ECE 3040 Microelectronic Circuits

Exam 2

November 1, 2023

Dr. W. Alan Doolittle 22 minutes

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. 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 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 are more efficient at generating power when they are held at a reverse bias like used for a photodiode.

2.) (2-points) True / False: The small base current of a BJT is dominated by the majority carriers of the base injected into the emitter.

3.) (2-points) True / False: Since the collector collects the majority carrier it is always doped with the largest concentration possible.

4.) (2-points) True / False: The Ebers-Moll Model is not valid in saturation.

5.) (2-points) True / False: The Ebers-Moll Model is linear.

6.) (2-points) True / False: For a BJT in forward active mode, the energy barrier between the base and emitter is smaller than it is in equilibrium.

7.) (2-points) True / False: The small signal (ac) conductance of a diode with no current flowing is always zero.

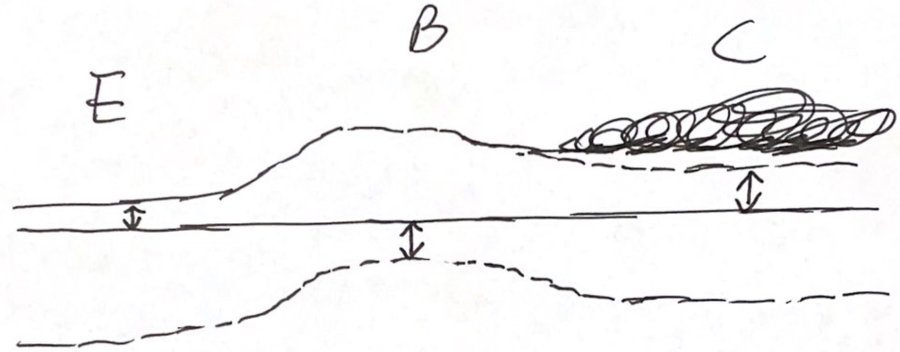
8.) (2-points) True / False: The depletion capacitance and the diffusion capacitance of a diode or BJT junction can cause the diode to have lower impedance at high frequencies.

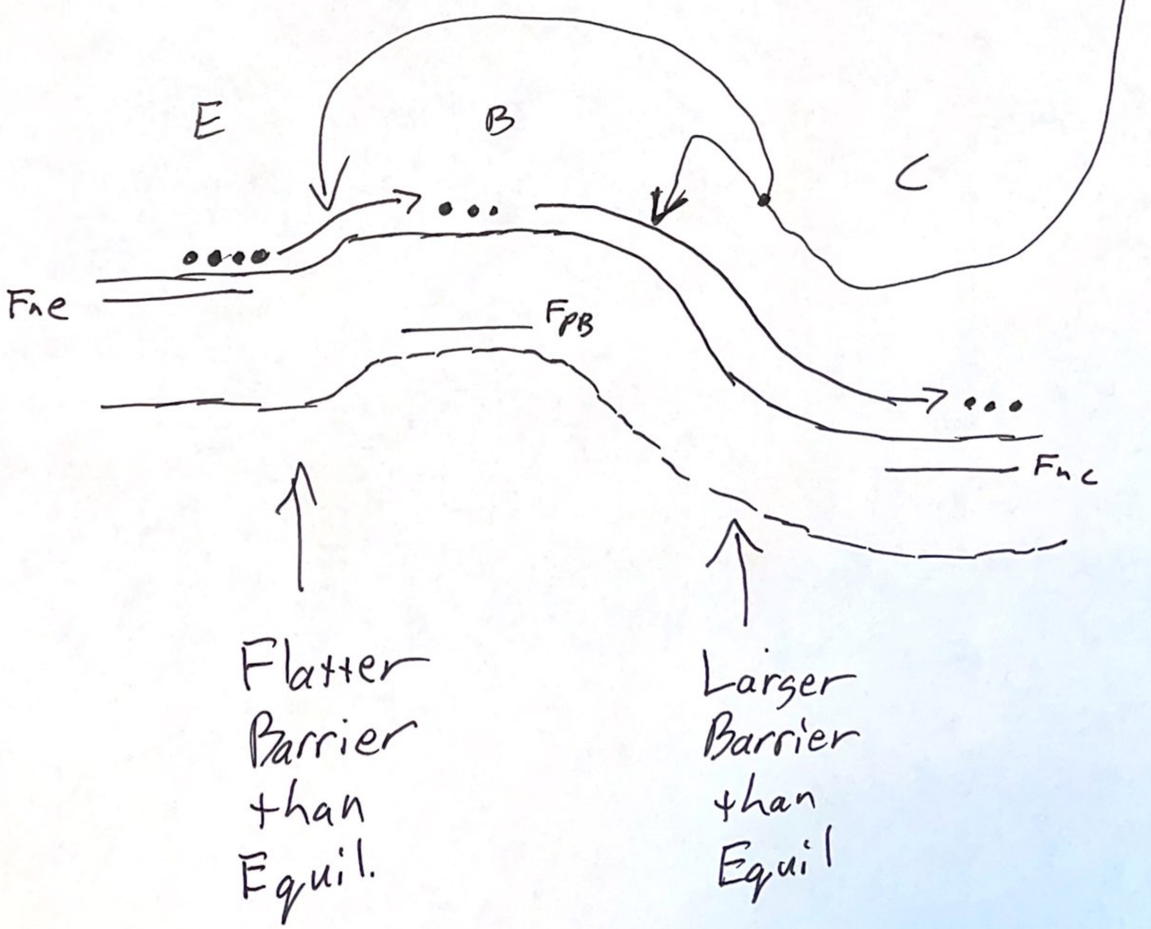
9.) (2-points) True / False: The output conductance (1/resistance) of the Hybrid pi model, $1/r_o$, originates from the slopes of the I_C vs. V_{CE} curve.

