ECE 3040 Microelectronic Circuits

Exam 2

March 26, 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 Ebers-Moll model is valid for all bias modes of a BJT except inverse active which is never used.

2.) (2-points) True / False: When powering a light, motor or any other device in which the device needs to be turned on and off a transistor is driven from saturation to cutoff.

3.) (2-points) True / False: As the base quasi-neutral width is varied under varying base-collector voltages, the Beta of the transistor changes.

4.) (2-points) True / False: Photodiodes are biased in forward bias to increase the depletion width and thus the collected current.

5.) (2-points) True / False: Common Emitter amplifiers have the output at the base terminal.

6.) (2-points) True / False: The AC resistance of a zero biased (neither forward nor reverse biased) diode is infinity.

7.) (2-points) True / False: A zener diode can conduct large currents in both forward bias and reverse bias.

8.) (2-points) True / False: In a forward biased diode, electrons from the n-type side are injected into the p-type side where they recombine and diffuse away from the junction.

9.) (2-points) In order to design a high beta (current gain) transistor, ...

a. ...increase the emitter doping
b. ...decrease the base quasi-neutral width
c. ... increase the base doping
d. ... decrease the base depletion width
e. ... forget this stuff, I will just "live in a van down by the river".

10.) 2-points) In a forward active biased npn BJT...

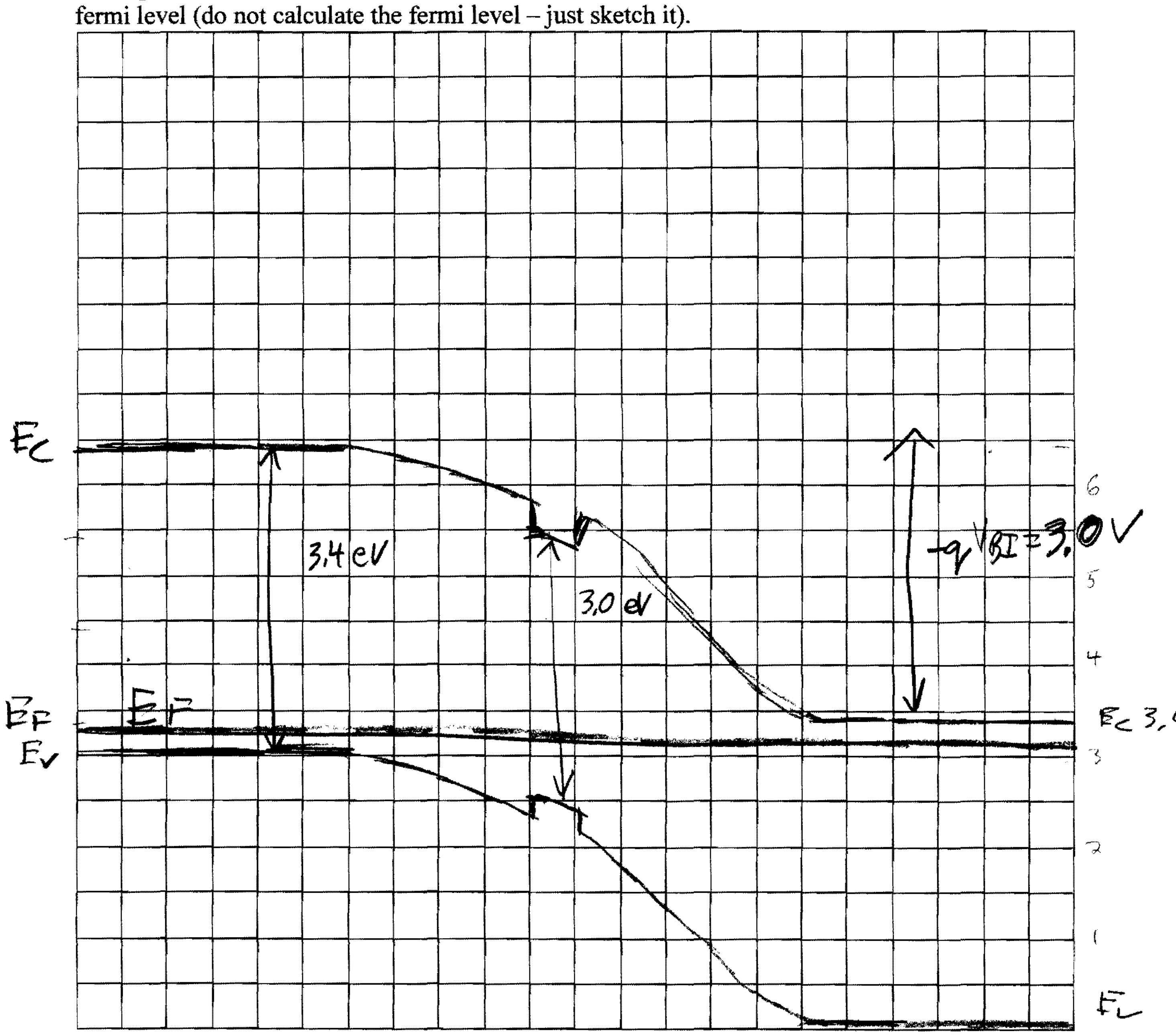
a. ... the base-collector junction extracts electrons from the p-type base.
b. ... the emitter injects electrons into the base.
c. ... the dominant capacitance for the base emitter junction is diffusion capacitance.
d. ... the dominant capacitance for the base emitter junction is depletion capacitance.
e. ... the energy barrier between the base and emitter is lower than in equilibrium
f. ... the energy bands are almost flat.
g. None of the above.

