SRI MANAKULA VINAYAGAR ENGINEERING COLLEGE
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Madagadipet, Puducherry - 605 107

DEPARTMENT OF MECHANICAL ENGINEERING

Subject Name: Electrical and Electronics Engineering **Subject Code:**MET35

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4. ELECTRONCS

Op.Amp. – Characteristics – Inverting amplifier - Non-inverting amplifier -differentiation integration I/V converter - V/I converter - Instrumentation amplifier – adder – subtractor – First order low pass filter and High pass filter using op. Amp

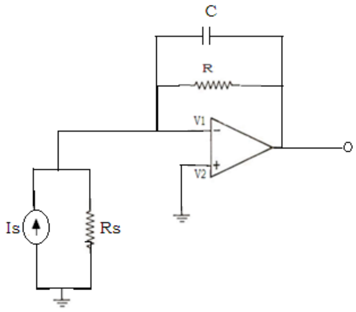
Part –A (2 Marks)

1. **List out the ideal characteristics of OPAMP.**(APRIL/2013)(APRIL/2014)(NOV/2014)
   - An ideal op amp draws no current in both the input terminals. Therefore its impedance is infinite. Any source can drive it and there is no loading on the driver stage.
   - The gain of an ideal op-amp is infinite, hence the differential input $V_d = (V_1 - V_2)$ is essentially zero for the infinite output voltage.
   - The output voltage V_0 is independent of the current drawn from the output terminals. Thus its output impedance is zero and hence output can drive an infinite number of other circuits.
2. **Mention some of the applications of OPAMP** (NOV/2014)
   - Instrumentation amplifier
   - V to I converter
   - I to V converter
   - comparator
3. **What do you mean by inverting amplifier?**(APRIL/2012/2014)

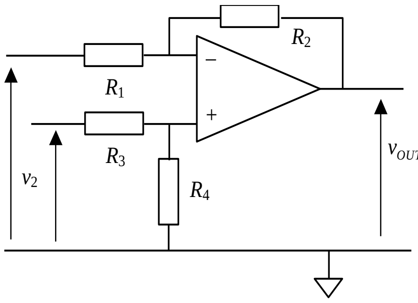
   The output of such an amplifier is inverted as compared to the input signal. The inverted output signal means having a phase shift of 180° as compared to the input signal. So, am amplifier which provides a phase shift of 180° between input and output is called inverting amplifier.
4. **What is an operational amplifier** (NOV/2013)

   The operational amplifier most commonly referred as 'op-amp' was introduced in 1940s. The operational amplifiers performs addition, subtraction, multiplication etc. due to its use in performing mathematical operations, it has been given as operational amplifier.

5. **Draw the circuit diagram of I to V converter** (NOV/2013)

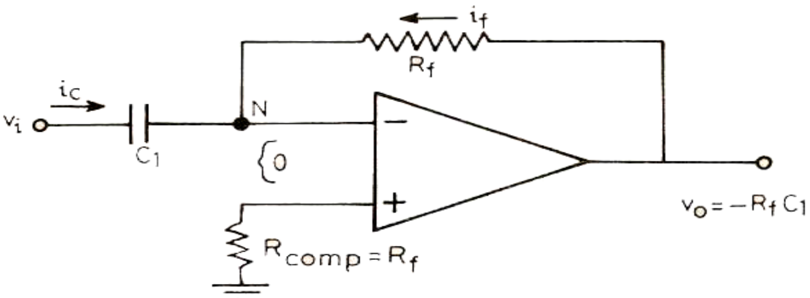


6. **Draw the circuit diagram of subractor.** (APRIL/2013)



$$v_{OUT} = v_2 \frac{R_4}{R_3 + R_4}\left(1 + \frac{R_2}{R_1}\right) - v_1 \frac{R_2}{R_1}$$

7. **Draw the circuit diagram of op-amp differentiator**. (NOV/2012)

