GURU NANAK DEV ENGINEERING COLLEGE
BIDAR -585403

Affiliated to Visvesvaraya Technological University, Belagavi
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2022 SCHEME

BASIC ELECTRONICS
(BBEE103/203)

[As per Choice Based Credit System (CBCS)]

(Strictly for internal circulation only)

MODULE- 3

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3) The output terminal

4) The inverting input terminal, marked as −ve

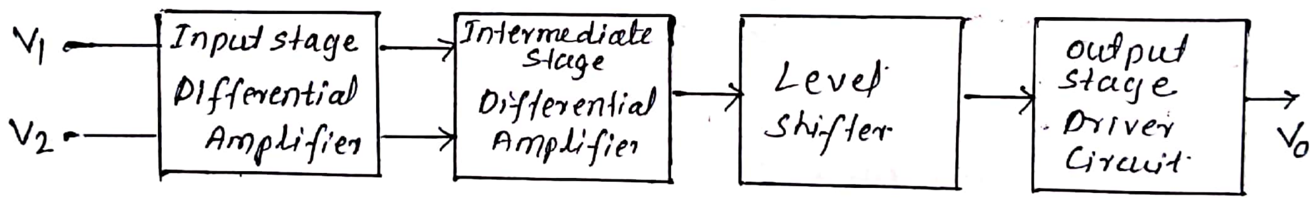
5) Non inverting input terminal, marked as +ve

The input at inverting input terminal results in opposite polarity output while the input at non inverting terminal results in the same polarity output.

The op-amp works on dual supply. A dual supply consists of two supply voltages and both dc. The dual supply is generally balanced i.e the voltages of the +ve supply $+V_{cc}$ and that of the −ve supply $-V_{EE}$ are same in magnitude.

* Block diagram representation of an op-amp

Following fig. shows block diagram of an op-amp.



A dual input, balanced output differential amplifier is used as an input stage. The output of the input stage drives the next stage which is intermediate stage.

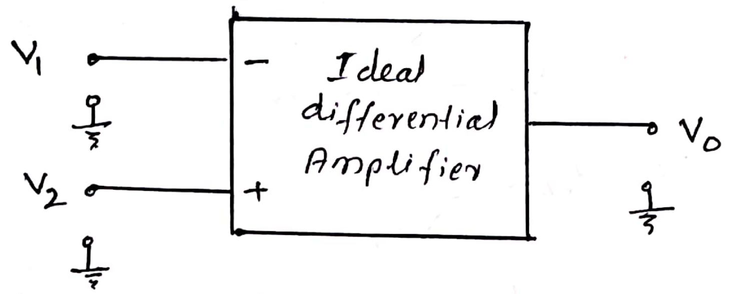
This is another differential amplifier with dual input, unbalanced i.e single ended output. The overall gain requirement of op-amp is very high. The main function of the intermediate stage is to provide an additional gain required.

A level shifter stage brings the dc level to ground potential.

output stage (driver circuit) increases the output voltage swing, raises the current supplying capability and provides low output resistance.

* Ideal op-amp.

The ideal op-amp is basically an amplifier which amplifies the difference between the two input signals. In it's basic form, the op-amp is nothing but a differential amplifier.



In ideal differential amplifier, the output v_o is proportional to the difference between the two input signals

$$v_o \propto (V_2 - V_1)$$

$$\therefore \; v_o = A_d V_d$$

where $V_d = V_2 - V_1$
A_d, const. of proportionality

$$A_d = \frac{V_o}{V_d}$$

A_d is the open loop gain, which is called differential gain.

when expressed in dB.

$$A_d = 20 \log_{10} A_d \text{ in dB.}$$

- Common mode gain A_{cm}.

Output voltage of the practical differential amplifier not only depends on the difference voltage but also depends on the average common level of the two input signal is called common mode signal denoted as V_{cm}.

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

The gain with which it amplifies the common mode signal to produce the output is called common mode gain of the differential amplifier denoted as A_{cm}

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

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

So the total output of any differential amplifier can be expressed as.

$$V_o = A_d V_d + A_{cm} V_{cm}$$

For an ideal differential amplifier the A_d must be infinite (∞) while A_{cm} must be Zero (0). This ensures Zero output voltage for $V_1 = V_2$.

* Op-amp parameters.

1) Open-loop Voltage gain. ($A_{V(OL)}$)

The open loop voltage gain of an operational amplifier is defined as the ratio of output voltage to input voltage measured with no feedback applied.

$$\therefore A_{V(OL)} = \frac{V_{out}}{V_{in}}$$

where $A_{V(OL)}$ = open loop voltage gain

V_{out} & V_{in} = output and input voltages.

The open-loop voltage gain is often expressed in decibels (dB) rather than as a ratio.

$$A_{V(OL)dB} = 20 \log_{10} \left(\frac{V_{out}}{V_{in}}\right)$$

most op-amp have $A_{V(OL)}$ of 90 dB.

2) Closed-loop Voltage gain ($A_{V(CL)}$)

The closed-loop voltage gain of an operational amplifier is defined as the ratio of output voltage to input voltage measured with feedback.

$$\therefore A_{V(CL)} = \frac{V_{out}}{V_{in}}$$

$$A_{V(CL)dB} = 20 \log_{10} \left(\frac{V_{out}}{V_{in}}\right)$$

where $A_{V(CL)}$ = closed loop voltage gain

V_{out} & V_{in} = output and input voltages.

Feed back is small portion of output voltage applying back to the input either +ve or −ve. op-amp uses −ve feed back.

Ex: An op-amp operating with negative feedback produces an output voltage of 2V when supplied with an input of 400 μV. Determine the value of Closed - loop voltage gain

Soln:
$$A_{V(CL)} = \frac{V_{out}}{V_{in}} \qquad V_{out} = 2V, \quad V_{in} = 400 \times 10^{-6} V$$

$$= \frac{2}{400 \times 10^{-6}}$$

$$\therefore \boxed{A_{V(CL)} = 5000}$$

$$A_{V(CL)dB} = 20 \log_{10}(5000)$$

$$\boxed{A_{V(CL)dB} = 74 \text{ dB}}$$

3) Input Resistance. (Rin)

The input resistance of an op-amp is defined as the ratio of input voltage to input current expressed in ohms.

$$R_{in} = \frac{V_{in}}{I_{in}}$$

where R_{in} = input resistance in ohms

V_{in} & I_{in} = input voltage and currents

It is the resistance that can be measured at either the inverting or non-inverting terminal with the other terminal connected to ground.

Ex: An op-amp has an input resistance of 2MΩ. Determine the input current when an input voltage of 5mv is present.

Soln:
$$R_{in} = \frac{V_{in}}{I_{in}} \qquad \text{But } V_{in} = 5mv = 5 \times 10^{-3} V, \quad R_{in} = 2M\Omega = 2 \times 10^{6} \Omega$$

$$\therefore I_{in} = \frac{V_{in}}{R_{in}} = \frac{5 \times 10^{-3}}{2 \times 10^{6}} = 2.5 \times 10^{-9} A = 2.5 nA.$$

4) Output Resistance (R_o).

Output resistance, R_o is the equivalent resistance that can be measured between the output terminal of the op-amp and the ground.

It is $75\ \Omega$ for 741 C op-amp.

5) Common mode Rejection Ratio (CMRR)

It is defined as the ratio of differential voltage gain A_d to the common mode voltage gain A_{cm}

$$\therefore \ CMRR = \frac{A_d}{A_{cm}}$$

A very high value of CMRR means that A_d is high and common mode gain A_{cm} is low.

For Ideal op-amp CMRR is infinite (∞)

CMRR is often expressed in decibels (dB)

$$CMRR = 20 \log_{10} \left(\frac{A_d}{A_{cm}} \right) \ dB.$$

Ex: A certain op-amp has an open-loop differential voltage gain of 100,000 and common mode gain of 0.2. Determine the CMRR and express in dB

Soln: $A_d = 100{,}000 \qquad A_{cm} = 0.2.$

$$\therefore \ CMRR = \frac{A_d}{A_{cm}} = \frac{100{,}000}{0.2} = 500{,}000.$$

in decibels.

$$CMRR = 20 \log_{10} (500{,}000) = 114 \ dB.$$

6) Slew rate.

