8-5. Short electric dipole antenna. (a) Using [7.18a] along with $\beta = \omega\sqrt{\mu_0\epsilon_0}$ and $\eta = \sqrt{\mu_0/\epsilon_0} \simeq 120\pi\Omega$, the magnetic field $\mathbf{H}(r, \theta)$ can be found as

$$\begin{aligned}
\mathbf{H}(r,\theta) &= -\frac{1}{j\omega\mu_0}\nabla \times \mathbf{E}(r,\theta) = -\frac{1}{j\omega\mu_0}\nabla \times [\hat{\boldsymbol{\theta}}E_\theta(r,\theta)] \\
&= -\frac{1}{j\omega\mu_0}\left\{\hat{\boldsymbol{\phi}}\frac{1}{r}\frac{\partial}{\partial r}[rE_\theta(r,\theta)]\right\} = \hat{\boldsymbol{\phi}}\frac{j30\beta I_0 l \sin\theta(-j\beta)e^{-j\beta r}}{-j\omega\mu_0 r} \\
&= \hat{\boldsymbol{\phi}} j\frac{\beta I_0 l}{4\pi r}\sin\theta e^{-j\beta r}
\end{aligned}$$

(b) The time-average Poynting vector can be found as

$$\mathbf{S}_{\text{av}} = \frac{1}{2}\Re e\{\mathbf{E} \times \mathbf{H}^*\} = \hat{\mathbf{r}}\frac{30\beta^2 I_0^2 l^2}{4\pi r^2}\sin^2\theta$$

where we used $\hat{\boldsymbol{\theta}} \times \hat{\boldsymbol{\phi}} = \hat{\mathbf{r}}$ and $(e^{-j\beta r})^* = e^{j\beta r}$.

(c) The total power radiated by the dipole source is given by

$$\begin{aligned}
P_{\text{total}} &= \oint_S \mathbf{S}_{\text{av}} \cdot d\mathbf{s} = \int_0^{2\pi}\int_0^{\pi} \frac{30\beta^2 I_0^2 l^2}{4\pi r^2}\sin^2\theta\hat{\mathbf{r}} \cdot \hat{\mathbf{r}} r^2 \sin\theta d\theta d\phi \\
&= \frac{30\beta^2 I_0^2 l^2}{4\pi}(2\pi)\int_0^{\pi} \sin^3\theta d\theta \\
&= (15\beta^2 I_0^2 l^2)\int_0^{\pi}(-\sin^2\theta)d(\cos\theta) \\
&= (15\beta^2 I_0^2 l^2)\int_0^{\pi}(\cos^2\theta - 1)d(\cos\theta) \\
&= (15\beta^2 I_0^2 l^2)\left[\frac{\cos^3\theta}{3} - \cos\theta\right]_0^{\pi} = 20\beta^2 I_0^2 l^2
\end{aligned}$$

8-7. VHF TV signal. We start with

$$\overline{\mathcal{H}} = \hat{\mathbf{z}}\, H_0 \sin(\omega t - ax - ay + \pi/3)$$

(a) Since the signal propagates in air, we must have $E_0 = \eta_{\text{air}} H_0$ and the wave power density is $E_0^2/(2\eta_{\text{air}}) = \eta_{\text{air}} H_0^2/2$, which gives $H_0 = \sqrt{2 \times 10 \times 10^{-6}/377} \simeq 0.23$ mA-m^{-1}. To determine a, we can find $\overline{\mathcal{E}}$ from the given $\overline{\mathcal{H}}$ using [7.18c] and then use the $\overline{\mathcal{E}}$ so found to find $\overline{\mathcal{H}}$ from [7.18a]. Using [7.18c] we have

$$\frac{\partial(\epsilon_0 \overline{\mathcal{E}})}{\partial t} = \nabla \times \overline{\mathcal{H}} = \hat{\mathbf{x}} \left[-aH_0 \cos(\omega t - ax - ay + \pi/3)\right] + \hat{\mathbf{y}} \left[aH_0 \cos(\omega t - ax - ay + \pi/3)\right]$$

$$\rightarrow \quad \overline{\mathcal{E}} = \hat{\mathbf{x}} \left[\frac{-aH_0}{\epsilon_0 \omega} \sin(\omega t - ax - ay + \pi/3)\right] + \hat{\mathbf{y}} \left[\frac{aH_0}{\epsilon_0 \omega} \sin(\omega t - ax - ay + \pi/3)\right]$$

