1994-1995 Physics Olympiad Preparation Program

– University of Toronto –

Problem Set 6: Electronics

Due April $3^{\rm rd}$*, 1995*

1. You just gotta love electronics. All of those little resistors and capacitors to play with. And just when you think there can be nothing as exciting as that, out come those digital circuits with all of the chips that can be used. It's even better than having... sorry about that, just got rambling...on to the business at hand. This problem concerns itself with a circuit called a tank circuit (see figure #1). I have no idea why it is called that, but whatta name.

   (a) Find the absolute value of the impedance of the tank circuit as a function of frequency. The impedance of this circuit is called the transfer function because it describes how signals are transferred across the circuit. At what frequency is the impedance of the circuit infinite? To do this you will need the resistance of both a capacitor $Z_c = 1/i\omega C$ and an inductor $Z_l = i\omega L$, where $i = \sqrt{-1}$. The absolute value of a complex number is defined as

   $$Z = \sqrt{Z \times Z^*}$$

   where Z^* is the complex conjugate of Z.

   (b) Sketch this impedance function as a function of frequency.

   (c) How will the transfer function change if the inductor has some resistance? Just determine the complex transfer function.

2. Often in electronics one uses filter circuits to remove unwanted frequencies in signals. Most of them work by using the frequency dependent resistance of capacitors and inductors. If a certain frequency signal is put into a circuit it will either be allowed to pass through or get blocked by the circuit depending on the frequency dependent resistance of the components. Filter circuits fall into the following categories:

   (a) High pass filters only allow high frequencies through them.

   (b) Low pass filters do the opposite.

   (c) Band rejection filters block an intermediate range of frequencies.

   (d) Not a filter at all.

   Classify the five circuits given in figure #2.

3. You're out with your friends one day and you stumble across an ornately carved lamp lying on the ground. One of your friends says that it must be a magical lamp with a genie inside. You all tease him mercilessly until, sobbing uncontrollably, he rubs the lamp and out comes a genie. The ethereal entity speaks, and I quote:"For teasing my master so ruthlessly, I will ask you one question which you must get right to live. What is the resistance between opposite vertices of an octahedron, if each of the twelve edges has the same resistance." You begin to sweat and really wish you hadn't skipped your electronics class all last term......

4. "Could the Romulin Warbird be hiding in that interstellar gas?" Captain Picard said from the bridge of the Enterprise.

   "Our sensors cannot penetrate the gaseous cloud, but I think it quite likely Captain," says Data in his usual monotone.

   Then Wesley piped up, "The homogeneous material of the cloud has known conductivity σ_c, whereas the Warbird has a conductivity of σ_w. By measuring the resistance of the cloud we could determine if the Warbird is in there." He sits in his chair with a stupid smile on his face.

Picard's face turns red as he shouts, "Will you shut your insolent little face. Worf, stun Wesley and throw him in the brig. After Wesley is unconscious, the captain remarks to Data, "Make it so."

(a) Data assumes that the cloud is cylindrical with radius b and length L, and that the input and output currents are uniformly distributed across the ends of the cloud. Show that Data computes the resistance to be

$$R = \frac{L}{\pi \sigma_c b^2}.$$

(b) Data decides to model the Romulin Warbird as a metallic cylinder of radius a, length a and conductivity σ_w in the centre of the cloud. Estimate the relative change in resistance of the cloud to first order in $\sigma_c - \sigma_w$ if $\sigma_c \simeq \sigma_w$. Assume that $b >> a$. Model the various parts of the cloud as resistors in series or parallel with each other.

5. This problem concerns itself with the rectification of AC voltage. The circuit shown in figure #3 is called a full wave rectifier and is used to turn an AC signal into a DC signal. The funny looking circuit elements are called diodes and only allow current to pass in the direction of the arrow.

   (a) If the voltage source produces a sinusoidal signal, what signal is expected across the resistor? What will be seen at the resistor for a square wave signal as input? Give reasons for your answer and sketch the output and input waveforms. Ignore the capacitor for this part.

   (b) If I add a large capacitor in parallel with the resistor, how will it affect the voltage signal at the resistor? To be more specific, why must the capacitor be large to produce an almost DC signal at the resistor?

6. This just wouldn't be an electronics problem set without at least one question on digital circuits. See figure #4 for a type of circuit that shows up when designing computers and such.

   (a) Find the truth table of the circuit. What is this circuit actually doing and how could it be useful?

   (b) Using the circuit from (a), design a full adder that can add three one digit binary numbers. Give the truth table for your circuit.