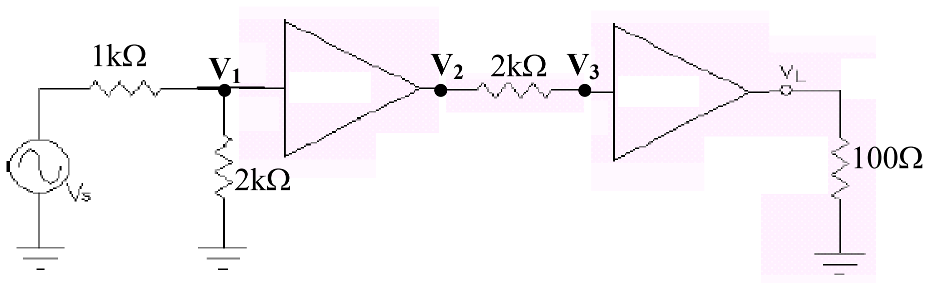
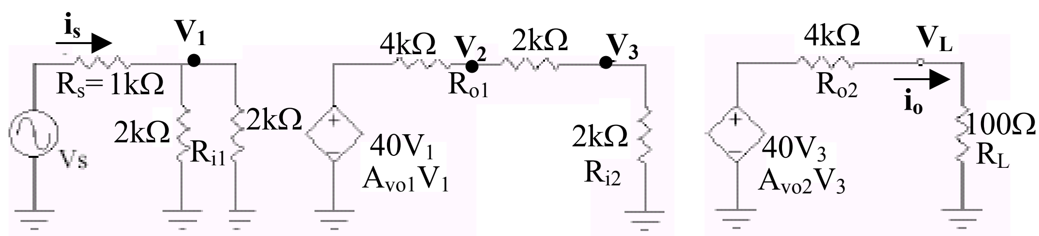
# EXAM #1 - Solution

## 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)**

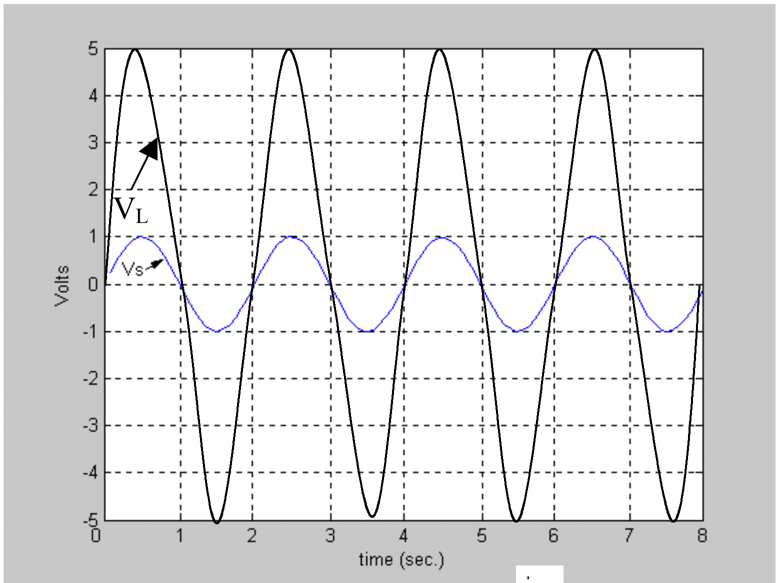
$$\frac{v_L}{V_s} = A_v := \left(\frac{R_{i1}}{R_S+R_{i1}}\right)\cdot A_{vo1}\cdot\left(\frac{R_{i2}}{R_{o1}+R_{i2}}\right)\cdot A_{vo2}\cdot\left(\frac{R_L}{R_{o2}+R_L}\right)$$

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

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

(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)) * Vs_peak=5*Vs_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)**

