ECE 3040 Microelectronic Circuits

Exam 2

October 28, 2019

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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. **Turn in all note sheets with your exam.** There are 100 total points in this exam+10 additional bonus points. 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 and ***DO NOT SEPARATE THE EXAM PAGES***. 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: Solar Cells, Photodiodes, LEDs, LASER Diodes are all forms of diodes performing different optoelectronic functions.

2.) (2-points) True / False: An ideal diode model acts as a perfect switch and can [redacted] be used when the turn on voltage is negligible.

3.) (2-points) True / False: Large n and p-type doping concentrations lead to large leakage currents in diodes.

4.) (2-points) True / False: The Ebers-Moll Model suggests that a BJT biased into saturation can be replaced with two very small current sources.

5.) (2-points) True / False: The EBERS-Moll Model can be used for all bias modes of the BJT except Inverse Active.

6.) (2-points) True / False: For a BJT in forward active mode, the electric field in a reverse biased collector-base junction acts like a carrier extractor that strips the carriers from the base that were injected from the emitter.

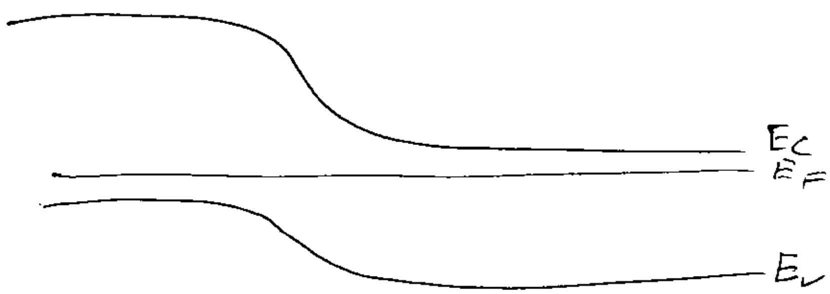
7.) (2-points) True / False: The amplification process of a forward active BJT results from a small base current controlling a much larger collector – emitter current.

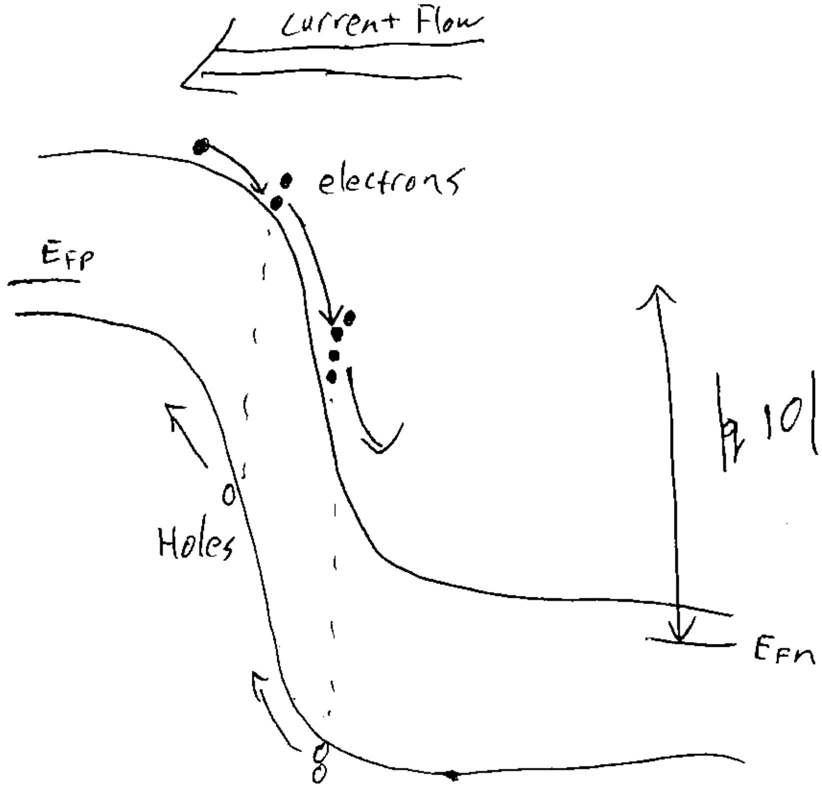
8.) (2-points) True / False: Zener breakdown results from the Pauli Exclusion principle from Quantum Mechanics.

