National Institute of Technology, Tiruchirappalli
E. E. E. Department

OPERATIONAL AMPLIFIERS

Introduction to Operational Amplifiers

- ‘Integrated Circuit’ is a multi-component circuit in which all the components are fabricated on the same chip
- ‘Integrating’ is a process of fabricating a single device which functions as a multi-component circuit

Advantages of integration

- Miniaturisation
- Superior performance (better than discrete component circuits)
- Economical (when ?)
- Long and trouble-free operation

Disadvantages?

Types of ICs: a) Linear ICs and b) Digital ICs

Linear ICs:

- Equivalents of discrete transistor networks such as amplifiers, filters, modulators, frequency multipliers etc.
- Often require additional components for satisfactory operation.
- Output signals vary in proportion to the input signal (s). Signals are analogous to physical quantities (**Analog ICs**).

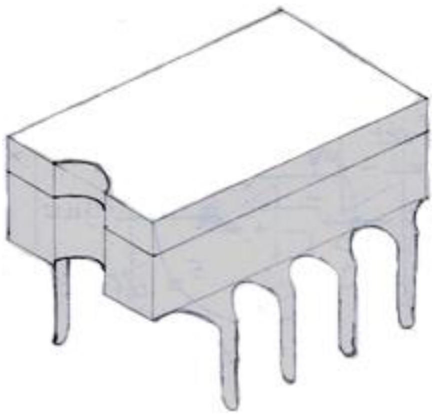
Digital ICs:

- These are complete, functioning logic circuits such as gates, counters, flip-flops etc.
- Only a power supply and input signal are required. Primarily concerned with High or Low logic voltage levels
- Easy to design since accuracy is not required

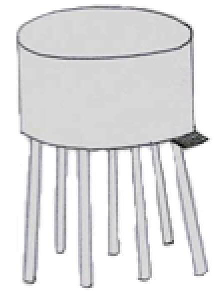
The Operational Amplifier

- Op-Amp is the most fundamental of the Linear ICs.
- Is a direct coupled high gain amplifier
- Most widely used linear IC – versatile amplifier
- Historically been the great grand-parent of computers
- OP-Amp μA741 Introduced for first time in 1968 by Fairchild company

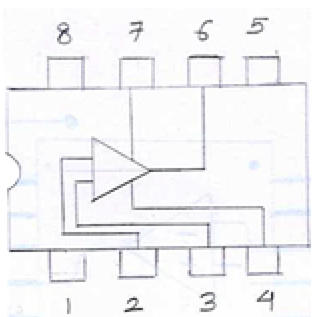
OP-AMP 741 IC



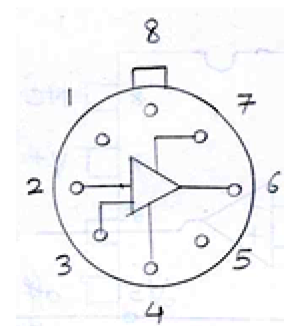
Plastic DIP



Metal Can Package (MCP)

