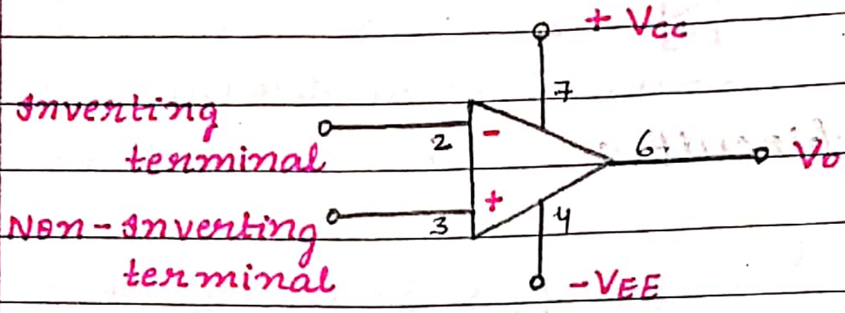
Unit - 03

* Operational Amplifier (OP-Amp)

⇒ Symbol. -



- The operational Amplifier or OP-AMP is a very high gain differential Amplifier with high input and low output impedence.

- It can perform various operations like addition, subtraction, integration, differentiation and many more; that is why it is named as OPERATIONAL AMPLIFIER or OP-AMP.

⇒ Differential Inputs :

- When seperate inputs are applied to the OP-AMP, the resulting difference signal is the difference between two inputs.

$$V_d = V_{i1} - V_{i2}$$

⇒ Common Inputs :

- When both input signals are same, a common signal due to two inputs can be defined as the average of sum of two signals.

$$V_c = \frac{V_{i1} + V_{i2}}{2}$$

⇒ output voltage :

- Since any signal applied to an OP-AMP, in general have both In-phase and outer phase components, the resulting output can be expressed as –

$$V_o = A_d V_d + A_c V_c$$

where, A_d → Difference Gain (Dominant factor)
V_d → Difference Input voltage
A_c → Common gain
V_c → Common Input voltage

* CMRR (Common Mode R[illegible] Ratio) :

- The ability of an OP-AMP to reject common mode signals is expressed by the ratio called Common Mode Rejection.

- Mathematically, it is defined as the ratio of differential voltage gain to common voltage gain.

$$CMRR = \frac{A_d}{A_c}$$

$$CMRR(dB) = 20 \log\left(\frac{A_d}{A_c}\right)$$

Ques Find the output voltage 'V_o' of an OP-AMP where differential gain is 10^3, common mode rejection ratio is 1000 and input voltages are 10 µV and 20 µV.

⇒ $A_d = 10^3$, CMRR = 1000

$V_d = V_1 - V_2 = 10\,\mu V$

$$V_o = \frac{V_1 + V_2}{2} = 15\,\mu V$$

$$CMRR = \frac{A_d}{A_c} \Rightarrow 1000 = \frac{10^3}{A_c}$$

$$\Rightarrow A_c = \frac{10^3}{1000}$$

$$\Rightarrow \boxed{A_c = 1}$$

Ques Determine the V_o of an OP-AMP for the V_{in} of 300 µV and 240 µV. The $A_d = 5000$ and CMRR = 10^5.

⇒ $A_d = 5000$, $V_1 = 300\,\mu V$, $V_2 = 240\,\mu V$

$V_d = V_1 - V_2 = (300 - 240)\,\mu V$

$$V_c = \frac{V_1 + V_2}{2} = \frac{300 + 240}{2} = \frac{540}{2}$$

$$\Rightarrow V_c = 270\,\mu V$$

$$CMRR = \frac{A_d}{A_c}$$

$$\Rightarrow 10^5 = \frac{5000}{A_c} \Rightarrow A_c = \frac{5000}{10^5} = 5 \times 10^{-2} = 0.05$$

$V_o = A_d V_d + A_c V_c$

$= (5000)(60 \times 10^{-6}) + (0.05)(270 \times 10^{-6})$

$= (30 \times 10^{-6+3}) + 13.5 \times 10^{-6}$

$V_o = \underline{0.3000135 \text{ V}}$

Ques Two inputs of the OP-AMP are 745 μV and 740 μV and $A_d = 5 \times 10^5$ and CMRR = 80 dB. Calculate V_o and % error due to common mode ($A_c V_c$).

⇒ $CMRR = 20 \log\left(\frac{A_d}{A_c}\right)$

$\Rightarrow 80 = 20 \log\left(\frac{5 \times 10^5}{A_c}\right)$

$\Rightarrow \frac{80}{20} = \log\left(\frac{5 \times 10^5}{A_c}\right)$

$\Rightarrow 10^4 = \frac{5 \times 10^5}{A_c}$

$\Rightarrow A_c = \frac{5 \times 10^5}{10^4} = 50$

$V_d = V_1 - V_2 = 745 - 740 = \underline{5 \, \mu V}$

$V_c = \frac{V_1 + V_2}{2} = \frac{745 + 740}{2} = \frac{1485}{2} = \underline{742.5 \, \mu V}$

$V_o = A_d V_d + A_c V_c$

$\Rightarrow V_o = (5 \times 10^5)(5 \times 10^{-6}) + (50)(742.5 \times 10^{-6})$

$\Rightarrow V_o = \underline{2.537275 \text{ V}}$

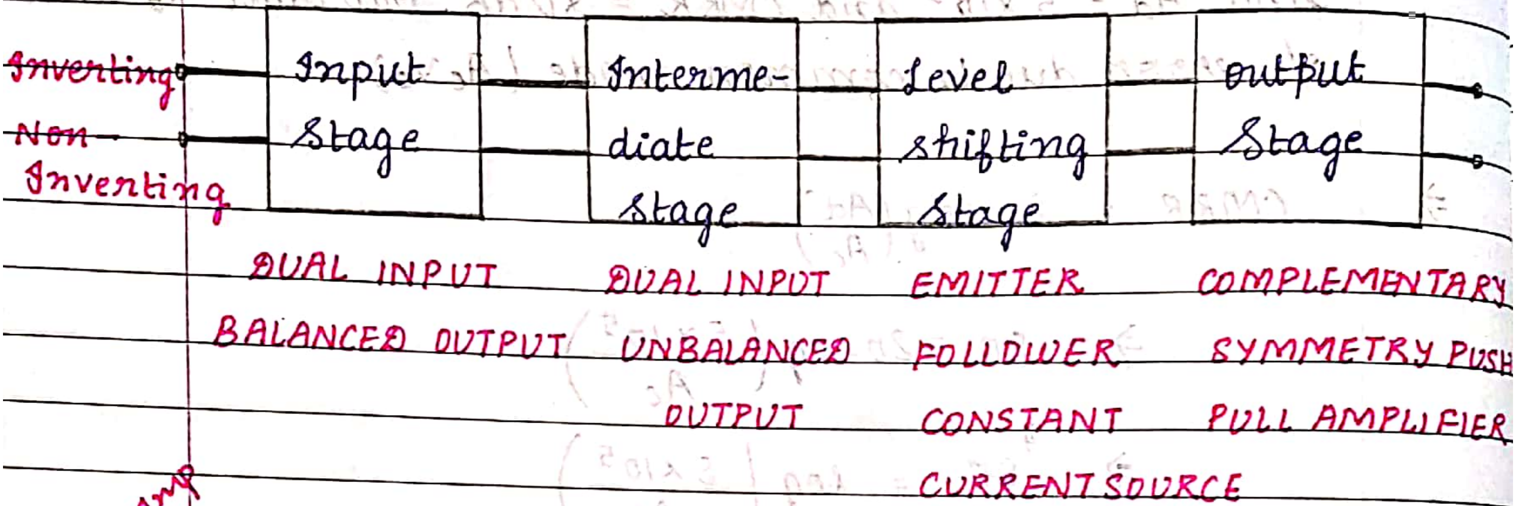
$\% \text{ Error} = \left[\frac{V_o - A_d V_d}{V_o}\right] \times 100$ { we are finding for $A_c V_c$ }

$= \frac{A_c V_c}{V_o} \times 100$

$$\% \text{ Error} = \frac{0.037 \times 100}{2.537} = 1.458\%$$

V.V.Imp

* BLOCK DIAGRAM OF OP-AMP :-



V.V.V.V.V.Imp ★★★

* IDEAL AND PRACTICAL CHARACTERISTICS OF OPAMP :

S.No	Characteristics	Symbol	Ideal Value	Practical Value
1)	Voltage Gain	A_v	∞	2×10^5
2)	Input Impedence	R_{in} or Z_{in}	∞	$2\,M\Omega$
3)	Output Impedence	R_o or Z_o	0	$75\,\Omega$
4)	CMRR	CMRR	∞	90 dB
5)	Bandwidth	BW	∞	1 MHz
6)	PSRR	PSRR	0	150 μV/V

S.No.	Characteristics	Symbol	Ideal Value	Practical Value
7)	Slew Rate	SR	∞	0.5 v/μsec
8)	Offset Voltage	V_{ios}	0	2 mV
9)	Offset Current	I_{ios}	0	6 nA

* Slew Rate :

- The parameter slew rate is actually defined as the maximum rate of change of output voltage with time and expressed in v/μs

Mathematically given as –

$$SR = \left(\frac{dV_0}{dt}\right)_{max}$$

- Infinite slew rate indicates that the output changes simultaneously with the changes in the input voltage.

* Power Supply Rejection Ratio : (PSRR)

- The degree of dependance of output on the changes in the power supply voltage.
- It is expressed in μv/v or dB and its ideal value is 0 (zero)

* Offset Voltage :

The presence of small output voltage, even when both the inputs, i.e. $V_1 = V_2 = 0$ is called offset voltage. And ideally it is 0 (zero) for OP-AMP.

* Offset Current :

$$(I_i)_{os} = |I_{b1} - I_{b2}|$$

BIASE CURRENT, $$I_B = \frac{I_{b1} + I_{b2}}{2}$$

Ques If the base currents of the emitter coupled transistors of a differential amplifier are 18 uA and 22 uA. Determine –

(i) Input bias current

(ii) Input offset current

Ans (i) $I_b = \frac{22+18}{2} = \frac{40}{2} = 20\,\mu A$

(ii) $(I_i)_{os} = |I_{b1} - I_{b2}| = |22-18| = 4\,\mu A$

Ques An OP-AMP has slew rate 15 v/us. Then calculate its full power bandwidth for a peak voltage of 10 V.

Ans $V_o = V \sin \omega t$

$$S.R. = \left(\frac{dV_o}{dt}\right)_{max} = 15\ V/\mu s$$

$$\Rightarrow \frac{dV_o}{dt} = V\omega \cos \omega t$$

$$\left(\frac{dV_o}{dt}\right)_{max} \rightarrow (\cos \omega t)_{max} \rightarrow 1$$

$$\Rightarrow V\omega_{max} = 15$$

$$\Rightarrow \omega_{max} = \frac{15}{V} = \frac{15}{10} = 1.5$$

$$f_{max} = \frac{S.R.}{2\pi V} = \frac{15}{2\pi 10} \times \frac{1}{10^{-6}} = 0.238 \times 10^6 \text{ Hz}$$

$$= 238.7 \text{ KHz}$$

Ques For an OP-AMP the input offset current in 20 nA while input bias current is 60 nA. Calculate the values of two input bias current.

