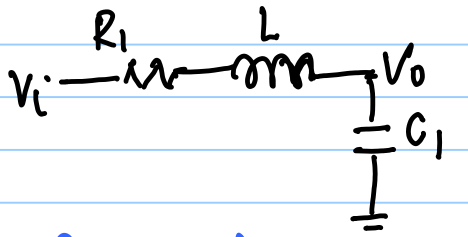
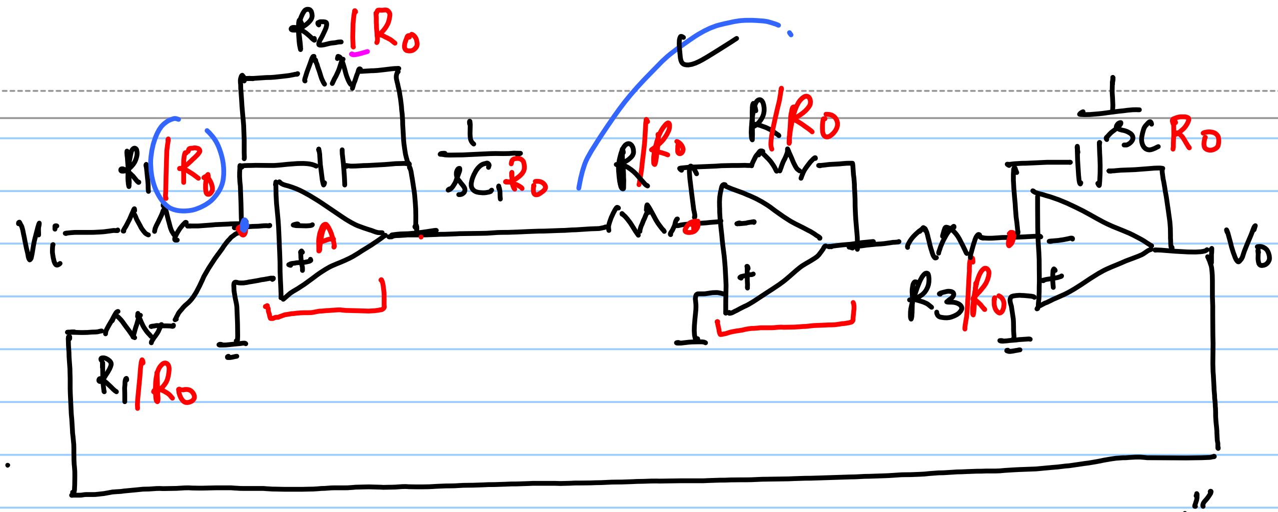
Lecture # 38

