Manonmaniam Sundaranar University

Directorate of Distance & Continuing Education,
Tirunelveli - 627 012 Tamilnadu, India

OPEN AND DISTANCE LEARNING (ODL) PROGRAMMES

(For those who joined the programmes
from the academic year 2023–2024 onwards)

B.Sc. Physics

Course Material

Core -XI

JMPH53

Analog and Communication Electronics

Prepared
by

Dr. Sabarinathan Venkatachalam
Assistant Professor
Department of Physics
Manonmaniam Sundaranar University
Tirunelveli – 627 012

COURSE TITLE	**ANALOG AND COMMUNICATION ELECTRONICS**
UNIT–I	**DIODES:** Diode characteristics – half wave rectifier, center tapped and bridge full wave rectifiers, calculation of efficiency and ripple factor - clipper circuits, clamping circuits. DC power supply: Block diagram of a power supply, Zener diode as voltage regulator.
UNIT–II	**TRANSISTOR AMPLIFIERS:** Transistor configurations: CB, CE and CC modes – I-V characteristics and hybrid parameters – DC load line - Q pointself-bias – RC coupled CE amplifier – power amplifiers – push-pull amplifiers – tuned amplifiers.
UNIT–III	**TRANSISTOR OSCILLATORS:** Feedback amplifier – principle of feedback, positive and negative feedback – voltage and current gain – advantages of negative feedback – Barkhausen’s criterion – Transistor oscillators: Hartley, Colpitts, Phase shift oscillators.
UNIT–IV	**OPERATIONAL AMPLIFIERS AND TIMER:** Differential amplifiers – OP-AMP characteristics – IC 741 pin configuration – inverting and non-inverting amplifiers – summing and difference amplifiers – differentiator and integrator – IC 555 pin configuration – astable multivibrator (square wave generator) – monostable vibrator.
UNIT–V	**MODULATION AND DEMODULATION:** Theory of amplitude modulation – frequency modulation – comparison of AM and FM – phase modulation – pulse width modulation – pulse modulation systems: PAM, PPM, and PCM – Demodulation: AM and FM detection.

TEXTBOOKS

1. V. K. Mehta – Principles of Electronics, S. Chand and Co. Ltd., 2004.
2. V. Vijayendran – Integrated Electronics, S. Viswanathan Publishers, Chennai.
3. B. L. Theraja – A Textbook of Electrical Technology.
4. John D. Ryder – Electronic Fundamentals and Applications.
5. Malvino – Electronic Principles, Tata McGraw Hill.

UNIT– I

Diodes

Unit 1: DIODES

Diode characteristics – half wave rectifier, center tapped and bridge full wave rectifiers, calculation of efficiency and ripple factor - clipper circuits, clamping circuits. DC power supply: Block diagram of a power supply, Zener diode as voltage regulator.

Diode Characteristics

An ordinary resistor is a linear device because the graph of its current versus voltage is a straight line. A diode is different. It is a nonlinear device because the graph of its current versus voltage is not a straight line. The reason is the barrier potential. When the diode voltage is less than the barrier potential, the diode current is small. When the diode voltage exceeds the barrier potential, the diode current increases rapidly.

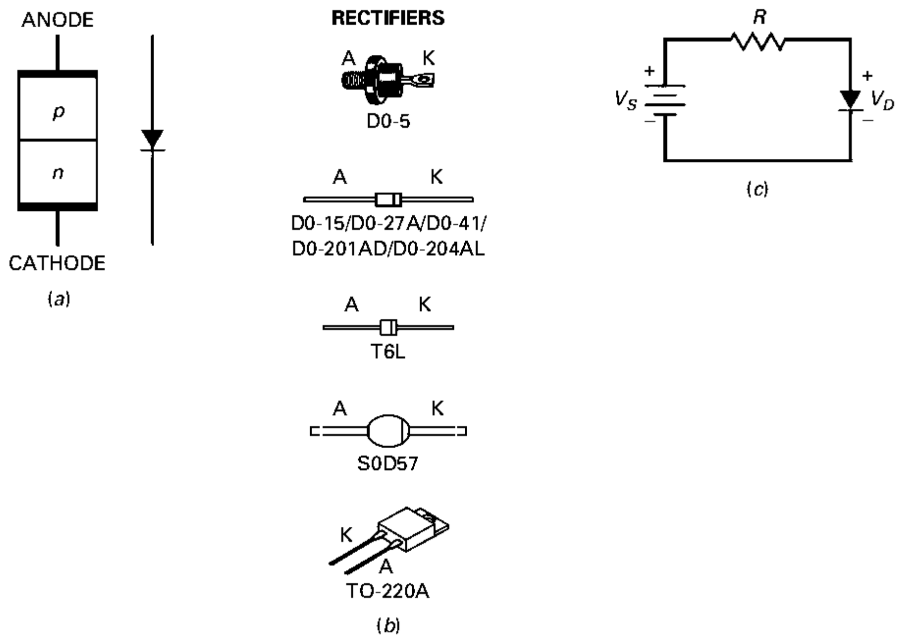


Figure 1-1. (a) Schematic symbol of a diode, (b) diode casing styles, (c) diode in forward bias condition in a simple circuit.

Figure 1-1a shows the schematic symbol of a diode. The p side is called the anode, and the n side the cathode. The diode symbol looks like an arrow that points from the p side to the n side, from the anode to the cathode. Figure 1-1b shows some of the many typical diode case styles. Many, but not all, diodes have the cathode lead (K) identified by a colored band.

Figure 1-1c shows a diode circuit. In this circuit, the diode is forward-biased. How do we know? Because the positive battery terminal drives the p side through a resistor, and the negative battery terminal is connected to the n side. With this connection, the circuit is trying to push holes and free electrons toward the junction.

In more complicated circuits, it may be difficult to decide whether the diode is forward-biased. Here is a guideline. Ask yourself this question: Is the external circuit pushing current in the easy direction of flow?

If the answer is yes, the diode is forward-biased. What is the easy direction of flow? If you use conventional current, the easy direction is the same as the diode arrow. If you prefer electron flow, the easy direction is the other way.

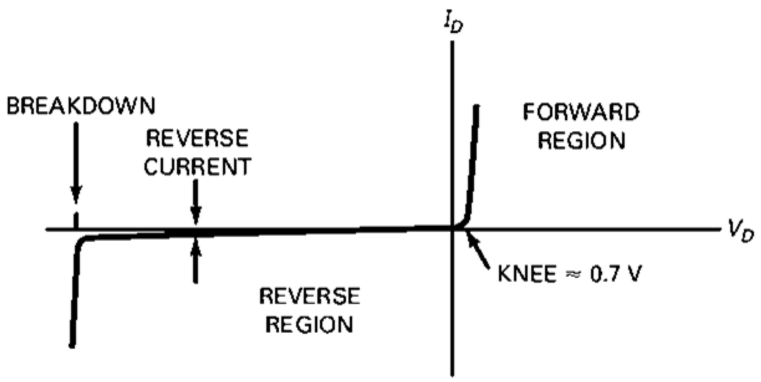


Figure 1-2. Diode curve

When the diode is part of a complicated circuit, we can also use Thevenin's theorem to determine whether it is forward biased. For instance, assume that we have reduced a complex circuit with Thevenin's theorem to get Figure 1-1c We would know that the diode is forward-biased.

The Forward Region

Figure 1c is a circuit that you can set up in the laboratory. After you connect this circuit, you can measure the diode current and voltage. You can also reverse the polarity of the DC source and measure the diode current and voltage for reverse bias. If you plot the diode current versus the diode voltage, you will get a graph that looks like Figure 1-2. when the diode is forward biased, there is no significant current until the diode voltage is greater than the barrier potential. On the other hand, when the diode is reverse biased, there is almost no reverse current until the diode voltage reaches the breakdown voltage. Then, avalanche produces a large reverse current, destroying the diode.

Knee Voltage

In the forward region, the voltage at which the current starts to increase rapidly is called the knee voltage of the diode. The knee voltage equals the barrier potential. Analysis of diode circuits usually comes down to determining whether the diode voltage is more or less than the knee voltage. If it's more, the diode conducts easily. If it's less, the diode conducts poorly. We define the knee voltage of a silicon diode as:

$$\mathbf{V_K \sim 0.7\ V}$$

(Note: The symbol ~ means "approximately equal to.)

Even though germanium diodes are rarely used in new designs, you may still encounter germanium diodes in special circuits or in older equipment. For this reason, remember that the knee voltage of a germanium diode is approximately 0.3 V. This lower knee voltage is an advantage and accounts for the use of a germanium diode in certain applications.

Bulk Resistance

Above the knee voltage, the diode current increases rapidly. This means that small increases in the diode voltage cause large increases in diode current. After the barrier potential is overcome, all that impedes the current is the ohmic resistance of the p and n regions. In other words, if the p and n regions were two separate pieces of semiconductor, each would have a resistance that you could measure with an ohmmeter, the same as an ordinary resistor. The sum of the ohmic resistances is called the bulk resistance of the diode. It is defined as:

$$\mathbf{R_B = R_P + R_N}$$

The bulk resistance depends on the size of the p and n regions, and how heavily doped they are. Often, the bulk resistance is less than 1Ω.

Maximum DC Forward Current

If the current in a diode is too large, the excessive heat can destroy the diode. For this reason, a manufacturer’s data sheet specifies the maximum current a diode can safely handle without shortening its life or degrading its characteristics.

The maximum forward current is one of the maximum ratings given on a data sheet. This current may be listed as I_{max}, $I_{F(max)}$, I_O, etc., depending on the manufacturer. For instance, a 1N456 has a maximum forward current rating of 135 mA. This means that it can safely handle a continuous forward current of 135 mA.

Power Dissipation

You can calculate the power dissipation of a diode the same way as you do for a resistor. It equals the product of diode voltage and current. As a formula:

$$\mathbf{P_D = V_D\, I_D}$$

The power rating is the maximum power the diode can safely dissipate without shortening its life or degrading its properties. In symbols, the definition is:

$$\mathbf{P}_{max} = \mathbf{V}_{max}\ \mathbf{I}_{max}$$

where V_{max} is the voltage corresponding to I_{max}. For instance, if a diode has a maximum voltage and current of 1 V and 2 A, its power rating is 2 W.

The Ideal Diode

Figure 1-3 shows a detailed graph of the forward region of a diode. Here you see the diode current ID versus diode voltage VD. Notice how the current is approximately zero until the diode voltage approaches the barrier potential. Somewhere in the vicinity of 0.6 to 0.7 V, the diode current increases. When the diode voltage is greater than 0.8 V, the diode current is significant and the graph is almost linear.

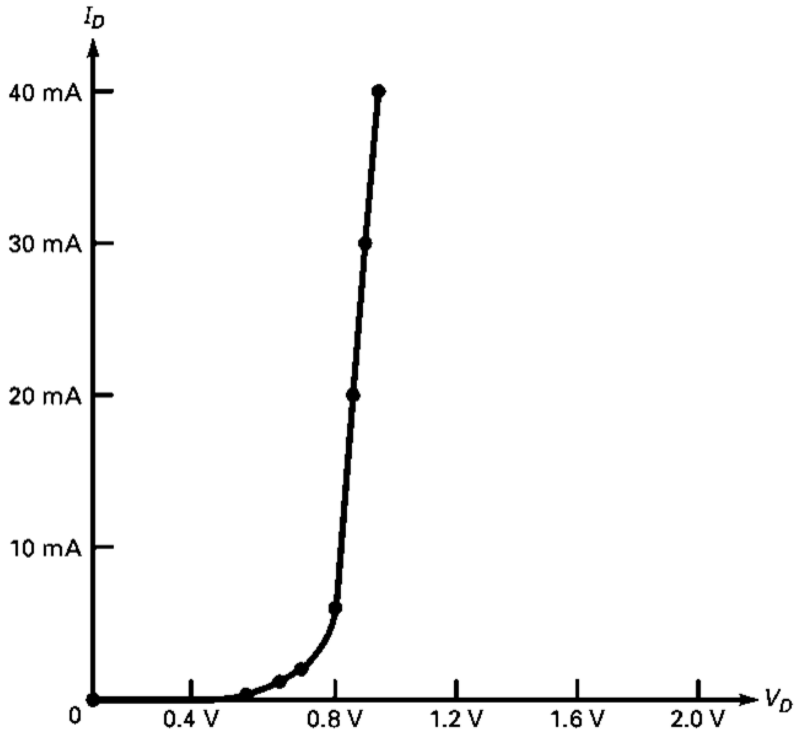


Figure 1-3. Graph of forward current.

Depending on how a diode is doped and its physical size, it may differ from other diodes in its maximum forward current, power rating, and other characteristics. If we need an exact solution, we would have to use the graph of the particular diode. Although the exact current and voltage points will differ from one diode to the next, the graph of any diode is similar to Figure 1-3. All silicon diodes have a knee voltage of approximately 0.7 V.

Most of the time, we do not need an exact solution. This is why we can and should use approximations for a diode. We will begin with the simplest approximation, called an ideal diode. In the most basic terms, what does a diode do? It conducts well in the forward direction and poorly in the reverse direction. Ideally, a diode acts like a perfect conductor (zero resistance) when forward biased and like a perfect insulator (infinite resistance) when reverse biased.

Figure 1-4a shows the current-voltage graph of an ideal diode. It echoes what we just said: zero resistance when forward biased and infinite resistance when reverse biased. It is impossible to build such a device, but this is what manufacturers would produce if they could.

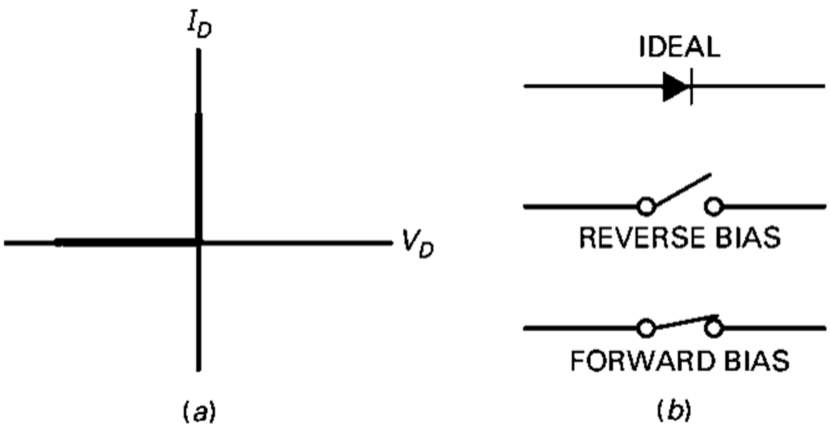


Figure 1-4. (a) Ideal diode curve; (b) ideal diode acts like a switch.

Is there any device that acts like an ideal diode? Yes. An ordinary switch has zero resistance when closed and infinite resistance when open. Therefore, an ideal diode acts like a switch that closes when forward-biased and opens when reverse-biased. Figure 1-4b summarizes the switch idea.

Half-Wave Rectifier

In half-wave rectification, the rectifier conducts current only during the positive half-cycles of input a.c. supply. The negative half-cycles of a.c. supply are suppressed *i.e.* during negative half-cycles, no current is conducted and hence no voltage appears across the load. Therefore, current always flows in one direction (*i.e.* d.c.) through the load though after every half-cycle

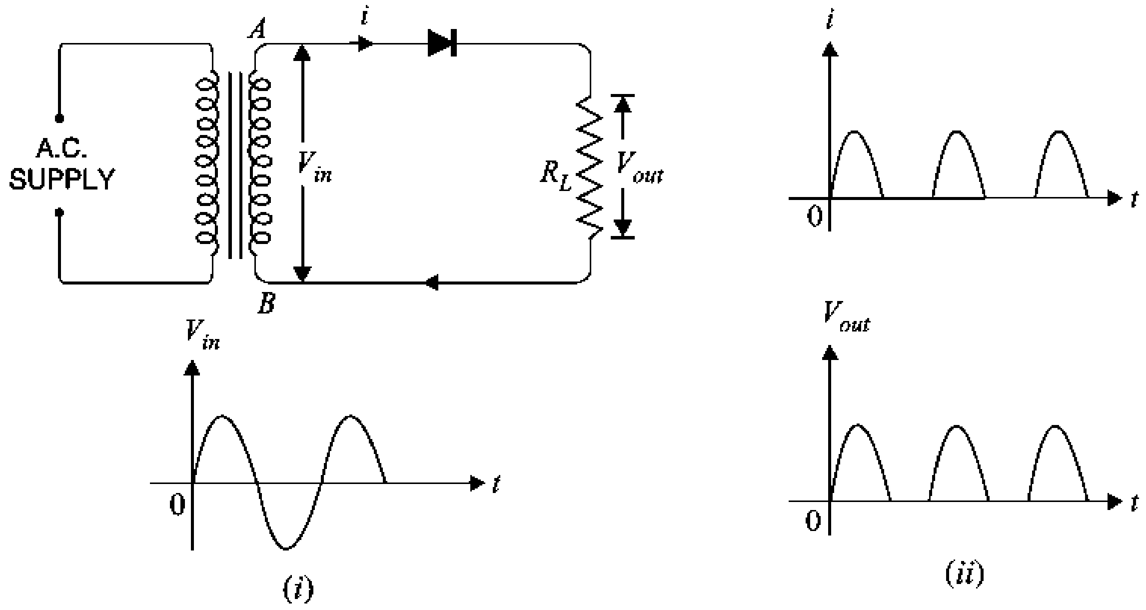


Figure 1-5. Half-Wave Rectifier Circuit with Input AC Waveform and Corresponding Output Voltage and Current Waveforms.

Circuit details.

Figure 1-5 shows the circuit where a single crystal diode acts as a half-wave rectifier. The a.c. supply to be rectified is applied in series with the diode and load resistance *RL*. Generally, a.c. supply is given through a transformer. The use of transformer permits two advantages. Firstly, it allows us to step up or step down the a.c. input voltage as the situation demands. Secondly, the transformer isolates the rectifier circuit from power line and thus reduces the risk of electric shock.

Operation.

The a.c. voltage across the secondary winding *AB* changes polarities after every half-cycle. During the positive half-cycle of input a.c. voltage, end *A* becomes positive *w.r.t.* end *B*. This makes the diode forward biased and hence it conducts current. During the negative half-cycle, end *A* is negative *w.r.t.* end *B*. Under this condition, the diode is reverse biased and it conducts no current. Therefore, current flows through the diode during positive half-cycles of input a.c. voltage only ; it is blocked during the negative half-cycles [See Figure 1-5 (*ii*)]. In this way, current flows through load R_L always in the same direction. Hence d.c. output is obtained across R_L. It may be noted that output across the load is pulsating d.c. These pulsations in the output are further smoothened with the help of *filter circuits* discussed later.

Disadvantages :

The main disadvantages of a half-wave rectifier are :

(*i*) The pulsating current in the load contains alternating component whose basic frequency is equal to the supply frequency. Therefore, an elaborate filtering is required to produce steady direct current.

(*ii*) The a.c. supply delivers power only half the time. Therefore, the output is low.

Output Frequency of Half-Wave Rectifier

The output frequency of a half-wave rectifier is equal to the input frequency (50 Hz). Recall how a complete cycle is defined. A waveform has a complete cycle when it repeats the same wave pattern over a given time. Thus in Figure 1-6 (*i*), the a.c. input voltage repeats the same wave pattern over 0° – 360°, 360° – 720° and so on. In Figure 1-6 (*ii*), the output waveform also repeats the same wave pattern over 0° – 360°, 360° – 720° and so on. This means that when input a.c. completes one cycle, the output halfwave rectified wave also completes one cycle. In other words, the output frequency is equal to the input frequency *i.e.*

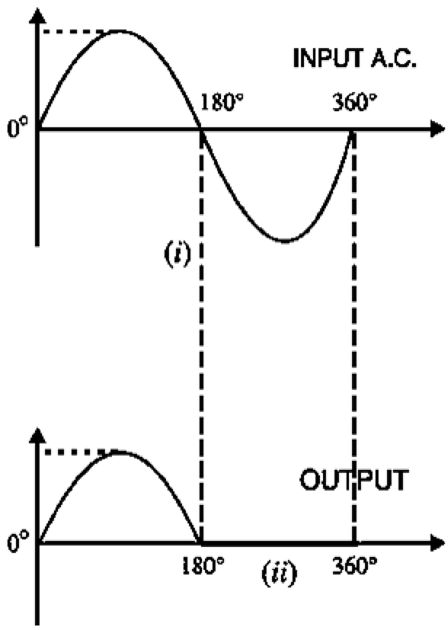


Figure 1-6. Input AC Waveform and Corresponding Half-Wave Rectified Output

$$f_{out} = f_{in}$$

For example, if the input frequency of sine wave applied to a half-wave rectifier is 100 Hz, then frequency of the output wave will also be 100 Hz.

Efficiency of Half-Wave Rectifier

The ratio of d.c. power output to the applied input a.c. power is known as rectifier efficiency i.e.

