In general, all electronic circuits require a source of DC power. The amplifier and oscillator circuits you studied previous year employ a DC power supply named \( V_{cc} \). Batteries can be used for providing DC supply. But they are costly and require frequent replacement. Also, the electric power supply available is AC. So the DC power required for electronic circuits is obtained from 230 V AC lines by using a rectifier filter system followed by a regulator. This system which is used to convert AC supply to the required DC power is known as DC power supply.

The DC voltage from power supply remains constant so long as either AC mains voltage or load is constant. In most of the applications, it is desired that DC voltage should remain constant irrespective of the changes in AC mains or load. To make the DC voltage constant, voltage regulating devices are used. A power supply including a voltage regulator circuit is called a regulated DC power supply. Its output is a DC voltage which is fairly constant. The process of rectification and filtering were discussed previous year. In this chapter, we shall focus our attention on various voltage regulating circuits used to obtain regulated power supply.
1.1 Need for regulated power supply

Consider the block diagram of a DC regulated power supply. It consists of a rectifier, filter and a voltage regulator as shown in Fig 1.1.

Use your school laboratory to assemble the above circuit and verify the output waveforms using a CRO. The output from the rectifier is a pulsating DC. These pulsations are due to the presence of AC components in the rectifier output. We have seen that a filter circuit helps to obtain steady DC voltage across the load. But the DC voltage may change due to variations in the input voltage and load current.

Limitations: An ordinary DC power supply has the following drawbacks.

1) The DC output voltage decreases as the load current increases. This is due to the voltage drop in the transformer winding, rectifier and filter circuits. When the load current increases, the internal drop increases and the output voltage decreases.

2) In practice, there are considerable variations in the AC line voltage caused by outside factors beyond our control. We know that the DC output voltage of a fullwave rectifier is given by the equation $V_{dc} = 2V_m / \pi$, where $V_m$ is the peak value of input AC voltage and it is quite clear that the output DC voltage depends on the input AC voltage. Most of the electronic circuits refuse to work satisfactorily on such output voltage fluctuations. This necessitates the use of regulated DC power supply as the DC voltage source of electronic circuits.

3) The internal resistance of ordinary power supply is relatively large (>30 $\Omega$). Therefore, the output voltages will be considerably affected by the amount of load current drawn from the supply.

These variations in DC voltage may cause erratic operation of electronic circuits. Therefore, regulated DC power supply is essential in most electronic applications.

1.2 Regulated Power supply

A DC power supply which maintains the output voltage constant irrespective of AC mains fluctuations or load variations is known as a regulated DC power supply.
A regulated power supply consists of an ordinary power supply and a voltage regulating device. Fig 1.1 shows the block diagram of a regulated power supply. You have studied about rectifier, capacitor, filter and zener voltage regulator the previous year. Now you can set up the circuit as shown in the block diagram in your lab. You may observe the output of each section using a CRO and ensure that what you are seeing is similar to the output shown in the figure. The output of ordinary power supply is fed to the voltage regulator which produces the final output. The output voltage remains constant irrespective of the load current changes or fluctuations in the input AC voltage. The performance of a voltage regulator is measured using the following parameters.

i) **Load Regulation**

The DC voltage available across the output terminals of a given power supply depends upon the load current. If the load current $I_L$ is increased by decreasing $R_L$, the terminal voltage drops by a small amount. It is expected that the regulator minimizes this variation in the terminal voltage. The load regulation is a measure of the ability of the power supply to reduce the variation in output voltage with the change in load current. The percentage load regulation is represented as

$$% \text{ of Voltage regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

Where $V_{NL}$ is the DC output voltage at no load (zero load current), that is, the voltage at the minimum load. The minimum load is the one that draws the least current, i.e. at the highest specified load resistance.
$V_{FL}$ is the DC output voltage at full-load (maximum load current), that is, the voltage at the maximum load. The maximum load is the maximum current that can be drawn from the power supply as per its current rating. As an example, for a 5 V, 1 A power supply, the maximum current or current rating is 1 A and hence the full load is 1 A. In order to obtain this condition a 5 Ω resistance (5 V/1 A) should be connected as the load resistance.

In a well designed power supply, the full-load voltage is only slightly less than the no-load voltage, that is the voltage regulation approaches zero. Lower the voltage regulation, lesser is the difference between full-load and no-load voltages and better is the power supply. Power supplies used in practice have a voltage regulation of 1 % that is the full-load voltage is within 1 % of the no-load voltage.

**ii) Line Regulation**

Any change in the line voltage out of the normal value (i.e., 230 V AC) will affect the performance of the power supply. We know that the DC output voltage of a full wave rectifier is given by $V_{dc} = 2V_m / \pi$. Here, $V_m$ is the peak voltage of the AC input. So any change in AC input voltage will change the output DC voltage also. Line regulation is a measure of the ability of the power supply to maintain its output voltage constant against the changes in the input line voltage. Line regulation is expressed as the percentage change in the output voltage relative to the change in the input line voltage. The line regulation is represented as:

$$\text{Line regulation} = \frac{V_{HL} - V_{LL}}{V_{LL}} \times 100$$

Where $V_{HL}$ = load voltage with high line voltage
$V_{LL}$ = load voltage with low line voltage

The smaller the line regulation, the better is the power supply. A well-regulated power supply can have a line regulation of less than 0.1%.

**Types of Voltage Regulators**

A device which maintains the output voltage of an ordinary power supply constant irrespective of load variations or changes in input AC voltage is known as voltage regulator. A voltage regulator generally employs electronic devices to achieve this objective. There are basically two types of voltage regulators.

(i) Shunt voltage regulator
(ii) Series voltage regulator
The series regulator is placed in series with the load as shown in Fig 1.2(a). On the other hand, the shunt regulator is placed in parallel with the load as shown in Fig 1.2(b). Each type of regulator provides output voltage that remains constant even if the input voltage varies or the load current changes.

1.3 Zener diode Voltage Regulator

We have studied that, when the zener diode is operated in the break down or zener region, the voltage across it is constant for large change of current through it. This characteristic of zener diode helps it to be used as voltage regulator. Fig 1.3 shows the circuit of a zener diode regulator. As long as the input voltage $V_{in}$ is greater than the zener voltage $V_z$, the zener operates in the breakdown region and maintains constant voltage across the load. The zener diode will operate in the breakdown region only if the current through it is greater or equal to a minimum current as its specifications. Also a zener diode cannot withstand current above the maximum value. Hence, for voltage regulators, zener diodes of appropriate voltage and current ratings should be selected. The series resistance $R_s$ is used for limiting the input current.
The zener will maintain constant voltage across the load in spite of the changes in the load current or the input voltage. Now, let us see how this regulator maintains constant output voltage when the input voltage $V_{in}$ varies. Assume that $V_{in}$ varies above a specific voltage so that the zener diode is always in break down condition.

