UNIT 5

SYLLABUS

UNIT 5 SPECIAL FUNCTION ICs 9 Hrs.

Integrated circuit Tuned amplifier, Instrumentation Amplifier, Series and shunt voltage regulator, Opto coupler, CMOS Operational Amplifier- DC analysis- small signal analysis- specifications of IC MC 14573.

TABLE OF TOPICS

5.1. Integrated circuit Tuned amplifier

The circuit shown in this section is an IC tuned amplifier that amplifies a signal over a narrow band of frequencies centered at f_r. here the input signal is applied through the tuned transformer T_1 to the base of Q_1. The load R_L is connected across the tuned transformer T_2 in the collector circuit of Q_3. The transistor Q_1 and Q_3 provides the amplification whereas Q_2 provides the control of magnitude of the gain. The combination of Q_1 and Q_3 acts as a common-emitter and common-base cascade (CE-CB) pair. The input resistance and the current gain of a cascade pair are essentially the same as those of a CE stage the output resistance is the same as that of a CB stage.

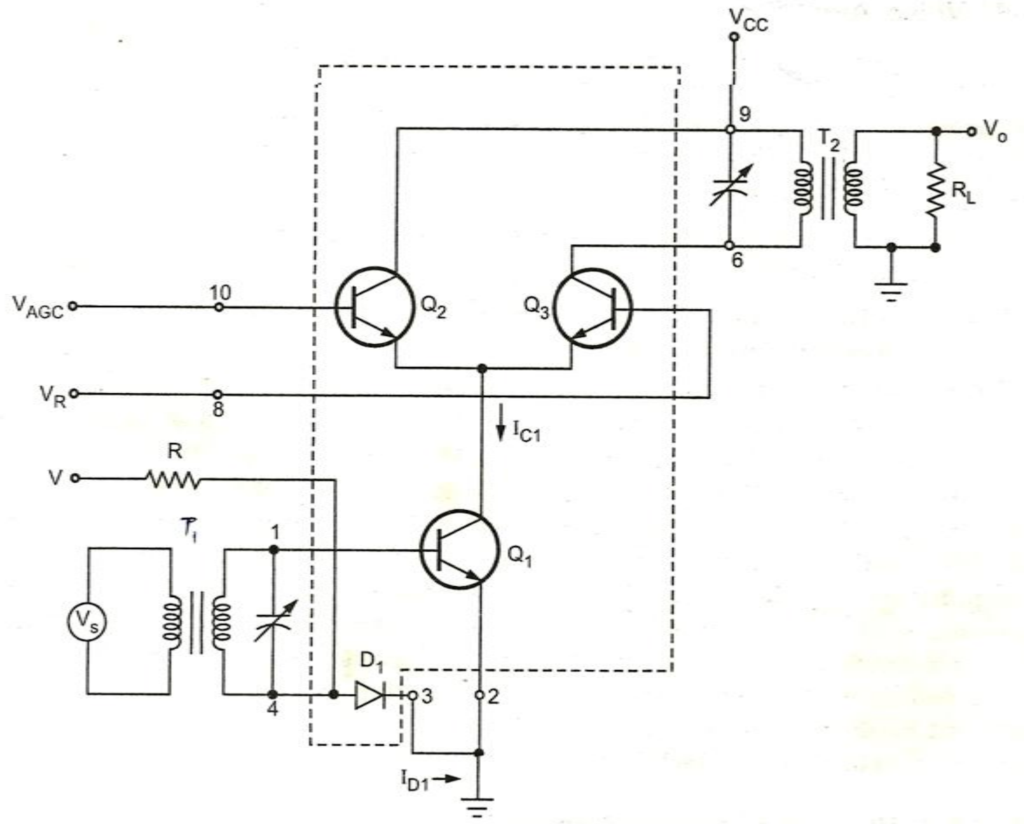

Fig. 5.1.Integrated Circuit tuned amplifier.

The voltage V_{AGC} applied to the base of transistor Q_2 is used to provide automatic gain control. The variation in V_{AGC} cause changes in the division of the current between transistors Q_2 and Q_3. When V_{AGC} is greater than V_R Q_2 conducts more than Q_3, reducing voltage gain. On the other hand when V_R greater than V_{AGC}, Q_3 conducts more than Q_2, which increases voltage gain.

V_R greater than V_{AGC}, Q2 is cut-off and the collector current of Q_1 flows through Q_3 providing maximum voltage gain A_V. the change in V_{AGC} causes the change in the division of current and not the collector current of Q_1. Thus the input impedance of Q_1 remains constant and the input circuit is not tuned.

The voltage V and resistance R establish the dc current I_{D1} through the diode D_1. The voltage V_{BE1} is nearly equal to V_{D1} and the collector current I_{C1} is within the ± 5% of I_{D1}.

Advantages of tuned amplifiers

1. Signal to noise ratio is good
2. They are suited for radio transmitters and receivers.
3. Required bandwidth of amplification can be selected

Disadvantages of tuned amplifiers

1. Inductors and capacitors of tuned amplifiers become bulky and costly.
2. As the band of frequency is increased, the design is complex.
3. They are not suitable for amplifying audio frequencies.

