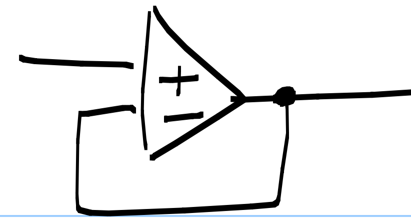
Op amp data sheet:

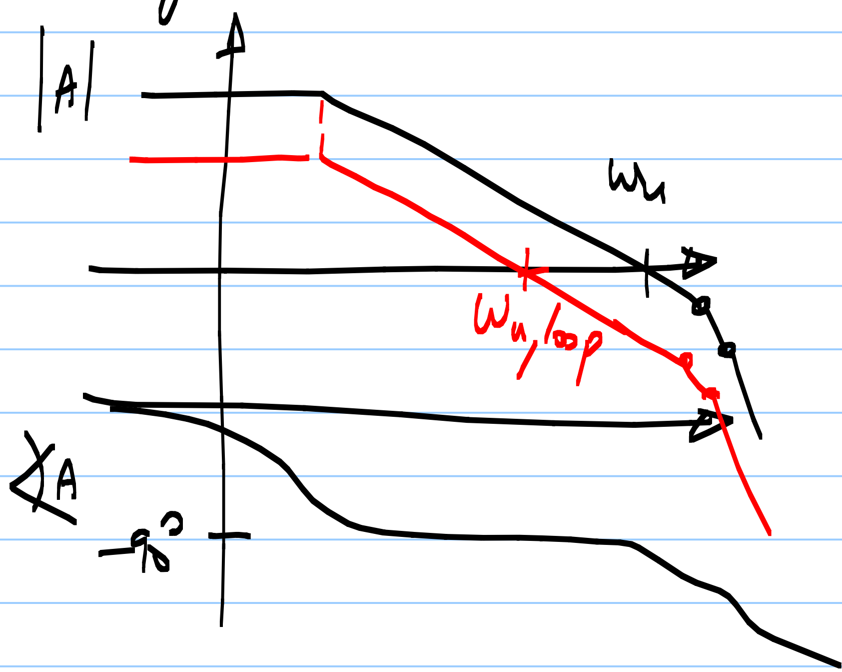
- dc gain; dc v_o vs. v_e; saturation voltages (V_+, V_-)
- ac magnitude response $\{ |A(j\omega)|, \measuredangle A(j\omega) \}$
- Slew rate
- offset & noise voltages
- Maximum supply voltage; Maximum load current

$\boxed{\text{Dominant pole (compensated) opamps}}$

Unity gain compensated:



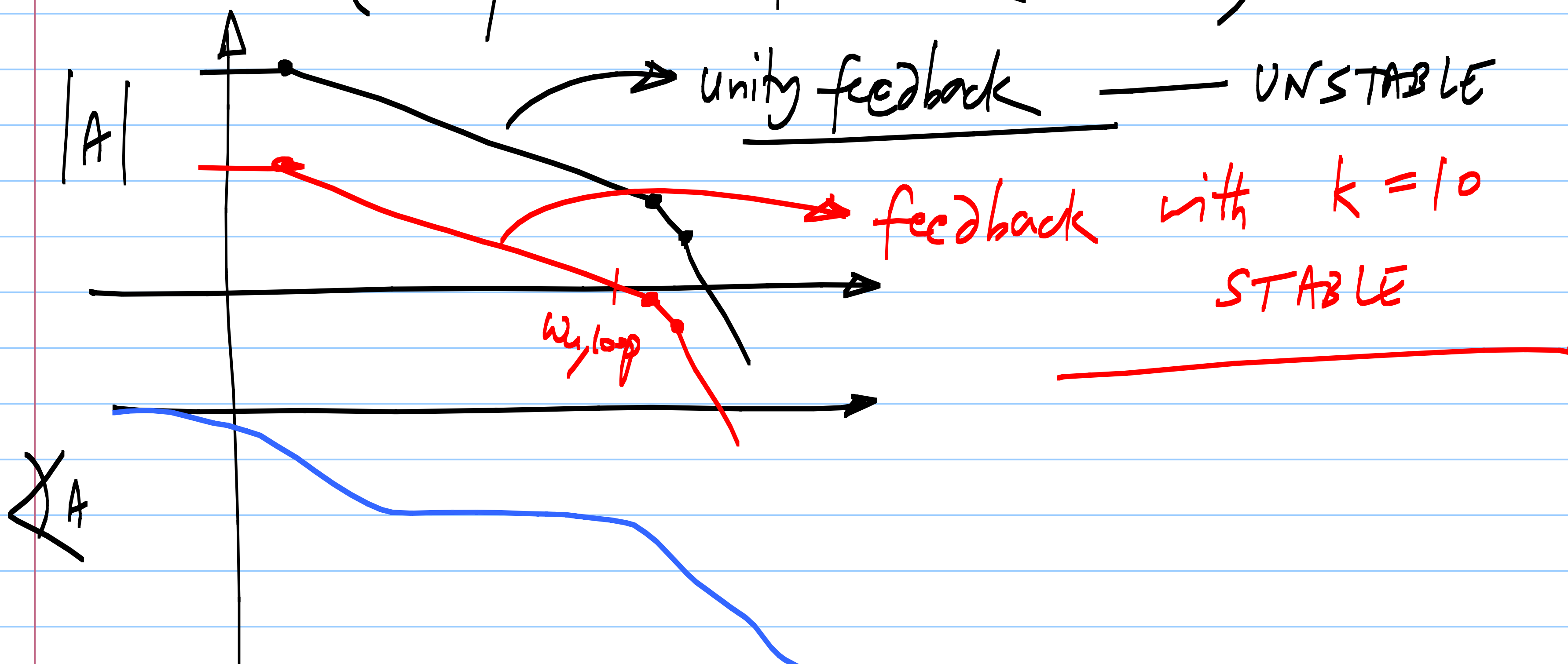
* If the opamp is connected in unity negative feedback, it will be stable.