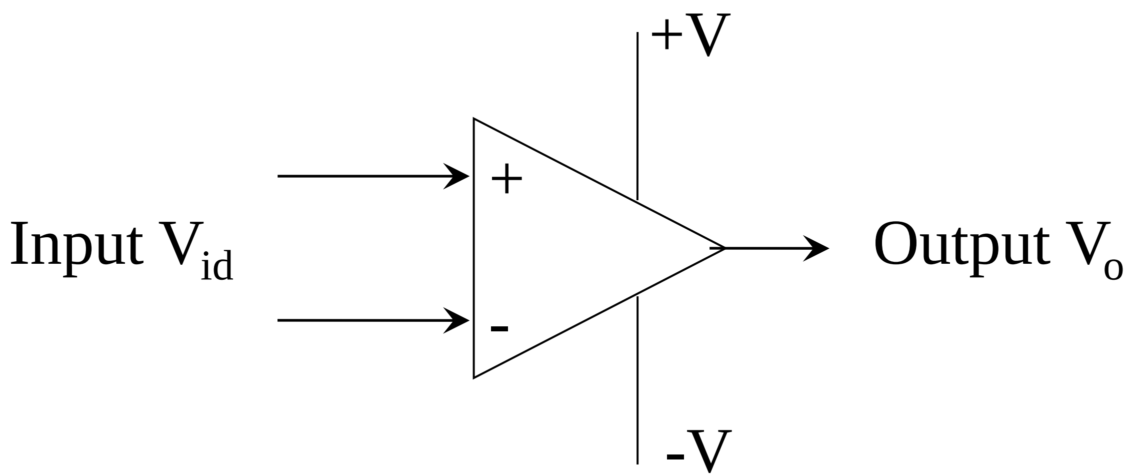


Top view of DIP



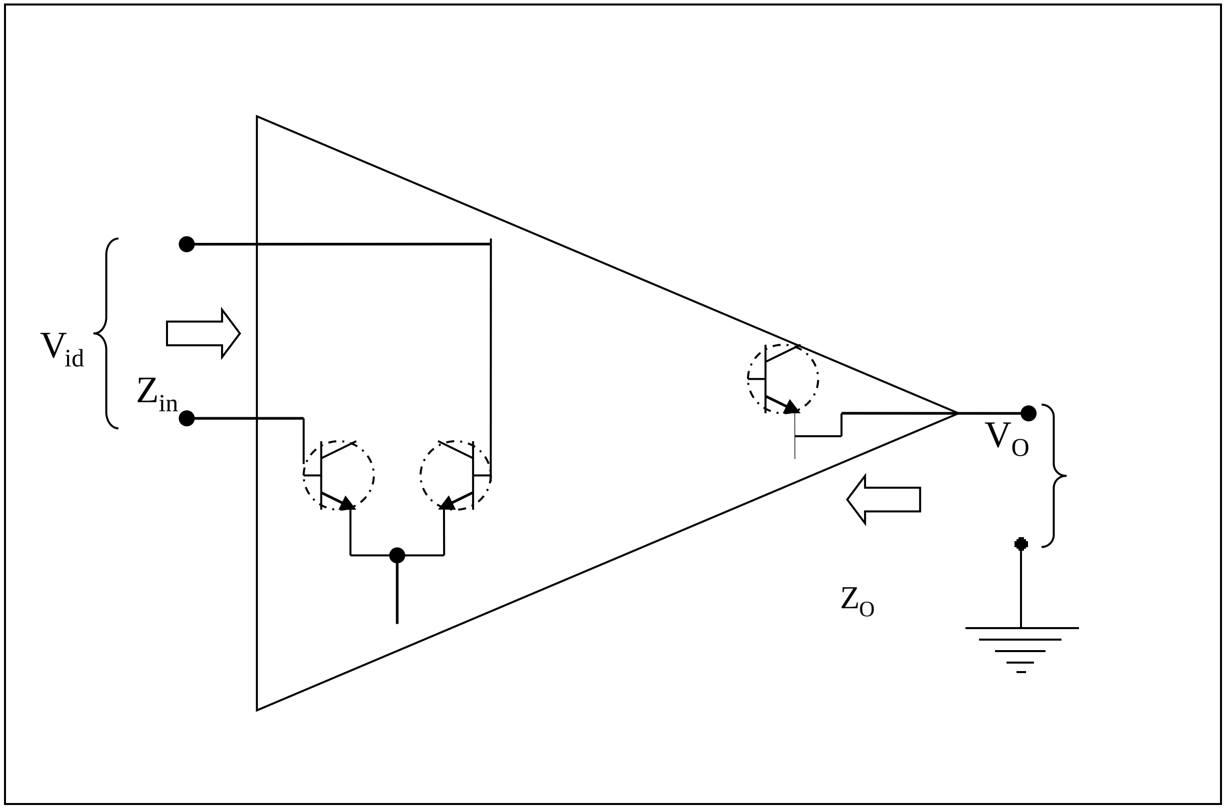
Top view of MCP

Circuit symbol



$$\text{Output } V_o = AV_{id}$$

THE INSIDE STORY



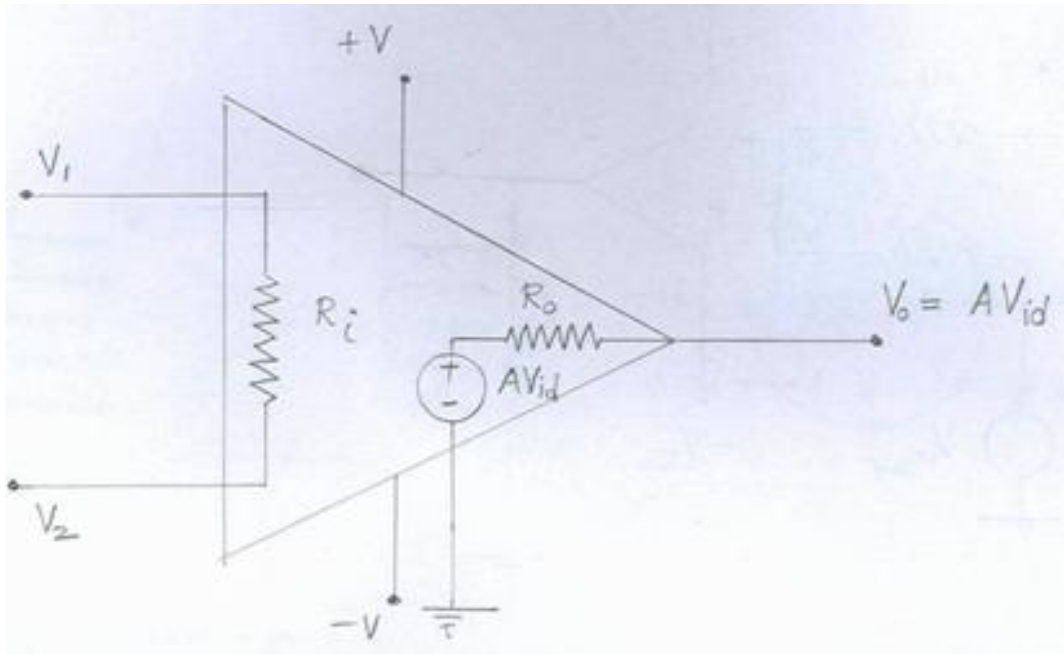
Differential Amplifier Input Stage and Emitter Follower Output Stage

Characteristics of an ideal op-amp

1. Infinite voltage gain A in open loop
2. Infinite input resistance R_i – no loading
3. Zero output resistance R_o – can drive a no. of loads
4. Infinite bandwidth – no attenuation or distortion to '∞' Hz
5. Infinite common mode rejection ratio
6. Zero output voltage when input voltage is zero
7. Infinite slew rate -- output changes simultaneously with the input

