CDEEP
IIT Bombay

EE 618 L 22 / Slide 01

OTA Applications

OTA use in Realisation of Active Filters

Continous (Analog) Filters are mostly used in cases which have lower cut-off.

For example a RC filter is a Passive Continous Filter. The cut-off frequency is function of RC time constant. For higher frequency cutoffs, one must get v.small values of R and C. R realisation on Silicon has limits of getting extreme value of R (larger & v.smaller). Thus frequency response of Filters are limited bandwidths one.

On Silicon an Active filter can satisfy both Input-output relations by realising Resistors by $1/g_m$ values.

Such filters are also called g_m-C continuous filters.

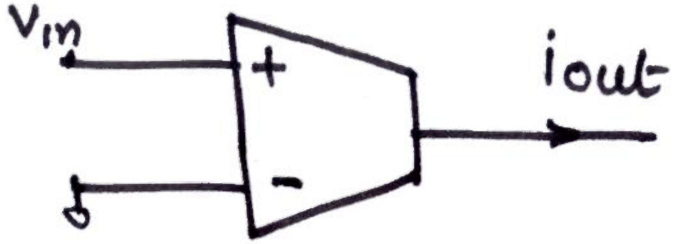
OTA is a device, whose output could be controlled 'transconductance'.

Take an OTA as shown

$$i_{out} = G_M \cdot (V_+ - V_-)$$

If we put $V_- = 0$

