**EECS 3604 Lab 4 : Antennas and Sources**

**Submission details:** Write your responses to the following questions and submit them electronically as a lab report, along with any code that you write. If your responses are handwritten, scan them for electronic submission. Submission is via Moodle. Due date: April 8, 2016.

**Grading details:** 70% of your lab grade is for correctly completing the lab requirements; 20% is for clear writing and good presentation, including readable and well-documented code; 10% is for extra work or analysis that expands on or goes beyond the lab requirements.

Note: You may complete this lab in python (using numpy) instead of MATLAB if you wish.

**Lab part 1:** In class, we discussed how to calculate the antenna pattern of a Hertzian dipole. This lab will consider the antenna patterns due to arrays of dipoles.

Recall that the **far-field** electric and magnetic field strengths for a Hertzian dipole (oriented in the $\hat{z}$ direction) are given by

$$\vec{E} = \hat{\theta}\frac{jkId}{4\pi r}\sqrt{\frac{\mu_0}{\epsilon_0}}e^{-jkr}\sin\theta \tag{1}$$

$$\vec{H} = \hat{\phi}\frac{jkId}{4\pi r}e^{-jkr}\sin\theta \tag{2}$$

where $k$ is the wavenumber, $I$ is the complex phasor amplitude of the current, $d$ is the length of the dipole (which should be much smaller than $1/k$), $(r, \theta, \phi)$ are the spherical coordinates, and $\mu_0$ and $\epsilon_0$ are the magnetic permeability and electric permittivity of free space, respectively.

Write two functions in MATLAB, as follows:

1. Write a function, `dipole(i, omega, r, theta, phi, he)`, that gives the **far-field** complex phasor amplitude of either the electric or the magnetic field strength, observed at the point in spherical coordinates `(r, theta, phi)`, where: the complex

phasor amplitude of the current is `i`, the frequency is `omega`, and function returns the electric field strength for `he = 'e'` and magnetic for `he = 'h'`; (you don't need to handle the case where `he` is neither `'e'` nor `'h'`).

2. Write a function, `array(locations, i, omega, r, theta, phi, he)`, that gives the **far-field** complex phasor amplitude due to multiple simultaneous dipoles. Here, all parameters are the same as in `dipole`, except `locations`, which is a $3 \times n$ matrix: the number of columns $n$ gives the number of antennas, and each column contains the location of an antenna $(r, \theta, \phi)$ in spherical coordinates. *Note: Since we are using the far-field approximation, the values of $r$ in* `locations` *should be much smaller than the observer's location* `r`*.)*

**Lab part 2:** The antenna pattern is given by the magnitude of the complex phasor amplitude for either the electric or magnetic field strength. We showed how to obtain the antenna pattern of the Hertzian dipole in class.

1. Using your functions, obtain and plot the antenna pattern for $n = 2$, for various separations $r$ between the antenna arrays. One element should be at the origin and the other should be at $(r, \pi/2, 0)$. The most interesting and useful results will be found if the separation between antenna elements is on the order of the wavelength. Are there any directions where the field strength is zero? Explain.

2. Do the same for $n = 3$, where the elements are located at the origin, $(r, \pi/2, 0)$, and $(2r, \pi/2, 0)$

**Ideas for extra work portion**

1. Find the antenna pattern for $n = 4$, where the antenna elements are placed in a two-dimensional square.

2. For $n = 2$, find a relationship between antenna pattern, frequency $\omega$, and the separation between antenna elements.