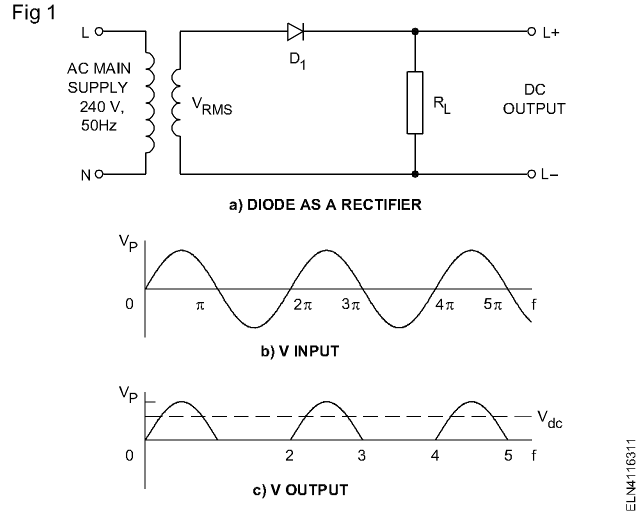
Rectifiers

Objectives: At the end of this lesson you shall be able to
- **state the purpose of rectifier in power supply circuit**
- **explain the working of half-wave, full-wave and bridge rectifier circuit**
- **state the need of filter circuit to rectifier circuits**
- **state the different types filter circuit for rectifiers and their working.**

Most of the electronic equipment, both entertainment and professional, need DC voltage for operation. The power supply converts AC supply voltage into DC. Diodes are used as rectifier in a power supply circuit.

Half wave rectifier: This simplest form of AC to DC converter is by using one diode such an AC to DC converter is known as half-wave rectifier as in Fig 1.

Fig 1



A diode D_1 and a load resistance R_L in series are connected across the secondary of a step down transformer (Fig 1(a). The transformer steps up or steps down the supply voltage as needed. Further the transformer isolates the power line and reduces the risk of electrical shock. During the positive half-cycle of the input line frequency, (Fig 1b) the diode anode is made positive with respect to the cathode. The diode D_1 conducts because it is forward-biased. Current flows from the positive end of the supply through diode D_1 and R_L to the negative terminal of the input. During this period of time, a voltage is developed across R_L. The polarity of the voltage is as indicated in Fig 1C.

During the negative half cycle of AC input line frequency, the diode is reverse-biased. Practically no current flows through the diode and the load R_L and there is no voltage output.

DC output: The voltage drop across the forward biased diode is low, because the resistance of the forward-biased diode is very low. Ge diode drops 0.3V and Si diode drops 0.7V. Ignoring the small voltage drop across the diode. We can find the relationship between AC input and DC output voltage.

The AC input wave-form is shown in Fig 1b.

$V_{rms} = 0.707\ V_p$

$$V_p = \frac{V_{rms}}{0.707}$$

In Fig 1C, the DC output is shown. The diode produces only half cycle of the Ac input. The average value of this half wave is the DC output voltage.

$$V_{dc} = 0.318\ V_p$$

$$= 0.318 \times \frac{V_{rms}}{0.707}$$

$$= 0.45\ V_{rms}$$

For example if the input AC voltage is 24 volts the output DC of the half wave rectifier will be V_{dc} = 0.45 x 24= 10.8 V

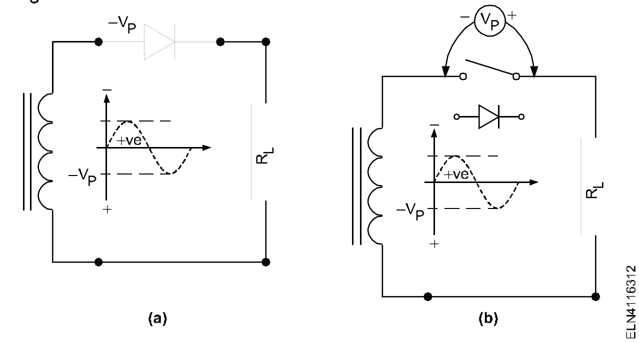
The DC load current is $I_{dc} = \frac{V_{dc}}{R_L}$

Ripple frequency: From Fig 1 it is evident that the frequency of the rectified pulsating DC is same as the frequency of the input AC signal. This is true for all half-wave rectifiers.

Peak inverse voltage: Fig 1(a) shows the half-wave rectifier at the instant the secondary voltage is at its maximum negative peak.

In this condition, since the diode is reverse biased, it behaves as an open switch as in Fig 2b. Since the diode is reverse biased, there is no voltage across the load R_L. Therefore, from Kirchhoff's Voltage law, all the secondary voltage appears across the diode as shown in Fig 2a. This is the maximum reverse voltage that appears across the diode in the reverse biased condition. This voltage is called the peak reverse voltage or more commonly as the peak inverse voltage (PIV). Therefore, in a half-wave rectifier the peak inverse voltage across the diode is equal to the -ve peak value of the secondary voltage $V_{s(peak)}$. Since the -ve peak voltage and +ve peak voltage in a sinusoidal wave is same in magnitude, the peak inverse voltage (PIV) across the diode in a halfwave rectifier can be taken as a $V_{s(peak)}$.

Fig 2



In the example considered earlier, the PIV across the diode will be,

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 33.9 = 34 \text{ volts}$$

To avoid break down of the diode used, the PIV appearing across the diode of the designed HW rectifier must be less than the PIV rating of the diode. For instance, in the above example to avoid break down of the diode, the PIV rating of the diode should be greater than 34 volts.

However this condition changes when a filter capacitor is used in the output DC circuit.

Full wave rectifier (FW): A full wave rectifier circuit is in Fig 3. The secondary winding of the transformer is centre-tapped. The secondary voltage is divided equally into two halves, one end of the load R_L is connected to the centre tap and the other end of R_L to the diodes.

It is seen that two half-wave rectifiers are conducting on alternate half cycles of the input Ac.

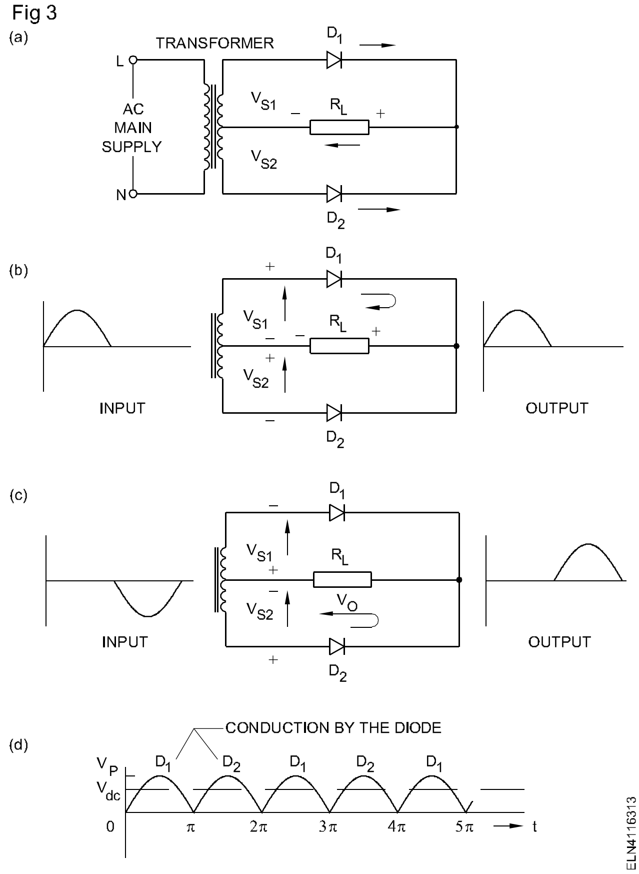
During the positive half cycle of the secondary voltage, diode D_1 is forward-biased and diode D_2 is reverse-biased. (Fig 3b) The current flows through the load resistor R_L, diode D_1 and the upper half of the secondary winding.

During the negative half cycle of secondary voltage, diode D_2 is forward-biased and diode D_1 is reverse-biased. Therefore, current flows through the load resistor RL diode D_2 and the lower half of the secondary winding. (Fig 3c)

The load current is in the same direction during both the half-cycles of the AC input. The output of the full-wave rectifier is shown in Fig 3d.

DC output : Since a full wave rectifier is nothing but a combination of two half-wave rectifiers, the average or DC value of a full wave rectifier is naturally twice the output of a half wave rectifier driven by the same secondary voltage.

Fig 3



From Fig 3 it i s evident that the average of DC value of a full wave rectified output is

$V_{dc} = 0.318\ V_{s(peak)} + 0.318\ V_{s(peak)}$

$V_{dc} = 0.636\ V_{s(peak)}$

where, $V_{s(peak)}$ is the equal peak voltage between the centre-tap and any one end A or B of the transformer secondary.

