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PROBLEMS

4.1. A horizontal infinitesimal electric dipole of constant current I_0 is placed symmetrically about the origin and directed along the x-axis. Derive the

(a) far-zone fields radiated by the dipole

(b) directivity of the antenna

4.2. Repeat Problem 4.1 for a horizontal infinitesimal electric dipole directed along the y-axis.

4.3. Repeat Problem 4.1 using the procedure of Example 4.5.

4.4. For Example 4.5,

(a) formulate an expression for the directivity.

(b) determine the radiated power.

(c) determine the maximum directivity by integrating the radiated power. Compare with that of Problem 4.2 or any other infinitesimal dipole.

(d) determine the maximum directivity using the computer program **Dipole**; compare with that of part (c).

4.5. For Problem 4.1 determine the polarization of the radiated far-zone electric fields (E_θ, E_ϕ) and normalized amplitude pattern in the following planes:
(a) $\phi = 0^\circ$ (b) $\phi = 90^\circ$ (c) $\theta = 90^\circ$

4.6. Repeat Problem 4.5 for the horizontal infinitesimal electric dipole of Problem 4.2, which is directed along the y-axis.

4.7. For Problem 4.3, determine the polarization of the radiated far-zone fields (E_θ, E_ϕ) in the following planes:
(a) $\phi = 0^\circ$ (b) $\phi = 90^\circ$ (c) $\theta = 90^\circ$
Compare with those of Problem 4.5.

4.8. For Example 4.5, determine the polarization of the radiated far-zone fields (E_θ, E_ϕ) in the following planes:
(a) $\phi = 0^\circ$ (b) $\phi = 90^\circ$ (c) $\theta = 90^\circ$
Compare with those of Problem 4.6.

4.9. An infinitesimal magnetic dipole of constant current I_m and length l is symmetrically placed about the origin along the z-axis. Find the

(a) spherical **E**- and **H**-field components radiated by the dipole in all space
(b) directivity of the antenna

4.10. For the infinitesimal magnetic dipole of Problem 4.9, find the far-zone fields when the element is placed along the
(a) x-axis, (b) y-axis

4.11. An infinitesimal electric dipole is centered at the origin and lies on the x-y plane along a line which is at an angle of 45° with respect to the x-axis. Find the far-zone electric and magnetic fields radiated. The answer should be a function of spherical coordinates.

4.12. Repeat Problem 4.11 for an infinitesimal magnetic dipole.

4.13. Derive (4-10a)–(4-10c) using (4-8a)–(4-9).

4.14. Derive the radiated power of (4-16) by forming the average power density, using (4-26a)–(4-26c), and integrating it over a sphere of radius r.

4.15. Derive the far-zone fields of an infinitesimal electric dipole, of length l and constant current I_0, using (4-4) and the procedure outlined in Section 3.6. Compare the results with (4-26a)–(4-26c).

4.16. Derive the fifth term of (4-41).

4.17. For an antenna with a maximum linear dimension of D, find the inner and outer boundaries of the Fresnel region so that the maximum phase error does not exceed
(a) $\pi/16$ rad (b) $\pi/4$ rad (c) 18° (d) 15°

4.18. The boundaries of the far-field (Fraunhofer) and Fresnel regions were selected based on a maximum phase error of 22.5°, which occur, respectively, at directions of 90° and 54.74° from the axis along the largest dimension of the antenna. For an antenna of maximum length of 5λ, what do these maximum phase errors reduce to at an angle of 30° from the axis along the length of the antenna? Assume that the phase error in each case is totally contributed by the respective first higher order term that is being neglected in the infinite series expansion of the distance from the source to the observation point.

4.19. The current distribution on a terminated and matched long linear (traveling wave) antenna of length l, positioned along the z-axis and fed at its one end, is given by

$$\mathbf{I} = \hat{\mathbf{a}}_z I_0 e^{-jkz'}, \quad 0 \le z' \le l$$

where I_0 is a constant. Derive expressions for the

(a) far-zone spherical electric and magnetic field components

(b) radiation power density

4.20. A line source of infinite length and constant current I_0 is positioned along the z-axis. Find the

(a) vector potential $\mathbf{A}$

(b) cylindrical $\mathbf{E}$- and $\mathbf{H}$-field components radiated

$$\text{Hint: } \int_{-\infty}^{+\infty} \frac{e^{-j\beta\sqrt{b^2+t^2}}}{\sqrt{b^2+t^2}}\, dt = -j\pi H_0^{(2)}(\beta b)$$

where $H_0^{(2)}(\alpha x)$ is the Hankel function of the second kind of order zero.

