1) Short Answers (22 points)

Question 1 (5 points)

T / F Ideal diodes consume no power

T / F Minimizing ripple voltage improves efficiency in rectifier circuits

T / F It is possible that the output voltage due to bias terms can be negative

T / F The real (not ideal) input resistance of the OP27 is in the 1-10MegΩ range

T / F For a Miller Integrator, when the input is DC, the output is zero.

Question 2 (2 points)

During the 'diode off' time of a rectifier circuit, the load voltage is $V_L = V_o e^{-\frac{t}{\tau}}$ where $\tau = RC$. What relationship must hold for the ripple voltage to be considered small.

RC must be much greater than the period

Question 3 (4 points)

For a two input amplifier circuit, two measurements were taken

V1 = 1.9V and V2 = 2.1V, Vout = 5V

V1 = 3.9V and V2 = 4.1V, Vout = 5.2V

Determine the common mode gain and the differential gain.

$\frac{1.9+2.1}{2} = 2 = V_{cm}$ $\frac{2.1-1.9}{2} = .1 = V_{dm}$

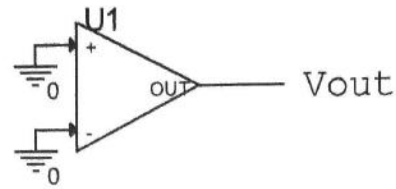
$\frac{4.1-3.9}{2} = .1 = V_{dm}$ $\frac{4.1+3.9}{2} = 4 = V_{cm}$

$A_{cm} \cdot 2 + .1 \cdot A_{dm} = 5$

$4 \cdot A_{cm} + .1 \cdot A_{dm} = 5.2$

Thus $A_{cm} = 0.1$
$A_{dm} = 48$

Question 4 (2 points)



When considering real amplifiers, briefly describe why the output of the above op-amp is at the saturation voltage (Vout = Vsat) when both the inputs are grounded.

When considering real op amps there is always some input DC bias inherent. Thus, in this config of a comparator, that DC bias will drive a saturation output.

Question 5 (2 points)

Under what conditions is a Taylor's series approximation reasonable in rectifier analysis?

For a very small x we can say that only the first two terms are needed.

$e^{-x} = 1 - x$

Question 6 (4 points)

For a slew rate of 4 V/μs, what is the maximum frequency of a voltage follower with a triangle wave input Vpeak-to-peak = 10V such that the output appears as expected.

slope = 4×10^6 Thus max $f = 10^6$ Hz

Question 7 (3 points)

When considering ideal balanced difference amplifiers

The common mode gain is ideally, A_{CM} = 0

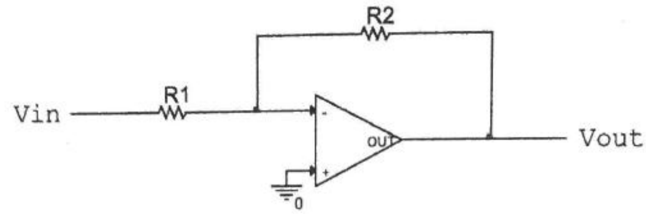
The common mode rejection ratio is ideally, CMRR = ∞

Why is that unlikely with real amplifier circuits?

For functionality the op amp must have some small current draw and small current output. This causes non-ideal behavior.

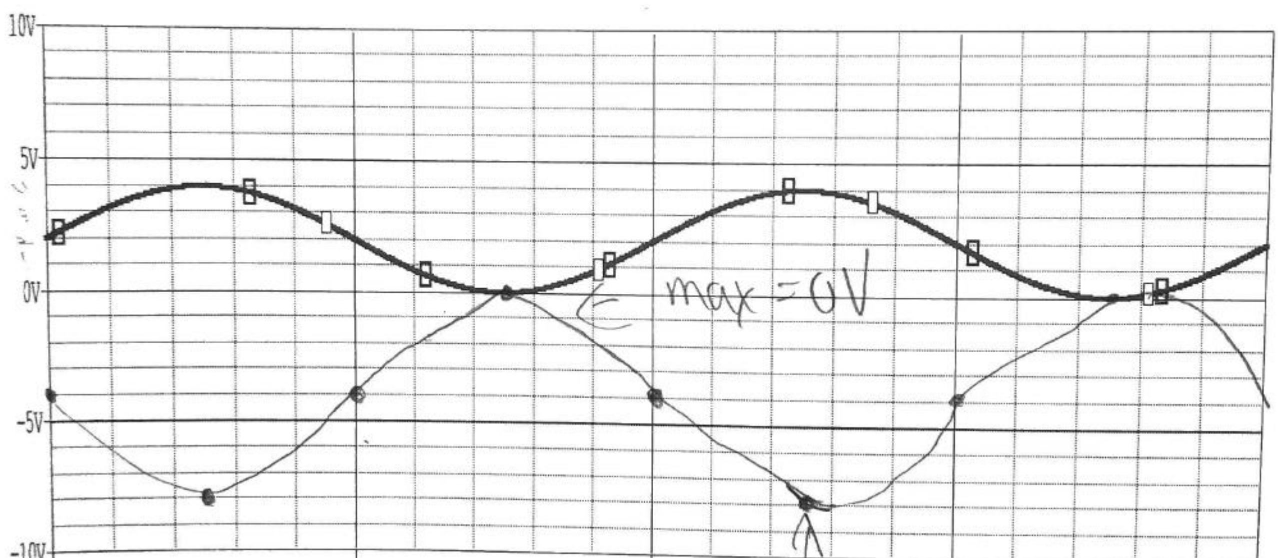
2) Op-amp circuits (14 points)

All op-amps in this problem have power supplies of +9/-9V.



