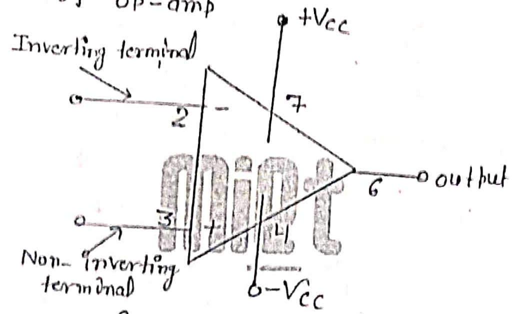
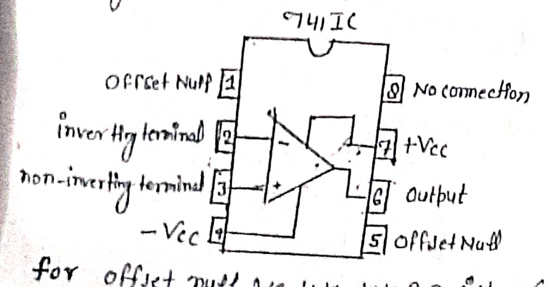
operational amplifier (Op-amp) ÷

- Op-amp is a direct coupled high gain amplifier which can be used to amplify ac as well as dc signals.
- It is mainly used for mathematical operation like addition, subtraction, integration differentiation etc and hence named as operational amplifier
- Symbol of op-amp



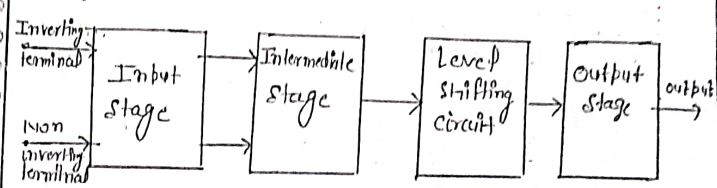
Pin diagram of op-amp



for offset null we use 10KΩ resistance (as a potentiometer) between pin no. 1 & 5

Ques1 ÷ What is op-amp. Draw its block diagram. Also draw its equivalent circuit (2015-16, 2017-18, 2020-21)

Ans ÷



Input stage ÷

- The input stage is the dual input balance output (DIBO) differential amplifier
- Its function is to amplify the difference between two input signals
- It provides high differential gain, high input impedance.

Intermediate stage ÷

- The overall gain requirement of an op-amp is very high. Intermediate stage is used to provide the required additional gain
- It consist of another differential amplifier with dual input and unbalanced (single ended) output.

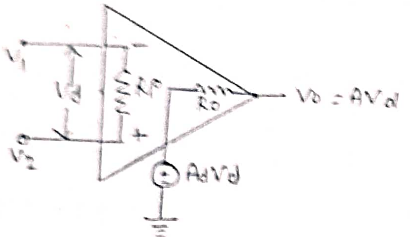
Level shifting circuit ÷

- 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 complementry amplifier
- The output stage decreases the output impedance and increases the current supplying capability of the op-amp.

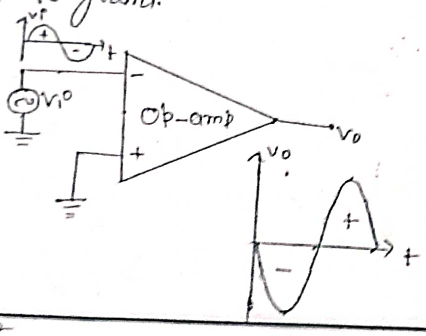
Equivalent circuit (Practical circuit) of op-amp :



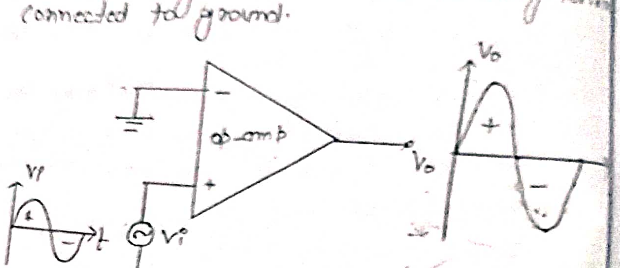
mode of operation (open loop) :

i) Single Ended operation : Single ended input operation results when I/P signal is connected to one input with the other input connected to ground.

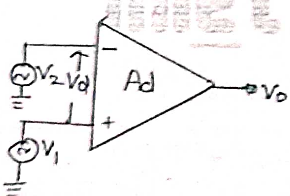
a) Inverting Amplifier :– Input is applied at inverting terminal and non-inverting terminal is connected to ground.



ii) Non inverting amplifier : Input is applied at non inverting terminal and inverting terminal is connected to ground.



Double Ended operation (Differential mode) :
When input signals are applied at both terminals then it is called differential mode.



for an ideal amplifier

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

$$V_o = A_d(V_1 - V_2)$$

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

where
Ad : differential gain
Vd : difference in input voltage.

...mode: If same input is applied at both ... i.e. $V_1 = V_2$ then ideally $V_0 = 0$. But ...ally we get some value of V_0 because of ... and mismatch in internal circuitry.

So the output of practical differential ... not only depends on difference voltage but ... depends on the average common level of two ... such signal is common mode signal (V_c).

... common mode o/p of op-amp is given as:

$$\boxed{V_0 = A_c V_c}$$

...re- A_c : common mode gain

V_c : common mode voltage $\boxed{= \frac{V_1 + V_2}{2}}$

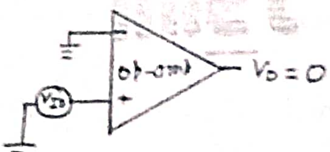
...ce the total output of any practical differential ...plifier can be expressed as:

$$\boxed{V_0 = A_d V_d + A_c V_c}$$

Ques 1 : Write short notes on the following:
(i) Input offset voltage (ii) Input offset current
(iii) Input bias current

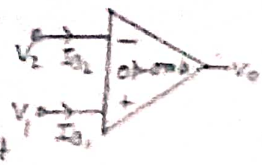
Ans : (i) Input offset voltage (V_{IO}) :

- In ideal op-amp, the output will be zero when both the input terminals are grounded.
- For practical op-amp it is found that output is not zero (called offset output voltage) if input is zero. This is due to imbalance present in the op-amp.
- An extra small amount of voltage is applied at any one of the input terminals to make the output voltage zero. This extra voltage is called input offset voltage (V_{IO})
- For ideal op-amp it is zero but for practical op-amp it is 2mV.



