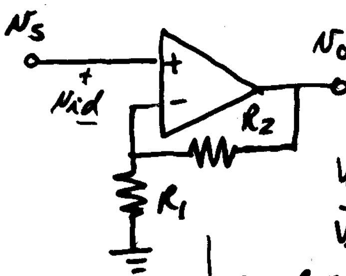
Frequency Response of the Noninverting Amplifier

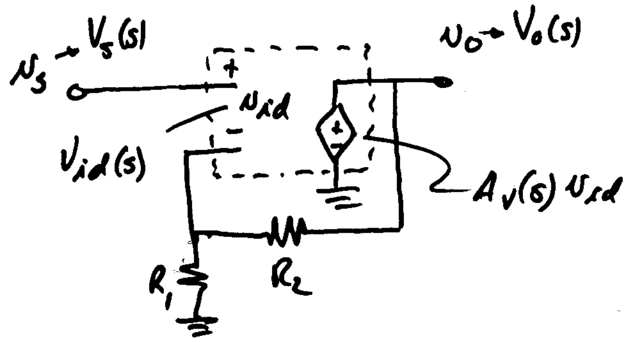


If the differential voltage gain of the op amp is

$$\frac{V_o(s)}{V_{id}(s)} = A_v(s) = \frac{GB}{s+\omega_B}, \quad GB = A_o\,\omega_B$$

what is $\frac{V_o(j\omega)}{V_s(j\omega)}$?

↓ Model



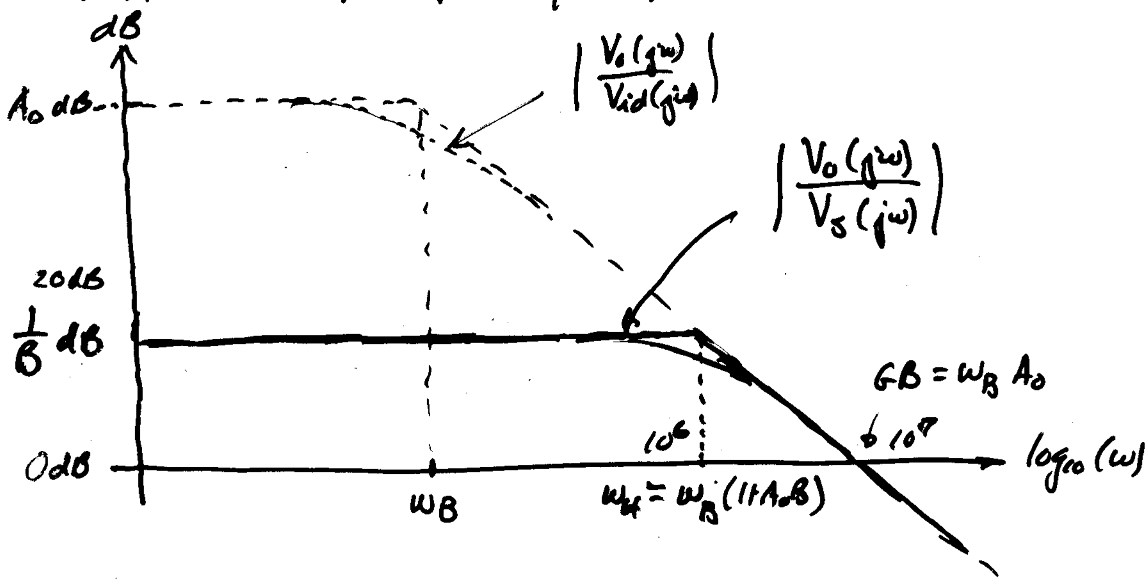
$$V_o(s) = A_v(s)\,V_{id}(s)$$

$$V_{id}(s) = V_s - \frac{R_1}{R_1+R_2} V_o(s)$$

$$V_o(s) = A_v(s)\left[V_s(s) - \frac{R_1}{R_1+R_2} V_o(s)\right]$$

$$\frac{V_o(s)}{V_s(s)} = \frac{A_v(s)}{1 + A_v(s)\frac{R_1}{R_1+R_2}} = \frac{A}{1+AB} \rightarrow \quad A = A_v(s), \quad B = \frac{R_1}{R_1+R_2}$$

