ECE 3040 Microelectronic Circuits

Exam 2

April 5, 2011

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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: As you increase the magnitude of the reverse bias on a diode the capacitance of the diode increases.

2.) (2-points) True / False: A saturated transistor behaves like a closed switch except that the transistor has a voltage drop across it's collector-emitter terminals whereas a perfect switch has no voltage drop.

3.) (2-points) True / False: To make a BJT operate faster (higher frequencies), you should design the base quasi-neutral region width to be as narrow as possible.

4.) (2-points) True / False: Considering small signals only, the collector-emitter output terminals of a forward active biased transistor with an infinite Early voltage can be considered a perfect current source.

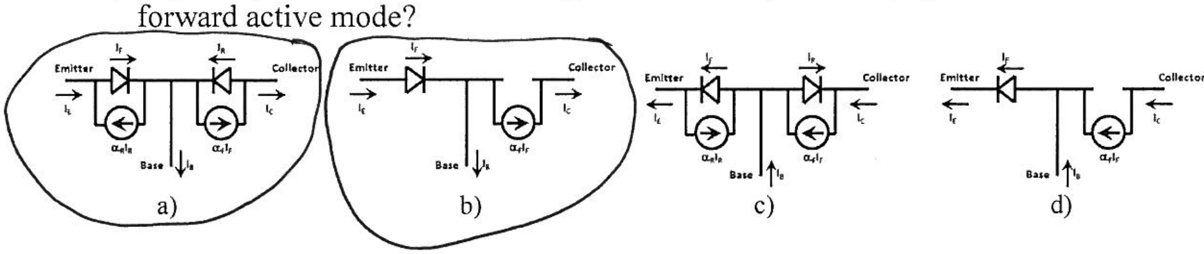
5.) (2-points) True / False: A reverse biased diode acts as a near perfect voltage reference (i.e. has an approximately constant voltage for a large range of current).

6.) (2-points) True / False: Dr. Doolittle is really nice because he gave me a free two points on this problem. (Humor break to lower tension level)

7.) (2-points) If r_d is the small signal resistance of the diode and noting the proper use of our current and voltage symbols for small and large signals, which of the following is true?

a. $i_D=r_dV_D$
b. $i_d=r_dV_D$
c. $i_D=r_dv_D$
d. $i_d=r_dv_d$
e. None of the above.

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



9.) (2-points) Regarding Large signal vs Small signal models of diodes and transistors, which of the following are NOT true:

a. Large signal models are linear models F

b. Mathematically, small signals are when voltages are less than the thermal voltage T

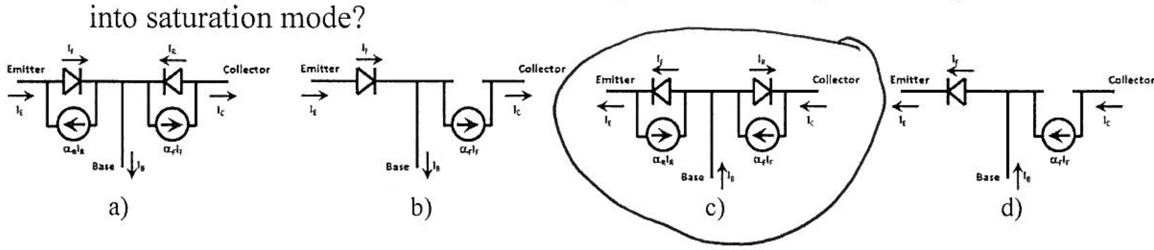
c. Ohms law applies for small signals T

d. The AC conductance is determined by finding the slope of current vs voltage curves at a DC operating point. T

e. Small signal resistances are small when p-n junctions are reverse biased. F

f. This question is completely unfair!

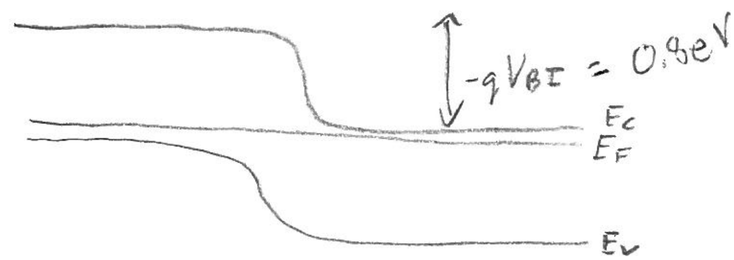
10.) (2-points) Which of the following circuits can represent a npn transistor biased into saturation mode?



