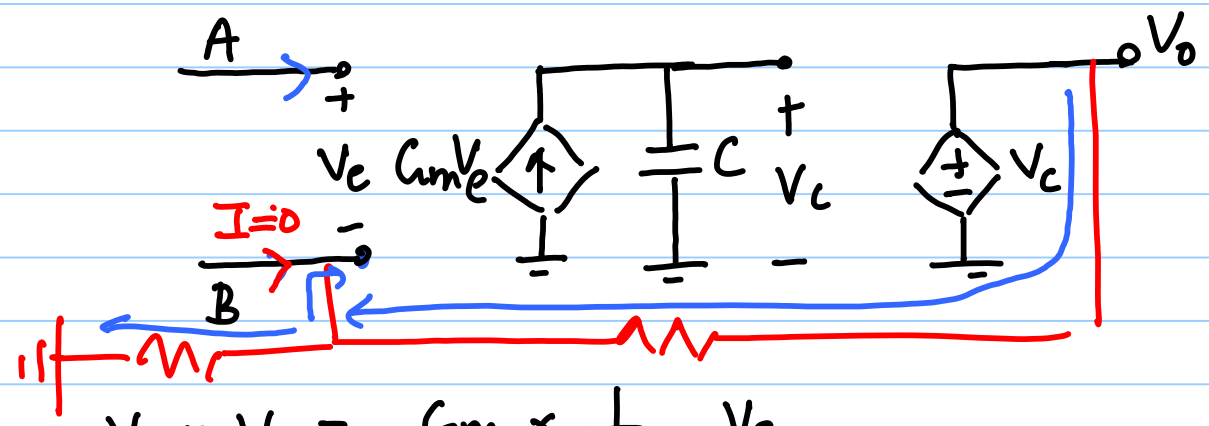
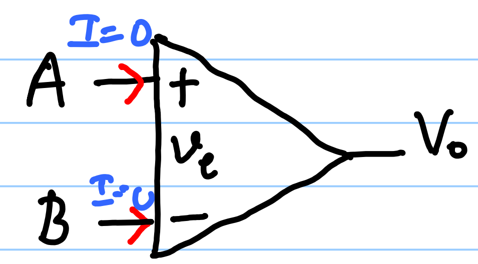
Note Title 28-01-2022

Lecture # 6



Opamp. (in open loop)



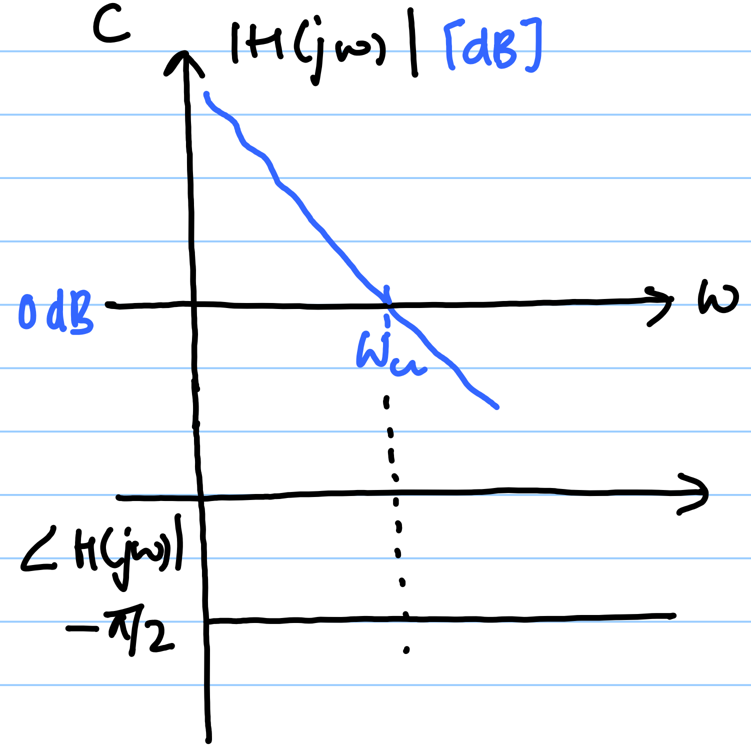
$$V_o = V_c = G_m \times \frac{1}{sC} V_e$$

