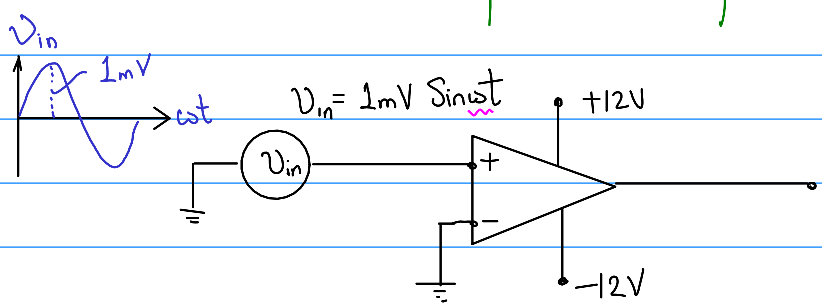
21.12.2023

Op-Amp.

Recap: (i) Ideal & Practical Op-Amp. Parameters

(ii) Differential & Common mode Operation

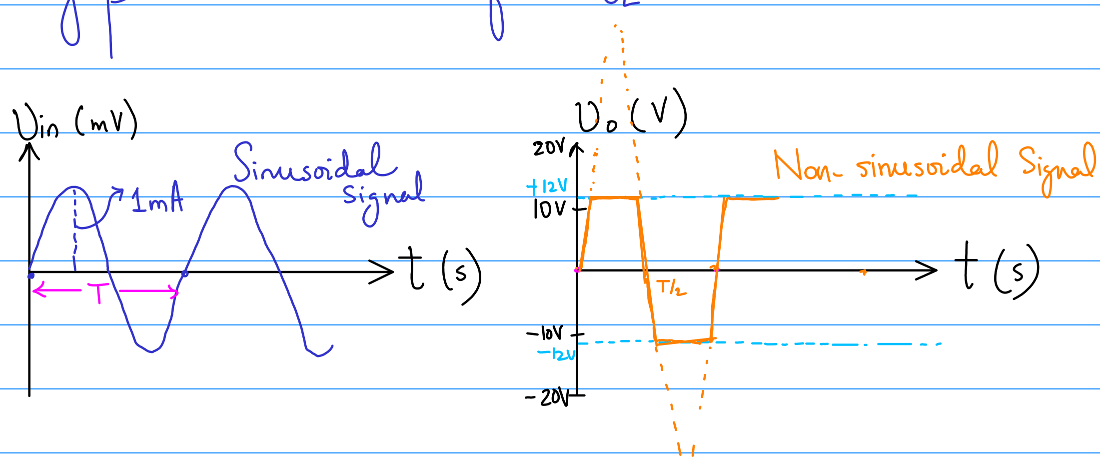
Q: Lets us understand what will happen when we connect the ckt. as per the following:



$v_o = A_{OL} \cdot v_{in} = 10^5 \cdot 1mV \sin\omega t$

$v_o = \underline{100V \sin\omega t}$

Assuming practical value of $A_{OL} = 10^5$

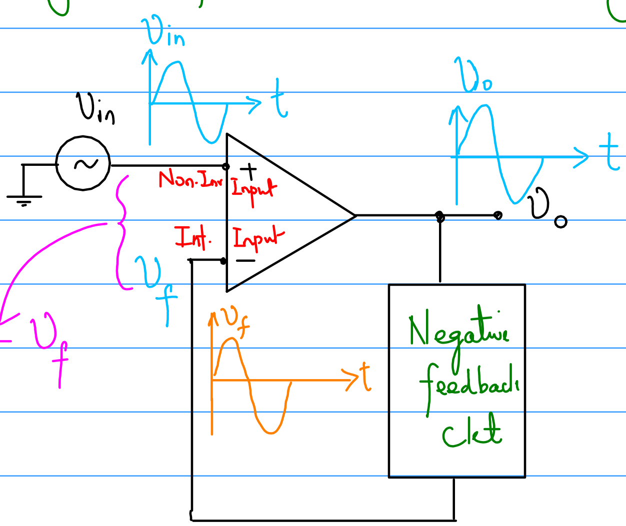


Open loop configuration leads to distortion in the signal.

