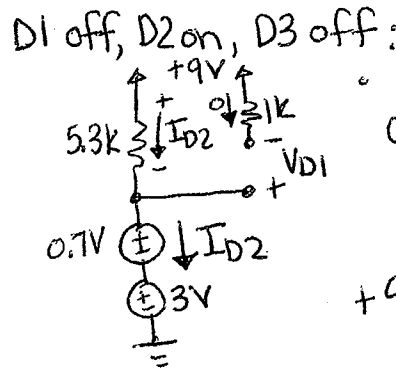
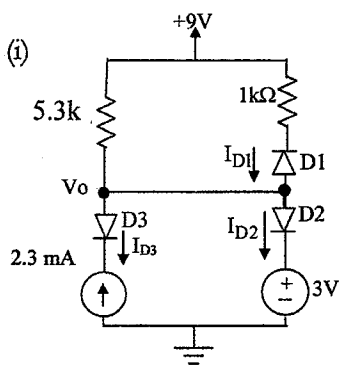


The material we have covered so far this semester is summarized (but NOT limited to) below:

1. Understand the difference between AC & DC signals.
2. Understand how to analyze circuit (with or without cap in it) to obtain transfer function.
3. Understand how to plot the Bode plots from an equation or circuit.
4. Amplifiers:
 - a) Understand how to apply Amplifier models (voltage, current, etc.) to multistage amplifiers
 - b) Analyze single input Amplifier (with model) for transfer function.
 - c) Analyze amplifier's gain in different configurations (inverting, noninverting, voltage follower)
 - d) Understand frequency response of amplifiers for single amplifiers
 - e) Compensation of real op-amp imperfections (Slew Rate, Clipping, Input bias currents, Voltage offset, frequency limitations, finite gain)
5. Diodes:
 - a) Analyze diode circuit using ideal model
 - b) Analyze diode circuit using constant voltage drop model
 - c) Analyze diode circuit with both DC and AC signals

- (a) Find I_{D1} , I_{D2} , I_{D3} , and V_o using constant voltage drop method with $n=1$, $V_T=25mV$, and $V_{D0}=0.7V$.
- (b) Find $V_{o_{total}}$ if the 3V source has $0.5\sin(\omega t)$ noise.



D1 off, D2 on, D3 off:
 D3 has to be off because current is not allowed to flow in that direction through the diode.

$$+9 - I_{D2}(5.3k) - 3.7 = 0$$

$$I_{D2} = \frac{(9 - 3.7)}{5.3k} = \frac{5.3}{5.3k} = 1mA > 0$$

\therefore D2 on

Check V_{D1} :

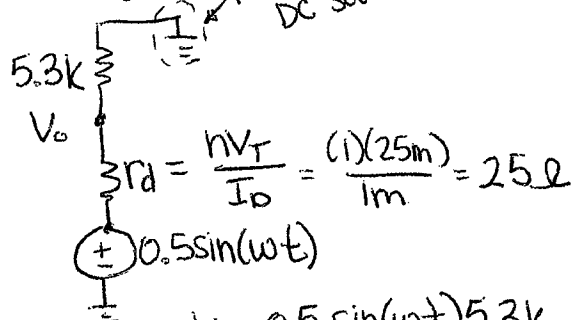
$$+3V + 0.7 - V_{D1} - 9 = 0$$

$$V_{D1} = -9 + 3 + 0.7 = -5.3 < 0.7$$

\therefore D1 is off

$$\begin{aligned}
 I_{D1} &= 0 \\
 I_{D2} &= 1mA \\
 I_{D3} &= 0 \\
 V_o &= 3.7V
 \end{aligned}$$

