ECE 3040 Microelectronic Circuits

[redacted]*Exam 2*

March 16, 2004

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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 **<u>ONE</u>** of the two following cases:

I DID NOT observe any ethical violations during this exam:

___

I observed an ethical violation during this exam:

___

First 40% **True /False and Multiple Choice - Select the most correct answer(s)**

1.) (2-points) True / False: Diffusion capacitance is due to majority carriers separated by a depletions region.

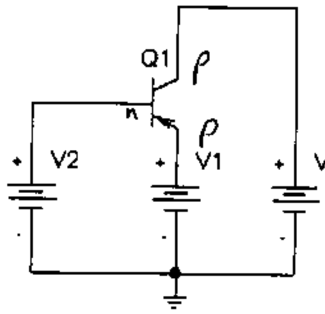
2.) (2-points) True / False: LEDs, solar cells and photodiodes are all forms of diodes.

3.) (2-points) True / False: Photodiodes are biased into reverse bias while solar cells operate in forward bias.

4.) (2-points) True / False: Base width modulation is when the base quasi-neutral region is partially consumed by the reverse biased base-collector depletion region resulting in a smaller base quasi-neutral width.

5.) (2-points) True / False: For a transistor operated in forward active mode, heavy doping in the emitter is needed to insure large current flow in the collector-emitter circuit.

6.) (5-points) If an engineer wanted to bias this transistor into saturation mode, which of the following is true?



a. V3>V1 and V1>V3
b. V2>V1 and V2<V3
c. V2>V3 and V1>V3
d. V1>V2 and V3>V2
e. You cannot bias a transistor without resistors.

7.) (5-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
b. ...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™.

8.) (5-points) It is desired to have the small signal impedance (neglecting capacitance) of a diode with a saturation current, Io=1e-12 amps, equal 50 ohms to match the impedance of a RG-58 transmission line. Which of the following are true:

a. The diode should be biased deep into reverse bias.
b. The diode should be biased with a forward current of 518 uA
c. The diode should be biased with a reverse current of 518 uA
d. The diode should be biased with a forward current of 14 mA
e. The voltage across the diode should be ~0.52 volts
f. The voltage across the diode should be ~0.605 volts
g. This question is completely unfair!

9.) (5-points) Zener breakdown in a p-n diode...

a. ... is another name for avalanche breakdown
b. ...is the only means of providing high current flows in reverse bias
c. ...results from the carriers tunneling through a thin energy barrier
d. ...results from the fact that small particles can have a finite probability of existing in different places centered around a single location
e. ...is used for tuning circuits due to it's capacitance variation with reverse bias.

10.) (5-points) The current flowing in a reverse bias diode...

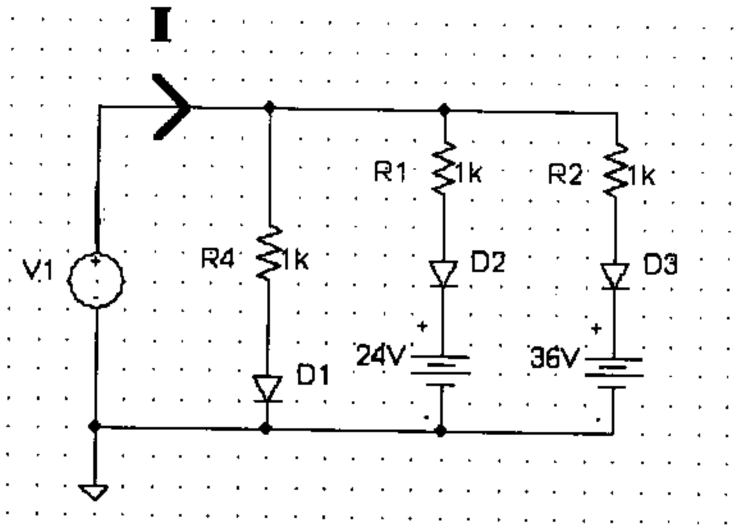
a. ...is mostly due to minority carriers drifting across the depletion region in response to the electric field
b. ...is mostly due to majority carriers drifting across the depletion region in response to the electric field
c. ...is mostly due to minority carriers diffusing across the depletion region due to a lowered energy barrier
d. ...is mostly due to minority carriers diffusing across the depletion region due to a raised energy barrier
e. None of the above

