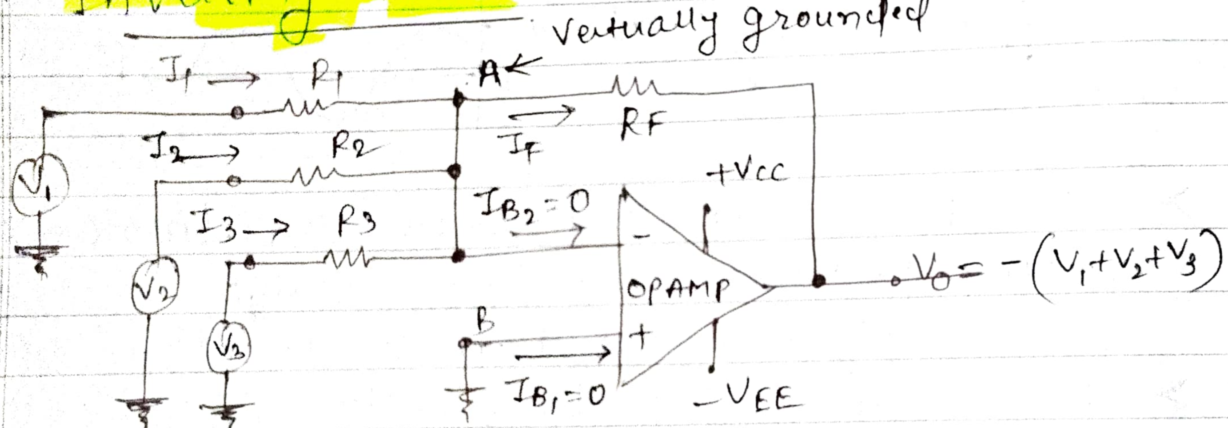
→ **Inverter** (Sign changer)

It is same as the inverting ampr in closed loop configuration.
But value of both resistors are same

→ **OPAMP as a Summing Ampr or Adder.**

→ It is possible to apply more than one i/p s/g to an inverting ampr. This ckt will then add all these i/p s/gs to produce their addition at the o/p.

→ **Inverting Adder**



- Fig. shows Inverting summing ampr with '3' i/ps V_1, V_2 & V_3. Also depending upon the value of i/p resistance R_1, R_2 & R_3 this same ckt can be used as scaling ampr or averaging ampr. R_F is the f/b resistor.

- Applying KCL at node (A),

$$I_1 + I_2 + I_3 = I_{B_2} + I_F$$

but $I_{B_2} = 0$ —— $R_i = \infty$ Ideally

& $V_A = V_B = 0$ due to Virtual ground.

[ckt → Circuit, ampr → amplifier]

Chintan Jethva

Hence $I_1 + I_2 + I_3 = I_F$

$I_1 = \frac{V_1 - V_A}{R_1}$, $I_2 = \frac{V_2 - V_A}{R_2}$, $I_3 = \frac{V_3 - V_A}{R_3}$ but $V_A = 0$.

& $I_F = \frac{V_A - V_O}{R_F} = \frac{-V_O}{R_F}$ ... $\because V_A = 0$.

$\therefore \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = \frac{-V_O}{R_F}$

or

$$V_O = -\left[\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right] \rightarrow \text{(A)}$$

If we substitute $R_F = R_1 = R_2 = R_3 = R$ then,

$$\boxed{V_O = -(V_1 + V_2 + V_3)}$$

As we see o/p is negative sum of i/p v/gs. $\therefore$ It is called as Inverting adder. Also we can add any no. of i/ps.

→ **As an Scaling or Weighted ampr**

Inverting adder ckt can also be used as an scaling or weighted ampr.

- This can be done if each i/p v/g is amplified by a different factor & this can be happened if resistors R_1, R_2 & R_3 are different in value. ie. From equation (A) shown above,

$$\boxed{V_O = -\left[\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right]}$$

where $R_1 \neq R_2 \neq R_3$

So we can 'scale' each i/p as per our requirement.

[no. of → number of, ckt → Circuit]

→ Averaging ampr

- Also inverting adder ckt can be used as an averaging ampr if $R_1 = R_2 = R_3 = R$ & $R_F = \frac{R}{3}$. substituting these values in equation (A),

