ECE 5317/6351

Microwave Engineering

Fall 2019

Homework #2

Text: *Microwave Engineering* by David M. Pozar, 4th edition, Wiley, 2011.

1) A coaxial cable is attached to a semi-infinite coplanar strip (CPS) transmission line on a printed-circuit board (PCB) that runs in the z direction. The inner conductor of the coax is directly connected to the left strip of the CPS at the beginning of the strip (called $z = 0$), while the right strip of the CPS is directly connected to the ground plane (i.e., shorted). Therefore, no balun is being used to connect the coax to the CPS line. Assume that the coax delivers a 1 [V] signal to the left strip of the CPS line (at some frequency f, which is not important here).

   Solve for the following:

   (a) the current on the left strip of the CPS at $z = 0$

   (b) the current on the right strip of the CPS at $z = 0$

   (c) the amplitude of the differential mode current on the CPS at $z = 0$

   (d) the amplitude of the common mode current on the CPS at $z = 0$.

   Leave your answers in terms of the (assumed) known characteristic impedances Z_{0d} and Z_{0c} of the differential and common modes. For the differential mode, the two strips form the two conductors of the transmission line (carrying equal current in opposite directions). For the common mode, the two strips act together as one conductor (carrying equal current in the same directions) and form a transmission with the ground plane being the other conductor.

   Note: The amplitude of the differential mode current is defined as the amplitude of the current on the left strip (the + strip, which has current flowing in the +z direction) when the mode is a pure differential mode. The amplitude of the common mode current is defined as the sum of the currents on both strips when a pure common mode is present. For the characteristic impedance Z_{0d}, the voltage is the voltage between the two strips, while the current is the current flowing in the z direction on the + strip (the one with the positive voltage). For the characteristic impedance Z_{0c}, the voltage is the voltage between the strips (which are now at the same voltage) and the ground, while the current is the total current flowing in the z direction on both strips.

2) A Smith chart is often helpful for visualizing and explaining things without doing any calculations. Use a Smith chart (or at least a sketch of one) to explain why the following statements are true, without dong any mathematical calculations. Assume that the transmission line is lossless in all of the following cases. The load may be lossy (i.e., a complex load impedance) unless otherwise stated. Use a "regular" Smith chart (i.e., the one called a "Z chart") in your discussion.

- If you are at a point on a transmission line where the impedance looking towards the load is inductive, and you go one-fourth of a guided wavelength from this point, the impedance looking towards the load must be capacitive.

- If you are on a transmission line that has a lossless load, and you stay at a fixed location on the line while increasing the frequency, the reactance seen looking towards the load must always increase as the frequency increases. (This is a special case of Foster's theorem, which actually holds for any lossless system.)

- If you are at a point on a transmission line where the impedance looking towards the load is inductive, and you go away from the load, the input resistance (the real part of the input impedance) seen looking towards the load must be increasing as you go away from the load.

- If you are on a transmission line with a lossy load, you can always find a position on the line (if it is long enough) where the real part of the input impedance looking towards the load is equal to Z_0.

- If you are on a transmission line with a lossy load, you can always find a position on the line (if it is long enough) where the real part of the input admittance looking towards the load is equal to Y_0.

- If you are on a transmission line with a lossy load, the real part on the input impedance looking towards the load will be maximum at a point on the line where the reflection coefficient $\Gamma(z)$ is a real number and has a phase angle of zero. The real part on the input impedance looking towards the load will be minimum at a point on the line where the reflection coefficient $\Gamma(z)$ is a real number and has a phase angle of 180°.

3) The outer shield of a coaxial cable is made of copper having a conductivity of 3.0×10^{7} [S/m]. If the cable operate at 1.0 [GHz], how thick does the shield have to be if we want the field that penetrates to the outside of the coax to be down by 100 [dB] from the field level at the inner surface of the shield?

4) A 75 [Ω] coaxial line used for TV has an outer radius of $b = 0.25$ [cm] and an inner radius of $a = 0.039$ [cm]. The coax is filled with Teflon ($\varepsilon_r = 2.2$) that has a loss tangent of 0.001. The conductors are made of copper, which is nonmagnetic. Assume that the conductivity of copper is 3.0×10^{7} [S/m] (this value is for practical copper and accounts for surface roughness). Make a table that shows the conductive attenuation, the dielectric attenuation, and the total attenuation, all in [dB/m] for various frequencies, including 1 KHz, 10 KHz, 100 KHz, 1 MHz, 10 MHz, 100 MHz, 1 GHz, 10 GHz, and 100 GHz.

Note that formulas for the characteristic impedance of the lossless coax and the resistance per unit length of the coax were given in Notes 3. All per-unit length terms (R,L,G,C) can be found from these two values, together with the material parameters and frequency, as explained in Notes 3. Use the formula for γ in terms of (R,L,G,C) to obtain the total attenuation constant α. Which of the four parameters (R,L,G,C) would you set to zero to find the conductor attenuation α_c? What about the dielectric attenuation α_d?

5) A twin-lead transmission line used for television has a characteristic impedance of 300 [Ω]. The separation between the centers of the two wires is 0.6 [cm]. The wires are made of copper, having a conductivity of 3.0×10^7 [S/m]. The wires may be assumed to be in lossless air. Make a table that shows the total attenuation in [dB/m] for various frequencies, including 1 KHz, 10 KHz, 100 KHz, 1 MHz, 10 MHz, 100 MHz, 1 GHz, 10 GHz, and 100 GHz. (Note that there is only conductive attenuation for this twin lead, since the filling material is air.) Compare with the result for the 75 [Ω] coax, using your results from Prob. 1. Note: You should find the radius of the wires by using the known characteristic impedance of the twin lead.

   Note that formulas for the characteristic impedance of the lossless twin lead and the resistance per unit length of the twin lead were given in Notes 3. All per-unit length terms (R,L,G,C) can be found from these two values, together with the material parameters and frequency, as explained in Notes 3. Use the formula for γ in terms of (R,L,G,C) to obtain the attenuation constant α.

6) For the coax in Prob. 4, calculate the total attenuation constant α [np/m] at 100 [MHz] in two different ways and compare: (1) Use the (R,L,G,C) method to directly calculate the total attenuation constant α. (2) Take the total α to be the sum of α_d and α_c. Note: Which of the four parameters (R,L,G,C) would you set to zero to find the conductor attenuation α_c? What about the dielectric attenuation α_d?

7) An engineer wants to determine whether it is better to transmit a 1 [GHz] signal using an RG59 coaxial cable or a wireless system consisting of two dipole antennas. Calculate the distance (in meters) between the transmitter and receiver where the "breakeven" point would be (where we have equal dB of total attenuation between the two systems). Note: You can use the attenuation table given in Notes 7 for the RG59 coax.

8) Assume that a microstrip line is approximately modeled as a parallel-plate structure, carrying a TEM mode. The height h of the substrate is 60 [mils] (one mil = 0.001 inches) and the strip width w is three time the substrate thickness. The substrate has $\varepsilon_r = 2.2$ and a loss tangent of 0.001. The microstrip line and the ground plane are both made of copper, with a conductivity of 3.0×10^7 [S/m]. Calculate the characteristic impedance Z_0 using the parallel-plate formula. Then calculate the attenuation α_d in [np/m] at 10 [GHz] due to the dielectric loss and the attenuation α_c in [np/m] at 10 [GHz] due to the conductor loss, and then find the total attenuation α in [np/m] at 10 [GHz]. At what frequency will the first waveguide mode appear? (This sets an upper limit on the frequency of operation of the microstrip line.)