If $V_{in}$ increases, then the input current $I_s$ also increases because

$$I_s = \frac{(V_{in} - V_Z)}{R_s} \quad \quad \quad (1.1)$$

Also we have

$$I_s = I_z + I_l \quad \quad \quad (1.2)$$

$$V_o = V_z = I_l R_l \quad \quad \quad (1.3)$$

From the equation 1.3, it is seen that $I_l$ cannot vary since $V_z$ and $R_l$ do not vary. So from the equation 1.2, it is clear that when $I_z$ increases, $I_s$ also increases. For a zener diode it is possible that the current through it can vary without changing the voltage across it, if the diode is in the break down condition. Thus the output voltage remains constant even when the input voltage increases. The increased input voltage causes $I_s$ to increase and hence this voltage drops across the series resistor $R_s$.

When $V_{in}$ decreases, the $I_s$ also decreases, so that the voltage across $R_s$ decreases and the output voltage $V_z$ remains constant. Thus any change in the input voltage changes the voltage across $R_s$ and not the output voltage.

What happens to the regulator circuit when load varies? We shall discuss now the regulation against the load variation. Let us assume that the line voltage or input voltage remains constant. So $V_{in}$ is constant. Hence the total current drawn from the circuit, $I_s$ should be constant according to the equation 1.1.

If $R_l$ increases, $I_l$ also decreases. Then the current $I_z$ flowing through the zener diode increases, so that, $I_s$ remains constant. Similarly when $R_l$ decreases, $I_l$ increases. So the zener current $I_z$ decreases in order to keep $I_s$ constant. Thus if the regulator can keep $I_s$ constant, then the output voltage $V_z$ can be made constant as per equation 1.1. In order to keep $I_s$ constant, $I_z$ should vary according to equation 1.2. Now it is clear that the regulator circuit keeps the output voltage constant, since the zener diode under breakdown condition can vary the current flowing through it without varying the voltage across it.

**Limitations**

A zener diode regulator has the following drawbacks

(i) It has low efficiency because of the considerable power loss in the series
resistance. We have seen that the regulator circuit draws a constant current $I_s$ from the supply irrespective of the required load current $I_L$. So even if a small load current is required, the circuit will draw constant $I_s$ and large power will be dissipated in $R_s$.

(ii) The output voltage slightly changes due to the slope in zener characteristic.

Hence, the changes in the load current produces changes in the zener current. Consequently, the output voltage also changes. Therefore, the use of this circuit is limited only to such applications, where the variations in the load current and the input voltage are small.

**Know your progress**

1. Discuss the property of zener diode which makes it suitable for voltage regulation.

### 1.4 Transistor Series Voltage Regulator

Fig 1.4 shows a simple series voltage regulator using a transistor and a zener diode. The circuit is called a series voltage regulator because the load current passes through the series transistor Q1 connected in series with the load as shown in Fig 1.4. The unregulated DC voltage is fed to the input terminals and the regulated output is obtained across the load. The zener diode provides the reference voltage.

The base voltage of transistor Q1 is held to a relatively constant voltage with the voltage across the zener diode. For example, if 8 V Zener (that is $V_Z = 8$ V) is used, the base of Q1 will remain approximately at 8 V. Referring to Fig 1.4.

$$V_{Out} = V_Z - V_{BE}$$

![Fig 1.4 Transistor Series voltage regulator](image)
i) If the output voltage decreases, $V_{be}$ increases since $V_z$ is a constant. The increased base-emitter voltage causes transistor Q1 to conduct more so that, load current flowing through $R_L$ increases thereby raises the output voltage ($V_o = I_L R_L$). As a result, the output voltage is maintained at a constant level.

ii) If the output voltage increases, the decreased base-emitter voltage causes the transistor Q1 to conduct less, thereby reduces the output voltage. Consequently, the output voltage is maintained at a constant level.

The advantage of this circuit is that, the changes in the zener current are reduced by a factor $\beta$. This is because in order to affect large change in the load current ($I_L = I_C$), small change in the zener current is sufficient ($I_Z = I_B = I_C / \beta$). Therefore, the effect of zener impedance is greatly reduced and much more stabilized output is obtained.

In addition to this, the circuit draws current from the supply according to the load requirement. It makes the system highly energy efficient.

**Limitations:**

i) Although the changes in zener current are much reduced, the output is not absolutely constant. It is because both $V_{be}$ and $V_z$ decrease with the increase in the room temperature.

ii) The output voltage cannot be changed easily as no such means are provided.

**Know your progress**

1. Find the reasons for the energy efficiency of transistor series regulator over the zener voltage regulator.

**1.5. IC Voltage regulators**

Voltage regulators comprise a class of widely used ICs. Regulator IC unit contains the circuitry for reference source, comparator amplifier, control device and over load protection circuit all within a single IC. Although the internal construction of IC is somewhat different from that of a discrete voltage regulator circuit, the external operation is more or less the same. IC unit provides regulation of a fixed positive voltage, a fixed negative voltage or a variable voltage. They are of low cost, high reliability and reduced size and give excellent performance. IC voltage regulators are of the following types:
i) Fixed output voltage regulator: Positive and Negative output voltage

ii) Adjustable output voltage regulators: Positive and negative output voltage

1.6 Fixed Voltage Regulators

i) Positive voltage regulator

The 78XX (7800) series consists of three terminal positive voltage regulators with eight voltage options. This series of regulators provides fixed regulated voltages from 5 V to 24 V. Table 1.1 shows the voltage options of 78XX series. These 78XX series regulators give a maximum output current of about 1.5 amperes at fixed stabilized voltages of 5, 6, 8, 10, 12, 15, 18 and 24V respectively.

<table>
<thead>
<tr>
<th>IC Part</th>
<th>Output Voltage (V)</th>
<th>Minimum $V_V$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7805</td>
<td>+5</td>
<td>+7.3</td>
</tr>
<tr>
<td>7806</td>
<td>+6</td>
<td>+8.3</td>
</tr>
<tr>
<td>7808</td>
<td>+8</td>
<td>+10.5</td>
</tr>
<tr>
<td>7810</td>
<td>+10</td>
<td>+12.5</td>
</tr>
<tr>
<td>7812</td>
<td>+12</td>
<td>+14.5</td>
</tr>
<tr>
<td>7815</td>
<td>+15</td>
<td>+17.7</td>
</tr>
<tr>
<td>7818</td>
<td>+18</td>
<td>+21.0</td>
</tr>
<tr>
<td>7824</td>
<td>+24</td>
<td>+27.1</td>
</tr>
</tbody>
</table>

Table 1.1 Positive voltage regulators in the 78XX Series

The minimum $V_V$ shown in the third column of the above table indicates the minimum input voltage required for the IC to provide the regulated voltage as required. These ICs are designed as fixed voltage regulators and with adequate heat sinking and they can deliver high output currents say, 0.5 A or more. Fig 1.5 below shows the typical package and pin out configuration of 78XX series regulator.

Fig 1.5 Typical package and pinout diagram of IC 7805
The proper operation of 7805 requires a common ground between input and output voltages as shown in Fig 1.6. The only additional components required are capacitors across the input and the output.

![Fig 1.6 Connection diagram of IC-7805](image)

The input capacitor bypasses any spike voltage in the input so as to make the operation of the IC stable. The output capacitor avoids the sudden changes in the output voltage when the load is suddenly changed. It can be typically between 0.1μF and 0.33μF.