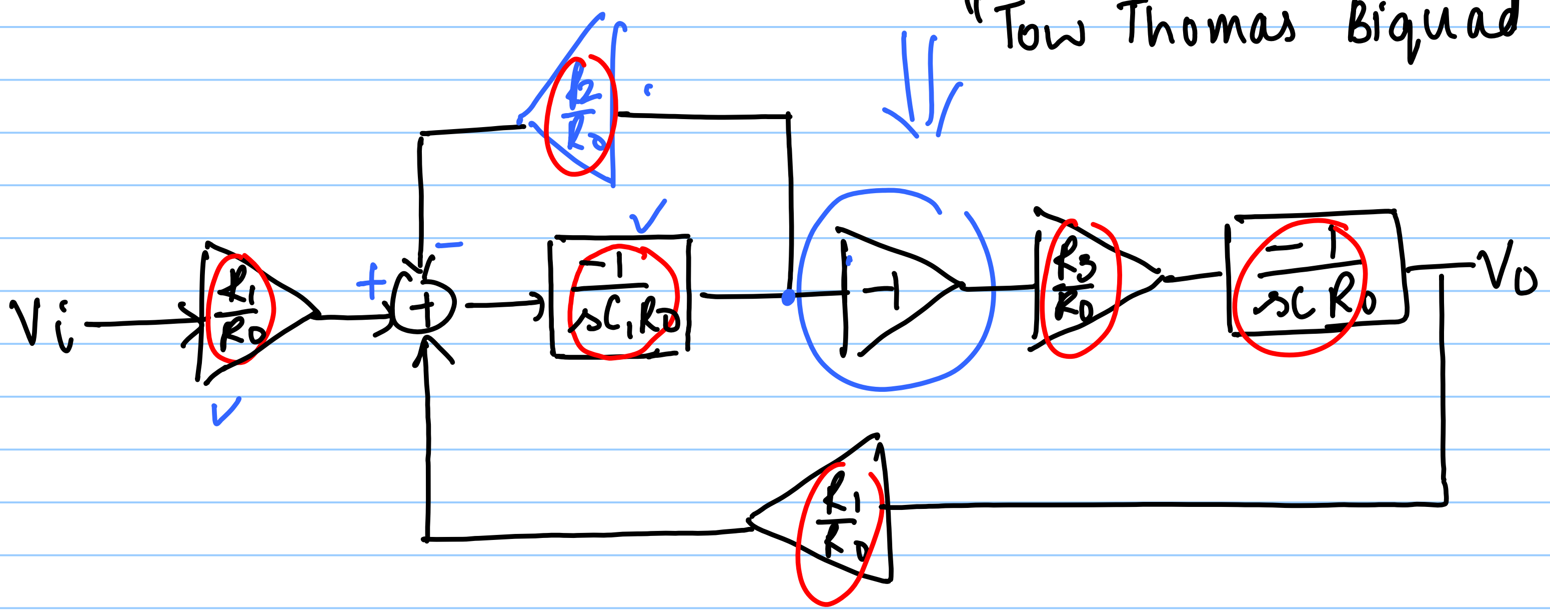


Passive Filter

⇒



"Tow Thomas Biquad"



$$H(s) = \frac{1}{\frac{s^2}{\omega_0^2} + \frac{s}{\omega_0 Q_p} + 1} \checkmark = \frac{V_o(s)}{V_i(s)}$$

Relationship b/w V_i and V_o in terms of gain blocks and integrators

Integrator $\propto \frac{1}{s}$

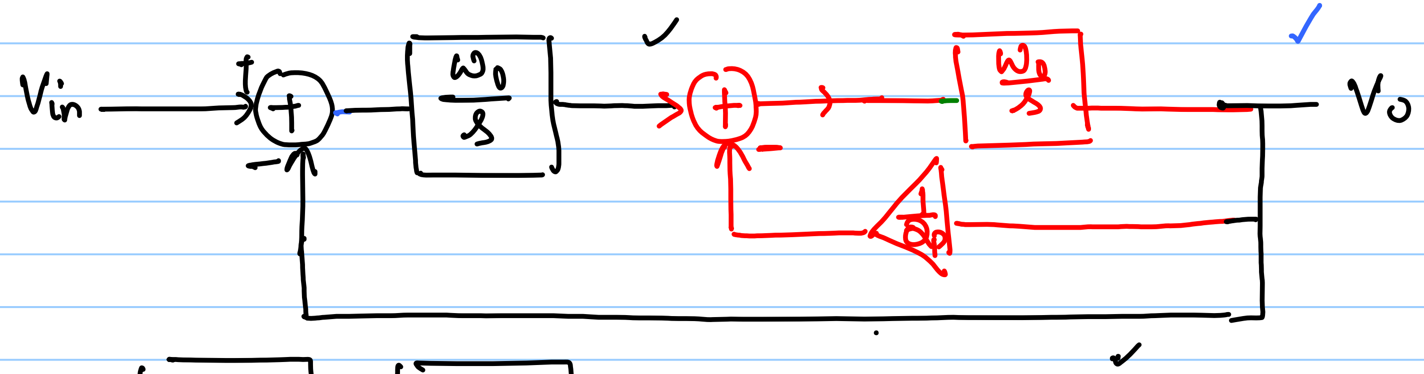
$$V_i(s) = V_o(s)\left(1 + \frac{s}{\omega_0 Q_p} + \frac{s^2}{\omega_0^2}\right)$$

$$\frac{\omega_0^2}{s^2} V_{in}(s) = V_o(s)\left(1 + \frac{\omega_0}{s} \cdot \frac{1}{Q_p} + \frac{\omega_0^2}{s^2}\right)$$