4.21. Show that (4-67) reduces to (4-68) and (4-88) to (4-89).

4.22. A thin linear dipole of length l is placed symmetrically about the z-axis. Find the far-zone spherical electric and magnetic components radiated by the dipole whose current distribution can be approximated by

(a) $I_z(z') = \begin{cases} I_0\left(1 + \dfrac{2}{l}z'\right), & -l/2 \le z' \le 0 \\ I_0\left(1 - \dfrac{2}{l}z'\right), & 0 \le z' \le l/2 \end{cases}$

(b) $I_z(z') = I_0 \cos\left(\dfrac{\pi}{l}z'\right), \quad -l/2 \le z' \le l/2$

(c) $I_z(z') = I_0 \cos^2\left(\dfrac{\pi}{l}z'\right), \quad -l/2 \le z' \le l/2$

4.23. A center-fed electric dipole of length l is attached to a balanced lossless transmission line whose characteristic impedance is 50 ohms. Assuming the dipole is resonant at the given length, find the input VSWR when
(a) $l = \lambda/4$ (b) $l = \lambda/2$ (c) $l = 3\lambda/4$ (d) $l = \lambda$

4.24. Use the equations in the book or the computer program of this chapter. Find the radiation efficiency of resonant linear electric dipoles of length
(a) $l = \lambda/50$ (b) $l = \lambda/4$ (c) $l = \lambda/2$ (d) $l = \lambda$
Assume that each dipole is made out of copper [$\sigma = 5.7 \times 10^7$ S/m], has a radius of $10^{-4}\lambda$, and is operating at $f = 10$ MHz. Use the computer program of this chapter to find the radiation resistances.

4.25. Write the far-zone electric and magnetic fields radiated by a magnetic dipole of $l = \lambda/2$ aligned with the z-axis. Assume a sinusoidal magnetic current with maximum value I_{mo}.

4.26. A resonant center-fed dipole is connected to a 50-ohm line. It is desired to maintain the input VSWR = 2.

(a) What should the largest input resistance of the dipole be to maintain the VSWR = 2?

(b) What should the length (in wavelengths) of the dipole be to meet the specification?

(c) What is the radiation resistance of the dipole?

4.27. The radiation field of a particular antenna is given by:

$$\mathbf{E} = \hat{\mathbf{a}}_\theta j\omega\mu k \sin\theta \frac{I_0 A_1 e^{-jkr}}{4\pi r} + \hat{\mathbf{a}}_\phi \omega\mu \sin\theta \frac{I_0 A_2 e^{-jkr}}{2\pi r}$$

The values A_1 and A_2 depend on the antenna geometry. Obtain an expression for the radiation resistance. What is the polarization of the antenna?

4.28. For a $\lambda/2$ dipole placed symmetrical along the z-axis, determine the

(a) vector effective height

(b) maximum value (magnitude) of the vector effective height

(c) ratio (in percent) of the maximum value (magnitude) of the vector effective height to its total length

(d) maximum open-circuit output voltage when a uniform plane wave with an electric field of

$$\mathbf{E}^i|_{\theta=90^\circ} = -\hat{\mathbf{a}}_\theta 10^{-3} \text{ volts/wavelength}$$

impinges at broadside incidence on the dipole.

4.29. A base-station cellular communication system utilizes arrays of $\lambda/2$ dipoles as transmitting and receiving antennas. Assuming that each element is *lossless* and that the *input power* to each of the $\lambda/2$ dipoles is 1 watt, determine at *1,900 MHz* and a distance of *5 km* the maximum

(a) radiation intensity *Specify also the units.*

(b) radiation density (*in watts*$/m^2$)

for each $\lambda/2$ *dipole*. This determines the safe level for human exposure to EM radiation.

4.30. A $\lambda/2$ dipole situated with its center at the origin radiates a time-averaged power of 600 W at a frequency of 300 MHz. A second $\lambda/2$ dipole is placed with its center at a point $P(r, \theta, \phi)$, where $r = 200$ m, $\theta = 90^\circ, \phi = 40^\circ$. It is oriented so that its axis is parallel to that of the transmitting antenna. What is the available power at the terminals of the second (receiving) dipole?