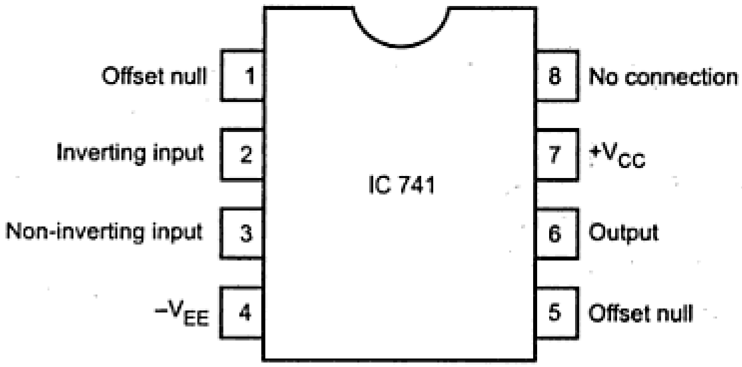


8. **What is meant by filter?** (NOV/2012)

A filter is a circuit that is designed to pass a specific band of frequencies while attenuating all the signals outside that band. It is a frequency selective circuit.

9. **Mention some applications of an instrumentation amplifier**. (APRIL/2012)
   - Temperature controller
   - Temperature indicator
   - Light intensity meter
   - Analog weight scale

10. **Draw the pin configuration of IC741**.

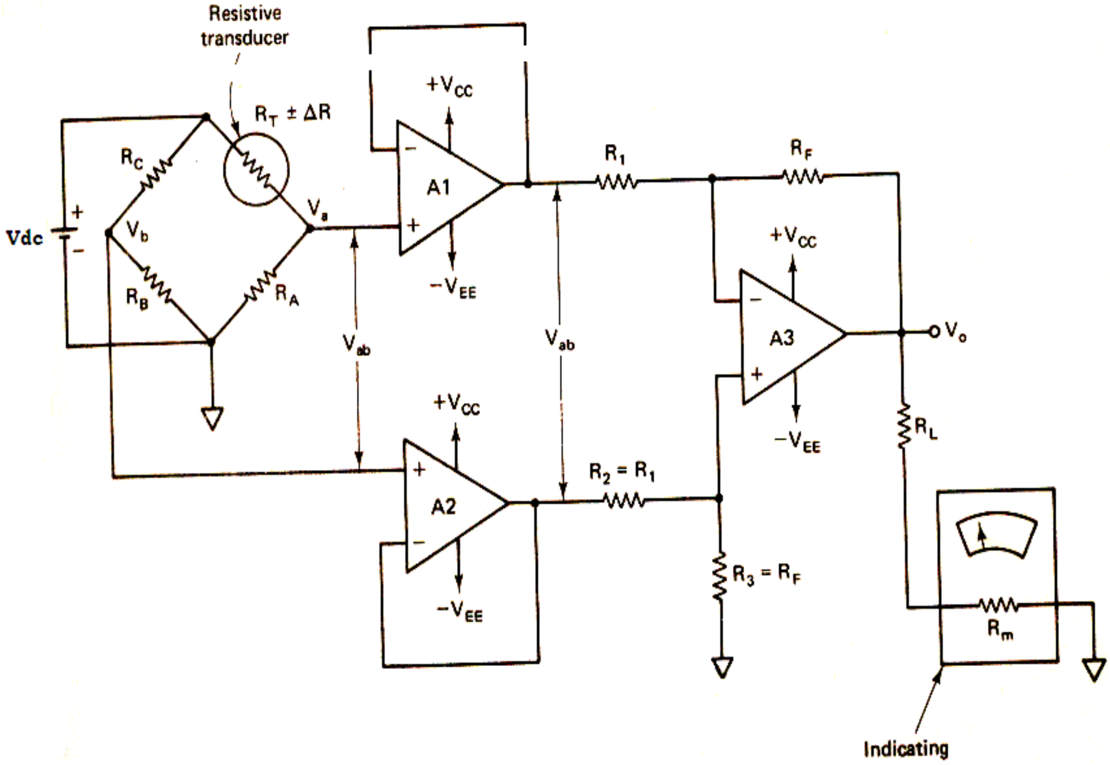


Part-B (11 Marks)

1. Explain the working of an instrumentation amplifier with a circuit. Give its characteristics and application (11) (NOV2012/APRIL/NOV/2014)

In many industrial and consumer applications the measurement and control of physical conditions are very important.(foreg) measurement of temperature & humidity inside a dairy or a meat plant permit the operators make necessary adjustments to maintain product quality. Similarly precise temperature control of plastic furnace is needed to produce a particular type of plastic.Generally, a transducer is used at the measuring site to obtain the required information easily & safely. The transducer is a device that converts one form of energy into another.

