Op Amp Non-Idealities

What is the relation between GB and ω_u?

Recall

$$A(s) = \left.\frac{A_o \omega_{3dB}}{s + \omega_{3dB}}\right|_{s=j\omega} = \frac{A_o \omega_{3dB}}{j\omega + \omega_{3dB}} = \frac{GB}{j\omega + \omega_{3dB}}$$

$$\left|A(j\omega_u)\right| = 1 \quad ; \quad \text{yields} \quad \omega_u^2 + \omega_{3dB}^2 = GB^2$$

thus

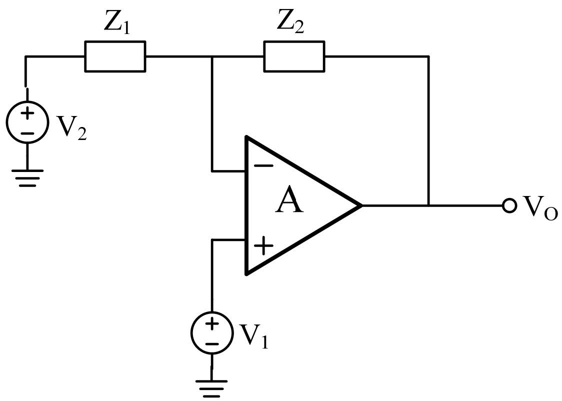
$$\omega_u = \left\{GB^2 - \omega_{3dB}^2\right\}^{1/2} = \left\{A_o^2 - 1\right\}^{1/2} \omega_{3dB}^2$$

In many cases $GB >> \omega_{3dB}^2$, therefore the unity gain frequency is approximated as:

$$\omega_u \cong GB$$

Let us look now the GB for the closed loop cases (inverter and non-inverting).

Gain Bandwidth Product and Unity Gain



$$V_o = \left. \frac{-\frac{Z_F}{Z_1}V_2 + \left(1+\frac{Z_F}{Z_1}\right)V_1}{1+\frac{1}{A}\left(1+\frac{Z_F}{Z_1}\right)} \right|_{A=GB/s} = \frac{-\frac{Z_F}{Z_1}V_2 + \left(1+\frac{Z_F}{Z_1}\right)V_1}{1+\frac{s}{GB}\left(1+\frac{Z_F}{Z_1}\right)}$$

For resistive components $Z_F=R_{F,}$ $Z_1=R_1$

The 3dB cut-off frequency is given by

$$\omega_{3dB} = \frac{GB}{1+\frac{R_2}{R_1}} = \beta GB \qquad (1)$$

This can be written for the non-inverting and inverting case as

$$\omega_{3dB} = \frac{GB}{A_{NI}} = \beta GB \qquad (2a)$$

$$\omega_{3dB} = \frac{GB}{1+A_I} \qquad (2b)$$

Where A_{NI} , A_I are the non-inverting and inverting ideal gains.

The corresponding closed loop gain-bandwidth product become

$$GB_{CL-non} = A_{NI}\omega_{3dB} = \frac{A_{NI}}{A_{NI}} GB = GB \qquad (4)$$

$$GB_{CL\text{-}INV} = A_I \omega_{3dB} = A_I \frac{GB}{1+A_I} = \frac{A_I}{1+A_I} GB = (1-\beta) GB \qquad (5)$$

Observe that for equal closed loop gains, the closed loop gain-bandwidth product of the Non-inverting configuration is larger.

Let us calculate the unity gain frequency for both conguration.

<u>Inverting</u>

$$\left| \frac{-\dfrac{R_F}{R_1}}{1+\dfrac{j\omega_u}{GB}\left(1+\dfrac{R_F}{R_1}\right)} \right| = 1 \Longrightarrow \pm \left(\frac{R_F}{R_1}\right)^2 = 1 + \left(1+\frac{R_F}{R_1}\right)^2 \frac{\omega_u^2}{GB^2}$$

Therefore

$$\omega_u = \frac{GB\sqrt{\left(R_F / R_1\right)^2 - 1}}{1+\dfrac{R_F}{R_1}} = GB\sqrt{1-2\beta}$$

Non-Inverting

$$\left| \frac{1+\frac{R_F}{R_1}}{1+\frac{j\omega_u}{GB}\left(1+\frac{R_F}{R_1}\right)} \right| = 1$$

yields

$$\omega_u = \frac{GB\sqrt{\left(1+\frac{R_F}{R_1}\right)^2 - 1}}{1+\frac{R_F}{R_1}} = GB\sqrt{1-\beta^2}$$

