University of California, Berkeley *Fall 2017*
EECS 142/242A *Prof. A. Niknejad*

Problem Set 3

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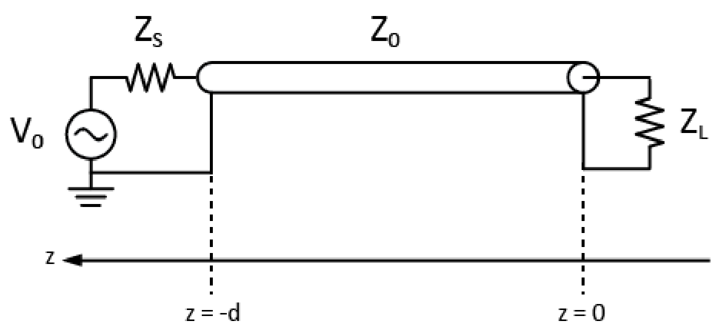
1. Consider the transmission line circuit shown below. A voltage source generating 10V amplitude of sinewave at 10 GHz is driving a transmission line terminated with load Z_L = 80 - j40 ohm. The transmission line has a characteristic impedance of Z_0 (= 100 ohm), effective dielectric constant of 4, and length d = 22.5 mm.



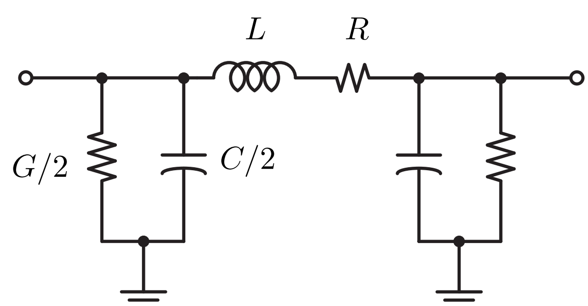
   (a) Find the reflection coefficient at the load (z = 0) and at the source (z = -d).

   (b) Find the input impedance at the source (z = -d) and at z = 18.75 mm.

   (c) Plot the magnitude of the voltage along the line. Find voltage maximum, voltage minimum, and standing wave ratio.

2. In this problem you will derive an equivalent two-port circuit model for a short section of transmission line($l \ll \lambda$), include loss.

   (a) For a "pi" equivalent circuit shown below, find the two-port Z matrix.



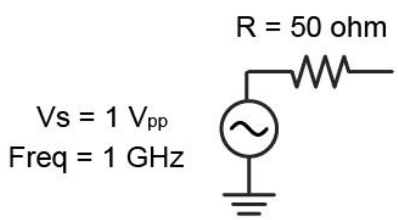
   (b) Now consider a section of transmission line with loss. Find the two-port Z matrix. You can either derive from first principles or use the transmission line impedance equation derived in the notes (make sure you use the general expression with loss).

(c) Take the limit of a very short line and simplify the answer (*Hint:* Use a Taylor series expansion and keep only the first few terms.)

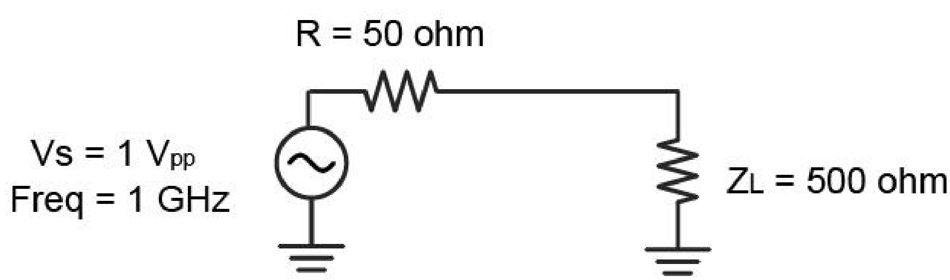
(d) Using the previous results, now derive the values for L, R, C, and G for the equivalent circuit.