What is the op amp frequency response?



$$\frac{V_o(s)}{V_s(s)} = \frac{A_v(s)}{1+\frac{R_1}{R_1+R_2}A_v(s)} = \frac{1}{\frac{1}{A_v(s)}+\frac{R_1}{R_1+R_2}} = \frac{1}{\frac{s+\omega_B}{GB}+\frac{R_1}{R_1+R_2}} = \frac{GB}{s+\omega_B+\frac{R_1}{R_1+R_2}GB}$$

Using $\beta \equiv \frac{R_1}{R_1+R_2}$ → $\frac{V_o(s)}{V_s(s)} = \frac{A_o\omega_B}{s+\omega_B+\beta\omega_B A_o} = \frac{A_o\omega_B}{s+\omega_B(1+A_o\beta)} \times \frac{1+A_o\beta}{1+A_o\beta}$

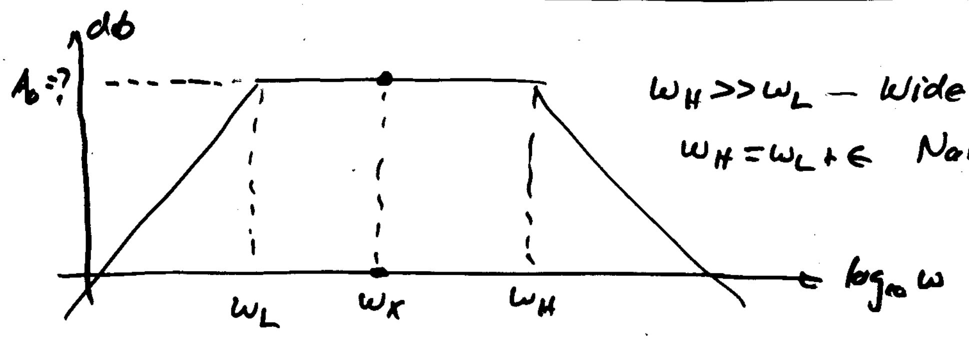
$$\frac{V_o(s)}{V_s(s)} = \left(\frac{A_o}{1+A_o\beta}\right)\left(\frac{\omega_B(1+A_o\beta)}{s+\omega_B(1+A_o\beta)}\right) = \frac{A_o}{1+A_o\beta}\,\frac{1}{\frac{s}{\omega_B(1+A_o\beta)}+1}$$

$$\frac{V_o(j\omega)}{V_s(j\omega)} = \left(\frac{A_o}{1+A_o\beta}\right)\frac{1}{1+j\frac{\omega}{\omega_H}}, \quad \omega_H = \omega_B(1+A_o\beta)$$

Example: $A_o = 10{,}000$, $\omega_B = 1000$ rad/s & $R_2 = 9R_1$

$$\beta = \frac{R_1}{R_1+R_2} = \frac{1}{1+\frac{R_2}{R_1}} = \frac{1}{10}, \quad \frac{10^4}{1+10^4\cdot\frac{1}{10}} = \frac{10^4}{1+10^3} \approx 10$$

$$\omega_H = 1000(1+10^3) \approx 10^6 \text{ rad s/sec}$$

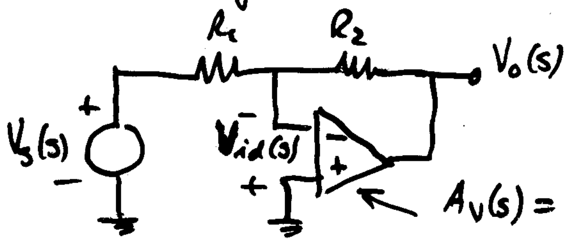


$\omega_H >> \omega_L$ — Wideband

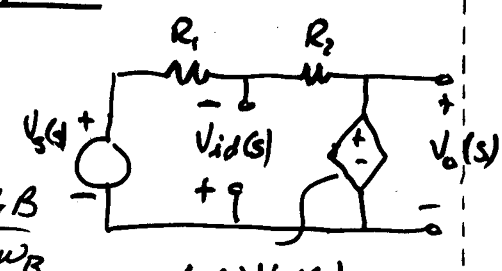
$\omega_H = \omega_L + \epsilon$ Narrowband

$$A_v(s) = 100\left(\frac{10^4}{s+10^4}\right)\left(\frac{s}{s+10}\right) = \frac{10^6 s}{(s+10)(s+10^4)}$$

