ECE 3040 Microelectronic Circuits

Exam 2

March 31, 2007

Dr. W. Alan Doolittle

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 **plus two bonus problems at the end of the 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 to be a wrong answer. Numeric answers without supporting work will be counted as wrong. 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 depletion capacitance of a junction is due to minority carriers separated across the junction.

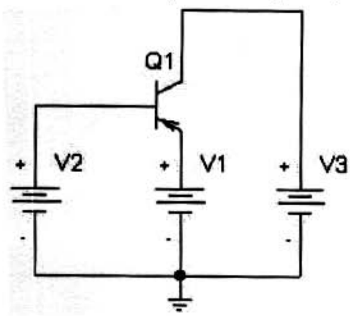
2.) (2-points) True / False: Diode leakage current is proportional to the area of the device and the voltage across the diode..

3.) (2-points) True / False: Zener diodes can operate based on tunneling when an electron jumps through a very thin energy barrier even though it does not have enough energy to go over the barrier.

4.) (2-points) True / False: A transistor biased into saturation is turned on as hard as the circuit allows and thus makes the best amplifiers.

5.) (2-points) True / False: A BJT with a thin base quasi neutral width results in high common emitter current gain.

6.) (2-points) True / False: The base current of the BJT is dominated by the majority carriers in the base not the minority carriers injected from the emitter.



7.) (2-points) If an engineer wanted to bias this transistor into saturation mode, which of the following is true?

a. V1>V2 and V2>V3
b. V2>V1 and V2>V3
c. V1>V2 and V3>V2
d. V1<V2 and V3>V2
e. None of the above.

8.) (2-points) The law of the junction relates

a. ... the leakage current of one side of the junction to the leakage current on the opposite side of the junction
b. ... voltage produced across a junction to the excess carrier concentrations on both sides of the junction
c. ... capacitance of the depletion region to the diffusion current in the junction.
d. ... the doping concentrations on either side of the junction

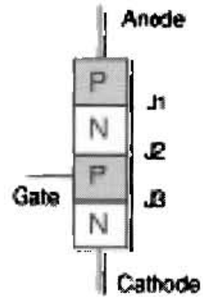
9.) (2-points) When a diode is forward biased to near the built in voltage...

a. ...the dominant current is drift current.
b. ... the dominant current is diffusion current.
c. ... the dominant capacitance is diffusion capacitance.
d. ... the dominant capacitance is depletion capacitance.
e. ... the energy bands are strongly sloped
f. ... the energy bands are almost flat.
g. None of the above

10.) (2-points) The current flowing in the collector-base junction of a forward active biased transistor ...

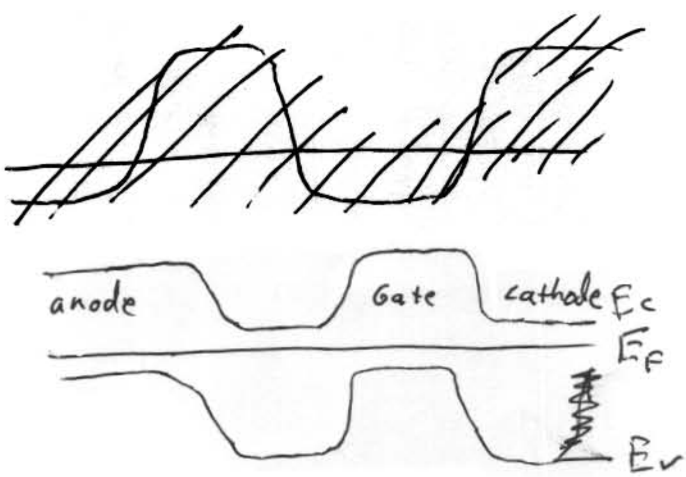
a. ...is mostly minority carriers in the base that were stripped out by the large electric field of the base-collector junction.
b. ...is mostly current originating in the emitter.
c. ...is mostly drift current originating in the base
d. ...is small due to it originating as base current.
e. None of the above

12.) (20 points total in 2 parts)