5.2 Instrumentation Amplifier

Many instruments use sensors (transducers) for measurement of temperature, pressure, weight, humidity, viscosity etc.

The sensors convert other form of energy to proportional electrical energy.

But the sensor outputs are very low-level signals.

These low-level signals cannot drive next stages of the system. And other external noises shall still reduce the signal level.

So to enhance such signals to desired level using a special amplifier with high CMRR, high input impedance, and low power consumption termed **Instrumentation amplifier**.

The instrumentation amplifier is also called data amplifier and is a difference amplifier basically. The expression for its voltage gain is in the form shown below,

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

Where

V_o = The amplifier output Voltage

$V_2 - V_1$ = Differential input voltage of the amplifier

Requirements of Instrumentation amplifier

1. Accurate and stable gain is the basic requirement. And the gain shall be finite.
2. Gain shall be easily adjusted and shall be precisely done.
3. High input impedance
4. Low output impedance
5. High CMRR
6. Low power consumption
7. Low temperature drifts
8. High Slew Rate

Two-op amp Instrumentation amplifier

The instrumentation amplifier with two op amp is shown below.

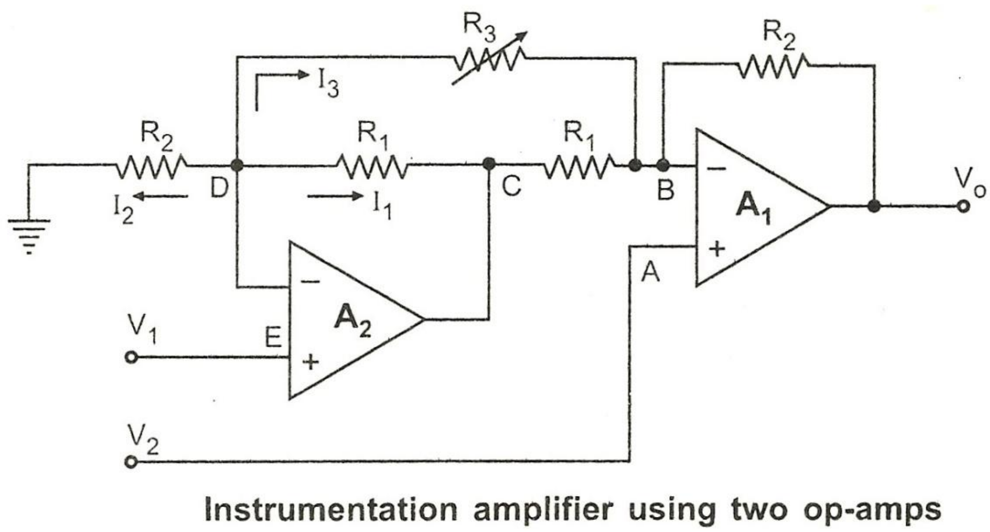

Fig. 5.2.1. Instrumentation amplifier using two op amps

The above circuit consists of two operational amplifiers A1 and A2.

Analysis:

For amplifier A1,

Node voltage at A shall be same as node B.

$$V_A = V_B = V_2$$

Similarly for amplifier A_2, Node voltage at E shall be same as node D.

$$V_D = V_E = V_1$$

Now,

$$I_2 = \frac{V_D}{R_2} = \frac{V_1}{R_2}$$

$$I_1 = \frac{V_D - V_C}{R_1} = \frac{V_1 - V_C}{R_1}$$

$$I_3 = \frac{V_D - V_B}{R_3} = \frac{V_1 - V_2}{R_3}$$

Applying KCL at node D, $I_1 + I_2 + I_3 = 0$

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

$$V_1\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right] - \frac{V_2}{R_3} = \frac{V_C}{R_1}$$

Similarly applying KCL at node B and neglecting input current of op-amps we can write,

$$\frac{V_B - V_D}{R_3} + \frac{V_B - V_C}{R_1} + \frac{V_B - V_o}{R_2} = 0$$

$$\frac{V_2 - V_1}{R_3} + \frac{V_2 - V_C}{R_1} + \frac{V_2 - V_o}{R_2} = 0$$

$$V_2 \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right] - \frac{V_1}{R_3} - \frac{V_o}{R_2} = \frac{V_C}{R_1}$$

Equating both the expressions V_C/R_1, we get,

$$V_1 \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right] - \frac{V_2}{R_3} = V_2 \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right] - \frac{V_1}{R_3} - \frac{V_o}{R_2}$$

Simplifying we get

$$\frac{V_o}{V_2 - V_1} = 1 + \frac{R_2}{R_1} + \frac{2R_2}{R_3}$$

The differential input is $V_2 - V_1$ while V_o is the output voltage. Thus the voltage gain of this circuit is

$$A_V = 1 + \frac{R_2}{R_1} + \frac{2R_2}{R_3}$$

As the resistance R_3 is variable, the circuit permits gain variation, precisely.