Slew rate is defined as the maximum rate of change of output voltage per unit of time and is expressed in volts per microsecond V/µs.

$$SR = \left.\frac{dV_o}{dt}\right|_{max} \quad V/\mu s.$$

The slew rate of an op-amp is fixed. The slew rate is one of the important factor in selecting the op-amp for ac applications.

The slew rate for 741 IC is 0.5 V/µs.

7) Bandwidth (BW) (GB)

The gain-bandwidth product (GB) is the bandwidth of the op-amp when the voltage gain is 1. This is the maximum frequency at which op-amp can operate with expected behavior.

741 op-amp has GB of 1MHz.

8) Input-offset voltage (V_{io}).

Input offset voltage is the voltage that must be applied between the two input terminals such that output voltage becomes zero.

Typical value of V_{io} = 2mV.

The smaller the value of V_{io}, the better the input terminals are matched

741 op-amp has V_{io} = 150µV maximum.

9) Input offset current (I_{io})

The input offset current, I_{io} is the difference of the input bias currents, expressed as an absolute value.

$$I_{io} = |I_1 - I_2|$$

where, I_1 = current in to the inverting terminal

I_2 = current in to the non inverting terminal.

- for 741 op-amp I_{io} = 200 nA maximum

10) Input Bias current (I_B).

It is the average of the currents that flow in to the inverting and non-inverting input terminals of the op-amp.

$$I_B = \frac{I_1 + I_2}{2}$$

where I_1 = current in to the inverting terminal

I_2 = current in to the non inverting terminal.

- for 741 op-amp I_B = 500 nA. precision value ± 7 nA.

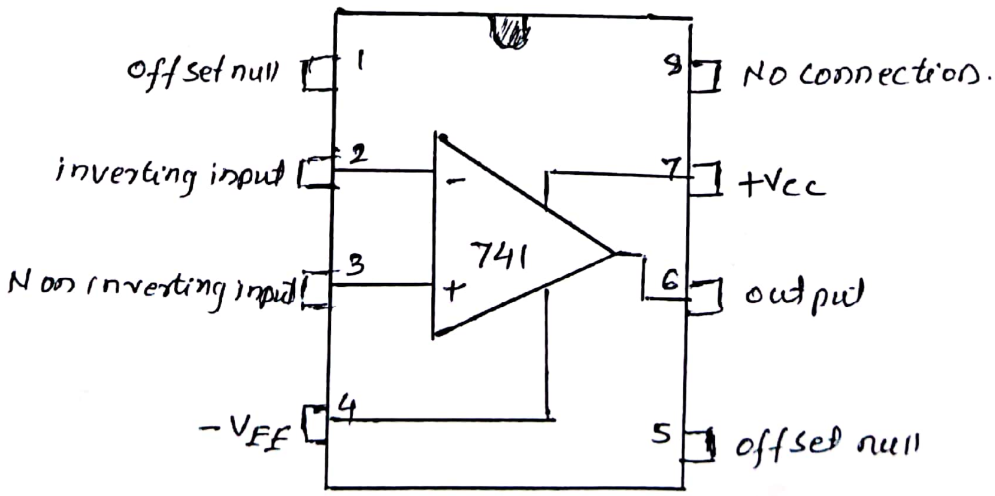
11) Supply voltage Rejection Ratio (SVRR) or PSRR.

The change in op-amps input offset voltage V_{io} caused by variations in supply voltages called SVRR

i,e $$SVRR = \frac{\Delta V_{io}}{\Delta V}$$

* Op-amp IC 741

The pin diagram of IC 741 op-amp is shown in fig.



* The Ideal op-amp characteristics.

The ideal op-amp would exhibit the following electical characteristics.

1) Infinite voltage gain, $A_v = \infty$

2) Infinite input resistance R_i, so that almost any signal source can drive it i.e $R_i = \infty$

3) Zero output resistance R_o, so that output can drive an infinite number of other devices, i.e $R_o = 0$

4) Zero input offset voltage, $V_{io} = 0$

5) Infinite bandwidth so that any frequency signal from 0 to ∞ Hz can be amplified without attenuation.

6) Infinite common-mode rejection ratio (CMRR) so that the output common-mode noise voltage is zero. i.e CMRR = ∞.

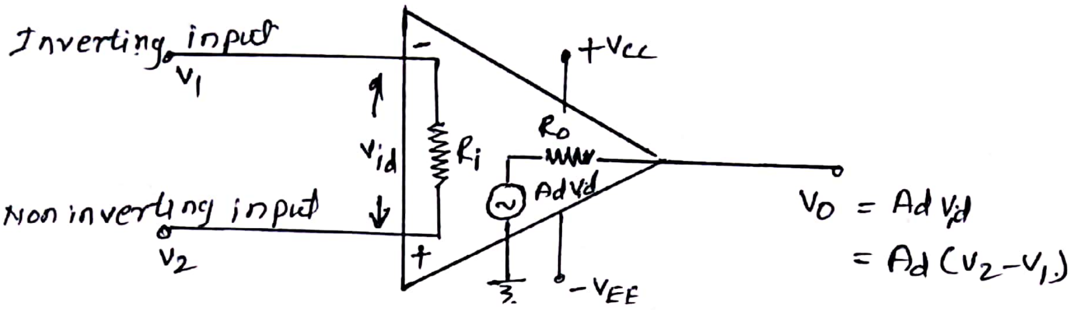
7) Infinite slew rate so that output voltage changes occur simultaneously with input voltage changes. i.e SR = ∞

8) Zero SVRR, i.e SVRR = 0

9) No effect of temperature.

* Equivalent Circuit of an op-amp.

Fig. shows an equivalent circuit of an op-amp.



The equivalent circuit is useful in analysing the basic operating principles of op-amp and in observing the effects of feed back arrangements.

The output voltage for the above ckt is

$$V_o = A_d V_{id}$$
$$= A_d (V_2 - V_1)$$

where A_d = open-loop gain for difference input
V_d = difference input voltage.

Note that the output voltage V_o cannot exceed the positive and negative saturation voltages $+V_{CC}$ and $-V_{EE}$ respectively.

Since open loop gain is very large, a small V_{id} will cause the output voltage V_o to be driven all the way to its extreme $\pm V_{sat}$ i.e $+V_{CC}$ or $-V_{EE}$.

* Open loop Op-Amp Configurations.

Open-loop indicates that output signal is not feedback in any form as a part of input signal. When connected in open-loop configurations, the op-amp simply functions as high-gain amplifier.

There are three open-loop configurations.

1) Differential amplifier
2) Inverting amplifier
3) Non inverting amplifier.

1) Differential Amplifier.