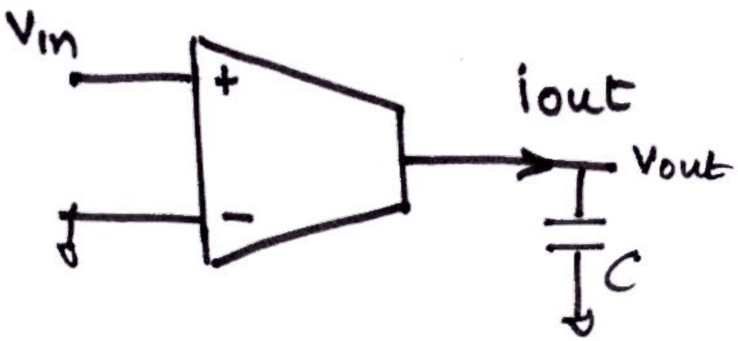
Then $i_{out} = G_M \cdot V_{in}$



$G_m = g_{m_1}$

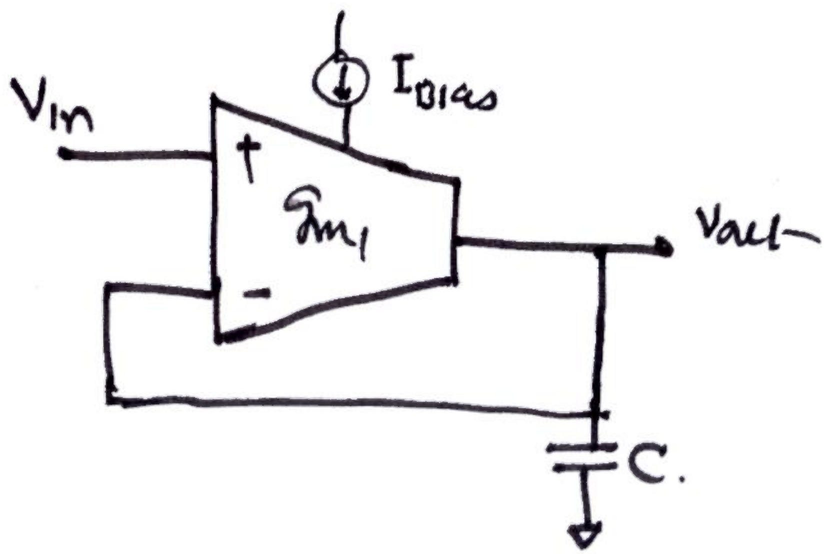
Unloaded

$i_{out} = g_{m_1} V_{in}$



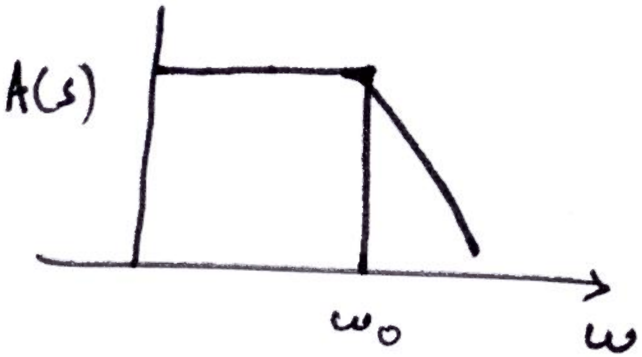
Loaded

$V_{out} = i_{out} / j\omega C$



Loaded with -ve feedback

Low Pass Filter



$$\omega_0 = \frac{g_{m_1}}{C}$$

$$v_- = V_{out} \qquad i_{out} = g_{m_1}(V_+ - V_-)$$

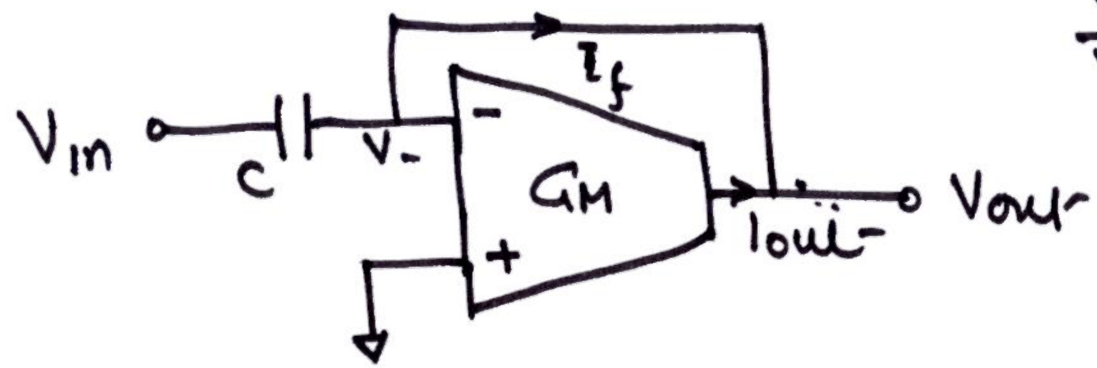
$$= g_{m_1}(V_{in} - V_{out})$$

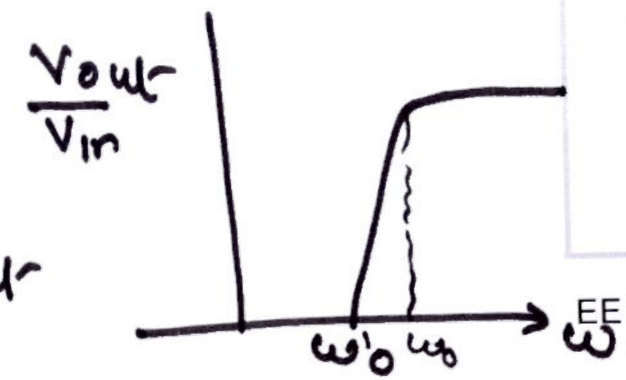
$$V_{out} = i_{out} \cdot \frac{1}{j\omega C} = \frac{g_{m_1}}{j\omega C}(V_{in} - V_{out})$$

$$V_{out}\left[1 + \frac{g_{m_1}}{j\omega C}\right] = \frac{g_{m_1}}{j\omega C} V_{in}$$

$$\boxed{A(s) = \frac{V_{out}(j\omega)}{V_{in}(j\omega)} = \frac{g_{m_1}/j\omega C}{1 + \frac{g_{m_1}}{j\omega C}} = \frac{1}{1 + j\omega \frac{C}{g_m}} = \frac{1}{1 + j(\omega/\omega_0)}}$$