Advantages of two op amp Instrumentation amplifier

The instrumentation amplifier with two op amp has following advantages.

1. The gain variation is easy and precise
2. The CMRR value is completely independent of the setting of resistance R_3. Hence with the precision ratios for R_2/R_1, the gain can be changed without degrading the performance of the amplifier.
3. The resistance R_3 is separate from the accurately matched resistances R_1 and R_2, which are required for symmetric arrangement.

Limitations of two op amp Instrumentation amplifier

1. The problem is resistances R_1 and R_2 must be accurately matched.
2. The input V_1 has to propagate through A_2 before reaching A_1. Due to this additional delay, common mode components of the two signals will no longer cancel out with each other, at high frequencies. Thus symmetry of input is not there where V_1 has time delay than V_2 to reach A_1.
3. CMRR decreases with frequency because of the above asymmetrical input with time delay.

Three-op amp Instrumentation amplifier

The instrumentation amplifier with three op amp is shown below.

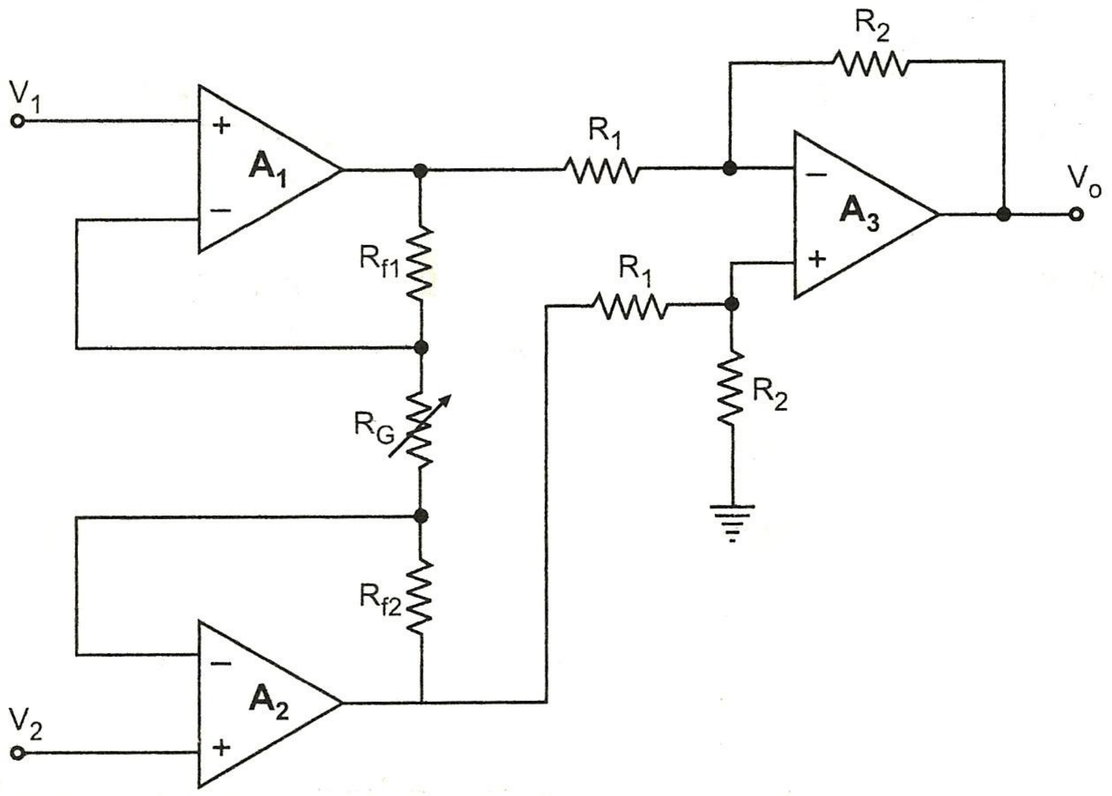

Fig. 5.2.2. Instrumentation amplifier using three op amps

The above circuit consists of three operational amplifiers A_1, A_2 and A_3.

Since a non-inverting amplifier A_3 is added to each of the basic difference amplifier inputs. The op-amps A_1 and A_2 are non-inverting amplifiers forming first stage of the amplifier. The op-amp A_3 is a difference amplifier forming an output stage of the amplifier.