4.31. A half-wave dipole is radiating into free-space. The coordinate system is defined so that the origin is at the center of the dipole and the z-axis is aligned with the dipole. Input power to the dipole is 100 W. Assuming an overall efficiency of 50%, find the power density (in W/m^2) at $r = 500$ m, $\theta = 60^\circ$, $\phi = 0^\circ$.

4.32. A small dipole of length $l = \lambda/20$ and of wire radius $a = \lambda/400$ is fed symmetrically, and it is used as a communications antenna at the lower end of the VHF band ($f = 30$ *MHz*). *The antenna is made of perfect electric conductor (PEC)*. The *input reactance* of the dipole is given by

$$X_{in} = -j120 \frac{[\ln(l/2a) - 1]}{\tan\left(\dfrac{\pi l}{\lambda}\right)}$$

Determine the following:

(a) Input impedance of the antenna. *State whether it is inductive or capacitive.*

(b) Radiation efficiency (*in percent*).

(c) Capacitor (*in farads*) *or* inductor (*in henries*) that must be connected *in series* with the dipole at the feed in order to resonate the element. *Specify which element is used and its value.*

4.33. A half-wavelength ($l = \lambda/2$) dipole is connected to a transmission line with a characteristic impedance of 75 ohms. Determine the following:

(a) Reflection coefficient. Magnitude and phase (*in degrees*).

(b) VSWR.

It is now desired to resonate the dipole using, *in series*, an inductor or capacitor. At a frequency of 100 MHz, determine:

(c) What kind of an element, inductor or capacitor, is needed to resonate the dipole?

(d) What is the inductance or capacitance?

(e) The new VSWR of the resonant dipole.

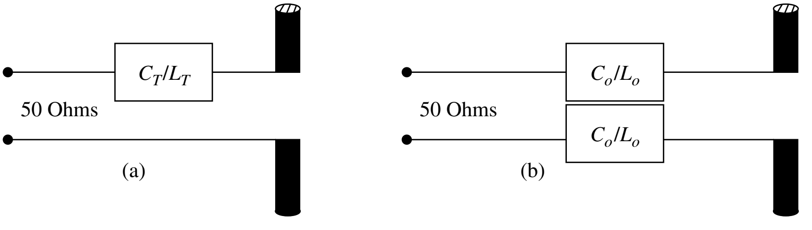
4.34. A $\lambda/2$ dipole is used as a radiating element while it is connected to a 50-ohm lossless transmission line. It is desired to resonate the element at *1.9 GHz* by placing *in series capacitor(s) or inductor(s)* (whichever are appropriate) at its input terminals. Determine the following:

(a) VSWR inside the transmission line *before the dipole is resonated [before the capacitor(s) or inductor(s) are placed in series].*

(b) Total single capacitance C_T (in farads) or inductance L_T (in henries) that must be placed *in series* with the element at its input terminals in order to resonate it. (*See diagram a*).

(c) Individual two capacitances C_o (in farads) or inductances L_o (in henries) that must be placed *in series* with the element at its input terminals in order to resonate it. We need to use two capacitors or two inductors to keep the system balanced by placing in series one with each arm of the dipole (*see diagram b*).

(d) VSWR after the element is resonated with capacitor(s) or inductor(s).



4.35. The input impedance of a $\lambda/2$ dipole, assuming the input (feed) terminals are at the center of the dipole, is equal to $73 + j42.5$. Assuming the dipole is lossless, find the

(a) input impedance (real and imaginary parts) assuming the input (feed) terminals have been shifted to a point on the dipole which is $\lambda/8$ from either end point of the dipole length

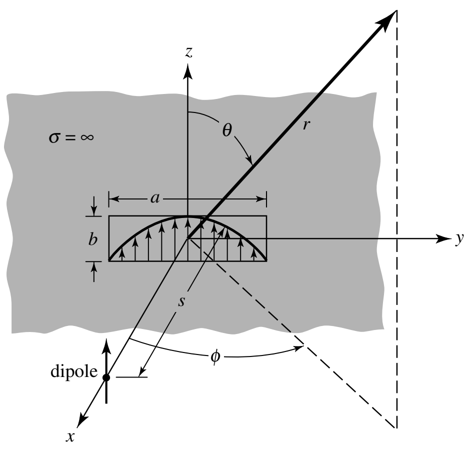
(b) capacitive or inductive reactance that must be placed across the new input terminals of part (a) so that the dipole is self-resonant

(c) VSWR at the new input terminals when the self-resonant dipole of part (b) is connected to a "twin-lead" 300-ohm line

4.36. A linear half-wavelength dipole is operating at a frequency of 1 GHz; determine the capacitance *or* inductance that must be placed *across* (in parallel) the input terminals of the dipole so that the antenna becomes resonant (make the total input impedance real). What is then the VSWR of the resonant half-wavelength dipole when it is connected to a 50-ohm line?

