Chapter 23: Magnetic Field Shielding

23.1 Using the Biot-Savart law, verify the magnetic field expression *X* (provided by your instructor) given in the current distributions and their magnetic fields table in this chapter.

23.2 Using the integral definition for the magnetic vector potential, completely setup (but do not solve) the integral(s) to determine the magnetic vector potential for the current distribution *Y* (provided by your instructor) given in the current distribution and their magnetic fields table in this chapter.

23.3 Determine the magnetic vector potential using the vector Poisson's equation for the following current distributions:

a) infinite slab of volume current $\vec{J} = Jz\hat{a}_y$ of thickness *d* parallel to and centered about the *xy* plane

b) infinite slab of volume current $\vec{J} = Je^z\hat{a}_y$ of thickness *d* parallel to and centered about the *xy* plane

c) infinitely long cylinder of volume current $\vec{J} = J\hat{a}_z$ of radius *a* centered about the *z* axis

d) infinitely long cylinder of volume current $\vec{J} = \left(J/\rho\right)\hat{a}_z$ of radius *a* centered about the *z* axis.

Determine the magnetic flux density using this vector potential.

23.4 The current distribution for multiple concentric cylindrical conducting (nonmagnetic) shells follows. Using Ampère's law, completely set up the integrals to determine the magnetic field everywhere. Evaluate all dot products. Assume, as in this chapter, that the axes of the cylinders are along the *z* axis and the shells are insulated from each other. The variables *A*, *I*, and δ are independent of position.

a) $$\begin{cases} 0 \le \rho < a & I \text{ in the } +z \text{ direction} \\ a < \rho < b & \text{free space} \\ b < \rho < c & I/2 \text{ in the } -z \text{ direction} \\ c < \rho & \text{free space} \end{cases}$$

b) $$\begin{cases} 0 \le \rho < a & J_z = Ae^{-\frac{(\rho-a)}{\delta}} \\ a < \rho < b & \text{free space} \\ b < \rho < c & I \text{ in the } -z \text{ direction} \\ c < \rho & \text{free space} \end{cases}$$

c) $\begin{cases} 0 \le \rho < a & \text{free space} \\ a < \rho < b & I \text{ in the } +z \text{ direction} \\ b < \rho < c & \text{free space} \\ c < \rho < d & J_z = -Ae^{-\frac{(\rho - c)}{\delta}} \\ d < \rho & \text{free space} \end{cases}$

d) $\begin{cases} 0 \le \rho < a & I \text{ in the } +z \text{ direction} \\ a < \rho < b & J_z = -Ae^{-\frac{(b - \rho)}{\delta}} \\ b < \rho < c & \text{free space} \\ c < \rho < d & I/3 \text{ in the } +z \text{ direction} \\ d < \rho & \text{free space} \end{cases}$

23.5 A flat interface between two linear magnetic materials exists in the *xz* plane. A surface current of $K_o\hat{a}_x$ exists along the interface. For $y > 0$ near the interface,

$$\vec{H}_3 = -4\hat{a}_x + 2\hat{a}_y + 3\hat{a}_z \quad y > 0 \quad \text{where } \mu_r = 3$$

Determine both $\vec{H}_2$ and $\vec{B}_2$ for $y < 0$ near the interface where $\mu_r = 2$.

23.6 A flat interface between two linear magnetic materials exists in the *yz* plane. A surface current of $K_o\hat{a}_y$ exists along the interface. For $x < 0$ near the interface,

$$\vec{B}_4 = 4\hat{a}_x - 2\hat{a}_y + 3\hat{a}_z \quad x < 0 \quad \text{where } \mu_r = 4$$

Determine both $\vec{H}_5$ and $\vec{B}_5$ for $x > 0$ near the interface where $\mu_r = 5$.

23.7 A flat interface between two dielectrics is described by the surface $\phi = \pi/4$ in the cylindrical coordinate system. A surface current of $K_o\hat{a}_z$ exists along the interface. For $\phi > \pi/4$ near the interface,

$$\vec{B}_4 = -2\hat{a}_\rho + 4\hat{a}_\phi + 3\hat{a}_z \quad \phi > \frac{\pi}{4} \quad \text{where } \mu_r = 4$$

Determine both $\vec{H}_2$ and $\vec{B}_2$ for $\phi < \pi/4$ near the interface where $\mu_r = 2$.