Ans

$$(I_i)_{os} = |I_{b1} - I_{b2}|$$

$$\Rightarrow 20 = I_{b1} - I_{b2} \quad \text{--- (1)}$$

$$I_{b1} + I_{b2} = (60)(2) = 120 \quad \text{--- (2)}$$

$$\Rightarrow I_{b1} - I_{b2} = 20$$

$$I_{b1} + I_{b2} = 120$$

$$2I_{b1} = 140 \Rightarrow I_{b1} = 70 \text{ nA}$$

$$I_{b2} = 70 - 20 = 50 \text{ nA}$$

V.V.V.V.V. Imp

* VIRTUAL SHORT AND VIRTUAL GROUND CONCEPT :-

- **VIRTUAL SHORT :-**

→ If the non-inverting terminal of an OP-AMP have some voltage, then, the inverting terminal will also have the same voltage. This concept is called Virtual Short Concept.

* Whatever potential will be there at the non-inverting terminal (i.e. +ve) same will be there on inverting terminal (i.e. −ve).
⇒ Vice-versa is not possible.

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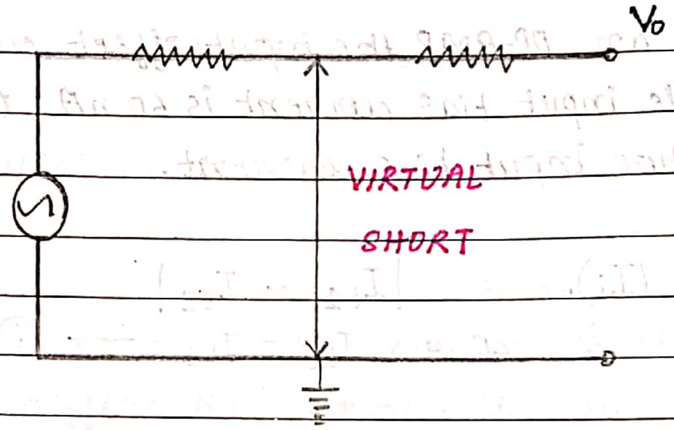
- VIRTUAL GROUND :

If the non-inverting terminal is grounded by the concept of virtual short, the inverting terminal is also at ground potential even though there is no physical connection between terminal and ground. This is called the principle of VIRTUAL GROUND.



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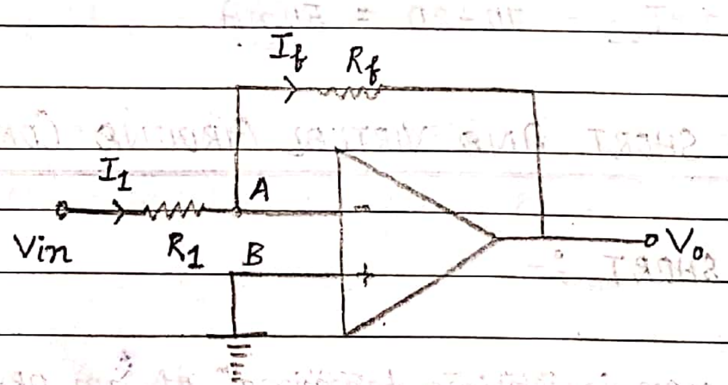
* Inverting Amplifier :-



- An amplifier which provides a phase shift of 180° between input and output is called Inverting Amplifier.

- The basic circuit diagram of inverting amplifier using OP-AMP is shown in figure.

From virtual ground concept,

$$V_A = V_B = 0 \quad \text{--- (1)}$$

On Applying KCL on node A,

Incoming current = Outgoing current

$$\therefore I_1 = I_f \quad \text{--- (2)}$$

$$\Rightarrow \frac{V_{in} - V_A}{R_1} = \frac{V_A - V_o}{R_f}$$

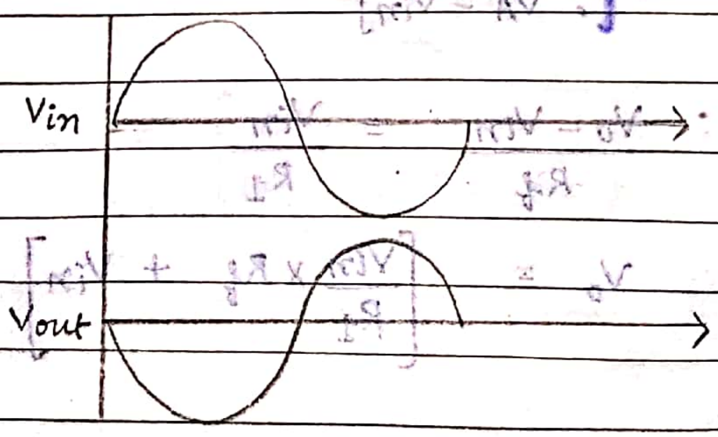
$$[\because V_A = 0]$$

$$\Rightarrow \frac{V_{in}}{R_1} = \frac{-V_o}{R_f}$$

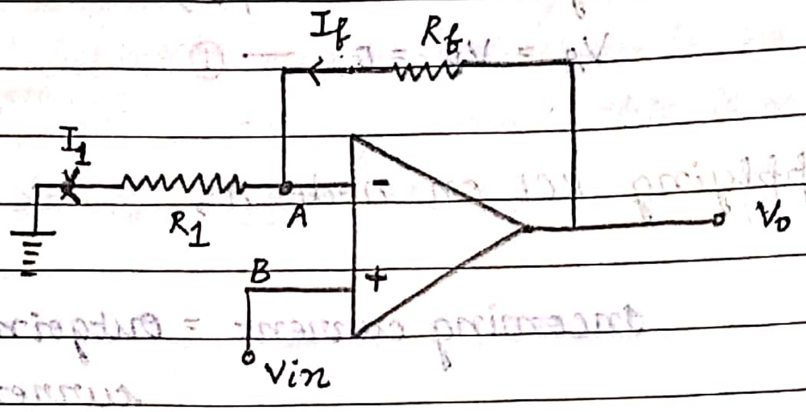
$$\therefore \boxed{V_o = -\frac{V_{in} R_f}{R_1}}$$

Now, $\frac{V_o}{V_{in}} = -\left(\frac{R_f}{R_1}\right)$

$$\boxed{\text{Voltage gain, } \frac{V_o}{V_{in}} = -\left(\frac{R_f}{R_1}\right)}$$



* Non-Inverting Amplifier :



- An amplifier which amplifies the input without producing any face shift between input and output is known as Non-Inverting Amplifier.
- The basic circuit diagram of non-inverting amplifier using OP-AMP is shown in the figure.

From virtual short concept,

$$V_A = V_B = V_{in} \quad \text{—— (1)}$$

On appling KCL at node A,

$$I_f = I_1 \quad \text{—— (2)}$$

$$\Rightarrow \frac{V_o - V_A}{R_f} = \frac{V_A - 0}{R_1}$$

$$[\because V_A = V_{in}]$$

$$\Rightarrow \frac{V_o - V_{in}}{R_f} = \frac{V_{in}}{R_1}$$

$$\Rightarrow V_o = \left[\frac{V_{in}}{R_1} \times R_f + V_{in}\right]$$

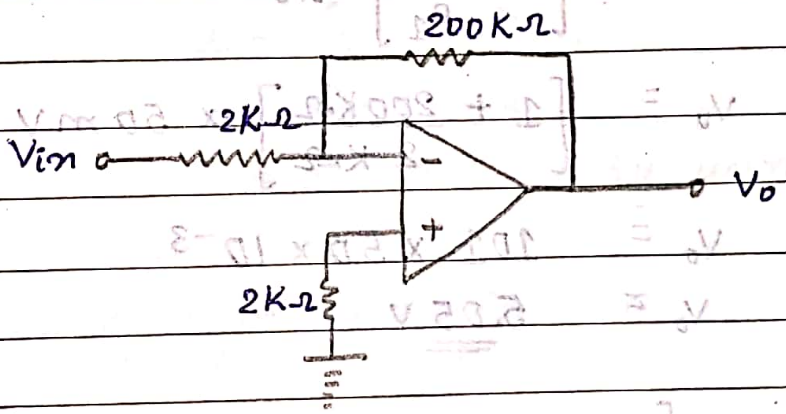
$$\Rightarrow V_o = V_{in}\left[\frac{R_f}{R_1} + 1\right]$$

$$\Rightarrow \boxed{V_o = \left[1 + \frac{R_f}{R_1}\right] V_{in}}$$

$$\Rightarrow \boxed{\frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1} = \text{Voltage Gain}}$$

Ques: For an input of 50 mV in the circuit given, determine the maximum frequency that may be used when the slew rate of OP-AMP is 0.4 V/μs.

Sol^n



$$f_{max} = \left[\frac{S.R.}{2\pi V_o}\right]$$

From inverting amplifier,

$$V_o = -\frac{R_f}{R_1} V_{in} = \frac{-200\ K\Omega}{2\ K\Omega} \times 50\ mV$$

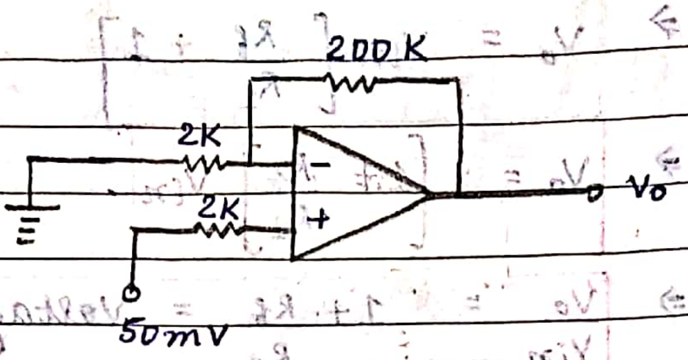
$$V_o = -100 \times 50 \times 10^{-3}$$

$$V_o = 5\ V$$

$$f_{max} = \left[\frac{0.4\ V}{10^{-6} \times 2 \times 3.14 \times 5}\right] = 12.73 \times 10^3\ Hz$$