High Pass Filter





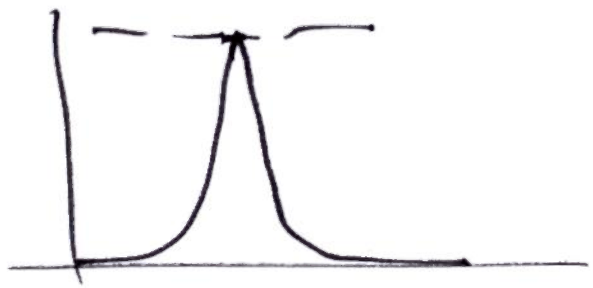
$$i_{out} = G_M (V_+ - V_-) = -G_M V_{out}$$

$$-I_{out} = +I_f = +(V_{in} - V_-) j\omega C = j\omega C (V_{in} - V_{out})$$

$$\therefore \quad G_M V_{out} = j\omega C V_{in} - j\omega C V_{out}$$

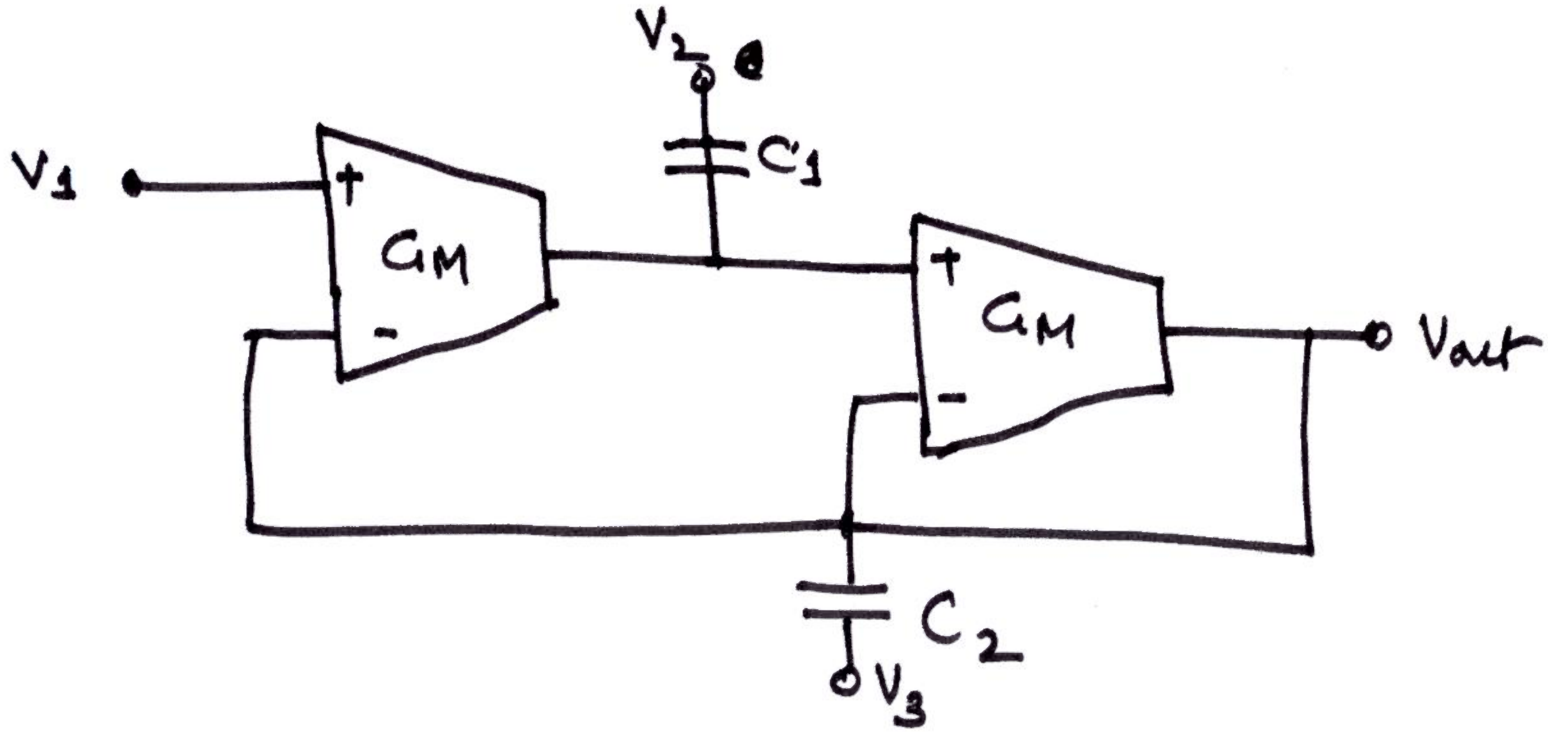
$$\text{or} \quad \left(1 + \frac{j\omega C}{g_m}\right) V_{out} = j\omega C/g_m \; V_{in}$$

