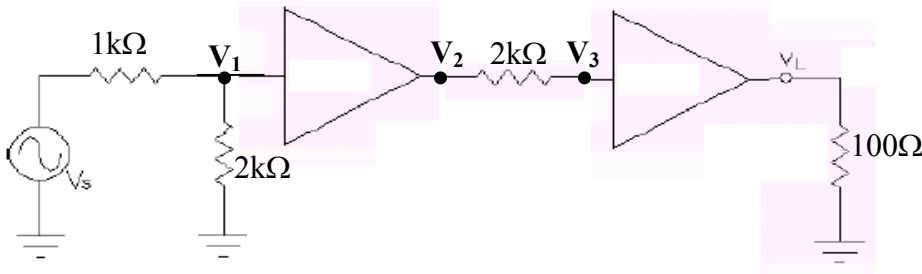


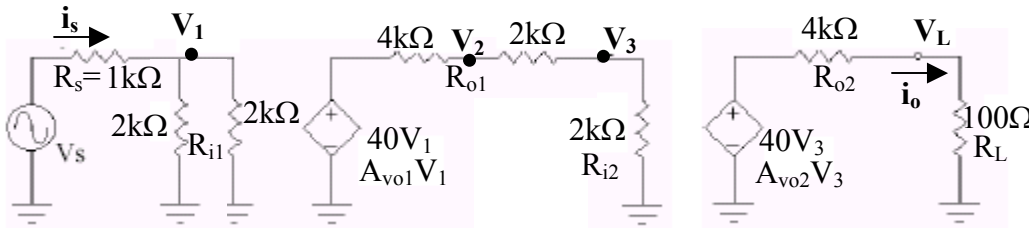
EXAM #1 - Solution

Problem 1 – (43 points)

- Both amplifiers have the following characteristics:
 $A_{vo}=40$ $R_i=2k\Omega$ $R_o=4k\Omega$ Clipping levels: $L=\pm 12V$ (unloaded)



- (a) Redraw this 2 stage amplifier using the amplifier model. Make sure to label V_1 , V_2 , V_3 , and V_L on the schematic. (15 points)



- (b) Find $A_v = \frac{v_L}{V_s}$. Express your answer as a ratio(V/V) and in dB. [Round to a whole number] (10 points)

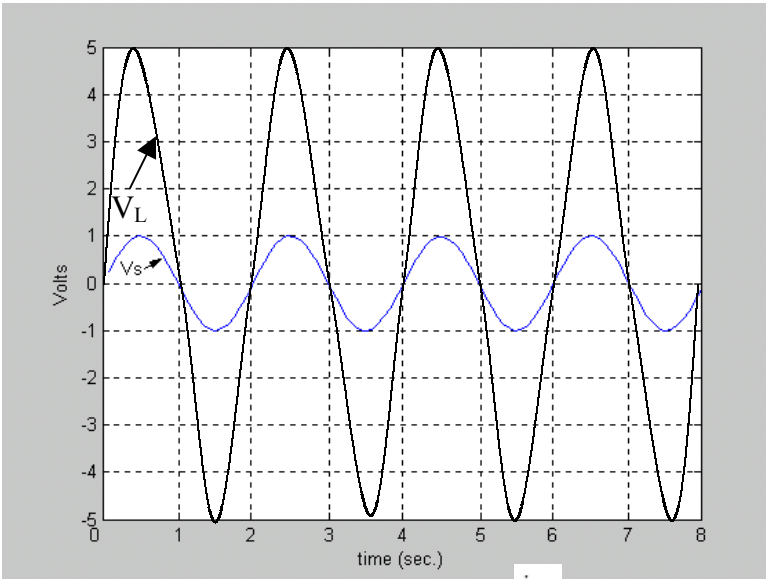
$$\frac{v_L}{V_s} = A_v := \left(\frac{R_{i1}}{R_s + R_{i1}} \right) \cdot A_{vo1} \cdot \left(\frac{R_{i2}}{R_{o1} + R_{i2}} \right) \cdot A_{vo2} \cdot \left(\frac{R_L}{R_{o2} + R_L} \right)$$

$$R_{i1} = \frac{1}{\frac{1}{2k} + \frac{1}{2k}} = 1k \quad R_{o1} = 4k + 2k = 6k$$

$$A_v = \frac{1k}{1k + 1k} \cdot 40 \cdot \frac{2k}{6k + 2k} \cdot 40 \cdot \frac{100}{100 + 4000} = 4.878 \quad (\text{rounded} = 5V/V) \quad \text{or} \quad 20 \cdot \log(5) = 13.979$$

(c) For the input V_s as shown, sketch (make the peaks exact and estimate between the peaks) the output at V_L on the graph below. (8 points)

Amplitude => peak will be at: gain (from 1(b)) * $V_{s_peak} = 5 * V_{s_peak} = 5(+1) = 5$



