Chapter-7

Prof. ... M.Tech.
Assistant Professor
Cambridge Institute of Technology
K. R. Puram, Bengaluru - 560 036.

Module-2

OP-AMP's and its Applications

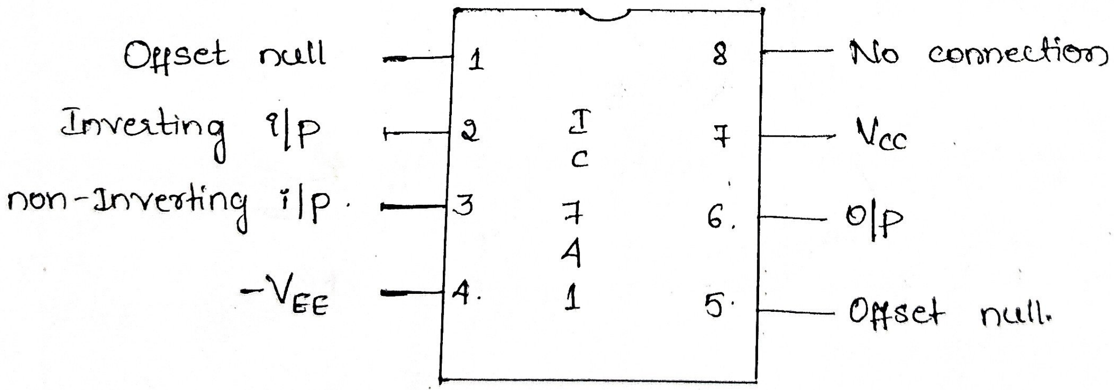
Define op-amp ?.

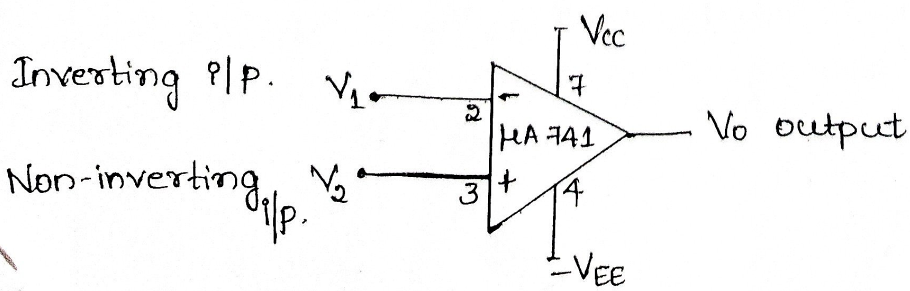
Op-amp is a directly coupled multistage voltage amplifier with high gain. It has very high input impedance and very low output impedance.

Op-amps are used for performing mathematical operations such as addition, subtraction, multiplication, integration and differentiation.

NOTE :- The op-amp is used to perform various mathematical operations. Thus it is called operational amplifier.

Pin diagram and op-amp symbol.





V_1 is the voltage at the inverting input.
V_2 is the voltage at the non-inverting input.
V_0 is the output voltage.

* The o/p voltage V_0 is proportional to the difference between the i/p voltage.

i.e $V_0 = A(V_2 - V_1)$

Where A is the open-loop voltage gain.

Inverting mode :-

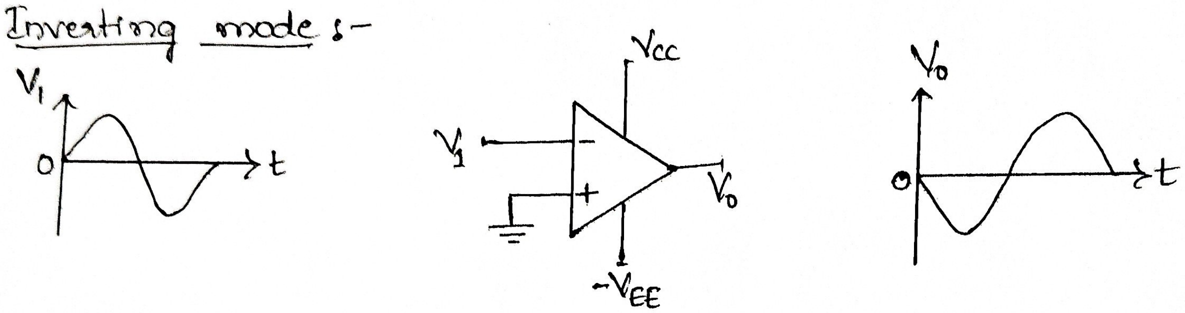


fig 1 : Inverting amplifier.