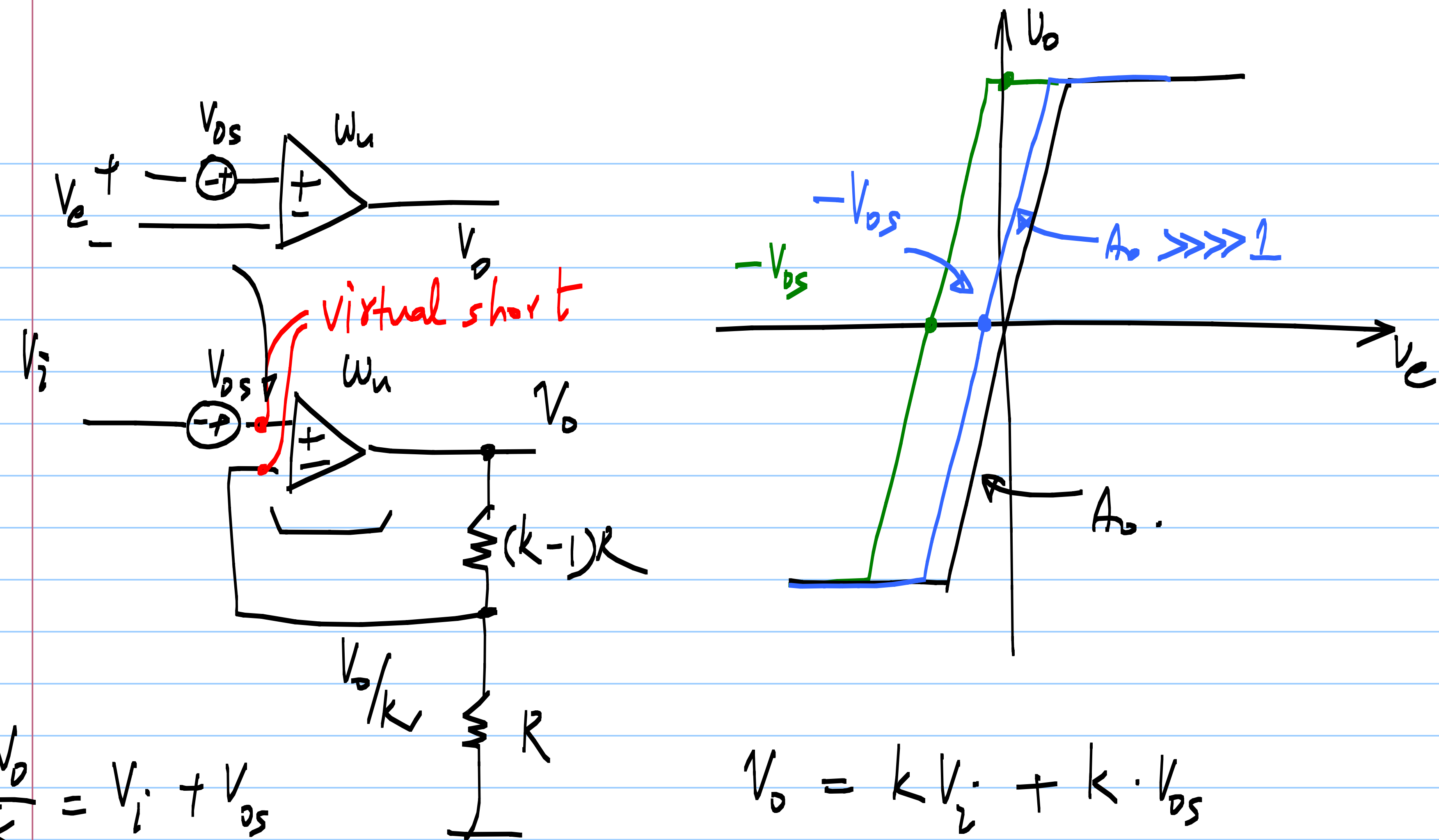


* For any gain $k > 1$ stability is guaranteed.

