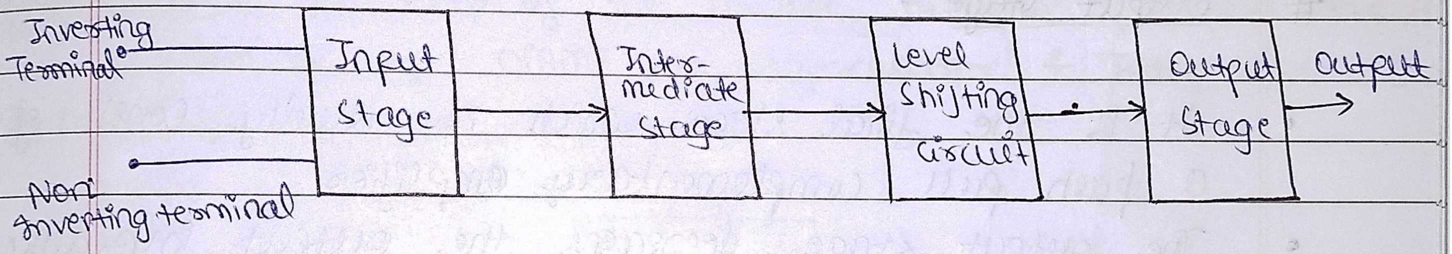
20/12/22

UNIT-3 OPERATIONAL AMPLIFIERS

Ques1:- What is an operational amplifier? Draw & Explain its block diagram. Write the characteristic of an ideal operational amplifier.

Ans:- • Op-Amp is a direct coupled high gain amplifier which can be used to amplify as as well as dc signals.

• It is mainly used for mathematical operation like addition, subtraction, integration differentiation, etc.



Input Stage -

• The input stage is the dual input balance output (DIBO) differential amplifier.
• It's function is to amplify the difference between two input signals.
• It provide High differential gain, High input impedence.

Intermediate Stage :-

• The overall gain requirement of an op-amp is very high. Indermediate stage is used to provide the required additional gain.

- It consist of another differential amplifier with dual input and unbalanced (single ended) output.

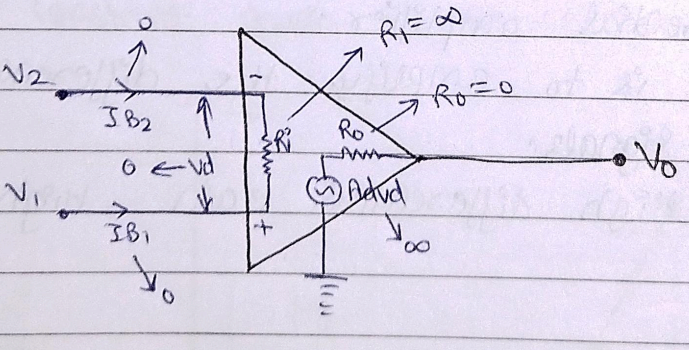
Level Shifting :-

- As the op-amp amplifies dc signal also, the small dc voltage level of previous stage may get amplified and applied as the input to the next stage causing distortion in the final output.
- So, level shifting circuit is used to bring down the dc level to ground potential.

Output Stage :-

- It is the final stage which is usually consist of a push pull complementary amplifier.
- The output stage decreases the output impedence and increases the current supplying capability of the op-amp.

Characteristics :-



(i) open loop gain should be infinite

$$A_d\ (A_{VDL}) = \infty$$

(ii) Input resistance should be infinite.

$$R_i = \infty$$

(iii) Slew rate should be infinite

$SR = \infty$

(iv) CMRR should be infinite

$CMRR = \infty$

(v) Input offset voltage should be zero

$V_{IO} = 0$

(vi) Input offset current should be zero

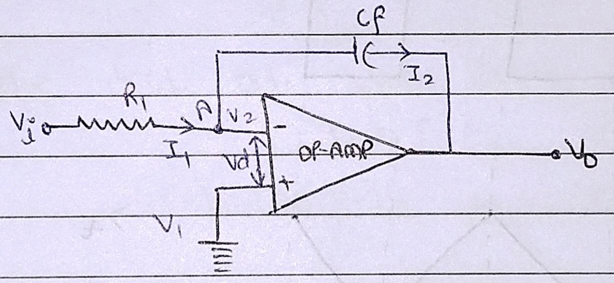
$I_{IO} = 0$

(vii) Input bias current should be zero.