* In inverting mode i/p is applied to the inverting terminals and non-inverting terminal is grounded.

* The amplified voltage is 180° out of phase with respect to applied i/p voltage.

ie $V_0 = -AV_1$.

NOTE :- Negative sign indicates that o/p is 180° out of phase.

Non-Inverting Mode :-

In non-inverting mode, i/p is applied to the non-inverting terminal and inverting terminal is grounded.

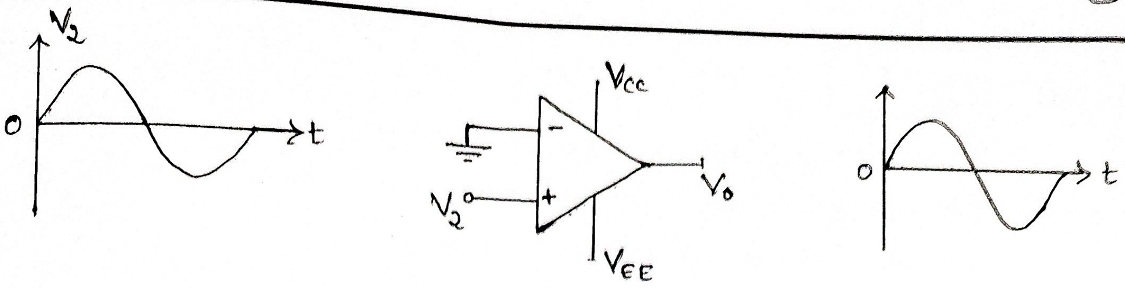


fig 2 :- Non - Inverting amplifier.

* The amplified o/p voltage is in phase w.r.t to applied i/p voltage.

i.e. $V_0 = AV_2$.

Block - diagram of op-amp :-

Draw the block schematic of an op-amp and explain the function of each stage. June - 04, 6M

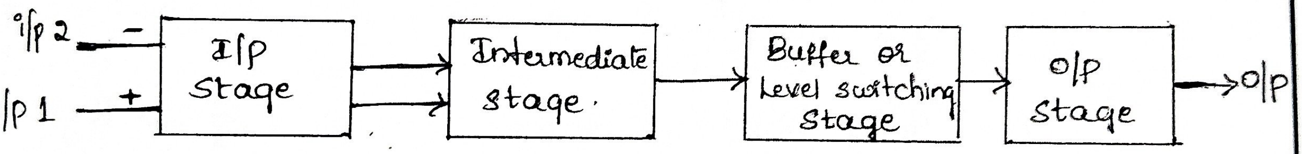


fig 1 : Block diagram of op-amp.

Input stage :-

The op-amp has two i/p terminals. Its o/p stage requires dual i/p terminals with high i/p impedance. These requirements are satisfied by the dual i/p balanced o/p differential amplifier. [Two i/p's & two o/p's].

Its function is to amplify the difference between the two i/p signals. It provides high differential gain, high i/p impedance and low o/p impedance.

Intermediate stage :-

The overall gain requirement of an op-amp is very high, since the i/p stage alone cannot provide such a high gain. The main function of the intermediate stage is provide such a high gain.

It consist of another differential amplifier with the dual i/p unbalanced o/p (Single ended). Practically the intermediate stage is chain of cascaded amplifiers called as multistage amplifiers are used.

Buffer and level shifting stage :-

In intermediate stage all amplifiers are directly coupled. In the absence of coupling capacitors. DC voltage level gets amplified. such a high dc level may drive the transistor into saturation. It causes distortion.

The level shifting stage brings the DC level to ground (zero).

O/P stage :- The o/p stage requires low o/p impedance large voltage swing. This is satisfied by class B push pull emitter follower circuit.

Ideal characteristics :-

* List the important characteristics of an Ideal op-amp.

* Explain the term op-amp. List the characteristics of an Ideal op-amp.

* Describe an op-amp and its important characteristics

* What are the characteristics of an Ideal op-amp.

Jan-03, 5M July-03, 4M Jan-04, 4M Jan-07, 6M.
Jan-08, 6M July-08, 6M Jan-10, 4M July-09, 4M
Dec-10, 6M Jan-11, 8M.