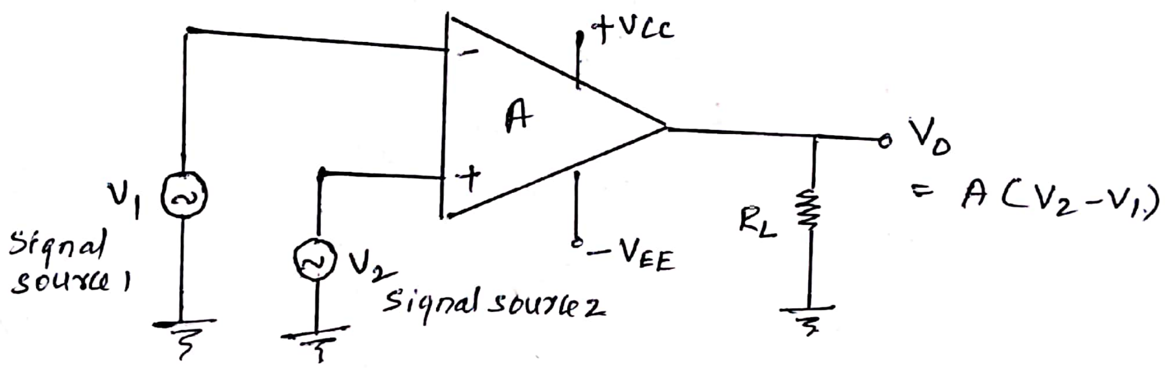


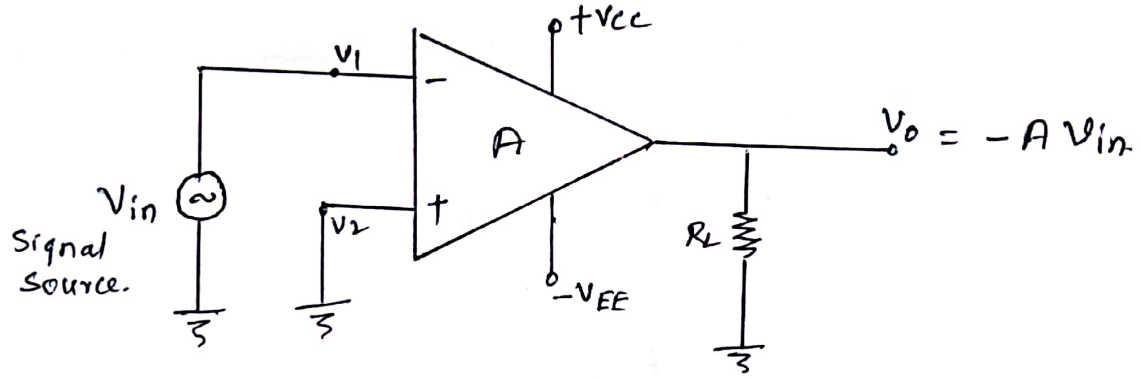
Fig. shows the open-loop differential amplifier in which input signals V_1 and V_2 are applied to the negative and positive input terminals.

Since the op-amp amplifies the difference between the two input signals, this configuration is called the differential amplifier.

Thus, $V_o = A(V_2 - V_1)$

Hence, the output voltage is equal to the voltage gain A times the difference between two input voltages, where A is open-loop voltage gain.

2) Inverting Amplifier.



in the inverting amplifier only one input is applied and that is to inverting input terminal. The non-inverting input terminal is grounded.

Since, $V_2 = 0$ and $V_1 = v_{in}$

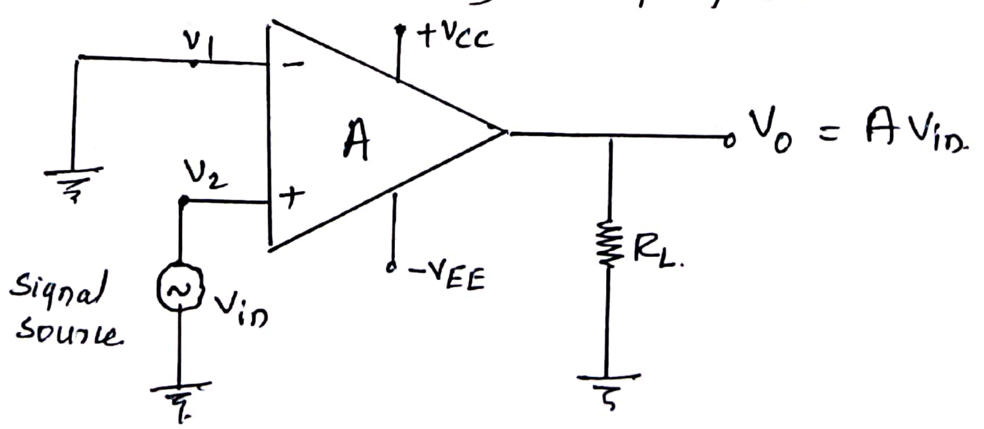
WKT, $v_o = A(V_2 - V_1)$

$= A(0 - v_{in})$

$\therefore \boxed{v_o = -A V_{in}}$

The negative sign indicates that the output voltage is out of phase with respect to input by 180°. Thus in the inverting amplifier the input signal is amplified by gain A and is also inverted at the output.

3) Non-Inverting Amplifier.



The fig. shows non-inverting amplifier. The input is applied to the non-inverting input terminal and the inverting terminal is connected to the ground.

Hence $V_1 = 0$ and $V_2 = V_{in}$

WKT, $V_o = A(V_2 - V_1)$

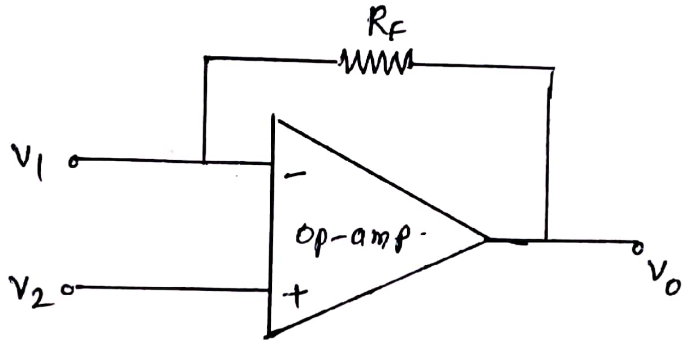
$= A(V_{in} - 0)$

$\therefore \boxed{V_o = A V_{in}}$

This means that the output is larger than the input voltage by gain A and is in phase with the input signal.

* closed loop configuration of op-amp.

The utility of op-amp increases considerably if it is used in a closed loop configuration. The closed-loop mode is possible using feedback. The feedback helps to control the gain which otherwise drives op-amp in to saturation. The negative feedback is possible by adding a resistor as shown in fig. called feedback resistor.



The feed back is said to be negative as the feedback resistor connects the output to the inverting input terminal. The gain resulting with feed back is called closed-loop gain of the op-amp. Due to feedback resistor there is reduction in the gain.

- Advantages of negative feedback.

1) It reduces the gain and makes it controllable.
2) It reduces distortion
3) It increases bandwidth.
4) Increases input resistance, R_i
5) It decreases output resistance, R_o.

- Two realistic simplifying assumptions.

i) Zero input current.

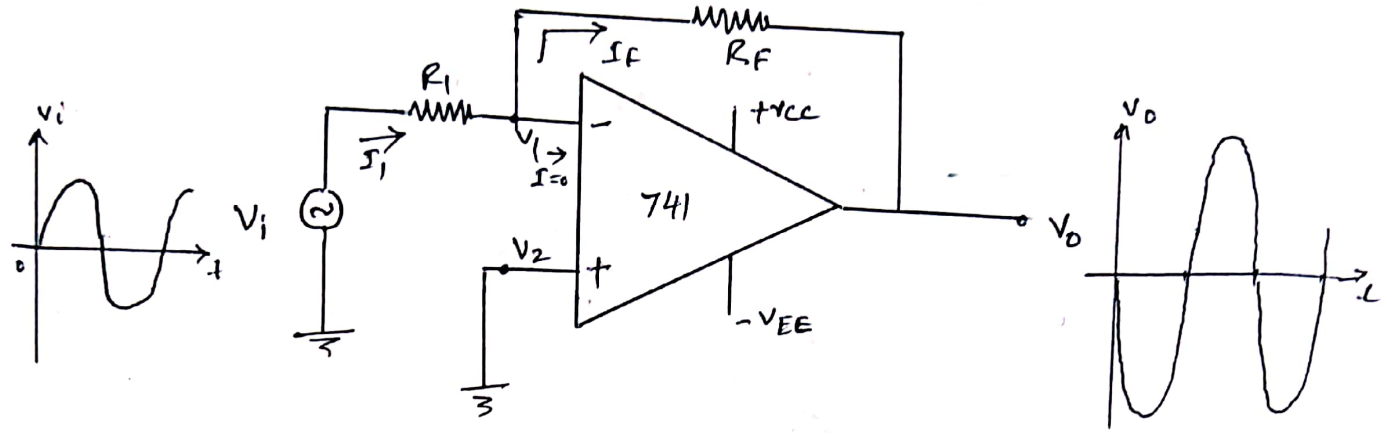
The current drawn by either of the input terminals is zero.

ii) Virtual ground.

This means the V_d between the non-inverting and inverting input terminals is essentially zero

* Inverting amplifier using op-amp.