$I_B = 0$

Ques2:- With the help of the circuit diagram, explain the working of OPAMP as differentiator & Integrator.

Ans:- OP-AMP as Integrator.



Expression for O/P -

Here $V_1 = 0$ —(1)

from concept of virtual ground

$Vd = 0$

$V_1 - V_2 = 0$

$V_1 = V_2$ $[V_1 = 0]$

$\therefore \quad V_2 = 0$ —(2)

Apply KCL at Node A

$I_1 = I_2$

$$\frac{V_i - V_2}{R_1} = \frac{C_f\, d\,(V_2 - V_0)}{dt}$$

but $V_2 = 0$

$$\frac{V_i}{R_1} = \frac{C_f d(-V_0)}{dt}$$

$$dV_0 = -\frac{1}{R_1 C_f} V_i dt$$

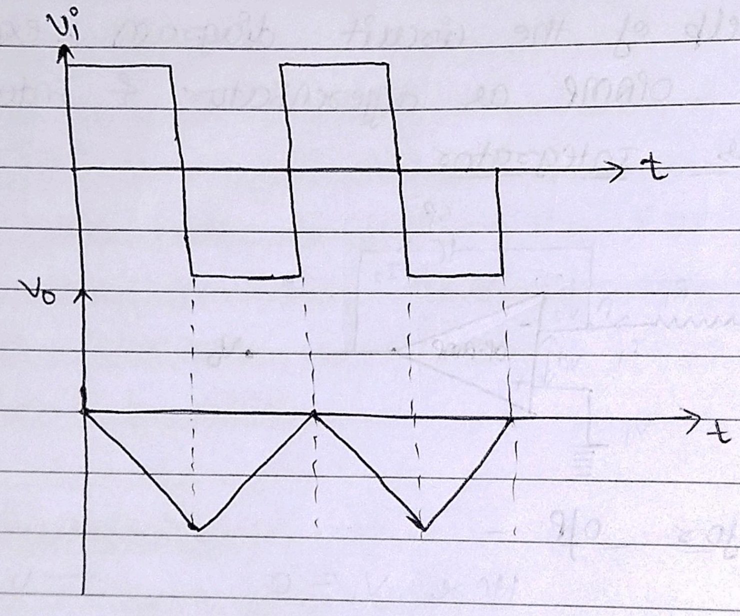
Now, Apply integration both sides

$$\int dV_0 = -\int \frac{1}{R_1 C_f} V_i dt$$

$$V_0 = \frac{-1}{R_1 C} \int_0^t V_i dt$$

$$\boxed{V_0 \propto \int_0^t V_i dt}$$

I/P / O/P



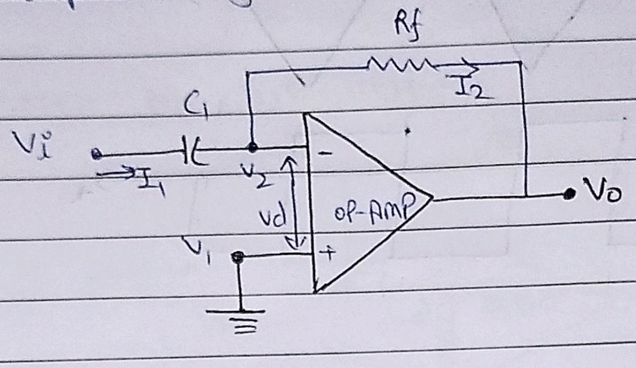
→ A circuit that perform the integration of input signal is called integrator.
Since, the output voltage is directly proportional to the integration of input signal, Hence circuit is called integrator circuit.

