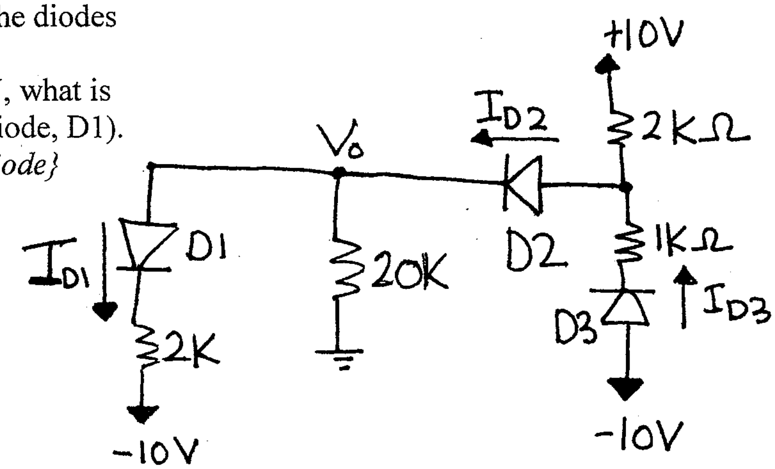
Problem 1 – (20 points)

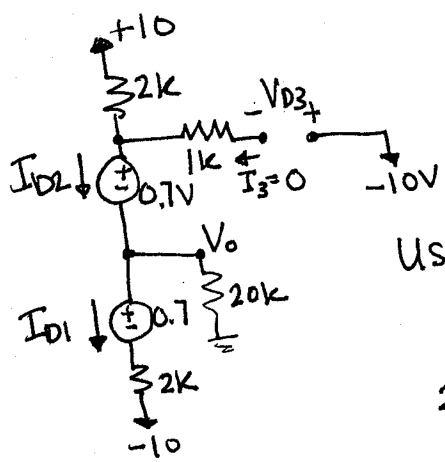
Solution

Assume all diodes are identical and have V_{DO}=0.7V, n=5, and V_T=25mV. 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).
b) The current I_{D1}
c) The current I_{D2}
d) The current I_{D3}
e) The voltage Vo
f) Verification to prove your assumptions for the diodes are correct.
g) If there is noise on the +10V supply of ± 1V, what is the total value for I_{D1} (the AC current through diode, D1). *{Hint: remember to use the AC model for the diode}*



Assume D1, D2 on, D3 off:



Using node Voltage:

$$\frac{V_o}{20K} + \frac{V_o \overbrace{-0.7+10}^{+9.3}}{2K} + \frac{V_o \overbrace{+(+0.7)-10}^{-9.3}}{2K} = 0$$

$$V_o\left(\frac{1}{20k} + \frac{1}{2k} + \frac{1}{2k}\right) = 0 \quad \therefore \boxed{V_o = 0}$$

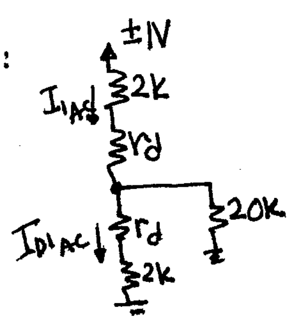
$$I_{D2} = I_{D3} = \frac{10-0.7}{2k} = \frac{9.3}{2k} = \boxed{4.65mA}, \quad \boxed{I_{D3} = 0A}$$

check: $I_{D2}, I_{D3} > 0$ ✓

V-loop with V_{D3}: $+V_o + 0.7 + V_{D3} + 10 = 0$, $V_o = 0$

$V_{D3} = -10.7V < 0.7 \therefore$ off ✓

g) AC:



$$I_{1AC} = \frac{\pm 1V}{2K + r_d + \underbrace{20K \| (2K + r_d)}_{1.84K}} \quad \text{where } r_d = \frac{nV_T}{I_D} = \frac{5(25m)}{4.65m} \approx 27\Omega$$

$I_{1AC} \cong \pm 259\mu A$

$$I_{D1AC} = \frac{\pm 259\mu(20k)}{22.027k} \cong \pm 235\mu A \qquad \boxed{I_{D1} = 4.65m \pm 235\mu A}$$

Problem 2 – (30 points)

a) Sketch the Bode (both magnitude & phase) plot for: {label as many y values as possible for both magnitude and phase and/or each slope along with showing all your work}

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

b) What is the estimated or actual magnitude value at ω=200 rad/sec (in dB):