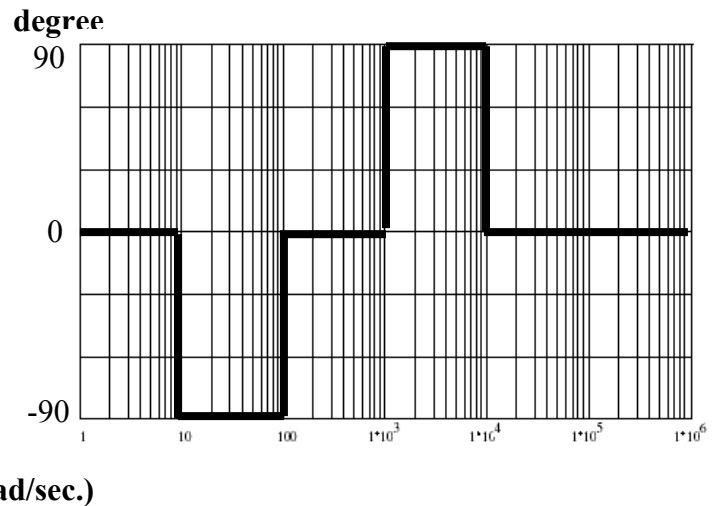
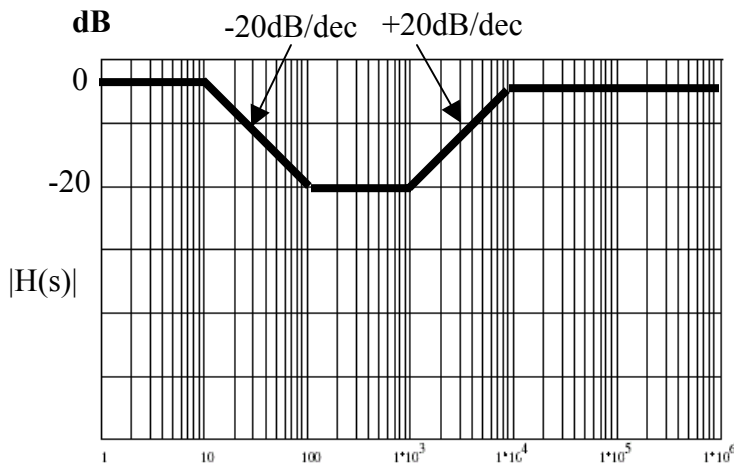
(d) Evaluate the overall current gain. ($\frac{i_o}{i_s}$) [round to the nearest whole number and express as A/A]. (10 points)

$$i_o = \frac{V_L}{R_L} \quad i_s = \frac{V_s}{(R_s + R_{i1})} A_i = \frac{V_o}{V_s} \cdot \frac{R_s + R_{i1}}{R_L} = A_v \cdot \frac{1k + 1k}{100} = 100 \text{ A/A}$$

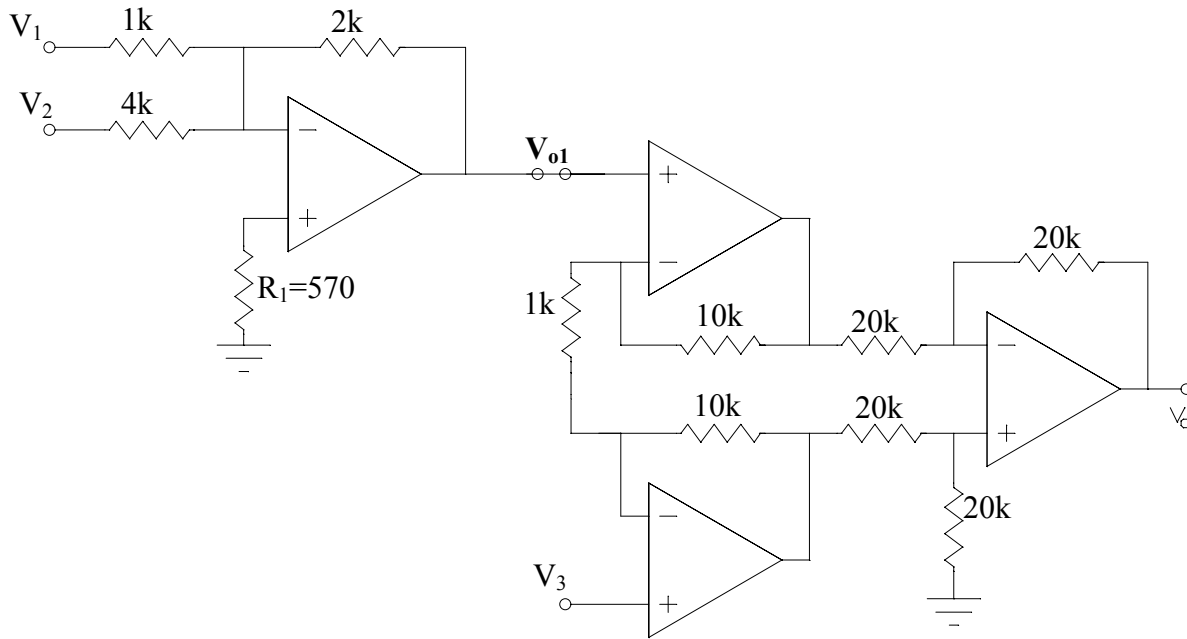
Problem 2 – (20 points)

