ECE 4880 RF Systems Fall 2016
Homework 1

Due 9/2/2016 at 5pm in the Phillips Hall 2nd-Floor Dropbox

Reading before homework:

- Chap. 1: Review of EM theory and resonator circuits
- ECE 3030 lecture notes: lecture1, lecture2 and lecture13
- Lee's *The Design of CMOS Radio Frequency Integrated Circuits*, *2nd Ed.*, Chap. 1 and Chap. 2.1.

1. (**Radio as Traveling Waves**) If we define radio as a device that uses "electromagnetic radiation of traveling waves into space without wires or waveguides", answer and briefly explain the following:
   (a) Is a microwave oven a radio? (**4 pts**)
   (b) Is the cable TV a radio? (**4 pts**)
   (c) Is the portable GPS device a radio? (**4 pts**)
   (d) Are two inductor coils separated in space with nonzero mutual inductance "radio"? This is basically a smart card with near-field communication (NFC). (**4 pts**)
   (e) Is the Easy Pass on cars for highway tolling a radio? (**4 pts**)
   (f) Does playing Pokemon-Go involve a radio? (**4 pts**)

2. (**Maxwell Equations**) From the Maxwell equations,

$$\nabla . \varepsilon_o \vec{E} = \rho$$

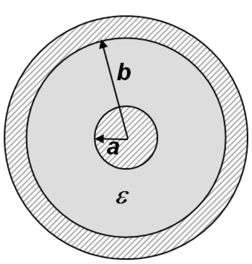
$$\nabla . \mu_o \vec{H} = 0$$

$$\nabla \times \vec{E} = -\frac{\partial \mu_o \vec{H}}{\partial t}$$

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \varepsilon_o \vec{E}}{\partial t}$$

   Use the simplest steps and assumptions to derive a plane-wave propagation equation in free space (no net charge or polarization). You can assume a plane wave traveling in *z* direction with electric field ONLY in the *x* direction and magnetic field ONLY in the *y* direction. A wave equation is a second-order differentiation in both space and time. (**8 pts**) What is the propagation speed of the plane wave? (**4 pts**) Write down the wave solution for the plane-wave electric fields and magnetic fields. (**4 pts**)

3. (**Circuits and Waveguides**) The RF signal is embedded in a 1GHz carrier wave in a coaxial cable to be connected to an antenna. The permittivity of the media in the coaxial cable is $4\varepsilon_0$.



Solution:

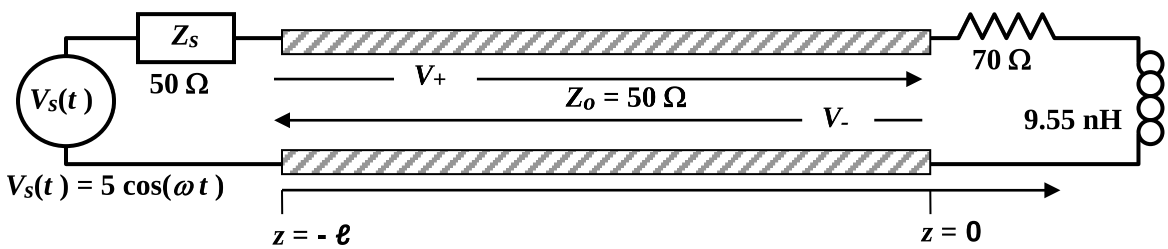
$$C = \frac{2\pi\,\varepsilon}{\log\left(\frac{b}{a}\right)}$$

log(): natural log

$$L = \frac{\mu_o}{2\pi}\log\left(\frac{b}{a}\right) \qquad LC = \mu_o\,\varepsilon$$

(a) What is the quarter wavelength in the air and in the coaxial cable? (**5 pts**)
(b) In your radio system of 1GHz when you use a 100cm coaxial cable between the power amplifier and the antenna, should this cable be modeled as a resistor, a RC circuit, a RLC circuit, or a transmission line? Briefly explain. (**5 pts**)
(c) If you are requested to describe the 100cm cable as a discrete LC line, what is the constraint on the length you can use for each *L* and *C* segment? (Hint: use the Bragg frequency). (**5 pts**)
(d) If the characteristic impedance of the coaxial cable is 50Ω, what is the unit-length inductance and capacitance in nH/cm and pF/cm, respectively? (**5 pts**) If you need to imitate the behavior of this coaxial cable on a PCB board, how many stages of discrete LC you have to use? (**5 pts**)
(e) If the coaxial cable has an inner conductor diameter of 1mm, what will be the diameter of the outer metal shield? (**5 pts**)

4. (**Transmission line review**) Consider the following transmission line where the transmission velocity is 1.5×10^{10}cm/s:



The circuit is operating at a frequency of 1.0 GHz. At the load end of the circuit there is a 70 Ω resistor in series with a 9.55 nH = 9.55×10^{-9} H inductor. The length of the transmission line is such that: $\ell = \frac{21}{16}\lambda$, where λ is the wavelength of waves in the transmission line at a frequency of 1.0 GHz.

(Do not worry about the precision reading off the Smith Chart if you choose to use one. For homework and learning, the Smith Chart is actually preferred, as the visualization will give you more intuition than pure algebra.) However, you can also use the equations directly for computation.

(a) Find the load reflection coefficient Γ_L (give a numerical value). (**5 pts**)
(b) Find the impedance $Z(z = -\ell)$ looking into the transmission line at $z = -\ell$ (feel free to use the Smith Chart or calculation). Give a numerical value for your answer. (**5 pts**)
(c) Find the average power dissipated in the impedance $Z(z = -\ell)$ in the above circuit (give a numerical value). Notice that $V_s(t) = 5\cos(\omega t)$ in volt. (**5 pts**)
(d) What is the impedance at $z = 0$ looking towards the source? (**5 pts**)
(e) In the following, we will change the length of the transmission line for impedance purposes. If we need the real part of the $Z(z = -\ell)$ to be 50Ω, what is the smallest ℓ we can use? What is the complex impedance $Z(z = -\ell)$? (**5 pts**)
(f) A impedance match to Z_s is needed. Give a series stub runner design with the stub line length (**5 pts**). Give a parallel stub runner design with the stub line length. (**5 pts**). Assume the stub runner is open terminated.