A resistive transducer whose resistance changes as a function of some physical energy is connected in one arm of bridge with a small circle around it & is denoted by (R ± ΔR), where R_T is the resistance of transducer and ΔR the change in resistance of RT. The bridge in the circuit is dc exited but could be ac exited as well. For the balanced bridge at some reference condition,



$$V_b = V_a$$

$$\frac{R_B(V_{dc})}{R_B + R_c} = \frac{R_A(V_{dc})}{R_A + R_T}$$

$$\frac{R_c}{R_B} = \frac{R_T}{R_A}$$

Generally resistors R_A, R_B, R_C are selected so that they are equal in value to the transducer resistance R_T at some reference condition the reference condition is the specific value of the physical quantity under measurement at which the bridge is balanced this value is normally established by the designer and depends on the transducer's characteristics, the type of physical quantity to be measured, and the desired application.The bridge is balanced initially at a desired reference condition. However, as the physical quantity to be measured changes, the resistance of the transducer also changes, which causes the bridge to unbalance (Va ≠ Vb). The output voltage of the bridge can be expressed as a function of the change in resistance of the transducer.

Let the change in resistance of the transducer be Δ_R . Since R_b&R_c Are fixed resistors, the voltage V_b is constant. However, the voltage V_a varies as a function of the change in transducer resistance. Therefore, according to the voltage divider rule,

$$V_a = \frac{R_A(V_{dc})}{R_A + (R_T + \Delta R)}$$

$$V_a = \frac{R_{BA}(V_{dc})}{(R_B + R_c)}$$

Consequently, the voltage V_{ab} across the output terminals of the bridge is,

$V_{ab} = V_a - V_b$

$$V_{ab} = \frac{R_A V_{dc}}{R_A + R_T + \Delta R} - \frac{R_B V_{dc}}{R_B + R_c}$$

However, if $R_A = R_B = R_C = R_T = R$, then

$$V_{ab} = \frac{\Delta R(V_{dc})}{2(2R + \Delta R)}$$

the (-)ve sign indicates that $V_a<V_b$(since RT increases)

The basic gain differential amplifier is $(-R_F/R_1)$

$$V_0 = V_{ab} - \frac{R_f}{R_1} = \frac{\Delta R(V_{dc})}{2(2R + \Delta R)} \frac{R_f}{R_1}$$

Generally, R is very small. Therefore we can approximate (2R + R) = 2R.

$$V_0 = \frac{R_f}{R_1} \frac{\Delta R}{4R} V_{dc}$$

This equation indicates that V is directly proportional to the change in resistance R of the transducer since the change in resistance is caused by a change in physical energy, a meter connected at the output can be calibrated in terms of the units of that physical energy.

Features of Instrumentation Amplifier

- High gain
- High CMRR
- Low Power consumption
- High slew rate

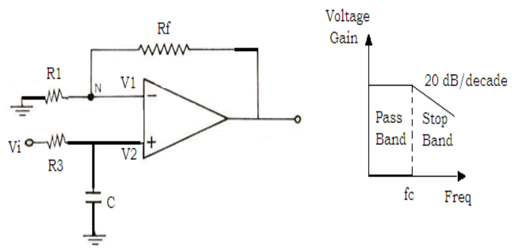
Applications of Instrumentation Amplifier

- Temperature indicator
- Light-intensity meter
- Thermal conductivity meter
- Analog weight scale

2. Draw the circuit of a first order and second order butter worth active low pass filter and derive the transfer function (11) (APRIL/2013)(NOV/2014)

(i)Low pass filter

The first order low pass Butterworth filter is realized by RC circuit used along with an op-amp, used in the non- inverting configuration. This is also called one pole low pass Butterworth filter. The resistances R_f and R_1 decide the gain of the filter in the pass band.



First Order Low Pass Butterworth Filter

Analysis of the filter circuit

The impedance of the capacitor C is $-jX_c$ where X_c is the capacitive reactance given by

$X_c = 1/(2\pi fC)$.

