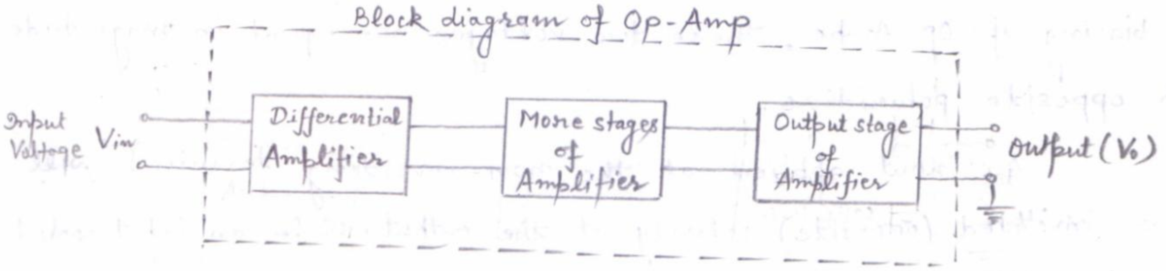
UNIT-5

Operational Amplifiers

An operational amplifier (commonly referred to as Op-Amp) is a multi-terminal device, whose internal circuitry is quite complex. One of the reasons for the popularity of op-Amp is its versatility (used for ac as well as dc).

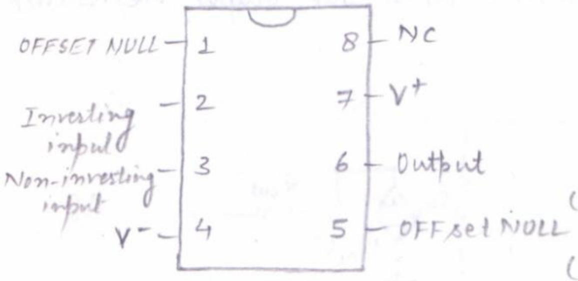
Definition: An Op-Amp is an active circuit element designed to perform mathematical operations of addition, subtraction, multiplication, division, differentiation and integration.

Block diagram of an Op-Amp: An op-Amp is basically a multistage amplifier (consisting of many amplifier stages, directly coupled with the previous one).



Block diagram of Op-Amp

Pin diagram:

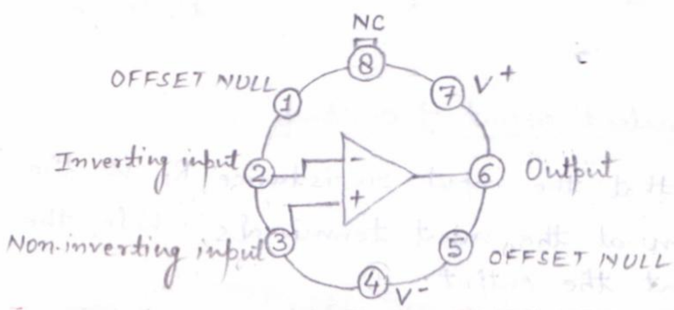


(a)

The 741 package style and pin outs

(a) Dual-in-line

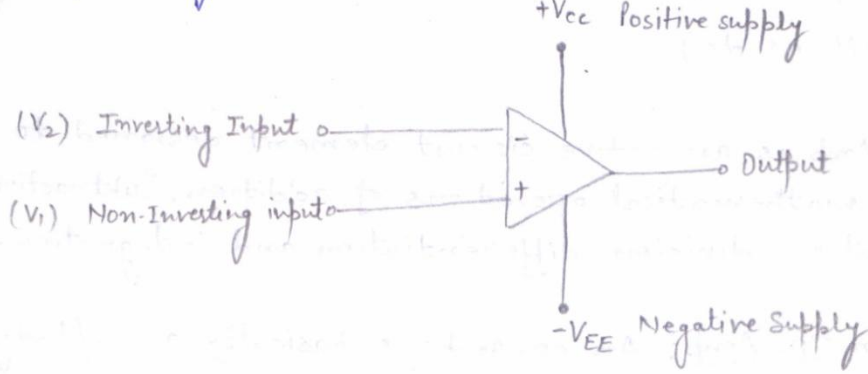
(b) Metal can Package



(b)

Op-Amp Symbol:

An Op-Amp has two inputs and one output. The inputs are marked with (-) and plus (+) to specify inverting and noninverting inputs respectively.



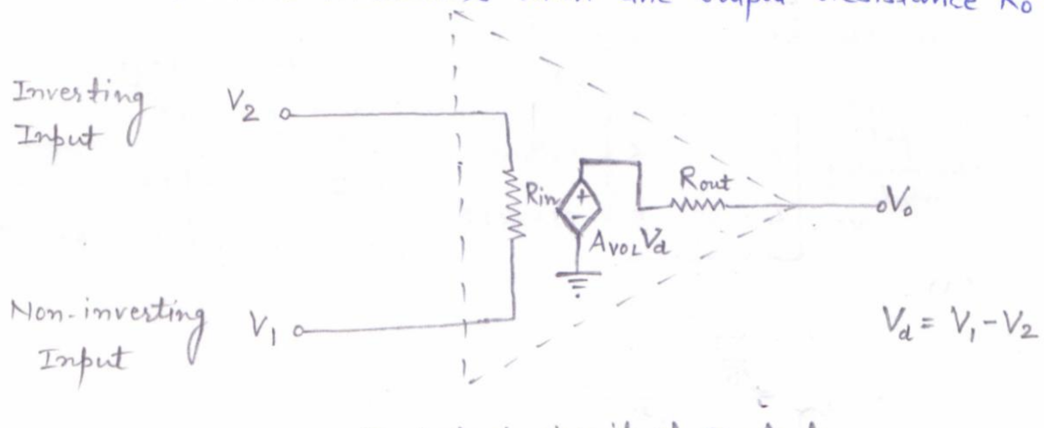
Circuit symbol of an Op-Amp

The two dc sources, named as $+V_{cc}$ and $-V_{EE}$ are required for the biasing of Op-Amps. These two voltages are equal in magnitude with opposite polarities.

An input applied at the non-inverting terminal will appear ~~with same~~ polarity at the output, while an input applied to the inverting terminal will appear inverted (opposite) polarity at the output.

Op-Amp Equivalent Circuit:

In an equivalent circuit the output section consist of a voltage controlled source in series with the output resistance R_o.



Equivalent circuit of Op-Amp

It is evident from fig. that the input resistance R_i is the Thevenin equivalent resistance seen at the input terminals, while the output resistance R_o is seen at the output.