In terms of $V_{s(rms)}$ V_{dc} of full wave rectifier is given by,

$Vs_{(rms)} = 0.707\ V_{s(peak)}$

$$\text{Therefore, } V_{dc} = 0.636 = \frac{V_{s(rms)}}{0.707} = 0.9\ V_{s(rms)}$$

Example

Suppose the secondary voltage of the transformer is 24-0-24V(rms), the Dc output voltage of a full wave rectifier using this transformer will be,

For a two diode full wave rectifier

$V_{dc} = 0.9\ V_{s(rms)}$

Therefore, in the given example

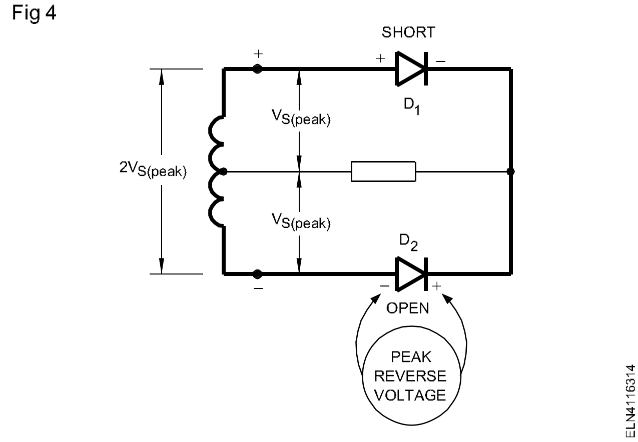
$V_{dc} = 0.9 \times V_{s(rms)} = 0.9 \times 24 = 21.6$ volts

Ripple frequency in a full wave rectifier: From Fig 3c it can be seen that two cycles of output occur for each input cycle of AC voltage. This is because, the full wave rectifier has inverted the negative half cycle of the input voltage. As a result, the output of a full wave rectifier has frequency double the input AC frequency. If mains AC supply is used as input to a full wave rectifier, the mains frequency is 50 Hz, the output frequency of the pulsating DC will be 100 Hz.

Note: This increased ripple frequency has certain advantages when the pulsating DC is smoothed. This will be dealt with in further lesson.

Peak inverse voltage: Fig 4 shows the full wave rectifier at the instant the secondary voltage reaches its maximum positive value.

Fig 4



Applying Kirchhoff's law around the outside loop, we get, $2V_{s(peak)}$ - Reverse voltage(PIV)

across D_2 + Forward voltage across $D_1 = 0$

Neglecting the small forward voltage across D_1 we have, $2V_{s(peak)}$ = PIV across $D_2 + 0 = 0$

or PIV across $D_2 = 2V_{s(peak)}$

From the above it can be seen that each diode in a fullwave rectifier must have PIV rating greater than the peak value of the full secondary voltage. $2V_{s(peak)}$

In the example considered earlier, the PIV of diodes should be $2\ V_{s(peak)}$.

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} \quad = \quad 2\ V_{s(peak)} = \frac{2 \times V_{s(rms)}}{0.707}$$

$$= \frac{2 \times 24}{0.707} = 68 \text{ volts (approx.)}$$

Current rating of diodes in a full wave rectifier : If the load, R_L connected in the fullwave rectifier is, say 10Ω the DC current through it will be,

$$I_{dc} = \frac{V_{dc}}{10\ \Omega}$$

In the example considered above, $V_{dc} = 21.6$ volts

Therefore, $I_{dc} = \frac{21.6}{10} = 2.16$ amps.

It is interesting to note this current I_{dc} is shared by the two diodes D_1 and D_2. This is because each diode conducts only for one half cycle. Therefore, the DC current through each diode is half the total DC load current I_{dc}. Hence, the maximum current through each diode with 10Ω load will be 2.16/2 = 1.08 amps. From this it follows that the current rating (If(max)) of each diode need only be half the maximum/rated load current.

NOTE: In a halfwave rectifier, since there is only one diode, the current rating of the diode used should be the maximum current through the load unlike in the case of a full wave rectifier in which the current rating of the diodes used is only half the maximum current through the load.

Example: In a two diode full wave rectifier, with a load current requirement of 1.8 amps, what should be the current ratings of the diodes used?

Since it is a two diode full wave rectifier, the current rating of each diode should be = 1/2 the total load current.

Therefore I_f(max) of diodes should be = 1.8 amps/2 = 0.9 amps.

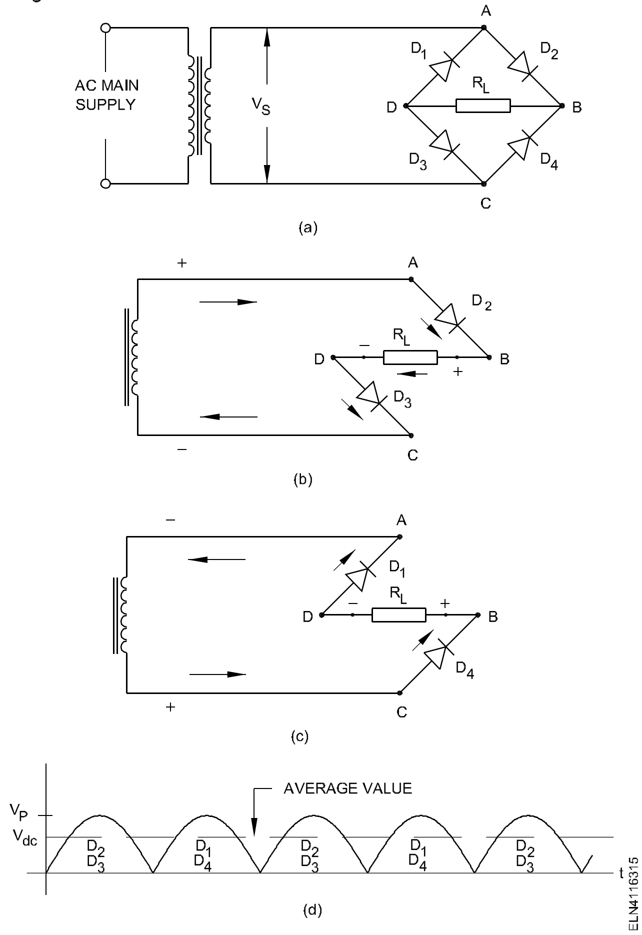
It is fine if a diode of 1 amp current rating is used for this rectifier circuit.

Disadvantages of TWO DIODE full wave rectifier : The full wave rectifier using two diodes and centre tap transformer has the following disadvantages

- A centre-tapped transformer that produces equal voltages on each half of the secondary winding is difficult to manufacturer and, hence, expensive.
- Centre-tapped transformers are generally bulkier than ordinary transformers, and, hence, occupy larger space.
- In a two diode full wave rectifier, only half of the secondary voltage is made use at a time although it works in both +ve and -ve half cycles.

Bridge rectifier : It is a full-wave rectifier. The circuit is in Fig 5a. In the bridge rectifier four diodes are used. There is no centre tap on the secondary of the transformer.

Fig 5



During the positive half of the secondary voltage, diodes D_2 and D_3 are forward-biased. Hence current flows through diode D_2 load resistance R_L and D_3 to the other end of the secondary. This is illustrated in Fig 5b. During the negative half of the secondary voltage, diodes D_1 and D_4 are conducting . The current flows through diode D_4, resistor R_L and diode D_1 to the other end of the secondary. This is illustrated in Fig 5c.

In both cases the current flows through the load resistor in the same direction. Hence, a fluctuating DC is developed across the load resistor RL. This is shown in Fig 5d.

DC output: Fig 6 shows the input AC and the output pulsating DC wave-form of a bridge rectifier.

This wave-form is similar to that of the full wave rectifier using a centre-tap transformer. Hence, the average DC value of the output is,

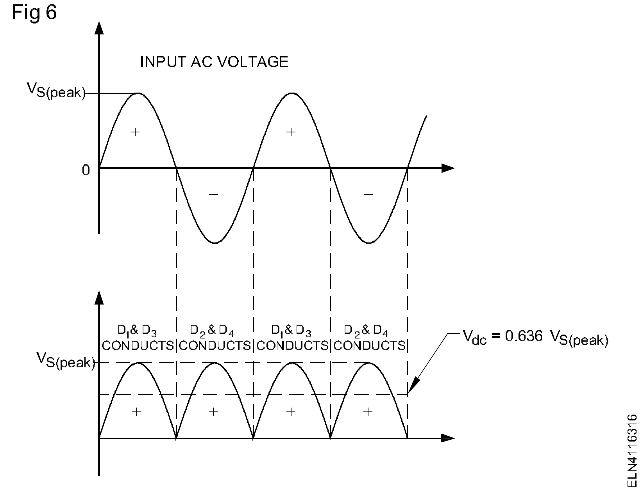
V_{dc} = 0,636 $V_{s(peak)}$

or V_{dc} = 0.9 $V_{s(rms)}$

where, Vs(rms) is the full secondary AC rms voltage.

NOTE: In a two -diode full wave rectifier $V_{s(rms)}$ refers to only half for the total secondary voltage whereas in a bridge rectifier $V_{s(rms)}$ refers to full secondary voltage.