11.) (5-points) Which of the following are **NOT** common uses of a transistor:

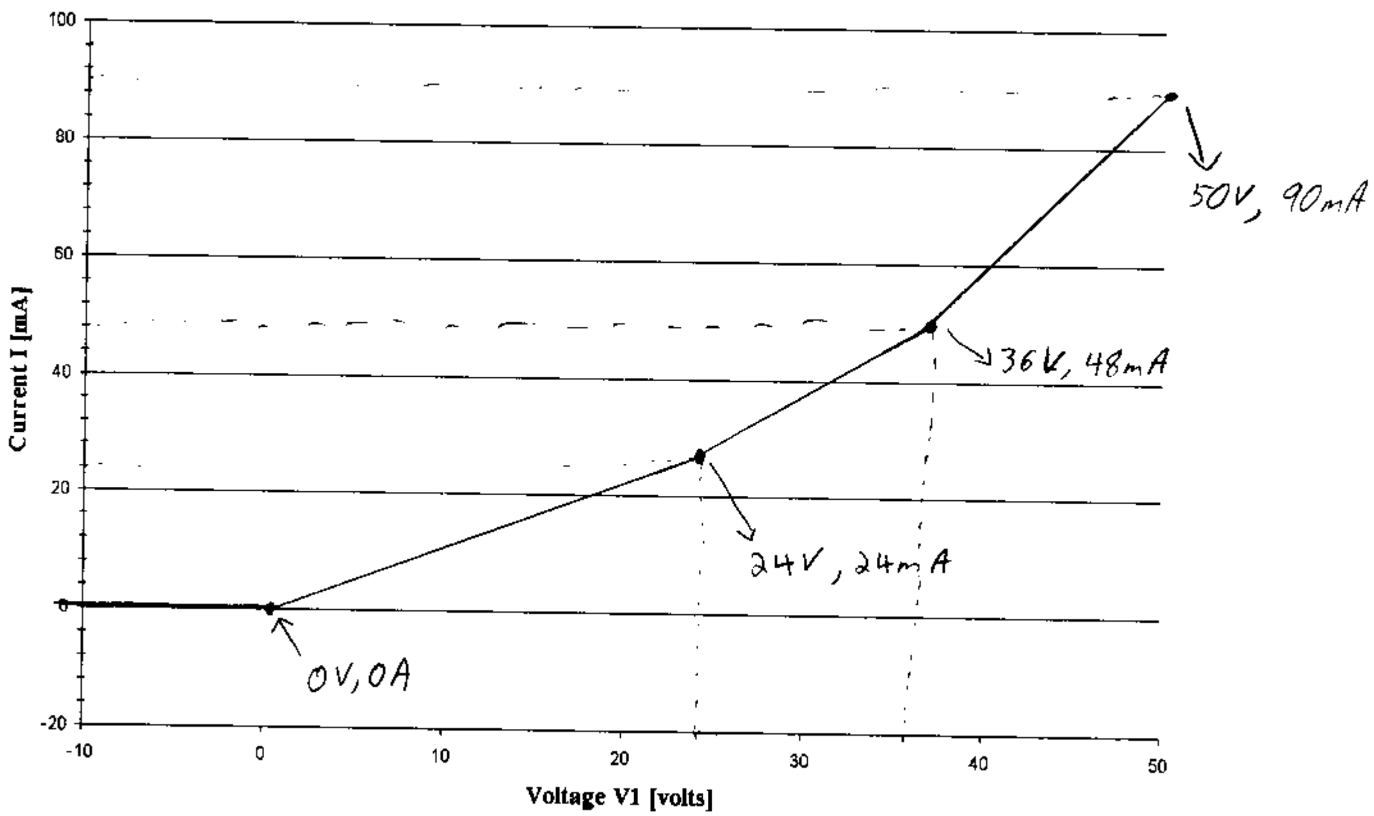
a. Low Frequency Switch
b. High Frequency Switch
c. Amplification
d. Solar cells
e. Cooking Pop tarts

12.) (20 points)

For the following circuit, the voltage source V1 is varied from –10 V to +50 volts. As this happens, a current I begins to flow. On the graph paper provided, use the ideal diode model for each diode and graph to scale the current flowing verses voltage V1. Be sure to label all voltage and currents where the slope of your graph changes (i.e. label each vertices). Hint: consider each branch as a separate circuit with the total current summed up to equal current I.