12.) (20 points total in 3 parts)

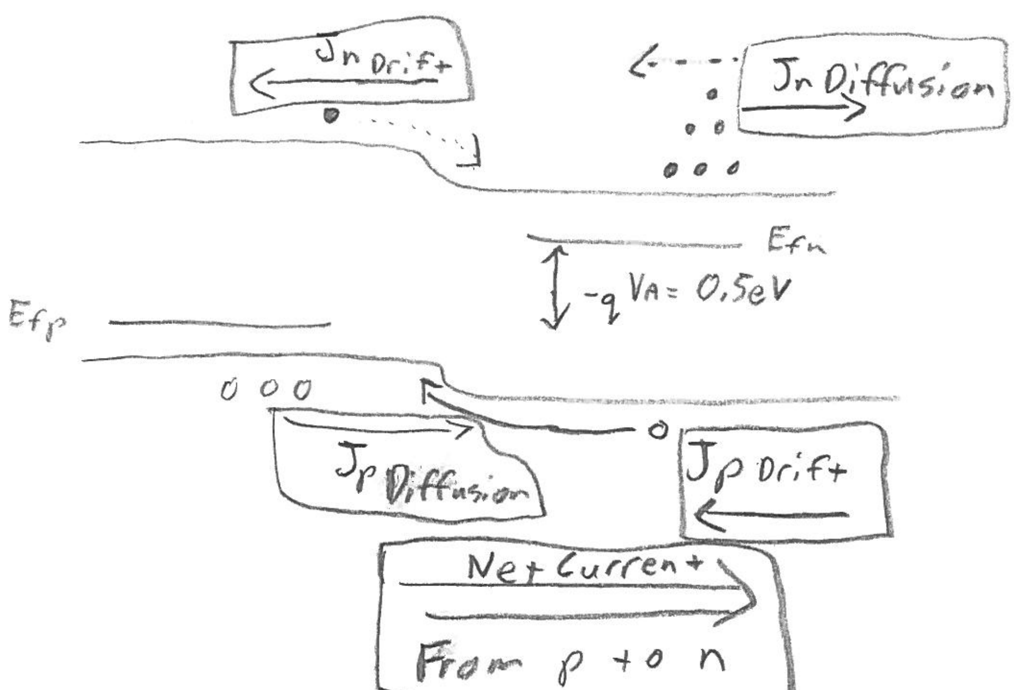
Note: Neatness and clarity counts in the drawings for this problem.
A room temperature silicon p-n junction solar cell is initially operated in the dark. It has a 0.8 volt built in potential and a 1.1 eV bandgap.

(a – 4 points) Draw the equilibrium energy band diagram, labeling the built in voltage and fermi level (do not calculate the fermi level – just sketch it).



(b – 9 points) The device is still in the dark but is electrically forward biased (by a power source). If 0.5 volts is applied to the diode,
i) Sketch and label the energy band diagram of the solar cell
ii) Label the magnitude of the quasi-fermi level split between the n-type and p-type sides of the solar cell.
iii) Using four separate arrows, label the direction of the four components of <u>current</u> flowing in this device (Drift hole current, Diffusion hole current, Drift electron current and Diffusion electron current).
iv) Net current Flow

Drawings must show flatter bands than in part a)



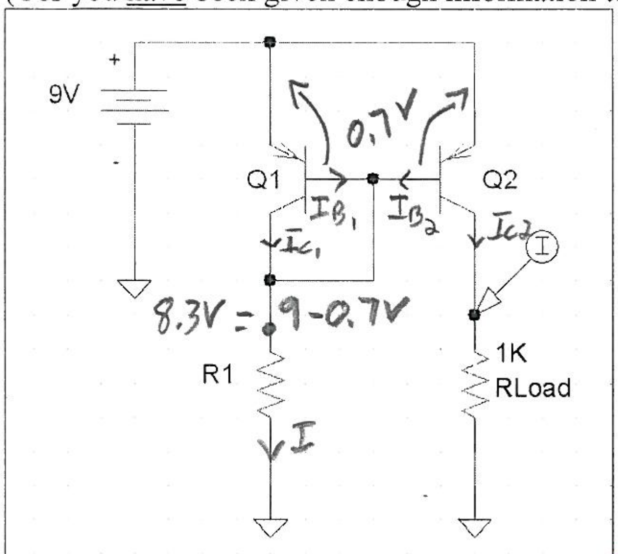
12 continued:

(c – 7 points) The device is now operated in the bright sun and is allowed to "float" (i.e. no external power source is used). It is found that once again, 0.5 volts is measured at the diode's terminals. Is the current measured in the same or opposite direction as was found in part b? Explain the reasons for your answer in 3 sentences or less. (No credit given without an explanation).

