1) (a) An amplifier is a device whose output voltage is the same as its input voltage multiplied by some constant gain.

(b) R_i is the input resistance, that is the resistance between the input terminals.

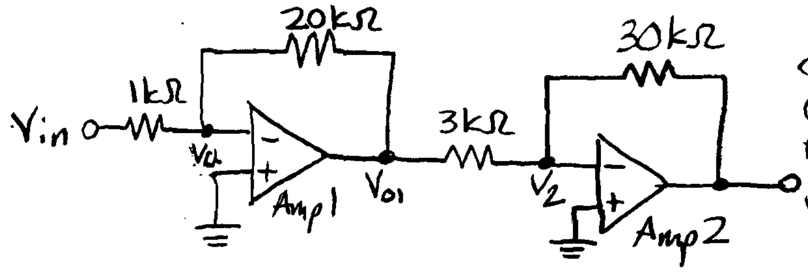
(c) R_o is the output resistance, a resistor in series with the voltage output. It can load the circuit and reduce the gain of the amplifier.

(d) Ideal Characteristics for an amplifier are $A_{vo} = \infty$, $R_i = \infty$, and $R_o = 0$.

(e) A buffer amplifier is a voltage follower. It tracks the input voltage to the output terminals. They are used as impedance transformers or power amplifiers. It requires $A_{vo} = 1\,V/V$.

(f) The gain-bandwidth product is the bandwidth achieved when a unity gain is desired. If we double the gain, we get half the bandwidth. The gain-bandwidth is specified on the op-amps' datasheets.

(2) Here is the circuit redrawn:



The two 10kΩ resistors in series were combined. The two 60kΩ resistors in parallel were combined

Amp1: <u>Need to find the gain</u> $\left(\frac{V_{o1}}{V_{in}}\right)$

$$\frac{V_a - V_{in}}{1k\Omega} + \frac{V_a - V_{o1}}{20k\Omega} = 0A$$

$$V_a = 0V \Rightarrow \frac{-V_{in}}{1k\Omega} - \frac{V_{o1}}{20k\Omega} = 0A$$

$$\frac{V_{o1}}{V_{in}} = \frac{-20k\Omega}{1k\Omega} = -20\,V/V$$

<u>Need to find f_{3dB}</u>

From Datasheet: $f_T = 4.5\,MHz$ (Gain-Bandwidth Product)

$$\left|\frac{V_{o1}}{V_{in}}\right| f_{3dB} = f_T \Rightarrow 20 f_{3dB} = 4.5\,MHz$$

$$f_{3dB} = 225\,kHz$$

Amp 2: $\frac{V_o}{V_{o1}} = \frac{-30k\Omega}{3k\Omega} = -10\frac{V}{V}$ (same algebra as above)

$$f_{3dB} = \frac{\text{gain} \times \text{bandwidth}}{\text{gain}} = \frac{100k \times 10}{10} = 100kHz$$

values from graph.

$\left|\frac{V_o}{V_{o1}}\right|$

Overall: Gain $= (-20)(-10) = 200\,V/V$

(a) $$\frac{V_{o1}}{V_{in}} = \frac{V_1}{V_{in}} = \frac{\text{Gain}}{\left(\frac{s}{f_{3dB}} + 1\right)} = \frac{-20}{\left(\frac{s}{2\pi \times 225k} + 1\right)}$$

$$\boxed{\therefore \frac{V_1}{V_{in}} = \frac{-20}{\left(\frac{s}{2\pi \times 225k} + 1\right)}}$$

$$\frac{V_o}{V_{o1}} = \frac{V_o}{V_1} = \frac{-10}{\left(\frac{s}{2\pi \times 100K} + 1\right)}$$

$$\boxed{\therefore \frac{V_o}{V_1} = \frac{-10}{\left(\frac{s}{2\pi \times 100K} + 1\right)}}$$

(b) $$\frac{V_o}{V_{in}} = \frac{V_o}{V_1} \cdot \frac{V_1}{V_{in}} = \frac{-10}{\left(\frac{s}{2\pi \times 100k} + 1\right)} \cdot \frac{-20}{\left(\frac{s}{2\pi \times 225k} + 1\right)}$$

$$\boxed{\therefore \frac{V_o}{V_{in}} = \frac{200}{\left(\frac{s}{200k\pi} + 1\right)\left(\frac{s}{450k\pi} + 1\right)}}$$

(Matlab assumes rad/sec.)

