ECE 3040 Microelectronic Circuits

Exam 2

March 27, 2013

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Print your name clearly and largely: Solutions

Instructions:
Read all the problems carefully and thoroughly before you begin working. 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. 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 can not read it, it will be considered to be a wrong answer. 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 current in the solar cell comes from minority carriers generated by light that are sweep across the depletion region by an electric field.

2.) (2-points) True /~~False:~~ A saturated transistor behaves like a open switch.

3.) (2-points) ~~True~~/ False: Regardless of whether it is a pnp or npn, the majority carriers in the emitter of a forward active biased BJT are always injected into the base quasi-neutral region and diffuse toward the collector.

4.) (2-points) ~~True~~/ False: The Ebers-Moll model of a BJT is valid for all transistor modes including the inverse active mode we seldom use.

5.) (2-points) ~~True~~/False: Common Emitter amplifiers have the input entering the base and the output leaving the collector.

6.) (2-points) ~~True~~/ False: (Humor break to lower tension level - I promised you I would even things out and offend republicans like I did democrats on the first exam so here is two free points)...Republicans are just as corrupt as democrats while libertarians can't stop smoking pot long enough to know how to be corrupt.

7.) (2-points) ~~True~~/ False: When a transistor amplifier leaves forward active mode due to a large output signal swing, the first mode of operation it enters is either saturation or cutoff.

8.) (2-points) ~~True~~/ False: In forward bias, the junction capacitance is greater than the zero bias junction capacitance ($C_j > C_{jo}$).

9.) (2-points) According to the "Law of the Junction" for a forward biased p-n diode, ...
   a. ...there are fewer minority carriers at the depletion region edges than in equilibrium
   ⓑ ...there are more minority carriers at the depletion region edges than in equilibrium
   c. ...the voltage on the diode should always be 0.7 volts
   d. ... breakdown will occur at high electron concentrations near the depletion region edges
   e. ... forget this stuff, I will go work at Walmart[TM].

10.)   2-points) When a diode is forward biased to near the built in voltage...
   a.   ...the dominant current is drift current.
   ⓑ   ... the dominant current is diffusion current.
   ⓒ   ... the dominant capacitance is diffusion capacitance.
   d.   ... the dominant capacitance is depletion capacitance.
   e.   ... the energy bands are strongly sloped
   ⓕ   ... the energy bands are almost flat.
   g.   None of the above.

11.) (20 points)

Note: Neatness and clarity counts in the drawings for this problem.

A room temperature SiGe semiconductor pnp BJT is to be operated in forward active mode. It has the following parameters:

SiGe bandgap=1.0 eV.

V_{BI-EB}=0.8 volt (built in potential of the emitter base junction)

V_{BI-CB}=0.6 volt (built in potential of the collector base junction)