Inverting Amplifier Frequency Response



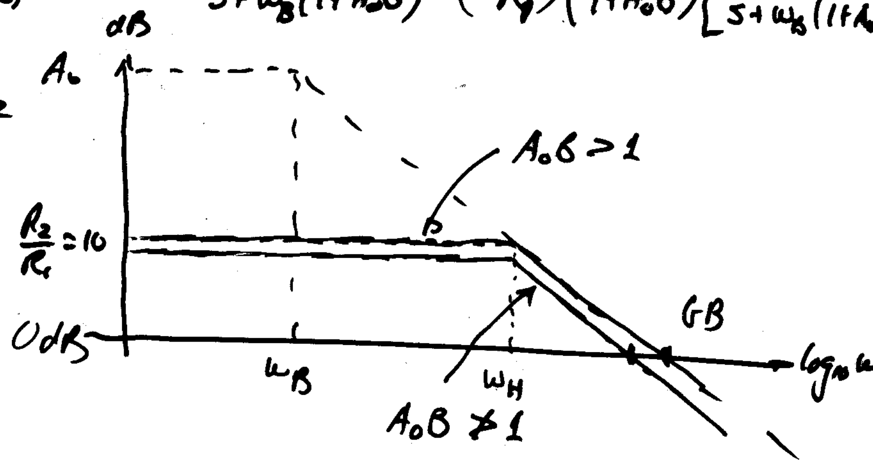
$$A_v(s) = \frac{A_o\omega_B}{s+\omega_B} = \frac{GB}{s+\omega_B}$$



Result:

$$\frac{V_o(s)}{V_s(s)} = -\frac{R_2}{R_1}\frac{\omega_B A_o B}{s+\omega_B(1+A_oB)} = \left(-\frac{R_2}{R_1}\right)\left(\frac{A_oB}{1+A_oB}\right)\left[\frac{\omega_B(1+A_oB)}{s+\omega_B(1+A_oB)}\right]$$

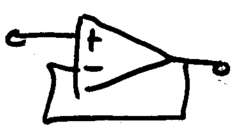
$$B \equiv \frac{R_1}{R_1+R_2}$$



Examples

a.) An op amp with $A_o = 100$ dB and $GB = 10$ MHz is used to build an voltage amplifier with a gain of +1 and then a gain of −1. Find ω_H of the amplifiers.

+1:

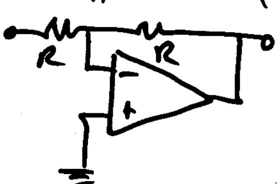


$\rightarrow B = 1 \qquad \omega_H = \omega_B(1+A_oB) = ?$

$$\omega_B = \frac{GB}{A_o} = \frac{10^7 \times 2\pi}{10^5} = 200\pi \rightarrow 100\text{ Hz}$$

$$f_H = 100(1+10^5\cdot 1) \cong 10.0\text{ MHz}$$

−1:



$\Rightarrow B = \frac{1}{2} \rightarrow f_H = 100\left(1+10^5\cdot\frac{1}{2}\right) = 5\text{ MHz}$

+100: $B = \frac{1}{100} = \frac{R_1}{R_1+R_2} \rightarrow f_H = 50\text{ kHz}$

−100: $B = \frac{1}{101} = \frac{R_1}{R_1+R_2} \qquad f_H = 49.5\text{ kHz}$

$\frac{R_1+R_2}{R_1}$

Chapter 13