Opamps not unity gain compensated: E.g. OPA657

(Compensated for $k > 10$)

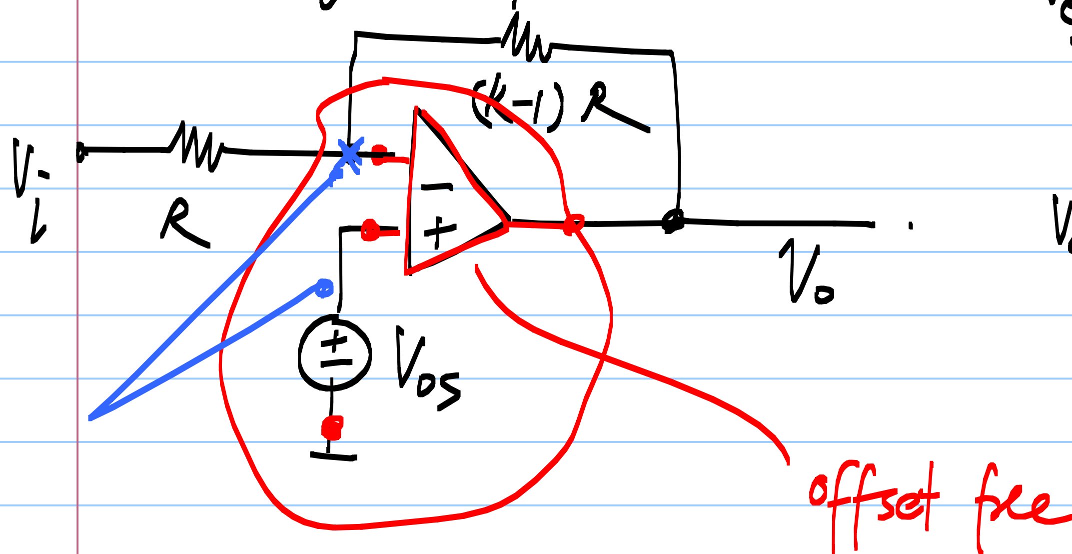


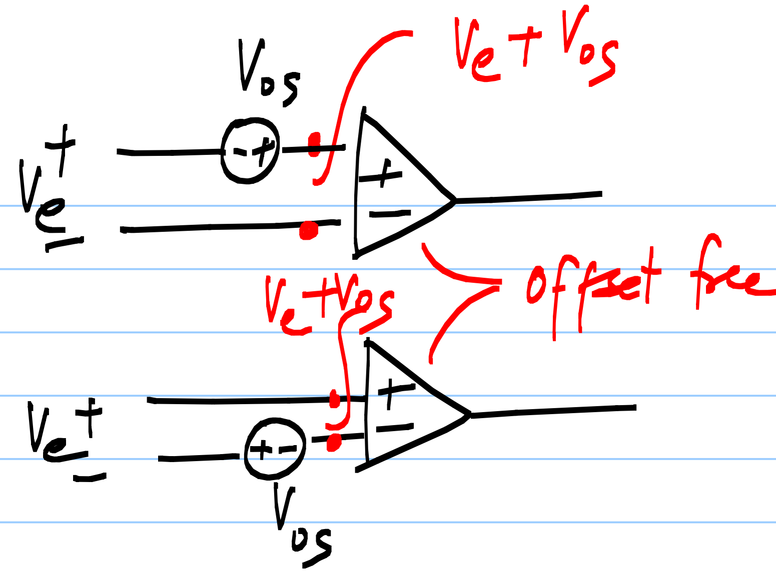


$$\frac{V_o}{k} = V_i + V_{os}$$

$$V_o = kV_i + k \cdot V_{os}$$

Inverting amplifier:

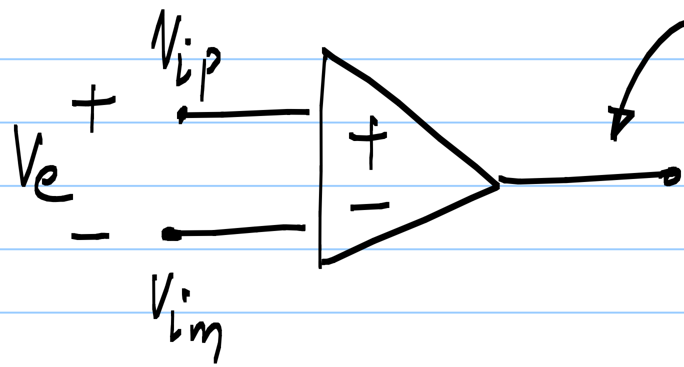




$$V_i \cdot \frac{k-1}{k} + V_o \cdot \frac{1}{k} = V_{os}$$

$$V_o = -(k-1)\,V_i + k \cdot V_{os}$$

Common mode gain — Common mode rejection ratio



$\sim (V_{ip} - V_{im})$

$$A_0 \underbrace{(V_{ip} - V_{im})}_{\text{Diff. input voltage}} + A_{cm} \underbrace{\left(\frac{V_{ip} + V_{im}}{2}\right)}_{\text{Common mode input of the opamp}}$$