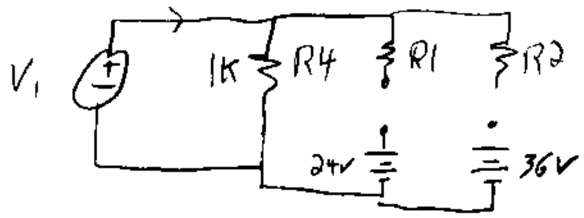


For $V_1 < 0$ all diodes are off $\Rightarrow I = 0$



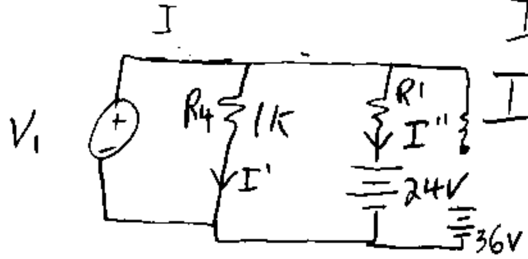
Extra work can be done here, but clearly indicate with problem you are solving.

For $0 < V1 < 24$



$$I = \frac{V1}{R4} = \frac{V1}{1K} = (0.001\ V1)\ \text{Amps}$$

For $24 < V1 < 36$



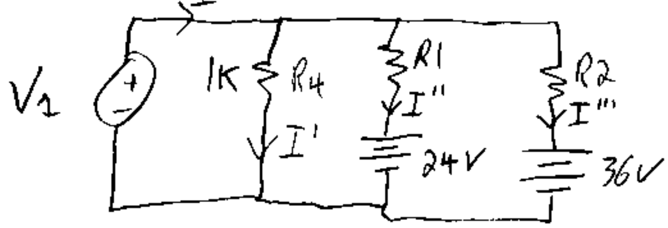
$$I = I' + I''$$

$$I = \frac{V1}{R4} + \frac{V1 - 24}{R1}$$

$$= V1\ (0.001 + 0.001) - 24(0.001)$$

$$= V1\ (0.002) - 0.024\ A$$

for $V1 > 36$



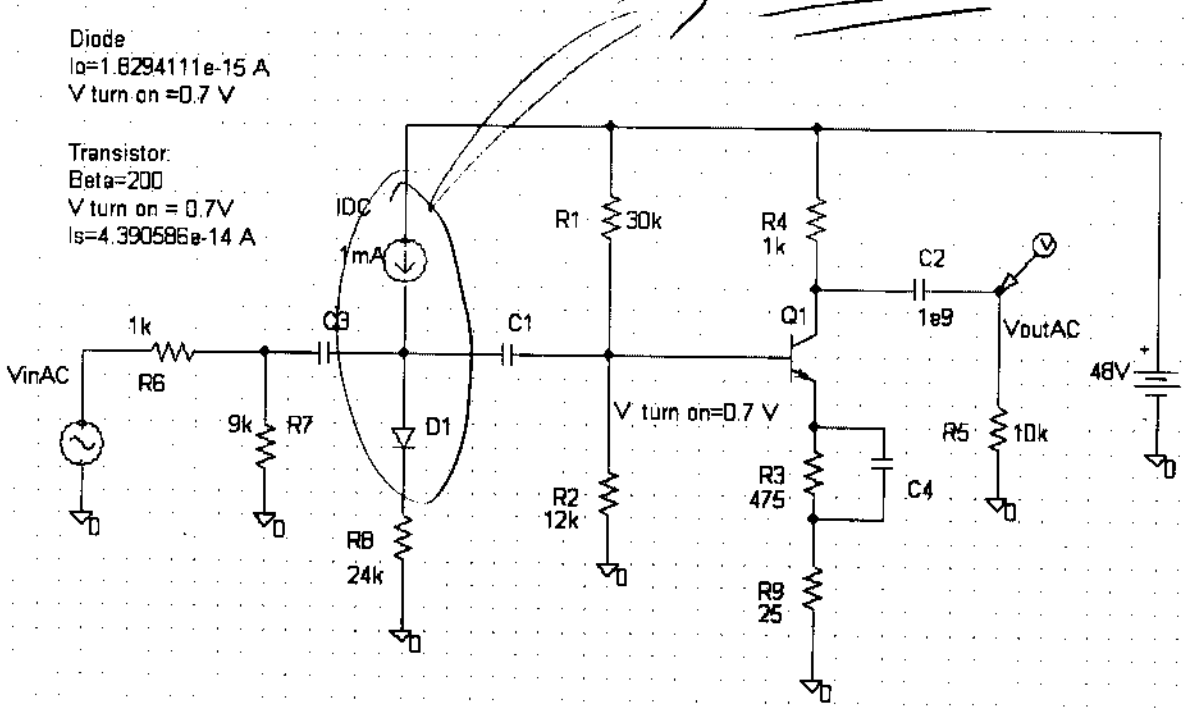
$$I = I' + I'' + I'''$$

$$= \frac{V1}{R4} + \frac{V1-24}{R_1} + \frac{V1-36}{R2}$$

$$= V_1\ (0.003) - 0.024 - 0.036$$

$$I = V_1\ (0.003) - 0.06\ \text{Amps}$$

Pulling all the concepts together for a useful purpose: $I_D = 1mA$



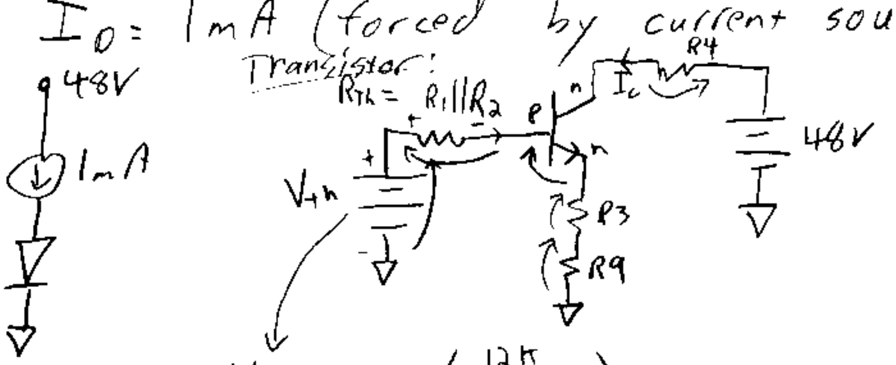
13.) (40-points) What is the AC voltage gain, Vout/Vac? Assume: β_{DC}=200, Early voltage is infinite, and the turn on voltages for all forward biased junctions are 0.7 V. You may assume all capacitors are very large values and are thus, AC shorts and any inductors are very large values, and thus AC opens. Additionally consider the circuit to be operated at low frequencies where you can neglect all small signal capacitances. 