$$H(s) = \frac{(s + 100) \cdot (s + 1k)}{(s + 10) \cdot (s + 10k)} \quad \text{Starts at } H(0) = \frac{(100 \cdot 1k)}{(10 \cdot 10k)} = 1 \text{ so } 20\log(1) = 0 \text{ dB, angle} = 0$$

Remember: the **location** for corner frequency is when **real=imaginary**. The **shape** (i.e. +20dB/dec or -20dB/dec.) of the signal at that location depends on the location of the pole/zero at that location. At $\omega = 10$: a LHP pole => -20dB/dec., -90deg.; $\omega = 100$: a LHP zero => +20dB/dec., +90deg.; $\omega = 1k$: a LHP zero => +20dB/dec., +90deg.; $\omega = 10k$: a LHP pole => -20dB/dec., -90deg.



Problem 3 – (37 points)



(a) Assume all operational amplifiers are ideal

$$V_1=10\text{mVpp}, V_2=20\text{mVpp}, V_3=50\text{mVpp}$$

(i) What is the voltage value at V_{o1} (express as Vpp)? (10 points)

This is a weighted summer:

$$V_{o1} = -(V_2(2k/4k) + V_1(2k/1k)) = -(10\text{m} + 20\text{m}) = -30\text{mVpp}$$

(ii) What is the voltage value at V_o (express as Vpp)? (10 points)

$$V_{id} := V_3 - V_{o1} \quad V_o := \frac{R_4}{R_3} \cdot \left(1 + \frac{2 \cdot R_2}{2 \cdot R_1} \right) \cdot V_{id}$$

$$V_o = 1 \cdot \left(1 + \frac{20k}{500} \right) \cdot (50\text{m} - (-30\text{m})) = 1.68\text{V}$$

(b) All operational amplifiers are NOT ideal and have the following characteristics:

(i) Explain the purpose of the R_1 resistor? (5 points)

It reduces the error on the output of the amplifier due to the input bias currents. The value of the resistor is the value of the dc resistance seen by the inverting terminal.

(ii) When $V_1=V_2=V_3=0$ calculate the voltage that will be observed at V_{o1} . (12 points) {Hint: there are two effects}

Input offset voltage: $V_{ios}=2.0\text{mV}$

Input offset current: $I_{os}=100\text{nA}$

$$V_{o1}(\text{due to offset voltage}) = V_{os} \cdot \left(1 + \frac{R_2}{R_1} \right) = .02 \cdot \left[1 + \left(\frac{2000}{800} \right) \right] = 0.07$$

$$V_{o1}(\text{due to input offset current}) = I_{os} \cdot R_2 = 100 \cdot 10^{-9} \cdot 2000 = 2 \cdot 10^{-4}$$

$$V_{o1}(\text{total}) = 7\text{m} + 200\mu = 7.2\text{mV}$$

Problem 1 – (25 points)

Assume both diodes are identical and ideal. Verify that your assumption for the diode operation (i.e. on or off) are correct.

a) 9 points – The current I_1

b) 9 points – The current I_2

c) 7 points – The voltage V_o

! Assume "on":
 $-12 + I(1k) + V_o = 0 \Rightarrow I = \frac{(12 - V_o)}{1k}$

$$I_2 = \frac{V_o}{2k}$$

$$-V_o + 2V + I_1(1k) = 0$$

$$I_1 = \frac{(V_o - 2V)}{1k}$$

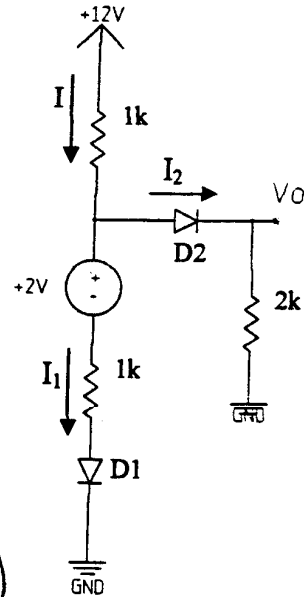
$$I = I_1 + I_2 \Rightarrow \frac{(12 - V_o)}{1k} = \frac{(V_o - 2V)}{1k} + \left(\frac{V_o}{2k}\right)$$

$$\Rightarrow V_o = \frac{\left(\frac{12}{1k}\right) + \left(\frac{2}{1k}\right)}{\left(\frac{1}{1k} + \frac{1}{1k} + \frac{1}{2k}\right)} = \frac{(0.014)}{2.5m} = \boxed{5.6V}$$

$$I = \frac{(12 - 5.6)}{1k} = 6.4mA, \quad I_2 = \frac{5.6}{2k} = \boxed{2.8mA}$$

$$I_1 = \frac{(V_o - 2V)}{1k} = \frac{(5.6 - 2)}{1k} = \boxed{3.6mA}$$

$I_1, I_2 > 0 \therefore$ diodes on



Problem 2 – (25 points)