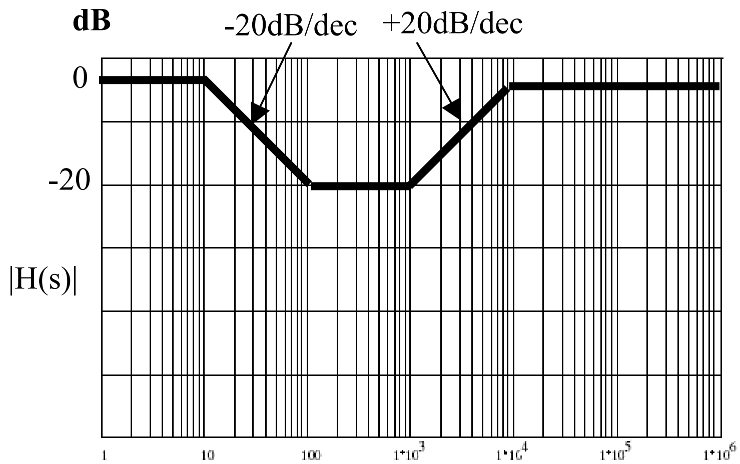
$i_o = \frac{V_L}{R_L}$ $\quad i_s = \frac{V_s}{(R_s + R_{i1})}$ $\quad A_i = \frac{Vo}{Vs} \cdot \frac{R_s + R_{i1}}{R_L} = A_v \cdot \frac{1k + 1k}{100}$ **=100 A/A**

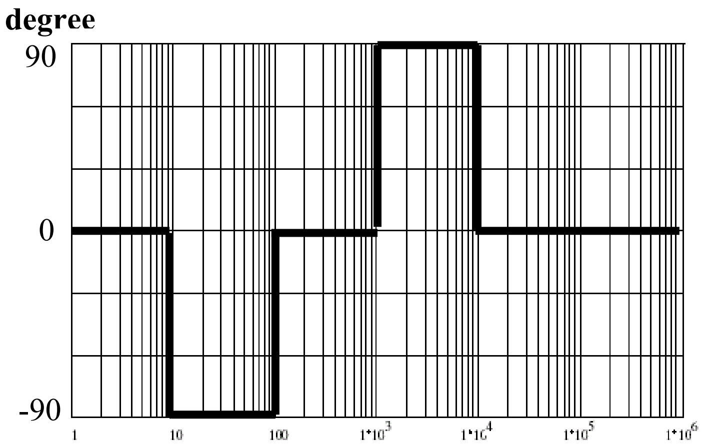
## Problem 2 – (20 points)

$$H(s) = \frac{(s+100)\cdot(s+1k)}{(s+10)\cdot(s+10k)}$$

**Starts at H(0) = (100*1k)/(10*10k)=1 so 20log(1)=0 dB, angle =0**

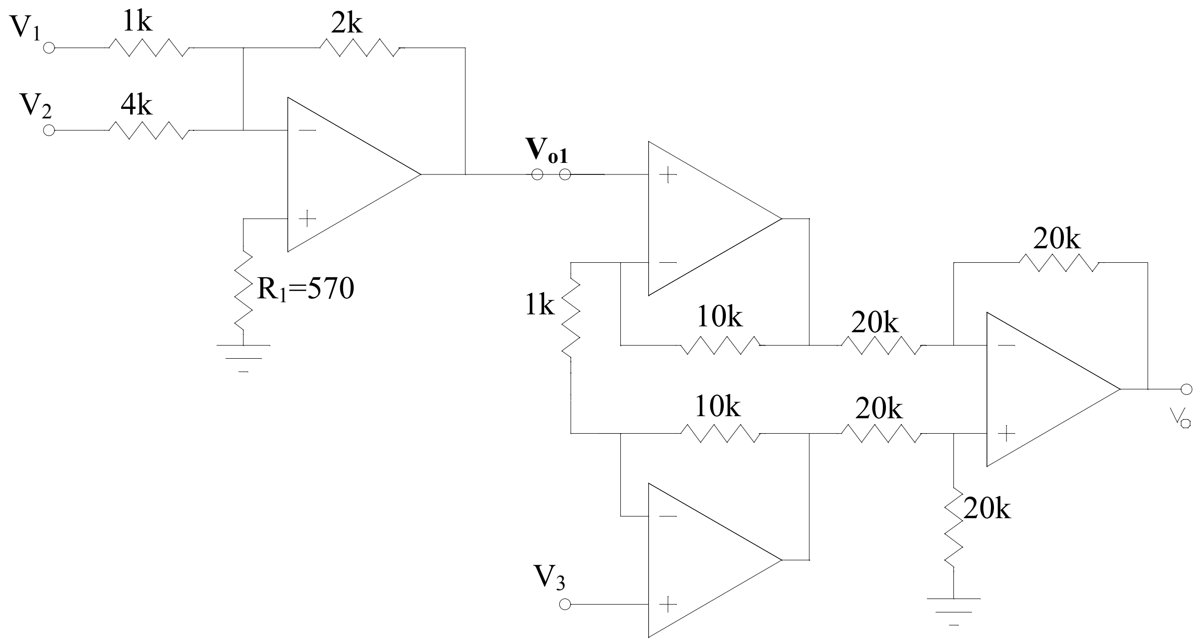
Remember: the **location** for corner frequency is when **real=imaginary**. The **shape** (i.e. +20dB/dec or –20dB/dec.) of the signal at that location depends on the location of the pole/zero at that location. At w=10: a LHP pole => -20dB/dec., –90deg.; w=100: a LHP zero => +20dB/dec., +90deg.; w=1k: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