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

11) (15 Points)

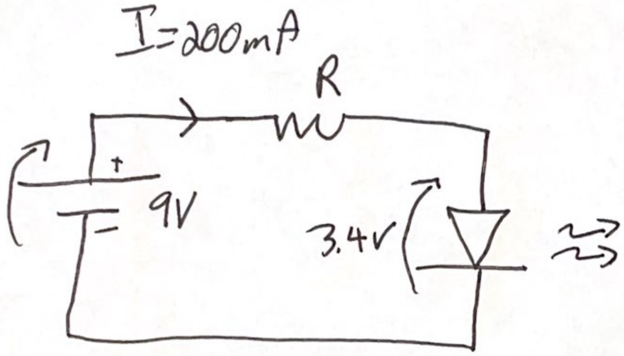
Draw the Energy band diagram of a Si (Eg=1.1 eV) npn BJT biased under equilibrium conditions and (separately) under forward active bias. Label the p and n sides of the junction, the conduction band and fermi and quasi-fermi levels in the quasi-neutral regions. With the help of arrows indicated carrier motion and current flows, empty circles representing holes and solid circles representing electrons, show the path the majority carrier takes moving from emitter to collector.





12.) (15 points total in 2 parts)

A blue LED is specified to have rated optical output at 200 mA and 3.4 volts turn on voltage (typically called $V_{forward}$ in data sheets). Using only an LED, a resistor and a 9V battery, design a circuit and specify resistor values (both resistance and power rating) for your circuit such that you produce the rated optical output.



$$R = \frac{(9.0 - 3.4)\,V}{0.2\,A}$$

$$\boxed{R = 28\,\Omega}$$

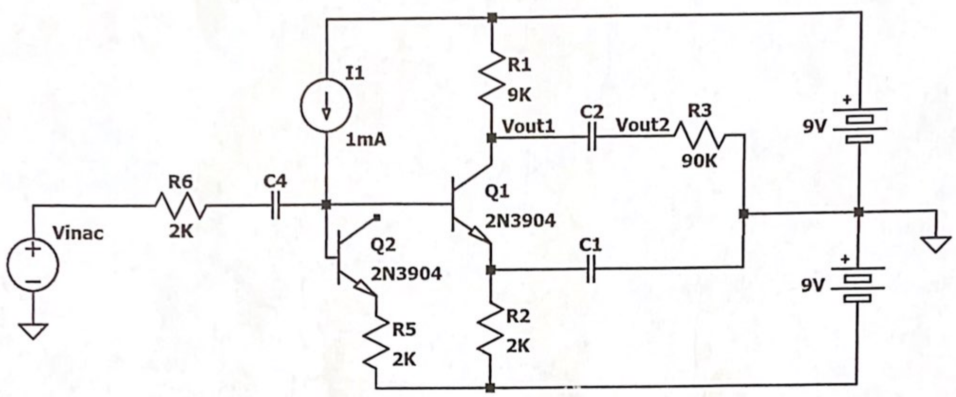
$$P = I^2 R = (0.2)^2\,28$$

$$P = 1.12 \text{ watts}$$

We need a resistor with power capability greater than 1.12 watts

DC:__________out of 15 Conv:__________out of 15 AC:__________out of 15 Graph:________out of 5

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.