4.37. The field radiated by an infinitesimal electric dipole, placed along the z-axis a distance s along the x-axis, is incident upon a waveguide aperture antenna of dimensions a and b, mounted on an infinite ground plane, as shown in the figure. The normalized electric field radiated by the aperture in the E-plane (x-z plane; $\phi = 0^\circ$) is given by

$$\mathbf{E} = -\hat{\mathbf{a}}_\theta j \frac{\omega \mu b I_0 e^{-jkr}}{4\pi r} \frac{\sin\left(\dfrac{kb}{2}\cos\theta\right)}{\dfrac{kb}{2}\cos\theta}$$



Assuming the dipole and aperture antennas are in the far field of each other, determine the polarization loss (in dB) between the two antennas.

4.38. We are given the following information about antenna A:

(a) When A is transmitting, its radiated far-field expression for the E field is given by:

$$\mathbf{E}_a(z) = E_0 \frac{e^{-jkz}}{4\pi z} \left(\frac{\hat{\mathbf{a}}_x + j\hat{\mathbf{a}}_y}{\sqrt{2}} \right) \quad V/m$$

(b) When A is receiving an incident plane wave given by:

$$\mathbf{E}_1(z) = \hat{\mathbf{a}}_y e^{jkz} \quad V/m$$

its open-circuit voltage is $V_1 = 4e^{j20^\circ} V$.

If we use the same antenna to receive a second incident plane given by:

$$\mathbf{E}_2(z) = 10(2\hat{\mathbf{a}}_x + \hat{\mathbf{a}}_y E^{j30^\circ})e^{jkz} \quad V/m$$

find its received open-circuit voltage V_2.

4.39. A 3-cm long dipole carries a phasor current $I_0 = 10e^{j60}$A. Assuming that $\lambda =$ 5 cm, determine the E- and H-fields at 10 cm away from the dipole and at $\theta = 45^\circ$.

4.40. The radiation resistance of a thin, lossless linear electric dipole of length $l =$ 0.6λ is 120 ohms. What is the input resistance?

4.41. A lossless, resonant, center-fed $3\lambda/4$ linear dipole, radiating in free-space is attached to a balanced, lossless transmission line whose characteristic impedance is 300 ohms. Calculate the

(a) radiation resistance (referred to the current maximum)

(b) input impedance (referred to the input terminals)

(c) VSWR on the transmission line

For parts (a) and (b) use the computer program at the end of the chapter.

4.42. Repeat Problem 4.41 for a center-fed $5\lambda/8$ dipole.

4.43. A dipole antenna, with a triangular current distribution, is used for communication with submarines at a frequency of 150 kHz. The overall length of the dipole is 200 m, and its radius is 1 m. Assume a loss resistance of 2 ohms in series with the radiation resistance of the antenna.

(a) Evaluate the input impedance of the antenna including the loss resistance. The input reactance can be approximated by

$$X_{in} = -120\frac{[\ln(l/2a) - 1]}{\tan(\pi l/\lambda)}$$

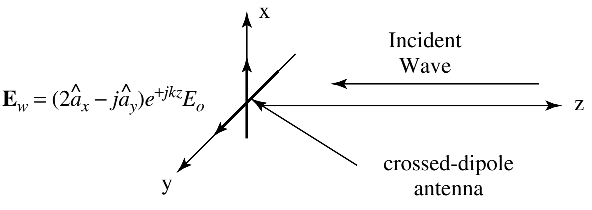
(b) Evaluate the radiation efficiency of the antenna.

(c) Evaluate the radiation power factor of the antenna.

(d) Design a conjugate-matching network to provide a perfect match between the antenna and a 50-ohm transmission line. Give the value of the series reactance X and the turns ratio n of the ideal transformer.

(e) Assuming a conjugate match, evaluate the instantaneous 2:1 VSWR bandwidth of the antenna.