The unregulated input voltage is connected to the IC’s IN terminal (Pin-1). The ICs OUT terminal (Pin – 3) provides a regulated output which is filtered by the output capacitor. The third terminal is connected to the ground GND.

Now let us see the regulator using 7815.

![Fig 1.7 Connection of 7815 Voltage regulator](image)

Here in this circuit IC-7815 is used which is a fixed positive voltage regulator so the output will be +15 V.

ii) **Negative Voltage regulator**

The 79XX (7900) series of fixed output negative voltage regulators are similar to the 78XX series devices. The negative regulators are available in different voltage options as the 78XX devices. In addition to these two extra voltage
<table>
<thead>
<tr>
<th>IC Part</th>
<th>Output Voltage (V)</th>
<th>Minimum $V_i$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7905</td>
<td>-5</td>
<td>-7.3</td>
</tr>
<tr>
<td>7906</td>
<td>-6</td>
<td>-8.4</td>
</tr>
<tr>
<td>7908</td>
<td>-8</td>
<td>-10.5</td>
</tr>
<tr>
<td>7909</td>
<td>-9</td>
<td>-11.5</td>
</tr>
<tr>
<td>7912</td>
<td>-12</td>
<td>-14.6</td>
</tr>
<tr>
<td>7915</td>
<td>-15</td>
<td>-17.7</td>
</tr>
<tr>
<td>7918</td>
<td>-18</td>
<td>-20.8</td>
</tr>
<tr>
<td>7924</td>
<td>-24</td>
<td>-27.1</td>
</tr>
</tbody>
</table>

Table 1.2 Negative voltage regulators in the 79XX series

options, -2V and -5.2V are also available in the 79XX series. Table 1.2 shows the voltage options of 79XX devices and fig 1.8 shows the package type and the connection diagram of 79XX series.

![Connection Diagram](image)

Fig 1.8 Typical package and connection diagram of 79XX series

### 1.7 Adjustable voltage regulators

Voltage regulators are also available in circuit configurations that allow the user to set the output voltage to a desired regulated value. The adjustable voltage regulators have become more popular because of versatility, performance and reliability. The LM 317 series is the most commonly used general purpose adjustable voltage regulators. Fig 1.9 shows typical package of LM317. The three terminals are $V_{in}$, $V_{out}$ and Adjustment (ADJ).

![Package Diagram](image)

Fig 1.9 Typical package of LM317
The LM317T is a fully adjustable 3-terminal positive voltage regulator capable of supplying 1.5 A with heat sink, with an output voltage ranging from 1.25 to 37 V. By using two resistors, one of a fixed value and the other, variable the output voltage can be set to the desired level. Fig 1.10 shows typical connection diagram of the LM 317 regulator. From this diagram it is obvious that the LM 317 requires only two external resistors to set the output voltage. The output voltage of the LM317 is determined by the ratio of these two external resistors R₁ and R₂ which form a potential divider network across the output terminal as shown below.

![Typical connection diagram of the LM 317 regulator](image)

The voltage produced between the 'output' and the 'adjustment' terminals is a constant and its value is 1.25 V. This voltage is taken as the reference voltage by the IC and hence it is denoted as V\text{ref}. Let I₁ be the current flowing through R₁. The current from pin 1 of LM317, I\text{adj} is negligible compared to I₁. So we can consider that the current through R₂ is also I₁. Now the equation for output voltage is

\[ V_o = I_1 (R_1 + R_2) \]

But \( I_1 = V_{\text{ref}} / R_1 \)

So \( V_o = \left[ V_{\text{ref}} / R_1 \right] (R_1 + R_2) \)

\[ V_o = V_{\text{ref}} \left( 1 + \frac{R_2}{R_1} \right) \]

From the figure, it is clear that the voltage across R₁ is equal to V_{\text{ref}}. Since this voltage is constant, the current I₁ is also constant for a given value of R₁. Since the resistor R₁ sets the current I₁, it is called current set or program resistor. In addition to the current I₁, the current I_{\text{adj}} from the adjustment terminal also flows through the output set resistor R₂. The adjustment terminal current is a constant current of 100 μA and is comparatively very small and so
that we can neglect it. Since the reference voltage across resistor \( R_1 \) is a constant, a constant current \( I \) will flow through the other resistor \( R_2 \), resulting in an output voltage of:

\[
V_o = 1.25 \left( 1 + \frac{R_2}{R_1} \right)
\]

This indicates that the output voltage \( V_o \) is a function of \( R_2 \) for a given value of \( R_1 \), and can be varied by adjusting the value of \( R_2 \). The current set resistor \( R_1 \) is usually 240 \( \Omega \).

**Adjustable Negative Voltage Regulator**

LM 337 series of adjustable negative voltage regulators is similar to the LM 317 series devices. These negative regulators are available in the same voltage and current options as the LM 317 devices.

**Know your progress**

1. List out the electronic equipments which use DC power supply.
2. Discuss how the output voltage is fixed in an LM 317 regulator.

### 1.8 Typical DC regulated power supply design

As an example, let us discuss the design of regulated 5 V, 500 mA power supply. Let’s start with the choosing of components

**Component List:**
1. Step down transformer
2. Voltage regulator
3. Capacitors
4. Diodes

Let’s discuss about the ratings of the required devices.

**Voltage regulator:**

As we require a 5 V, we need LM7805 Voltage Regulator IC.

7805 IC Rating:
- Input voltage range 7 V- 35 V
- Current rating \( I_c = 1 \) A

![Fig 1.11 LM7805 - Pin Diagram](image)
Transformer

Selecting a suitable transformer is of great importance. The current rating and the secondary voltage rating of the transformer are the factors to be considered.

- The current rating of the transformer depends upon the current required for the load to be driven.
- The input voltage to the 7805 IC should be at least 2 V greater than the required output; therefore, it requires an input voltage at least to 7 V.
- 6-0-6 transformer with a current rating of 500 mA (Since \( 6 \times \sqrt{2} = 8.4 \) V) can be chosen.

Note: Any transformer which supplies secondary peak voltage up to 35 V can be used but as the voltage increases, the size of the transformer and the power dissipation across the regulator increases.

Rectifying circuit:

It is best to use a full wave rectifier here considering its efficiency and ripple factor.

- 1N4007 diodes can be used as it is capable of withstanding a higher reverse voltage of 1000 V, whereas the maximum reverse voltage of 1N4001 is 50 V.

Capacitors

To avoid ripples, it is better to use a large value capacitor as filter. Let us choose the capacitor 2200 \( \mu \)F.

The Datasheet of 7805 prescribes the use of a 0.01 \( \mu \)F capacitor at the output side to avoid transient changes in voltages.