$$V_o = -\frac{R_F}{R}(V_1+V_2+V_3) = -\frac{R/3}{R}(V_1+V_2+V_3)$$

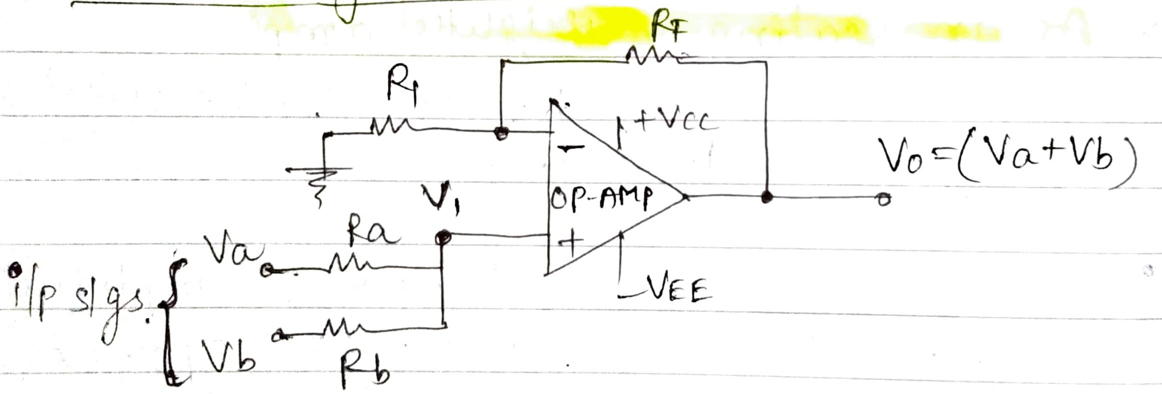
$$\therefore \boxed{V_o = -\frac{(V_1+V_2+V_3)}{3}}$$

- So the magnitude of o/p v/g is equal to average of three i/p v/gs.

We can increase the 'n' no. of i/ps by setting $R_F = R/n$ & $R_1 = R_2 = \dots = R_n = R$ Then o/p v/g is,

$$V_o = -\frac{(V_1+V_2+V_3+\dots+V_n)}{n}$$

→ Non-Inverting Adder



- In this adder circuit, we can produce addition of its i/p sigs without inversion. Here Two i/ps Va & Vb are applied to the non-inverting terminal through their resistors.

[no. of → number of, ampr = amplifier, ckt = circuit]

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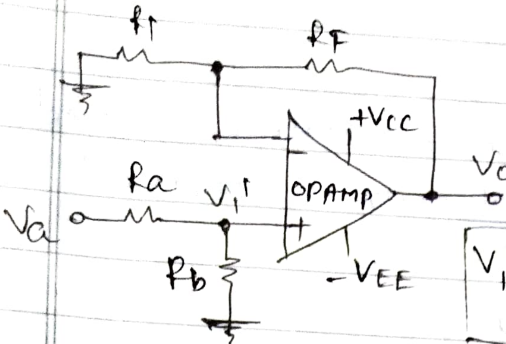
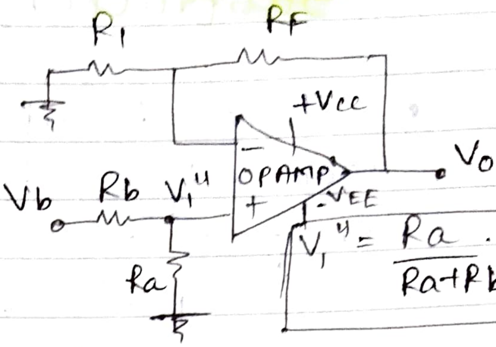


$$\boxed{V_1' = \frac{R_b}{R_a+R_b}\cdot V_a}$$

If $V_b = 0$.



$$\boxed{V_1'' = \frac{R_a}{R_a+R_b}\cdot V_b}$$

If $V_a = 0$.

Case 1 :- Let $V_b = 0$ ie. connected to ground.
v/g at non-inverting due to 'Va' is given by,

$$V_1' = \frac{R_b}{R_a+R_b}\cdot V_a$$

Assuming $R_a = R_b = R$ $\therefore V_1' = V_a/2 \rightarrow (1)$

Case 2 : Now $V_a = 0$ ie. connected to ground.

$$V_1'' = \frac{R_a}{R_a+R_b}\cdot V_b$$

Assuming $R_a = R_b = R$ $\therefore V_1'' = V_b/2 \rightarrow (2)$

$V_1 = V_1' + V_1''$ ie. addition of equation (1) & (2)

$$V_1 = \frac{V_a+V_b}{2} \rightarrow (3)$$

- The amplifier is non-inverting, so the gain is,

$$A_{VF} = 1 + \frac{R_f}{R_1} \rightarrow$$

& $R_F = R_1 = R$

then $A_{VF} = 1+1 = 2 \rightarrow (4)$

o/p v/g $V_o = A_{VF} \times V_1$

$V_o = 2\left(\frac{V_a+V_b}{2}\right)$ ---- from equation (3) & (4)

$\therefore \boxed{V_o = V_a + V_b}$

- Thus o/p v/g is addition of two i/p & it is +ve $\therefore$ it is known as non Inv. adder.