(a – 5 points) Draw the equilibrium energy band diagram, labeling the built in voltages and fermi level (do not calculate the fermi level – just sketch it).
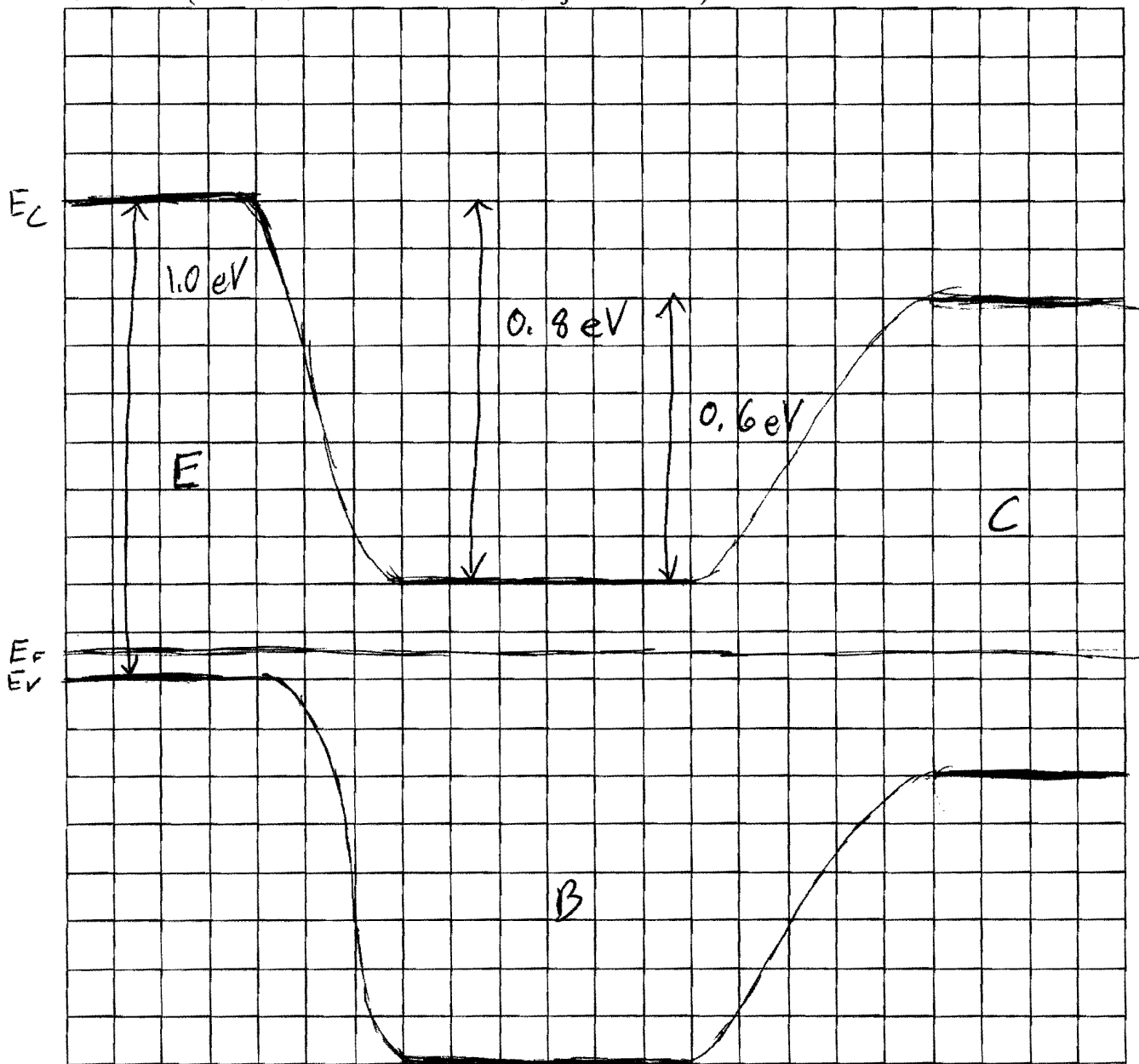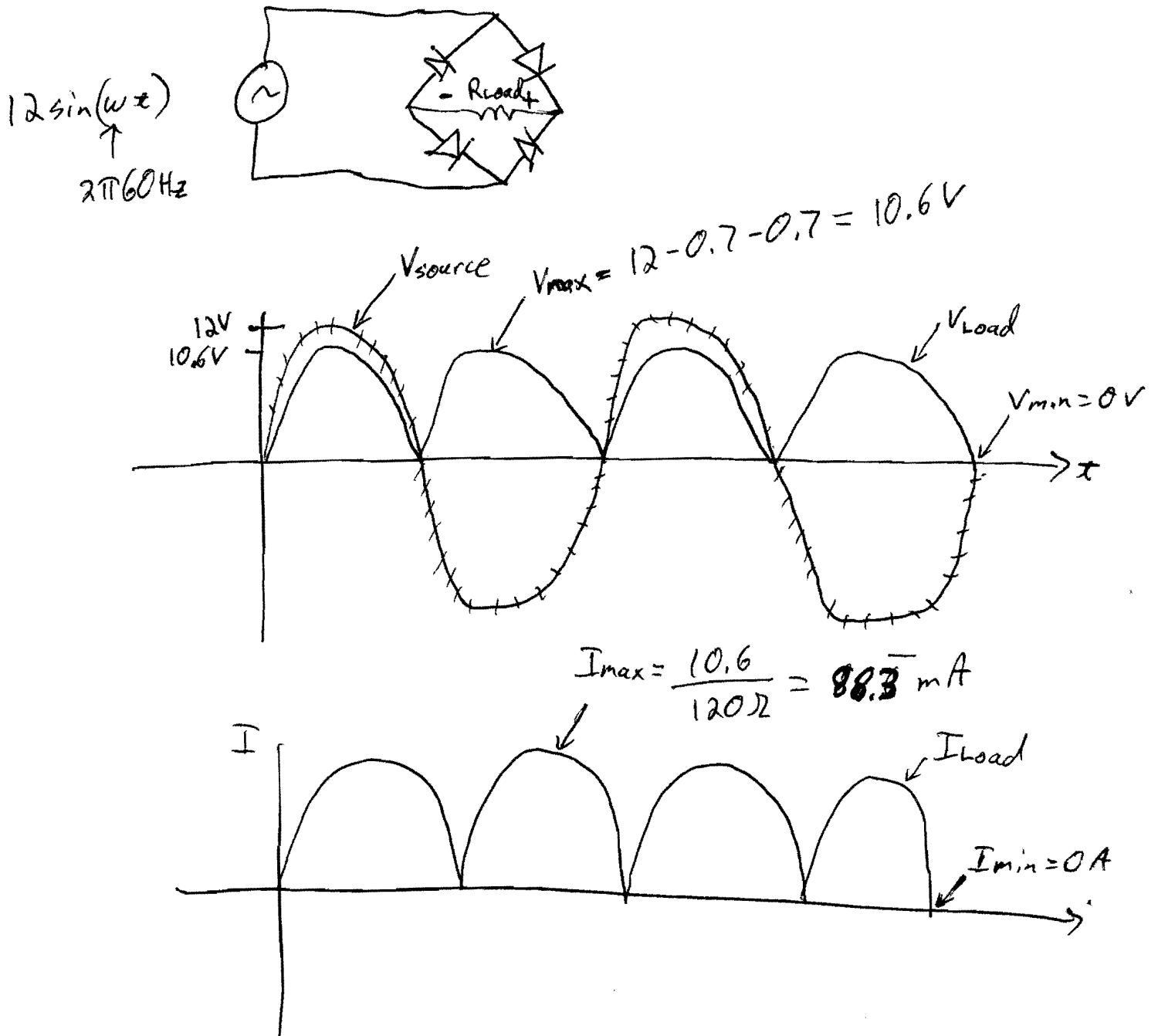
