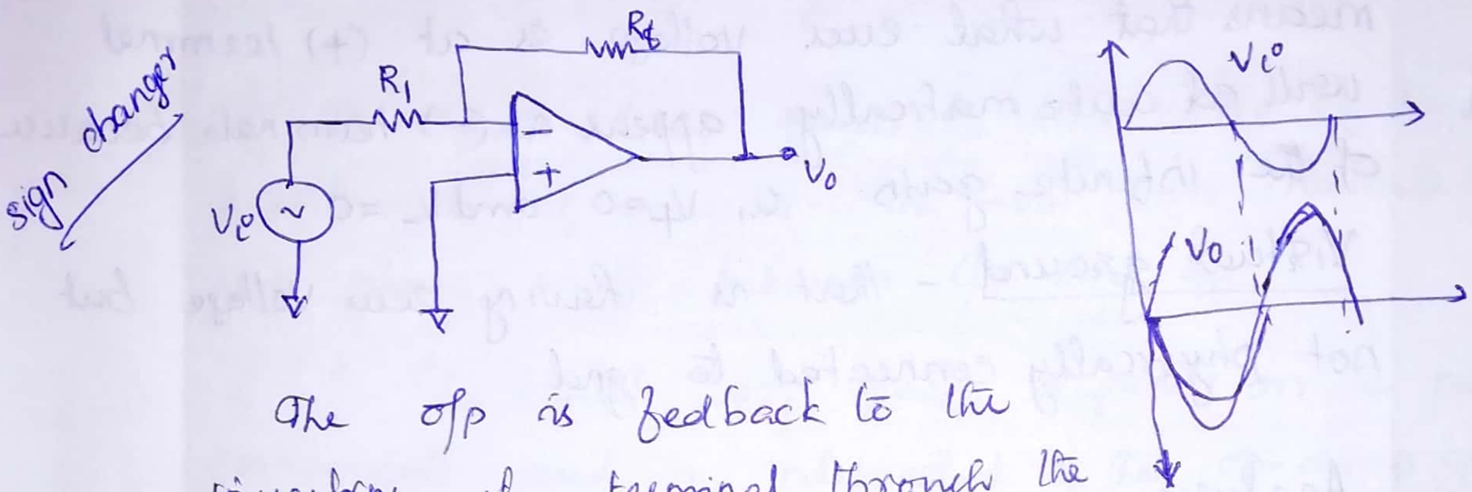
Closed Loop Config :- Connection exists b/w i/p and o/p terminals

Inverting Amplifier - Voltage shunt feedback amplifier



The o/p is feedback to the inverting i/p terminal through the feedback resistor R_f. Input signal V_i is applied to the inverting i/p terminal through R_1 and the non-inverting terminal is grounded.

Virtual Ground

The open loop gain of an op amp is very large or ideally it is infinite. If we assume that the ckt is working and producing a finite o/p voltage, then the voltage between the op-amp i/p terminals should be negligibly small and ideally zero

$$V_0 = A\,(V_2 - V_1)$$

$$V_2 - V_1 = \frac{V_0}{A}$$

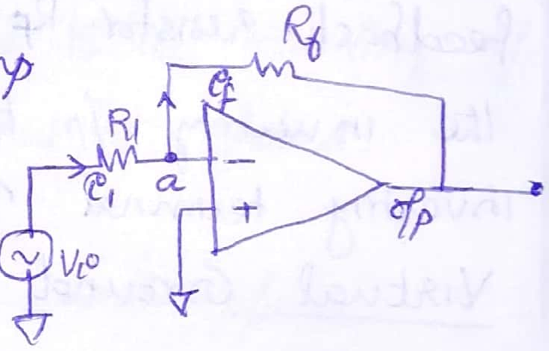
As 'A' is infinite $V_2 - V_1 \cong 0$ or $V_2 = V_1$.