Op-amp is direct coupled multistage voltage amplifier with very high gain. It has very high i/p impedance and a very low o/p impedance.

The ideal characteristics of op-amp are :-

1. Infinite voltage gain ($A_{OL} = \infty$) :-

The gain loop voltage gain (A_{OL}) of the ideal op-amp is very large infinity.

$A_{OL} = \infty$.

2. Infinite i/p impedance [$R_i = \infty$] :-

An ideal op-amp does not drawn any content from the voltage source connected to its i/p terminals. Thus its o/p impedance is infinite.

i.e. $R_{in} = \infty$.

3. Zero output impedance [$R_o = 0$] :-

The o/p voltage of an ideal op-amp is independent of the current drawn from it. This means op-amp has zero o/p impedance. ~~is infinite~~.

i.e. $\cancel{R_{in} = \infty}$, ie. $R_o = 0$.

4. Infinite Bandwidth ($BW = \infty$) :-

An ideal op-amp amplifies signals of any frequency with a constant gain, which implies that op-amp has infinite BW ie. $BW = \infty$.

5} Infinite CMRR [$\rho = \infty$] :-

[CMRR is defined as the ratio of differential voltage gain to common mode voltage gain

i.e $CMRR = \rho = \frac{A_d}{A_c}$]

The common mode rejection ratio of an ideal op-amp is infinite ie $CMRR = \infty$.

6} Infinite slew rate [$SR = \infty$] :-

An Ideal op amp has infinite slew rate this implies that the o/p voltage changes simultaneously with the i/p voltages.

7} the characteristics of an ideal op-amp do not change with temperature.

8} the power supply rejection ratio of an ideal op-amp is zero. i.e. $PSRR = 0$.

9} Zero offset voltage :-

the presence of small o/p voltage when $V_1 = V_2 = 0$. is called an offset voltage.

For an ideal op-amp offset voltage is zero.

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* Define and mention the importance of the following terms with respect to op-amp.

July-05, 10M

i) CMRR (ii) Slew rate (iii) PSRR.

(iv) I/P offset voltage.

* Define and explain briefly the following terms with respect to op-amp.

i) o/p offset voltage (ii) CMRR (iii) SVRR (iv) Slew Rate.

Jan-06, 10M

* Define the term slew rate and CMRR of an op-Amp and mention their typical values for 741 op-amp.

July-04, 4M

i) CMRR :-

CMRR is defined as the ratio of the differential gain 'A_d' to the common mode gain 'A_c'.

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

CMRR is always expressed in decibels as

$$\boxed{(CMRR)_{dB} = 20 \log_{10} \frac{A_d}{A_c}}$$

The typical value of CMRR for μA741 op-amp is 90 dB.

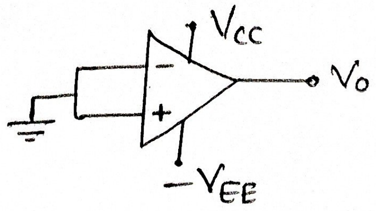
ii) Slew Rate :-

Slew rate of the op-amp is defined as the maximum rate of change of its o/p voltage w.r.t time & is expressed in volts per microsecond.

$$\boxed{SR = \left.\frac{dV_o}{dt}\right|_{max.}} \; V/\mu sec.$$

For 741, SR = 0.5 V / μsec.

(iii) o/p offset voltage :-



When both the I/p terminals are shorted and connected to ground, the o/p should be ideally zero but practically there exists a small dc o/p voltage known as o/p offset voltage.

{ To make this o/p voltage zero, a small voltage is required to be applied to one of the I/p terminals. Such a voltage makes the o/p exactly zero. This dc voltage, which makes the o/p voltage zero is called I/p offset voltage 'V_{ios}'. }.

iv) Power supply voltage rejection ratio (PSRR) :-

PSRR is defined as the ratio of change in I/p offset voltage due to change in the supply voltage producing it, keeping other power supply voltage constant.