(ii) Input offset current :

- The algebraic difference between the currents flowing into the non inverting terminal and inverting terminal is called input-offset current (I_{IO})
- In practice these currents are not equal because of imbalance present in the op-amp.

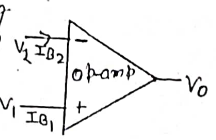


$$\boxed{I_{IO} = |I_{B_1} - I_{B_2}|}$$

- For ideal op-amp it is zero but for practical op-amp it is 20nA

(iii) Input bias current :

- It is the average of currents flowing into the inverting and non inverting terminals.
- for ideal op-amp it is zero but for practical op-amp it is 80nA



$$\boxed{I_B = \frac{I_{B_1} + I_{B_2}}{2}}$$

Ques 2 : Define CMRR (common mode rejection ratio). (2015-16, 2020-21)

Ans. CMRR : It is the ability of a op-amp to reject the common mode signal (Noise) successfully.
CMRR is defined as the ratio differential mode gain (Ad) and common mode gain (Ac)

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

For No noise (ideal op-amp) $A_c = 0$
so $CMRR = \infty$

for ideal op-amp CMRR is infinite but for practical op-amp it is 90 dB.

CMRR in dB:

$$\boxed{CMRR = 20 \log_{10} \frac{A_d}{A_c}}$$

Ques 3 : Define slew rate. Also find the expression for maximum frequency. (2015-16)

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

$$\boxed{SR = \frac{\Delta V_o}{\Delta t}\Big|_{max}} \quad (V/\mu s)$$

for ideal op-amp slew rate is infinite but for practical op-amp it is 0.5 V/μs.
If changes in o/p voltage are small then

$$\boxed{SR = \frac{dv_o}{dt}\Big|_{max} = \text{slope of signal}}$$

for proper amplification :

$$\boxed{SR \geq \frac{dv_o}{dt}\Big|_{max}}$$

Expression for maximum frequency :
Let o/p voltage of op-amp is

$$V_o = V_m \sin \omega t$$

$$\frac{dv_o}{dt} = V_m \cos \omega t \times \omega$$

$$\frac{dv_o}{dt}\Big|_{max} = \omega V_m = 2\pi f V_m \quad \text{--- (1)}$$

for proper amplification

$$SR \geq \frac{dv_o}{dt}\Big|_{max}$$

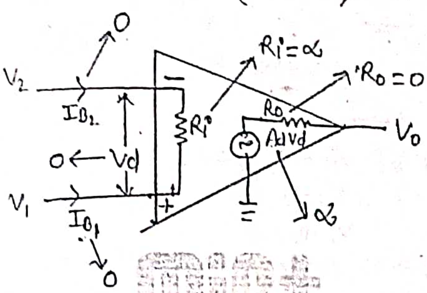
$$SR \geq 2\pi f V_m$$

$$f \leq \frac{SR}{2\pi V_m}$$

$$\boxed{f_{max} = \frac{SR}{2\pi V_m}}$$

Ques4: write the characteristics of ideal op-amp. (2016-17, 2017-18, 2020-21)

Ans:



Characteristics:

i) open loop gain should be infinit

$$A_d\,(A_{VOL}) = \infty$$

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.

$$I_B = 0$$

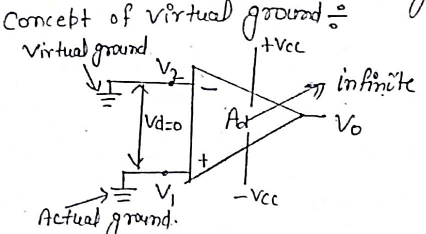
Ques5: Compare ideal and practical op-amp.

Ans: Ideal op-amp vs practical op-amp.

SN.	Parameters	Ideal Value	Practical Value
1.	CMRR	∞	90 dB
2.	Slew rate	∞	.5 V/sec
3.	open loop voltage gain	∞	10^5
4.	Input resistance	∞	2 MΩ
5.	output resistance	0	75 Ω
6.	Input offset Voltage	0	2 mV
7	Input offset current	0	20 nA
8.	Input bias current	0	80 nA

Ques: 1 Explain the concept of virtual ground.

Ans: Concept of virtual ground:



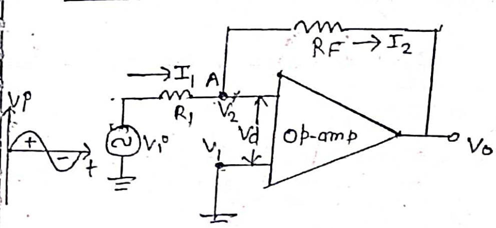
- For an ideal op-amp $A_d = \infty$

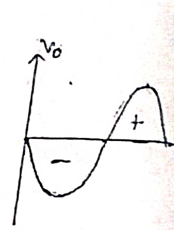
$$V_o = A_d V_d$$
$$V_d = \frac{V_o}{A_d}$$
$$V_d = \frac{V_o}{\infty} = 0$$
$$\text{So } V_1 - V_2 = 0$$
$$\boxed{V_1 = V_2}$$

- If one terminal of op-amp is connected to ground then other terminal will also be at ground. This is called concept of virtual ground.
- Concept of virtual ground is used to determine closed loop voltage gain and output voltage.

Ques 2: Explain the inverting amplifier and derive the expression for closed loop voltage gain. (2015-16, 2016-17, 2017-18)

Ans: Inverting amplifier: An op-amp circuit that produce an amplified output signal that is 180° out of phase with input signal.





Expression for output voltage:

Here $V_1 = 0$ - - - - 1

From concept of virtual ground

$$V_d = 0$$
$$V_1 - V_2 = 0$$
$$V_1 = V_2$$
$$\text{But } V_1 = 0$$
$$\text{So } V_2 = 0 \quad \text{- - - - 2}$$

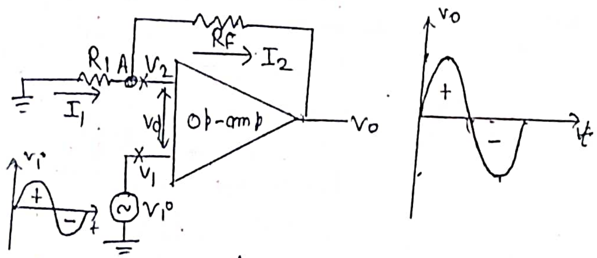
Applying KCL at Node A

$$I_1 = I_2$$
$$\frac{V_i - V_2}{R_1} = \frac{V_2 - V_o}{R_F}$$
$$\text{But } V_2 = 0$$
$$\frac{V_i}{R_1} = -\frac{V_o}{R_F}$$
$$\boxed{A_V = \frac{V_o}{V_i} = -\frac{R_F}{R_1}}$$

- The negative sign denotes a 180° phase difference between input and output.
- Gain can be set to any value by manipulating the value of R_F and R_1.