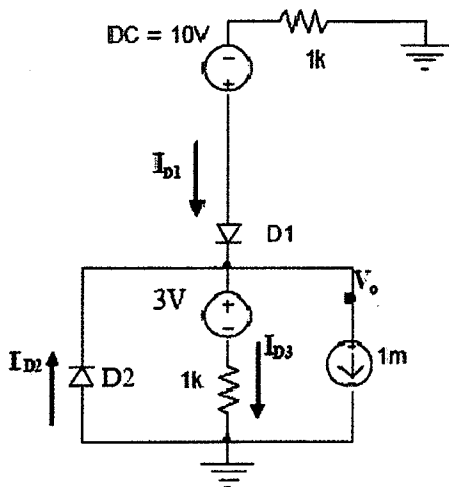
AC analysis: remove DC source ($V=0$ is a wire)



$$V_o = \frac{0.5 \sin(\omega t) 5.3k}{5.3k + 25} \approx 0.5 \sin(\omega t)$$

$$V_{total} = 3.7 + 0.5 \sin(\omega t) V$$

(ii)



$$V_o = +3 + I_{D3}(1k)$$

Kloop:

$$-I_{D1}(1k) + 10 - 0.7 - 3 - I_{D3}(1k) = 0$$

Σ I:

$$-I_{D1} + 1m + I_{D3} = 0$$

$$I_{D1} = (1m + I_{D3})$$

$$\therefore -(1m + I_{D3})(1k) + 6.3 - I_{D3}(1k) = 0$$

$$-1(-2k)I_{D3} + 6.3 = 0$$

$$I_{D3} = \frac{5.3}{2k} = 2.65m > 0$$

$$\therefore \underline{D3 \text{ is on}} \Rightarrow V_o = 3 + 1k(2.65m)$$

$$V_o = \underline{5.65V}$$

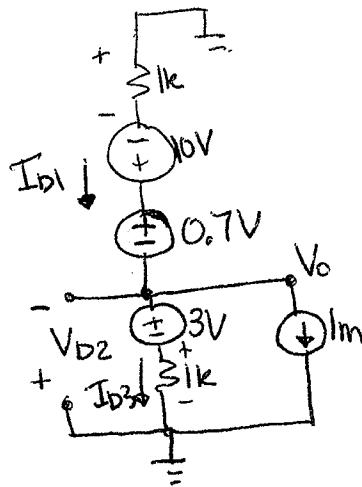
Check V_{D2} :

$$-V_{D2} - 3 - I_{D3}(1k) = 0$$

$$V_{D2} = -3 - 1k(2.65m) = -5.65 < 0.7$$

$$\therefore \underline{D2 \text{ is off}}$$

Assume D1 on, D2 off:



OR use node-voltage

$$\frac{V_o - 3}{1k} + 1m + \frac{-(10 - 0.7) + V_o}{1k} = 0$$

$$V_o \left(\frac{1}{1k} + \frac{1}{1k} \right) = 3m - 1m + 9.3m$$

$$\therefore V_o = \frac{11.3m}{\frac{1}{1k} + \frac{1}{1k}} = \underline{5.65V}$$

$$I_{D3}(1k) + 3 - V_o = 0$$

$$I_{D3} = \frac{V_o - 3}{1k} = \frac{2.65}{1k} = 2.65m$$

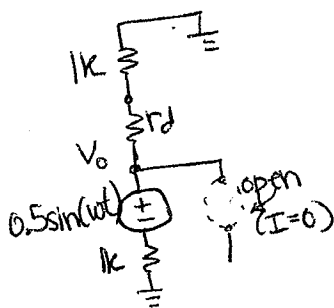
$$I_{D1} = 1m + 2.65m = 3.65m$$

$$I_{D2} = 0$$

$$I_{D3} = 2.65m$$

$$V_o = 5.65V$$

$$\text{AC analysis: } r_d = \frac{nV_T}{I_{D3}} = \frac{(1)(25m)}{2.65m} = 9.4\Omega$$



$$V_{oAC} = \frac{0.5\sin(\omega t)(1k + r_d)}{(1k + r_d) + 1k} \approx 0.25\sin(\omega t)$$

$$V_{oTotal} = 5.65 + 0.25\sin(\omega t)$$

2. Sketch Bode Plots for (a) $H(s) = \frac{-1 \times 10^{14} (s^2)}{(s+10k)^2 (s+100k)}$ \Rightarrow Standard Form: $\frac{-1 \times 10^{14} (s^2)}{(10k)^2 (\frac{s}{10k} + 1)^2 (100k) (\frac{s}{100k} + 1)}$

critical frequencies: origin(x2), 10k(x2), 100k

at $\omega=1$: $\frac{-1 \times 10^{14} (1)}{(10k)^2 (100k) \left(\sqrt{1 + \frac{1}{10k^2}}\right)^2 \left(\sqrt{1 + \frac{1}{100k^2}}\right)} = 10^4 V \Rightarrow 20 \log(10) = \underline{20dB}$

