ECE 3317
Fall 2023

Homework #7

Do Problems 1–3, 7–11. You are welcome to do the other problems for practice.

1) How long does it take light to travel from the surface of the earth to the following:

   (a) An overhead aircraft at an altitude of 35,000 feet (1 inch = 2.54 cm)

   (b) An overhead geostationary satellite (altitude 36,000 km)

   (c) The moon (238,000 miles away).

   (d) The maximum distance to the sun (94.5 million miles away).

   (e) The star Alpha Centauri (4.35 light years away).

2) A K-band police radar operates at a frequency of 24.15 GHz. Calculate the period of the wave (in seconds), the wavelength λ_0 in air (in meters), and the wavenumber k_0 of the wave in air (with units of rad/m).

3) A "dipole" antenna consists of a metal wire that is fed at the center. The dipole antenna is optimum in receiving signals when its length is approximately equal to one-half the wavelength for the signal of interest. What are the optimum dipole antenna lengths for receiving signals for the following TV stations:

   (a) Channel 8 (f = 184.25 MHz)

   (b) Channel 26 (f = 543.25 MHz)

4) A uniform plane wave has an electric field vector that is given by

$$\underline{\mathscr{E}}(x,y,z,t) = \left(120\underline{\hat{x}} - 50\underline{\hat{y}}\right)\cos\left(10^9 t - kz\right) \quad \text{[V/m]}.$$

This plane wave is propagating in polypropylene (ε_r = 2.0), which may be assumed lossless and non-magnetic. Find the following (and make sure that you include units!):

(a) k

(b) λ

(c) $\underline{E}(x, y, z)$

(d) $\underline{H}(x, y, z)$

(e) $\underline{\mathscr{H}}(x, y, z, t)$

5) A plane wave in free space has a wavelength of 10 cm. When the wave propagates through a lossless homogeneous material of unknown characteristics, its wavelength decreases to 7 cm. In this material, the E-field amplitude is 50 [V/cm] and the H-field amplitude is 0.1 [A/cm]. (The amplitude means the peak value that is measured in the time domain – this is equivalent to the magnitude of the corresponding phasor quantity.) Find the frequency of the plane wave as well as μ_r and ε_r for the unknown material.

6) Find the magnetic field vector $\underline{\mathscr{H}}(x,y,z,t)$ at a point in space $(x, y, z) = (10, 8, 50)$ [m] at $t = 6$ [μs] for each of the electric fields given below, if $\omega = 10^7$ [rad/s] and the plane wave is propagating through a lossless material for which $\varepsilon_r = 12$ and $\mu_r = 1$:

(a) $\underline{E} = 600\, e^{-jkz}\, \underline{\hat{x}}$ [V/m]

(b) $\underline{E} = 600\, e^{-jkx}\, \underline{\hat{z}}$ [V/m]

(c) $\underline{E} = 600\, e^{jkz}\, \underline{\hat{x}}$ [V/m]

7) A certain electromagnetic wave that is in vacuum has frequency f_0, wavelength λ_0, wavenumber k_0, and phase velocity v_{p0}. When it enters a nonmagnetic lossless dielectric medium characterized by $\varepsilon_r = 2.56$, what are the new values of f, λ, k, and v_p for the wave in this medium (in terms of the values for the same wave in vacuum)?

8) A lossy nonmagnetic dielectric has $\varepsilon_r = 2.0$ and $\tan\delta = \sigma/(\omega\varepsilon_0\varepsilon_r) = 2.0\times10^{-4}$.
For a frequency of 250 [MHz], how far can a wave propagate in the material before (a) it undergoes an attenuation of 1 [Np]; (b) it undergoes an attenuation of 10 dB; (c) its amplitude is halved; (d) its phase shifts 180°.

9) Typical (nonmagnetic) soil has $\varepsilon_r = 10$ and $\sigma = 0.1$ [S/m]. By calculating values for the attenuation constant, obtain yes or no answers to each of the following questions. Make sure

your calculations justify your answers!

(a) Will a 24 [GHz] antenna be effective if it is buried one meter deep in the ground?

(b) Can a 20 [GHz] radar system be used to look for metal ores at depths of 200 meters?

(c) Is an angleworm much safer from exposure to electromagnetic radiation if it detours one meter underground when passing a 60 [Hz] power line?

10) The ocean has a relative permittivity of $\varepsilon_r = 81$ and a conductivity of $\sigma = 4.0$ [S/m]. The ocean water may be assumed to be nonmagnetic. Determine the dB of attenuation for a plane wave that propagates from the surface of the ocean to a depth of 100 [m], if the frequency is 750 [Hz].

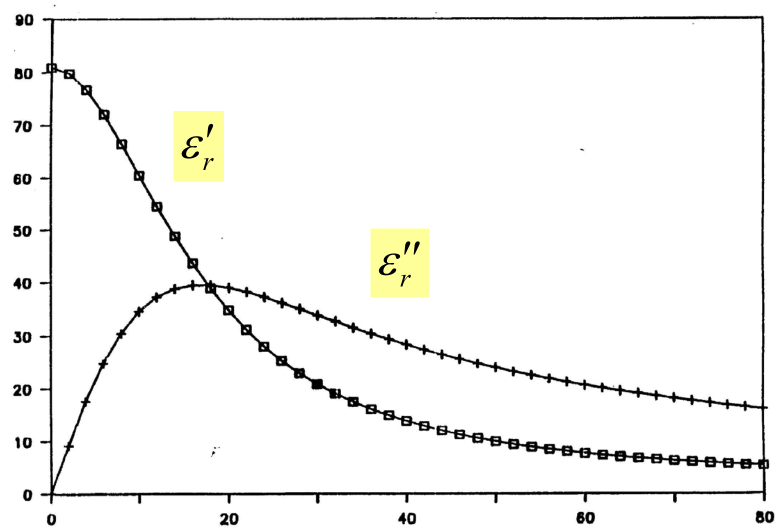
11) Consider pure (distilled) water. Pure (distilled) water has essentially no actual conductivity, since there are almost no charges (ions) that are free to move. Therefore, $\sigma = 0$. But is has "polarization loss" (loss due to molecular friction as the molecules rotate in a high-frequency field), so it still has an effective conductivity σ_{eff}. The real and imaginary parts of the complex relative permittivity are shown in the plot below.

Calculate the loss tangent and the depth of penetration for pure water at the frequency of a microwave oven, 2.45 [GHz]. (Read from the plot as best you can when doing the calculation.) Also calculate σ_{eff} at 2.45 [GHz].

Next, compare with the loss tangent and depth of penetration for ocean water at 2.45 [GHz], which has $\sigma = 4.0$ [S/m] and $\varepsilon_r = 81$. (For ocean water we may neglect polarization loss, so that $\sigma_{\text{eff}} \approx \sigma$.)

Note that $\varepsilon_c = \varepsilon' - j\varepsilon''$, $\quad \varepsilon_{rc} = \varepsilon_c / \varepsilon_0 = \varepsilon_r' - j\varepsilon_r''$.

Complex relative permittivity for pure (distilled) water



Frequency [GHz]