For R1 = 1kΩ, R2 = 2kΩ and $V_{in} = 2\sin(1000t) + 2$ [V] (shown below), sketch the output voltage as a function of time on the same plot. Clearly label the minimum and maximum voltages. (6 pts)

A = -2



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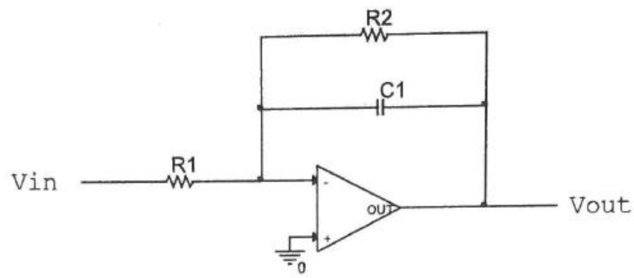
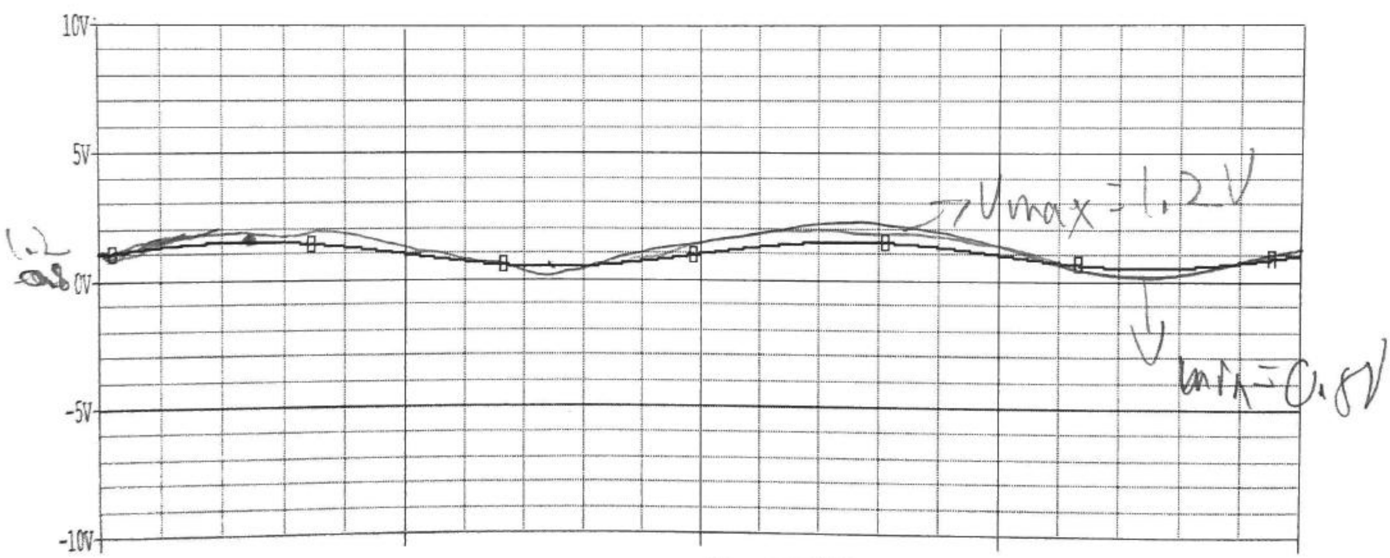
All op-amps in this problem have power supplies of +9/-9V.



For R1 = 1kΩ, R2 = 1kΩ, C1 = 0.1μF and $V_{in} = 0.2\sin(1000t)+1$ [V] (shown below), sketch the **steady state** output voltage as a function of time on the same plot. Clearly label the minimum and maximum voltages. (8 pts)

$Z_F = \left(\frac{1}{\frac{1}{j\omega C}} + \frac{1}{1000}\right)^{-1}$ $A = \frac{-Z_F}{Z_R} = -1 + 0.1j$

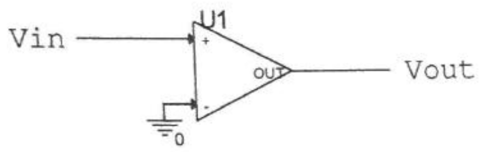


$\sqrt{-1^2 + 0.1^2} = 1$

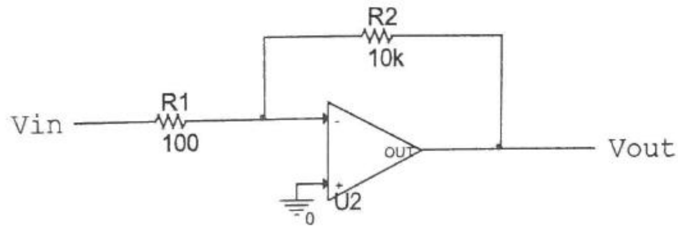
gain ≈ 1

3) Amplifier Transfer Functions (16 points)

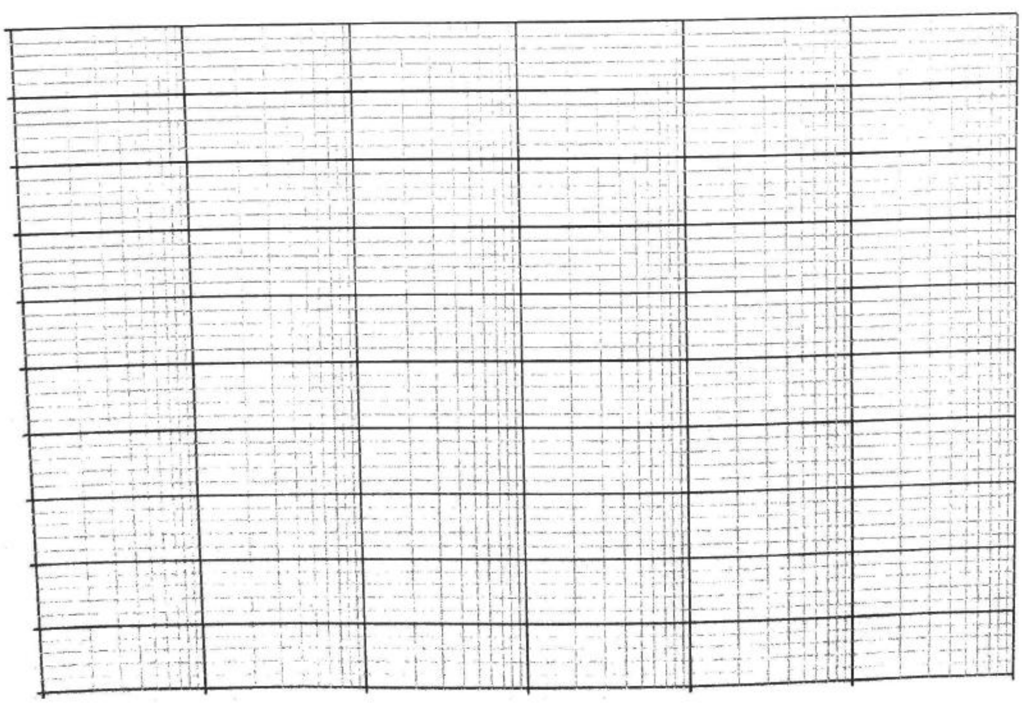
a) The op-amps in the following two circuits have an internal gain of 10^5 V/V and a GBP of 1 MHz. For both the following two circuits, sketch the Bode magnitude plot. Label the axis as appropriate. Both plots should be on the same axis. Clearly indicate the circuit that corresponds to the plot. (8 pts)