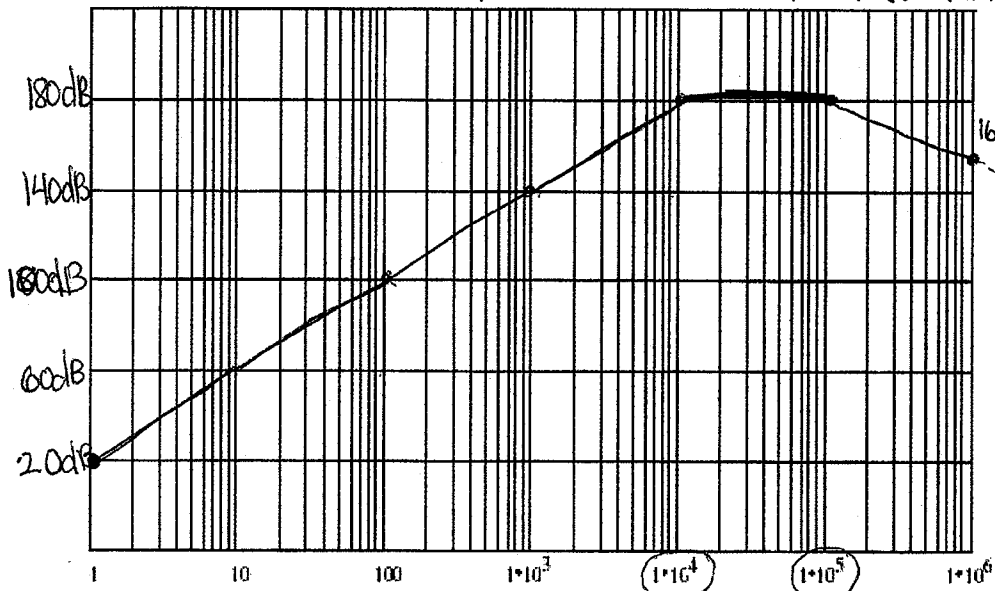
magnitude:

2 at origin (zeros)	+2(+20dB/decade)
10k(x2) pole	2(-20dB/decade)
100k pole	-20dB/decade

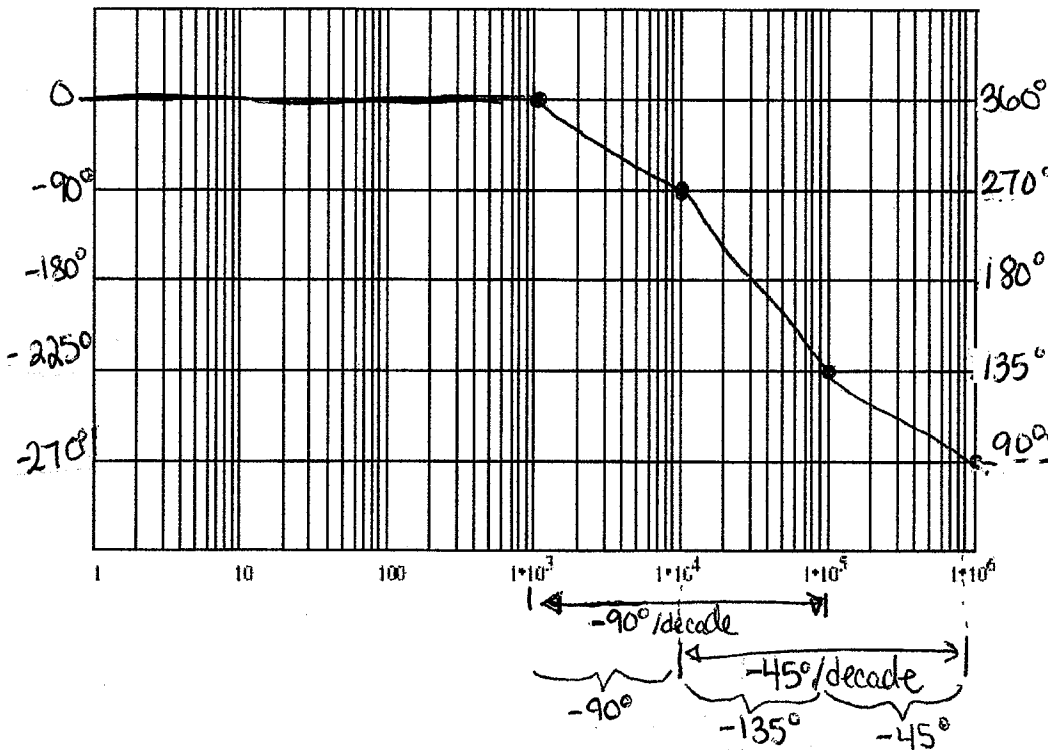
phase:

(\rightarrow) sign starts phase at $\pm 180^\circ$

2 at origin (zeros)	2(+90) = +180°
10k < ω < 100k pole	(-45°/decade x 2)
100k < ω < 1M pole	-45°/decade

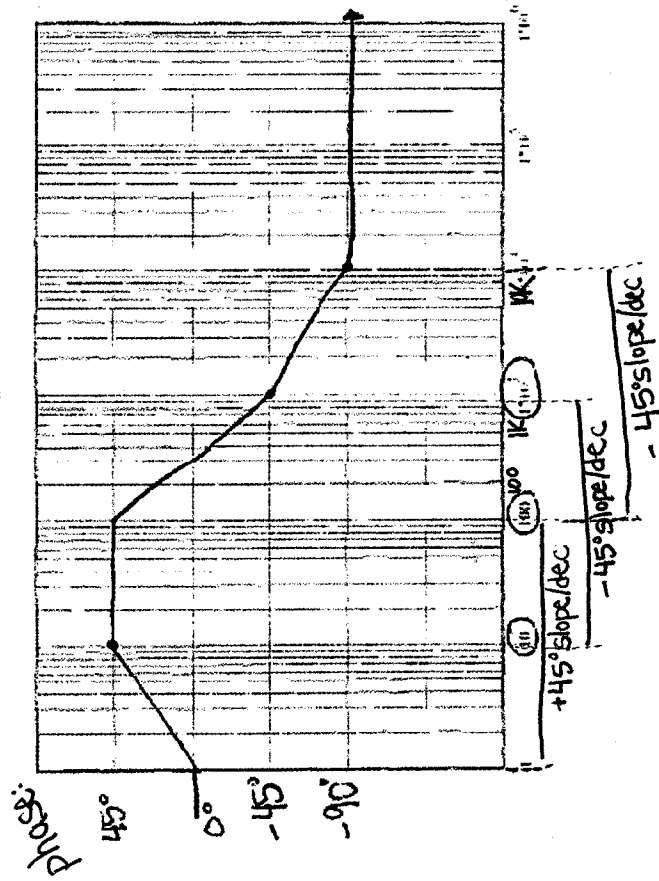
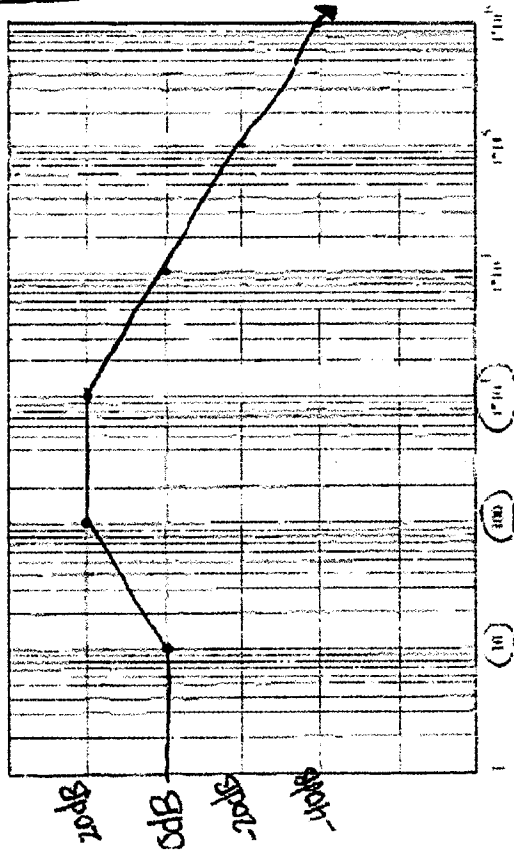