$$= 12.73\ KHz$$

Ques. $S.R. = 0.4 V/\mu s$



Ans. $$f_{max} = \left[\frac{S.R.}{2\pi V_o}\right]$$

From non-inverting amplifier,

$$V_o = \left[1 + \frac{R_f}{R_1}\right] V_{in}$$

$$V_o = \left[1 + \frac{200 K\Omega}{2 K\Omega}\right] \times 50 mV$$

$$V_o = 101 \times 50 \times 10^{-3}$$

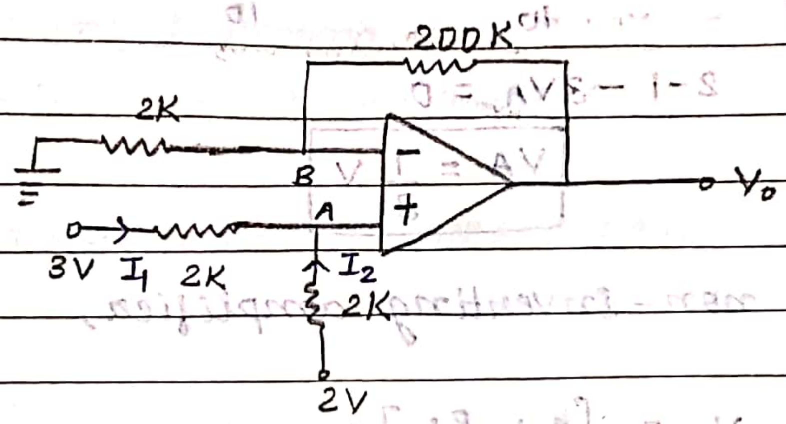
$$V_o = 5.05 V$$

$$f_{max} = \left[\frac{0.4 V}{10^{-6} \times 2 \times 3.14 \times 5.05}\right]$$

$$= 12.606 \times 10^3 Hz$$

$$= 12.606 KHz$$

Ques Determine the V_o for the given circuit,



Sol^n From non-inverting amplifier,

$$V_o = \left[1 + \frac{R_f}{R_1}\right] V_A$$

$\Rightarrow \quad I_1 + I_2 = 0 \qquad$ {By using KCL}

$$\frac{3 - V_A}{2} + \frac{2 - V_A}{2} = 0$$

$\Rightarrow \quad 3 - V_A + 2 - V_A = 0$

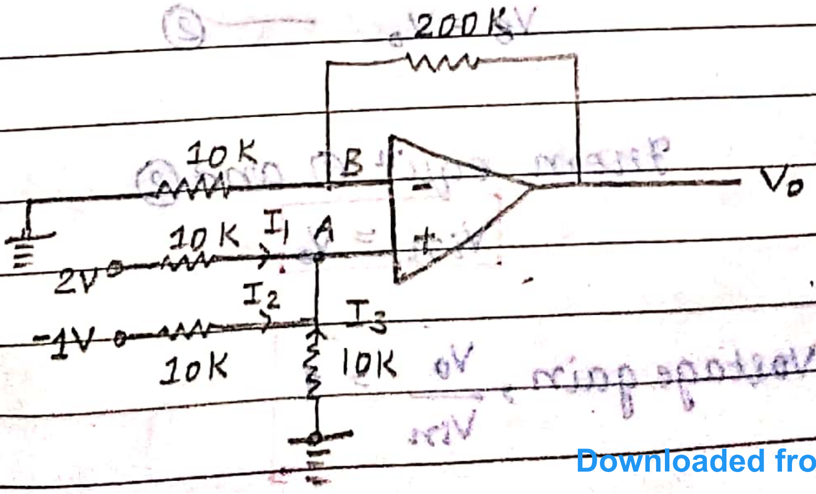
$\Rightarrow \quad 2V_A = 5 \Rightarrow \boxed{V_A = 2.5V}$

$$V_o = \left[1 + \frac{200\,K\Omega}{2\,K\Omega}\right] 2.5$$

$V_o = 101 \times 2.5$

$V_o = 252.5\ V$

Ques



$$I_1 + I_2 + I_3 = 0$$

$$\frac{2 - V_A}{10} + \frac{-1 - V_A}{10} + \frac{0 - V_A}{10} = 0$$

$$2 - 1 - 3V_A = 0$$

$$\boxed{V_A = \frac{1}{3} V}$$

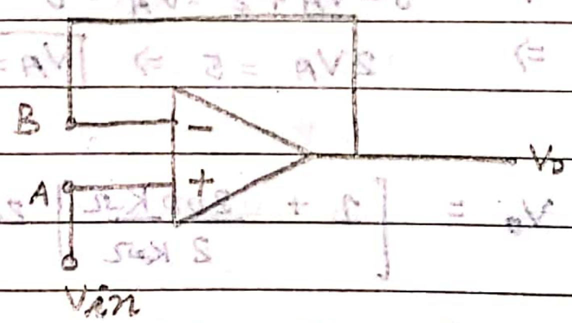
For non-inverting amplifier,

$$V_o = \left[1 + \frac{R_f}{R_1}\right] V_A$$

$$V_o = \left[1 + \frac{20 K\Omega}{10 K\Omega}\right] \times \frac{1}{3}$$

$$V_o = [1 + 2] \times \frac{1}{3} = 3 \times \frac{1}{3} = 1V$$

* **Unity Gain Or Voltage Follower :**



From virtual short concept,

$$V_A = V_B = V_{in} \quad —① $$

$$V_B = V_o \quad —②$$

From equ^n ① and ②

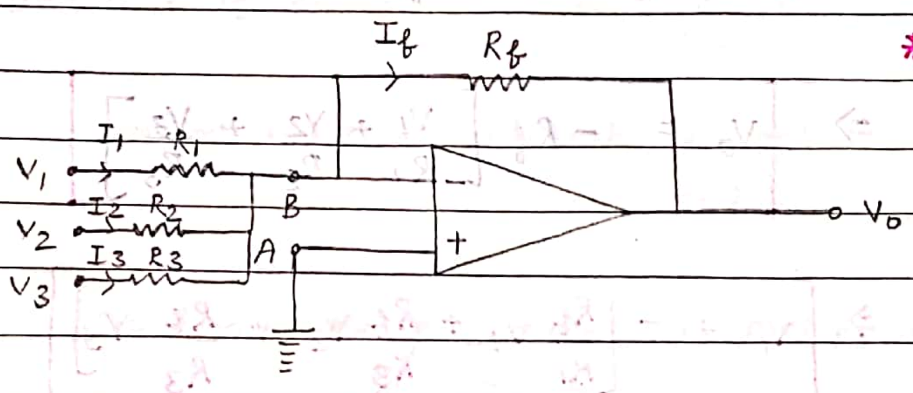
$$\boxed{V_{in} = V_o}$$

$$\boxed{\text{Voltage gain, } \frac{V_o}{V_{in}} = 1}$$

* Summing Amplifier :

(a) Inverting Summing
(b) Non-inverting Summing

(a) ⇒ INVERTING SUMMING AMPLIFIER :



* No. of inputs given should be greater than 1.

- More than one input is provided at the inverting terminal and it will be added at the output side with 180° phase shift is named inverting summing amplifier.

- The circuit diagram of INVERTING SUMMING AMPLFIER using OP-AMP is shown in the figure.

⇒ As terminal A (non-inverting terminal) is grounded from virtual ground concept,

$$V_A = V_B = 0$$

On applying KCL at node B,

$$I_1 + I_2 + I_3 = I_f \quad \text{— ①}$$

$$I_1 = \frac{V_1 - V_B}{R_1}, \quad I_2 = \frac{V_2 - V_B}{R_2}, \quad I_3 = \frac{V_3 - V_B}{R_3}$$

$$I_f = \frac{V_B - V_o}{R_f}$$

As $V_B = 0$ and putting all the values in equ^n ①

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = \frac{-V_o}{R_f}$$

$$\Rightarrow \boxed{V_o = -R_f \cdot \left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right]}$$

$$\Rightarrow \boxed{V_o = -\left[\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right]}$$

If $R_1 = R_2 = R_3 = R$

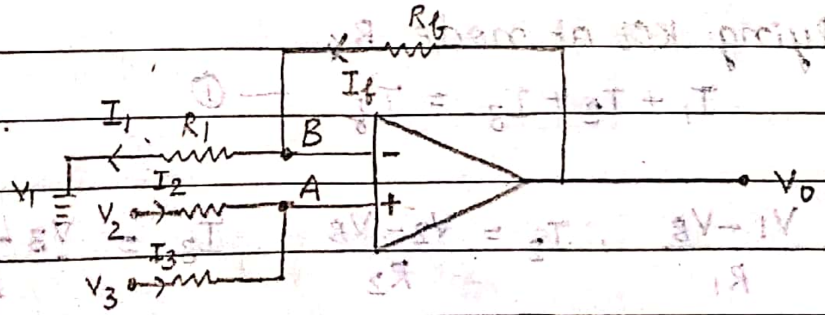
$$\Rightarrow \boxed{V_o = -\frac{R_f}{R}\left[V_1 + V_2 + V_3\right]}$$

If $R_1 = R_2 = R_3 = R_f$

$$\Rightarrow V_o = -\frac{R_f}{R_f}\left[V_1 + V_2 + V_3\right]$$

$$\Rightarrow \boxed{V_o = -\left[V_1 + V_2 + V_3\right]}$$

(b) * NON-INVERTING SUMMING AMPLIFIER :



- A summer circuit that gives amplification of non-inverted sum of input signals is called non-inverting summing amplifier.

- More than one input is applied to the non-inverting terminal and the circuit diagram using OP-AMP is shown in the figure.

From virtual short concept,

$$V_A = V_B \quad \text{—(1)}$$

To find the potential at A i.e. V_A,

$$I_2 + I_3 = 0$$

$$\frac{V_2 - V_A}{R_2} + \frac{V_3 - V_A}{R_3} = 0$$

$$\frac{V_2}{R_2} - \frac{V_A}{R_2} + \frac{V_3}{R_3} - \frac{V_A}{R_3} = 0$$

$$\frac{V_A}{R_2} + \frac{V_A}{R_3} = \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

$$V_A\left[\frac{1}{R_2} + \frac{1}{R_3}\right] = \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

$$V_A\left[\frac{R_2 + R_3}{\cancel{R_2 R_3}}\right] = \left[\frac{V_2 R_3 + V_3 R_2}{\cancel{R_2 R_3}}\right]$$

$$\Rightarrow \boxed{V_A = \frac{V_2 R_3 + V_3 R_2}{R_2 + R_3}} \quad \text{—(2)}$$

Now, applying KCL at node B,

$$I_1 = I_f$$

$$\Rightarrow \frac{V_B - 0}{R_1} = \frac{V_0 - V_B}{R_f}$$

$$\Rightarrow \frac{V_B R_f}{R_1} = V_0 - V_B$$

$$\Rightarrow V_0 = \frac{V_B R_f}{R_1} + V_B$$

$$\Rightarrow V_0 = V_B \left[\frac{R_f}{R_1} + 1 \right] \quad \text{--- (3)}$$

From equ^n (2) and (3)

$$V_0 = \left[1 + \frac{R_f}{R_1} \right] \left[\frac{V_2 R_3 + V_3 R_2}{R_2 + R_3} \right]$$