In inverting amplifier output signal having a phase shift of 180° as compared to input signal.



from the concept of virtual ground

$V_1 = V_2 = 0$

KCL at node V_2.

$I_1 = I_F$.

$$\Rightarrow \frac{V_i - V_1}{R_1} = \frac{V_1 - V_0}{R_F} \qquad \because V_1 = 0$$

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

$$\therefore \boxed{V_0 = -\frac{R_F}{R_1} \cdot V_i}$$

$V_0 = -A \cdot V_1$ where $A = \frac{R_F}{R_1}$ for inverting amplifier.

$A \rightarrow$ gain of the amplifier.

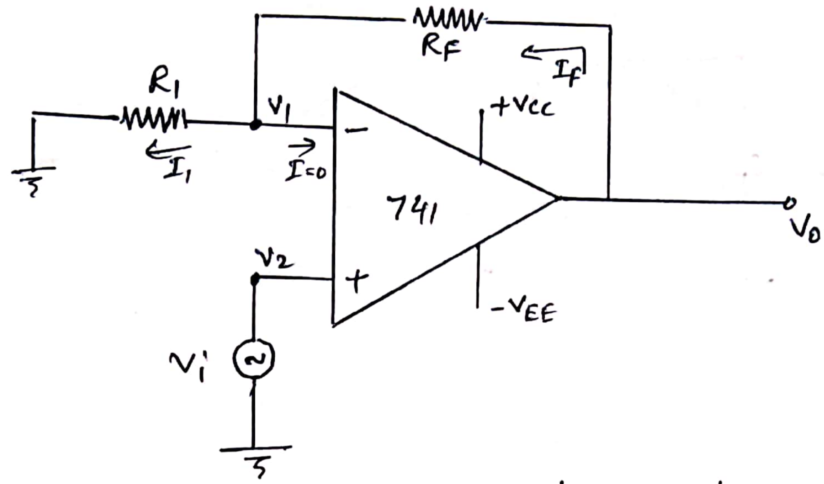
Ex: In op-amp inverting amplifier, if input resistance $R_1 = 1k\Omega$ and feed back resistance $R_F = 10k\Omega$. calculate the voltage gain. If $V_i = 0.5V$, Find V_0

Soln: Voltage gain $A = \frac{R_F}{R_1} = \frac{10 \times 10^3}{1 \times 10^3} = 10.$

$$V_0 = -\frac{R_F}{R_1} \times V_i = -10 \times 0.5$$
$$= -5V$$

* Non-inverting amplifier using op-amp.

An amplifier which amplifies the input without producing any phase shift between input and output is called non-inverting amplifier.



from the concept of virtual ground.

$$V_1 = V_2 = V_i$$

KCL at node V_1, gives

$$I_1 = I_F$$

$$\frac{V_1 - 0}{R_1} = \frac{V_o - V_1}{R_F} \qquad \because V_1 = V_i$$

$$\frac{V_i}{R_1} = \frac{V_o - V_i}{R_F}.$$

$$\Rightarrow \frac{V_o}{R_F} = \frac{V_i}{R_1} + \frac{V_i}{R_F} = V_i \left[\frac{1}{R_1} + \frac{1}{R_F}\right]$$

$$\Rightarrow \frac{V_o}{\cancel{R_F}} = V_i \left[\frac{R_1 + R_F}{R_1 \cancel{R_F}}\right]$$

$$\therefore \boxed{V_o = \left[1 + \frac{R_F}{R_1}\right] V_i}$$

$V_o = A \cdot V_i$ where $A = 1 + \frac{R_F}{R_1}$

$A \rightarrow$ gain of the non-inverting amplifier.

1) Ex: Find the gain of non-inverting amplifier if $R_F = 10k\Omega$ and $R_1 = 1k\Omega$ and output voltage for $V_i = 10V$.

Soln: gain, $A = \left(1 + \frac{R_F}{R_1}\right)$ for non inverting amplifier

$$= \left(1 + \frac{10\times10^3}{1\times10^3}\right) = 11 \qquad \boxed{A = 11}$$

$$\therefore V_o = A \cdot V_i = 11 \times 10 = 110V \qquad \boxed{V_o = 110V}$$

2) Ex: A non-inverting amplifier has a closed loop gain of 25. If input voltage $V_i = 10mv$, $R_F = 10k\Omega$, Determine the value of R_1 and o/p voltage V_o.

soln: given: Closed loop gain, $A = 25$, $V_i = 10mv$, $R_F = 10k\Omega$

for non inverting amplifier $A = 1 + \frac{R_F}{R_1}$

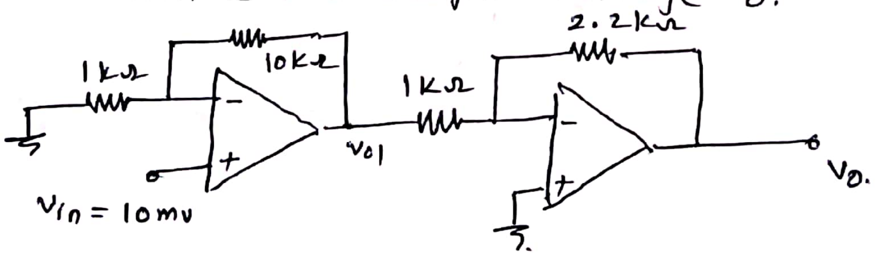
$$25 = 1 + \frac{10\times10^3}{R_1}$$

$$\Rightarrow \boxed{R_1 = \frac{10\times10^3}{24} = 416.6\,\Omega.}$$

$$V_o = \left(1 + \frac{R_F}{R_1}\right) V_i = \left(1 + \frac{10\times10^3}{416.6}\right) 10\times10^{-3}$$

$$\boxed{V_o = 250\,mV.}$$

3) Ex: for the cascaded amplifier shown in fig., determine the output voltage V_o.



Soln: The output voltage of non inverting amplifier (1st stage) is given by $V_{o1} = \left(1 + \frac{R_f}{R_1}\right) V_{in} = \left(1 + \frac{10\times10^3}{1\times10^3}\right) 10\times10^{-3}$

$$= 110\ mv.$$

$\therefore$ V_{o1} will be the input to inverting amplr (2nd stage)

$$V_o = -\left(\frac{R_F}{R_1}\right) \cdot V_{o1} = -\left(\frac{2.2\times10^3}{1\times10^3}\right) \cdot 110\times10^{-3}$$

$$\boxed{V_o = -242\,mV}$$

Ex: Design an inverting and non inverting op-amp to have a gain of 15

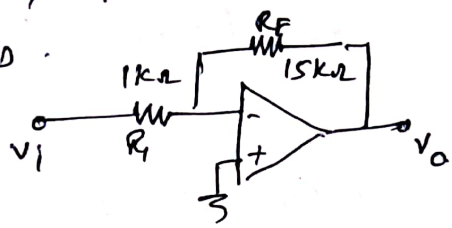
soln: Given: $A = 15$

* for inverting amplifier

$$A = \frac{R_F}{R_1} = 15 \Rightarrow R_F = 15 R_1$$

Select $R_1 = 1k\Omega$, $R_F = 15 \times 1k\Omega = 15k\Omega$.