Applications :-

- Used for generating triangular waves., as a low pass filter
- Used in D to A (Digital to analog) convertor circuit

Op-Amp as a Differentiator -

A circuit that performs the mathematical differentiation of input signal is called differentiator.



Expression for o/p voltage

Here $V_1 = 0$

from concept of virtual ground, $Vd = 0$

$V_1 - V_2 = 0$

$V_1 = V_2$ $\quad \therefore (V_1 = 0)$

$\therefore V_2 = 0$

Apply KCL at Node A

$I_1 = I_2$

$$C_1 \frac{d(V_i - V_2)}{dt} = \frac{V_2 - V_o}{R_f}$$

$$C_1 \frac{dV_i}{dt} = -\frac{V_o}{R_f}$$

$$V_o = -R_f C_1 \frac{dV_i}{dt}$$

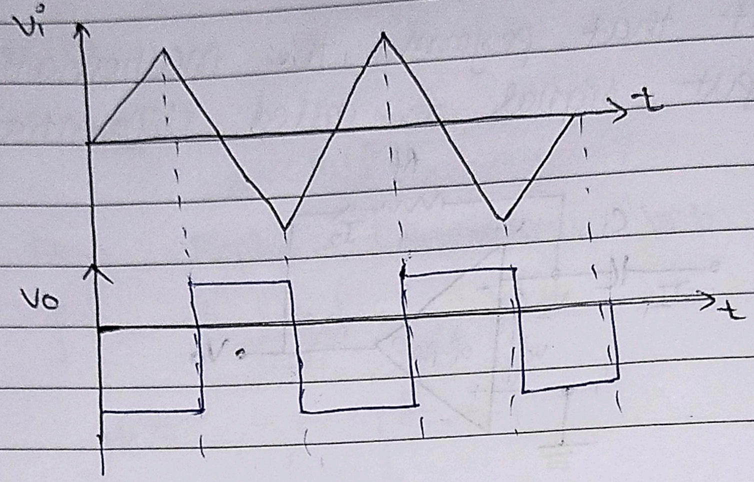
$$\boxed{V_o \propto \frac{dV_i}{dt}}$$

Since output voltage is directly proportional to the differentiation of input signal so circuit is called differentiator circuit.

Application :-

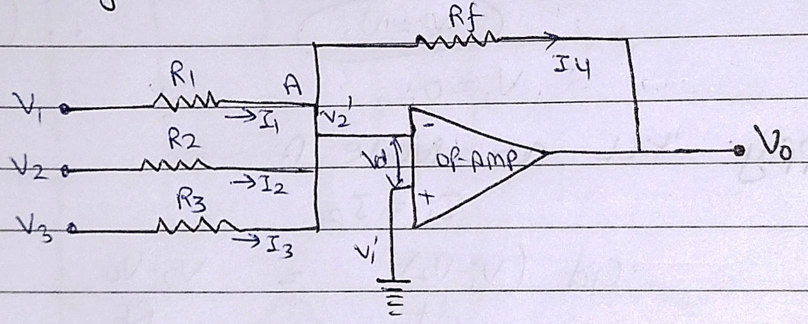
- Used in high pass filter
- Used in generating square waves.
- Used in A to D convertor circuit.

Input, output waveform -



Ques3:- Draw the subtractor & Adder using op-amp and explain its working.

Ans:- Summing or Adder Amplifier -



It is an op-Amp circuit which can accept two or more inputs and produce output as the sum of these inputs.