The differential input voltage V_d is given by

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

Where

V_1 = Voltage between the noninverting terminal & ground

V_2 = Voltage between the inverting terminal and ground

The Op-Amp senses the difference between the two inputs, multiplies it by the gain A, and causes the resulting voltage to appear at the output. Thus, the output V_o is given by

$$\boxed{V_o = A_{VOL} V_d = A_{VOL}(V_1 - V_2)}$$

Where A_{VOL} is called the open-loop voltage gain because it is the gain of the Op-Amp without any internal feedback from o/p to input.

Ideal Op-Amp and its characteristics or Parameters:

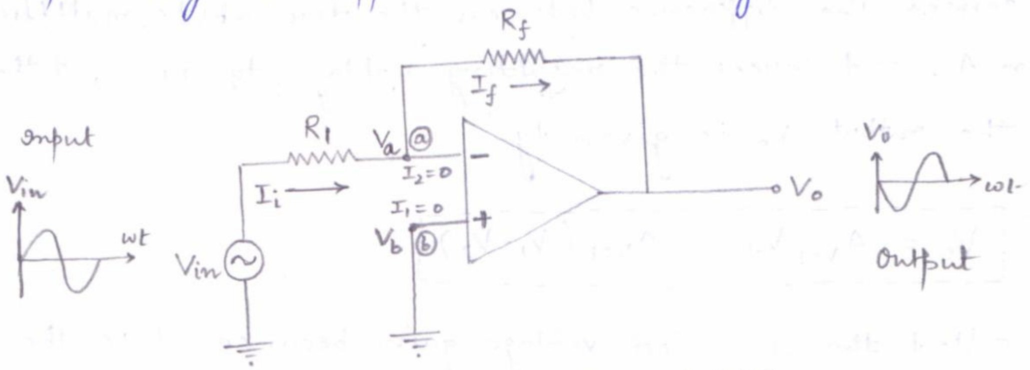
Definition: An ideal Op-Amp is an amplifier with infinite open loop gain, infinite input resistance and zero output resistance.

Parameters	Symbol	Ideal value
1) Open loop voltage gain	A_{VOL}	Infinite (∞)
2) Input Resistance	R_{in}	Infinite (∞)
3) Output Resistance	R_{out}	Zero (0)
4) Input bias current	$I_{in(bias)}$	Zero (0)
5) Input offset current	$I_{in(off)}$	Zero (0)
6) Input offset voltage	$V_{in(off)}$	Zero (0)
7) Common-mode rejection ratio (CMRR)	CMRR	Infinite (∞)
8) Slew Rate	SR	Infinite (∞)

i> The Inverting Amplifier:

Definition: An Op-Amp circuit that produces an amplified output signal that is 180° out of phase with the input signal.

Circuit diagram: In this circuit, the noninverting terminal is grounded, Input voltage V_i is applied to the inverting terminal through R_1.



Inverting Amplifier

The feedback resistor R_f is connected between the inverting input and output terminals.

Expression for Output Voltage (V_o):

Applying KCL at node a

$$I_i = I_f \quad \text{------(i)}$$

Here input current $I_i = \dfrac{V_{in} - V_a}{R_1}$ ------(ii) $\left[\text{Current}(I) = \dfrac{\text{Pot. difference}}{\text{Resistance}}\right]$

Output current $I_f = \dfrac{V_a - V_o}{R_f}$ ------(iii)

Therefore

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

But $V_a = V_b = 0$ for an ideal Op-Amp, for inverting amplifier noninverting terminal is grounded, Hence

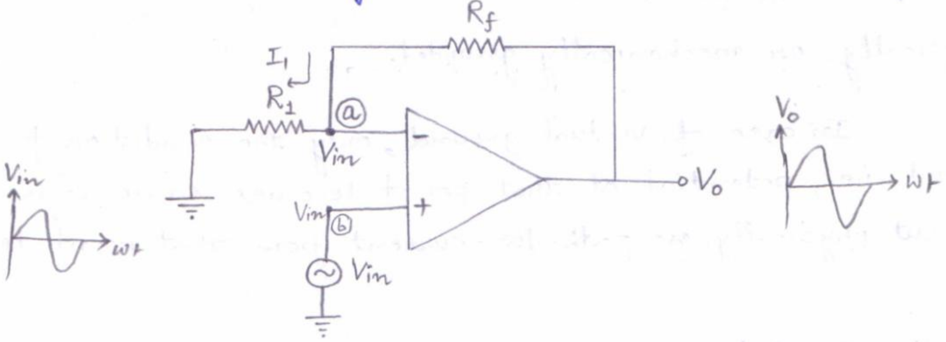
$$V_a = V_b = 0$$

Now $\dfrac{V_{in}}{R_1} = -\dfrac{V_o}{R_f} \Rightarrow \boxed{V_o = -\dfrac{R_f}{R_1} V_{in}}$ & Voltage gain: $\boxed{A_V = \dfrac{V_o}{V_i} = -\dfrac{R_f}{R_1}}$

ii) **The Non-inverting Amplifier:**

Definition: A noninverting amplifier is an Op-Amp circuit designed to provide positive voltage gain. The input is applied directly to the noninverting terminal.

Circuit diagram: Another basic circuit of the Op-Amp is the noninverting amplifier. In this case the input voltage V_{in} is applied directly at the noninverting input terminal and resistor R_1 is connected between the ground and the inverting terminal.



Expression for output Voltage (V_o): As the differential voltage V_d at input terminals of Op-Amp is zero (which means both input terminals have same potential), hence the voltage at node ⓐ is same as the input voltage applied to the noninverting input terminal.

Now apply KCL at node ⓐ

$$\frac{V_o - V_{in}}{R_f} = \frac{V_{in} - 0}{R_1}$$

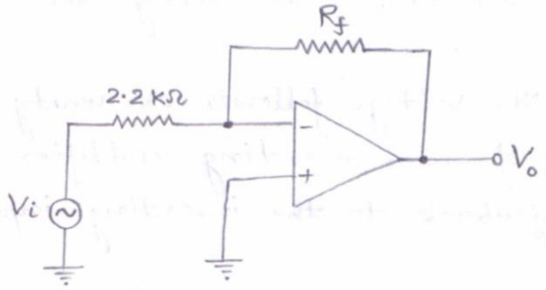
$$\Rightarrow \frac{V_o - V_{in}}{R_f} = \frac{V_{in}}{R_1} \quad \Rightarrow \frac{V_o}{R_f} = \frac{V_{in}}{R_1} + \frac{V_{in}}{R_f}$$

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

Now the gain of the noninverting amplifier is given by

$$\boxed{A_V = \frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1}}$$

Prob.1: Given the op amp configuration shown in below fig., determine the value of R_f required to produce a closed-loop voltage gain of -100.