Low frequency equivalent ckt

n.Inv input V_1



Inv input V_2

Output $V_o = AV_{id} - i_0R_0 = A(V_1 - V_2) - i_0R_0$

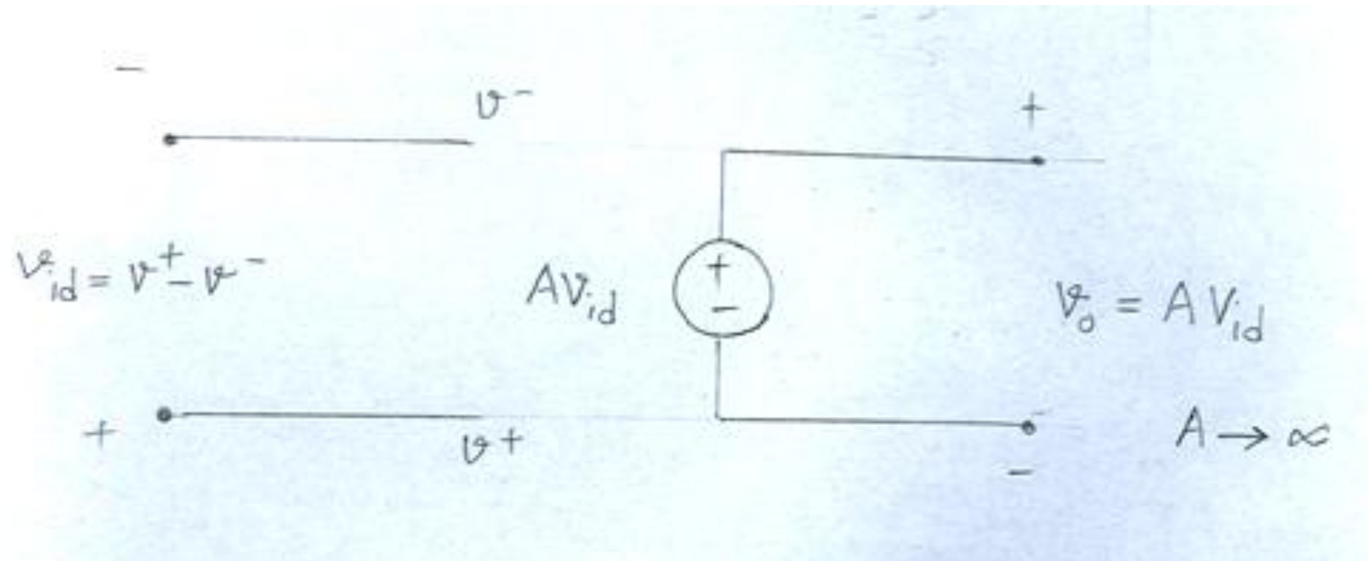
Where A = large signal voltage gain.

V_{id} = differential input voltage.

V_1 = voltage at n.inv. input terminal (w.r..t ground)

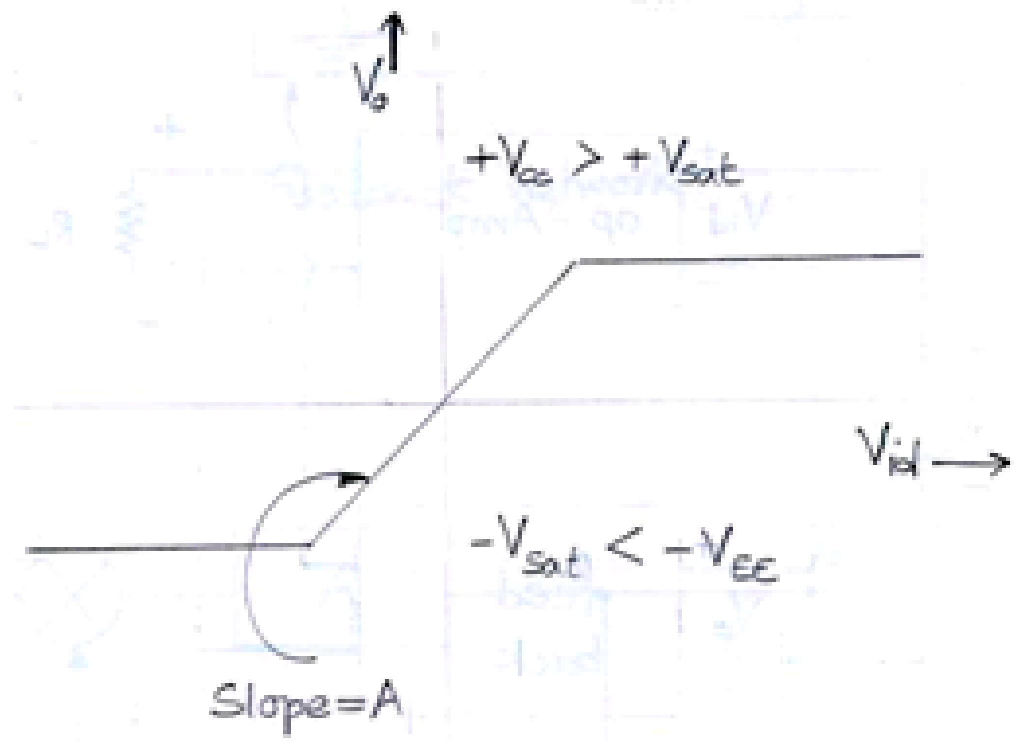
V_2 = voltage at inv. Input terminal (w.r..t ground)

Operational model of OP-Amp



Open-loop Voltage Transfer Characteristics

Maximum possible output voltage is governed by $+V_{cc}$ & $-V_{ee}$.
$+V_{sat}$ & $-V_{sat}$ are slightly less
Than $+V_{cc}$ & $-V_{ee}$ respectively.