9.) (2-points) True / False: In a forward biased diode, the current results from the electric field drifting carriers over the energy barrier and thus, drift current dominates over diffusion current. Diffusion dominates

10.) (2-points) True / False: A BJT in saturation is modeled as two series connected batteries.

11) (15 Points)
Draw the Energy band diagram of a Si (Eg=1.1 eV) Zener diode biased under equilibrium conditions and (separately) under 10 Volts reverse bias. Label the p and n sides of the junction, the conduction band and fermi and quasi-fermi levels in the quasi neutral regions. With the help of arrows indicated carrier motion and current flows, empty circles representing holes and solid circles representing electrons, show the avalanche multiplication process resulting a large current flow.

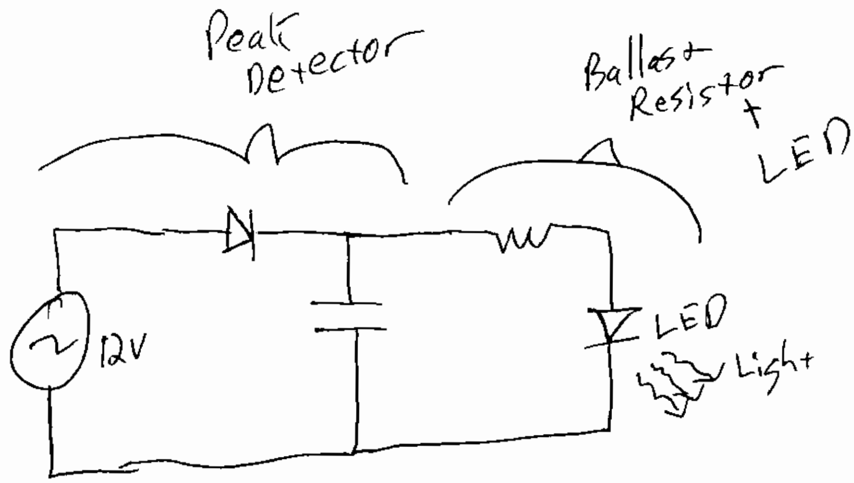




12.) (15 points total in 2 parts)

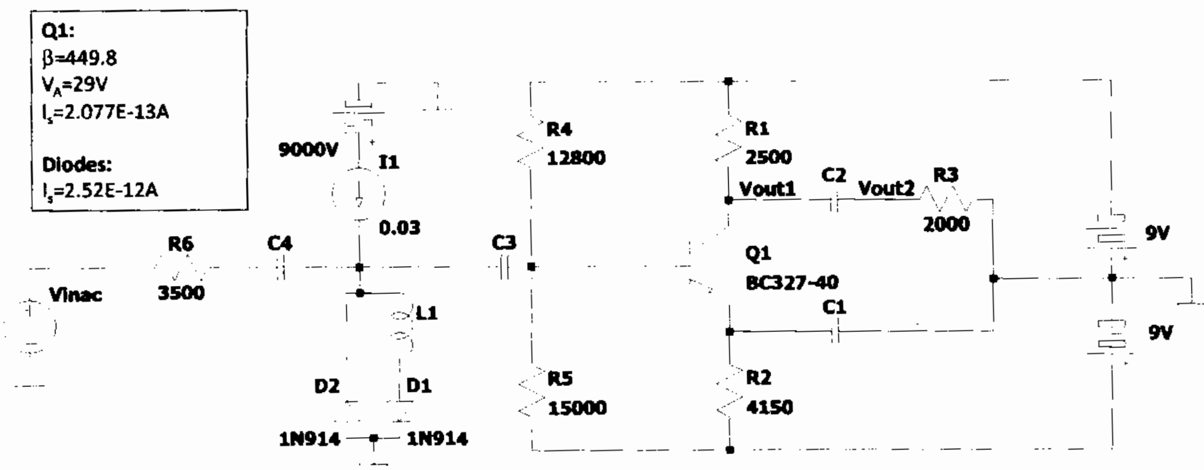
An LED is specified to have rated optical output at 20 mA and 1.4 volts turn on voltage (typically called $V_{forward}$ in data sheets). Given a standard 120 volt AC wall plug receptacle voltage, design a schematic for a circuit that converts the AC voltage to DC Voltage and powers the diode with the rated DC current and voltage to act as a visible power status indicator. At minimal you should use a diode, capacitor, resistor and the LED. Note: do not use and LED as part of any rectifier circuit as they cannot withstand large reverse biases.

No need to analyze the circuit — just design it.