The complete circuit showing the power supply is in fig. 1.13

![Fig 1.13 5V Power supply circuit using voltage regulator IC 7805](image-url)
The variation in DC voltage may cause malfunctioning of electronic circuits. So regulated DC power supply is essential in most electronic applications. A regulated power supply contains a rectifier, filter and a regulator. The load regulation is a measure of the ability of the power supply to reduce the variation of output voltage with the change in load current. Line regulation is a measure of the ability of a power supply to maintain the output voltage constant against the changes in the input line voltage. The two basic types of voltage regulators are shunt voltage regulator and series voltage regulator. A zener diode regulator circuit keeps the output voltage constant. Since the zener diode can vary the current flowing across it. In a transistor series voltage regulator the load current passes through the transistor connected in series with the load the zener diode provides the reference voltage.

A regulator IC unit contains the circuit for reference source, comparator amplifier, control device and overload protection circuit, all in a single chip. Fixed IC voltage regulators and adjustable voltage regulators are available for positive and negative output voltages. For designing a typical DV regulated power supply, the transformer, IC voltage regulator diodes and capacitors with appropriate rating have to be selected.

The contents of this chapter were learned through general discussion, drawing circuit diagrams, designing circuits and conducting practical experiments.
1. The output from the rectifier is a pulsating dc. These pulsations are due to the presence of ac components in the rectifier output.
   a) Which of the following component is generally used to remove the ac ripples?
      i) inductor  ii) capacitor  iii) resistor  iv) diode
   b) What happens to the output when the value of this component is increased?

2. Voltage regulation is essential in all power supplies.
   a) In an unregulated power supply, if input ac voltage increases, the output voltage ...........
      (i) increases (ii) decreases (iii) remains the same (iv) none of the above
   b) Discuss the limitations of an unregulated power supply

3. A dc power supply which maintains the output voltage constant irrespective of the fluctuations of the ac mains or load variations is known as regulated dc power supply.
   a) Draw the block diagram of a regulated power supply.
   b) The performance of a voltage regulator is measured using two parameters. Mention the names of these parameters. What are their significance?
   c) If the dc output voltage is 15 V with no-load attached to the power supply and decreases to 14.6 V at full load. Find the percentage voltage regulation.

4. Zener diode can be used as both dc and ac voltage regulator
   a) A zener diode utilizes .......... characteristics for voltage regulation.
   b) The zener diode will maintain constant voltage across the load in spite of the changes in load current or input voltage. Draw and explain the circuit of zener diode voltage regulator.
   c) Zener operates in the breakdown region and maintains constant voltage across the load. Explain the limitations of zener voltage regulator.
5. The series voltage regulator employs a transistor in the circuit as the regulating element.
   a) Discuss the role of transistor in the circuit.
   b) How does the transistor make the operation of the regulator power supply efficient?
6. Fixed output voltage regulator can be divided into positive and negative voltage regulator.
   a) IC 7805 has ........ output voltage.
   b) Draw the circuit arrangement of fixed voltage regulator IC 7805.
   c) Draw the pin diagram of IC 7905.
7. Commonly used variable voltage regulator IC is LM 317.
   a) IC LM 337 is ................ Voltage regulator.
      (i) Fixed negative (ii) Variable Positive
      (iii) Fixed positive (iv) Variable Negative
   b) The output voltage range of LM 317 is ------ to ------.
   c) Draw the circuit arrangement of IC - LM 317 as voltage regulator.
8. Describe the steps to design a +12 V, 500 mA regulated power supply.
In signal processing, quite often, the signal wave form has to be properly shaped for various applications. For example, we know that a sawtooth waveform is required in CRT for deflecting the beam. Wave shaping is the process of modifying the shape of a signal to obtain a signal of desired shape. It becomes also necessary to generate one waveform from another, like sharp narrow pulses generated from a rectangular waveform. For wave shaping, we use various circuits like clipper, clamper, differentiator and integrator etc.

Wave shaping circuits that make use of only linear circuit elements, such as inductor, capacitor and resistor are known as the linear wave shaping circuits. Such circuits can perform differentiation, integration and summation. For clipping and clamping circuits, we have to use a non-linear element-diode. Wave shaping circuits using diodes in conjunction with other linear circuit elements, are called non-linear wave shaping circuits.

2.1 Clipping Circuits

Clipping circuits (known as limiters, amplitude selectors, or slicers), are used to remove or clip off the part of a signal that is above or between some defined reference levels. The
circuit with which a waveform is shaped by removing (or clipping) a portion of the applied wave is known as clipping circuit. Depending on the orientation of the diode, the positive or/and negative region of the input signal is clipped off.

There are two general categories of clippers: series and parallel. The series configuration is defined as one in which the diode is in series with the load, while a parallel configuration has the diode in a branch parallel to the load. The main diode clippers are

I) Positive clipper
II) Negative clipper
III) Biased clipper
IV) Combinational clipper

I) Positive clipper

A positive clipper is that which removes the positive half cycles of the input voltage. Fig 2.1 shows the circuit diagram of a positive clipper using a diode. As shown, the output voltage has all the positive half-cycles removed or clipped off.

![Fig 2.1 Positive Clipper](image)

The circuit action is as follows. During the positive half cycle of the input voltage, the diode is forward biased and conducts heavily. Therefore, the voltage across the diode is almost zero (which behaves as short circuit). Hence, the output voltage during positive half cycle is zero.

During the negative half cycle of the input voltage, the diode is reverse biased and behaves as open circuit. Therefore, the input voltage is dropped across the diode. That is, the negative half cycle of the input voltage appears across
the diode. The input and output waveforms are shown in Fig 2.1. In practice, the output voltage during positive half cycles will not be zero since there is a voltage drop of 0.7V across a forward biased diode (silicon). So the output voltage during positive half cycles will be 0.7V.

I) Negative clipper

A negative clipper is that which removes the negative half cycle of the input voltage. Fig 2.2 shows the circuit diagram of a negative clipper.

![Fig 2.2 Negative clipper](image)

During positive half cycle of the input voltage, the diode is reverse biased and it acts as an open circuit. So the input voltage appears at the output. But during the negative half cycle, the diode is forward biased and it conducts. Therefore, the voltage across the diode is approximately zero. So the output voltage at the terminals is also zero. The input and output waveforms are also shown in Fig 2.2.

**Know your progress**

Draw the output wave form of Fig 2.3 (a) and (b)

![Fig 2.3](image)
III) Biased Clipper

Sometimes, it is required to remove a small portion of positive or negative half cycles of the signal voltage. For this purpose biased clipper is used.

a) Positive clipper with positive biasing

Fig 2.4 shows the circuit of a biased clipper using a diode and with a battery of $V_{dc}$ volts. With polarities of the battery shown, a portion of each positive half cycle will be clipped. However the negative half cycle will appear as such across the load. Such clipper is called positive clipper with positive biasing.

![Positive clipper circuit diagram]

Fig 2.4: Positive clipper with positive biasing

The circuit action is as follows. The diode will conduct heavily as long as input voltage is greater than the battery voltage $V_{dc}$. When the input voltage is greater than the battery voltage $V_{dc}$, the diode behaves as a short and the output voltage equals the battery voltage $V_{dc}$. The output will stay at battery voltage $V_{dc}$ as long as the input voltage is greater than battery voltage $V_{dc}$. During the period the input voltage is less than battery voltage $V_{dc}$, the diode is reverse biased and behaves as an open circuit. Therefore, most of the input voltage appears across the output. In this way, the biased positive clipper removes the input voltage which is above the battery voltage $V_{dc}$.