A_0: Differential gain

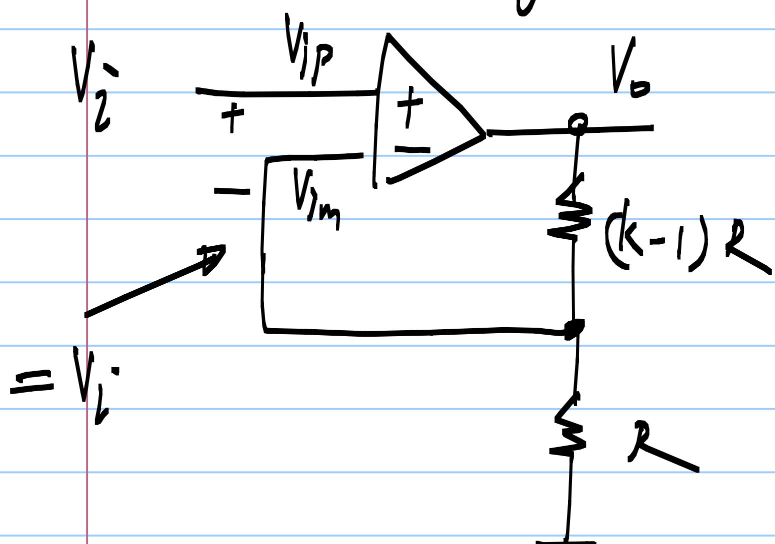
A_{cm}: Common mode gain

$V_e = V_{ip} - V_{im}$

$$20 \log_{10}\left(\frac{A_0}{A_{cm}}\right) = 20 \log_{10}\left(\frac{10^3}{0.1}\right) = \underline{\underline{80\,\text{dB}}}$$

Effect of non-zero common mode gain A_{cm}

Non inverting amp:



Differential gain is very large

$V_{ip} = V_i$, $V_{im} = V_i$; $V_o = kV_i$

$$V_o = \underbrace{kV_i}_{\text{Ideal}} + \boxed{A_{cm} V_i}$$

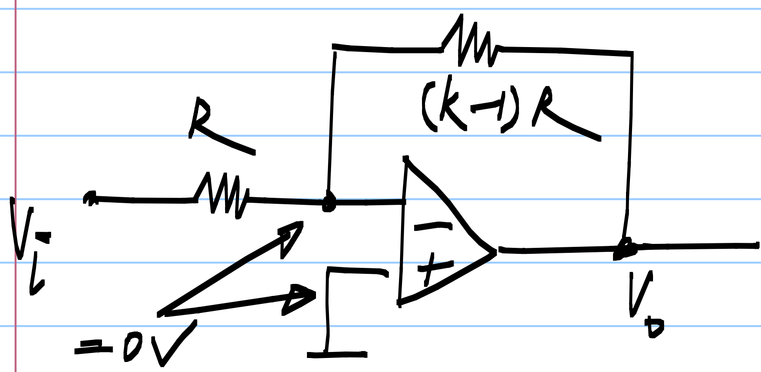
{Non linearly related to V_i}

$$V_o = A_o (V_{ip} - V_{im}) + A_{cm} \left(\frac{V_{ip} + V_{im}}{2} \right)$$

$$V_{im} = \frac{V_o}{k}; \quad V_{ip} = V_i$$

Calculate V_o

Inverting amplifier:



$A_0 \to \infty$

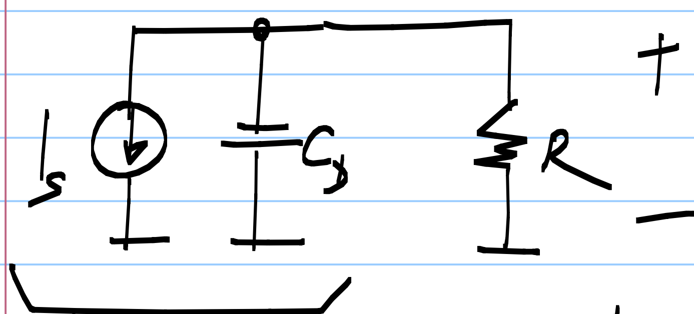
$$\frac{V_{ip}+V_{im}}{2} = 0$$

$\simeq$ zero common mode input for the opamp.

$$V_o = \underbrace{-(k-1)\,V_i}_{\text{Ideal}} + \underbrace{A_{cm} \cdot 0}_{\text{Error due to } A_{cm}}$$

Transimpedance amplifier:

Photodiode:

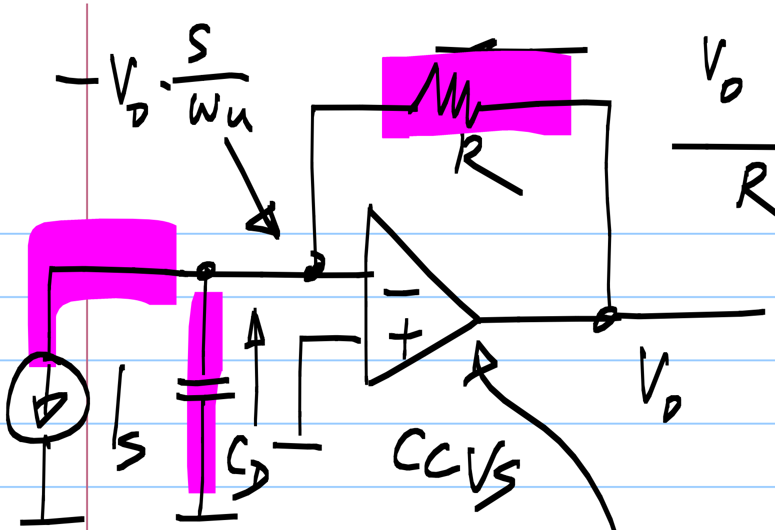


$$V_o = I_s \cdot \frac{1}{sC_D + 1/R} = I_s \cdot \frac{R}{1 + sC_D R}$$

DC transimpedance : R

Bandwidth : $\frac{1}{C_D R} > \omega_{BW}$

For a given bandwidth : R is fixed $\therefore$ $R < \frac{1}{C_D \omega_{BW}}$



$$-V_o \cdot \frac{s}{\omega_u}$$

$$\frac{V_o\left(1+\frac{s}{\omega_u}\right)}{R}$$

$$V_o \cdot \frac{s}{\omega_u} \cdot sC_D$$

$$\frac{\omega_u}{s}$$

$$I_s = \frac{V_o}{R}\left(1+\frac{s}{\omega_u}\right) + V_o \cdot \frac{s}{\omega_u} \cdot sC_D$$

$$I_s R = V_o\left(1+\frac{s}{\omega_u}+\frac{s^2 C_D R}{\omega_u}\right)$$

$$\frac{V_o}{I_s} = \frac{R}{\underbrace{1+\frac{s}{\omega_u}+\frac{s^2 C_D R}{\omega_u}}_{1+2\zeta\frac{s}{\omega_n}+s^2/\omega_n^2}}$$

$$\omega_n = \sqrt{\frac{\omega_u}{C_D R}}$$

$$\frac{2\zeta}{\omega_n} = \frac{1}{\omega_u} \qquad \zeta = \frac{1}{2}\frac{\omega_n}{\omega_u}$$

$$= \frac{1}{2}\sqrt{\frac{1}{\omega_u C_D R}}$$

Damping factor: ξ ; Quality factor: Q

$$\xi = \frac{1}{2Q} \quad ; \quad Q = \frac{1}{2\xi}$$

Underdamped system : $\xi < 1$; $Q > \frac{1}{2}$

Critically damped : $\xi = 1$; $Q = 1/2$

Overdamped system : $\xi > 1$; $Q < 1/2$

$$\frac{V_o}{I_s} = \frac{R}{1 + \frac{s}{\omega_u} + \frac{s^2 C_D R}{\omega_u}}$$

dc gain: R

$$\omega_n = \sqrt{\frac{\omega_u}{C_D R}}$$

$$\xi = \frac{1}{\sqrt{2}} \; ; \quad \frac{1}{2}\sqrt{\frac{1}{\omega_u C_D R}} = \frac{1}{\sqrt{2}}$$

$$\xi = \frac{1}{2}\sqrt{\frac{1}{\omega_u C_D R}}$$

$$\omega_u C_D R = \frac{1}{2} \; ; \quad \omega_u = \frac{1}{2 C_D R}$$

$$\omega_n = \sqrt{\frac{1}{2 C_D R} \cdot \frac{1}{C_D R}} = \frac{1}{\sqrt{2}\, C_D \cdot R}$$

$$\frac{V_o}{I_s} = \frac{R}{1 + \frac{s}{\omega_u} + \frac{s^2 C_D R}{\omega_u}}$$

dc gain: R

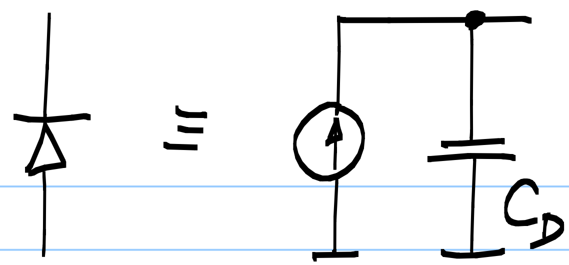
$$\omega_n = \sqrt{\frac{\omega_u}{C_D R}}$$

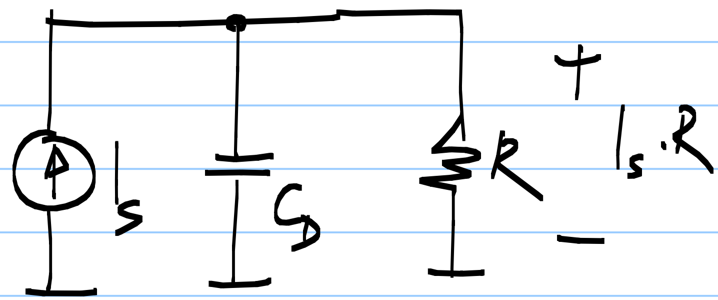
$$\xi = \frac{1}{2}\sqrt{\frac{1}{\omega_u C_D R}}$$

$$\xi = \frac{1}{\sqrt{2}} \; ; \quad \frac{1}{2}\sqrt{\frac{1}{\omega_u C_D R}} = \frac{1}{\sqrt{2}}$$

$$\omega_u C_D R = \frac{1}{2} \; ; \quad \omega_u = \frac{1}{2 C_D R}$$

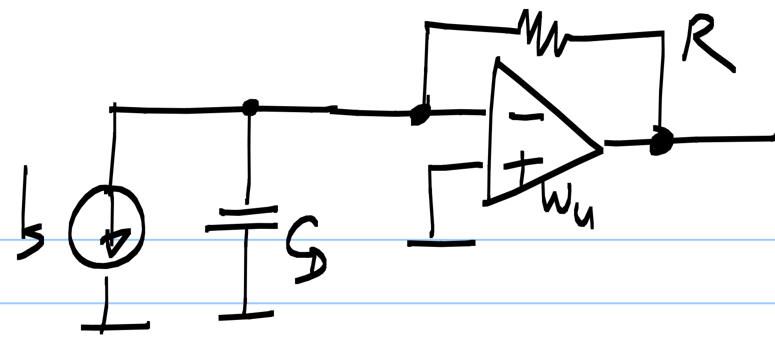
$$\omega_n = \sqrt{\frac{1}{2 C_D R} \cdot \frac{1}{C_D R}} = \frac{1}{\sqrt{2}\, C_D \cdot R}$$