Closed loop configurations of Op-Amp

Disadvantages of open loop operation of Op-Amp

- Clipping of output signal due to saturation
- Practically negligible operating range of input voltages (μV) due to very high open loop gain
- Susceptible to noise
- Open loop gain not constant, affected by changes in temperature, power supply and production techniques
- The open loop bandwidth almost zero for the Op-Amp – unsuitable for ac applications
- Very limited applications such as a comparator

Advantages of closed loop operation of Op-Amp

- Controllable gain using negative feedback of output – degenerative feedback
- Positive or regenerative feedback - used in oscillator circuits
- Increased bandwidth with negative feedback– suitable for ac applications
- Can further increase the input resistance and decrease output resistance
- Noise immunity and stability

The golden rules for op-Amp circuits

virtual ground concept

- When operated with negative feedback, an ideal op-Amp will do whatever it takes to drive v_{id} to zero. That is, it will force v_- to track v_+ but without drawing any input current. Hence v_- tracks v_+
- the input port looks like an open circuit for current (currents into op-Amp are zero)
- The input port looks like a short circuit for voltage (v_{id} is zero –**virtual short**)
- Due to very large open loop gain, the closed loop gain is independent of the open loop gain

INVERTING AMPLIFIER

Inverting amplifier gain --

Assumptions: Infinite input impedance: hence $i_1 = 0$; $i_2 = 0$ and zero voltage drop between inputs i.e., $V_1 = V_2$, and $A = \infty$

Let $R_s = 0$, or include it as part of R_{in} ; then: $i_{in} - i_f = 0$; i.e.,

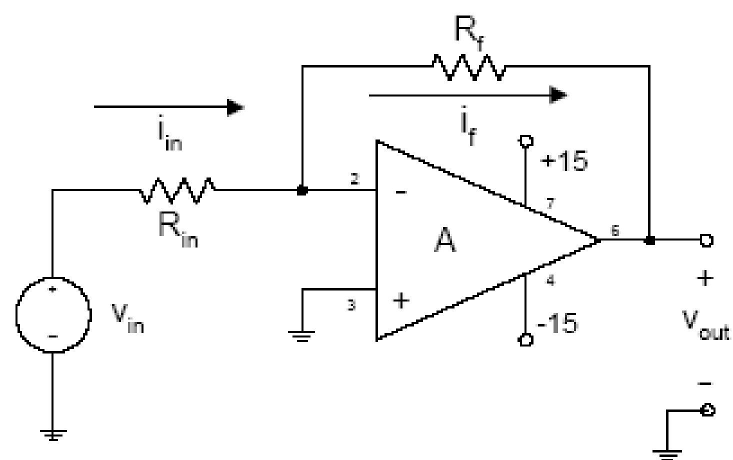
$$\frac{V_{in} - 0}{R_{in}} - \frac{0 - V_{out}}{R_f} = 0$$

$$\text{closed loop gain} = \frac{V_{out}}{V_{in}}$$

Since A is very large $\quad \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$