During the negative half cycle of the input voltage, the diode remains reverse biased. Therefore, the entire negative cycle appears across the load.

b) Negative clipper with negative biasing

![Negative clipper circuit diagram]

Fig 2.5 Negative clipper with negative biasing
If it is required to clip a portion of the negative cycles of the input voltage, the only thing to be done is reverse the polarities of diode and battery of positive clipper with positive biasing. Such circuit is then called a biased negative clipper.

IV) Combinational clipper

It is a combination of biased positive and negative clippers. With a combination clipper, a portion of both positive and negative half cycles of the input voltage can be removed or clipped as shown in Fig 2.6.

![Fig 2.6 Combinational clipper](image)

The circuit action is as follows. When positive input voltage is greater than $+V_1$, the diode $D_1$ conducts heavily while diode $D_2$ remains reverse biased. Therefore a voltage $+V_1$ appear across the load. Thus the output stays at $+V_1$ as long as the input voltage exceeds $+V_1$. On the other hand, during the negative half cycle, the diode $D_2$ will conduct heavily and the output stays at $-V_2$ as long as the input voltage is greater than $-V_2$. Note that $+V_1$ and $-V_2$ are less than $+V_m$ and $-V_m$ respectively.

Between $+V_1$ and $-V_2$ neither of the diodes is ON. Therefore, in this condition, most of the input voltage appears across the load. It is interesting to note that this clipping circuit can give a square wave output if $V_m$ is much greater than the clipping levels.

Know your progress

Draw the output wave form of the given circuit.

![Fig 2.7](image)
2.2 Clamping Circuits

A circuit that places either the positive or negative peak of a signal at a desired level by shifting its dc value is known as clamping circuit. Clamping circuits are also known as dc restorers. The network consists of a capacitor, diode and a resistive element, but it employs an independent DC supply to introduce an additional shift. The values of R and C must be chosen such that the time constant $T = RC$ is large enough to ensure that the capacitor cannot discharge significantly during the interval when the diode is not conducting. The important clamping circuits are

I) Positive clamper
II) Negative clamper
III) Biased clamper

Fig 2.8 shows the key idea behind clamping. The input signal is sine wave having a peak-to-peak value of 2 V. The positive clamper in Fig 2.8(a) adds the dc component and pushes the signal upwards, so that, the negative peaks falls on the zero level. As you can see, the waveform now has peak values of $+2$ V and $0$ V. It may be seen that the shape of the original signal has not changed; there is only a vertical positive shift in the signal. Such clamper is called a positive clamper. The negative clamper does the reverse. It will push the signal downwards, so that the positive peak falls to the zero level. It is shown in Fig 2.8 (b).

![Fig 2.8 Positive and negative clamping](image)
I) Negative Clamper

The circuit for a negative clamper is shown in Fig 2.9.

![Fig 2.9 Negative clamper](image)

Do you know that during the positive half cycle the diode conducts and acts like a short circuit as shown in Fig 2.10? The capacitor charges to peak value of input voltage $V_m$ so that the capacitor voltage is $V_c = V_m$. During this interval, the output $V_o$ is taken across the short circuit and therefore, will be equal to zero.

![Fig 2.10](image)

During the negative half cycle, the diode becomes reverse-biased and acts as an open-circuit as shown in Fig 2.11. Thus, there will be no effect on the capacitor voltage. The resistance $R$, being a very high value, cannot discharge $C$ during the negative portion of the input waveform. Thus during the negative input, the output voltage will be the sum of the input voltage and the capacitor voltage. The output voltage can be found by applying KVL and is equal to

$$-V_m - V_m - V_o = 0$$
$$V_o = -2V_m$$

![Fig 2.11](image)
II) Positive Clamper

The circuit for a positive clamper is shown in the Fig 2.12. During the negative half cycle of the input signal, the diode conducts and acts like a short circuit. The output voltage $V_o = 0V$. The capacitor is charged to the peak value of input voltage $V_m = V_c$ and it behaves like a battery. During the positive half of the input signal, the diode does not conduct and acts as an open circuit. Hence the output voltage, $V_o = V_m + V_m = 2V_m$. This gives a positively clamped output voltage.

![Fig 2.12 Positive Clamper](image)

III) Biased Clamper

The circuit of a positively biased clamper is shown in the Fig 2.13. During the negative half cycle of the input signal, the diode is forward biased and acts like a short circuit. The capacitor charges to $V_m + V_1$. Applying KVL to the input side

\[-V_m + V_c - V_1 = 0V\]

\[V_c = V_m + V_1\]

![Fig 2.13 Biased positive clamper](image)

The voltage across the resistor will be equal to the source voltage $V_{in}$. During the positive half cycle of the input signal, the diode is reverse biased and it
acts as an open circuit. Hence $V_s$ has no effect on $V_o$. Applying KVL around the outside loop

$$V_m + V_c - V_o = 0 \text{ V}$$

$$V_o = v_m + V_c = v_m + v_m + v_l = 2v_m + v_l$$

**Know your progress**

Set up a positive clamper and its output is given to a CRO. What change will you notice in the output signal, when the AC/DC switch of the CRO is kept in AC position first and then in DC position.

### 2.3 Differentiating Circuit

A circuit in which the output voltage is directly proportional to the derivative of the input is known as a differentiating circuit.

$$\text{Output } \propto \frac{d}{dt} (\text{Input})$$

It is a simple RC series circuit with output taken across the resistor $R$ and it can be used as a differentiating circuit. If a DC or constant input is applied to such circuit, the output will be zero. It is because the derivative of a constant is zero.

![Differentiating Circuit](image)

Fig 2.14 Differentiating Circuit

Fig 2.14 shows a typical differentiating circuit. The output across R will be the derivative of the input. It is important to note, that merely using voltage across R does not make the circuit a differentiator: it is also necessary to set proper circuit values for R and C. In order to achieve good differentiation, the following two conditions should be satisfied:

(i) The time constant $RC$ of the circuit should be much smaller than the time period of the input wave.

(ii) As a thumb rule the value of $X_C \left( \frac{1}{2\pi fC} \right)$ should be 10 or more times larger than R at the operating frequency $f$. 
Fulfilling these conditions, the output across R in fig 2.14 will be the derivative of the input.

Let $V_i$ be the input alternating voltage and let $I$ be the resulting alternating current. The charge $Q$ on the capacitor at any instant is

$$Q = C \cdot V_c$$

$$I = \frac{dQ}{dt} = \frac{d}{dt} (Q) = \frac{d}{dt} (C \cdot V_c)$$

$$I = C \cdot \frac{d(V_c)}{dt}$$

Since the capacitive reactance is very much larger than $R$, the input voltage can be considered to be equal to the capacitor voltage with negligible error i.e: $V_c = V_i$

$$I = C \cdot \frac{d(V_i)}{dt}$$

Output voltage $V_o = IR$

$$= RC \cdot \frac{d(V_i)}{dt}$$

$$\alpha \frac{dV_i}{dt} \quad (\therefore \text{RC is constant})$$

Output voltage $\alpha \frac{d}{dt} \text{ (input)}$

The output waveform from a differentiating circuit depends upon the time constant and the shape of the input wave. If the input fed to a differentiating circuit is a square wave, the output will consist of sharp narrow pulses (spikes) as shown in fig 2.15,

![Fig 2.15]
2.4 Integrating Circuit

A circuit in which the output voltage is directly proportional to the integral of the input is known as integrating circuit.