Rectifier efficiency, η = d.c. power output/Input a.c. power

Consider a half-wave rectifier shown in Figure 1-6. Let $v = V_m \sin\theta$ be the alternating voltage that appears across the secondary winding. Let r_f and R_L be the diode resistance and load resistance respectively. The diode conducts during positive half-cycles of a.c. supply while no current conduction takes place during negative half-cycles.

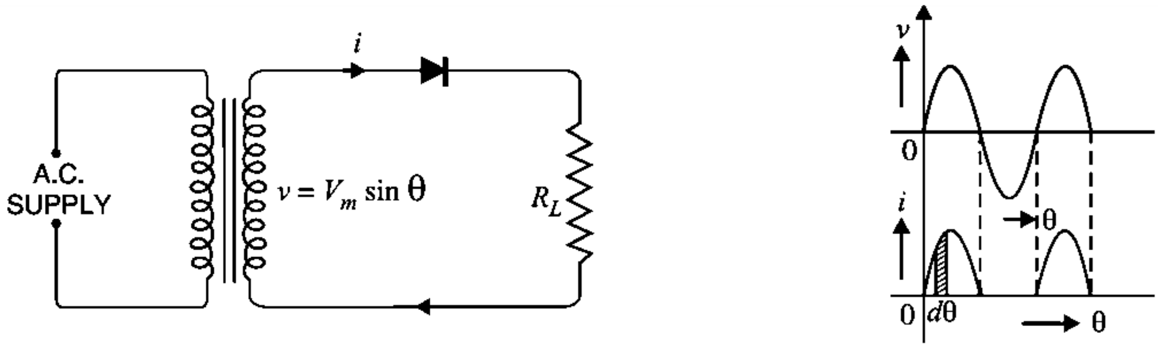


Figure 1-7. Half-Wave Rectifier Circuit and Its Input–Output Waveforms

d.c. power.

The output current is pulsating direct current. Therefore, in order to find d.c. power, average current has to be found out.

$$I_{av} = I_{dc} = \frac{1}{2\pi}\int_0^{\pi} i\, d\theta = \frac{1}{2\pi}\int_0^{\pi}\frac{V_m \sin\theta}{r_f + R_L}d\theta$$

$$= \frac{V_m}{2\pi\left(r_f + R_L\right)}\int_0^{\pi} \sin\theta\, d\theta = \frac{V_m}{2\pi\left(r_f + R_L\right)}[-\cos\theta]_0^{\pi}$$

$$= \frac{V_m}{2\pi\left(r_f + R_L\right)} \times 2 = \frac{V_m}{\left(r_f + R_L\right)} \times \frac{1}{\pi}$$

$$\therefore \mathrm{I}_m = \frac{V_m}{\left(r_f + R_L\right)}$$

$$= \frac{\mathrm{I}_m}{\pi}$$

$\therefore$ dc Power, $P_{dc} = I_{dc}^2 \times R_L = \left(\frac{\mathrm{I}_m}{\pi}\right)^2 \times R_L$

a.c. power input : The a.c. power input is given by :

$$P_{ac} = I_{rms}^2 \left(r_f + R_L\right)$$

For a half-wave rectified wave, $I_{rms} = \frac{I_m}{2}$

$$P_{ac} = \left(\frac{I_m}{2}\right)^2 \times \left(r_f + R_L\right)$$

$$\text{Rectifier efficiency} = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{\left(\frac{I_m}{\pi}\right)^2 \times R_L}{\left(\frac{I_m}{2}\right)^2 \times \left(r_f + R_L\right)}$$

$$= \frac{0.406\ R_L}{r_f + R_L} = \frac{0.406\ R_L}{1 + \frac{r_f}{R_L}}$$

The efficiency will be maximum if r_f is negligible as compared to R_L.

∴ Max. rectifier efficiency = 40.6%

This shows that in half-wave rectification, a maximum of 40.6% of a.c. power is converted into d.c. power.

Full-Wave Rectifier

In full-wave rectification, current flows through the load in the same direction for both half-cycles of input a.c. voltage. This can be achieved with two diodes working alternately. For the positive halfcycle of input voltage, one diode supplies current to the load and for the negative half-cycle, the other diode does so ; current being always in the same direction through the load. Therefore, a full-wave rectifier utilises both half-cycles of input a.c. voltage to produce the d.c. output. The following two circuits are commonly used for full-wave rectification:

(i) Centre-tap full-wave rectifier

(ii) Full-wave bridge rectifier

Centre-Tap Full-Wave Rectifier

The circuit employs two diodes D_1 and D_2 as shown in Fig. 6.24. A centre tapped secondary winding *AB* is used with two diodes connected so that each uses one half-cycle of input a.c. voltage. In other words, diode D_1 utilises the a.c. voltage appearing across the upper half (*OA*) of secondary winding for rectification while diode D_2 uses the lower half winding *OB*.

Operation. During the positive half-cycle of secondary voltage, the end *A* of the secondary winding becomes positive and end *B* negative. This makes the diode D_1 forward biased and diode D_2 reverse biased. Therefore, diode D_1 conducts while diode D_2 does not. The conventional current flow is through diode D_1, load resistor R_L and the upper half of secondary winding as shown by the dotted arrows. During the negative half-cycle, end *A* of the secondary winding becomes negative and end *B* positive. Therefore, diode D_2 conducts while diode D_1 does not. The conventional current flow is through diode D_2, load R_L and lower half winding as shown by solid arrows. Referring to Figure 1-8, it may be seen that current in the load R_L is *in the same direction* for both half-cycles of input a.c. voltage. Therefore, d.c. is obtained across the load R_L. Also, the polarities of the d.c. output across the load should be noted.

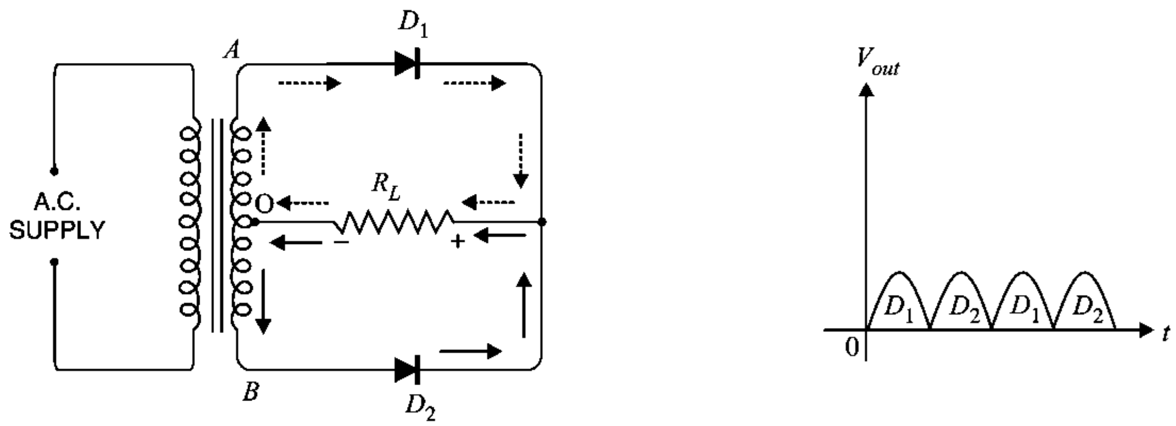


Figure 1-8. Centre-Tap Full-Wave Rectifier Circuit Showing Current Paths and Output Voltage Waveform.

Peak inverse voltage.

Suppose V_m is the maximum voltage across the half secondary winding. Figure 1-9. Centre-Tapped Transformer Full-Wave Rectifier Showing Diode Arrangement and Peak Voltages. shows the circuit at the instant secondary voltage reaches its maximum value in the positive direction. At this instant, diode D_1 is conducting while diode D_2 is non-conducting. Therefore, whole of the secondary voltage appears across the non-conducting diode. Consequently, the peak inverse voltage is twice the maximum voltage across the half-secondary winding *i.e.*

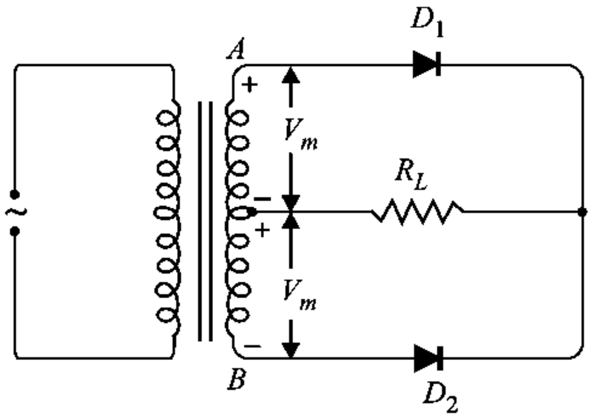


Figure 1-9. Centre-Tapped Transformer Full-Wave Rectifier Showing Diode Arrangement and Peak Voltages.

$$\textbf{PIV} = \textbf{2}\ V_m$$

Disadvantages

(*i*) It is difficult to locate the centre tap on the secondary winding.

(*ii*) The d.c. output is small as each diode utilises only one-half of the transformer secondary voltage.

(*iii*) The diodes used must have high peak inverse voltage.

Full-Wave Bridge Rectifier

The need for a centre tapped power transformer is eliminated in the bridge rectifier. It contains four diodes D_1, D_2, D_3 and D_4 connected to form bridge as shown in Figure 1-10. The a.c. supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer. Between other two ends of the bridge, the load resistance R_L is connected.

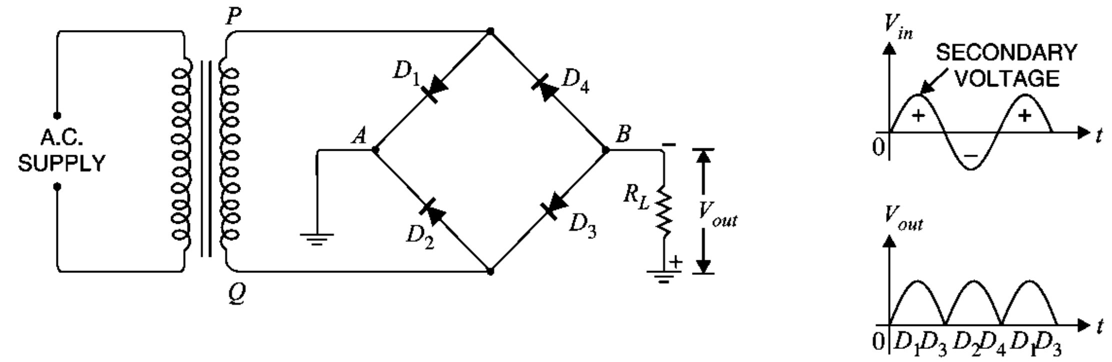


Figure 1-10. Full-Wave Bridge Rectifier Circuit and Its Input–Output Waveforms

Operation.

During the positive half-cycle of secondary voltage, the end *P* of the secondary winding becomes positive and end *Q* negative. This makes diodes D_1 and D_3 forward biased while diodes D_2 and D_4 are reverse biased. Therefore, only diodes D_1 and D_3 conduct. These two diodes will be in series through the load R_L as shown in Figure 1-11 (*i*). The conventional current flow is shown by dotted arrows. It may be seen that current flows from *A* to *B* through the load R_L.

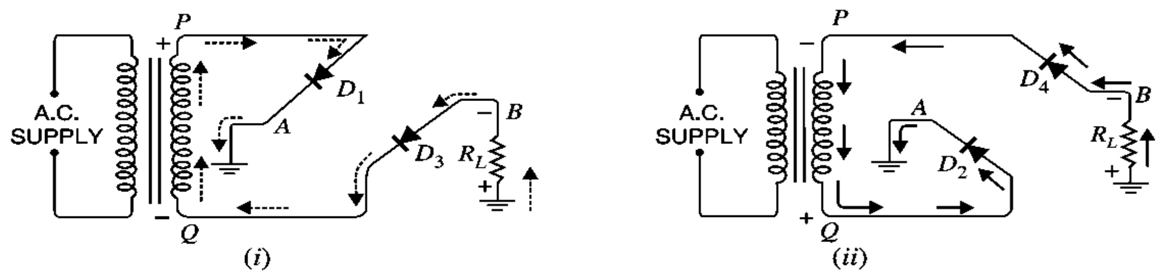


Figure 1-11. Full-Wave Bridge Rectifier operation and flow of current.

During the negative half-cycle of secondary voltage, end *P* becomes negative and end *Q* positive. This makes diodes D_2 and D_4 forward biased whereas diodes D_1 and D_3 are reverse biased. Therefore, only diodes D_2 and D_4 conduct. These two diodes will be in series through the load R_L as shown in Figure 1-11 (*ii*). The current flow is shown by the solid arrows. It may be seen that again current flows from *A* to *B* through the load *i.e.* in the same direction as for the positive half-cycle. Therefore, d.c. output is obtained across load R_L.

Peak inverse voltage.

The peak inverse voltage (PIV) of each diode is equal to the maximum secondary voltage of transformer. Suppose during positive half cycle of input a.c., end *P* of secondary is positive and end *Q* negative. Under such conditions, diodes D_1 and D_3 are forward biased while diodes D_2 and D_4 are reverse biased.

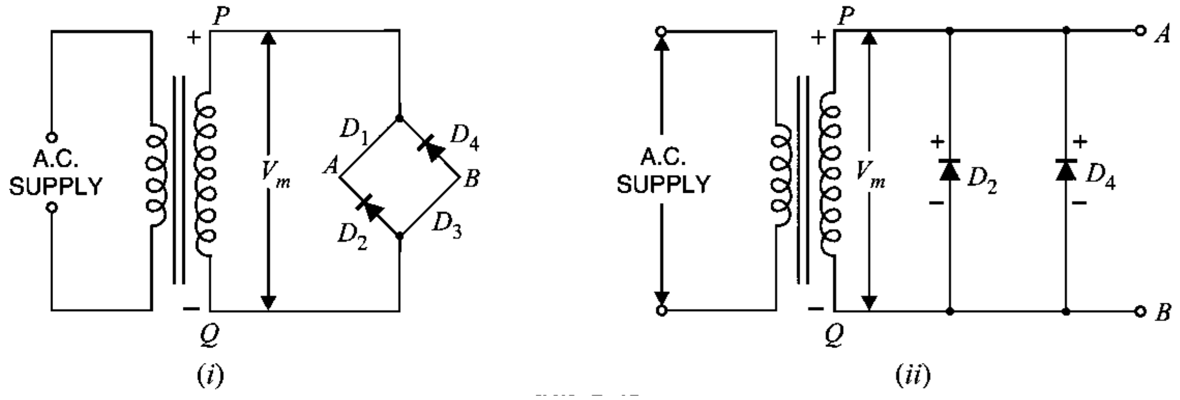


Figure 1-12. Full-wave rectifier circuits. (i) Bridge rectifier; (ii) Center-tap full-wave rectifier.

Since the diodes are considered ideal, diodes D_1 and D_3 can be replaced by wires as shown in Figure 1-12 (*i*). This circuit is the same as shown in Figure 1-12 (*ii*). it is clear that two reverse biased diodes (*i.e.*, D_2 and D_4) and the secondary of transformer are in parallel. Hence PIV of each diode (D_2 and D_4) is equal to the maximum voltage (V_m) across the secondary. Similarly, during the next half cycle, D_2 and D_4 are forward biased while D_1 and D_3 will be reverse biased. It is easy to see that reverse voltage across D_1 and D_3 is equal to V_m.

Advantages

(i) The need for centre-tapped transformer is eliminated.

(ii) The output is twice that of the centre-tap circuit for the same secondary voltage.

(iii) The PIV is one-half that of the centre-tap circuit (for same d.c. output).

Disadvantages

(i) It requires four diodes.

(ii) As during each half-cycle of a.c. input two diodes that conduct are in series, therefore, voltage drop in the internal resistance of the rectifying unit will be twice as great as in the centre tap circuit. This is objectionable when secondary voltage is small.

Output Frequency of Full-Wave Rectifier

The output frequency of a full-wave rectifier is double the input frequency. Remember that a wave has a complete cycle when it repeats the same pattern. In Figure 1-13 (*i*), the input a.c. completes one cycle from 0° – 360°. However, the full-wave rectified wave completes 2 cycles in this period [See Figure 1-13 (*ii*)]. Therefore, output frequency is twice the input frequency *i.e.*

$$f_{out} = 2 f_{in}$$

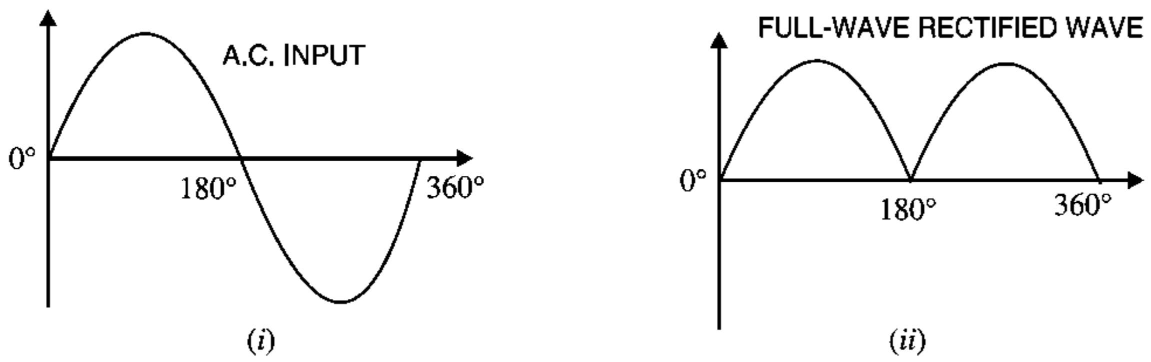


Figure 1-13.(i) AC Input (ii) Output Waveforms of a Full-Wave Rectifier

For example, if the input frequency to a full-wave rectifier is 100 Hz, then the output frequency will be 200 Hz.

Efficiency of Full-Wave Rectifier

Figure 1-14 shows the process of full-wave rectification. Let $v = V_m \sin\theta$ be the a.c. voltage to be rectified. Let r_f and R_L be the diode resistance and load resistance respectively. Obviously, the rectifier will conduct current through the load in the same direction for both half-cycles of input a.c. voltage. The instantaneous current i is given by :

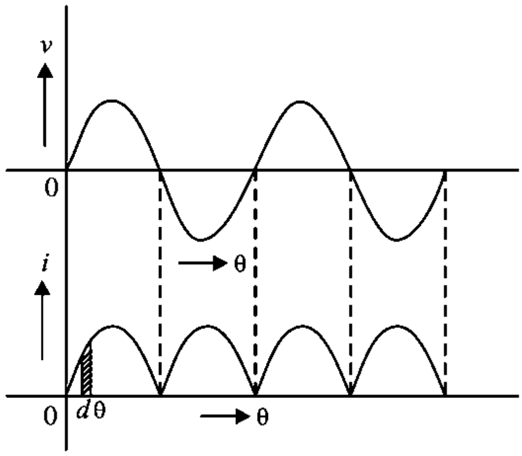


Figure 1-14. Full wave rectification represented in waveform

$$i = \frac{v}{r_f + R_L}$$

$$= \frac{v_m \sin\theta}{r_f + R_L}$$

d.c. output power.

The output current is pulsating direct current. Therefore, in order to find the d.c. power, average current has to be found out. From the elementary knowledge of electrical engineering,

$$I_{dc} = \frac{2I_m}{\pi}$$

∴ d.c. power output,

$$P_{dc} = I_{dc}^2 \times R_L$$

$$= \left(\frac{2I_m}{\pi}\right)^2 \times R_L$$

a.c. input power.

The a.c. input power is given by :

$$P_{ac} = I_{rms}^2 \ (r_f + R_L)$$

For a full-wave rectified wave, we have,

$$\mathrm{I}_{rms} = \mathrm{I}_m/\sqrt{2}$$

$$P_{ac} = \left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)$$

∴ Full-wave rectification efficiency is

$$\eta = \frac{P_{ac}}{P_{dc}} = \frac{(2I_m/\pi)^2 \times R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)}$$

$$= \frac{8}{\pi^2} \times \frac{R_L}{(r_f + R_L)} = \frac{0.812\ R_L}{(r_f + R_L)}$$

$$\eta = \frac{0.812}{1 + \frac{r_f}{R_L}}$$

The efficiency will be maximum if r_f is negligible as compared to R_L.

∴ Maximum efficiency = 81.2%

This is double the efficiency due to half-wave rectifier. Therefore, a full-wave rectifier is twice as effective as a half-wave rectifier.

Ripple Factor

The output of a rectifier consists of a d.c. component and an a.c. component (also known as *ripple*). The a.c. component is undesirable and accounts for the pulsations in the rectifier output. The effectiveness of a rectifier depends upon the magnitude of a.c. component in the output ; the smaller this component, the more effective is the rectifier.

The ratio of r.m.s. value of a.c. component to the d.c. component in the rectifier output is known as **ripple factor** i.e.

$$\text{Ripple factor} = \frac{\text{r. m. s. value of a. c component}}{\text{value of d. c. component}} = \frac{I_{ac}}{I_{dc}}$$

Therefore, ripple factor is very important in deciding the effectiveness of a rectifier. The smaller the ripple factor, the lesser the effective a.c. component and hence more effective is the rectifier.