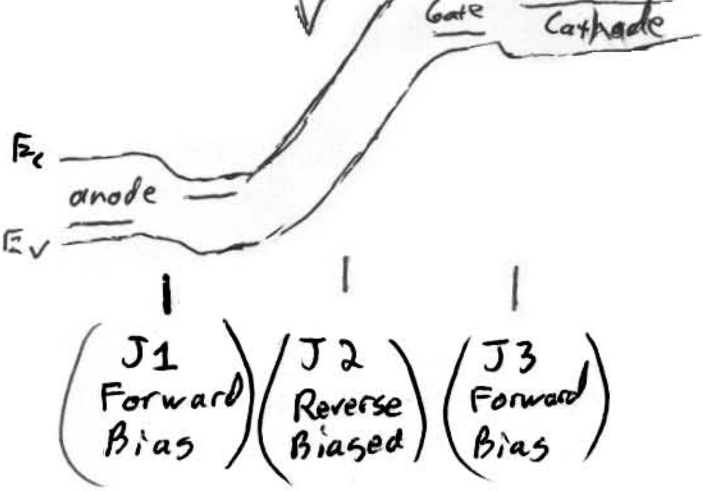


A thyristor is a family of power devices that consists of 4 alternating p-n-p-n type regions creating 3 metallurgical junctions as pictured here. If the anode (see figure) is positively biased relative to the cathode, junction J2 (see figure) is reversed biased while junctions J1 and J3 are forward biased. Under these normal conditions no current flows from the anode to the cathode. However, if a voltage or current pulse is applied to the gate, the reverse biased junction J2 can go into avalanche breakdown and a huge current can flow between the anode and cathode. These modern thyristors can switch large amounts of power (up to megawatts).

(a – 6 points) Draw the energy band diagram of the thyristor in equilibrium. Be sure to label the anode, cathode and gate and the fermi energy, and conduction and valence band.

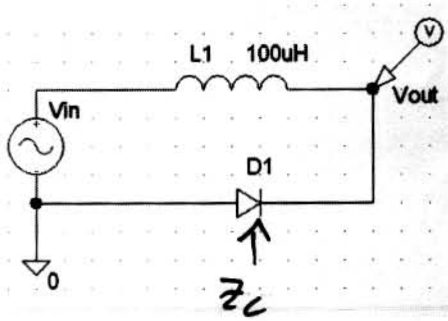


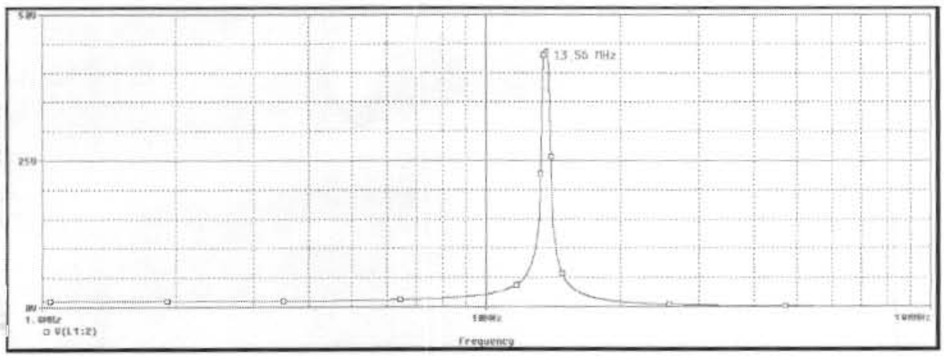
(b – 14 points)) Draw the energy band diagram of the thyristor biased as described above in the conducting state. Be sure to label the anode, cathode and gate and the ~~fermi energy~~, and conduction and valence band and identify the region of the device that has the large electric field that is in avalanche breakdown.