Output $\propto \int \text{input}$

![Integrating Circuit Diagram](image)

Fig. 2.16 Integrating Circuit

An integrating circuit is a simple RC series circuit with output taken across the capacitor $C$ as shown in fig 2.16. It can be seen that, $R$ and $C$ of the differentiating circuit have interchanged their positions. In order that the circuit renders good integration, the following conditions should be fulfilled:

i) The time constant $RC$ of the circuit should be very large as compared to the time period of the input wave.

ii) The value of $R$ should be 10 or more times larger than $X_C$.

Let $V_i$ be the input alternating voltage and let $I$ be the resulting alternating current. Since $R$ is very large as compared to capacitive reactance $X_C$ of capacitor, it is reasonable to assume that the voltage across $R$ (i.e., $V_R$) is equal to the input voltage. That is

$$V_i = V_R$$

Now $I = \frac{V_R}{R} = \frac{V_i}{R}$

The charge $Q$ on the capacitor at any instant is

$$Q = \int I dt$$

Output voltage $V_o = \frac{Q}{C} = \int \frac{Idt}{C}$
\[ \int \frac{V_i}{R} \, dt = \frac{1}{RC} \int V_i \, dt \]

\( \alpha \int V_i \, dt \) (RC is constant)

\therefore \text{Output } \alpha \int \text{ input }

The output waveform of an integrating circuit depends upon the time constant and shape of the input wave. When the input fed to an integrating circuit is a square wave, the output will be triangular wave as shown in Fig 2.17.

**Fig 2.17 Input and output waveform of an integrator**

1. Predict the output of a differentiator if the input signal is a sine wave.
2. Set up a differentiator circuit in which a sine wave is to be given as input. Observe both the input and output of this circuit simultaneously in a CRO using a dual input mode. Find out the difference.

Repeat this for an integrator also.

### 2.5 OP-AMP Circuits

This section shows how the inverting and non-inverting configurations of op-amp are useful in applications such as voltage follower, adder, subtractor, integrator, differentiator and comparator.
i) **Voltage Follower (Buffer)**

The lowest gain that can be obtained from a non-inverting amplifier with feedback is 1. When the non-inverting amplifier is configured for unity gain, it is called *voltage follower* because the output voltage is equal in amplitude and phase with the input. In other words, in the voltage follower the output voltage follows (tracks) the input voltage.

Although it is similar to the discrete emitter follower, the voltage follower is preferred to because it has a much higher input resistance, and the output amplitude is exactly equal to the input.

![Non inverting amplifier configuration](image)

**Fig 2.18 Non inverting amplifier configuration**

We have studied about the non inverting configuration the previous year. Fig 2.18 shows the non inverting amplifier configuration and we know that the voltage gain

\[
A = 1 + \frac{R_F}{R_1}
\]

To obtain the voltage follower from the non-inverting amplifier, simply remove \( R_1 \) and short \( R_F \) \((R_F = 0)\). When the voltage gain of the amplifier is \( A = 1 \), the amplifier is called *unity gain buffer*. The resulting circuit is shown in Fig 2.19. In this figure all the output voltage is fed back into the inverting terminal of the op-amp; consequently, the gain of the feedback circuit is 1.

![Voltage follower](image)

**Fig 2.19 Voltage follower**
A voltage buffer amplifier is used to transfer voltage from one circuit, having high output impedance level, to the following circuit with a low input impedance level. The interposed buffer amplifier prevents the second circuit from loading the first circuit unacceptably and interfering with its desired operation. This is also called impedance matching which is done to ensure maximum power transfer from the preceding stage to the next stage. For example, impedance matching should be applied between a power amplifier stage and loud speaker for maximum power transfer to the loud speaker. This is because the output impedance of the power amplifier is comparatively large and the impedance of the loudspeaker is small. In the ideal voltage buffer, the input resistance is infinite and the output resistance is zero.

i) Summing Amplifier (Adder Circuit)

Fig 2.20 shows the inverting configuration with three inputs $V_a$, $V_b$ and $V_c$. Depending on the relationship between the feedback resistor $R_f$ and the input resistors $R_a$, $R_b$ and $R_c$, the circuit can be used as a summing amplifier. The circuit function can be verified by examining the expression for the output voltage, $V_o$.

![Fig 2.20 Summing Amplifier](image)

$$V_o = -\left(\frac{R_f}{R_a} V_a + \frac{R_f}{R_b} V_b + \frac{R_f}{R_c} V_c\right)$$

If $R_a = R_b = R_c = R$ then the equation can be rewritten as

$$V_o = -\frac{R_f}{R} (V_a + V_b + V_c)$$
This means that the output voltage is equal to the negative sum of all the inputs times the gain of the circuit $R_f / R$; hence the circuit is called a summing amplifier. Obviously, when the gain of the circuit is 1 that is $Ra = Rb = Rc = Rf$, the output voltage is equal to the negative sum of all the input voltages. Thus $Vo = -(Va + Vb + Vc)$

We see that the output is the sum of input voltages. The negative sign can be avoided by using an inverting amplifier with unity gain ($Rf = Rf$) at the output of the summing amplifier.

**Know your progress**

Find the output of a summing amplifier with three input voltages $Va = 2\, \text{V}$, $Vb = 1\, \text{V}$ and $Vc = 3\, \text{V}$.

**ii) Subtractor Circuit**

A basic differential amplifier can be used as a subtractor as shown in Fig 2.21. Here, all the external resistors are equal in value, so the gain of the amplifier is equal to 1. From this figure, the output voltage of the differential amplifier with gain of 1 is

$$Vo = \frac{R}{R} (Vb - Va)$$

That is, $Vo = Vb - Va$

![Fig 2.21 Subtractor Circuit using OPAMP](image)
Thus the output voltage $V_o$ is equal to the voltage $V_b$ applied to the non inverting terminal minus the voltage $V_a$ applied to the inverting terminal; hence, the circuit is called a subtractor.

iii) The Integrator

A circuit in which the output voltage waveform is the integral of the input voltage waveform is called an integrator or integration amplifier. Such a circuit is obtained by using a basic inverting amplifier configuration and the feedback resistor $R_f$ is replaced by a capacitor $C_f$. The expression for the output voltage $V_o$ is

$$V_o = \frac{-1}{R_f C_f} \int V_{in} \, dt$$

The equation indicates that the output voltage is directly proportional to the negative integral of the input voltage and inversely proportional to the time constant $R_f C_f$. For example, if the input is a sine wave, the output will be a cosine wave. If the input is square wave, the output will be a triangular wave as shown in Fig 2.23.