Bandwidth is from 10k to 100k



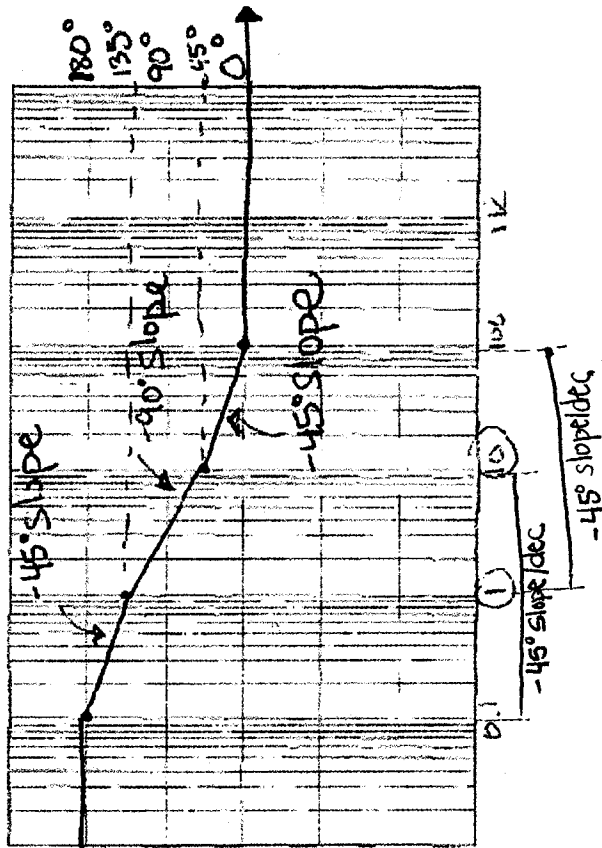
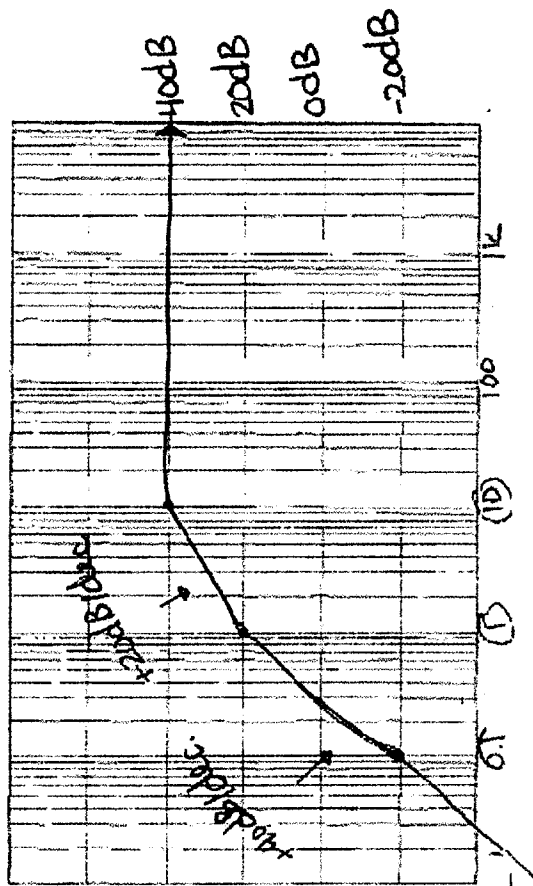
$$4. b \quad H(s) = \frac{10K(10)(\frac{s}{10}+1)}{1K(\frac{s}{1K}+1)(100)(\frac{s}{100}+1)} = \frac{(\frac{s}{10}+1)}{(\frac{s}{1K}+1)(\frac{s}{100}+1)}$$