* If V_{EE} is constant & due to change in V_{cc}, there is change in I/p offset voltage then PSRR is expressed as

$$\boxed{PSRR = \left.\frac{\Delta V_{ios}}{\Delta V_{cc}}\right|_{V_{EE}\ \text{constant}}}$$

* If V_{cc} is constant & due to change in V_{EE}, there is change in I/p offset voltage then PSRR is expressed as

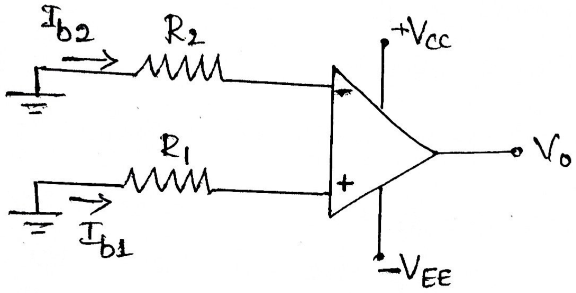
$$\boxed{PSRR = \left.\frac{\Delta V_{ios}}{\Delta V_{cc}}\right|_{V_{cc}\ \text{constant}}}$$

v) I/P offset voltage :-

The dc voltage, which makes the o/p voltage zero, when the other terminal is grounded is called I/P offset voltage. It also depends upon temperature.

* The ideal value of I/P offset voltage is zero but practically this value is small.

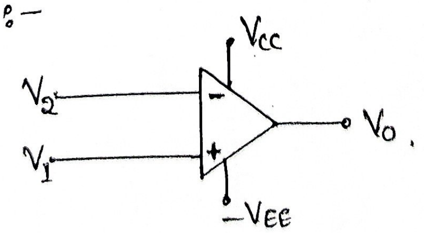
vi) I/P bias current :-



It is defined as the average value of the individual current flowing into the INV and Non-INV I/P terminals of the op-amp.

$$\boxed{I_B = \frac{I_{b1} + I_{b2}}{2}}$$

Open-loop amplifier :-



In open loop amplifier, there will be no feedback signal from o/p to I/P.

The o/p voltage is $\boxed{V_o = A_{OL}(V_1 - V_2)}$

Closed loop amplifier :-

* Explain why closed loop configuration of op-amp is used in all the practical amplifier circuit and bring out the advantages of closed loop operation with negative feedback. **June - 07, 6M**

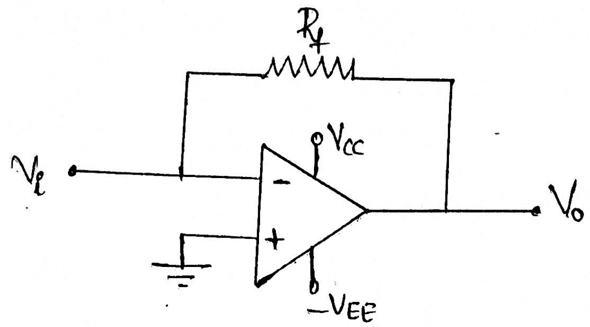


Fig: op-amp with negative feedback.

* The closed loop amplifier is possible using feedback i.e feeding some part of the o/p back to the I/p through resistor. Always op-amp is used with negative feedback.

The gain resulting with feedback is called closed loop gain of the op-amp. Due to -ve feedback gain decreases.

Advantages of -ve feedback :-

1) It reduces the gain and makes it controllable.
2) It reduces the distortion.
3) It increases the bandwidth
4) It increases the I/p resistance of the op-amp
5) It decreases the o/p resistance of the op-amp.
6) It reduces the effects of temperature and power supply.

op-amp Applications :-

The applications of op-amps are :-

1) Inverting amplifier.
2) Non-Inv amplifier.
3) Voltage follower.
4) Summer or Adder.
5) Subtractor or Difference amplifier
6) Integrator. &
7) Differentiator etc.

What is an op-amp? Mention some of the applications State the reason for its widespread applications.

June-05, 8M

op-amp is a directly coupled multistage voltage amplifier with high gain. It has very high I/p impedance & a very low o/p impedance.

Applications of op-amp :-

1) INV amplifier.
2) Non-INV amplifier
3) Voltage follower.
4) INV Summer.
5) Non-INV Summer
6) Difference or Subtractor amplifier.
7) Integrator
8) Differentiator.

... clipped at ~~±12V due~~ to saturable property of the op-amp.