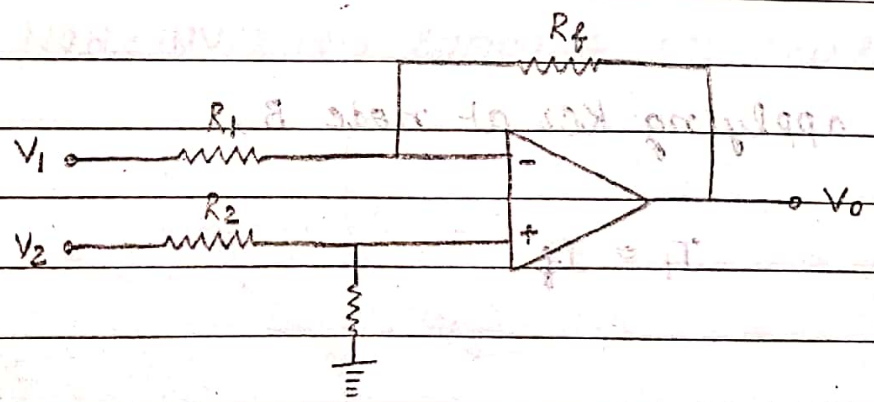
If $R_2 = R_3 = R$

$$\Rightarrow V_0 = \left[1 + \frac{R_f}{R} \right] \left[\frac{V_2 + V_3}{2} \right]$$

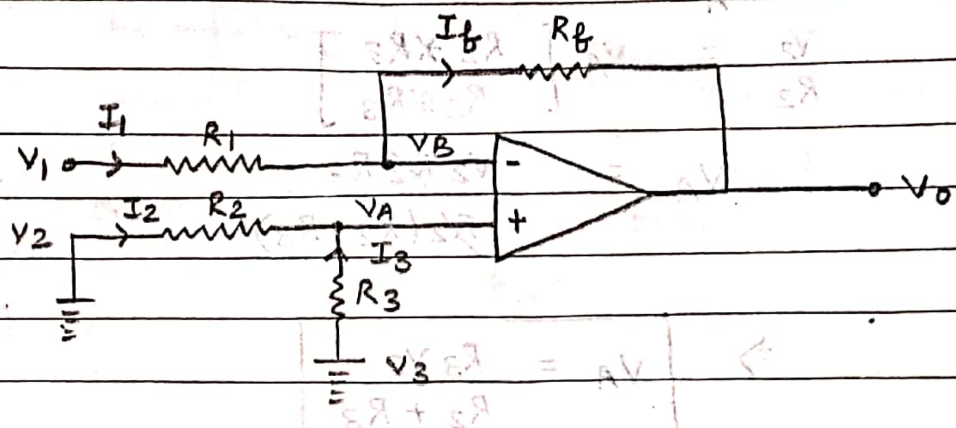
If $R_1 = R_2 = R_3 = R_f$

$$\Rightarrow V_0 = V_2 + V_3$$

* Difference Amplifier (Subtractor):

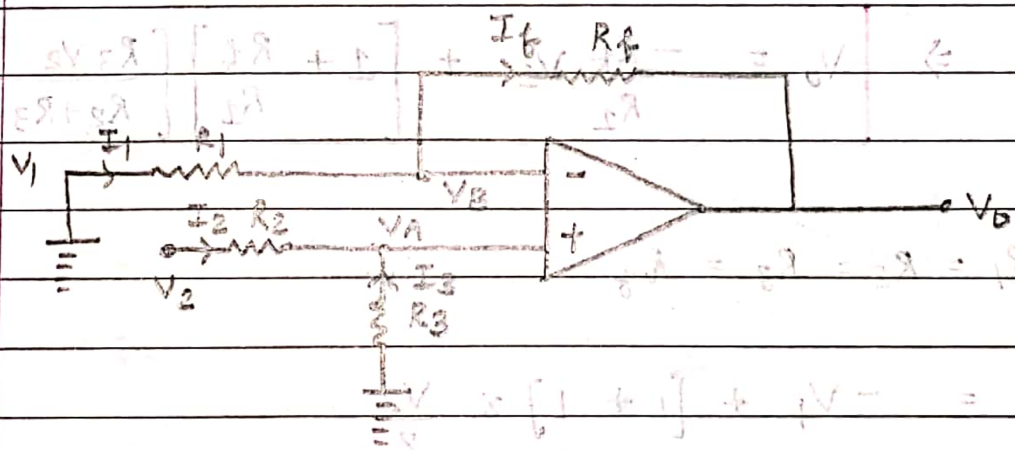


let V_1 is the only input when V_2 is zero and corresponding output is V_{o1}



$$V_{o1} = \frac{-R_f}{R_1} V_1 \quad \text{— ①}$$

let V_2 be the only input when V_1 is zero and corresponding output is V_{o2}.



$$V_{o2} = \left[1 + \frac{R_f}{R_1}\right] V_A$$

Applying KCL at node A,

$$I_2 + I_3 = 0$$

$$\frac{V_2 - V_A}{R_2} + \frac{0 - V_A}{R_3} = 0$$

$$\Rightarrow \frac{V_2}{R_2} - \frac{V_A}{R_2} - \frac{V_A}{R_3} = 0$$

$$\frac{V_2}{R_2} - V_A\left[\frac{1}{R_2} + \frac{1}{R_3}\right] = 0$$

$$\frac{V_2}{R_2} = V_A\left[\frac{R_2 + R_3}{R_2 \times R_3}\right]$$

$$V_A = \frac{V_2 \cancel{R_2} R_3}{\cancel{R_2}(R_2 + R_3)}$$

$$\Rightarrow \boxed{V_A = \frac{R_3 V_2}{R_2 + R_3}}$$

$$\Rightarrow \boxed{V_{o2} = \left[1 + \frac{R_f}{R_1}\right]\left[\frac{R_3 V_2}{R_2 + R_3}\right]} \quad — (2)$$

Therefore, total output, $V_o = V_{o1} + V_{o2}$

$$\Rightarrow \boxed{V_o = -\frac{R_f}{R_1} V_1 + \left[1 + \frac{R_f}{R_1}\right]\left[\frac{R_3 V_2}{R_2 + R_3}\right]}$$

If $R_1 = R_2 = R_3 = R_f$

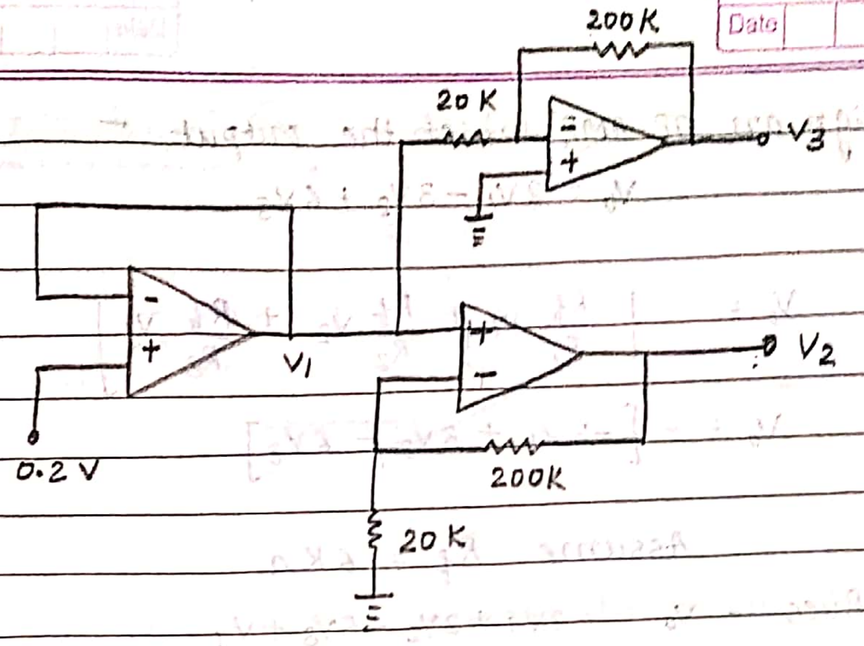
$$V_o = -V_1 + [1 + 1] \times \frac{V_2}{2}$$

$$\boxed{V_o = V_2 - V_1}$$

−ve par input → Inverting

+ve par input → Non-Inverting

Ques

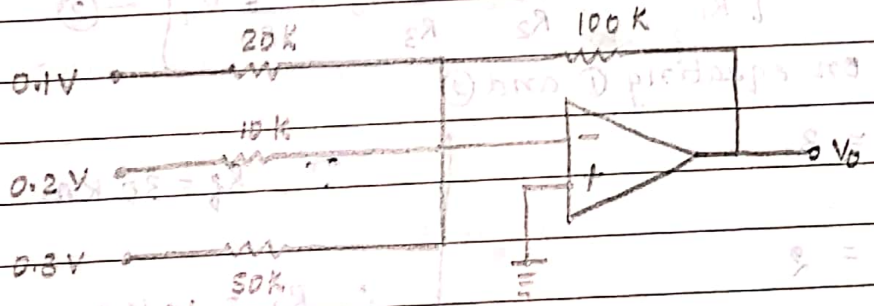


$V_1 = 0.2\,V$ [Unity Gain]

$$V_2 = \left[1 + \frac{R_f}{R_1}\right] V_{in} = \left(1 + \frac{200}{20}\right) 0.2 =$$

$$V_3 = \frac{-R_f}{R_1} V_{in} = \frac{-200}{20}(0.2) = 2V$$

Ques



$$V_0 = -\left[\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right]$$

$$= -\left[\frac{100}{20} \times 0.1 + \frac{100}{10} \times 0.2 + \frac{100}{50} \times 0.3\right]$$

$$= [0.5 + 2 + 0.6]$$

$$= 3.1\ V$$

Ques Design an OP-AMP which the output –

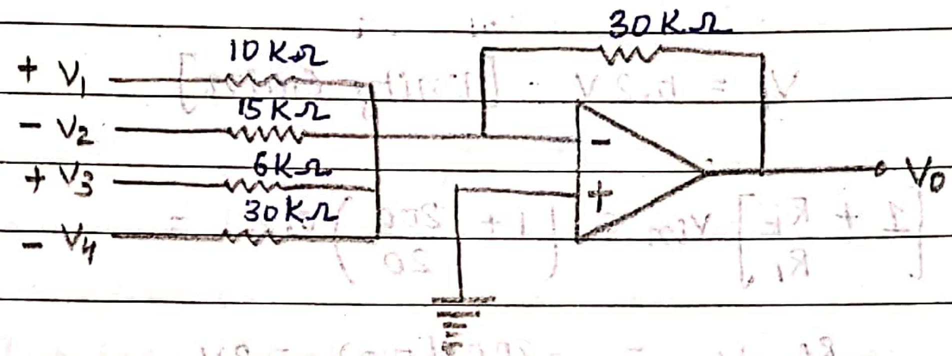
$$V_0 = 2V_1 - 3V_2 + 6V_3$$

$$V_0 = -\left[\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right]$$

$$V_0 = -\left[-2V_1 + 3V_2 - 6V_3\right]$$

Assume $R_f = 6\,K\Omega$

⇒ ~~Ques – $V_0 = -3V_1 + 2V_2 - 5V_3 + V_4$~~



2, 3, 6
3, 1, 1, 3
3

$$V_0 = -[3V_1 - 2V_2 + 5V_3 - V_4] \quad \text{—} ①$$

$$V_0 = -\left[\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3 + \frac{R_f}{R_4}V_4\right] \quad \text{—} ②$$

On equating ① and ②

Resistance can not be −ve ∴ don't take the sign.