Break freq: $\omega = 10, 100, 1K$

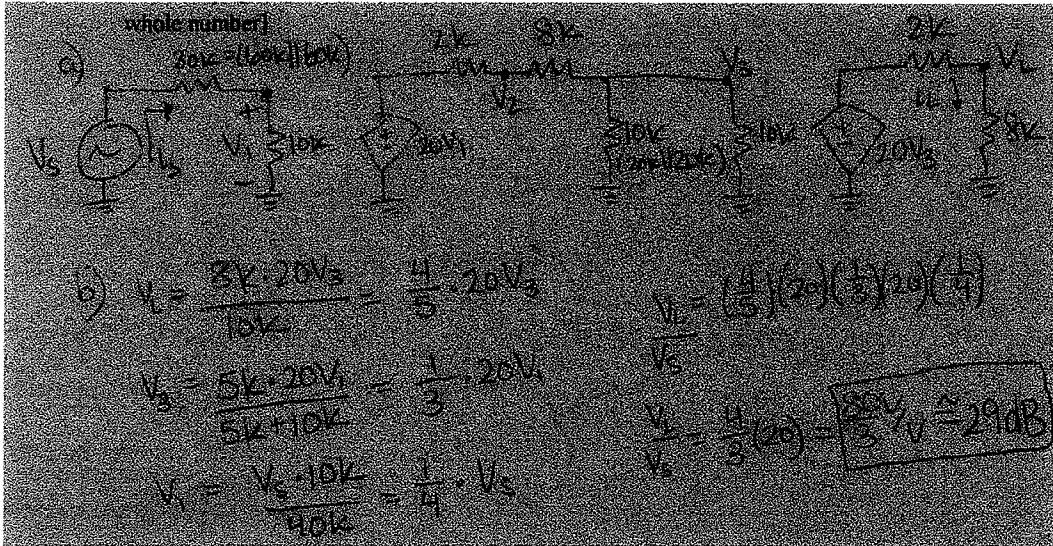
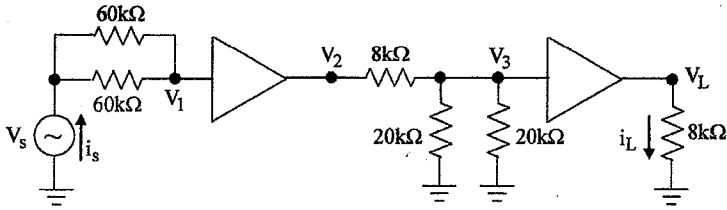


$$5. \quad H(s) = \frac{100s^2}{(s+1)(\frac{s}{10}+1)} = \frac{10s^2}{(s+1)(\frac{s}{10}+1)}$$

Break freq: $\omega = 1, 10$
 Phase starts at 180°
 Slope starts at $+40dB/dec$
 @ $\omega = 1 \Rightarrow 20 \log(10) = 20dB$

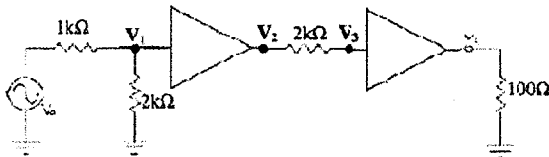


3. (a) Use voltage amplifier model to find voltage gain. $A_{vo}=20$, $R_i=10k\Omega$, $R_o=2k\Omega$.



(b)

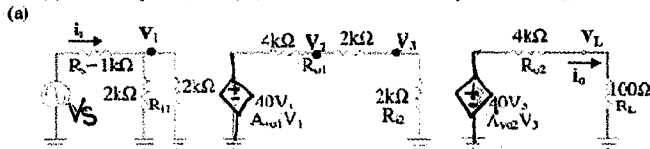
- Both amplifiers have the following characteristics:
 $A_{vo}=40$ $R_i=2k\Omega$ $R_o=4k\Omega$ Clipping levels: $L=\pm 12V$ (unloaded)



(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.

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

(c) For the input $V_s = \sin(\omega t)$. State the maximum output value at V_L .