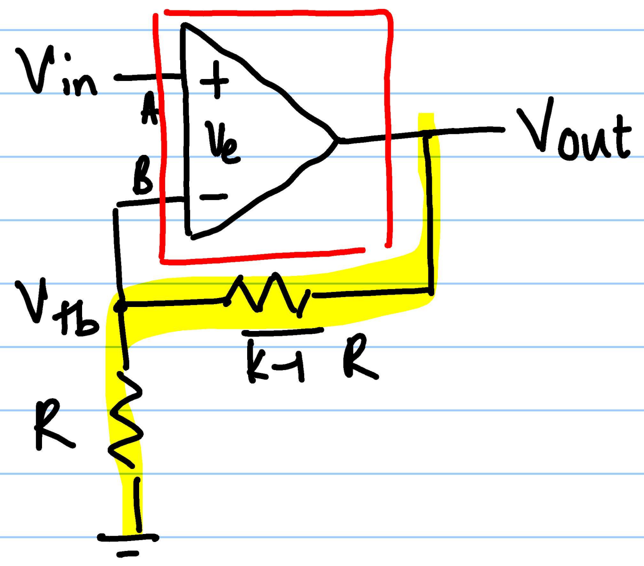
$$H(s) = \frac{V_o}{V_e} = \frac{G_m}{C}\frac{1}{s} = \frac{\omega_u}{s} \quad \text{where } \omega_u = \frac{G_m}{C}$$

pole at $s=0$,

Unity gain freq. $= \omega_u = \dfrac{G_m}{C}$

$$\measuredangle H(j\omega) = \measuredangle\left(\frac{\omega_u}{j\omega}\right)$$





$\checkmark$ $V_{out}(t) = K V_{in}(0) \left(1 - e^{-\omega_n t/K}\right)$

for $V_{in}(t) = V_{in}(0) \cdot u(t)$

In open loop

$$\frac{V_{out}}{V_e} = \frac{\omega_n}{s}$$

$$V_e = V_{in} - V_{fb}$$

$$V_e = V_{in} - \frac{V_{out}}{K}$$

$$V_{out} = \frac{\omega_n}{s} V_e = \frac{\omega_n}{s}\left[V_{in} - \frac{V_{out}}{K}\right]$$

$$V_{out}\left[1 + \frac{\omega_n}{s} \cdot \frac{1}{K}\right] = \frac{\omega_n}{s} V_{in}$$

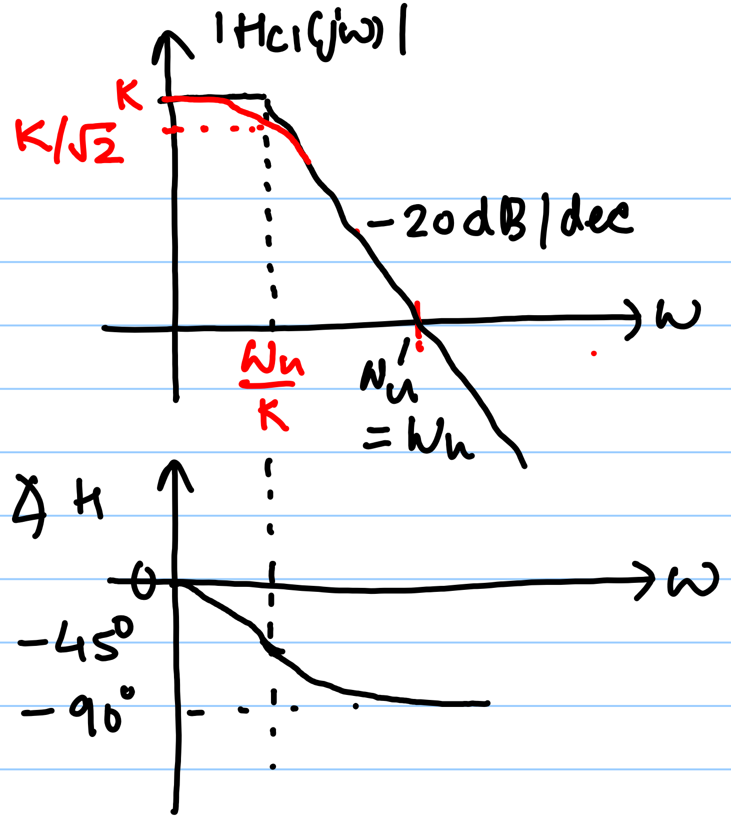
$$\frac{V_{out}}{V_{in}} = \frac{1}{\frac{1}{K} + \frac{s}{\omega_n}}$$

$$H_{cl}(s) = \frac{V_{out}}{V_{in}} = \frac{1}{\frac{1}{K} + \frac{s}{\omega_u}} \quad \checkmark$$

