Lecture 22

Introduction of Op-Amp: Block diagram, Differential and Common mode operation

Introduction of Operational Amplifier

- This term is used by John R. Ragazzini in 1947.
- Op-Amp performs a variety of operations such as amplifications, addition, subtraction, differentiation and integration.
- Op-Amp is a multistage amplifier which uses a number of differential amplifier stages interconnected to each other in a complicated manner.
- These internal differential amplifiers use BJT (Bipolar Junction Transistor) or FET (Field Effect Transistor) as an amplifying device.

- Differential amplifier is the combination of two BJT in CE (common emitter) mode configuration or two FET in CS (common source) mode configuration.

- Space occupied to a pin-head.

- Op-Amp offers all the advantages of monolithic IC's such as small size, high reliability, reduced cost, less power consumption.

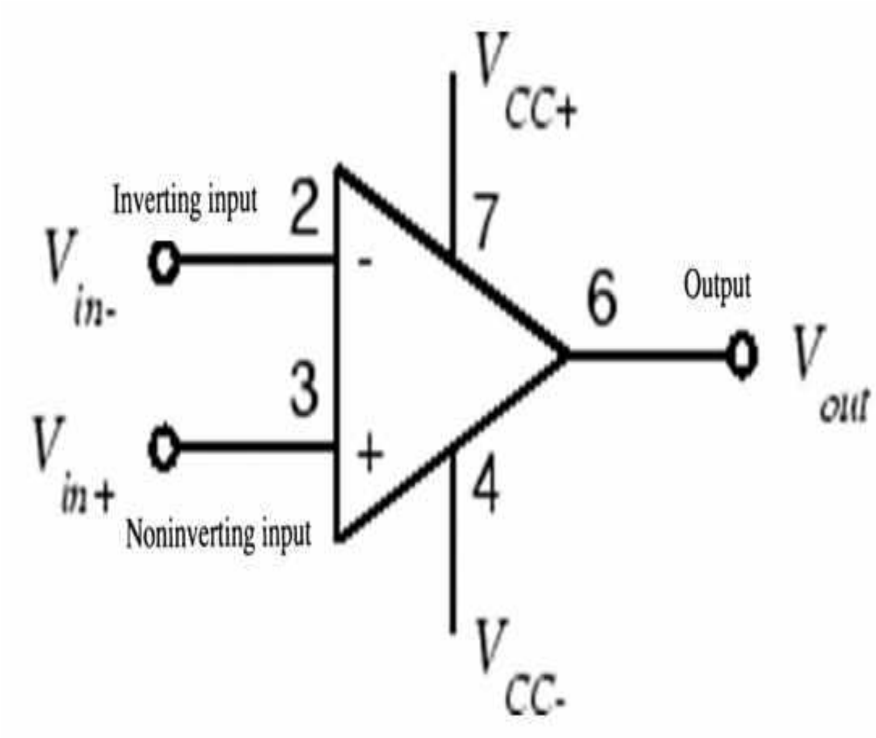
- Op-Amp brought in the market by the "Fair Child" company named as µA741

What is Operational Amplifier ?

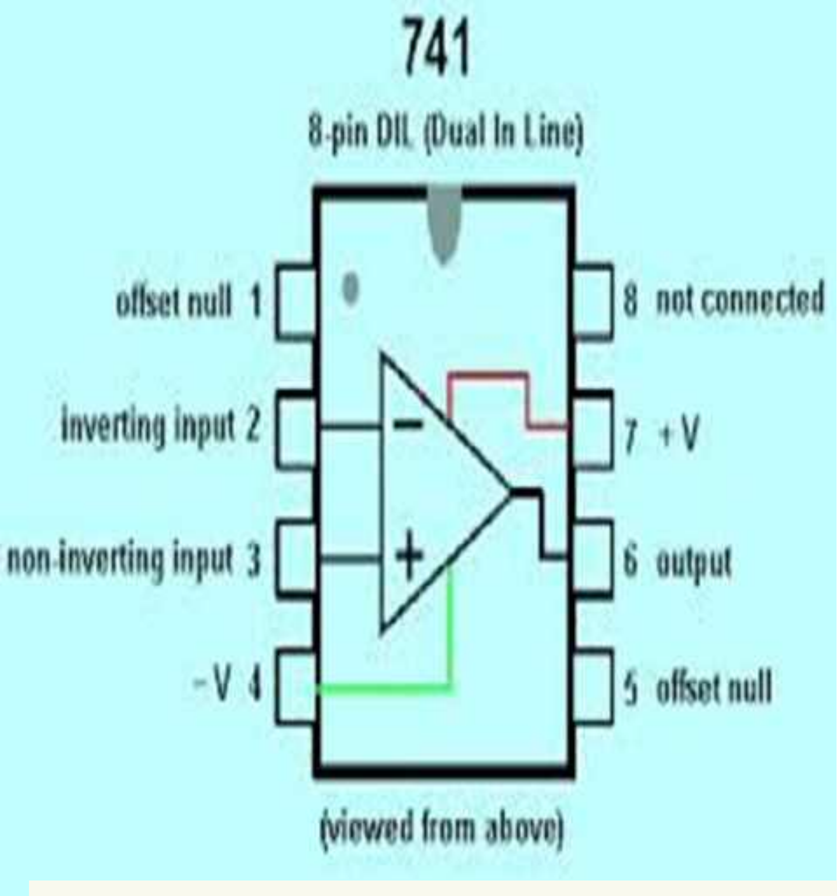
- A direct coupled high gain amplifier which can be used to amplify ac as well as dc input signals.

- It is mainly used for mathematical operation like addition, subtraction, integration, differentiation etc. and hence named as operational amplifier.

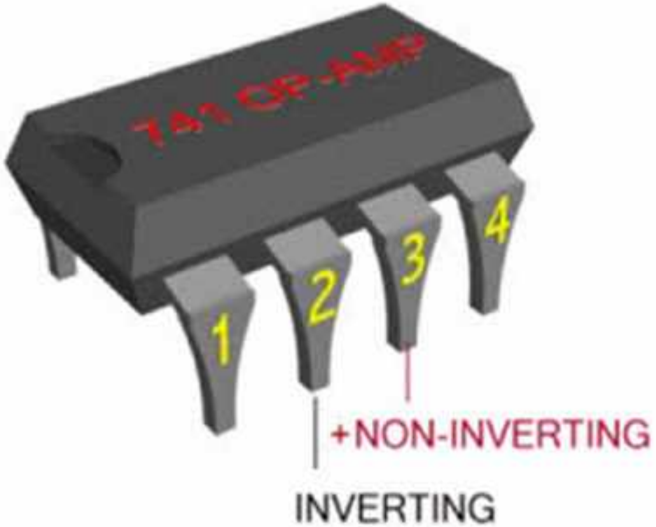
Schematic diagram of Op-Amp(Symbol)

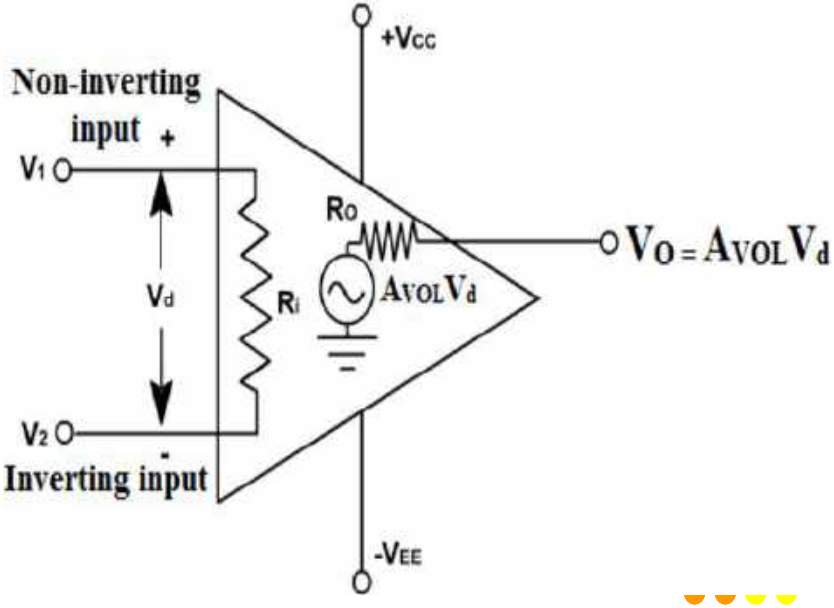


Pin Diagram and Equivalent Circuit of Op-Amp

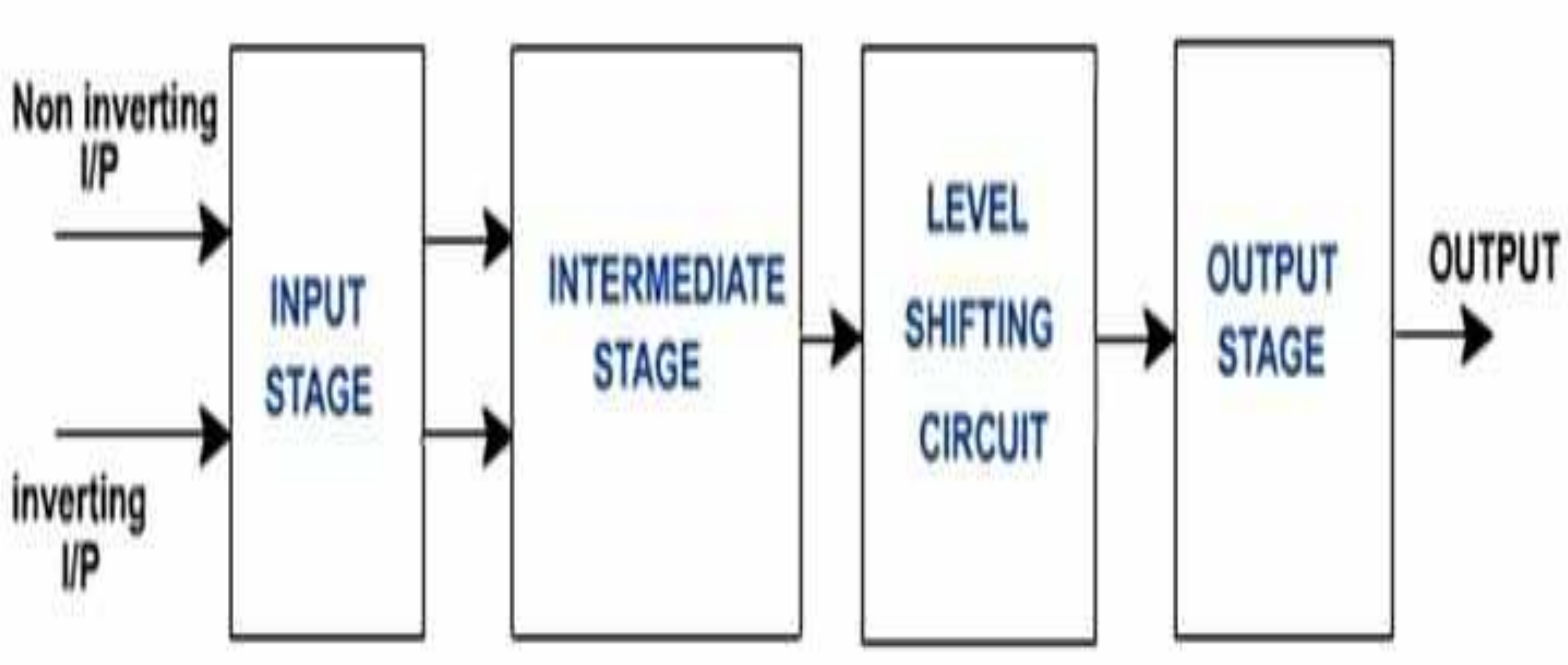


** For Offset null we use 10kΩ resistance (as a potentiometer) between pin no. 1 & 5.





BLOCK DIAGRAM OF OP-AMP



Input stage:

- It consists of a dual input, balanced output differential amplifier.
- Its function is to amplify the difference between the two input signals.
- It provides high differential gain, high input impedance and low output impedance.
- It consists of another differential amplifier with dual input, and unbalanced (single ended) output.

