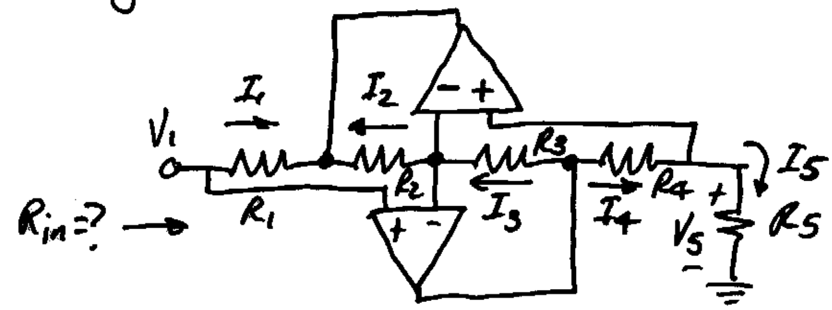
Challenge from last lecture –



Because $v_{id} = 0$ and no current flows into the op amp inputs, we can write –

(1.) $I_1 + I_2 = 0$ (2.) $I_1 R_1 = I_2 R_2$ (3.) $I_3 + I_4 = 0$

(4.) $I_3 R_3 = I_4 R_4$ (5.) $I_4 = I_5$ (6.) $V_5 = I_5 R_5$

(7.) $V_1 = V_5$ (8.) $I_2 = I_3$

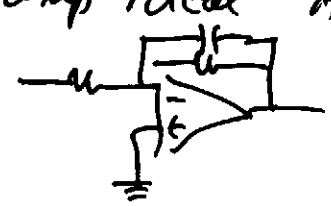
Now,

$$V_1 = V_5 = I_5 R_5 = I_4 R_5 = \left(\frac{I_3 R_3}{R_4}\right) R_5 = I_2 \left(\frac{R_3 R_5}{R_4}\right)$$

$$V_1 = \left(I_1 \frac{R_1}{R_2}\right)\left(\frac{R_3 R_5}{R_4}\right) = \frac{R_1 R_3 R_5}{R_2 R_4} I_1 \rightarrow \boxed{\frac{V_1}{I_1} = \frac{R_1 R_3 R_5}{R_2 R_4}}$$

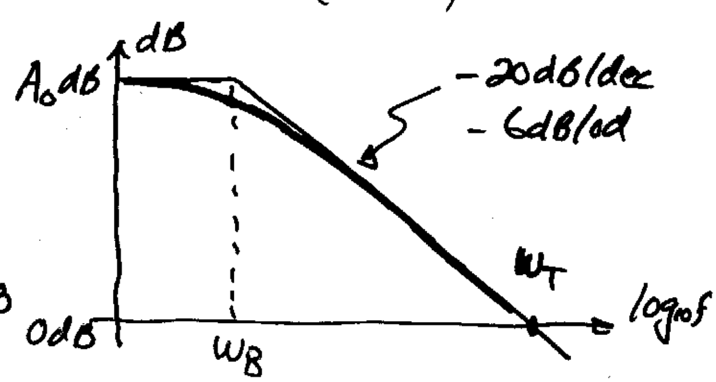
Frequency Response of Op Amp –

1.) Op amp ideal $A \to \infty$ GB (UGB) $\to \infty$

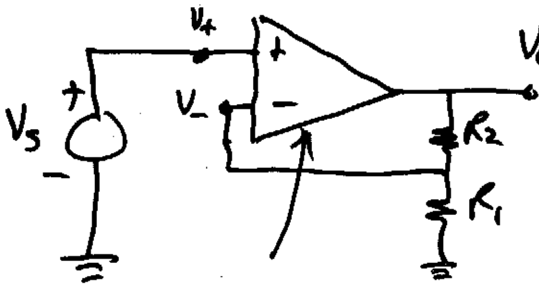


2.) Op amp has a finite GB ($\neq \infty$) (ω_T)

$$A(s) = \frac{A_o \omega_B}{s + \omega_B} = \frac{\omega_T}{s + \omega_B}$$

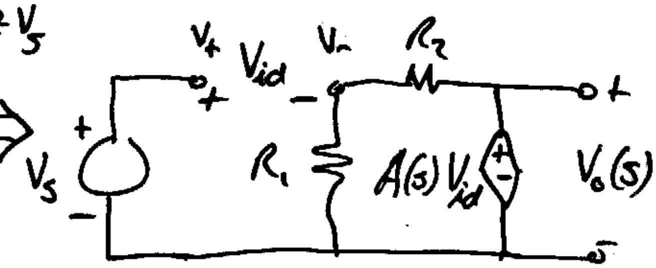


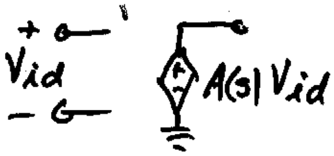
2.) Frequency response of the noninverting amplifier