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.

Hint: Use the CVD/Beta analysis for the DC solution. Then apply your results to convert to the small signal model for both the BJT and diode (i.e. do not ignore the small signal model of the diode).

DC Solution: Assume forward active.

Diode $I_D = 1mA$ (forced by current source)

Transistor:



$$V_{th} = 48V\left(\frac{12k}{30k+12k}\right) = 13.7V$$

$$R_{th} = R1 || R_2 = 8.57 K$$

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

$$0 = V_{th} - I_B R_{th} - V_{BE} - I_E R_3 - I_E R_9$$

$$13.7 = I_B (R_{th}) + 0.7 + I_E (R_3 + R_9)$$

$$13 = I_B (8.57K) + (\beta + 1) I_B (475 + 25)$$

β → 200

$$I_B = \frac{13}{8.57K + 201(500)} = 119 \mu A$$

$$I_C = \beta I_B = 200 (I_B) = 23.8 mA$$

$$I_E = (\beta + 1) I_B = 200 \ I_B = 23.9 \ mA$$

$$V_B = V_{Th} - I_B R_{th} = 13.7 - 119 \mu A (8.57k)$$

$$= 12.67 V$$

$$V_C = 48V - R4 I_C = 24.1 V$$

$$V_E = I_E (500 \Omega) = 11.97 \ V$$

500Ω ← $R3 + R9$

$V_C > V_B$ + $V_B > V_E$ ⇒ Forward active verified!