Ques2 : Explain the working of non inverting amplifier. Also derive the expression for output voltage. (2013-14, 2017-18)

Ans: Non inverting amplifier :



A non-inverting amplifier is an op-amp circuit design to provide positive voltage gain. The input is directly applied to non inverting terminal.

Expression for output voltage :

Here $V_1 = V_i$ ---- (1)

From concept of virtual ground

$$V_d = 0$$

$$V_1 - V_2 = 0$$

$$V_1 = V_2$$

But $V_1 = V_i$

So $V_2 = V_i$ ----- (2)

Applying KCL at Node A.

$$I_1 = I_2$$

$$\frac{0 - V_2}{R_1} = \frac{V_2 - V_o}{R_F}$$

But $V_2 = V_i$

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

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

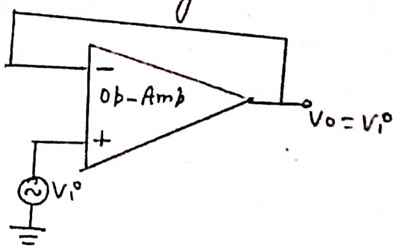
$$\frac{V_o}{V_i} = \frac{R_F}{R_F} + \frac{R_F}{R_1}$$

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

- The positive sign denotes that input and output are in same phase.
- Gain can be set to any value by manipulating the value of R_F and R_1.

Ques3 : Draw the circuit of op-amp as voltage follower and find the expression for voltage gain. (2016-17)

Ans: Voltage follower or unit gain : In voltage follower output voltage follows the input voltage i.e $V_o = V_i$. Closed loop voltage gain of this circuit is 1. It has high input impedance and low output impedance, so used for impedance matching..



$A_v = 1$ [requirement]

Gain of non inverting amplifier is given as :-

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

let $R_F = 0$ & $R_1 = \infty$

$$A_v = 1 + \frac{0}{\infty}$$

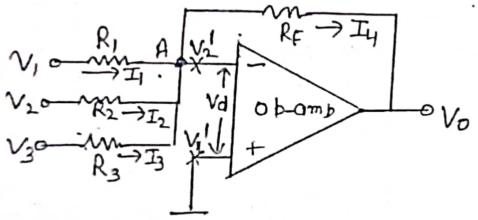
$\boxed{A_v = 1}$ [unity gain amplifier]

$$\frac{V_o}{V_P} = 1$$

$\boxed{V_o = V_P}$ [voltage follower]

Ques4 :- Explain summing or adder amplifier using ideal op-amp (2015-16).

Ans :- Summing amplifier :- summing amplifier is an op-amp circuit, which can accept two more inputs and produces output as the sum of these input.



Expression for output voltage :-

Here $V_1' = 0$ ---- 1

from concept of virtual ground

$V_d = 0$

B. Tech I Year [Subject Name: Electronics Engineering]

$$V_1' - V_2' = 0$$

$$V_1' = V_2'$$

but $V_2' = 0$

So $V_1' = 0$ ---- 2

Applying KCL at Node A

$$I_1 + I_2 + I_3 = I_4$$

$$\frac{V_1 - V_2'}{R_1} + \frac{V_2 - V_2'}{R_2} + \frac{V_3 - V_2'}{R_4} = \frac{V_2' - V_o}{R_F}$$

But $V_2' = 0$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = -\frac{V_o}{R_F}$$

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

a) If $R_1 = R_2 = R_3 = R$

then $V_o = -\frac{R_F}{R}[V_1 + V_2 + V_3]$

So ckt works as summing amplifier

b) If R_1, R_2, R_3

then $V_o = -[V_1 + V_2 + V_3]$

So ckt works as a summer ckt.

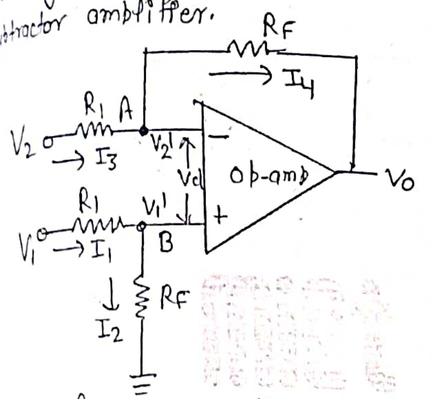
c) If $R_1 = R_2 = R_3 = 3R_F$

then $V_o = \frac{V_1 + V_2 + V_3}{3}$

So ckt works as an average circuit.

Ques 5: Draw and explain the difference amplifier. [2016-17].

Ans: Difference or subtractor amplifier: A circuit that amplifies the difference between two input signal is called difference amplifier or subtractor amplifier.



Expression for output voltage:

Applying KCL at Node B

$$I_1 = I_2$$

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

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

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

$$V_1' = \left(\frac{R_F}{R_1+R_F}\right) \cdot V_1 \quad ----1$$

from concept of virtual ground

$$V_d = 0$$

$$V_1' - V_2' = 0$$

$$V_1' = V_2' \quad -----2$$

Applying KCL at Node A

$$I_3 = I_4$$

$$\frac{V_2 - V_2'}{R_1} = \frac{V_2' - V_o}{R_F}$$

$$\frac{V_2}{R_1} - \frac{V_2'}{R_1} = \frac{V_2'}{R_F} - \frac{V_o}{R_F}$$

$$\frac{V_o}{R_F} = \frac{V_2'}{R_F} + \frac{V_2'}{R_1} - \frac{V_2}{R_1}$$

$$\frac{V_o}{R_F} = V_2'\left(\frac{R_1+R_F}{R_1 R_F}\right) - \frac{V_2}{R_1}$$

But $V_1' = V_2'$

$$\frac{V_o}{R_F} = \left(\frac{R_F}{R_1+R_F}\right) \cdot V_1 \left(\frac{R_1+R_F}{R_1 R_F}\right) - \frac{V_2}{R_1}$$

$$\boxed{V_o = \frac{R_F}{R_1}\left[V_1 - V_2\right]}$$

So ckt works as a difference amplifier or subtractor amplifier

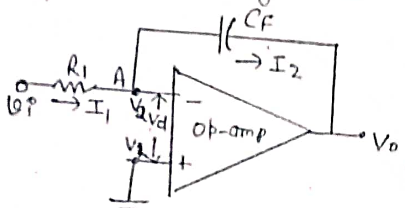
If $R_1 = R_F$

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

So ckt works as a difference or subtractor.

