

4:25 4:50

# ECE 3040 Microelectronic Circuits

*Exam 2*

*October 26, 2009*

*Dr. W. Alan Doolittle*

Print your name clearly and largely:

*Solutions*

---

**Instructions:**

Read all the problems carefully and thoroughly before you begin working. DO NOT REMOVE ANY PAGES FROM THIS EXAM. You are allowed to use 1 new sheet of notes (1 page front and back), your note sheet from the previous exam as well as a calculator. There are 100 total points in this exam plus 10 points bonus (all or nothing grading). Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. If I cannot read it, it will be considered to be a wrong answer. Numeric answers without supporting work will be counted as wrong. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on ONE of the two following cases:

I DID NOT observe any ethical violations during this exam:

---

I observed an ethical violation during this exam:

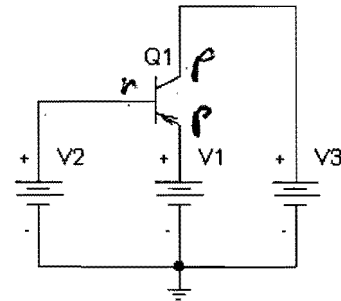
---

**First 20% True/False and Multiple Choice - Select the most correct answer(s)**

- 1.) (2-points)  True /  False: The diffusion capacitance of a junction is due to minority carriers separated across the junction.
- 2.) (2-points)  True /  False: Diode leakage current,  $I_0$ , has two terms summed together. Each of the two terms come from minority carriers drifting (leaking) across the junction, so one term is from holes and one term is from electrons.
- 3.) (2-points)  True /  False: Avalanche breakdown of a diode is always a destructive process that will burn up the diode if left uncorrected.
- 4.) (2-points)  True /  False: If one wants to use a transistor to “switch a motor” coil on and off, the transistor would primarily be switched from saturation to cutoff.
- 5.) (2-points)  True /  False: A BJT with a thin base quasi neutral width is best for high voltage (large  $V_{CE}$ ) applications.
- 6.) (2-points)  True /  False: Zener diodes are used as voltage references but their “noisy” avalanche process can introduce undesirable noise.

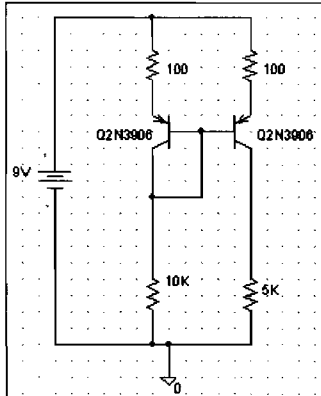
7.) (2-points) If an engineer wanted to bias this transistor into forward active mode, which of the following is true?

- a.  $V_1 > V_2$  and  $V_2 > V_3$
- b.  $V_2 > V_1$  and  $V_2 > V_3$
- c.  $V_1 > V_2$  and  $V_3 > V_2$
- d.  $V_1 < V_2$  and  $V_3 > V_2$
- e. None of the above.

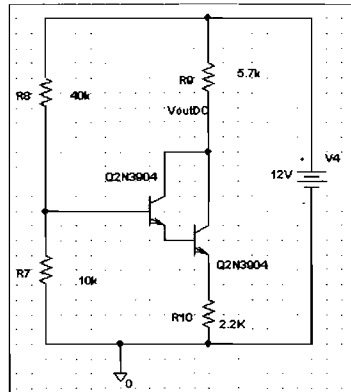


8.) (3-points) For the 6 circuits shown below, indicate what the function/name of the circuit is. Place letter of answer in the blanks to the right of each circuit. Choices are:

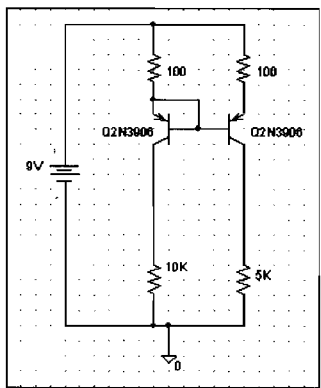
- a. Current mirror circuit
- b. Voltage Reference circuit
- c. High current gain (super beta) circuit (Darlington)
- d. Non-functional (Auburn engineered) circuit.



