ECE 3040 Microelectronic Circuits

Exam 2

April 2, 2012

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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:

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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: Diffusion capacitance results from the injection of minority carriers across the junction and thus is dominant in reverse bias.

2.) (2-points) True / False: If using a BJT to control current flowing to a motor, when you want current to fully turn on the motor, you would want the transistor in forward active mode since it supplies both voltage across it's base-collector terminals and current from its base-emitter terminals.

3.) (2-points) True / False: The source of the finite output impedance, r_o, of a BJT is the fact that the base quasi-neutral region width changes with applied base-collector reverse bias.

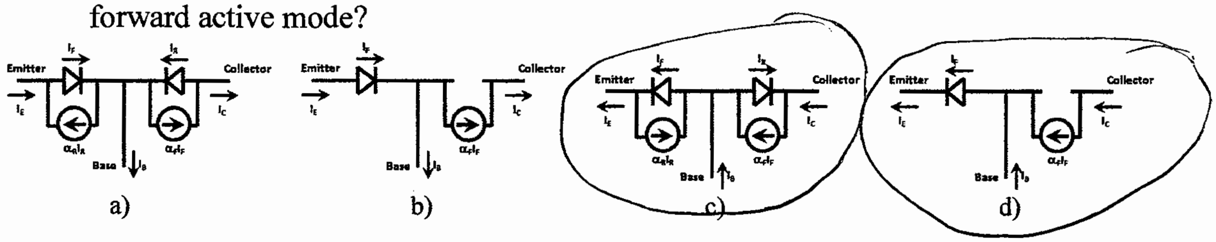
4.) (2-points) True / False: Since a BJT is a minority carrier device, the carrier injected from the emitter into the base for a forward active biased pnp BJT is an electron.

5.) (2-points) True / False: The law of the junction describes the carrier concentration at the depletion region edges as a function of the applied voltage across the junction such that negative changes in electron concentrations can only occur in reverse bias.

6.) (2-points) True / False: A solar cell differs from a photodiode only in that a solar cell is reverse biased to enhance collection of carriers where as a photodiode is forward biased.

7.) (2-points) True / False: Given any non-linear current voltage curve bound by real current and voltage values (i.e. neither voltage nor current can be infinite) even for devices we have not yet studied, a small signal conductance can be defined as the slope of the I-V curve taken around a DC operating point

8.) (2-points) Which of the following circuits can represent a npn transistor biased into forward active mode?



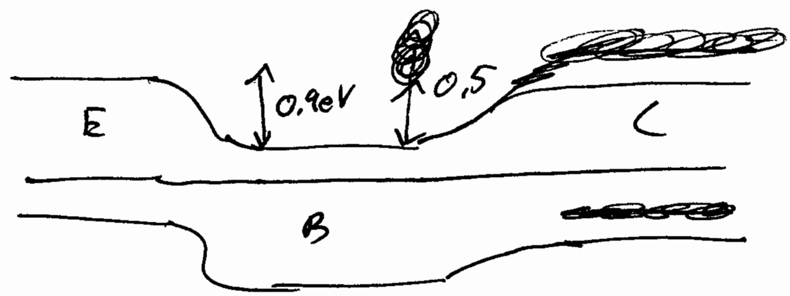
9.) (2-points) True / False: For a silicon Zener diode with a bandgap of 1.1 eV, if it's breakdown voltage is 2 volts, it is likely operating in avalanche mode not Zener mode.

10.) (2-points) True / False: If a cat gets hit by a car crossing the road, it is still a cat so no one really cares.

12.) (20 points total in 2 parts)
Note: Neatness and clarity counts in the drawings for this problem.
All parts refer to a room temperature silicon pnp BJT with a 0.9 volt base-emitter and 0.5 volt base collector built in potential and a 1.1 eV bandgap.