Since the light generates more minority carriers than found in equilibrium, the drift current (minority carrier current) is increased. Thus, the measured current is in the opposite direction as was found in part b. The current direction is the same as the direction of the reverse leakage current since they are both drift currents.

13) (20 – points) The following circuit implements a pnp transistor, current mirror to be used as a current source driving resistor RLoad. It is desired to have a "programmed" current of 1 mA flowing through resistor, RLoad. Transistors Q1 and Q2 are identical in every parameter and have a β_{DC}=1000 and have a turn on voltage of 0.7 V for any forward biased junction. You can assume the transistors Q1 and Q2 are always maintained in forward active mode (no need to verify for this problem). You can assume that the base currents, I_B , are small (and thus can be neglected) compared to all other currents. What value of resistance R1 is needed to achieve the desired programed current?

(Yes you have been given enough information to solve the problem).



Since $I_C = I_S(e^{V_{EB}/V_T} - 1)$ and since $I_{S_1} = I_{S_2}$ and $V_{EB_1} = V_{EB_2}$, $\underline{I_{C_1} = I_{C_2}}$.

Since we can neglect $I_{B_1} + I_{B_2}$, $I_{C_1} = I = I_{C_2}$

Thus,

Basically a simpler version of a homework problem!!!

$$8.3V = 1mA(R_1)$$

$$\boxed{R_1 = 8.3\,k\Omega}$$

<u>Note:</u> If you did not use the hint to neglect the Base currents:

$$I = I_{C_1} + 2I_{B_1}$$

$$I = I_{C_1} + 2\frac{I_{C_1}}{\beta} = I_{C_2} + 2\frac{I_{C_2}}{\beta}$$

(Set to 1 mA)

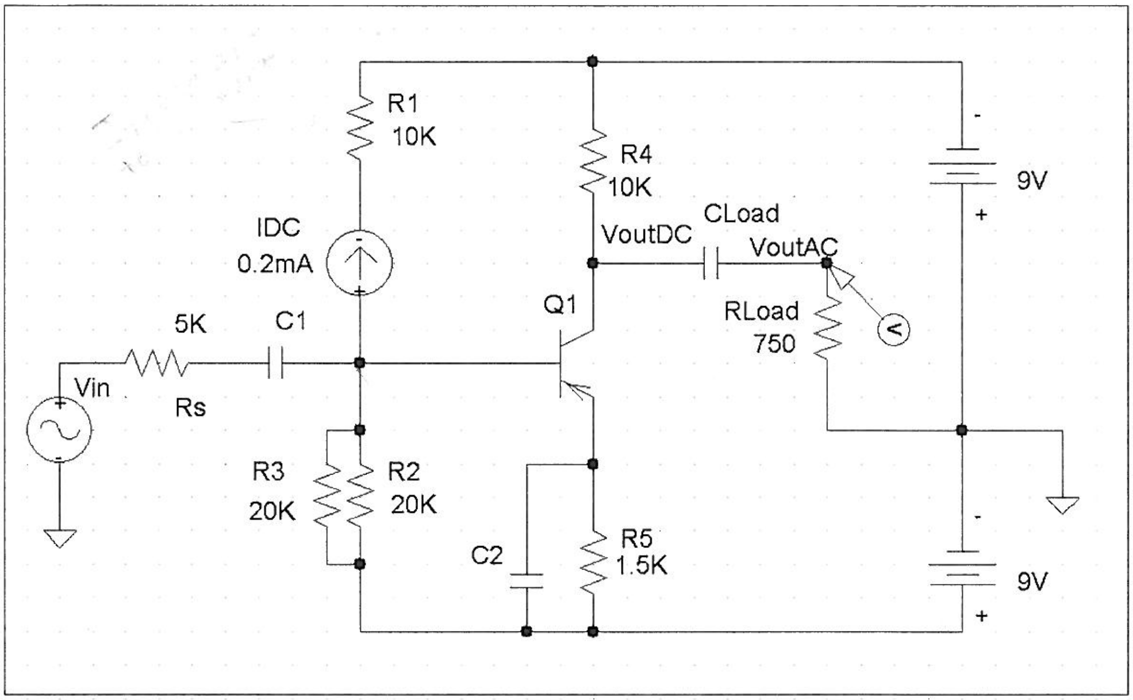
$$I = 1mA + \frac{2}{1000}1mA = 1.002mA$$