Sol. Gain for inverting amplifier $A_v = -\frac{R_f}{R_1}$

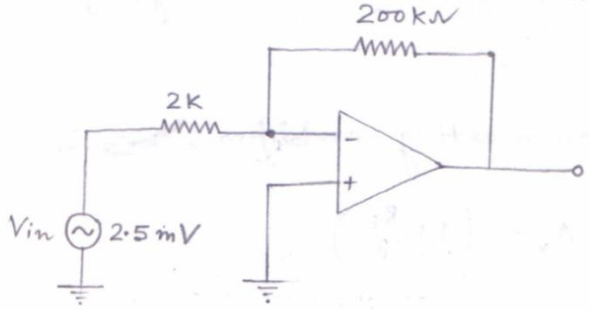
$$R_f = -A_v R_1$$

$$R_f = 100 \times 2.2 \times 10^3$$

$$R_f = 220\,k\Omega$$

Ans

Prob 2: Determine the output voltage for the circuit of below fig.



Sol. The above circuit is inverting amplifier

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

$$V_o = -\frac{200k}{2k} \times 2.5\,mV$$

$$V_o = -0.25\,V$$

Ans

Op-Amp Applications: Some Op-Amp applications are as follows;

i) Adder or Summing Amplifier ii) Subtractor

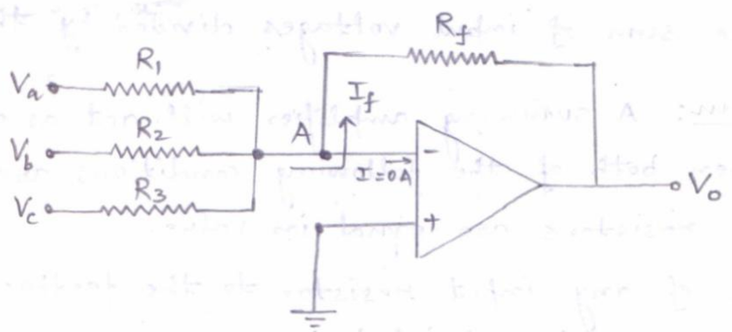
iii) Differentiator iv) Integrator

The summing Amplifier or Adder: Definition - Adder is an Op-Amp circuit, which can accept two or more inputs and produces output as the sum of these inputs.

Circuit diagram: Adder (or) summing amplifier is constructed using inverting configuration that can accept two or more inputs.

The output voltage of an adder is proportional to the negative of the algebraic sum of its input voltages.

Below fig. shows a three input adder using inverting configuration. Three voltages V_a, V_b and V_c are applied to the inputs and produce three currents I_a, I_b and I_c respectively. These input currents I_a, I_b and I_c combine at the summing point A and form the total current I_f which goes through R_f as shown in fig.



Three input Adder

Expression for output Voltage: Apply KCL at node A

$$I_a + I_b + I_c = I_f \quad \text{-----(1)}$$

When all the inputs are applied to the Op-Amp, the output voltage is

$$V_o = -I_f R_f$$
$$= -R_f (I_a + I_b + I_c).$$

$$\boxed{V_o = -R_f\left(\frac{V_a}{R_1} + \frac{V_b}{R_2} + \frac{V_c}{R_3}\right)}$$

If $R_1 = R_2 = R_3 = R$, then we have

$$V_o = -R_f\left(\frac{V_a}{R} + \frac{V_b}{R} + \frac{V_c}{R}\right)$$

$$\boxed{V_o = -\frac{R_f}{R}\left(V_a + V_b + V_c\right)}$$

From above equation we can see the output voltage V_o is equal to the negative sum of all the inputs times the gain of the circuit (R_f/R).

Adder with unity gain: In this case $R_f = R_1 = R_2 = R_3$ and the output voltage is

$$V_o = -(V_a + V_b + V_c)$$

Thus when the gain of adder amplifier is unity, the output voltage is the algebraic sum of all the input voltages.

The Averager: Averaging amplifier gives an output voltage proportional to the average of all the input voltages.

If there are three input voltages, the average should be the sum of input voltages divided by three

Circuit diagram: A summing amplifier will act as an averaging amplifier when both of the following conditions are met

1) All input resistors are equal in value
2) The ratio of any input resistor to the feedback resistor is equal to the number of inputs.

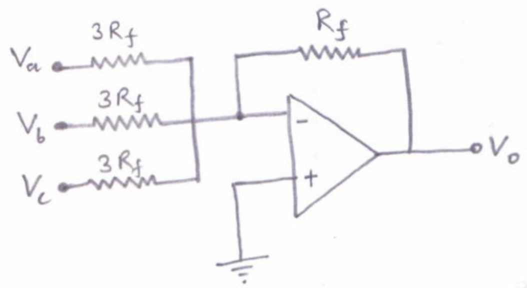
$$\boxed{\frac{R_i}{R_f} = n}$$

Where

R_i = Input Resistor

R_f = feedback Resistor

n = number of inputs



Three input averaging amplifier

Note that it is a summing amplifier meeting the mentioned two conditions. All input resistors are equal in value which is equal to $3R_f$. If we take the ratio of any input resistor to the feedback resistor, we get $3R_f/R_f = 3$. This is equal to the number of inputs to the circuit.

The general expression of output for three input summing amplifier is

$$V_o = -\frac{R_f}{R_1}(V_a + V_b + V_c)$$

For averaging amplifier circuit $R_i = 3R_f$ (for three input)

Therefor

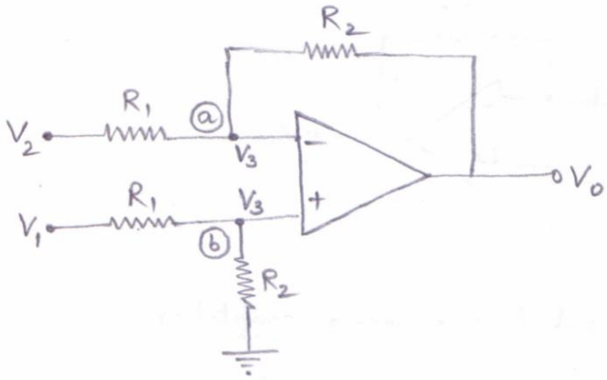
$$V_o = -\frac{R_f}{3R_f}(V_a + V_b + V_c)$$

$$\boxed{V_o = -\left(\frac{V_a + V_b + V_c}{3}\right)}$$

The Subtractor:

Definition: A circuit that amplifies the difference between two signals is called difference amplifier or subtractor.

Circuit diagram: Fig. on next page is the circuit of subtractor. Nodes ⓐ and ⓑ are at the same potential designated as V_3.