13) (20 – points)

For the following circuit, the output voltage is desired to peak at a frequency the FCC (Federal Communications Commission) reserves for use by industrial "noisy" equipment, 13.56 MHz as shown below. The voltage source, has a DC plus AC combined voltage equal to $V_{in} = V_{DC} + \sin[t\,(2\pi)\,(13.56\text{MHz})]$ volts. If the zero bias junction capacitance, $C_{jo} = 4$ pF (i.e. 4e-12 F) and the built in voltage of the diode is 0.9V, what is the value of V_{DC} required to obtain the output voltage spike (resonance) at 13.56 MHz? You may ignore all resistances of the diode in reverse bias but not in forward bias. (Hint: The magnitude of the voltage at 13.56 MHz is irrelevant only the frequency is meaningful.)





$$v_{out} = v_{in}\,\frac{Z_C}{Z_L + Z_C} = v_{in}\,\frac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + j\omega L} = \frac{1}{1 - \omega^2 LC}$$

$\Rightarrow$ resonance $= \omega^2 = \frac{1}{LC}$

$\omega = 2\pi(13.56\ \text{MHz})$

$L = 1\text{e-}4\ \text{H}$

$C = 1.37\ \text{pF}$ $\quad < 4\ \text{pF} \Rightarrow$ reverse bias required

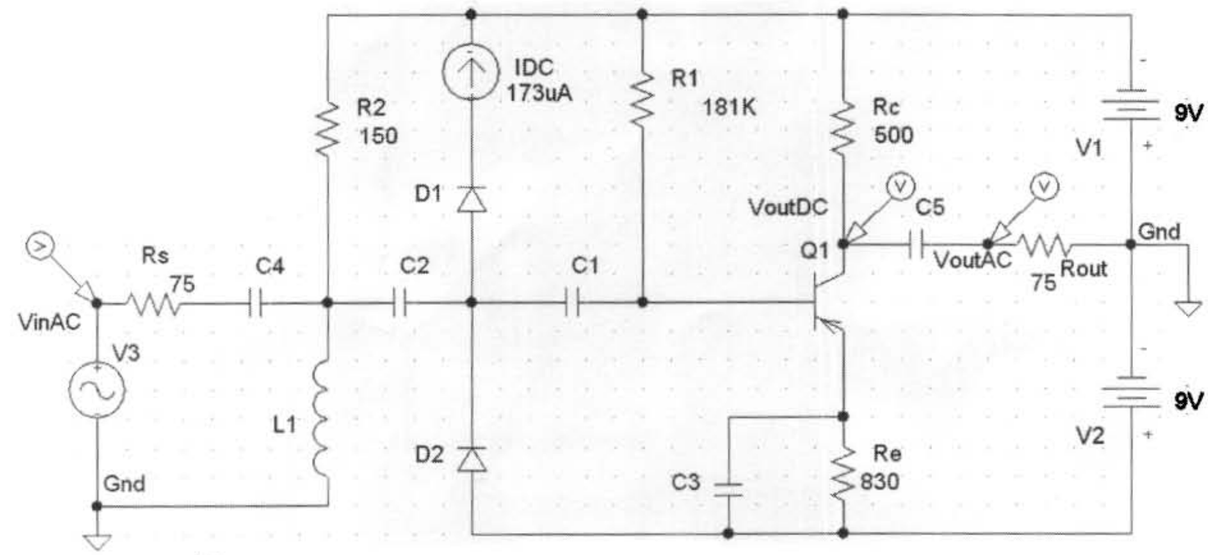
$\Downarrow$

$$C_j = \frac{C_{jo}}{\sqrt{1 - \frac{V_A}{V_{bi}}}} = \frac{4\text{pF}}{\sqrt{1 - \frac{V_A}{0.9}}} = 1.37\text{pF}$$

$V_A = -6.77$ Volts (reverse Bias)

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)

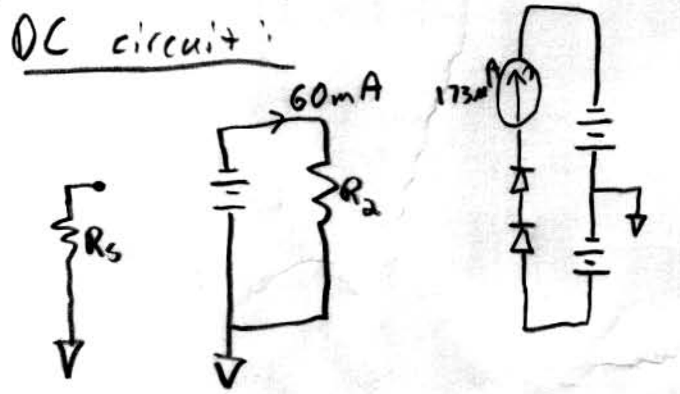
For the circuit below:
Diodes: $V_{turn\ on}$=0.7 V and I_o=I_s=1.83e-14A
Q1: $V_{turn\ on}$=0.7 V, I_s=1.83e-14A, β_{DC}=200, V_A=200V
VinAC = 1mV amplitude (i.e. 2mV peak to peak) at 1 kilohertz (period of 1 millisecond)