(b – 10 points) Read part C first so you can plan ahead. Sketch and label the energy-band diagram of the BJT when the $|V_{EB}|$ =0.5V and $|V_{CB}|$ =0.7V.
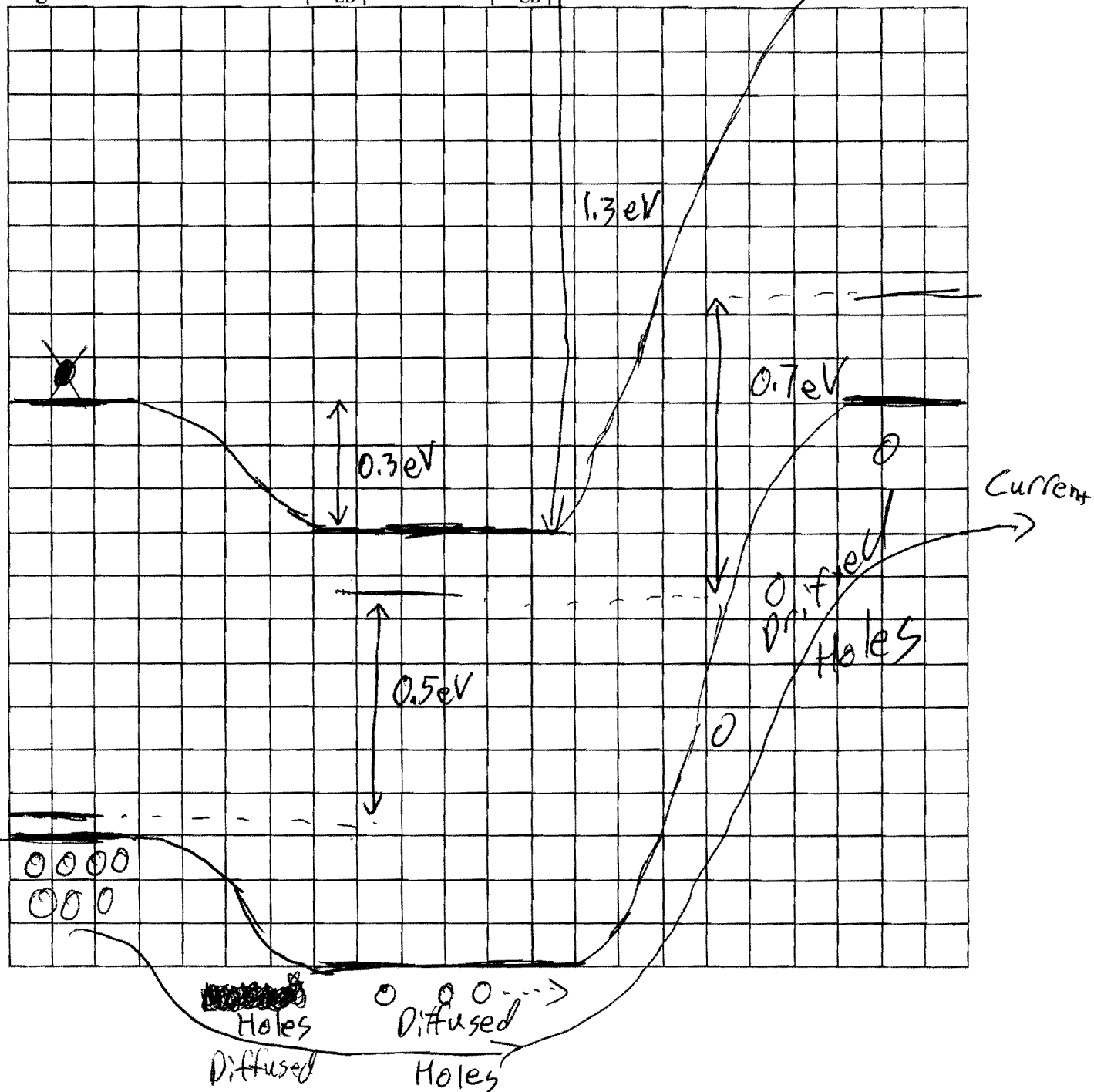
(c – 5 points) On the sketch in part b indicate with holes (open circles) and electrons (filled circles) the direction of carrier motion of the majority carrier in the emitter as it passes through the device and indicate with arrows the direction of the net current flow.