11.) (20 points)

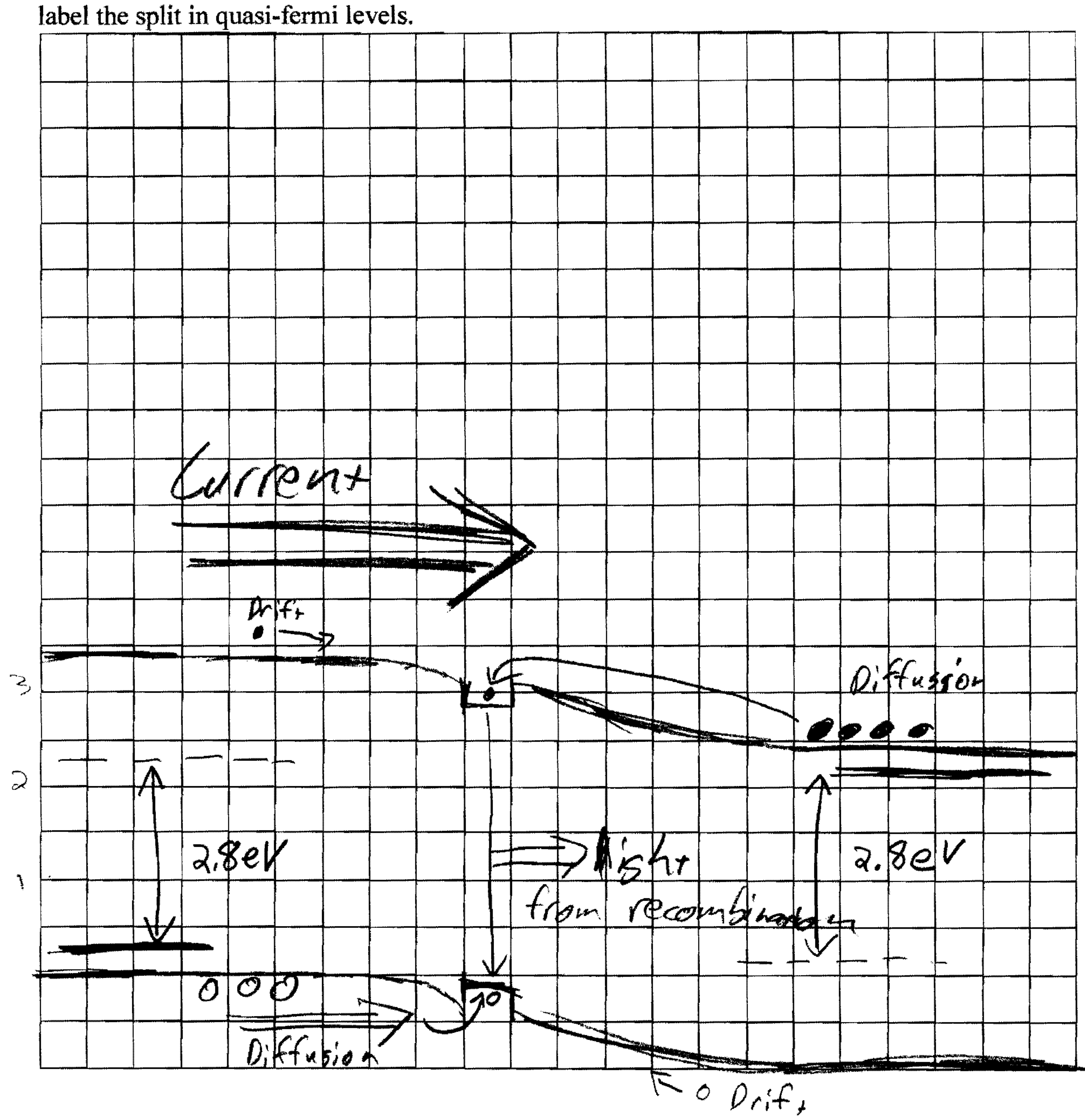
Note: Neatness and clarity counts in the drawings for this problem.