By potential divider rule, the voltage at the non-inverting input terminal 2 which is the voltage across the capacitor C is given by

RC filter is connecting non inverting input

$$V_2 = \left[\frac{1/_{j\omega C}}{R_3 + 1/_{j\omega C}}\right] V_i$$

$$\omega = 2\pi f$$

$$V_2 = \left[\frac{1}{1 + j\omega R_3 C}\right] V_i$$

General non inverting output

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

We can write,

$$V_0 = \left[1 + \frac{R_f}{R}\right]\left[\frac{1}{1 + j\omega R_3 C}\right] V_i$$

$$\frac{V_0}{V_i} = \left[1 + \frac{R_f}{R}\right]\left[\frac{1}{1 + j\omega R_3 C}\right]$$

$$\frac{V_0}{V_i} = \left[1 + \frac{R_f}{R}\right]\left[\frac{1}{1 + j2\pi f R_3 C}\right]$$

$$\frac{V_0}{V_i} = \frac{A_f}{1 + j\left(f/_{f_C}\right)}$$

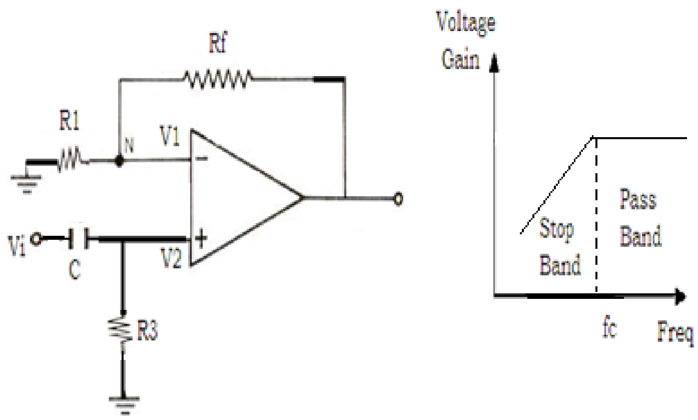
$$A_f = 1 + \frac{R_f}{R}$$

f- *Frequency of input signal*

f_C-*Cutoff frequency of filter*

$$f_C = \frac{1}{2\pi R_3 C}$$

(i) **HighPass Filter**



High Pass Filter

$$V_2 = \frac{R_3}{R_3 + \frac{1}{j\omega C}}$$

$$V_2 = \frac{j\omega R_3 C}{1 + j\omega R_3 C} V_i$$

For non inverting output

$$V_0 = \left[1 + \frac{R_2}{R_1}\right] V_2$$

$$\frac{V_0}{V_i} = \left[1 + \frac{R_2}{R_1}\right]\left[\frac{j\omega R_3 C}{1 + j\omega R_3 C}\right]$$

$$\frac{V_0}{V_i} = \left[1 + \frac{R_2}{R_1}\right]\left[\frac{j2\pi f R_3 C}{1 + j2\pi f R_3 C}\right]$$

$$\frac{V_0}{V_i} = A_f \left[\frac{j\frac{f}{f_C}}{1 + j\frac{f}{f_C}}\right]$$

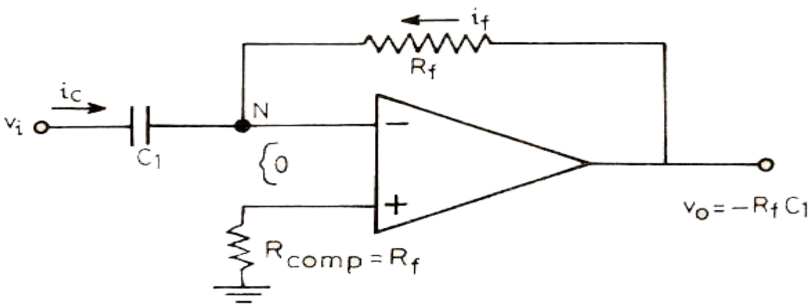
Where $A_f = \frac{R_2}{R_1} + 1$

$$f_C = \frac{1}{2\pi R_3 C}$$

3. Explain the analysis of differentiator. (NOV/2013)(APRIL/2014)

The circuit which produces the differentiation of the input voltage at its output is called differentiator. The differentiator circuit which does not use any active device is called passive differentiator. While the differentiator using an active device like op-amp is called an active differentiator.The circuit performs the mathematical operation of differentiation. i.e. the output wave form is the derivative of the input waveform. The differentiator provides a constant output above a cut-off frequency and passes no signal below this frequency. So the differentiator is also called as high pass filter (HPF).The non-inverting terminal (3) is grounded. Therefore node 'a' voltage is zero.