Mathematical analysis.

The output current of a rectifier contains d.c. as well as a.c. component. The undesired a.c. component has a frequency of 100 Hz (*i.e.* double the supply frequency 50 Hz) and is called the *ripple*

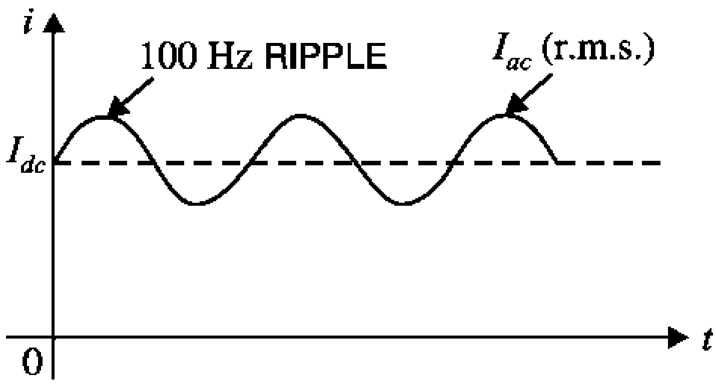


Figure 1-15. Output Current Waveform of the Rectified a.c. to d.c. current.

(See Figure 1-15). It is a fluctuation superimposed on the d.c. component. By definition, the effective (*i.e.* r.m.s.) value of total load current is given by :

$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2}$$

or

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

Dividing throughout by I_{dc}, we get,

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2}$$

But I_{ac}/I_{dc} is the ripple factor.

$$\text{Ripple factor} = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

***(i)* For half-wave rectification.**

In half-wave rectification,

$$I_{rms} = I_m/2;\ I_{dc} = I_m/\pi$$

$$\text{Ripple factor} = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = 1.21$$

It is clear that a.c. component exceeds the d.c. component in the output of a half-wave rectifier. This results in greater pulsations in the output. Therefore, half-wave rectifier is ineffective for conversion of a.c. into d.c.

***(ii)* For full-wave rectification.**

In full-wave rectification,

$$I_{rms} = I_m/\sqrt{2};\ I_{dc} = 2I_m/\pi$$

$$\text{Ripple factor} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1} = 0.48$$

i.e.,

$$\frac{\text{effective a.c. component}}{\text{d.c. component}} = 0.48$$

This shows that in the output of a full-wave rectifier, the d.c. component is more than the a.c. component. Consequently, the pulsations in the output will be less than in half-wave rectifier. For this reason, full-wave rectification is invariably used for conversion of a.c. into d.c.

Clipping Circuits

The circuit with which the waveform is shaped by removing (or clipping) a portion of the applied wave is known as a clipping circuit.

Clippers find extensive use in radar, digital and other electronic systems. Although several clipping circuits have been developed to change the wave shape, we shall confine our attention to diode clippers. These clippers can remove signal voltages above or below a specified level. The important diode clippers are

(*i*) positive clipper

(*ii*) biased clipper

(*iii*) combination clipper

(i) Positive clipper.

A positive clipper is that which removes the positive half-cycles of the input voltage. Figure 1-16 shows the typical circuit of a positive clipper using a diode. As shown, the output voltage has all the positive half-cycles removed or clipped off.

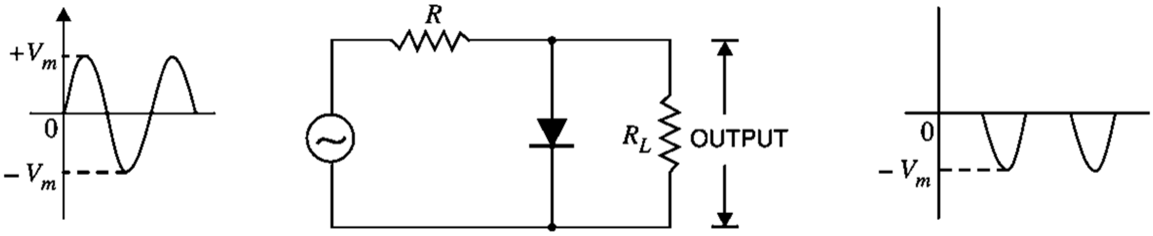


Figure 1-16. A Positive Clipper Circuit and its input and output waveforms.

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 (which behaves as a short) and hence across the load R_L is zero. Hence *output voltage during positive half-cycles is zero.

During the negative half-cycle of the input voltage, the diode is reverse-biased and behaves as an open. In this condition, the circuit behaves as a voltage divider with an output given by :

$$\textbf{Output Voltage} = -\frac{R_L}{R + R_L} V_m$$

Generally, R_L is much greater than R.

$$\textbf{Output voltage} = -V_m$$

It may be noted that if it is desired to remove the negative half-cycle of the input, the only thing to be done is to reverse the polarities of the diode in the circuit shown in Fig. 18.25. Such a clipper is then called a *negative clipper*.

(*ii*) Biased clipper.

Sometimes it is desired to remove a small portion of positive or negative half-cycle of the signal voltage. For this purpose, biased clipper is used. Figure 1-17 shows the circuit of a biased clipper using a diode with a battery of V volts. With the polarities of battery shown, a portion of each positive half-cycle will be clipped. However, the negative half-cycles will appear as such across the load. Such a clipper is called *biased positive clipper*.

The circuit action is as follows. The diode will conduct heavily so long as input voltage is greater than $+V$. When input voltage is greater than $+V$, the diode behaves as a short and the output equals $+V$. The output will stay at $+V$ so long as the input voltage is greater than $+V$. During the period the input voltage is less than $+V$, the diode is reverse biased and behaves as an open. Therefore, most of the input voltage appears across the output. In this way, the biased positive clipper removes input voltage above $+V$. During the negative half-cycle of the input voltage, the diode remains reverse biased. Therefore, almost entire negative half-cycle appears across the load.

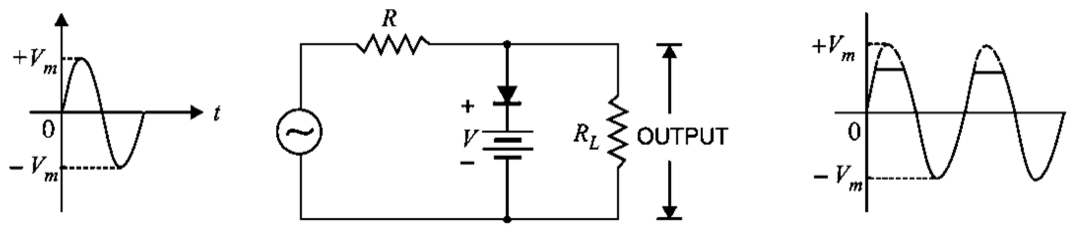


Figure 1-17. A Biased Clipper Circuit and its input and output waveforms.

If it is desired to clip a portion of negative half-cycles of input voltage, the only thing to be done is to reverse the polarities of diode or battery. Such a circuit is then called a *biased negative clipper*.

(*iii*) Combination 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 input voltage can be removed or clipped as shown in Figure 1-18.

The circuit action is as follows. When positive input voltage is greater than $+V_1$, diode D_1 conducts heavily while diode D_2 remains reverse biased. Therefore, a voltage $+V_1$ appears across the load. This output stays at $+V_1$ so long as the input voltage exceeds $+V_1$.

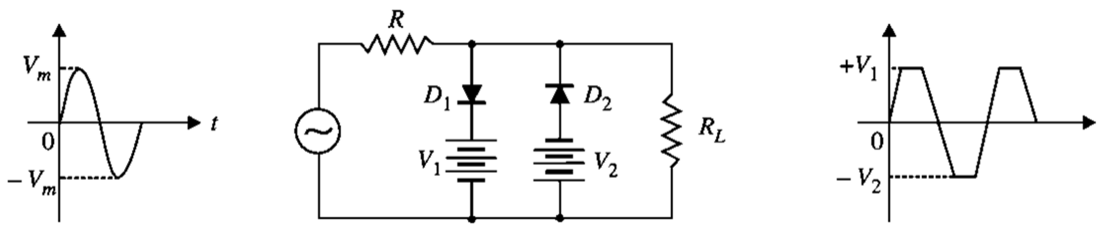


Figure 1-18. A Combination Clipper Circuit and its input and output waveforms.

On the other hand, during the negative half-cycle, the diode D_2 will conduct heavily and the output stays at $-V_2$ so 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 diode 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 square wave output if V_m is much greater than the clipping levels.

Clamping Circuits

A circuit that places either the positive or negative peak of a signal at a desired d.c. level is known as a clamping circuit.

Figure 1-19. Block diagram of a Positive Clapper Circuit.

A clamping circuit (or a clamper) essentially adds a *d.c.* component to the signal. Figure 1-19 shows the key idea behind clamping. The input signal is a sine wave having a peak-to-peak value of 10 V. The clamper adds the *d.c.* component and pushes the signal upwards so that the negative peaks fall on the zero level. As you can see, the waveform now has peak values of +10 V and 0 V.

It may be seen that the shape of the original signal has not changed; only there is vertical shift in the signal. Such a clamper is called a *positive clamper*. The *negative clamper* does the reverse *i.e.* it pushes the signal downwards so that the positive peaks fall on the zero level.

The following points may be noted carefully :

(*i*) The clamping circuit does not change the peak-to-peak or r.m.s. value of the waveform. Thus referring to Fig. 18.45 above, the input waveform and clamped output have the same peak-topeak value *i.e.*, 10 V in this case. If you measure the input voltage and clamped output with an a.c. voltmeter, the readings will be the same.

(*ii*) A clamping circuit changes the peak and average values of a waveform. This point needs explanation. Thus in the above circuit, it is easy to see that input waveform has a peak value of 5 V and average value over a cycle is zero. The clamped output varies between 10 V and 0 V. Therefore, the peak value of clamped output is 10 V and *average value is 5 V. Hence we arrive at a very important conclusion that *a clamper changes the peak value as well as the average value of a waveform.*

Basic Idea of a Clamper

A clamping circuit should not change peak-topeak value of the signal; it should only change the *dc* level. To do so, a clamping circuit uses a capacitor, together with a diode and a load resistor R_L. Figure 1-20 shows

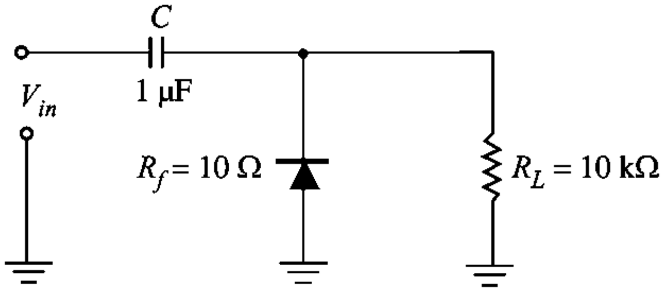


Figure 1-20. Circuit Diagram of a Positive Clamper.

the circuit of a positive clamper. The operation of a clamper is based on the principle that charging time of a capacitor is made very small as compared to its discharging time.

Positive Clamper

Figure 1-21 shows the circuit of a positive clamper. The input signal is assumed to be a square wave with time period *T*. The clamped output is obtained across R_L. The circuit design incorporates two main features. Firstly, the values of *C* and R_L are so selected that time constant $\tau = CR_L$ is very large. This means that voltage across the capacitor will not discharge significantly during the interval the diode is non-conducting. Secondly, R_LC time constant is deliberately made much greater than the time period *T* of the incoming signal

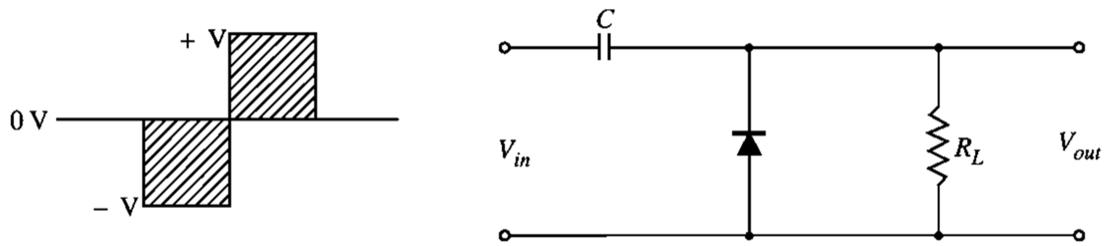


Figure 1-21. A Positive Clamper Circuit and its input and output waveforms.

Operation

(*i*) During the negative half-cycle of the input signal, the diode is forward biased. Therefore, the diode behaves as a short as shown in Figure 1-22. The charging time constant (= C_{Rf} , where R_f = forward resistance of the diode) is very small so that the capacitor will charge to *V* volts very quickly. It is easy to see that during this interval, the output voltage is directly across the short circuit. Therefore, V_{out} = 0.

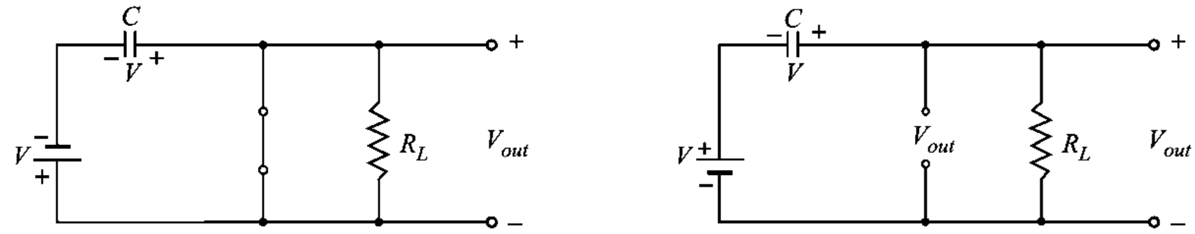


Figure 1-22. Operation of a Positive Clamper Circuit.

When the input switches to $+V$ state (*i.e.*, positive half-cycle), the diode is reverse biased and behaves as an open as shown in Figure 1-22. Since the discharging time constant (= CR_L) is much greater than the time period of the input signal, the capacitor remains almost fully charged to V volts during the off time of the diode. Referring to Figure 1-22 and applying Kirchhoff 's voltage law to the input loop, we have,

$$V + V - V_{out} = 0$$

or

$$V_{out} = 2V$$

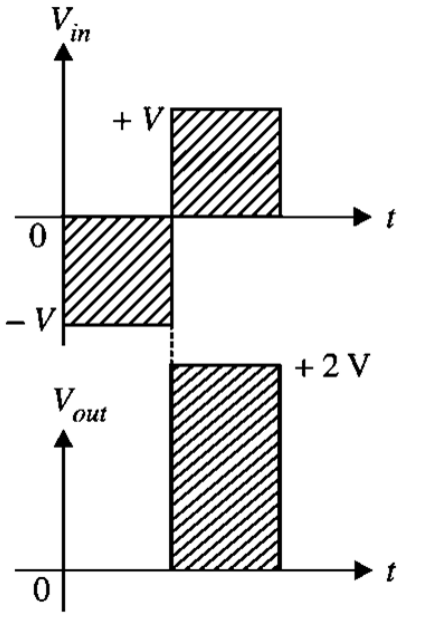


Figure 1-23. Output Waveform of Positive Clamper Circuit.

The resulting waveform is shown in Figure 1-23. It is clear that it is a positively clamped output. That is to say the input signal has been pushed upward by V volts so that negative peaks fall on the zero level.

Negative Clamper

Figure 1-24 shows the circuit of a negative clamper. The clamped output is taken across R_L. Note that only change from the positive clamper is that the connections of diode are reversed.

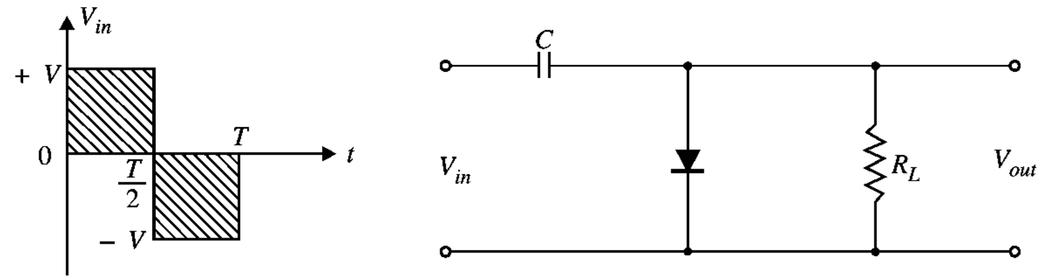


Figure 1-24. A Negative Clamper Circuit and its input and output waveforms.

(*i*) During the positive half-cycle of the input signal, the diode is forward biased. Therefore, the diode behaves as a short as shown in Figure 1-25. The charging time constant (= C_{Rf}) is very small so that the capacitor will charge to V volts very quickly. It is easy to see that during this interval, the output voltage is directly across the short circuit. Therefore, $V_{out} = 0$.

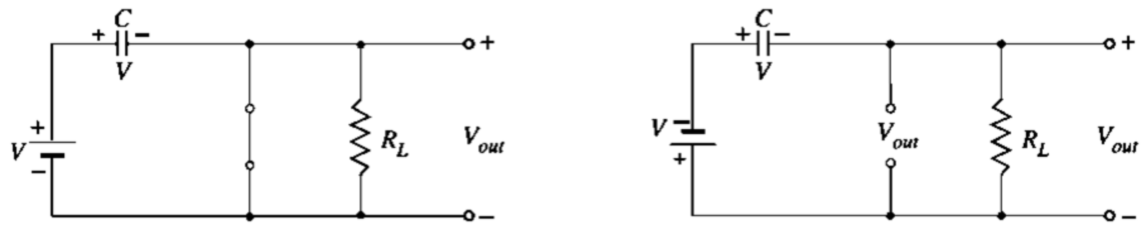


Figure 1-25. Operation of a Negative Clamper Circuit.

(*ii*) When the input switches to $-V$ state (*i.e.*, negative half-cycle), the diode is reverse biased and behaves as an open as shown in Figure 1-25. Since the discharging time constant (= C_{RL}) is much greater than the time period of the input signal, the capacitor almost remains fully charged to V volts during the off time of the diode. Referring to Figure 1-25 and applying Kirchhoff 's voltage law to the input loop, we have,

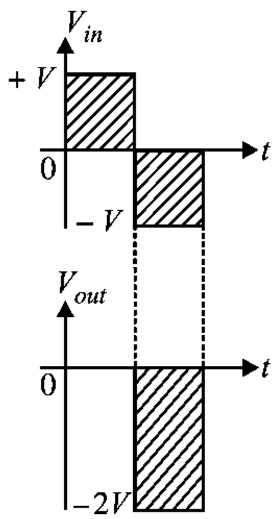


Figure 1-26. Output Waveform of Negative Clamper Circuit.

$$-V - V - V_{out} = 0$$

or

$$V_{out} = -2\text{ V}$$

The resulting waveform is shown in Figure 1-26. Note that total swing of the output signal is equal to the total swing of the input signal.

DC power supply: Block diagram of a power supply

In general, electronic circuits using tubes or transistors require a source of d.c. power. For example, in tube amplifiers, d.c. voltage is needed for plate, screen grid and control grid. Similarly, the emitter and collector bias in a transistor must also be direct current. Batteries are rarely used for this purpose as they are costly and require frequent replacement. In practice, d.c. power for electronic circuits is most conveniently obtained from commercial a.c. lines by using rectifier-filter system, called a *d.c. power supply*.

The rectifier-filter combination constitutes an ordinary d.c. power supply. The d.c. voltage from an ordinary power supply remains constant so long as a.c. mains voltage or load is unaltered. However, in many electronic applications, it is desired that d.c. voltage should remain constant irrespective of changes in a.c. mains or load. Under such situations, *voltage regulating devices* are used with ordinary power supply. This constitutes *regulated d.c. power supply* and keeps the d.c. voltage at fairly constant value. In this chapter, we shall focus our attention on the various voltage regulating circuits used to obtain regulated power supply.

An ordinary or unregulated d.c. power supply contains a rectifier and a filter circuit as shown in Figure 1-27. The output from the rectifier is pulsating d.c. These pulsations are due to the presence of a.c. component in the rectifier output.

The filter circuit removes the a.c. component so that steady d.c. voltage is obtained across the load.

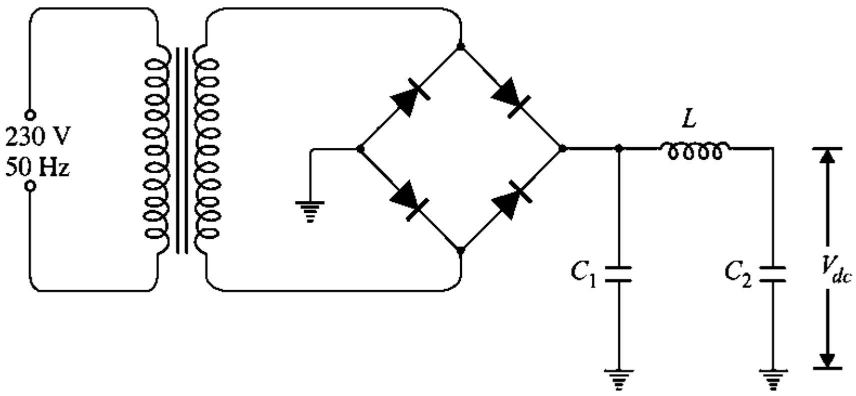


Figure 1-27. Unregulated D.C. Power Supply Contains a Rectifier and a Filter Circuit.