Could have also used a full or ½ wave Rectifier instead of a peak detector

13) **Pulling all the concepts together for a useful purpose**:
(50-points total: DC solution = 15 points, conversion to small signal model = 15 points, AC solution = 15 points and 5 points for accuracy of the graphs and 10 points for the bonus solution of the correct turn on voltage) .



For the circuit above, you will be asked to solve for two cases, the second being 10 points Bonus:

A) The small signal gain of the amplifier and plot the small signal output waveforms Vout 1 and Vout 2 when the input Vinac=1 mV AC and

B) (Bonus 10 points) The output waveforms when the input Vinac=100 mV AC.

Initially Assume Q1: **$V_{\text{Base-Emitter turn on}}$=0.6 V**, $V_{\text{Base-Collector turn on}}$=0.4 V, β_{DC}=449.8, Early Voltage=29V, I_s=2.077E-13 Amps

D1: **$V_{\text{turn on}}$=0.6 V** , Is=2.52E-12 amps
V_{in} = 1mV amplitude (i.e. 2mV peak to peak) at 1 KiloHertz

Given the above input voltage, Vinac, sketch and accurately label a plot of the output waveforms V_{out1} on the graph paper provided on the next page. Assume the turn on voltages for all forward biased junctions are as described above. You may assume all capacitors are very large values and any inductors are very large values. 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 diodes and to clearly label the axes of your plot.**

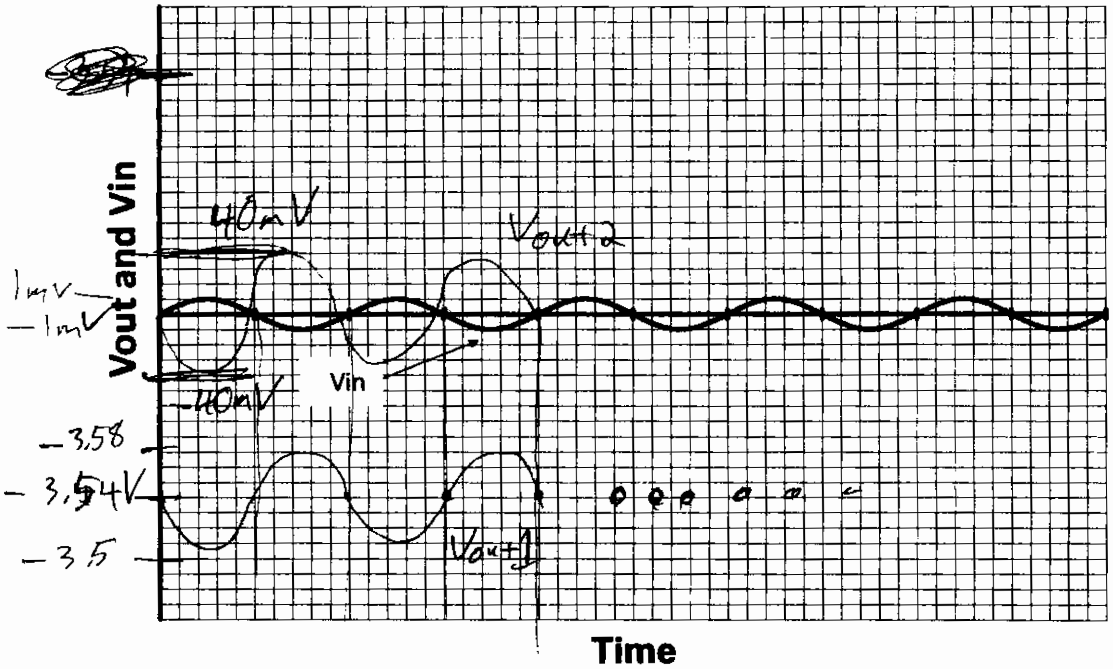
D.C. D2 is Reverse Biased, $\Rightarrow I_{D2} = 0$ or $(-2.52e-12\ A)$
D1 is Forward Biased: Could use 0.6V VA or,,,