(3) $\boxed{\text{Overall } f_{3dB} \cong 800K \text{ rad/s or } 127KHz}$

See attached plot with code

200 V/V ⇒ 46dB
43dB

$43 \Rightarrow 10^{43/20} \cong 141$ V/V

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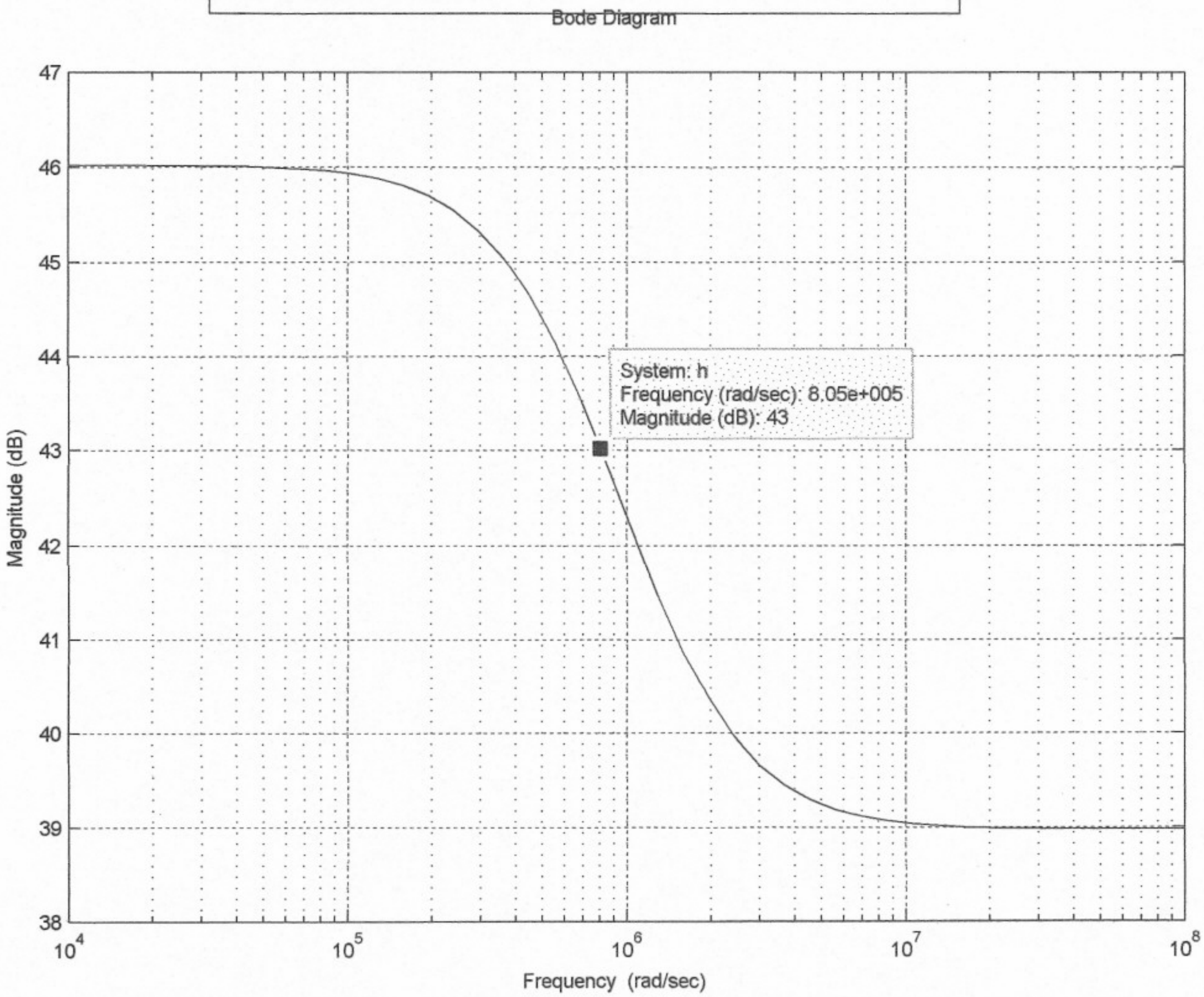
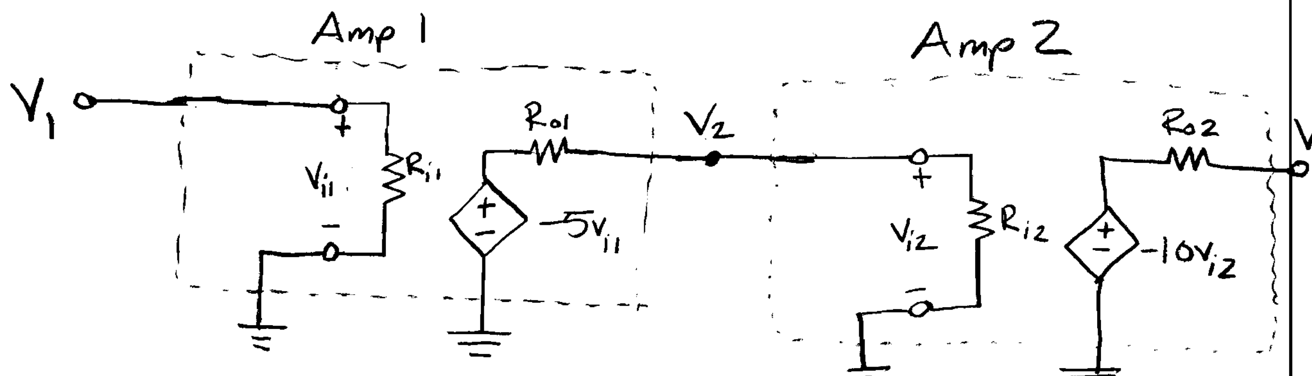
h=200/((s/(2*pi*100e3))+1)*((s/(2*pi*225e3))+1)