$$8.3V = (1.002mA)R_1$$

$$R_1 = 8.3\,k\Omega$$

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: $V_{turn\ on}$=0.64 V, β_{DC}=200, V_A=100V
Current source, IDC= 0.2 mA DC
VinAC = 1mV amplitude (i.e. 2mV peak to peak) at 1 KiloHertz

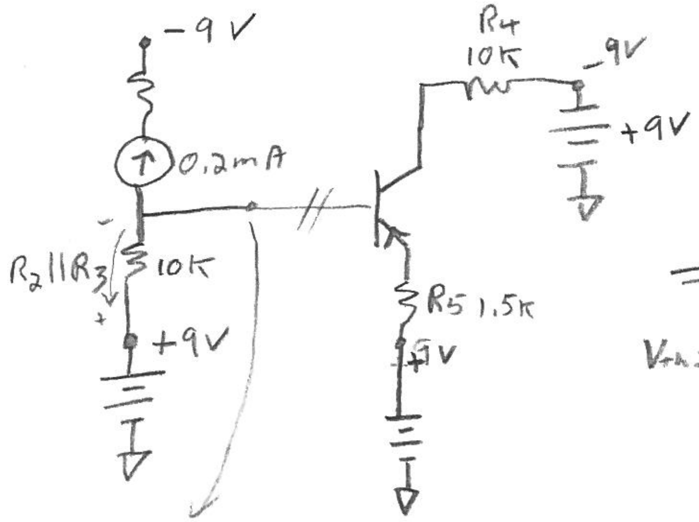


Given the above input voltage, Vin, sketch and accurately label a plot the TWO output waveforms VoutAC and VoutDC on the graph paper provided on the next page. Assume the turn on voltages for all forward biased junctions are 0.64 V. You may assume all capacitors are very large values and are thus, AC 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.**

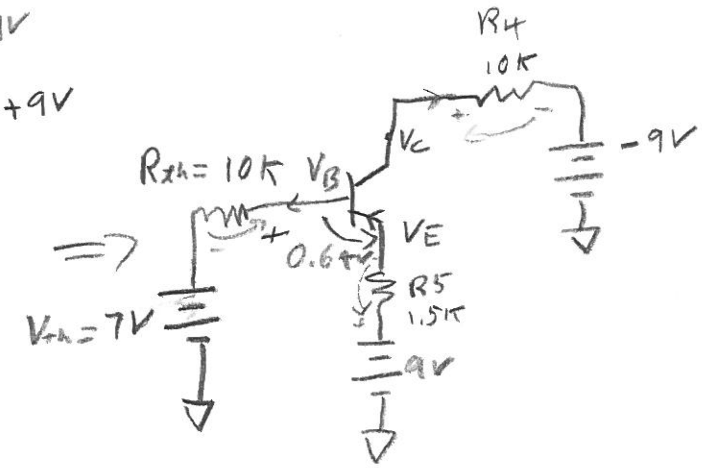
Extra work can be done here, but clearly indicate with problem you are solving.

DC Solution:

$\beta = 200$



$\Rightarrow$



$V_{Th} = 9V - (0.2mA)10K$

$= 7V$

$7V + I_B 10K + 0.64 + I_E 1.5K - 9V = 0$

$I_B (10k + (200+1)1.5K) = 2 - 0.64$

$I_B = 4.36\ \mu A$

$I_C = \beta I_B = 873\ \mu A$

$I_E = (\beta+1) I_B = 877\ \mu A$

Verify Assumptions

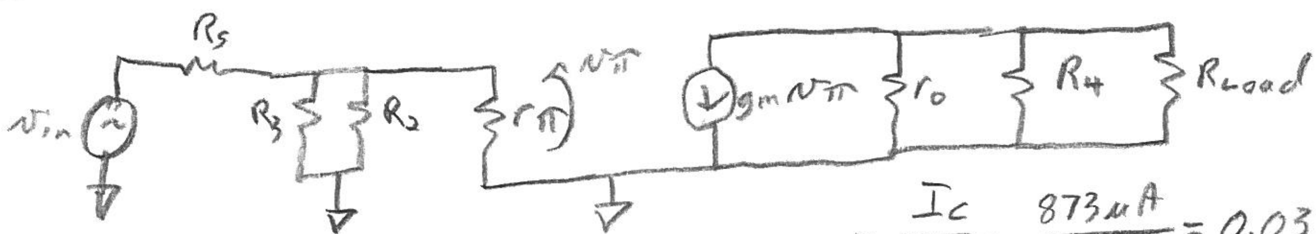
RB ✓ $V_C = -9V + 10K I_C = -0.27V$

$V_B = 7V + I_B 10K = 7.044V$

FB $V_E = 9V - I_E 1.5K = 7.68V$

= 0.64V ✓

Conversion to small signal model



$g_m = \frac{I_C}{V_T} = \frac{873\mu A}{0.0259} = 0.0337 S$

$r_\pi = \frac{\beta}{g_m} = \frac{200}{0.0337} = 5933 \Omega$

$r_o = \frac{V_A + V_{EC}}{I_C} = \frac{100 + 7.95}{876\mu A}$

$= 123 K\Omega$

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

$$A_v = \frac{v_\pi}{v_{in}} \frac{v_{out}}{v_\pi}$$

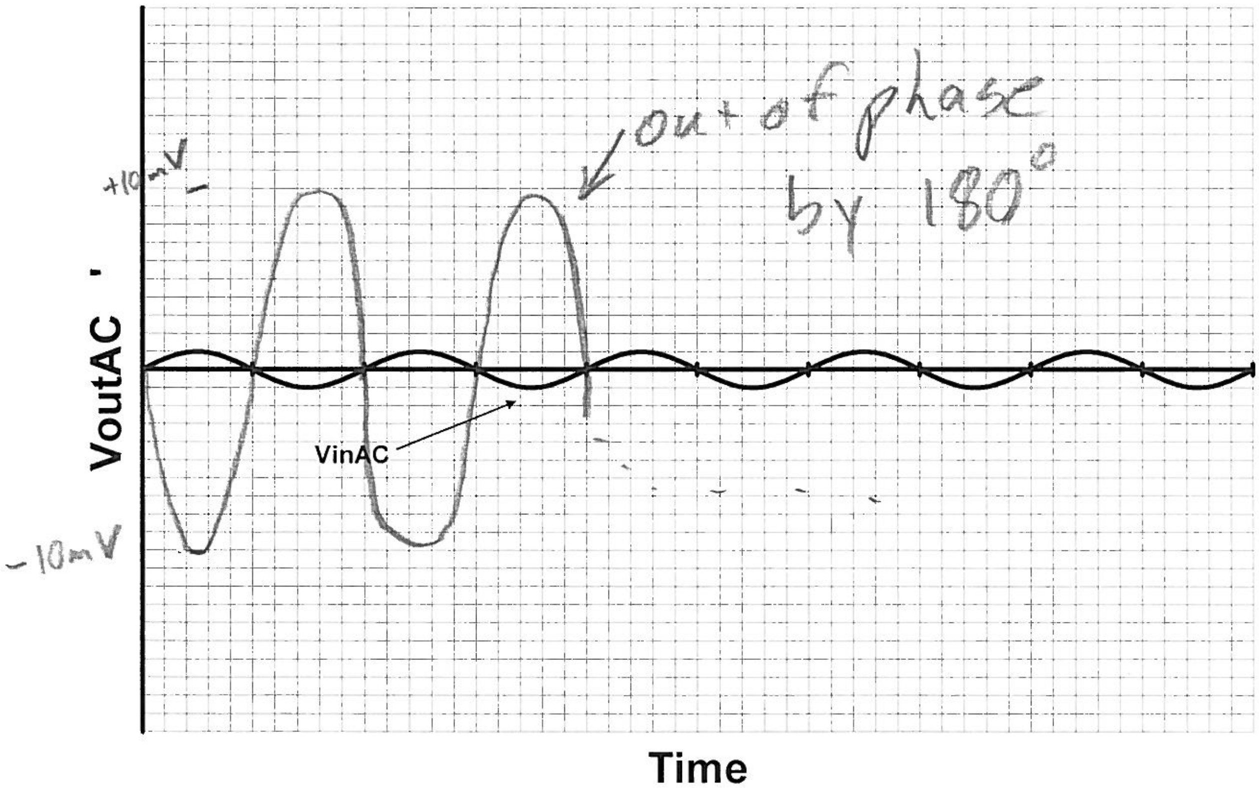
$$v_\pi = v_{in}\left(\frac{r_\pi || R_2 || R_3}{R_S + r_\pi || R_2 || R_3}\right) \qquad v_{out} = -g_m v_\pi (r_o || R_4 || R_{Load})$$

$$A_v = -\left(\frac{5933 || 10k}{5k + 5933 || 10k}\right)(0.0337)(123k || 10k || 750)$$