**Fig 2.22 Integrator Circuit using OPAMP**

**Fig 2.23 Output waveform of integrator**
The advantage of op-amp integrator over the simple RC integrator is that integration will be good for a large range of frequencies in an op-amp integrator. But in a simple RC integrator good integration can be obtained only for a very small range of frequencies.

iv) The Differentiator

Fig 2.24 shows the differentiator or differentiating amplifier. As its name implies, the circuit performs the mathematical operation of differentiation; that is the output waveform is the derivative of the input waveform. The differentiator may be constructed from a basic inverting amplifier, if the input resistor $R_1$ is replaced by a capacitor $C_1$. The expression for the output voltage $V_o$ can be expressed as

\[ V_o = -R_f C_1 \frac{dV_{in}}{dt} \]

Thus output $V_o$ is equal to $R_f C_1$ times the negative instantaneous rate of change of the input voltage $V_{in}$ with time. If the input fed to a differentiating circuit is a square wave, the output will consist of sharp narrow pulses (spikes) as shown in fig 2.25.

Fig 2.24 Differentiator circuit using OP-AMP

Fig 2.25 Differentiator- output waveform
In op amp differentiator also, the differentiation will be good for a wide range of frequencies compared to a simple RC differentiator.

**vi) Comparator**

A comparator, as its name implies, compares a signal voltage of one input of an op-amp with a known voltage called the reference voltage of the other input. Comparators are used in circuits such as digital interfacing, Schmitt triggers, voltage level detectors and oscillators.

![Comparator circuit](image)

Fig 2.26 Comparator circuit

Fig 2.26 shows an op-amp used as a comparator. Here open loop configuration (no negative feedback) is used. A fixed reference voltage $V_{ref}$ of 1V is applied to the negative input and the other time varying signal voltage $V_{in}$ is applied to the positive input. Because of this arrangement, this circuit is called the non inverting comparator. When $V_{in}$ is less than $V_{ref}$, the output voltage $V_{o}$ is at $-V_{sat} (= -V_{EE})$ because the voltage at the negative input is higher than that at the positive input. On the other hand, when $V_{in}$ is greater than $V_{ref}$, the positive input becomes positive with respect to the negative input, the $V_{o}$ is $+V_{sat} (= +V_{CC})$. Thus $V_{o}$ changes from one saturation level to the other whenever $V_{in}$ oscillates above and below $V_{ref}$, as shown in fig 2.27. In short, the comparator is a type of analog-to-digital converter. At any given time the $V_{o}$ waveform shows whether $V_{in}$ is greater or lesser than $V_{ref}$. The comparator is sometimes called a voltage-level detector because for a desired value of $V_{ref}$, the voltage level of the input $V_{in}$ can be detected.
2.6 Filters

In electronic systems the desired signal is often affected by unwanted signals called noise. Signals are distinguished by their frequency characteristics and some form of frequency selective circuit or filter can accomplish the extraction of signals from the noise. A filter is a frequency selective circuit that allows a band of frequencies to pass through it and blocks or attenuates signals of frequencies outside this band. A general classification of filters is shown in Fig. 2.28.

Depending on the type of elements used in their construction, filters may be classified as passive and active. Elements used in passive filters are resistors, capacitors and inductors. Active filters on the other hand, employ transistor or op-amps in addition to resistors and capacitors. Depending upon the frequency range, filters are divided into audio frequency and radio frequency filters.
Audio frequency filters are low frequency filters which commonly use resistors and capacitors, while radio frequency filters use inductor, capacitor or crystals. The most commonly used filters are:

a) Low pass filter
b) High pass filter
c) Band pass filter
d) Band stop (rejection) filter

The figure 2.29 shows the ideal frequency response of these filters. However, in practice, this response cannot be attained. The band of frequencies that are allowed to pass through a filter is called its pass-band. The band of frequencies that are not allowed to pass through them is called stop band or attenuation band. The frequency that differentiates between pass and stop band is called cut-off frequency. An ideal filter will have an amplitude response that is unity or a fixed value in the pass band and zero in the stop band.
Figure 2.29 (a) shows frequency response of an idealized low pass filter. In this filter the low frequencies are in the pass band and the higher frequencies are in the stop band. Figure 2.29 (b) shows the idealized high-pass filter frequency response. Here, the low frequencies are in the stop band, and the high frequencies are in the pass band. If a high-pass filter and a low-pass filter are cascaded, a band pass filter is created. The band pass filter passes a band of frequencies between a lower cut-off frequency, \( f_L \), and an upper cut-off frequency, \( f_H \). Frequencies below \( f_L \) and above \( f_H \) are in the stop band. An idealized band pass filter frequency response is shown in Figure 2.29(c).

Figure 2.29(d) shows the idealized frequency response of the band-reject or band-stop or notch filter. The pass bands include frequencies below \( f_L \) and above \( f_H \). The band from \( f_L \) to \( f_H \) is in the stop band.

i) **Low pass filter (LPF)**

A low pass filter (LPF) is a filter which passes low-frequency signals and blocks high frequency signals. In other words, low-frequency signals go through the filter much easier and with less resistance and high-frequency signals have a much harder getting through, which is why it is a low pass filter. Low pass filters can be constructed using resistors or with either capacitors or inductors. A low pass filter composed of a resistor and a capacitor is called a low pass RC filter. And a low pass filter with a resistor and an inductor is called a low pass RL filter.

A low pass RC filter, again, is a filter circuit composed of a resistor R and capacitor C which passes low-frequency signals, while blocking high frequency signals. A low pass RC filter is shown in the circuit below:

![Fig 2.30 RC Low Pass Filter Circuit](image-url)
As capacitor is a reactive device, it offers differing resistance to the signals of different frequencies passing through it. It offers very high resistance to low-frequency, or DC, signals and low resistance to high-frequency signals. So the DC as well as low frequency signals will be dropped across the capacitor and will be available at the output. The high-frequency signals will go through the capacitor, the capacitor offers them a very low-resistance path. So high frequency signal will be dropped across the resistor and not reaches the output. Fig 2.31 shows frequency response of low pass filter.

![Frequency Response of a Low Pass Filter](image)

**Fig 2.31 Frequency Response of a Low Pass Filter.**

The cut-off frequency of low pass filter is given by $f_c = 1/2\pi RC$

Applications of passive low pass filters are seen in audio amplifiers and speaker systems where they are used to direct the low frequency bass signals to the large bass speakers or to reduce any high frequency noise or “hiss” type distortion.

**ii) High Pass Filter**

A high pass filter (HPF), is obtained by interchanging the positions of the components $R$ and $C$ of the low pass filter and the output signal ($V_{out}$) is taken across the resistor as shown in Fig 2.32.