$\frac{R_f}{R_1} = 3$

$\frac{R_f}{R_2} = 2$

$\frac{R_f}{R_3} = 5$

$\frac{R_f}{R_4} = 1$

Assume $R_f = 30\,K\Omega$

(R_f = L.C.M of 3, 2, 5, 1)

∴ $R_f = 30\,K\Omega$

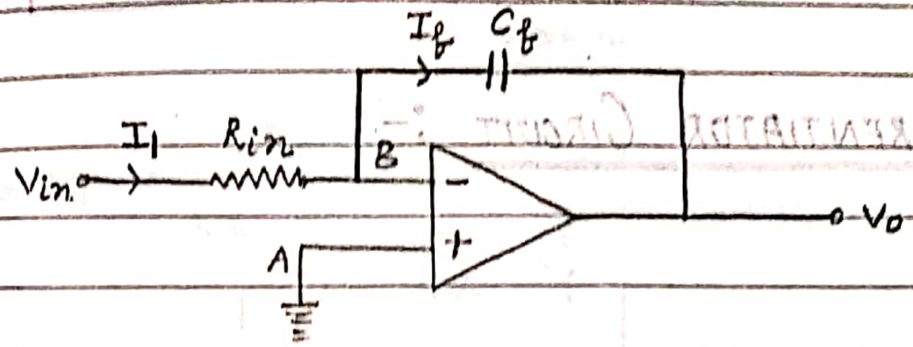
∴ $R_1 = 10\,K\Omega$

$R_2 = 15\,K\Omega$

$R_3 = 6\,K\Omega$

$R_4 = 30\,K\Omega$

* INTEGRATOR CIRCUIT :-



- The circuit which integrate the input at output side is known as Integrator circuit.
- The circuit diagram of integrator using OP-AMP is given in the fig.

Terminal A is grounded, hence, from virtual ground concept,

$$V_A = V_B = 0 \quad \text{—①}$$

Now, applying KCL at node B,

$$I_1 = I_f$$

$$\frac{V_{in} - V_B}{R_{in}} = C_f \frac{d}{dt}(V_B - V_o) \quad \text{—②}$$

Putting the value of ① in ②

$$\Rightarrow \frac{V_{in} - 0}{R_{in}} = -C_f \frac{d}{dt} V_o$$

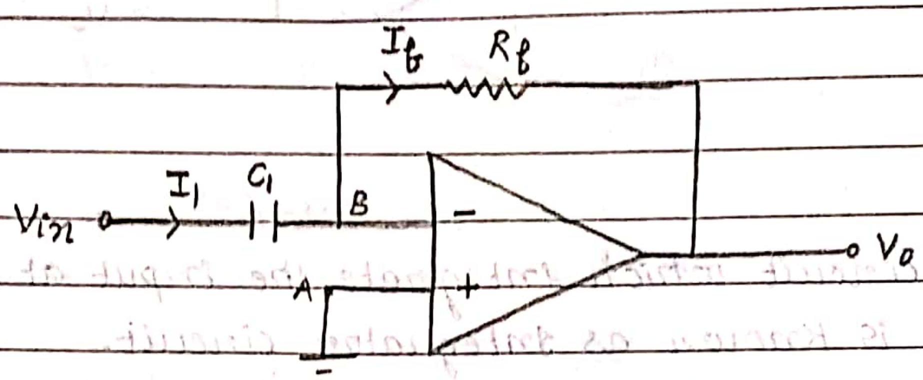
$$\Rightarrow \frac{V_{in}}{R_{in}} = -C_f \frac{d}{dt} V_o$$

$$\Rightarrow \frac{V_{in}}{R_{in}} \int dt = -C_f \int dV_o$$

$$\Rightarrow \int \frac{V_{in} dt}{R_{in}} = -C_f V_o$$

$$\Rightarrow \boxed{V_o = \frac{-1}{C_f R_{in}} \int V_{in}\, dt}$$

* DIFFERENTIATOR CIRCUIT :-



- The circuit which differentiates the input at output side is known as Differentiator circuit.
- The circuit diagram of the differentiator using OP-AMP is given in the circuit Diagram.

Terminal A is grounded, hence, by virtual ground concept,

$$V_A = V_B = 0 \quad \text{—} \ (1)$$

Now on applying KCL at node B,

$$I_1 = I_f$$

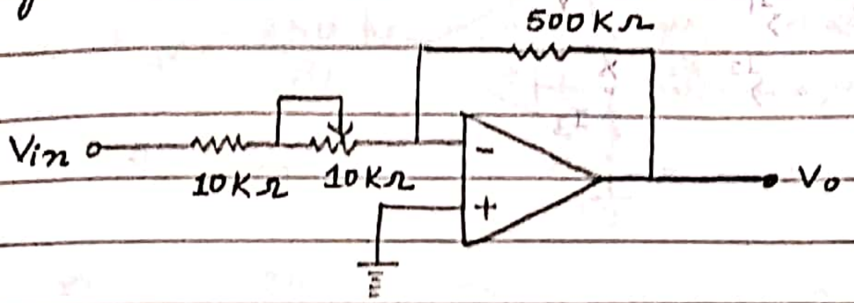
$$C_1 \frac{d}{dt}(V_{in} - V_B) = \frac{V_B - V_o}{R_f}$$

$$\Rightarrow C_1 \frac{d}{dt}(V_{in} - 0) = \frac{0 - V_o}{R_f} \quad (\text{From } (1))$$

$$\Rightarrow C_1 \frac{dV_{in}}{dt} = \frac{-V_o}{R_f}$$

$$\Rightarrow \boxed{V_o = -C_1 R_f \frac{dV_{in}}{dt}}$$

Ques Find the range of gain for the given circuit diagram.



Soln R_2 is variable.

$\therefore (R_2)_{min} = 0\,K\Omega$

$(R_2)_{max} = 10\,K\Omega$

$R_S = R_1 + R_2$

$R_1 = 10\,K\Omega$

$(R_S)_{min} = 10 + 0 = 10\,K\Omega$

$(R_S)_{max} = 10 + 10 = 20\,K\Omega$

$\Rightarrow \quad V_0 = -\frac{R_f}{R_1} V_{in}$

Here, $\frac{V_0}{V_{in}} = -\frac{R_f}{R_S}$

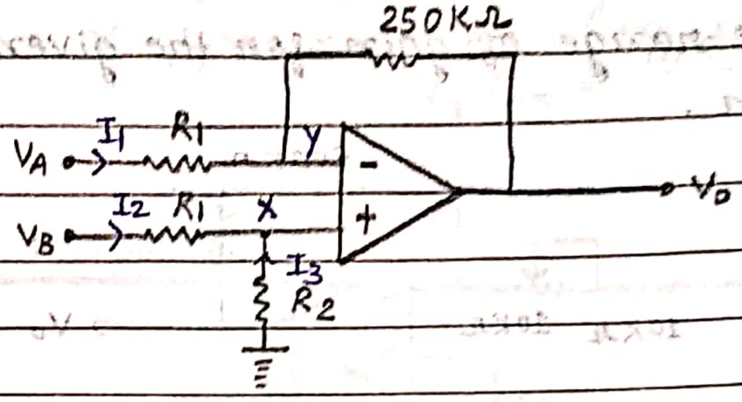
$\left(\frac{V_0}{V_{in}}\right)_{min} = \frac{-500}{10} = -50$

$\left(\frac{V_0}{V_{in}}\right)_{max} = \frac{-500}{20} = -25$

$\therefore$ Range of voltage gain is between -50 to -25.

Ques Find the value of R_1 and R_2 for the output to be $V_0 = -5V_A + 3V_B$ for the OP-AMP shown in the figure.

Solⁿ



$$V_o = -5V_A + 3V_B$$

Consider, V_A to be ground the circuit will be non-inverting amplifier.

$$V_{o1} = \left[1 + \frac{250}{R_1}\right] V_x$$

Consider, V_B to be ground the circuit will be inverting amplifier.

$$V_{o2} = \left[-\frac{250}{R_1}\right] V_A$$

Applying KCL at Node X,

$$I_2 + I_3 = 0$$

$$\Rightarrow \frac{V_B - V_X}{R_1} + \frac{0 - V_X}{R_2} = 0$$

$$\Rightarrow \frac{V_B}{R_1} - \frac{V_X}{R_1} - \frac{V_X}{R_2} = 0$$

$$\Rightarrow \frac{V_B}{R_1} - V_X\left[\frac{1}{R_1} + \frac{1}{R_2}\right] = 0$$

$$\Rightarrow \frac{V_B}{R_1} - V_X \frac{R_1 + R_2}{R_1 R_2} = 0$$

$$\Rightarrow V_X = \frac{V_B R_1 R_2}{R_1(R_1 + R_2)} = \frac{V_B R_2}{R_1 + R_2}$$

$$\Rightarrow V_{01} = \left[1+\frac{250}{R_1}\right]\left[\frac{V_B R_2}{R_1+R_2}\right]$$

$$V_0 = \frac{-250}{R_1} V_A + \left[1+\frac{250}{R_1}\right]\left[\frac{V_B R_2}{R_1+R_2}\right]$$

As $V_0 = -5V_A + 3V_B$

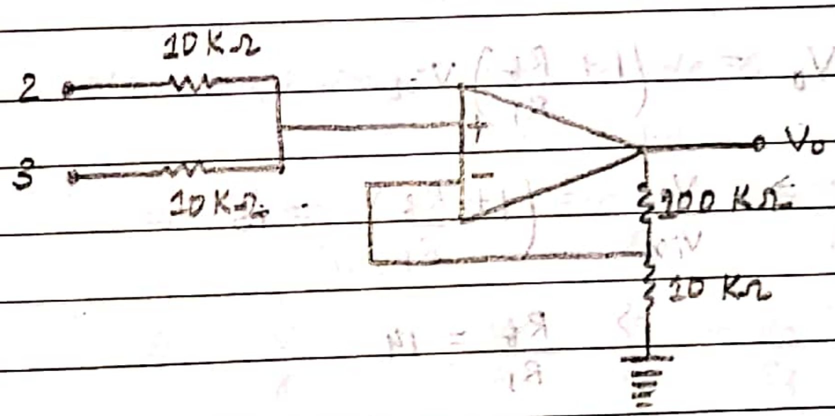
$$\Rightarrow \frac{-250}{R_1} = -5 \Rightarrow R_1 = 50\,\Omega$$

$$\Rightarrow \left[1+\frac{250}{50}\right]\left[\frac{R_2}{50+R_2}\right] = 3$$

$$\Rightarrow 6R_2 = 150 + 3R_2$$

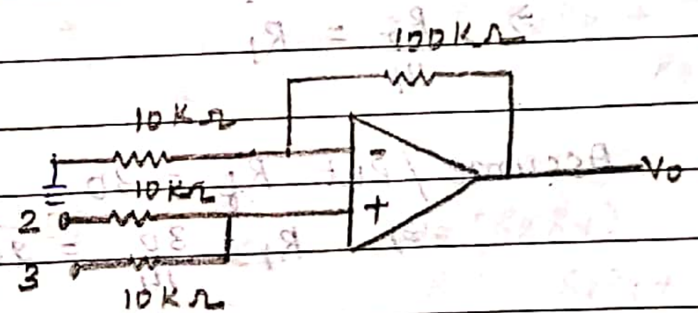
$$\Rightarrow 3R_2 = 150 \Rightarrow R_2 = 50\,\Omega$$

Ques



Solⁿ

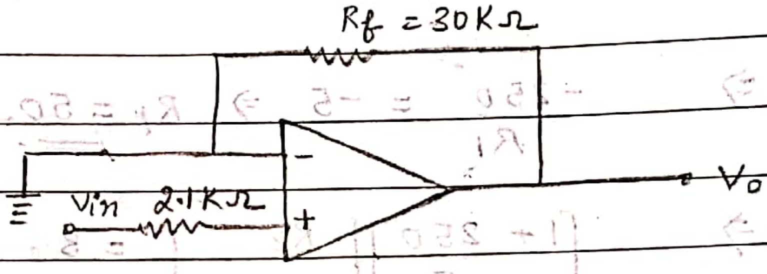
⇒



$$V_0 = \left[1+\frac{100}{10}\right] \times \frac{5}{2} = 11 \times \frac{5}{2} = \frac{55}{2}\,V$$

Ques: Design a non-inverting amplifier that is capable of providing a voltage gain of 15. Assume ideal OP-AMP and resistances ~~st~~ used should not exceed 30 KΩ.