If A is not very large, then gain

$$= -\frac{R_f}{R_{in}}\left[\frac{1}{1 + (R_{in} + R_f)/AR_{in}}\right]$$



NON-INVERTING AMPLIFIER

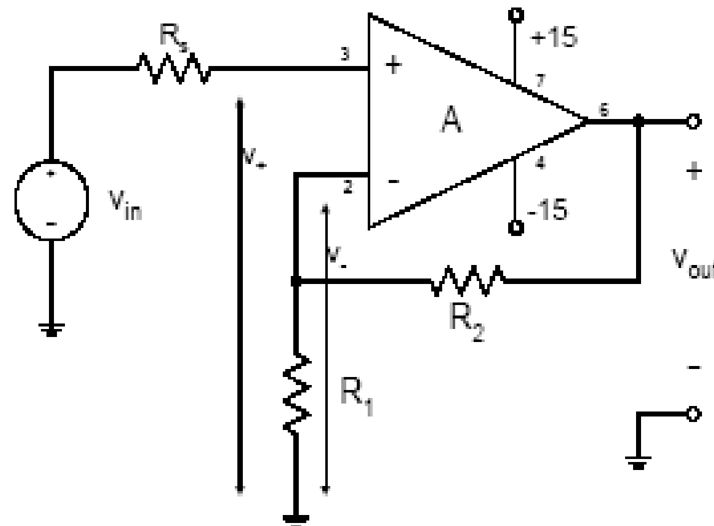
- Derivation of gain
- Assumptions: infinite input impedance: hence $i_1 = 0$; $i_2 = 0$; zero voltage drop between inputs i.e., $V_1 = V_2$ and $A = \infty$.

Since $i_1 = 0$, $V_1 = V_{in}$

Due to potential division,

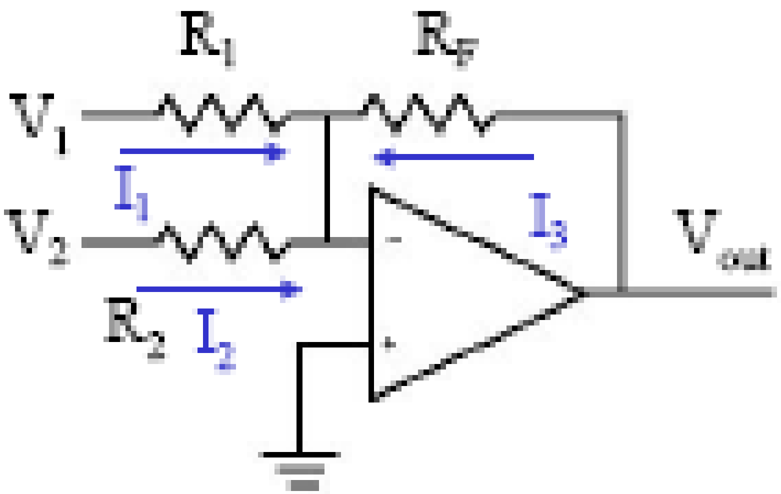
$$V_2 = \frac{V_{out} R_1}{(R_1 + R_2)} = V_1 = V_{in}$$

$$hence \frac{V_{out}}{V_{in}} = \frac{R_1 + R_2}{R_1}$$



SUMMING AMPLIFIER (INVERTING)

Summing amplifier



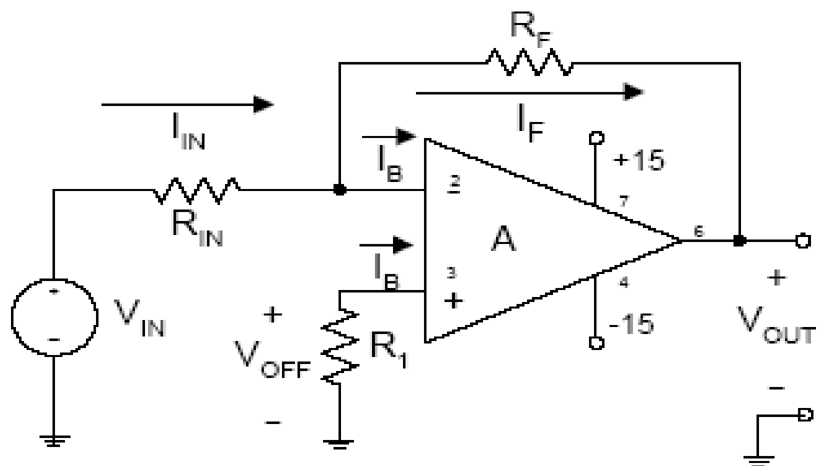
$$I_2 = -(I_1 + I_3)$$

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

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

If $R_1 = R_2 = R_F$, then $V_{out}=-(V_1+V_2)$

INVERTING AMPLIFIER OFFSET DUE TO BIAS CURRENT



$$I_{IN} - I_B - I_F = 0$$

$$V_{OFF} = -R_1 I_B$$

$$\frac{V_{IN} - V_{OFF}}{R_{IN}} - I_B - \frac{V_{OFF} - V_{OUT}}{R_F} = 0$$

but with no input signal, $V_{IN} = 0$, and we want $V_{OUT} = 0$, so :