$$\text{or} \quad \frac{V_{out}}{V_{in}} = \frac{j\omega (C/g_m)}{1 + j\omega (C/g_m)} = \frac{j(\omega/\omega_0)}{1 + j(\omega/\omega_0)} \quad \text{HPass response}$$

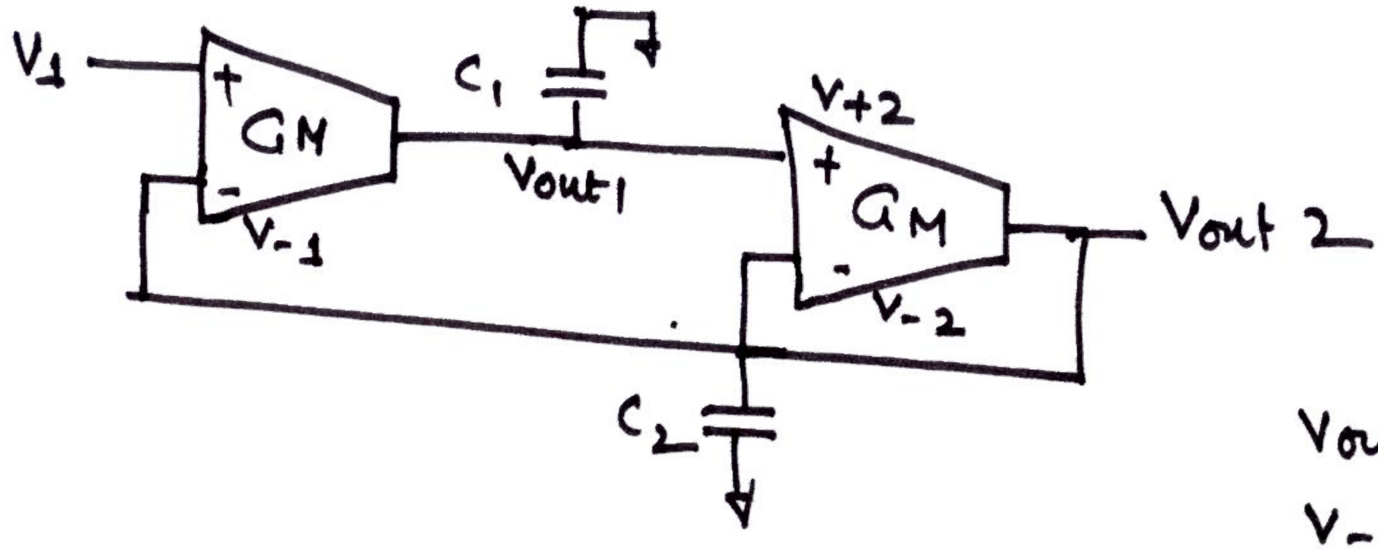


"General Purpose Biquad Filter with OTA"

Combining LP & HP filter architectures as seen earlier, we can create, both Band Pass and Band Reject filters.



If we put V_2 and V_3 to Ground, we get



We have

$V_{out1} = V_{+2}$

$V_{-1} = V_{-2} = V_{out2}$

$V_1 = V_{in}$

$$V_{out1} = G_M (V_1 - V_{-1}) \cdot \frac{1}{jwC_1}$$

$$V_{out1} = G_M (V_{in} - V_{out2}) \cdot \frac{1}{jwC_1} \quad \text{— (1)}$$

$$V_{out2} = G_M (V_{+2} - V_{-2}) \cdot \frac{1}{jwC_2}$$

$$= G_M (V_{out1} - V_{out2}) \cdot \frac{1}{jwC_2} \quad \text{— (2)}$$

Substituting (1) in (2)

$$V_{out2} = \frac{G_m}{j\omega C_2}\left[\frac{G_M}{j\omega C_1}(V_{in} - V_{out2}) - V_{out2}\right]$$

or $$\frac{j\omega C_2}{g_{m1}} \cdot V_{out2} = \frac{g_{m1} V_{in}}{j\omega C_1}$$

