1995-1996 Physics Olympiad Preparation Program

– University of Toronto –

Problem Set 6: Electronics

Due March 18th, 1996

1. The circuit in Figure 1 is one that you can't easily escape from. Whether you're taking in tunage from *Offspring*, *Metallica*, or a Bach fugue for harpsichord, this little gem will most likely come into play (oops, no pun intended). It's a – wait for it – noninverting operational amplifier circuit.

   (a) Find an exact expression for the voltage gain ratio, $A_v = \frac{v_o}{v_2}$, in terms of R_1, R_2, R_d (the effective resistance between the "+" and "-" terminals), and $A_{\rm OL} \equiv \frac{v_o}{v_d}$ (the open loop voltage gain).

   (b) Assume that $i_{\rm in}$ is zero, so that $v_d \approx 0$ and $v_1 \approx v_2$. Derive an expression for the voltage gain ratio for this simplified case.

2. Gill Bates is the billionaire founder of Sicromoft Corp., the creator of *ScreenDoors 96* (a soon-to-be popular operating system). It is a little known fact that Gill spent her teen-age summer months designing power supplies for a small Ontario electronics firm. One year, she dreamed up the $5/2\pi$ kHz circuit shown in Figure 2. Her boss wanted it put on the market immediately, and asked her to write a specification sheet for it, including the magnitude and phase of (a) the open circuit voltage across the terminals AB and (b) the driving point impedance at AB (with the internal voltage source set to zero). Solve for these quantities and you too may be a billionaire someday.

3. Let me tell you about a nightmare I once had. It was a dark and stormy night and I had somehow become trapped in a dripping dungeon guarded by a band of simian subterranean gypsies. Their leader, Murd, handed me a circuit breadboard and a baggy containing half a dozen NOR gates. He told me that if I could realize the logic function $f = A \cdot B + \overline{A} \cdot B$ using the devices provided, then I would be free to leave his dungeon. How did I do it in my dream, using all the given gates? Of course, I then awoke in a cold sweat and realized how stupid I (and Murd's band for that matter) had been. Why?

4. Aren't CDs just too cool, with their glittering colours and cute size? In the early 80s they were heralded as the "perfect sound" medium, and thanks to the power of advertising many folks still think this to be true. The shortcomings of the CD format, which are rooted in the fact that the standard was established way back in the late 70s, could form the basis of many POPTOR problems. CDs are here to stay for a while, anyway, so let's be positive and examine the medium a little. First of all, the data words on a CD are 16 bits long. The digital sampling rate is 44.1 kHz, and the nominal frequency limits of human hearing are ∼20 Hz to ∼20 kHz.

   (a) How many different levels of sound pressure can be represented with this medium?

   (b) Discuss why the digital sampling rate was chosen to be 44.1 kHz.

   (c) What is the maximum possible dynamic range (in decibels)?

   (d) What is the data density (in bytes/m^2) on a CD if the angular speed is 500 rpm when the laser pickup is at the innermost point and 200 rpm when it's at the outermost point. Assume the outer diameter to be 120 mm, that a CD plays for 74 minutes, and that there's no data redundancy or error-checking information.

5. The configuration in Figure 3 contains two AND gates and two NOR gates. The input marked CLK is connected to a square wave generator that oscillates between the "1" and "0" logic states.

   (a) Give a truth table for this logic circuit.

   (b) How do you think this configuration could be useful?