Limitations.

An ordinary d.c. power supply has the following drawbacks :

(*i*) The d.c. output voltage changes directly with input a.c. voltage. For instance, a 5% increase in input a.c. voltage results in approximately 5% increase in d.c. output voltage.

(*ii*) The d.c. output voltage decreases as the load current increases. This is due to voltage drop in

(*a*) transformer windings

(*b*) rectifier and

(*c*) filter circuit.

These variations in d.c. output voltage may cause inaccurate or erratic operation or even malfunctioning of many electronic circuits. For example, in an oscillator, the frequency will shift and in transmitters, distorted output will result. Therefore, ordinary power supply is unsuited for many electronic applications and is being replaced by regulated power supply.

Zener Diode Voltage Regulator

Zener diode is operated in the breakdown or zener region, the voltage across it is substantially constant for a large change of current through it. This characteristic permits it to be used as a voltage regulator. Fig. 17.10 shows the circuit of a zener diode regulator. As long as input voltage *Vin* is greater than zener voltage *VZ* , the zener operates in the breakdown region and maintains constant voltage across the load. The series limiting resistance *RS* limits the input current.

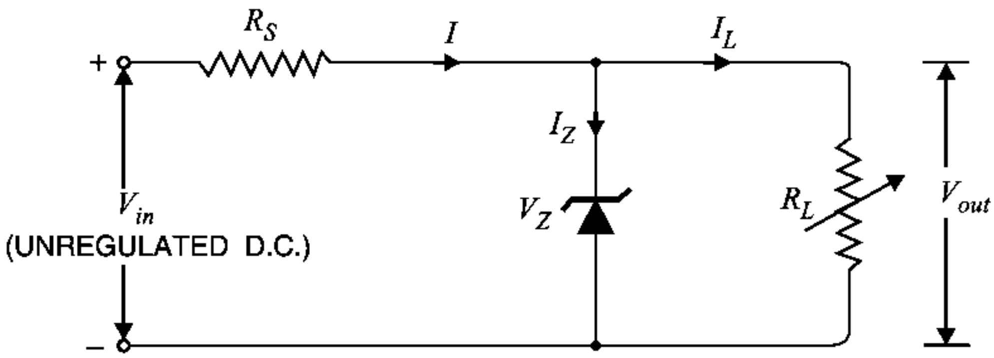


Figure 1-28. Zener Diode as Voltage Regulator

Operation. The zener will maintain constant voltage across the load inspite of changes in load current or input voltage. As the load current increases, the zener current decreases so that current through resistance R_S is constant. As output voltage = $V_{in} – IR_S$, and I is constant, therefore, output voltage remains unchanged. The reverse would be true should the load current decrease. The circuit will also correct for the changes in input voltages. Should the input voltage V_{in} increase, more current will flow through the zener, the voltage drop across R_S will increase but load voltage would remain constant. The reverse would be true should the input voltage decrease.

Limitations.

A zener diode regulator has the following drawbacks :

(*i*) It has low efficiency for heavy load currents. It is because if the load current is large, there will be considerable power loss in the series limiting resistance.

(*ii*) The output voltage slightly changes due to zener impedance as $V_{out} = V_Z + I_Z Z_Z$. Changes in load current produce changes in zener current. Consequently, the output voltage also changes. Therefore, the use of this circuit is limited to only such applications where variations in load current and input voltage are small.

UNIT – II

Transistor Amplifiers

Unit 2: TRANSISTOR AMPLIFIERS

Transistor configurations: CB, CE and CC modes – I-V characteristics and hybrid parameters – DC load line - Q point self-bias – RC coupled CE amplifier – power amplifiers – push-pull amplifiers – tuned amplifiers.

Transistor Circuit Configurations

Basically, there are three types of circuit connections (called configurations) for operating a transistor.

1. common-base (*CB*),
2. common-emitter (*CE*),
3. common-collector (*CC*).

The term 'common' is used to denote the electrode that is common to the input and output circuits. Because the common electrode is generally grounded, these modes of operation are frequently referred to as grounded-base, grounded-emitter and grounded-collector configurations as shown in Figure 2-1 for a *PNP* – transistor. Since a transistor is a 3-terminal (and not a 4-terminal) device, one of its terminals has to be common to the input and output circuits.

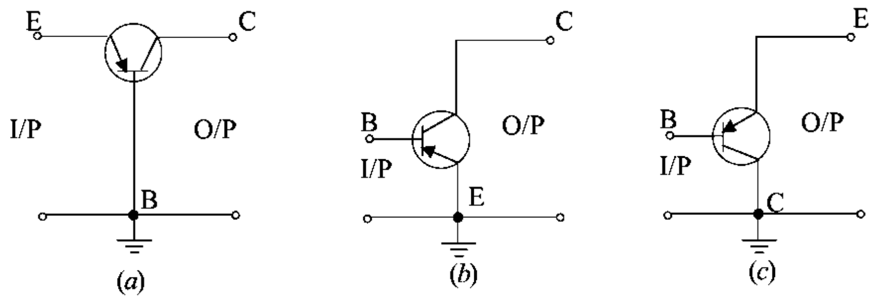


Figure 2-1. Transistor Configuration Common-Base , Common-Emitter and Common-Collector.

CB Configuration

In this configuration, emitter current I_E is the input current and collector current I_C is the output current. The input signal is applied between the emitter and base, whereas the output is taken out from the collector and base as shown in Figure 2-1(*a*). The ratio of the collector current to the emitter current is called dc alpha (αdc) of a transistor.

$$\alpha_{dc} = \frac{-I_C}{I_E}$$

The negative sign is due to the fact that current I_E flows into the transistor, whereas I_C flows out of it. Hence, I_E is taken as positive and I_C as negative.

$$I_C = -\alpha_{dc}.I_E$$

If we write adc simply as α**, then α = I_E /I_C It is also called forward current transfer ratio ($-h_{FB}$). In h_{FB}, subscript *F* stands for forward and *B* for common-base. The subscript d.c. on a signifies that this ratio is defined from dc values of I_C and I_E. The α of a transistor is a measure of the quality of a transistor ; the higher the value of α, the better the transistor in the sense that the collector current more closely equals the emitter current. Its value ranges from 0.95 to 0.999. Obviously, it applies only to *CB* configuration of a transistor. As seen from above and Figure 2-2.

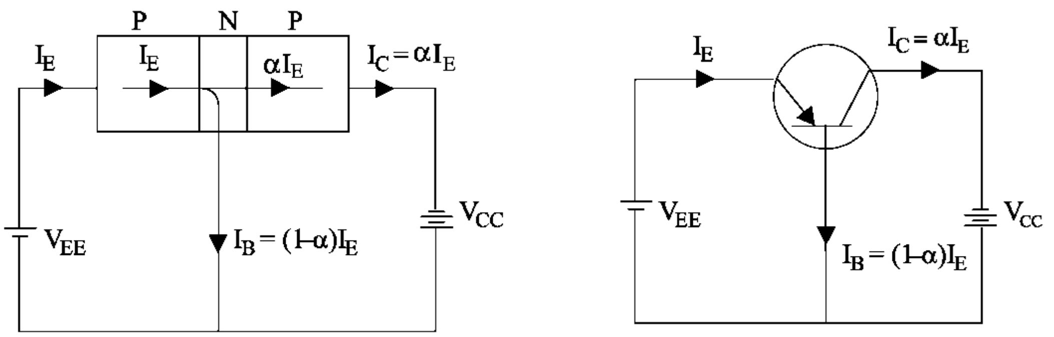


Figure 2-2. Common Base Configuration of a Transistor Amplifier.

$$I_C = \alpha I_E$$

$$I_B = I_E - \alpha I_E = (1-\alpha) I_E$$

Incidentally, there is also an a.c. α for a transistor. It refers to the ratio of ***change*** in collector current to the ***change*** in emitter current.

$$\alpha_{ac} = \frac{-\Delta I_C}{\Delta I_E}$$

It is also, known as short-circuit gain of a transistor and is written as – h_{fb}. It may be noted that upper case subscript '*FB*' indicates dc value whereas lower case subscript '*fb*' indicates ac value. For all practical purposes, $\alpha_{dc} = \alpha_{ac} = \alpha$.

CE Configuration

Here, input signal is applied between the base and emitter and output signal is taken out from the collector and emitter circuit. As seen from Figure 2-1(*b*), I_B is the input current and I_C is the output current.

The ratio of the d.c. collector current to dc base current is called dc beta (β_{dc}) or just β of the transistor.

$$\beta = -I_C/-I_B = I_C/I_B$$

It is also called common-emitter d.c. ***forward transfer ratio*** and is written as h_{FE}. It is possible for β to have as high a value as 500. While analysing ac operation of a transistor, we use ac β which is given by $\beta_{ac} = \Delta IC / \Delta IB$. It is also written as *hfe*. The flow of various currents in a *CE* configuration both for *PNP* and *NPN* transistor is shown in Figure 2-3. As seen

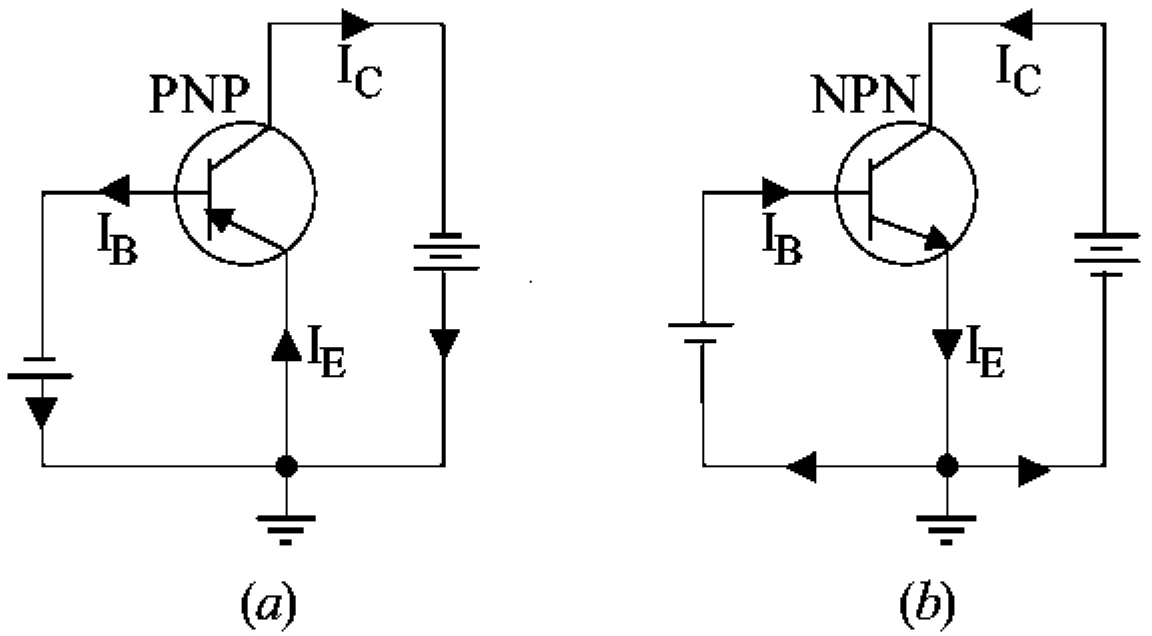


Figure 2-3. Common Emitter Configuration of a Transistor Amplifier.

CC Configuration

In this case, input signal is applied between base and collector and output signal is taken out from emitter-collector circuit [Figure 2-1 (*c*)]. Conventionally speaking, here I_B is the input current and I_E is the output current as shown in Fig. 57.9. The current gain of the circuit is

$$\frac{I_E}{I_B} = \frac{I_E}{I_C}.\frac{I_C}{I_B} = \frac{\beta}{\alpha} = \frac{\beta}{\beta/(1+\beta)} = (1+\beta)$$

The flow paths of various currents in a *CC* configuration are shown in Fig. 57.9. It is seen that

$$I_E = I_B + I_C = I_B + \beta I_B = (1 + \beta) I_B$$

∴ output current = (1 + β) × input current.

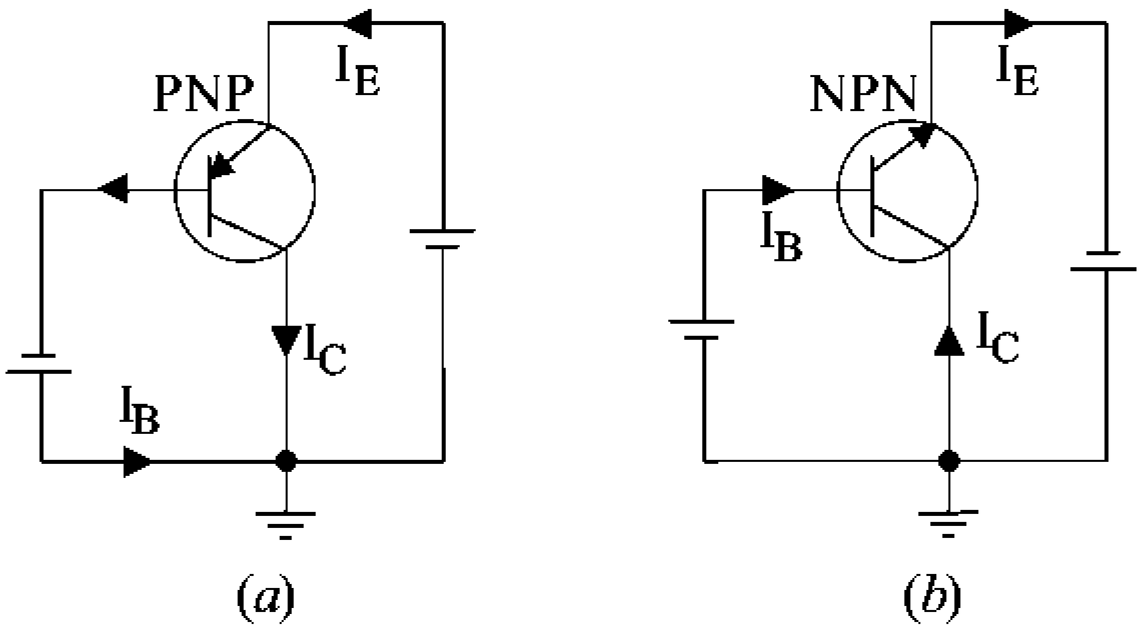


Figure 2-4. Collector Emitter Configuration of a Transistor Amplifier.

I-V characteristics

The curve of Figure 2-5 has different regions where the action of a transistor changes. First, there is the region in the middle where VCE is between 1 and 40 V. This represents the normal operation of a transistor. In this region, the emitter diode is forward biased, and the collector diode is reverse biased. Furthermore, the collector is gathering almost all the electrons that the emitter has sent into the base. This is why changes in collector voltage have no effect on the collector current. This region is called the active region. Graphically, the active region is the horizontal part of the curve. In other words, the collector current is constant in this region. Another region of operation is the breakdown region. The transistor should never operate in this region because it will be destroyed. Unlike the zener diode, which is optimized for breakdown operation, a transistor is not intended for operation in the breakdown region. Third, there is the early rising part of the curve, where VCE is between 0 V and a few tenths of a volt. This sloping part of the curve is called the saturation region. In this region, the collector diode has insufficient positive voltage to collect all the free electrons injected into the base. In this region, the base current I_B is larger than normal and the current gain dc is smaller than normal.

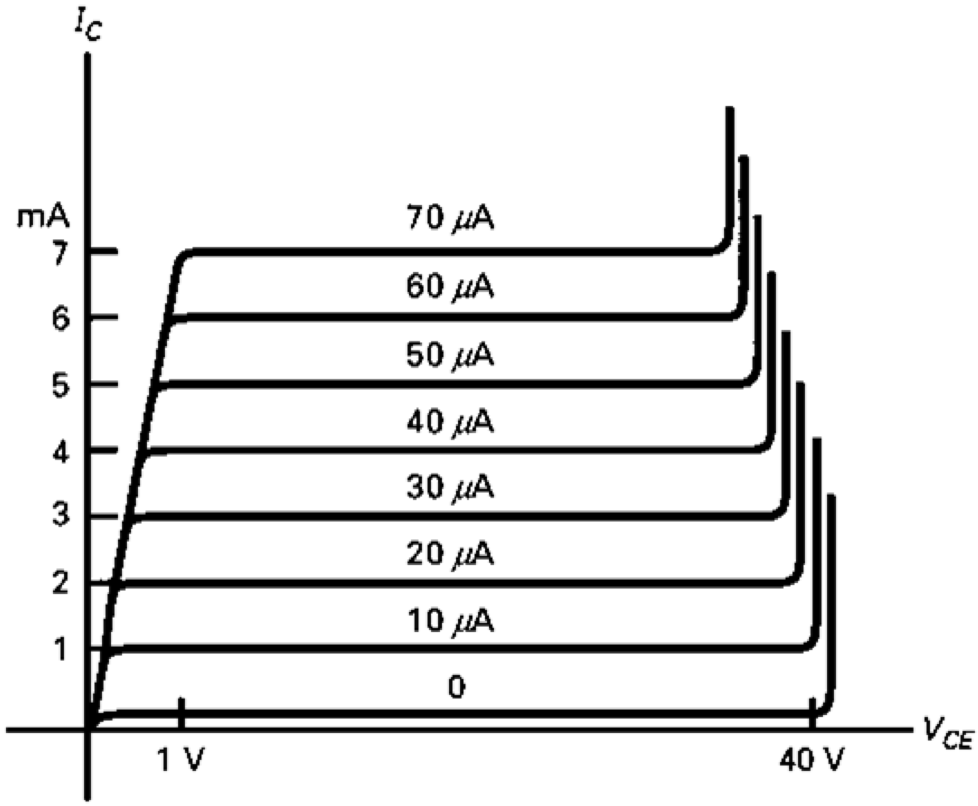


Figure 2-5. IV Curve of Transistor Amplifier in CE Configuration.

Hybrid Parameters

Every *linear circuit having input and output terminals can be analysed by four parameters (one measured in ohm, one in mho and two dimensionless) called hybrid or h Parameters.

Hybrid means “mixed”. Since these parameters have mixed dimensions, they are called hybrid parameters. Consider a linear circuit shown in Figure 2-6. This circuit has input voltage and current labelled v_1 and i_1. This circuit also has output voltage and current labelled v_2 and i_2.

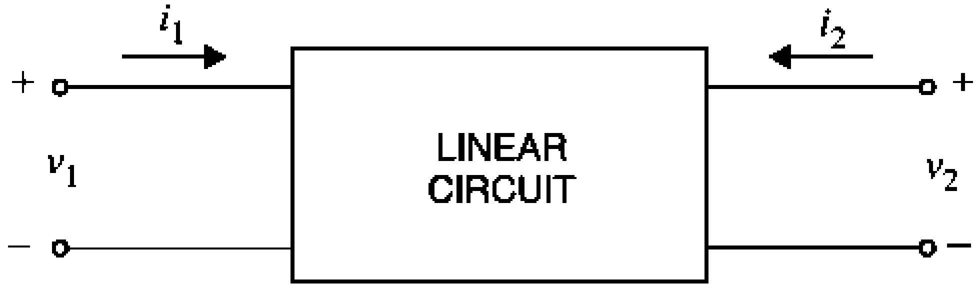


Figure 2-6. Block diagram of a Linear Circuit of Hybrid Parameters.

Note that both input and output currents (i_1 and i_2) are assumed to flow *into* the box ; input and output voltages (v_1 and v_2) are assumed *positive* from the upper to the lower terminals. These are standard conventions and do not necessarily correspond to the actual directions and polarities. When we analyse circuits in which the voltages are of opposite polarity or where the currents flow out of the box, we simply treat these voltages and currents as negative quantities.

It can be proved by advanced circuit theory that voltages and currents in Figure 2-6 can be related by the following sets of equations :

$$v_1 = h_{11}\, i_1 + h_{12}\, v_2 \; ...(i)$$

$$i_2 = h_{21}\, i_1 + h_{22}\, v_2 \; ...(ii)$$

In these equations, the *hs* are fixed constants for a given circuit and are called *h* parameters. Once these parameters are known, we can use equations (*i*) and (*ii*) to find the voltages and currents in the circuit. If we look at *eq*.(*i*), it is clear that **h_{11} has the dimension of ohm and h_{12} is dimensionless. Similarly, from *eq*. (*ii*), h_{21} is dimensionless and h_{22} has the dimension of mho. The following points may be noted about *h* parameters :

(i) Every linear circuit has four *h* parameters ; one having dimension of ohm, one having dimension of mho and two dimensionless.