Now we use [7.18a] to find $\overline{\mathcal{H}}$ back

$$\frac{\partial(\mu_0 \overline{\mathcal{H}})}{\partial t} = -\nabla \times \overline{\mathcal{E}} = \hat{\mathbf{z}} \left[\frac{-a^2 H_0}{\omega \epsilon_0} \cos(\omega t - ax - ay + \pi/3) - \frac{a^2 H_0}{\omega \epsilon_0} \cos(\omega t - ax - ay + \pi/3)\right]$$

$$\rightarrow \quad \overline{\mathcal{H}} = \left[\frac{a^2 H_0}{\mu_0 \epsilon_0 \omega^2} \sin(\omega t - ax - ay + \pi/3) + \frac{a^2 H_0}{\mu_0 \epsilon_0 \omega^2} \sin(\omega t - ax - ay + \pi/3)\right]$$

$$\overline{\mathcal{H}} = \hat{\mathbf{z}} \left[\frac{2a^2 H_0}{\mu_0 \epsilon_0 \omega^2}\right] \sin(\omega t - ax - ay + \pi/3)$$

In order for this magnetic field to be identical to the original one we must have

$$\frac{2a^2 H_0}{\mu_0 \epsilon_0 \omega^2} = H_0 \quad \rightarrow a^2 = \frac{\omega^2}{2c^2} \quad \rightarrow \quad a = \pm \frac{\omega}{c\sqrt{2}} \simeq \pm \frac{2\pi(200 \times 10^6)}{\sqrt{2}(3 \times 10^8)} \simeq \pm 2.96$$

We arbitrarily choose the positive value of $a \simeq 2.96$ rad-m^{-1}.

(b) The electric field was already found in part (a). We have

$$\overline{\mathcal{E}} = \left[\frac{aH_0}{\epsilon_0 \omega} \sin(\omega t - ax - ay + \pi/3)\right] (-\hat{\mathbf{x}} + \hat{\mathbf{y}})$$

$$\overline{\mathcal{E}}(x, y, t) \simeq 61.3[-\hat{\mathbf{x}} + \hat{\mathbf{y}}] \sin(\omega t - 2.96x - 2.96y + \pi/3) \ \text{mV-m}^{-1}$$

(c) The antenna essentially measures the projection of the electric field upon its wire. Thus we have

(i)	from $\overline{\mathcal{E}} \cdot \hat{\mathbf{x}}$	$\mathcal{E}_{\max} \simeq 61.3$ mV-m^{-1}
(ii)	from $\overline{\mathcal{E}} \cdot \hat{\mathbf{y}}$	$\mathcal{E}_{\max} \simeq 61.3$ mV-m^{-1}
(iii)	from $\overline{\mathcal{E}} \cdot \left[\frac{(\hat{\mathbf{x}} - \hat{\mathbf{y}})}{\sqrt{2}}\right]$	$\mathcal{E}_{\max} = 0$

8-10. Propagation through wet versus dry earth. (a) For wet earth with properties $\sigma_{\text{wet}} = 0.01$ S-m^{-1}, $\epsilon_{\text{wet}} = 10\epsilon_0$ and $\mu_{\text{wet}} = \mu_0$, the loss tangent can be calculated as

$$\tan\delta_{c_{\text{wet}}} = \frac{\sigma_{\text{wet}}}{\omega\epsilon_{\text{wet}}} \simeq \frac{0.01}{2\pi(20\times10^6)10(8.85\times10^{-12})} \simeq 0.899$$