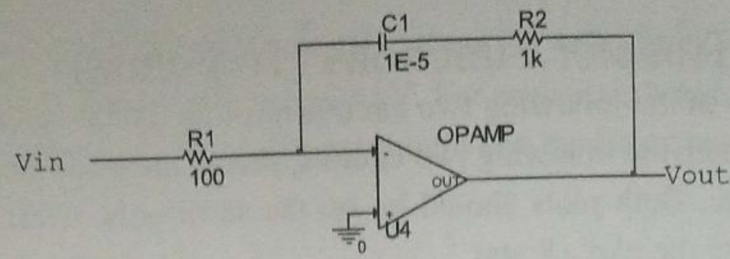
Circuit A



Circuit B



log(f)

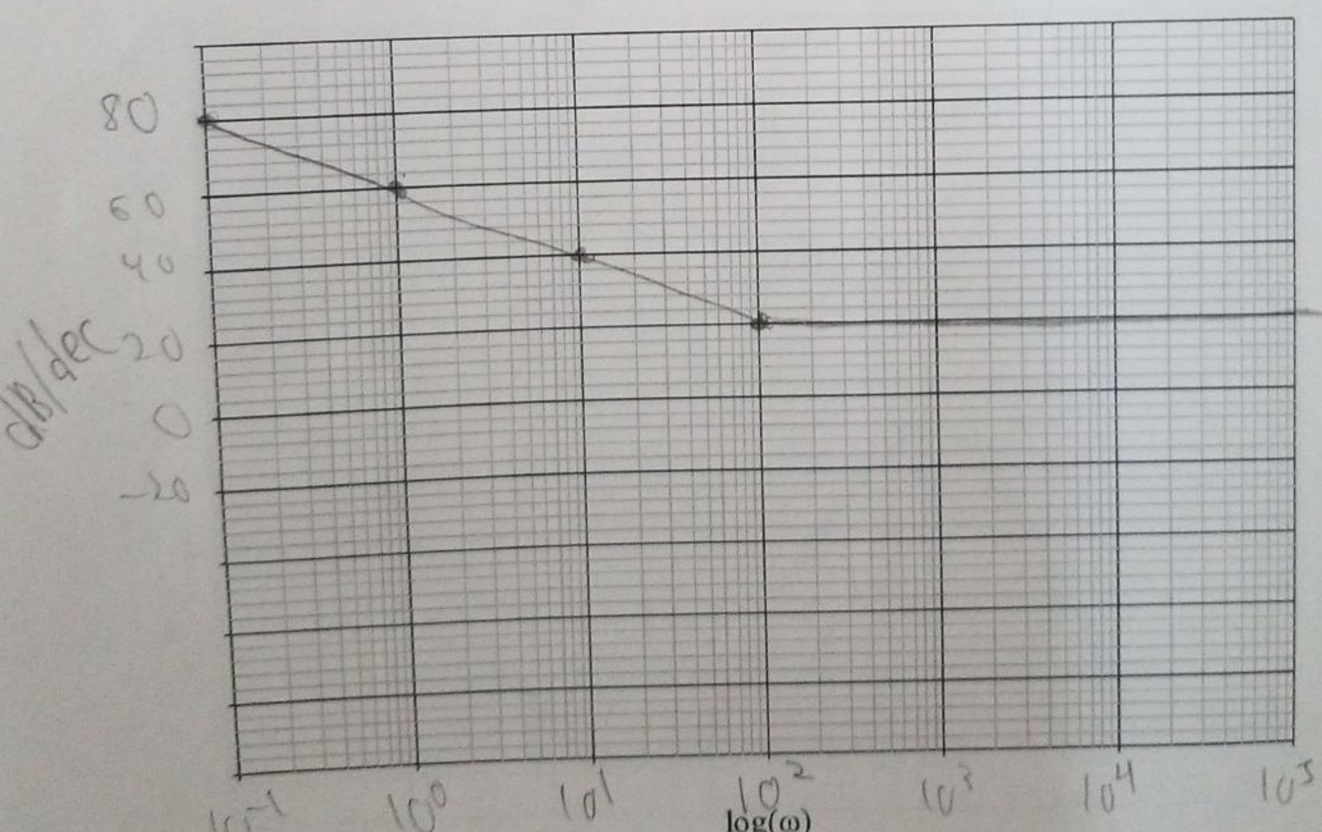


b) Determine the transfer function for the above circuit and sketch the Bode magnitude plot. Label the axis as appropriate. (GBP is not part of this problem.) (8 pts)

$$\frac{V_{out}}{V_{in}} = \frac{-Z_f}{Z_R} = \frac{\frac{1}{sC} + 1000}{100} = \frac{-10(s+100)}{s} = H(s)$$