(*ii*) The *h* parameters of a given circuit are constant. If we change the circuit, *h* parameters would also change.

(*iii*) Suppose that in a particular linear circuit, voltages and currents are related as under:

$$v_1 = 10i_1 + 6v_2$$

$$i_2 = 4i_1 + 3v_2$$

Here we can say that the circuit has *h* parameters given by $h_{11} = 10\ \Omega$; $h_{12} = 6$; $h_{21} = 4$ and $h_{22} = 3$ mho.

DC Load Line

For drawing the dc load line of a transistor, one need to know only its cut-off and saturation points. It is a straight line jointing these two points. For the *CE* circuit of Figure 2-8, the load line is drawn in Figure 2-7. *A* is the cut-off point and *B* is the saturation point. The voltage equation of the collector-emitter is Consider the following two particular cases :

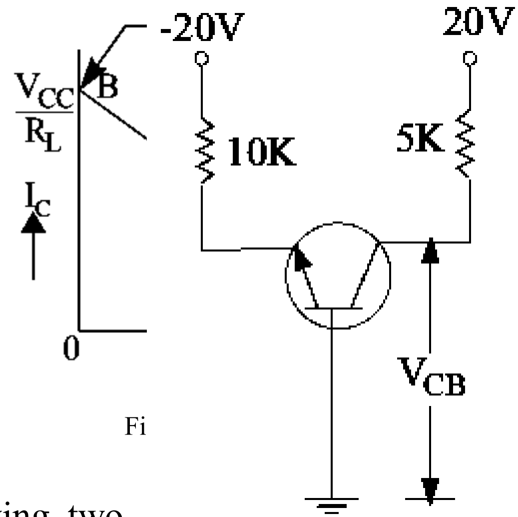


Figure 2-8. Transistor Circuit.

(*i*) when *IC* = 0, *VCE*= *VCC* (cut-off point A)

(*ii*) when $V_{CE} = 0$, $I_C = V_{CC}/R_L$ (saturation point B)

Obviously, load line can be drawn if only V_{CC} and R_L are known. Incidentally slope of the load line $AB = -1/R_L$

It is a linear equation similar to $y = -mx + c$

The graph of this equation is a straight line whose slope is $m = -1/R_L$

Active Region

All operating points (like *C, D, E* etc. in Figure 2-7) lying between cut-off and saturation points form the ***active region*** of the transistor. In this region, *E*/*B* junction is forward-biased and *C/B* junction is reverse-biased conditions necessary for the proper operation of a transistor.

Quiescent Point (Q-Point self bias)

It is a point on the dc load line, which represents the values of I_C and V_{CE} that exist in a transistor circuit when ***no input signal is applied.***

It is also known as the ***dc operating point or working point.*** The best position for this point is midway between cut-off and saturation points where $V_{CE} = \frac{1}{2} V_{CC}$ (like point *D* in Figure 2-7).

RC Couple CE Amplifier

Figure 2-9 and Figure 2-10 show the circuit of a single-stage CE amplifier using an NPN transistor. Here, base is the driven element. The input signal is injected into the base emitter circuit whereas output signal is taken out from the collector emitter circuit. The E/B junction is forward-biased by VBB and C/B junction is reversed-biased by VCC (in fact, same battery VCC can provide dc power for both base and collector as in Figure 2-10). The Q-point or working condition is determined by VCC together with RB and RC.

The dc equation is,

$$I_B \cong \frac{V_{BB}}{R_B}$$

$$I_C = \beta I_B \text{ and } V_{CE} = V_{CC} - I_C R_C$$

Now, let us see what happens when an ac signal is applied at the input terminals of the circuit.

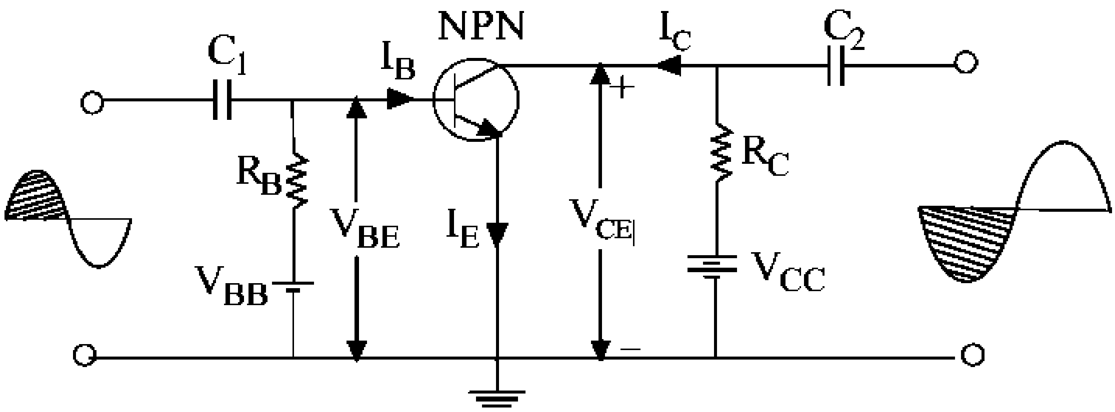


Figure 2-9. Circuit Diagram of the RC Coupled CE Amplifier.

Circuit Operations

When positive half-cycle of the signal is applied (Figure 2-9)

1. V_{BE} is **increased** because it is already positive w.r.t. the ground as per biasing rule.

2. it leads to increase in forward bias of base emitter junction

3. I_B is **increased** somewhat

4. I_C is increased by α times the **increased** in I_B.

5. drop $I_C R_C$ is **increased** considerably and consequently.

6. V_{CE} is decreased as seen from the equation given above.

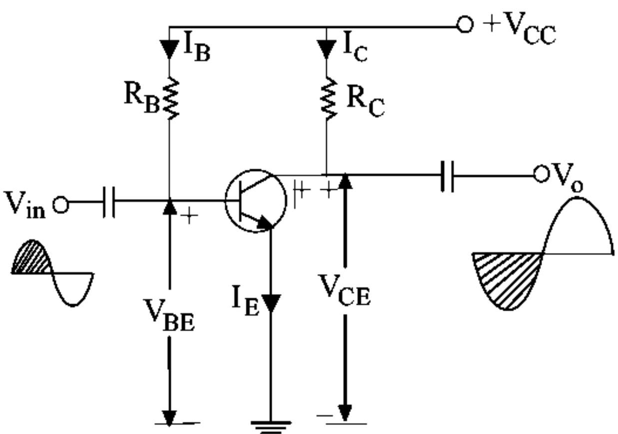


Figure 2-10. Single Stage CE Amplifier

Hence, negative half-cycle of the output is obtained. It means that a positive-going input signal becomes a negative going output signal.

Power Amplifier

A transistor amplifier which raises the power level of the signals that have audio frequency range is known as transistor audio power amplifier.

In general, the last stage of a multistage amplifier is the *power stage*. The power amplifier differs from all the previous stages in that here a concentrated effort is made to obtain maximum output power.

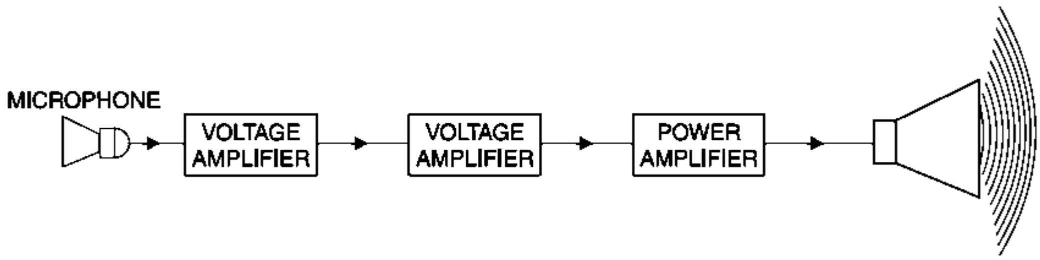


Figure 2-11. Block Diagram of Power Amplifier Amplifying the Audio Power

A transistor that is suitable for power amplification is generally called a *power transistor*. It differs from other transistors mostly in size ; it is considerably larger to provide for handling the great amount of power. Audio power amplifiers are used to deliver a large amount of power to a low resistance load. Typical load values range from 300Ω (for transmission antennas) to 8Ω (for loudspeakers). Although these load values do not cover every possibility, they do illustrate the fact that audio power amplifiers usually drive low-resistance loads. The typical power output rating of a power amplifier is 1W or more.

Push-Pull Amplifier

The push-pull amplifier is a power amplifier and is frequently employed in the output stages of electronic circuits. It is used whenever high output power at high efficiency is required. Figure 2-12 shows the circuit of a push-pull amplifier. Two transistors T_{r1} and T_{r2} placed back to back are employed. Both transistors are operated in class *B* operation *i.e*. collector current is nearly zero in the absence of the signal. The centre-tapped secondary of driver transformer T_1 supplies equal and opposite voltages to the base circuits of two transistors. The output transformer T_2 has the centre-tapped primary winding. The supply voltage V_{CC} is connected between the bases and this centre tap. The loudspeaker is connected across the secondary of this transformer.

Circuit operation.

The input signal appears across the secondary *AB* of driver transformer. Suppose during the first half-cycle (marked 1) of the signal, end *A* becomes positive and end *B* negative. This will make the base-emitter junction of T_{r1} reverse biased and that of *Tr*2 forward biased.

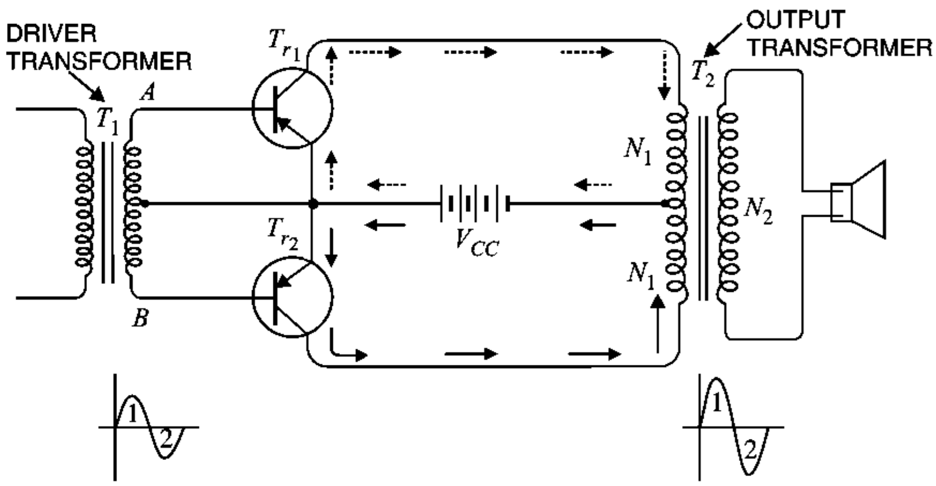


Figure 2-12. Circuit Diagram of a Push-Pull Amplifier.

The circuit will conduct current due to T_{r2} only and is shown by solid arrows. Therefore, this half-cycle of the signal is amplified by T_{r2} and appears in the lower half of the primary of output transformer. In the next halfcycle of the signal, T_{r1} is forward biased whereas T_{r2} is reverse biased. Therefore, T_{r1} conducts and is shown by dotted arrows. Consequently, this half-cycle of the signal is amplified by T_{r1} and appears in the upper half of the output transformer primary. The centre-tapped primary of the output transformer combines two collector currents to form a sine wave output in the secondary. It may be noted here that push-pull arrangement also permits a maximum transfer of power to the

load through impedance matching. If R_L is the resistance appearing across secondary of output transformer, then resistance R'_L of primary shall become :

$$R'_L = \left(\frac{2N_1}{N_2}\right)^2 R_L$$

Where

N_1 = Number of turns between either end of primary winding and centre-tap

N_2 = Number of secondary turns

Advantages

(*i*) The efficiency of the circuit is quite high (j 75%) due to class *B* operation.

(*ii*) A high a.c. output power is obtained.

Disadvantages

(*i*) Two transistors have to be used.

(*ii*) It requires two equal and opposite voltages at the input. Therefore, push-pull circuit requires the use of driver stage to furnish these signals.

(*iii*) If the parameters of the two transistors are not the same, there will be unequal amplification of the two halves of the signal.

(*iv*) The circuit gives more distortion.

(*v*) Transformers used are bulky and expensive.

Tuned Amplifiers

Amplifiers which amplify a specific frequency or narrow band of frequencies are called **tuned amplifiers.**

Tuned amplifiers are mostly used for the amplification of high or radio frequencies. It is because radio frequencies are generally single and the tuned circuit permits their selection and efficient amplification.

However, such amplifiers are not suitable for the amplification of audio frequencies as they are mixture of frequencies from 20 Hz to 20 kHz and not single. Tuned amplifiers are widely used in radio and television circuits where they are called upon to handle radio frequencies. Figure 2-13 shows the circuit of a simple transistor tuned amplifier. Here, instead of load resistor, we have a parallel tuned circuit in the collector. The impedance of this tuned circuit strongly depends upon frequency. It offers a very high impedance at *resonant frequency* and very small impedance at all other frequencies. If the signal has the same frequency as the resonant frequency of *LC* circuit, large amplification will result due to high impedance of *LC* circuit at this frequency. When signals of many frequencies are present at the input of tuned amplifier, it will select and strongly amplify the signals of resonant frequency while *rejecting all others. Therefore, such amplifiers are very useful in radio receivers to select the signal

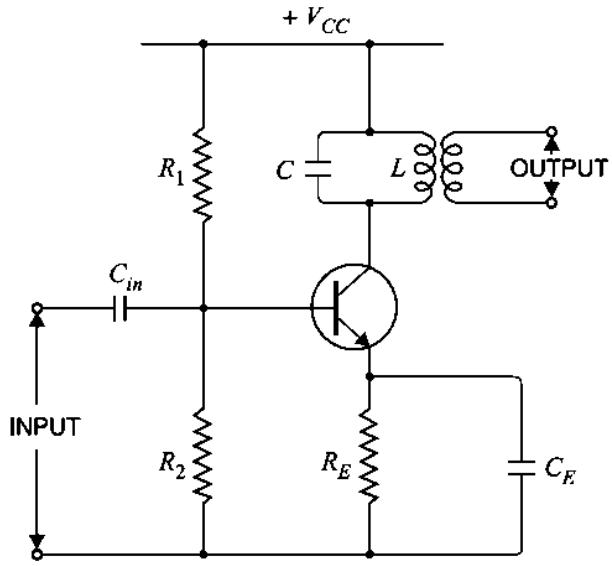


Figure 2-13. Circuit of a Transistor-tuned Amplifier

from one particular broadcasting station when signals of many other frequencies are present at the receiving aerial.

UNIT – III

Transistor Oscillators

Unit 3: TRANSISTOR OSCILLATORS

Feedback amplifier – principle of feedback, positive and negative feedback – voltage and current gain – advantages of negative feedback – Barkhausen's criterion – Transistor oscillators: Hartley, Colpitts, Phase shift oscillators.

Feedback amplifier

A feedback amplifier is one in which a fraction of the amplifier output is fed back to the input circuit. This partial dependence of amplifier output on its input helps to control the output. A feedback amplifier consists of two parts : an amplifier and a feedback circuit.

(*i*) *Positive feedback*

If the feedback voltage (or current) is so applied as to increase the input voltage (*i.e.* it is in phase with it), then it is called positive feedback. Other names for it are : *regenerative* or *direct* feedback. Since positive feedback produces excessive distortion, it is seldom used in amplifiers. However, because it increases the power of the original signal, it is used in oscillator circuits.

(*ii*) *Negative feedback*

If the feedback voltage (or current) is so applied as to reduce the amplifier input (*i.e.* it is 180° out of phase with it), then it is called negative feedback. Other names for it are : *degenerative* or *inverse* feedback. Negative feedback is frequently used in amplifier circuits.

Principle of Feedback Amplifiers

For an ordinary amplifier *i.e.* one without feedback, the voltage gain is given by the ratio of the output voltage V_o and input voltage V_i. As shown in the block diagram of Figure 3-1, the input voltage V_i is amplified by a factor of A to the value V_o of the output voltage.

$$A = V_o / V_i$$

This gain A is often called ***open-loop*** gain. Suppose a feedback loop is added to the amplifier (Figure 3-1).

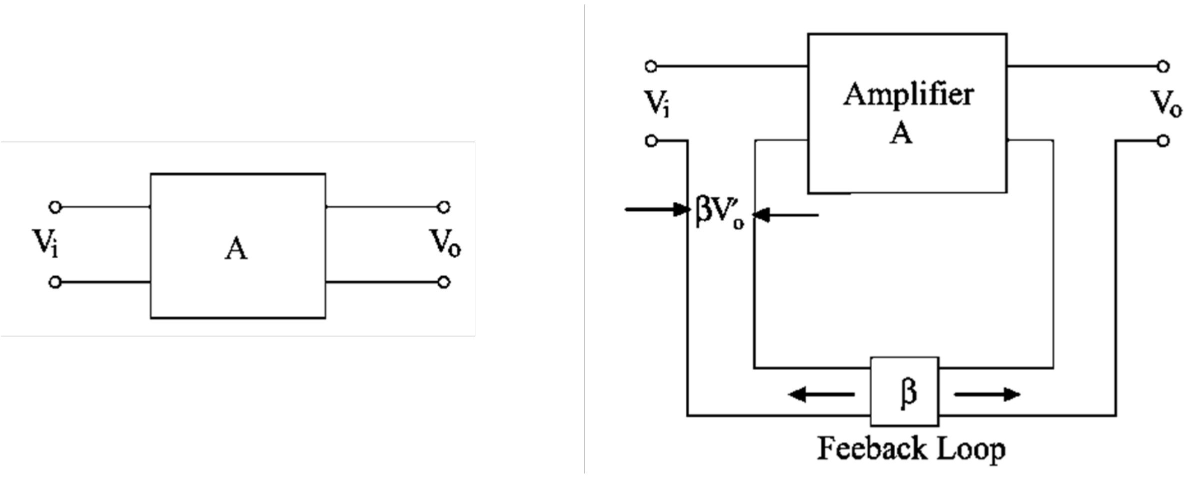


Figure 3-1. Block Diagram of Amplifier representing the amplification of Voltage with and without the feedback.

If V_o' is the output voltage with feedback, then a fraction β* of this voltage is applied to the input voltage which, therefore, becomes ($V_i \pm \beta V_o'$) depending on whether the feedback voltage is in phase or antiphase with it. Assuming positive feedback, the input voltage will become ($V_i + \beta V_o'$). When amplified A times, it becomes $A(V_i + \beta V_o')$.

$$A\,(V_i + \beta V_o') = V_o'$$

or

$$V_o'\,(1 - \beta A) = AV_i$$

The amplifier gain A' with feedback is given by

$$A' = \frac{V_o'}{V_i} = \frac{A}{1 - \beta A}$$

$$A = \frac{A}{1-\beta A}$$ Positive Feedback

$$= \frac{A}{1-(-\beta A)} = \frac{A}{1+\beta A}$$ Negative Feedback

The term 'βA' is called **feedback factor** whereas β is known as **feedback ratio**. The expression $(1 \pm \beta A)$ is called **loop gain**. The amplifier gain A' with feedback is also referred to as **closed loop gain** because it is the gain obtained after the feedback loop is closed. The sacrifice factor is defined as $S = A/A'$.

Positive Feedback (Voltage and current gain)

The amplifier gain with positive feedback is given by

$$A^{`} = \frac{A}{1-\beta A}$$

Suppose gain without feedback is 90 and $\beta = 1/100 = 0.01$, then gain with positive feedback is

$$A^{`} = \frac{90}{1-(0.01 \times 90)} = 900$$

Since positive feedback increases the amplifier gain. It is called ***regenerative*** feedback. If $\beta A = 1$, then mathematically, the gain becomes infinite which simply means that there is an output without any input! However, electrically speaking, this cannot happen. What actually happens is that the amplifier becomes an oscillator which supplies its own input. In fact, two important and necessary conditions for circuit oscillation are

1. the feedback must be positive,

2. feedback factor must be unity *i.e.* $\beta A = +1$.

Negative Feedback (Voltage and current gain)

The amplifier gain with negative feedback is given by $A^{`} = \frac{A}{1+\beta A}$

Obviously, $A' < A$ because $| 1 + \beta A | > 1$.

Suppose, $A = 90$ and $\beta = 1/10 = 0.1$

Then, gain without feedback is 90 and with negative feedback is

$$A^{`} = \frac{A}{1+\beta A} = \frac{90}{1+0.1\times 90} = 9$$

As seen, negative feedback reduces the amplifier gain. That is why it is called ***degenerative*** feedback. A lot of voltage gain is sacrificed due to negative feedback. When $| \beta A | \gg 1$, then

$$A^{`} \cong \frac{A}{\beta A} \cong \frac{1}{\beta}$$

It means that A' depends only on β. But it is very stable because it is not affected by changes in temperature, device parameters, supply voltage and from the aging of circuit components etc. Since resistors can be selected very precisely with almost zero temperature-coefficient of resistance, it is possible to achieve highly precise and stable gain with negative feedback.