4.44. A uniform plane wave traveling along the negative z-axis given by



impinges upon an crossed-dipole antenna consisting of *two identical dipoles*, one directed along the x-axis and the other directed along the y-axis, *both fed with the same amplitude*. The *y-directed dipole is fed with a 90° phase lead* compared to the x-directed dipole.

(a) Write an expression for the polarization unit vector of the incident wave.

(b) Write an expression for the polarization unit vector of the receiving antenna *along the + z-axis*.

(c) For the incident wave, state the following:
   1. Polarization (linear, circular, elliptical) and axial ratio.
   2. Rotation of the polarization vector (CW, CCW).

(d) For the receiving antenna, state the following:
   1. Polarization (linear, circular, elliptical) and axial ratio.
   2. Rotation of the polarization vector (CW, CCW).

(e) Determine the polarization loss factor (*dimensionless* and *in dB*) between the incident wave and the receiving antenna.

4.45. A half-wavelength ($l = \lambda/2$) dipole, positioned symmetrically about the origin along the z-axis, is used as a receiving antenna. A 300 MHz uniform plane wave, traveling along the x-axis in the negative x direction, impinges upon the $\lambda/2$ dipole. The incident plane wave has a power density of 2μ watts/m^2, and its electric field is given by

$$\mathbf{E^i}_w = (3\hat{a}_z + j\hat{a}_y)E_0 e^{+\mathrm{jkx}}$$

where E_0 is a constant. Determine the following:

(a) Polarization of the incident wave (*including its axial ratio and sense of rotation*, if applicable).

(b) Polarization of the antenna toward the x-axis (*including its axial ratio and sense of direction*, if applicable).

(c) Polarization losses (*in dB*) between the antenna and the incoming wave (assume far-zone fields for the antenna).

(d) Maximum power (*in watts*) that can be delivered to a matched load connected to the $\lambda/2$ dipole (assume no other losses).

4.46. Derive (4-102) using (4-99).

4.47. Determine the smallest height that an infinitesimal vertical electric dipole of $l = \lambda/50$ must be placed above an electric ground plane so that its pattern has only one null (aside from the null toward the vertical), and it occurs at 30° from the vertical. For that height, find the directivity and radiation resistance.

4.48. A $\lambda/50$ linear dipole is placed vertically at a height $h = 2\lambda$ above an infinite electric ground plane. Determine the angles (in degrees) where all the nulls of its pattern occur.

4.49. A linear infinitesimal dipole of length l and constant current is placed vertically a distance h above an infinite electric ground plane. Find the first five smallest heights (in ascending order) so that a null is formed (for each height) in the far-field pattern at an angle of 60° from the vertical.

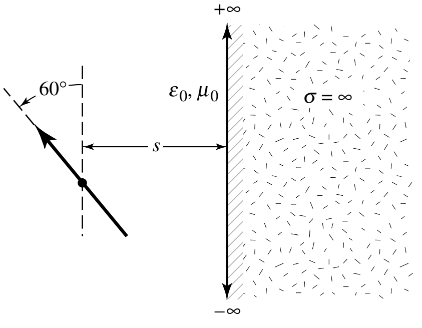
4.50. A vertical infinitesimal linear dipole is placed a distance $h = 3\lambda/2$ above an infinite perfectly conducting flat ground plane. Determine the

(a) angle (*in degrees* from the vertical) where the *array factor* of the system will achieve its *maximum* value

(b) angle (*in degrees* from the vertical) where the maximum of the *total field* will occur

(c) relative (compared to its maximum) field strength (*in dB*) of the total field at the angles where the array factor of the system achieves its maximum value (as obtained in part a).

4.51. An infinitesimal dipole of length ℓ is placed a distance s from an air-conductor interface and at an angle of $\theta = 60^\circ$ from the vertical axis, as shown in the figure. Determine the location and direction of the image source which can be used to account for reflections. Be very clear in indicating the location and direction of the image. Your answer can be in the form of a very clear sketch.



4.52. It is desired to design an antenna system, which utilizes a vertical infinitesimal dipole of length ℓ placed a height h above a flat, perfect electric conductor of infinite extent. The design specifications require that the pattern of the array factor of the source and its image has only one maximum, and that maximum is pointed at an angle of 60° from the vertical. Determine (in wavelengths) the height of the source to achieve this desired design specification.