Ideal: $V_o = \frac{R_1+R_2}{R_1} V_s$

$\Rightarrow$





$$V_o = A(s)V_{id} = A(s)\left[V_+ - V_-\right] = A(s)V_s - A(s)\underbrace{\frac{R_1}{R_1+R_2}}_{B} V_o$$

$$V_o = A(s)V_s - A(s)BV_o \quad \text{where } B = \frac{R_1}{R_1+R_2}$$

$$V_o\left[1 + A(s)B\right] = A(s)V_s \rightarrow \frac{V_o}{V_s} = A_v(s) = \frac{A(s)}{1+BA(s)}$$

Note: $\lim_{A(s)\to\infty} \frac{V_o}{V_s} = \frac{1}{B} = \frac{R_1+R_2}{R_1}$

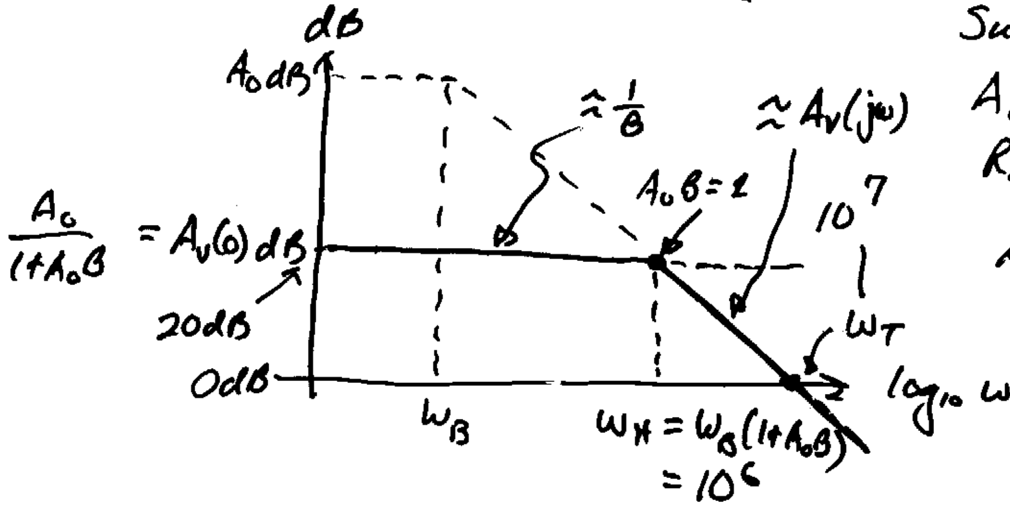
$$A_v(s) = \frac{1}{\frac{1}{A(s)} + B} = \frac{1}{\frac{s+\omega_B}{A_o\omega_B} + B} = \frac{A_o\omega_B}{s+\omega_B + BA_o\omega_B}$$

$$= \frac{A_o\omega_B}{s+\omega_B(1+A_oB)} = \frac{A_o\omega_B}{\omega_B(1+A_oB)}\left(\frac{1}{\frac{s}{\omega_B(1+A_oB)}+1}\right)$$

$$= \frac{A_v(0)}{\frac{s}{\omega_H}+1} \quad \text{where} \quad A_v(0) = \frac{A_o}{1+A_oB}$$

$$\omega_H = \omega_B(1+A_oB) \approx \overbrace{\omega_B A_o B}^{\omega_T}$$

Noninverting Conf. - Cont'd



Suppose:

$A_o = 10{,}000$ & $\omega_B = 10^3$

$R_2 = 9R_1 \Rightarrow \beta = \frac{1}{10}$

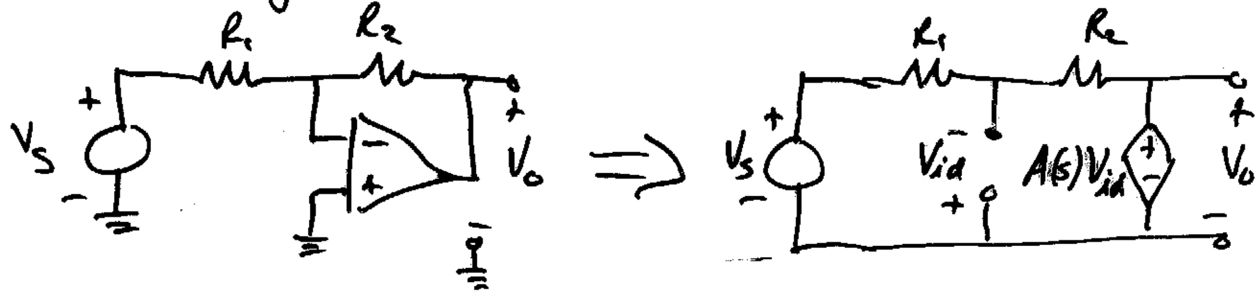
$A_v(0) = \frac{10^4}{1+10^3} \approx 10$

$\omega_H = 10^3(1+10^3)$

$\omega_H \approx 10^6$

$\omega_T = A_o\,\omega_B$

3.) Inverting Amplifier -



Homework Assignment No. 2 – Solutions

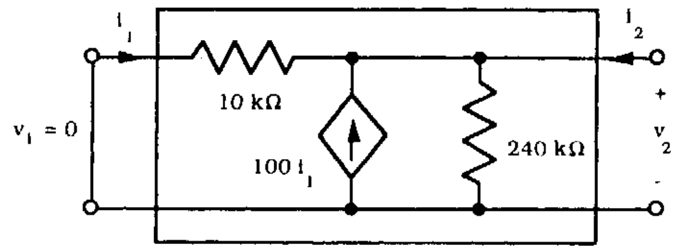
11.16

$$g_{11} = \left.\frac{i_1}{v_1}\right|_{i_2=0} : v_1 = 10^4 i_1 + 101\, i_1(240k\Omega) \rightarrow g_{11} = 4.124 \times 10^{-8} S = 4.12 \times 10^{-8} S$$

$$g_{12} = \left.\frac{i_1}{i_2}\right|_{v_1=0} : i_1 = -\frac{240k\Omega}{240k\Omega + 10k\Omega}(i_2 + 100 i_1) \rightarrow g_{12} = -9.90 \times 10^{-3}$$

$$g_{21} = \left.\frac{v_2}{v_1}\right|_{i_2=0} : v_2 = 101 i_1(240k\Omega) \mid i_1 = g_{11} v_1 \rightarrow g_{21} = 1.00$$

$$g_{22} = \left.\frac{v_2}{i_2}\right|_{v_1=0} : i_2 = \frac{v_2}{240k\Omega} + \frac{v_2}{10k\Omega} + 100\frac{v_2}{10k\Omega} \rightarrow g_{22} = 99.0\ \Omega$$



11.34

$$V_O = V_S \frac{R_{IN}}{R_{IN} + R_S} A \frac{R_{IN}}{R_{IN} + R_{OUT}} A \frac{R_L}{R_L + R_{OUT}}$$

$$A_V = \frac{5000}{5000 + 1000}(-1000)\frac{5000}{5000 + 250}(-1000)\frac{100}{100 + 250} = +2.27 \times 10^5$$

$$A_I = \frac{I_O}{I_S} = \frac{2.27 \times 10^5 V_S}{100} \frac{1}{\frac{V_S}{6000}} = +1.36 \times 10^7$$

$$A_P = \frac{2.27 \times 10^5 V_S (+1.36 \times 10^7 I_S)}{V_S I_S} = +3.09 \times 10^{12}$$