Using [8.19], [8.20], and [8.22], the attenuation constant α, the phase constant β and the intrinsic impedance η can be evaluated as

$$\alpha \simeq 2\pi(20\times10^6)\frac{\sqrt{10}}{\sqrt{2}(3\times10^8)}\left[\sqrt{1+(0.899)^2}-1\right]^{1/2} \simeq 0.550 \text{ np-m}^{-1}$$

$$\beta \simeq 2\pi(20\times10^6)\frac{\sqrt{10}}{\sqrt{2}(3\times10^8)}\left[\sqrt{1+(0.899)^2}+1\right]^{1/2} \simeq 1.434 \text{ rad-m}^{-1}$$

$$\eta \simeq \frac{\frac{377}{\sqrt{10}}}{\left[1+(0.899)^2\right]^{1/4}} e^{j\frac{1}{2}\tan^{-1}(0.899)} \simeq 102.8e^{j21.0^\circ}\ \Omega$$

>From the above values, the wavelength λ, the phase velocity v_p and the penetration depth d are found as

$$\lambda = \frac{2\pi}{\beta} \simeq \frac{2\pi}{1.434} \simeq 4.38 \text{ m}$$

$$v_p = f\lambda \simeq (20\times10^6)(4.38) \simeq 8.76\times10^7 \text{ m-s}^{-1}$$

$$d = \alpha^{-1} \simeq (0.550)^{-1} \simeq 1.82 \text{ m}$$

(b) For dry earth with properties $\sigma_{\text{dry}} = 10^{-4}$ S-m^{-1}, $\epsilon_{\text{dry}} = 3\epsilon_0$ and $\mu_{\text{dry}} = \mu_0$, the loss tangent is found as

$$\tan\delta_{c_{\text{dry}}} = \frac{\sigma_{\text{dry}}}{\omega\epsilon_{\text{dry}}} = \frac{10^{-4}}{2\pi(20\times10^6)3(8.85\times10^{-12})} \simeq 0.0300 \ll 1$$

Since $\tan\delta_{c_{\text{dry}}} \ll 1$, dry earth is assumed to be a low-loss medium. Using the approximate expressions, α, β and η can be calculated as

$$\alpha \simeq \frac{\sigma_{\text{dry}}}{2}\sqrt{\frac{\mu_{\text{dry}}}{\epsilon_{\text{dry}}}} \simeq \frac{10^{-4}}{2}\frac{377}{\sqrt{3}} \simeq 0.0109 \text{ np-m}^{-1}$$

$$\beta \simeq \omega\sqrt{\mu_{\text{dry}}\epsilon_{\text{dry}}} \simeq \frac{2\pi(20\times10^6)\sqrt{3}}{3\times10^8} \simeq 0.726 \text{ rad-m}^{-1}$$

$$\eta \simeq \sqrt{\frac{\mu_{\text{dry}}}{\epsilon_{\text{dry}}}}\left(1 + j\frac{\sigma_{\text{dry}}}{2\omega\epsilon_{\text{dry}}}\right) \simeq \frac{377}{\sqrt{3}}\left(1 + j\frac{0.03}{2}\right) \simeq 218e^{j0.858^\circ}\ \Omega$$

Using these values, λ, v_p and d is computed as

$$\lambda = \frac{2\pi}{\beta} \simeq \frac{2\pi}{0.726} \simeq 8.66 \text{ m}$$

$$v_p = f\lambda \simeq (20 \times 10^6)(8.66) \simeq 1.73 \times 10^8 \text{ m-s}^{-1}$$

$$d = \alpha^{-1} \simeq 0.0109^{-1} \simeq 92 \text{ m}$$

The results in parts (a) and (b) indicate that a uniform plane wave propagating in wet earth experiences a much higher attenuation rate (i.e., a much smaller penetration depth), travels with a lower velocity, has a smaller wavelength and an intrinsic impedance with smaller magnitude in comparison to the same plane wave propagating in dry earth.