i.e. Va = 0



(i.e.) $V_o \propto dVi$

At node 'a',

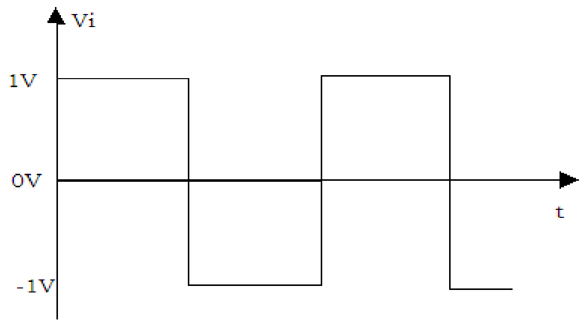
$$C_f \frac{dV_i}{dt} + \frac{V_0}{R_f} = 0$$

- ✓ The node 'a' is virtually grounded. Therefore $V_n = V_a = 0$

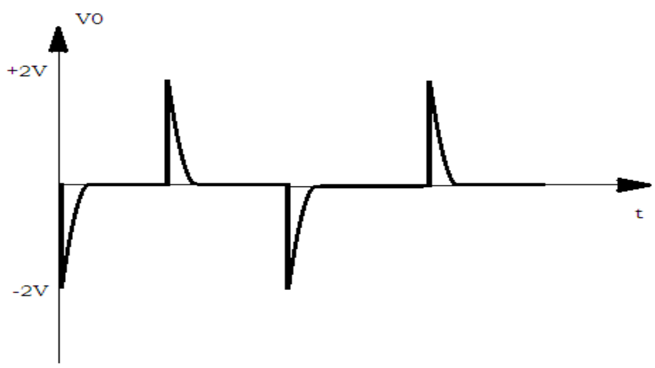
$$\frac{V_0}{R_f} = -C_1 \frac{dV_i}{dt}$$

- ✓ Here the –ve sign is introduced because the input is given to the inverting terminal

The equation shows that the output is C_1R_f times the differentiation of the input and product C_1R_f is called time constant of the differentiator.



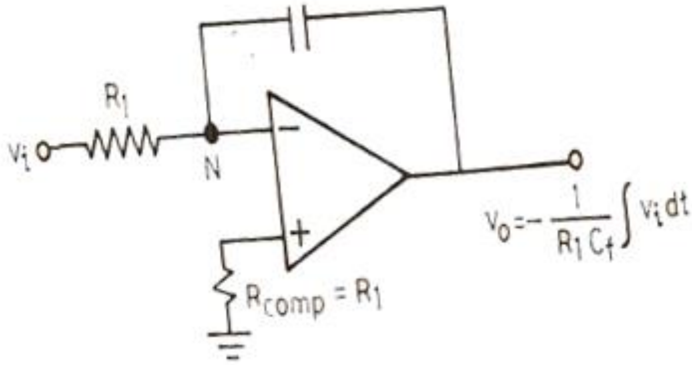
Input to Differentiator



Output of Differentiator

4. Draw and explain the operation of integrator circuits. (NOV/2013)

In an integrator circuit, the output voltage is the integration of the input voltage. The integrator circuit can be obtained without using active devices like op-amp, transistors etc. in such a case an integrator is called passive integrator. While an integrator using an active device like an op-amp is called active integrator. The integrator provides a constant output below a cut-off frequency and passes no signal above this frequency. So the integrator is also called as low pass filter (LPF). If we inter change the resistor and the capacitor of the differentiator we get the circuit of an integrator.



The non- inverting terminal is grounded. The node N is also at ground potential from the concept of virtual ground.$V_N = 0$, as input current of op-amp is zero, the entire current I flowing through R_1, also flows through C_f (i.e) Vo ∞ Vi