DC Gain : $\cdot R$

BW : $\dfrac{1}{C_D \cdot R}$



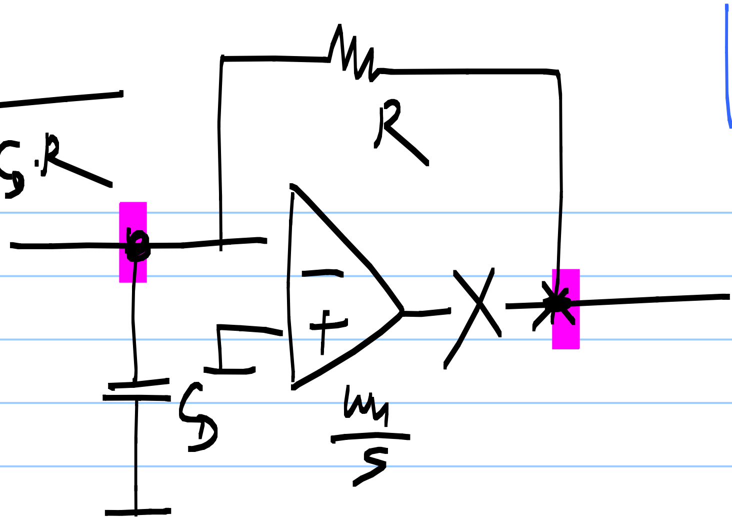
DC gain : R

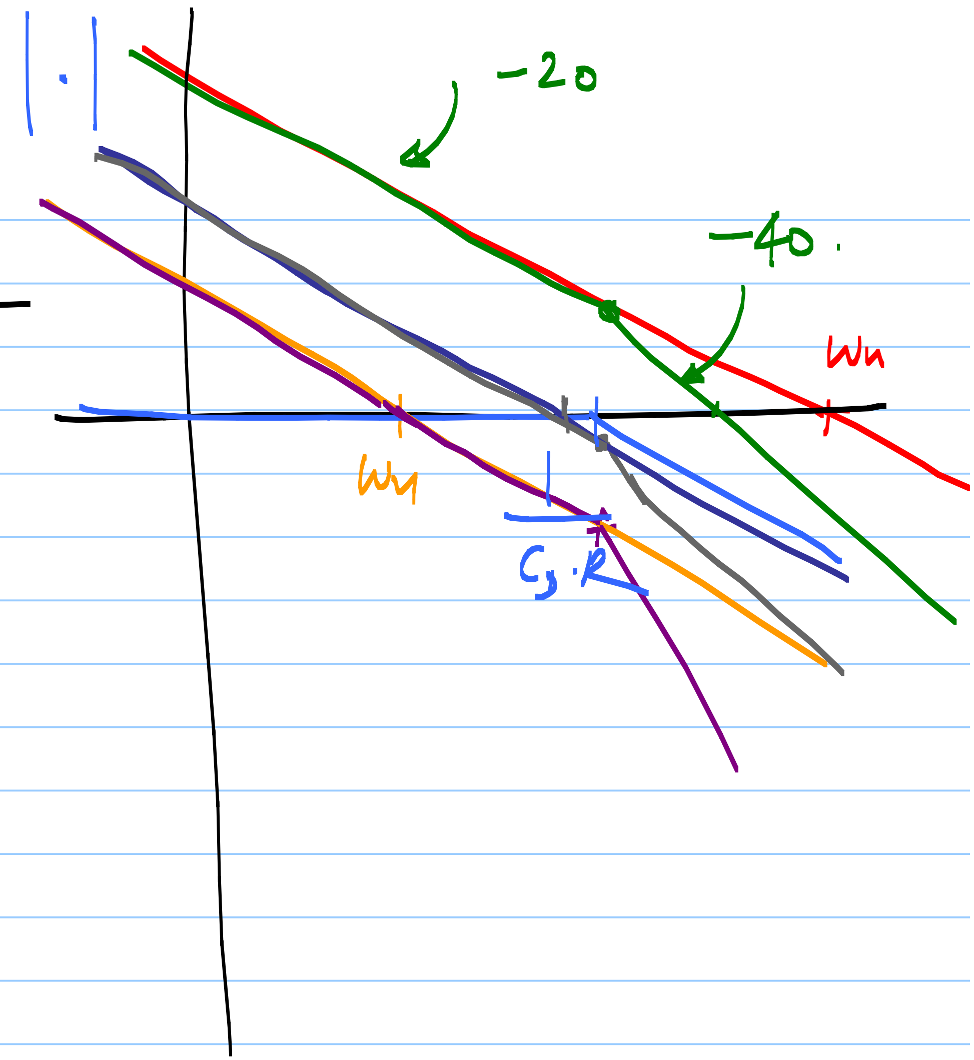
BW : $\dfrac{1}{\sqrt{2}\, C_D \cdot R}$