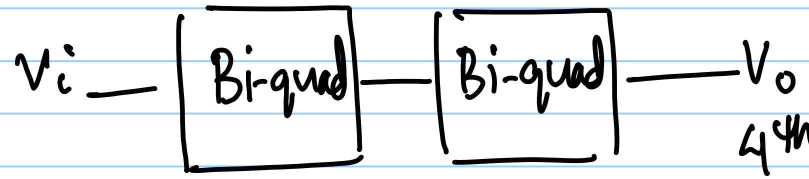
$$V_o(s) = \left\{V_{in}(s) - V_o(s)\right\} \frac{\omega_0^2}{s^2} - V_o(s) \cdot \frac{\omega_0}{s Q_p}$$

$$= \left[\left(V_{in}(s) - V_o(s)\right)\frac{\omega_0}{s} - \frac{1}{Q_p} V_o(s)\right] \frac{\omega_0}{s}$$

$$V_o(s) = \frac{\omega_o}{s}\left[\left(V_{in}(s) - V_o(s)\right)\frac{\omega_o}{s} - \frac{V_o(s)}{Q_P}\right]$$



Bi-quad.



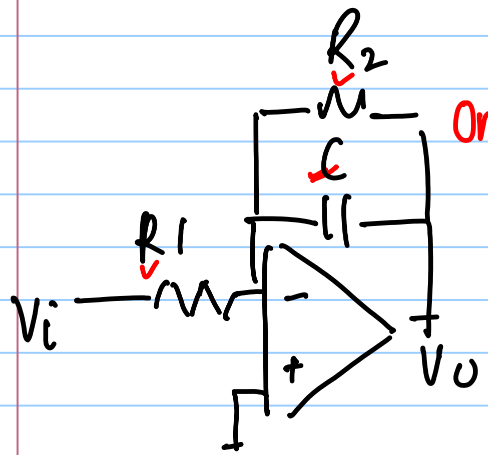
4th order

3rd order.

Passive $\longrightarrow$ Active RC-filter $\longrightarrow$ Gm-C filters

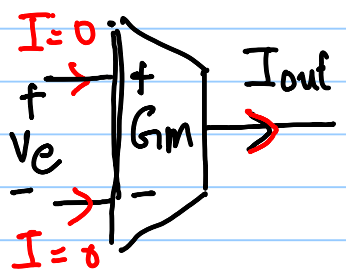
(R, L, C) $\quad$ (R, C, Opamp) $\quad$ (C, ~~Opamp~~, Gm)

R $\to$ On-chip (PVT variations)



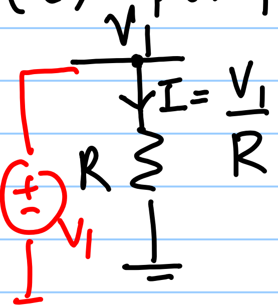
$$\frac{R_1 \pm 0.3R_1 + R_{tune}}{R_2 \pm 0.3R_2 + R_{tune}}$$

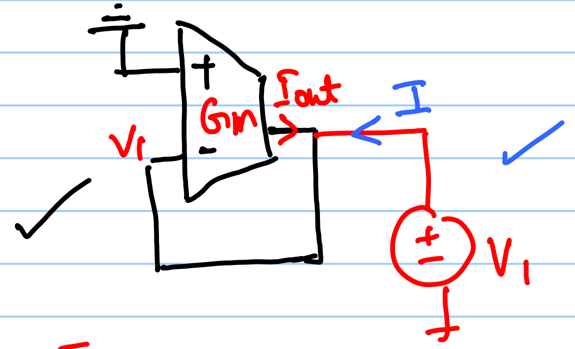
Gm-block



$I_{out} = G_m V_e$

$G_m \to$ function of operating point of active block.



