Final Exam: Electronics 323
April 17, 2009

Formula sheet provided. In all questions give at least some explanation of what you are doing to receive full value. Total 100 points. Individual values follow each question.

1. (a) What chemical elements are most often used to build semi-conductor devices (don't need to include doping elements)? Give a brief diagram of the "bands" to show what makes a semiconductor a semiconductor. At $T = 0$ K what states are occupied and what states are vacant? (4)

   (b) Where do the electrons and holes come from in intrinsic semiconductors? Use the appropriate formula from your sheet to make an estimate of the instrinsic concentration of holes (p) at room temperature if we assume that $m_e = m_h = 6 \times 10^{-31}$ kg, $E_g = 0.8$ eV$= 1.28 \times 10^{-19}$ J, $k_B = 1.38 \times 10^{-23}$ J/K, $\hbar = 1.055 \times 10^{-34}$ J s. Please include some of the intermediate steps in this calculation. State the further assumption concerning the number of holes versus the number of electrons in intrinsic semiconductors. (If you are unable to do this calculation then just assume some reasonable values for n and p and use these in the rest of the question.) (4)

   (c) Suppose the electron and hole mobilities are identical and equal to 0.15 $m^2V^{-1}s^{-1}$. The electronic charge $e = 1.6 \times 10^{-19}$ C. Calculate the conductivity of this intrinsic semiconductor. (2)

   (d) What are the names given to the group III and group V dopants used to modify the electrical properties of the semiconductors? Suppose that we add arsenic (Group V) to a concentration of 5×10^{21} m^{-3} to the semiconductor discussed in parts (b) and (c). Make a new estimate n, p, and the conductivity. State your assumptions. (4)

2. Draw a diagram of a p-n junction and explain (either on the diagram or in words) the following terms: depletion region, background charge, diffusion current, drift current, recombination, potential barrier, forward bias, reverse bias, limiting factors for the different currents under different bias conditions. You may also explain the terms in "prose" style if you explain the behaviour of the p-n junction as a whole. Specific mathematical details are not necessary. (16)

3. Draw the $I - V$ curve for a diode that is assumed to have infinite conductivity when it reaches a turn-on voltage of 0.7 V but zero conductivity otherwise. How is this assumption manifest in our DC description of bipolar junction transistors? Assuming the input is a sine wave of amplitude 3 V draw the voltage across R_L for the circuit in Fig. 1 assuming the diode has a turn-on voltage of 0.7 V. What kind of a circuit is this? How could you make the voltage supplied to the load more constant with time? (10)

4. Sketch the input and output characteristics of a typical silicon-based npn bipolar junction transistor in the common-emitter arrangement. Include scales on the axes whenever possible. You may assume that $h_{fe} = 100$ and typical base currents are 10's of μA. What does it mean to establish an operating point? Indicate it on the graphs. How are h_{ie} and h_{oe} represented on these diagrams (I have purposely left out h_{re})? (10)

5. Consider the transistor amplifier circuit shown in Fig. 2. The h_{fe} of the transistor is 80. $h_{oe} = 80$ μS. It is a silicon-based transistor.

(a) Stating your assumptions calculate the DC or quiescent current through the collector resistor and also calculate V_0. (4)

(b) I assume one of the assumptions you used was that I_B was small compared to the current through the voltage divider. Verify this assumption. (2)

(c) Construct the small signal h-parameter model neglecting h_{re} and calculate the small signal voltage gain (should agree with equation 34 on the formula sheet). Again state your assumptions. (6)

(d) This ciruit uses negative feedback and one benefit of negative feedback is to increase input resistance. By employing the small signal model verify that equations 36 and 37 on the formula sheet are correct. (Hints: you need to find a relationship between v_b and i_b so you are "looking into" the base. Use the $h_{fe}i_b$ expression for the constant current generator and assume that R_E carries this current plus the base current.) (6)

(e) Where would you include a "coupling capacitor"? What is its purpose? Give a value for C such that the lower frequency cutoff (a 3 dB point) for the input is 80 Hz assuming a small source resistance. (4)

(f) Where would you include a "decoupling" capacitor? What would be the benefit? (2)

6. (a) In general, what is a trigger? How is a Schmitt trigger different from a simple comparator? (An output versus input diagram would be very useful here.) (4)

(b) Give the expression for the gain of a system that employs feedback, defining the terms. Give a reason why negative feedback is useful in this context. What is one of the uses for positive feedback? Name (but don't design) one of these circuits. (6)

(c) Draw a low pass filter and derive an expression for $\left|\frac{V_{\text{out}}}{V_{\text{in}}}\right|$ as a function of ω. What are the values of $\left|\frac{V_{\text{out}}}{V_{\text{in}}}\right|$ and f at the "3 dB" point? (6)

(d) A computer mouse and computer screen can both be considered as transducers. Give the categories that distinguish the two and describe the physical quantities involved. (4)

(e) What is an "op-amp"? The '+' and '-' inputs mean it is a specific kind of amplifier; what kind? Design a non-inverting amplifier with a gain of 11 based on an op-amp. (Recall you use a voltage divider connected to the output and the inverting input.) Use resistors of values that we typically used in the lab. If you use a 741 op-amp the gain begins to drop significantly at 17 Hz. Does this mean this circuit can only be used for essentially DC frequencies? Explain. (8)