Intermediate stage:

The overall gain requirement of an Op-Amp is very high. Since the input stage alone cannot provide such a high gain.

Intermediate stage is used to provide the required additional voltage gain.

Buffer and Level shifting stage:

As the Op-Amp amplifies D.C signals also, the small D.C. quiescent voltage level of previous stages may get amplified and get applied as the input to the next stage causing distortion the final output.
Hence the level shifting stage is used to bring down the D.C. level to ground potential, when no signal is applied at the input terminals. Buffer is usually an emitter follower used for impedance matching.

- **Output stage:**

  It consists of a push-pull complementary amplifier which provides large A.C. output voltage swing and high current sourcing and sinking along with low output impedance.

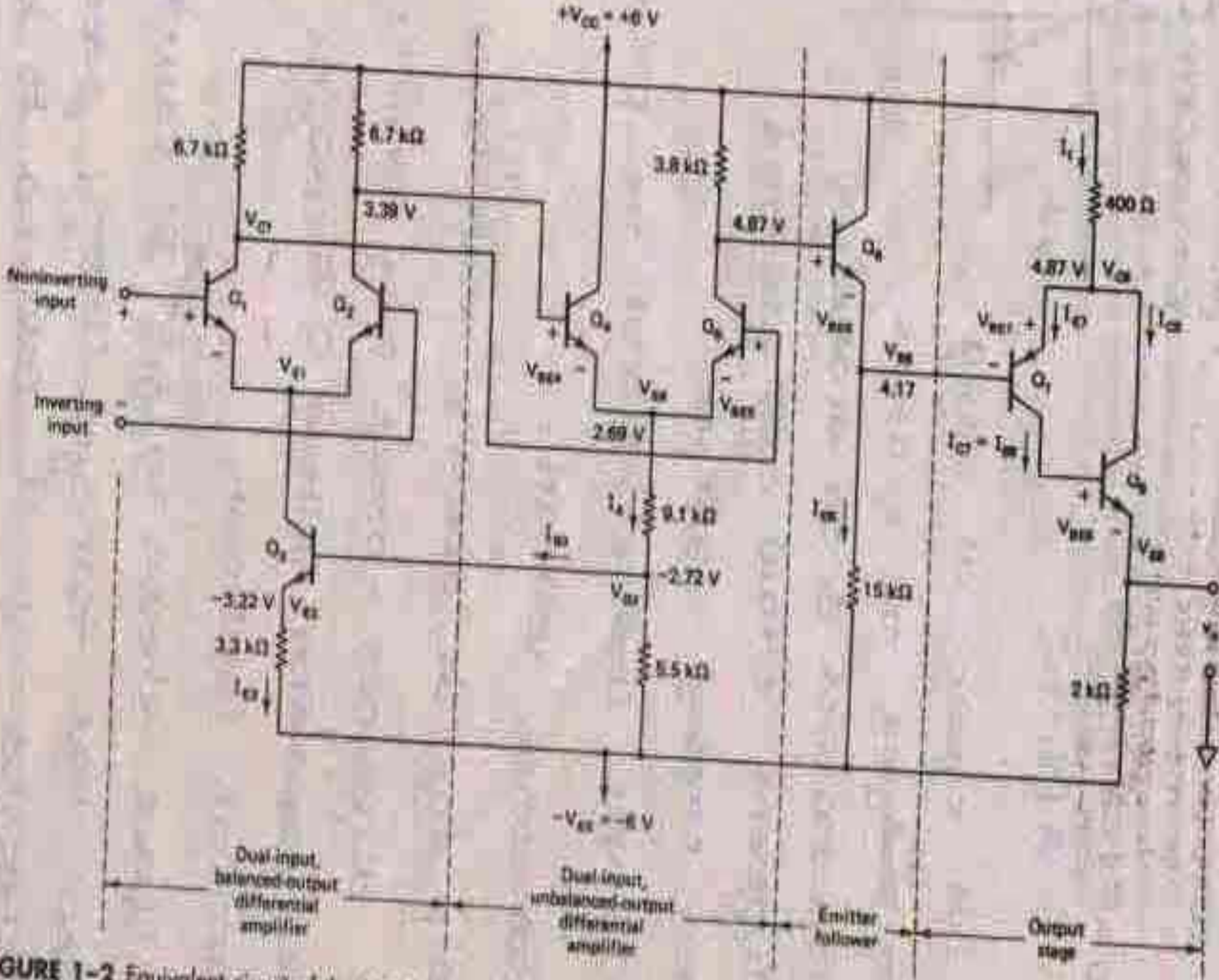
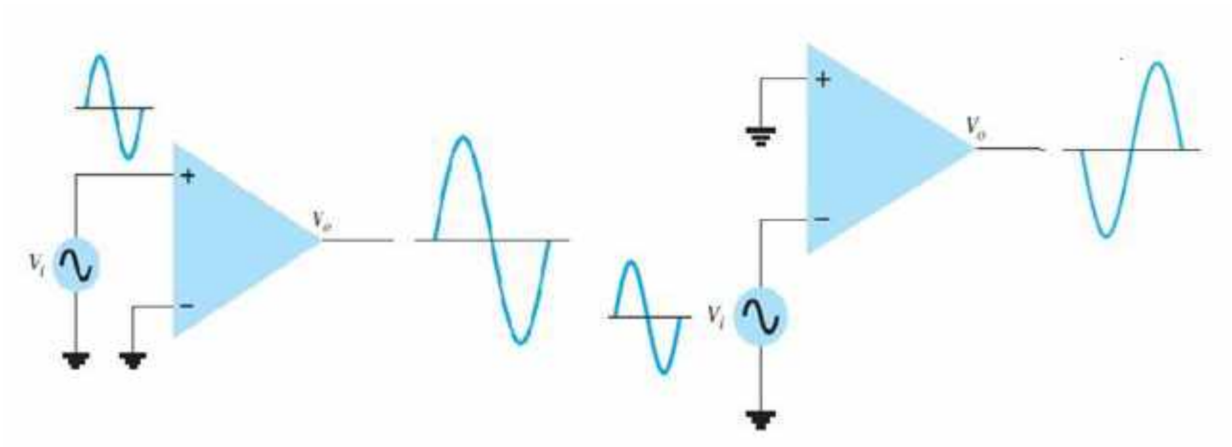


FIGURE 1-2 Equivalent circuit of the MC 1435 op-amp. (Courtesy of Motorola Semiconductor, Inc.)

Mode of Operation (Open Loop)

Single Ended Input



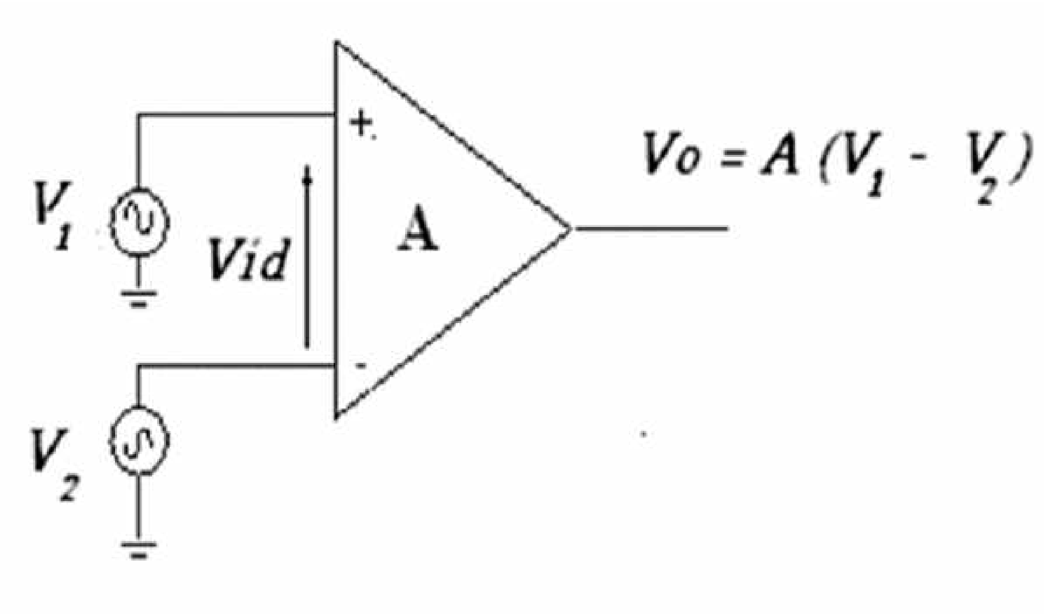
$$V_0 = A \, X \, V_i$$

Non- Inverting Input **Inverting Input**

Single-ended input operation results when the input signal is connected to one input
with the other input connected to ground.