A low pass filter allows signals with frequency below its cut-off frequency $f_c$ to pass, whereas a high pass filter circuit as its name implies, only passes signals above the selected cut-off point. $f_c$ eliminating any low frequency signals. Consider the circuit shown in Fig.2.32.
In this circuit arrangement, the reactance of the capacitor is very high at low frequencies so the capacitor acts like an open circuit and blocks any input signals until the cut-off frequency point \( f_c \) is reached. Above this cut-off frequency point, the reactance of the capacitor is reduced sufficiently so that only a small amount of input signal is dropped across the capacitor and the remaining input reaches the output. When the frequency is very large, the reactance of the capacitor becomes almost zero and hence, most of the input signal reaches the output.

The cut-off frequency of high pass filter is given by \( f_c = \frac{1}{2\pi RC} \)

A very common application of a passive high pass filter is in speaker systems where it is used to direct the high frequency signals to the small “tweeter” type speakers while blocking the low bass signals or is also used to reduce any low frequency noise or ‘rumble’ type distortion. When used like this in audio applications, the high pass filter is sometimes called a “low-cut”, or “bass cut” filter.
iii) Band Pass Filter

Sometimes it is necessary to pass signals of certain range of frequencies and this range can be anywhere between 0 Hz and infinity.

By connecting or ‘cascading’ together a single **Low Pass Filter** circuit with a **High Pass Filter** circuit, we can produce another type of passive RC filter that passes a selected range or ‘band’ of frequencies that can either be narrow or wide while attenuating all those outside this range. This new type of passive filter arrangement produces a frequency selective filter commonly known as a **Band Pass Filter** (BPF). Fig 2.34 shows the circuit diagram of band pass filter.

![Fig 2.34 Band Pass Filter Circuit](image)

**Know your progress**

Fig 2.35 shows the practical circuit of band pass filter. Draw its frequency response after finding the lower and upper cut off frequencies.

![Fig 2.35 Practical Band pass filter circuit](image)
Fig 2.36 shows how the frequency response of a band pass filter is arranged using high pass and low pass filter responses and Fig 2.37 shows the frequency response of a practical band pass filter. The high pass filter removes all frequencies below the cut off frequency $f_L$ and low pass filter removes all frequencies above the cut off $f_H$.

![Diagram showing high pass, low pass, and band pass filters](image)

**Fig 2.36 Combining frequency responses of LPF and HPF**

Here, the cut off frequency of the LPF is high compared to the cut off frequency of the HPF. The difference between their cut off frequencies is the width of the pass band of the band pass filter.

![Diagram showing frequency response](image)

**Fig 2.37 Frequency Response of a Band Pass Filter**

### iv) Band Reject Filters

A filter that allows all the frequencies other than a band of frequency is called band rejection filter. Such filters are also called as band stop filter. Its frequency response is opposite to that of a band pass filter. Fig 2.38 shows the block diagram of band reject filter. Fig 2.39 shows the frequency responses of a band rejection filter.
Here, the cut off frequency of the LPF should be small compared to the cut off frequency of the HPF. The difference between their cut off frequencies is the width of the stop band of the band reject filter.

Let us consolidate

Wave shaping is the process of modifying a signal to obtain it in desired shape. It includes differentiation, integration, clipping, clamping, etc. The components like resistor, capacitor, inductor, diode etc are used for this purpose. Clipping circuits are used to remove a part of the signal. The different types of clippers are positive clipper, negative clipper, biased clipper and combinational clipper. A positive clipper removes positive half of a signal and a negative clipper removes the negative half. A biased clipper removes a portion of either positive half or negative half of the signal depending on the bias voltage. A combinational clipper removes a portion of both positive and negative halves and the level of removal depends on the bias voltages. Clamping
circuits add a DC voltage to a signal so that it will be shifted up or down depending on the polarity of the added DC voltage. This addition of DC voltage is achieved not with a battery but with a large value capacitor. If the signal is shifted up, it is positive clamping and if it is shifted down, it is negative clamping. In biased clamping the level of shifting up or down can be decided with a DC power supply of the given voltage.

A differentiator circuit produces the differential or derivative of the input signal at its output. It is a simple RC network. The quality of differentiation depends on the values of R and C and the frequency of the input signal. An integrator is also a RC network for which the output is the integral of the input signal. Here also the quality of integration depends on the values of R and C and the frequency of the input signal. A voltage follower or buffer circuit is usually used for impedance matching. It has unit voltage gain or the output signal is same as the input signal. A summing amplifier or adder circuit can be used to obtain the sum of input voltages at the input terminals of the circuit. An op-amp based circuit is used for this purpose. The basic differentiator and integrator circuits can be modified using op-amp circuits so that their performance will be improved. A comparator is an op-amp circuit in which the voltage level of an input signal is compared with a fixed reference voltage.

Filter circuits are used to separate signals of different frequencies. Depending on the frequency characteristic, the filters can be broadly classified as LPF, HPF, BPF and Band reject filters.

The contents of this unit were learned through general discussion, sketching wave forms, designing circuits and experimentation.
1. Clipping circuits are used to remove or clip off a part of the signal.
   a) A positive clipper is that which removes the ........ half cycles of the input signal:
      i) negative  ii) positive  iii) both positive and negative
   b) Describe the working of a negative clipper with neat diagram.
   c) Draw the output waveform for the clipper circuit shown below.

   ![Clipping Circuit Diagram]

2. A circuit that places either the positive or negative peak of a signal at a desired DC level is known as a clamping circuit.
   a) Draw the output waveform for the clamping circuit shown below.

   ![Clamping Circuit Diagram]

3. A circuit in which output voltage is directly proportional to the derivative of the input is known as a differentiating circuit. Sketch the output waveform of a differentiating circuit when the input is a square wave.

4. A circuit in which output voltage is directly proportional to the integral of the input is known as integrating circuit.
   a) An integrating circuit is a simple RC series circuit with output taken across ........
      i) both R and C  ii) R  iii) C  iv) None of the above
   b) Show that the output from an integrating circuit is the integral of the input.
5. In a voltage follower, the output voltage follows (tracks) the input voltage.
   a) In the ideal voltage buffer, the input resistance is ...........
   b) Draw the voltage follower circuit using OPAMP.
   c) Voltage follower circuit is also called unity gain buffer. Why?

6. In summing amplifier the output voltage is equal to the negative sum of all
   the inputs times the gain of the circuit  $R_f/R$. For a summing amplifier
   the three inputs voltages are $V_a = 2.5\, \text{V}$, $V_b = 2\, \text{V}$ and $V_c = 1.5\, \text{V}$. Find the
   output voltage.

7. A comparator, compares a signal voltage of one input of an op-amp with
   a known voltage called the reference voltage of the other input.
   a) Draw and explain the working of comparator circuit.
   b) Mention the important applications of the comparator.

8. An electric filter is a frequency selective circuit that allowing a band of
   frequencies and blocks or attenuates signals of frequencies outside this
   band.
   a) Draw the low pass filter circuit and describe its working.
   b) List down the applications of LPF.

9. .......... filter is used to reduce any low frequency noise or “rumble”
   type distortion.

10. Sketch the practical frequency response of a high pass filter.

11. A filter that allows all the frequencies other than a band of frequency is
    called band rejection filter.
    a) Compare band pass and band rejection filter.
    b) Describe the working of BPF with help of a circuit diagram.