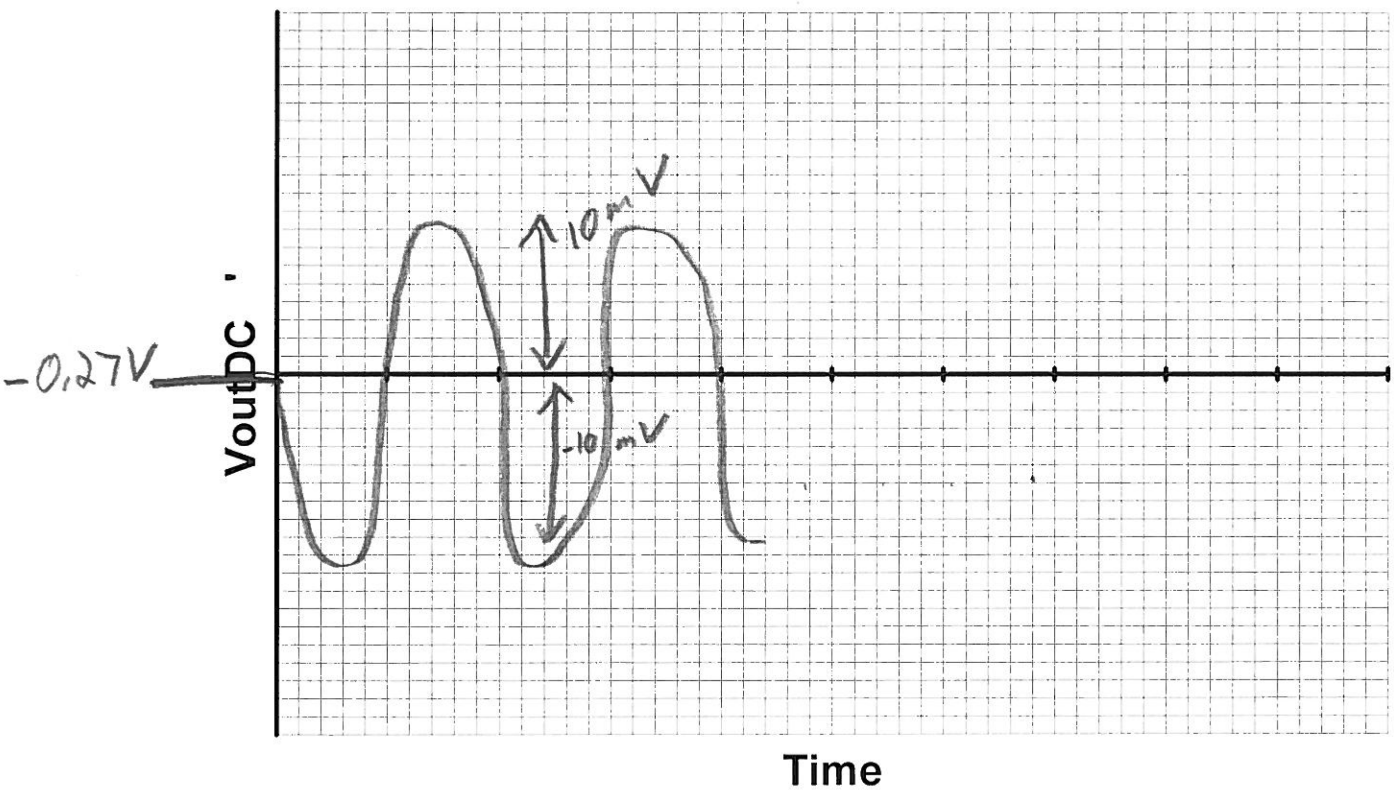
$$= -(0.4268)(0.03375)(693.7\Omega)$$

$$\boxed{A_v = -9.97 \text{ V/V}}$$

Answer Page



+10mV
-10mV
VoutAC
VinAC
out of phase
by 180°
Time



-0.27V
VoutDC
10mV
-10mV
Time