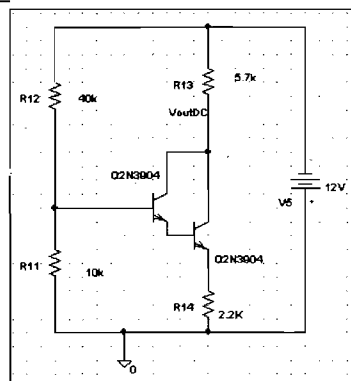
a



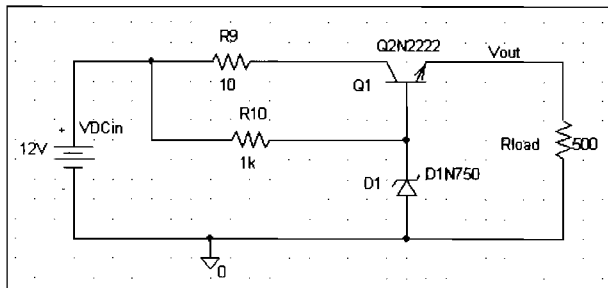
c



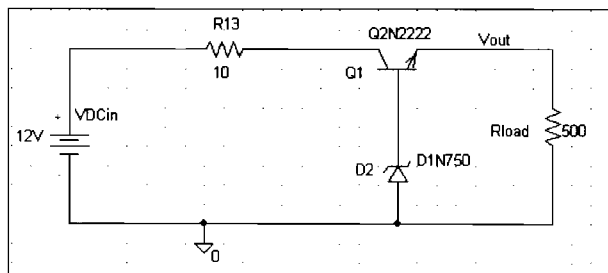
d



d



b



d

\* 9.) (3-points) The common base current gain,  $\alpha_{DC}$ ...

- a. ...depends on the number ratio of majority carriers to total carriers emitted from the emitter into the base.
- b. ...depends on the collector-base voltage in a real transistor. *base width modulation*
- c. ...depends on the fraction of minority carriers in the base that can "survive" long enough to be collected in by the base-collector **reverse** biased junction
- d. ...depends on the fraction of minority carriers in the base that can "survive" long enough to be collected in by the base-collector **forward** biased junction
- e. None of the above

10.) (20 points total in 3 parts)

A silicon diode with the following parameters is biased into reverse bias with a 5 volt bias.

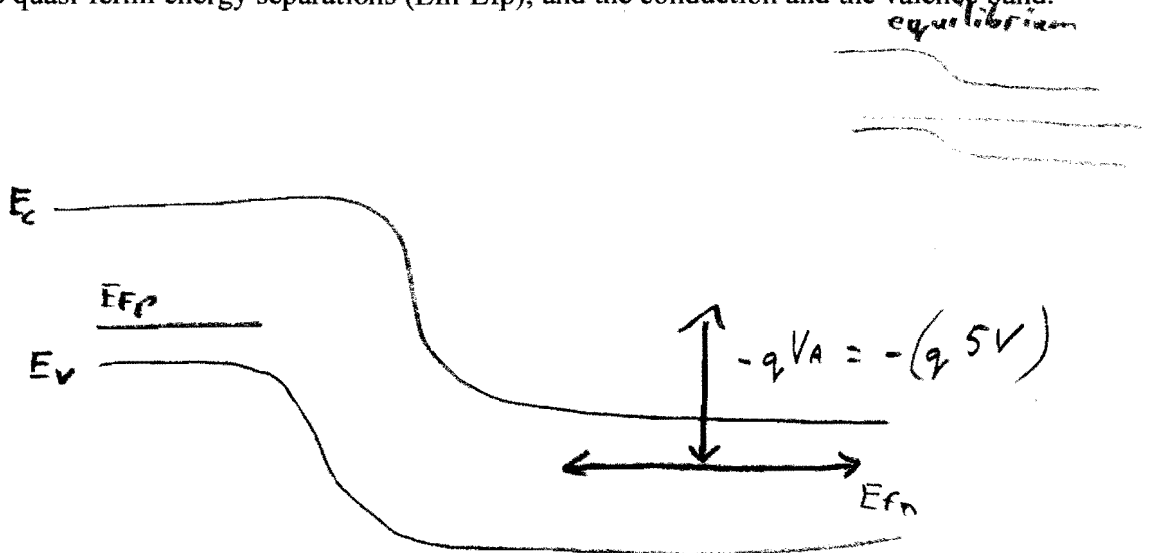
$$n_i = 1 \times 10^{10} \text{ cm}^{-3} \quad N_D = 1 \times 10^{19} \text{ cm}^{-3} \quad N_A = 1 \times 10^{15} \text{ cm}^{-3}$$