Fig 6



Example: In Fig 5, if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, the rectified DC voltage V_{dc} across the load R_L will be,

From equation ....2, V_{dc} for a bridge rectifier is given by, V_{dc} = 0.9 $V_{s(rms)}$

In the given example, $V_{s(rms)}$ = 24 volts

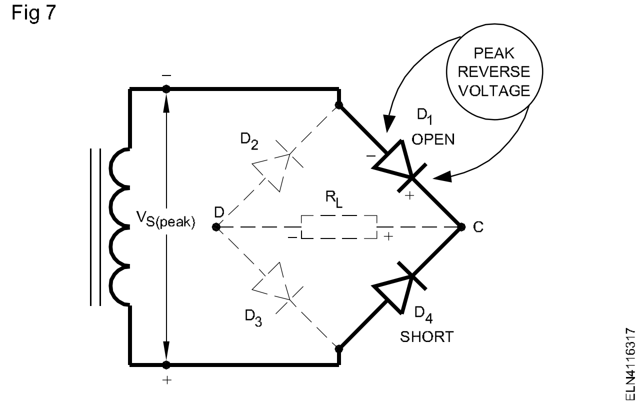
Therefore, V_{dc} = 0.9 x 24 = 21.6 volts

NOTE: Using the same transformer, a two-diode full wave rectifier would have given only 10.8 volts which is half of that of bridge rectifier output.

Ripple frequency - Bridge rectifier: The pulsating DC output of a bridge is similar to the two diode full wave. Hence as in a two diode fullwave rectifier, the output ripple frequency of the bridge rectifier is also twice the input AC frequency.

Peak inverse voltage - Bridge rectifier: Fig 7 shows a bridge rectifier at the instant the secondary voltage has reached its maximum value.

Fig 7



Diode D_4 is ideally short (as it is conducting) and D_1 is ideally open. summing the voltages around the outside loop and applying Kirchhoff's law,

$V_{s(peak)}$ - PIV across D_1 + 0 = 0

or PIV across $D_1 = V_{s(peak)}$

Therefore, the peak inverse voltage across D_1 is equal to the peak secondary voltage $V_{s(peak)}$

In a similar way, the peak inverse voltage across each diode will be equal to the peak secondary voltage $V_{s(peak)}$ of the transformer secondary. Hence the PIV ratings of the diodes used should be greater than $V_{s(peak)}$

Example

In Fig 7 if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, find the minimum PIV of diodes used. In a bridge rectifier PIV across the diodes is same and is equal to $V_{s(peak)}$

Therefore, in the given example,

$$PIV = V_{sd(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 34 \text{ volts}$$

Current rating of diodes in bridge rectifiers : As in the case of a two diode fullwave rectifier even in a bridge rectifier is in Fig 5, diode pairs D_1, D_3 and D_2 D_4 carry half the total load current1. This is because each diode pair is conducting only during one half of the AC input cycle.

The only disadvantage of bridge rectifiers, D_1, D_3 and D_2, D_4 is that, this circuit uses four diodes for full wave rectification instead of two as in two-diode fullwave rectifier. But this disadvantage is compensated by the simple transformer requirement of the bridge rectifier and higher DC output level. Hence, bridge rectifiers are the most popular AC to DC rectifiers for most applications.

Encapsulated bridge rectifiers are available as a single pack with two terminals for AC input and two terminals for DC output.

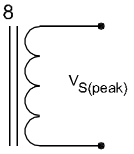
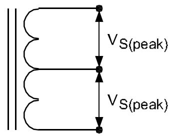
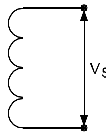
The following table provides data for a normally used diode having the current rating of one ampere.

Maximum ratings

Rating	Symbol	Type Number							Unit
		IN 4001	IN 4002	IN 4003	IN 4004	IN 4005	IN 4006	IN 4007	
Peak repetitive reverse voltage Working peak reverse voltage DC blocking voltage	$V_{RM(rep)}$ $V_{RM(wkg)}$ V_R	50	100	200	400	600	800	1000	Volts
Non-repetitive peak reverse voltage (half wave, single phase, 50 Hz peak)	$V_{RM\ (nonrep)}$	75	150	300	600	900	1200	1500	Volts
RMS reverse voltage	Vr	35	70	140	280	420	560	700	Volts
Average rectified forward current (Single phase, resistive load, 50Hz, T_A = 75°C)	Io			1.0					Amp
Non-repetitive (Half sine wave t=10m sec)	IFM			30					
Maximum thermal resistance junction temperature to ambient (lead length = 25 mm)	TJA			85					
Maximum Operating and storage junction temperature range	T_jT_{stg}			-65 to 175					

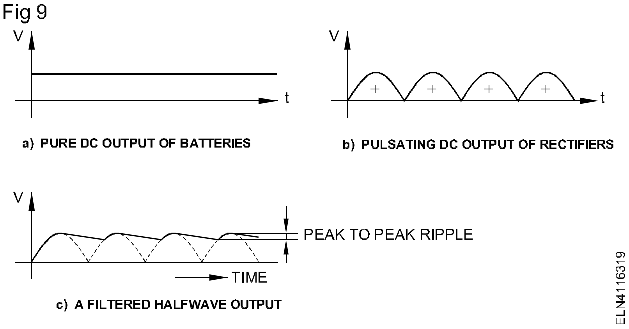
Other diode specifications can be obtained from the data book).

A comparison of half-wave, fullwave and bridge rectifier is given below in a tabular form

	Half wave	**Full wave**	**Bridge**
Number of diodes required	1	2	4
Transformers peak output voltage	Fig 8 		
DC output voltage in terms of $V_{s(peak)}$	$0.318\ Y_{s(peak)}$	$0.636V\ V_{s(peak)}$	$0.636V\ V_{s(peak)}$
DC output voltage in terms of $V_{s(rms)}$	$0.45\ V_{s(rms)}$	$0.9\ V_{s(rms)}$	$0.9V_{s(rms)}$
Diode current rating	$I_{L(max)}$	$0.5\ I_{L(max)}$	$0.5I_{L(max)}$
Peak inverse voltage	$V_{s(peak)}$	$2V_{s(peak)}$	$V_{s(peak)}$
Ripple frequency	f_{input}	$2f_{input}$	2_{finput}

Filter circuits : Alternating current is rectified to provide a steady DC voltage similar to the output of a battery as shown in Fig 9a. But the output of rectifiers in a pulsating DC as in Fig 9b.

Fig 9



Pulsating DC voltages cannot be used in most of the electronic circuits. For example a buzzing sound will be obtained from a radio if these pulsations are not removed in the output of the rectifiers. The circuits used to filter off or reduce the pulsation in the DC output of rectifiers are known as smoothing circuits or popularly as Ripple filters.

Ripple : The small voltage fluctuations in the output of a filter like those shown in figure 9c are called Ripple.

Filter circuit components : Filter circuits are normally combinations of capacitors, inductors and resistors.

Types of filter circuits : The different filter circuits in use are

1 Capacitor input filter.

2 RC filter

3 Series inductor filter

4 Choke input LC filter

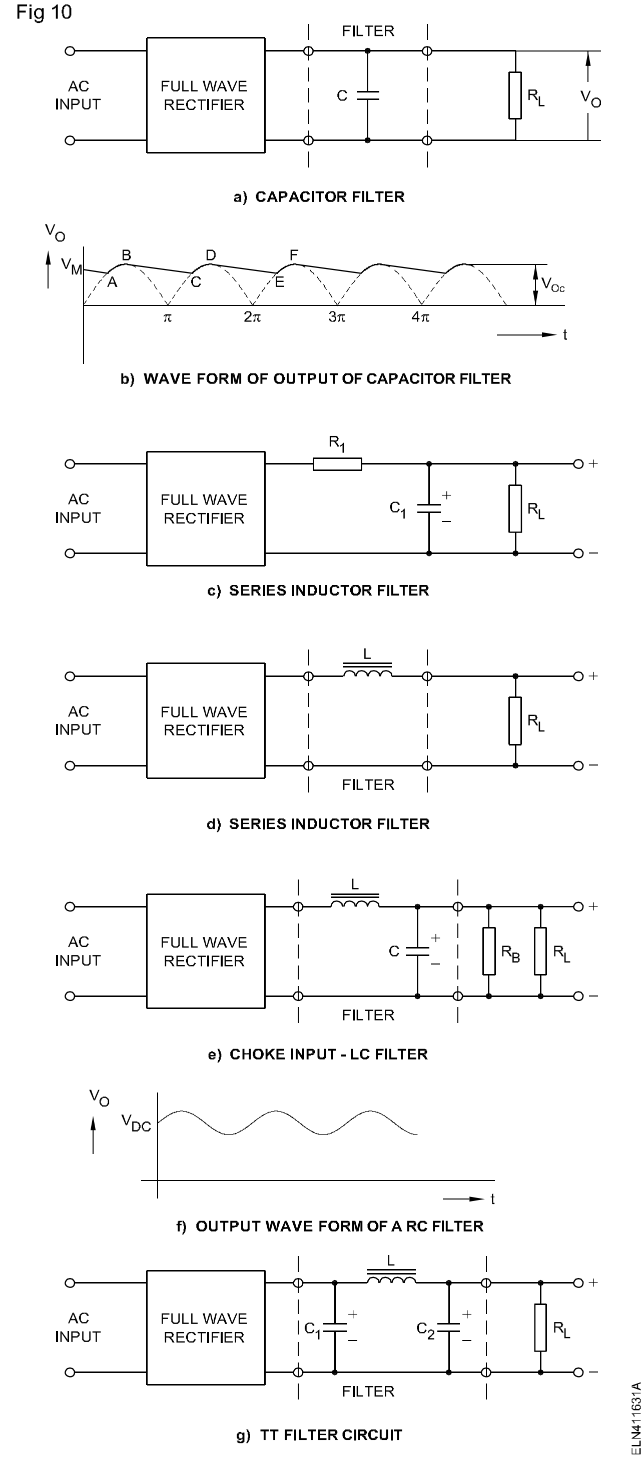
5 π filter.