NON-INVERTING amplifier :-

* Draw the circuit diagram of a non-inverting summing amplifier and derive an equation for the output voltage. $\boxed{\text{June-06, 8M}}$

* Show how an op-amp can be used of an Inverting and non-inverting amplifier. Derive the expression for their o/p voltages. $\boxed{\text{Jan-03, 6M}}$

* List out the properties of an Ideal op-amp and with the circuit single. explain the significance of inverting of and non-inverting I/p's. $\boxed{\text{Jan-05, 8M}}$

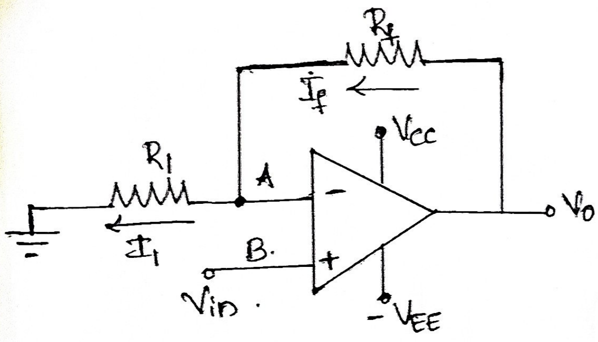
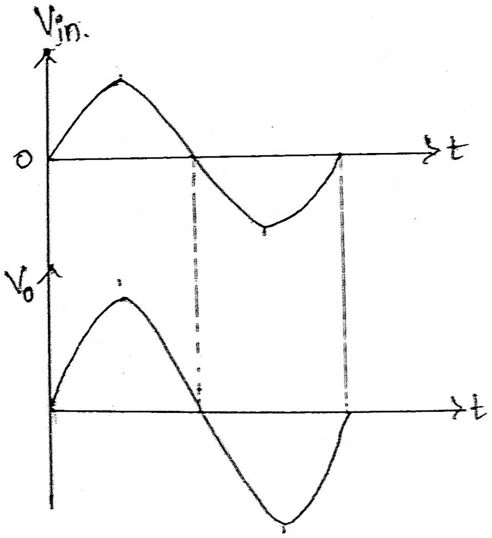


fig 1 ⓐ : Non - INV amplifier.



R₁ Rf

* In Non-INV amplifier o/p voltage is amplified & is in-phase with the I/p signal.

* The potential at node B is V_{in}, hence the potential at node A is same as node B i.e $\underline{V_A = V_B = V_{in}}$.

From I/p side, the current I is

$$I_1 = \frac{V_A - 0}{R_1}$$

WKT - $\boxed{V_A = V_{in}}$

$$\boxed{I_1 = \frac{V_{in}}{R_1}} \rightarrow (1)$$

From o/p side.

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

$$\boxed{I_f = \frac{V_o - V_{in}}{R_f}} \rightarrow (2)$$

Equating eq (1) & (2)

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

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

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

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

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

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

$$\boxed{A = \left(1 + \frac{R_f}{R_1}\right)}$$

o/p is in phase with i/p

$$\boxed{\frac{V_o}{V_{in}} = \left(1 + \frac{R_f}{R_1}\right)} \rightarrow ③$$

In eq ③ , +ve sign indicates that the o/p is in-phase with the I/p.

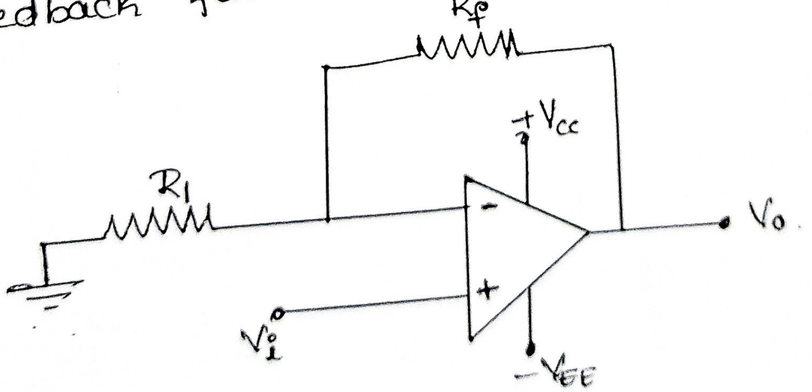
* Draw the non-inverting voltage amplifier circuit using an op-amp and show that the closed loop voltage gain is given by.

$$A_{vf} = \frac{A_V}{(1 + A_V \beta)}$$

A_V = open loop voltage gain of an op-amp.

β = feedback factor.