(a - 4 points) Which side of the depletion region,  $x_n$  or  $x_p$ , is larger? Note: you do not have to calculate  $x_n$  and  $x_p$  to answer this (although you could) but you do need to justify your answer.

$$N_A x_p = N_D x_n$$

$$\frac{N_A}{N_D} = \frac{x_n}{x_p} = \frac{1 \times 10^{15}}{1 \times 10^{19}} \Rightarrow x_p \gg x_n$$

(b - 6 points) Draw the energy band diagram of the diode under this reverse bias. Be sure to label the quasi-fermi energy separations ( $E_{fn} - E_{fp}$ ), and the conduction and the valence band.



(c - 10 points) ) For each side of the junction, determine the equilibrium minority carrier concentration and the minority carrier concentrations under the specified reverse bias (4 total numeric answers) at the depletion region edges.

$$\Delta n_p = \frac{n_i^2}{N_A} \left( e^{V_A/V_T} - 1 \right) + \Delta p_n = \frac{n_i^2}{N_D} \left( e^{V_A/V_T} - 1 \right)$$

$\uparrow$   $n_0$   $\uparrow$   $p_0$

$$\Delta n_p = \frac{10^{20}}{10^{15}} \left( e^{-5V/0.0259} - 1 \right)$$

$$\boxed{n_0 = 10^5 \text{ cm}^{-3}}$$

$$\Delta n_p = -n_0$$

$$\boxed{n = 0}$$

$$\Delta p_n = \frac{10^{20}}{10^{19}} \left( e^{-5V/0.0259} - 1 \right)$$

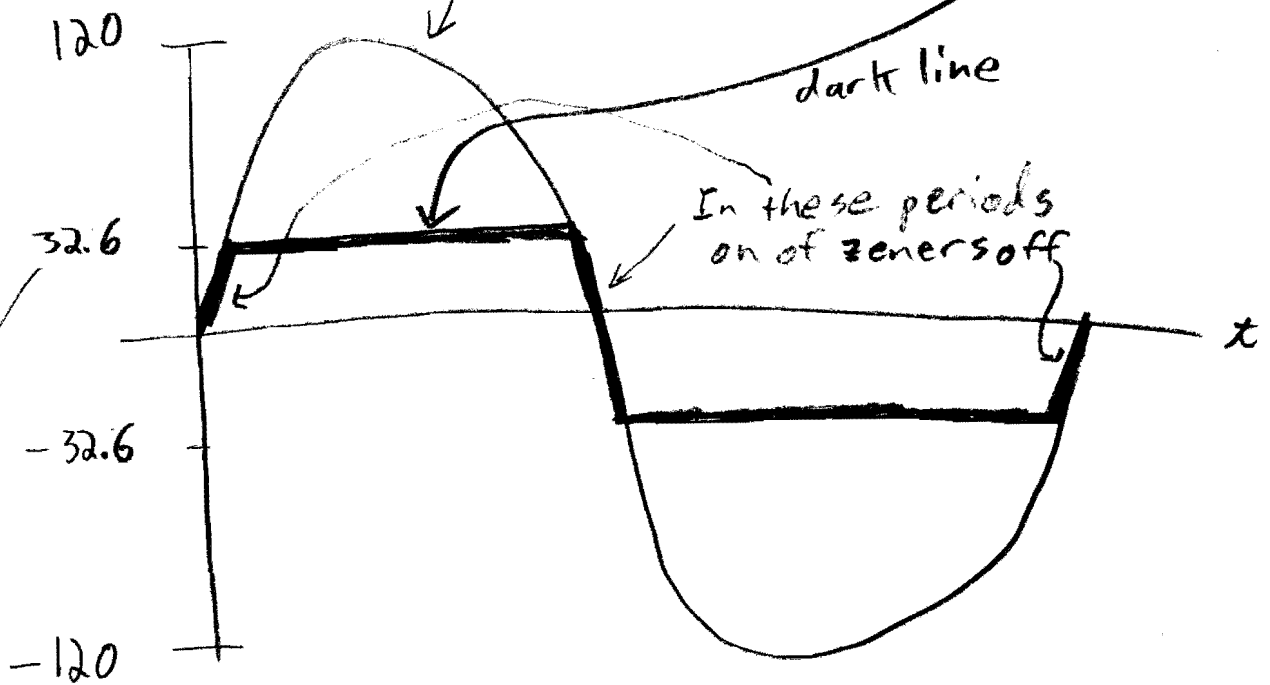
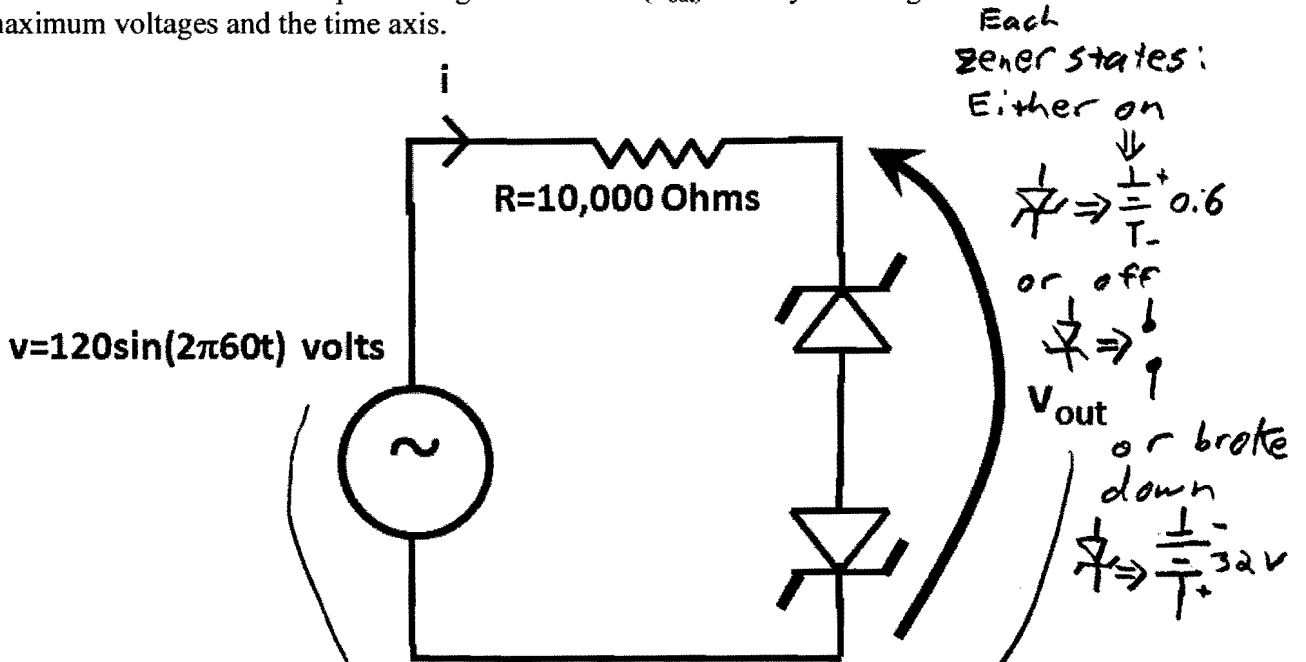
$$\boxed{p_0 = 10 \text{ cm}^{-3}}$$

$$\Delta p_n = -p_0$$

$$\boxed{p = 0}$$

11) (20 – points)

The following circuit has diodes that have a turn on voltage of 0.6 volts and a breakdown voltage of 32 volts. You may assume the diodes have no resistance in forward bias nor in breakdown. Draw the output voltage waveform ( $v_{out}$ ) clearly labeling the minimum and maximum voltages and the time axis.