$$|H_{cl}(j0)| = K$$

$$s = -\frac{\omega_n}{K} \quad \text{pole}$$

$$H_{cl}(s) = \left(\frac{K}{1 + \frac{s}{\omega_n/K}} \right)$$



$$|H_{cl}(j\omega_n')| = 1 \Rightarrow 1 = \frac{K}{\sqrt{1 + \underbrace{\left(\frac{\omega_n'^2}{(\omega_n/K)^2}\right)}}}$$

$$1 = \frac{K}{\omega_n' / (\omega_n/K)}$$

$$\omega_n' : \omega_n$$

$$\measuredangle H(j\omega) = -\tan^{-1}\left(\frac{\omega}{\omega_n/K}\right)$$

$$x = \underbrace{a+jb} \qquad Y = \frac{1}{a+jb}$$

$$\measuredangle x : \tan^{-1}\left(\frac{b}{a}\right) \qquad \measuredangle Y = \frac{a-jb}{a^2+b^2}$$

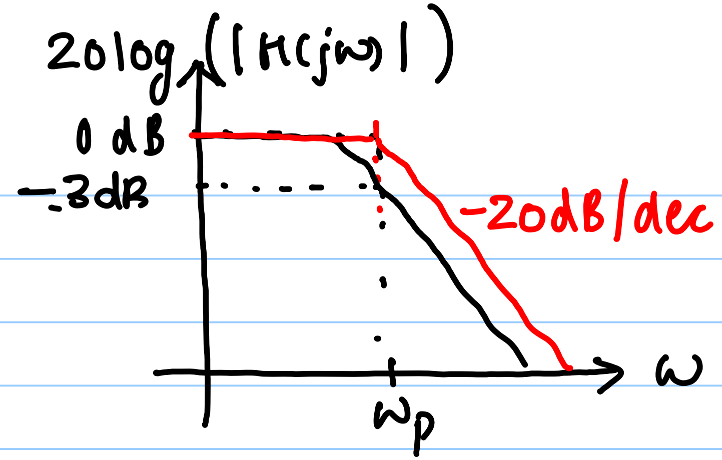
$$H(s) = \frac{1}{1 + s/\omega_p}$$

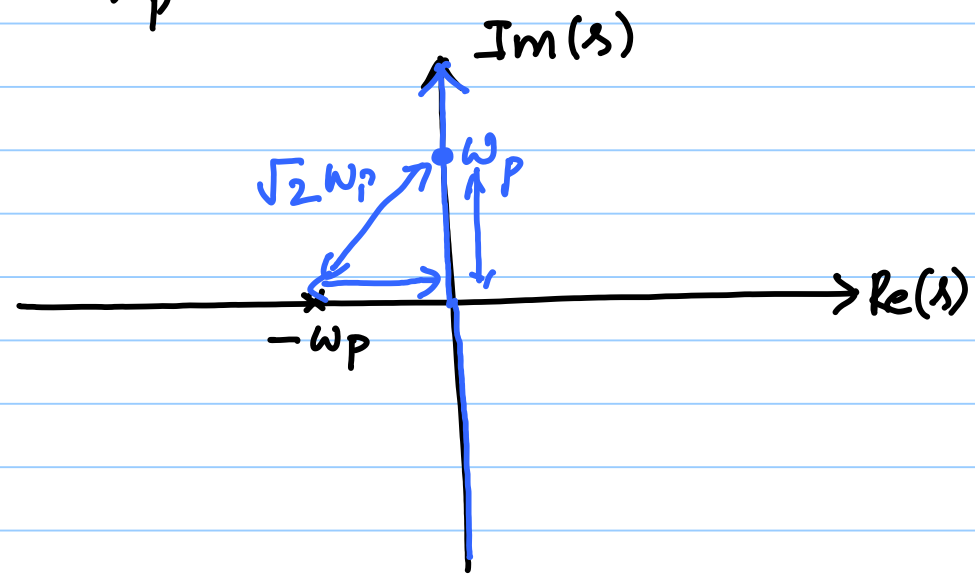
pole: $s = -\omega_p$

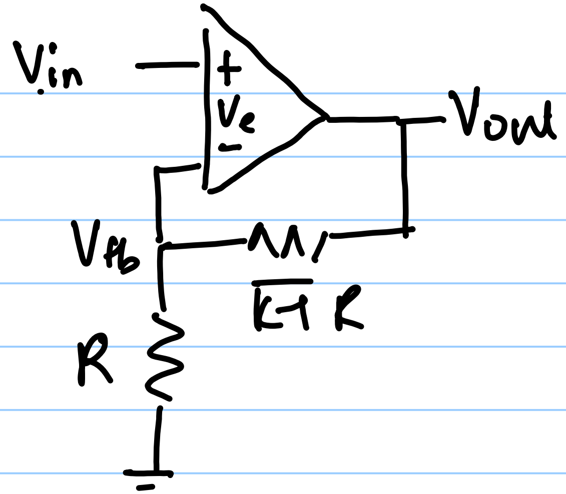
$$|H(j\omega)| = \left| \frac{1}{1 + j\frac{\omega}{\omega_p}} \right|$$

$$= \frac{1}{\sqrt{1 + \omega^2/\omega_p^2}}$$

$$20\log_{10}\left(\frac{1}{\underbrace{\sqrt{1 + \omega^2/\omega_p^2}}} \right)$$







$$\frac{V_{out}}{V_{in}} = \frac{1}{\frac{1}{K} + \frac{s}{\omega_u}}$$

at $t=0$, $V_{in}(t) = \underset{\sim}{V_{in}(0)}\ u(t)$

$$\lim_{t\to\infty} \underset{\sim}{V_{out}(t)} = \lim_{s\to 0} s \cdot V_{out}(s) \quad ✓$$

