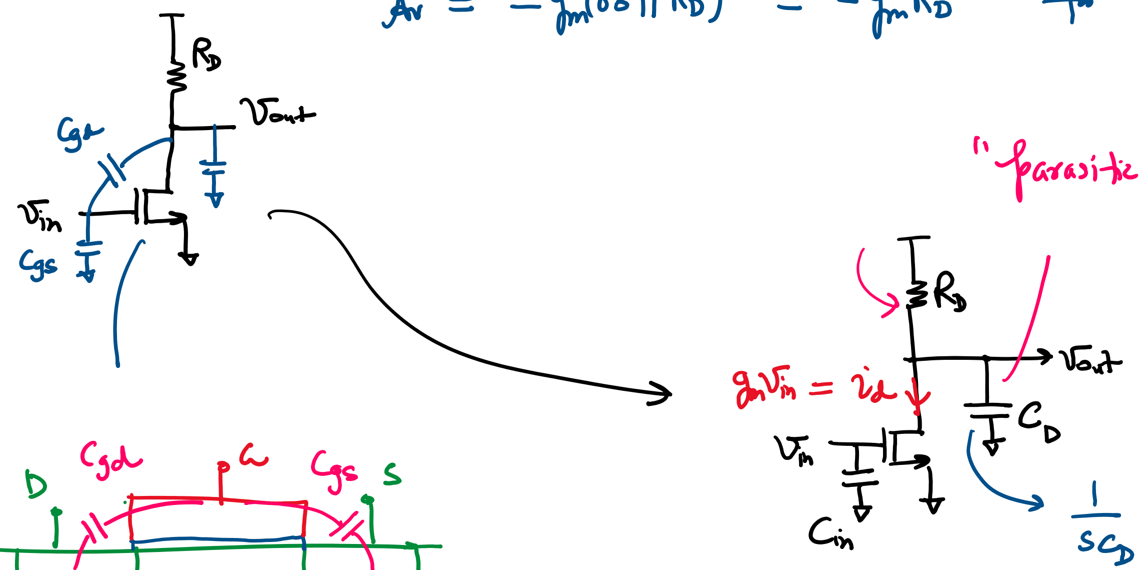
ECE 310 - Lecture 37

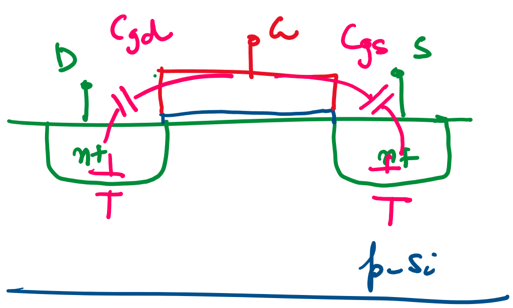
Monday, April 30, 2018 10:25 AM

Opamps:

$$A_v = -g_m(r_o \| R_D) \simeq -g_m R_D \quad \text{for } R_D \ll r_o$$

"parasitic capacitances"