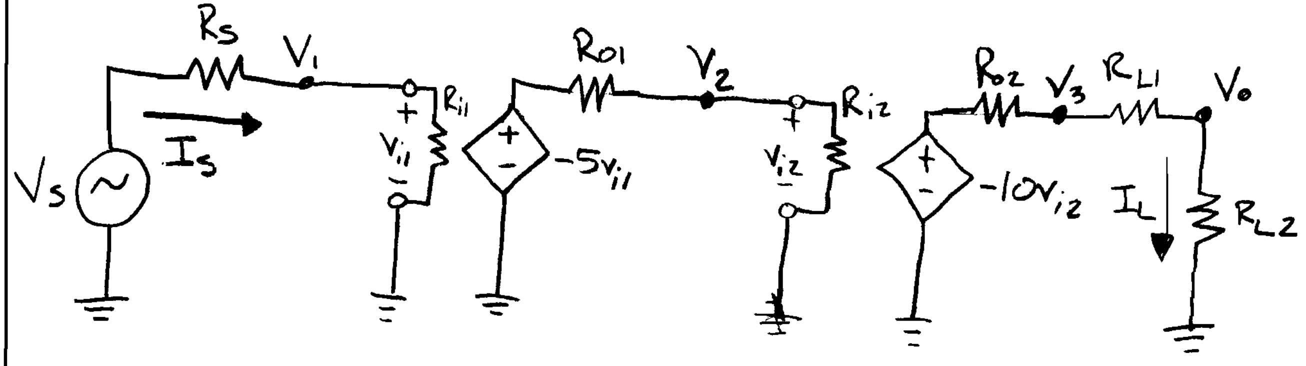
(4) (a) The algebra to find the gain for each amplifier is identical to the algebra used in $\boxed{2a}$ the gain was found to be $A_{vo} = -\frac{R_2}{R_1}$ where R_2 is the feedback resistor and R_1 is the resistor connected to the input voltage.

$$\boxed{\begin{array}{ll} \frac{V_2}{V_1} = \frac{-10k\Omega}{2k\Omega} = -5\,V/V & \text{(Amp 1)} \\ \frac{V_3}{V_2} = \frac{-20k\Omega}{2k\Omega} = -10\,V/V & \text{(Amp 2)} \end{array}}$$

(b) Redraw the two-stage amplifier



Note: $R_{i1} = R_{i2} = 100k\Omega$ $R_{o1} = R_{o2} = 5k\Omega$ Clips at $\pm 12V$



5 a Find overall gain for circuit from #4.