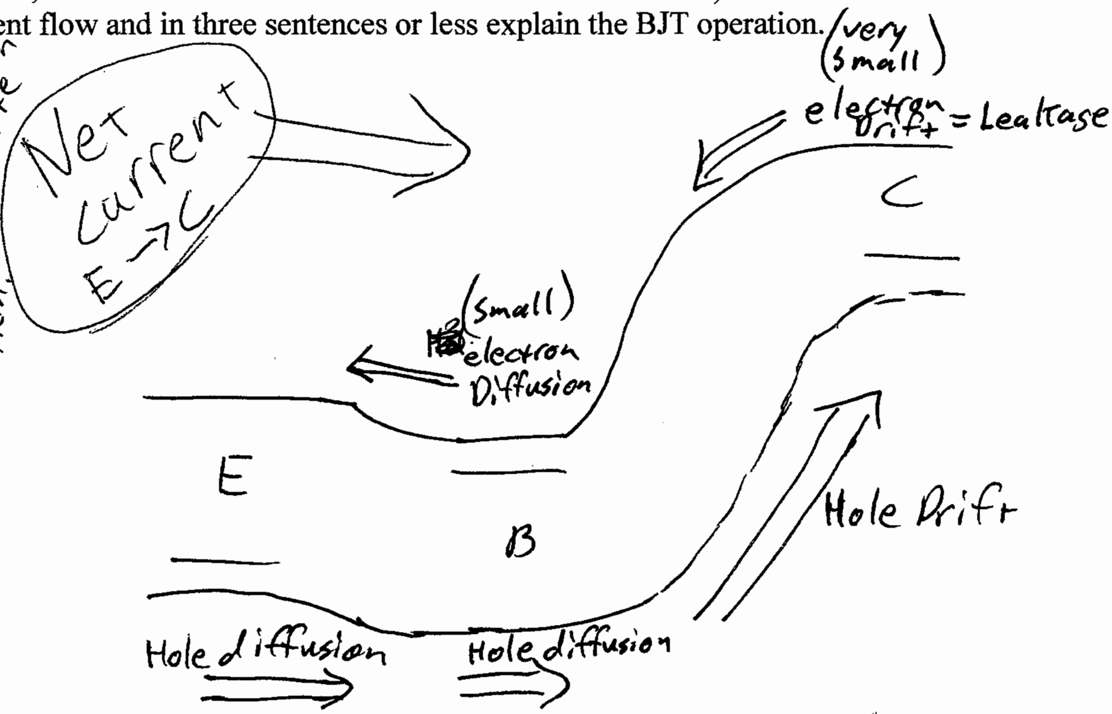
(a – 6 points) Draw the equilibrium energy band diagram, labeling the built in voltages and fermi level (do not calculate the fermi level – just sketch it).

Ignore scribbled lines



(b – 14 points) If the device is biased into forward active mode, draw and label the energy band diagram using LARGE (for me to see them) arrows to label the direction of the major components of current flowing in this device (for example: Drift hole current, Diffusion hole current, Drift electron current and Diffusion electron current). Indicate the direction of the net current flow and in three sentences or less explain the BJT operation.

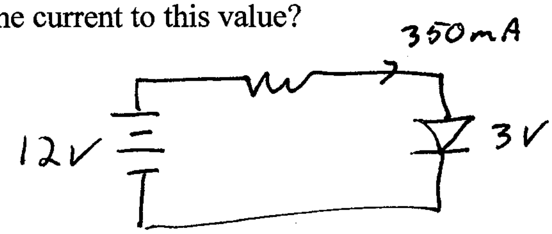
Note: arrows indicate carrier flow. Current direction for electrons is opposite arrow direction



Emitter Majority carriers (Holes) are emitted into the base where they diffuse as minority carriers and are collected by the large electric field of the base-collector junction. A forward bias on the base-emitter lowers the barrier for diffusion of the holes into the base.