11.37

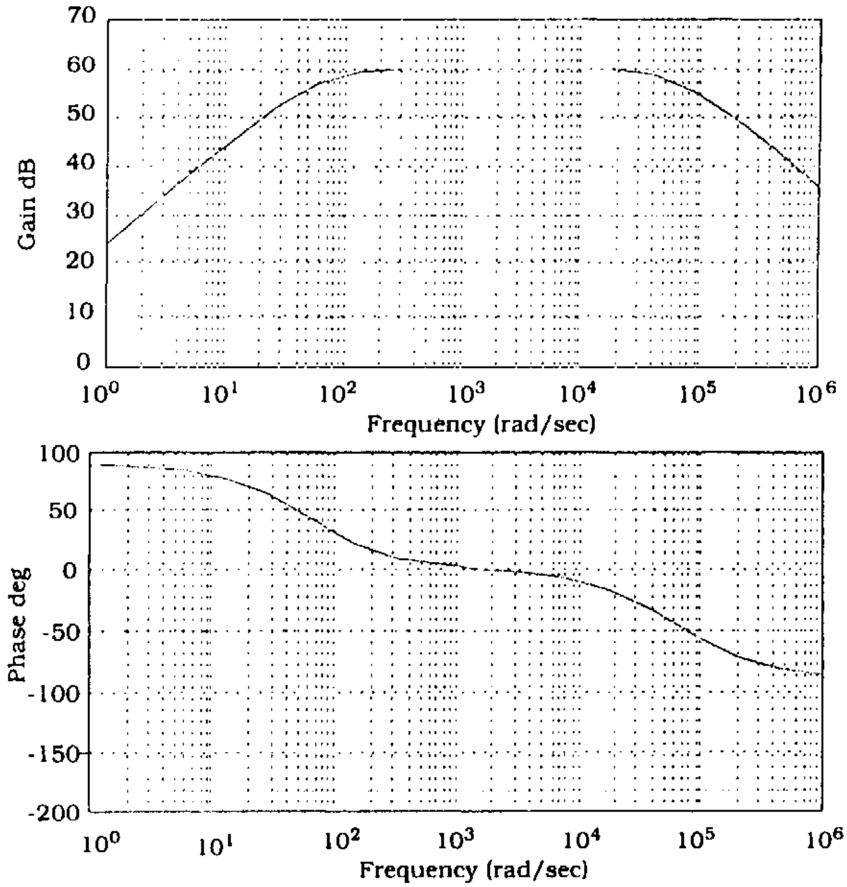
$$A_V = \frac{2\pi \times 10^7 s}{(s + 20\pi)(s + 2\pi \times 10^4)} = \frac{1000s}{(s + 20\pi)\left(1 + \frac{s}{2\pi \times 10^4}\right)} \quad \mid \quad A_{mid} = +1000 = 60\ dB$$

$$f_L = \frac{20\pi}{2\pi} = 10\ Hz \mid f_H = \frac{2\pi \times 10^4}{2\pi} = 10\ kHz \mid BW = 10kHz - 10Hz = 9.99\ kHz$$

Bandpass Amplifier

11.43

Using MATLAB: n=[2e7*pi 0]; d=[1 (20*pi+2e4*pi) 40e4*pi^2]; bode(n,d)



11.55

(a) $A_{mid} = +10^{\frac{20}{20}} = +10 \ | \ A_V = \dfrac{10}{1 + \dfrac{s}{2\pi \times (5 \times 10^6)}} = \dfrac{10}{1 + \dfrac{s}{10^7 \pi}} = \dfrac{10^8 \pi}{s + 10^7 \pi}$

(b) $A_{mid} = -10^{\frac{20}{20}} = -10 \ | \ A_V = -\dfrac{10^8 \pi}{s + 10^7 \pi}$

Problem 6

(a.) Find $V_{out}(s)/V_{in}(s)$ and identify the numerical value of the midband gain and all poles and zeros if g_m is 1mA/V.

$$\frac{V_{out}}{V_{in}} = \left(\frac{V_{out}}{V_1}\right)\left(\frac{V_1}{V_{in}}\right) = \left(\frac{g_m R_2 R_3}{R_2+R_3+\frac{1}{sC_1}}\right)\left(\frac{V_1}{V_{in}}\right)$$

$$V_1 = V_{in} - V_{R2} \rightarrow V_1 = V_{in} - \frac{g_m V_1 R_2\left(R_3 + \frac{1}{sC_1}\right)}{R_2+R_3+\frac{1}{sC_1}} \rightarrow \frac{V_1}{V_{in}} = \frac{1}{1 + \frac{g_m R_2\left(R_3+\frac{1}{sC_1}\right)}{R_2+R_3+\frac{1}{sC_1}}}$$

$$\therefore \frac{V_{out}}{V_{in}} = \left(\frac{g_m R_2 R_3}{R_2+R_3+\frac{1}{sC_1}}\right)\left(\frac{R_2+R_3+\frac{1}{sC_1}}{R_2+R_3+\frac{1}{sC_1} + g_m R_2\left(R_3 + \frac{1}{sC_1}\right)}\right)$$