"Final Value Theorem"

$$V_{out}(t) = \mathcal{L}^{-1}\left[V_{out}(s) \right]$$

$$\lim_{t\to\infty} V_{out}(t) = \lim_{s\to 0} s \cdot V_{in}(s) \frac{1}{\frac{1}{K} + \frac{s}{\omega_u}}$$

$$= \lim_{s\to 0} \cancel{s} \cdot \frac{V_{in}(0)}{\cancel{s}} \frac{1}{\frac{1}{K} + \frac{s}{\omega_u}}$$

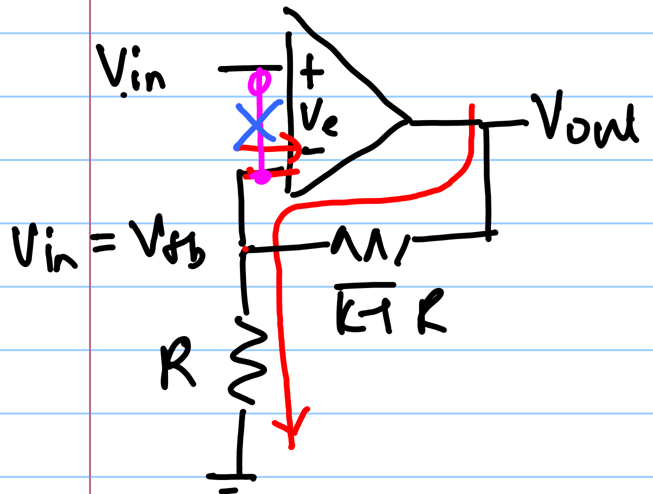
$$= K \cdot V_{in}(0)$$

$$V_e(t) = V_{in}(t) - \frac{V_{out}(t)}{K}$$

$$V_e(s) = V_{in}(s) - \frac{V_{out}(s)}{K}$$

$$= V_{in}(s)\left[\frac{s/(\omega_u/K)}{1 + s/\left(\frac{\omega_u}{K}\right)}\right] \quad ✓$$

$$\lim_{t\to\infty} V_e(t) = \lim_{s\to 0} s \cdot V_e(s)$$



$$V_e = 0 \Rightarrow V_{in} - V_{fb} = 0$$

$$V_{fb} = V_{in}$$

$$\frac{V_{out} - V_{in}}{\overline{K-1}\ \cancel{R}} = \frac{V_{in}}{\cancel{R}}$$

$$\boxed{V_{out} = K \cdot V_{in}}$$

$$V_e(s) = V_{in}(s) - \frac{V_{in}(s)}{K} \frac{1}{\frac{1}{K} + \frac{s}{\omega_n}}$$

$$= V_{in}(s) \left[1 - \frac{1}{1 + \frac{s}{\omega_n/K}} \right]$$

$$= V_{in}(s) \frac{s/(\omega_n/K)}{1 + s/(\omega_n/K)}$$

$$\lim_{t \to \infty} V_e(t) = \lim_{s \to 0} s \cdot \frac{V_{in}(0)}{s} \frac{s/(\omega_n/K)}{1 + s/(\omega_n/K)}$$