13) (20 – points) Design Problem: A GaN semiconductor LED is used in an automotive headlight application that has a 12 volt battery. The device is specified to run at 3 volts turn on voltage and a current of 350 mA (called $V_{forward}$ and $I_{forward}$ in a LED data sheet).

a) 4 points - What "ballast" resistor (give both ohm value and minimum power rating) will limit the current to this value?



$$\boxed{R = \frac{12-3}{0.35} = 25.7\,\Omega}$$

$P = I^2 R = 3.14$ watts

need a power rating of minimum 3.14 watts

LEDs are sensitive to overvoltage, i.e. using excessive voltage on the LED. This can happen for example when the battery is being charged at greater than 12 V.

b) 6 points - What current results when the LED applied voltage ON THE DIODE NOT THE BATTERY is changed to 3.2 Volts? Be sure your answer takes into consideration where inside the diode, the light in an LED comes from. (Yes you have been given enough information to solve the problem).

$$0.35 = I_s\left(e^{3V/2(0.0259)} - 1\right)$$

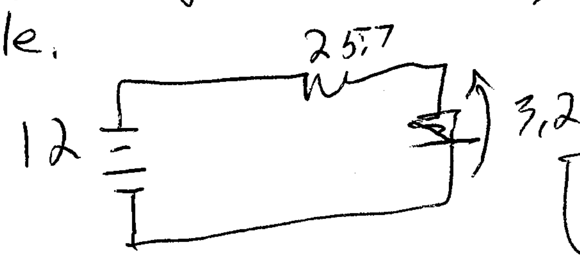
$$I_s = 2.465\text{e-}26$$

$$I_{new} = I_s\left(e^{3.2/2(0.0259)} - 1\right)$$

$$= \underline{16.6 \text{ Amps}}$$

Note: Since an LED is designed with quantum wells to insure depletion region recombination, $\eta = 2$ in the exponential.

Some assumed V^+ & R were same; This was acceptable.



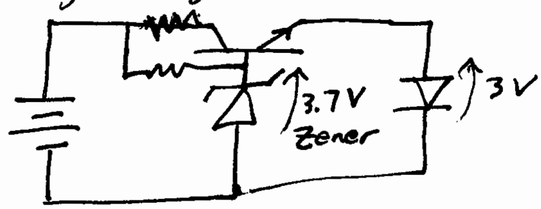
$$I = \frac{12-3.2}{25.7}$$

$$\boxed{I = 0.342 \text{ Amps}}$$

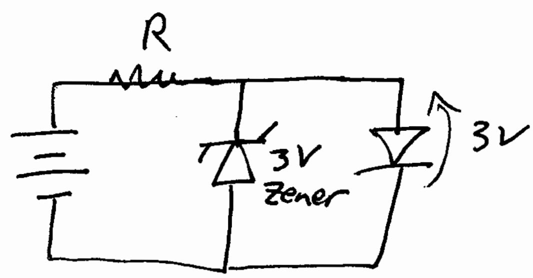
c) 10 points – Using only one or two extra semiconductor components of your choice, and any number of resistors you need, (certainly you can use the battery, and LED as well), design a circuit that will protect the LED from overvoltage. Your semiconductor components (npn, pnp, diodes, zener diodes, etc…) can have any voltage or current rating you need. If you can do this design problem, you are an engineer and not a technician.