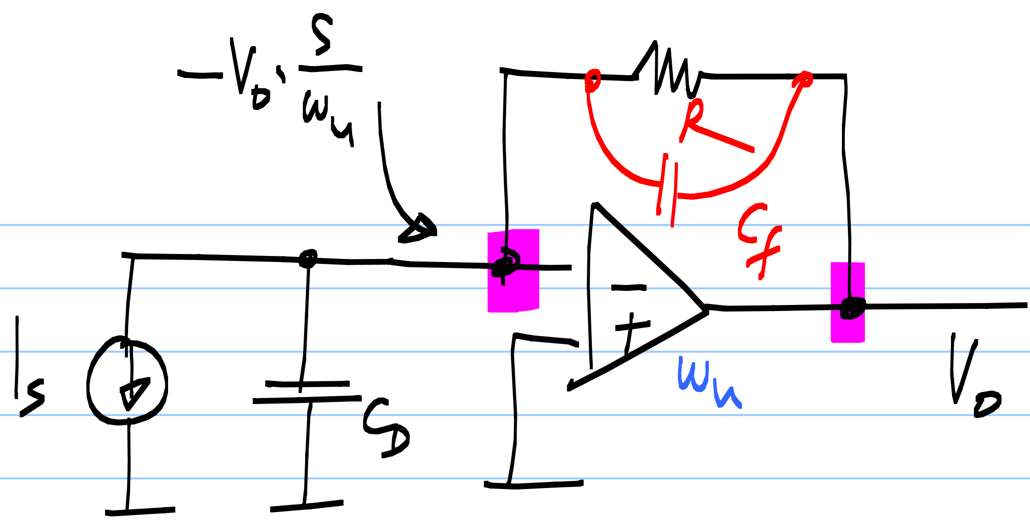
$\left\{ \zeta = 1/\sqrt{2} \;\; \Rightarrow \omega_{-3dB} = \omega_u \right\}$

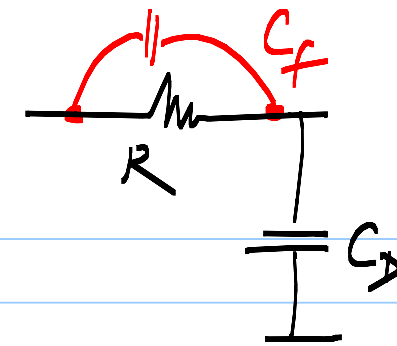
$$\omega_u = \frac{1}{2\, C_D \cdot R}$$

$$\frac{1}{1+sC_g R}$$









$$\frac{1}{1+sC_DR}$$

$$\frac{1+sC_fR}{1+s(C_f+C_D)R}$$

$$-V_o \cdot \frac{s}{\omega_u}\left(sC_f + G + sC_D\right) - V_o\left(sC_f + G\right) = I_s$$

$$\frac{V_o}{I_s} = \frac{R_f}{s^2\frac{(C_D+C_f)R_f}{\omega_u} + s\left(\frac{1}{\omega_u} + C_fR_f\right) + 1}$$

$$\omega_n = \sqrt{\frac{\omega_u}{(C_i + C_f)R}}$$

$$\zeta = \frac{1}{\sqrt{2}}$$

$$\boxed{\omega_{-3dB} = \omega_n}$$

$$\frac{2 \cdot \zeta}{\omega_n} = \frac{1}{\omega_u} + C_f \cdot R$$

$$\left\{ (C_f R)^2 = \frac{2 \cdot C_i R \omega_u - 1}{\omega_u^2} \right\}$$

$$\sqrt{2} \cdot \sqrt{\frac{(C_i + C_f)R}{\omega_n}} = \frac{1}{\omega_u} + C_f R$$

$$2 \cdot \frac{(C_i + \cancel{C_f})R}{\omega_u} = \frac{1}{\omega_u^2} + \cancel{\frac{2 \cdot C_f R}{\omega_u}} + (C_f R)^2$$

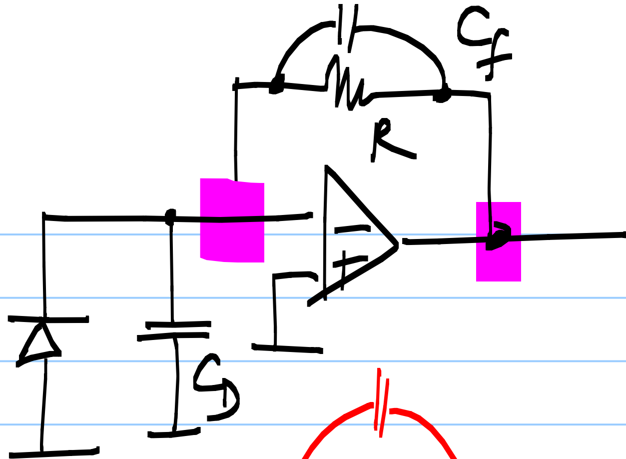
$$(C_f \cdot R)^2 = \frac{2C_D \cdot R \cdot \omega_u - 1}{\omega_u^2}$$