Ques:- 1 Draw the circuit of an integrator using op-amp and explain its working (2016-17, 2017-18).

Ans: Integrator :- A circuit that performs the integration of input signal is called integrator circuit.



Expression for output voltage :-

Here $V_1 = 0$ ---- 1

From concept of virtual ground -

$V_d = 0$

$V_1 - V_2 = 0$

$V_1 = V_2$

but $V_1 = 0$

so $V_2 = 0$ ---- 2

Applying KCL at Node A

$I_1 = I_2$

$$\frac{V_i - V_2}{R_1} = C_F \frac{d(V_2 - V_o)}{dt}$$

but $V_2 = 0$

$$\frac{v_i}{R_1} = \frac{C_F d(-V_o)}{dt}$$

$$dv_o = -\frac{1}{R_1 C} v_i dt$$

Now applying integration on both side

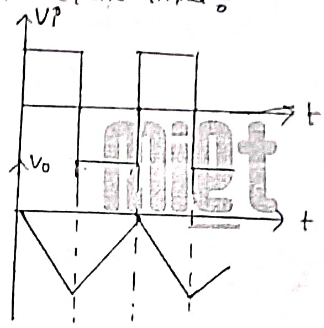
$$\int dV_o = \int -\frac{1}{R_1 C} v_i dt$$

$$V_o = -\frac{1}{R_1 C} \int_0^t v_i dt$$

$$V_o \propto \int_0^t v_i dt$$

Since output voltage is directly proportional to the integ[ration] of input signal, hence circuit is called integrator circuit.

Output wave for square input :-

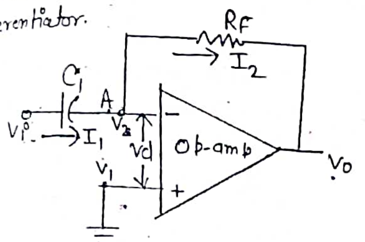


Application :-

- It is used for generating triangular wave.
- It is used in digital to analog convertor circuit.
- It is used as low pass filter.

Ques 2: Draw the circuit diagram of differentiator using op-amp and explain its working. (2015-16, 2017-18, 2020-21)

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



Expression for output voltage:

Here $V_1 = 0$ ---- 1

From concept of virtual ground

$V_d = 0$

$V_1 - V_2 = 0$

$V_1 = V_2$

but $V_1 = 0$

so $V_2 = 0$ ---- 2

Applying KCL at Node A

$I_1 = I_2$

$$C\frac{d(v_i - V_2)}{dt} = \frac{V_2 - V_o}{R_F}$$

but $V_2 = 0$

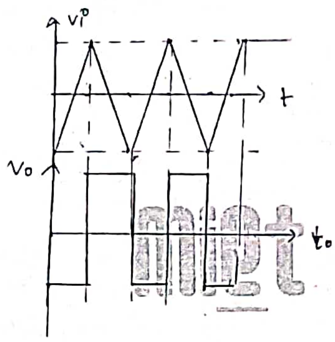
$$C\frac{dv_i}{dt} = -\frac{V_o}{R_F}$$

$$V_o = -R_F C\frac{dv_i}{dt}$$

$$V_o \propto \frac{dv_i}{dt}$$

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

Output for triangular input wave:



Application:

- It is used to generate square wave.
- It is also used in analog to digital convertor circuit.
- It is used as high pass filter.

Ques 3: Write short notes on comparator.

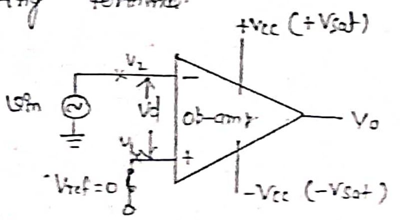
Ans: Comparator: Comparator is a circuit which compare signal voltage applied at one terminal of op-amp with reference voltage applied at another terminal. Comparator produce High (+Vsat) or low (-Vsat) output depending which input is higher. It is also called

Voltage comparator. Comparator are of two types.

(i) Inverting comparator (ii) Non-Inverting comparator

(i) Inverting comparator (inverting zero crossing detector):

In inverting comparator input is applied at inverting terminal and reference voltage is applied at non-inverting terminal.



Working principle:

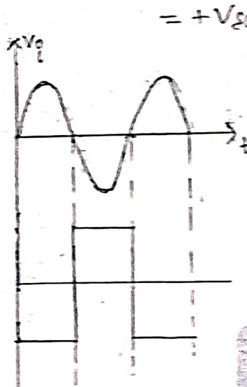
- During the positive half cycle of input signal, the voltage at the inverting terminal is greater than zero. So, output of the inverting comparator will be equal to $-V_{sat}$.

$$V_d = V_1 - V_2$$
$$= 0 - V_{in}$$
$$= -V_e$$
$$V_o = A_{OL} \times V_d$$
$$= -V_{sat}$$

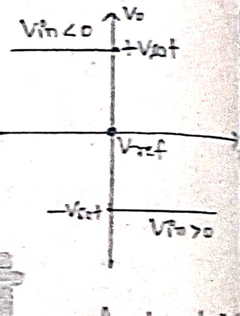
- During the negative half cycle of input signal, the voltage at the inverting terminal is less than zero. So, output of the inverting comparator will be equal to $+V_{sat}$.

$$V_d = V_1 - V_2$$

$$= 0 - (-V_{in})$$
$$= +V_e$$
$$V_o = A_{OL} \times V_d$$
$$= +V_{sat}$$

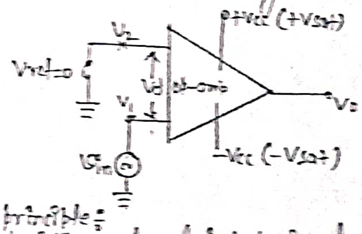


Input output characteristics



Transfer characteristics

(ii) Non inverting comparator: In non-inverting comparator input is applied at non inverting terminal and reference voltage is applied at inverting terminal.