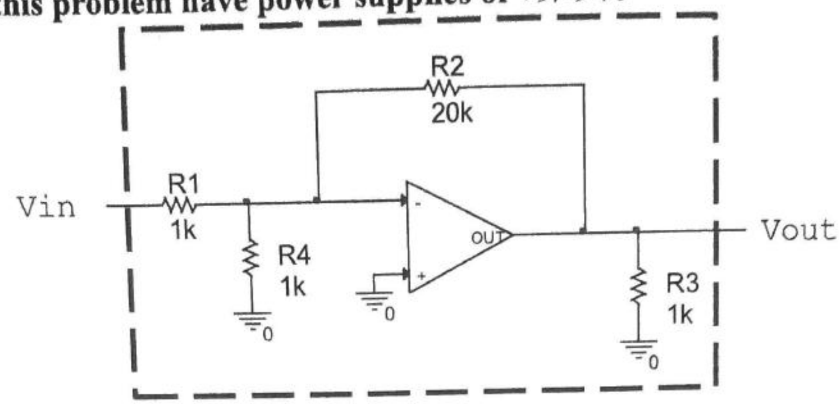
pole at 0

zero at -100

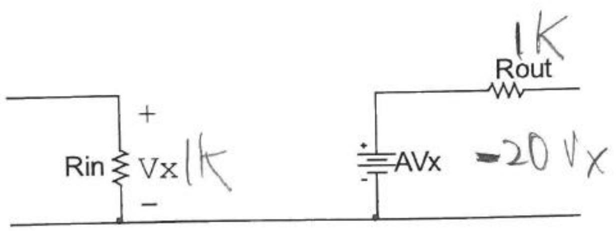


4) Op-amp circuits and Dependent Source models (12 points)

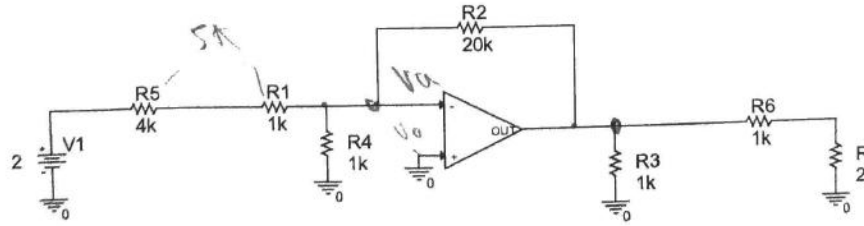
All op-amps in this problem have power supplies of +9/-9V.



a) For the indicated dashed box, identify Rin (looking 'in' from the 'left'), Rout (looking 'in' from the 'right') and the circuit gain, A = Vout/Vin. Add those numerical values to the following dependent source circuit. (6 pts)

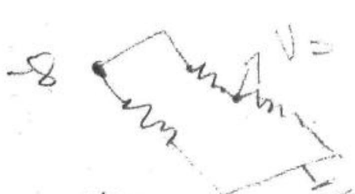


b) Determine VR7 for the following circuit. (6 pts)



$$\frac{0-2}{5k} + \frac{0}{1k} + \frac{0-V_{out}}{20k} = \frac{-2}{5k} - \frac{V_{out}}{20k} = 0$$

$$-8V = V_{out}$$



$$V = \frac{-8(2k)}{3k} = \boxed{-5.33\ V = V_{R7}}$$

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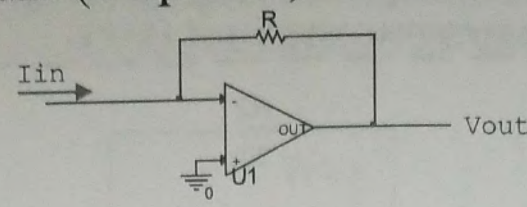
5) Finite Internal Gain (10 points)

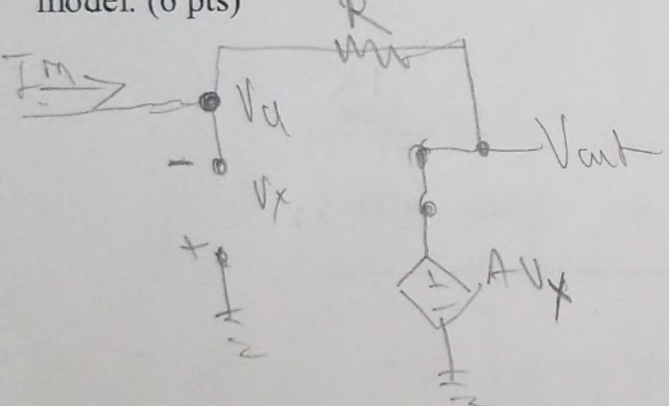


The above amplifier circuit is a transresistance amplifier with the transfer function defined as $H(s)=\frac{Vout(s)}{Iin(s)}$.

a) If the op-amp is ideal, determine the transfer function. (2 pts)

$-I_{in} = \frac{V_{out}}{R} \rightarrow \frac{V_{out}}{I_{in}} = -R$

b) If the op-amp has finite internal gain, A_{int}, determine the transfer function. As part of your analysis, include a schematic of the circuit, replacing the op-amp with the dependent source model. (6 pts)



$-I_{in} + \frac{-V_x - V_{out}}{R} = 0$

$V_a = -V_x$

$-I_{in} + \frac{-\frac{V_{out}}{A} - V_{out}}{R} = 0$

$\frac{V_{out}}{I_{in}} = \frac{-R}{1+\frac{1}{A}} = H(s)$

c) When R = 1kΩ A_{int} = 10^5 V/V and the op-amp has a GBP of 10 MHz, determine the approximate 3dB cutoff frequency. (2 pts)