1 Capacitor filter : A capacitor filter is the most simplest and cheapest filter. Here a large value capacitor C is connected across the load resistor RL as in Fig 10a. The capacitance offers a low reactance path to the AC components of current and offers very high resistance to DC. So all the DC current passes through the load.

Working : When the rectifier output voltage is increasing the capacitor charges to the peak voltage Vm. After reaching the positive peak the rectifier output voltage tries to fall. Observe the wave form in Fig 10b. At point 'B' the capacitor has $+V_m$ volts across it. Since the source voltage becomes slightly less than Vm, the capacitor will try to send current back through the diode, which reverse biases the diode.

The diode disconnects the source from load. The capacitor starts to discharge through the load. Thus the voltage across load will not fall to zero. The capacitor continues to discharge until the source voltage becomes more than the capacitor voltage at point C. The diode again starts conducting and the capacitor is again charged to peak value V_m. During the charging period for the capacitor the rectifier supplies the charging current I_c through capacitor as well as the load current I_L. Thus the current is maintained through the load always.

Fig 10



The rate at which the capacitor discharges between points B and C in Fig 10b depends upon the time constant $R_L C$. longer this time constant is, the steadier is the output voltage.

Calculation of Ripple : While designing a filter circuit the following methods can be used to calculate theoretically the ripple voltage in the output of the filter circuit.

Method 1

Knowing the required load current, I_L, for a given value of frequency f and capacitance C, the peak-to-peak ripple voltage can be found using the formula,

$$V_{rip(p-p)} = \frac{I_L}{F_r C} \text{ .... (2)}$$

Where

$V_{r(p-p)}$ = peak-to-peak ripple voltage in volts

I_L = required Dc load current, in Amps

F_r = ripple frequency, in Hz

C = capacitance in Farads

Fixing the permissible $V_{r(p-p)}$ and knowing f and I_L the required value for C can also be found using this formula

Method 2

Another method of expressing the ripple in the output DC is by ripple factor r defined as,

$$\text{Ripple factor, } r = \frac{V_{r(rms)}}{V_{dc}}$$

where,

r = ripple factor (dimension less)

$V_{r\,(rms)}$ = rms value for ripple voltages.

V_{dc} is the measured dc voltage at the output.

2 RC filter

A simple RC filter circuit is in Fig 10c. It consists of a resistor R_1 and capacitor C_1 connected as shown . The resistor R_1 help the filtering provided by the capacitor by lengthening the discharge time of the capacitor.

3 Series inductor filter

The figure 10d shows a series inductor filter circuit. An inductor is a device which has the fundamental property of opposing any change in current flowing through it. This property is used in the series inductor filter.

Working : Whenever the current through an inductor tends to change, a back emf is induced in the inductor which prevents the current from changing its value. The operation of a series inductor filter depends upon the current through it. Therefore this filter can be used together with a full wave rectifier only. further an increase in load current result in reduced ripple.

4 Choke-input LC filter

A choke input filter consists of an inductor L in series and a capacitor C in shunt with load as shown in Figure 10e.

Working : An LC filter combines the features of both the series inductor filter and shunt capacitor filter. The choke (iron-core inductor) allows the DC component to pass through easily because it offers no resistance to DC. While the capacitor allows AC ripples to pass through but blocks DC. As a result all the DC current passes through the load resistor R_L. The output wave form of a LC filter is an shown in Figure 10f.

Bleeder resistor : An inductor functions better when large steady current flows. For optimum functioning of choke filter a bleeder resistance R_B , which by passes the fluctuating current is included in the circuit as shown in Fig 10e.

5 PI-Filter (π filter)

This circuit is shown in Fig 10g. It is also called as a capacitor input filter. This circuit uses one inductor and two electrolytic capacitors. It is called capacitor-input filter because C_1 is the first filtering component. It is also called PI filter because the circuit looks like π (Greek letter)

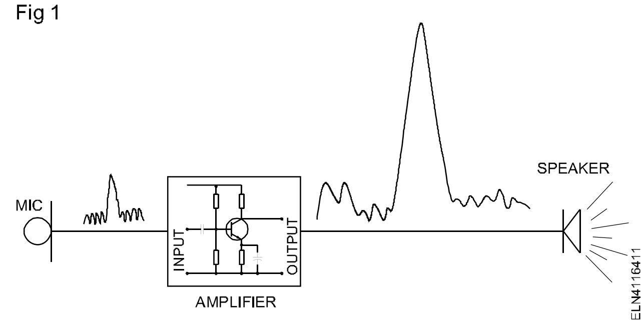
Working : The rectifier output first goes to C, which alternately charge and discharges as in the case of a capacitor filter. The capacitor C_2 also provides a similar filtering action. The inductor opposes the changes in both the output of C_2 and in the current drawn by the load. Also the LC filters are capable of removing the voltage spikes at the input.

Transistors

Objectives: At the end of this lesson you shall be able to
- **explain the construction of bipolar transistors**
- **explain the classification and working of PNP and NPN transistors**
- **state the important packages and type number systems of transistor**
- **explain the methods of testing transistor.**

Introduction: Transistor is an active device which can be compared to the heart of modern electronics. It accepts small electrical signal either in the form of current or voltage at the input and then amplifies (increase the amplitude) and provides a large signal at the output as in Fig 1. Transistors are used in almost all electronic gadgets such as radio, TV, tape recorder, computer etc.,

Fig 1



Before the transistors were invented (1947), certain devices are used known as vaccum tubes or valves which were used in amplifiers.

Compared with the present day transistors the vacuum tubes were big in size, consumed more power, generated lot of unwanted heat and were fragile. Hence vaccum tubes became obsolete as soon as transistors came to market.

Transistors were invented by walter H. Brazil and John Barlow of Bell Telephone Laboratories on 23rd Dec. 1947. Compared to vaccum tubes transistors have several advantages. Some important advantages are listed below.

- Very small in size
- Light in weight
- Minimum power loss in the form of heat
- Low operating voltage
- Rugged in construction
- Long life and cheap.

To satisfy the requirements of different applications, several types of transistors in different types of packaging are available. As in diodes, depending upon the characteristics, transistors are given a type number such as BC 107, 2N 6004 etc., The characteristics data corresponding to these type numbers are given in Transistor data books.

Transistor are available as bi polar, field effect and unijunction etc.,

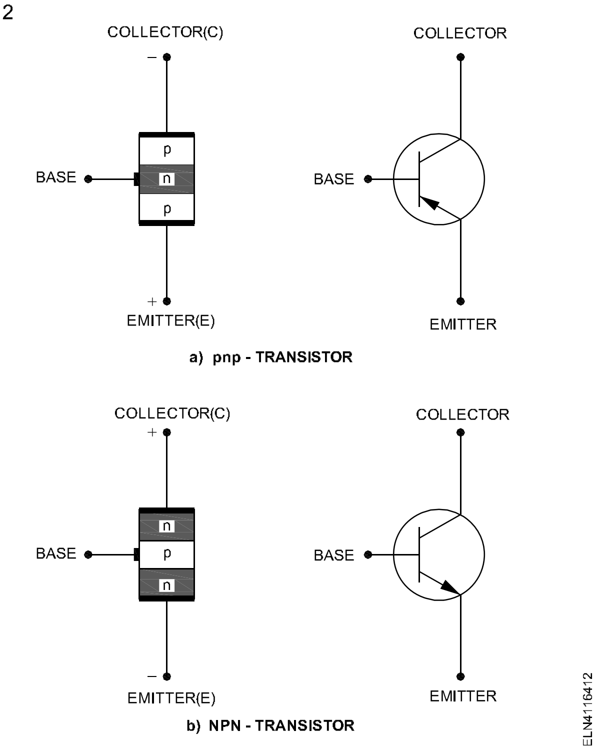
A bipolar junction transistor uses two opposite polarity of doped semiconductor i.e. 'N' type and 'P' type.

A field-effect transistor uses electrostatic field of charged carriers for its working.

An unijunction transistor uses a single junction of 'P' and 'N' type semiconductor.

Construction of bipolar junction transistors : The bipolar junction transistor is a three-element device (emitter, base, collector) made up of silicon or germanium materials by various methods like point contact, grown junction, alloy junction, diffusion junction and epitaxial. The construction of the transistor and the symbols, NPN and PNP, are shown in Fig 2.