Working principle:

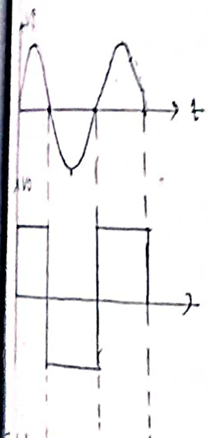
- During positive cycle of input signal the voltage at the non inverting terminal is greater than zero. So, the

...ut of the non-inverting comparator will be $+V_{sat}$

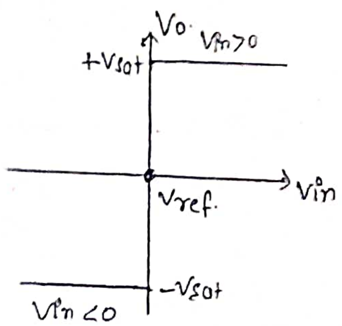
$V_d = V_1 - V_2$
$= V_{in} - 0$
$= +ve$
$V_o = A_{OL} \times V_d$
$= +V_{sat}$

During the negative half cycle of input signal the voltage present at the non inverting terminal is less than zero. So the output of non-inverting comparator will be $-V_{sat}$.

$V_d = V_1 - V_2$
$= -V_{in} - 0$
$= -ve$
$V_o = A_{OL} \times V_d$
$= -V_{sat}$



Input output characteristics



Transfer characteristics

Ques 1: An operational amplifier has a differential gain of 10^3 and CMRR of 100, input voltages are $120\,\mu V$ and $80\,\mu V$. Define the output voltage. (2017-18)

Ans:

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

$A_c = \frac{10^3}{100} = 10$

$V_o = A_d V_d + A_c V_c$

$= 10^3 (V_1 - V_2) + 10\left(\frac{V_1 + V_2}{2}\right)$

$= 10^3 (120 - 80) \times 10^{-6} + 10\left(\frac{120 + 80}{2}\right) \times 10^{-6}$

$= 40 \times 10^{-3} + 10^{-3}$

$= 41\,mV$

Ques-2 An operational amplifier has differential gain of 10^2 and CMRR of 80 dB. Input voltages are $100\,\mu V$ and $60\,\mu V$. Find output voltage. (2016-17).

Solⁿ:

$CMRR = 20 \log \left| \frac{A_d}{A_c} \right|$

$80 = 20 \log \left| \frac{10^2}{A_c} \right|$

$4 = \log \left| \frac{10^2}{A_c} \right|$

Taking antilog we get

$10^4 = 10^2 / A_c$

$A_c = 10^{-2}$

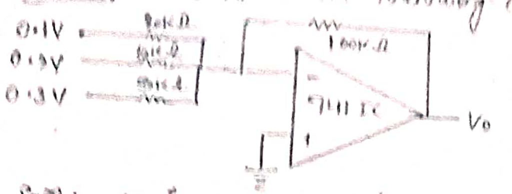
$V_o = A_d V_d + A_c V_c = A_d (V_1 - V_2) + A_c \left(\frac{V_1 + V_2}{2}\right)$

$= 10^2 (100 - 60) \times 10^{-6} + 10^{-2}\left(\frac{100 + 60}{2}\right) \times 10^{-6}$

$= 10^2 \times 40 \times 10^{-6} + 80 \times 10^{-8}$

$\simeq 4\,mV$

Ques 3: Find V_0 for the following circuit (2009-10, 2018-19).



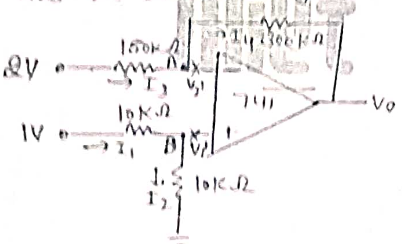
Soln: It is adder amplifier circuit.

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

$$= -\left[\frac{100}{20}\times 0.1 + \frac{100}{10}\times 0.2 + \frac{100}{50}\times 0.3\right]$$

$$= -3.1\,V$$

Ques 4. Find the output voltage for the following circuit (2017-18).



Soln: Let voltage at Node B is V_1'

Applying KCL at Node B

$$I_1 = I_2$$

$$\frac{1 - V_1'}{10} = \frac{V_1' - 0}{10}$$

$$V_1' = 0.5\,V$$

From concept of virtual ground voltage at node A is 0.5V

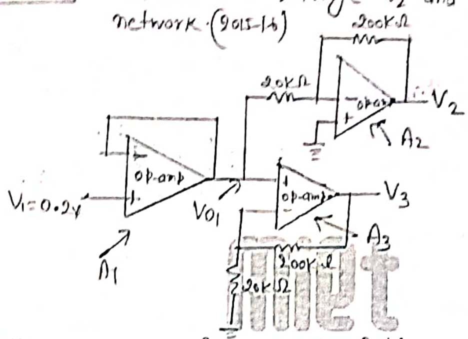
Now Applying KCL at node A

$$\frac{2 - 0.5}{150} = \frac{.5 - V_0}{300}$$

$$1.5 = \frac{.5 - V_0}{2}$$

$$V_0 = -2.5\,V$$

Ques: 5 Find out the voltage V_2 and V_3 of the given network (2015-16)



Soln: op-amp A_1 is voltage follower so

$$V_{01} = V_{in} = 0.2V$$

op-amp A_2 is inverting amplifier.

So $V_2 = -\frac{R_F}{R_1}\times V_P$

$$= -\frac{200}{20}\times 0.2V$$

$$V_2 = -2V$$

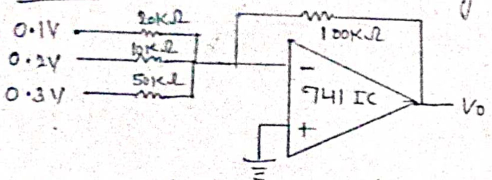
op-amp A_3 is non-inverting Amplifier

So $V_2 = \left(1 + \frac{R_F}{R_1}\right)\cdot V_P$

$$= \left(1 + \frac{200}{20}\right)\times 0.2V$$

$$V_2 = 2.2V$$

Ques 3: Find Vo for the following circuit (2009-10, 2018-19).