Mode of Operation (Open Loop)

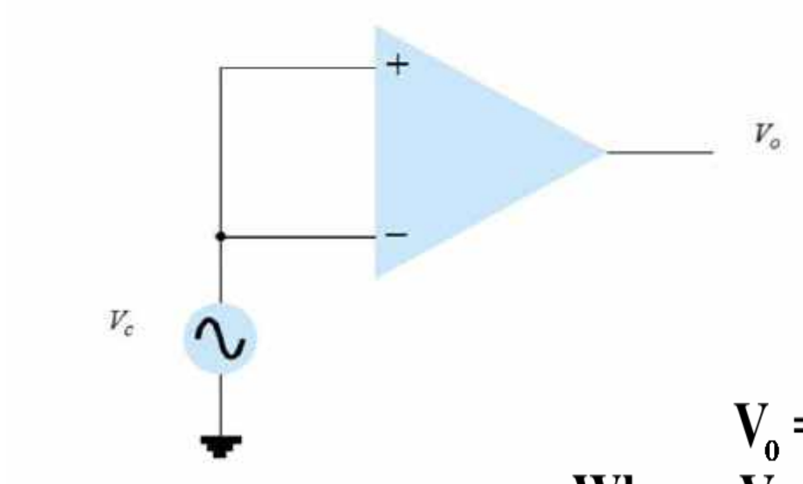
Double- Ended (Differential) Input



In addition to using only one input, it is possible to apply signals at each input—this being a double-ended operation

Mode of Operation (Open Loop)

Common Mode



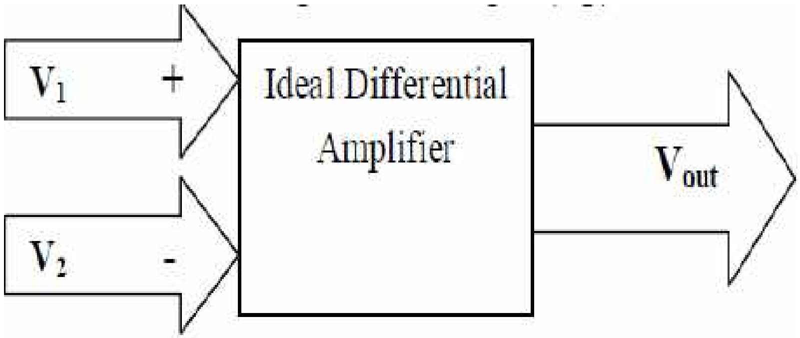
$$V_0 = A_c V_c$$

$$\text{Where; } V_c = (V_1 + V_2) / 2$$

When the same input signals are applied to both inputs, common mode operation results.

Differential Amplifier

- A differential amplifier amplifies the difference between two input voltage signals.



For an ideal differential amplifier;

$$V_{out} \propto (V_1 - V_2)$$

Differential Gain (A_d): We can write above equation as;

$$V_{out} = A_d (V_1 - V_2) \text{ or}$$

$$V_{out} = A_d V_d$$

Where;

A_d = Differential Gain

V_d = Difference in input voltage

We can write;

$$A_d = \frac{V_{out}}{V_d} \quad \textbf{OR} \quad A_d = 20\log\left(\frac{V_{out}}{V_d}\right) \text{ dB}$$

(dB - decibel)

Differential Amplifier (continue…

- **Common Mode Gain (A_{cm} or A_c):**

- If $V_1 = V_2$ then ideally $V_{out} = 0$.
- But practically we get some value of V_{out} because of noise and mismatch in internal circuitry.
- That means the output of practical amplifier not only depends on difference voltage but also depends on the average common level of two inputs. Such signals is called as common mode signal (V_{cm} or V_c) and given as;

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

Differential Amplifier (continue…

- Therefore here;

$$V_{out} \alpha V_{cm}$$

OR

$$V_{out} = A_{cm} V_{cm}$$

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

Where;
A_{cm} = Common Mode Gain
V_{cm} = Common Mode signal

- **Therefore; the total output of any differential amplifier can be expressed as;**

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

It is preferrred in differential mode as it gives high gain.

- Here; A_d is very large and A_{cm} is very small.

Lecture 23

Ideal and practical Parameters

of

OP-Amp

OP-Amp Parameters

- An Op-Amp is a wide-bandwidth amplifier. The following factors affect the bandwidth of the Op-Amp:

- CMRR (Common Mode Rejection Ratio)
- Slew rate
- Open loop Gain
- BandWidth

OP-Amp Parameters continue…

- Input Offset Voltage
- Input Offset Current
- Input Bias Current
- Input Impedance
- Output Impedance

Common Mode Rejection Ratio(CMRR)

It is the ability of a Differential Amplifier (Op-Amp) to reject the common mode signals successfully and defined as the ratio of Differential mode gain and Common mode gain.

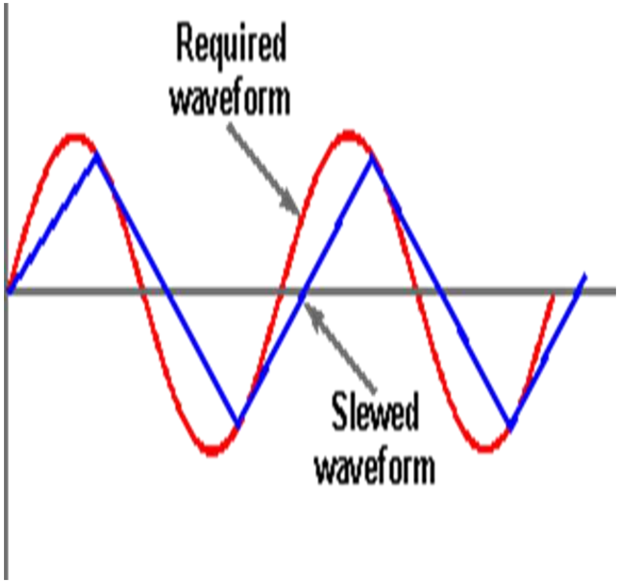
$$\mathrm{CMRR} = \left|\frac{A_d}{A_c}\right| \quad \textbf{OR} \quad \mathrm{CMRR(dB)} = 20\log\left|\frac{A_d}{A_c}\right|$$

- For ideal op-amp, CMRR is infinite
- For practical op-amp,CMRR is 90db.

miet

GROUP OF INSTITUTIONS

• It is also defined as the maximum rate at which an Op-Amp can change output without distortion and expressed in Volt per microsecond.



Maximum Signal Frequency

Let Output voltage of op-amp $V_O = V_m \sin \omega t$

$$\frac{dV_O}{dt} = V_m(\omega \cos \omega t)$$

$$\left(\frac{dV_O}{dt}\right)_{max} = \omega Vm = 2\pi f Vm \ldots .1$$

Now for proper amplification of input signal

$$SR \geq \left(\frac{dV_O}{dt}\right)_{max}$$

$$SR \geq 2\pi f Vm$$

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

Or

$$f_{max} = \frac{SR}{2\pi Vm}$$

- **Open Loop Gain :**

It is the ratio of the output voltage and the differential input voltage.

A = Output voltage/Differential input= Vo/Vid

Bandwidth :

An ideal op amp has an infinite bandwidth that is it can amplify any signal from DC to the highest AC frequencies without any losses. So therefore, an ideal op amp is said to have infinite frequency response. In real op amps, the bandwidth is generally limited. The limit depends on the gain bandwidth (GB) product. GB is defined as the frequency where the amplifier gain becomes unity.

- Even when the input voltage is zero, an Op-Amp can have non zero output voltage called as output offset voltage. The following parameters can cause this offset

Input offset voltage (V_{IO}):

- In ideal op-amp, the output will be zero when both the input terminal is are grounded.

- An extra small amount of voltage is applied at any one of the input terminals to make output voltage zero.

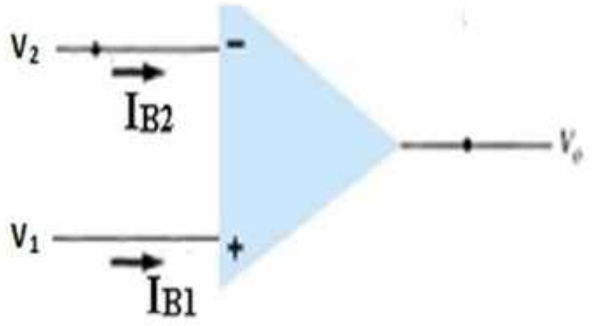
- This extra voltage is called input off set voltage.

- For ideal op-amp it is zero but for practical op-amp it is 2mv.

- For practical op-amp it is found that output is not zero if input is zero. This is due to imbalance present in the op-amp.

Input offset current (I_{IO}):

- The algebraic difference between the currents between 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.
- For ideal op-amp it is zero but for practical op-amp it is 20 nA..

$$I_{IO} = |I_{B1} - I_{B2}|$$

Input bias current(I_B)

- It is the average of the currents flowing in the input terminals of the Op-Amp.

- For ideal op-amp it is zero but for practical op-amp it is 80 nA..

$$\boxed{I_B = \frac{I_{B1} + I_{B2}}{2}}$$

Input Impedance Z_{IN}

- Input impedance is the ratio of input voltage to input current and is assumed to be infinite to prevent any current flowing from the source supply into the amplifiers input circuitry ($I_{IN} = 0$). Real op-amps have input leakage currents from a few pico-amps to a few milli-amps.

Output Impedance (Z_{OUT})

- The output impedance of the ideal operational amplifier is assumed to be zero acting as a perfect internal voltage source with no internal resistance so that it can supply as much current as necessary to the load. This internal resistance is effectively in series with the load thereby reducing the output voltage available to the load. Real op-amps have output impedances in the 100-20kΩ range.

IDEAL OP-AMP CHARACTERISTICS

- Infinite Open Loop gain
- Infinite input impedance
- Zero output impedance
- Infinitely fast (infinite bandwidth)

IDEAL OP-AMP CHARACTERISTICS continue…

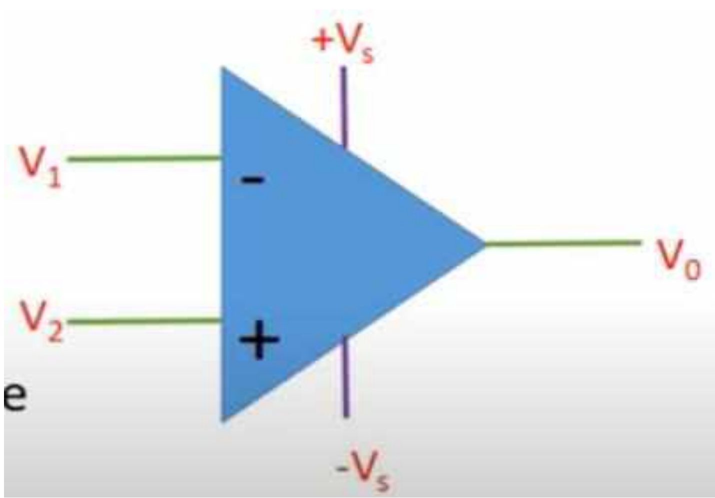
- Infinite CMRR
- Infinite Slew Rate
- Zero input offset voltage
- Zero Input offset Current
- Zero Input Bias Current

Lecture 24

Non-inverting and Inverting OPAMP,

OPAMP as an adder, subtractor

Concept of Virtual Short

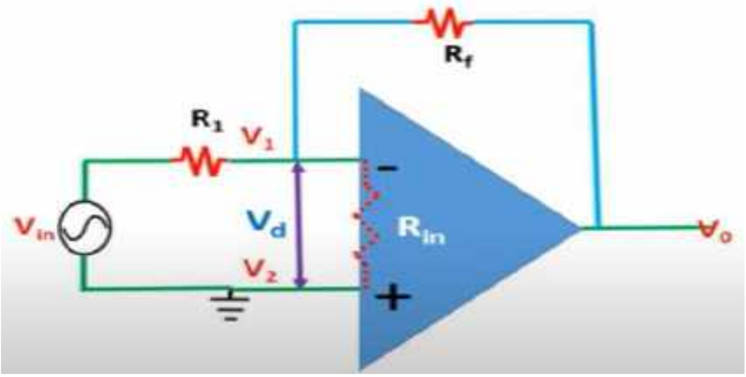


- According to virtual short concept the potential difference between the two input terminals of an opamp is almost equal to zero