Fig 2



A transistor is represented with the symbol shown. The arrow at the emitter shows the current flow through the transistor.

In most of the transistors, the collector region is made physically larger than the emitter region since it is required to dissipate more heat. The base is very lightly doped and is very thin. The emitter is heavily doped. The doping of the collector is more than that of the base but less than of the emitter.

Classification of transistors

1 Based on the semiconductor used

- Germanium transistors
- Silicon transistors

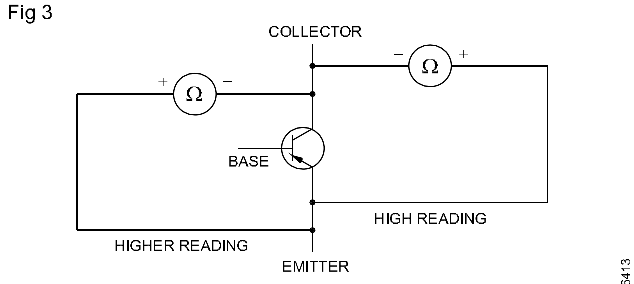
Like in diodes, transistors can be made, using any one of the above two important semiconductors. However, most of the transistors are made using silicon. this is because, silicon transistors work better over a wide temperature range (higher thermal stability) compared to germanium transistor.

Method of finding the semi conductor used in Transistor

Transistor data books give information about the semi conductor used in any particular transistor.

In the absence of data, still a quick check can be made with an ohmmeter to determine whether a transistor is made from silicon or germanium. In the test of a PNP transistor in Fig 3 first connect the ohmmeter negative lead to the collector and the positive lead to the emitter. With this hook-up a high resistance reading from the emitter to the collector will be shown.

Fig 3



OHMMETER TEST RESULTS PROVE WHETHER THE PNP TRANSISTOR UNDER TEST IS MADE FROM GERMANIUM OR SILICON

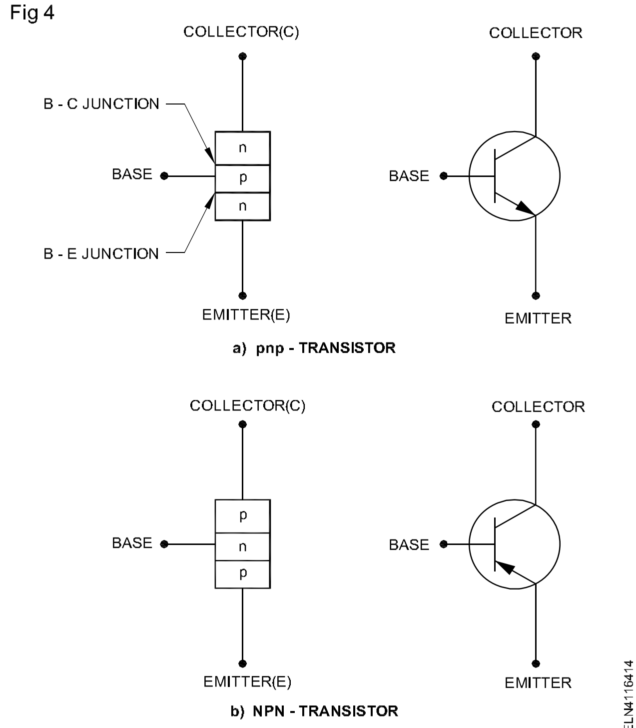
Then reverse the ohmmeter lead connections, and the resistance reading will go even higher. If it is possible to read the ohms on the meter scale, it is germanium transistor. If the reading is in the megohms-to-infinity range, it is a silicon transistor.

2 Based on the way the P and N junctions are organised as in Fig 4

- NPN transistor
- PNP transistor

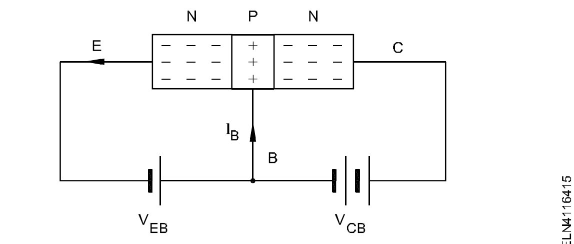
Both NPN and PNP transistors are equally useful in electronic circuits. However, NPN transistors are preferred for the reason that NPN has higher switching speed compared to PNP.

Fig 4



Operation of NPN transistor: During the normal operation of the transistor for amplifications the emitter base junction must be forward-biased, and the base collector junction must be reverse-biased, as in Fig 5.

Fig 5



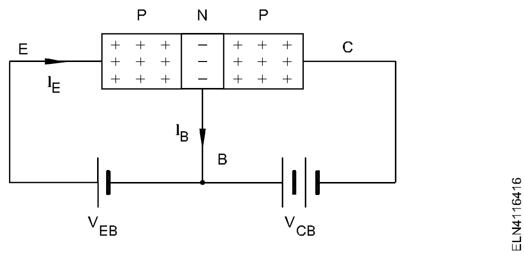
If V_{EB} is greater than the barrier potential (0.3 V for germanium and 0.7 V for silicon), the electrons in the emitter are repelled by the negative polarity of V_{EB} and sent to the base. After filling a few holes in the base, these electrons can flow in either of the two directions. A few of the electrons are attracted to the positive terminal of V_{EB}, producing base current I_B. Many electrons in the base and collector are attracted by the high position potential of V_{CB}, producing collector current I_c. Emitter current I_E is equal to base and collector currents.

$I_E = I_B + I_c$

Working of PNP transistor: For proper operation of a PNP transistors as amplifier the base emitter junction must be forward-biased and the collector-base junction must be reverse-biased as in Fig 6.

Holes which are the majority carries are injected from the emitter into the base region. By the reverse biasing of the base-collection junction, the collector region is made negative with respect to the base, and hence holes, which carry a positive charge, penetrate into to base and flow across the collector junction and flow into the external applied voltage.

Fig 6



Method of identifying PNP and NPN transistors : Whether a transistor is PNP or NPN can be found with the help of transistor data book.

In the absence of data the following procedure may be adopted to identify the type of transistor whether it is PNP or NPN.

PNP identification : To identify the type of transistor first, make sure which is the positive lead and which is the negative lead from the ohmmeter. If necessary, take of the back for the instrument and check the polarity of the battery against the lead connections (positive to positive, negative to negative).

To test the transistor for its type:

1 Hook the positive lead from the ohmmeter to the base of the transistor. Fig 7

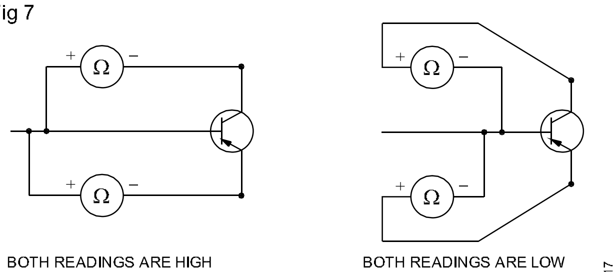
2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

3 If both readings shows high resistance, hook the negative ohmmeter lead to the base of the transistor. (Fig 7)

4 Connect the positive lead from the ohmmeter first to one transistor lead, then to he other.

5 If both readings show low resistance, then it is a PNP transistor.

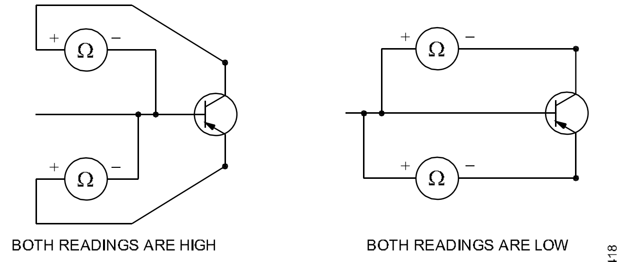
Fig 7



RESULTS OF THESE OHMMETER TESTS PROVE THAT TRANSISTOR IS THE PNP TYPE

NPN identification : Suppose the ohmmeter tests show high resistance with the negative ohmmeter lead connected to the base of the transistor and the other lead is switched from transistor lead to transistor lead. See Fig 8 for reference.

Fig 8



RESULTS OF THESE OHMMETER TESTS PROVE THAT TRANSISTOR IS THE NPN TYPE

Continue testing as follows:

1 Reverse the ohmmeter leads, connecting the positive lead to the base of the transistor.

2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

3 If the readings show low resistance, then it is a NPN transistor.

3 Based on the power handling capacity of transistors, they are classified as

1 Low power transistors less than 2 watts

2 Medium power transistors is 2 to 10 watts

3 High power transistors more than 10 watts

Low power transistors, also known as small signal amplifiers, are generally used at the first stage of amplification in which the strength of the signal to be amplified is low. For example to amplify signals from a microphone, tape head, transducers etc.,

Medium power and high power transistors, also known as large signal amplifiers are used for achieving medium to high power amplification. For example, signals to be given to loudspeakers etc. High power transistors are usually mounted on metal chassis or on a physically large piece of metal known as heat sink. The function of heat sink is to, take away the heat from the transistor and pass it to the surrounding air.