13) (20 – points) Design Problem: Design a circuit which uses only 4 diodes to create a full wave rectifier powering a resistor, R_{Load}=120 ohms. Assume your diodes have negligible leakage current and have a 0.7V turn on voltage. Draw the schematic and sketch and label the maximum and minimum values of the voltage and current waveform across the load resistor. Assume a 24 volt peak to peak AC input voltage at 60 Hertz. (Yes you <u>have</u> been given enough information to solve the problem).

$12 \sin(\omega t)$

$2\pi 60 Hz$

- Rload +

V_{source}

$V_{max} = 12 - 0.7 - 0.7 = 10.6\,V$

V_{Load}

$12V$
$10.6V$

$V_{min} = 0\,V$

t

$I_{max} = \dfrac{10.6}{120\,\Omega} = 88.\overline{3}\,mA$

I

I_{Load}

$I_{min} = 0\,A$

14). **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)
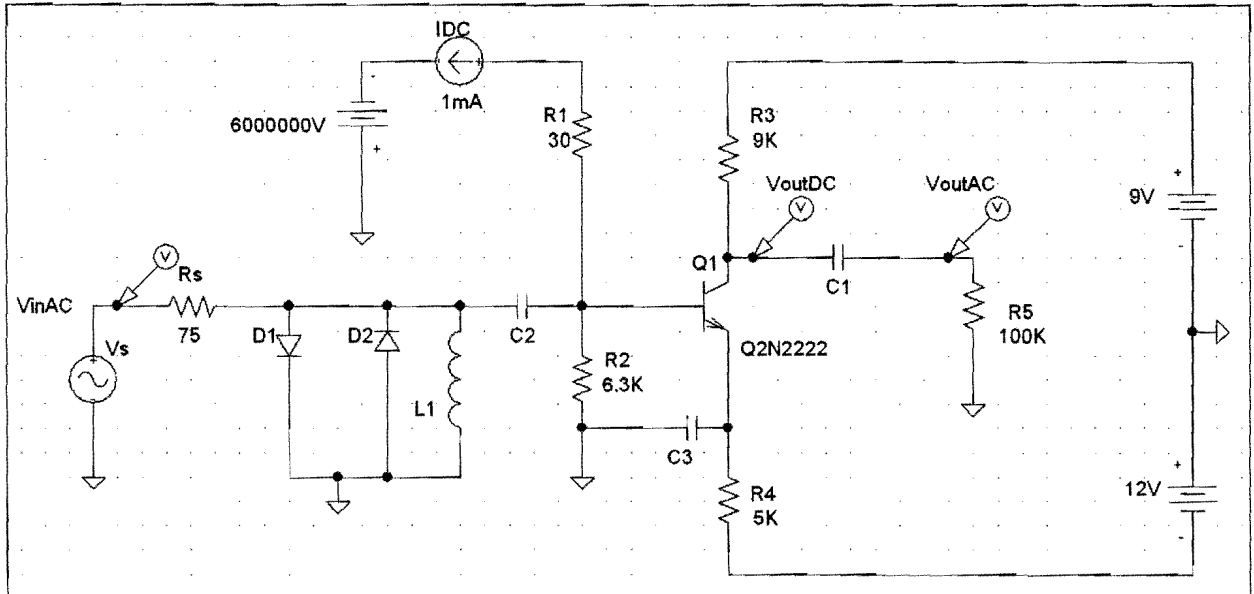
For the circuit below:
Q1: $V_{turn\ on}=0.7$ V, $\beta_{DC}=255.9$, $V_A=100$V
D1 and D2: $I_s=I_o=172.666$ uA (i.e. 172.666E-6A)
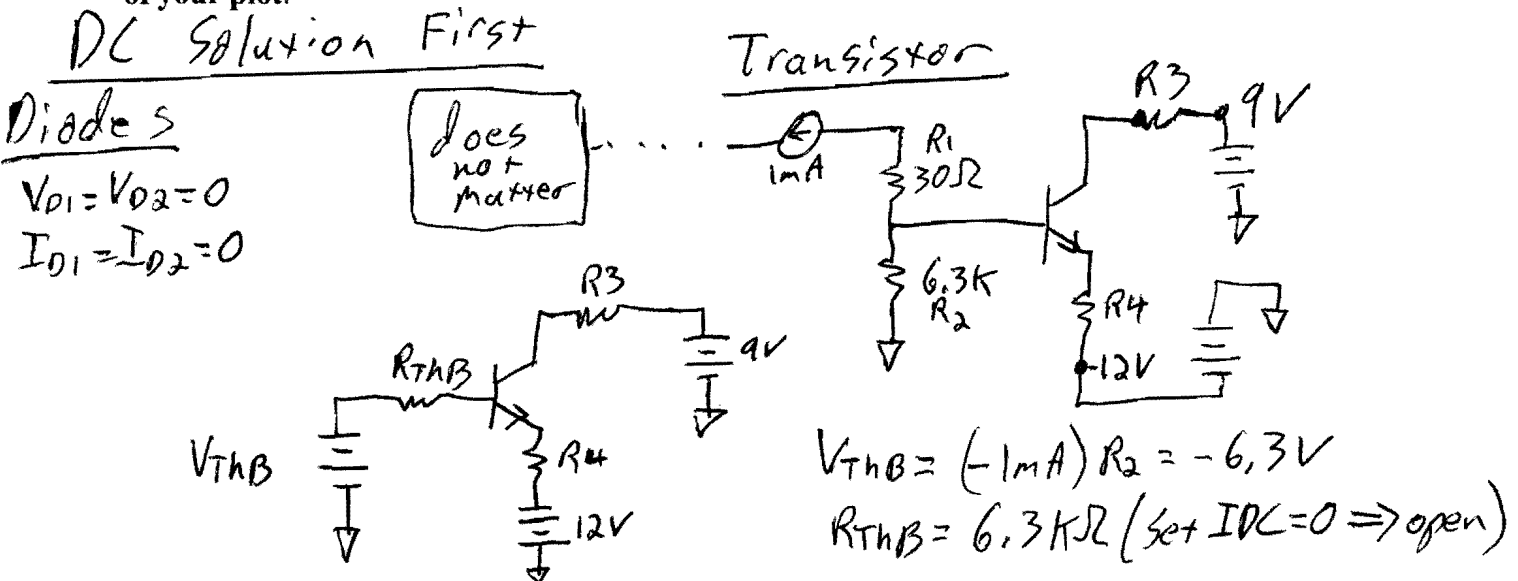Current source, IDC= 1.0 mA DC
NOTE: There are 3 different DC power supply values, 12V, 9V, and 6,000,000V (not a typo).
VinAC = 1mV amplitude (i.e. 2mV peak to peak) at 1 KiloHertz