At node ‘a’

$$\frac{V_i}{R_1} + C_f\frac{dV_0}{dt} = 0$$

$$C_f\frac{dV_0}{dt} = -\frac{V_i}{R_1}$$

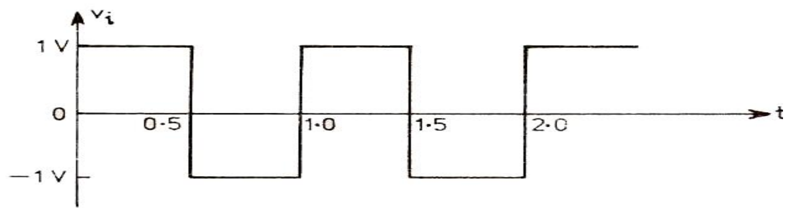
$$\frac{dV_0}{dt} = -\frac{V_i}{R_1 C_f}$$

$$dV_0 = -\frac{V_i dt}{R_1 C_f}$$

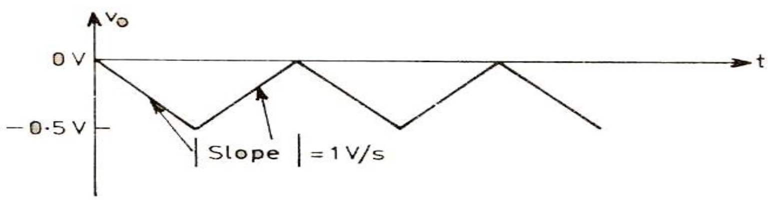
Integrating on both sides

$$\int dV_0 = -\frac{V_i * dt}{R_1 C_f}$$

$$\int dV_0(t) = \left(\frac{1}{C_f R_1}\right)\int V_i(t)$$



Input to Integrator



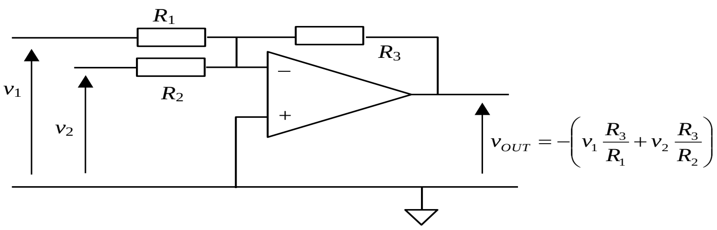
Output of Integrator

5. With neat circuit diagram explain the operation of adder and subtractor. (APRIL2012) (NOV/2012) (NOV/2013)

A circuit whose output is the sum of all the inputs given is called summer or summing amplifier. There are two types of summer (i) inverting summer & (ii) non-inverting summer.

(i) Inverting Summer

A summer amplifier with two input voltages V1 and V2, two input resistors R1 and R2, feedback resistor Rf is shown in the fig. below



Inverting Summer

The voltage at the node ‘a’ is zero as the non- inverting input terminal is virtually grounded.

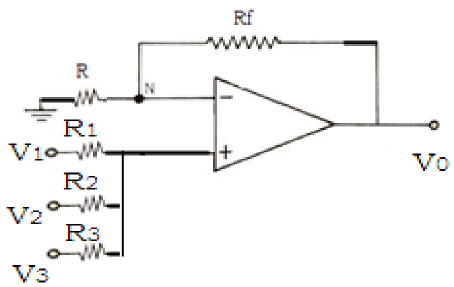
The nodal equation by KCL at node ‘a’ is

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_0}{R_3} = 0$$

$$V_0 = {R_f}/{R_1}\,(V_1 + V_2)$$

$$V_0 \infty (V_1 + V_2)$$

(ii) Non Inverting Summer



Non Inverting Summing amplifier

For non inverting,

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

$$V_{in} = \frac{{V_1}/{R_1} + {V_2}/{R_2} + {V_3}/{R_3}}{{1}/{R_1} + {1}/{R_2} + {1}/{R_3}}$$

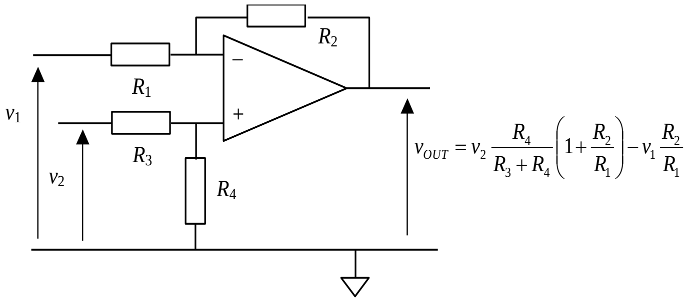
$$V_0 = \left[1 + \frac{R_f}{R}\right]\left[\frac{{V_1}/{R_1} + {V_2}/{R_2} + {V_3}/{R_3}}{{1}/{R_1} + {1}/{R_2} + {1}/{R_3}}\right]$$

If $R_1 = R_2 = R_3 = R$

$$V_0 = \left[1 + \frac{R_f}{R}\right]\left[\frac{V_1 + V_2 + V_3}{3}\right]$$

(iii)DIFFERENTIAL AMPLIFIER (or) SUBTRACTOR

A circuit that amplifier the difference between the two signals. The differential amplifier is very useful in instrumentation circuits. The voltage V_1 and V_2 are applied at op-amp input terminals. The different voltage at the input terminal of the op-amp is zero. Node 'a' and 'b' are at the same potential designated as V_3.



