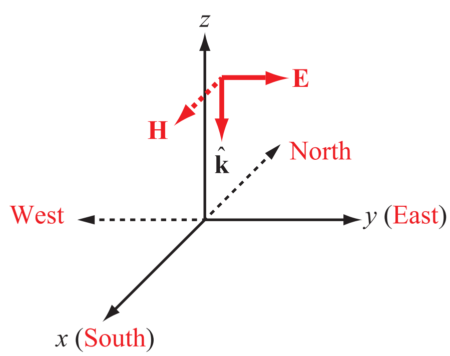
Test 7.1 TEM Wave

Solution: (c)



Since $\mathbf{E}$ is along $\hat{\mathbf{y}}$ and $\hat{\mathbf{k}}$ along $-\hat{\mathbf{z}}$, the direction of $\mathbf{H}$ should be along

$$\hat{\mathbf{k}} \times \hat{\mathbf{E}} = -\hat{\mathbf{z}} \times \hat{\mathbf{y}} = \hat{\mathbf{x}} \text{ (south)}.$$

Test 7.2 Wavelength

Solution: (b) From the expression, the wavenumber $k = \pi$ (rad/m). Also, $k = 2\pi/\lambda$. Hence,

$$\lambda = \frac{2\pi}{k} = \frac{2\pi}{\pi} = 2 \text{ m}.$$

Test 7.3 Relative Permittivity

Solution: (d) From the expression, the angular frequency $\omega = \pi \times 10^8$ (rad/s) and the wavenumber $k = \pi$ (rad/m). Also, $k = 2\pi/\lambda$ and

$$\omega = 2\pi f = 2\pi \frac{u_\mathrm{p}}{\lambda} = \frac{2\pi c}{\lambda\sqrt{\varepsilon_\mathrm{r}}} = \frac{kc}{\sqrt{\varepsilon_\mathrm{r}}} .$$

Hence,

$$\varepsilon_\mathrm{r} = \left(\frac{kc}{\omega}\right)^2 = \left(\frac{\pi \times 3 \times 10^8}{\pi \times 10^8}\right)^2 = 9.$$

Test 7.4 Wavelength

Solution: **(a)** From

$$\omega = 2\pi f = 6\pi \times 10^9 \text{ rad/s},$$
$$f = 3 \times 10^9 \text{ Hz} = 3 \text{ GHz}.$$

Also,

$$u_\text{p} = \frac{c}{\sqrt{\varepsilon_\text{r}}} = \frac{3 \times 10^8}{\sqrt{2.56}} = 1.875 \times 10^8 \text{ m/s}.$$

Hence,

$$\lambda = \frac{u_\text{p}}{f} = \frac{1.875 \times 10^8}{3 \times 10^9} = 6.24 \text{ cm}.$$

Test 7.5 Intrinsic Impedance

Solution: **(c)**

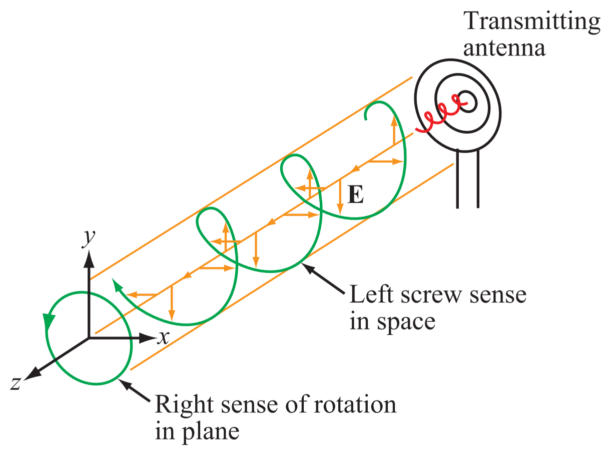
$$\eta = \frac{\eta_0}{\sqrt{\varepsilon_\text{r}}} = \frac{377}{\sqrt{14.2}} = \frac{377}{3.77} = 100\ \Omega.$$

Test 7.6 RFID

Solution: **(b)** A microwave RFID tag has a read range of about 10 m, compared with 0.5 m to 5 m for lower-frequency tags. Also, the microwave RFID tag can support a data rate of 100 kbits/s, compared with 1–30 kbits/s at the lower frequencies.