The Subtractor

Expression for output Voltage (V_o): Apply Nodal equation at node (a)

$$\frac{V_2 - V_3}{R_1} = \frac{V_3 - V_o}{R_2} \quad \text{--------} \quad (i)$$

Again apply Nodal equation at node (b)

$$\frac{V_1 - V_3}{R_1} = \frac{V_3 - 0}{R_2} \quad \text{--------} \quad (ii)$$

Subtracting equation (ii) from (i), we get

$$\frac{V_2 - V_1}{R_1} = -\frac{V_o}{R_2}$$

$$\Rightarrow \quad \frac{V_1 - V_2}{R_1} = \frac{V_o}{R_2}$$

$$\Rightarrow \quad V_o = \frac{R_2}{R_1}(V_1 - V_2)$$

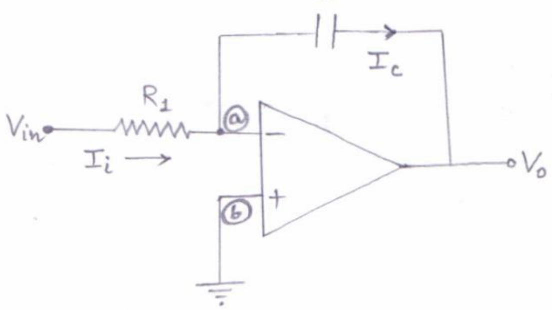
Hence the output voltage of subtractor circuit is;

$$\boxed{V_o = \frac{R_2}{R_1}(V_1 - V_2)}$$

Integrator:

Definition: A circuit that performs integration of input signals is called an integrator. The output of an integrator is proportional to the area of the input waveform over a period of time.

Circuit diagram: If we place a capacitor C in the feedback path and a resistor R_1 in the input path, the circuit realizes the mathematical operation of integration and hence known as integrator circuit.



Integrator circuit

Expression for output Voltage or Circuit Analysis: A time varying input voltage $V_{in}(t)$ is applied at the input of the circuit. Point A in above fig. is at virtual ground. Because of virtual ground and infinite impedance of the Op-Amp, all of the input current I_i flows through the capacitor i.e.

$$I_i = I_c$$

Now input current

$$I_i = \frac{V_{in} - 0}{R_1} = \frac{V_{in}}{R_1} \quad \text{-------} (1)$$

Also voltage across capacitor is

$$V_c = 0 - V_o = V_o$$

$$\therefore \quad I_c = C\frac{dV_c}{dt} = -\frac{C\,dV_o}{dt} \quad \text{-----} (2)$$

$$\left[\begin{array}{c} Q = CV \\ \frac{dQ}{dt} = C\frac{dV}{dt} \\ I = C\frac{dV}{dt} \\ I_c = C\frac{dV_c}{dt} \\ I_c = -C\frac{dV_o}{dt} \end{array}\right]$$

From equation (1) and (2)

$$\frac{V_{in}}{R_1} = -C\frac{dV_o}{dt}$$

or $$\frac{dV_o}{dt} = \frac{-1}{RC} V_{in} \quad \text{-------- (3)}$$

To find the output Voltage, we integrate both sides of equation (3)

$$\boxed{V_o = -\frac{1}{R_1 C}\int_0^t V_{in}\,dt}$$

Applications of an integrator:

1) It is used to generate triangular wave form.
2) It is also used in Analog to digital converter circuit.
3) It is used as low pass filter

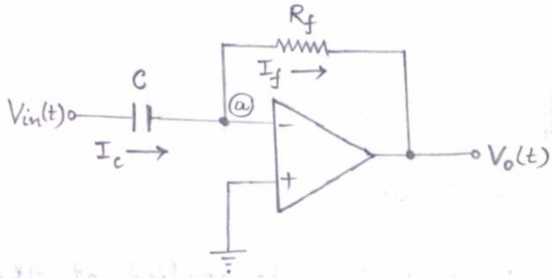
Differentiator:

Definition: A circuit that performs mathematical differentiation of input signal is called a differentiator.

The output of a differentiator is proportional to the rate of change of its input signal.

Circuit diagram: If the position of resistor and capacitor is interchanged in the integrator, then the resulting circuit is called a differentiator.

In a below circuit we can see that capacitor is connected in input while resistor is connected in feedback.



Differentiator

Expression for output Voltage: Using the concept of virtual ground we can write

$$I_c = I_f \quad \text{------ (1)}$$

where

I_c = current through the capacitor

$$I_c = C\frac{d}{dt}V_{in}(t) \quad \text{------ (2)}$$

and

$$I_f = -\frac{V_o(t)}{R_f} \quad \text{------ (3)}$$

Now substituting equation (2) and (3) into equation (1)

$$C\frac{dV_{in}(t)}{dt} = -\frac{V_o(t)}{R_f}$$

$$\boxed{V_o(t) = -R_f C\frac{dV_{in}(t)}{dt}}$$

Here, $R_f C$ is time constant differentiator circuit

Now $R_f C << T$ (condition)

Op-Amp Parameters: The important parameters of Op-Amp are as follows -

i) Input offset Voltage ($V_{in(off)}$)

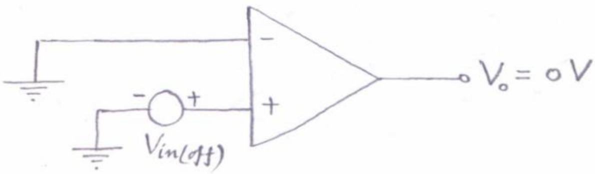
ii) Input offset current ($I_{in(off)}$)

iii) Bias current ($I_{in\,bias}$)

iv) Slew rate (SR)

v) Common Mode Rejection Ratio (CMRR)

i) Input offset Voltage: In an ideal Op-Amp, the output should be zero when both the inputs are grounded. For practical op-amps, it is found the output voltage may still not be zero with input voltage grounded. This is due to imbalances inside the Op-Amp.



A small amount of voltage is applied at the anyone input terminal to make output voltage zero. This input voltage is called input offset voltage ($V_{in(off)}$) as shown in above figure.

ii) Input offset current ($I_{in(off)}$): For ideal Op-Amp, the input bias currents I_{B_1} (I_1) and I_{B_2} (I_2) should be equal and zero. In practice, these currents are not equal because of the internal imbalances in the Op-Amp circuit.

The algebraic difference between the currents into the inverting and noninverting terminals is called input offset current $I_{in(off)}$.

Mathematically $\boxed{I_{in(off)} = |I_{B_1} - I_{B_2}|}$

where I_{B_1} = Input bias current for inverting terminal

I_{B_2} = Input bias current for noninverting terminal iii> Bias Current or Input bias current ($I_{in(bias)}$): Input bias current is the average of the currents that flow into the inverting and noninverting terminals of the op-Amp. In equation form

$$\boxed{\text{Bias current } I_B \text{ or } I_{in(bias)} = \frac{I_{B_1} + I_{B_2}}{2}}$$

where

I_{B_1} = Input bias current for inverting terminal

I_{B_2} = Input bias current for noninverting terminal

iv> Slew Rate (SR): The slew rate is defined as the maximum rate of change of output voltage with respect to time.