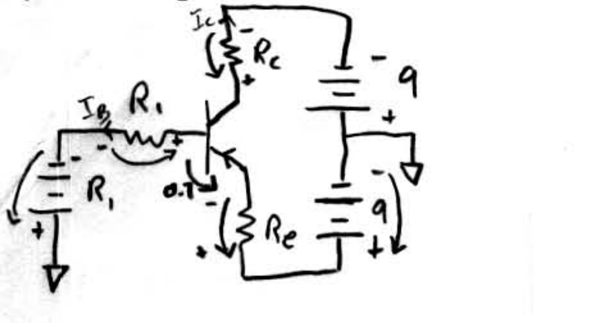


Given the above input voltage, VinAC, sketch and accurately label a plot the TWO output waveforms VoutAC and VoutDC on the graph paper provided on the next page. To do this you must solve the DC and AC solutions of the circuit. Assume the turn on voltages for all forward biased junctions are 0.7 V. You 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.**

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

DC circuit:





$-9V + I_B R_1 + 0.7 + I_E R_E - 9V = 0$

$17.3 = I_B(R_1 + (\beta+1)R_E)$

$I_B = 49.7\ \mu A$ $I_C = \beta I_B = 9.94\ mA$

$I_E = 10$ ...

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

Verify F.A. Mode:

Base-Emitter is Forward Biased.