Consider node 'a',

$$\frac{V_3 - V_2}{R_1} + \frac{V_3 - V_0}{R_2} = 0$$

Consider node 'b'

$$\frac{V_3 - V_1}{R_1} + \frac{V_3}{R_2} = 0$$

Rewriting equation (a) & (b)

$$\left(\frac{1}{R_1} + \frac{1}{R_2}\right)V_3 - \frac{V_2}{R_1} = \frac{V_0}{R_2}$$

$$\left(\frac{1}{R_1} + \frac{1}{R_2}\right)V_3 - \frac{V_1}{R_1} = 0$$

Subtracting equating (3) from (4)

$$-\frac{V_2}{R_1} + \frac{V_1}{R_1} = \frac{V_0}{R_2}$$

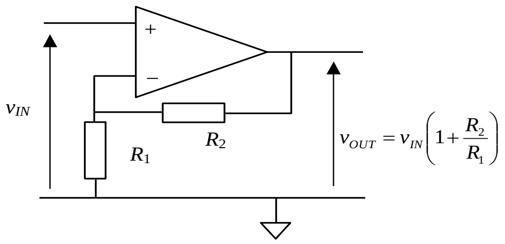
$$\frac{V_1 - V_2}{R_1} = \frac{V_0}{R_2}$$

$$V_0 = \frac{R_2}{R_1}(V_1 - V_2)$$

6. Explain the analysis of inverting amplifier and non- inverting amplifier (APRIL/2013)

(i) INVERTING AMPLIFIER

An inverting amplifier not only amplifies the input signal but also produce a phase shift in voltage between the input and the output.



Inverting Amplifier

The op amp circuit consists of a resistor R_1 and a feedback resistor R_f.R_1 is connected between the input and the inverting terminal of the op amp.The R_f is connected between the input inverting(2) terminal and the output(6) of the op amp. The non- inverting terminal (3) is grounded. The input and the output of the inverting amplifier are out of phase with each other.Since the input impedance of the op-amp is large, current cannot enter into the op-amp. So output current is same as the input current i.e. $I_1 = I_0$. The input is given to the inverting terminal and the non-inverting terminal is virtually grounded therefore the node voltage is zero.So voltage developed across R_f is equal to the output voltage Vn of the circuit.

W.K.T,

$V_i = I_1R_1$

$I_1 = V_i/R_1$

$V_o = I_o * R_f$

$V_o = -I_1*R_f \ (I_o = -I_1)$

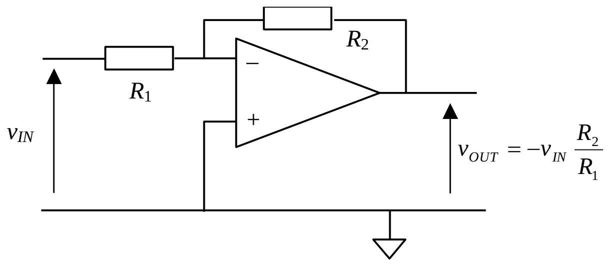
Here the –ve sign indicates that the input and the output are in the opposite direction

$V_o = -V_i * R_f / R_1$

$Av = -R_f / R_1$

(ii) NON-INVERTING AMPLIFIER:

A non-inverting amplifier amplifies the signal and the output is same as that of the input. In the non-inverting amplifier the input is applied to the non-inverting terminal (3) and the resistor R_1 is grounded. The voltage at the inverting terminal (Vi) must be same as that at the non-inverting terminal. The input impedance of the op-amp is very high so that the entire voltage given is obtained at the node 'a'.If I_1 is the current through the resistor R_1,$V_i= I_1.R_1$