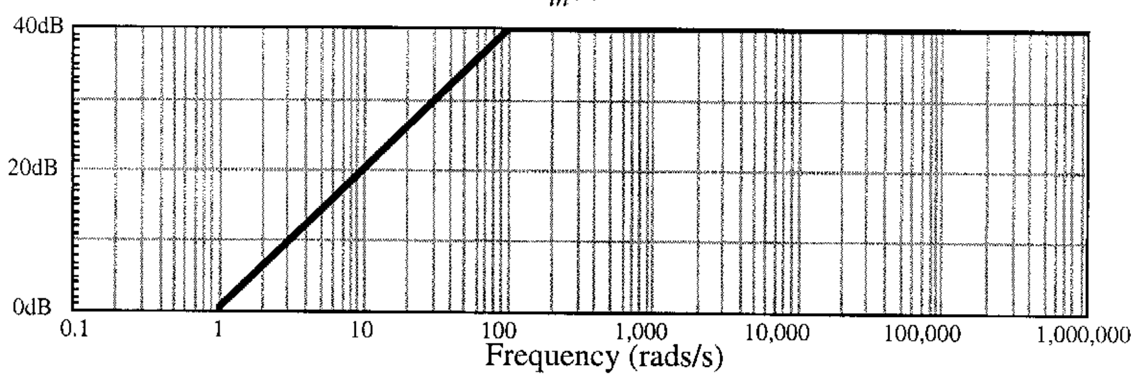
$$= \frac{(g_m R_2 R_3)\, s}{s(R_2+R_3+g_m R_2 R_3) + \frac{1+g_m R_2}{C_1}} = \left(\frac{\frac{g_m R_2 R_3}{R_2+R_3}}{1 + \frac{g_m R_2 R_3}{R_2+R_3}}\right)\left(\frac{s}{s + \frac{1+g_m R_2}{C_1(R_2+R_3+g_m R_2 R_3)}}\right)$$

$$\therefore \boxed{\text{MBG} = \frac{\frac{g_m R_2 R_3}{R_2+R_3}}{1 + \frac{g_m R_2 R_3}{R_2+R_3}} = \frac{5}{6}}$$

Zero at s = 0

Pole at $s = \frac{-(1+g_m R_2)}{C_1(R_2+R_3+g_m R_2 R_3)} = -91.67$ rads/sec.

(b.) The asymptotic magnitude plot for $\frac{V_{out}(s)}{V_{in}(s)} = \frac{100\, s}{s+100}$ is shown below.

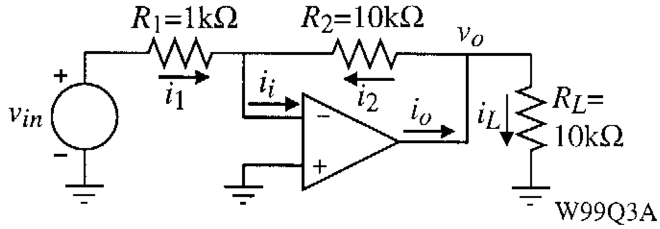


Homework Assignment No. 3

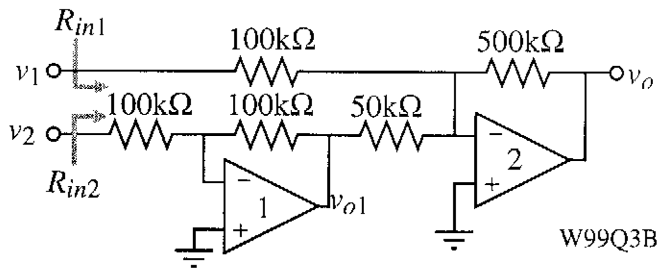
Due on Monday, September 9, 2002

1.) The op amps in this problem are ideal.

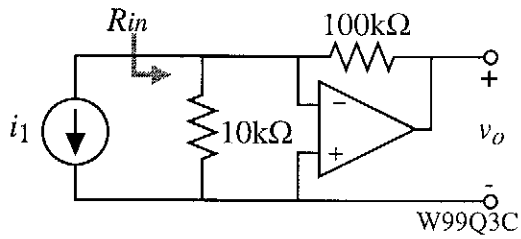
a.) If v_{in} = +1V, find the value the currents i_1, i_i, i_2, i_o, and i_L including the sign.



b.) Express v_o as a function of v_1 and v_2 and find R_{in1} and R_{in2}.



c.) Find R_{in} and v_o if i_1 = 0.1mA.



2.) Problem 12.24 of the text [Ans. $v_{o2} = -\frac{R_2}{R_1}v_s$. and $v_{o1} = -\left(\frac{R_2}{R_1}+\frac{R_3}{R_1}\right)v_s$]

3.) Problem 12.29 of the text.

4.) Problem 12.74 of the text.