8-17. Communication in seawater. (a) For ELF frequencies ($f \leq 3$ kHz), sea water ($\sigma = 4$ S-m^{-1}, $\epsilon_r = 81$, and $\mu_r = 1$) is a good conductor since loss tangent

$$\tan\delta_c = \frac{\sigma}{\omega\epsilon_r\epsilon_0} = \frac{4}{(2\pi f)(81 \times 8.85 \times 10^{-12})} \simeq \frac{8.88 \times 10^8}{f} \ll 1$$

To find the ELF frequency which results in a skin depth of 80 m, we have

$$\delta = \frac{1}{\sqrt{\pi f \mu_0 \sigma}} = \frac{1}{\sqrt{f}\sqrt{\pi(4\pi \times 10^{-7})(4)}} \simeq \frac{251.6}{\sqrt{f(\text{Hz})}} = 80 \text{ m}$$

from which we solve for the frequency $f \simeq 9.89$ Hz.

(b) Using the skin depth expression found in part (a), we have

$$\delta \simeq \frac{251.6}{\sqrt{f(\text{Hz})}} = \frac{1}{2}(80) = 40 \text{ m}$$

from which the frequency $f \simeq 39.6$ Hz.

(c) The amplitude of the electric field at a depth z in sea water below the surface can be written as

$$E_0 e^{-\alpha z}$$

(where $z = 0$ is the sea surface and the z axis points downward into the sea) and its dB value is

$$20\log(E_0 e^{-\alpha z}) = 20\log E_0 + 20\log e^{-\alpha z}$$

where the last term represents the dB attenuation over a distance of z traveled by the signal. Equating the dB attenuation term to -40 dB, we have

$$20 \log e^{-\alpha z} = -40 \text{ dB}$$

where the attenuation constant α at 100 Hz can be found from part (a) as

$$\alpha = \delta^{-1} \simeq \frac{\sqrt{f(\text{Hz})}}{251.6} = \frac{\sqrt{100}}{251.6} \simeq 0.0397 \text{ np-m}^{-1}$$

we solve for the depth z as

$$z = -\frac{1}{\alpha} \ln 10^{-40/(20)} \simeq -\frac{1}{0.0397} \ln(0.01) \simeq 116 \text{ m}$$

(d) At 1 kHz, the amplitude of the electric field at the maximum depth z_{max} below the sea surface beyond which the submerged vehicle which can measure signals with peak values as low as 1 μV-m^{-1} can not communicate with the surface vehicle is given by

$$1e^{-\alpha z_{\text{max}}} = 10^{-6} \text{ V-m}^{-1}$$

where α at 1 kHz can be found from part (a) to be

$$\alpha = \delta^{-1} \simeq \frac{\sqrt{1000}}{251.6} \simeq 0.126 \text{ np-m}^{-1}$$

Using this α value in the amplitude expression yields

$$z_{\text{max}} \simeq -\frac{1}{\alpha} \ln(10^{-6}) \simeq -\frac{1}{0.126} \ln(10^{-6}) \simeq 110 \text{ m}$$

8-23. Aluminum foil. The loss tangent of aluminum ($\sigma = 3.54 \times 10^7$ S-m^{-1}, $\epsilon_r = \mu_r = 1$) at 100 MHz is

$$\tan \delta_c = \frac{\sigma}{\omega \epsilon_r \epsilon_0} = \frac{3.54 \times 10^7}{2\pi(10^8)(8.85 \times 10^{-12})} \simeq 6.36 \times 10^9 \gg 1$$