The collector of Q2 is left unconnected making Q2 function as a Diode and NOT a transistor (a diode connected transistor).
Thus, Q2's BE junction can be treated as a diode for BOTH DC AND SMALL SIGNAL.
Thus, you may want to replace Q2 with a Diode for clarity.
2N3904 Beta=100, Va=300V and IS=1e-14A with a Vbe Turn On voltage of 0.66V

For the circuit above, you will be asked to solve the small signal gain of the amplifier and plot the small signal output waveforms Vout1 and Vout2 when the input Vinac=1 mV AC

Assume Q1: $V_{\text{Base-Emitter turn on}}$=0.66 V, $V_{\text{Base-Collector turn on}}$=0.4 V, β_{DC}=100,
Early Voltage=300V, I_s=1E-14 Amps

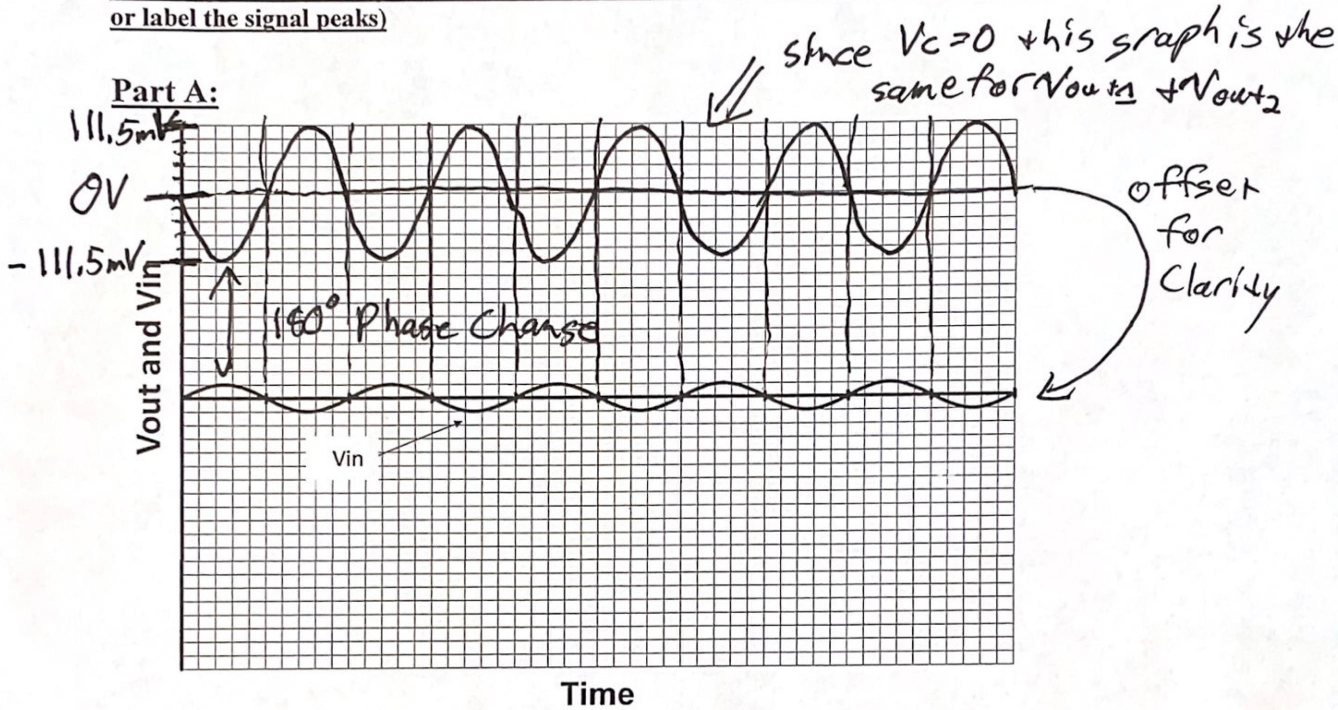
Q2: The collector is not connected so Q2 acts as a diode (as discussed in class).
Thus, assume the diode turn on voltage is the same as the turn on voltage of Q1's BE junction and $I_{o2}=I_s$=1e-14A

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} and V_{out2} <u>on the graph paper provided on the next page</u>. 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.**