$$\frac{V_{out}}{V_{in}} = ?$$

$$\Rightarrow \quad V_{out} = -i_d\left(R_D \| \frac{1}{sC_D}\right)$$

$$= -i_D \cdot \frac{R_D \cdot \frac{1}{sC_D}}{R_D + \frac{1}{sC_D}}$$

$$= -i_D \cdot \frac{R_D}{1 + sR_DC_D}$$

$$\boxed{\frac{V_{out}}{V_{in}}(s) = -\frac{g_m R_D}{1 + sR_DC_D}}$$

low-frequency gain

no zero
1 pole

Single-pole Transfer function

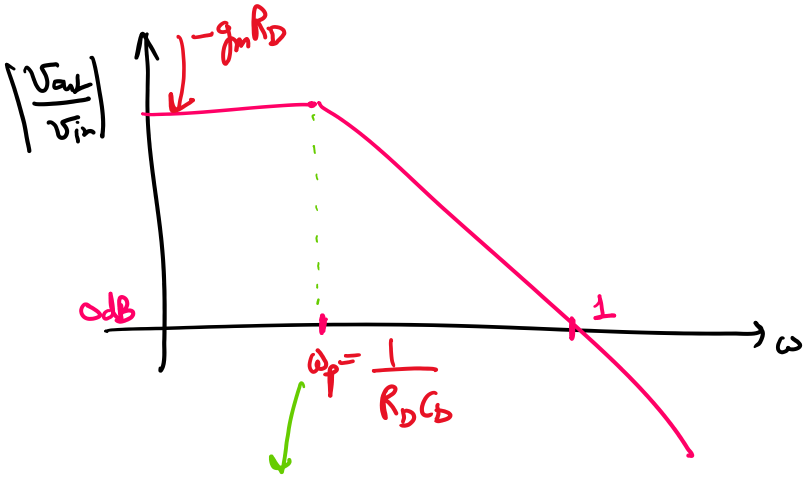
$$P(s) = \frac{N(s)}{D(s)}$$

roots are zeros

roots are

Single-pole Transfer function

$D(s)$ ← roots are poles



3 dB Bandwidth of the CS amplifier.

$1 + s R_D C_D = 0$

$\Rightarrow s = j\omega_p = -\frac{1}{R_D C_D}$

$\omega_p = \frac{1}{R_D C_D}$

Any Amplifier will have finite bandwidth

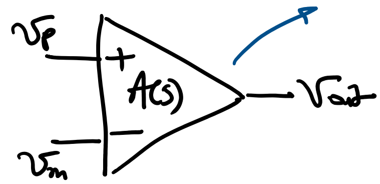
↳ finite speed.

Frequency Response of Amplifiers → ECE 410

Opamp Speed Limitations:

$V_{out} = A(V_p - V_m)$

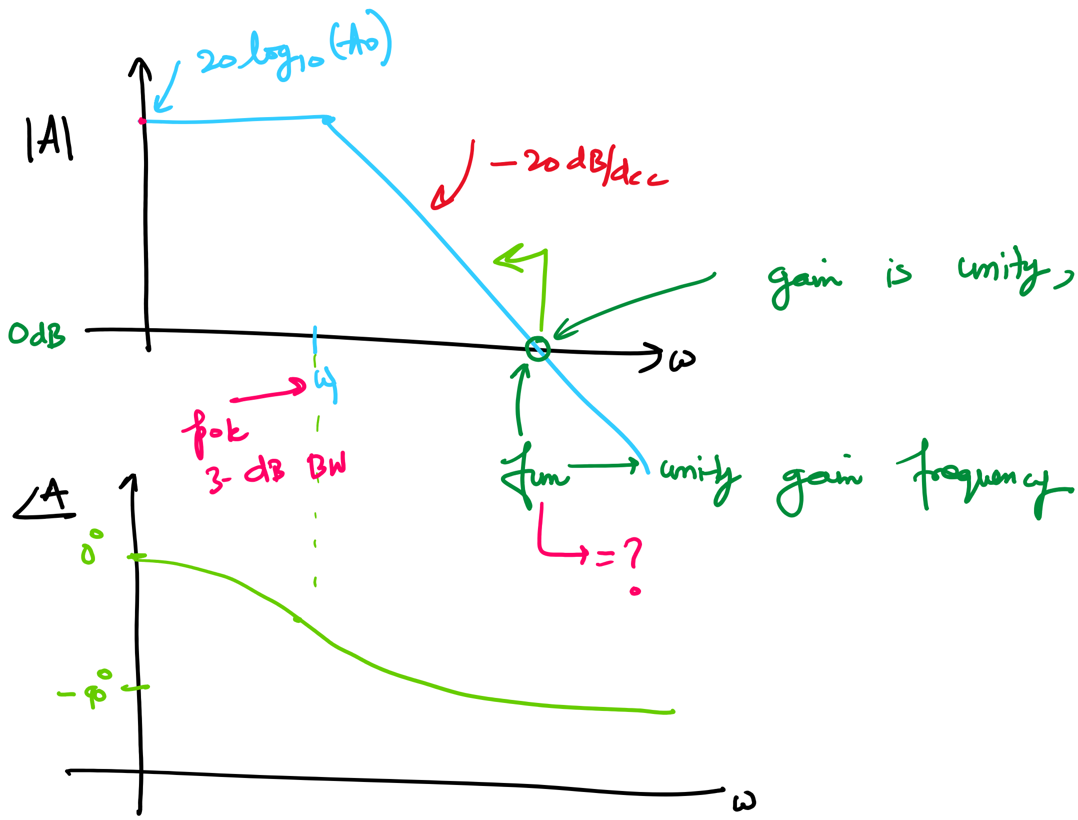
$A \rightarrow A(s)$



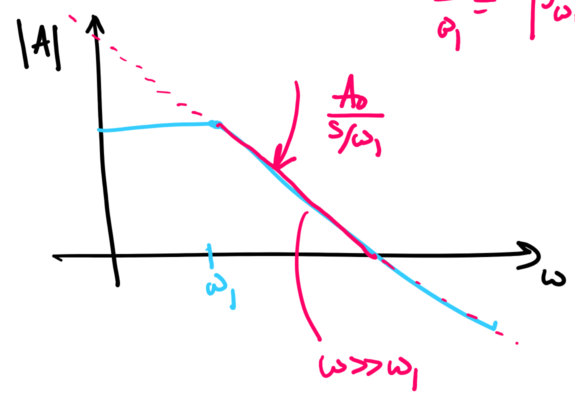
Single-pole model

$$A(s) = \frac{\overset{\text{DC gain}}{A_0}}{1 + s/\underset{\text{pole}}{\omega_1}}$$

* One pole at $\omega = \omega_1$ dominates the opamp frequency response



$$\frac{s}{\omega_1} = \left|\frac{j\omega}{\omega_1}\right|$$



$$A(s) = \frac{A_0}{1 + \frac{s}{\omega_1}}$$

At high frequencies $\left|\frac{s}{\omega_1}\right| \gg 1$

$$\simeq \frac{A_0}{s/\omega_1} = \frac{A_0 \omega_1}{s}$$

at $\omega = \omega_{un} \Rightarrow |A(s)| = 1$

$$\Rightarrow \left|\frac{A_0 \omega_1}{j\omega_{un}}\right| = 1$$

$$\Rightarrow \frac{\omega_{un}}{2\pi} = \frac{A_0 \omega_1}{2\pi} \qquad \boxed{\omega_{un} = A_0 \omega_1}$$

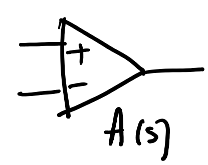
$$\boxed{f_{un} = A_0 f_1} \rightarrow ?$$

Unity-gain frequency

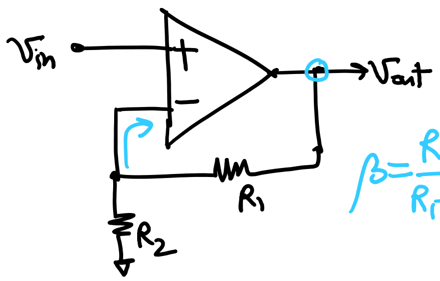
DC Gain

3-dB frequency (BW)

$$f_{un} = \underbrace{\text{Gain} \times \text{BW}}_{\text{Gain BW product}}$$



Now consider the non-inverting Amplifier



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

$$A(s) = \frac{A_0}{1+s/\omega_1}$$

Closed-loop Transfer Function

$$\frac{V_{out}}{V_{in}}(s) = \frac{A(s)}{1+\beta A(s)}$$

$$= \frac{\dfrac{A_0}{1+s/\omega_1}}{1+\dfrac{\beta A_0}{1+s/\omega_1}}$$

$$= \frac{A_0}{1+\dfrac{s}{\omega_1}+\beta A_0}$$

$$= \frac{A_0}{(1+\beta A_0)+s/\omega_1}$$

$$= \frac{\dfrac{A_0}{1+\beta A_0}}{1+\dfrac{s}{\omega_1(1+\beta A_0)}}$$ single-pole form