Solⁿ



Voltage gain A.V. $= \frac{V_o}{V_{in}} = 15$

$\Rightarrow \frac{V_o}{V_{in}} = 15$ ~~Vin~~

$V_o = \left(1 + \frac{R_f}{R_1}\right) V_{in}$

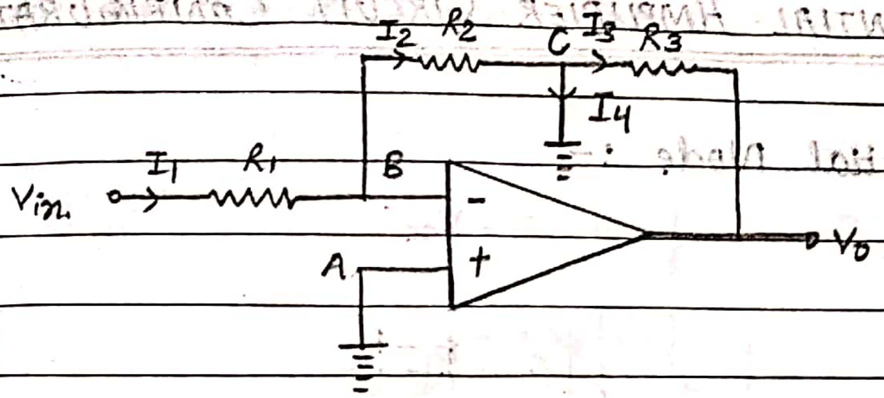
$\Rightarrow \frac{V_o}{V_{in}} = \left(1 + \frac{R_f}{R_1}\right) = 15$

$\Rightarrow \frac{R_f}{R_1} = 14$

$\Rightarrow \frac{R_f}{14} = R_1$

Assume / Put $R_f = 30$

$\Rightarrow R_1 = \frac{30}{14} = 2.1 K\Omega$



By virtual ground concept,

$$V_A = V_B = 0 \quad \text{--- (1)}$$

Now applying KCL at node B,

$$I_1 = I_2$$

$$\Rightarrow \frac{V_{in} - V_B}{R_1} = \frac{V_B - V_C}{R_2} \Rightarrow \frac{V_{in}}{R_1} = \frac{-V_C}{R_2} \quad \text{--- (2)}$$

Now applying KCL at node C,

$$I_2 = I_3 + I_4$$

$$\Rightarrow \frac{V_B - V_C}{R_2} = \frac{V_C - V_o}{R_3} + \frac{V_C}{R_4}$$

$$\Rightarrow \frac{V_o}{R_3} = \frac{V_C}{R_2} + \frac{V_C}{R_3} + \frac{V_C}{R_4}$$

$$\Rightarrow \frac{V_o}{\cancel{R_3}} = V_C \left[\frac{R_3 R_4 + R_2 R_4 + R_2 R_3}{R_4 R_2 \cancel{R_3}} \right]$$

$$\Rightarrow V_C = \frac{V_o (R_2 R_4)}{(R_3 R_4 + R_2 R_4 + R_2 R_3)}$$

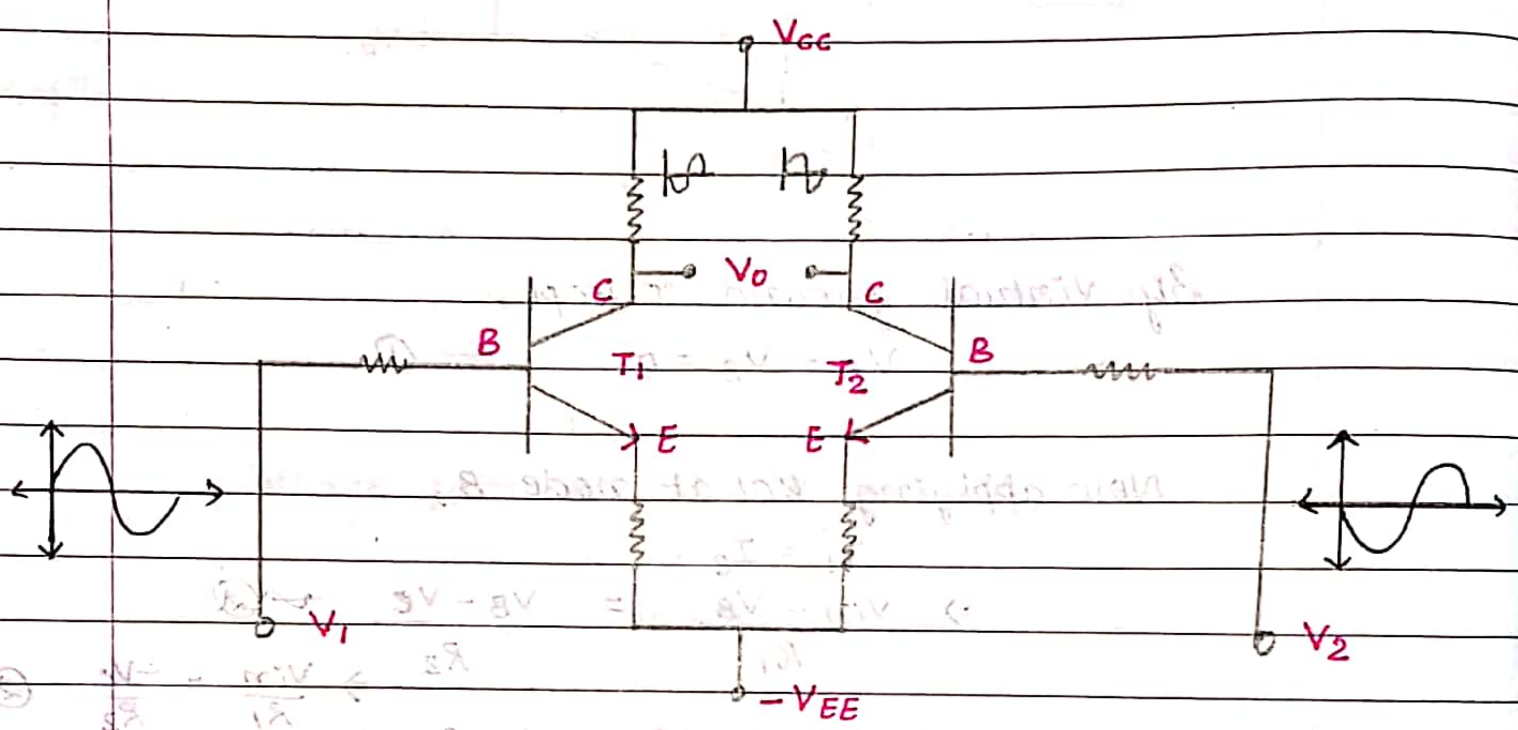
From equ^n (2),

$$\frac{V_{in}}{R_1} = \frac{-V_o (\cancel{R_2} R_4)}{\cancel{R_2} [R_3 R_4 + R_2 R_4 + R_2 R_3]}$$

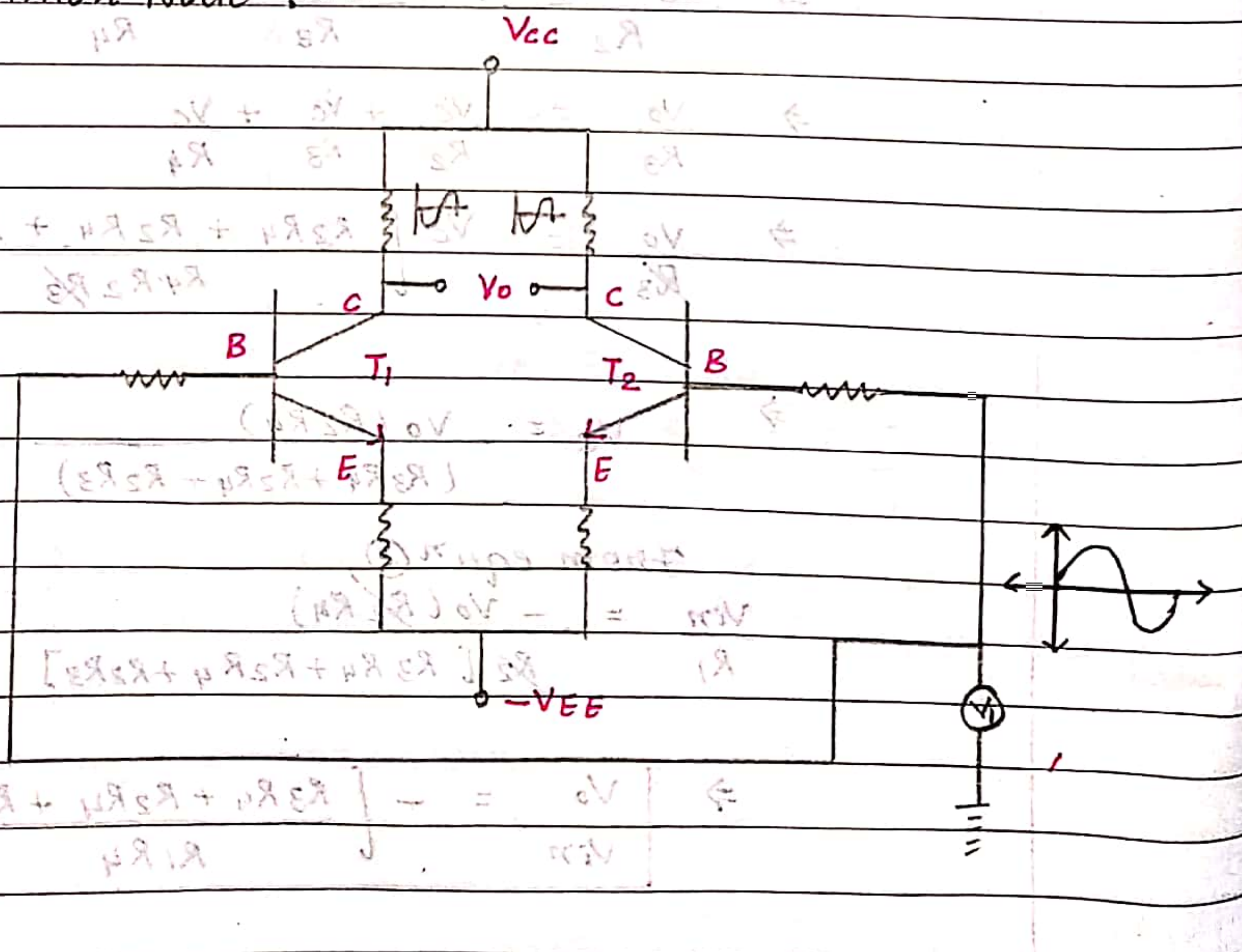
$$\Rightarrow \boxed{\frac{V_o}{V_{in}} = -\left[\frac{R_3 R_4 + R_2 R_4 + R_2 R_3}{R_1 R_4} \right]}$$