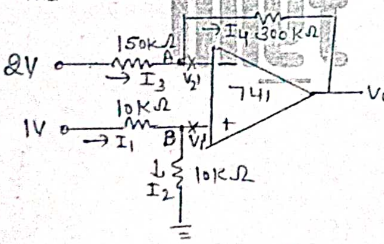
Solⁿ: It is adder amplifier circuit.

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

$$= -\left[\frac{100}{20}\times 0.1 + \frac{100}{10}\times 0.2 + \frac{100}{50}\times 0.3\right]$$

$$= -3.1\,V$$

Ques 4 Find the output voltage for the following circuit (2017-18).



Solⁿ: Let voltage at Node B is V_1'.
Applying KCL at Node B

$$I_1 = I_2$$

$$\frac{1-V_1'}{10} = \frac{V_1'-0}{10}$$

$$V_1' = 0.5V$$

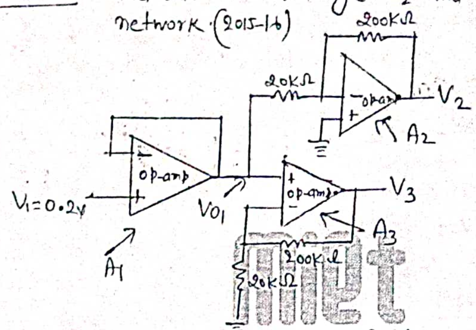
From concept of virtual ground voltage at node A is 0.5V
Now Applying KCL at node A

$$\frac{2-0.5}{150} = \frac{.5-V_o}{300}$$

$$1.5 = \frac{.5-V_o}{2}$$

$$V_o = -2.5V$$

Ques: 5 Find out the voltage V_2 and V_3 of the given network (2015-16)



Solⁿ: op-amp A_1 is voltage follower so

$$V_{01} = V_{in}$$
$$= 0.2V$$

op-amp A_2 is inverting amplifier.

So $$V_2 = -\frac{R_F}{R_1}\times V_P$$

$$= -\frac{200}{20}\times 0.2V$$

$$V_2 = -2V$$

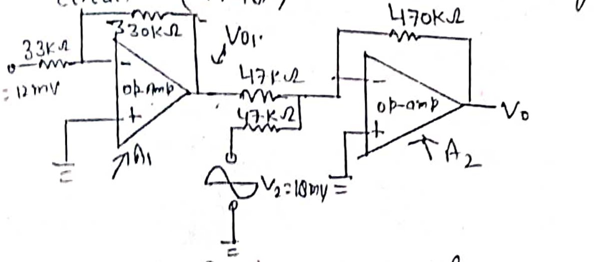
op-amp A_3 is non-inverting Amplifier

so $$V_2 = \left(1+\frac{R_F}{R_1}\right)\cdot V_P$$

$$= \left(1+\frac{200}{20}\right)\times 0.2V$$

$$V_2 = 2.2V$$

Ques 6 ÷ Find the output voltage for the following circuit. (2017-18)



Soln ÷ op-amp A_1 is inverting amplifier. so output of op-Amp A_1 is

$$V_{01} = -\left(\frac{R_F}{R_1}\right) \times V_P$$

$$= \frac{330}{33} \times 12mV$$

$$= -120mV$$

op-amp A_2 is adder circuit. so output of op-amp A_2 is

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

$$= -\left[\frac{470}{47} \times (-120mV) + \frac{470}{47} \times 10mV\right]$$

$$= -[-1200mV + 100mV]$$

$$= 1020mV$$

$$= 1.02V$$

Ques 7 ÷ for an op-amp having a slew rate of $2.4V/\mu s$, what is the maximum closed loop voltage gain that can be used when the input signal varies [illegible] in $10\mu s$. (2014-15)

Soln ÷ given $\Delta t = 10\mu s = 10 \times 10^{-6} s$

$$SR = 2.4V/\mu s = 2.4 \times 10^6 V/s$$

Now $SR = \frac{\Delta V_0}{\Delta t}$

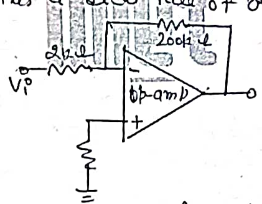
but $\Delta V_0 = A_{CL} \times \Delta V_P$

So $SR = \frac{A_{CL} \times \Delta V_P}{\Delta t}$

$$2.4 \times 10^6 = \frac{A_{CL} \times 0.3}{10 \times 10^{-6}}$$

$$A_{CL} = 80$$

Ques 8 ÷ for an input of $V_i = 50mV$ in the given circuit, determine the maximum frequency that can be used. The op-amp has a slew rate of $0.4V/\mu s$. (2018-19).



Soln ÷ given $V_i = 50mV$, $SR = 0.4V/\mu s$
$= 0.4 \times 10^6 V/s$

Now $V_0 = -\frac{R_F}{R_1} \times V_P = -\frac{200}{2} \times 50 \times 10^{-3} = -5V$

So $V_m = 5V$ (maximum voltage at o/p)

$$f_{max} = \frac{SR}{2\pi V_m} = \frac{0.4 \times 10^6}{2\pi \times 5}$$

$$f_{max} = 12.732 \text{ KHz}$$

Q. Determine the output voltage of an OP-Amp for the input voltage of $V_1 = 150\mu V$ and $V_2 = 140\mu V$. The amplifier has differential gain $A_d = 4000$ and CMRR is 100. (2021-22 odd)

Sol:- Given:- $V_1 = 150\mu V$ $\quad A_d = 4000$

$V_2 = 140\mu V$ $\quad CMRR = 100$

We know that, $CMRR = \frac{A_d}{A_c} \Rightarrow A_c = \frac{A_d}{CMRR} = \frac{4000}{100} = 40 \Rightarrow \boxed{A_c = 40}$

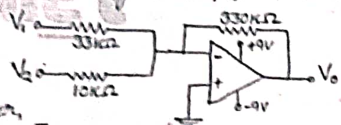
$V_d = V_1 - V_2$
$= 150 - 140 = 10\mu V$

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

Now, $V_o = A_d.V_d + A_c.V_c$
$= (4000).(10\mu V) + (40).(145\mu V)$
$= 40{,}000\mu V + 5800\mu V$
$= 45800\mu V$

$\boxed{V_o = 45.8mV}$ Ans.