$V_2 – V_1 = 0$

- That means the both the input terminals are at approximately at same potential

$v_1 = v_2 = 0$



Proof

R_{in} = ∞ means open circuit

$I_{b1} = I_{b2} = 0$

$I_{in} = 0$

Drop across input resistance is equal to zero

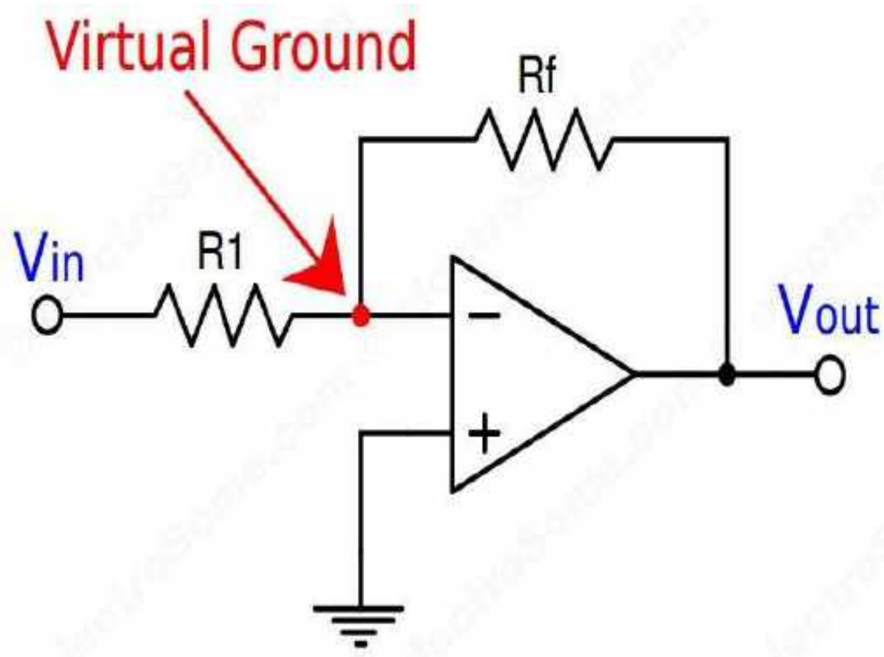
$V_d = I_{in} \times R_{in} = 0 \times \infty = 0$

$V_d = V_2 - V_1 = 0$

$V_1 - V_2 = 0$

Pot. at 1=Pot. At 2. it is virtually short Hence, current in-to Op-Amp is always zero.

Concept of Virtual Ground



For the Op-Amp, we know that; Gain,

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

$$V_d = V_1 - V_2$$

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

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

$$V_1 - V_2 = \frac{V_o}{\infty} = 0$$

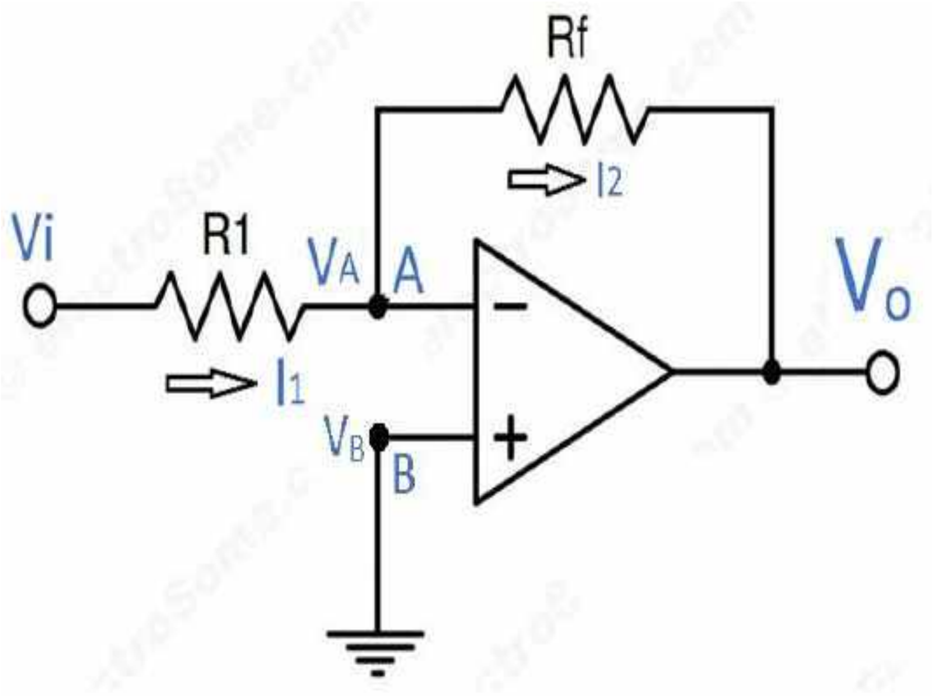
$$V_1 = V_2$$

Since $V_1 = 0$ (actual ground), then $V_2 = 0$ (but it is not actually grounded , which means it is virtual ground)."

Also, if V_1= any value e.g. K, then"
V2 = K.

Inverting Amplifier

- **An op-amp circuit that produces an amplified output signal that is 180° out of phase with input signal.**



From concept of virtual ground

$V_d = 0,$
$V_A - V_B = 0$
$V_A = V_B$

But $V_B = 0$

So $V_A = 0$ ……………1…

$I_1 = I_2$

$$\frac{V_i - V_A}{R_1} = \frac{V_A - V_O}{R_f}$$

But $V_A = 0$

$$\frac{V_i}{R_!} = -\frac{V_O}{R_f}$$

$$A_V = \frac{V_o}{v_I} = -\frac{R_f}{R_1}$$

$$A_V = \frac{V_o}{v_I} = -\frac{R_f}{R_1}$$

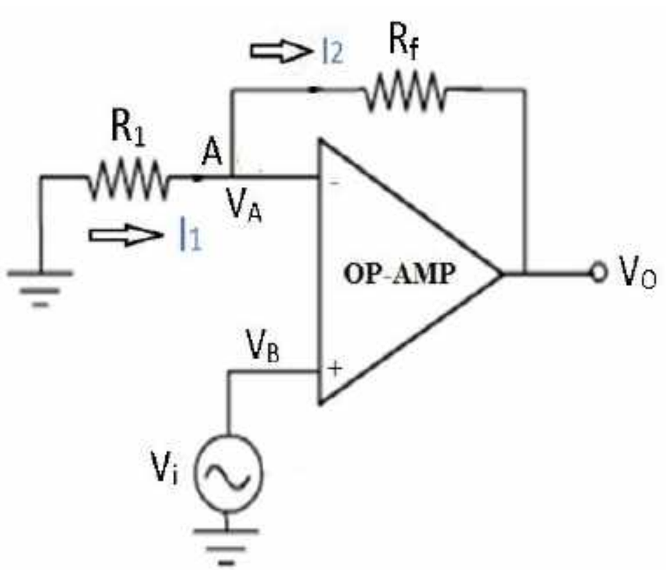
$$A_V = \frac{V_o}{v_I} = 1 + \frac{R_f}{R_1}$$

Gain can be set to any value by manipulating the values of R_f and R_1

The positive sign denotes that input and output are in same phase

Non-Inverting Amplifier

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



From concept of virtual ground

$V_d = 0 \Rightarrow V_A - V_B = 0$

$V_A = V_B$ But $V_B = V_i$

So $V_A = V_i$ 1

Apply KCL at node A

$I_1 = I_2$

$$\frac{0 - V_A}{R_1} = \frac{V_A - V_O}{R_f}$$

But $V_A = V_i$

$$-\frac{V_i}{R_!} = \frac{V_i}{R_f} - \frac{V_0}{R_f}$$

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

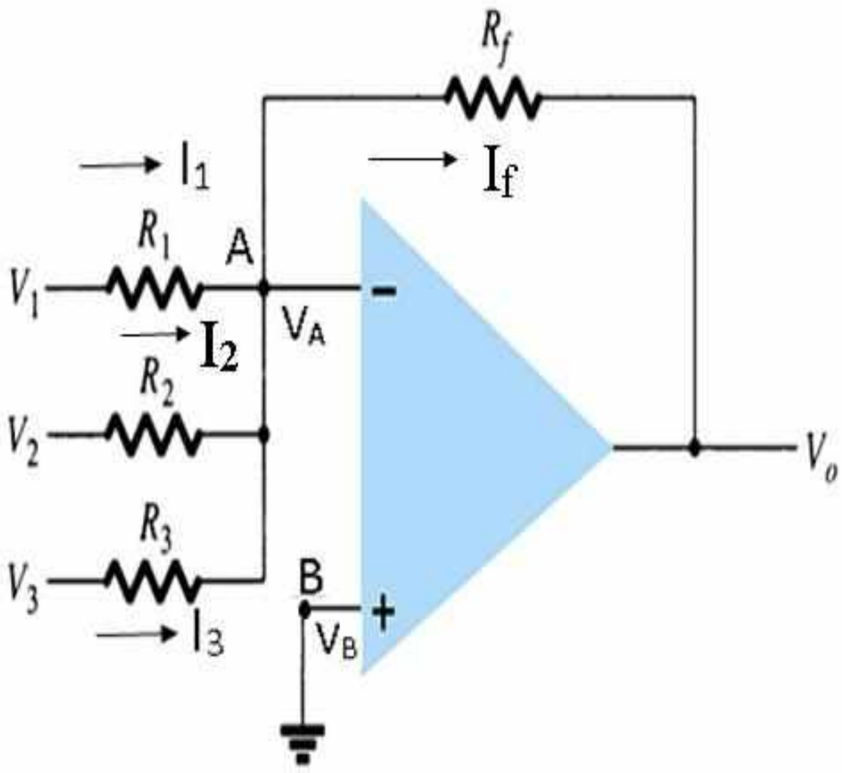
$$A_V = \frac{V_o}{v_I} = 1 + \frac{R_f}{R_1}$$

Gain can be set to any value by manipulating the values of R_f and R_1

The positive sign denotes that input and output are in same phase

Voltage Summing Amplifier or Adder Amplifier

Adder is an op-amp circuit, which can accept two more inputs and produces output as the sum of these inputs.



Expression for output voltage: -

From concept of virtual ground

$V_d = 0$

$V_A - V_B = 0$

So $V_A = V_B$

But $V_B = 0$

Therefor $V_A = 0$ --------------1

Applying KCL at node A

$I_1 + I_2 + I_3 = I_f$

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

But $V_A = 0$

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

$$Vo = -(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3)$$

a) If R_1, R_2, R_3 = R

Then $$Vo = -\frac{R_f}{R}(V_1 + V_2 + V_2)$$

So, Circuit works as a summing amplifier.

b) If R_1, R_2, R_3 = R_f

Then $$Vo = -(V_1 + V_2 + V_2)$$

So, Circuit works as a summer or adder.