$32 + 0.6 \text{ V}$   
 $\downarrow$   
 Brake down  
 $\rightarrow$  Turned on

12). Pulling all the concepts together for a useful purpose:

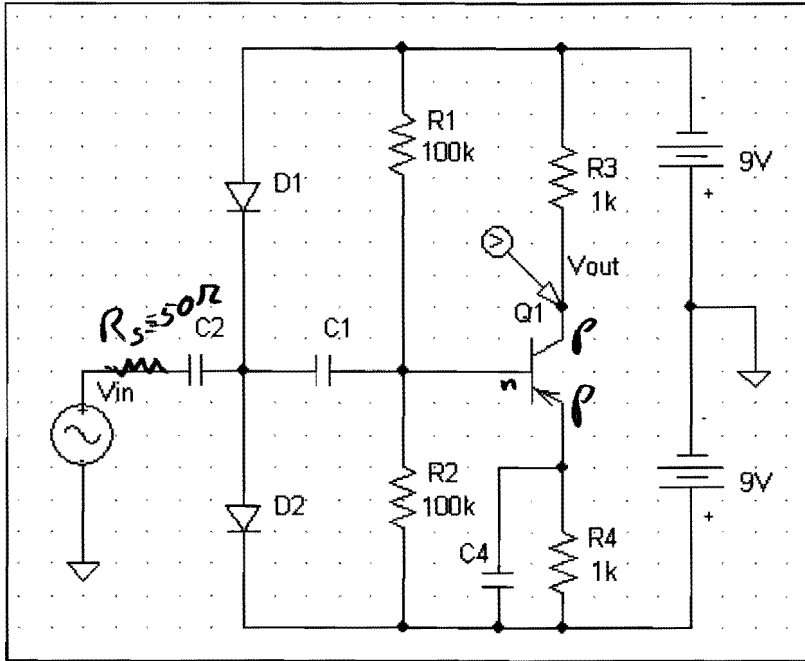
(40-points total: DC solution = 12 points, conversion to small signal model = 12 points, AC solution = 12 points and 4 points for accuracy of the graph)

For the circuit below:

Diodes:  $V_{\text{turn on}}=0.7 \text{ V}$  and  $I_0=I_s=1.83e-14\text{A}$

Q1:  $V_{\text{turn on}}=0.7 \text{ V}$ ,  $I_s=1.83e-14\text{A}$ ,  $\beta_{\text{DC}}=200$ ,  $V_A=200\text{V}$

$V_{\text{inAC}} = 1\text{mV}$  amplitude (i.e.  $2\text{mV}$  peak to peak) at 1 kilohertz (period of 1 millisecond)



Given the above input voltage,  $V_{\text{in}}$ , sketch and accurately label a plot of the output waveform  $V_{\text{out}}$  including the DC average output and the magnitude and phase of the signal. To do this you must solve the DC and AC solutions of the circuit. Assume the turn on voltages for all forward biased junctions are  $0.7 \text{ V}$ . You may assume all capacitors are very large values and are thus, AC shorts and any inductors are very large values, and thus AC opens. Additionally consider the circuit to be operated at low frequencies where you can neglect all small signal capacitances of transistors and diodes. Also, neglect all resistances that result from quasi-neutral regions. For full Credit, be sure to check your assumptions on the mode of operation of the transistor and to clearly label the axes of your plot. For full credit, do not ignore the diodes.

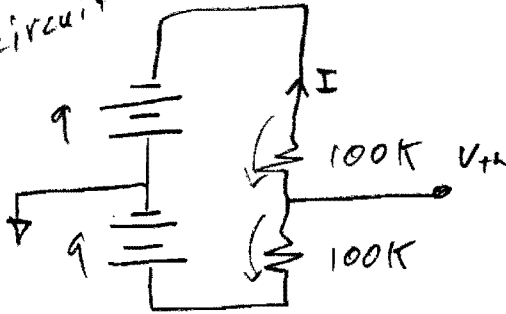
DC: Diodes: both are reverse biased (can see since each is tied to power supply)  
 $I_{D1} = I_{D2} = -I_s (\approx 0)$



Extra work can be done here, but clearly indicate with problem you are solving.