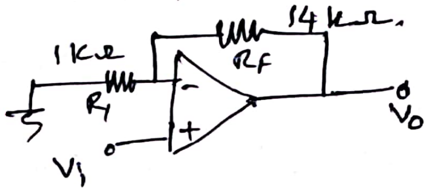
The designed ckt is:



* For non inverting amplifier.

$$A = 1 + \frac{R_F}{R_1} = 15, \quad \frac{R_F}{R_1} = 15 - 1 = 14$$

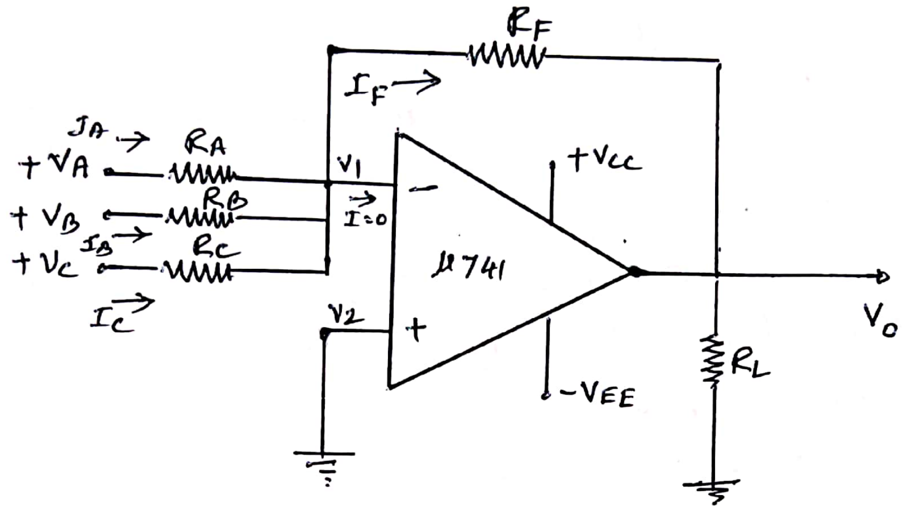
$\therefore R_F = 14 R_1$, select $R_1 = 1k\Omega$ R_F becomes $14k\Omega$



* Op-Amp Applications.

* 1) Inverting configurations:

- Three input inverting configuration (adder or summer circuit).



The above circuit with three inputs can be used as a summing, scaling and averaging amplifier. Depending on the relationship between feed back resistor R_F and input resistors R_A, R_B and R_C, the circuit can be used as a summing amplifier, scaling amplifier or an averaging amplifier.

Apply KCL at node V_1, we get.

$$I_A + I_B + I_C = I_F \quad \text{--- 1)}$$

from virtual ground, $V_1 = V_2 = 0$

$$\therefore \frac{V_A - 0}{R_A} + \frac{V_B - 0}{R_B} + \frac{V_C - 0}{R_C} = \frac{0 - V_o}{R_F}$$

$$\Rightarrow \frac{V_A}{R_A} + \frac{V_B}{R_B} + \frac{V_C}{R_C} = -\frac{V_o}{R_F}$$

$$\therefore V_o = -\left[\frac{R_F}{R_A} \cdot V_A + \frac{R_F}{R_B} \cdot V_B + \frac{R_F}{R_C} \cdot V_C\right] \quad \text{--- 2)}$$

* Summing amplifier

If $R_A = R_B = R_C = R$.

then eqn 2), becomes

$$\Rightarrow V_o = -\frac{R_F}{R}\left[V_A + V_B + V_C\right] \quad \text{--- 3)}$$

This means that the output voltage is equal to the ~~sum~~ negative sum of all the inputs times the gain of the circuit R_F/R. Hence the circuit is called as summing amplifier. here $A_F = \frac{R_F}{R}$

$A_F \rightarrow$ gain of the amplifier with negative feedback.

when gain is 1

Then $V_o = -(V_A + V_B + V_C)$ —4>

* Scaling amplifier.

If each input is amplified by a different factor, then they are called scaling amplifier.

This condition can be accomplished if R_A, R_B and R_C are different in value.

Thus the output voltage of scaling amplifier is

$$V_o = -\left[\frac{R_F}{R_A} \cdot V_A + \frac{R_F}{R_B} \cdot V_B + \frac{R_F}{R_C} \cdot V_C\right]$$

where $\frac{R_F}{R_A} \neq \frac{R_F}{R_B} \neq \frac{R_F}{R_C}$.

* Averaging circuits.

The output voltage is equal to the average of all the input voltages.

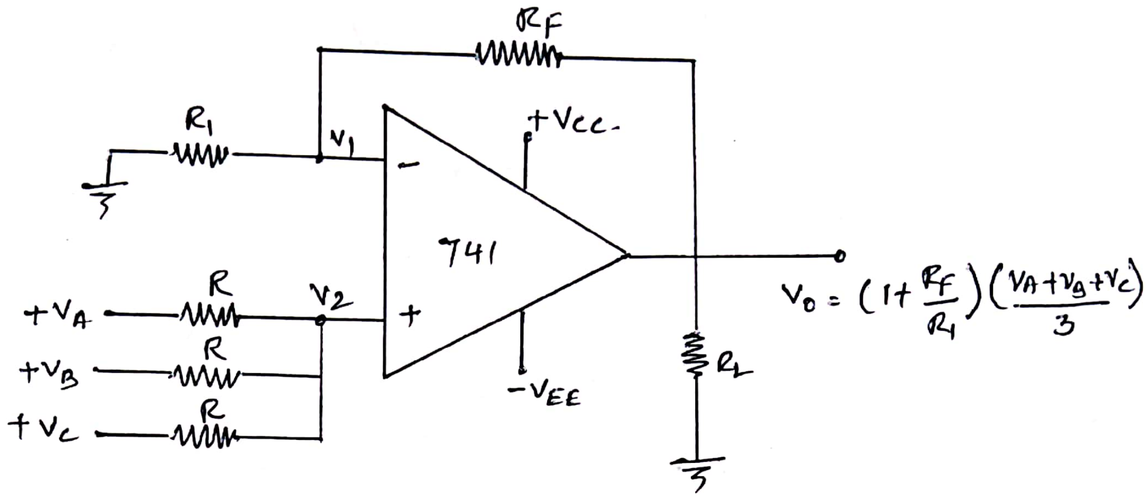
This is accomplished by using all input resistors of equal values $R_A = R_B = R_C = R$

here $\frac{R_F}{R} = \frac{1}{n}$, where n is the number of inputs.

∴ for three inputs, we want $\frac{R_F}{R} = \frac{1}{3}$

$$\therefore \quad V_o = -\frac{(V_A + V_B + V_C)}{3}$$

2) * Non-inverting configuration.



The input voltage sources and resistors are connected to the non-inverting terminal. The voltage V_2 at non-inverting terminal is

$$V_2 = \frac{V_A}{3} + \frac{V_B}{3} + \frac{V_C}{3} = \frac{V_A + V_B + V_C}{3}$$

The gain of non-inverting amplifier is

$$A_F = 1 + \frac{R_F}{R_1}$$

Hence the output voltage V_o is

$$V_o = A_F \cdot V_{in} \qquad \because V_{in} = V_2$$

$$\boxed{V_o = \left(1 + \frac{R_F}{R_1}\right)\left(\frac{V_A + V_B + V_C}{3}\right)} \quad \text{— I)}$$

* Averaging amplifier

above eqn shows that output voltage is equal to the average of all input voltages times the gain of the circuit $\left(1 + \frac{R_F}{R_1}\right)$. Hence the name averaging amplifier.

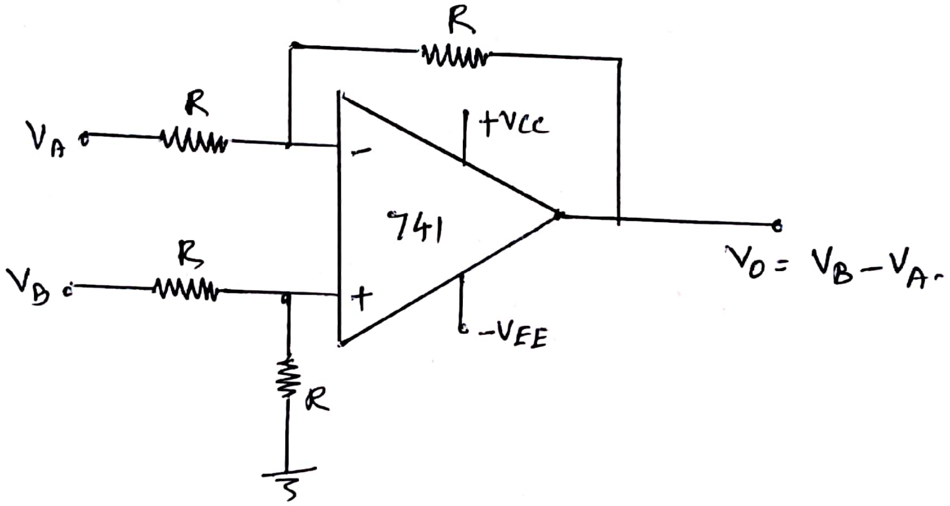
* summing amplifier (Non-inverting).

eqn I) reveals that if the gain $(1+\frac{R_F}{R_1})$ is equal to the number of inputs, the output voltage becomes equal to the sum of all the input voltages.

i.e, if $(1+\frac{R_F}{R_1}) = 3$ in eqn. I).