Q. Determine the output of the following circuit. (2021-21 odd)
Given $V_1 = V_2 = 0.15V$



Sol:- It is an example of inverting summer amplifier,

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

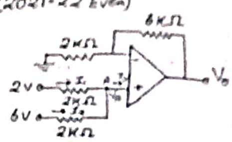
$= \left(-\frac{R_f}{R_1}\right)V_1 + \left(-\frac{R_f}{R_2}\right).V_2$

$= -\frac{330K\Omega}{33K\Omega} \times 0.15V - \frac{330K\Omega}{10K\Omega} \times 0.15$

$= -1.5V - 4.95V$

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

Q. Explain the concept of Virtual ground in OP-Amp. Determine output Voltage for given network. (2021-22 Even)



Sol:- Apply KCL at node A

$\frac{2V - V_A}{2K\Omega} + \frac{6V - V_A}{2K\Omega} = 0$

$2V - V_A + 6V - V_A = 0$

$2V_A = 8V \Rightarrow \boxed{V_A = 4V}$

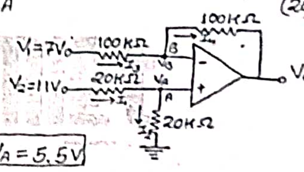
Now, $V_o = \left(1 + \frac{R_f}{R_1}\right).V_A = \left(1 + \frac{6K\Omega}{2K\Omega}\right).4V = 4 \times 4V = 16V$

$\boxed{V_o = 16V}$ Ans.

Q. Determine the output Voltage of following Circuit. (2021-22 Even)

Sol:- Apply KCL at node-A

$I_1 = I_2$



$\frac{11V - V_A}{20K\Omega} = \frac{V_A - 0}{20K\Omega}$

$11V - V_A = V_A$

$2V_A = 11V \Rightarrow \boxed{V_A = 5.5V}$

Now due to Virtual ground

$V_A = V_B = 5.5V$

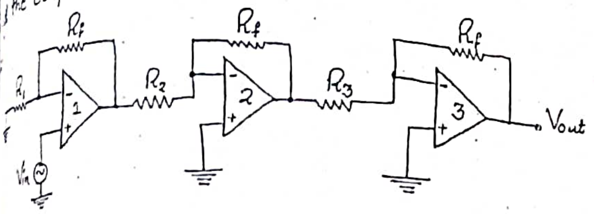
Apply KCL at node-B

$\frac{7V - 5.5V}{100K\Omega} = \frac{5.5V - V_o}{100K\Omega}$

$1.5V = 5.5V - V_o$

$\boxed{V_o = 4V}$ Ans.

...e shows the multi-stage OP-Amp Circuit. The resistor ...s are: $R_f = 470K\Omega$; $R_1 = 4.3K\Omega$; $R_2 = 33K\Omega$ and $R_3 = 33K\Omega$. ... the output voltage for an input of $80\mu V$.



...:- $R_f = 470K\Omega$
$R_1 = 4.3K\Omega$ $\quad V_{in} = 80\mu V$
$R_2 = 33K\Omega$
$R_3 = 33K\Omega$

...ge gain of first stage, $A_1 = 1 + (R_f/R_1) = 1 + \left(\frac{470K\Omega}{4.3K\Omega}\right) = 110.3$

...ge gain of second stage, $A_2 = -R_f/R_2 = -\frac{470K\Omega}{33K\Omega} = -14.2$

...ge gain of third stage, $A_3 = -R_f/R_3 = -\frac{470K\Omega}{33K\Omega} = -14.2$

$\therefore$ Overall Voltage gain, $A = A_1 . A_2 . A_3 = (110.3)\times(-14.2)\times(-14.2) = 22240.89$

Output Voltage, $V_{out} = A \times V_{in} = 22240.89 \times 80\mu V = 1.78V$

$\boxed{V_{out} = 1.78V}$ Ans

Q. Two voltages of +0.6V and -1.4V are applied to the two input ...tions of a Summing amplifier. The respective input resistors ...e 400KΩ and 100KΩ and feedback resistor is 200KΩ. Determine ...e output voltage.

Sol:- The output voltage of the summing amplifier is given by:

$$V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)$$

Here $R_f = 200K\Omega$, $R_1 = 400K\Omega$, $R_2 = 100K\Omega$, $V_1 = +0.6V$, $V_2 = -1.4V$

$$V_{out} = -200K\Omega\left(\frac{0.6}{400K\Omega} + \frac{-1.4}{100K\Omega}\right) = 2.5V$$

$\boxed{V_{out} = 2.5V}$ Ans

Q. A differential amplifier has an output of 1V with a differential input of 10mV and an output of 5mV with a Common-mode input of 10mV. Find the CMRR in dB.

Sol:- Differential gain, $A_{DM} = \frac{1V}{10mV} = 100$

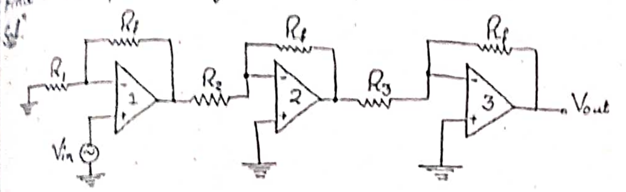
Common-mode gain, $A_{CM} = \frac{5mV}{10mV} = 0.5$

$CMRR_{dB} = 20\log_{10}(100/0.5) = 46dB$

$\boxed{CMRR_{dB} = 46dB}$ Ans.

Q/. Figure shows the multi-stage OP-Amp Circuit. The resistor values are: $R_f = 470K\Omega$; $R_1 = 4.3K\Omega$; $R_2 = 33K\Omega$ and $R_3 = 33K\Omega$. Find the output voltage for an input of $80\mu V$.

Sol:



Given:- $R_f = 470K\Omega$
$R_1 = 4.3K\Omega$ $\quad V_{in} = 80\mu V$
$R_2 = 33K\Omega$
$R_3 = 33K\Omega$

Voltage gain of first stage, $A_1 = 1 + (R_f/R_1) = 1 + \left(\frac{470K\Omega}{4.3K\Omega}\right) = 110.3$

Voltage gain of Second Stage, $A_2 = -R_f/R_2 = -\frac{470K\Omega}{33K\Omega} = -14.2$

Voltage gain of third Stage, $A_3 = -R_f/R_3 = -\frac{470K\Omega}{33K\Omega} = -14.2$

$\therefore$ Overall Voltage gain, $A = A_1.A_2.A_3 = (110.3)\times(-14.2)\times(-14.2) = 22240.89$

Output Voltage, $V_{out} = A \times V_{in} = 22240.89 \times 80\mu V = 1.78V$

$\boxed{V_{out} = 1.78V}$ Ans.