* DIFFERENTIAL AMPLIFIER CIRCUIT CONFIGURATIONS :-

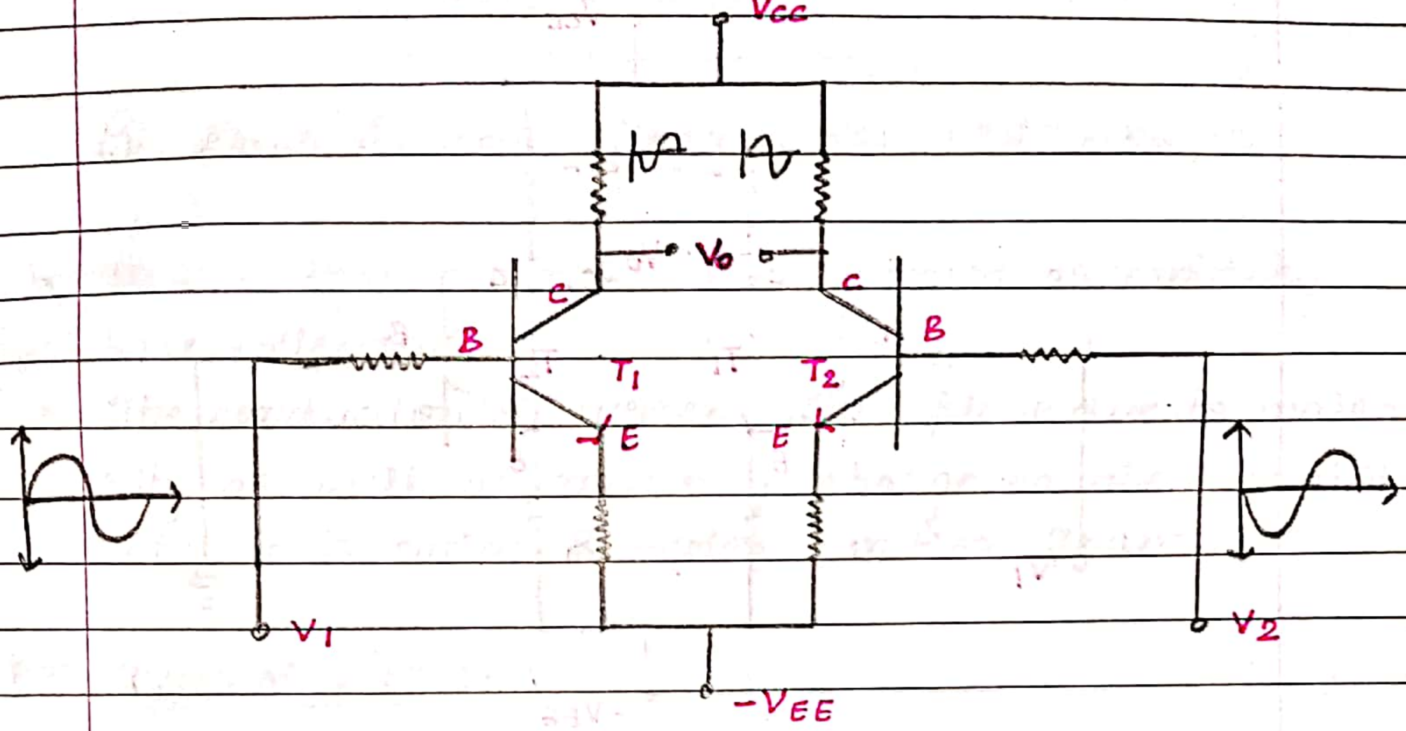
1] Differential Mode :-



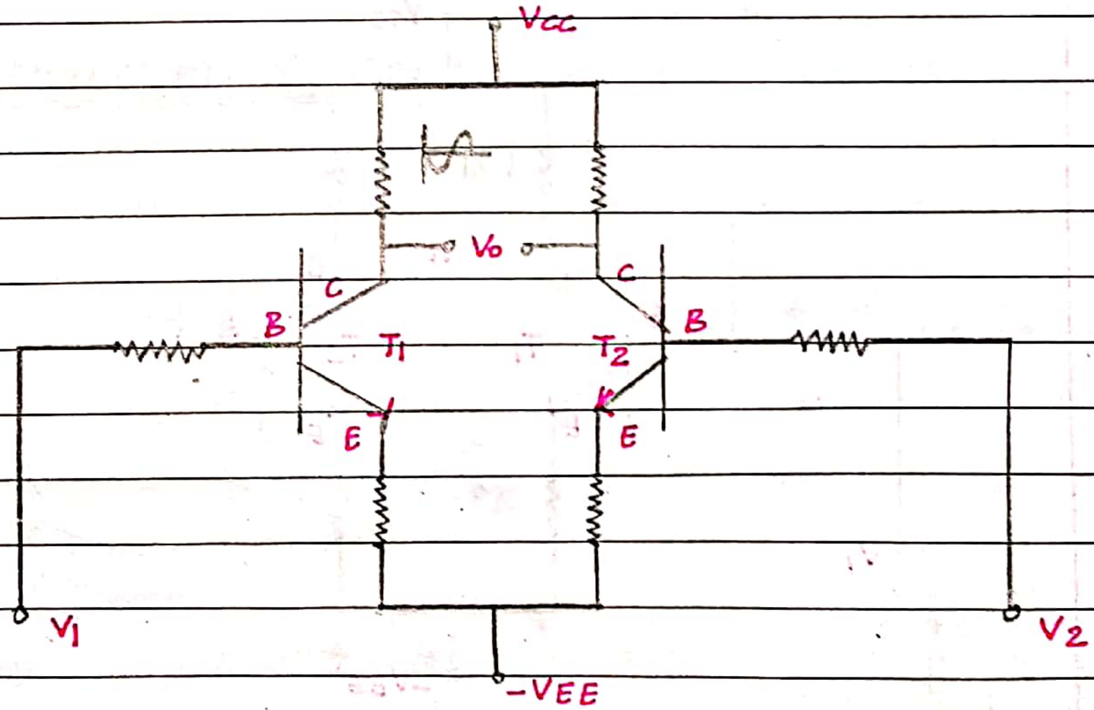
2] Common Mode :-



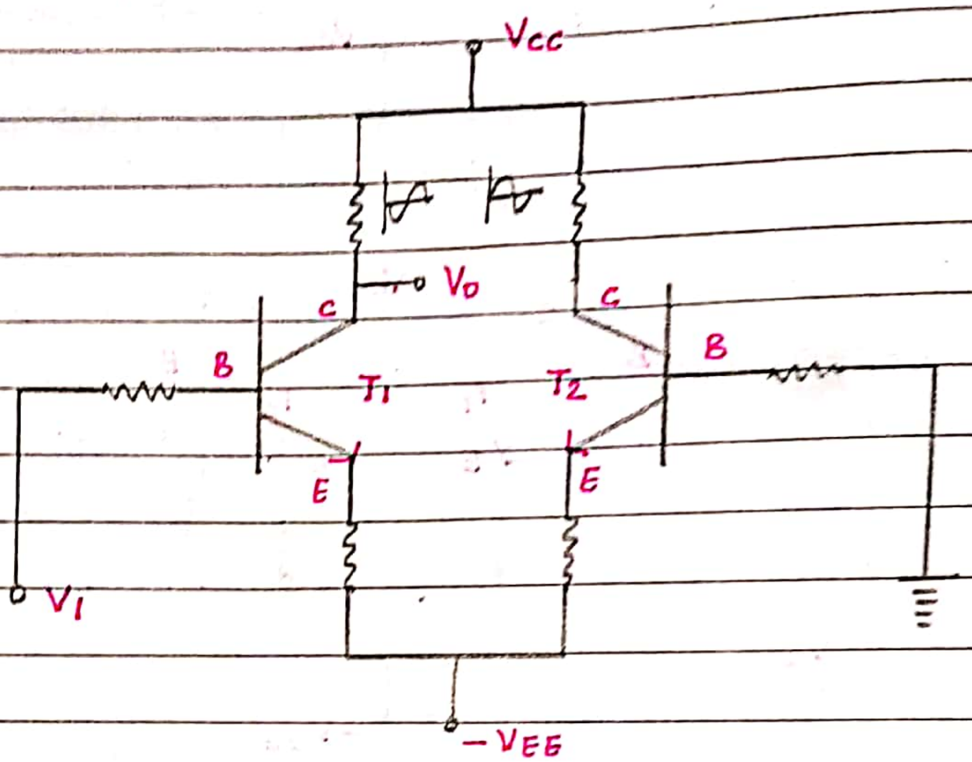
* Dual Input - Balanced Output :



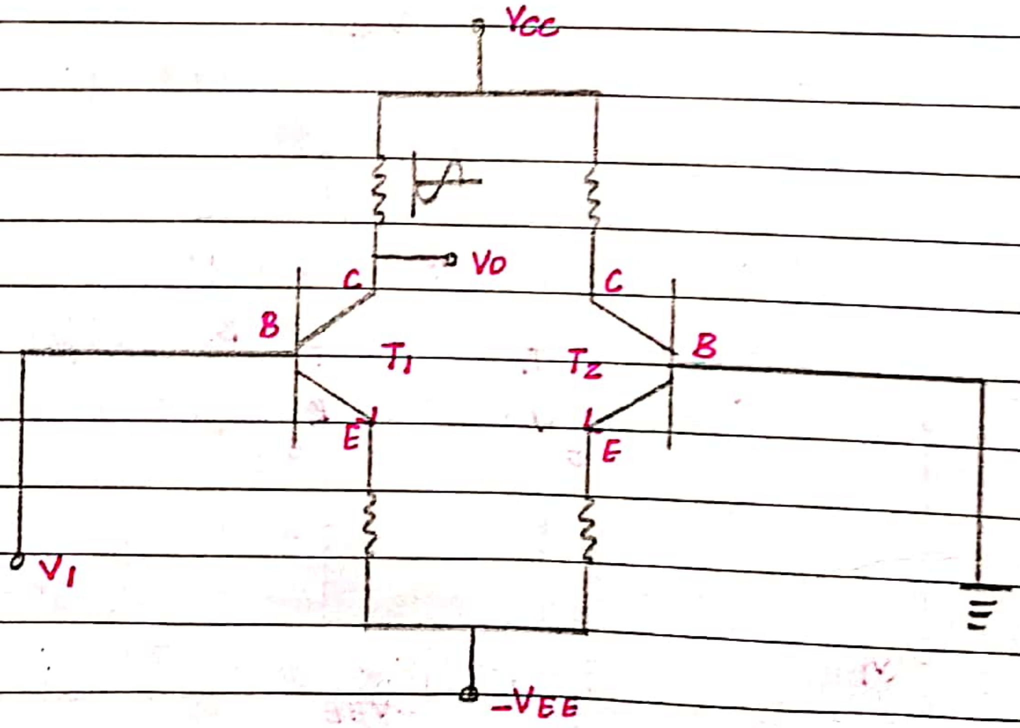
* Dual Input - Unbalanced Output :



* Single Input - Balanced Output :



* Single Input - Unbalanced Output :



Unit 3 (Introduction of IoT System)

Internet of Things

- The Internet of Things (IoT) refers to a system of interrelated, internet-connected objects that are able to collect and transfer data over a wireless network without human intervention.
- A thing in the internet of things can be a person with a heart monitor implant, a farm animal with a biochip transponder, an automobile that has built-in sensors to alert the driver when tire pressure is low or any other natural or man-made object that can be assigned an Internet Protocol (IP) address and is able to transfer data over a network.