Taking $G_M = g_{m1}$

$$- \left[+ \frac{g_{m1}}{j\omega C_1} + 1\right] V_{out2}$$

or $$V_{out2}\left[1 + \frac{g_{m1}}{j\omega C_1} + \frac{j\omega C_2}{g_{m1}}\right] = \frac{g_{m1}}{j\omega C_1} \cdot V_{in}$$

$\therefore$ Trans. f^n $$\frac{V_{out2}}{V_{in}} = \frac{g_{m1}/j\omega C_1}{1 + \frac{g_{m1}}{j\omega C_1} + \frac{j\omega C_2}{g_{m1}}} = A(j\omega)$$

or $A(s) = A(jw) = \dfrac{g_{m1}/sC_1}{1 + \dfrac{g_{m1}}{sC_1} + \dfrac{sC_2}{g_{m1}}}$

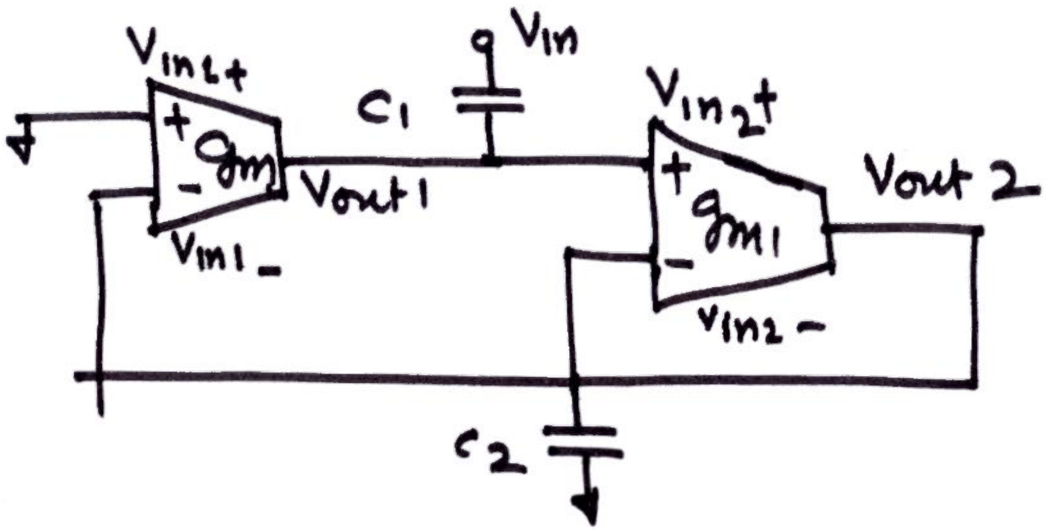
$$= \frac{g_{m1}}{sC_1 + g_{m1} + \dfrac{s^2 C_1 C_2}{g_{m1}}}$$

$$= \frac{g_{m1}^2}{s^2 C_1 C_2 + s\, g_{m1} C_1 + g_{m1}^2}$$

$\Rightarrow \quad H(s) = \dfrac{c}{as^2 + bs + c} \rightarrow$ Two Poles only.
Dominant Pole is cut-off frequency

$\therefore$ This is a Low Pass filter.