For ideal op-Amp, slew rate is infinite. It is specified in V/µs.

In mathematical form

$$\boxed{\text{Slew Rate (SR)} = \left.\frac{dV_o}{dt}\right|_{max} \quad \text{or} \quad \left.\frac{\Delta V_o}{\Delta t}\right|_{max.}}$$

v> Common Mode Rejection Ratio (CMRR): The common mode rejection ratio (CMRR) may be defined as the ratio of the differential voltage gain (A_d) to the common mode gain (A_{cm})

Mathematically

$$\boxed{CMRR = \frac{|A_d|}{|A_{cm}|}}$$

Where A_d is differential voltage gain

A_{cm} is common mode voltage gain

The differential voltage gain is defined as

$$A_d = \frac{V_o}{V_{id}}$$ where V_{id} is differential input ($V_1 - V_2$)

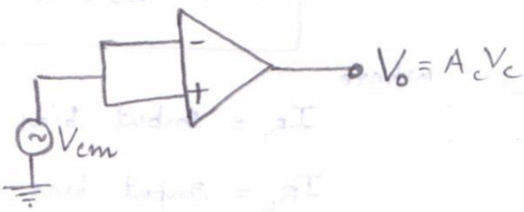
The common mode voltage gain is defined as

$$A_{cm} = \frac{V_o}{V_{cm}}$$

$A_{cm} = A_c$
$V_{cm} = V_c$

where V_{cm} is the common mode input as shown in fig.

$$V_{cm} = \frac{V_1 + V_2}{2}$$



In general A_{cm} is very small as compared to A_d hence CMRR is very large. Therefore, ideally CMRR is infinite (∞).

* The ability of an Op-Amp to reject a common mode signal is expressed by a ratio called 'Common Mode Rejection Ratio' denoted as CMRR.

$$\boxed{CMRR\,(\log) = 20 \log_{10} \frac{A_d}{A_c}}$$

$$\boxed{V_d = V_{i_1} - V_{i_2}}$$

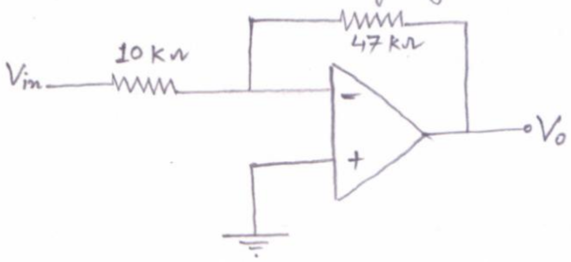
Total output voltage $\boxed{V_o = A_d V_d + A_c V_c}$

$$\boxed{V_c = \frac{1}{2}(V_{i_1} + V_{i_2})}$$

V_d = Difference voltage
V_c = Common Voltage
A_d = Differential gain of the amplifier
A_c = Common-mode gain of the amplifier

Problems on Op-Amp

Prob1: Determine the Voltage gain of the Op-Amp circuit shown in fig.



Sol: Ckt is inverting amplifier

$$Gain = \frac{V_o}{V_{in}} = -\frac{R_f}{R_1} = -\frac{47\,k\Omega}{10\,k\Omega} = -4.7$$ Ans

Prob2: If the base currents for the emitter coupled transistors of a differential amplifier are 18 µA and 22 µA, determine
i) Input bias current and ii) Input offset current for an Op-Amp

Sol: Here Input bias currents $I_{B_1} = 18\,\mu A$, $I_{B_2} = 22\,\mu A$

i) Input bias current $I_B = \frac{I_{B_1} + I_{B_2}}{2} = \frac{18\,\mu A + 22\,\mu A}{2} = \frac{40}{2} = 20\,\mu A$ Ans

ii) The input offset current $I_{in(off)} = |I_{B_1} - I_{B_2}| = |18 - 22| = 4\,\mu A$ Ans

Prob3: For a particular Op-Amp, the input offset current is 20 nA while input bias current is 60 nA. Calculate the values of two input bias currents.

Sol: $I_B = 60\,nA$, $I_{in(off)} = 20\,nA$

$I_B = \frac{I_{B_1} + I_{B_2}}{2}$ $\quad I_{in(off)} = |I_{B_1} - I_{B_2}|$

$\Rightarrow I_{B_1} + I_{B_2} = 2 I_B$ $\quad \boxed{I_{B_1} - I_{B_2} = 20\,nA}$ — (2)

$\boxed{I_{B_1} + I_{B_2} = 120\,nA}$ — (1)

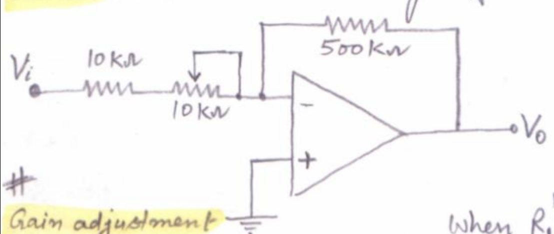
Solve eqn (1) & (2)

$I_{B_1} = 70\,nA$

$I_{B_2} = 50\,nA$

Ans.

Prob4: What is the range of the voltage gain adjustment in the circuit



Sol: The circuit shown is inverting amplifier with gain $-\frac{R_f}{R_1}$

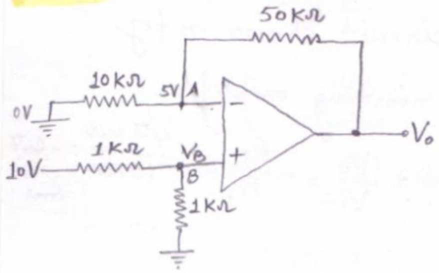
$R_f = 500\,k\Omega$, $R_1 = 10\,k\Omega + R_1'$ (R_1' varies from 0 to 10 kΩ)

When $R_1' = 0\,\Omega$ $R_1 = 10\,k\Omega$ Gain $= -\frac{500}{10} = -50$

" $R_1' = 10\,k\Omega$ $R_1 = 20\,k\Omega$ Gain $= -500/20 = -25$

Gain adjustment possible is −25 to −50 Ans.