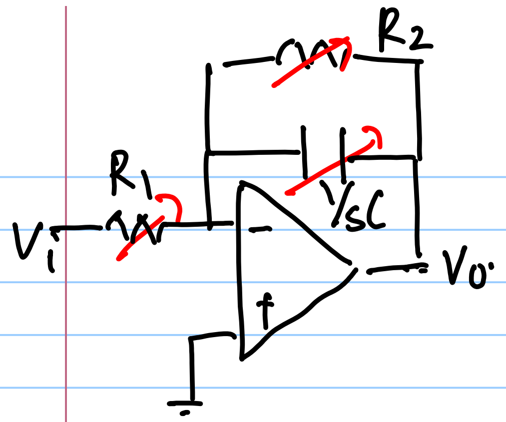


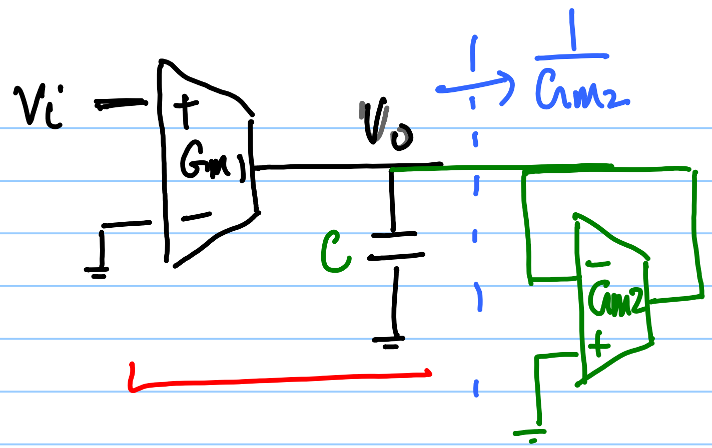
$I_{out} = G_m(-V_1)$

$I = -I_{out} = G_m V_1$

$\frac{V_1}{I} = \frac{1}{G_m} = R$

We will make sure that Gm remains fixed or easily tuned to compensate PVT variations in filter bandwidth.