Analysis:

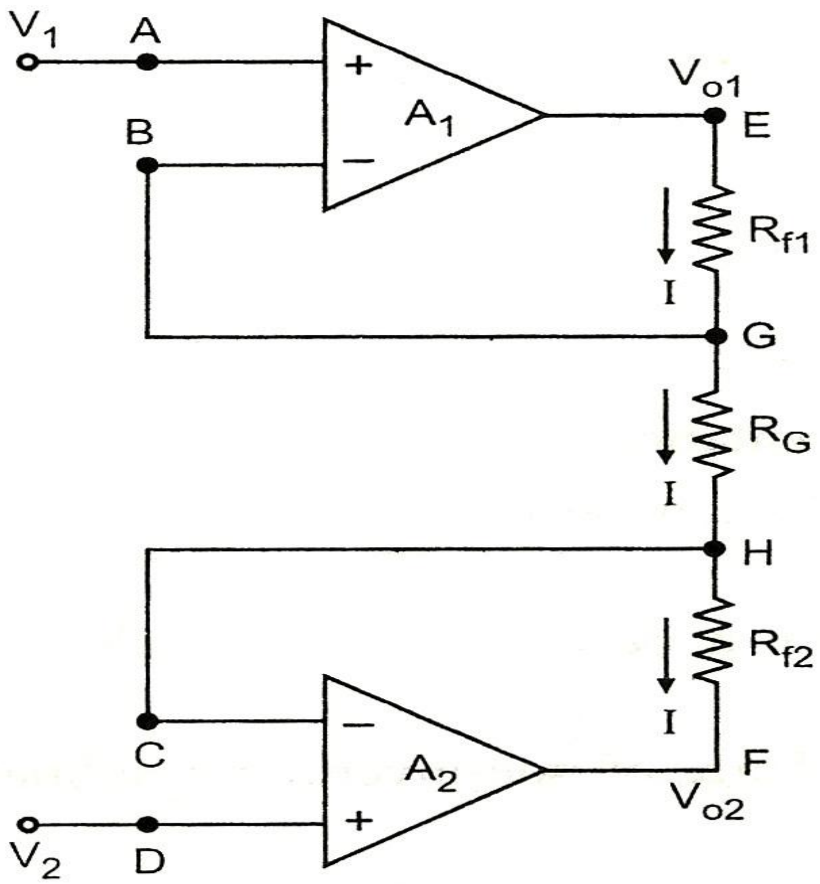

Fig. 5.2.3. Analysis of Three op-amp Instrumentation Amplifier

If the output of the op-amp A_1

If the output of the op-amp A_1 is V_{01} and op-amp A_2 is V_{02},

$$V_o = \frac{R_2}{R_1}(V_{02} - V_{01})$$

Expression for V_{02}, V_{01} in terms of V_1, V_2, R_{f1}, R_{f2} and R_G: From above fig. 5.2.3

The node potential of op-amp A_1 is V_1 thus node B shall also B and G are V_1.

The node D potential of op-amp A_2 is V_2. Node C and H potential is also V_2.

Input current of Op-amp A_1 and A_2, are zero. Hence current I remain the same through R_{f1}, R_{f2}, and R_G.

Applying ohms law between the nodes E and F, we get,

$$\mathrm{I} = \frac{\mathrm{V}_{01} - V_{02}}{\mathrm{R}_{f1} + \mathrm{R}_{f2} + \mathrm{R}_G}$$

Let $R_{f1} = R_{f2} = R_f$

$$\mathrm{I} = \frac{\mathrm{V}_{01} - V_{02}}{2\mathrm{R_f} + \mathrm{R_G}}$$

Now from observations of Nodes G and H,

$$\mathrm{I} = \frac{\mathrm{V_G} - \mathrm{V_H}}{\mathrm{R_G}} = \frac{\mathrm{V_1} - \mathrm{V_2}}{\mathrm{R_G}}$$

Equating above two equations,

$$\frac{\mathrm{V}_{01} - V_{02}}{2\mathrm{R_f} + \mathrm{R_G}} = \frac{\mathrm{V_1} - \mathrm{V_2}}{\mathrm{R_G}}$$

$$\mathrm{V}_{01} - V_{02} = \frac{(\mathrm{V_1} - \mathrm{V_2})(2\mathrm{R_f} + \mathrm{R_G})}{\mathrm{R_G}}$$

Substituting the above $\mathrm{V}_{01} - V_{02}$ in the equation $V_o = \frac{R_2}{R_1}(V_{02} - V_{01})$, we get,

$$\mathrm{V_0} = \frac{\mathrm{R_2}}{\mathrm{R_1}} \frac{(\mathrm{V_1} - \mathrm{V_2})(2\mathrm{R_f} + \mathrm{R_G})}{\mathrm{R_G}}$$

$$\mathrm{V_0} = \frac{\mathrm{R_2}}{\mathrm{R_1}} \left[1 + \frac{2\mathrm{R_f}}{\mathrm{R_G}}\right] (V_1 - V_2)$$

This is the overall gain of the circuit.

Advantages of three op-amp instrumentation amplifier.

Following are the advantages of three op-amp instrumentation amplifier circuit:

1. With the hep of variable resistor R_G, the gain of the amplifier can be easily varied.
2. Gain depends on external resistances and hence can be adjusted accurately and made stable by selecting high quality resistances.
3. The input impedance depends on the input impedace of non-inverting amplifiers which is extremely high.

5.3 Voltage Regulators

The voltage regulator in its simplest form consists of

Voltage reference, V_R

Error amplifier

Feedback network

Active series or shunt control element

The voltage reference generates a voltage level which is applied to the comparator circuit, which is generally an error amplifier. The second input to the error amplifier is obtained through feedback network. Generally using the potential divider, the feedback signal is derived by sampling the output voltage. The error amplifier converts the difference between the output sample and the reference voltage into an error signal. This error signal in-turn controls the active element of the regulator circuit in order to compensate the change in the output voltage. Such an active element is generally a transistor.