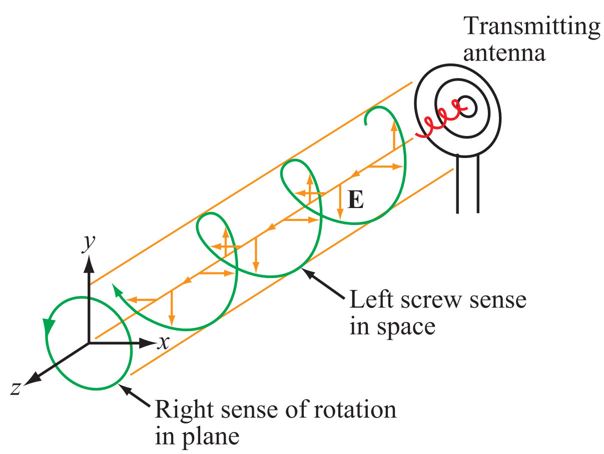
Test 7.7 Wave Polarization

Solution: **(c)** A helical antenna generates circularly polarized waves.



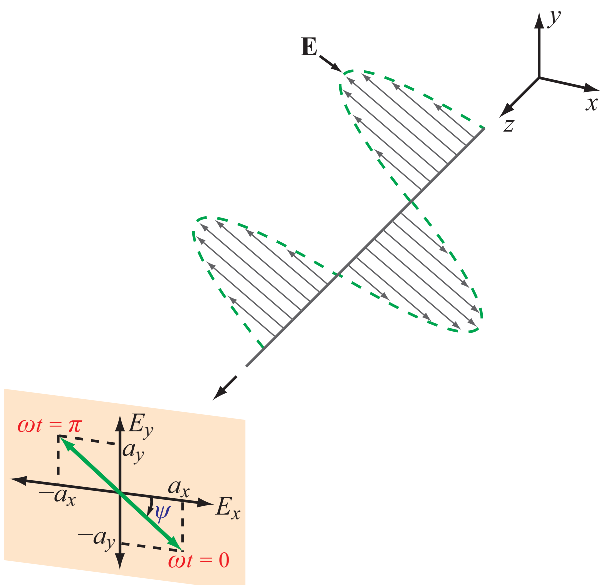
Test 7.8 RHC Polarization

Solution: (d)



Test 7.9 Linear Polarization

Solution: (a)



So long as the x- and y-components are in-phase ($\delta = 0$) or out of phase ($\delta = \phi$), the $\mathbf{E}$ field traces a straight line along a direction determined by the amplitude ratio:

$$\psi = \begin{cases} \tan^{-1}\left(\dfrac{a_y}{a_x}\right) & \text{for } \delta = 0, \\ \tan^{-1}\left(\dfrac{-a_y}{a_x}\right) & \text{for } \delta = \pi. \end{cases}$$

Test 7.10 RHC Polarization

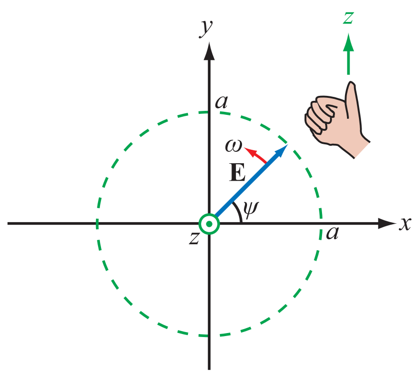
Solution: (d) For $a_x = a_y = a$ and $\delta = -\pi/2$,

$$\begin{aligned} \mathbf{E} &= a[\hat{\mathbf{x}}\cos(\omega t - kz) + \hat{\mathbf{y}}\cos(\omega t - kz - \pi/2)] \\ &= a[\hat{\mathbf{x}}\cos(\omega t - kz) + \hat{\mathbf{y}}\sin(\omega t - kz)]. \end{aligned}$$