10^8 Hz

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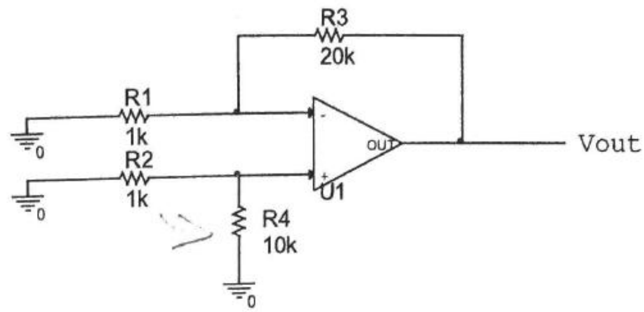
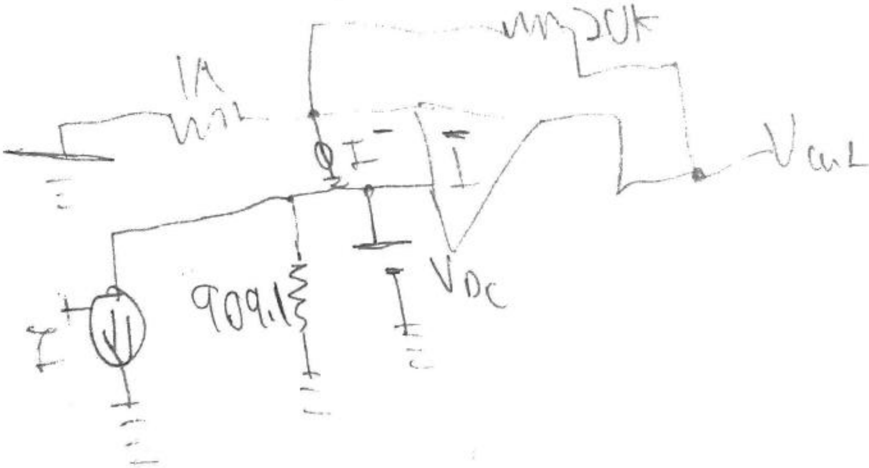
6) DC Bias Characteristics (15 points)

The bias characteristics for the amplifier are
1) $V_{DCoffset} = 4mV$
2) $I^-_{bias} = 5\mu A$
3) $I^+_{bias} = 5\mu A$



a) For each bias component, determine the output voltage. (3 pts each)

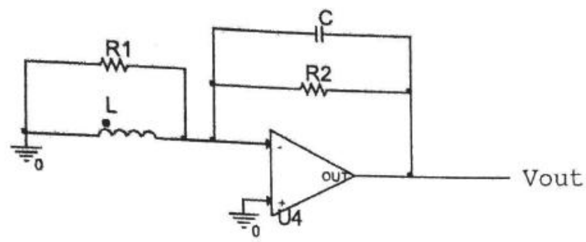


$$V_{out}|_{V_{DC}} = V_{DC}\left(1+\frac{20}{1}\right) = 0.084 V$$

$$V_{out}|_{I^-} = I^- \cdot 20k = .1 V$$

$$V_{out}|_{I^+} = -909.1\left(1+\frac{20}{1}\right) I^+ = -0.0954$$

I^+_{bias}	-95.4 [mV]
I^-_{bias}	100 [mV]
$V_{DCoffset}$	84 [mV]



b) For the above circuit, determine a symbolic expression for the output voltage due to the $V_{DCoffset}$ bias term. (6 pts)

inductor ~~differentiates~~ integrates
cap integrates

$$V_{out}\Big|_{V_{DC}} = V_{dc}\left(1+\frac{\left(\frac{1}{Z_C}+\frac{1}{Z_{R_2}}\right)^{-1}}{\left(\frac{1}{Z_L}+\frac{1}{Z_{R_1}}\right)^{-1}}\right)$$

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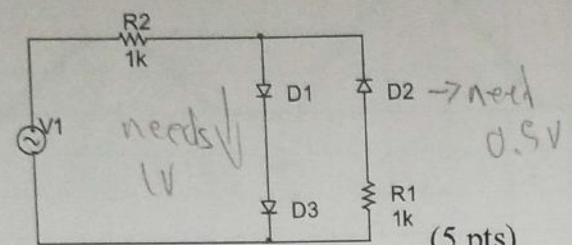
7) Op-amp circuits and Dependent Source models (15 points)

All diodes on this page have a turn-on voltage of 0.5V. For each circuit and source voltage, plot the source current on the same graph. Label the maximum and minimum current values. (Pay attention to the voltage axis)

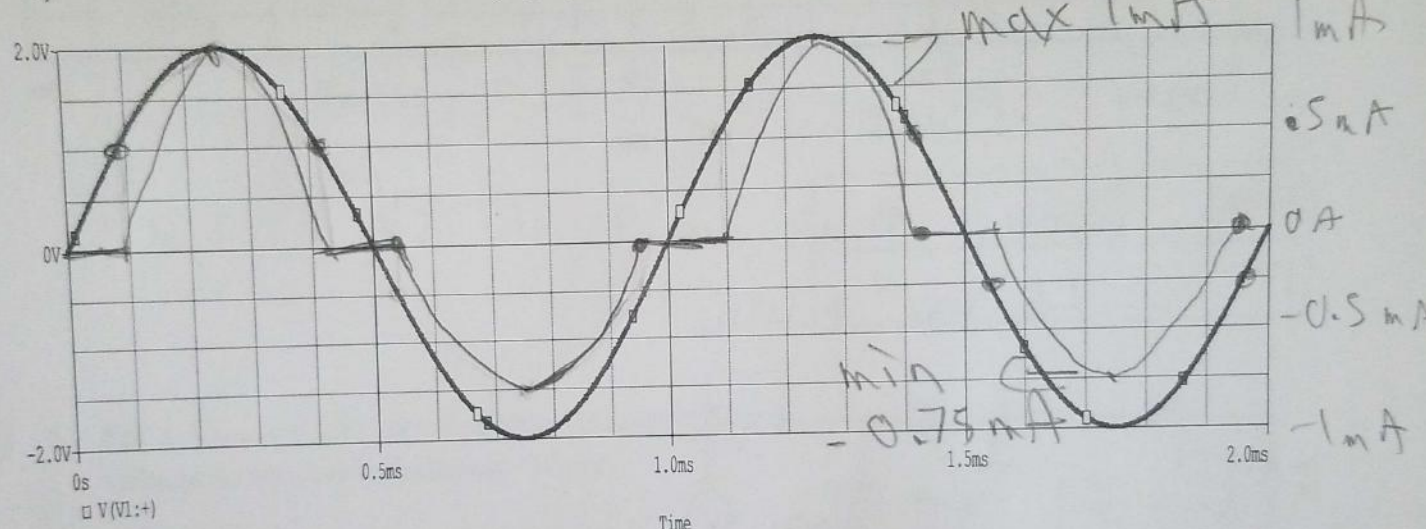
a)