$$\omega_{-3dB} = \omega_u$$

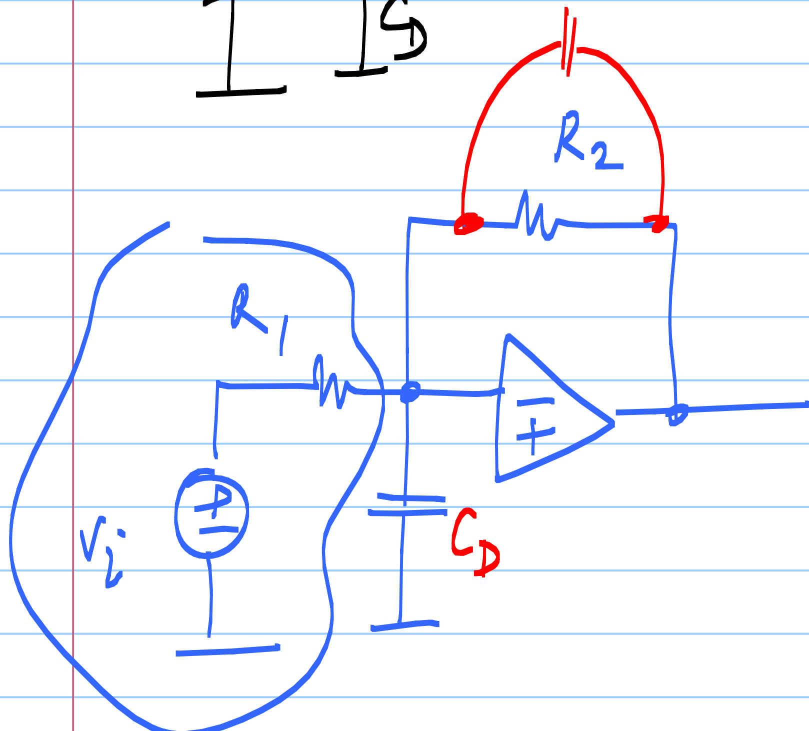
$$= \sqrt{\frac{\omega_u}{C_D \cdot R + C_f \cdot R}}$$

$$= \sqrt{\frac{\omega_u}{C_D \cdot R + \frac{\sqrt{2C_D R \omega_u - 1}}{\omega_u}}} = \frac{\omega_u}{\sqrt{\omega_u \cdot C_D R + \sqrt{2C_D R \omega_u - 1}}}$$

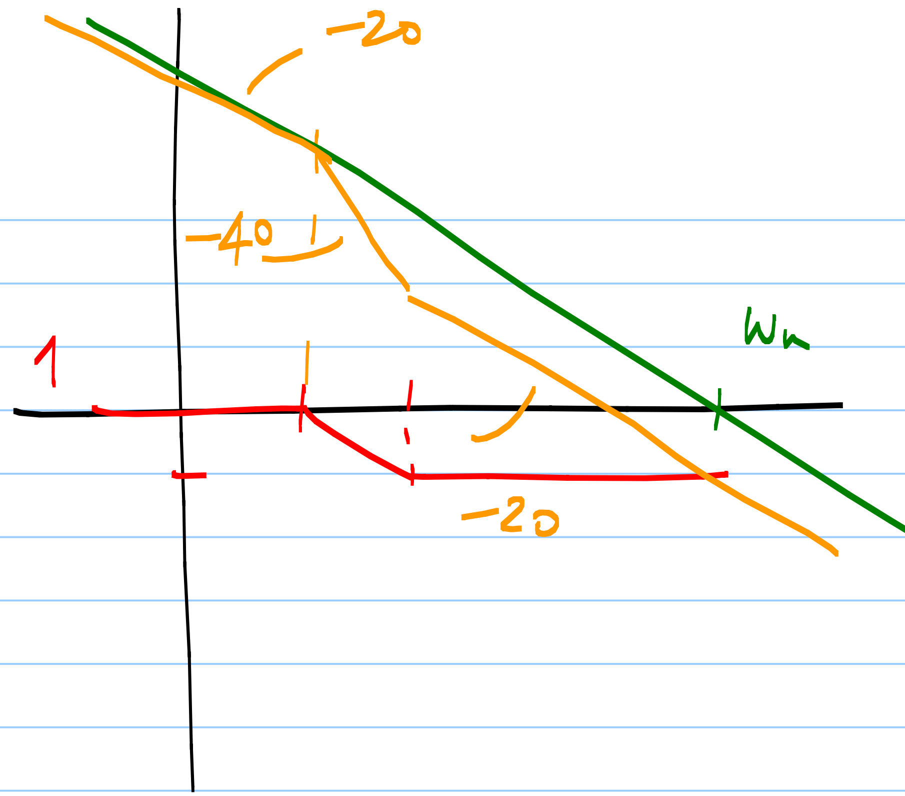
$$\omega_{-3dB} = \frac{\omega_u}{\sqrt{\omega_u C_D R + \sqrt{2C_D R \omega_u - 1}}}$$



C_f
R
C_D



R_2
R_1
v_i
C_D



-20
-40
1
-20
ω_u