(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]

$$\frac{V_L}{V_s} = A_v = \frac{R_{i1}}{R_s + R_{i1}} \cdot A_{vo1} \cdot \frac{R_{i2}}{R_{o1} + R_{i2}} \cdot A_{vo2} \cdot \frac{R_L}{R_{o2} + R_L}$$

$$R_{i1} = \frac{1}{\frac{1}{2k} + \frac{1}{2k}} = 1k$$

$$R_{i2} = 4k + 2k = 6k$$

$$A_v = \frac{1k}{1k + 2k} \cdot 40 \cdot \frac{6k}{4k + 6k} \cdot 40 \cdot \frac{100}{4k + 100} = 4.878 \text{ (rounded to } 5V/V) \text{ or } 20 \log(5) = 13.98 \text{ dB}$$

(c) Amplitude \Rightarrow maximum output will be the peak value: $\text{gain} = V_L/V_s = 5V/V$ $V_L = 5 * V_{s_peak} = 5V$

checking for clipping $\Rightarrow \frac{V_2}{V_s} = \frac{40 \cdot (1k)}{2k} \cdot \frac{4k}{8k} = 40V < 12V$
 \rightarrow No clipping at 1st amp
 if $V_s = 1V_{max}$.

4 (a) You are given the following characteristics for a real amplifier.

Input offset voltage, $V_{ios} = 4\text{mV}$

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

Input bias current, $I_{ib} = 1\mu\text{A}$

Input Resistance, $R_i = 1\text{M}\Omega$

Output Resistance, $R_o = 50\Omega$

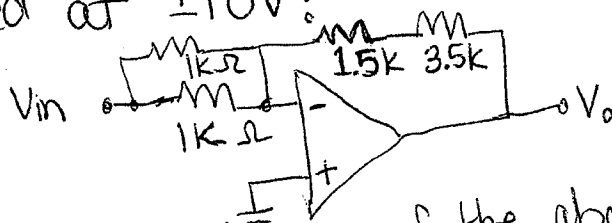
Open-loop gain, $A_{vo} = 180\text{dB}$

Unity-gain bandwidth, $f_T = 11\text{MHz}$

Output swing limits, within 2Volts of supply

Slew Rate, $\text{SR} = 2\text{V}/\mu\text{sec}$.

Given the following circuit with the operational amplifier powered at $\pm 10\text{V}$:



i) Find the ideal gain of the above circuit:

$$\frac{V_o}{V_{in}} = \frac{-5\text{k}}{1\text{k}} = -5 \Rightarrow 20\text{dB}$$

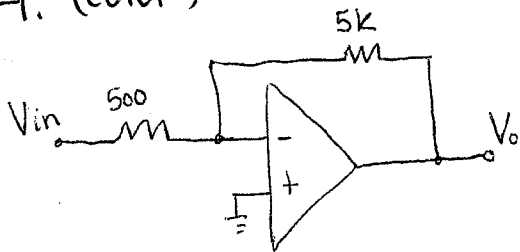
ii) For small input signals, what is the bandwidth of the circuit: $f_{3\text{dBnew}} = \frac{11\text{MHz}}{10} = 1.1\text{MHz}$

iii) If a circuit needs to operate up to 5MHz, what is the maximum gain I can achieve using an inverting amplifier configuration?

$$f_{3\text{dBnew}} = 5\text{MHz} = \frac{11\text{MHz}}{\left(\frac{R_2}{R_1}\right)} \Rightarrow \left|\frac{R_2}{R_1}\right| = \frac{11}{5} = 2.2$$

(e.g. $R_1 = 1\text{k}$, $R_2 = 2.2\text{k}$)

4. (cont)



(v) If the above circuit is operated to produce the maximum possible peak voltage,

a) what is the bandwidth?

b) what is the maximum peak voltage value for the input?

$$a) f_{max} = \frac{SR}{V_p \cdot 2 \cdot \pi} = \frac{2}{1 \times 10^{-6} \times (8)(2)\pi} = \underline{\underline{39.8 \text{ KHz}}}$$

b) maximum peak voltage = +8V output max.

