\mu}{2\sigma}}\left[\left(1+\frac{\omega\varepsilon}{2\sigma}\right)+j\left(1-\frac{\omega\varepsilon}{2\sigma}\right)\right]$$

Provide a better approximation for the intrinsic impedance of a good conductor. Compare the two approximations for copper at 1 GHz. Then, assuming that the electric field transmitted through a specific medium can be roughly described by the equation

$$E_t = \left(2\sigma - \omega\varepsilon\right)^{-2}$$

determine three different approximations for this equation if the medium is a good conductor. The approximations should not contain any terms of the form $\left(a+b\right)^c$ where *a*, *b*, and *c* are any real or imaginary nonzero numbers or variables.

21.4 The intrinsic impedance of a good insulator was given in this chapter as

$$\eta \approx \sqrt{\frac{\mu}{\varepsilon}}\left(1+j\frac{\sigma}{2\omega\varepsilon}\right)$$

Provide a better approximation for the intrinsic impedance of a good insulator. Then compare the two approximations for Bakelite at 10 kHz. Repeat the second part of the question given in Problem 21.3 (dealing with E_t) assuming that the medium is a good insulator instead of a good conductor.

21.5 Discuss the differences between an ideal insulator, a good insulator, a poor insulator, a poor conductor, a good conductor, an ideal conductor, a perfect dielectric, a good dielectric, and a poor dielectric. (A good dielectric is not necessarily a good insulator.)

21.6C Plot the real part, imaginary part, and magnitude of the intrinsic impedance on the same set of axes for medium dry ground from 10 kHz to 100 GHz. At what frequency is the conduction current equal to the displacement current? Over what frequencies is this ground a good conductor?

21.7C Plot the real part, imaginary part, and magnitude of the intrinsic impedance on the same set of axes for wet ground from 10 kHz to 100 GHz. At what frequency is the conduction current equal to the displacement current? Over what frequencies is this ground a good conductor?

21.8 Sketch the power field for a lossless open-air twin-lead line and coaxial cable. Do these results seem reasonable?

21.9 Qualitatively compare the strengths of the electric and magnetic field components of a lossless twin-lead line with a lossy twin-lead line. [Moore, '60]

21.10 If the maximum power that a small transmitter can produce is 100 mW, what is the maximum possible electric field and power density 5 m from the device? State all assumptions.

21.11 Completely setup all the necessary equations (in the frequency domain), which includes the boundary conditions, to determine the electric and magnetic fields everywhere for a flat shield of thickness d (the left side of the shield is located in the $x = 0$ plane and the shield's thickness is not necessarily electrically small). The electric field is polarized in the z direction. The incident field is traveling in the $-x$ direction as shown in Figure 1. The intrinsic impedance of the shield is η and the corresponding propagation constant is γ. Free space surrounds both sides of the shield with a free space impedance of η_o and propagation constant of $\gamma = j\beta_o$. Do not solve for the electric or magnetic fields in these equations. Use the subscript notation given in the figure.

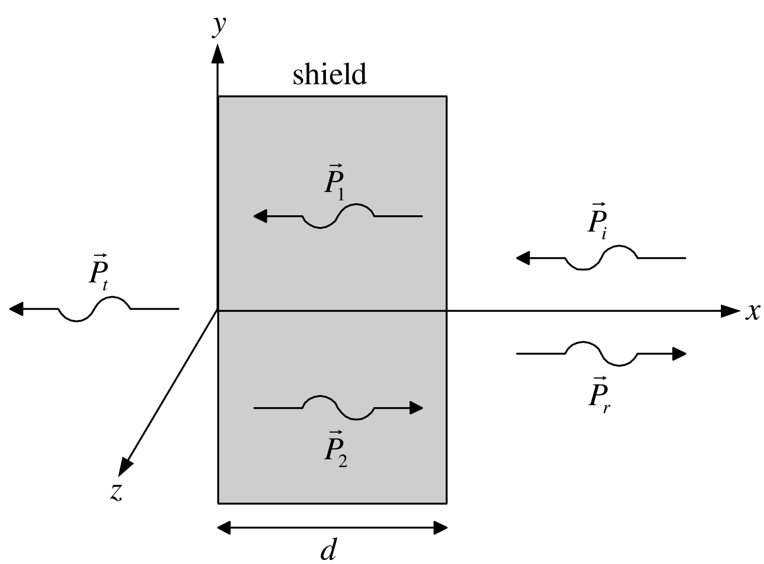

Figure 1

21.12 Completely setup all the necessary equations (in the frequency domain) to determine the electric and magnetic fields everywhere for a flat shield of thickness d, conductivity σ, permeability μ, and free-space permittivity. In direct contact with the shield is a one-sided insulating coating of thickness Δ and relative permittivity ε_r. Do not solve for the electric or magnetic fields in these equations. (Do not use the material contained in the *Additional Shielding Concepts chapter* to solve this problem. Solve this problem using the boundary condition approach as in this chapter.)