Transistor data books give information about the power handling capacity of different transistor.

4 Based on the frequency of application

- Low frequency transistor (Audio Frequency of A/F transistors)
- High frequency transistor (Radio frequency of R/F transistors)

Amplification required for signals of low or audio range of frequencies in Tape recorders, PA systems etc., make use of A/F transistors. Amplifications required for signals of high and very high frequencies as, in radio receivers, television receivers etc., use R/F transistors.

Transistors data books give information for any particular transistor as to whether it is a AF of RF transistor.

5 Based on the manufacturing method

- Grown junction
- Alloy junction
- Planar contact
- Epitaxial
- Mesa

The aim of each manufacturing process is to yield transistors most suitable for a particular type of application.

Transistor data books generally do not give information about the adopted manufacturing process of transistor. However, the relevant details can be obtained from the transistor manufacturer.

6 Based on the type of final packaging

- Metal
- Plastic
- Ceramic

Metal packaged transistors are generally used in medium and high power amplifications. Plastic packaging is generally used for low power amplification. Some plastic packages come with a metal heat sink. Such transistors are used for medium power amplification. Ceramic packaging is used for special purpose very high frequency applications, for higher temperature stability etc.,

Some examples of packaging type codes used with transistors are, TO-3, TO-92- SOT-25 and so on.

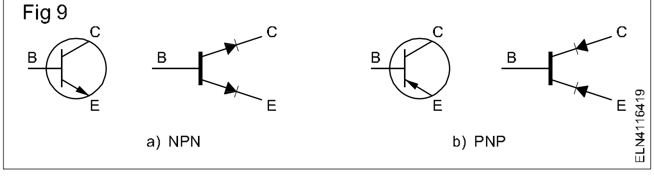
Transistor data books give information about the type of packaging and its case outline.

Three lead devices such as transistors, SCRs, triacs etc., are cased in packages numbered as TO (transistor outline) or SOT (semi-conductor outline for transistors) followed by a number. A number of packages after designs are rarely used by circuit designers and have become obsolete.

Testing of transistor : A transistor can be tested for all specifications shown in the data book. But verification of almost all specifications, except a few requires an elaborate step up and can damage the transistor permanently.

The condition of a transistor with two diodes connected back to back will be as shown in Fig 9(a) & (b)

Fig 9



An ohmmeter can be used to check the junction either for an open circuit or a short circuit. The short is indicated by R practically zero ohms. A very high R of many megohms, in the direction of infinite ohms, means an open circuit. Power must be off in the circuit for ohmmeter readings. Preferably, the device is out of the circuit to eliminate any parallel paths that can affect the resistance readings for a transistor, low resistance from base to emitter or base to collector indicate forward bias and when the ohm-meter/multimeter leads are transferred the resistance should be very high indicate reverse bias.

Probable possibilities are

1 When the ratio of reverse to forward R is very high, the junction is good.

2 When both the forward and reverse R are very low, close to zero, the junction is short-circuited.

3 When both the forward and reverse R are very high, close to infinity, the junction is open.

4 When both junctions are good transistor is good.

5 For a transistor without terminal details, base can be identified easily by identifying between collector and emitter terminal.

Normally for any power transistor, collector is connected to the metallic part/case to dissipate excess heat generated.

6 With a high voltage multimeter (MOTWANE multimeter with 9 V cell in Ω x 100 range), emitter base junction shows some reverse resistance due to zener action which should be treated as high resistance for all purpose.

A germanium transistor has very low forward resistance for each of junction and a high resistance in the reverse direction, while a silicon transistor has moderate forward resistance and infinity reverse resistance.

Fig 10

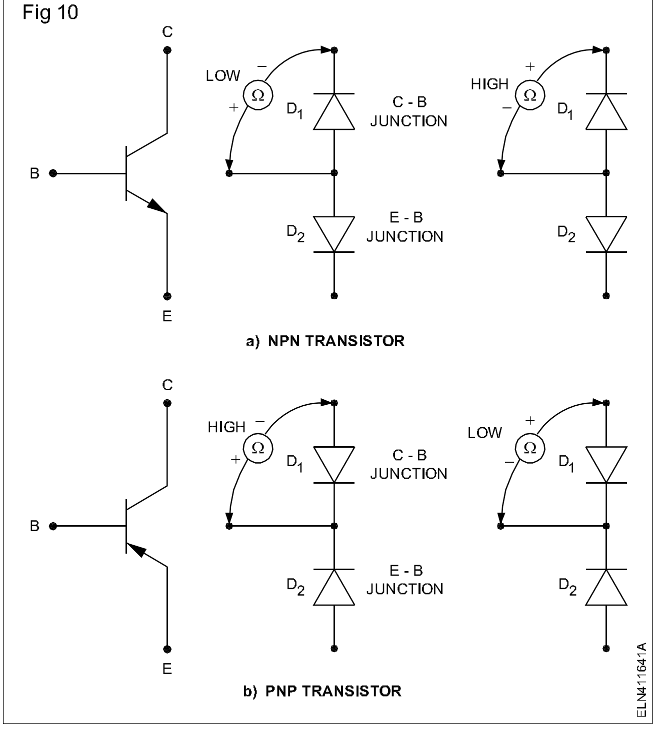


Fig 10a shows a NPN transistor and Fig 10b shows a PNP transistor. The imaginary diodes1 and 2 can be tested as similar to testing any diode. When a diode is tested, if the ohmmeter shows high resistance in one direction and low resistance in another direction, then the diode corresponding to that diode junction can be regarded as GOOD. One important point to note in a transistor is that, both the diodes of the transistor should be GOOD to declare the transistor as GOOD.

When testing, a transistor using ohmmeter, it is suggested to use the middle ohmmeter range (Rx 100) because, ohmmeters in low range can produce excessive current and ohmmeters in high range can produce excessive voltage which may be sufficient to damage small signal transistors.

Transistor biasing and characteristics

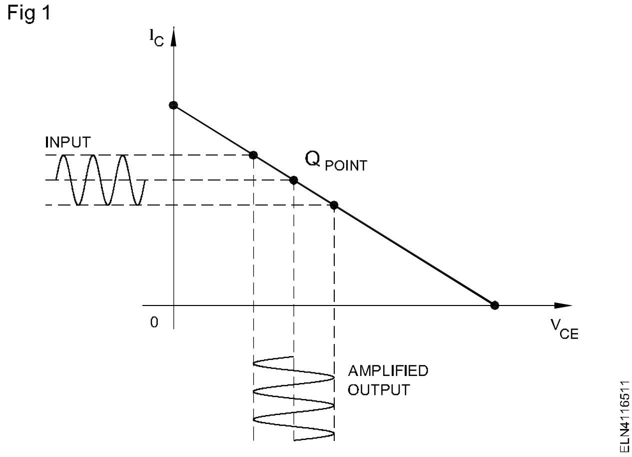
Objectives: At the end of this lesson you shall be able to
- **state the need and type of transistors biasing**
- **state the reason for shifting Q point due to temperature and β_{dc} changes**
- **state the necessity and importance of transistor characteristics**
- **state the importance of DC load line and meaning of Q point in transistors characteristics.**

Need of biasing of transistor

Before any one rides a motor cycle or drives a car, he has to start the engine and keep the engine running. In simple terms biasing transistors is similar to keeping the transistor started before making the real use of it. Once the transistor is started, like the engine of a car, it can be made to amplify, like covering the distance by driving the car.

Before an AC signal is fed to a transistor, it is necessary to set up an operating point or the quiescent(Q) point of operation. Generally this Q point is set at the middle of the DC load line. Once the Q point is set, then the incoming AC signals can produce fluctuations above and below this Q point as in Fig 1.

Fig 1



For the normal operation of a transistor amplifier circuit, it is essential that there should be

a) a forward bias on the emitter-base junction and

b) reverse-bias on the collector-base junction

In addition, the amount of bias required is important for establishing the Q point which is dictated by the mode of operation desired.

If the transistor is not biased correctly, it would

1) work inefficiently and

2) produce distortion in the output signal.

It is desirable, that once selected, the Q point should remain stable i.e. should not shift its position due to temperature rise which cause variation in β (V_{BE}) or leakage currents.

Further the amplitude variations in current and voltage of the input signal must not drive the transistor either into saturation of cut off.

Stable Q point: A set Q point of a transistor amplifier may shift due to increased temperature and transistor β value changes. Therefore, the objective of good biasing is to limit this shifting of the Q point or to achieve a stable Q point.

The Q point is nothing but a point in the output characteristic of the transistor. This point corresponds to a particular value of I_B, I_C and V_{CE}. Further , the collector current I_C depends both on I_B and β of the transistor. If I_B changes, I_c also changes, and hence, the Q point changes. If β changes, again I_C changes, and hence, the Q point gets shifted.