[ie. → that is]

→ Subtractor

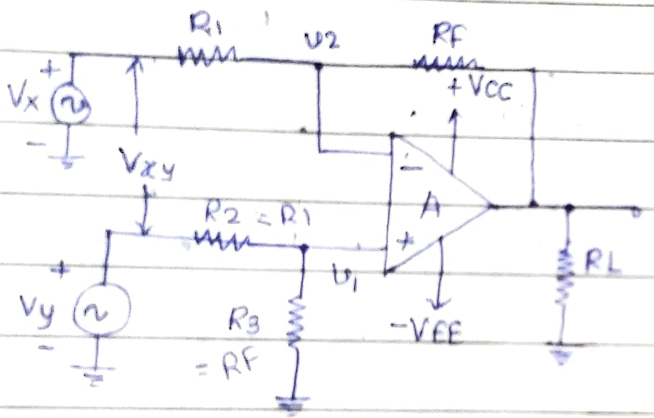
- The circuit of subtracter is same as closed loop differential ampr. as shown & derived in page No. 12.
  Its o/p v/g $V_o = \frac{R_F}{R_1}(V_1 - V_2)$
- If we substitude $R_1 = R_F = R$ then o/p v/g is,
  $V_o = (V_1 - V_2)$
  So differential ampr gets transformed into a subtractor.

→ Differential Amplifiers :-

- Closed looped differential amplifiers :
  1) Diffⁿ ampʳ with one - op-amp
  2) Diffⁿ ampʳ with two op-amps.

- Applications :-
  - In instrumentation & industrial applications. to amplify diffⁿ betⁿ two I/P signals.
  - These are preferred because they are better able to reject common mode (noise) voltages than single I/P ckts.

1) Differential ampʳ with one op-amp:



$$v_o = -\frac{R_F}{R_1}(V_x - V_y)$$

$R_1 = R_2$ & $R_F = R_3$

- It is a combⁿ of inverting & non-inv ampʳ. i.e when $v_x = 0$ the ckt will be a non inv ampʳ & when $V_y = 0$, the ckt will be a inv ampʳ.

→ Vtg gain of diffⁿ ampʳ:

- It has 2 I/Ps therefore use the superposition theorem in order to establish the relationship betⁿ I/Ps & O/Ps.

when $V_y = 0V$, the config. becomes Inv. ampʳ, hence the O/P is due to V_x only & given by,

$$V_{ox} = -\frac{R_F(V_x)}{R_1}$$

- similarly when $v_x = 0V$, non-inv. ampʳ. with a vtg. divider n/w composed of R_2 & R_3 at the non-inverting I/P.

$$\therefore v_1 = \frac{R_3(v_y)}{R_2 + R_3}$$

& the O/P due to Vy then is

$$v_{oy} = \left(1 + \frac{R_F}{R_1}\right) \cdot v_1$$

i.e
$$V_{oy} = \frac{R_3}{R_2 + R_3}\left(\frac{R_1 + R_F}{R_1}\right) \cdot V_y$$

$\because R_1 = R_2$ & $R_F = R_3$,

$$V_{oy} = \frac{R_F (V_y)}{R_1}.$$

i.e $v_o = V_{ox} + V_{oy}$.

$$= -\frac{R_F}{R_1}(v_x - V_y) = -\frac{R_F (V_{xy})}{R_1}$$

or the vtg. gain, $\boxed{A_D = \frac{v_o}{V_{xy}} = -\frac{R_F}{R_1}.}$ — (1)

- The gain of the diffⁿ ampʳ. is the same as that of the inverting ampʳ.

→ **I/P resistance of the diffⁿ ampʳ :- (RiF)**

- Is the resi. determined looking into either one of the two I/P terminals with the other grounded.
- ∴ with $V_y = 0V$, inv ampʳ.