Two Options

Best Voltage Regulator



Okay

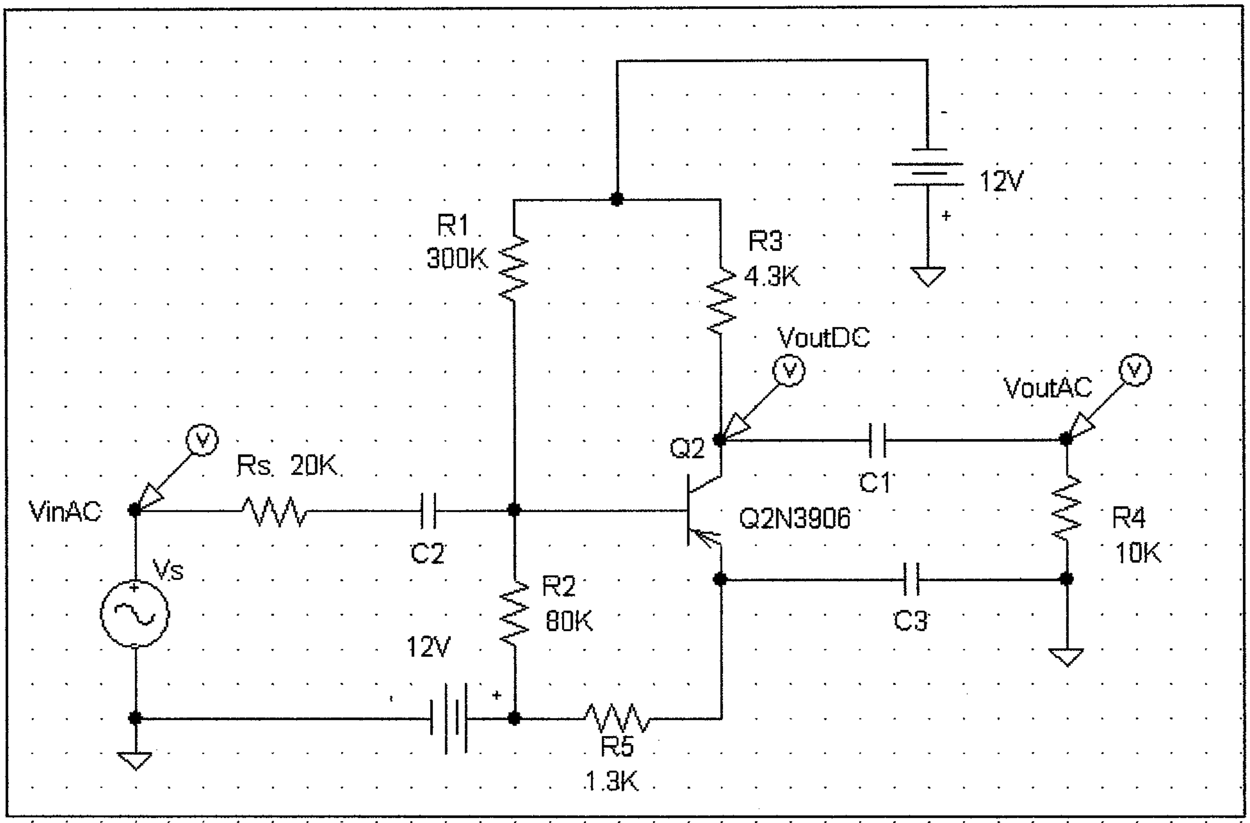


Note: several of you thought of this option but the Zener will have a less sudden turn-on than the LED so it is not very effective @ clamping the LED voltage to exactly 3V

DC - 12 points
conv - 12 points
AC - 12 points
Graph - 4 points

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, β_{DC}=180.7, V_A=100V
VinAC = 1mV amplitude (i.e. 2mV peak to peak) at 1 KiloHertz

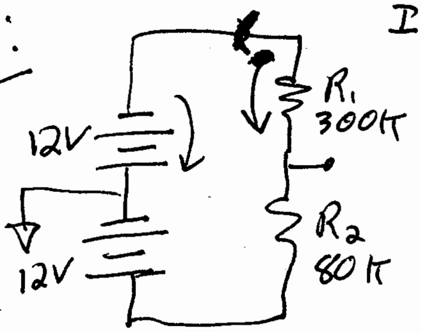


Given the above input voltage, VinAC, sketch and accurately label a plot the TWO output waveforms VoutAC and VoutDC on the graph paper provided on the next page. Assume the turn on voltages for all forward biased junctions are 0.7 V. You may assume all capacitors are very large values and are thus, AC 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, be sure to check your assumptions on the mode of operation of the transistor and to clearly label the axes of your plot.**