4.53. A very short ($l \leq \lambda/50$) vertical electric dipole is mounted on a pole a height h above the ground, which is assumed to be flat, perfectly conducting, and of infinite extent. The dipole is used as a transmitting antenna in a VHF ($f =$ 50 MHz) ground-to-air communication system. In order for the communication system transmitting antenna signal not to interfere with a nearby radio station, it is necessary to place a null in the vertical dipole system pattern at an angle of 80° from the vertical. What should the shortest height (in meters) of the dipole be to achieve the desired specifications?

4.54. A half-wavelength dipole is placed vertically on an infinite electric ground plane. Assuming that the dipole is fed at its base, find the

(a) radiation impedance (referred to the current maximum)

(b) input impedance (referred to the input terminals)

(c) VSWR when the antenna is connected to a lossless 50-ohm transmission line.

4.55. A vertical $\lambda/2$ *dipole* is the radiating element in a circular array used for over-the-horizon communication system operating at *1 GHz*. The circular array (*center of the dipoles*) is placed at a *height h* above the ground that is assumed to be flat, perfect electric conducting, and infinite in extent.

(a) In order for the array not to be interfered with by another communication system that is operating in the same frequency, it is desired to place *only one null* in the *elevation pattern of the array factor* of a single vertical $\lambda/2$ dipole at an angle of $\theta = 30^\circ$ from zenith (axis of the dipole). Determine the *smallest nonzero height h* (*in meters*) above the ground at which the center of the dipole must be placed to accomplish this.

(b) If the height (*at its center*) of the vertical dipole is *0.3 m* above ground, determine *all the angles* θ from zenith (*in degrees*) where *all* the

1. null(s) of the *array factor* of a single dipole in the elevation plane will be directed toward.
2. main maximum (maxima) of the *array factor* of a single dipole in the elevation plane will be directed toward.

4.56. A vertical $\lambda/2$ dipole antenna is used as a ground-to-air, over-the-horizon communication antenna at the VHF band ($f = 200$ *MHz*). The antenna is elevated at a height *h* (*measured from its center/feed point*) above ground (*assume the ground is flat, smooth, and perfect electric conductor extending to infinity*). In order to avoid interference with other simultaneously operating communication systems, it is desired to place a null in the far-field amplitude pattern of the antenna system at an angle of 60° *from the vertical.*

Determine the *three smallest physical/nontrivial heights* (*in meters at 200 MHz*) above the ground at which the antenna can be placed to meet the desired pattern specifications.

4.57. A base-station cellular communication systems lossless antenna, which is placed in a residential area of a city, has a maximum gain of *16 dB* (above isotropic) *toward the residential area* at *1,900 MHz*. Assuming the *input* power to the antenna is 8 watts, what is the

(a) maximum radiated power density (*in watts*$/cm^2$) at a distance of 100 m (*line of sight*) from the base station to the residential area? This will determine the safe level for human exposure to electromagnetic radiation.

(b) power (*in watts*) received at that point of the residential area by a cellular telephone whose antenna is a *lossless* $\lambda/4$ vertical monopole and whose maximum value of the amplitude pattern is directed toward the maximum incident power density. *Assume the* $\lambda/4$ *monopole is mounted on an infinite ground plane*.

4.58. A vertical $\lambda/4$ monopole is used as the antenna on a cellular telephone operating at 1.9 GHz. Even though the monopole is mounted on a box-type cellular telephone, for simplicity purposes, assume here that it is mounted on a perfectly electric conducting (PEC) ground plane. Assuming an incident maximum power density of 10^{-6} watts/m^2, *state or determine*, for the monopole's omnidirectional pattern, the

(a) maximum directivity (*dimensionless and in dB*). *You must state the rationale or method you are using to find the directivity.*

(b) maximum power that can be delivered to the cellular telephone receiver. *Assume no losses*.

4.59. A homeowner uses a CB antenna mounted on the top of his house. Let us assume that the operating frequency is 900 MHz and the radiated power is *1,000 watts*. In order not to be exposed to a long-term microwave radiation, there have been some standards, although controversial, developed that set the maximum safe power density that humans can be exposed to and not be subject to any harmful effects. Let us assume that the maximum safe power density of long-term human RF exposure is 10^{-3} *watts*/cm^2 or 10 *watts*/m^2. Assuming no losses, determine the *shortest distance* (*in meters*) from the CB antenna you must be in order not to exceed the safe level of power density exposure. Assume that the CB antenna is radiating into free-space and it is

(a) an isotropic radiator.