The gain A approaches infinity, the voltage V_1 ideally equal V_2. i.e. the two i/p terminals tracking each other in potential. or a virtual short ckt exist between the two i/p terminals. A virtual short circuit means that what ever voltage is at (+) terminal will ~~act~~ automatically appear at (−) terminal because of the infinite gain. i.e, $V_+ = 0$ and $V_- = 0$.

Virtual ground - that is having zero voltage but not physically connected to gnd.

Analysis

Assume an ideal op-amp
As $V_{id} = 0$, node a is at gnd potential.



$i_1 = i_f$ since current flows in to the op-amp is zero (because of infinite i/p resistance of ideal op-amp).

Applying KCL at node a

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

i.e, $$\frac{V_1 - V_a}{R_1} = \frac{V_a - V_o}{R_f}$$

$V_a = 0$ (virtual gnd)

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

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

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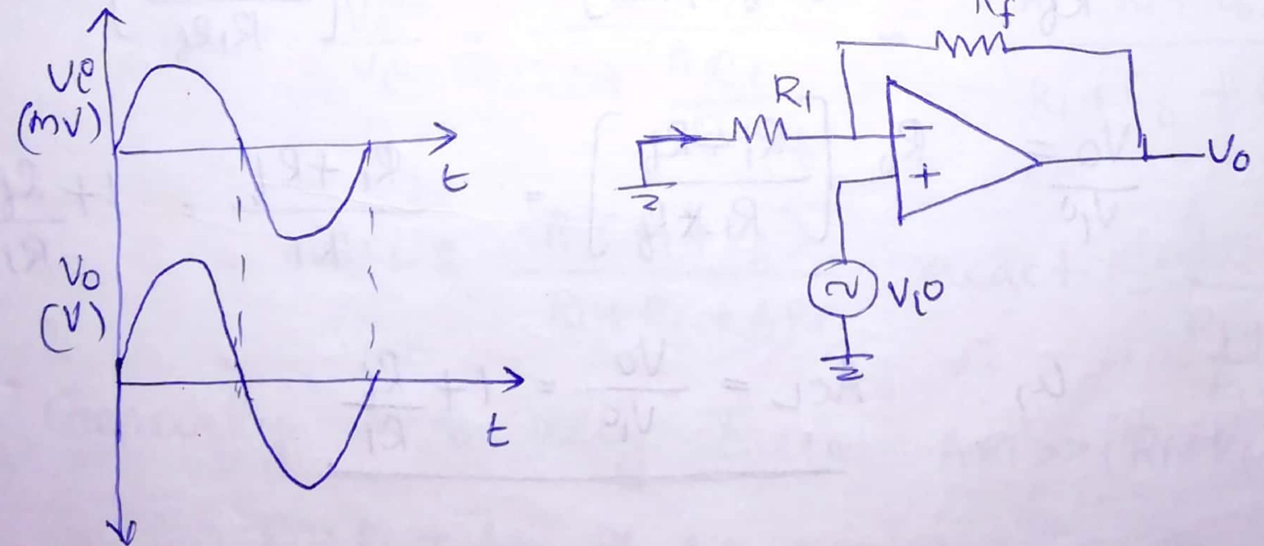
Closed Loop gain $\boxed{A_{CL} = \frac{V_0}{V_i} = \frac{-R_f}{R_1}}$

i.e, the closed loop gain is the ratio of two resistances R_f and R_1. The -ve sign indicate the 180° phase shift between i/p and o/p.

The closed loop gain depends on the passive components and is independent of the op-amp gain. This is due to the -ve feedback.