July-07, 6M



{Not Required}

fig ① : Non-INV amplifier.

WKT Gain of the Non-INV amplifier is.

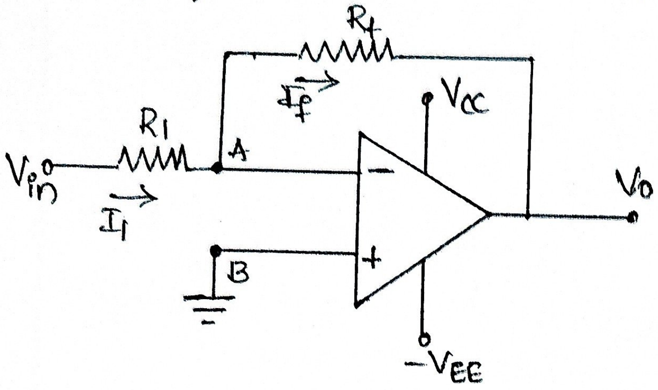
$$\boxed{A_{vf} = \frac{V_o}{V_i} = \left(1 + \frac{R_f}{R_1}\right)} \rightarrow ①$$

... loop gain $A_V = \infty$.

$$A_{vf} = \frac{A_v}{(1+A_v\beta)}$$

INVERTING AMPLIFIER :-

* Show how op-amp can be used as an Inverting amplifier ? Derive an expression for the voltage gain.



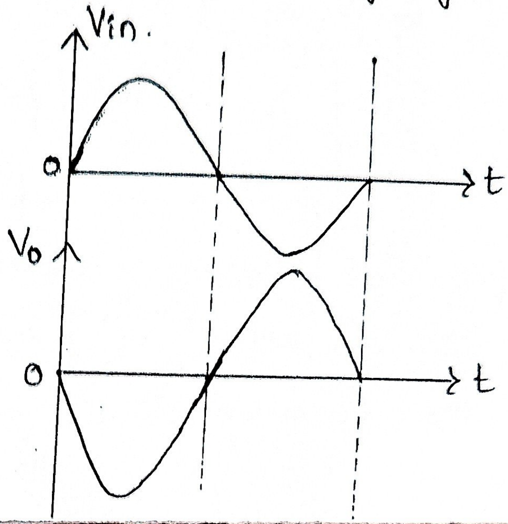


fig 1 (a) : INV amplifier

In INV amplifier o/p voltage is amplified and 180° out of phase with respect to the I/p signal.

The potential at node B is zero, due to virtual ground concept the potential at node A is also zero.

$$\therefore \boxed{V_A = V_B = 0}$$

From I/p side,

$$I_1 = \frac{V_{in} - V_A}{R_1} = \frac{V_{in} - 0}{R_1}.$$

$$\boxed{I_1 = \frac{V_{in}}{R_1}} \rightarrow ①$$

From o/p side,

$$I_f = \frac{V_A - V_o}{R_f} = \frac{0 - V_o}{R_f}$$

$$\boxed{I_f = -\frac{V_o}{R_f}} \rightarrow ②$$

Equating eq ① & ② we get

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

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

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

Where R_f/R_1 is closed loop gain & -ve sign indicates that the polarity of o/p is opposite to that of I/p.

Voltage follower :-

* Explain how the op-amp can be used as a voltage follower.

Jan - 08, 4M.

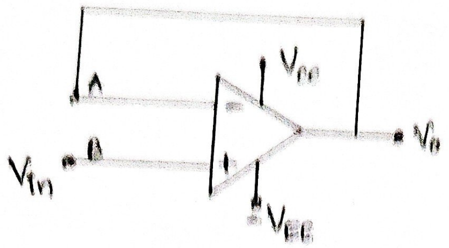


Fig 1 (a) : Voltage follower.

* A ckt in which the o/p follows
* i/p voltage is called voltage follower.

* The potential at node B is V_{in}. Due to virtual ground concept the potential at node A is also V_{in}.

i.e. $\boxed{V_A = V_B = V_{in}}$

* The node A is directly connected to o/p terminal.

$$V_0 = V_A$$

$$\therefore V_0 = V_{in}.$$

* This circuit is also called source follower, unity gain amplifier buffer or isolation amplifier.

SUMMING or ADDER amplifier :-

* With a neat diagram explain the working of an op-amp as summing amplifier.

Jan - 10, 6M.