Referring to the pn junction diode, determine the following: (5 points each)

1) For p-type material:

a) The majority carrier(holes or electrons) is holes (positive charge)

b) As the temperature DECREASES, what happens to the number of MAJORITY

carriers in this p-type material? stay the same
 $p_{po} = N_A$

2) For p-type material:

a) The minority carrier is electrons (negative charge)

b) As the temperature DECREASES, what happens to the number of MINORITY

carriers in this p-type material? Decrease $n_{po} = \frac{n_i^2}{N_A}$

$n_i^2 \propto T^3 \therefore$ dependent on T

3) As the temperature INCREASES, what happens to the number of unbound holes in

the n-type material? increases

4) As the temperature INCREASES, what happens to the reverse saturation current I_S ?

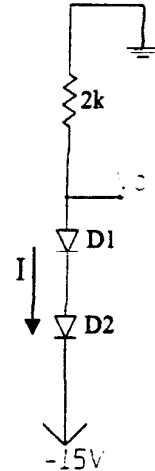
increases $\rightarrow I_S$ is created from the movement of minority carriers.

5) Explain how the diffusion current, I_D , is created.

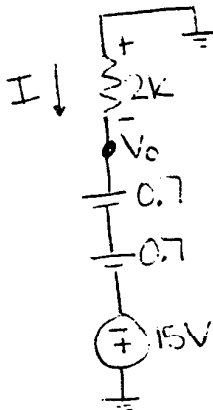
I_D is created from the movement of majority carriers

Problem 3 – (10 points)

- a) Use the constant voltage drop diode model with $V_{D0}=0.7$
 i) 2.5 points – Solve the circuit for I
 ii) 2.5 points – Solve the circuit for V_o



a. Assume "on":



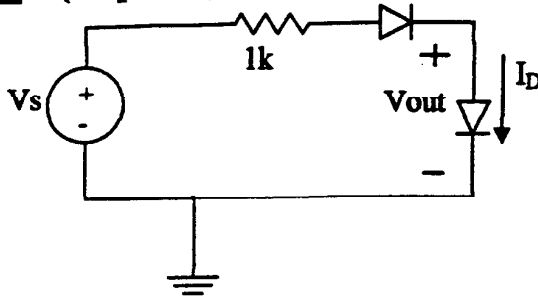
$$+I(2k) + 0.7 + 0.7 - 15 = 0$$

$$\Rightarrow I = \frac{(15 - 1.4)}{2k} = \boxed{6.8 \text{ mA}}$$

$I > 0 \therefore$ diodes on

$$-V_o - I(2k) = 0 \Rightarrow V_o = -I(2k) = \boxed{-13.6 \text{ V}}$$

Problem 4 – (15 points)



Given $V_s = 15 + 3\sin(\omega t)$ V
 Assume $V_D = 0.7$ V, $n=2$, and $V_T = 25$ mV
 Assume identical diodes
 Use the constant voltage drop method when appropriate

- c) 3 points – Determine the DC component of the diode current, I_D .
- d) 3 points - Determine the DC component at the output, V_{out} .
- e) 3 points – Determine the AC component of the diode current, i_d .
- f) 3 points - Determine the AC component at the output, V_{out} .
- g) 3 points – What is the total output for V_{out} .

DC model: Assume "on"

$$-15V + I_D(1k) + 0.7 + 0.7 = 0$$

$$\Rightarrow I_{D,DC} = \frac{(15 - 1.4)}{1k} = 13.6mA$$

$I_D > 0 \therefore \text{on}$

$V_{out,DC} = 0.7V$

AC model: $r_d = \frac{nV_T}{I_D} = \frac{(2)(25m)}{13.6m} = 3.7\Omega$

$$-3\sin\omega t + i_d(1k + 3.7 + 3.7) = 0$$

$$i_d = \frac{3\sin\omega t}{1007.4} = 3 \times 10^{-3} \sin\omega t$$

$$V_{out,AC} = i_d(3.7) = 11.1 \times 10^{-3} \sin\omega t$$

Total $V_{out} = 0.7 + 11.1 \times 10^{-3} \sin\omega t$

Problem 1 – (30 points)

Assume all diodes are identical and have $V_{DO}=0.7V$. Use the constant voltage drop method. Verify that your assumption for the diode operation (i.e. on or off) are correct. Find the following making sure you find the correct operation of the diodes.

a) State your assumptions (diode is on/off):