$$R_{ifx} \cong R_1$$

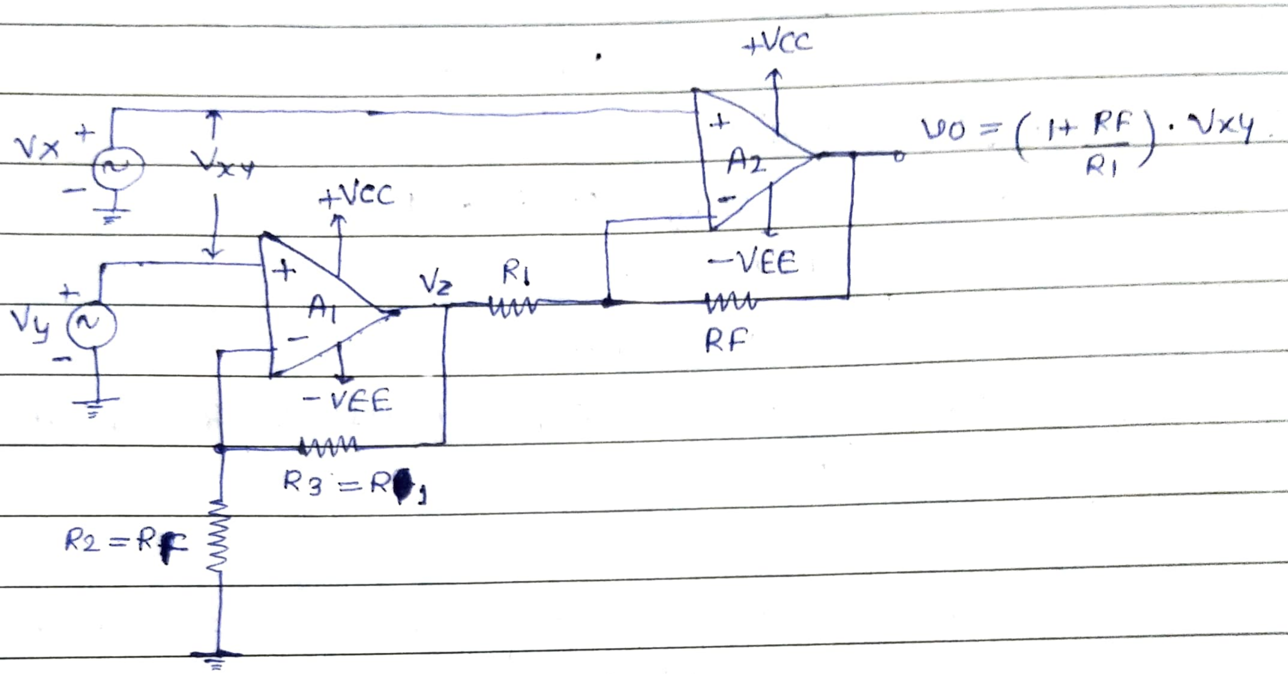
- similarly, $V_x = 0V$, non-inv ampʳ.

$$R_{ify} \cong (R_2 + R_3)$$

- we can see that both the resistances are not same.
- To make these resi. same, we have to modify the ckt
- To perform properly this ckt both R_1 & $(R_2 + R_3)$ can be made much larger than the source resi. so that the loading of the signal sources does not occur.

→ Differential ampr with two op-amps :-

- To ↑ gain & I/P resi. we can use 2 op-amps in diffn ampr.
- This chara. of this ampr are same to those of non-inv. ampr.



→ voltage gain →

- This ckt is composed of two stages:
  1) The non-inverting ampr &
  2) The diffn ampr with unequal gains.
- By finding the gain of two stages, we can obtain overall gain of the ckt as follows:

The O/P V_2 of the 1st stage is,

$$V_2 = \left(1 + \frac{R_3}{R_2}\right) \cdot V_y$$

By applying the superposition theorem to the 2nd stage, we can obtain the output voltage.

$$v_o = -\frac{R_F (V_2)}{R_1} + \left(1 + \frac{R_F}{R_1}\right) \cdot V_x$$

Substituting the value of V_2 from above eqn we get,

$$v_o = -\left(\frac{R_F}{R_1}\right) \cdot \left(1 + \frac{R_3}{R_2}\right) \cdot V_y + \left(1 + \frac{R_F}{R_1}\right) \cdot V_x$$

since $R_1 = R_3$ & $R_F = R_2$,

$$v_0 = \left(1 + \frac{R_F}{R_1}\right) \cdot (v_x - v_y).$$

$$\therefore \boxed{A_D = \frac{V_0}{V_{xy}} = 1 + \frac{R_F}{R_1}}$$

where $V_{xy} = v_x - v_y$.

→ **Input Resistance :**

- At the 1st stage A1 is a non-inv. ampr.

∴ its I/P resi is,

$$R_{ify} = R_i(1 + AB)$$

where R_i = open-loop I/P resi. of the op-amp.

$$B = \frac{R_2}{R_2 + R_3}$$

similarly, with $v_y = 0V$, A2 is also non-inv ampr.

$$\therefore R_{ifx} = R_i(1 + AB)$$

where R_i = open-loop I/P. resi. of the op-amp.