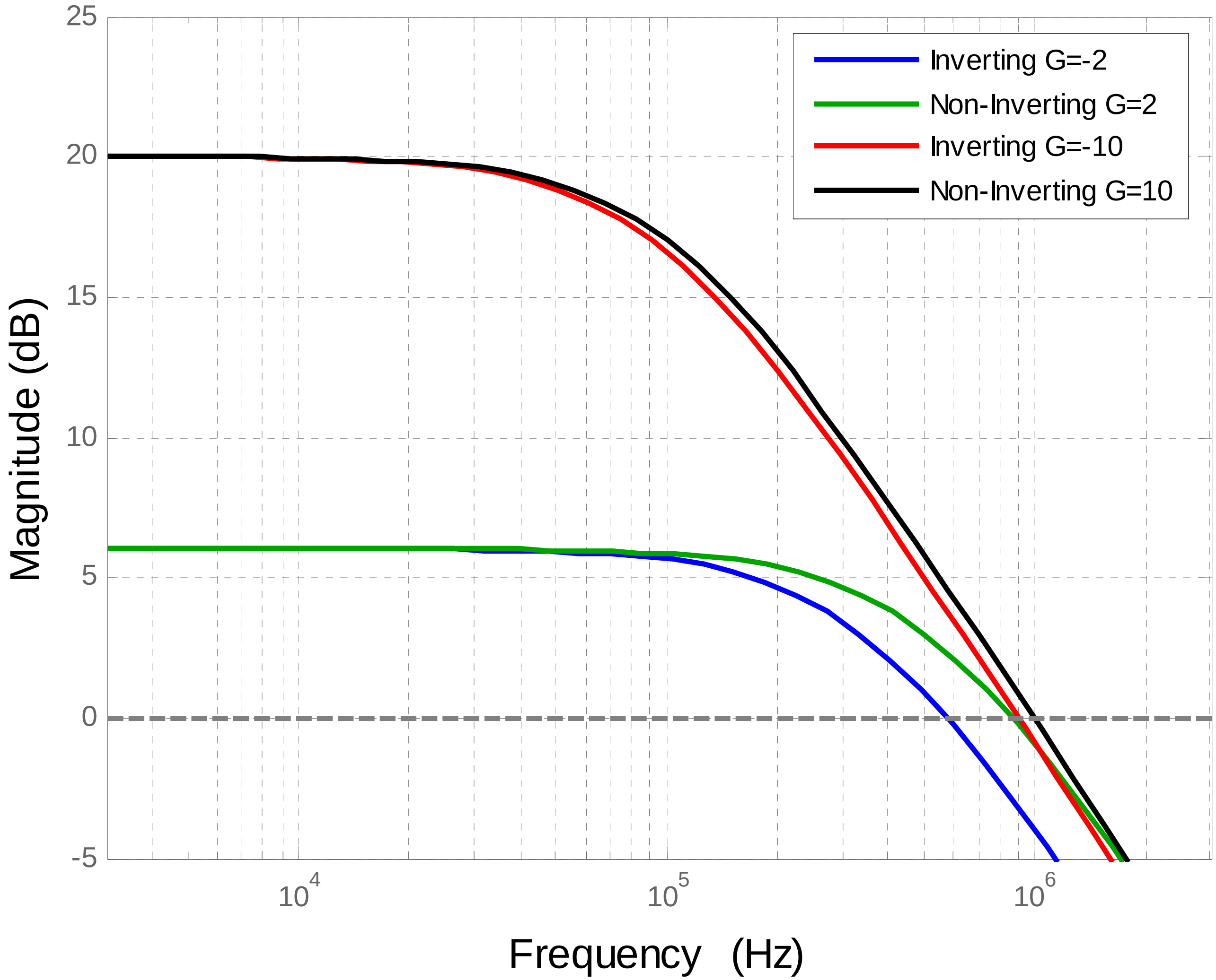
Note that for a gain of -2

$$\omega_{3dB} = \frac{GB}{3} \text{ and } \omega_u = \frac{\sqrt{3}}{3} GB = 0.577GB$$

And for a gain of +2

$$\omega_{3dB} = \frac{GB}{2} \text{ and } \omega_u = \frac{\sqrt{3}}{2} GB = 0.866GB$$

UGF versus Gain
(Inverting/Non-Inverting Amplifiers)



Comparison of the Results

Topology	|Gain|	GBW	UGF	% Error
Inverting	2	667kHz	577kHz	15.6
Non-inverting	2	1MHz	866kHz	15.5
Inverting	10	909kHz	905kHz	0.4
Non-inverting	10	1MHz	995kHz	0.5