A room temperature GaN semiconductor Light Emitting Diode (LED) with a 3.4 eV bandgap and a 3.0 eV quantum well is to be operated in forward bias, thus producing light. It has a V_{BI}=3.0 volt (built in potential).

(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).



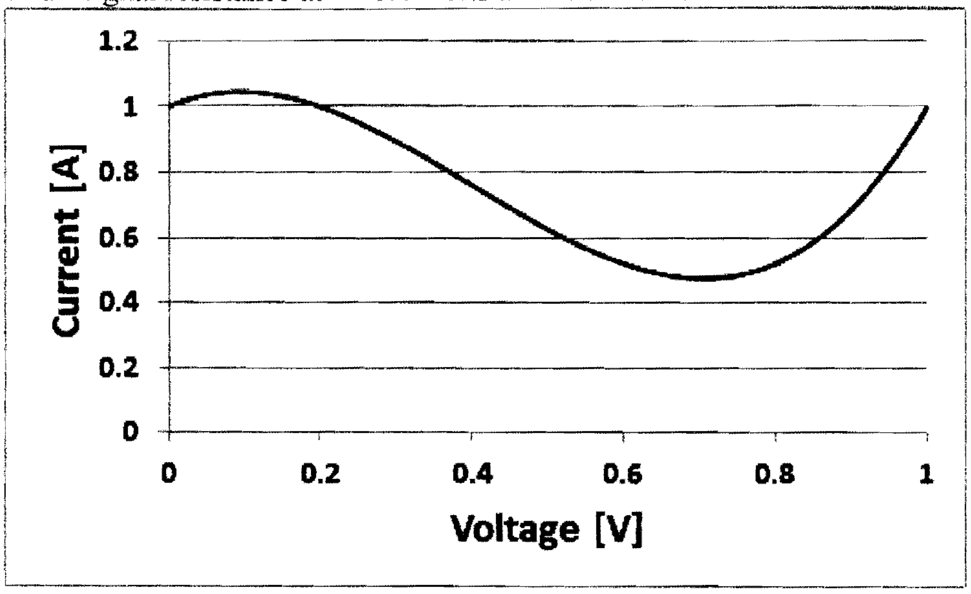
(b – 10 points) Read part C first so you can plan ahead. Sketch and label the energy band diagram of the LED when forward biased by 2.8V labeling the difference in quasi-fermi levels on the n-side vs the p-side. You do not need to calculate the values of quasi-fermi levels, just label the split in quasi-fermi levels.



(c – 5 points) On the sketch in part b indicate with holes (open circles) and electrons (filled circles) the direction of carrier motion as it passes through the device and indicate the source of light in the device.