Expression for o/p - $V_1' = 0$ — ①

from concept of virtual ground

$$V_1' - V_2' = 0$$

$$\therefore \quad V_1' = V_2' = 0 \qquad — ②$$

Apply KCL at Node A

$$I_1 + I_2 + I_3 = I_4$$

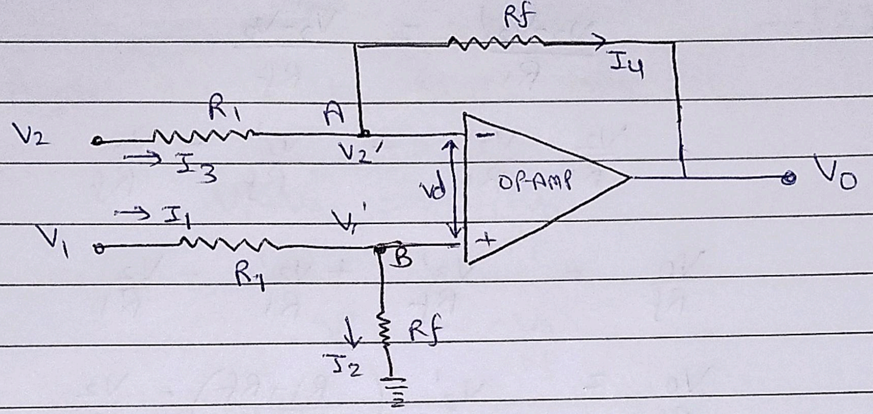
$$\frac{V_1 - V_2'}{R_1} + \frac{V_2 - V_2'}{R_2} + \frac{V_3 - V_2'}{R_3} = \frac{V_2' - V_0}{RF}$$

But $V_2' = 0$

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

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

Difference or Subtractor Amplifier -



~~Expression for o/p~~ voltage.

A circuit that amplify the difference b/w two input signal is called difference / subtractor amplifier.

Expression for o/p voltage -

Apply KCL at Node B

$$I_1 = I_2$$

$$\frac{V_1 - V_1'}{R_1} = \frac{V_1' - 0}{R_f}$$

$$\frac{V_1}{R_1} = \frac{V_1'}{R_f} + \frac{V_1'}{R_f}$$

$$\frac{V_1}{R_1} = V_1'\left(\frac{R_1 + R_f}{R_f R_1}\right)$$

$$V_1' = V_1 \frac{(R_f R_1)}{R_1 (R_1 + R_f)}$$

$$V_1' = V_1\left(\frac{R_f}{R_1 + R_f}\right) \quad \text{—(1)}$$

from concept of virtual Ground

$$V_d = 0$$

$$V_1' - V_2' = 0$$

$$V_1' = V_2'$$

Apply KCL at Node A

$$I_3 = I_4$$

$$\frac{V_2 - V_2'}{R_1} = \frac{V_2' - V_0}{R_f}$$

$$\frac{V_2}{R_1} - \frac{V_2'}{R_1} = \frac{V_2'}{R_f} - \frac{V_0}{R_f}$$

$$\frac{V_0}{R_f} = \frac{V_2'}{R_f} + \frac{V_2'}{R_1} - \frac{V_2}{R_1}$$

$$\frac{V_0}{R_f} = V_2' \left(\frac{R_1 + R_f}{R_f R_1} \right) - \frac{V_2}{R_1}$$

But $V_1' = V_2'$

$$\frac{V_0}{R_f} = \left(\frac{R_f}{R_1 + R_f} \right) V_1 \left(\frac{R_1 + R_f}{R_f R_1} \right) - \frac{V_2}{R_1}$$