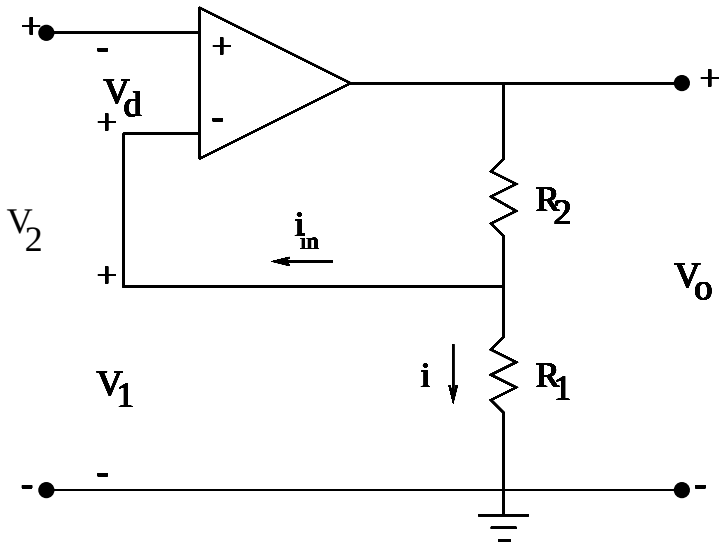

Figure 1: The noninverting op-amp circuit in Problem 1.

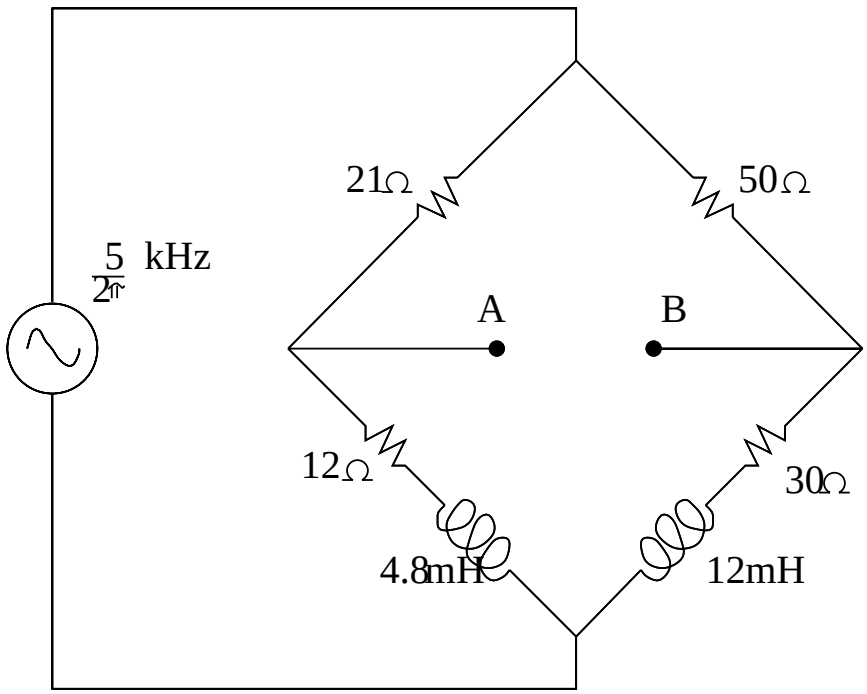

Figure 2: Gill's circuit in Problem 2.

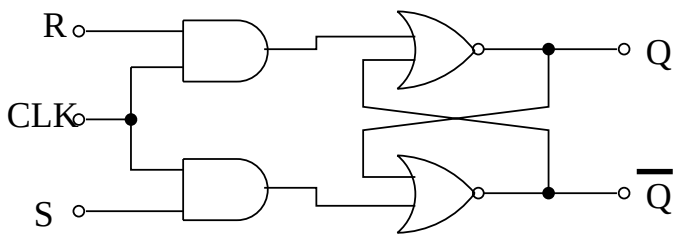

Figure 3: The digital circuit in Problem 5.

(c) Can Figure 3 be replaced by a system of NAND gates? If so, how? If not, why not?

6. Your fairy godmother gives you a black box with four terminals on it (two inputs, A and B, and two outputs, C and D). She tells you that the resistance between terminals B and C is equal to the resistance between terminals C and D, and that there is negligible resistance between terminals B and D. She also informs you that, when a sinusoidal voltage with a frequency f_o is applied across A and B, the output voltage across C and D is also sinusoidal, but has an amplitude that is 20% less than the input amplitude. If the input frequency, f, is varied either higher or lower, the output voltage amplitude is attenuated symmetrically about f_o, roughly as a function of $1/|f - f_o|$. What does the circuit inside the black box look like and what can you say about the values of the devices inside? *Note:* You may assume that there's no active electronics inside – only passive devices are used.