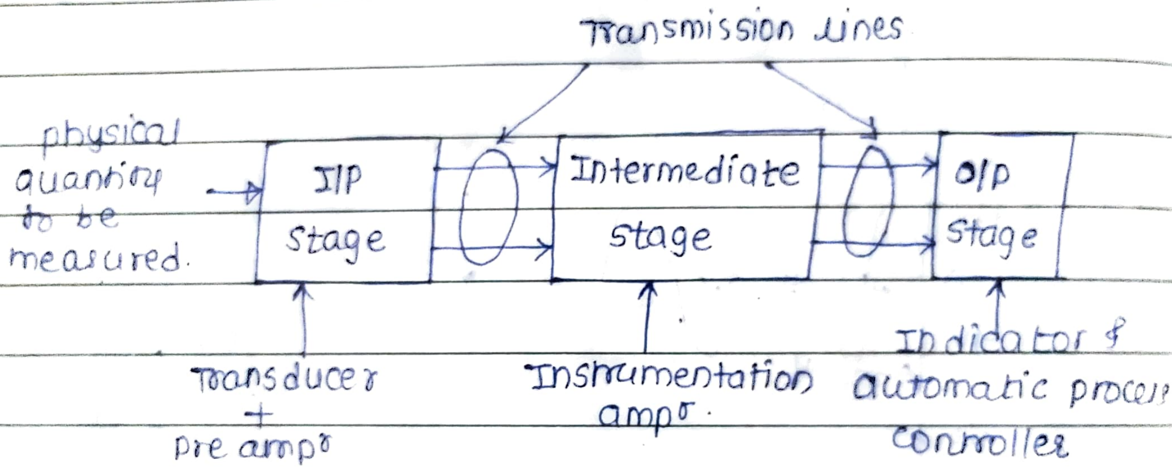
$$B = \frac{R_1}{R_1 + R_F}$$

- Here we use $R_1 = R_3$ & $R_F = R_2$, then also $R_{ify} \neq R_{ifx}$ & hence the loading of I/P source occur. i.e the O/P signal may be smaller in amplitude than expected.
- This reduction in O/P is the drawback of diffn ampr.
- To overcome this, with proper selection of components, both R_{ify} & R_{ifx} can be made much larger than the source resistances so that the loading of the I/P does not occur.

⇒ Instrumentation amp^r :→

- In many industrial & consumer applications the measurement & control of physical conditions are very important.
- Generally a transducer is used at the measuring site to obtain the required information easily & safely.
- Transducer converts one form of energy into another.

→ Block dia. of an instrumentation system:-



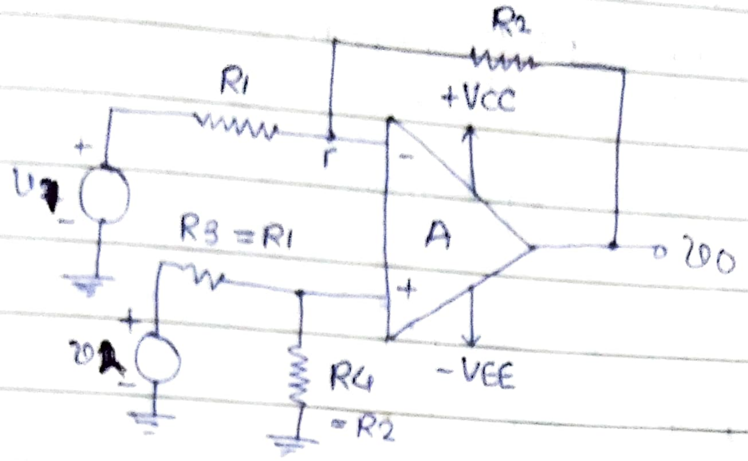
- To amplify the low level O/P signal of the transducer so that it can drive the indicator or display is the major func of the instrumentation amp^r.
- i.e IA is intended for precise, low level signal amplification where low noise, low thermal & time drifts, high I/P resistance & accurate closed-loop gain are required.
- Besides that, low power consumption, high CMRR & high slew rate are desirable for superior performance.

⇒ IA circuits:-

- Using one op-amp
- Using two op-amps

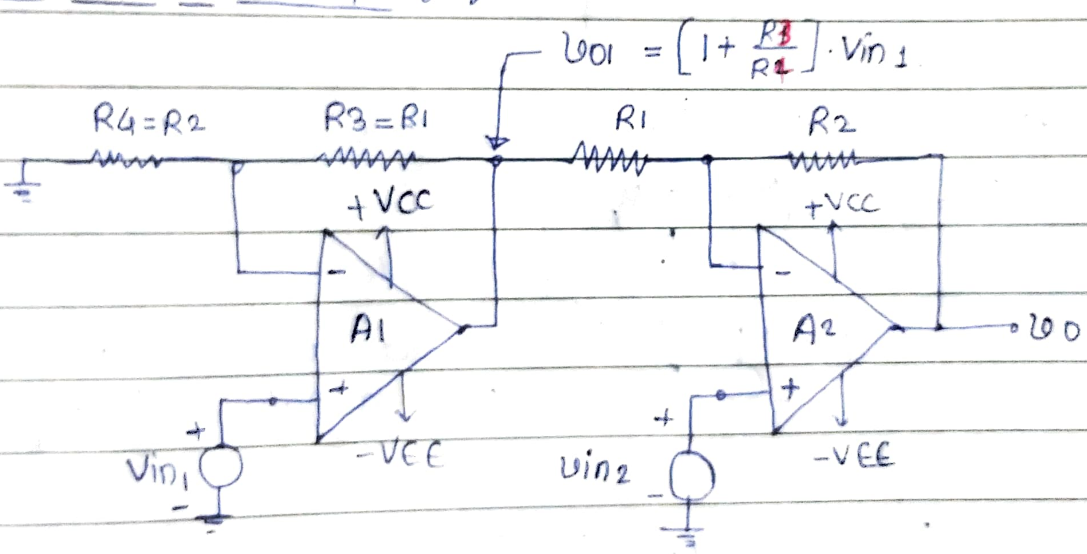
3 op-amps.