Shifting of Q point due to temperature: Remember that a transistor is a temperature sensitive device. Any increase in the junction temperature results in leakage current. this increased leakage current in turn increases the temperature and the effect is cumulative. This chain reaction is called thermal run away. If this thermal run away is not stopped, it may result in the complete destruction of the transistor due to excessive heat. In transistors, due to this increased leakage current, the base current increases, and hence, the Q point gets shifted. This change in the set Q point affects the performance of the amplifier resulting in distortion.

Shifting of Q point due to β_{dc} changes: Practically two transistors of the same type number may have different value of β. this is due to the manufacturing process of transistors. Hence, when a transistor is replaced or changed, due to different β of the replaced transistor, the Q point again gets shifted.

Therefore, a stable biasing is one which does not shift the Q-point even if temperature varies and/or the β of the transistor changes.

Different methods for transistor biasing: There are several ways to bias a transistor for linear operation. This means, there are several ways of setting up a Q point near the middle of the dc load line.

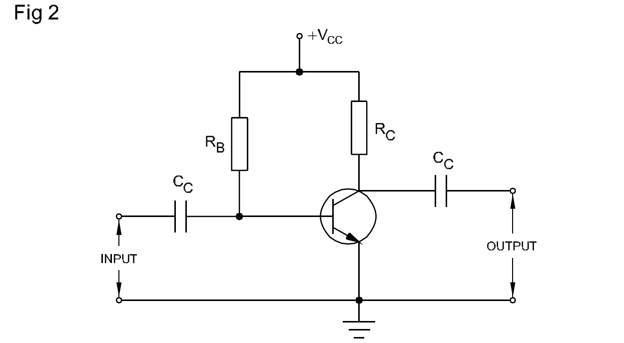
The methods used for providing a bias for transistors are 1 fixed bias or base bias

2 self-bias or emitter bias or emitter feed back bias

3 voltage divider bias

Fixed bias or base bias: The circuit in Fig 2 provides a fixed bias by means of the power source V_{cc} and the base resistor R_B

Fig 2



Self-bias arrangements are not practicable for small values of current because the DC Q point changes due to

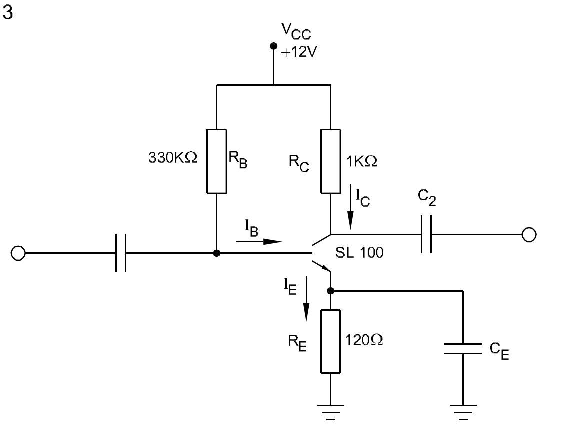
– poor Beta sensitivity

– bias voltages and current do not remain constant during transistor operation due to temperature variation.

Hence, in a base-biased transistor, it is impossible to set up a stable Q point. Therefore, base biasing of transistors is not generally done in linear amplifier circuits. However, base biasing is commonly used in digital circuits (discussed in further lessons) where transistor are used as a switch and not as a linear amplifier.

2 SELF BIAS or EMITTER BIAS or emitter feedback bias: Fig 3 shows a emitter-biased transistor. This type of biasing compensates for the variations in temperature and keeps the Q point fairly stable.

Fig 3



Let the temperature rise-causing rise in I_c and consequently rise in I_c. Then the current in R_E increases. The increased current in R_E increases the DC voltage drop across R_E, reduces the net emitter to the base bias, and the base current, and hence reduces the collector current. Thus the presence of the self-biasing resistor R_E reduces the increase in Ic and improves the operating point stability.

However if β_{dc} increases, the collector current increase. This inturn increases the voltage at the emitter. This increased emitter voltage decreases the voltage across the base-emitter junction and therefore, the base current reduces. This reduced base current results in less collector current, which partially offsets the increase in I_c due to increase β_{dc}.

Emitter bias is also referred to as emitter feedback bias. This is because an output quantity, i.e., the collector current, produces a change in an input quantity i.e., the base current. The term feedback means a portion of the output is given back to the input. In emitter bias, the emitter resistor is the feedback element because it is common to both the output and input circuits.

Referring Fig 3, if we go for further analysis of the circuit we find if we add the voltages around the collector loop, we get,

$I_CR_C + V_{CE} + I_ER_E - V_{CC} = 0$ ...... (1)

Since I_E approximately equals I_c (as I_B is comparatively very small), equation ..(1) can be arranged as,

$$I_C = \frac{V_{CC} - V_{CE}}{R_C + R_E} \text{ ....(2)}$$

If we add voltages around the base loop, we get,

$I_BR_B + V_{BE} + I_ER_E - V_{CC} = 0$ ...(3)

Since $I_E = I_c$ and $I_B = I_c / \beta_{dc}$, we can rewrite the equation as,

$$I_C = \frac{V_{CC} - V_{BE}}{R_B + R_D/\beta_{dc}} \text{ ....(4)}$$

From equation...(4), the presence of term β indicates that I_c is dependent on β. The intention f emitter-feedback bias to swamp out the effect β_{dc}. This is possible when R_E is made much larger than R_B/β_{dc}. However, in practical circuits R_E cannot be made very large because, large value of R_E takes the transistor out of the linear operating region. Due to this problem, the emitter-feedback bias is almost as sensitive to changes in β_{dc} as in the base-bias. Therefore, emitter-feedback bias is also not a preferred form of transistor bias and should be avoided.

In emitter-bias, the saturation current will be,

$$I_{C(sat)} = \frac{V_{CC} - V_{CE\,(sat)}}{R_E + R_C} \text{ ....(1)}$$

When the transistor is saturated, the value of V_{CE} will be between 0.2 to 0.3V. Hence can be neglected for all practical purposes.

In Fig 3, the saturation current is,

$$I_{C(sat)} = \frac{12V}{1000\Omega + 120\Omega} = 10.71\,mA$$

Note:

$V_{CE(sat)}$ of 0.2 volts is neglected.

When β_{dc} = 100, equation...(4) gives,

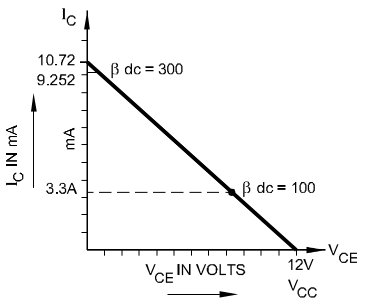
$$I_C = \frac{12V - 0.7V}{120\Omega + 330\,K\Omega/100} = 3.3mA$$

When β_{dc} = 300, the same equation...(4) gives,

$$I_C = \frac{12V - 0.7V}{120\Omega + 330\,K\Omega/300} = 9.262mA$$

Fig 4 summarizes the calculations by showing the DC load line and the two Q points. As can be seen, a 3:1 change in β_{dc} produces almost a 3:1 change in the collector current. This change is unacceptable as a stable-biased state.

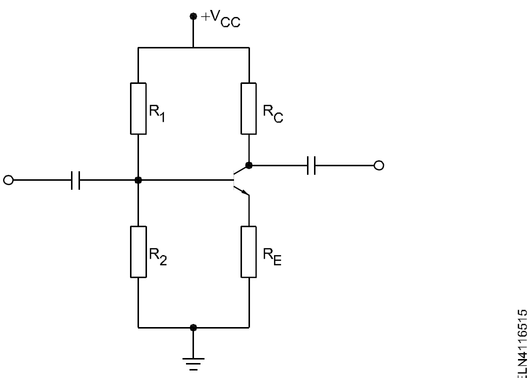
Fig 4



TIP: For linear operation of the transistor, the base resistor RB should be greater than βR_c. A base resistance of less than $\beta_{dc}R_c$ produces saturation in an emitter feedback-biased circuit.

3 VOLTAGE-DIVIDER bias: Collector to base bias: Fig 5 shows a typical voltage-divider bias. This type of biasing is also called the universal bias because, this is the most widely used type of biasing in linear circuits.

Fig 5



This type of biasing is known as voltage divider bias because of the voltage divider formed by resistors R_1 and R_2. The voltage drop across R_2 should be such that it forward biases the emitter diode.

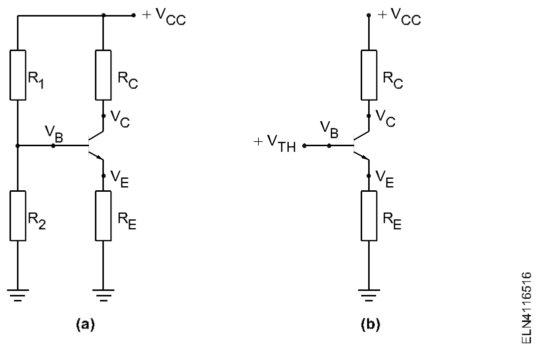
Emitter current in voltage divider bias : Assume that the base lead is open as shown in Fig 6b. Looking back at the unloaded voltage divider,

$$V_{TH} = \frac{R_2}{R_1 + R_2} = V_{CC}.$$

NOTE: V_{TH} is known as the Thevenin's voltage. Refer reference books for Thevinin's theorem.