23.8 A curved interface between two linear magnetic materials is described by the surface $\rho = 2$ in the cylindrical coordinate system. A surface current of $K_o\hat{a}_\phi$ exists along the interface. For $\rho < 2$ near the interface,

$$\vec{B}_3 = 4\hat{a}_\rho - 2\hat{a}_\phi - 5\hat{a}_z \quad \rho < 2 \quad \text{where } \mu_r = 3$$

Determine both $\vec{H}_4$ and $\vec{B}_4$ for $\rho > 2$ near the interface where $\mu_r = 4$.

23.9 A curved interface between two linear magnetic materials is described by the surface $r = 3$ in the spherical coordinate system. A surface current of $K_o\hat{a}_\theta$ exists along the interface. For $r > 3$ near the interface,

$$\vec{H}_2 = 4\hat{a}_r - 2\hat{a}_\theta - 5\hat{a}_\phi \quad r > 3 \quad \text{where } \mu_r = 2$$

Determine both $\vec{H}_4$ and $\vec{B}_4$ for $r < 3$ near the interface where $\mu_r = 4$.

23.10 A curved interface between two linear magnetic materials is described by the surface $\theta = \pi/3$ in the spherical coordinate system. A surface current of $K_o\hat{a}_\phi$ exists along the interface. For $\theta < \pi/3$ near the interface,

$$\vec{H}_3 = -3\hat{a}_r + 4\hat{a}_\theta - 5\hat{a}_\phi \quad \theta < \frac{\pi}{3} \quad \text{where } \mu_r = 3$$

Determine both $\vec{H}_2$ and $\vec{B}_2$ for $\theta > \pi/3$ near the interface where $\mu_r = 2$.

23.11 A flat interface between two linear magnetic materials exists in the *xy* plane described by the equation $y = -2x + 3$. No surface current exists along this curved interface. For $y > -2x + 3$ near the interface,

$$\vec{H}_2 = -4\hat{a}_x + 2\hat{a}_y - 3\hat{a}_z \quad y > -2x + 3 \quad \text{where } \mu_r = 2$$

Determine both $\vec{H}_5$ and $\vec{B}_5$ for $y < -2x + 3$ near the interface where $\mu_r = 5$.

23.12S Power is inductively transferred to a vehicle by using a pair of parallel conductors, carrying equal but oppositely directed currents, which are buried slightly below the surface. Assume that the amplitude of the current in each conductor ranges from 50 to 100 A rms, and the center-to-center distance between the conductors is 0.15 m. If the frequency is around 20 to 25 kHz, estimate the magnitude of the magnetic field directly between the conductors along the surface. Is this field level "safe?" Provide a copy of the specific reference used to determine this magnetic field exposure limit.

23.13C As in this chapter for the three-phase collinear system, plot the amplitude of the *x* and *y* components of the three-phase symmetrical line distribution shown in Figure 1 at a distance of $4d$ in all directions around the origin. Let $d = 4.12$ mm and $I = 10$ A. Then, also as in this chapter, plot the maximum and minimum possible magnitudes of the flux density in mG along the *x* and *y* axis. Compare these results to the collinear three phase system. Assume that the three conductors are parallel to the *z* axis and long compared to their spacing. The conductors are centered about the origin and equally spaced.

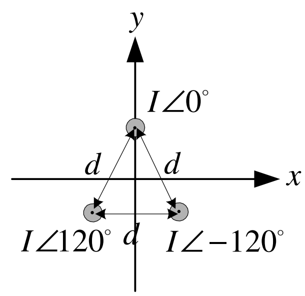

Figure 1

23.14 If a high-frequency plane wave hits (i.e., incident to) a human body, does the electric or magnetic field penetrate the body and potentially interact with any organs?

23.15 Can stray magnetic fields from a motor pass through the motor housing? Explain using the appropriate equations in this chapter.

23.16C Select a magnetic material for a body suit to "protect" a cosmetologist against magnetic fields from a hairdryer if 0.1 μT rms of field is acceptable. Assume the external magnetic field near the hairdryer is 10 μT rms at 60 Hz. Determine the thickness of the body suit. The body suit material should not saturate.

23.17 The magnetic field inside the cavity of a magnetic spherical shell of inner radius *b*, outer radius *a*, and relative permeability μ_r when placed in a uniform magnetic field of strength H_e is

$$H_i = \frac{9\mu_r}{9\mu_r - 2(\mu_r - 1)^2\left(\frac{b^3}{a^3} - 1\right)} H_e$$

Determine an approximation for this equation when the thickness is small (but not zero) and the relative permeability is not necessarily large.