IA using one op-amp :-



- It is same as a diff^n amp^r. (sub)
- when gain = 1 , $v_0 = v_1 - v_2$

IA with 2 op-amps :→



- This confg is used when the cost of ckt is to be reduced.
- A1 is a non-inv amp^r, hence it's o/p vtg. is given by,

$$v_{01} = \left[1 + \frac{R3}{R4}\right] \cdot v_{in1} \longrightarrow (1)$$

- v_{01} is applied at inv terminal of A2.
Hence A2 will act as a difference amp^r.
The o/p can be obtained by using superposition theorem.

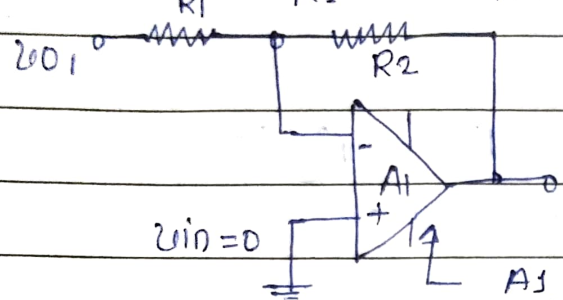
Consider v_{o1} & v_{in2} separately.

— O/P due to v_{o1} is v_o' can be calculated as

$$v_{o1}' = -\frac{R_F}{R_1}\left[1+\frac{R_3}{R_4}\right]\cdot v_{in1}.$$

$$\because v_{o1} = \left[1+\frac{R_3}{R_4}\right]\cdot v_{in1}.$$

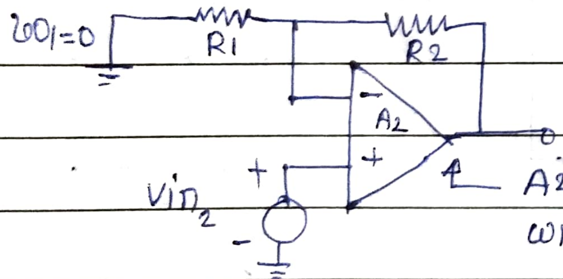
$$\therefore v_{o1}' = -\frac{R_2}{R_1}\cdot\left[1+\frac{R_3}{R_4}\right]\cdot v_{in1} \longrightarrow (2)$$



A1 acts as an inv. ampr. with gain of R2/R1.

: O/P due to v_{o1} only :-

→ O/P due to v_{in2} is v_o'' & is given as,



A2 acts as a non-inverting ampr with a gain of $\left(1+\frac{R_2}{R_1}\right)$.

$$v_o'' = \left[1+\frac{R_2}{R_1}\right]\cdot v_{in2}. \longrightarrow (3)$$

Hence the O/P vtg,

$$v_o = v_o' + v_o''$$

From eq^n (2) & (3) we get,

$$v_o = -\frac{R_2}{R_1}\left[1+\frac{R_3}{R_4}\right]\cdot v_{in1} + \left[1+\frac{R_2}{R_1}\right]\cdot v_{in2}$$

$$= \left[1+\frac{R_2}{R_1}\right]\cdot v_{in2} - \left[\frac{R_2}{R_1}\left(1+\frac{R_3}{R_4}\right)\right]\cdot v_{in1}$$

Take out $1 + (R2/R1)$ common from R.H.S.

$$vo = 1 + \frac{R2}{R1}\left[vin_2 - \frac{1 + (R3/R4)}{1 + (R1/R2)} . vin_1 \right]$$

The ckt will work as a true difference amp if

$$\frac{R1}{R2} = \frac{R3}{R4} \quad \text{or} \quad 1 + \frac{R1}{R2} = \frac{1+R3}{R4}.$$