Case II : $V_2 = V_{in}$, $V_1 = V_3 = 0$



$$V_{out1} = g_{m1}(0 - V_{out2}) \cdot \frac{1}{j\omega C_1} + V_{in}$$

$$V_{out1} = -\frac{g_{m1} V_{out2}}{j\omega C_1} + V_{in} \quad \text{— (1)}$$

$$V_{out2} = g_{m1}(V_{out1} - V_{out2}) \cdot \frac{1}{j\omega C_2} \quad \text{— (2)}$$

Substituting ① in ②

$$V_{out2} = \frac{g_{m1}}{j\omega C_2}\left[-\frac{g_{m1} V_{out2}}{j\omega C_1} + V_{in} - V_{out2}\right]$$

$$\left[1 + \frac{j\omega C_2}{g_{m1}} + \frac{g_{m1}}{j\omega C_1}\right] V_{out} = V_{in}$$

$$\left[1 + \frac{sC_2}{g_{m1}} + \frac{g_{m1}}{sC_1}\right] V_{out} = V_{in}$$

or

$$\frac{V_{out}}{V_{in}} = A(s) = \frac{1}{1 + \frac{sC_2}{g_{m1}} + \frac{g_{m1}}{sC_1}}$$

$$= \frac{g_{m1} s C_1}{s^2 C_1 C_2 + s g_{m1} C_1 + g_{m1}^2} = \frac{d \cdot s}{a s^2 + b s + C}$$

$$= \frac{s}{a_0 s^2 + b_0 s + c_0}$$

$$H(s) = \frac{s}{as^2+bs+c}$$ is for Bandpass Filter case.

$\therefore$ If we set $V_2 = V_{in}$ & $V_1 = V_3 = 0$

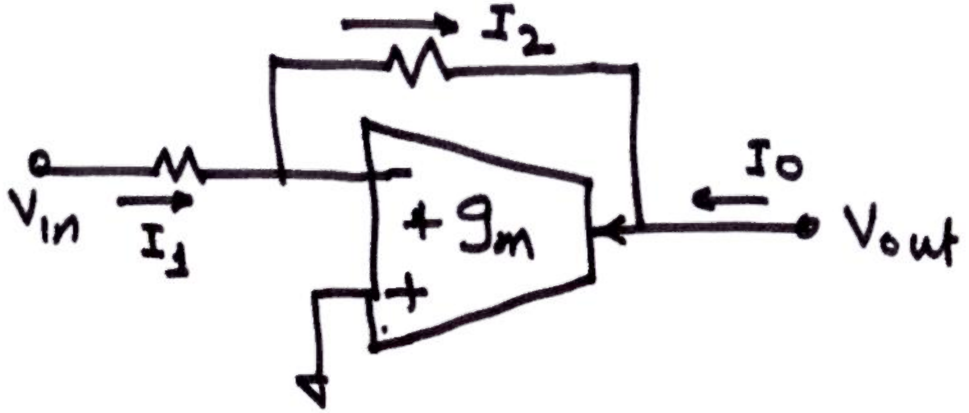
The TWO OTA architecture behaves as Bandpass filter.

Similarly if $V_3 = V_{in}$ & $V_1 = V_2 = 0$, we get

$$A(s) = \frac{s^2 c_1 c_2}{s^2 c_1 c_2 + s c_1 g_{m1} + g_{m1}^2}$$ which is

a transfer function for High pass filter

OTA as Voltage Amplifier



$$I_o = g_m(V^+ - V^-) = -g_m V^-$$

& $$\frac{V_{in} - V_-}{R_1} = I_1 = I_2 = \frac{V_- - V_{out}}{R_2}$$

But $I_o = -I_2$

$$\therefore \frac{V_- - V_{out}}{R_2} = g_m V_- \quad \text{or} \quad \frac{V_{out}}{R_2} = V_-\left(\frac{1}{R_2} - g_m\right)$$

or $V_- = V_o/(1 - g_m R_2)$

Also $I_1 = \dfrac{V_{in} - V_-}{R_1} = \dfrac{V_{in}}{R_1} - \dfrac{V_{out}}{R_1(1-g_mR_2)}$

$$I_2 = \frac{V_- - V_{out}}{R_2} = \frac{\frac{V_{out}}{(1-g_mR_2)} - V_{out}}{R_2}$$

$$= \frac{V_{out}}{R_2}\left[\frac{1}{1-g_mR_2} - 1\right] = \frac{V_{out}}{R_2} \cdot \frac{g_mR_2}{1-g_mR_2}$$