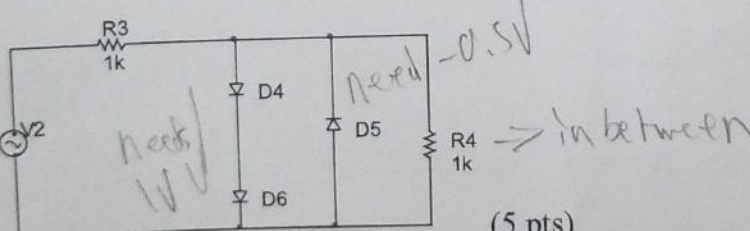
$max^+ = \frac{2-1}{1k} = 1mA$

$min^- = \frac{2-0.5}{2k} = .75\,mA$

(5 pts)

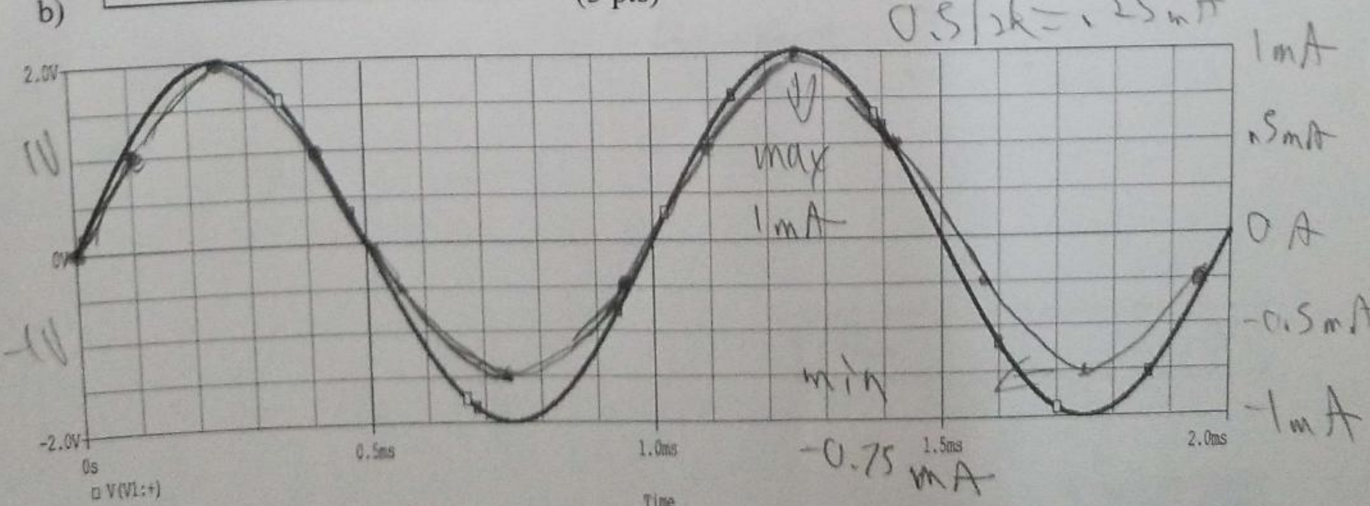


b)