5.3.1 Types of voltage regulators

Depending upon where the control element is connected in the regulator circuit, the regulators are basically classified as

Series voltage regulator

Shunt voltage regulator

Each type provides a constant d.c. output voltage which is regulated.

5.3.2 Advantages of IC voltage Regulators

1. Easy to use
2. It greatly simplifies power supply design
3. Due to mass production, low in cost
4. IC voltage regulators are versatile
5. Conveniently used for local regulation
6. These are provided with features lime built-in protection programmable output, current/voltage boosting, internal short circuit current limiting etc.

5.3.3 Classification of IC voltage regulators

The IC voltage regulators are classified as shown in the figure below.

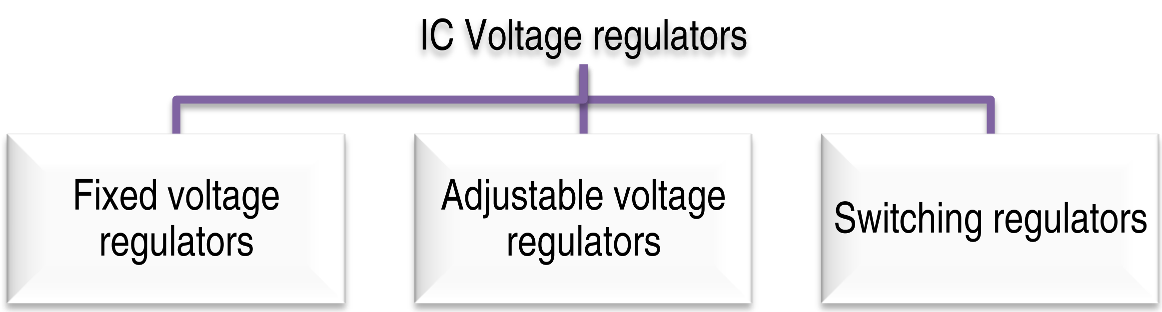

Fig. 5.3.3 Classification of IC regulators

5.3.4 Three terminal fixed voltage regulators

As the name suggest, three terminal voltage regulators have three terminals namely input which is unregulated (V_{in}), regulated output (V_o) and common or a ground terminal. These regulators do not require any feedback connections. The figure below shows the basic three terminal voltage regulators.

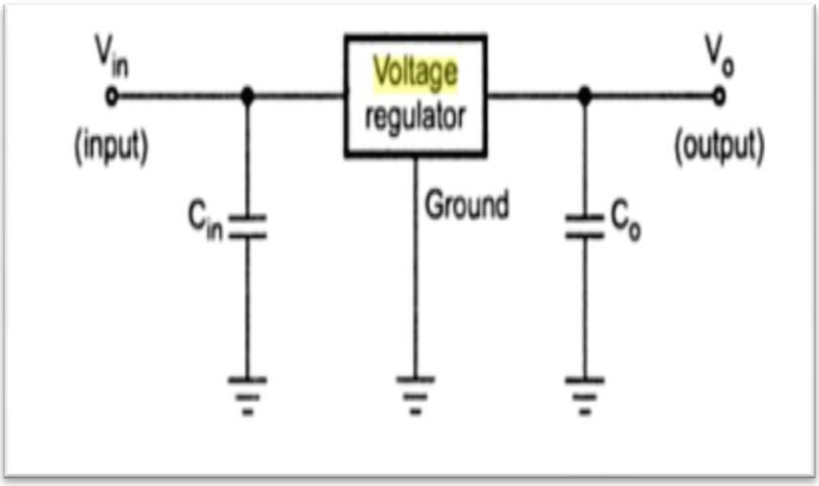

Fig.5.3.4. Basic regulator circuit (Three Terminals)

The capacitor C_{in} is required if regulator is located at appreciable distance more than 5 cm from a power supply filter. The output capacitor C_o may not be needed but if used it improves the transient response of the regulator i.e. regulator response to the transient changes in the load. This capacitor also reduces the noise present at the output. The difference between V_{in} and V_o ($V_{in} – V_o$) is called as dropout voltage and it must be typically 2.0V even during the low point on the input ripple voltage, for the proper functioning of the regulator.

5.3.5 IC series of three terminal fixed voltage regulators

The popular IC series of three terminal regulators is μA78XX and μA79XX. The series μA78XX is the series of three terminal positive voltage regulators while μA79XX is the series of three terminal negative voltage regulators. The last two digits denoted as XX indicate the output voltage rating of the IC.

Such series is available with seven voltage options as indicated in table below.