Components of IoT

There are four main components of IoT

i. **Sensors/Devices**
- First, sensors or devices collect data from their environment. This data could be as simple as a temperature reading or as complex as a full video feed.
- We use "sensors/devices," because multiple sensors can be bundled together or sensors can be part of a device that does more than just sense things.

ii. **Connectivity**
- The sensors/devices can be connected to the cloud through a variety of methods including: cellular, satellite, WiFi, Bluetooth, low-power wide-area networks (LPWAN), connecting via a gateway/router or connecting directly to the internet via Ethernet.
- Each option has tradeoffs between power consumption, range, and bandwidth. Choosing which connectivity option is best comes down to the specific IoT application, but they all accomplish the same task: getting data to the cloud.

iii. **Data Processing**
- Once the data gets to the cloud (we'll cover what the cloud means in our data processing section)), software performs some kind of processing on it.
- This could be very simple, such as checking that the temperature reading is within an acceptable range. Or it could also be very complex, such as using computer vision on video to identify objects (such as intruders on a property).

iv. **User Interface**
- Next, the information is made useful to the end-user in some way. This could be via an alert to the user (email, text, notification, etc). For example, a text alert when the temperature is too high in the company's cold storage.
- A user might have an interface that allows them to proactively check in on the system. For example, a user might want to check the video feeds on various properties via a phone app or a web browser.

Microprocessor and Microcontroller

	Microprocessor	Microcontroller
Application	It used where intensive processing is required. It is used in personal computers, laptops, mobiles, video games, etc.	It used where the task is fixed and predefined. It is used in the washing machine, alarm, etc.
Structure	It has only the CPU in the chip. Other devices like I/O port, memory, timer is connected externally. The structure of the microprocessor is flexible. Users can decide the amount of memory, the number of I/O port and other peripheral devices.	CPU, Memory, I/O port and all other devices are connected on the single chip. The structure is fixed. Once it is designed the user cannot change the peripheral devices.
Peripheral interface	The common peripheral interface for the microprocessor is USB, UART, and high-speed Ethernet.	The common peripheral interface for the microcontroller is I2C, SPI, and UART.
Programming	The program for the microprocessor can be changed for different applications. The programming of the microprocessor is difficult compared to the microcontroller.	The program for the microcontroller is fixed once it is designed.
Cost	The cost of the microprocessor is high compared to the microcontroller.	It is cheaper.
Power consumption	The power consumption for the microprocessor is high.	The power consumption for the microcontroller is less.
Size	The overall size of the system is large.	The overall size of the system is small.

Bluetooth Technology

- Bluetooth technology is a high-speed low powered wireless technology link that is designed to connect phones or other portable equipment together. It is a specification (IEEE 802.15.1) for the use of low-power radio communications to link phones, computers, and other network devices over short distances without wires. Wireless signals transmitted with Bluetooth cover short distances, typically up to 30 feet (10 meters).
- It is achieved by embedded low-cost transceivers into the devices. It supports the frequency band of 2.45GHz and can support upto 721KBps along with three voice channels.
- It can connect up to “eight devices” simultaneously and each device offers a unique 48-bit address from the IEEE 802 standard with the connections being made a point to point or multipoint.

WiFi Technology

- WiFi is a universal wireless networking technology that utilizes radio frequencies to transfer data. WiFi allows high-speed Internet connections without the use of cables.
- The term WiFi is a contraction of "wireless fidelity" and commonly used to refer to wireless networking technology. The WiFi Alliance claims rights in its uses as a certification mark for equipment certified to 802.11x standards.
- WiFi is a freedom – freedom from wires. It allows you to connect to the Internet from just about anywhere — a coffee shop, a hotel room, or a conference room at work.
- It is almost 10 times faster than a regular dial-up connection. WiFi networks operate in the unlicensed 2.4 radio bands, with an 11 Mbps (802.11b) or 54 Mbps (802.11a) data rate, respectively.
- To access WiFi, you need WiFi enabled devices (laptops or PDAs). These devices can send and receive data wirelessly in any location equipped with WiFi access.

Concept of Networking

Network

A network is a set of devices (often referred to as nodes) connected by communication links. A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network.

Network Criteria

A network must be able to meet a certain number of criteria. The most important of these are performance, reliability, and security.

Performance: Performance can be measured in many ways, including transit time and response time. Transit time is the amount of time required for a message to travel from one device to another. Response time is the elapsed time between an inquiry and a response.

Reliability: Network reliability is measured by the frequency of failure, the time it takes a link to recover from a failure, and the network's robustness in a catastrophe.

Security: Network security issues include protecting data from unauthorized access, protecting data from damage and development, and implementing policies and procedures for recovery from breaches and data losses.

NETWORK CATEGORIES

Local Area Networks (LAN): Local area networks, generally called LANs, are privately-owned networks within a single building or campus of up to a few kilometers in size. They are widely used to connect personal computers and workstations in company offices and factories to share resources (e.g., printers) and exchange information.

Metropolitan Area Network (MAN): A metropolitan area network, or MAN, covers a city. The best-known example of a MAN is the cable television network available in many cities. This system grew from earlier community antenna systems used in areas with poor over-the-air television reception.

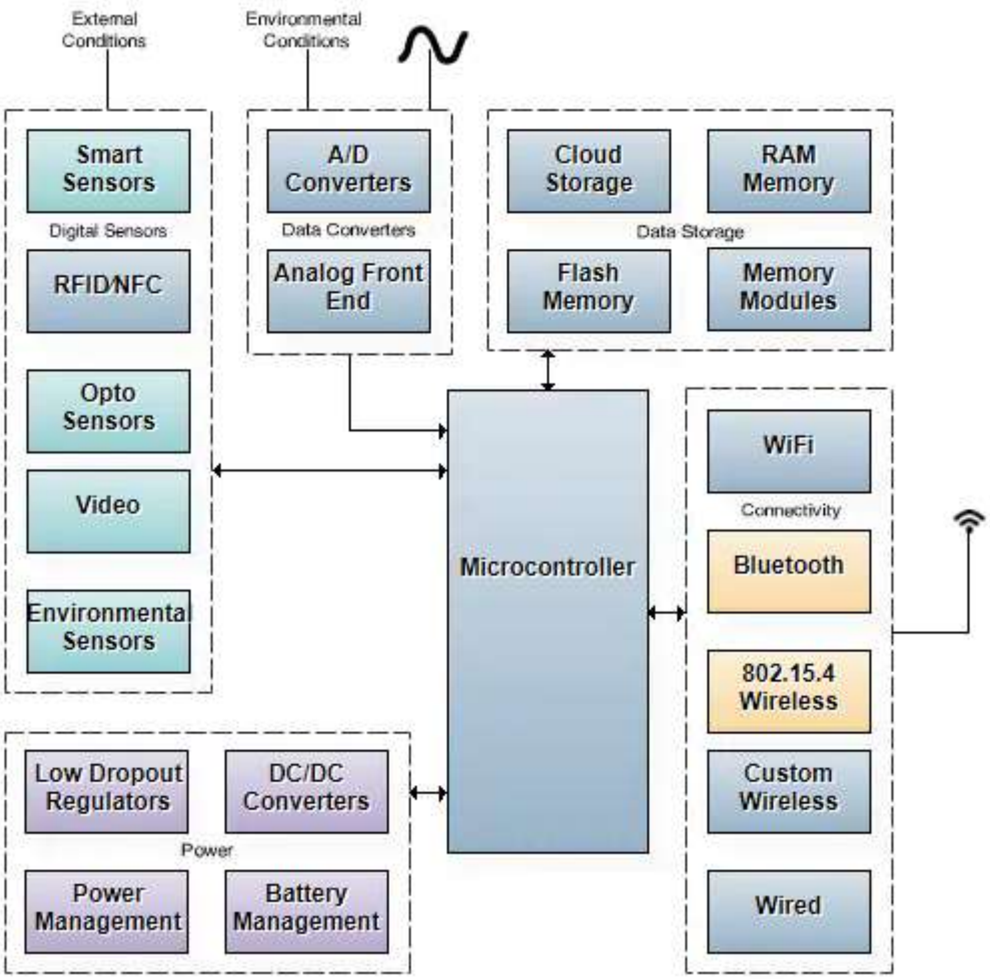
Wide Area Network (WAN): A wide area network, or WAN, spans a large geographical area, often a country or continent. It contains a collection of machines intended for running user (i.e., application) programs.

Sensor Nodes

• A Sensor node also known as mote, is a node in a sensor network that is capable of performing some processing. Gathering information and communicating with other connected nodes in a network.

• Sensors arc designed to specific types of conditions in the physical world & then generate a signal that can represent the magnitude of the condition being monitored. Those conditions may be light, heat, sound, distance, pressure etc.

IoT Sensor Node Block Diagram



Concept of Cloud

• An IoT Cloud is a massive network that supports IoT devices and applications.

•This includes the underlying infrastructure, servers and storage needed for real time operations and processing.
•An IoT Cloud also includes the services and standards necessary for connecting, managing and securing different loT devices and applications.

Why IoT Cloud?

• IoT cloud offers an efficient, flexible and scalable model for delivering the infrastructure and services needed to power IoT devices & applications for businesses with limited resources.
• IoT Cloud offers on-demand, cost efficient services, so organizations can leverage the significant potential of IoT without having to build underlying infrastructure and services from scratch.
• Cloud is important for aggregating large amount of data collected by sensors and for processing of that data.
• Cloud also allows for high scalability.
• The brain of the system is in the cloud as the processing/commanding/analytics takes place in cloud.