Then $\boxed{V_O = V_A + V_B + V_C}$

* 3) Differential Configuration.



* Subtractor

In the above fig. input signals can be scaled to desired values by selecting appropriate values for the external resistors.

The output voltage of the differential amplifier with gain of '1' is

$$V_o = V_B - V_A$$

Thus, we can say that it acts as a subtractor.

1) Ex: Calculate the output voltage of a three input inverting summing amplifier, given $R_1 = 200k\Omega$, $R_2 = 250k\Omega$, $R_3 = 500k\Omega$, $R_F = 1M\Omega$, $V_1 = -2V$, $V_2 = -1V$ and $V_3 = +3V$

Soln: Given: $R_1 = 200k\Omega$, $R_2 = 250k\Omega$, $R_3 = 500k\Omega$, $R_F = 1M\Omega$
$V_1 = -2V$, $V_2 = -1V$, $R_3 = +3V$.

we know that for three input summing amplifier

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

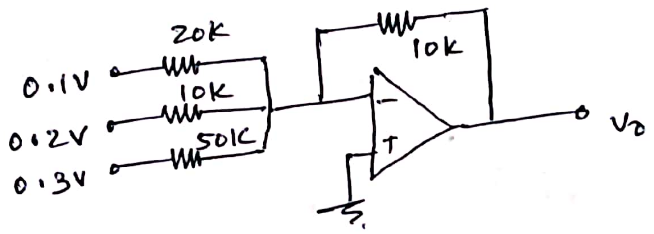
$$= -\left[\frac{1\times10^6}{200\times10^3}\cdot(-2) + \frac{1\times10^6}{250\times10^3}\cdot(-1) + \frac{1\times10^6}{500\times10^3}\cdot 3\right]$$

$$= -\left[5\times(-2) + 4\times(-1) + 2\times3\right]$$

$$= -\left[-10 - 4 + 6\right]$$

$$= -\left[-8\right] = 8V \qquad \boxed{\therefore V_0 = 8V}$$

2) Ex: Determine Vo for the circuit shown.



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

$$= -\left[\frac{10\times10^3}{20\times10^3}\times0.1 + \frac{10\times10^3}{10\times10^3}\times0.2 + \frac{10\times10^3}{50\times10^3}\times0.3\right]$$

$$= -\left[0.05 + 0.2 + 0.06\right]$$

$$\boxed{V_0' = -0.31\,V}$$

3) Ex: Design an adder circuit using op-amp to obtain an output voltage, $V_0 = -[2V_1 + 3V_2 + 5V_3]$ Assume, $R_F = 10k\Omega$.

Soln:
$$V_0 = -\left[\frac{R_F}{R_1}\cdot V_1 + \frac{R_F}{R_2}\cdot V_2 + \frac{R_F}{R_3}\cdot V_3\right] \quad -1)$$

Given $V_0 = -\left[2V_1 + 3V_2 + 5V_3\right] \quad -2)$

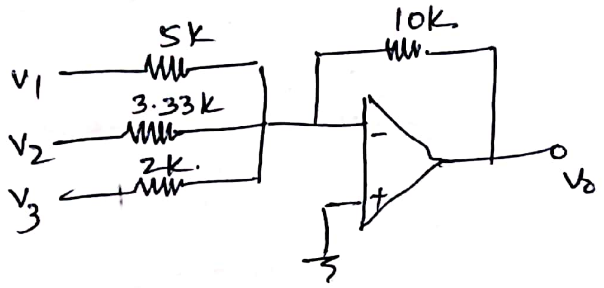
Comparing eqns 1) & 2):

$$\frac{R_F}{R_1} = 2, \quad \frac{R_F}{R_2} = 3, \quad \frac{R_F}{R_3} = 5$$

$$\Rightarrow R_1 = \frac{R_F}{2} = \frac{10k}{2} = 5k, \quad R_2 = \frac{R_F}{3} = \frac{10k}{3} = 3.33k$$

$$R_3 = \frac{R_F}{5} = \frac{10k}{5} = 2k.$$

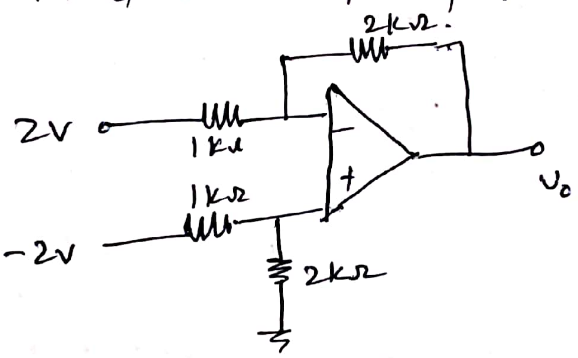
The designed adder circuit is.



4) Ex: Design an op-amp adder, $V_0 = -(4V_1 + V_2 + 0.1V_3)$ assume $R_F = 100k\Omega$.

Soln: Ans. $R_1 = 25k\Omega$, $R_2 = 100k\Omega$, $R_3 = 1M\Omega$

5) Ex: Find the output of following op-amp circuit.



Soln: Given $R_1 = R_2 = 1k\Omega$. $R_f = 2k\Omega$. $V_1 = 2V$, $V_2 = -2V$

WKT,
$$V_0 = \frac{R_F}{R_2} \cdot V_2 - \frac{R_F}{R_1} V_1$$

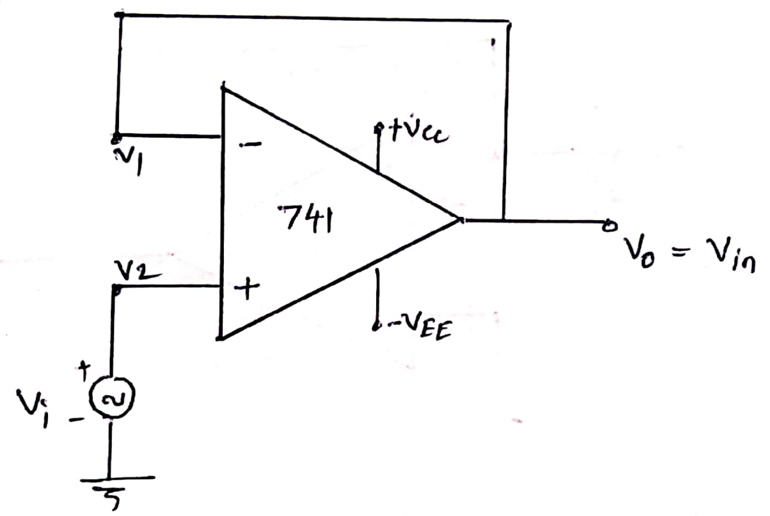
$$= \frac{2\times10^3}{1\times10^3} \times -2 - \frac{2\times10^3}{1\times10^3} \times 2$$

$$= -4 - 4$$

$$\boxed{V_0 = -8V}$$

* 4) Voltage Follower.

A circuit in which the output voltage follows the input voltage is called voltage follower circuit. The voltage follower circuit using op-amp is shown in fig.