$$-I_B = V_{OFF}\left[\frac{1}{R_{IN}} + \frac{1}{R_F}\right]; \quad -I_B = -R_1 I_B\left[\frac{1}{R_{IN}} + \frac{1}{R_F}\right]$$

thus : $\left[\frac{1}{R_{IN}} + \frac{1}{R_F}\right] = \left[\frac{1}{R_1}\right]$ as a condtion for no offset at V_o

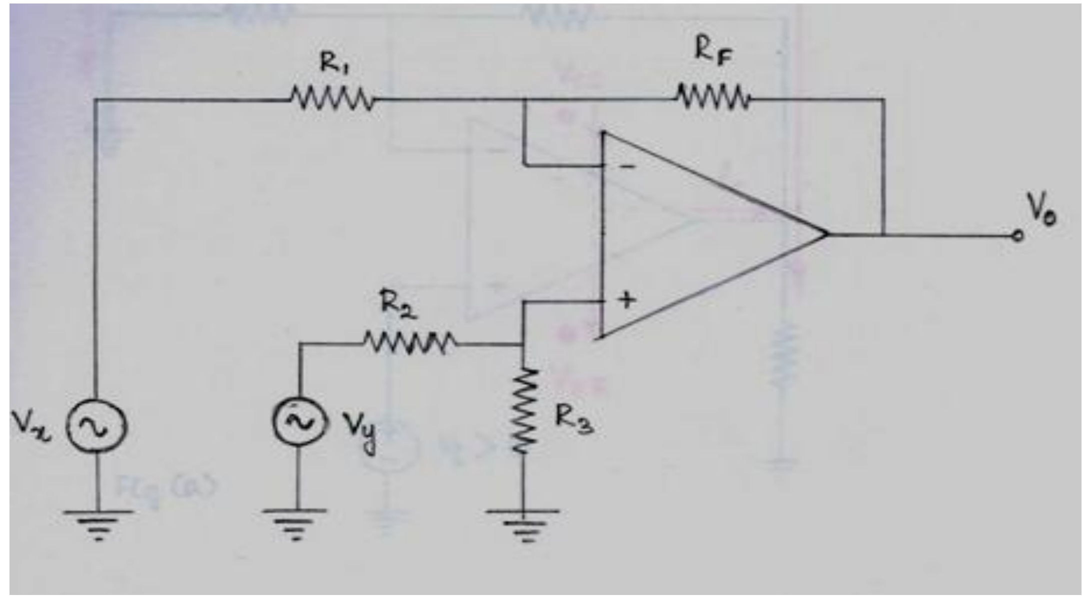
Closed loop Difference amplifier

Use superposition theorem to analyze.

First consider V_y= 0(grounded)

So, with V_x alone, output is

$V_{ox} = -V_x R_F/R_1$ -------(1)



With V_y alone (set $V_x = 0$)

$V_{oy} = [(R_1 + R_F)/R_1]V_1$

where $V_1 = V_y[R_3/(R_2+R_3)]$

is the voltage at the non-inverting input terminal

Therefore

$V_{oy} = [R_3/(R_2+R_3)][(R_1 + R_F)/R_1]V_y$ ----------(2)

Summing (1) & (2) for total output Vo ,

$$\mathbf{V}o = V_{ox} + V_{oy}$$

$$= \mathbf{V_y\,[R_3/(R_2+R_3)][(R_1+R_F)/R_1] - (R_F/R_1)V_x} \qquad \text{in general}$$

If $R_1 = R_2$ and $R_3 = R_F$, then

$$V_o = V_y R_F/R_1 \;-\; V_x R_F/R_1$$

$$= R_F/R_1(V_y - V_x)$$

$$= -V_{xy}.R_F/R_1 \quad \text{(similar to inv. Amp)}$$