$$= \overbrace{\underbrace{\frac{A_0}{1+\beta A_0}}_{\text{closed loop gain without BW-limitations}}}^{A_{cL}} \cdot \frac{1}{1+\dfrac{s}{\omega_1(1+\beta A_0)}}$$

single-pole transfer function

$\underbrace{\quad 1+\beta A_0 \quad}_{\text{closed loop gain without BW-limitations}} \qquad 1+ \frac{\quad}{\underbrace{\omega_1(1+\beta A_0)}}$ ← single-pole transfer function

$$A_{CL} = \frac{A_0}{1+\beta A_0} \simeq \overbrace{\frac{1}{\beta}}^{\text{Ideal gain}} \cdot \underbrace{\left(1-\frac{1}{A_0\beta}\right)}_{\text{precision error due to finite opamp gain}}$$

$$\frac{v_{out}}{v_{in}} = A_{CL} \cdot \frac{1}{1+s/\omega_{p,CL}}$$

$A_0\beta >> 1$

$$\omega_{p,CL} = \omega_1(1+\beta A_0) \simeq \underline{\omega_1 A_0 \beta}$$

$$A_{CL} \simeq \frac{1}{\beta}$$

$$A_{CL} \times \omega_{p,CL} = \omega_1 \cdot A_0 \cdot \cancel{\beta} \cdot \frac{1}{\cancel{\beta}}$$