$$V_o = -10 V_{i2} \frac{R_{L2}}{R_{L1}+R_{L2}+R_{o2}} \quad \text{Voltage Divider}$$

$$V_{i2} = -5 V_{i1} \frac{R_{i2}}{R_{i2}+R_{o1}}$$

$$V_{i1} = V_s \frac{R_{i1}}{R_s+R_{i1}}$$

$$V_o = (-10)(-5) V_s \frac{R_{i1}\, R_{i2}\, R_{L2}}{(R_s+R_{i1})(R_{i2}+R_{o1})(R_{L1}+R_{L2}+R_{o2})}$$

$$V_o = 50 V_s \frac{(100k\Omega)(100k\Omega)(2k\Omega)}{(100.1k\Omega)(105k\Omega)(9k\Omega)} = 10.57 V_s$$

$$\boxed{\therefore \frac{V_o}{V_s} = 11 \frac{V}{V} \quad \text{or} \quad 20\,dB}$$

b Find $\frac{I_L}{I_s}$

$$I_L = \frac{V_o}{R_{L2}} \qquad I_s = \frac{V_s}{R_s+R_{i1}}$$

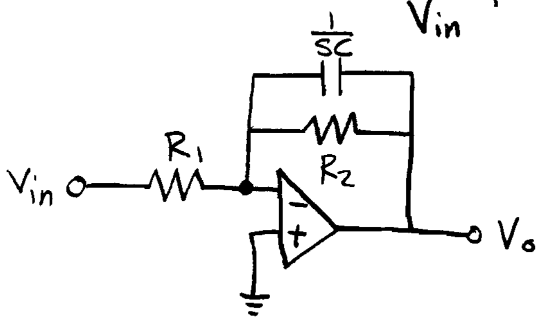
$$\frac{I_L}{V_o} = \frac{1}{R_{L2}} = \frac{1}{2k\Omega}$$

$$\frac{V_s}{I_s} = R_s + R_{i1} = 100\Omega + 100k\Omega = 100.1k\Omega$$

$$\frac{V_o}{V_s} = 11 \frac{V}{V} \Rightarrow \frac{I_L}{I_s} = \frac{I_L}{V_o} \cdot \frac{V_s}{I_s} \cdot \frac{V_o}{V_s} = \frac{100.1k\Omega}{2k\Omega}(11) = 550.55$$

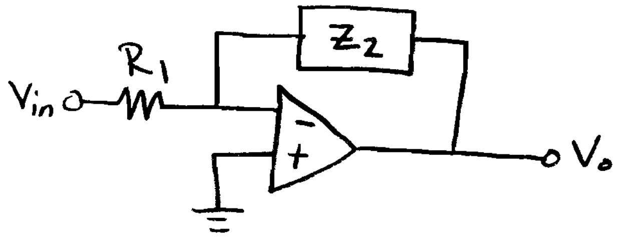
$$\boxed{\therefore \frac{I_L}{I_s} = 551 \frac{A}{A} \quad \text{or} \quad 55\,dB}$$

6) Analyze the circuit to obtain $\frac{V_o}{V_{in}}$, assuming an ideal op-amp.



Notice the feedback element can be rewritten as

$$Z_2 = \frac{1}{sC} \,||\, R_2 = \frac{R_2/sC}{R_2 + \frac{1}{sC}} = \frac{R_2}{sCR_2+1}$$

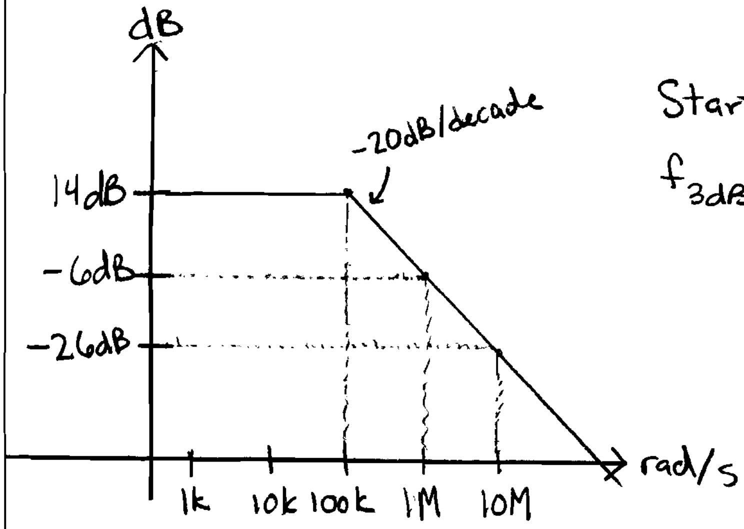


Now the algebra is identical to problem $\boxed{2a}$.