21.13EC Design a realistic coating for a thick flat copper object so that less than 1% of a 30 GHz incident signal is reflected from the coated metallic object. Provide one application of this coating.

21.14EC It is stated that two equal thickness layers of a metallic material provide greater shielding to plane waves when separated than when in direct contact. Use a numerical package and reasonable parameters to determine when and whether this is possibly true. Assume that each layer of the metal is several skin depths thick. (Do not use the material contained in the *Additional Shielding Concepts chapter* to solve this problem. Solve this problem using the boundary condition approach as in this chapter.)

21.15EC Repeat Problem 21.14 but assume that the layers are much less than one skin depth thick.

21.16C Using the approximate expression for the magnitude of the electric field transmitted through a thick conducting shield,

$$|E_{ts}| = 4|E_{is}|e^{-\frac{d}{\delta}}\sqrt{\frac{\omega\varepsilon_o}{\sigma}} \quad \text{where } \delta = \frac{1}{\sqrt{\pi f \mu_o \sigma}}$$

plot from 10 kHz to 1 GHz the difference between this approximation and the exact expression for a copper shield of δ, 3δ, and 5δ thickness.

21.17 Determine an approximate expression for the electric field transmitted through a three-layer flat shield, surrounded by air. Each good-conducting layer is several skin depths thick, and they are in direct contact. The conductivity and thickness of each layer are different. The incident electric field is E_i.

21.18 For a plane wave normally incident to a highly conducting thick shield, the shield acts like a “short” to the electric fields tangential to the shield. This is analogous to zero voltage across a short circuit. By deriving the expressions for the total electric and magnetic fields for a normally incident plane wave (in free space) to a “highly magnetic” (i.e., very large permeability) flat thick shield, show that the tangential magnetic fields to the shield are “shorted” or small. This is analogous to zero current across an open circuit. Why are shields that act like a “short” to electric fields at their surface much more physically realizable than shields that act like an “open” to magnetic fields at their surface?

21.19C The skin depth for good conductors was given in this chapter as

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

Provide a better approximation for the skin depth of a good conductor. For copper, plot on the same graph the skin depth of copper from 100 Hz to 1 GHz using both the standard expression and the better approximation. Also, plot the percent difference between the two equations over this same frequency range.

21.20 In this chapter the real part of the propagation constant, α, was derived starting from

$$\gamma = \alpha + j\beta = \sqrt{j\omega\mu\left(\sigma + j\omega\varepsilon\right)}$$

Derive the general expression for the imaginary part of the propagation constant, β. Determine a nontrivial approximation for the phase constant for good conductors and good insulators.

21.21 At what frequency is the free-space wavelength of a signal greater than the signal's skin depth in any material? Determine this frequency for copper, very dry ground, and wet ground. If a plane wave is incident to a curved surface, should the radius of curvature be much greater than the skin depth or the free-space wavelength so that the surface appears flat? [Lo]

21.22 Determine the Poynting vector and the real and average power for the following set of electric and magnetic fields:

a.)
$$\vec{E}_s = \left(2xj + y\right)\hat{a}_x + \left(z - 2y\right)\hat{a}_y + \left(xy - z^3\right)\hat{a}_z$$
$$\vec{H}_s = \left(xyz\right)\hat{a}_x + j\left(x + 3z\right)\hat{a}_y + \left(2y^2\right)\hat{a}_z$$

b)
$$\vec{E}_s = \left(\frac{j}{r} - \frac{1}{r^3}\right)\hat{a}_r + \left(\frac{1}{r\theta}\right)\hat{a}_\theta$$
$$\vec{H}_s = \left(\frac{1}{r} + \frac{2j}{r^2} - \frac{j}{r^3}\right)\hat{a}_\theta + \left(\frac{1}{r^2} + \frac{j}{r^3}\right)\hat{a}_\phi$$

21.23 Determine the conductivity of Bakelite at 100 Hz. Is this material a good or poor insulator at this frequency?

21.24S In reference to the skin depth for several good conductors discussion, using external sources, verify that each of the applications given for each of the conductor types (e.g., copper, brass, aluminum, etc.) are reasonable.