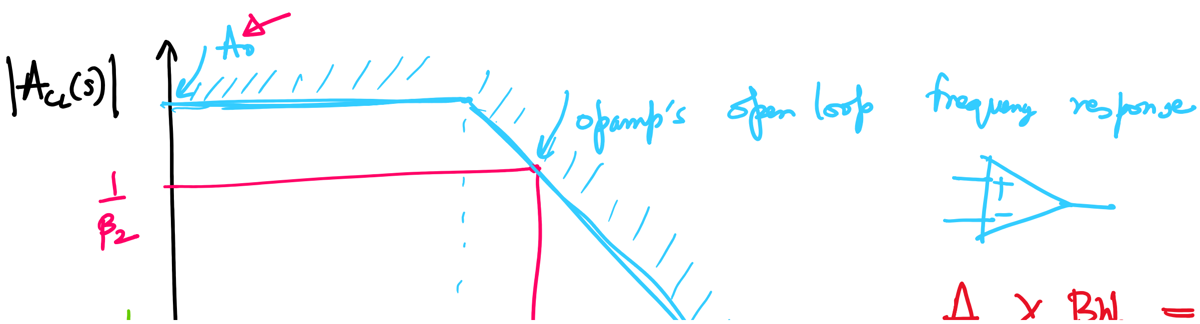
$$= \omega_1 A_0 = \omega_{un}$$

$$\boxed{A_{CL} \times \omega_{p,CL} = \omega_{un}}$$ ← Unity-gain frequency

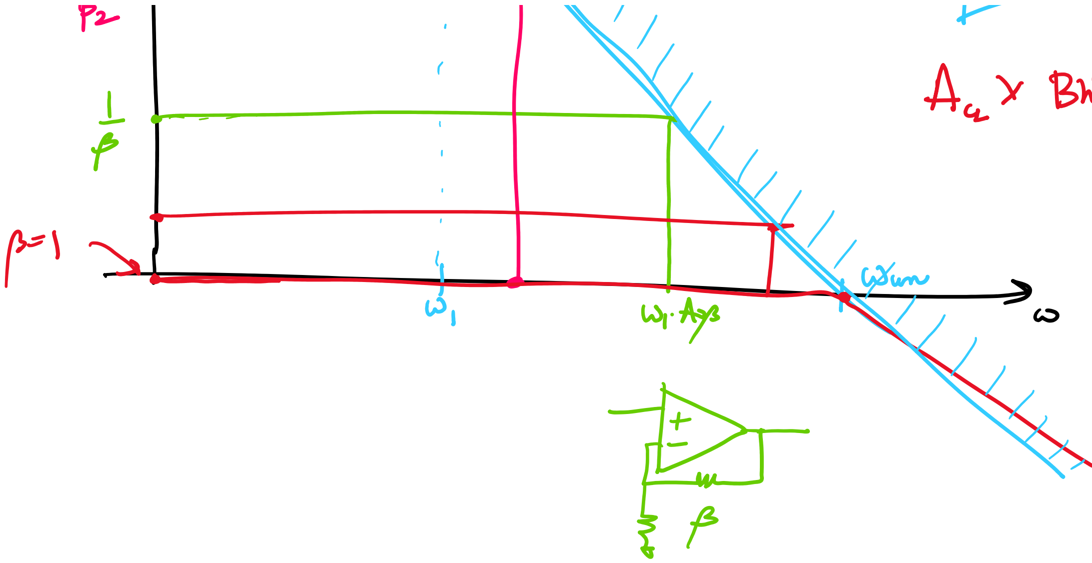
A_{CL}: Closed loop gain

$\omega_{p,CL}$: closed loop 3dB Bandwidth

This relation holds for all $0 \leq \beta \leq 1$



$A \times BW = \omega_{un}$



$A_{cl} \times BW_{cl} = \omega_{un}$

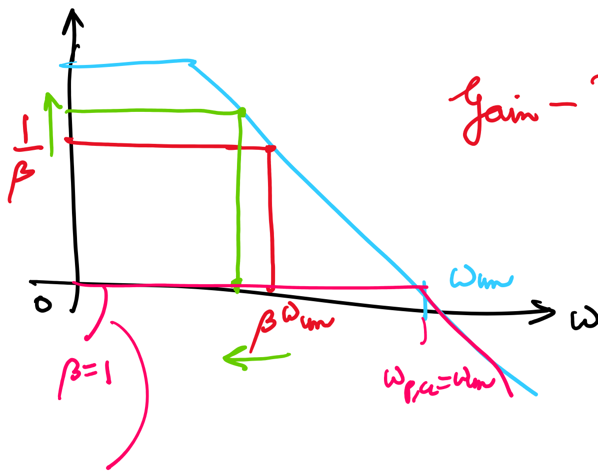
$= GBW$ product

$GBW = \cancel{10}^6 \rightarrow 10^7$

$A_{cl} = 10$

$BW_{cl} = 100\,kHz \rightarrow 1\,MHz$

If need higher gain × BW
⇒ go for higher GBW product opamp.

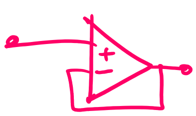


Gain – Bandwidth Tradeoff

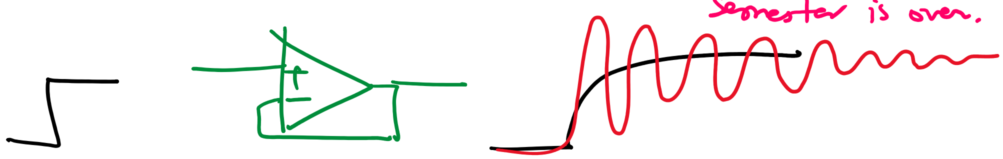
$A_{cl} \times \omega_{p,cl} = \omega_{un}$

$\downarrow \qquad \downarrow$

$\frac{1}{\beta} \qquad \beta\omega_{un}$



* Stability of opamp circuit is an important concern. (chapter 12)
Read After the semester is over.



* ECE 410/415