$$\frac{V_o}{V_{in}} = \frac{-Z_2}{R_1} = \frac{R_2/R_1}{sCR_2+1} = \frac{5}{10\mu s + 1}$$

$$\boxed{\therefore \frac{V_o}{V_{in}} = \frac{5}{\frac{s}{100k} + 1}}$$

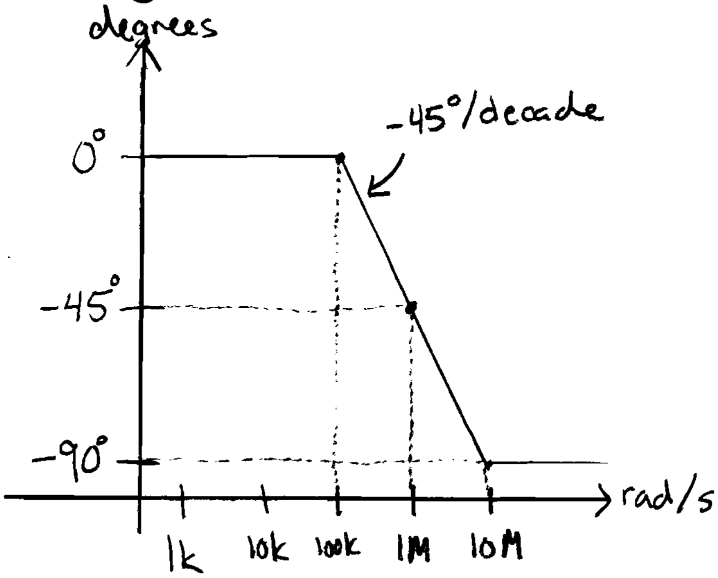
(7) Sketch the Straight Line Approx. for the Bode Plots from #6.



Start Value $= 20\log_{10}(5) \cong 14\,dB$

$f_{3dB} = 100k$ r/s or 15.9 kHz

Magnitude Plot



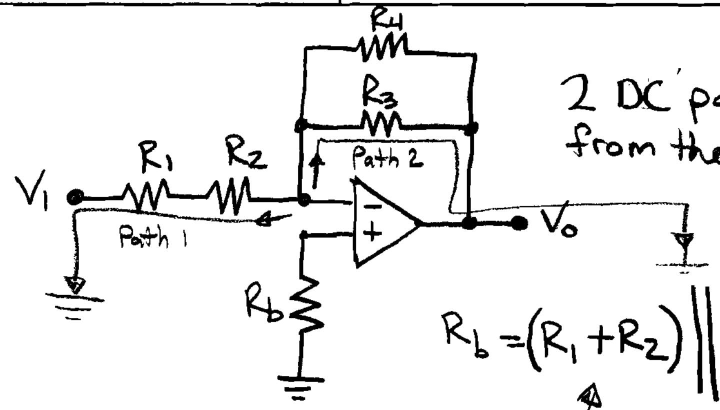
Start Value $= \angle 5 = 0°$

$f_{3dB} = 100k$ r/s or 15.9 kHz

Final Value $= \angle \frac{5}{j} = -90°$

Phase Plot

(8)

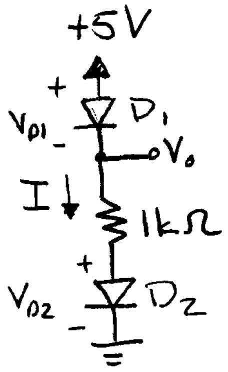


2 DC paths to ground from the negative terminal

$$R_b = (R_1 + R_2) \,||\, (R_3 || R_4)$$

from path 1 from path 2

(9)



Assume D_1, D_2 both on.

$V_{D1} = 0.7$

$V_{D2} = 0.7$

$V_o = 5V - V_{D1} = 4.3V$ (K's V Law)

$I = \dfrac{V_o - V_{D2}}{1k\Omega} = \dfrac{3.6V}{1k\Omega}$ (Ohm's Law)

$I = 3.6\,mA$

∴ $V_o = 4.3V$ and $I = 3.6\,mA$

Check: Current is flowing the correct direction in both diodes, and the voltage drops were defined in the correct direction. ☑

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