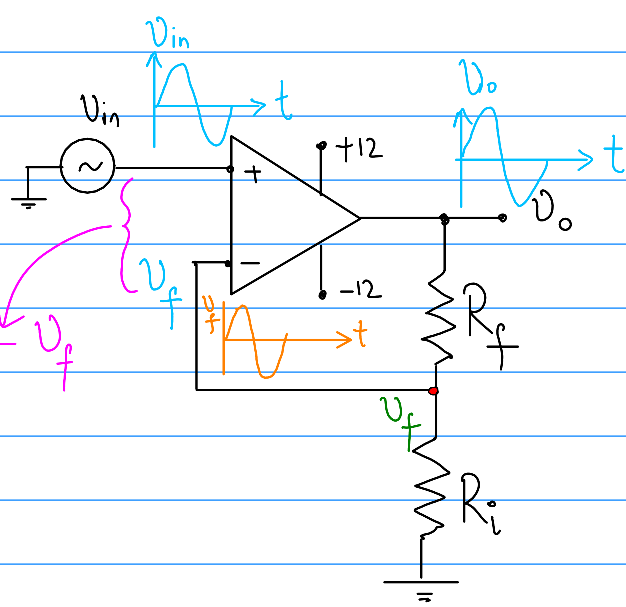
Negative Feedback:

1. Tune the gain of the op-amp with help of external ckt. element (Resistor.)
   — Controlled gain. (Tune the gain as per the need of the circuit)
2. By tuning the gain, we can restrict the op-amp to operate in linear regime. (Not to go into saturation regime).

Non-inverting Amp. ckt. with negative feedback:



$v_{diff} = v_{in} - v_f$



Differential Input

$v_{diff} = v_{in} - v_f$

$$v_f = \underbrace{\frac{R_i}{R_i + R_f}}\, v_o$$

$$v_f = B v_o$$

where $B = \frac{R_i}{R_i + R_f}$

Now, with the negative feedback ckt; the op-amp have effective differential input voltage;

$$V_{diff}(input) = \underbrace{V_{in}}_{\text{applied to NI input}} - \underbrace{V_f}_{\text{applied to inverting input}}$$

$$V_{diff}(input) = V_{in} - BV_o$$ where $B = \frac{R_i}{R_i+R_f}$

If we have open-loop gain A_{OL}

$$V_o = A_{OL} \cdot V_{diff}(input)$$ where A_{OL} = Open-loop gain.

$$\Rightarrow V_o = A_{OL} \cdot (V_{in} - BV_o)$$

$$\Rightarrow V_o + A_{OL} \cdot B \cdot V_o = A_{OL} \cdot V_{in}$$

$$\Rightarrow V_o (1 + A_{OL} \cdot B) = A_{OL} \cdot V_{in}$$

$$\Rightarrow \frac{V_o}{V_{in}} = \frac{A_{OL}}{1 + A_{OL} \cdot B}$$

$$\Rightarrow A_{CL(NI)} = \frac{V_o}{V_{in}} = \frac{A_{OL}}{1 + A_{OL} \cdot B}$$

$$\Rightarrow \boxed{A_{CL(NI)} = \frac{A_{OL}}{1 + A_{OL} \cdot B}}$$

as we know, $A_{OL} \sim 10^4 - 10^6$ & $B = \frac{R_i}{R_i + R_f}$

the product $A_{OL} \cdot B \gg 1$

Under this condⁿ:

$$A_{CL(NI)} = \frac{\cancel{A_{OL}}}{\cancel{A_{OL}} \cdot B}$$

$$\Rightarrow \quad A_{CL(NI)} \simeq \frac{1}{B} = \frac{R_i + R_f}{R_i}$$

Eg: $A_{CL(NI)} = 50$

$\frac{R_f}{R_i} \sim 50$

$R_f \simeq 50 R_i$

$$\Rightarrow \quad \boxed{A_{CL(NI)} = 1 + \frac{R_f}{R_i}}$$

under the condⁿ $A_{OL} \cdot B \gg 1$

Conclusion: • Closed loop gain is independent of the value of the open-loop gain.