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

DC Solution

V_{th}:
R_{th}:

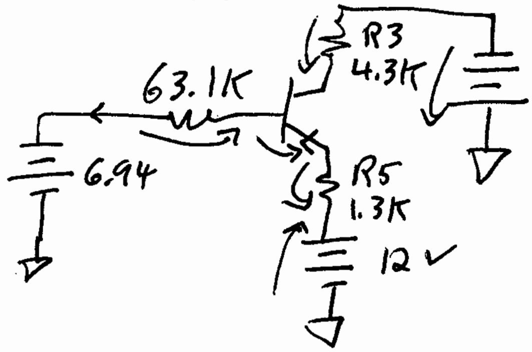


$$I = \frac{24V}{380K} = 63.16\,\mu A$$

$$V_{th} = -12V + I\,300K$$

$$V_{th} = 6.94V$$

$$R_{th} = 300K \| 80K = 63.1K$$



$$6.94V + I_B(63.1K) + 0.7V + I_E(1.3K) - 12 = 0$$

$I_E = (\beta+1)I_B$

$$I_B = \frac{12 - 6.94 - 0.7}{(63.1K) + (180.7+1)\,1.3K} = \frac{4.36}{299{,}310} = 14.5\mu A$$

$$I_C = \beta I_B = 2.63mA$$

$$I_E = (\beta+1)I_B = 2.65mA$$

Check assumptions

Forward Biased ⟸
- n $V_B = 6.94 + I_B(63.1K) = 7.85\,V$
- p $V_C = -12V + I_C R_3 = -0.681\,V$
- p $V_E = 12V - I_E R_5 = 8.559$

⟶ Reversed Biased

Forward Active Assumption Proven!

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

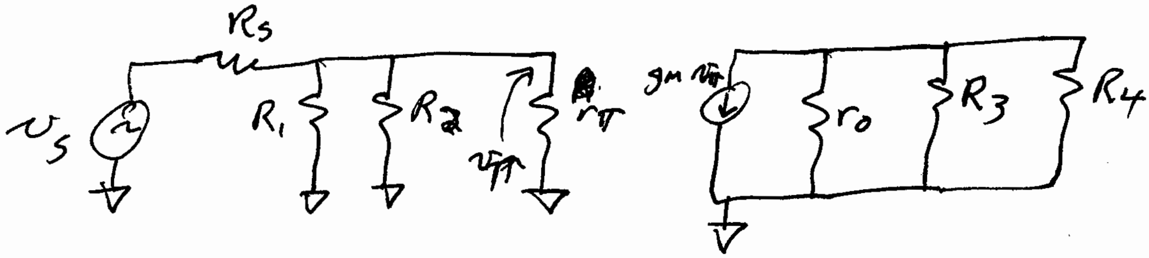
conversion to small signal model:

$\beta = g_m r_\pi$

$$g_m = \frac{I_C}{V_T} = \frac{2.63\,mA}{0.0259} = 0.101\ S$$

$$r_\pi = \frac{\beta}{g_m} = \frac{180.7}{0.101} = 1{,}779.5\,\Omega$$

$$r_o = \frac{V_{CE} + V_A}{I_C} = \frac{9.24 + 100}{0.00263} = 41{,}536\,\Omega$$



$$v_\pi = \frac{R_1 \| R_2 \| r_\pi}{R_S + R_1 \| R_2 \| r_\pi} v_S$$

$$v_{out} = -g_m (r_o \| R_3 \| R_4) v_\pi$$

$$A_v = -\left(\frac{300k \| 80k \| 1.78k}{20k + 300k \| 80k \| 1.78k}\right)(0.101)(41.5k \| 4.3k \| 1$$

$$= -\frac{1.731k}{21.731k}(283.2)$$

$$-(0.079)(283.2)$$

$$A_v = -22.37\ V/V$$

Answer Page