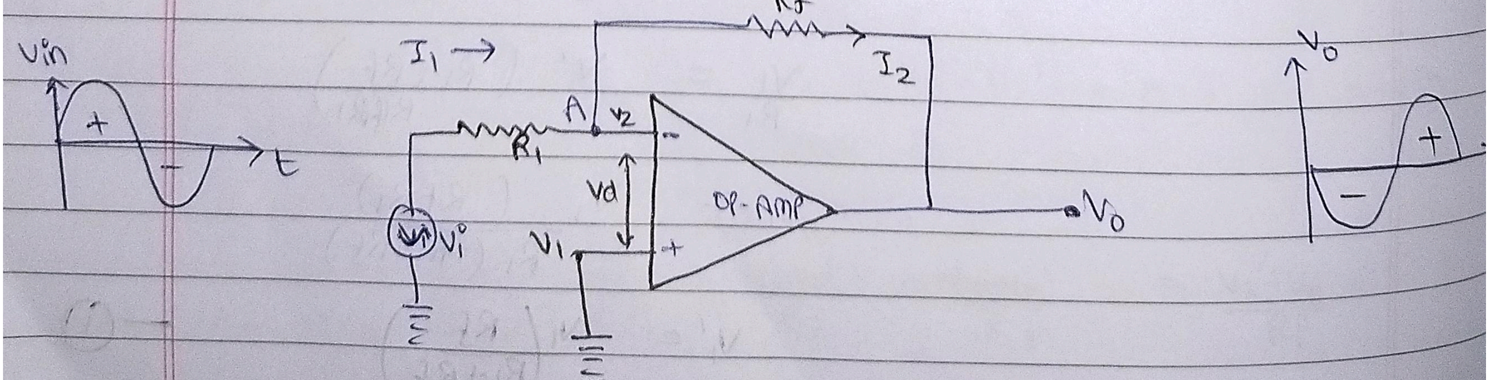
$$\boxed{V_0 = \frac{R_f}{R_1} \left[V_1 - V_2 \right]}$$

If $R_1 = R_f$

$$V_0 = V_1 - V_2$$

Ques:- Derive the expression for gain of OP-AMP as non-inverting & Inverting amplifier.

Ans:- Inverting Amplifier -



Expression for O/P voltage

Here $V_1 = 0$ — (1)

from concept of virtual ground $vd = 0$

$$V_1 - V_2 = 0$$

$$V_1 = V_2$$

But $V_1 = 0$

$\therefore V_2 = 0$ — (2)

Apply KCL at Node A

$$I_1 = I_2$$

$$\frac{V_i - V_2}{R_1} = \frac{V_2 - V_0}{R_f}$$

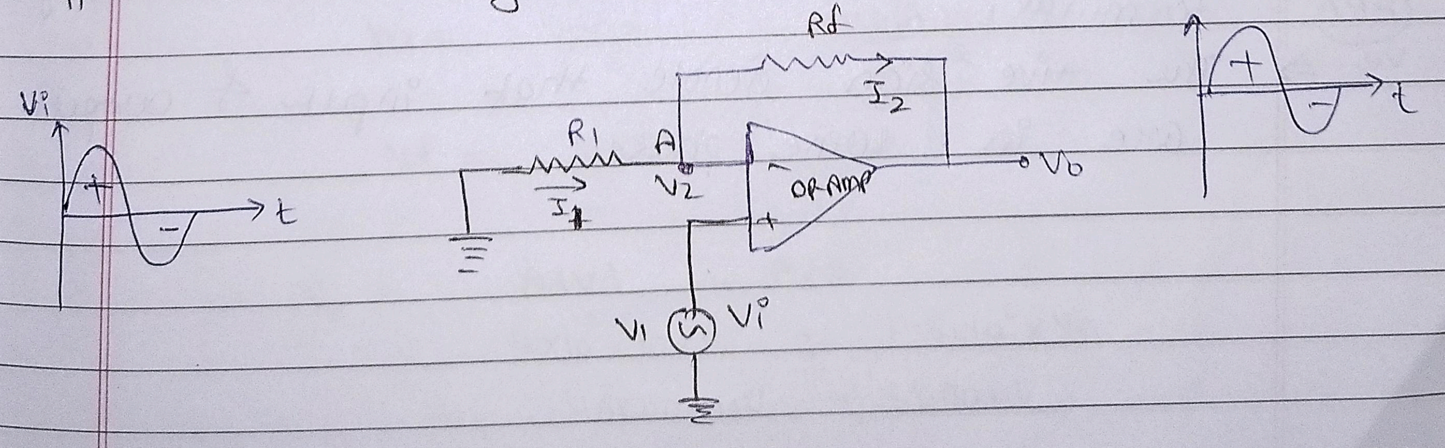
$$\frac{V_i}{R_1} = \frac{-V_0}{R_f}$$

$$\boxed{A_V = \frac{-V_0}{V_i} = -\frac{R_f}{R_1}}$$

⇒ -ive sign denotes a 180° phase difference with I/P & O/P.