The node V_2 is at potential V_i. from virtual ground concept node V_1 is also at same potential as V_2. i,e V_i

$$\therefore \quad V_1 = V_2 = V_i \quad \text{—— 1)}$$

Now node V_1 is directly connected to the output, Hence we can write

$$V_o = V_1 \quad \text{—— 2)}$$

equating eqn 1) & 2), we get.

$$\boxed{V_o = V_i}$$

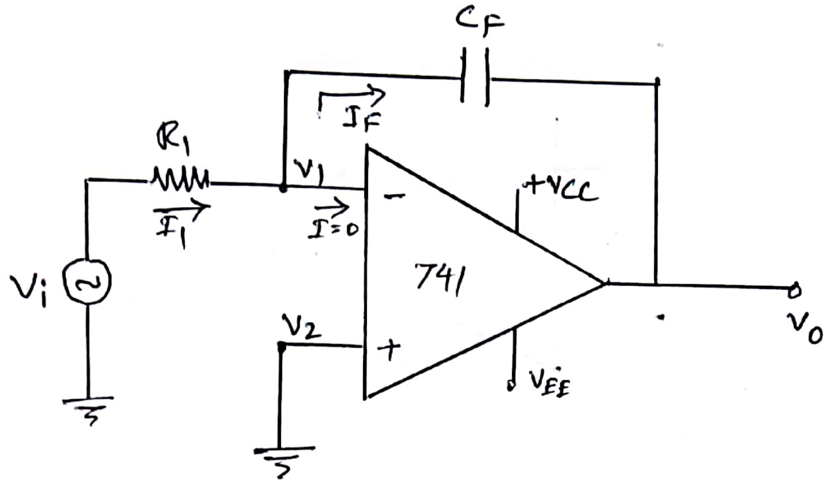
for this circuit voltage gain is unity.

This circuit can be used to connect high impedance source to a low impedance load as a buffer.

* 5) The Integrator.

In an integrator circuit, the output voltage is the integration of the input voltage.

Consider the op-amp integrator circuit as shown in fig.



The node V_2 is grounded. The node V_1 is also at ground potential from the concept of virtual ground.

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

Applying KCL at node V_1

$$I_1 = I_F$$

$$\Rightarrow \frac{V_i - V_1}{R_1} = C_F \frac{d(V_1 - V_o)}{dt}.$$

$$\frac{V_i}{R_1} = -C_F \frac{dV_o}{dt} \qquad \because V_1 = 0$$

integrating both sides.

$$\int_0^t \frac{V_i}{R_1}\, dt = -C_F \int_0^t \frac{dV_o}{dt}\,.dt.$$

$$= -C_F \cdot V_o$$

$$\therefore \quad \boxed{V_o = -\frac{1}{R_1 C_F} \int_0^t V_i \,.dt.}$$

output voltage is integration of input voltage V_i

* Input - output wave forms for integrator.

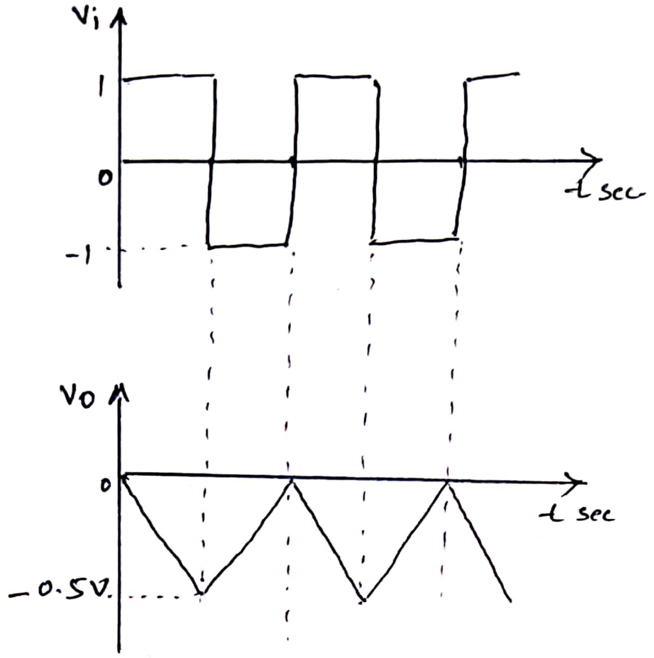


fig a. square wave input

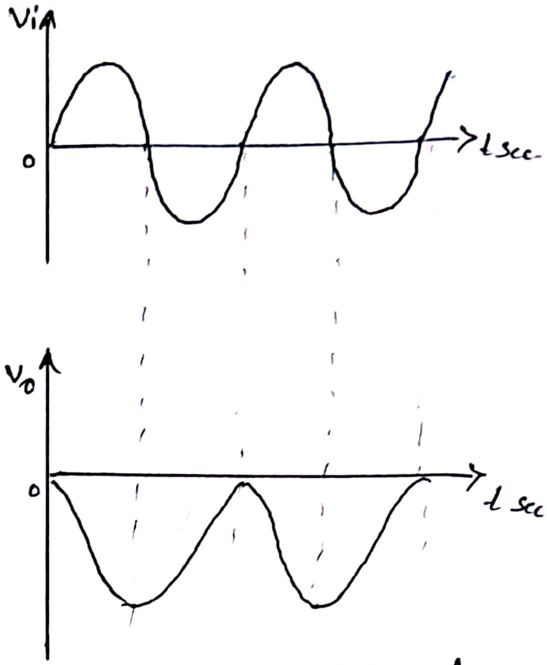


fig. b. sine wave input.

Ex: A sinusoidal signal with peak value 6 mv and 2 KHz frequency is applied to the input of an integrator with $R_1 = 100 k\Omega$ and $C_F = 1 \mu F$. Find the output voltage.

Soln: $R_1 = 100 k\Omega$, $C_F = 1 \mu F$ $V_m = 6 mv$, $f = 2 KHz$.

w.k.T $V_i = V_m \cdot \sin \omega t \cdot V$

$= 6 \times 10^{-3} \sin 2\pi \times f \cdot t$

$= 6 \times 10^{-3} \sin 2\pi \times 2 \times 10^{3} t \cdot V$.

$\therefore V_i = 6 \sin(4\pi \times 10^3 t)$ mV.

for an integrator.

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

$$= -\frac{1}{100 \times 10^3 \times 1 \times 10^{-6}} \int_0^t 6 \sin(4\pi \times 10^3 t) \cdot dt \ mV.$$

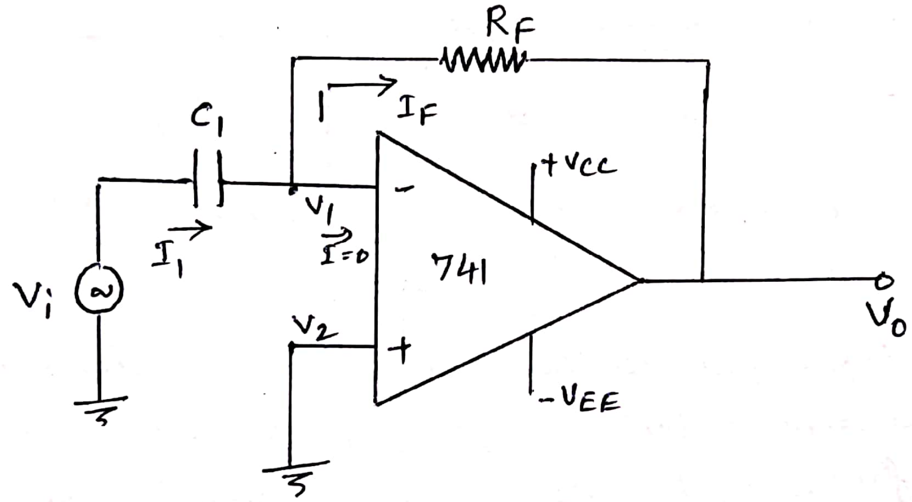
$$= \frac{-6}{100 \times 10^{-3}} \left[-\frac{\cos(4\pi \times 10^3)t}{4\pi \times 10^3} \right]_0^t mV.$$

$$V_0 = -\frac{0.015}{\pi} \left[-\cos(4\pi \times 10^3 t) - 1 \right] mV.$$

* 6) Differentiator.

The circuit which produces the differentiation of the input voltage at its output is called differentiator.