(b) a $\lambda/4$ monopole mounted on an infinite PEC and radiating towards its maximum.

4.60. Derive (4-118) using (4-116).

4.61. An infinitesimal horizontal electric dipole of length $l = \lambda/50$ is placed parallel to the y-axis a height h above an infinite electric ground plane.

(a) Find the smallest height h (excluding $h = 0$) that the antenna must be elevated so that a null in the $\phi = 90^\circ$ plane will be formed at an angle of $\theta = 45^\circ$ from the vertical axis.

(b) For the height of part (a), determine the (1) radiation resistance and (2) directivity (for $\theta = 0^\circ$) of the antenna system.

4.62. A horizontal $\lambda/50$ infinitesimal dipole of constant current and length l is placed parallel to the y-axis a distance $h = 0.707\lambda$ above an infinite electric ground plane. Find *all* the nulls formed by the antenna system in the $\phi = 90^\circ$ plane.

4.63. An infinitesimal electric dipole of length $l = \lambda/50$ is placed horizontally at a height of $h = 2\lambda$ above a flat, smooth, perfect electric conducting plane which extends to infinity. It is desired to measure its far-field radiation characteristics (e.g. amplitude pattern, phase pattern, polarization pattern, etc.). The system is operating at 300 MHz. What should the minimum radius (*in meters*) of the circle be where the measurements should be carried out? The radius should be measured from the origin of the coordinate system, which is taken at the interface between the actual source and image.

4.64. An infinitesimal magnetic dipole is placed vertically a distance h above an infinite, perfectly conducting electric ground plane. Derive the far-zone fields radiated by the element above the ground plane.

4.65. Repeat Problem 4.64 for an electric dipole above an infinite, perfectly conducting magnetic ground plane.

4.66. Repeat Problem 4.64 for a magnetic dipole above an infinite, perfectly conducting magnetic ground plane.

4.67. An infinitesimal vertical electric dipole is placed at height h above an infinite PMC (perfect magnetic conductor) ground plane.

(a) Find the smallest height h (excluding $h = 0$) to which the antenna must be elevated so that a null is formed at an angle $\theta = 60^\circ$ from the vertical axis

(b) For the value of h found in part (a), determine

1. the directive gain of the antenna in the $\theta = 45^\circ$ direction
2. the radiation resistance of the antenna normalized to the intrinsic impedance of the medium above the ground plane

Assume that the length of the antenna is $l = \lambda/100$.

4.68. A vertical $\lambda/2$ dipole, operating at 1 GHz, is placed a distance of 5 m (with respect to the tangent at the point of reflections) above the earth. Find the total field at a point 20 km from the source ($d = 20 \times 10^3$ m), at a height of 1,000 m (with respect to the tangent) above the ground. Use a 4/3 radius earth and assume that the electrical parameters of the earth are $\epsilon_r = 5, \sigma = 10^{-2}$ S/m.

4.69. Two astronauts equipped with handheld radios land on different parts of a large asteroid. The radios are identical and transmit 5 W average power at 300 MHz. Assume the asteroid is a smooth sphere with physical radius of 1,000 km, has no atmosphere, and consists of a lossless dielectric material with relative permittivity $\epsilon_r = 9$. Assume that the radios' antennas can be modeled as vertical infinitesimal electric dipoles. Determine the signal power (in microwatts) received by each radio from the other, if the astronauts are separated by a range (distance along the asteroid's surface) of 2 km, and hold their radios vertically at heights of 1.5 m above the asteroid's surface.

Additional Information Required to Answer this Question: Prior to landing on the asteroid the astronauts calibrated their radios. Separating themselves in outer space by 10 km, the astronauts found the received signal power at each radio from the other was 10 microwatts, when both antennas were oriented in the same direction.

4.70. A satellite S transmits an electromagnetic wave, at 10 GHz, via its transmitting antenna. The characteristics of the satellite-based transmitter are:

(a) The power radiated from the satellite antenna is 10 W.

(b) The distance between the satellite antenna and a point A on the earth's surface is 3.7×10^7 m, and

(c) The satellite transmitting antenna directivity in the direction SA is 50 dB Ignoring ground effects,

1. Determine the magnitude of the E-field at A.
2. If the receiver at point A is a $\lambda/2$ dipole, what would be the voltage reading at the terminals of the antenna?

4.71. Derive (4-133) based on geometrical optics as presented in section 13.2 of [7].