Non Inverting Amplifier

Since the voltage drop across R_1 is equal to the difference between V_i and V_o,

$$I_0 = \frac{V_0 - V_i}{R_f}$$

$$I_o * R_f = V_o - V_i$$

$$V_o = V_i + I_o. * R_f$$

We know that, $I_1 = I_o$,

$$V_o = V_i + I_1.R_f$$

From (1) & (2)=

$$A_V = \frac{V_0}{V_i}$$

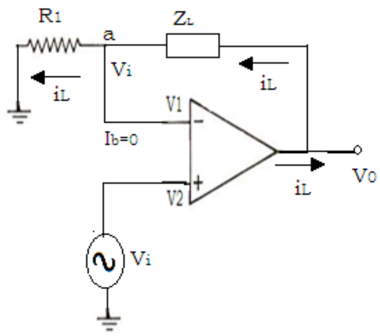
$$A_V = \frac{V_i + I_1 * R_f}{I_1 * R_1} = \frac{I_1 * R_1 + I_1 * R_f}{I_1 * R_1} = \frac{R_1 + R_f}{R_1}$$

7. Explain in detail about V to I converter. (APRIL/2012)

(i) Voltage To Current Converter [Transconductance Amplifier]

In many application it is necessary to convert voltage signal to a proportional output current.

- V- I converter with floating load
- V- I converter with grounded load



V-I Converter with Load Z_L

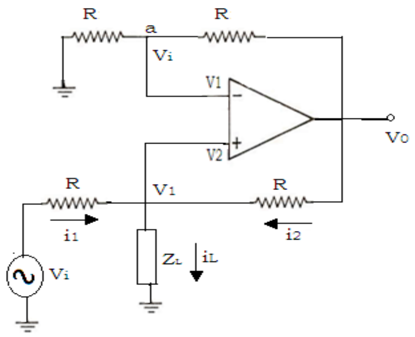
Since the voltage at node a is V_i

$$V_i = i_L R_1$$

$$i_L = \frac{V_i}{R_1}$$

(i.e.) the input voltage V_i is converted into an output current of $\frac{V_i}{R_1}$

Same current flows through signal source and load



Applying KCL, $i_1 + i_2 = i_L$

$$\frac{V_i - V_1}{R} + \frac{V_0 - V_1}{R} = i_L$$

$$\mathrm{V_i + V_0 - 2V_1 = Ri_L}$$

$$V_1 = \frac{Ri_L - V_0 - V_i}{-2}$$

$$V_1 = \frac{-Ri_L + V_0 + V_i}{2}$$

Since op-amp is used in non-inverting mode

$$\mathrm{Gain} = 1 + {}^{\mathrm{R}}/_{\mathrm{R}}$$

$$\mathrm{Gain} = 2$$

Output Voltage, $V_0 = 2V_1$

$$V_i = I_L R_1$$

$$I_L = \frac{V_i}{R_1}$$

Input impedance of non-inverting amplifier is very high.

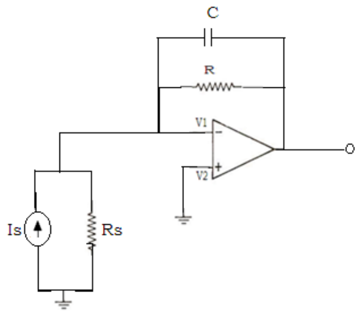
Applications:

- It is used in low voltage DC and AC voltmeter
- It is used in led and Zener diode

(ii) Current To Voltage Converter [Transresistance Amplifier]

Photocell, photodiode, photovoltaic cell give an output current, (i.e.) proportional to an incident radiant energy or light.The circuit through this device can be converted to voltage by using a current voltage converter and there by the amount of light or radiant energy incident on the photo device can be measured.-ve terminal is at virtual ground, no current flows through R_s and current Is flows through the feedback resistor R_f, thus the output voltage

$$V_0 = i_s R_f$$



Resistor R_f is sometime shunted with a capacitor C_f to reduce high frequency noise and the possibility of oscillation.

Reference:

1. *I. Albert Malvino and David Bates, "Electronic Principles", 7th Edition, Tata Mc-Graw Hill, New Delhi, 2006.*
2. *Ramakant A Gayakward, Operational Amplifiers and Linear Integrated circuits, 4th Edition, PHI Learning, Delhi, 2009.*