When more than one I/p signal is applied to the INV or Non-INV amplifier, the o/p contains addition of the applied i/p signals. Hence it is called summer or adder amplifier circuit.

INV Summer amplifier ckt :-

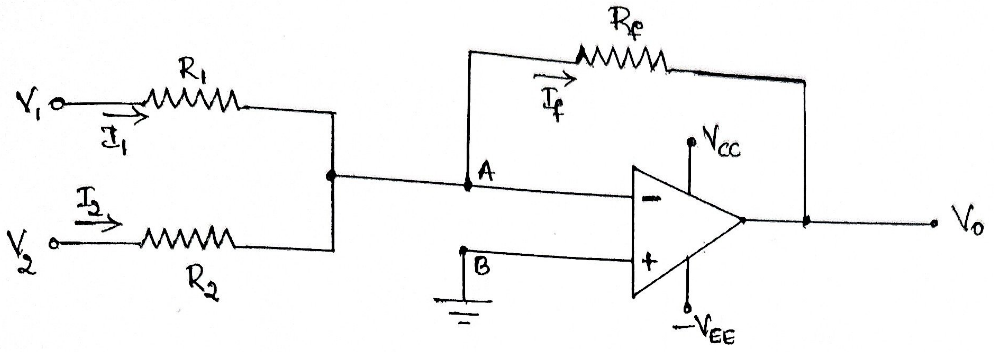


Fig ① : INV Summing amplifier.

* I/p signals which are to be added are applied to the INV I/p of op-amp.

* As node B is grounded, due to virtual ground concept the node A is also at ground potential ie. $V_A = V_B = 0$.

From I/p side,

$$I_1 = \frac{V_1 - V_A}{R_1} = \frac{V_1 - 0}{R_1}$$

$$\boxed{I_1 = \frac{V_1}{R_1}} \rightarrow ①$$

$$I_2 = \frac{V_2 - V_A}{R_2} = \frac{V_2 - 0}{R_2}$$

$$\boxed{I_2 = \frac{V_2}{R_2}} \rightarrow ②$$

From o/p side,

$$I_f = \frac{V_A - V_o}{R_f} = \frac{0 - V_o}{R_f}$$

$$\boxed{I_f = -\frac{V_o}{R_f}} \rightarrow ③$$

Applying KCL at node A,

$$I_1 + I_2 - I_f = 0.$$

$$I_f = I_1 + I_2$$

Substituting eq ①, ② & ③ in eq ④, we get

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

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

If $R_1 = R_2 = R_f = R$, then

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

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

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

From o/p side.

$$I = \frac{V_0 - V_A}{R_f} \qquad \text{as } V_A = V_B.$$

$$\boxed{I = \frac{V_0 - V_B}{R_f}} \rightarrow ⑥$$

Equating eq ⑤ & ⑥, we get

$$\frac{V_B}{R} = \frac{V_0 - V_f}{R_f}$$

$$\frac{V_B}{R} = \frac{V_0}{R_f} - \frac{V_B}{R_f}$$

$$\frac{V_B}{R} + \frac{V_F}{R_F} = \frac{V_0}{R_f}$$

$$V_B\left[\frac{1}{R} + \frac{1}{R_f}\right] = \frac{V_0}{R_f}$$

$$\frac{V_0}{R_f} = V_B\left[\frac{R+R_f}{RR_f}\right]$$

$$\boxed{V_0 = V_B\left[\frac{R+R_f}{R}\right]} \rightarrow ⑦$$

Substituting eq ④ in eq ⑦, we get

$$V_0 = \frac{V_1R_2 + V_2R_1}{R_1 + R_2}\left[\frac{R+R_f}{R}\right]$$

If $R_1 = R_2 = R_f = R$

$$V_0 = \frac{V_1R + V_2R}{\cancel{R+R}}\left(\frac{\cancel{R+R}}{R}\right)$$

$$= R(V_1 + V_2)\cdot\frac{1}{R}$$

$$\boxed{V_0 = V_1 + V_2}$$

INTEGRATOR :-

* Draw the circuit of op-amp as integrator and derive an expression for o/p voltage. [Jan-08, 6M]
* Show with a circuit diagram how the op-amp can be used as an integrator. [July-09, 6M.]
* Shown with a deviation and circuit diagram, how an op-amp can be used as an integrator. [Jun-05, 6M.]