Prob5: Determine the V_0 for the below circuit



Sol.: The Voltage at node B is V_B

Apply voltage divides rule

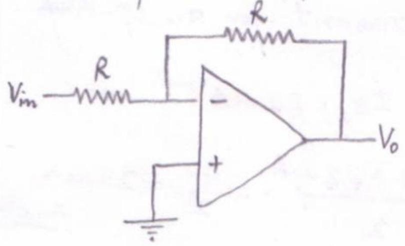
$$V_B = \frac{10V \times 1K\Omega}{1K\Omega + 1K\Omega} = 5V, \quad V_B = 5V$$

Hence $V_A = V_B = 5V$ (A & B Virtual short)

Apply Nodal at point A

$$\frac{0V - 5V}{10K\Omega} = \frac{5V - V_0}{50K\Omega} \Rightarrow \boxed{V_0 = 30V} \text{ Ans.}$$

Prob6: Determine the output Voltage (V_0) for below ckt



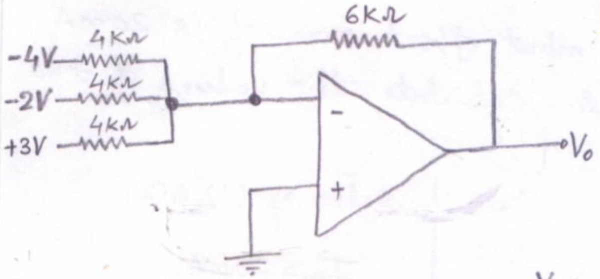
Sol.: The given ckt is of inverting amplifier

Output $V_0 = -\frac{R_f}{R_1} V_{in}$, Here $R_f = R_1 = R$

$$V_0 = -\frac{R}{R} V_{in} \Rightarrow \boxed{V_0 = -V_{in}} \text{ Ans.}$$

* This circuit is also called sign changer.

Prob7: Find the output Voltage of the 3 input adder circuit shown in below fig.



Sol.: The output of 3 input adder ckt is

$$V_0 = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right) \text{ - - - - - (i)}$$

Now for ckt:- $R_f = 6K\Omega$, $R_1 = R_2 = R_3 = 4K\Omega$

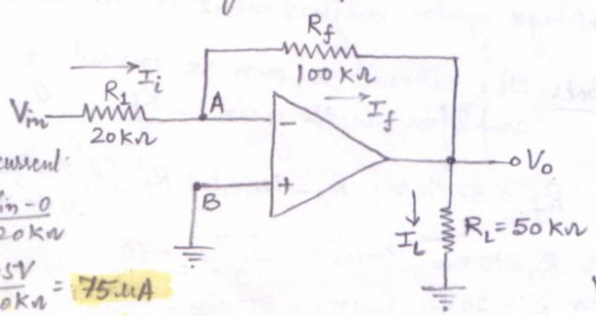
$V_1 = -4V$, $V_2 = -2V$, $V_3 = +3V$

Put the above values in equation (i)

$$V_0 = -6\left(\frac{-4V}{4K\Omega} + \frac{(-2V)}{4K\Omega} + \frac{3V}{4K\Omega}\right) \Rightarrow \boxed{V_0 = 4.5V} \text{ Ans.}$$

Prob8: An inverting amplifier circuit has input series resistor of 20kΩ, feedback resistor of 100KΩ and a load resistor of 50 KΩ. Draw the circuit and calculate the input current, load current and the output voltage, when the applied input voltage is equal to +1.5V.

Sol.:



Input current:

$$I_i = \frac{V_{in} - 0}{20K\Omega}$$

$$I_i = \frac{1.5V}{20K\Omega} = 75\mu A$$

Node B is ground, hence $V_B = 0V$

Now $V_A = V_B = 0V$ (node A is virtual ground)

Now Apply KCL at node A;

$$I_i = I_f$$

$$\frac{V_{in} - 0}{20K\Omega} = \frac{0 - V_0}{100K\Omega}$$

$$V_0 = -5V_{in} = -5 \times (1.5V)$$

Now Load current

$$I_L = \frac{V_0}{R_L} = \frac{-7.5V}{50K\Omega}$$

$$I_L = -0.15mA$$

Prob 9: Design a adder circuit using an Op-Amp to give the output $V_o = -(3V_1 + 4V_2 + 5V_3)$, given the inputs V_1, V_2 & V_3

Sol. Compare the output with 3 input adder ckt output expression

$$V_o = -(3V_1 + 4V_2 + 5V_3) \quad \text{compare by} \quad V_o = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

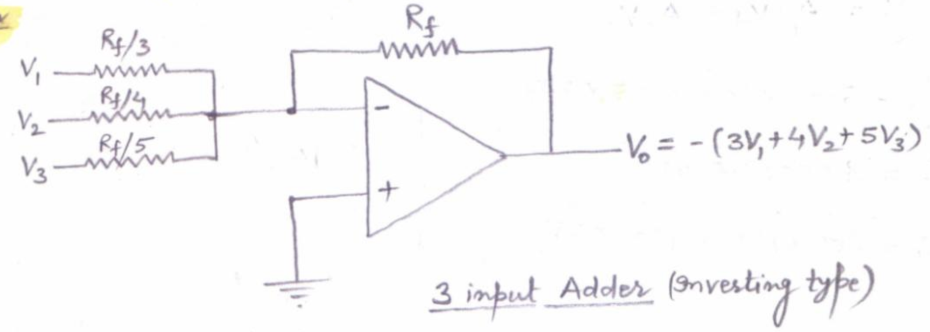
Now $\frac{R_f}{R_1} = 3$, $\frac{R_f}{R_2} = 4$, $\frac{R_f}{R_3} = 5$

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

(3 input Adder ckt output)

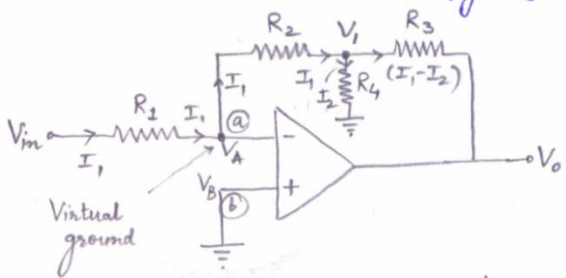
Hence $R_1 = \frac{R_f}{3}$, $R_2 = \frac{R_f}{4}$, $R_3 = \frac{R_f}{5}$

Design



3 input Adder (Inverting type)

Prob 10: For the circuit shown in below fig., find the output voltage V_o



Sol. Point or node (a) is at virtual ground, Hence $\boxed{V_A = V_B = 0}$

Now Apply KCL at node (a) $\frac{V_{in} - V_A}{R_1} = \frac{V_A - V_1}{R_2} \Rightarrow \boxed{I_1 = \frac{V_{in}}{R_1} = -\frac{V_1}{R_2}}$ —(1)

Hence $\boxed{V_1 = -\frac{R_2}{R_1}V_{in}}$ —(2)

Now current $I_2 = \frac{V_1 - 0}{R_4}$ and $I_1 - I_2 = \frac{V_1 - V_o}{R_3}$ —(4)

