Problem 1 – (43 points)

- Both amplifiers have the following characteristics:
  \( A_{vo} = 40 \quad R_i = 2k\Omega \quad R_o = 4k\Omega \)  
  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)

\[
\frac{v_L}{v_s} = A_v := \left( \frac{R_{i1}}{R_S + R_{i1}} \right) A_{vo1} \left( \frac{R_{i2}}{R_{o1} + R_{i2}} \right) A_{vo2} \left( \frac{R_L}{R_{o2} + R_L} \right)
\]

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

\[
A_v = \frac{1k}{1k + 1k} \cdot \frac{40}{2k} \cdot \frac{2k}{6k + 2k} \cdot \frac{40V_1}{40V_3} = 4.878 \quad (\text{rounded} = 5V/V) \quad \text{or} \quad 20\log(5) = 13.979
\]
(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)) * $V_S \_peak = 5 \times V_S \_peak = 5(1+1) = 5$

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

$$i_o = \frac{V_L}{R_L}, \quad i_s = \frac{V_S}{(R_S + R_{il})}, \quad A_i = \frac{V_o}{V_S} \frac{R_s + R_{il}}{R_L} = A \sqrt{\frac{1k + 1k}{100}} = 100 \ A/A$$

**Problem 2** – **(20 points)**

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

Starts at $H(0) = (100*1k)/(10*10k) = 1$ so $20\log(1) = 0 \text{ dB}, \text{ angle } = 0$

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

This is a weighted summer:
\[ V_{o1}=-(V_2(2k/4k) + V_1(2k/1k))=-10m-20m=-30mV_{pp} \]

(ii) What is the voltage value at \( V_o \) (express as \( V_{pp} \))? (10 points)

\[ V_{id} := V_3 - V_{o1} \]
\[ V_o := \frac{R_4}{R_3} \left[ 1 + \frac{2R_2}{2R_1} \right] V_{id} \]
\[ V_o = 1 \left[ 1 + \frac{20k}{500} \right] (50m - (-30m)) = 1.68V \]

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

Input offset voltage: \( V_{ios}=2.0\text{mV} \)
Input offset current: \( I_{ios}=100\text{nA} \)

\[ V_{o1}(\text{due to offset voltage}) = V_{os} \left[ 1 + \left( \frac{R_2}{R_1} \right) \right] = 0.02 \left[ 1 + \left( \frac{2000}{800} \right) \right] = 0.07 \]

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

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

Assume "ON":

\[-12 + I (1k) + V_o = 0 \Rightarrow I = \frac{(12 - V_o)}{1k}\]

\[I_2 = \frac{V_o}{2k}\]

\[-V_o + 2V + I_1(1k) = 0\]

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

\[I = I_1 + I_2 \Rightarrow \frac{(12 - V_o)}{1k} = \frac{(V_o - 2V)}{1k} + \frac{V_o}{2k}\]

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

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

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

$I_1, I_2 > 0 \Rightarrow$ 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 $n_{po} = \frac{n_i^2}{N_A}$

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 $V_o$

Assume "on":

\[ I \downarrow \]
\[ \overset{2k}{\downarrow} \]
\[ V_o \]
\[ -0.7 \]
\[ \overset{-15\text{V}}{\downarrow} \]

\[ +I(2k)+0.7+0.7-15\text{V}=C \]
\[ \Rightarrow I = \left( \frac{15-1.4}{2k} \right) = 6.8\text{mA} \]
\[ I>0 \quad \text{diodes on} \]
\[ -V_o \cdot I(2k)=0 \Rightarrow V_o = -I(2k) = -12.6\text{V} \]
Problem 4 – (15 points)

Given \( V_S = 15 + 3\sin(\omega t) \) V
- Assume \( V_D = 0.7V \), \( n=2 \), and \( V_T = 25\text{mV} \)
- 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"

\[
\begin{align*}
15V + I_D(1k) + 0.7 + 0.7 &= 0 \\
\Rightarrow I_D &= \frac{(15 - 1.4)}{1k} = 13.6\text{mA} \\
I_D > 0 & \implies \text{on}
\end{align*}
\]