Advantages of Negative Feedback

The numerous advantages of negative feedback outweigh its only disadvantage of reduced gain. Among the advantages are :

1. higher fidelity *i.e.* more linear operation,

2. highly stabilized gain,

3. increased bandwidth *i.e.* improved frequency response,

4. less amplitude distortion,

5. less harmonic distortion,

6. less frequency distortion,

7. less phase distortion,

8. reduced noise,

9. input and output impedances can be modified as desired.

Barkhausen Criterion

Barkhausen criterion is that in order to produce continuous undamped oscillations at the output of an amplifier, the positive feedback should be such that :

$$m_v A_v = 1$$

Once this condition is set in the positive feedback amplifier, continuous undamped oscillations can be obtained at the output immediately after connecting the necessary power supplies.

(*i*) Mathematical explanation. The voltage gain of a positive feedback amplifier is given by;

$$A_{vf} = \frac{A_v}{1 - m_v A_v}$$

$m_v A_v = 1$, then $A_{vf} \to \infty$

We know that we cannot achieve infinite gain in an amplifier. So what does this result infer in physical terms ? It means that a vanishing small input voltage would give rise to finite (*i.e.*, a definite amount of) output voltage even when the input signal is zero. Thus once the circuit receives the input trigger, it would become an oscillator, generating oscillations with no external signal source.

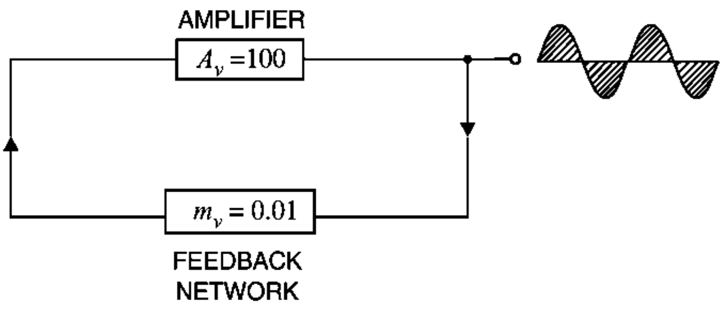


Figure 3-2. voltage gain of the amplifier without positive feedback.

***(ii)* Graphical Explanation.** Let us discuss the condition $m_v A_v = 1$graphically. Suppose the voltage gain of the amplifier without positive feedback is 100. In order to produce continuous undamped oscillations, *mv Av* = 1 or *mv* × 100 = 1 or $m_v = 0.01$. This is illustrated in Figure 3-2. Since the condition $m_v A_v = 1$ is met in the circuit shown in Figure 3-2, it will produce sustained oscillations. Suppose the initial triggering voltage is 0.1V peak. Starting with this value, circuit (A_v = 100 ; $m_v = 0.01$) will progress as follows

Cycle	V_{in}	V_{out}	V_f
1.	0.1Vpk	10Vpk	0.1Vpk
2.	0.1Vpk	10Vpk	0.1Vpk

The same thing will repeat for 3rd, 4th cycles and so on. Note that during each cycle, $V_f = 0.1V_{pk}$ and $V_{out} = 10\ V_{pk}$. Clearly, the oscillator is producing continuous undamped oscillations.

Transistor Oscillators

A transistor can work as an oscillator to produce continuous undamped oscillations of any desired frequency if tank and feedback circuits are properly connected to it. All oscillators under different names have similar function *i.e.*, they produce continuous undamped output. However, the major difference between these oscillators lies in the method by which energy is supplied to the tank circuit to meet the losses. The following are the transistor oscillators commonly used at various places in electronic circuits :

- ***(i)*** Tuned collector oscillator
- ***(ii)*** Colpitt's oscillator
- ***(iii)*** Hartley oscillator
- ***(iv)*** Phase shift oscillator
- ***(v)*** Wien Bridge oscillator
- ***(vi)*** Crystal oscillator

Hartley oscillator

In Figure 3-3(*a*) is shown a transistor Hartley oscillator using *CE* configuration. Its general principle of operation is similar to the tuned-collector oscillator. It uses a single tapped-coil having two parts marked L_1 and L_2 instead of two separate coils. So far as ac signals are concerned, one side of L_2 is connected to base *via* C_1 and the other to emitter *via* ground and C_3. Similarly, one end of L_1 is connected to collector *via* $C2$ and the other to common emitter terminal *via* C_3. In other words, $L1$ is in the output circuit *i.e.* collector-emitter circuit whereas L_2 is in the base-emitter circuit *i.e.* input circuit. These two parts are inductively-coupled and form an auto-transformer or a split-tank inductor. Feedback between the output and input circuits is accomplished through autotransformer action which also introduces a phase reversal of 180°.

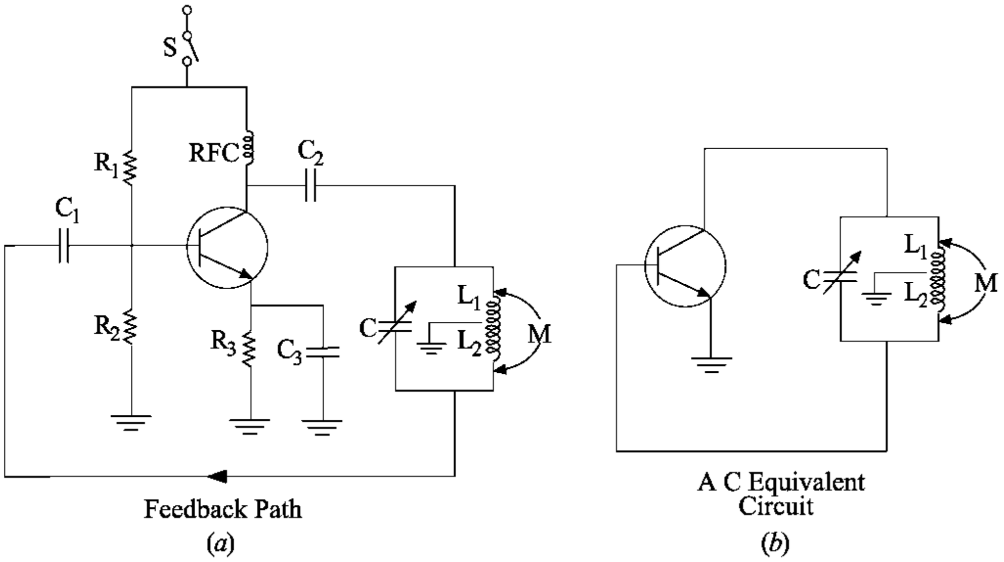


Figure 3-3. Hartley oscillator (a) Feedback Path, (b) AC equivalent circuit.

This phase reversal between two voltages occurs because they are taken from ***opposite ends*** of an inductor (L_1 - L_2 combination) with respect to the tap which is tied to common transistor terminal *i.e.* emitter which is ac grounded *via* C_3. Since transistor itself introduces a phase shift of 180°, the total phase shift becomes 360° thereby making the ***feedback positive* or *regenerative*** which is essential for oscillations. As seen, positive feedback is obtained from the tank circuit and is coupled to the base *via* C1. The feedback factor is given by the ratio of turns in L_2 and L_1 *i.e.* by N_2/ N_1 and its value ranges from 0.1 to 0.5. Figure 3-3(*b*) shows the equivalent circuit of Hartley oscillator. Resistors R_1 and R_2 form a voltage divider for providing the base bias and R_3 is an emitter swamping resistor to add stability to the circuit. Capacitor C_3 provides ac ground thereby preventing any signal degeneration while still providing temperature stabilisation. Radio-frequency choke (RFC) provides dc load for the collector and also keeps ac currents out of the dc supply V_{CC}.

When V_{CC} is first switched on through *S*, an initial bias is established by R_1 - R_2 and oscillations are produced because of positive feedback from the *LC* tank circuit (L_1 and L_2 constitute *L*). The frequency of oscillation is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Where, $L=L_1+L_2+2M$

The output from the tank may be taken out by means of another coil coupled either to L_1 or L_2.

Colpitts Oscillator

This oscillator is essentially the same as Hartley oscillator except for one difference. Colpitts oscillator uses **tapped capacitance** whereas Hartley oscillator uses **tapped inductance*.** Figure 3-4(*a*)

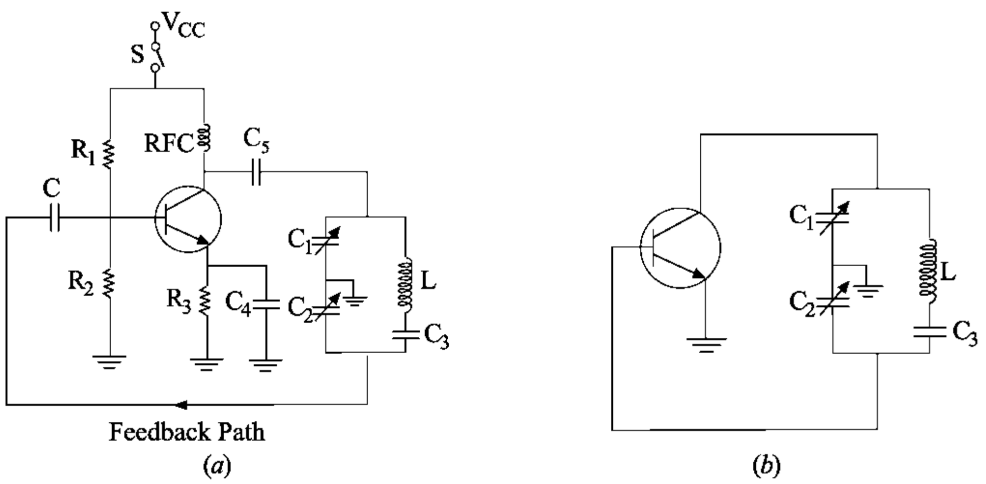


Figure 3-4. Colpitts oscillator (a) Feedback Path, (b) AC equivalent circuit.

shows the complete circuit with its power source and dc biasing circuit whereas Figure 3-4 (*b*) shows its ac equivalent circuit. The two series capacitors C_1 and C_2 form the voltage divider used for providing the feedback voltage (the voltage drop across C_2 constitutes the feedback voltage). The feedback factor is C_1/C_2. The minimum value of amplifier gain for maintaining oscillations is

$$A_v = \frac{1}{C_1/C_2} = \frac{C_1}{C_2}$$

The tank circuit consists of two ganged capacitors C_1 and C_2 and a single fixed coil. The frequency of oscillation (which does not depend on mutual inductance) is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Where, $C = \frac{C_1 C_2}{C_1 + C_2}$

Transistor itself produces a phase shift of 180°. Another phase shift of 180° is provided by the capacitive feedback thus giving a total phase shift of 360° between the emitter-base and collector base circuits.

Resistors R_1 and R_2 form a voltage divider across V_{CC} for providing base bias, R_3 is for emitter stabilisation and *RFC* provides the necessary dc load resistance R_C for amplifier action. It also prevents ac signal from entering supply dc V_{CC}. Capacitor C_5 is a bypass capacitor whereas C_4 conveys feedback from the collector-to-base circuit.

When *S* is closed, a sudden surge of collector current **shock-excites** the tank circuit into oscillations which are sustained by the feedback and the amplifying action of the transistor.

Colpitts oscillator is widely used in commercial signal generators upto 1 MHz. Frequency of oscillation is varied by gang-tuning the two capacitors C_1 and C_2.

Phase shift oscillators

Figure 3-5 shows the circuit of a phase shift oscillator. It consists of a conventional single transistor amplifier and a R_C phase shift network. The phase shift network consists of three sections R_1C_1, R_2C_2 and R_3C_3. At some particular frequency f_0, the phase shift in each R_C section is 60º so that the total phase-shift produced by the R_C network is 180º. The frequency of oscillations is given by :

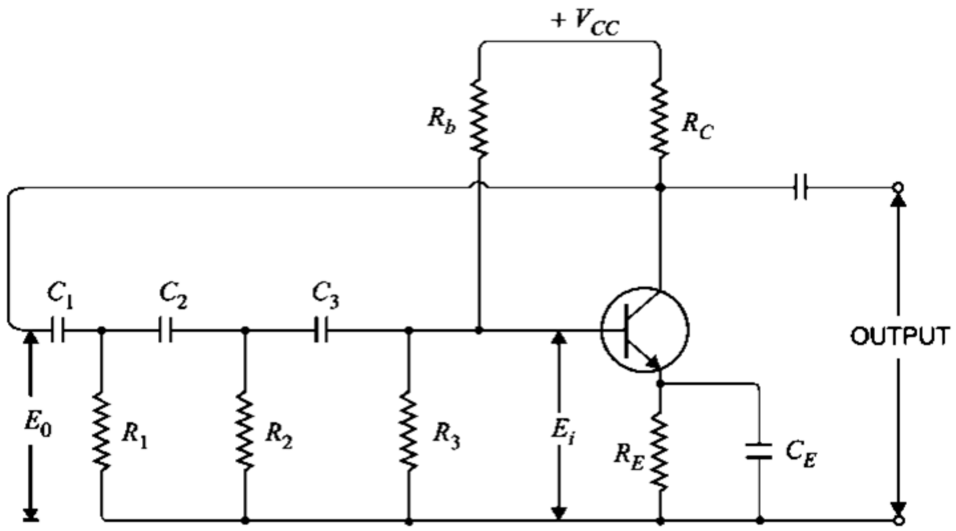


Figure 3-5.Circuit Diagram of Phase shift oscillator.

$$f_0 = \frac{1}{2\pi RC\sqrt{6}}$$

Where, $R_1 = R_2 = R_3 = R$; $C_1 = C_2 = C_3 = C$

Circuit operation.

When the circuit is switched on, it produces oscillations of frequency determined by exp. (*i*). The output E_0 of the amplifier is fed back to R_C feedback network. This network produces a phase shift of 180º and a voltage E_i appears at its output which is applied to the transistor amplifier. Obviously, the feedback fraction $m = E_i / E_0$. The feedback phase is correct. A phase shift of 180º is produced by the transistor amplifier. A further phase shift of 180º is produced by the R_C network. As a result, the phase shift around the entire loop is 360º.

Advantages

(*i*) It does not require transformers or inductors.

(*ii*) It can be used to produce very low frequencies.

(*iii*) The circuit provides good frequency stability.

Disadvantages

(*i*) It is difficult for the circuit to start oscillations as the feedback is generally small.

(*ii*) The circuit gives small output.

UNIT – IV

Operational Amplifiers and Timer

Unit 4: OPERATIONAL AMPLIFIERS AND TIMER

Differential amplifiers – OP-AMP characteristics – IC 741 pin configuration – inverting and non-inverting amplifiers – summing and difference amplifiers – differentiator and integrator – IC 555 pin configuration – astable multivibrator (square wave generator) – monostable vibrator.

Differential amplifiers

A **differential amplifier** is a circuit that can accept two input signals and amplify the difference between these two input signals.

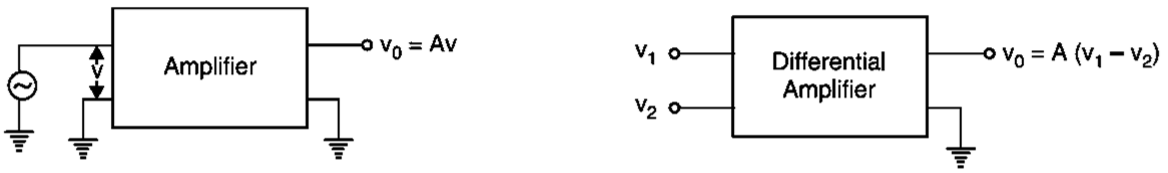


Figure 4-1. Block diagram of a Regular Amplifier and an Differential Amplifier.

Figure 4-1 shows the block diagram of an ordinary amplifier. The input voltage v is amplified to A_v where A is the voltage gain of the amplifier. Therefore, the ouput voltage is $v_0 = A_v$. Figure 4-1 shows the block diagram of a differential amplifier. There are two input voltages v_1 and v_2. This amplifier amplifies the difference between the two input voltages. Therefore, the output voltage is $v_0 = A(v_1 - v_2)$ where A is the voltage gain of the amplifier.

Since differential amplifier (*DA*) is key to the operation of *OP*-Amp, we shall discuss this circuit in detail. So far in the book we have considered general-purpose amplifiers. In these conventional amplifiers, the signal (generally single input) is applied at the input terminals and amplified output is obtained at the output terminals. However, we can design an amplifier circuit that accepts two input signals and amplifies the difference between these two signals. Such an amplifier is called a **differential amplifier* (*DA*).

Operational Amplifier (OP-AMP)

OP-Amp is a very high-gain, high-*rin* directly-coupled negative-feedback amplifier which can amplify signals having frequency ranging from **0 Hz to a little beyond 1 MHz.** They are made with different internal configurations in linear *ICs*.

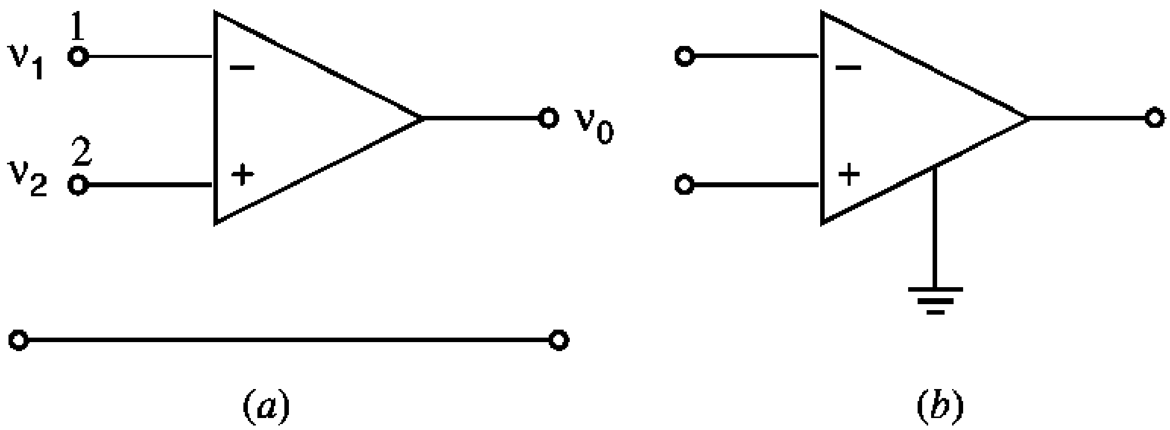


Figure 4-2. Operational Amplifier (OP-AMP)

Standard triangular symbol for an *OP-AMP* is shown in Figure 4-2 (*a*) though the one shown in Figure 4-2 (*b*) is also used often. In Figure 4-2 (*b*), **the common ground line has been omitted.**

It also does not show other necessary connections such as for dc power and feedback etc. The *OP-AMP's* input can be single ended or double-ended (or differential input) depending on whether input voltage is applied to one input terminal only or to both. Similarly, amplifier's output can also be either single-ended or double ended.

The most common configuration is ***two input terminals and a single output.*** All OP-AMPs have a minimum of five terminals :

1. inverting input terminal,

2. non-inverting input terminal,

3. output terminal,

4. positive bias supply terminal,

5. negative bias supply terminal.

Operational Amplifier characteristics

When an *OP-AMP* is operated without connecting any resistor or capacitor from its output to any one of its inputs (*i.e.*, without feedback), it is said to be in the open-loop condition. The word 'open loop' means that *feedback path or loop is open*.

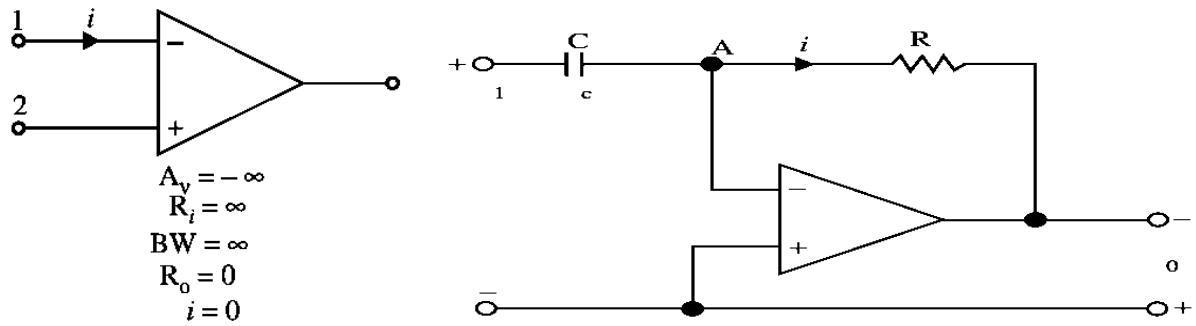


Figure 4-3. Characteristics of an Ideal OP-AMP and Circuit Diagram of an OP-AMP in Negative Feedback mode.