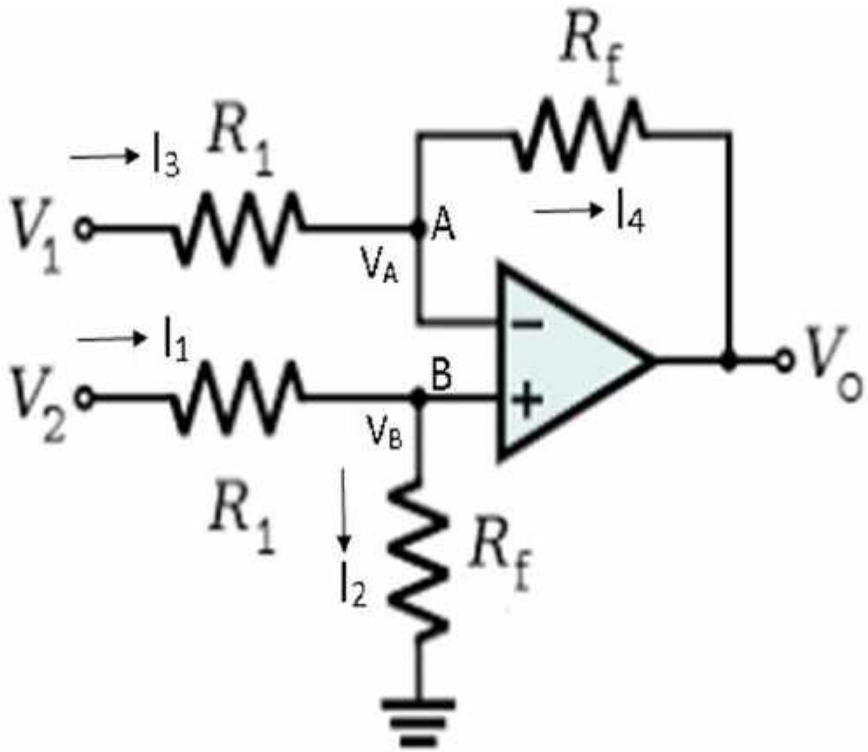
c) If R_1, R_2, R_3 = $3R_f$

Then $$Vo = -\left(\frac{(V_1+V_2+V_2)}{3}\right)$$

So, Circuit works as a summer or averager circuit.

Difference or Subtractor Amplifier

A circuit that amplifies the difference between two input signals is called difference amplifier or subtractor amplifier.



From concept of virtual ground

$$V_d = 0$$

$$V_A - V_B = 0$$

So $V_A = V_B$ 1

Applying KCL at node B

$$I_1 = I_2$$

$$\frac{V_2 - V_B}{R_1} = \frac{V_B - 0}{R_f}$$

$$V_B = \left(\frac{R_f}{R_1 + R_f}\right) V_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Applying KCL at node A

$I_3 = I_4$

$$\frac{V_1 - V_A}{R_1} = \frac{V_A - V_O}{R_f}$$

$$\frac{V_1}{R_1} - \frac{V_A}{R_1} = \frac{V_A}{R_f} - \frac{V_O}{R_f}$$

$$\frac{V_O}{R_f} = \frac{V_A}{R_f} + \frac{V_A}{R_1} - \frac{V_1}{R_1}$$

$$\frac{V_O}{R_f} = V_A\left(\frac{R_1 + R_f}{R_1 R_f}\right) - \frac{V_1}{R_1}$$

But $V_A = V_B$

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

$$\boxed{V_O = \frac{R_f}{R_1}(V_2 - V_1)}$$

So, Circuit works as a difference or subtractor amplifier.

If $R_1 = R_f$

$$\boxed{V_O = (V_2 - V_1)}$$

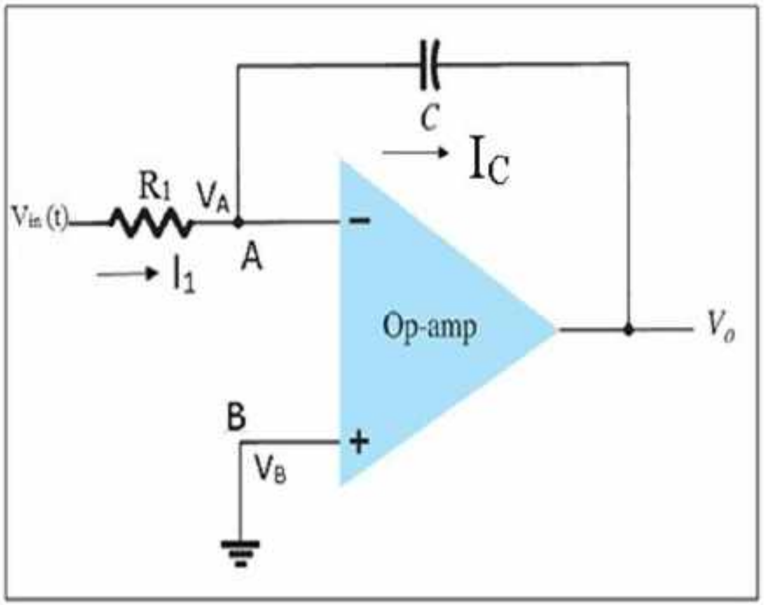
So, Circuit works as a difference or subtractor.

Lecture 25

Integrator & differentiator, Comparator

Integrator Circuit Using Op-Amp

A circuit that performs the integration of input signal is called integrator. The output of integrator is proportional to the area of input waveform over a period of time.



From concept of virtual ground

$V_d = 0$

$V_A - V_B = 0$

So $V_A = V_B$

But $V_B = 0$

Therefor $V_A = 0$ --------------1

Applying KCL at node A

$I_1 = I_C$

$$\frac{V_{in} - V_A}{R_1} = C\frac{d(V_A - V_0)}{dt}$$

But $V_A = 0$

$$\frac{V_{in}}{R_1} = C\frac{d(-V_0)}{dt}$$

$$dV_0 = -\frac{1}{R_1C}V_{in}dt$$

Now apply integration on both sides

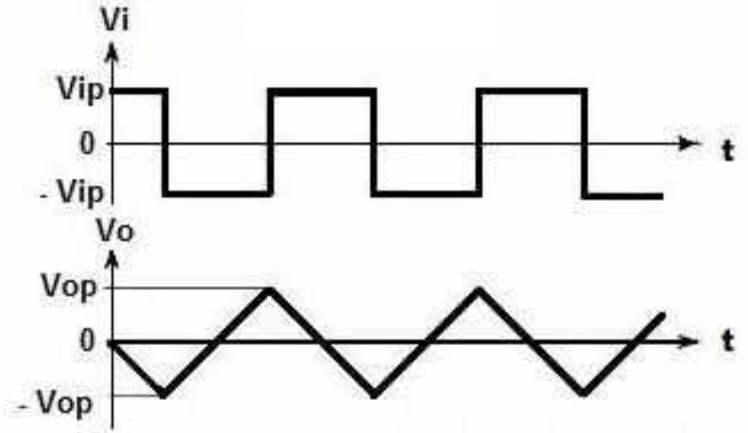
$$\int dV_0 = \int -\frac{1}{R_1C}V_{in}dt$$

$$\boxed{V_0 = -\frac{1}{R_1C}\int_0^t V_{in}dt}$$

$$\boxed{V_0 \, \alpha \int_0^t V_{in}dt}$$

Since output voltage is directly proportional to the integration of input signal, hence circuit is called integrator circuit.

Output for square wave input: -



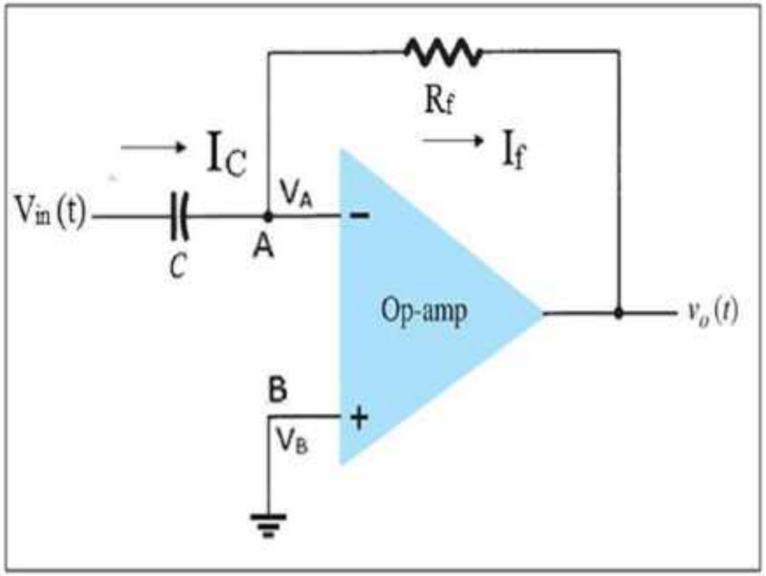
Integrator op amp output

Application of Integrator Circuit: -

a) It is used to generate triangular waveform.
b) It is also used in analog to digital convertor circuit.
c) It is used as low pass filter.

Differentiator Circuit Using Op-Amp

A circuit that performs the mathematical differentiation of input signal is called differentiator. The output of integrator is proportional to rate of change of its input signal.



From concept of virtual ground

$$V_d = 0$$

$$V_A - V_B = 0$$

So $V_A = V_B$

But $V_B = 0$

Therefor $V_A = 0$ --------------1

Applying KCL at node A

$$I_1 = I_C$$

$$C\frac{d(V_{in} - V_A)}{dt} = \frac{V_A - V_O}{R_f}$$

But $V_A = 0$

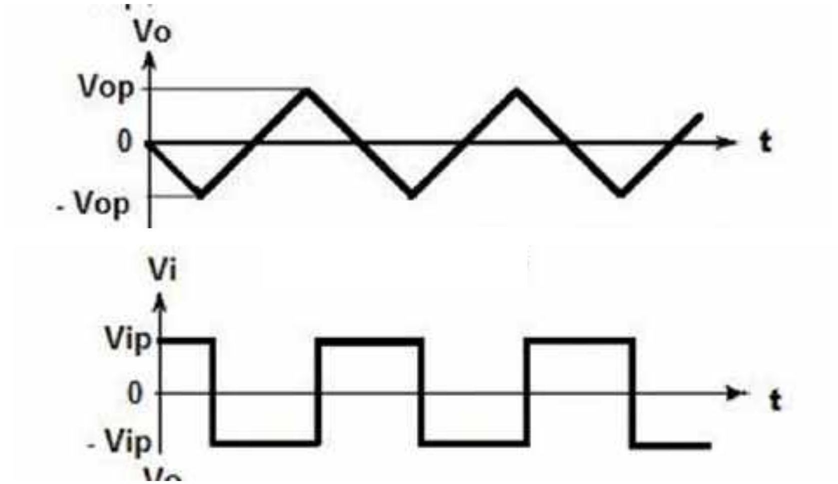
$$\frac{d(V_{in})}{dt} = -\frac{V_O}{R_f}$$

$$V_O = -R_f C \frac{d(V_{in})}{dt}$$

OR $$V_O \, \alpha \, \frac{d(V_{in})}{dt}$$

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

Output for triangular wave input:



Application of differentiator Circuit: -

a) It is used to generates quare waveform.
b) It is also used in digital to analog convertor circuit.
c) It is used as high pass filter.