The non inverting amplr (Voltage series feedback amplr)



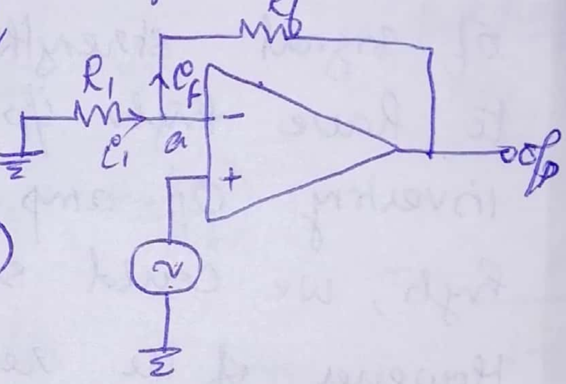
Here the i/p is applied to non inverting i/p terminal. i/p and o/p are in phase. This is also a -ve feedback system. as the o/p is fed back to the inverting i/p terminal through R_f.

Analysis

Assume an ideal op-amp.

At node a, $V_a = V_i$ (virtual) (Same as i/p)

$i_1 = i_f$ (infinite i/p R)



Apply KCL at node a

$$\frac{0 - V_a}{R_1} = \frac{V_a - V_o}{R_f}$$

$$\frac{-V_i}{R_1} = \frac{V_i - V_o}{R_f} \quad (\because V_a = V_i)$$

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

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

i.e., $$A_{CL} = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}$$

Gain of non-inverting configuration is +ve

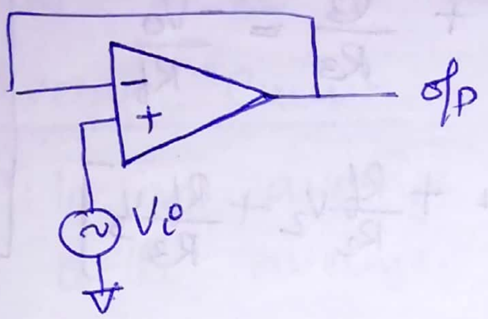
Voltage follower

The lowest gain that can be obtained from a non inverting amplifier with feedback is 1. When the non-inverting amplifier is configured for unity gain, it is called a voltage follower, because the o/p voltage is equal to and in phase with the i/p, or the o/p follows the i/p.

To obtain a voltage follower simply

open R_1 ($R_1 = \infty$) and short R_f ($R_f = 0$).

ckt diagram



In this ckt the o/p is fed back to the inverting terminal of the op-amp.

The i/p impedance of a voltage follower ckt is very high and o/p impedance is zero.
∴ it draws negligible current from the source. Thus a voltage follower may be used as a buffer for impedance matching. i.e, to connect a high impedance source to a low impedance load.

Summing Amplifier (Adder Circuits)

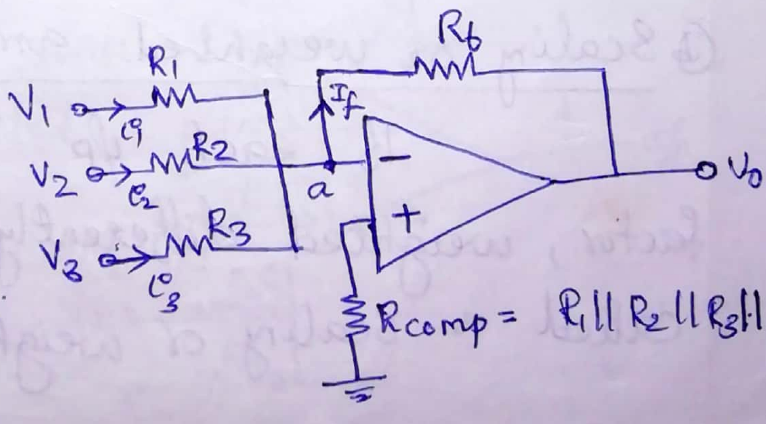
Summing ampr is an op-amp ckt whose o/p is the sum of several i/p's.

Inverting Summing Amplifier

i/p voltages V_1, V_2, V_3

feedback Resistor - R_f

i/p resistors R_1, R_2 & R_3.