The specifications of *OP-AMP* under such condition are called open-loop specifications. An ideal *OP-AMP* (Figure 4-3) has the following characteristics :

1. its open-loop gain *Av* is *infinite i.e.*, *A*v = − ∞

2. its input resistance *Ri* (measured between inverting and non-inverting terminals) is *infinite i.e.*, *Ri* = ∞ ohm

3. its output resistance *R*0 (seen looking back into output terminals) is *zero i.e.*, *R*0 = 0 Ω

4. it has *infinite bandwith i.e.*, it has flat frequency response from dc to infinity. Though these characteristics cannot be achieved in practice, yet an ideal *OP-AMP* serves as a convenient reference against which real *OP-AMPs* may be evaluated.

Following additional points are worth noting :

1. infinte input resistance means that input current $i = 0$ as indicated in Figure 4-3. It means that an ideal *OP-AMP* is a voltage-controlled device.

2. $R_0 = 0$ means that v_0 is not dependent on the load resistance connected across the output.

3. though for an ideal *OP-AMP* $A_v = \infty$, for an actual one, it is extremely high *i.e.*, about 106. However, it does not mean that 1 V signal will be amplified to 106 V at the output. Actually, the maximum value of v_0 is limited by the basis supply voltage, typically ± 15 V. With A_v = 106 and v_0 = 15 V_2 the maximum value of input voltage is limited to 15/106 = 15 μV. Though 1 μV in the *OP-AMP*, can certainly become 1 V.

IC 741 pin configuration:

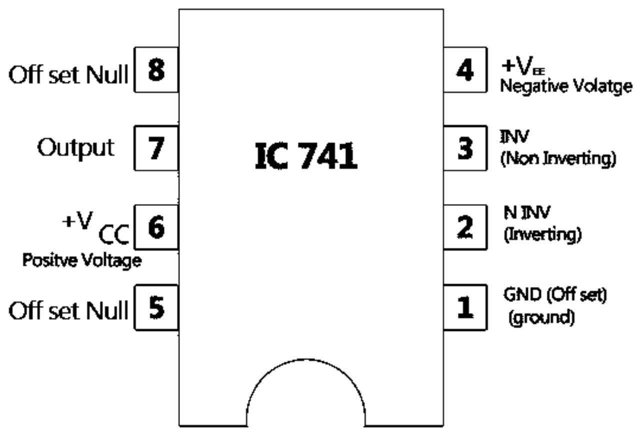


Figure 4-4. Pin Diagram of IC 741.

1. Offset Null (Pin 1 and 5): Used for offset voltage adjustment.
2. Inverting Input (Pin 2): Signal input to the inverting terminal of the op-amp.
3. Non-inverting Input (Pin 3): Signal input to the non-inverting terminal of the op-amp.

4. V- (Pin 4): Negative power supply terminal.
5. Offset Null (Pin 5): Same as pin 1, used for offset nulling.
6. Output (Pin 6): Output of the operational amplifier.
7. V+ (Pin 7): Positive power supply terminal.
8. NC (Pin 8): Not connected.

Inverting Amplifier

An *OP* amplifier can be operated as an inverting amplifier as shown in Figure 4-5. An input signal v_{in} is applied through input resistor R_i to the minus input (inverting input). The output is fed back to the same minus input through feedback resistor R_f. The plus input (noninverting input) is grounded. Note that the resistor R_f provides the **negative feedback*. Since the input signal is applied to the inverting input (–), the output will be inverted (*i.e.* 180° out of phase) as compared to the input. Hence the name inverting amplifier.

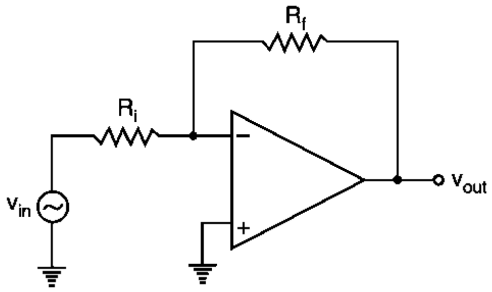


Figure 4-5. Inverting Amplifier.

Noninverting Amplifier

There are times when we wish to have an output signal of the same polarity as the input signal. In this case, the *OP*-amp is connected as noninverting amplifier as shown in Figure 4-6. The input signal is applied to the noninverting input (+). The output is applied back to the

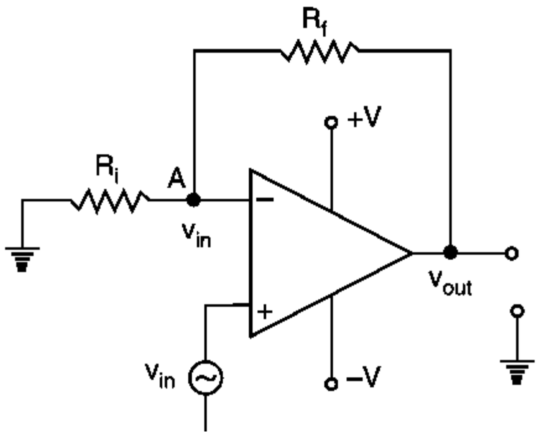


Figure 4-6. Non Inverting Amplifier.

input through the feedback circuit formed by feedback resistor *Rf* and input resistance *Ri*. Note that resistors *Rf* and *Ri* form a voltage divide at the inverting input (–). This produces **negative feedback* in the circuit. Note that *Ri* is grounded. Since the input signal is applied to the noninverting input (+), the output signal will be noninverted i.e., the output signal will be in phase with the input signal. Hence, the name non-inverting amplifier.

Summing Amplifiers

summing amplifier is an inverted *OP*-amp that can accept two or more inputs. *The output voltage of a summing amplifier* is *proportional to the negative of the algebraic sum of its input voltages.* Hence the name **summing amplifier**. Figure 4-7 shows a three-input summing amplifier but any number of inputs can be used. Three voltages *V*1, *V*2 and *V*3 are applied to the inputs and produce currents *I*1, *I*2 and *I*3. Using the concepts of infinite impedance and virtual ground, you can see that inverting input of the *OP*-amp is at virtual ground (0*V*) and there is no current to the input. This means that the three input currents *I*1, *I*2 and *I*3 combine at the summing point *A* and form the total current (*If*) which goes through *Rf* as shown in Figure 4-7.

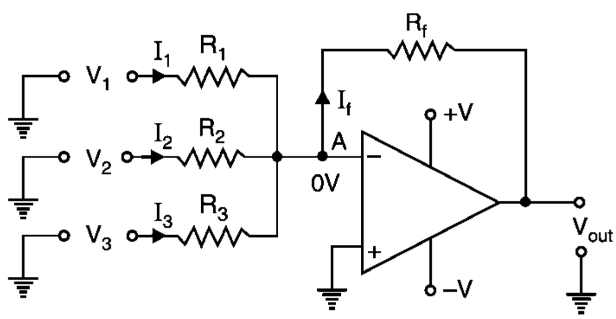


Figure 4-7. Circuit Diagram of a Summing Amplifier.

When all the three inputs are applied, the output voltage is

Output voltage, $V_{out} = - I_f R_f = - R_f (I_1 + I_2 + I_3)$

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

$$\therefore V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

If $R_1 = R_2 = R_3 = R$, then, we have,

$$V_{out} = \frac{R_f}{R}(V_1 + V_2 + V_3)$$

Thus the output voltage is proportional to the algebraic sum of the input voltages (of course neglecting negative sign). An interesting case results when the **gain of the amplifier is unity.** In that case, $R_f = R_1 = R_2 = R_3$ and output voltage is

$$V_{out} = -(V_1 + V_2 + V_3)$$

Thus, when the gain of summing amplifier is unity, the output voltage is the algebraic sum of the input voltages.

Differential amplifiers

A summing amplifier can be used to provide an output voltage that is equal to the difference of two voltages. Such a circuit is called a subtractor and is shown in Figure 4-8. As we shall see, this circuit will provide an output voltage that is equal to the difference between V_1 and V_2.

The voltage V_1 is applied to a standard inverting amplifier that has *unity gain.* Because of this, the output from the inverting amplifier will be equal to $-V_1$. This output is then applied to the summing amplifier (also having unity gain) along with V_2. Thus output from second *OP*-amp is given by;

$$V_{out} = -(V_A + V_B) = -(-V_1 + V_2) = V_1 - V_2$$

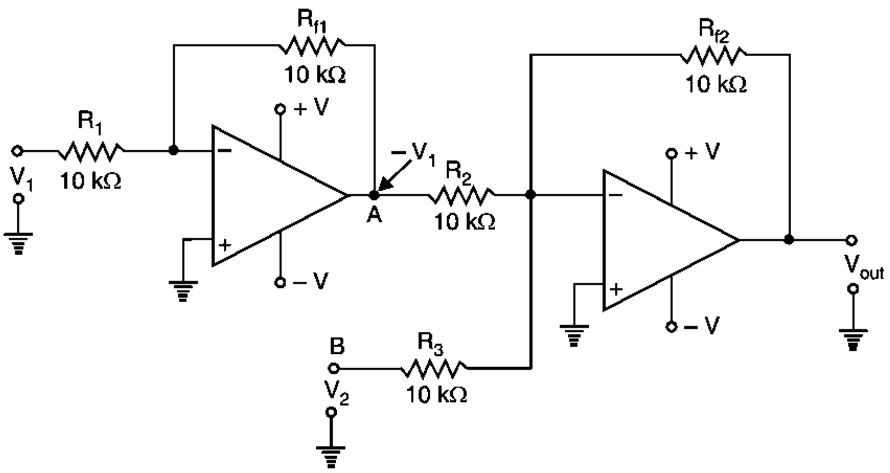


Figure 4-8. Circuit Diagram of a Differential Amplifier.

It may be noted that the gain of the second stage in the subtractor can be varied to provide an output that is proportional to (rather than equal to) the difference between the input voltages. However, if the circuit is to act as a subtractor, the input inverting amplifier *must* have unity gain. Otherwise, the output will not be proportional to the true difference between V_1 and V_2.

OP-Amp Differentiator

A differentiator is a circuit that performs differentiation of the input signal. In other words, a differentiator produces an output voltage that is proportional to the rate of change of the input voltage. Its important application is to produce a rectangular output from a ramp input. Figure 4-9 shows the circuit of OP-amp differentiator. It consists of an OP-amp, an input capacitor *C* and feedback resistor *R*. Note how the placement of the capacitor and resistor differs from the integrator. The capacitor is now the input element.

Circuit analysis. Since point *A* in Figure 4-9 is at virtual ground, the virtual-ground equivalent circuit of the operational differentiator will be as shown in Figure 4-9 Because of virtual ground and infinite impedance of OP-amp, all the input current *ic* flows through the feedback resistor *R i.e.* $i_c = i_R$.

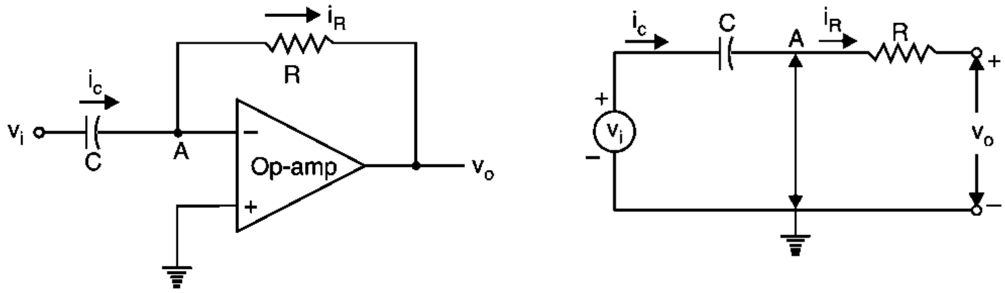


Figure 4-9. OP-Amp Differentiator.

$$i_R = \frac{0 - v_0}{R} = -\frac{v_0}{R}$$

and $v_c = v_i - 0 = v_i$

also $i_c = C\frac{dv_c}{dt} = C\frac{dv_i}{dt}$

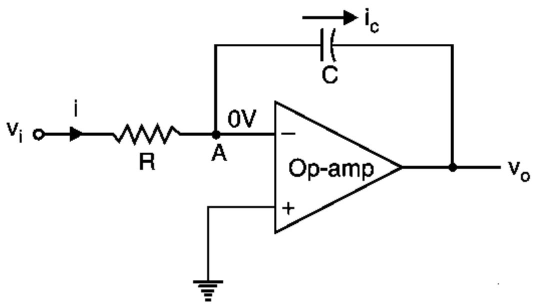
$$\therefore -\frac{v_0}{R} = C\frac{dv_i}{dt}$$

$$v_0 = -RC\frac{dv_i}{dt} \qquad \ldots\ldots \quad (i)$$

Eq. (*i*) shows that output is the differentiation of the input with an inversion and scale multiplier of *RC*. If we examine eq. (*i*), we see that if the input voltage is constant, dv_i/dt is zero and the output voltage is zero. The faster the input voltage changes, the larger the magnitude of the output voltage.

OP-Amp Integrator

As discussed above, an integrator is a circuit that performs integration of the input signal. The most popular application of an integrator is to produce a *ramp* output voltage (*i.e.* a linearly increasing or decreasing voltage). Fig. 25.80 shows the circuit of an *OP*-amp integrator. It consists of an *OP*-amp, input resistor *R* and feedback capacitor *C*. Note that the feedback component is a capacitor instead of a resistor. As we shall see, when a signal is applied to the input of this circuit, the output-signal waveform will be the integration of input-signal waveform.



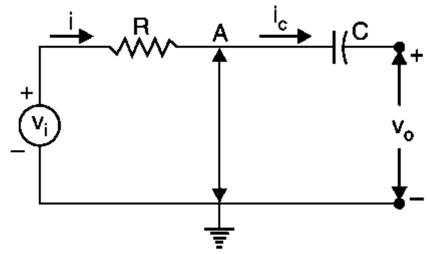


Figure 4-10. OP-Amp as Integrator.

Circuit Analysis.

Since point *A* in Fig. 25.80 is at virtual ground, the *virtual-ground equivalent circuit of operational integrator will be as shown in Fig. 25.81. Because of virtual ground and infinite impedance of the *OP*-amp, all of the input current *i* flows through the capacitor *i.e.* $i = i_c$.

$$i = \frac{v_i - 0}{R} = -\frac{v_i}{R} \qquad \ldots\ldots \quad (i)$$

Also voltage across capacitor is $v_c = 0 - v_o = - v_o$

$$\therefore i_c = C\frac{dv_c}{dt} = -C\frac{dv_O}{dt} \qquad \ldots\ldots \quad (ii)$$

From eqs. (*i*) and (*ii*),$\frac{v_i}{R} = -C\,\frac{dv_O}{dt}$

$$\frac{dv_O}{dt} = -= -\frac{1}{RC}v_i \qquad \ldots\ldots \quad (iii)$$

To find the output voltage, we integrate both sides of eq. (*iii*) to get

$$v_0 = -\frac{1}{RC}\int_0^t v_i\,dt \qquad \ldots\ldots \quad (iv)$$

Eq. (*iv*) shows that the output is the integral of the input with an inversion and scale multiplier of 1/*RC*.

IC 555 Pin Configuration

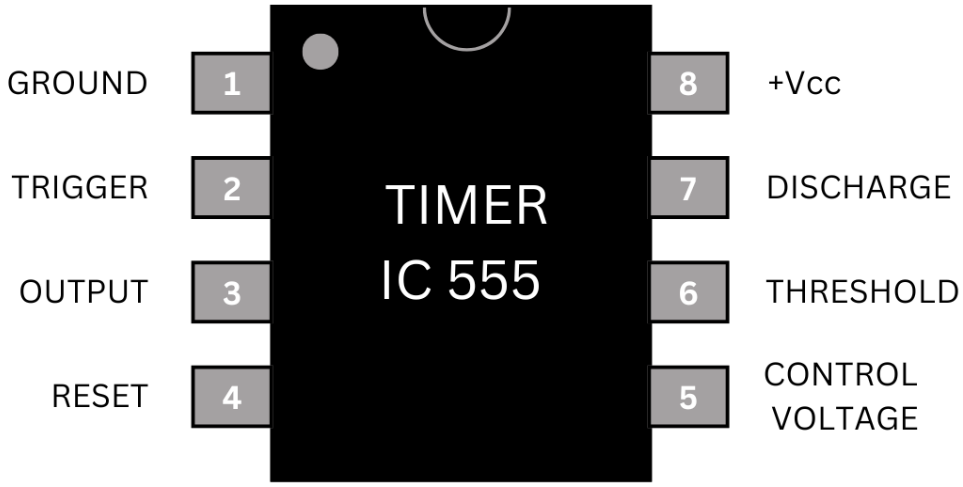


Figure 4-11. IC 555 Pin Diagram.

PIN	NAME OF THE PIN	FUNCTION
1.	GROUND / GND	Ground reference voltage, low level voltage (0V).
2.	TRIGGER / TRIG	Triggers the internal flip-flop with a negative pulse that causes the output switching from low to high when Vtrig drops below 1/3 VCC.
3.	OUTPUT / OUT	Drives any TTL circuit and can source or sink up to 200mA of current with an output voltage of approximately VCC-1.5V.
4.	RESET	Resets the internal flip-flop and controls the state of the output on pin 3. Typically connected to a logic "1" level when not in use.
5.	CONTROL / CTRL	Controls the timing of the 555 timer by varying the width of the output signal independently of the RC timing network. Connected to ground through a 10nF capacitor when not in use.
6.	THRESHOLD / THR	Resets the flip-flop by causing the output to switch from high to low when the voltage applied to it exceeds 2/3Vcc. Connects directly to the RC timing circuit.
7.	DISCHARGE / DIS	Discharges the timing capacitor to ground through an internal. Connects to ground when output is low
8.	Vcc / V+ SUPPLY	Supplies power, typically between 4.5V and 15V for general purpose TTL 555 timers.

Astable multivibrator (Square wave generator)

The 555 timer can also be connected to run as an astable multivibrator. When used in this way, the 555 timer has no stable states, which means that it cannot remain indefinitely in either state. Stated another way, it oscillates when operated in the astable mode and it produces a rectangular output signal. Figure 4-12 shows the 555 timer used in the astable mode. As we can see, the output is a series of rectangular pulses. Since no input trigger is needed to get an output, the 555 timer operating in the astable mode is sometimes called a free-running multivibrator

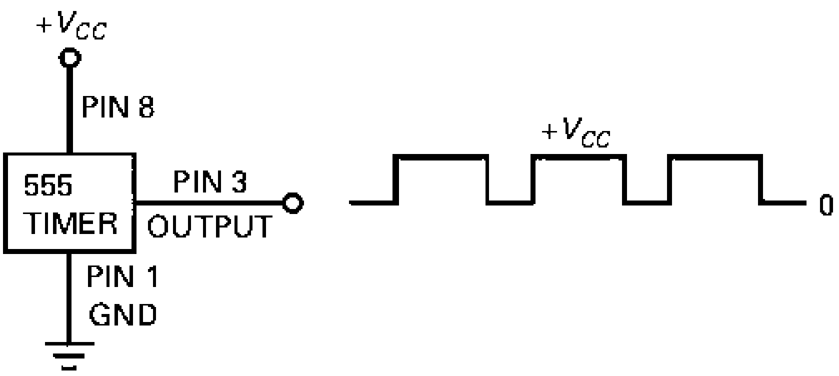


Figure 4-12. IC 555 Timer as astable multivibrator.

Monostable vibrator

Figure 4-13 illustrates monostable operation. Initially, the 555 timer has a low output voltage at which it can remain indefinitely. When the 555 timer receives a trigger at point A in time, the output voltage switches from low to high, as shown. The output remains high for a while and then returns to the low state after a time delay of W. The output will remain in the low state until another trigger arrives.

A multivibrator is a two-state circuit that has zero, one, or two stable output states. When the 555 timer is used in the monostable mode, it is sometimes called a monostable multivibrator because it has only one stable state.

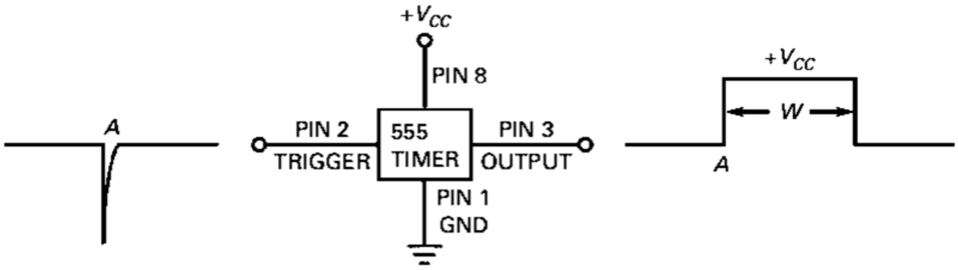


Figure 4-13. The 555 timer used in monostable (one-shot) mode.

It is stable in the low state until it receives a trigger, which causes the output to temporarily change to the high state. The high state, however, is not stable because the output returns to the low state when the pulse ends. When operating in the monostable mode, the 555 timer is often referred to as a one-shot multivibrator because it produces only one output pulse for each input trigger. The duration of this output pulse can be precisely controlled with an external resistor and capacitor. The 555 timer is an 8-pin IC. Figure 23-29 shows four of the pins. Pin 1 is connected to ground, and pin 8 is connected to the positive supply voltage. The 555 timer will work with any supply voltage between 4.5 and 18 V. The trigger goes into pin 2, and the output comes from pin 3. The other pins, which are not shown here, are connected to external components that determine the pulse width of the output.