Comparator

- Comparator is a circuit which compare signal voltage applied at one input terminal of op-amp with reference voltage applied at other terminal.

- Comparator produce High (+V_{sat}) or low (-V_{sat}) output demanding which input is higher
- Comparator are of two types.

  - ❖ Inverting Comparator
  - ❖ Non-inverting Comparator

Comparator

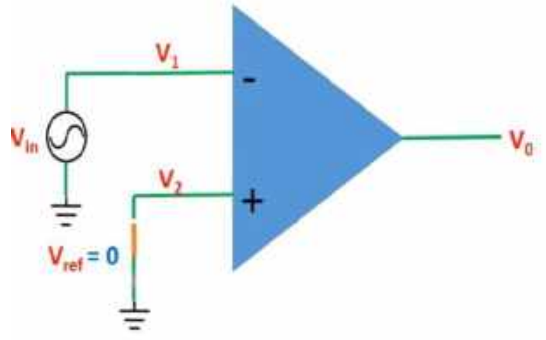
❖ **Inverting Comparator:**

- **Input is applied at inverting terminal.**
- **Reference voltage is applied at non-inverting terminal.**
- **Inverting comparators can be classified into two categories.**

❖ **Inverting Comparator with Zero Reference Voltage or Zero Crossing Detector**

❖ **Inverting Comparator with Non-Zero Reference Voltage**

Inverting Comparator with Zero Reference Voltage or Zero Crossing Detector

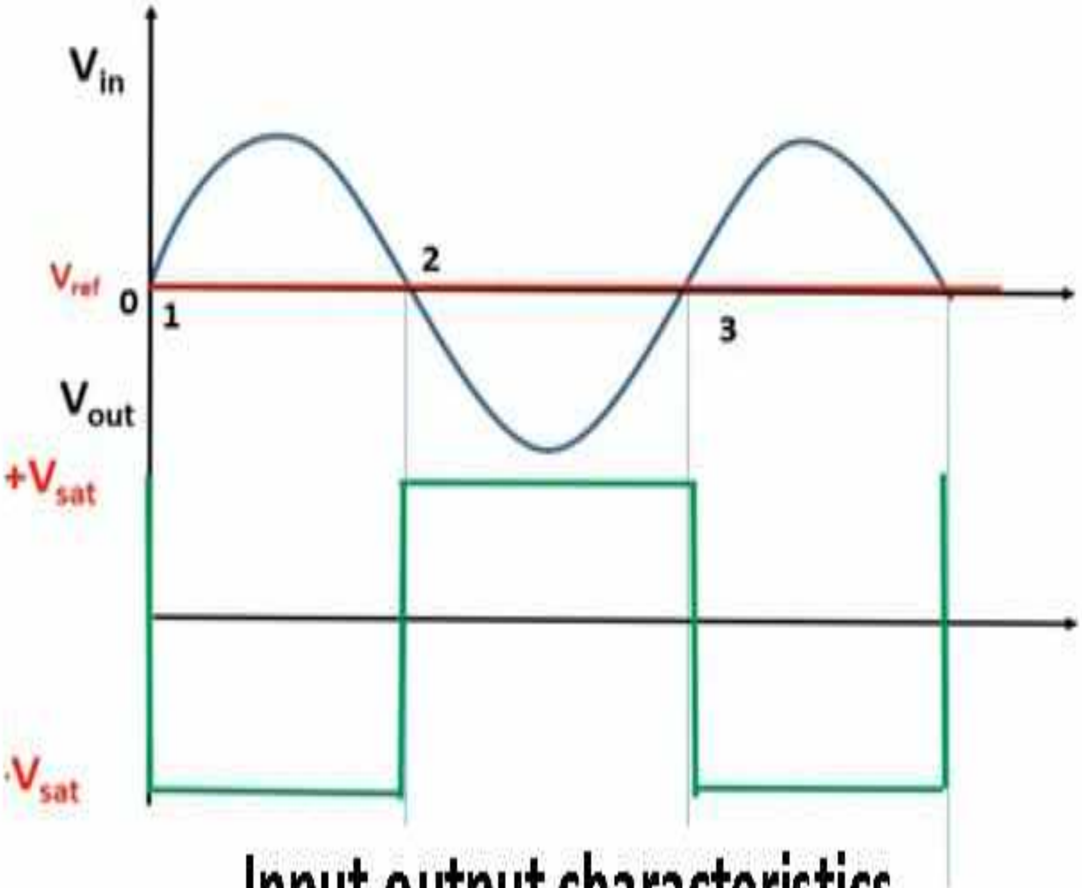


- In positive half cycle $V_{in} > V_{ref}$
- Hence the output value of the inverting comparator will be equal to −Vsat.

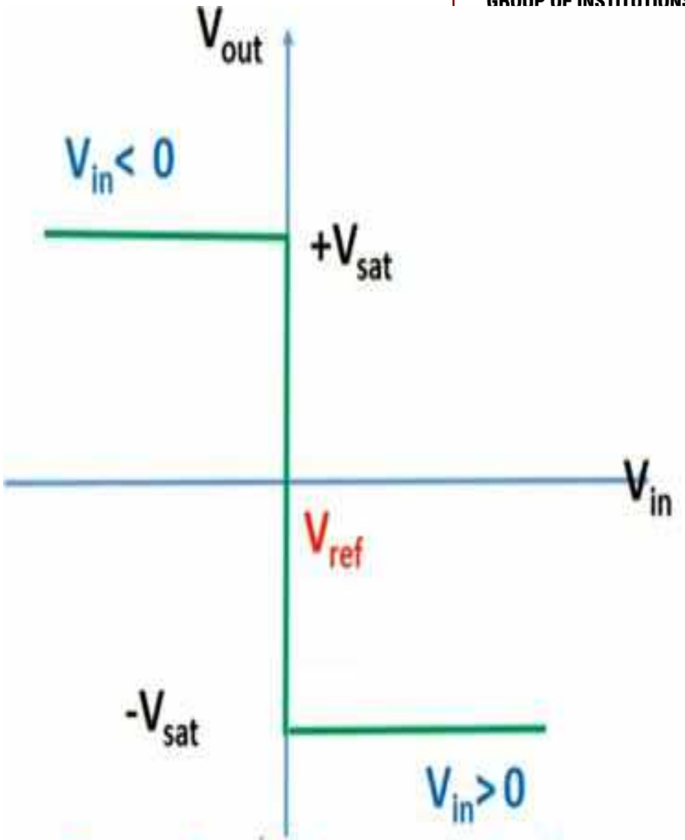
$$V_d = V_2 - V_1$$
$$= 0 - V_{in}$$
$$= -ve$$
$$V_O = A_{OL} \times V_d$$
$$= -V_{sat}$$

- In negative half cycle $V_{in} < V_{ref}$
- Hence the output value of the inverting comparator will be equal to + Vsat.

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

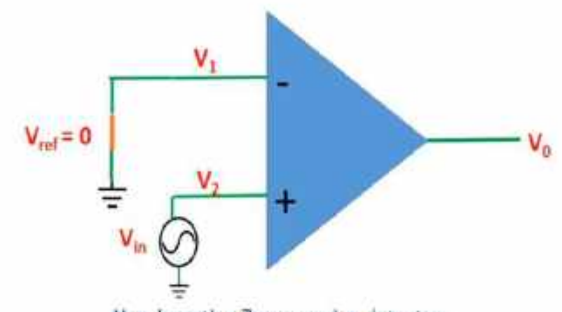


Input-output characteristics



Transfer characteristics

Non-inverting Comparator with Zero Reference Voltage or Zero Crossing Detector



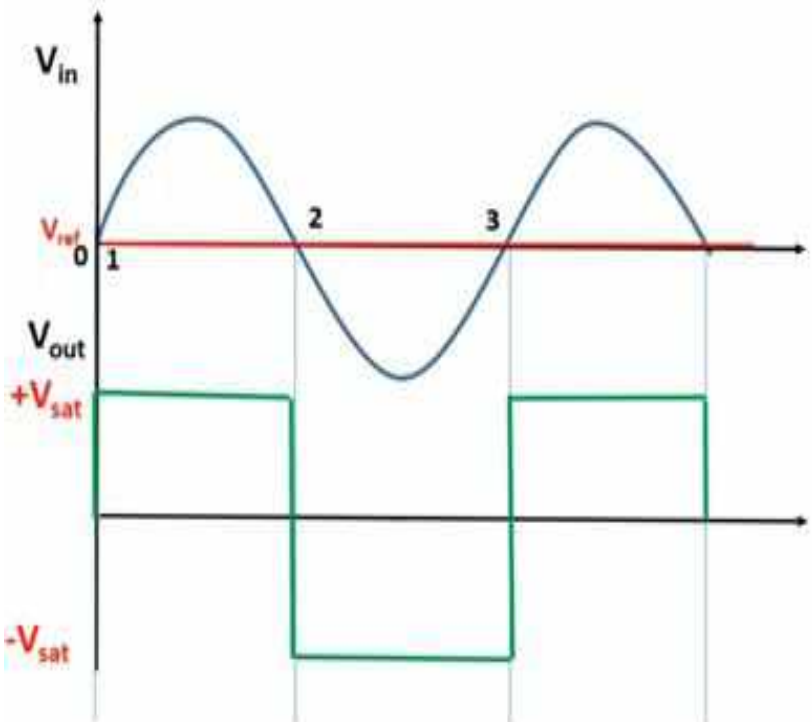
Non-Inverting Zero crossing detector

- **In positive half cycle $V_{in} > V_{ref}$**
- **Hence the output value of the non-inverting comparator will be equal to + Vsat.**