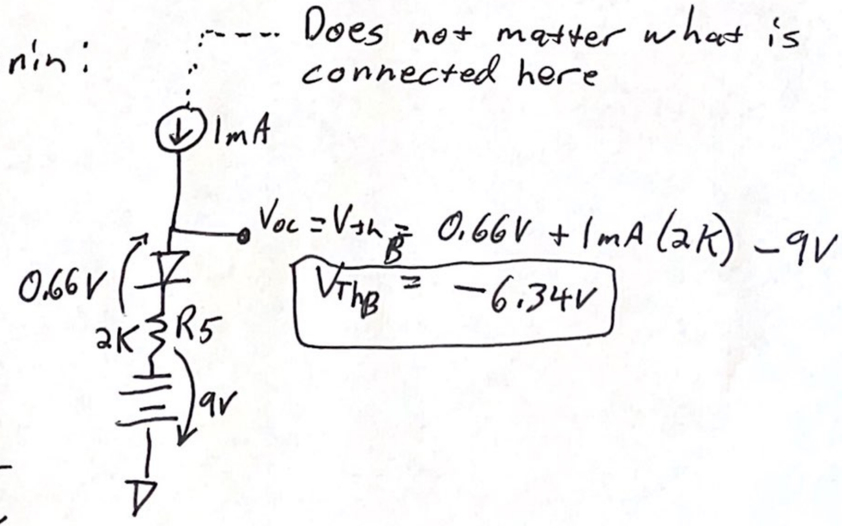
Small Signal answer Page (NOTE: Vin and Vout can have different y-axis values so label the axis or label the signal peaks)

Part A:

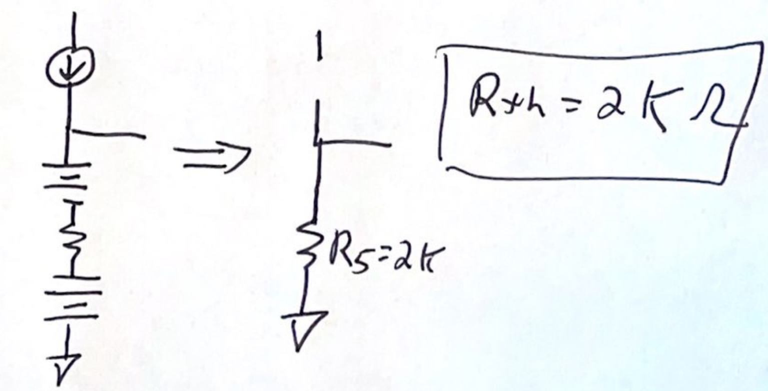


Therenin:

As noted in class: Stricktly speaking, a Thevenin circuit can only be used for linear circuits. However, the CVD or Ideal diode model is linear whearas the real diode is not.



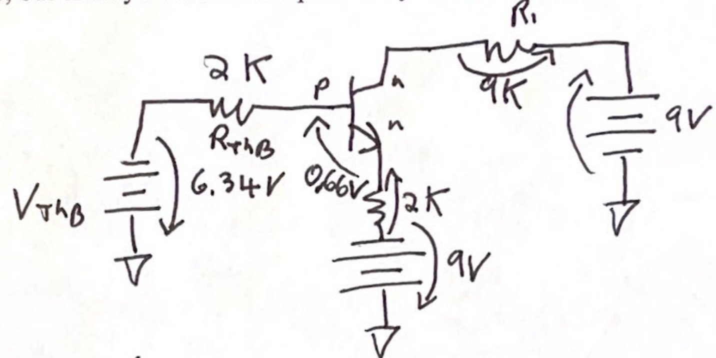
Rth:



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

DC Solution:

$\beta = 100$



$$-6.34V + I_B(2K) - 0.66V - \underbrace{(1+\beta)I_B}_{I_E}2K + 9V = 0$$

$$I_B[2K - (1+\beta)2K] = -2V$$

$$I_B = \frac{-2}{-100(2K)}$$

$$I_B = 10\mu A$$
$$I_C = 100 I_b = 1.00 mA$$
$$I_E = 101 I_b = 1.01 mA$$

$$V_B = -6.34V + (10\mu A)2K$$
$$V_B = -6.32V$$

$$V_C = 9V - I_C R_1$$
$$V_C = 0V$$

$$V_E = -9V + I_E 2K$$
$$V_E = -6.98V$$

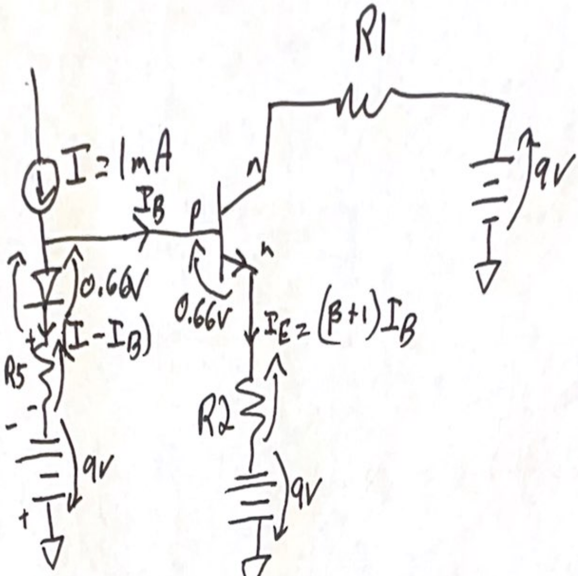
$V_{CB} \Rightarrow$ Reverse Biased

V_{BE} = Forward Biased

Forward Active Confirmed!

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

Alternative Solution (if you did not know how to Thevenize:



~~$-9V$~~ $+ (I - I_B)R_5$ ~~$+ 0.66V - 0.66V$~~ $- I_B(\beta+1)R_2$ ~~$+9V$~~ $= 0$

$$I_B\left(-(\beta+1)R_2 - R_5\right) = -I R_5 = -2V$$

$$I_B = \frac{-2V}{-[(\beta+1)R_2 + R_5]}$$

$I_B = 9.8\ \mu A$

$I_C = 980\ \mu A$

$I_E = 990\ \mu A$

$V_B = -9V + (1mA - 9.8\mu A)2K + 0.66V$

$= -6.36\ V$

$V_C = 9V - (980\mu A)9K$

$= 0.176V$

$V_E = -9V + (990\mu A)2K$

$= -7.02V$

The small descrepancy between methods results from the approximation that a diode can be modeled inside a Thevenin circuit as a simple battery.

F.A. Verified

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

$I_D \rightarrow$

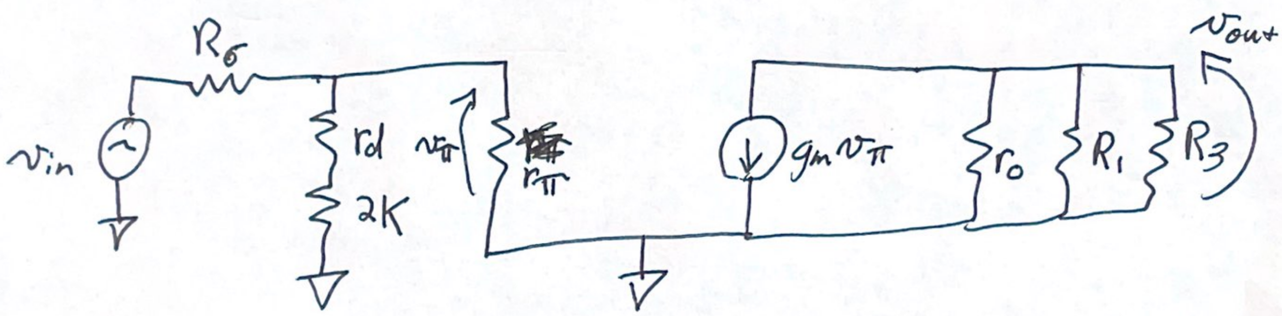
$$g_m = \frac{1mA}{V_T} = 0.03861\ \mho \qquad V_T \leftarrow 0.0259\ V$$

$$g_d = \frac{1}{r_d} = \frac{1mA}{0.0259} = 0.03861\ \mho$$

$$r_d = 25.9\ \Omega$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{0.03861\ \mho} = 2590\ \Omega$$

$$r_o = \frac{V_A + |V_{CE}|}{I_C} = \frac{300V + 9V}{1mA} = 309\ k\Omega$$



$$\left(\frac{v_\pi}{v_{in}}\right) = \frac{r_\pi \| (r_d + 2k)}{R_G + r_\pi \| (r_d + 2k)} = 0.362\ V/V$$

$$\left(\frac{v_{out}}{v_\pi}\right) = -g_m (r_o \| R_1 \| R_3) = -307.75\ V/V$$

$$\boxed{\left(\frac{v_{out}}{v_{in}}\right) = \left(\frac{v_\pi}{v_{in}}\right)\left(\frac{v_{out}}{v_\pi}\right) = -111.5\ V/V \text{ or } 40.9\ dB}$$