$I_2 = \frac{V_1}{R_4} \Rightarrow V_1 = I_2 R_4$,

Now $\boxed{I_2 = -\frac{R_2}{R_1 R_4}V_{in}}$ —(3)

Put the value of I_1, I_2 and V_1 in eq. (4)

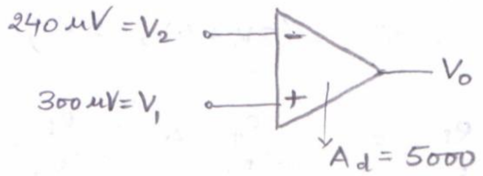
$$\frac{V_{in}}{R_1} + \frac{R_2}{R_1 R_4}V_{in} = -\frac{R_2}{R_1 R_3}V_{in} - \frac{V_o}{R_3}$$

$$\frac{V_{in}}{R_1} + \frac{R_2}{R_1 R_4}V_{in} + \frac{R_2}{R_1 R_3}V_{in} = -\frac{V_o}{R_3}$$

$$-\frac{V_o}{R_3} = V_{in}\left[\frac{1}{R_1} + \frac{R_2}{R_1 R_4} + \frac{R_2}{R_1 R_3}\right] \Rightarrow \boxed{V_o = \frac{-1}{R_1 R_4}\left[R_3 R_4 + R_2 R_3 + R_2 R_4\right] \times V_{in}}$$

Prob11: Determine the output voltage of an Op-Amp for the input voltages of 300 µV and 240 µV. The differential gain of the amplifier is 5000 and the value of the CMRR is 10^5.

Sol: Given $CMRR = 10^5$



Now we know that

$$CMRR = \frac{|A_d|}{|A_c|} \quad \therefore A_c = \frac{A_d}{CMRR}$$

$$A_c = \frac{5000}{10^5} = 0.05$$

Now output $V_o = A_d V_d + A_c V_c$

Here $V_c = \frac{V_1 + V_2}{2} = \left(\frac{300+240}{2}\right) \mu V$

$V_c = 270\ \mu V$

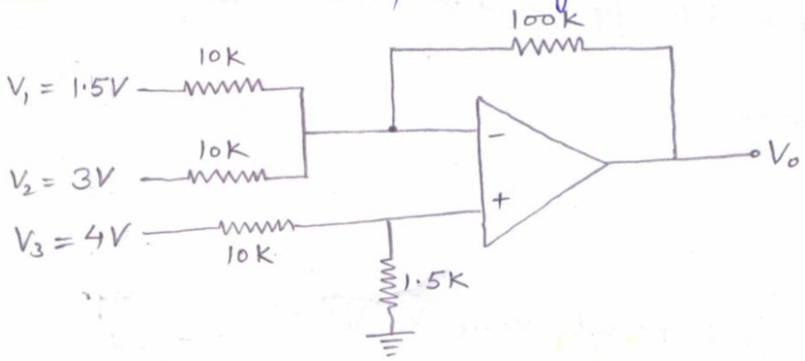
& $V_d = (V_1 - V_2) = 60\ \mu V$

$= 5000 \times 60 + 0.05 \times 270.$

$V_o = 300013.5\ \mu V$

$$\boxed{V_o = 300.0135\ mV = 0.3V}$$

Prob12: Calculate the output Voltage for the circuit shown in below fig.



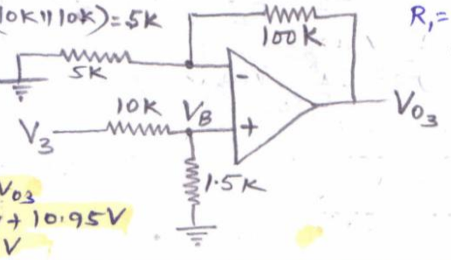
Sol. Using superposition principle,

Case 1: V_1 acting, $V_2 = V_3 = 0$, hence $V_{o1} = -\frac{R_f}{R_1} V_1 = \frac{-100k}{10k} \times 1.5V = -15V$

Case 2: V_2 acting, $V_1 = V_3 = 0$, hence $V_{o2} = -\frac{R_f}{R_2} V_2 = \frac{-100k}{10k} \times 3V = -30V$

Case 3: when V_3 acting, $V_1 = V_2 = 0$, Then ckt looks like as below

$(10K \| 10K) = 5K$



$R_1 = 10K \| 10K$
$= 5K$

Now $V_B = \frac{V_3 \times 1.5K}{(10K + 1.5K)} = 0.52V$

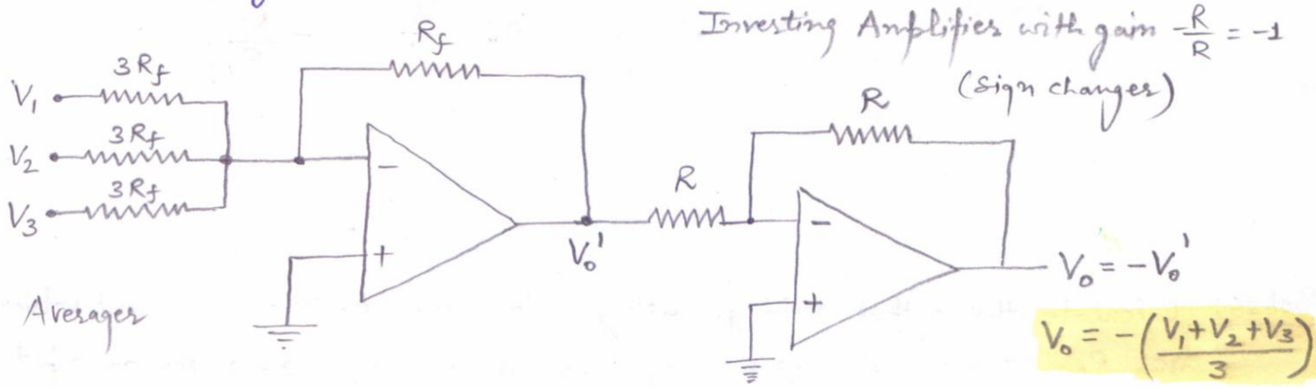
$V_{o3} = \left(1 + \frac{R_f}{R_1}\right) V_B = \left(1 + \frac{100K}{5K}\right) \times 0.52V$

$V_{o3} = 10.95V$

Now $V_o = V_{o1} + V_{o2} + V_{o3}$
$= -15V - 30V + 10.95V$
$V_o = -34.04V$

Prob 13: Design the circuit using Op-Amps, whose output Voltage is
$$V_o = (V_1+V_2+V_3)/3$$