$$\frac{V_i}{R_1} = -V_o\left(\frac{1}{R_2} + sC\right)$$

$$\frac{V_o}{V_i} = -\frac{R_2}{R_1}\,\frac{1}{1+sCR_2}$$

$R_1 \rightarrow R_1 + 0.3R_1$

$R_2 \rightarrow R_2 + 0.3R_2$

$C \rightarrow C$

$$\omega_{-3dB} = \frac{1}{R_2C} \rightarrow \frac{1}{1.3\,R_2C}$$

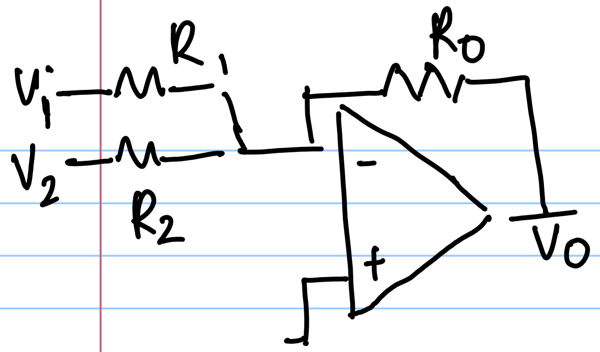
$C \rightarrow C + 0.2C$

$$\omega_{-3dB} \rightarrow \frac{1}{1.3\times 1.2\,R_2C}$$

$$V_o = (G_{m1}\cdot V_i)\left(\frac{1}{sC} \,\|\, \frac{1}{G_{m2}}\right)$$

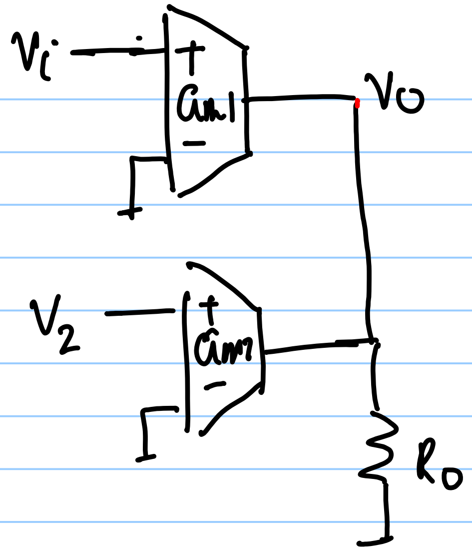
$$\frac{V_o}{V_i} = \frac{G_{m1}}{sC + G_{m2}} = \frac{G_{m1}/G_{m2}}{1 + sC/G_{m2}}$$

$$\omega_{-3dB} = \frac{G_{m2}}{C_1}$$

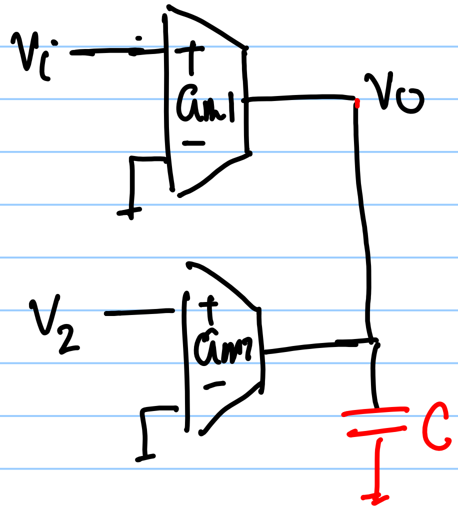


$V_0 = (-)\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right) R_0$

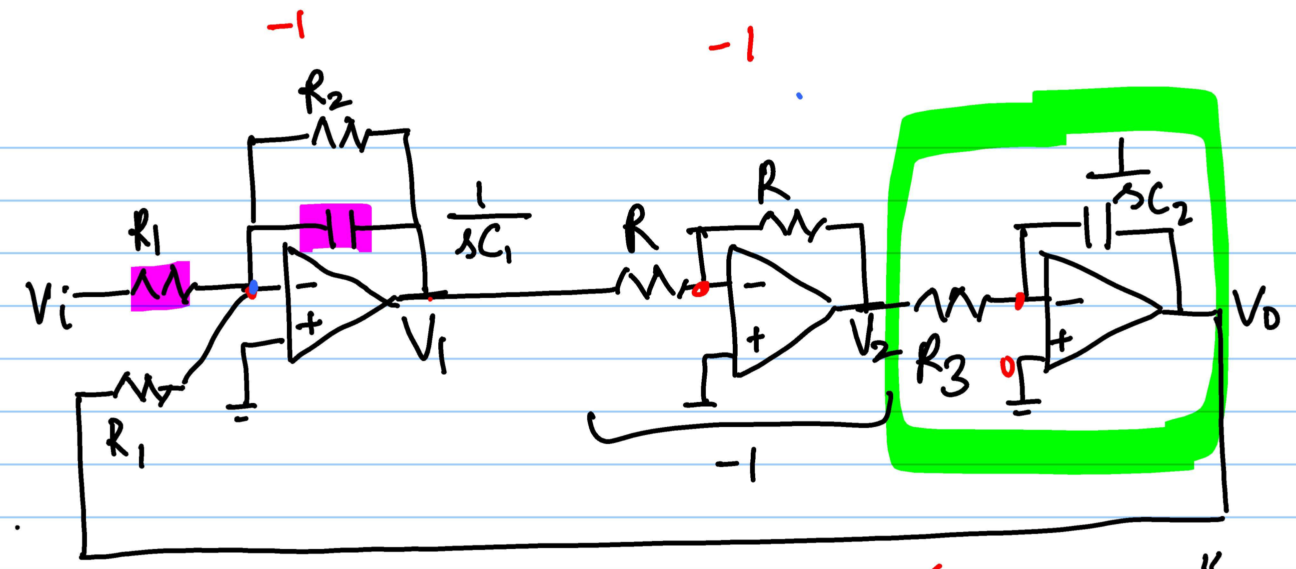
$\frac{V_1}{R_1} \to G_{m1}V_1$, $\frac{V_2}{R_2} \to G_{m2}V_1$