-0.714
0.425

13) (20 – points) The brilliant professor Doolittle (gag) has invented a new device with a DC current vs voltage characteristic described by $I=1.0+1.0V-6.0V^2+5.0V^3$.
Determine a generic function for the small signal resistance of the new device and evaluate this small signal resistance at V=0.4 Volts and at 0.9 Volts.



$$g_d = \frac{1}{r_d} = \frac{dI}{dV} = 1 - 12V + 15V^2$$

@ V = 0.4 V

$$r_d = \frac{1}{1 - 12(0.4) + 15(0.4)^2}$$

$$r_d = [-1.4]^{-1} \Omega$$ yes negative!

$$\boxed{r_d = -0.714\ \Omega}$$

@ V = 0.9 V

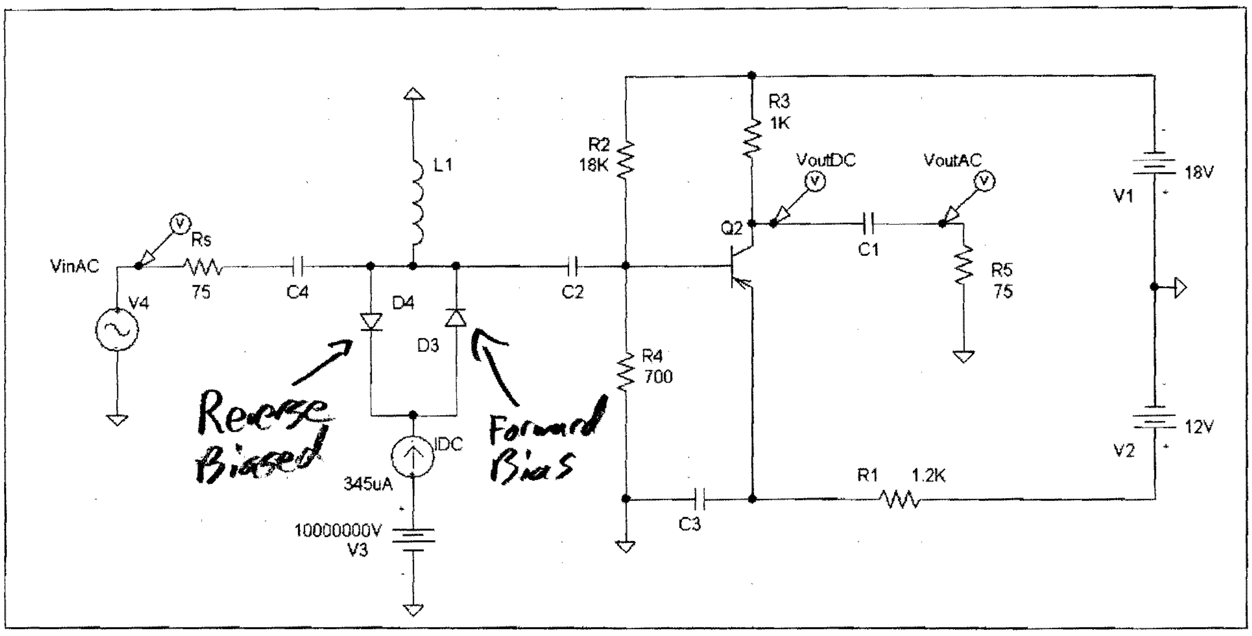
$$r_d = \frac{1}{1 - 12(0.9) + 15(0.9)^2}$$

$$r_d = [2.35]^{-1} \Omega = \boxed{0.425\ \Omega}$$

This device is an example of "negative differential resistance" and is similar to that found in a "tunnel diode" used to create very high speed oscillators.

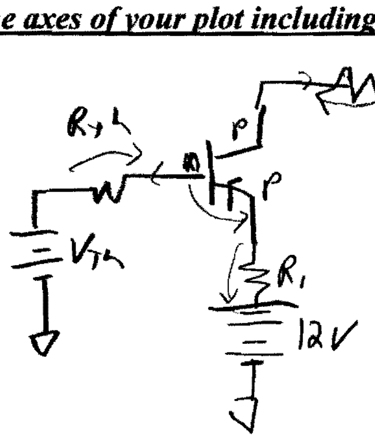
14). **Pulling all the concepts together for a useful purpose**:
(40-points total: DC solution = 12 points, conversion to small signal model = 12 points, AC solution = 12 points and 4 points for accuracy of the graph)