Since aluminum is a good conductor, the attenuation constant at 100 MHz can be calculated as

$$\alpha = \sqrt{\frac{\omega\mu\sigma}{2}} = \sqrt{\frac{2\pi(10^8)(4\pi \times 10^{-7})(3.54 \times 10^7)}{2}} \simeq 1.18 \times 10^5 \text{ np-m}^{-1}$$

Using the value of α, the dB attenuation experienced by a plane wave at 100 MHz traveling through an aluminum foil of thickness $d \simeq 25$ μm can be evaluated as

$$20 \log e^{-\alpha d} \simeq 20 \log e^{-(1.18 \times 10^5)(25 \times 10^{-6})} \simeq -25.7 \text{ dB}$$

8-26. Laser beams. We start with

$$\mathscr{E}_r = E_0 e^{-r^2/\omega^2}\cos(\omega t - \beta z)$$

(a) Since the wave is propagating in the $\hat{\mathbf{z}}$ direction, and $\overline{\mathscr{E}}$ is in the $\hat{\mathbf{r}}$ direction, the wave magnetic field must be in the $\hat{\boldsymbol{\phi}}$ direction, since in cylindrical coordinates $(\hat{\mathbf{r}} \times \hat{\boldsymbol{\phi}}) = \hat{\mathbf{z}}$. Note that this is true only approximately, since the given electric field cannot be the only nonzero component of the electric field, since otherwise its divergence is not zero (i.e., it is an r component, varying with r). We thus have

$$\mathscr{H}_\phi = \frac{1}{\eta}\mathscr{E}_r = \frac{E-0}{r}e^{-r^2/\omega^2}\cos(\omega t - \beta z)$$

(b) The power density of the laser beam, assuming it to be a uniform plane wave, is

$$\overline{\mathscr{S}} = \hat{\mathbf{r}}\mathscr{E}_r \times \hat{\boldsymbol{\phi}}\mathscr{H}_\phi = \hat{\mathbf{z}}\frac{E_0^2}{\eta}e^{-2r^2/\omega^2}\cos^2(\omega t - \beta z)$$

The time-average power is

$$\mathbf{S}_{\text{av}} = \hat{\mathbf{z}}\frac{E_0^2}{2\eta}e^{-2r^2/\omega^2}$$

(c) To find the total power we can integrate over the circular cross-section of the beam:

$$P_{\text{total}} = \int_0^\infty \frac{E_0^2}{2\eta}e^{-2r^2/\omega^2}2\pi r dr = \frac{E_0^2(2\pi)}{2\eta}\left[\frac{-\omega^2 e^{-2r^2/\omega^2}}{4}\right]_0^\infty$$

$$P_{\text{total}} = \frac{E_0^2(2\pi)}{2\eta}\frac{\omega 62}{4} = \frac{E_0^2\pi\omega^2}{4\eta}$$

$$5\times 10^{-3} = \frac{E_0^2\pi(400\times 10^{-6})^2}{4\eta} \quad \rightarrow \quad E_0 \simeq 3.87 \text{ kV-m}^{-1}$$

$$\rightarrow \quad |\mathbf{S}_{\text{av}}(r=0)| = \frac{E_0^2}{2\eta} \simeq 20 \text{ kW-m}^{-2}$$

(d) The power density falls off with radius as $(4\pi r)^{-2}$. We have

$$|\mathbf{S}_{\text{av}}(r)| = \frac{P_{\text{total}}}{4\pi r^2}$$

where P_{total} is the total electromagnetic power radiated by the sun, which can be found from

$$\frac{P_{\text{total}}}{4\pi R_{\text{SE}}^2} = 1400 \quad \rightarrow \quad P_{\text{total}} = 4\pi R_{\text{SE}}^2(1400)$$

where $R - \text{SE}$ is the sun-earth distance. The distance r from the sun at which the power density would equal that of the laser beam is defined by the relation

$$20 \times 10^3 = \frac{4\pi R_{\text{SE}}^2(1400)}{4\pi r^2} \quad \rightarrow \quad r \simeq 0.265 R_{\text{SE}}$$