OR

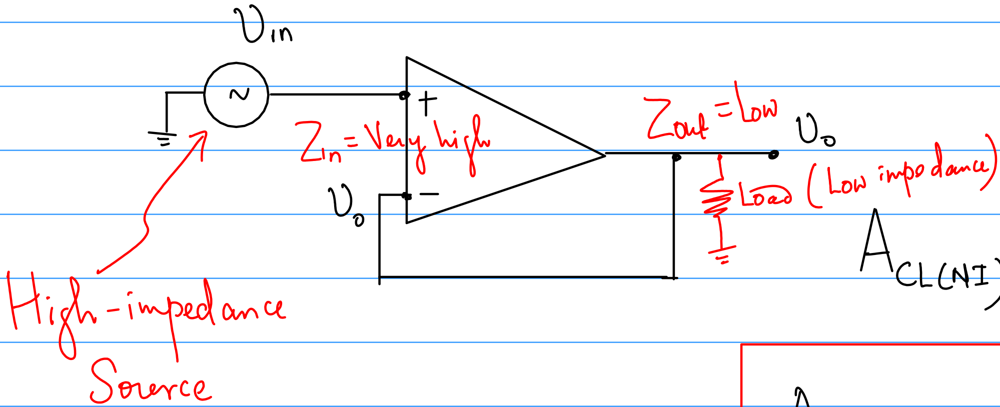
Closed loop gain is dependent on the external ckt element. (R_i & R_f)

	VOLTAGE GAIN	INPUT Z	OUTPUT Z	BANDWIDTH
1.) Without negative feedback (open loop)	A_{ol} is too high for linear amplifier applications $10^4 - 10^6$	Relatively high (see Table 12–1) ~ MΩ	Relatively low ~ few Ω	Relatively narrow (because the gain is so high) 1 Hz
2) With negative feedback	A_{cl} is set to desired value by the feedback circuit (R_i & R_f) $A_{CL} = 1 + \frac{R_f}{R_i}$ dependent	Can be increased or reduced to a desired value depending on type of circuit (R_i & R_f) dependent	Can be reduced to a desired value (R_i & R_f) dependent	Significantly wider dependent

Voltage-Follower ckt :

High-impedance Source → Low-impedance load!

$\Rightarrow$ in voltage-follower ckt : $A_v = 1$ (unity)

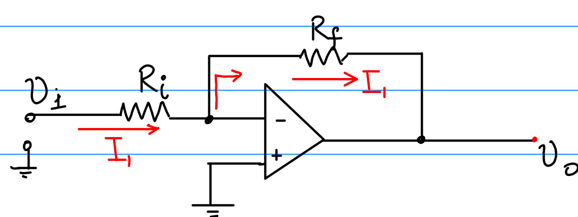


$$A_{CL(NI)} = 1 + \frac{R_f}{R_i}$$

Not connected

$$\boxed{A_{CL(NI)} \simeq 1}$$

Inverting Closed-Loop Configuration :



$$v_o = -R_f I_1 = -R_f \left(\frac{v_1}{R_i}\right) = \left(-\frac{R_f}{R_i}\right) v_1$$