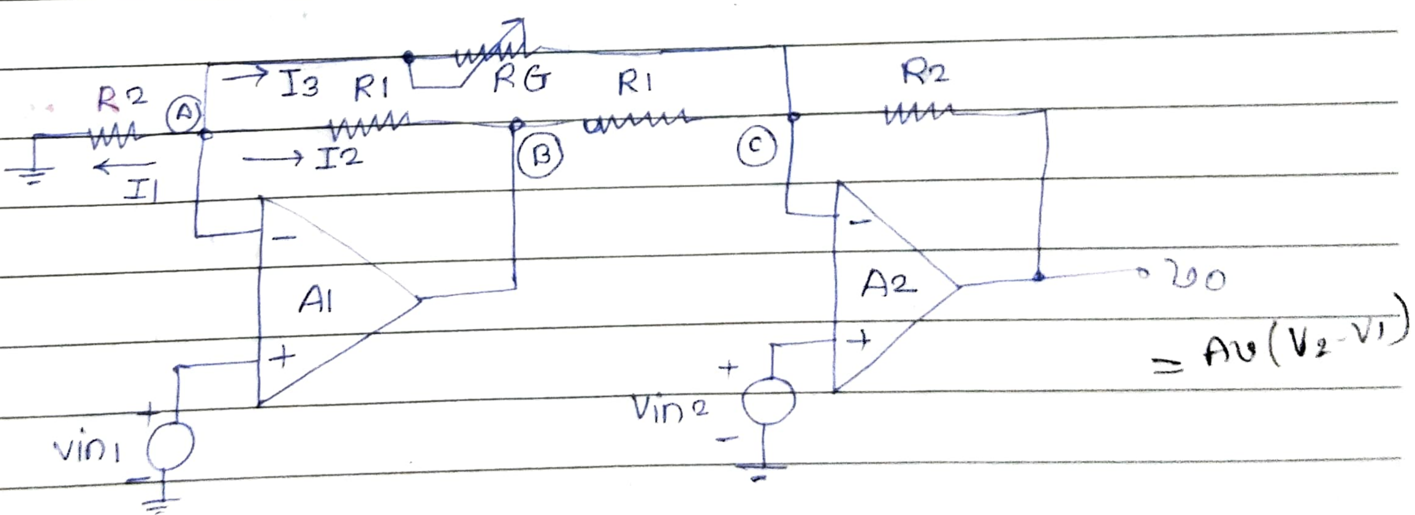
when this condition is true,

$$vo = \left[1 + \frac{R2}{R1}\right] . (vin_2 - vin_1). \rightarrow (4).$$

→ Advantages of dual op-amp IA :-

- High I/P resi
- low O/P resi
- CMRR can be maximized & unbalance can be minimized if we replace one of the resistors (say R4) by a trimmer i.e variable resistor.

→ IA using 2 op-amps with variable gain :-



→ Variable resistor RG is connected in betn inverting terminals of A1 & A2.

- gain is given by,

$$gain = Av = 1 + \frac{R2}{R1} + \frac{2R2}{RG}$$

- By varying R_G we can vary the gain.

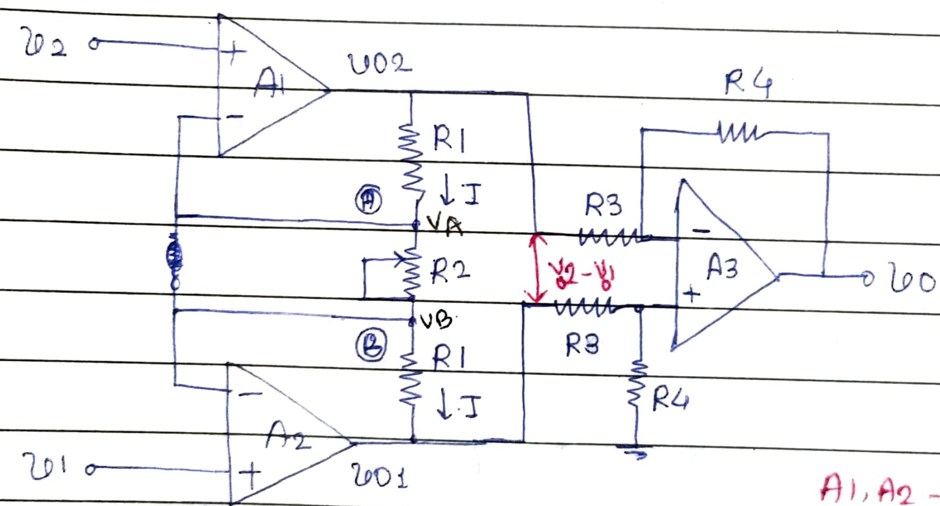
⇒ Advantages.

- Easy to vary the gain.
- variation in gain does not affect the performance of the ampⁿ. as CMRR does not change with change in gain.

⇒ Disadvantages:

- CMRR ↓ with ↑ freqⁿ.
- R_1 & R_2 should match exactly.