For the circuit below:
Q1: $V_{turn\ on}$=0.7 V, β_{DC}=100, V_A=1000V
D1 and D2: I_s=I_o= 0.6318 fA (i.e. 6.318E-16A), $V_{turn\ on}$=0.7 V
Current source, I_{DC}= 345uA DC
NOTE: There are 3 different DC power supply values, 18V, 12V, & 10,000,000V (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 of the output waveforms VoutAC and VoutDC <u>on the graph paper provided on the next page</u>. 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 *<u>clearly label the axes of your plot including the DC offset and amplitude of the output voltage</u>*.**

DC:



$V_{Th} = -18V \frac{R_4}{R_3 + R_4} = -18\left(\frac{700}{700+18k}\right)$

$= -0.674V$

$R_{Th} = R_2 \| R_4 \cong 700\Omega$

$V_{Th} + I_B R_{Th} + V_{EB} + I_E R_1 - 12V = 0$

$-0.674 + I_B 700 + 0.7 + I_B(100+1)1200 - 12V = 0$

$11.97 = I_B(700 + 101(1200))$

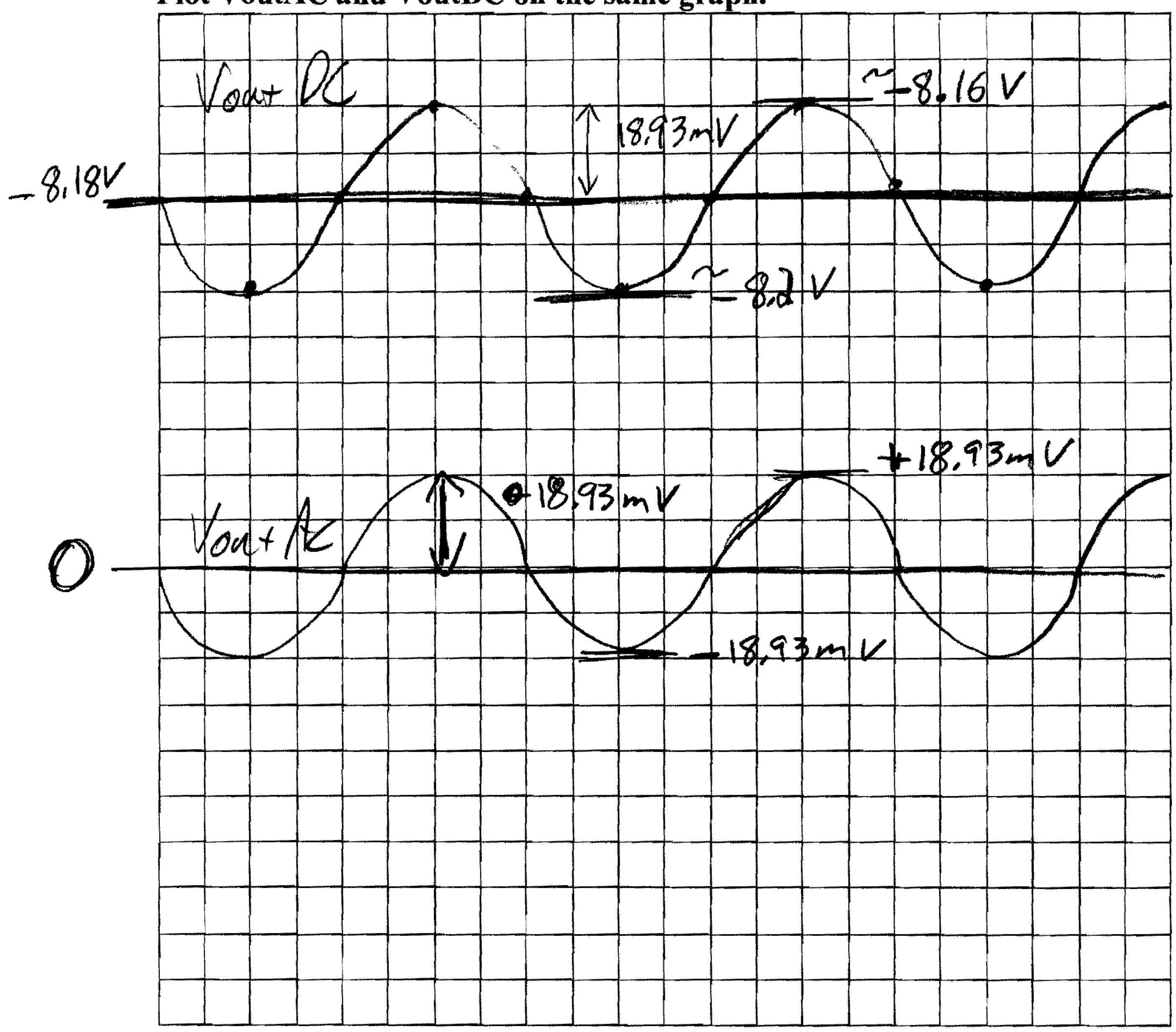
$I_b = 98.2\ \mu A$

$I_C = \beta I_B = 9.82\ mA$

$I_E = (\beta+1)\ I_B = 9.919\ mA$

Answer Page

Plot VoutAC and VoutDC on the same graph.