Q/. Two voltages of +0.6V and -1.4V are applied to the two input resistors of a Summing amplifier. The respective input resistors are $400K\Omega$ and $100K\Omega$ and feedback resistor is $200K\Omega$. Determine the output voltage.

Sol:- The output voltage of the Summing amplifier is given by:

$$V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)$$

Here $R_f = 200K\Omega$, $R_1 = 400K\Omega$, $R_2 = 100K\Omega$, $V_1 = +0.6V$, $V_2 = -1.4V$

$$V_{out} = -200K\Omega\left(\frac{0.6}{400K\Omega} + \frac{-1.4}{100K\Omega}\right) = 2.5V$$

$\boxed{V_{out} = 2.5V}$ Ans

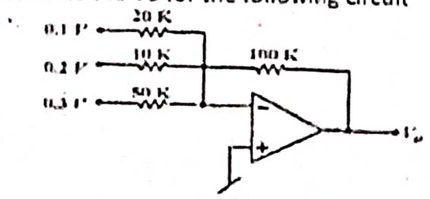
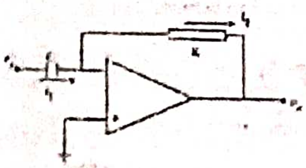
Q/. A differential amplifier has an output of 1V with a differential input of 10mV and an output of 5mV with a Common-mode input of 10mV. Find the CMRR in dB.

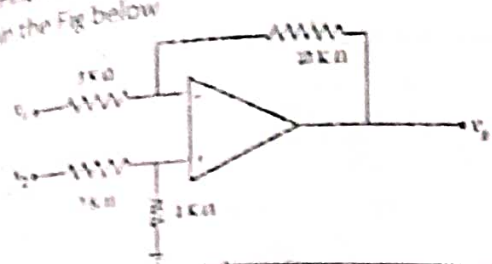
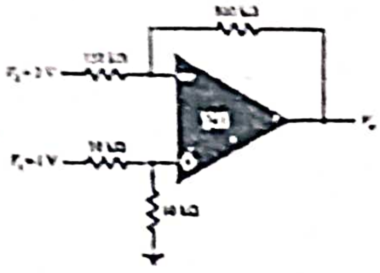
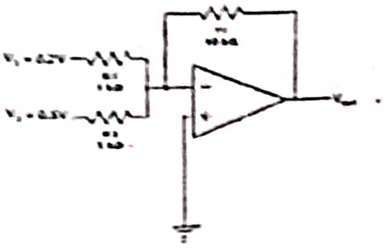
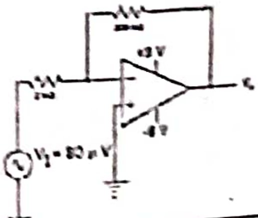
Sol:- Differential gain, $A_{DM} = \frac{1V}{10mV} = 100$

Common-mode gain, $A_{CM} = \frac{5mV}{10mV} = 0.5$

$$CMRR_{dB} = 20\log_{10}(100/0.5) = 46dB$$

$\boxed{CMRR_{dB} = 46dB}$ Ans.

5 Years AKTU University Examination Questions		Unit-3	
S. No	Questions	Session	Lecture No
1.	What is an op amp ? How it is used as an integrator and summer ?	2009-10(2)	22-27
2	Enlist the Characteristics of an ideal op amp. Draw the subtractor using op-amp and explain its working	2009-10(1)	22-27
3	(i)What is an operational amplifier? Draw its block diagram. Write the characteristics of an ideal operational amplifier. (ii) With help of the circuit diagram, explain the working of OPAMP as differentiator	2020-21(1) 2019-20(1)	22-27
4	Enlist the characteristics of an ideal OPAMP.	2013-14(1)	22-27
5	Draw the circuit diagram for unity gain amplifier. Where is it used and why ?	2009-10(2)	22-27
6	Write short note on Non Inverting Amplifier	2013-14(1) 2014-15(1)	22-27
7	Draw the circuit of subtractor using op Amp and explain its working . Also obtain expression for its output	2019-20(1) 2014-15(1)	22-27
8	Draw the circuit of integrator using op Amp and explain its working . Also obtain expression for its output .	2019-20(1) 2017-18(2)	22-27
9	Draw te op-amp based circuit to give: Vo= V1 + V2 + V3	2009-10(1)	22-27
10	Determine the Vo for the following circuit 	2009-10(1)	22-27
11	An ideal operational amplifier is used to make an inverting amplifier. There are two input terminals of the operational amplifier and are at the same potential because: (a) The two inputs are directly short circuited internally (b) The the resistance of operational amplifier is infinity (c) The open loop gain of the operational amplifier is unity (d) All the above except option (a)	2009-10(1)	22-27
12	For the circuit shown in the Fig . The output voltage V_o is given by  Figure-1 (i) $v_0 = -\frac{1}{RC}\frac{dv_i(t)}{dt}$ (ii) $v_0 = -\frac{1}{RC}\int_0^t v_i(t)\,dt$ (iii) $v_0 = -RC\frac{dv_i(t)}{dt}$ (iv) $v_0 = -RC\int_0^t v_i(t)\,dt$	2009-10(2)	22-27

13	Find the output voltage of the following op-amp circuit shown in the Fig below 	2009-10(2)	22-27
14	The output voltage in op amp differentiator with input voltage Vi the output voltage is given by ....when R=1k and C=1pf	2010-11(2)	22-27
15	A sinusoidal signal with peak value 6 mV and 2 KHz frequency is applied to the input of an ideal OP-AMP Integrator with R_{in} = 100K ohm and C_f = 1μF. Find the output voltage	2010-11(2)	22-27
16	(i) Determine the output voltage of an op-amp for input voltages of V_{i1}= 100V and V_{i2} = 120V. The amplifier has a differential gain of A_d= 4000 and the value of CMRR is: (a) 150 (b) 10^3 (ii) Find V_o for the circuit shown below in Figure6  Figure 6	2015-16(1)	22-27
17	Determine the output for the following circuits : (i)  (ii) 	2020-21(1)	22-27
18	(i) What do you mean by IOT? Discuss its various components. (ii) Define the following terms: (1) CMRR (2) Peak Inverse Voltage	2020-21(1)	22-27
19	State the basic difference between Bluetooth and Wi-Fi technology	2020-21(1)	22-27