Sol: First design an inverting adder to get the output,
$$V_o = -(V_1+V_2+V_3)/3$$
Then invert it by using an inverting amplifier with $R_f = R_1 = R$ i.e. gain = -1, to get the required output. The overall ckt is shown in below figure;

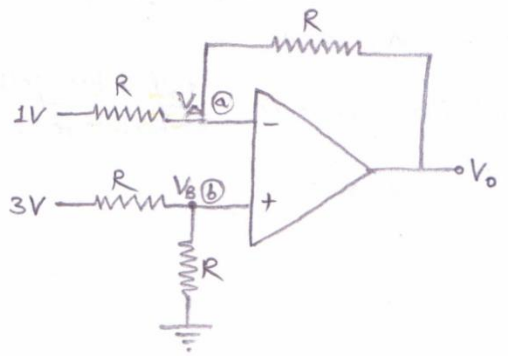


$$V_o = -\left(\frac{V_1+V_2+V_3}{3}\right)$$

$$V_o' = -\left[\frac{R_f}{3R_f}V_1 + \frac{R_f}{3R_f}V_2 + \frac{R_f}{3R_f}V_3\right]$$

$$V_o' = -\left(\frac{V_1+V_2+V_3}{3}\right)$$

Prob 14: What is the output Voltage of the following circuit?



Sol: The node voltage at ⓑ is assumed V_B;

$$\text{Now } V_B = \frac{3V \times R}{R+R} = \frac{3}{2}V = 1.5V$$

$$V_A = V_B = 1.5V$$

Apply nodal at node ⓐ

$$\frac{1V - 1.5V}{R} = \frac{1.5V - V_o}{R}$$

$$\Rightarrow V_o = 1.5V + 1.5V - 1V$$

$$\Rightarrow \boxed{V_o = 2V}$$

* If All the resistors are equal in the circuit of subtractor, then output Voltage

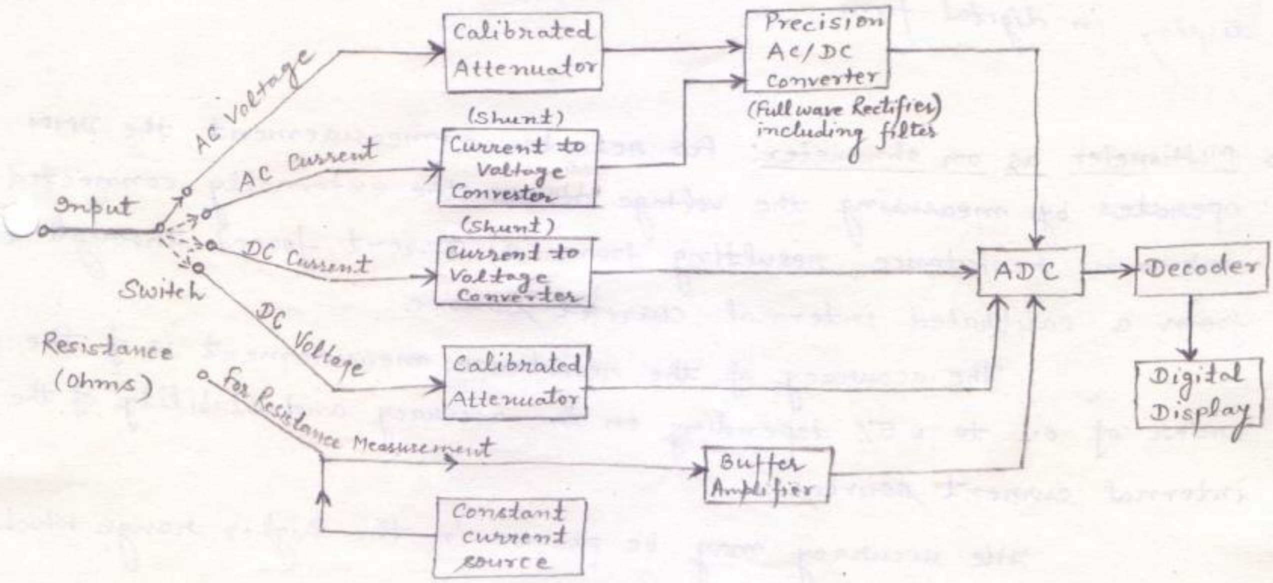
$$V_o = (V_1 - V_2) = (3V - 1V)$$

$$\boxed{V_o = 2V}$$

Digital Multimeter: A digital multimeter is an electronic instrument which can measure resistances, currents and voltages. It is a versatile instrument and can be used for measuring dc as well as a.c. voltages and currents.

Block diagram of digital Multimeter: The schematic block diagram of a digital multimeter is shown in below fig.

* ADC - Analog to Digital Converter



Block diagram of Digital Multimeter

Functions of digital multimeter: DMM is used to measure the following quantities mainly:

1> Voltages 2> Currents 3> Resistances

1> Multimeter as Voltmeter: In a.c voltage mode, the applied a.c. input voltage is fed through a calibrated, compensated attenuator, where the input is measured and attenuated to a suitable level which is accepted by the succeeding stages.

This attenuated voltage is converted into dc by a suitable precision a.c. to d.c. convertor which consists of a full wave recitifier circuit followed by a ripple reduction filter. The resulting d.c is fed to the ADC (Analog to Digital Convertor) and the subsequent decoder and display where the output display in decimal no. system

2) Multimeter as Ammeter: For current measurements, the current is applied to the shunt and the drop across an internal calibrated shunt is measured directly by ADC which is further fed to decoder and digital display system, which displays the output in numerical form in the d.c current mode.

In the a.c current mode current is applied to the shunt and then it will go to the precision AC to DC converter (Full wave Rectifier) further fed to ADC then decoded & digital display where the output display in digital form.

3) Multimeter as an ohmmeter: For resistance measurement, the DMM operates by measuring the voltage across the externally connected unknown resistance, resulting from a current forced through it from a calibrated internal current source.

The accuracy of the resistance measurement is of the order of 0.1 to 0.5% depending on the accuracy and stability of the internal current sources.

The accuracy may be poorer in the higher range which is often about 10 to 20 MΩ.

Application of Digital Multimeters:

1) For checking circuit continuity.
2) For measuring d.c voltage across various resistors in electronic circuits.
3) For measuring a.c voltages across power supply transformer.
4) For measuring A.C & D.C currents and the value of Resistance in ckts.

Merits & DeMerits of Multimeters: The merits (Advantage) & Demerits (disadvantage) of DMM are as follows:

Merits: 1) It is single meter that performs several measuring functions.
2) It has a small size and is easily portable.
3) It can make measurements with reasonable accuracy.

Demerits: 1) It is a costly instrument.
2) Technical skill is required to handle it.
3) It cannot make precise and accurate measurements due to the loading effect.