(e) The average power of this laser is

$$P_{\text{av}} = \frac{\Delta E}{\Delta t} = \frac{10.2 \times 10^3}{0.2 \times 10^{-9}} \simeq 5.1 \times 10^{13} \text{ W}$$

The corresponding peak electric field can be found from

$$5.1 \times 10^{13} = \frac{E_0^2 \pi \omega^2}{4\eta} \quad \rightarrow \quad E_0 = 6.25 \times 10^{11} \text{ V-m}^{-1} \gg 3 \times 10^6 \text{ V-m}^{-1}$$

Thus, the field is definitely intense enough to break down air.

(f) Radiation pressure can be simply thought of as the power density of the wave incident on a surface at the speed of light, namely

$$\text{Radiation Pressure} = \frac{|\mathbf{S}_{\text{av}}|}{c} = \frac{E_0^2}{2\eta c} \simeq 1.73 \times 10^{12} \text{ N-m}^{-2}$$

which corresponds to a weight of

$$\text{Weight} = (\text{Pressure})(\text{Area}) = mg = m(9.8) = 1.73 \times 10^{12} \quad \rightarrow \quad m = 34.7 \text{ kg}$$

8-37. Aircraft-submarine communication. The power density of the VLF signal right above the surface of the ocean can be calculated as

$$|\mathbf{S}_{\text{av}}| = \frac{P_{\text{total}}}{4\pi R^2} = \frac{2\times 10^5}{4\pi(10^4)^2} \simeq 1.59\times 10^{-4}\ \text{W-m}^{-2}$$

Using the value of the power density, the peak electric field right above the ocean surface (which is assumed to be at $z = 0$ with the z direction pointing vertically downward into the ocean) can be computed as

$$|\mathbf{S}_{\text{av}}| = \frac{1}{2}\frac{|E_1(z=0^-)|^2_{\text{peak}}}{\eta_1} \simeq 1.59\times 10^{-4} \quad\rightarrow\quad |E_1(z=0^-)|_{\text{peak}} \simeq 0.346\ \text{V-m}^{-1}$$

where we used $\eta_1 \simeq 377\Omega$. The transmission coefficient at the ocean surface is

$$\mathcal{T} = \frac{2\eta_{\text{sea}}}{\eta_1 + \eta_{\text{sea}}}$$

where η_{sea} is the intrinsic impedance of sea water given by

$$\eta_{\text{sea}} \simeq \sqrt{\frac{\mu_0\omega}{\sigma}}e^{j45°} = \sqrt{\frac{4\pi(10^{-7})2\pi(2\times 10^4)}{4}}e^{j45°} \simeq 0.199e^{j45°}\,\Omega$$

Substituting the value of η_{sea} yields

$$\mathcal{T} \simeq \frac{2(0.199e^{j45°}}{377+0.199e^{j45°}} \simeq \frac{2(0.199)e^{j45°})}{377} \simeq 1.05\times 10^{-3}e^{j45°}$$

Using $|\mathcal{T}| \simeq 1.05\times 10^{-3}$, the peak electric field right below the ocean surface can be computed as

$$|E_2(z=0^+)|_{\text{peak}} = |\mathcal{T}||E_1(z=0^-)|_{\text{peak}} \simeq (1.05\times 10^{-3})(0.346) \simeq 3.65\times 10^{-4}\ \text{V-m}^{-1}$$

The amplitude of the electric field at a depth z in the ocean below the $z = 0$ surface can be written as

$$|E_2(z=0^+)|e^{-\alpha z}$$

where α is the attenuation constant which can be calculated at 20 kHz as

$$\alpha = \sqrt{\pi f \mu_0 \sigma} = \sqrt{\pi(2\times 10^4)(4\pi\times 10^{-7})(4)} \simeq 0.562\ \text{np-m}^{-1}$$

Since the receiver sensitivity of the submarine is 1 μV-m^{-1}, the maximum depth of the submarine for communication with the aircraft can be found as

$$3.65\times 10^{-4}e^{-(0.562)z_{\max}} = 10^{-6}\ \text{V-m}^{-1}$$

from which we solve $z_{\max} \simeq 10.5$ m.