The op-amp differentiator circuit can be obtained by exchanging the positions of R and C in the basic integrator circuit. The op-amp differentiator circuit is shown in fig.



from virtual ground concept

$$V_1 = V_2 = 0.$$

Applying KCL at node V_1, we get

$$I_1 = I_F$$

$$C_1 \frac{d(v_i - v_1)}{dt} = \frac{V_1 - V_o}{R_F}$$

$$C_1 \frac{dv_i}{dt} = -\frac{V_o}{R_F} \quad \because V_1 = 0$$

$$\therefore \boxed{V_o = -R_F C_1 \frac{dv_i}{dt}.}$$

Output voltage is differentiation of input voltage V_i.

Input - output waveforms.

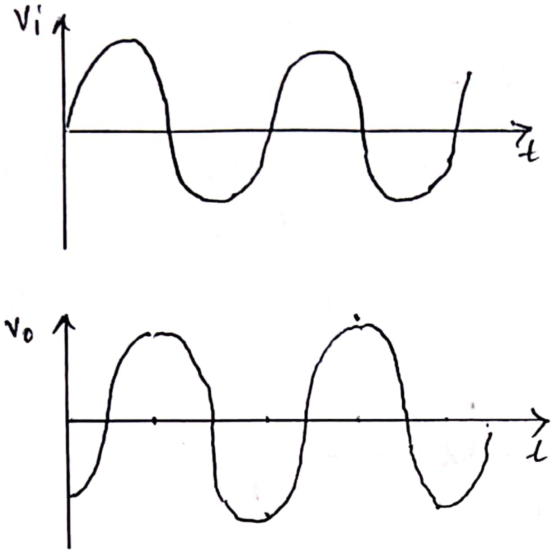


fig.a. sine-wave input

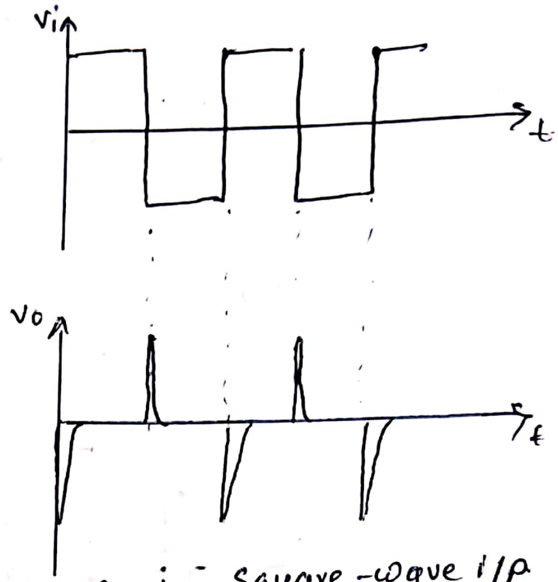


fig.b. square-wave i/p

Ex: The input to the basic differentiator circuit is a sinusoidal voltage of peak value of 10mv and frequency 1.5 KHz. Find the output if $R_F = 100\,k\Omega$ and $C_1 = 1\,\mu F$.

Soln: w.k.T $V_i = V_m \sin \omega t$. $V_m = 10mv$, $f = 1.5 KHz$.

$$= 10 \times 10^{-3} \sin 2\pi \times 1.5 \times 10^3 t$$

$$\therefore V_i = 10 \sin (3\pi \times 10^3 t) \text{ mv.}$$

for differentiator.

$$V_o = -R_F C_1 \frac{dv_i}{dt}. \qquad R_F = 100\,k\Omega,\ C_1 = 1\,\mu F.$$

$$= -100 \times 10^3 \times 1 \times 10^{-6} \frac{d}{dt} (10 \sin 3\pi \times 10^3 t) \text{ mv.}$$

$$\therefore V_o = -3000\pi \cos (3000\pi t) \text{ mv.}$$

QUESTION BANK

Module – 3

Operational Amplifiers

1. What is an operational amplifier? Mention its applications.
2. Describe block diagram representation of an op-amp. Also describe its operational behaviorwith an equivalent circuit.
3. Explain the following terms related to op-amp: (i) Open loop voltage gain (ii) Common mode gain (iii) CMRR (iv) Maximum Output Voltage Swing (v) Input Offset Voltage (vi) Input Offset Current (vii) Input bias current (viii) Input resistance (ix) Output resistance (x) Slew rate
4. A certain op-amp has an open loop voltage gain of 1,00,000 and a common mode gain of 0.2.Determine the CMRR and express it in decibels.
5. Briefly discuss the ideal characteristics of the op-amp.

Op-Amp Applications

1. Explain op-amp as an inverting and non-inverting amplifier.
2. An inverting amplifier using op-amp has a feedback resistor of 10 kΩ and one input resistor of 1 kΩ. Calculate the gain of the op-amp and the output voltage if it is supplied with an inputof 0.5 V.
3. A non-inverting amplifier has closed loop gain of 25. If input voltage v_i = 10 mV, R_f = 10 kΩ,determine the value of R_1 and output voltage v_o.
4. Briefly explain op-amp as a voltage follower.
5. Describe a summing amplifier using an op-amp in an inverting configuration with threeinputs.
6. Design an adder circuit using an op-amp to give the output $V_o = -(3V_1 + 4V_2 + 5V_3)$. Assume R_f = 120 kΩ.
7. Design the circuit diagram for the output voltage $v_o = -5(0.1v_1 + 0.2v_2 + 10v_3)$. Also draw the neat circuit diagram.
8. Describe an integrating amplifier using an op-amp in an inverting configuration. Derive an expression for integrator and differentiator.

MODULE- 3

Operational Amplifiers: Introduction, The Operational Amplifier, Block Diagram Representation of Typical Op-Amp, Schematic Symbol, Op-Amp parameters - Gain, input resistance, Output resistance, CMRR, Slew rate, Bandwidth, input offset voltage, Input bias Current and Input offset Current, The Ideal Op-Amp , Equivalent Circuit of Op-Amp, Open Loop Op-Amp configurations, Differential Amplifier, Inverting & Non Inverting Amplifier

Op-Amp Applications: Inverting Configuration, Non-Inverting Configuration, Differential Configuration, Voltage Follower, Integrator, Differentiator(Text 2: 1.1, 1.2, 1.3, 1.5, 2.2, 2.3, 2.4, 2.6, 6.5.1, 6.5.2, 6.5.3, 6.12, 6.13).

Text Books :

2. Op-amps and Linear Integrated Circuits, Ramakanth A Gayakwad, Pearson Education, 4th Edition

Prof. RAMESH PATIL
E&CE dept.
GNDEC, Bidar.

Module-3

Operational Amplifiers and it's Applications. (OP-Amp).

* Introduction to op-amp.

An operational amplifier is a direct coupled high gain amplifier that can be used to amplify dc as well as ac input signals.

op-amp was originally designed for computing mathematical functions such as Addition, Subtraction, Integration, differentiation etc.

Thus the name operational amplifier stems from it's original use for these mathematical operations and is abbreviated to "op-Amp" with addition of suitable external feed back components.

* Schematic symbol.

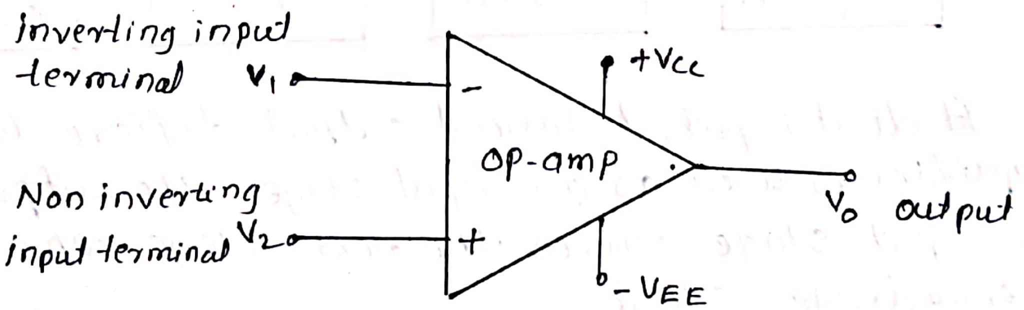


fig: schematic symbol for op-amp.

Op-amp are analog integrated circuits (ICs) designed for linear amplification.

All the op-amps have atleast following five terminals

1) The supply voltage +Vcc or V
2) The supply voltage −VEE or −V