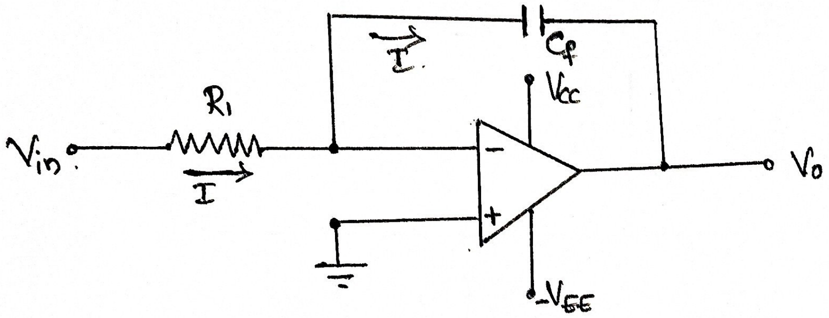


fig: op-amp as Integrator.

* In an Integrator ckt, the o/p voltage is the integration of the I/p voltage.
* From Virtual ground concept $V_A = V_B = 0$.
* As I/p current of op-amp is zero, the entire current I flows through R, also flows through C_f.

From I/p side, we get

$$I = \frac{V_{in} - V_A}{R_1} = \frac{V_{in} - 0}{R_1}$$

$$\boxed{I = \frac{V_{in}}{R_1}} \rightarrow (1)$$

from o/p side,

$$I = C_f \cdot \frac{d(V_A - V_o)}{dt}$$

$$I = C_f \cdot \frac{d}{dt}(0 - V_o)$$

$$\boxed{I = -C_f \frac{dV_o}{dt}} \longrightarrow (2)$$

Equating eq (1) & (2), we get.

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

Integrating both sides w.r.t dt, we get.

$$\int_0^t \frac{V_{in}}{R_1} dt = -C_f \int_0^t \frac{dV_o}{dt} \cdot dt$$

$$\int_0^t \frac{V_{in}}{R_1} dt = -C_f \cdot V_o.$$

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

<u>Differentiator :-</u>

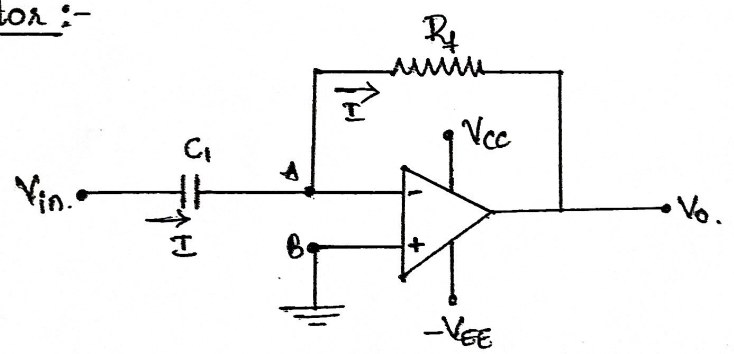


fig: op-amp as Differentiator.

* The ckt which produces the differentiation of the I/p voltage at its o/p is called differentiator.

* The node B is grounded. Due to virtual ground concept $V_A = V_B = 0$.

The I/p current of op-amp is zero, entire current I flows through the resistance R_f.

from I/p side,

$$I = C_1 \cdot \frac{d}{dt}(V_{in} - V_A)$$

as $\boxed{V_A = 0}$

$$\boxed{I = C_1 \frac{d}{dt} V_{in}} \rightarrow ①$$

from o/p side.

$$I = \frac{V_A - V_o}{R_f} = \frac{0 - V_o}{R_f}$$

$$\boxed{I = -\frac{V_o}{R_f}} \rightarrow ②$$

Equating eq ① & ②, we get

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

$$\boxed{V_o = -R_f C_1 \cdot \frac{dV_{in}}{dt}} \rightarrow ③$$

* The eq ③ shows that the o/p is $R_f C_1$ times the differentiation of the I/p & product $R_f C_1$ is called time constant of the differentiator.

SUBTRACTOR or DIFFERENCE amplifier :- (Not in Syllabus)

* Show that the op-amp circuit shown below can work as a subtractor. July-04, 3M | July 05, 5M.

* Explain how an op-amp can be used as subtract. Obtain an expression for its o/p. July, 04 - 5M