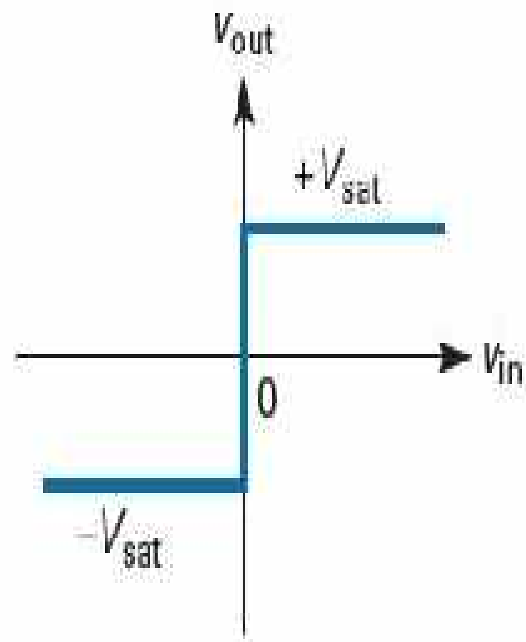
$$V_d = V_2 - V_1$$
$$= V_{in} - 0$$
$$= +ve$$
$$V_O = A_{OL} \times V_d$$
$$= + V_{sat}$$

- **In negative half cycle $V_{in} < V_{ref}$**
- **Hence the output value of the non-inverting comparator will be equal to - Vsat.**

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



Input-output characteristics



Transfer Characteristics

Lecture 26

Numerical Problems based upon Op-Amps

Numerical of Unit-3 (OP-AMP)

Ques-1. For a perticular op-amp, the input offset current is 20nA while input bias current is 60nA. Calculate the value of two input bias currents

Ans:- $I_{io} = 20nA$, $I_B = 60nA$

$I_{io} = I_{B_1} - I_{B_2} = 20 \quad \text{---} (1)$

$I_B = \frac{I_{B_1} + I_{B_2}}{2} = 6$

$\Rightarrow I_{B_1} + I_{B_2} = 120 \quad \text{---} (2)$

Solving (1) & (2)

$I_{B_1} = 70nA$ and $I_{B_2} = 50nA$

Ques:-2 Determine the output voltage of an op-amp for input voltages of $V_{i_1} = 200V$ and $V_{i_2} = 140V$. the amplifier has a differential gain $A_d = 600$ and the value of CMRR is :

i) 200 (ii) 10^5

Solution :-

(i) $V_o = A_d V_d + A_c V_c$

$= A_d V_d + \frac{A_d}{CMRR} V_c \quad \left[CMRR = \frac{A_d}{A_c}\right]$

$= A_d (V_{i_1} - V_{i_2}) + \frac{A_d}{CMRR} \left(\frac{V_{i_1} + V_{i_2}}{2}\right)$

$= 6000 (200 - 140) + \frac{6000}{200} \left(\frac{200+140}{2}\right)$

$= 41.100 \, KV.$

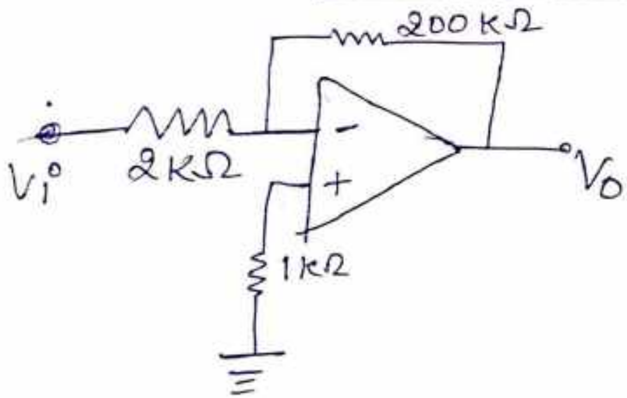
(ii) $CMRR = 10^5$

$V_o = A_d V_d + \frac{A_d}{CMRR} V_c$

$= 6000 (200 - 140) + \frac{6000}{10^5} \left(\frac{200+140}{2}\right)$

$= 36.102 \, KV$

Ques 3:- For an input of $V_i = 50mV$ in the given circuit, determine the maximum frequency that may be used. The op-amp slew rate is $0.4V/\mu s$



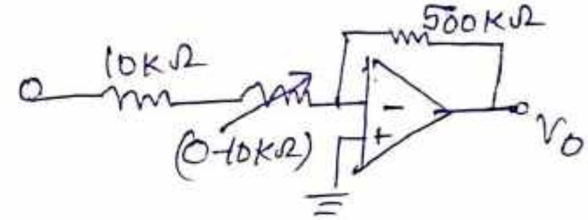
Ans:- $V_i = 50mV$, $SR = 0.4 V/\mu s$
$= 0.4 \times 10^6 V/S$

$$V_o = -\frac{R_F}{R_1} \times V_i = -\frac{200}{2} \times 50 \times 10^{-3}$$
$$= -5V$$

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

$$f_{max} = \frac{SR}{2\pi V_m} = \frac{0.4 \times 10^6}{2\pi \times 5}$$
$$= 12.732 \text{ KHz}$$

Ques 4. What is the range of the Voltage gain adjustment in the following circuit



Ans:- $R_F = 500$, $R_1 = 10k\Omega + R'$

(i) $R' = 0 \Rightarrow R_1 = 10K\Omega$

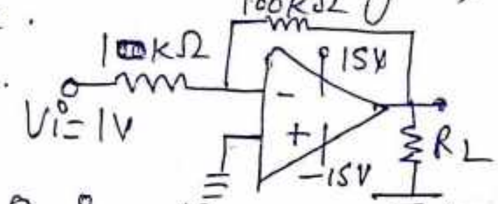
$$\text{Gain}(A_v) = -\frac{R_F}{R_1} = \frac{-500}{10} = -50$$

(ii) $R' = 10 \Rightarrow R_1 = 10K\Omega + 10K\Omega = 20K\Omega$

$$\text{Gain}(A_v) = -\frac{500}{20} = -25$$

So gain adjustment possible is -25 to -50

Ques:-5. For the following circuit find the closed loop gain, output Voltage.

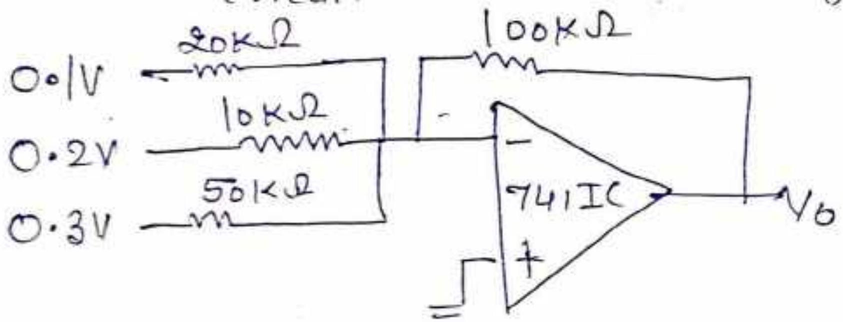


Ans:- It is inverting amplifier
$R_F = 100K\Omega$, $R_1 = 10K\Omega$

$$A_v = -\frac{R_F}{R_1} = -\frac{100}{10} = -10$$

$$V_o = A_v \times V_i = -10 \times 1V = -10V$$

Ques-6 Find V_0 for the following circuit.



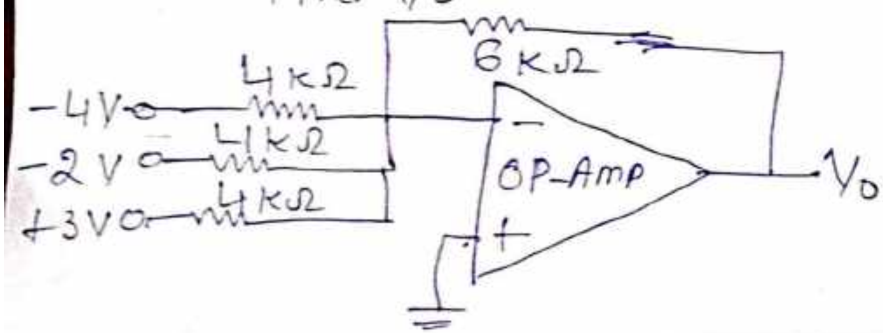
Ans- It is adder circuit

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

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

$$= -3.1V$$

Ques 7:- For the following circuit find V_0.



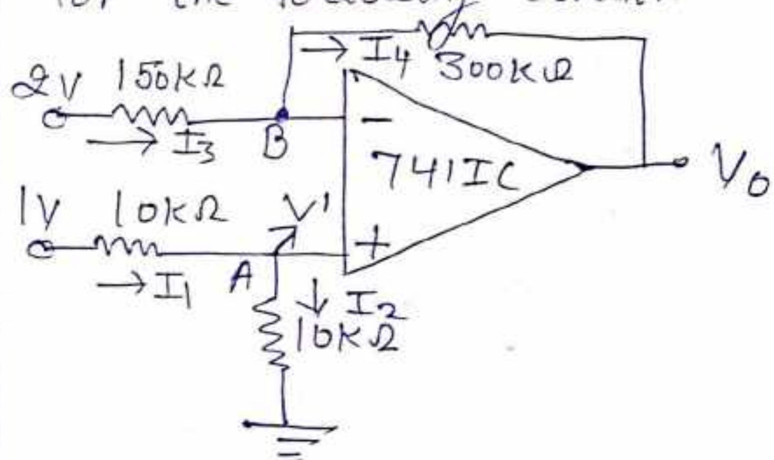
Ans:- It is adder circuit

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

$$= -\left[\frac{6}{4} \times (-4) + \frac{6}{4}(-2) + \frac{6}{4}(3)\right]$$

$$= 4.5V$$

Ques 8:- Find the output voltage for the following circuit.



Ans. Let Voltage at Node A is V'

Applying KCL at Node A.

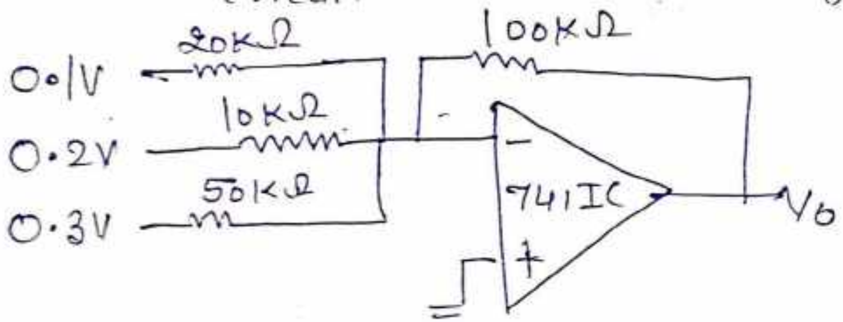
$$I_1 = I_2$$

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

Lecture 27

Numerical Problems based upon Op-Amps

Ques-6 Find V_0 for the following circuit.



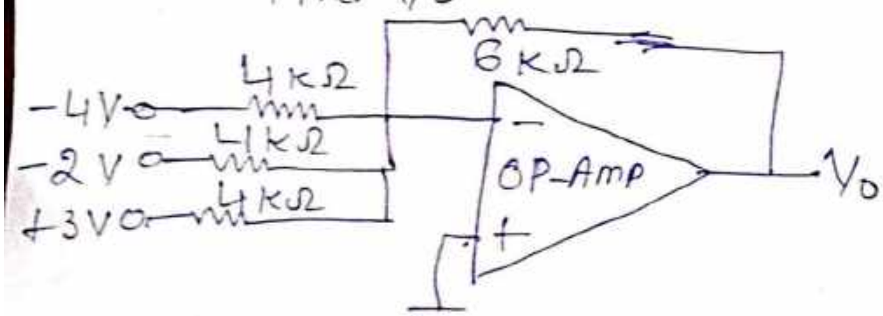
Ans:- It is adder circuit

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

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

$$= -3.1V$$

Ques 7:- For the following circuit find V_0.