DC cont'd:

Theninize  
Base circuit



$$R_{th} = 100k \parallel 100k = 50k$$

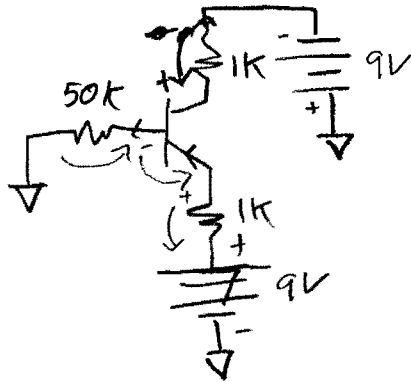
by symmetry  $V_{th} = 0$   
but if you did not see it,

$$-9V + 100k I + 100k I - 9V = 0$$

$$I = 90 \mu A$$

$$V_{th} = -9V + 100k I$$

$$V_{th} = 0V$$



Assume F.A.:

$$I_B 50k + 0.7 + I_E (1k) - 9 = 0$$

$$I_B (50k + 201(1k)) = 8.3V$$

↑  
( $\beta + 1$ )

$$I_B = 33 \mu A \quad I_C = \beta I_B = 6.61 mA$$

$$I_E = (\beta + 1) I_B = 6.646 mA$$

Check assumption:

$$V_B = 0 + I_B 50k = 1.65V$$

$$V_E = 9V - I_E (1k) = 2.354V$$

$$V_C = -9V + I_C (1k) = -2.4V$$

$$V_E > V_B > V_C \quad (\checkmark \text{ for pnp})$$

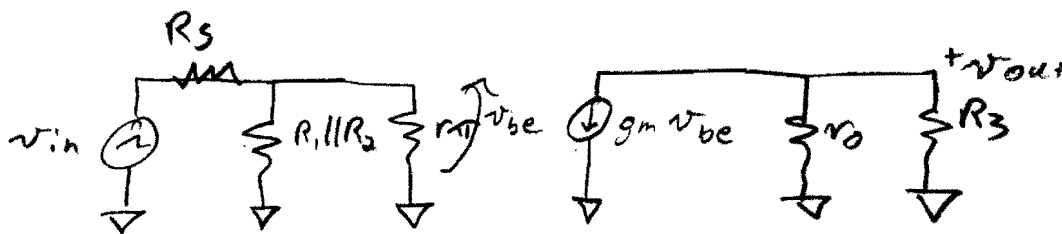
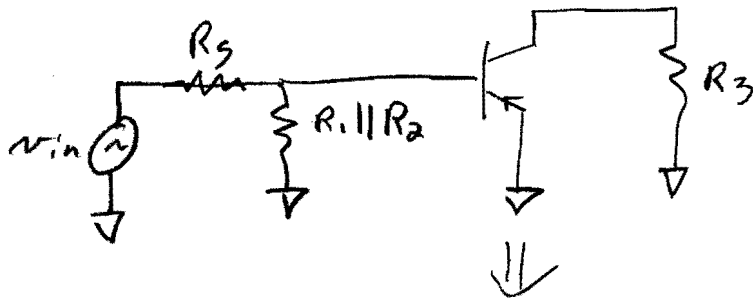
Extra work can be done here, but clearly indicate with problem you are solving.

Convert to small signal

$$g_m = \frac{I_C}{V_T} = \frac{6.61 \text{ mA}}{0.0259} = 0.255$$

$$r_{\pi} = \frac{\beta}{g_m} = \frac{200}{0.255} = 783.6 \Omega$$

$$r_o = \frac{V_A + V_{CE}}{I_C} = \frac{200 + (2.41 + 2.35)}{6.61 \text{ mA}} = 30,977$$



$$v_{be} = v_{in} \frac{R_1 \parallel R_2 \parallel r_{\pi}}{R_1 \parallel R_2 \parallel r_{\pi} + R_s}$$

$$v_{out} = -g_m v_{be} (r_o \parallel R_3)$$

$$A_v = \frac{v_{out}}{v_{in}} = \left( \frac{v_{out}}{v_{be}} \right) \left( \frac{v_{be}}{v_{in}} \right) = \left( \frac{50 \text{ k} \parallel 783.6}{50 \text{ k} \parallel 783.6 + 50} \right) \left( \dots \right)$$

$$\dots = 0.255 (30,977 \parallel 1 \text{ k})$$

$$= \cancel{232} - 232 \text{ V/V}$$

Extra work can be done here, but clearly indicate with problem you are solving.