$$= V_{out} \frac{g_m}{1-g_mR_2}$$

Equating $I_1 = I_2$

$$\frac{V_{in}}{R_1} - \frac{V_{out}}{R_1} \cdot \frac{1}{(1-g_mR_2)} = \frac{g_m}{1-g_mR_2} \cdot V_{out}$$

$$\therefore \quad V_{in} = \frac{1+g_m R_1}{1-g_m R_2} V_{out}$$

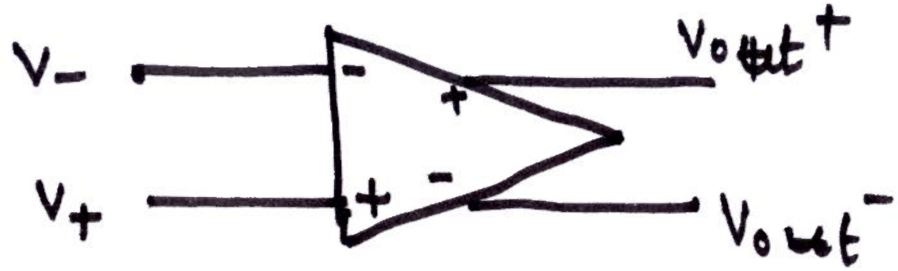
or $$\frac{V_{out}}{V_{in}} = \frac{1-g_m R_2}{1+g_m R_1}$$

If $g_m R_2$ & $g_m R_1 >> 1$

Then $$\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$$

Same as OPAMP based Amplifier.

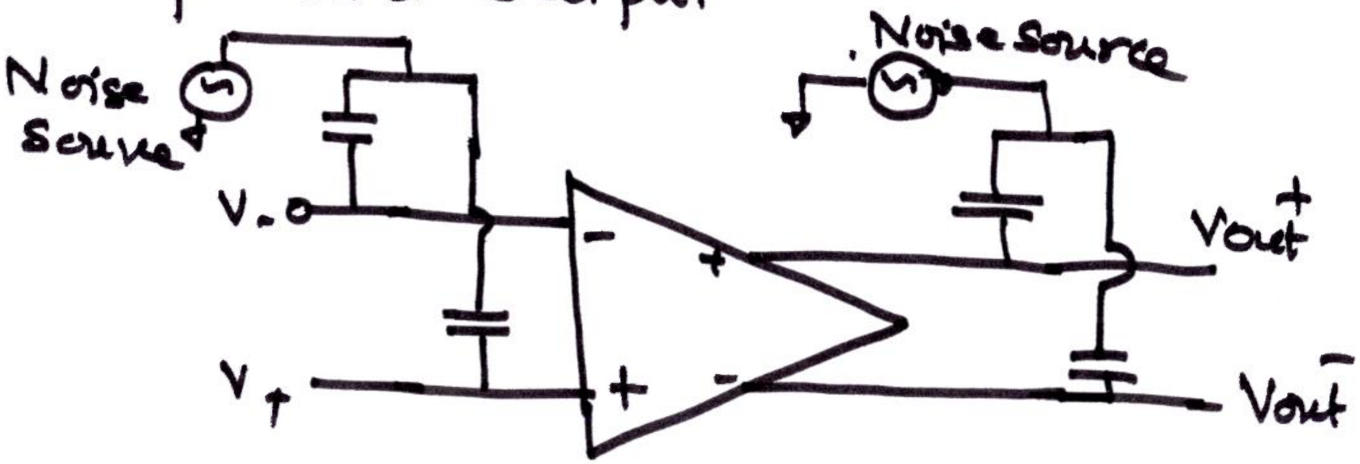
Fully Differential OPAMP



Fully differential (outputs) Amplifiers have certain advantages over Single ended OPAMPs.