8-44. Antireflection coating on a glass slab. (a) This is a three layer problem most suited for solution by using [8.50], namely

$$\Gamma_{\text{eff}} = \frac{(\eta_2 - \eta_1)(\eta_3 + \eta_2) + (\eta_2 + \eta_1)(\eta_3 - \eta_2)e^{-2j\beta_2 d}}{(\eta_2 + \eta_1)(\eta_3 + \eta_2) + (\eta_2 - \eta_1)(\eta_3 - \eta_2)e^{-2j\beta_2 d}}$$

where we have $\eta_1\eta_3 \simeq 377\Omega$, and $\eta_2 = 377/\sqrt{\epsilon_2} = 377/n = 377/1.86 \simeq 202.68\Omega$. The thickness of the medium is $d = 1$ cm and $\beta_2 = 2\pi/\lambda_2 = 2\pi n/\lambda$, where λ is the free space

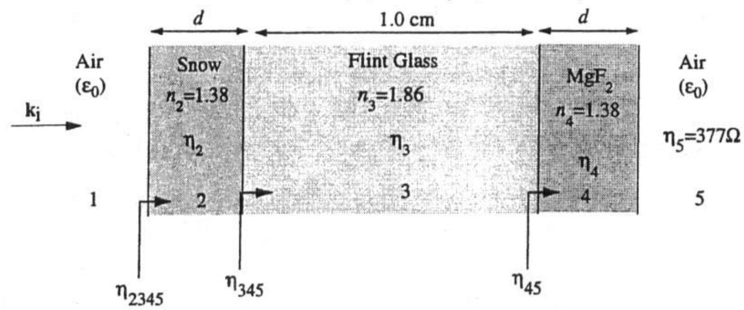

Fig. 8.7. Figure for Problem 8-44.

wavelength. For $\lambda = 550$ nm we find $\Gamma_{\text{eff}} = 0.515e^{-j159.15°}$, so that percentage power transmitted is $(1 - |\Gamma_{\text{eff}}|^2) \times 100 = 73.43\%$.

(b) We now have a five layer problem as shown in Figure 8.7. For complete transmission independent of the thickness of medium 3, we need a match on either side of medium 3. Noting that $n_4^2 \simeq n_3 n_5$ and $n_2^2 \simeq n_1 n_3$, mediums 4 and 2 should be quarter-wave transformers. Thus, we choose $d = \lambda_2/4 = \lambda/(n_2 4) = 99.63$ nm. Note that the coating thickness could be any odd multiple of this value (i.e., $3d$, $5d$, etc.) and still work as a quarter-wave transformer. To determine the effective reflection coefficient for the five-layer system, we follow the same approach as in Example 8-26 of the text, sequentially calcuating the various impedances (i.e., η_{45}, η_{345}, η_{2345}) using transmission line impedance transformation formulas. We then find the effective reflection coefficient from

$$\Gamma_{\text{eff}} = \frac{\eta_{2345} - \eta_1}{\eta_{2345} + \eta_1}$$

For $\lambda = 550$ nm, we find $\Gamma_{\text{eff}} = 0.02346e^{179.6°}$, so that only $\sim 0.55\%$ of the incident power is reflected.

(c) Similar calculations for 400 nm and 700 nm result in effective reflection coefficients respectively of $\Gamma_{\text{eff}} = 0.3195e^{-j148.11°}$ and $\Gamma_{\text{eff}} = 0.1754e^{-j85.55°}$. Thus, 10.2% reflects back for 400 nm and 3.07% reflects back for 700 nm. In other words, the MgF_2 coating works quite well across the entire visible wavelength range.