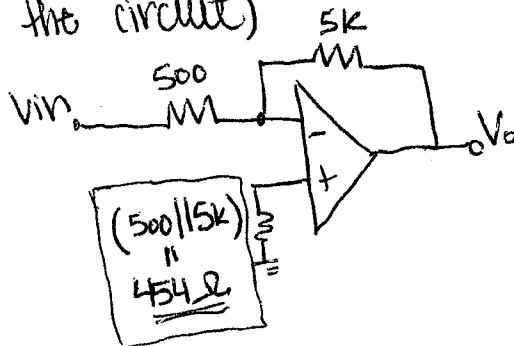
Using ideal gain = $-10 \frac{V}{V}$

$$\left| \frac{V_o}{V_{in}} \right| = +10 \Rightarrow V_{in} = \frac{V_o}{10} = \frac{8}{10} = \underline{\underline{0.8V \text{ max}}}$$

v) Find the effect of the input offset voltage when $V_{in} = 0V$.

$$V_{out} = 4m(-10) = \underline{\underline{-40mV}}$$

vi) How should the circuit above be modified to minimize the effect of the input bias current?
(Draw the circuit)



4. (b) You are given the following characteristics for a real amplifier:

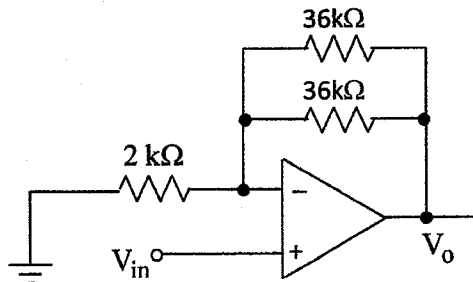
Input offset voltage,	$V_{ios}=3\text{mV}$
Input offset current,	$I_{os}=100\text{nA}$
Input bias current,	$I_{ib}=1\mu\text{A}$
Input Resistance,	$R_i=1\text{M}\Omega$
Output Resistance,	$R_o=50\Omega$
Open-loop gain,	$A_{vo}=180\text{dB}$
Unity-gain bandwidth,	$f_T=15\text{MHz}$
Output swing limits,	within 2Volts of power supply
Slew Rate,	$SR=4\frac{V}{\mu\text{sec}}$

If a circuit needs to operate at 5MHz using the above specifications for an operational amplifier and having a power supply of $\pm 15\text{V}$, what is the maximum gain that can be achieved using an:

ii) Non-inverting amplifier

$$f_{3dB\text{new}} = \frac{15 \times 10^6}{\left(1 + \frac{R_2}{R_1}\right)} = 5\text{MHz} \Rightarrow \left(1 + \frac{R_2}{R_1}\right) = \frac{15 \times 10^6}{5 \times 10^6} = 3 \frac{V}{V}$$

Given the following circuit with the operational amplifier powered at $\pm 15\text{V}$.



i) Find the ideal gain of the above circuit:

$$\frac{V_o}{V_{in}} = \left(1 + \frac{18k}{2k}\right) = 10 \frac{V}{V}$$

ii) For small input signals, what is the bandwidth of the circuit

$$f_{3dB\text{new}} = \frac{15 \times 10^6}{10} = 1.5\text{MHz}$$

iii) What is the bandwidth when the circuit is operated to produce the maximum possible peak voltage value?

$$f = \frac{4}{10^{-6}(13 \cdot \pi)} = 98\text{kHz}$$

iv) What is the maximum amplitude of the input ?

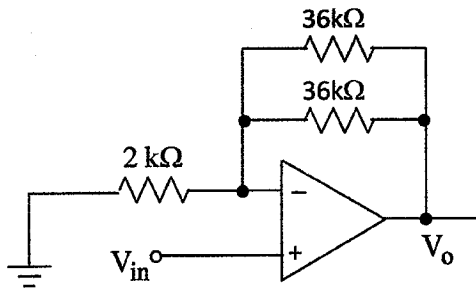
$$\frac{V_o}{V_{in}} = 10 \frac{V}{V} \Rightarrow V_{in} = \frac{V_o}{10} = \frac{13}{10} = 1.3\text{V}$$

v) For $V_{in} = 0.001 \sin(2\pi 90kt)$, what is the ideal value for the peak to peak voltage value at the output?

$$V_{o\text{pp}} = 2(0.001)(10) = 0.02\text{V}_{\text{pp}}$$

vi) For $V_{in} = 0.001 \sin(2\pi 90kt)$, what is the peak voltage value at the output considering the input offset voltage?

$$V_{o\text{pp}} = 2(0.001)(10) + 3\text{m}(10) = .02 + .030 = 0.05\text{V}$$



- vii) 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).