An OP-AMP circuit that produce an amplify output signal i.e. 180° out of phase with input signal.

Non-Inverting Amplifier -



classmate
Date
Page

Expression for o/p voltage ($V_1 = V_i$)
from concept of virtual ground $V_d = 0$

$$V_1 - V_2 = 0 \quad , \quad V_1 = V_2$$

But $V_1 = V_i$

$$\therefore V_2 = V_i$$

Apply KCL at Node A

$$I_1 = I_2$$

$$\frac{V_d\,(V_i) - V_2}{R_1} = \frac{V_2 - V_o}{R_f}$$

$$\frac{0 - V_2}{R_1} = \frac{V_2 - V_o}{R_f} \qquad V_2 = V_i$$

$$\frac{-V_i}{R_1} = \frac{V_i - V_o}{R_f}$$

$$\frac{V_o}{R_f} = \frac{V_i}{R_f} + \frac{V_i}{R_1}$$

$$\frac{V_o}{R_1} = \frac{R_f}{R_f} + \frac{R_f}{R_1}$$

$$\boxed{A_v = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}}$$

⇒ A non-inverting amplifier is an OP-AMP circuit design to provide +ive voltage gain. The input is directly applied to non-inverting terminal.

⇒ The +ive sign denote that input & output are in same phase.

classmate

Date
Page

Ques5:- What do you mean by CMRR? Determine the output voltage of an OPAMP for the input voltage of $V_1 = 150\mu V$ and $V_2 = 140\mu V$. The amplifier has differential gain $Ad = 4000$ and CMRR is 100.

Ans:- Common mode Rejection Ratio (CMRR) is defined as the ratio of differential mode gain (Ad) and common mode gain AC.
It is the ability to reject the common mode signal.

$$CMRR = \frac{Ad}{AC}$$

$$CMRR \text{ in } (dB) = 20 \log_{10} \frac{Ad}{AC}$$

$V_1 = 150\mu V$
$V_2 = 140\mu V$
$Ad = 4000$, CMRR = 100, $V_0 = ?$

$$CMRR = \frac{Ad}{AC}$$

$$100 = \frac{4000}{AC}$$

$$\boxed{AC = 40}$$

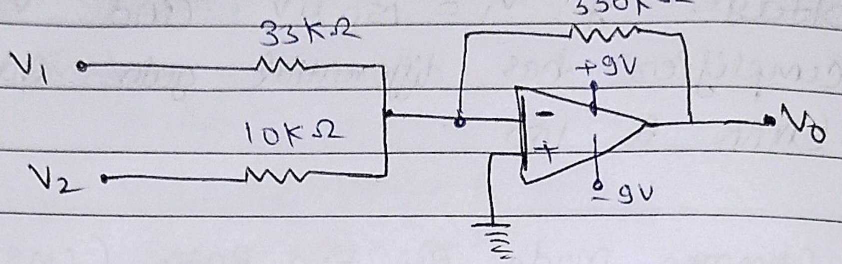
$$Vc = \frac{V_1+V_2}{2} = \frac{150+140}{2} = \frac{290}{2} = 145 \mu V$$

$$Vd = (150-140)\mu V = 10\mu V$$

$$V_0 = AdVd + AcVc$$
$$= 4\times10^3 \times 10\times10^{-6} + 145\times10^{-6}\times 40$$
$$= 40000 \mu V + 5800\mu V$$
$$= 45800 \mu V$$

$$\boxed{V_0 = 45.8\ mV}$$ Ans

Ques 6:- Determine the output of the following circuit Given $V_1 = V_2 = 0.15\,V$.