**(rad/sec.)**

## Problem 3 – (37 points)




(a) Assume all operational amplifiers are ideal

$V_1$=10mVpp, $V_2$=20mVpp, $V_3$=50mVpp

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

**This is a weighted summer:**

**Vo1=-(V2(2k/4k) + V1(2k/1k))=-(10m+20m) = -30mVpp**

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

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

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

**(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 $\mathbf{V_{o1}}$. **(12 points) {Hint: there are two effects}**

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

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

Vo1(due to offset voltage)= $V_{os}\cdot\left(1+\frac{R_2}{R_1}\right) = .02\cdot\left[1+\left(\frac{2000}{800}\right)\right] = 0.07$

Vo1(due to input offset current) = $I_{os}\cdot R_2 = 100\cdot 10^{-9}\cdot 2000 = 2\cdot 10^{-4}$

Vo1 (total) = 7m+200μ=**7.2mV**

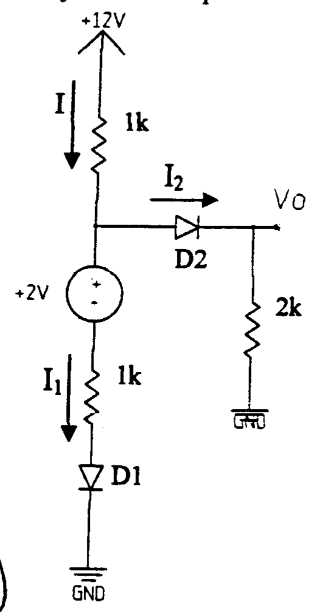
**Problem 1 – (25 points)**

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 Vo




! 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 $n_{po} = \frac{n_i^2}{N_A}$

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

3) As the temperature INCREASES, what happens to the number of unbound holes in the n-type material? Increases

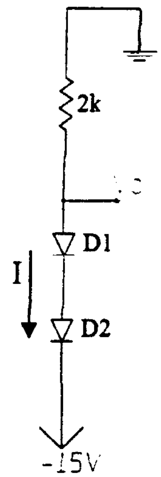
4) As the temperature INCREASES, what happens to the reverse saturation current $I_S$?

   Increases → $I_S$ is created from the movement of minority carriers.

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

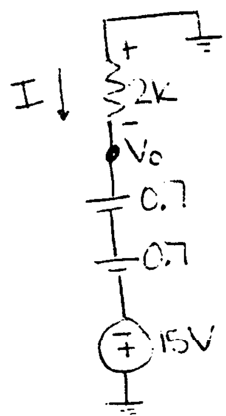
   $I_D$ is created from the movement of majority carriers

## 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 Vo

a. Assume "on":



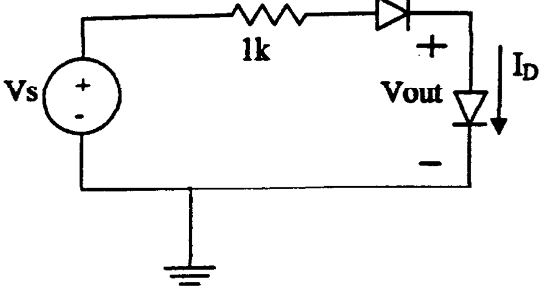

$+I(2K)+0.7+0.7-15=0$

$\Rightarrow I = \dfrac{(15-1.4)}{2K} = \boxed{6.8mA}$

$I>0$ ∴ diodes on

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

**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**, $I_D$.

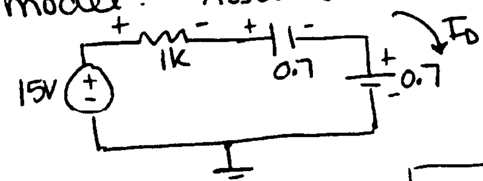
d) 3 points - Determine the **DC component** at the output, $V_{out}$.