D1: V_A $\quad 30mA = 2.52pA\,(e^{V_A/0.0259} - 1)$

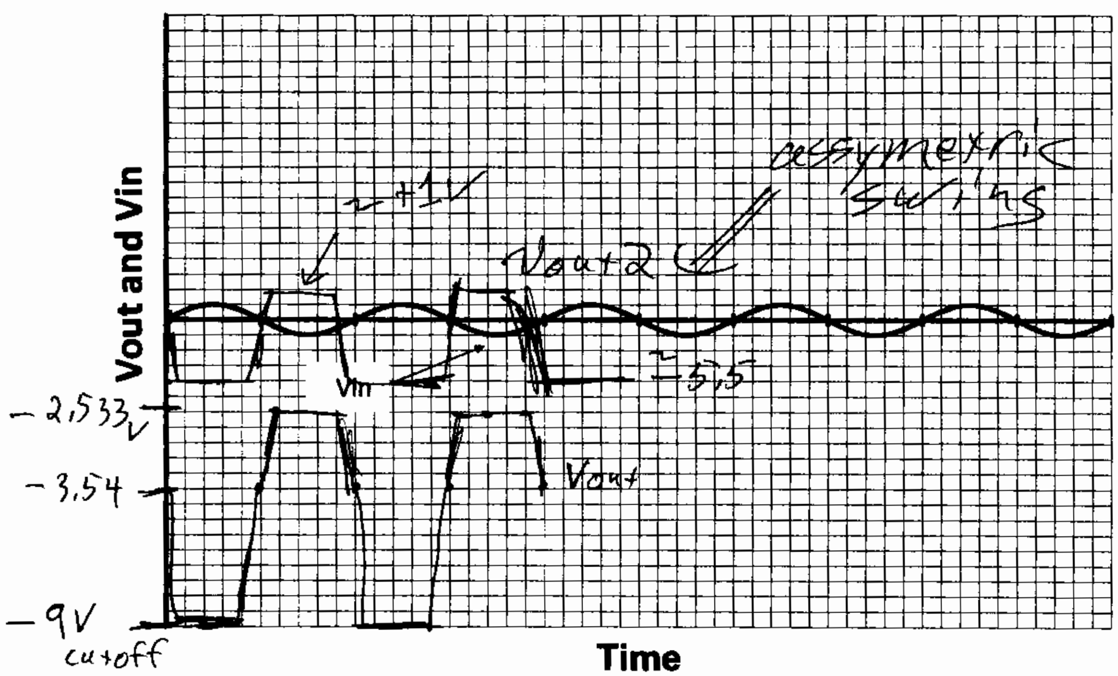
$V_{A_1} = 0.6\ V$

Small Signal answer Page (NOTE: Vin and Vout can have different y-axis values so label the axis or label the signal peaks)

Part A:



Bonus Part B



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

DC Q1:

$V_{then-Base}$:

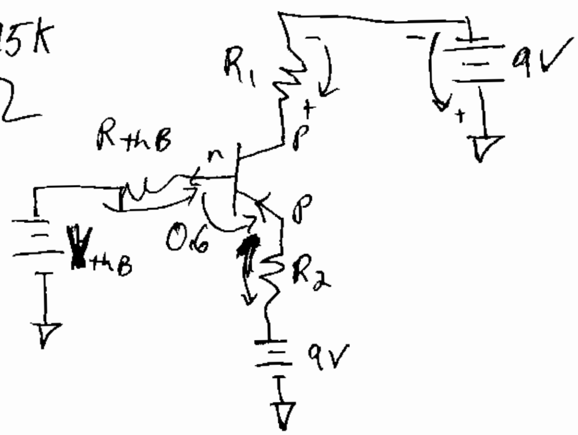
Superposition

$$V_{thB} = -9\left(\frac{R_5}{R_5+R_4}\right) + 9\left(\frac{R_4}{R_5+R_4}\right)$$