⇒ IA using 3-op-amps:



A1, A2 - vtg. follower

→ Voltage is given as,

Use ~~virtual gnd concept~~ short concept.

i.e $v_o = A_F \cdot v_{in}$

$v_o = A \cdot v_{id}$

$v_{id} = v_o / A$

∵ A is >> , $v_{id} = 0$

i.e $v_1 - v_2 = 0$ ∴ $v_1 = v_2$.

means v_1 & v_2 are at same potential.

i.e when we short two terminals, they will be at equipotential.

similarly here as $v_1 = v_2$ we can say that

v_1 & v_2 are virtually shorted, eventhough they are not actually shorted, they are at same potential.

- This phenomenon is called as virtual short concept.

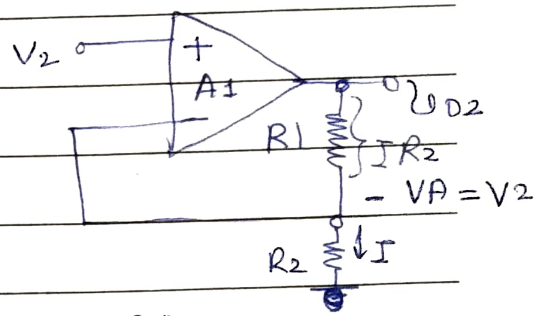
Using virtual short concept,

$$V_A = V_2 \quad \& \quad V_B = v_1$$

Hence expression for current I is,

$$I = \frac{V_A - V_B}{R_2} = \frac{V_2 - v_1}{R_2}$$

O/P vtg. of op-amp A_1 is given by,

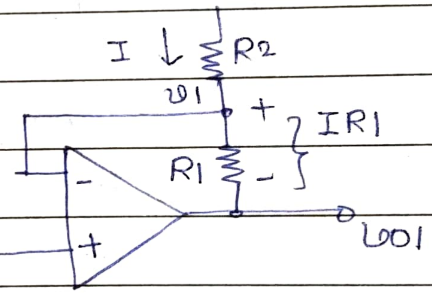


$$v_{o2} = V_A + IR_1 = V_2 + IR_1.$$

$$= V_2 + \frac{(V_2 - v_1)}{R_2} \times R_1.$$

$$= \frac{V_2R_2 + V_2R_1 - V_1R_1}{R_2} = \frac{(R_1+R_2)\cdot v_2 - R_1 v_1}{R_2}$$

O/P of O/P amp A_2 is given as,



$$v_{o1} = V_B - IR_1$$

$$= v_1 - IR_1$$

$$= v_1 - \frac{(v_2 - v_1)}{R_2} \times R_1$$

$$= \frac{V_1R_2 - V_2R_1 + V_1R_1}{R_2} = \frac{(R_1+R_2)\cdot v_1 - R_1 v_2}{R_2}$$

Hence the O/P of the first 1stage is given by,

$$V_{o2} - V_{o1} = \frac{(R_1+R_2)\cdot V_2 - R_1V_1}{R_2} - \frac{(R_1+R_2)\cdot V_1 - R_1 v_2}{R_2}$$

$$= \frac{(R_1+R_2)\cdot(V_2 - V_1) + R_1(V_2 - V_1)}{R_2} = \frac{2(R_1+R_2)\cdot(V_2 - V_1)}{R_2}$$

$$\therefore V_{o2} - V_{o1} = \left[1 + \frac{2R_1}{R_2}\right]\cdot(V_2 - V_1)$$

Hence the gain of the 1st stage is given by,

$$A_{v1} = \frac{V_{o2} - V_{o1}}{V_2 - V_1} = 1 + \frac{2R_1}{R_2}$$

- The 2nd stage is a difference ampr with a gain of,

$$A_{v2} = \frac{R_4}{R_3}. \qquad V_o = -\frac{R_4}{R_3}(V_1 - V_2) = \frac{R_4}{R_3}(V_2 - V_1)$$

- Hence the overall gain A_v of the 3 op-amp IA is given by,

$$A_v = A_{v1} \times A_{v2}.$$

$$\therefore A_v = \left[1 + \frac{2R_1}{R_2}\right] \times \frac{R_4}{R_3}.$$

- Hence by using a variable resistor R_2 the overall gain can be easily & linearly varied.
- The O/P vtg is then given by,

$$V_o = A_v \times (V_1 - V_2)$$

- These IA using 3 op-amps are available in IC form. e.g. IC AD 522 or INA 101
- Disadvantages of IA using 3 op-amps.
  - gain changes due to ageing of components & due to changes in temperature.
  - gain depends upon so many resistances.

⇒ Advantages of IA :-

- using a single variable resistor we can adjust the gain of the IA.
- I/P impedance is very high.
- O/P impedance is very low
- good capacity to reject common mode signals such as noise.

→ Applications :

- Temperature indicator.
- Temp. controller
- Pressure monitoring & control
- Electronic weighing scale.
- Light intensity meter.