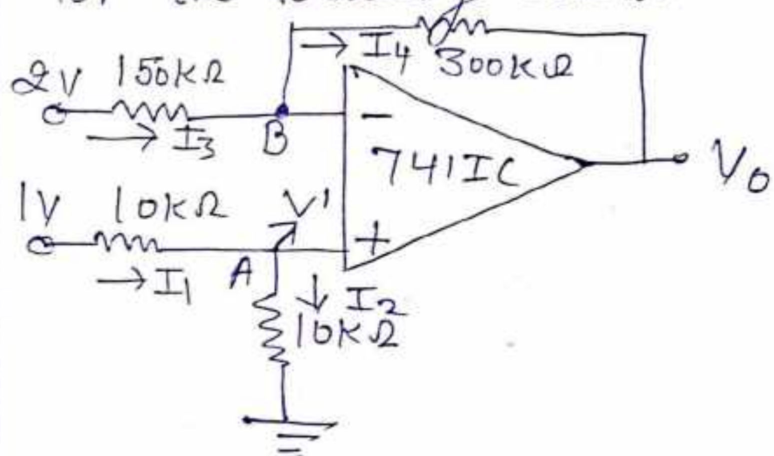
Ans:- It is adder circuit

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

$$= -\left[\frac{6}{4} \times (-4) + \frac{6}{4}(-2) + \frac{6}{4}(3)\right]$$

$$= 4.5V$$

Ques 8:- Find the output voltage for the following circuit.



Ans. Let Voltage at Node A is V'
Applying KCL at Node A.

$$I_1 = I_2$$

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

$V' = 0.5V$

From concept of virtual ground Voltage at Node B is 0.5 V

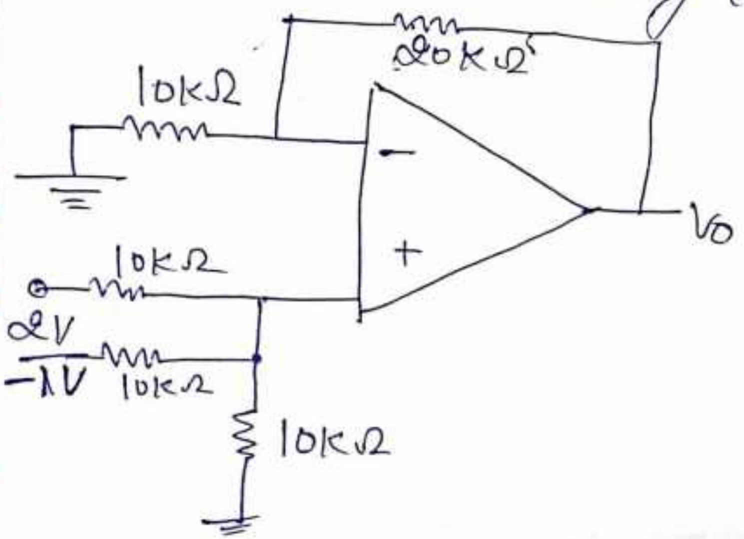
Now applying KCL at Node B

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

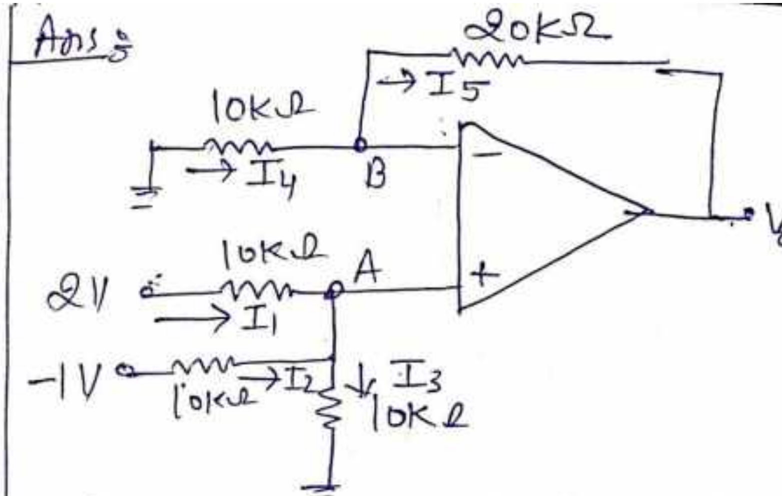
$$1.5 = \frac{.5-V_o}{2}$$

$$\Rightarrow V_o = -2.5\,V$$

Ques 9: Find the output Voltage for the following circuit.



Ans:



Let Voltage at Node A is V'.

Applying KCL at Node A

$$I_1 + I_2 = I_3$$

$$\frac{2-V'}{10} + \frac{-1-V'}{10} = \frac{V'-0}{10}$$

$$2-2V'-1 = V'$$

$$V' = \frac{1}{3}\,V$$

From concept of virtual ground voltage at Node B is $\frac{1}{3}V$

Applying KCL at Node B

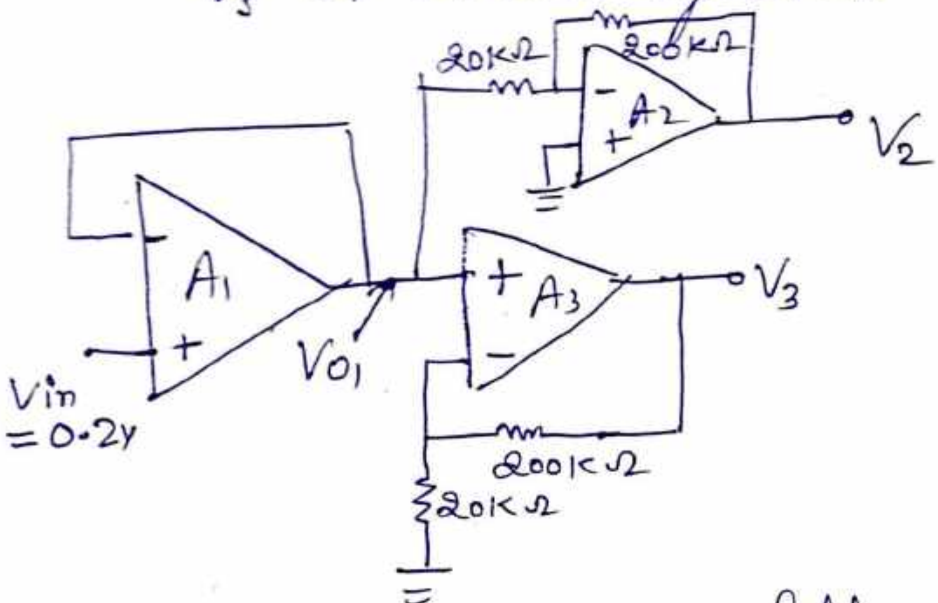
$$I_4 = I_5$$

$$\frac{0-\frac{1}{3}}{10k\Omega} = \frac{\frac{1}{3}-V_o}{20k\Omega}$$

$$-\frac{2}{3} = \frac{1}{3} - V_o$$

$$\boxed{V_o = 1V}$$

Ques 10 Find the voltage V_2 and V_3 of the following circuit.



Ans: Op-amp A_1 is voltage follower

so $V_{o1} = V_{in}$

$= 0.2V$

op-amp A_2 is inverting amplifier

so $V_2 = -\frac{R_F}{R_1} \times V_i$

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

$= -2V$

op-amp A_3 is non inverting amplifier.

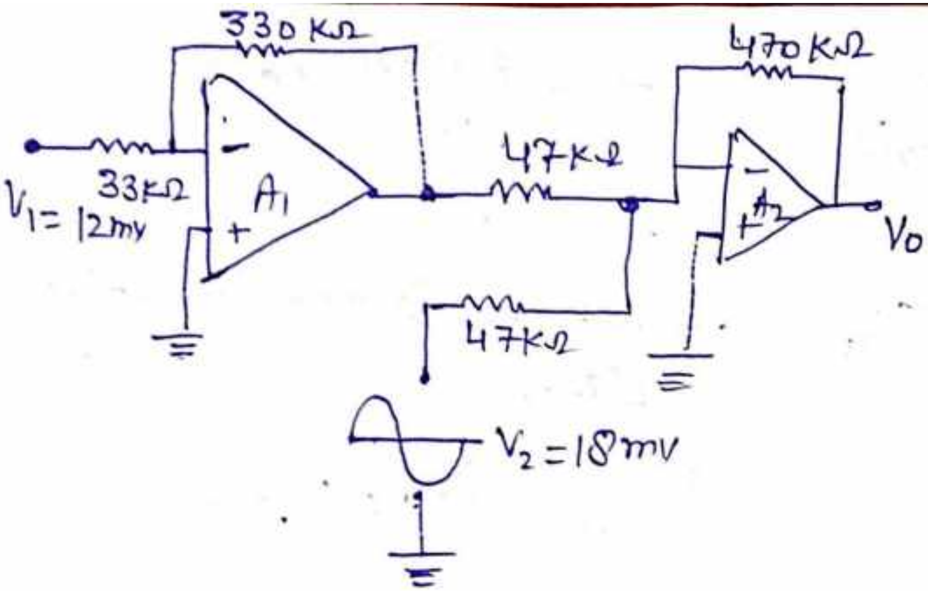
so $V_3 = \left(1 + \frac{R_F}{R_1}\right) \cdot V_i$

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

$= 2.2V$

Ques-11.

Calculate the output voltage for the following circuit.



Ans:- op-amp A_1 is inverting amplifier so output of op-amp A_1 is

$$V_{O_1} = -\left(\frac{R_F}{R_1}\right) \times V_1 = -\frac{330k\Omega}{33k\Omega} \times 12mV$$

$$= -120mV$$

Op-amp A_2 is adder circuit so o/p of op-amp A_2 is

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

$$= -\left[\frac{470}{47} \times (-120mV) + \frac{470}{47} \times 20mV\right]$$

$$= -[-1200mV + 180mV]$$

$$= 1020 mV$$

$$= 1.02 mV$$

Q.12:- For an op-amp having a slew rate of SR = 2.4V/µs, what is the maximum closed-loop voltage gain that can be used when the input signal varies by 0.3V in 10 µs.

Ans: Given $\Delta t = 10\mu s = 10 \times 10^{-6} s$

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

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

but $\Delta V_0 = A_{CL} \Delta V_i$

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

$$2.4 \times 10^6 = \frac{A_{CL} \times 0.3}{10 \times 10^{-6}} \Rightarrow \boxed{A_{CL} = 80}$$