Given the above input voltage, VinAC, sketch and accurately label a plot the output waveforms and VoutDC on the graph paper provided on the next page. Assume the turn on voltages for all forward biased junctions are 0.7 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, <u>CLEARLY SHOW ALL WORK</u> and be sure to check your assumptions on the mode of operation of the transistor and to clearly label the axes of your plot.**

<u>DC Solution First</u>

<u>Diodes</u>

$V_{D1} = V_{D2} = 0$

$I_{D1} = I_{D2} = 0$

does not matter

<u>Transistor</u>

$V_{ThB} = (-1mA) R_2 = -6.3 V$

$R_{ThB} = 6.3 K\Omega \ (set\ IDC = 0 \Rightarrow open)$

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

$$V_{ThB} = -12V + I_E R_4 + 0.7 + I_B R_{ThB}$$

$$-6.3V = -12V + 0.7 + I_B[(255.9+1)5000 + 6300]$$

$$I_B = 3.87 \mu A$$

$$I_c = \beta I_B = 255.9(3.87\mu A) = 0.9912 mA$$

$$I_E = (\beta+1)I_B = 256.9(3.87\mu A) = 0.9951 mA$$

$$V_B = V_{ThB} - I_B R_{ThB} = -6.3 - (3.87\mu A)6300$$

$$= -6.324V$$

$$V_E = -12 + I_E R_4 = -12 + (0.9951mA)5000$$

$$= -7.02V$$

$$V_c = 9V - I_c 9k = 9V - (0.9912mA)9000$$

$$= 0.0792 V$$

$$V_c > V_B > V_E \qquad FA \quad Verified$$

Convert to small signal model:
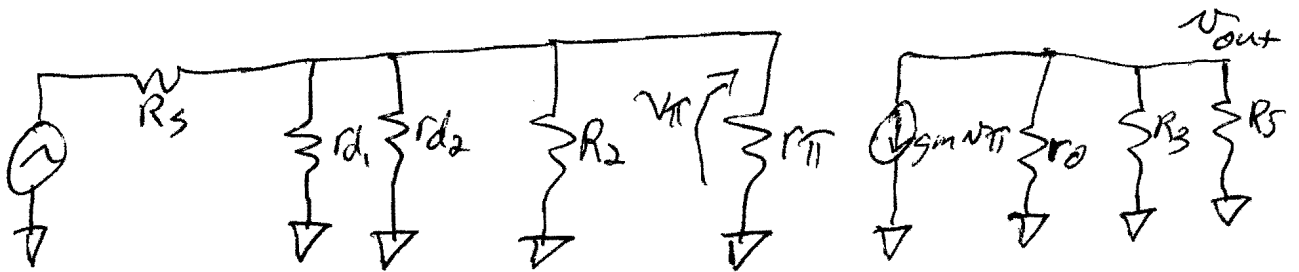
$$rd_1 = rd_2 = \frac{V_T}{I_D + I_S} = \frac{0.0259}{0 + 172.66\mu A} = 150\Omega$$

$$g_m = \frac{I_c}{V_T} = \frac{0.9912 mA}{0.0259} = 0.03827 S$$

$$\frac{\beta}{g_m} = r_\pi = 6686\Omega$$

$$* \, r_o = \frac{V_{CE} + V_A}{I_c} = \frac{(0.0787 - (-7.02V)) + 100V}{0.9912 mA}$$

$$* \, r_o = 108 K$$

$$v_\pi = v_S \frac{rd_1 || rd_2 || R_2 || r_\pi}{R_S + rd_1 || rd_2 || R_2 || r_\pi} \implies \frac{v_\pi}{v_S} = \frac{150||150||6300||6686}{75 + (\quad)}$$

$$\frac{v_\pi}{v_S} = 0.494 \, v/v$$

$$v_{out} = v_\pi g_m (r_o || (R_3 || R_5)) \implies \frac{v_{out}}{v_\pi} = -(0.03827)(108K || 9K || 100k)$$

$$\frac{v_{out}}{v_\pi} = -293 \, v/v$$

$$A_v = \frac{v_{out}}{v_S} = \left(\frac{v_\pi}{v_S}\right)\left(\frac{v_{out}}{v_\pi}\right) = (0.494)(-293)$$

$$\boxed{A_v = -145 \, v/v}$$

Answer Page

Plot VoutAC and VoutDC on the same graph.

$145 + 79mV = 224mV$

224mV

145mV

0.079V

0V

66mV

−145mV

$V_{out}DC$

$V_{out}AC$

66mV