Voltage at node $a = 0$. Also $i_1 + i_2 + i_3 = i_f$

i.e, write KCL at node a

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

$$\left[\frac{V_1 - V_a}{R_1} + \frac{V_2 - V_a}{R_2} + \frac{V_3 - V_a}{R_3} = \frac{V_a - V_0}{R_f} \qquad V_a = 0 \right]$$

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

Thus the o/p is inverted, weighted sum of the i/p's

@) Summing Amplifier

In the ckt $R_1 = R_2 = R_3 = R$.

$$V_0 = -(V_1 + V_2 + V_3) \frac{R_f}{R}$$

i.e, V_0 is $-ve$ sum of all the i/p's times the gain of the ckt R_f/R. Hence the ckt is called a summing amplr.

$R_1 = R_2 = R_3 = R_f = R$ then

$$V_0 = -(V_1 + V_2 + V_3).$$

ⓑ Scaling or weighted amplr

If each i/p is amplified by a different factor, weighted differently at the o/p, the ckt is called a scaling or weighted amplr.

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

$$\frac{R_f}{R_1} \neq \frac{R_f}{R_2} \neq \frac{R_f}{R_3}.$$

(c) Average Circuit

In an average circuit the o/p voltage is equal to the average of all i/p voltages.

If $R_1 = R_2 = R_3 = R$ and $\frac{R_f}{R} = 1/n$ where $n \rightarrow$ no. of i/p.

$\Rightarrow R = nR_f$

For three i/p's $\frac{R_f}{R} = 1/3$.

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

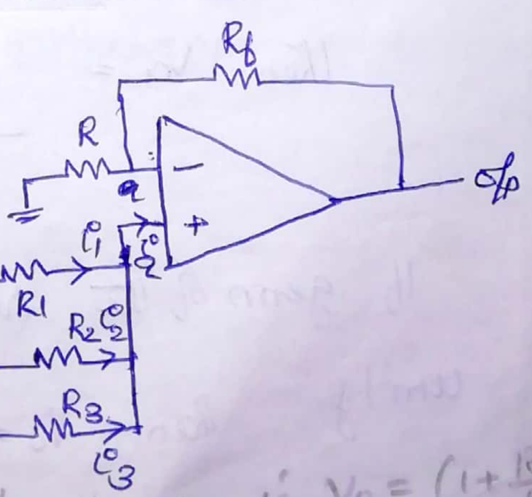
~~V~~ and V_1, V_2 and V_3 could be either d.c or a.c

$R_{com} \rightarrow$ offset minimizing resistor - is used to minimize the effect of i/p bias current on the o/p offset voltage.

$R_{com} = R_i \parallel R_f$ effective i/p R, $R_i = R_1 \parallel R_2 \parallel R_3$

Non Inverting Summing Amplifier

~~If~~ i/p Resistors and voltage source are connected to the non-inverting terminal.



$\Rightarrow$ a non-inv amp with i/p V_a ie $V_o = \left(1 + \frac{R_f}{R_1}\right)V_a$

$$i_1 + i_2 + i_3 = i$$

but $i = 0$ (due to high i/p impedance)

write KCL at node a,

$$\frac{V_1 - V_a}{R_1} + \frac{V_2 - V_a}{R_2} + \frac{V_3 - V_a}{R_3} = 0$$

$$V_a \left[1/R_1 + 1/R_2 + 1/R_3 \right] = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

ie, $$V_a = \frac{\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right)}{\left(1/R_1 + 1/R_2 + 1/R_3 \right)}$$

$$\therefore V_0 = \left(1 + \frac{R_f}{R}\right) V_a$$ (non-inverting ampl

$$\therefore V_0 = \left(1 + \frac{R_f}{R}\right) \left[\frac{\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}}{1/R_1 + 1/R_2 + 1/R_3} \right]$$