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 Vout.

DC model: Assume "on"




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

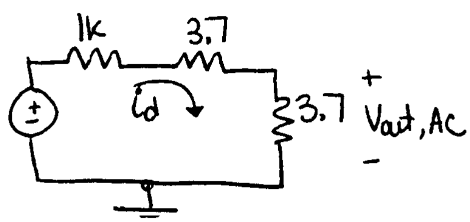
$\Rightarrow I_{D,DC} = \frac{(15-1.4)}{1k} = \boxed{13.6mA}$

$I_D > 0 \therefore$ on

$\boxed{V_{out,DC} = 0.7V}$

AC model:

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




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

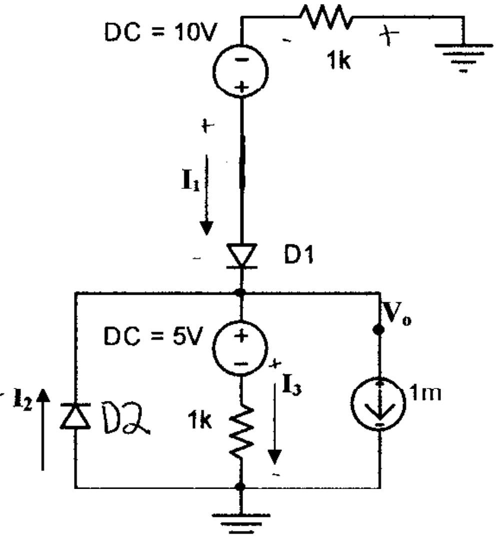
$i_d = \frac{3\sin\omega t}{1007.4} = \boxed{3 \times 10^{-3}\sin\omega t}$

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

Total Vout: $\boxed{0.7 + 11.1 \times 10^{-3}\sin\omega t}$

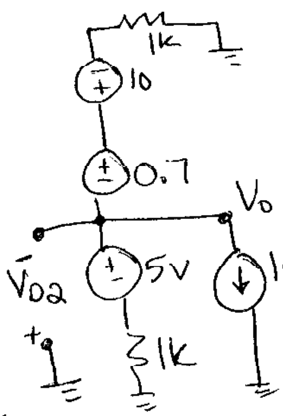
## Problem 1 – (30 points)

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 Vo

f) Your verification:

$+1K(I_1) - 10 + V_o + .7 = 0 \Rightarrow I_1 = \frac{10 - V_o - .7}{1K} = \frac{10 - 6.65 - .7}{1k} = \boxed{2.65m}$

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

$\boxed{I_2 = 0}$

$I_1 = I_3 + 1m$

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

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

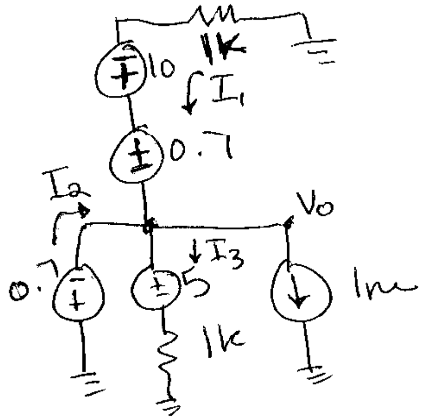
$V_o = \frac{13.3m}{2m} = \boxed{6.65V}$

verification:

$I_1 > 0 \Rightarrow$ on

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

D2 "on", D1 "on"




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

$I_1 = \frac{-V_o + 9.3}{1k} = .10m > 0$ ON

$-V_o - 0.7 = 0$

$V_o = -0.7V.$

$I_3 = \frac{(V_o - 5)}{1K} = -5.7m$

$I_2 = I_3 + 1m - I_1$

$I_2 = -5.7m + 1m - 10m = -14.7 < 0$

Not on

Not valid assumptions

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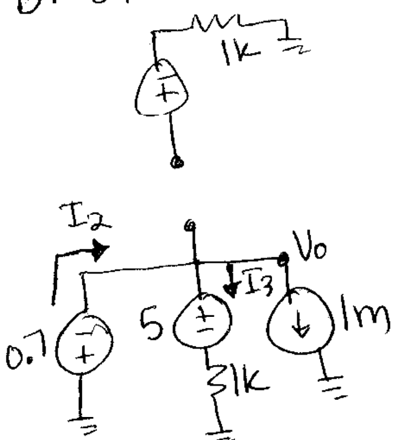
D1 "off", D2, "on"