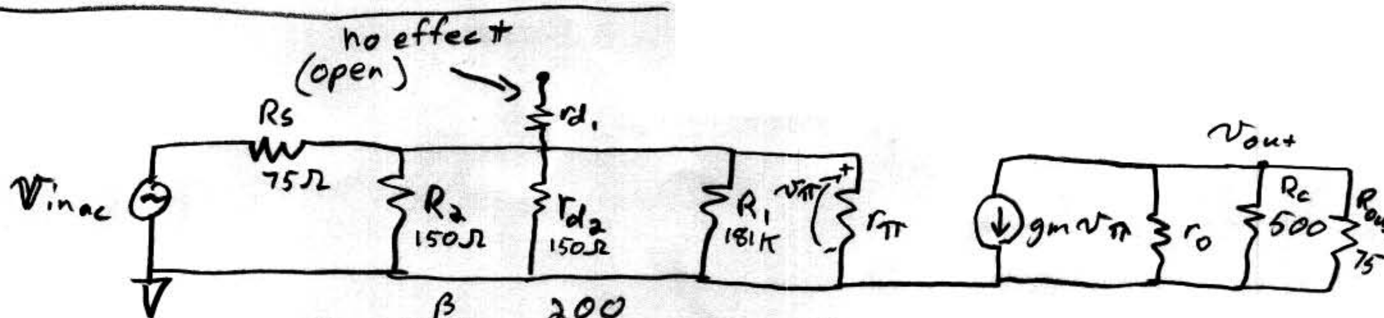
$V_B = -9V + I_B R_1 = \sim 0V$

$V_C = -9V + I_C R_C = -4V$

Base-Collector is Reverse Biased

$V_E = +9V - I_E R_E = 0.7V$

Small signal conversion

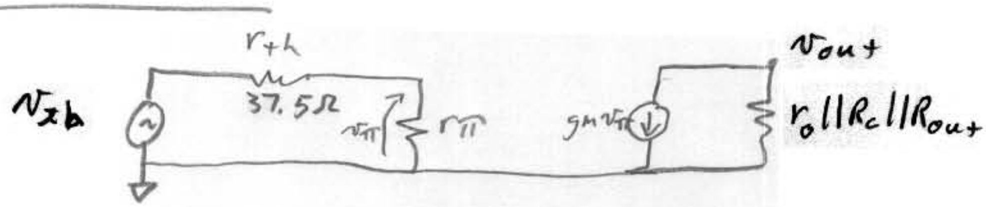


$r_\pi = \frac{\beta}{g_m} = \frac{200}{0.384} = 521\ \Omega$

$g_m = \frac{I_C}{V_T} = \frac{9.94mA}{0.0259} = 0.384\ S$

$r_o = \frac{V_{CE} + V_A}{I_C} = \frac{4.7V + 200V}{9.94mA} = 20,578\ \Omega$

Ac Solution



① $v_{th} = v_{inac} \frac{R_2 || r_{d2} || R_1}{R_2 || r_{d2} || R_1 + R_S} = (0.5) v_{inac}$

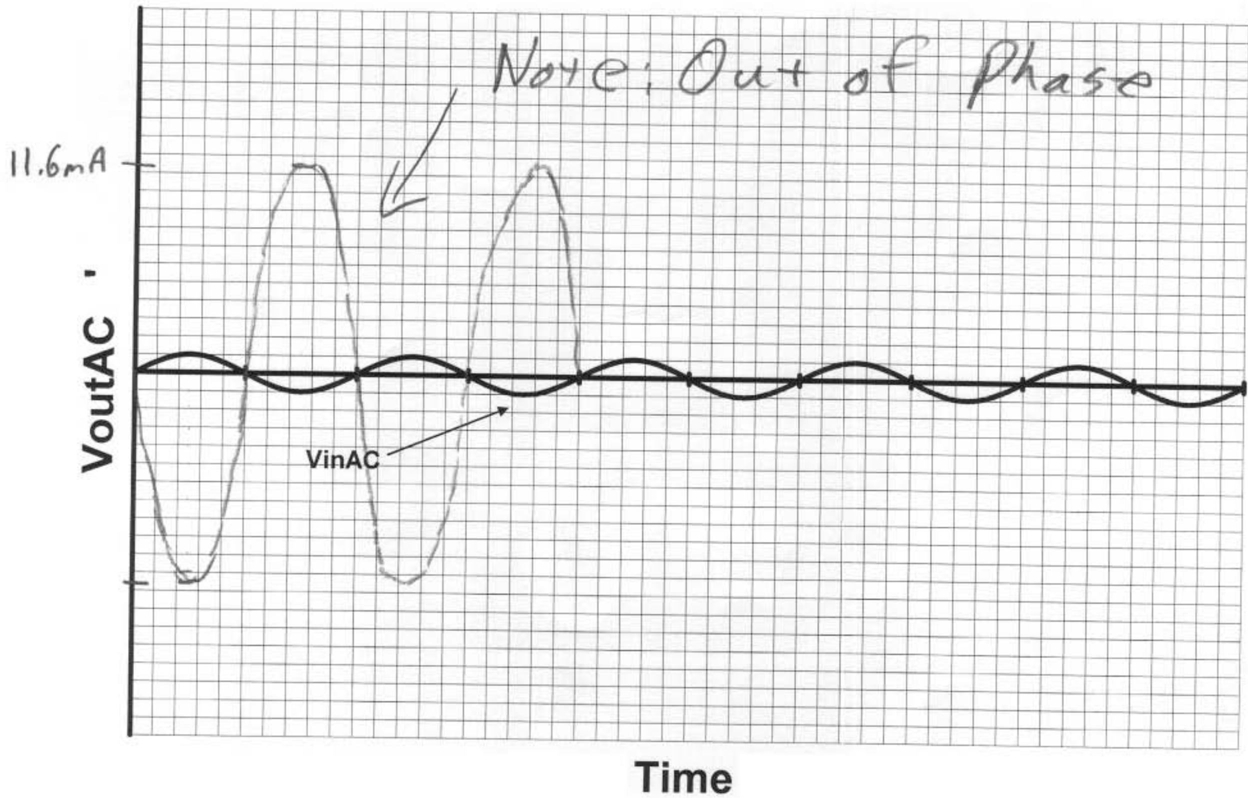
② $v_\pi = v_{th} \left(\frac{r_\pi}{r_\pi + r_{th}} \right) = \frac{521}{521 + 37.5} v_{th} = v_{th}(0.93)$