+40dB (from graph) or $\frac{10 \cdot \sqrt{\left(\frac{200}{10}\right)^2 + 1^2}}{\sqrt{\left(\frac{200}{100}\right)^2 + 1^2} \cdot \sqrt{\left(\frac{200}{1k}\right)^2 + 1^2}} \approx 40\text{dB}$

c) What range of frequency will this circuit operate correctly:

up to 10 $\frac{rad}{sec}$ and 100 to 1k $\frac{rad}{sec}$

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standard form:

only effects phase(180°) not magnitude

$$\frac{-100K(10)\left(\frac{s}{10}+1\right)}{100 \cdot 1K \cdot \left(\frac{s}{100}+1\right)\left(\frac{s}{1k}+1\right)} = \frac{(-)10\left(\frac{s}{10}+1\right)}{\left(\frac{s}{100}+1\right)\left(\frac{s}{1k}+1\right)}$$

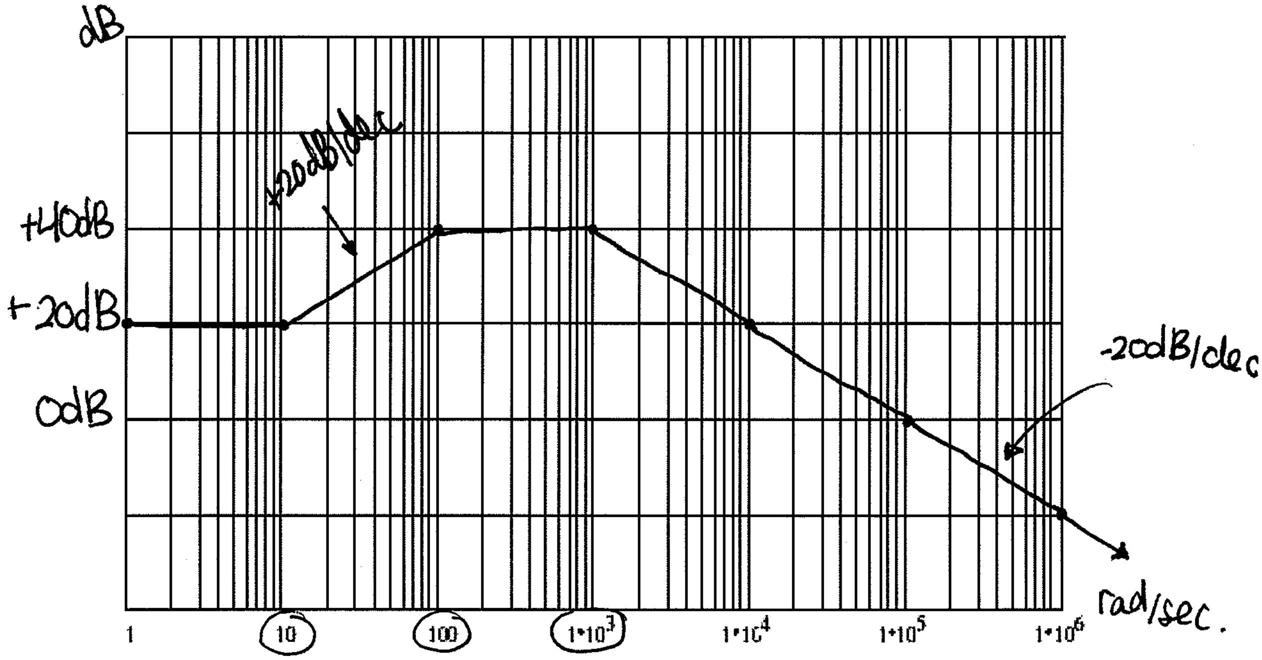
	magnitude	phase
zero at ω=10:	+20dB/dec starting at ω=10	1<ω<100 +45° slope/dec
pole at ω=100:	-20dB/dec " " ω=100	10<ω<1k -45° slope/dec
pole at ω=1k:	-20dB/dec " " ω=1k	100<ω<10k -45° slope/dec