\( V_{out,DC} = 0.7 \) V

AC model: \( I_D = \frac{2\times(2.5m)}{13.6m} = 3.7 \text{mA} \)

\[
\begin{align*}
1k + 3.7 &\rightarrow \text{Vs,AC} + 3.7 \\
-3\sin\omega t + i_d(1k + 3.7 + 3.7) &= 0 \\
i_d &= \frac{3\sin\omega t}{1007.4} = 3\times10^{-3}\sin\omega t \\
V_{out,AC} &= i_d(3.7) = 11.1\times10^{-3}\sin\omega t \\
\text{Total } V_{out} &= 0.7 + 11.1\times10^{-3}\sin\omega t
\end{align*}
\]
Problem 1 – (30 points)

Assume all diodes are identical and have \( V_{DO} = 0.7 \text{V} \). 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):

\[
\begin{align*}
\text{D1: } & \text{on} \\
\text{D2: } & \text{off}
\end{align*}
\]

b) The current \( I_1 \)

c) The current \( I_2 \)

d) The current \( I_3 \)

e) The voltage \( V_0 \)

f) Your verification:

\[
\begin{align*}
+1k(I_1) - 10 + V_0 + 7 & = 0 \Rightarrow I_1 = \frac{10 - V_0 - 7}{1k} \\
-V_0 + 5 + I_3 (1k) & = 0 \Rightarrow I_3 = \frac{(V_0 - 5)}{1k}
\end{align*}
\]

\[
\begin{align*}
I_2 = 0 \\
I_1 = I_3 + 1m
\end{align*}
\]

\[
\begin{align*}
\frac{(9.3 - V_0)}{1k} & = \frac{(V_0 - 5)}{1k} + 1m \\
V_0 \left( \frac{1}{1k} + \frac{1}{1k} \right) & = \frac{5}{1k} + \frac{9.3}{1k} - 1m \\
V_0 & = \frac{13.3m}{2m} = 6.65 \text{V}
\end{align*}
\]

Verification:

\[
\begin{align*}
I_1 > 0 & \Rightarrow \text{on} \\
+ V_0 + V_0 & = 0 \Rightarrow V_D = -(6.65 < 0) \Rightarrow \text{off}
\end{align*}
\]
D2 "on", D1 "on"

\[ +I_1 (1k) = 10 + 0.7 + V_o = 0 \]

\[ I_1 = \frac{-V_o + 0.3}{1k} = 10 \text{mA} \iff \text{on} \]

\[-V_o - 0.7 = 0 \]

\[ V_o = -0.7 \text{V}. \]

\[ I_3 = \frac{(V_o - 5)}{1k} = -5.7 \text{mA} \]

\[ I_a = I_3 + 1 \text{mA} - I_1 \]

\[ I_a = -5.7 \text{mA} + 1 \text{mA} - 10 \text{mA} = -14.7 \text{mA} \iff \text{not on} \]

D1 "off", D2 "on"

\[ V_o = -0.7 \]

\[ I_3 = \frac{(V_o - 5)}{1k} = -5.7 \text{mA} \]

\[ I_a = I_2 + 1 \text{mA} = -4.7 \text{mA} \iff \text{not on} \]

\[ -V_o + 5 - 1 \text{mA} (1k) = 0 \]

\[ V_o = 5 - 1 = 4 \text{V} \]

\[ -V_o - V_{D1} + 10 = 0 \]

\[ V_{D1} = 10 - V_o = 6 \text{V} \iff \text{not off} \]
Problem 2 – (25 points)

a) Sketch the Bode (both magnitude & phase) plot for: \( H(s) = \frac{(100)(s + 100)(s + 10)}{(s^2)(s + 10,000)} \)