3. Impedance Matching for Maximum Power Delivery

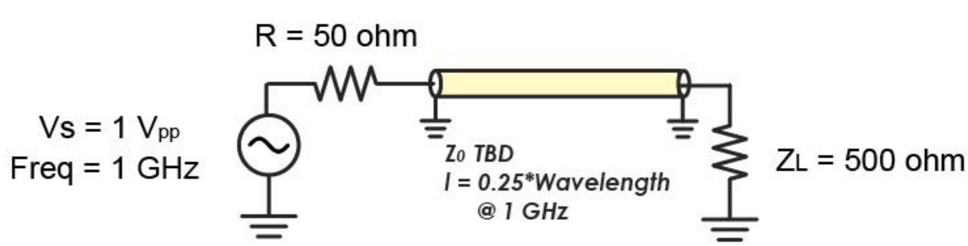
(a) What is the maximum power that can be extracted from the source shown below? What is the optimal load impedance for the maximum power delivery to happen?



(b) Use this source to drive a 500Ω load and we directly connect the load to the source, as illustrated by the figure below. What is the power delivered to the 500Ω load and the load voltage?

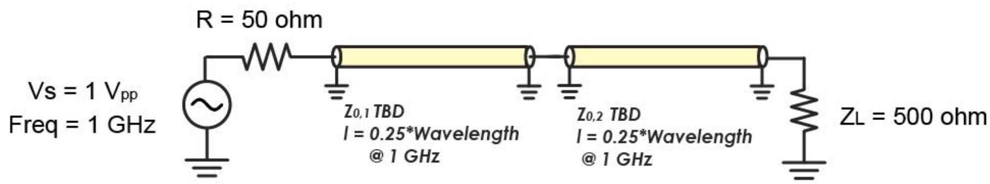


(c) Lets try to achieve impedance matching by putting a quarter-wavelength transmission line between the load and the source, as indicated by the below figure. Find the characteristic impedance Z_0 that maximizes the power delivered to the load. What are the corresponding power and voltage at the load?



(d) Following part c, assume the source frequency can change, what is the frequency interval where the power delivered to the 500Ω load is less than 3 dB from the maximum value (3-dB bandwidth)? Use ADS simulation to verify your hand calculation. Notice the transmission line is only a quarter wavelength at 1 GHz.

(e) (*242A only*)In order to achieve a better 3-dB bandwidth, a two-section transmission line is employed, as illustrated in the below figure. Find the two characteristic impedances $Z_{0,1}$ and $Z_{0,2}$ that maximize the power delivered to the 500Ω load at 1 GHz. Are there multiple ($Z_{0,1}$, $Z_{0,2}$) solutions?



(f) (*242A only*) Following part (e), what is the ($Z_{0,1}$, $Z_{0,2}$) solution that corresponds to the best 3-dB bandwidth? What is the best 3-dB bandwidth? Use ADS simulation to verify your hand calculation.

4. (**242A only**) In this problem, compare an LC tank with a quarter wave line in terms of the quality factor (Q). Suppose that we wish to realize a 60 GHz resonator with the highest Q possible. For simplicity, assume that the only source of loss is the resistance of the metal (neglect skin effect), with sheet resistance given by $R_\square = 25\text{m}\Omega/\square$. Assume that the integrated circuit process has 8 metal layers with the distance between the top metal and the bottom metal at 10μm.

   (a) Calculate the dimensions of a microstrip line to resonate at 60 GHz.

   (b) What is the optimal characteristic impedance of the line to minimize the losses?

   (c) Calculate the radius of a loop inductor that occupies approximately the same area as the transmission line.

   (d) Assuming that lumped capacitors of infinite Q are available, compare the quality factor of the loop inductor in resonance with the transmission line resonator.

   (e) Compare the impedance of the LC tank at second and third harmonic to the transmission line.

You may find the following paper interesting to read: C. Marcu and A. M. Niknejad, "A 60 GHz high-Q tapered transmission line resonator in 90nm CMOS," *Microwave Symposium Digest*, 2008, IEEE MTT-S International, pp. 775- 778