$V_o = -0.7$

$I_3 = \frac{(V_o - 5)}{1k} = -5.7m$

$I_2 = I_3 + 1m = -4.7m < 0 \Rightarrow$ Not on

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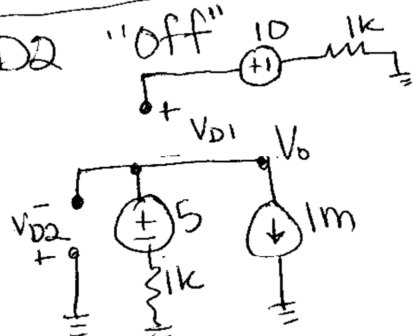
D1, D2 "off"




$-V_o + 5 - 1m(1k) = 0$

$V_o = 5 - 1 = 4V$

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

$V_{D1} = 10 - V_o = 6V < 0$ ∴ 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 ω=1 rad/sec:

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

$\omega_{start} = 1$ ⟹ $20 \log(10(1)^{-2}) = +20dB$

$n = -2$

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

$n * 20dB/dec = -40dB/dec.$

d) What is the estimated phase value at ω =1 rad/sec:

$K>0$ ∴ $n * 90° =$ -180 degrees

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

0

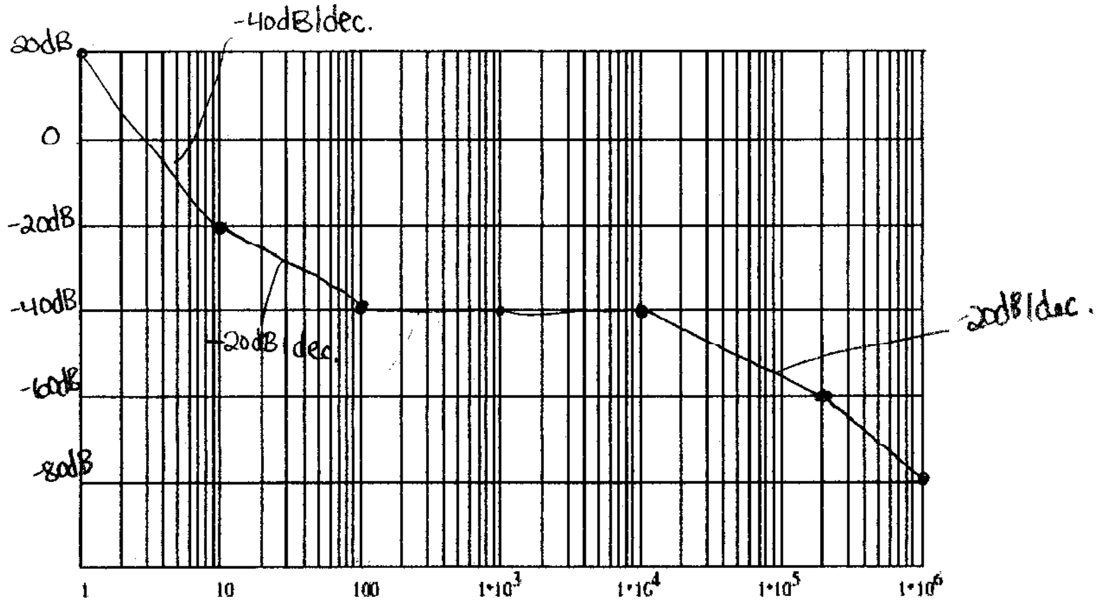
f) For the phase plot, what is the slope of the line to the right of ω =1 rad/sec:

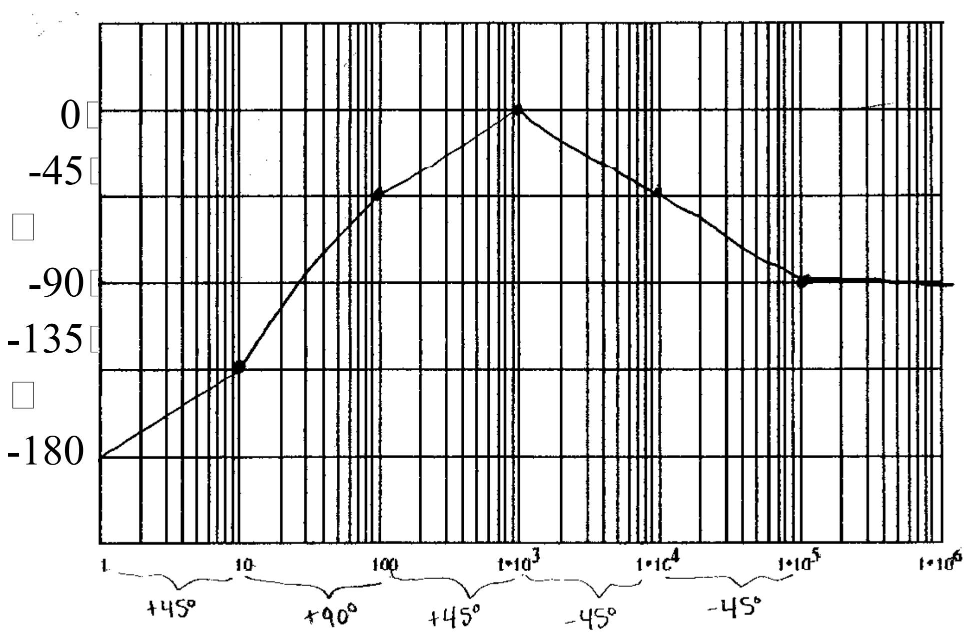
+45° slope/dec.

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

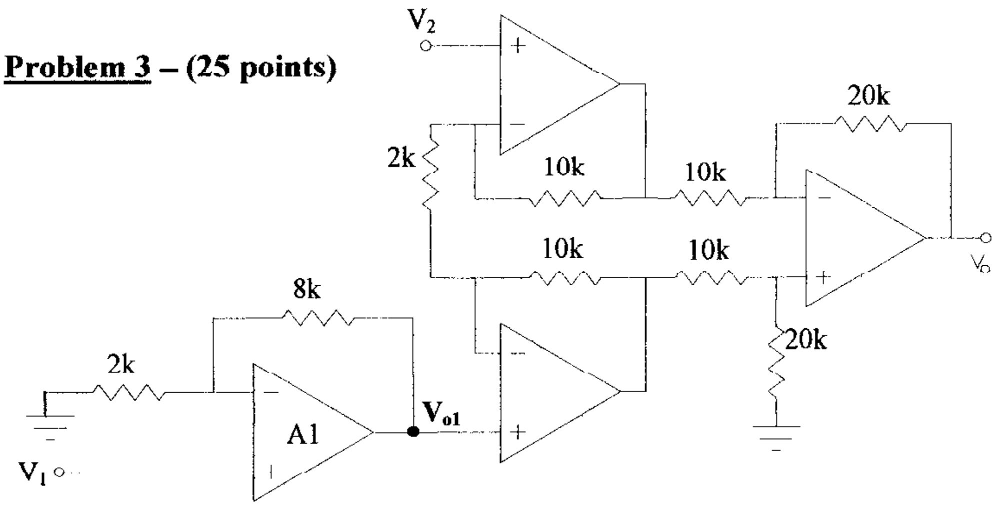
ω = 10,000 : neg. pole → ω = 1,000 → 100,000 : -45°
-20dB/dec.
ω = 100 : +20 dB/dec. → ω = 10 → 1,000 : +45°
ω = 10 : +20dB/dec. → ω = 1 → 100 : +45°