D1 - on
D2 - off

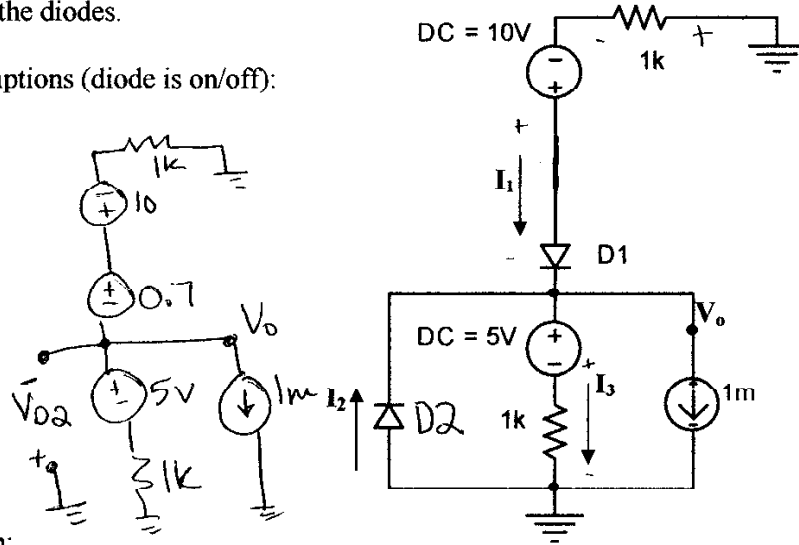
b) The current I_1

c) The current I_2

d) The current I_3

e) The voltage V_o

f) Your verification:



$$+1k(I_1) - 10 + V_o + 0.7 = 0 \Rightarrow I_1 = \frac{10 - V_o + 0.7}{1k} = \frac{10 - 6.65 + 0.7}{1k} = \frac{2.65}{1k} = 2.65m$$

$$-V_o + 5 + I_3(1k) = 0 \Rightarrow I_3 = \frac{V_o - 5}{1k} = \frac{6.65 - 5}{1k} = 1.65m$$

$I_2 = 0$

$I_1 = I_3 + 1m$

$$\frac{9.3 - V_o}{1k} = \frac{V_o - 5}{1k} + 1m$$

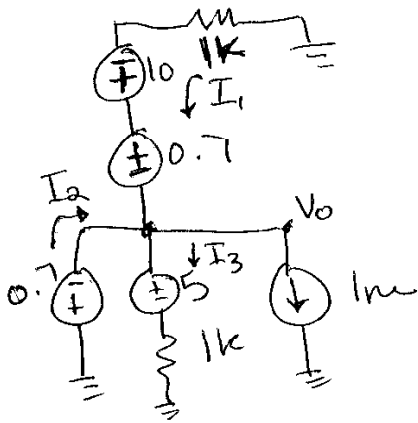
$$V_o \left(\frac{1}{1k} + \frac{1}{1k} \right) = \frac{5}{1k} + \frac{9.3}{1k} - 1m$$

$$V_o = \frac{13.3m}{2m} = 6.65V$$

Verification:

$I_1 > 0 \Rightarrow$ on
 $+V_D + V_o = 0 \Rightarrow V_D = -6.65 < 0 \therefore$ off

D2 "on", D1 "on"



$$+I_1(1k) - 10 + 0.7 + V_0 = 0$$

$$I_1 = \frac{-V_0 + 9.3}{1k} = 10\mu A > 0 \quad \underline{\text{ON}}$$

$$-V_0 - 0.7 = 0$$

$$V_0 = \underline{\underline{-0.7V}}$$

$$I_3 = \frac{(V_0 - 5)}{1k} = \underline{\underline{-5.7mA}}$$

$$I_2 = I_3 + 1mA - I_1$$

$$I_2 = -5.7mA + 1mA - 10\mu A = \underline{\underline{-14.7mA}} < 0 \quad \underline{\text{Not on}}$$

Not valid assumptions

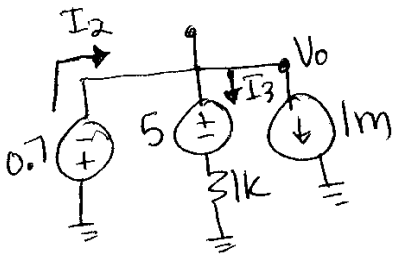
D1 "off", D2, "on"



$$V_0 = -0.7$$

$$I_3 = \frac{(V_0 - 5)}{1k} = -5.7mA$$

$$I_2 = I_3 + 1mA = -4.7mA < 0 \Rightarrow \underline{\text{Not on}}$$

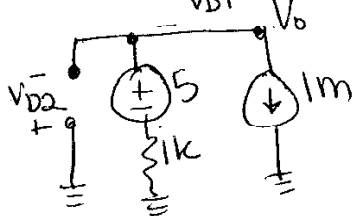
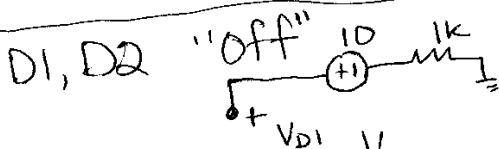


$$-V_0 + 5 - 1mA(1k) = 0$$

$$V_0 = 5 - 1 = 4V$$

$$-V_0 - V_{D1} + 10 = 0$$

$$V_{D1} = 10 - V_0 = 6V < 0 \quad \therefore \underline{\underline{\text{Not off}}}$$