Small signal parameters

$\beta = g_m r_\pi$

$$r_d = \frac{V_T}{I_D} = \frac{0.0259}{1mA} = 25.9 \Omega$$

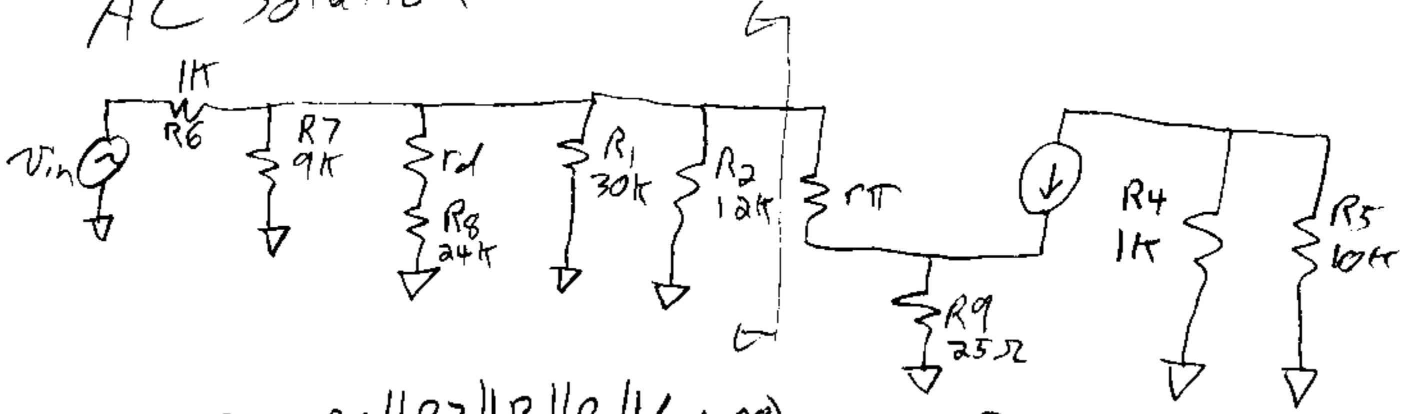
$$g_m = \frac{I_C}{V_T} = \frac{23.8 mA}{0.0259} = 0.919 \ \mho$$

$$r_o = \frac{V_A + V_{CE}}{I_C} = \infty \text{ because } V_A = \infty$$

$$r_\pi = \frac{\beta}{g_m} = \frac{200}{} = 217.6 \Omega$$

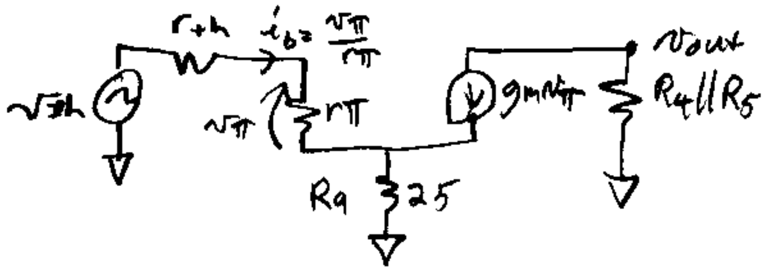
Extra work can be done here, but clearly indicate with problem you are solving.

AC Solution



$$r_{th} = R6 \| R7 \| R_1 \| R_2 \| (r_d + R8) = 787.7\,\Omega$$

(3) $$v_{th} = \frac{R7 \| R_1 \| R_2 \| (r_d + R_8)}{R6 + R_7 \| R_1 \| R_2 \| (r_d + R_8)} v_{in} = 0.787\, v_{in}$$



(1) $$v_{out} = -g_m v_\pi (R_4 \| R_5)$$

(2) $$v_{th} = \left(\frac{v_\pi}{r_\pi}\right) r_{th} + v_\pi + \left(g_m v_\pi + \frac{v_\pi}{r_\pi}\right) R_9$$

$$\frac{v_{out}}{v_{in}} = \overset{①}{\left(\frac{v_{out}}{v_\pi}\right)} \overset{②}{\left(\frac{v_\pi}{v_{th}}\right)} \overset{3}{\left(\frac{v_{th}}{v_{in}}\right)}$$

$$= \left[-g_m (R_4 \| R_5)\right] \left[\frac{1}{\frac{r_{th}}{r_\pi} + 1 + g_m R_9 + \frac{R_9}{r_\pi}}\right] \left[0.787\right]$$

$$= [-835]\,[0.03608]\,[0.787]$$

$$\boxed{\frac{v_{out}}{v_{in}} = -23.7\ V/V}$$