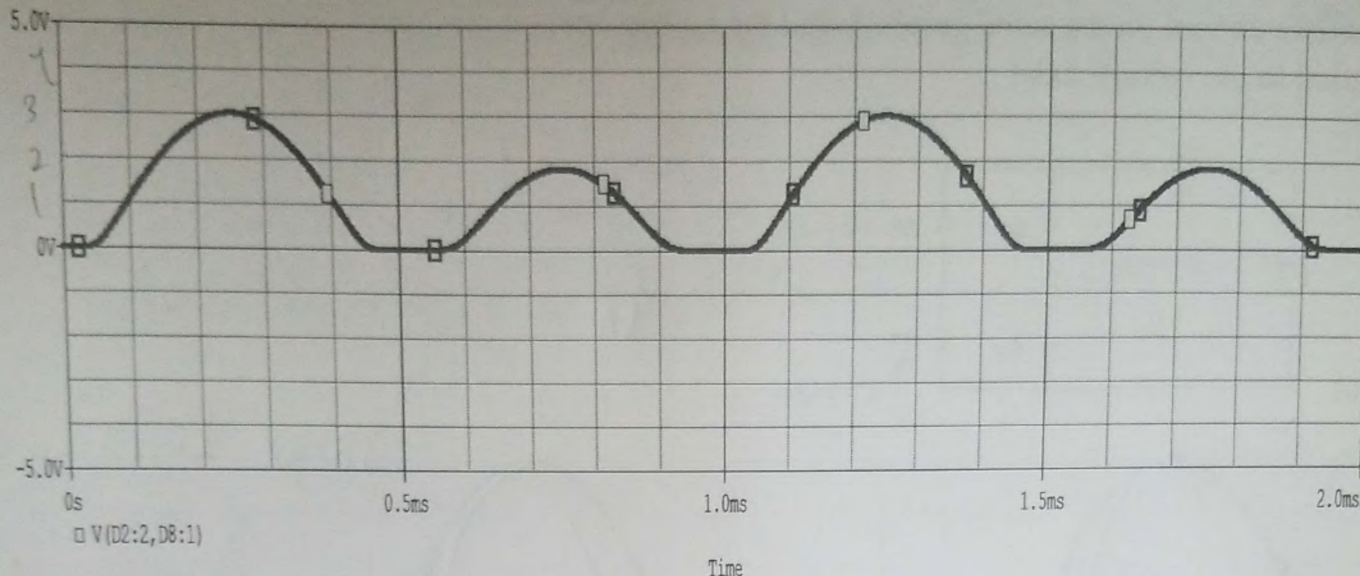


max⁺ = 1mA
min − −0.75mA
1V/2k = 0.5 mA
0.5/2k = .25 mA

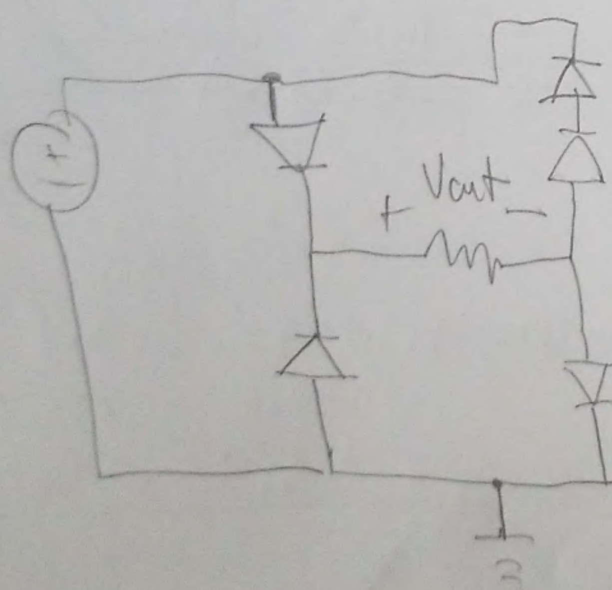
(5 pts)



c) Using diodes with $V_{turn\text{-}on} = 1V$, design a circuit that has the following output voltage. The source voltage is 5sin(1000t). (5 pts)



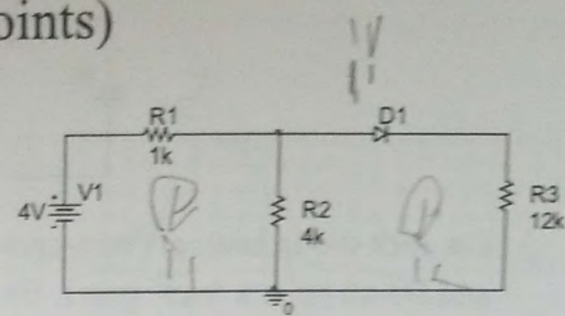
negative circuit has to drop 1V
full wave rectifier?



8) Ideal Diodes – DC Analysis (14 points)

All diodes in this problem are ideal.

a) For a $V_{turn\text{-}on} = 1V$, determine the voltage across and current through the diode in the circuit shown to the right. (4 pts)



$-4 + i_1R_1 + i_1R_2 - i_2R_2 = 0$

$i_2R_2 + 1V + i_2R_3 - i_1R_2 = 0$

$i_2 = I_D$

$5ki_1 - 4ki_2 = 4$

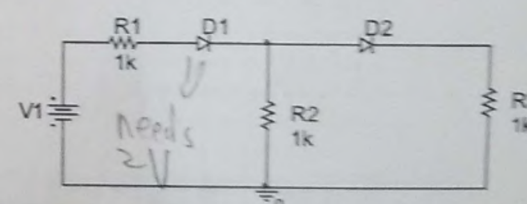
$16ki_2 - 4ki_1 = -1$

$i_1 = 9.375 \times 10^{-4}$

$i_2 = 1.718 \times 10^{-4}$

I_D	.1178	[mA]
V_D	1	[V]

b) For a $V_{turn\text{-}on} = 2V$, determine the minimum source voltage to turn both diodes on. (4 pts)



2V drop immediate

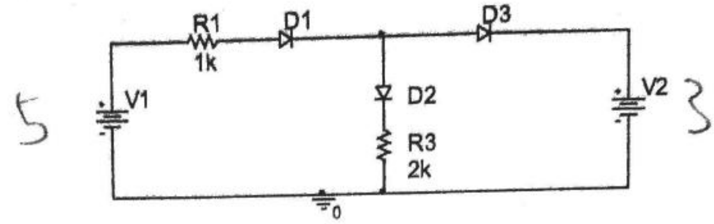
Then it's a voltage divide which cuts in half.

meaning that without D1 need at least 4V.

So 4+2 = 6

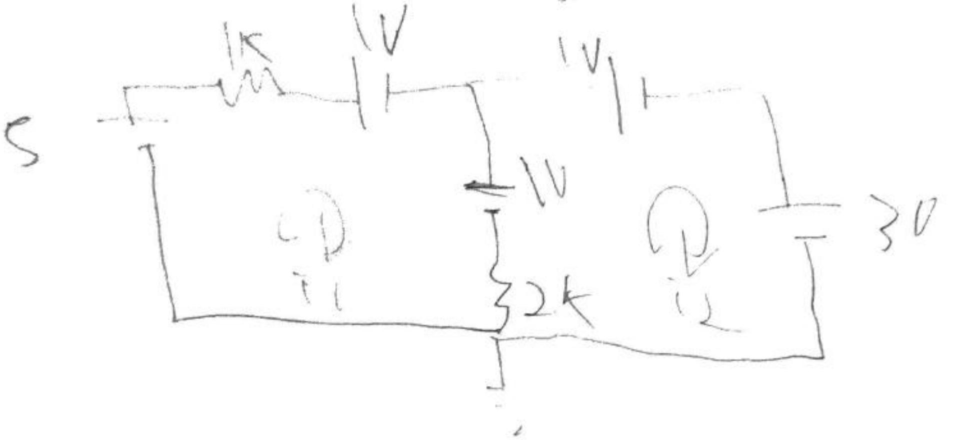
6V is Vmin

V_{min}	6	[V]



c) For each diode having Vturn-on = 1V, V1 = 5V and V2 = 3V, verify that guessing D1, D2 and D3 all on is a 'bad' guess. Be specific in your analysis. (6 pts)