$V_0 = +\left(G_{m1}V_1 + G_{m2}V_2\right) R_0$



$V_0 = \left(G_{m1}V_1 + G_{m2}V_2\right) \frac{1}{sC}$



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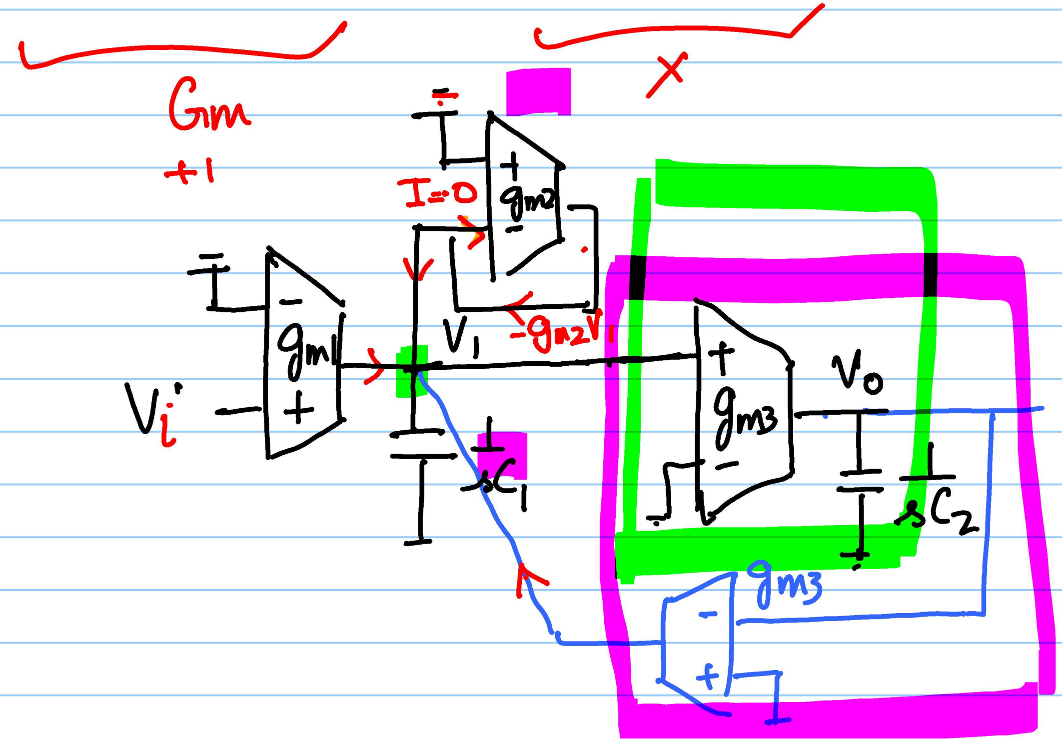


$$g_{m1}V_i - g_{m3}V_0 - g_{m2}V_1 = V_1 sC_1$$

$$g_{m1}V_i = g_{m2}V_1 + g_{m3}V_0 + sC_1V_1$$

$$= V_1(g_{m2} + sC_1)$$

$$+ g_{m3}\, g_{m3}\frac{V_1}{sC_2}$$

$$g_{m1} V_i = V_1 \left(g_{m2} + sC_1 + \frac{g_{m3}^2}{sC_2} \right)$$

$$= \frac{V_1}{sC_2} \left(g_{m2} sC_2 + s^2 C_1 C_2 + g_{m3}^2 \right)$$

$$\frac{V_1}{V_i} = \frac{g_{m1} \cdot sC_2}{s^2 C_1 C_2 + s C_2 g_{m2} + g_{m3}^2}$$