b) What is the estimated magnitude value at \( \omega = 1 \) rad/sec:
\[
K = |H(1)| = \frac{100 \cdot (100)(10)}{10,000} = 10
\]
\[
\omega_{\text{start}} = 1 \Rightarrow \omega \log \left( 10 \left( \frac{10}{1000} \right)^2 \right) = 20 \text{dB}
\]
\[n = -2\]

c) For the magnitude plot, what is the slope of the line going through \( \omega = 1 \) rad/sec:
\[n \times 20 \text{dB/dec} = -40 \text{dB/dec}.
\]

d) What is the estimated phase value at \( \omega = 1 \) rad/sec:
\[K > 0 \Rightarrow \forall \omega > 90^\circ = 180 \text{ degrees}
\]

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

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):
\[
\omega = 10,000 \quad \Rightarrow \quad \text{neg. pole} \rightarrow \omega = 1,000 \rightarrow 100,000 : -45^\circ
\]
\[
\omega = 100 \quad \Rightarrow \quad +20 \text{ dB/dec.} \rightarrow \omega = 10 \rightarrow 1,000 : +45^\circ
\]
\[
\omega = 10 \quad \Rightarrow \quad +20 \text{ dB/dec.} \rightarrow \omega = 1 \rightarrow 100: +45^\circ
\]
\[ H(s) = \frac{(100)(s + 100)(s + 10)}{(s^2)(s + 10,000)} \]
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 $V_{pp}$)?

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

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

\[
V_o = 2(11)(100mV_{pp}) = -2.2V
\]
(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 \( V_i = 0 \) V at room temperature.

\[
V_{b1} = V_{i\infty} \left( 1 + \frac{R_1}{R_f} \right) = 7.5 \times 10^{-3} (5) = 0.375 \text{ V}
\]

\[
V_o = 2 \left( 1 + 10 \right)(0.375 - 0) = 8.25 \text{ V}
\]

(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 \( V_{DD} = 0.6V, n = 1, \) and \( V_T = 25mV \)
Assume identical diodes
Use the constant voltage drop method when appropriate

a) Determine the DC component of the diode current through \( D_1, I_{D1} \)
b) Determine the DC component at the output, \( V_o \).
c) Determine the AC component of the diode current through \( D_3, i_d \).
d) Determine the AC component at the output, \( V_o \).
e) What is the total output for \( V_o \).

Assume: \( D_1 \)-on, \( D_3 \)-on, \( D_2 \)-off

\[
\begin{align*}
a. & \quad -10 + I_{D1}(75\Omega) + 0.6V + I_{D1}(200) \cdot 10 - 10 = 0 \\
& \quad I_{D1} = \frac{0.6 - 1.2}{75,200} = \frac{250\mu}{A} \\
& \quad \text{I}_D \text{ also goes through } D_3 \\
& \quad \text{I}_D > 0 \quad : \text{D}1, \text{D}3 \text{ on} \\
& \quad \text{D}2: -V_o - V_{oa} = -15 = 0 \\
& \quad V_{oa} = -9.35 - 15 \\
& \quad V_{oa} = 24.35 < 0 \quad : \text{off} \\
b. & \quad -V_o + I_{D1}(200) + 0.6 - 10 = 0 \\
& \quad V_o - I_{D1}(200) - 9.4 = -9.35 \\
c. & \quad V_{ac} = \frac{\sin(60t)}{(75,200 + r_d + r_d)} \\
& \quad r_d = r_{ac} = V_{oa} \\
& \quad r_d = \frac{r_{ac}}{I_{0}} = \frac{1V_{25m}}{250\mu} = 100 \\
& \quad V_{ac} = \frac{\sin(60t)(300)}{(75,400)} = 4m \sin(60t) \\
& \quad i_d = \frac{\sin(60t)}{75,200 + 200} = 13.3\mu \sin(60t) \\
& \quad \text{check validity:} \\
& \quad V_{ac} = i_d (100) = 1.3m \sin(60t) < 10mV \\
& \quad V_{total} = -9.35 + 4m \sin(60t) \]