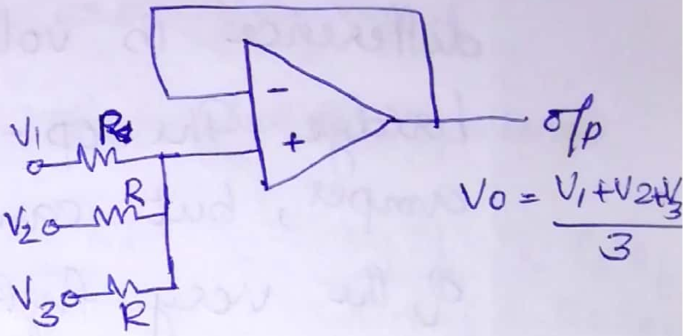
(a) Averaging Amplifier

Let $R_1 = R_2 = R_3 = R$.

then $$V_a = \frac{\frac{V_1 + V_2 + V_3}{R}}{1/R + 1/R + 1/R} = \frac{V_1 + V_2 + V_3}{3}$$

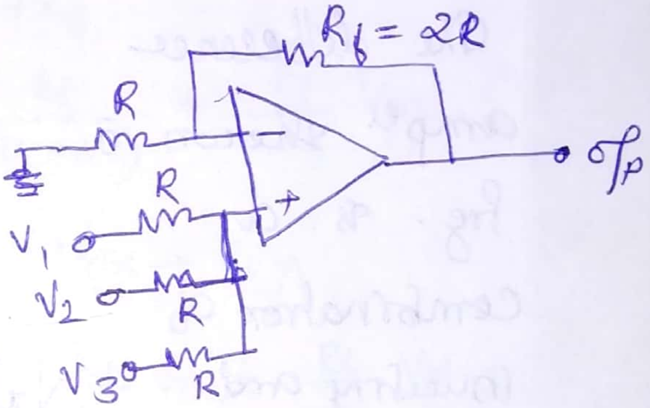
If gain of the non inverting amper is set as unity then $V_0 = \frac{V_1 + V_2 + V_2}{3}$. Thus an averagi ampr can be obtained.

No phase reversal occurs between i/p and o/p.



⑤ Summing ampr

Summing ampr can be obtained by setting the gain of non-inverting ampr equal to the no. of i/p's.



ie, $1+\frac{R_f}{R} = 3$

$\frac{R_f}{R} = 2$ $\quad R_f = 2R$

$R_f = (n-1)R$
where $n \rightarrow$ no. of i/p's

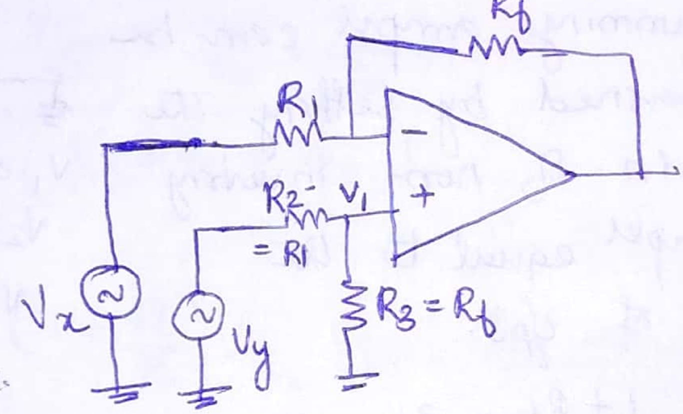
$$V_0 = \left(1+\frac{R_f}{R_1}\right)\left(\frac{V_1+V_2+V_3}{3}\right) = 3\left(\frac{V_1+V_2+V_3}{3}\right)$$

ie, $V_0 = V_1+V_2+V_3$

Differential ampr or Difference ampr or Subtractor

A difference amplifier is one that responds to the difference between the two signals applied at its i/p and ideally rejects signals that are common to two i/p's. These are mainly used is instrumentation application to ~~amply~~ ampli difference in voltages such as o/p of wheatstone bridge. The op-amp itself is a difference ampr, but can not be used as it is, because of the very high gain of op-amp. We have to use appropriate feedback N/w.