UNIT – V

Modulation and Demodulation

Unit 5: MODULATION AND DEMODULATION

Theory of amplitude modulation – frequency modulation – comparison of AM and FM – phase modulation – pulse width modulation – pulse modulation systems: PAM, PPM, and PCM – Demodulation: AM and FM detection.

Amplitude Modulation

When the amplitude of high frequency carrier wave is changed in accordance with the intensity of the signal, it is called **amplitude modulation**.

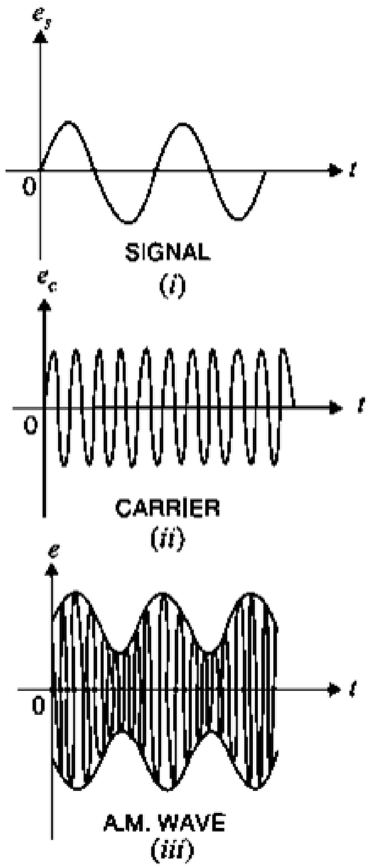


Figure 5-1. Signal, Carrier and Amplitude modulated waves.

In amplitude modulation, only the amplitude of the carrier wave is changed in accordance with the intensity of the signal. However, the frequency of the modulated wave remains the same *i.e.* carrier frequency. Figure 5-1 shows the principle of amplitude modulation. Figure 5-1 (*i*) shows the audio electrical signal whereas Figure 5-1 (*ii*) shows a carrier wave of constant amplitude. Figure 5-1(*iii*) shows the amplitude modulated (AM) wave. Note that the amplitudes of both positive and negative half-cycles of carrier wave are changed in accordance with the signal. For instance, when the signal is increasing in the positive sense, the amplitude of carrier wave also increases. On the other hand, during negative half-cycle of the signal, the amplitude of carrier wave decreases. Amplitude modulation is done by an electronic circuit called *modulator*.

The following points are worth noting in amplitude modulation :

(*i*) The amplitude of the carrier wave changes according to the intensity of the signal.

(*ii*) The amplitude variations of the carrier wave is at the signal frequency f_s.

(*iii*) The frequency of the amplitude modulated wave remains the same *i.e*. carrier frequency f_c.

Frequency Modulation (FM)

When the frequency of carrier wave is changed in accordance with the intensity of the signal, it is called **frequency modulation (FM)**.

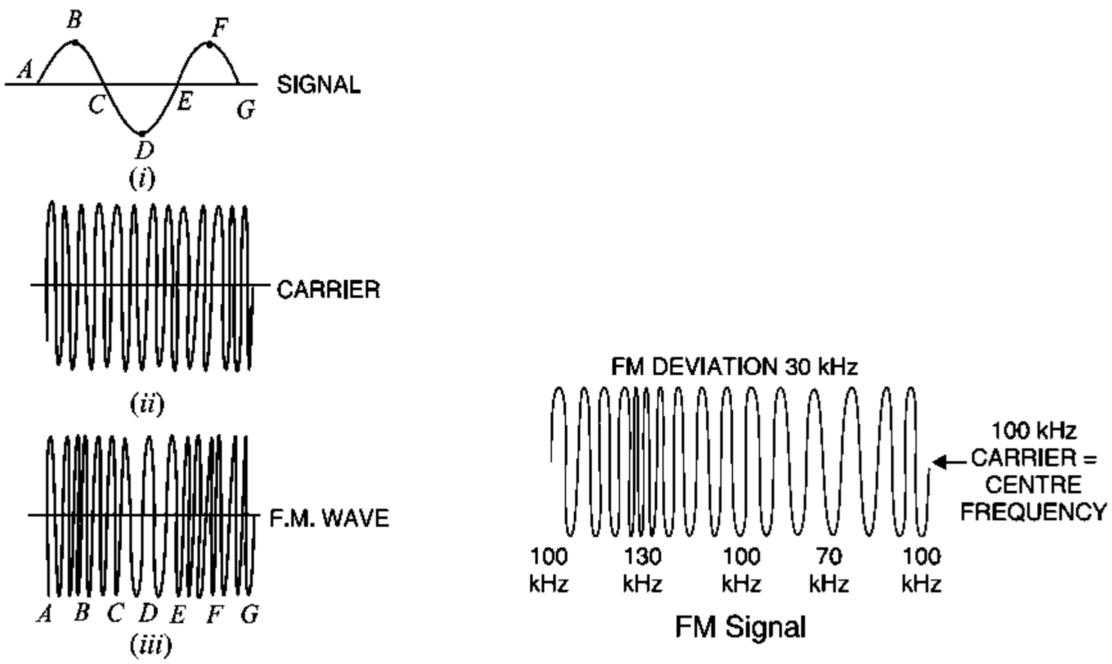


Figure 5-2. Frequency Modulation of waves.

In frequency modulation, only the frequency of the carrier wave is changed in accordance with the signal. However, the amplitude of the modulated wave remains the same *i.e*. carrier wave amplitude. The frequency variations of carrier wave depend upon the instantaneous amplitude of the signal as shown in Figure 5-2 (*iii*). When the signal voltage is zero as at *A*, *C*, *E* and *G*, the carrier frequency is unchanged. When the signal approaches its positive peaks as at *B* and *F*, the carrier frequency is increased to maximum as shown by the closely spaced cycles. However, during the negative peaks of signal as at *D*, the carrier frequency is reduced to minimum as shown by the widely spaced cycles.

Illustration.

The process of frequency modulation (FM) can be made more illustrative if we consider numerical values. Figure 5-2 shows the FM signal having carrier frequency f_c = 100 kHz. Note that FM signal has constant amplitude but varying frequencies above and below the carrier frequency of 100 kHz (= f_c). For this reason, f_c (= 100 kHz) is called *centre frequency*. The changes in the carrier frequency are produced by the audio-modulating signal. The amount of change in frequency from f_c (= 100 kHz) or *frequency deviation* depends upon the amplitude of the audio-modulating signal. The frequency deviation increases with the increase in the modulating signal and viceversa. Thus the peak audio voltage will produce maximum frequency deviation. Referring to Figure 5-2, the centre frequency is 100 kHz and the maximum frequency deviation is 30 kHz.

The following points about frequency modulation (FM) may be noted carefully :

(*a*) The frequency deviation of FM signal depends on the amplitude of the modulating signal.

(*b*) The centre frequency is the frequency without modulation or when the modulating voltage is zero.

(*c*) The audio frequency (*i.e.* frequency of modulating signal) does not determine frequency deviation.

Comparison of FM and AM

The comparison of FM and AM is given in the table below

S. no	FM	AM
1.	The amplitude of carrier remains constant with modulation.	The amplitude of carrier changes with modulation.
2.	The carrier frequency changes with modulation.	The carrier frequency remains constant with modulation.
3.	The carrier frequency changes according to the strength of the modulating signal.	The carrier amplitude changes according to the strength of the modulating signal.
4.	The value of modulation index (*mf*) can be more than 1.	The value of modulation factor (*m*) cannot be more than 1 for distortionless AM signal.

Phase Modulation (PM)

Here, the information signal changes the phase of the carrier wave without changing its other two parameters.

Pulse-Width Modulation

Figure 5-3 shows a circuit used for **pulse-width modulation (PWM)**. The 555 timer is connected in the monostable mode. The values of R, C, UTP, and V_{CC} determine the width of the output pulse as follows:

$$W = -RC\ ln\left(1 - \frac{UTP}{V_{CC}}\right)$$

A low-frequency signal called a modulating signal is capacitively coupled into pin 5. This modulating signal is voice or computer data. Since pin 5 controls the value of UTP, vmod is being added to the quiescent UTP. Therefore, the instantaneous UTP is given by:

$$UTP = \frac{2V_{CC}}{3} + v_{mod}$$

For instance, if V_{CC} =12 V and the modulating signal has a peak value of 1 V, then

UTP_{max} = 8 V +1 V = 9 V

UTP_{min} = 8 V – 1 V = 7 V

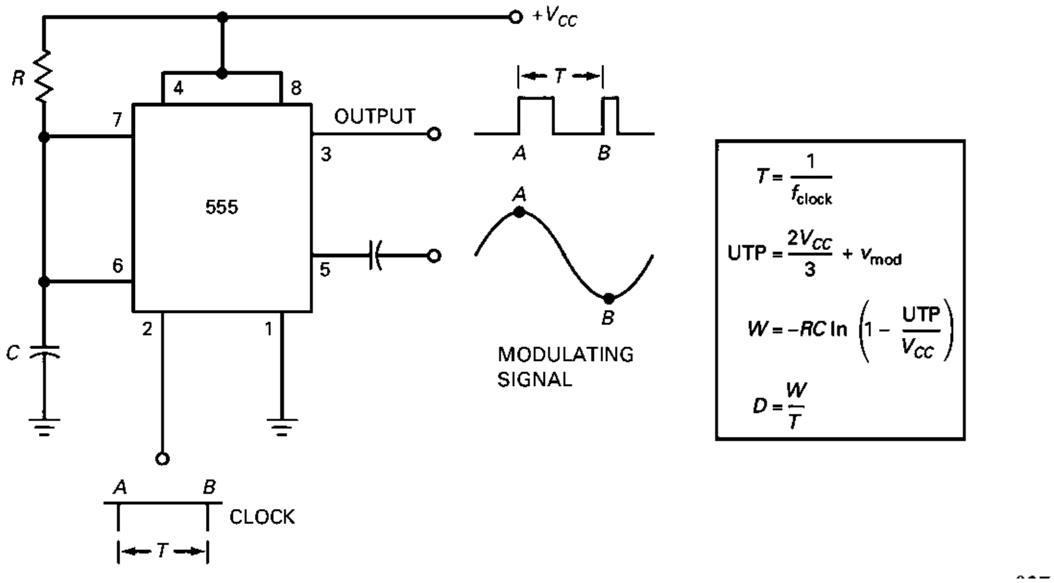


Figure 5-3. 555 Timer connected as pulse-width modulator.

This means that the instantaneous UTP varies sinusoidally between 7 and 9 V. A train of triggers called the clock is the input to pin 2. Each trigger produces an output pulse. Since the period of the triggers is T, the output will be a series of rectangular pulses with a period of T. The modulating signal has no effect on the period T, but it does change the width of each output pulse. At point A, the positive peak of the modulating signal, the output pulse is wide as shown. At point B, the negative peak of the modulating signal, the output pulse is narrow.

PWM is used in communications. It allows a low-frequency modulating signal (voice or data) to change the pulse width of a high-frequency signal called the carrier. The modulated carrier can be transmitted over copper wire, over fiber-optic cable, or through space to a receiver. The receiver recovers the modulating signal to drive a speaker (voice) or a computer (data).

Pulse Modulation Systems:

Pulse-Position Modulation (PPM)

With PWM, the pulse width changes, but the period is constant because it is determined by the frequency of the input triggers. Because the period is fixed, the position of each pulse is the same, which means that the leading edge of the pulse always occurs after a fixed interval of time.

Pulse-position modulation (PPM) is different. With this type of modulation, the position (leading edge) of each pulse changes. With PPM, both the width and the period of pulses vary with the modulating signal.

Figure 5-4a shows a pulse-position modulator. It is similar to the VCO discussed earlier. Since the modulating signal is coupled into pin 5, the instantaneous UTP is given by:

$$UTP = \frac{2V_{CC}}{3} + v_{mod}$$

When the modulating signal increases, UTP increases and the pulse width increases. When the modulating signal decreases, UTP decreases and the pulse width decreases. This is why the pulse width varies as shown in Figure 5-4b.

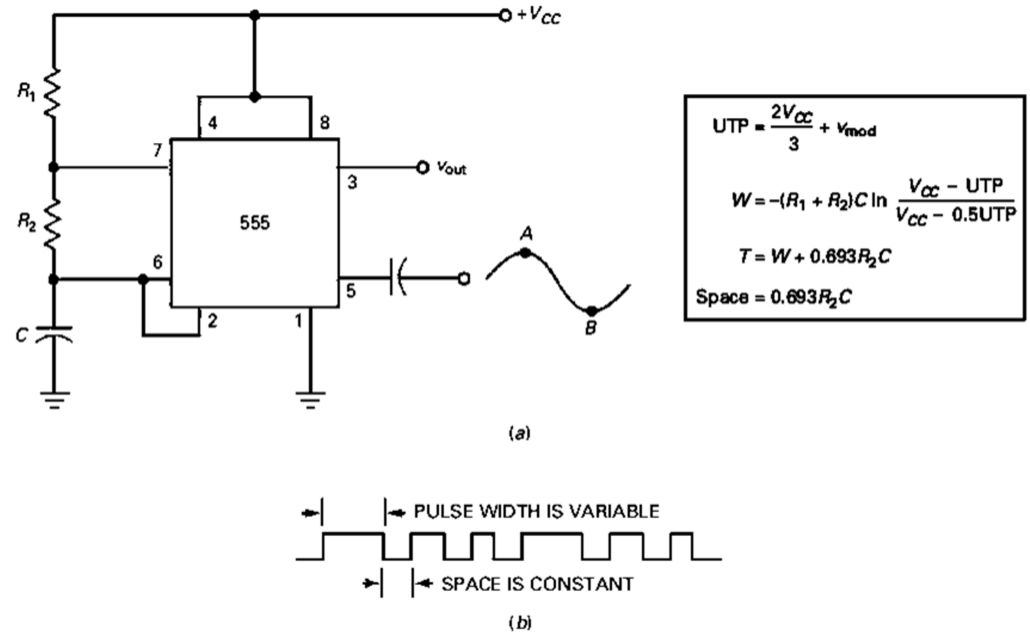


Figure 5-4. 555 Timer connected as pulse-position modulator.

The pulse width and period equations are:

$$W = -(R_1 + R_2)C\ ln\frac{V_{CC} - UTP}{V_{CC} - 0.5UTP}$$

$$T = W + 0.693R_2C$$

In the above, the second term is the space between pulses:

$$Space = 0.693R_2C$$

This space is the time between the trailing edge of one pulse and the leading edge of the next pulse. Since V_{con} does not appear, the space between pulses is constant, as shown in Figure 5-4b. Since the space is constant, the position of the leading edge of any pulse depends on how wide the preceding pulse is. This is why this type of modulation is called pulse-position modulation. Like PWM, PPM is used in communication systems to transfer voice or data.

Demodulation

The process of recovering the audio signal from the modulated wave is known as **demodulation** or **detection.**

At the broadcasting station, modulation is done to transmit the audio signal over larger distances to a receiver. When the modulated wave is picked up by the radio receiver, it is necessary to recover the audio signal from it. This process is accomplished in the radio receiver and is called demodulation. *Necessity of demodulation.* It was noted previously that amplitude modulated wave consists of carrier and sideband frequencies. The audio signal is contained in the sideband frequencies which are radio frequencies. If the modulated wave after amplification is directly fed to the speaker as shown in Figure 5-5, no sound will be heard. It is because diaphragm of the speaker is not at all able to respond to such high frequencies. Before the diaphragm is able to move in one direction, the rapid reversal of current tends to move it in the opposite direction i.e. diaphragm will not move at all. Consequently, no sound will be heard.

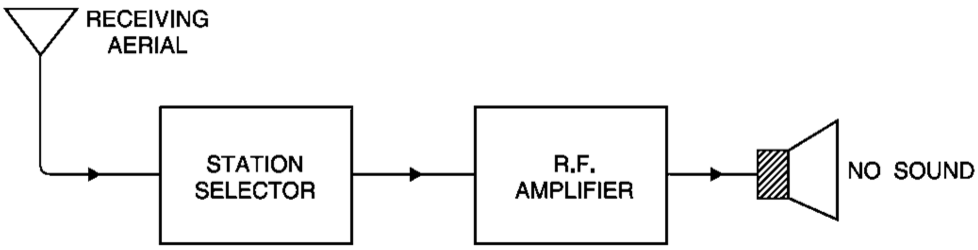


Figure 5-5. Modulated wave after amplification.

From the above discussion, it follows that audio signal must be separated from the carrier at a suitable stage in the receiver. The recovered audio signal is then amplified and fed to the speaker for conversion into sound.

AM Detection

Diode detection is also known as **envelope-detection** or **linear detection**. In appearance, it looks like an ordinary half-wave rectifier circuit with capacitor input as shown in Figure 5-6. It is called **envelope detection** because it recovers the *AF* signal envelope from the composite signal.

Similarly, diode detector is called **linear detector** because its output ***is proportional to the voltage of the input signal*.***

Circuit Action

Of the various *RF* voltages induced in the receiver aerial, only those having the ***same*** frequency as the resonant frequency of *LC* circuit are tuned in due to electromagnetic induction between coils L_1 and L. By varying C, the resonant frequency of the *LC* circuit can be varied and hence *RF* signal of any desired frequency can be tuned in. This input signal is rectified by the diode and passed on to the low-pass filter RC_1.

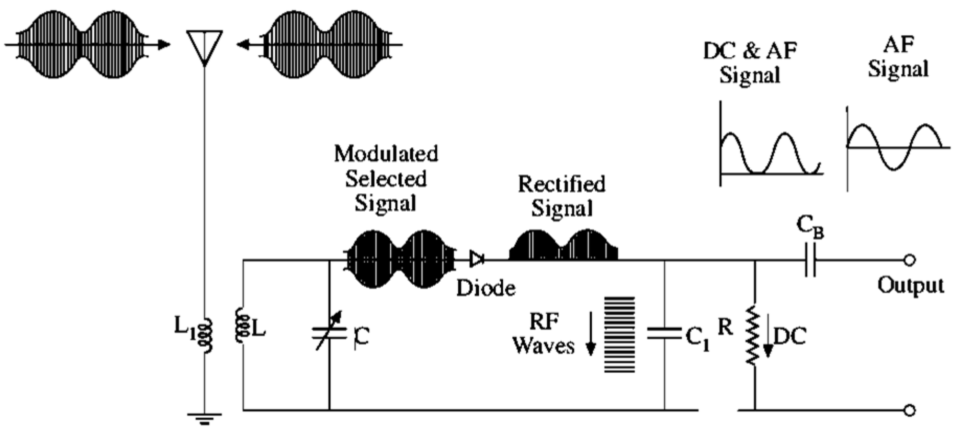


Figure 5-6. AM Detection half-wave rectifier circuit with capacitor input.

The *RF* carrier wave is filtered out by low-reactance capacitor C_1 which is called *RF* filter capacitor or *RF* by-pass capacitor. The dc component of the remaining signal is shunted out through *R* because it cannot pass through blocking capacitor

CB. But the low, frequency *AF* signal can easily get through *CB* and becomes available across the output. When passed through a suitable device, say, a headphone, the original sound can be heard.

Diode detectors are extensively used in AM broadcast receivers because they have the following

Advantages :

1. They can handle comparatively large input signals;

2. They can be operated as linear or power detectors;

3. They rectify with negligible distortion and, hence, have good linearity;

4. They are well-adopted for use in simple automatic-gain control circuits.

Disadvantages

However, the disadvantages are that

1. they do not have the ability to amplify the rectified signal by themselves as is done by a transistor detector. However, it is not a very serious drawback since signal amplification can be affected both before and after rectification;

2. while conducting, the diode consumes some power which reduces the *Q* of its tuned circuit as well as its gain and selectivity.

FM Detection

As discussed earlier, an *FM* carrier signal contains information (or intelligence we wish to convey) in the form of frequency variations above and below the centre frequency of the carrier. For recovering the information, we must first convert the *FM* signal in such a way that it appears as a modulated *RF* voltage across the diode. A simple method of converting frequency variations into voltage variations is to make use of the principle that reactance (of coil or capacitor) varies with frequency. When an *FM* signal is applied to an inductor, the current flowing through it varies in amplitude according to the changes in frequency of the applied signal. Now, changes in frequency of the *FM* signal depend on the amplitude of the modulating *AF* signal. Hence, the current in the inductor varies as per the amplitude of the original modulating signal. In this way, frequency changes in *FM* signal are converted into amplitude changes in current. These changes in current when passed through a resistor produce corresponding changes in voltage.

Hence, we find that, ultimately, frequency variations in *FM* signal are converted into voltage changes. Also, there exists a linear relation between the two – something essential for distortion-less demodulation. *FM* demodulation may be carried out with the help of

(i) ratio detector and

(ii) quadrature detector.