Device type	Output voltage	Device type	Output voltage
7805	5.0 V	7905	-5.0 V
7806	6.0 V	7906	-6.0 V
7808	8.0 V	7908	-8.0 V
7812	12.0 V	7912	-12.0 V
7815	15.0 V	7915	-15.0 V
7818	18.0 V	7918	-18.0 V
7824	24.0 V	7924	-24.0 V

The 79XX series voltage regulators are available with same seven options as 78XX series, as indicated in the above table. In addition, two extra voltages – 2 V and – 5.2 V are also available with ICs 7902 and 7905.2 respectively.

These ICs are provided with adequate heat sinking and can deliver output currents more than 1 A. these ICs do not require external components. These are provided with internal thermal protection, overload and short circuit protection.

The two series are available in various versions like low-power and high-power versions. The low-power versions are available in plastic or metal packages, like small signal transistors. The higher power versions are packaged in TO-3 type metal cans or in TO-220 type moulded plastic packages like power transistors.

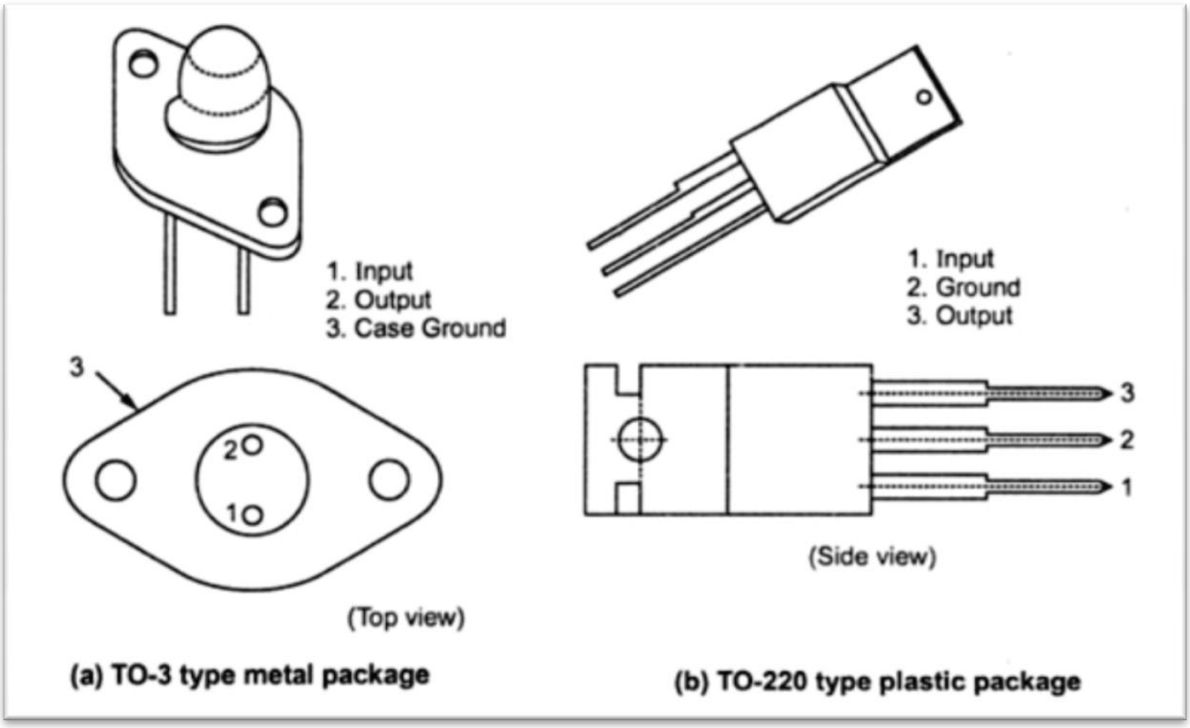

Fig. 5.3.5. Types of IC packages (Voltage Regulators)

5.4. Opto-coupler.

The combined package of an LED and a photo diode is termed as an optocoupler. It is otherwise called as opto-isolator or optically coupled isolator.