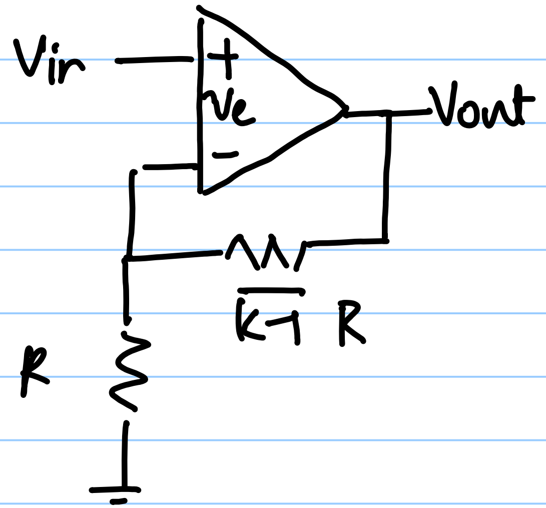
$$= 0$$

- $V_A = V_B \Rightarrow V_e = 0$

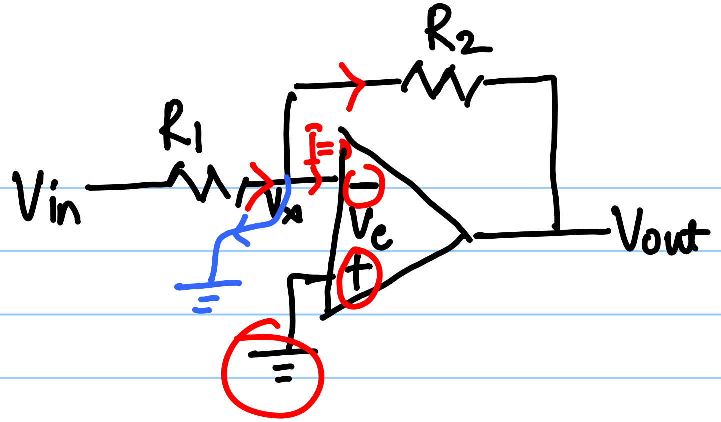
  I/P terminals of OPAMP are virtually short.

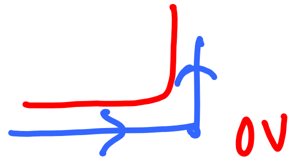
- Non-inverting amplifier

$$\frac{V_{out}}{V_e} = \frac{\omega_u}{s}$$



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





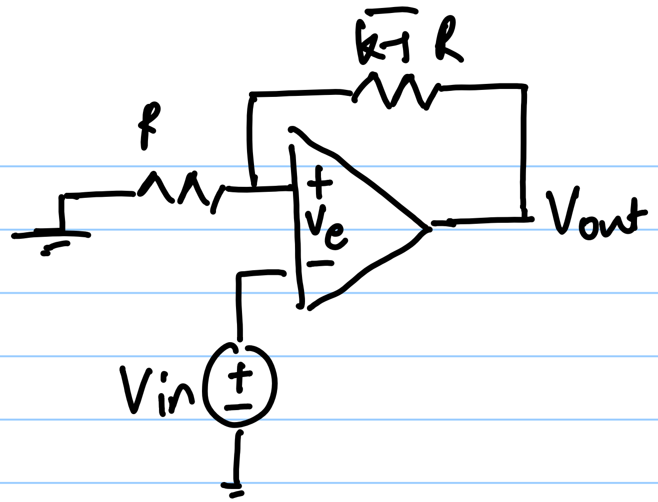
- Assume $V_e = 0$ in steady state
- $V_x = 0$

$$\Rightarrow \quad \frac{V_{in} - 0}{R_1} = \frac{0 - V_{out}}{R_2}$$

$$\frac{V_{out}}{V_{in}} = -\left(\frac{R_2}{R_1}\right)$$

$= -ve.$

Inverting Amplifier



$$V_e = \frac{V_{out}}{K} - V_{in}$$

$$V_{out} = \frac{\omega_n}{s} V_e = \frac{\omega_n}{s}\left(\frac{V_{out}}{K} - V_{in}\right)$$

$$V_{out}\left(\frac{s}{\omega_n} - \frac{1}{K}\right) = -V_{in}$$

$$\frac{V_{out}}{V_{in}} = \frac{-1}{\left(\frac{s}{\omega_n} - \frac{1}{K}\right)}$$