Problem 2 – (25 points)

a) Sketch the Bode (both magnitude & phase) plot for: {label your axis and show all your work}

$$H(s) = \frac{(100)(s+100)(s+10)}{(s^2)(s+10,000)}$$

b) What is the estimated magnitude value at $\omega=1$ rad/sec:

$$K = H(0) = \frac{100(100)(10)}{10,000} = 10$$

$$\omega_{\text{start}} = 1 \quad n = -2 \quad \Rightarrow \quad 20 \log(10(1)^{-2}) = \boxed{+20\text{dB}}$$

c) For the magnitude plot, what is the slope of the line going through $\omega=1$ rad/sec:

$$n * 20\text{dB/dec} = -40\text{dB/dec.}$$

d) What is the estimated phase value at $\omega = 1$ rad/sec:

$$K > 0 \quad \therefore n * 90^\circ = -180 \text{ degrees}$$

e) For the phase plot, what is the slope of the line to the left of $\omega = 1$ rad/sec:

○

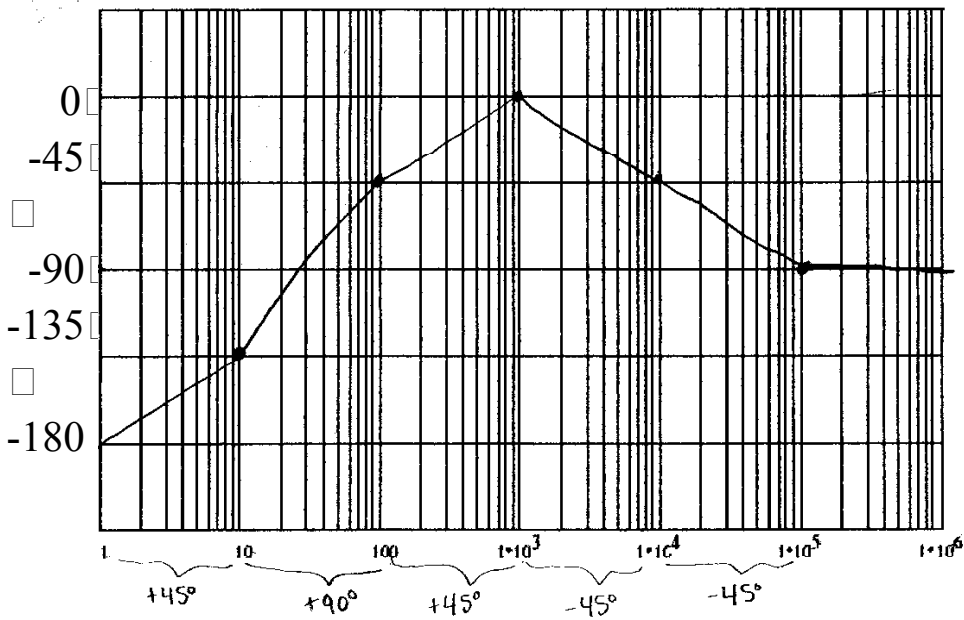
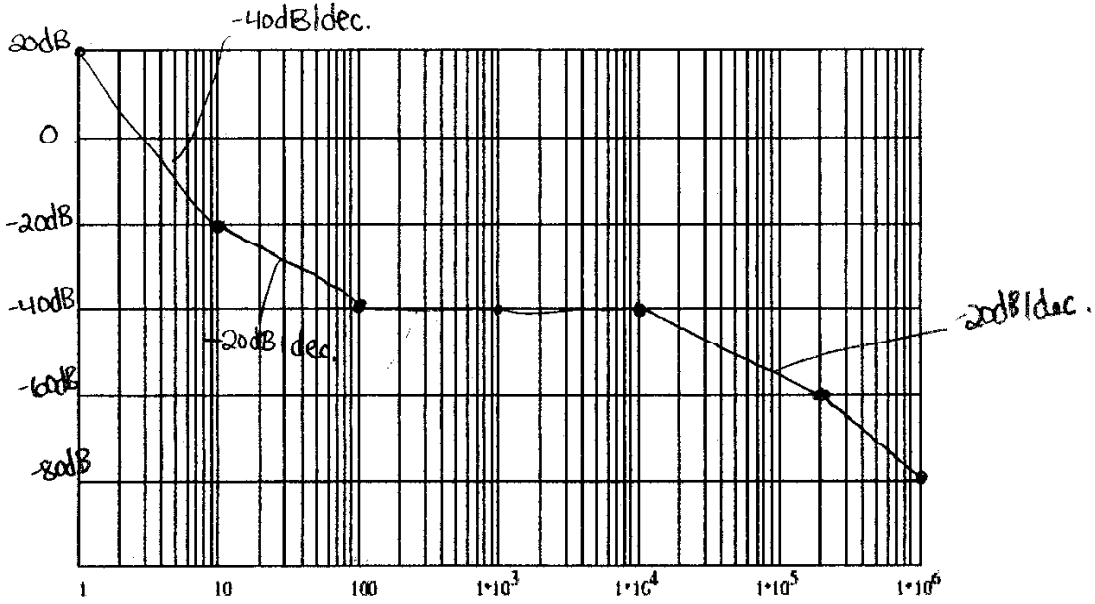
f) For the phase plot, what is the slope of the line to the right of $\omega = 1$ rad/sec:

$$+45^\circ \text{ slope/dec.}$$

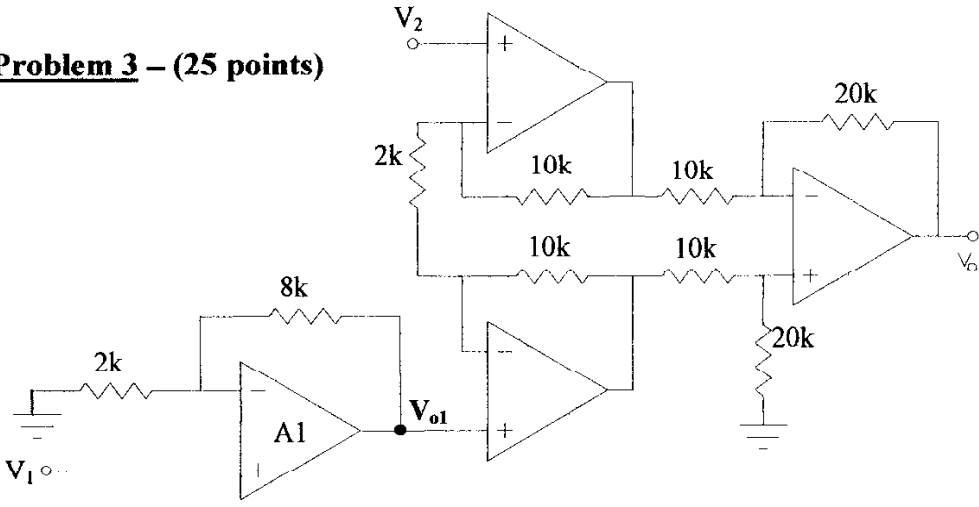
g) List the three frequencies other than 0 where the bode plots will have a change in slope (or value):

$\omega = 10,000$:	neg. pole $\rightarrow \omega = 1,000 \rightarrow 100,000$:	-45°
$\omega = 100$:	$+20 \text{ dB/dec.} \rightarrow \omega = 10 \rightarrow 1,000$:	$+45^\circ$
$\omega = 10$:	$+20 \text{ dB/dec.} \rightarrow \omega = 1 \rightarrow 100$:	$+45^\circ$

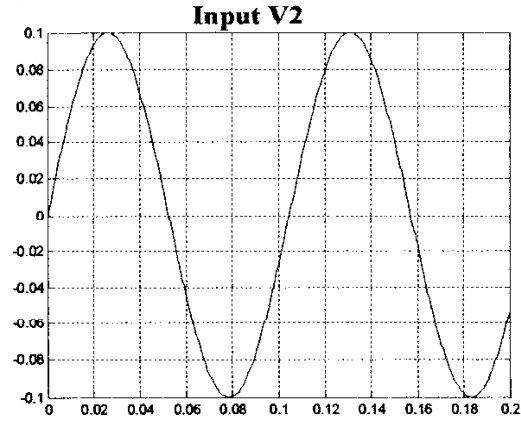
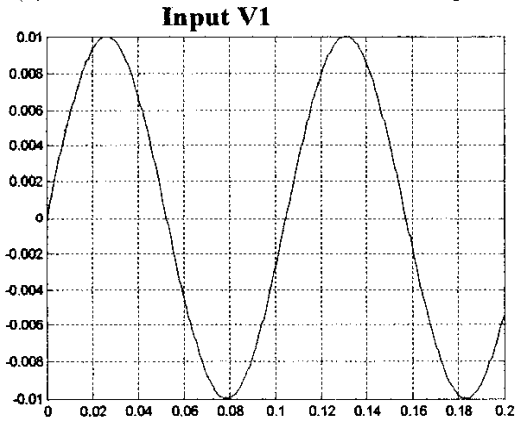
$$H(s) = \frac{(100)(s+100)(s+10)}{(s^2)(s+10,000)}$$



Problem 3 – (25 points)



(a) For the circuit above, assume all operational amplifiers are ideal



- (i) What is the voltage value at V_{o1} (express as V_{pp})? $V_i = 20mV_{pp}$
- (ii) What is the voltage value at V_o (express as V_{pp})?