$$= -0.7122\ V$$

$$R_{thB} = 12.8K \| 15K$$

$$= 6906\ \Omega$$



$$V_{thB} + I_B R_{thB} + 0.6 + I_E R_2 - 9V = 0$$

$$-0.7122 + I_B(6906 + (1+449.8)4150) + 0.6 - 9V = 0$$

$$I_B = \frac{9.1122}{1{,}877{,}726} = 4.852\ \mu A$$

$$I_C = \beta I_B = 2.182 mA$$

$$I_E = (1+\beta) I_B = 2.187 mA$$

$$V_B = V_{thB} + I_B R_{thB}$$

$$= -0.678$$

$$V_C = -9V + I_C R_1 \leftarrow 2500$$

$$= -3.543$$

$$V_E = 9V - I_E R_2$$

$$= -0.0787\ V$$

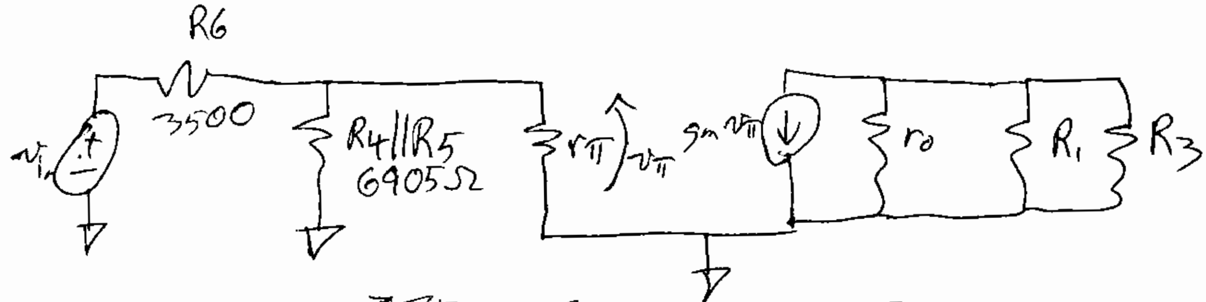
Assumption Verified

$V_{EB} = 0.6$ ✓

$V_{CB} = -2.86\ V$ (p n) ✓

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

Ac solution



$r_\pi = \beta / g_m = 5337\ \Omega$

$g_m = I_C / V_T = 0.0843\ \mho$

$r_o = \dfrac{V_A + V_{CE}}{I_C} = \dfrac{29 + (3.543 - 0.0787)}{2.18\text{mA}} = 14.87\text{k}\Omega$

1) $v_\pi = \dfrac{R_4 || R_5 || r_\pi}{R_4 || R_5 || r_\pi + R_6} v_{in} = v_{in} \dfrac{3010.3}{3010.3 + 3500}$

$= 0.4624 v_{in}$

2) $v_{out} = -g_m v_\pi (r_o || R_1 || R_3)$

$= -v_\pi\ 0.0843 (1033.8)$

$= -v_\pi\ 87.15$

$\dfrac{v_{out}}{v_{in}} = \underset{(1)}{\left(\dfrac{v_\pi}{v_{in}}\right)} \underset{(2)}{\left(\dfrac{v_{out}}{v_\pi}\right)}$

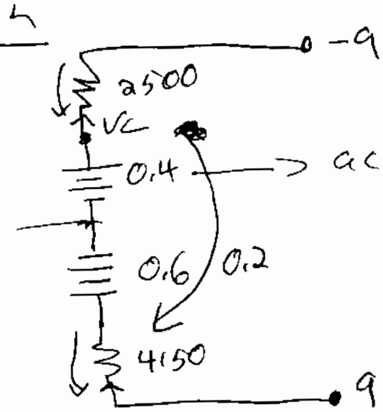
$= -40.3\ V/V$

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

Bonus

$V_c = -9V$ @ cutoff

Saturation



Assume: $I_c \approx I_E$

$$-9V + 2500 I_E + 0.2 + I_E(4150) = 9V$$

$$I_c = \frac{18 - 0.2}{2500 + 4150}$$

$$= 2.58 mA$$

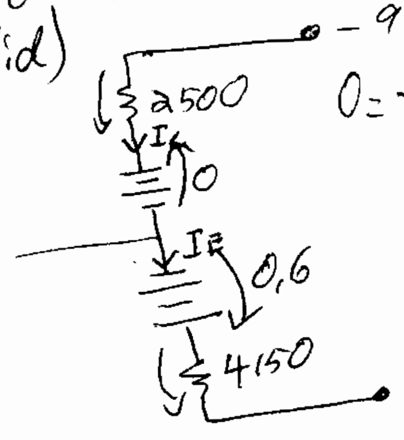
$$V_{c\,saturated} = -9 + I_c 2500$$

$$= -2.533 V$$ ✓

Alternate Approach

Assume operation on border of Forward Active/Saturation

(β is marginally valid)



$$0 = -9 - 9 + 2500 I_c + 0.7 + I_E(4150)$$

(αI_E)

$$I_E = \frac{18 - 0.7}{2500\alpha + 4150}$$

$$I_E = 2.6 mA$$

$$I_c = \alpha I_E = 2.598 mA$$

$$V_{c\,saturated} = -9 + I_c 2500$$

$$V_{c\,saturated} = -2.5 V$$

$$\alpha = \frac{\beta}{\beta + 1} = \frac{449.8}{450.8} = 0.99778$$