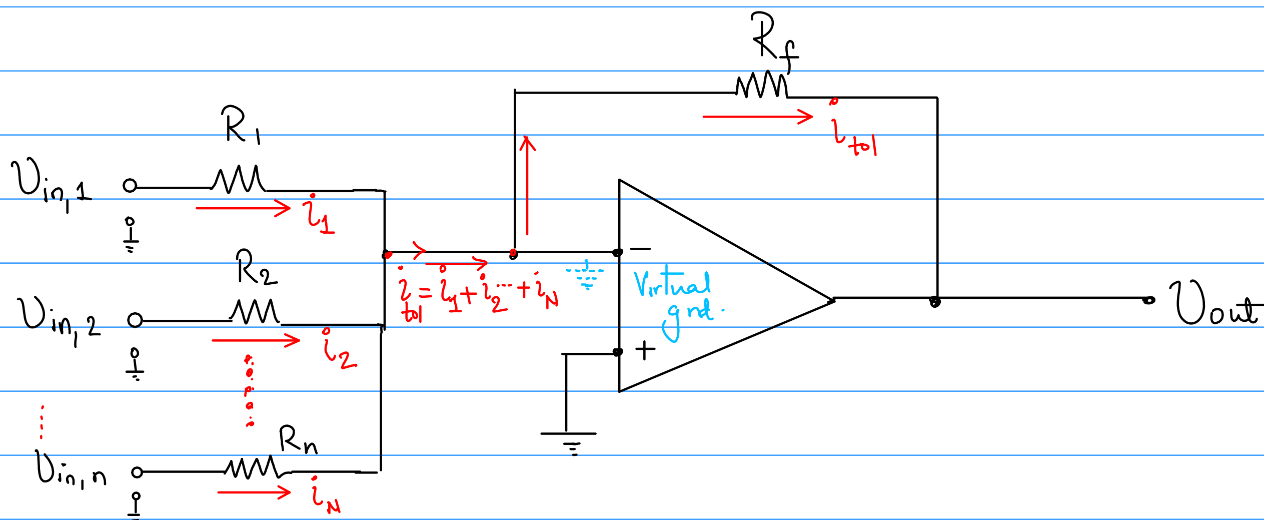
$$\Rightarrow A_{CL(IN)} = \frac{v_o}{v_1} = \frac{-R_f}{R_i}$$

$$\boxed{A_{CL(IN)} = -\frac{R_f}{R_i}}$$

Op-Amp : Applications

1. Summing Amplifiers :

- Make use of inverting op-amp configuration
- It has two or more input voltages connected to the inverting input terminal.
- Output voltage is proportional to negative of the algebraic sum of its input voltages



Total current through R_f is given as

$$i_{tot} = i_1 + i_2 \cdots + i_N \quad \text{where,} \quad i_1 = \frac{V_{in,1}}{R_1}$$

$$i_2 = \frac{V_{in,2}}{R_2}$$

here,

$$V_{out} = -R_f \, i_{tot} = -R_f \left(i_1 + i_2 + \cdots + i_N \right)$$

$$V_{out} = -R_f \left[\frac{V_{in,1}}{R_1} + \frac{V_{in,2}}{R_2} + \cdots + \frac{V_{in,N}}{R_N} \right]$$

$$V_{out} = -\left[\frac{V_{in1}}{R_1} + \frac{V_{in,2}}{R_2} + \cdots \frac{V_{in,N}}{R_N}\right] R_f$$

finally,

$$\boxed{V_{out} = -\left[V_{in1}\left(\frac{R_f}{R_1}\right) + V_{in,2}\left(\frac{R_f}{R_2}\right) + \cdots V_{in,N}\left(\frac{R_f}{R_N}\right)\right.}$$

Special Case: $R_1 = R_2 = \cdots R_N = R_f = R$

$$\boxed{V_{out} = -\left(V_{in,1} + V_{in,2} + \cdots V_{in,N}\right)}$$

(i) Generalization: Let we have 'n' number of input voltages and $R_1 = R_2 = R_3 \cdots\cdots = R_f = R$

$$V_{out} = -\left(V_{in,1} + V_{in,2} + \cdots\cdots + V_{in,n}\right)$$

(ii) Summing amplifier with gain greater than unity

$$R_1 = R_2 = R_3 = \cdots R_n = R$$

$$R \neq R_f$$

$$V_{out} = \underbrace{-\left(\frac{R_f}{R}\right)}_{\text{factor with which the sum of inputs is multiplied with.}}\left[V_{in,1} + V_{in,2} + \cdots\cdots + V_{in,n}\right]$$

(iii) Lets choose $\frac{R_f}{R} = \frac{1}{n}$ where 'n' is the number of input voltages.

$$V_{out} = -\frac{1}{n}\left[V_{in,1} + V_{in,2} + \cdots + V_{in,n}\right]$$

V_{out} (ave.) $\rightarrow$ Averaging Operation.

(iv) Scaling Adder :

— Assigning different weights to each of the input of the summing amplifier.