$$= \frac{s \frac{C_2}{g_{m3}^2} \cdot g_{m1}}{s^2 C_1 \frac{C_2}{g_{m3}^2} + s \frac{C_2}{g_{m3}^2} \cdot g_{m2} + 1}$$

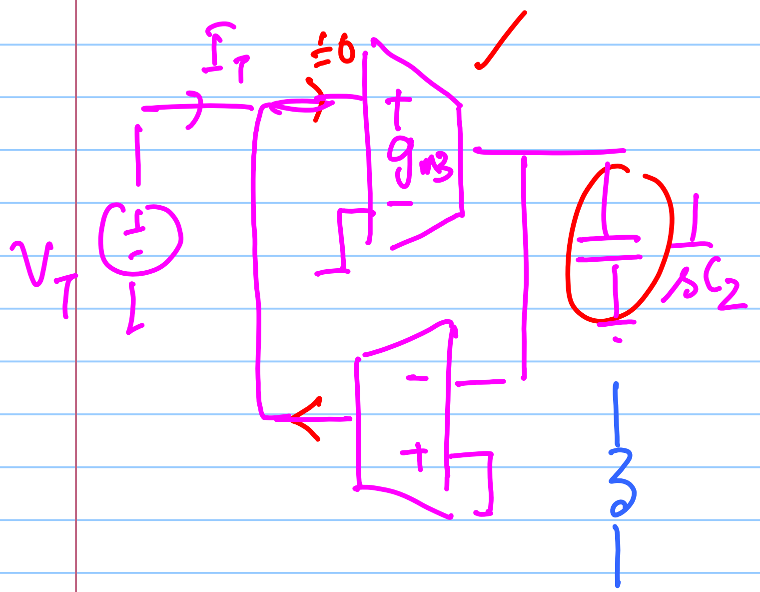
$$= \frac{s L / (1/g_{m2})}{s^2 C_1 L + s L / (1/g_{m2}) + 1} \times \frac{g_{m1}}{g_{m2}}$$

$\frac{g_{m1}}{g_{m2}}$: peak gain

$L = \frac{C_2}{g_{m3}^2}$

$$\frac{V_1}{V_i} = \frac{s/\omega_0 Q_p}{\frac{s^2}{\omega_0^2} + \frac{s}{\omega_0 Q_p} + 1} \times \frac{g_{m1}}{g_{m2}}$$

$$\frac{V_o}{V_i} = \frac{1}{\frac{s^2}{\omega_0^2} + \frac{s}{\omega_0 Q_p} + 1} \times \frac{g_{m1}}{g_{m2}}$$



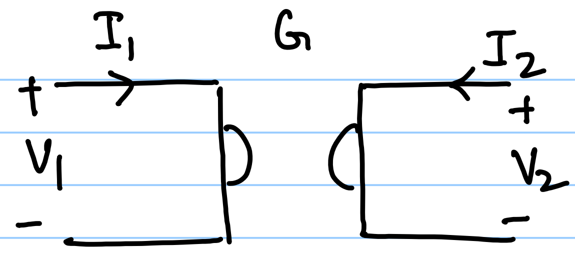
$$I_T = g_{m3} \frac{1}{sC_2} \times g_{m3} \cdot V_T$$

($\frac{1}{sC_2}$ → sL)

$$\frac{V_T}{I_T} = s\frac{C_2}{g_{m3}^2} \rightarrow \frac{1}{sL\, g_{m2}^2}$$

Capacitor

Gyrator (Impedance Inverter)



$$I_1 = G V_2$$

$$I_2 = -G V_1$$