21.25 Determine the necessary thickness of body muscle at a frequency of 27 MHz to absorb plane waves. The electrical properties of the muscle at this frequency are

$$\varepsilon = \varepsilon_o\left(\varepsilon' - j\varepsilon''\right),\ \varepsilon' = 160,\ \varepsilon'' = 1{,}100$$

Determine the reflection loss. Compare these results to body fat. [Gandhi, '90]

21.26 Determine the necessary thickness of body muscle at a frequency of 2.45 GHz to absorb plane waves. The electrical properties of the muscle at this frequency are

$$\varepsilon = \varepsilon_o\left(\varepsilon' - j\varepsilon''\right),\ \varepsilon' = 47,\ \varepsilon'' = 16$$

Determine the reflection loss. Compare these results to body fat. [Gandhi, '90]

21.27 Name a material that is a poor conductor at low frequencies and a poor or good insulator at high frequencies. Define "low" and "high" frequencies.

21.28 Name a material that has a very high dielectric constant from the kHz to GHz range.

21.29 Name a material that is a good insulator from the kHz to GHz range.

21.30 Verify that the complex Poynting vector for a magnetic dipole in the far field is

$$\bar{P}_s = 36{,}700 I_m^2 \left(\frac{a^2}{\lambda_o^2} \right)^2 \frac{\sin^2\theta}{r^2} \hat{a}_r$$

where a is the radius of the loop carrying a current of I_m. Then, compare the real power of a Hertzian dipole to the real power of a magnetic dipole in the far field. Assume that the length of the dipole is equal to the circumference of the loop. When is the real power for the *Hertzian* dipole greater than the real power from the *magnetic* dipole? Is this result reasonable?

21.31 Compare the real and reactive power at the near-far field transition point for a Hertzian dipole.

21.32 Compare the real and reactive power at the near-far field transition point for a magnetic dipole.

21.33 What happens when the aperture far-field approximation is used for wire antenna less than a wavelength in dimension?

21.34 For a Hertzian and magnetic dipole, which electric and magnetic field components dominate very near to the antenna? Why do these results seem reasonable?

21.35EC For a dipole of total length $\lambda/8$, $\lambda/4$, and $\lambda/2$, plot all of the components (in the spherical coordinate system) of the electric and magnetic fields versus distance from the dipole for various positions around the dipole. Determine a near-field transition approximation and far-field approximation from these plots, and compare these to the approximations provided in this chapter. (One possible definition for this transition point is where the equivalent wave impedance is about 377 Ω.) The complete expressions for the electric and magnetic fields for a dipole located along the z axis (and centered at the origin) with a sinusoidal current distribution are

$$E_{ys} = j30 I_o \left[\frac{(z - l_{th})}{y} \frac{e^{-j\beta R_1}}{R_1} + \frac{(z + l_{th})}{y} \frac{e^{-j\beta R_2}}{R_2} - \frac{2z\cos(\beta l_{th})}{y} \frac{e^{-j\beta r}}{r} \right]$$

$$E_{zs} = -j30 I_o \left[\frac{e^{-j\beta R_1}}{R_1} + \frac{e^{-j\beta R_2}}{R_2} - 2\cos(\beta l_{th}) \frac{e^{-j\beta r}}{r} \right]$$

$$H_{\phi s} = \frac{j30 I_o}{\eta_o y} \left[e^{-j\beta R_1} + e^{-j\beta R_2} - 2\cos(\beta l_{th}) e^{-j\beta r} \right]$$

where $\beta = 2\pi/\lambda$, r is the distance between the center of the dipole (i.e., the origin) and the field point of interest, R_1 is the distance between the top of the dipole ($z = +l_{th}$) and the field point of interest, and R_2 is the distance between the bottom of the dipole ($z = -l_{th}$) and the field point of interest. These expressions were derived assuming symmetry in the ϕ direction (ϕ was set to 90°). [Jordan]

21.36 Analytically (not numerically) show that in the far field of the dipole given in Problem 21.35 that

$$R_1 \approx r - l_{th}\cos\theta,\ \ R_2 \approx r + l_{th}\cos\theta$$

To obtain the far-field expressions, why are these approximations necessary for the phase terms (i.e., those involving complex exponentials) while the approximations

$$r \approx R_1 \approx R_2$$

are adequate for the nonphase terms? Then, analytically determine whether the complete expressions for the electric and magnetic field for a dipole (given in Problem 21.35) are equivalent to the standard expressions for the electric and magnetic fields in the far field:

$$E_{\theta s} = j\sqrt{\frac{\mu}{\varepsilon}} I_o \frac{e^{-j\beta r}}{2\pi r} \frac{\cos\left[(\beta l_{th})\cos\theta\right] - \cos(\beta l_{th})}{\sin\theta},\ \ H_{\phi s} = \frac{E_{\theta s}}{\eta_o}$$

21.37 A music amplifier is susceptible to a low-power, near-field, AM broadcast station. How close can the amplifier be operated to this station and still be outside its near field?