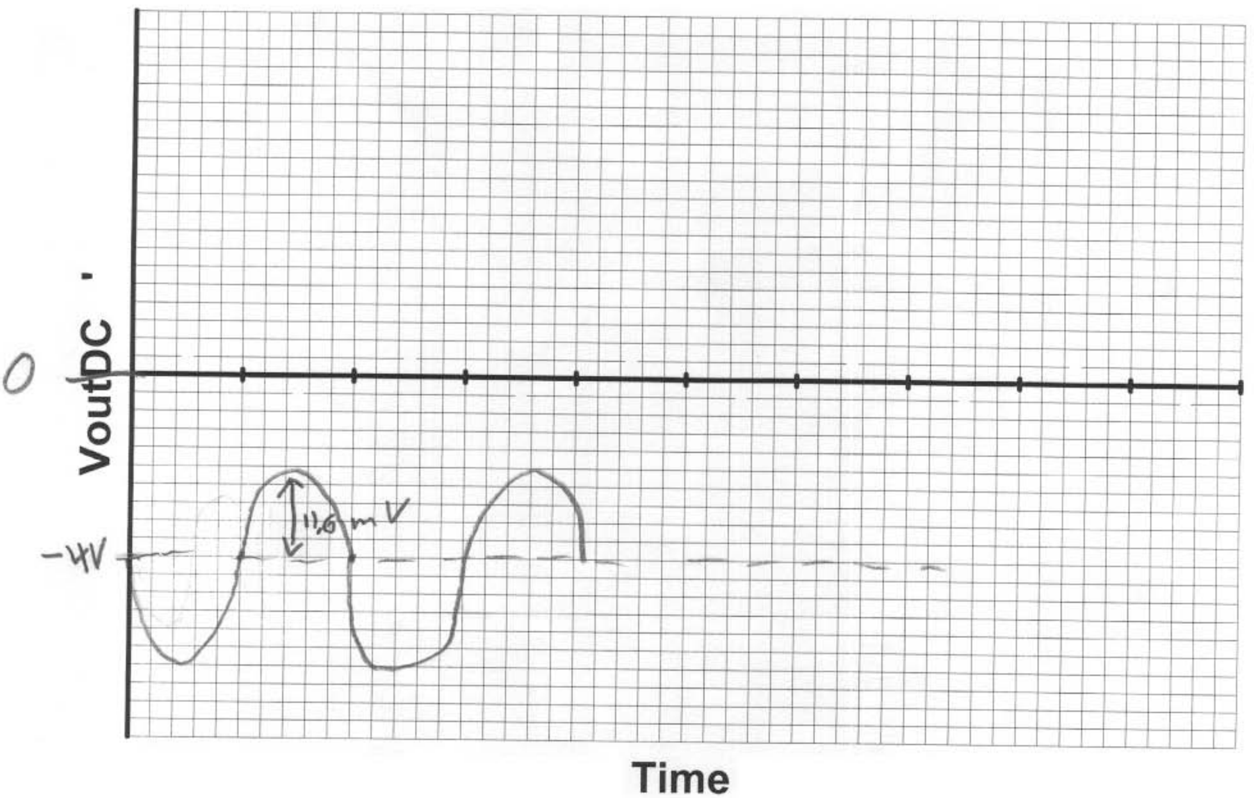
③ $v_{out} = -(g_m v_\pi)(r_o || R_C || R_{out}) = -(0.384)(65) v_\pi = -24.95 v_\pi$

$A_v = \overset{③}{\left(\frac{v_{out}}{v_\pi} \right)} \overset{②}{\left(\frac{v_\pi}{v_{th}} \right)} \overset{①}{\left(\frac{v_{th}}{v_{inac}} \right)} = (-24.95)(0.93)(0.5)$

$\boxed{A_v = -11.6\ V/V}$

Answer Page


Note: Out of Phase
11.6mA
VoutAC
VinAC
Time


0
VoutDC
11.6 mV
-4V
Time