Hence,

$$|\mathbf{E}| = a[\cos^2(\omega t - kz) + \sin^2(\omega t - kz)]^{1/2} = a,$$

$$\psi = \tan^{-1}\cos\left[\frac{\sin(\omega t - kz)}{\cos(\omega t - kz)}\right] = \omega t - kz.$$



Test 7.11 Good Conductor

Solution: **(a)** A material is considered a good conductor if

$$\frac{\varepsilon''}{\varepsilon'} = \frac{\sigma}{\omega\varepsilon} = \frac{\sigma}{2\pi f \varepsilon_{\rm r}\varepsilon_0} > 100,$$

which is equivalent to

$$\frac{4}{2\pi f 80 \times 8.85 \times 10^{-12}} > 100,$$

or $f < 9$ MHz.

Test 7.12 Good Conductor

Solution: **(b)** A material is considered a good conductor if

$$\frac{\varepsilon''}{\varepsilon'} = \frac{\sigma}{\omega\varepsilon} = \frac{\sigma}{2\pi f \varepsilon_{\rm r}\varepsilon_0} > 100,$$

which is equivalent to

$$\frac{10^{-4}}{2\pi f \times 2.5 \times 8.85 \times 10^{-12}} > 100,$$

or $f < 700$ kHz.

Test 7.13 Skin Depth

Solution: (d) Since the ratio

$$\frac{\varepsilon''}{\varepsilon'} = \frac{\sigma}{\omega\varepsilon} = \frac{\sigma}{2\pi f \varepsilon_r \varepsilon_0} = \frac{4}{2\pi \times 10^6 \times 80 \times 8.85 \times 10^{-12}} = 900,$$

which is larger than 100, seawater is a good conductor at 1 MHz. Hence, we can use the approximate expression for α given by

$$\begin{aligned}\alpha &= \sqrt{\pi f \mu \sigma} \\ &= \sqrt{\pi \times 10^6 \times 4\pi \times 10^{-7} \times 4} \approx 4 \text{ (Np/m)}.\end{aligned}$$

The corresponding skin depth is

$$\delta_s = \frac{1}{\alpha} = \frac{1}{4} = 0.25 \text{ m} = 25 \text{ cm}.$$

Test 7.14 Power Density

Solution: (b)

$$\eta = \frac{\eta_0}{\sqrt{\varepsilon_r}} = \frac{120\pi}{\sqrt{9}} = 40\pi \qquad (\Omega).$$

The wave is traveling in the negative x direction.

$$\mathbf{S}_{av} = -\hat{\mathbf{x}} \frac{[6^2 + 4^2]}{2\eta} = -\hat{\mathbf{x}} \frac{52}{2 \times 40\pi} = -\hat{\mathbf{x}} 0.2 \qquad (\text{W/m}^2).$$

Test 7.15 Phase Velocity

Solution: (c)

$$S_{av} = \frac{|E_0|^2}{2\eta}, \qquad \eta = \frac{|E_0|^2}{2S_{av}},$$

or

$$\eta = \frac{(47.56)^2}{2 \times 6} = 188.5 \ \Omega.$$

But

$$\eta = \frac{\eta_0}{\sqrt{\varepsilon_r}} = \frac{377}{\sqrt{\varepsilon_r}}, \qquad \varepsilon_r = \left(\frac{377}{188.5}\right)^2 = 4.$$

Hence,

$$u_p = \frac{c}{\sqrt{\varepsilon_r}} = \frac{3 \times 10^8}{2} = 1.5 \times 10^8 \text{ m/s}.$$

Test 7.16 Radar-Safe Region

Solution: (d)

$$S_{\text{av}} = \frac{|E(R)|^2}{2\eta_0}\,, \qquad 1\ (\text{mW/cm}^2) = 10^{-3}\ \text{W/cm}^2 = 10\ \text{W/m}^2,$$

$$10 = \left(\frac{1\times 10^3}{R}\right)^2 \times \frac{1}{2\times 377} = \frac{1.33\times 10^3}{R^2}\,,$$

$$R = \left(\frac{1.33\times 10^3}{10}\right)^{1/2} = 11.52\ \text{m}.$$