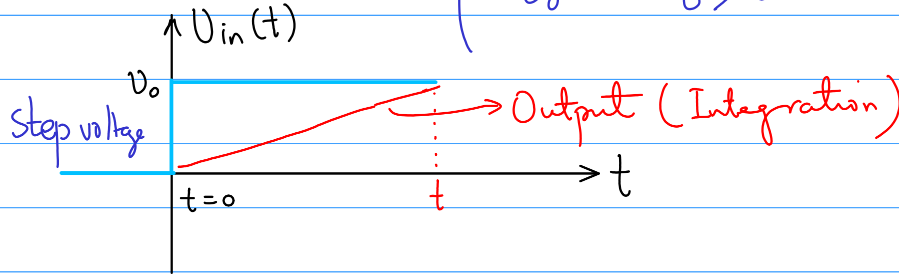
$$V_{out} = -\left[\underbrace{V_{in,1}\left(\frac{R_f}{R_1}\right)}_{\text{Weight to } V_{in\,1}} + \underbrace{V_{in,2}\left(\frac{R_f}{R_2}\right)}_{\text{Weight to } V_{in,2}} + \cdots + \underbrace{V_{in,n}\left(\frac{R_f}{R_n}\right)}_{\text{Weight to } V_{in,n}}\right]$$

2 Integrator Circuit :

Iput is step voltage : $V_{in}(t) = \begin{cases} 0 & t<0 \\ V_0 & t>0 \end{cases}$

$y(x) = \begin{cases} 0 & x<0 \\ C & x>0 \end{cases}$

$\int y(x)dx = \{ Cx$



Integration of input voltage

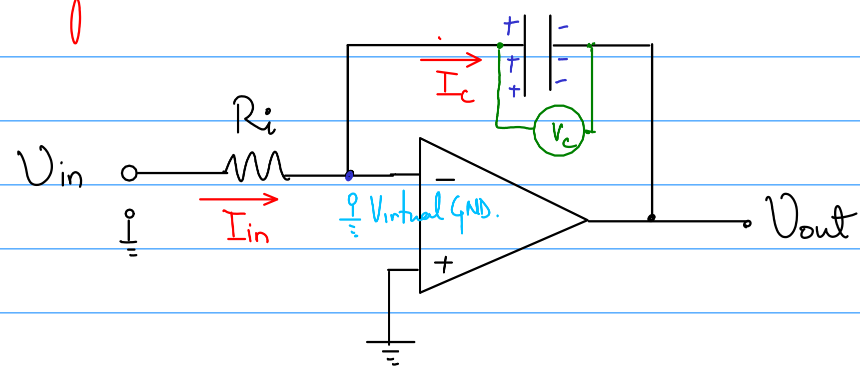
$$\int_{-\infty}^{\infty} V_{in}(t)\,dt = \underbrace{\int_{-\infty}^{0} V_{in}(t)\,dt}_{0} + \underbrace{\int_{0}^{\infty} V_{in}(t)\,dt}_{\int_0^t V_s\,dt}$$

$$= \quad = V_s t$$

Integration of constant input voltage (w.r.t 't') is a linear function of 't'.

Ideal Integrator ckt :

C (Feedback Element)



$$I_{in} = \frac{V_{in}}{R_i} = \text{Constant}$$

$$I_c = I_{in} = \text{Constant}$$

We know that the charge on the capacitor at any time 't' is given as

$$Q = I_c t$$

$$V_c = \frac{Q}{C} = \left(\frac{I_c}{C}\right) t$$

$$\boxed{V_c = \left(\frac{I_c}{C}\right) t}$$

$$\{ Y = MX + C \}$$

Now, $$V_{out} = -V_c = -\left(\frac{I_c}{C}\right) t$$

$$V_{out} = -\left(\frac{V_{in}}{R_i C}\right) t$$

$\left\{ I_c = I_{in} = \frac{V_{in}}{R_i} \right.$

$$\boxed{V_{out} = \frac{-1}{R_i C} V_{in}\, t}$$

$Y = MX$

$M = \frac{-V_{in}}{R_i C}$

$X = t$

$Y = V_{out}$