all diodes on mesh analysis

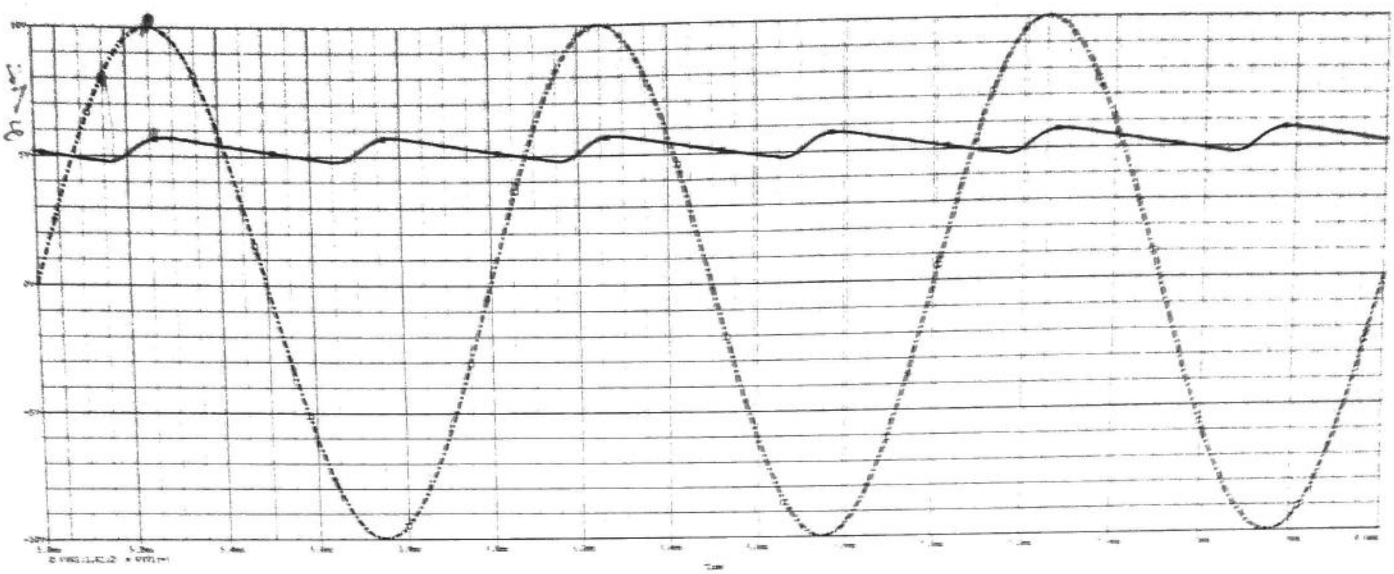


$i_1 3k - i_2 2k = 3$ $\quad i_1 = 0$

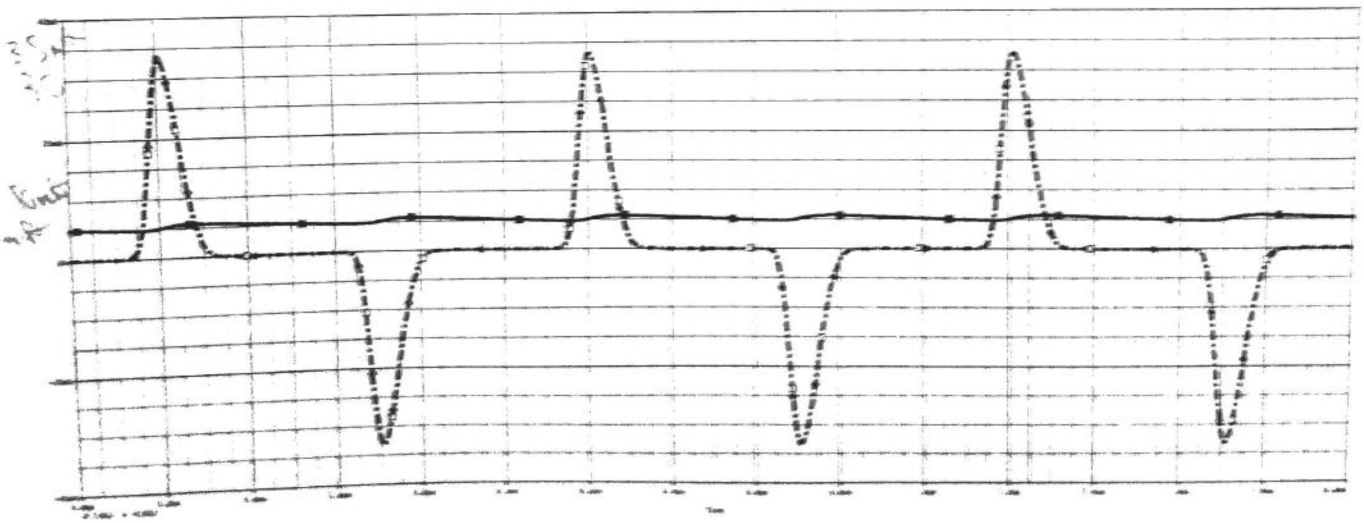
$i_2 2k - i_1 2k = -3$ $\quad i_2 = -0.0015$

This means current flows (i_2) opposite which we defined. meaning that it supposedly goes against D3. This is impossible thus all on is a bad guess.

9) Rectifiers (20 points)



Dashed line: Source voltage
Solid line: Load voltage
x-axis: 5ms to 8ms
y-axis: -10V to 10V



Dashed line: Source current
Solid line: Load current
x-axis: 5ms to 8ms
y-axis: -40mA to 40mA

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The plots on the previous page were obtained from the simulation of a rectifier circuit, with the top plot being voltage plots and the bottom plot being current plots of the source and the load, respectively.

a) Is the circuit a half-wave or full-wave rectifier? (1 pt) Full wave

b) Estimate the turn-on voltage of a diode. (2 pts)

$10V - 6V = 4V \div 2 = 2V$

c) Approximately determine the value of the load resistor. (1 pt)

$\frac{6V}{R} = 5mA = 1200$

d) Approximately determine the value of the smoothing capacitor. (3 pts)

$V_R = 6-5 = 1 = \frac{6V}{10^3(1200)C}$ $C = \frac{10^3}{6} 1200 = 2\times10^5 F$

e) Estimate the energy consumed by the load per cycle. (2 pts)

f) Estimate the energy produced by the source per cycle. (3 pts)

g) Estimate the energy consumed by the diode(s) per cycle. (3 pts)

h) Determine the approximate efficiency of this circuit. (1 pt)

i) Indicate one possible way to improve the efficiency of this circuit, keeping all the same components. (3 pts)

make it half wave

j) Sketch the circuit. (1 pt)