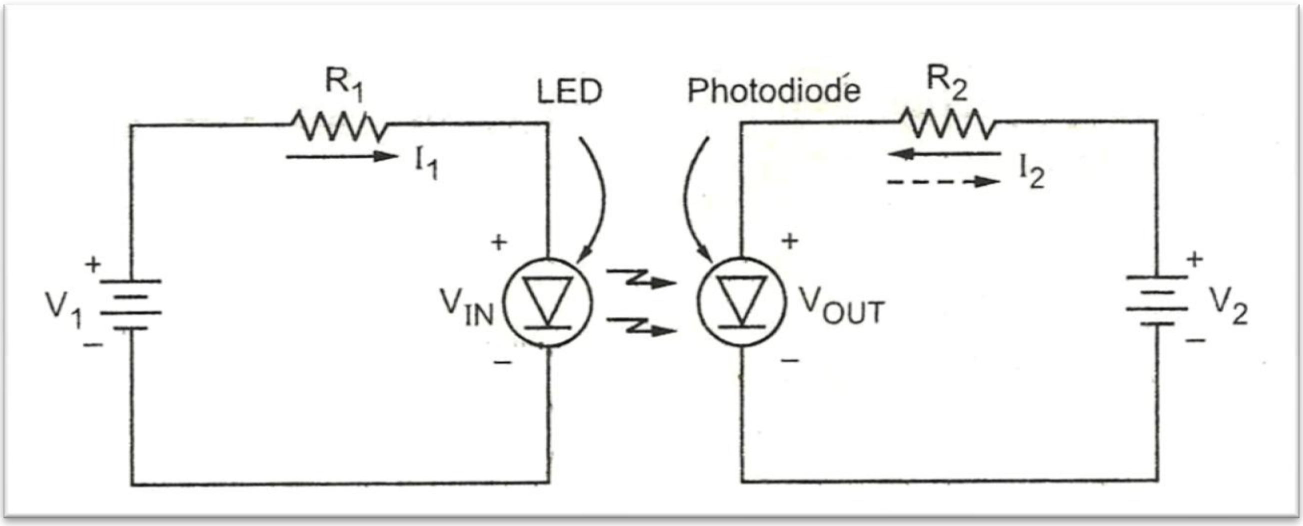

Fig. 5.4.1. Basic Opto-coupler.

The source V_1 and series resistance R_1 decide the forward current I_1 through the LED. Hence LED emits the light. This light is incident on a photodiode. Due to this a reverse current is set up in the output circuit. This current produces a drop across output resistance R_2, the output voltage is the difference between the supply voltage V_2 and the drop across the resistor R_2.

$$V_{out} = V_2 - I_2 R_2$$

Now if input voltage is changed the amount of light emitted by LED changes. This varies the reverse current in the output circuit and hence the output voltage. The output voltage is thus varying in step with the input voltage. This coupling between LED and photodiode is hence called optocoupler. As the name suggest his device can couple an input signal to the output circuit.

The figure 5.4.1 (a) shows the typical optoisolator. It consists of LED and phototransistor.

When the input voltage forward biases the LED light transmitted to the phototransistor turns it on resulting current through the external load as shown in the fig. 5.4.2 (b).

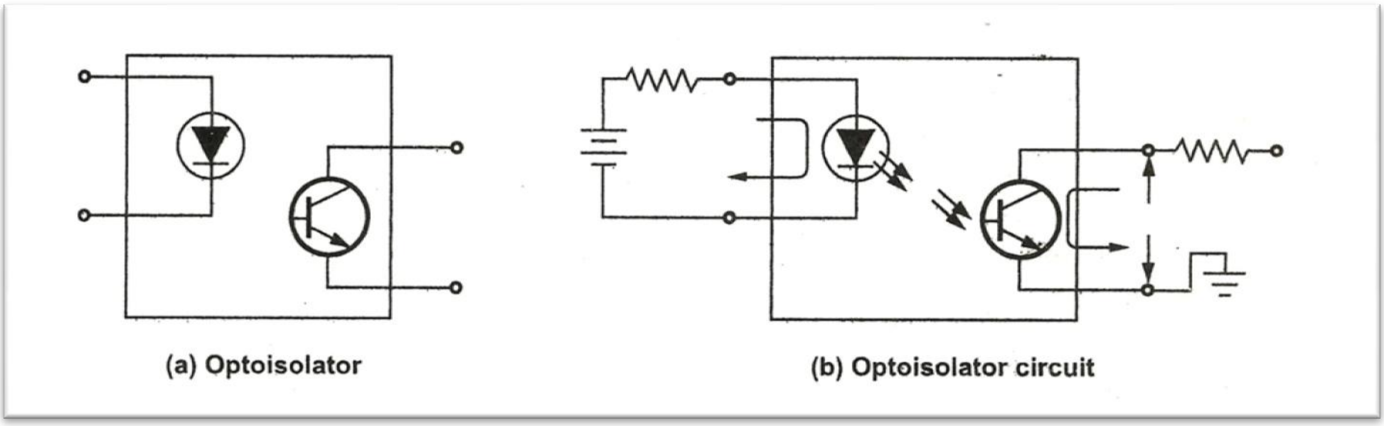

Fig.5.4.2. Optoisolator circuits with Phototransistor

5.4.1 Types of optocouplers

Other than the combination of LED and phototransistor two more types of optocouplers are available which are

1. LED-Photodiode
2. LED-Photodarlington
3. In both the circuits the input current which is the forward current of LED results in the emission of light by LED. This light is detected by photodiode and Photodarlington to produce the output current. These two optocouplers are shown in the fig.5.4.3 (a) and fig. 5.4.3(b)