1. Larger Output Swings as V_{out}^+ & V_{out}^- are independently handled
2. May result in Better or Superior Frequency performance as 'No' Miller Capacitance is used

The biggest advantage of fully Differential System is Rejection of Noise overiding at parasitic capacitances both at the Input and output.



$$V_-' = V_- + V_N \quad , \quad V_+' = V_+ + V_N$$

$$\therefore \quad V_+' - V_-' = V_+ - V_-$$

Same wave $V_{out}^{+}{}' - V_{out}^{-}{}' = V_{out}^+ - V_{out}^-$

However to achieve these better properties we need to create a 'COMMON MODE FEEDBACK' circuit (CMFB) which maintains

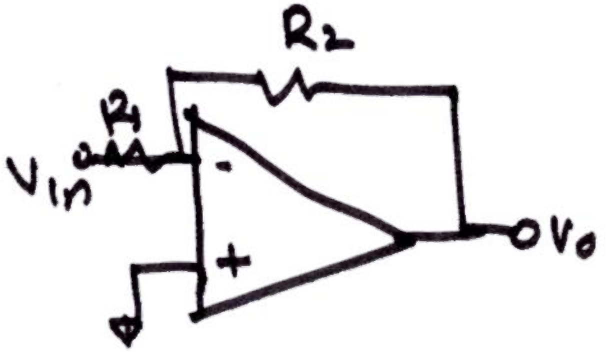
For Fully Differential OPAMP, the Open-Loop Gain (DC) A_{OLDC} is

$$A_{OL} = \frac{V_{out}^{+} - V_{out}^{-}}{V_{+} - V_{-}}$$

If we have single-ended OPAMP, then

$$A_{OL} = \frac{V_{out}^{+}}{V_{+} - V_{-}}$$

Hence if we only consider one of the output V_o^+ in Fully Differential case and use −ve Feedback similar to that we use in Single-ended OPAMP based Amplifier.



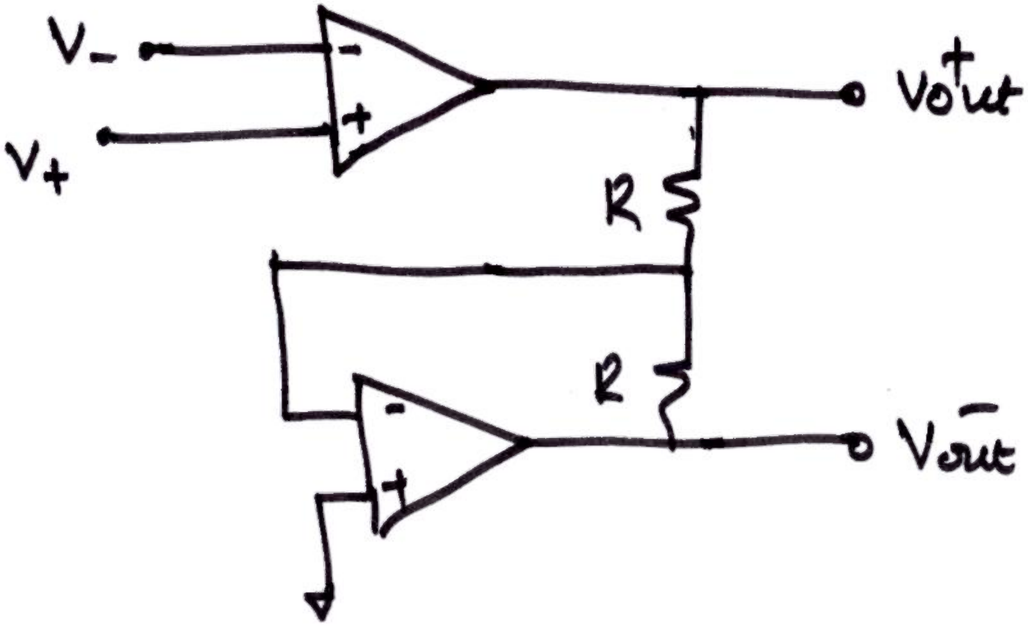
Here we invoke the rule that R_{in} is Very Very Large, or to say currents donot enter in OPAMP for −ve or +tive inputs, then we get $V_- = V_+$

$$A_{OCL} = -\frac{R_2}{R_1}$$

$$A_{OOL} = -\frac{V_o}{V_{in}}$$

Extending this to Differential Case we can say $V_o^+ = -V_o^-$

This is equivalently saying, a Differential Amplifier can be realised by two single ended Amplifiers



Due to difference in Input connectivity in two OPAMPs, the Phase Margins for two Differs a lot and hence Bandwidth observed for this case is very much Limited.