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



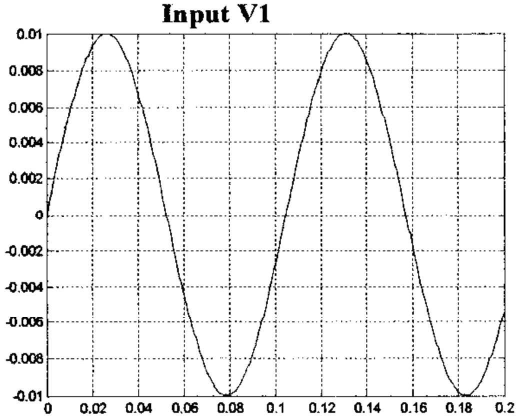



**Problem 3 – (25 points)**

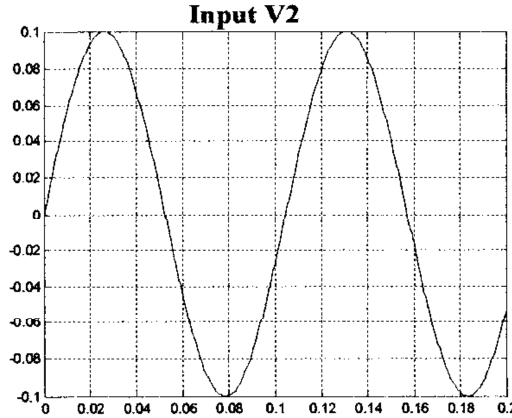



(a) For the circuit above, assume all operational amplifiers are <u>ideal</u>

**Input V1**



**Input V2**



(i) What is the voltage value at $V_{o1}$(express as Vpp)? $V_1 = 20m\,V_{pp}$

(ii) What is the voltage value at Vo (express as Vpp)?

$$V_{o1} = \left(1+\frac{8k}{2k}\right)V_1 = 5(V_1) = \boxed{100mV_{pp}}$$

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

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

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

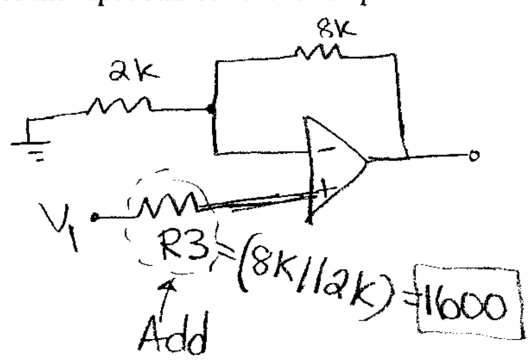
(i) Assume that you have no Slew Rate distortion on your output signal. Neglecting the input bias current, calculate the voltage that will be the maximum value observed at $\mathbf{V_o}$ when $V_1$=0V at room temperature.

$(V_2=0)$

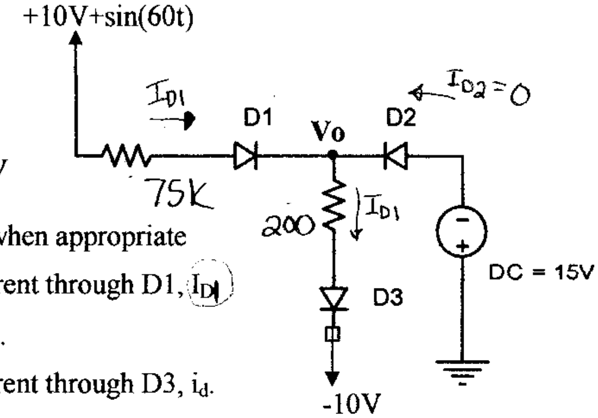
$$V_{o1} = V_{os}(1+4) = 7.5m(5) = \boxed{0.375V}$$

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

(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

a) Determine the **DC** components of the diode current through D1, $I_{D1}$.

b) Determine the **DC** component at the output, $V_o$.

c) Determine the **AC** component of the diode current through D3, $i_d$.

d) Determine the **AC** component at the output, $V_o$.

e) What is the **total** output for $V_o$.

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

a. $-10 + I_{D1}(75k) + .6V + I_{D1}(200) + .6 - 10 = 0$

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

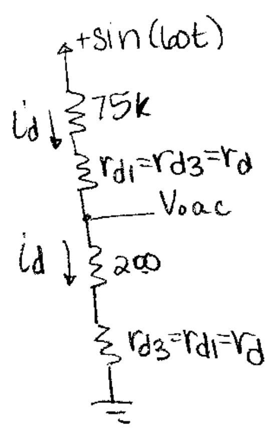
$I_{D1}$ also goes through D3
$I_{D1} > 0 \quad \therefore$ D1, D3 on

D2: $-V_o - V_{D2} - 15 = 0$
$V_{D2} = -9.35 - 15$
$V_{D2} = -24.35 < 0$
$\therefore$ OFF

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

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

c.




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

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

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

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

check validity:

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

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