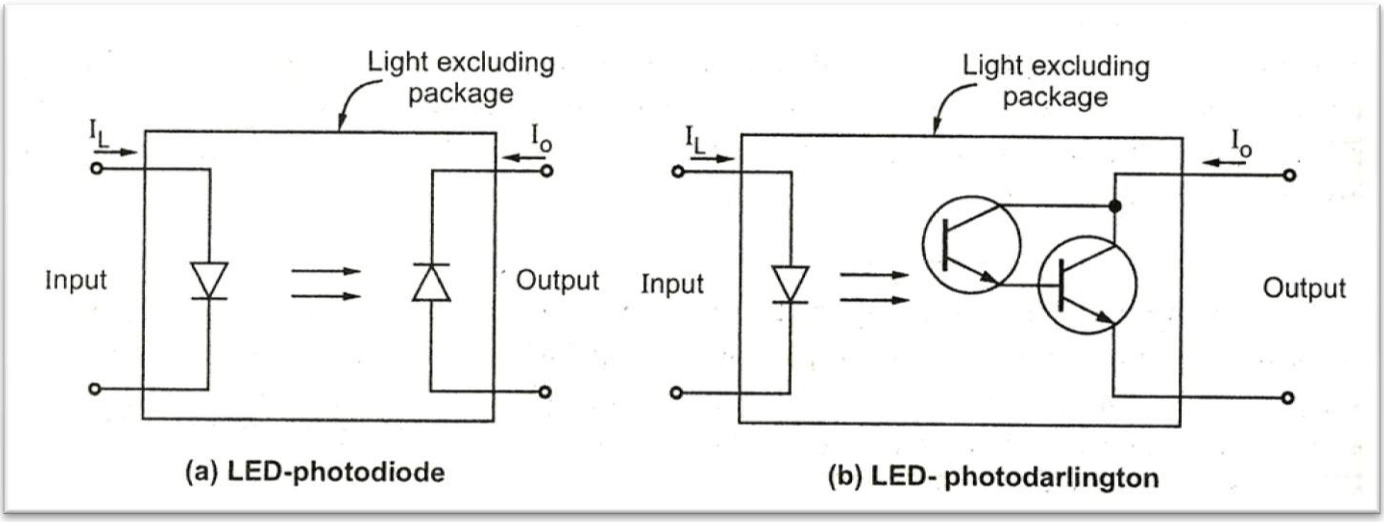

Fig.5.4.3. Types of Optoisolator circuits

The ratio of output current I_0 to the input LED current I_L is called current transfer ratio CTR). This CTR is different for different optocouplers as indicated in the below table.

Table. 5.4.1. Current transfer ratio (CTR) for different detectors

Device	CTR
LED-Photodiode	0.01 – 0.03
LED-Transistor	0.1 – 1
LED-Darlington	1 - 5

The most important point of above devices is that a circuit connected to its input can be electrically fully isolated from the output circuit and that a potential difference of hundreds or thousands of volts can safely exists between two circuits without adversely influencing the optocoupler action.

5.4.2 Characteristics of optocoupler

Following are important characteristics of an optocoupler:

1) Current transfer ratio (CTR)
2) Isolation voltage
3) Response time
4) Common mode rejection
5) V_{CE} (max)
6) I_L (max)
7) Bandwidth
8)

1) **Current transfer ratio (CTR):**

The current transfer ration refers to the ratio of the output collector current (I_C) to the input forward current (I_F).

$$\text{Current transfer ratio} = \frac{I_C}{I_F} \times 100\%$$

The CTR greatly differs depending on the type of the phototransistor used in photocoupler. The photocoupler using Darlington phototransistor can provide a relatively large collector current from a small input current the CTR also varies with ambient temperature.

2) **Isolation voltage(V_{iso}) Between input and output:**

Isolation voltage (V_{iso}) between input and output is another important factor in choosing a photocoupler. This is because photocouplers are often used for signal transmission between circuits that have different potentials or as interfaces with actuator circuits which tend to generate impulsive voltage such as motor controllers or solenoid driver circuits. Isolation voltage is specified in KV_{rms} with a relative humidity of 40% to 60%.

3) **Response time:**

The response time of an optocoupler depends mainly on the output phototransistor. The response time also depends on the input forward current and load resistance. Since load resistance has a greater influence on the response time, careful setting is required while defining the circuit constant.

4) **Common mode rejection:**

While the photocouplers output is electrically isolated from its input for relatively low frequency signal an impulsive input voltage may cause a displacement current ($i_d = C_f$. dv / dt) to flow due to the floating capacitance (C_f) between the input and output of the optocoupler casing noise voltage to appear at the output.

5) <u>V_{CE} (max):</u>

This is the maximum allowable d.c. voltage that can be applied across output transistor or output photodiode.

6) <u>I_L (max):</u>

This is the maximum permissible d.c. current that can be allowed to flow in the input LED. Typical values vary from 40 mA to 100 mA.

7) Bandwidth:

This is the maximum signal frequency that can be usefully passed through the optocoupler when device is operated in its normal mode. Typical values vary from 20 KHz to 500 KHz.

The various advantages of optocouplers are,

1) The electrical isolation provides electrical insulation between input and output but data is transmitted from input to output through beam of light.
2) The response time of optocouplers is so small that they transmit data in Megahertz range.
3) It is capable of transmitting wide-band signal.
4) Unidirectional signal transfer means that output does not loop back to the input circuit.
5) Easy interfacing with logic devices.
6) Compact and light weight.
7) Must faster than the isolation transformers and relays.
8) As signal transfer is unilateral changing load do not affect input.