The difference ampr shown in fig. is a combination of inverting and non-inverting ampr.



$V_x = 0 \rightarrow$ non-inverting ampr

$V_y = 0 \rightarrow$ Inverting ampr.

Analysis

The o/p of the ckt can be obtained using superposition theorem

$$V_o = V_{ox} + V_{oy}.$$

$V_{ox} \rightarrow$ o/p due to V_x alone

$V_{oy} \rightarrow$ o/p due to V_y alone

Case 1

$V_y = 0V$, inv. ampr with $V_{in} = V_x$

$$V_{ox} = -\frac{R_f}{R_1} V_x \quad \text{(o/p due to } V_x \text{ alone)}$$

Case 2

$V_x = 0V$ non-inv. ampr with $V_i = V_y$

$V_{oy} = \left(1+\frac{R_f}{R_1}\right) V_1$ (o/p voltage due to V_y alone)

From the circuit $V_1 = \frac{V_y \times R_3}{R_2 + R_3} = \frac{V_y R_f}{R_1 + R_f}$ $\because R_3 = R_f$, $R = R_1$

$\therefore V_{oy} = \left(1+\frac{R_f}{R_1}\right) \times V_y \frac{R_f}{R_1 + R_f}$

$= \frac{R_1 + R_f}{R_1} \times V_y \cdot \frac{R_f}{(R_1 + R_f)} = \frac{R_f}{R_1} V_y$

$\therefore$ Net o/p voltage $= V_{ox} + V_{oy}$

$= -\frac{R_f}{R_1} V_x + \frac{R_f}{R_1} V_y$

$= \frac{-R_f}{R_1} \left[V_x - V_y\right]$

Differential gain of ampr $A_D = \frac{V_o}{V_x - V_y} = \frac{-R_f}{R_1}$.

If $R_f = R_1 = R$ $V_o = V_y - V_x$.

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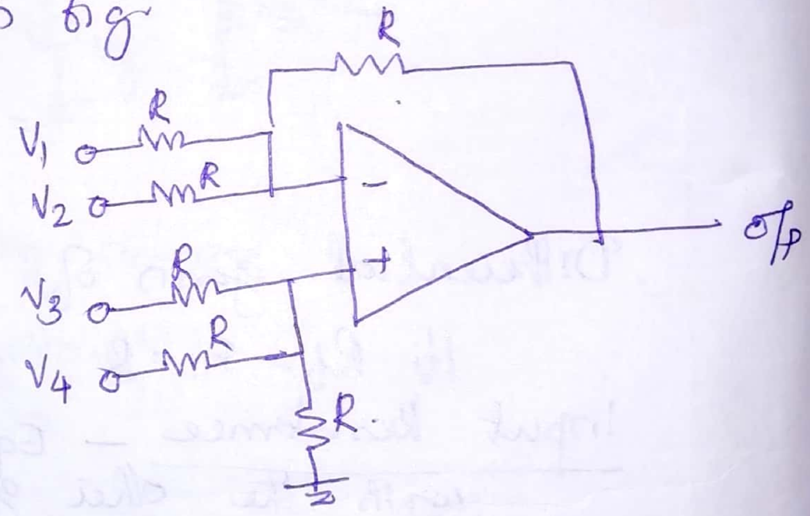
Adder Substractor Circuits

It is possible to perform addition and subtraction simultaneously with a single op-amp using the ckt shown in fig.



The o/p voltage V_o can be obtained by using superposition theorem.

Analysis of this ckt same as previous ckt.

The o/p voltage V_o due to all four i/p voltages is given by

$$V_o = V_{o1} + V_{o2} + V_{o3} + V_{o4}$$

$$= -V_1 - V_2 + V_3 + V_4$$

So the ckt is an adder - subtractor.