23.18 The magnetic field inside the cavity of a magnetic cylindrical shell of inner radius *b*, outer radius *a*, and relative permeability μ_r when placed in a uniform magnetic field of strength H_e at right angle to it is

$$H_i = \frac{4\mu_r}{4\mu_r - (\mu_r - 1)^2\left(\frac{b^2}{a^2} - 1\right)} H_e$$

Determine an approximation for this equation when the thickness is small (but not zero) and the relative permeability is not necessarily large.

23.19 An approximation sometimes seen for the magnetic cylindrical shell equation given in Problem 23.18 is

$$H_i \approx \frac{2a}{\mu_r \Delta} H_e$$

Derive this expression and determine its range of usefulness.

23.20 For magnetic cylindrical shells, if $Q = \omega L / R$, will the shielding effectiveness increase or decrease as the Q of the shell increases? Explain from a circuit's perspective.

23.21 The general relationship between the internal and external magnetic fields parallel to the axis of a magnetic thin-walled cylinder of relative permeability μ_r, propagation constant γ, thickness Δ, and radius a (much greater than Δ) is

$$\frac{H_i(\omega)}{H_e(\omega)} = \frac{1}{\cosh(\gamma\Delta) + \frac{\gamma a}{2\mu_r}\sinh(\gamma\Delta)}$$

Starting with this expression, verify the low-frequency and high-frequency expressions given in this chapter. [Cooley]

23.22 The general relationship between the internal and external magnetic fields transverse to the axis of a magnetic thin-walled cylinder of relative permeability μ_r, propagation constant γ, thickness Δ, and radius a (much greater than Δ) is

$$\frac{H_i(\omega)}{H_e(\omega)} = \frac{1}{\cosh(\gamma\Delta) + \frac{1}{2}\left(\frac{\gamma a}{\mu_r} + \frac{\mu_r}{\gamma a}\right)\sinh(\gamma\Delta)}$$

Starting with this expression, verify the low-frequency and high-frequency expressions given in this chapter. [Hasselgren]

23.23 Determine the permeability, conductivity, and thickness of body suit around a individual using an electric drill if 0.1 mT of field is acceptable. Assume the external magnetic field near the drill is 2.5 mT at 60 Hz.

23.24 Would you expect the magnetic flux density near a hair dryer to increase, decrease, or remain the same when the "high-heat" button is depressed? Explain.

23.25 The density requirements for a circuit dictates that a solenoid must be close to a sensitive component. What low-cost method is available to reduce the magnetic field coupling between the solenoid and component?

23.26C The average 60 Hz magnetic field from a refrigerator's motor is 2.6 mG at 10.5". At a distance of 24" the field drops to 1.1 mG. At a distance of 48" the field drops to 0.4 mG. At what rate is this field decreasing? Explain this behavior.

23.27C The magnetic flux density along the axis of a cylindrical magnet uniformly magnetized along the axis of the magnet is

$$B_z = \frac{B_{is}}{2}\left[\frac{\frac{L}{2} - z}{\sqrt{\left(z - \frac{L}{2}\right)^2 + r_m^2}} + \frac{\frac{L}{2} + z}{\sqrt{\left(z + \frac{L}{2}\right)^2 + r_m^2}}\right]$$

where B_{is} is the magnitude of the saturation induction, L is the total length of the magnet, and r_m is the radius of the magnet. Show that the field varies as $1/z^3$ far from the magnet. The magnet is along the z axis centered about $z = 0$. Why does the field not vary as $1/z$ far from the magnet? For a 1" long magnet with a diameter of 3/16", magnetized to a saturation level of 1.25 T, plot on the same set of axes the flux density for $0 < z < 10L$ using both previous expression and the as $1/z^3$ approximation and compare the results. The previous equation compares well with measurements at distances greater than L from the face of the magnet and for large length-to-diameter ratios. [Watson; Lai]

23.28 Is a good magnetic field shield usually a good electric field shield? Is the converse true?

23.29 The picture tube of a TV is being interfered with by nearby speaker magnets. Prove one no cost solution and one low-cost solution to remedy this problem.

23.30 How effective is the water surrounding a self-contained, battery-operated air pump in a fish tank in reducing the magnetic and electric fields generated by the pump? Can the water actually increase the magnetic fields?