Sol:- This is a Summing or Adding amplifier

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

$$= -\left[\frac{330 \times 0.15}{33} + \frac{330 \times 0.15}{10}\right]$$

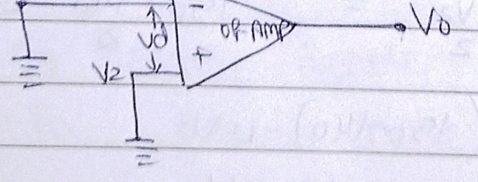
$$= -\left[\frac{49.5}{33} + \frac{49.5}{10}\right]$$

$$V_o = -\left[1.5 + 4.95\right]$$

$$\boxed{V_o = -6.45}\ V$$ Ans

Ques 7:- Explain the concept of virtual ground in OP-AMP. Determine output voltage for given network.

Ans:-



If one terminal of OP-amp is connecting to ground then another terminal will also be at ground this is called concept of virtual ground.
The concept of virtual ground is used to determine close loop voltage gain & output voltage.

For an ideal OP-AMP

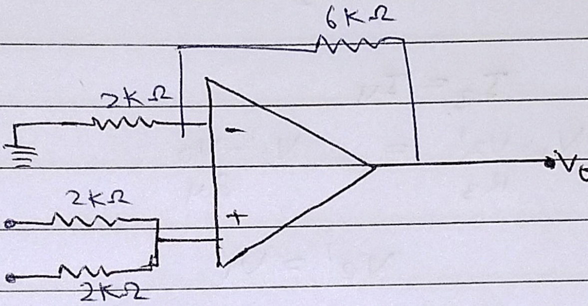
$$A_d = \infty$$

$$V_o = A_d v_d$$

$$v_d = \frac{V_o}{A_d} = \frac{V_o}{\infty} = 0$$

$$V_1 - V_2 = 0$$

$$V_1 = V_2$$



This is non-inverting adder.

$$V_o = A_{Vf} \times V_1$$

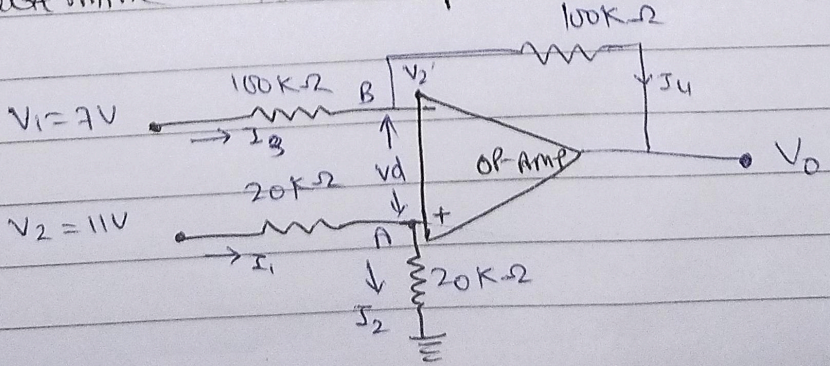
$$= \left[1 + \frac{R_f}{R_1}\right] \times \left[\frac{V_a + V_b}{2}\right]$$

$$= \left[1 + \frac{6}{2}\right] \times \left[\frac{2+6}{2}\right]$$

$$= \left[\frac{8}{2}\right] \times \frac{8}{2}$$

$$= \boxed{16 \text{ volt}}$$ Ans

Ques: Also determine the output voltage of following circuit.



Sol:

$$I_1 = I_2$$

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

$$\frac{11 - V_1'}{20} = \frac{V_1'}{20}$$

$$11 - V_1' = V_1'$$

$$2V_1' = 11$$

$$V_1' = \frac{11}{2} = 5.5\ K\Omega$$

$$I_3 = I_4$$

$$\frac{V_1 - V_2'}{R_3} = \frac{V_2' - V_0}{R_4}$$

$$V_2' = V_1'$$

$$\frac{7 - 5.5}{100} = \frac{5.5 - V_0}{100}$$

$$\frac{1.5}{100} = \frac{5.5 - V_0}{100}$$

$$150 = 550 - 100V_0$$

$$+100V_0 = 550 - 150$$

$$V_0 = \frac{400}{100}$$

$$\boxed{V_0 = 4V}$$