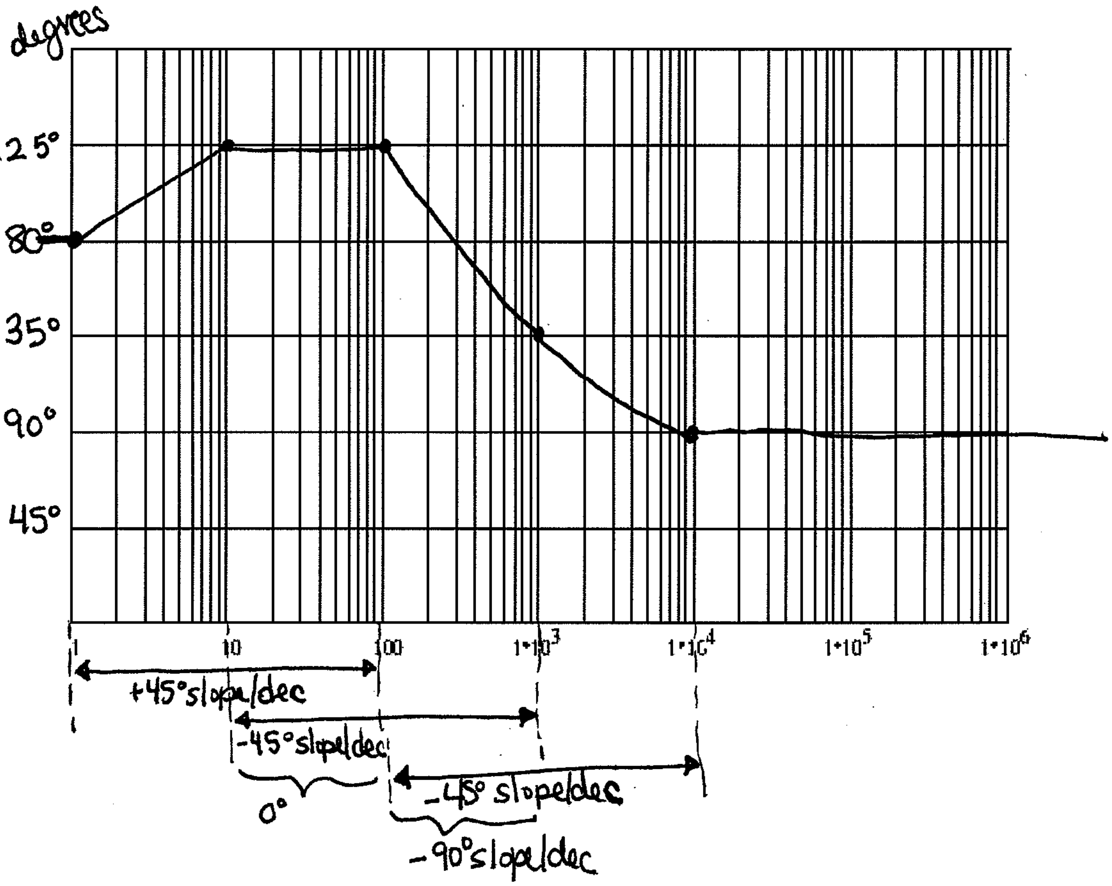
magnitude: at ω=1 : $\frac{10 \cdot \sqrt{\left(\frac{1}{10}\right)^2 + 1^2}}{\left(\sqrt{\left(\frac{1}{100}\right)^2 + 1^2}\right)\left(\sqrt{\left(\frac{1}{1k}\right)^2 + 1^2}\right)} = 10\,V/V$ or $20\log(10)$ 20dB

There is a flat line in magnitude until the first critical f(ω=10)

phase: a flat line at 180° until first frequency range

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

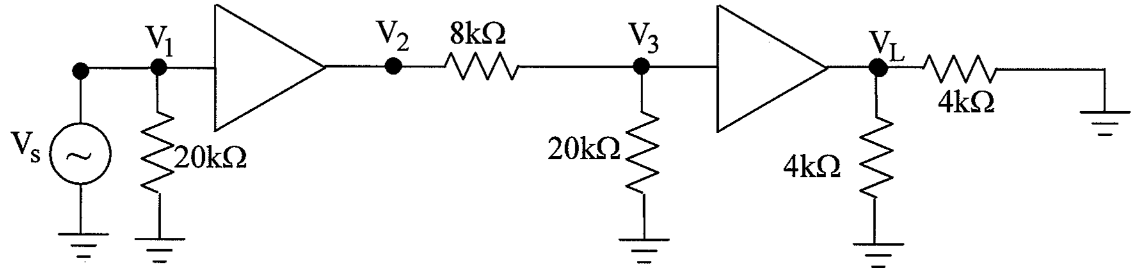




Problem 3 – **(30 points)**

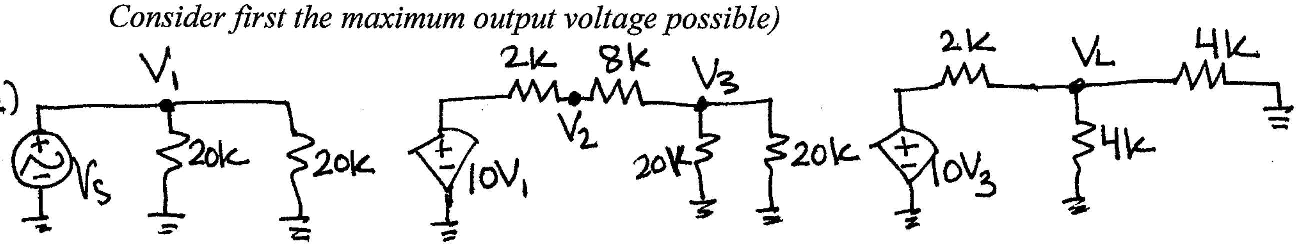
V_s is an AC signal. Assume linear operation for both amplifiers with only the following nonideal effects:

$A_{vo}=10$, $R_{in}=20k\Omega$, $R_o=2k\Omega$ power supplies = ± 12 V



(a) Draw this 2 stage amplifier using the voltage amplifier model. Make sure to label V_S, V_1, V_2, V_3, and V_L on the schematic.
(b) Find the voltage gain V_L/V_s without frequency dependence or amplifier imperfections.
(c) What are the pole locations if both amplifiers are internally compensated with f_T=5MHz. *(Hint: Find V_2/Vs and V_L/V_2)*
(d) What is the maximum amplitude for Vs considering the limits of a nonideal amplifier? *(Hint: Consider first the maximum output voltage possible)*

(a)



(b) $V_L = \dfrac{10 \cdot V_3 (2k)}{4k} = 5 \cdot V_3$

$V_3 = \dfrac{V_2 \cdot 10K}{18K} = \dfrac{5}{9} \cdot V_2$

$V_2 = \dfrac{10V_1 \cdot 18K}{20K} = 9 \cdot V_1$

$V_1 = V_S$

$V_L = 5 \cdot \frac{5}{9} \cdot 9 \cdot V_S$

$\boxed{\dfrac{V_L}{V_S} = 25 \, V/V}$

(c) For first amplifier:

$$\frac{V_2}{V_s} = 9$$

$$f_{3dB} = \frac{5M}{9}$$

For second amplifier:

$$\frac{V_L}{V_2} = 5 \cdot \frac{5}{9} = \frac{25}{9}$$

$$f_{3dB} = \frac{5M}{25} \cdot 9 = \frac{9}{5}M$$

overall transfer function:

$$\frac{9 \cdot 25/9}{\left(\frac{jf}{5/9 M} + 1\right)\cdot\left(\frac{jf}{9/5 M} + 1\right)} = \boxed{\frac{25}{\left(\frac{9jf}{5M} + 1\right)\cdot\left(\frac{5jf}{9M} + 1\right)}}$$

555k   1.8M

(d) $V_{out\,max} = +12$

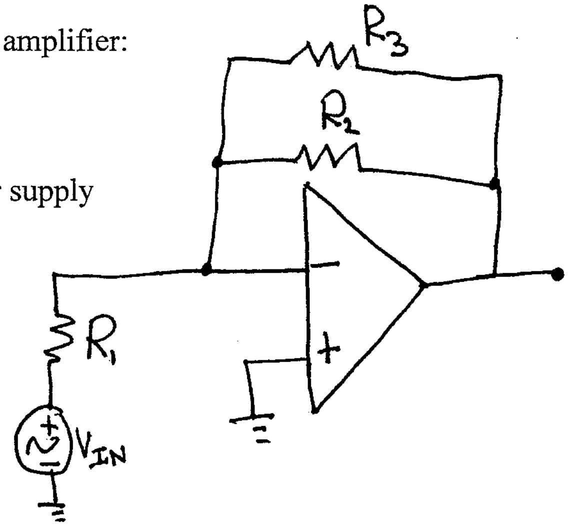
$$\therefore V_{S\,max} = \frac{+12}{25} = \boxed{0.48\,V}$$

Problem 4 – (20 points)

You are given the following characteristics for a real amplifier:

Input offset voltage, V_{ios}=3mV
Input Resistance, R_i=2MΩ
Unity-gain bandwidth, f_T=20MHz
Output swing limits, within 2Volts of power supply
Slew Rate, $SR = 6\frac{V}{\mu sec}$

The following circuit is powered at ±15V:



a) If R_1=20k and R_2= R_3=100k, what is the bandwidth of the circuit. Consider both the effect due to slew rate (use the maximum output value possible) compared to the effect due to the unity gain bandwidth.

b) For $V_{in}=0.002\sin(2\pi 90kt)$, what is the PEAK(not peak to peak) value at the output considering the input offset voltage?

c) How should the circuit above be modified to minimize the effect of the input bias current? Draw the schematic of the modified circuit and state values of added component(s).

(a) $R_2 \| R_3 = 50k$

inverting amp gain $= -\frac{50k}{20k} = \boxed{-2.5 V/V}$

$f_{3dB} = \frac{20M}{2.5} = 8MHz$

SR effect: $f_{max} = \frac{SR}{2 \cdot V_p \cdot \pi} = \frac{6}{1\times10^{-6} \cdot 2 \cdot 13 \cdot \pi} = \boxed{73.5KHz}$

↑ bandwidth

(b) $-5m \sin(2\pi 90kt) - 2.5(3m)$

peak ⇒ $-7.5m + 5m = \boxed{-2.5mV}$

(c)