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

$V_B = V_{Th} + I_B R_{Th}$
$= -0.674 + 98.2\mu A(700)$
$= -0.605V$ $V_C < V_B$ ✓

$V_C = -18V + I_C R_3$
$= -18V + (9.82mA) 1K$
$= -8.18V$

$V_E = 12V - I_E R_1$
$= 12V - (9.918mA) 1.2K$ $V_E > V_B$
$= 0.0984 V$

Forward Active Confirmed

$rd = \frac{V_{Th}}{I_D + I_S}$

$g_m = \frac{I_C}{V_{th}} = \frac{9.82mA}{0.0259} = 0.379 \Omega^{-1}$

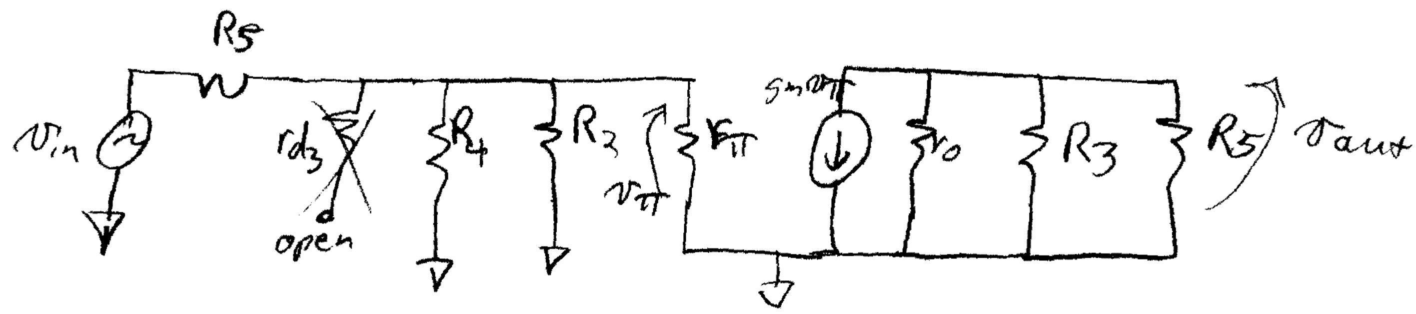
$\beta = g_m r_\pi \Rightarrow r_\pi = 263.7 \Omega$

$rd_4 = \infty$

$rd_3 = \frac{0.0259}{345\mu A + 6e-16}$
$= 75 \Omega$

$r_o = \frac{V_A + V_{EC}}{I_C} = \frac{1000 + 8.28}{9.82 mA} = 102676 \Omega$

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



$$\frac{v_\pi}{v'_{in}} = \frac{R_4 \| R_2 \| r_\pi}{R_S + R_4 \| R_2 \| r_\pi} = \frac{189.5}{75+189.5} = 0.716 \text{ V/V}$$

$$\frac{v_{out}}{v_\pi} = -g_m (r_o \| R_3 \| R_5) = -g_m(69.72)$$

$$= -26.42 \text{ V/V}$$

$$\frac{v_{out}}{v_{in}} = (-26.42)(0.716) = -18.93 \text{ V/V}$$