$$V_{o1} = \left(1 + \frac{8k}{2k}\right) V_i = 5(V_i) = \boxed{100mV_{pp}}$$

$$V_o = \frac{20k}{10k} \left(1 + \frac{10k}{1k}\right) (V_{o1} - V_2) = 2(1+10)(100mV_{pp} - 200mV_{pp})$$

$$V_o = 2(11)(-100mV_{pp}) = \boxed{-2.2V}$$

(b) Assume all operational amplifiers are ideal EXCEPT amplifier A1 which is LM307. Use the attached datasheet to determine the following:

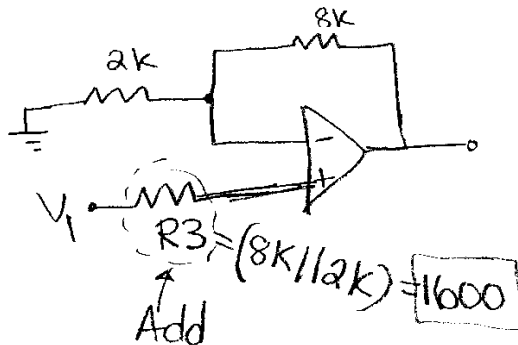
- (i) Assume that you have no Slew Rate distortion on your output signal. Neglecting the input bias current, calculate the voltage that will be the maximum value observed at V_o when $V_1=0V$ at room temperature.

$(V_2=0)$

$$V_{o1} = V_{os} (1 + 4) = 7.5m(5) = \boxed{0.375V}$$

$$V_o = 2(1+10)(0.375-0) = \boxed{8.25V}$$

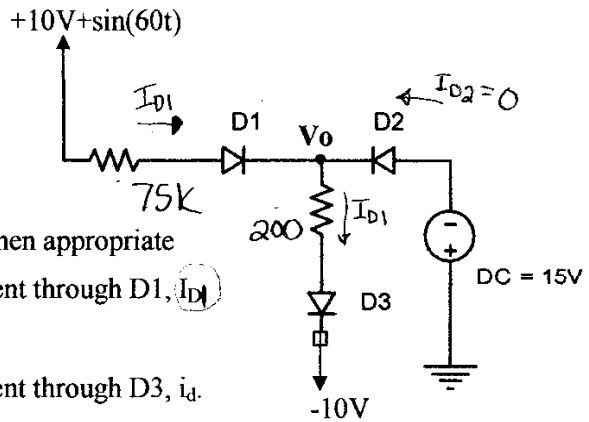
- (ii) Explain in detail, by giving exact values and drawing any schematics, the technique used to reduce the input bias current for amp A1.



Problem 4 – (20 points)

Given Assume $V_{DO}=0.6V$, $n=1$, and $V_T=25mV$
 Assume identical diodes
 Use the constant voltage drop method when appropriate

- Determine the **DC** components of the diode current through D1, I_{D1}
- Determine the **DC** component at the output, V_o .
- Determine the **AC** component of the diode current through D3, i_d .
- Determine the **AC** component at the output, V_o .
- What is the **total** output for V_o .



Assume: D1-on, D3-on, D2-off

a. $-10 + I_{D1}(75k) + 0.6V + I_{D1}(200) + 0.6 - 10 = 0$

$$I_{D1} = \frac{20 + 1.2}{75,200} = 250\mu$$

I_{D1} also goes through D3
 $I_{D1} > 0 \therefore$ D1, D3 on

b. $-V_o + I_{D1}(200) + 0.6 - 10 = 0$

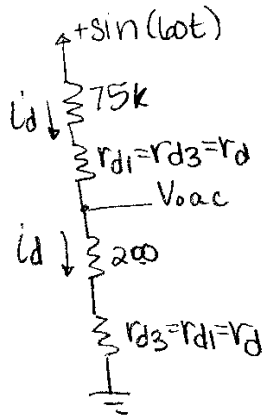
$$V_o = I_{D1}(200) - 9.4 = -9.35V$$

D2: $-V_o - V_{D2} - 15 = 0$

$$V_{D2} = -9.35 - 15$$

$$V_{D2} = -24.35 < 0 \therefore \text{OFF}$$

c.



$$V_{oac} = \frac{\sin(60t)(200 + r_d)}{(75,200 + r_d + r_d)}$$

$$r_d = \frac{nV_T}{I_D} = \frac{1 \times 25m}{250\mu} = 100$$

$$\therefore V_{oac} = \frac{\sin(60t)(300)}{(75,400)} = 4m \sin(60t)$$

$$i_d = \frac{\sin(60t)}{75,200 + 200} = 13.3\mu \sin(60t)$$

check validity:

$$V_{d,ac} = i_d(100) = 1.3m \sin(60t) < 10mV$$

$$V_{ototal} = -9.35 + 4m \sin(60t)$$