Now assume that, the base lead is connected back to the voltage divider as in Fig 6a. then, voltage V_{TH} drives the base of the transistor. In other words, the circuit simplifies to Fig 6a and the transistor acts like the controlled current source.

Fig 6



Because the emitter is boot-strapped to the base,

$$I_E = \frac{V_{TH} - V_{BE}}{R_E}$$

The collector current I_c will be approximately equal to I_E.

Notice that β_{dc} does not appear in the formula for emitter current. This means that the circuit is not dependent on variations in β_{dc}. This means that the divider-biased transistor has a stable Q point.

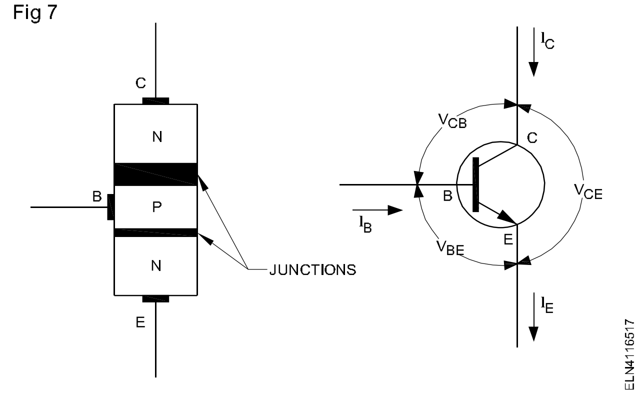
Because of the stable Q point, voltage-divider bias is the most preferred form of bias in linear transistor circuits. Hence, divider bias is used almost universally.

Transistor characteristics

In a transistor there are two PN junctions followed by three voltage parameters V_{BE}, V_{BC}, V_{CE} and three current parameters I_B, I_C, I_E is in Fig 7.

Any change in any one parameter causes changes in all the other parameters. Hence it is not very easy to correlate the effect of one parameter with the others. To have a clear understanding of their relationship a minimum of two characteristics graphs should be plotted for any transistor. They are,

Fig 7



– Input characteristics

– Output characteristics

For simplicity in understanding, consider a common-emitter amplifiers circuit (Fig 8). The two characteristics graphs are in Fig 9 and Fig 10.

Fig 8

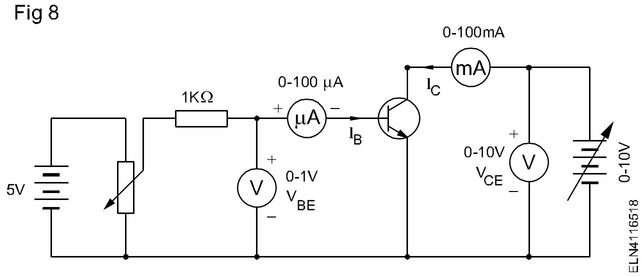
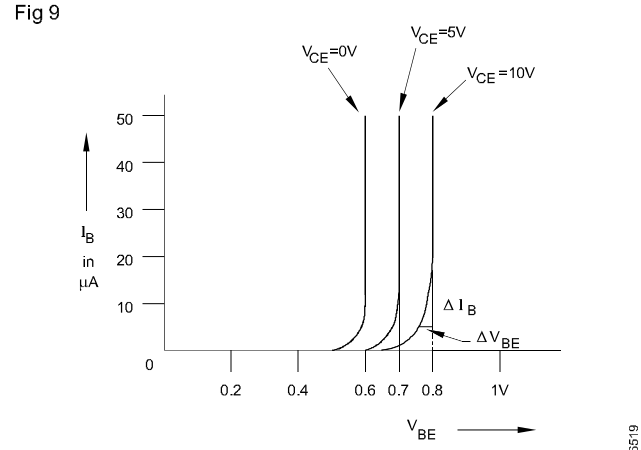


Fig 9



INPUT CHARACTERISTICS OF A COMMON EMITTER AMPLIFIER

The graph at Fig 9 shows the relationship between the input voltage V_{BE} and input current I_B for different values of V_{CE}

To find the input characteristics from the circuit as in Fig 8 keep V_{CE} = 0 constant; increase V_{BE} at regular steps of 0.1V and note the value of I_B at each step. Repeat the above procedure for different value of V_{CE} say V_{CE} = 5V and 10V.

Input characteristic curves can be obtained by plotting I_B on the Y axis against V_{BE} on the X axis. A typical input characteristic is in Fig 9.

The reason for deviation of the characteristic curve for V_{CE}, 5V and 10V from V_{CE} 0 volt is, at higher values of V_{CE} the collector gathers a few more electrons flowing through the emitter. This reduces the base current. Hence the curve with higher V_{CE} has slightly less base current for a given V_{BE}. This phenomenon is known as early effect.

However for the practical purposes the difference in gap is so small it can be regarded as negligible.

The CE input characteristic curves resemble the forward characteristic of a PN diode. The input resistance can be calculated by using the formula.

$$R_{in} = \frac{V_{BE}}{I_B} = \frac{0.72 - 0.7}{20\,\mu\,A - 10\mu\,A} = \frac{0.02}{10\mu\,A} = 2k\Omega$$

$(\mu = \text{micro})$

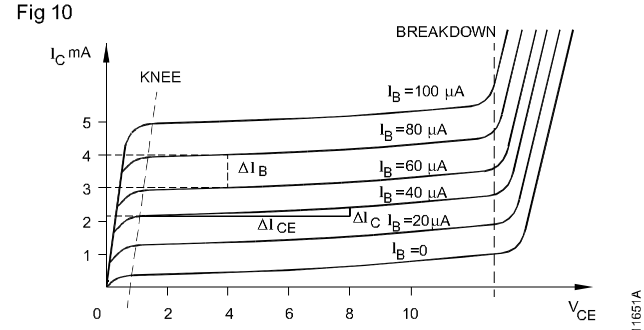
The voltage gain can be calculated by using the formula:

$$V_{gain} = \frac{V_{CE}}{I_{BE}} = \frac{10\,V - 5\,V}{0.15\,\mu\,A - 0.65\mu\,A} = \frac{5\,V}{0.1\mu\,A} = 50$$

Output CE characteristics: To find the output characteristics, keep I_B=0 micro-amp constant, increase V_{CE} in regular steps of 1V and note the value of I_B at each step. Repeat the above procedure for I_B = 20 micro-amp, 40 micro-amp and 60 micro–amp.

Output characteristics curves can be obtained by plotting I_c on the Y axis against V_{CE} on the X axis. A typical output characteristics curve is shown in Fig 10.

Fig 10



OUTPUT CHARACTERISTICS

It is seen that as V_{CE} increases from zero, I_c rapidly increases to a near saturation level for a fixed value of I_B. As shown, a small amount of collector current flows even when I_B= 0. It is called leakage current I_{CEO}. Since the main collector current is zero, the transistor is said to be cut-off.

For simplicity in understanding consider on the output characteristic curve where I_B = 40 μA.

The output resistance can be calculated by the formula

$$R_0 = \frac{V_{CE}}{I_C} = \frac{8 - 2}{2.15\,mA - 2mA} = \frac{6}{0.15m\,A} = 40\text{ k ohms.}$$

Current gain can be calculated by the formula

$$\text{Beta } \beta = \frac{I_C}{I_B} = \frac{4mA - 3\,mA}{80\,\mu A - 60\,\mu A} = \frac{1mA}{20\,\mu A} = 50$$

In the common base configuration, the current gain can be calculated by the formula:

$$\text{Alpha } \alpha = \frac{I_C}{I_E} = \frac{\beta}{1+\beta} = \frac{50}{1+50} = 0.98$$

Analysis of common emitter output characteristics

Active region : In the active region the collector junction is reverse-biased and the emitter junction is forward-biased. In the active region, the collector current is Beta times greater than the base current. Thus, a small input current I_B produces a large output current I_c.

Saturation regions : In the saturated region, the emitter and collector junctions are forward-biased. When the transistor is operated in the saturated region, it acts as a closed switch having V_{CE} = 0 and I_c maximum.

Behaviour of Ic for different values of V_{CE} is explained below:

- When V_{CE} is 0, the collector-base diode is not reverse-biased. Therefore, the collector current is negligibly small and this continues upto knee point.
- For V_{CE} between 0.7V and 1V, say up to knee point voltage the collector diode gets reverse-biased. Once reverse biased, the collector gather all the electrons that reach its depletion layer. Hence the collector current rises sharply and then becomes almost constant.
- Above the knee voltage and below the break down voltage, the collector current does not rise steeply or the current is almost constant even if the value of V_{CE} is increased. Thus the transistor works like a controlled constant current source in this region.
- Assuming that the transistor has a $ß_{dc}$ of approximately 50, the collector current is approximately 100 times the base current as in Fig 4 (1mA is 50 times 20 µA).
- If V_{CE} is further increased, beyond the break down level, $V_{CE(max)}$, the collector-base diode breaks down and normal transistor action is lost. The transistor no longer acts like a current. As the collector-base gets ruptured, the junction is shorted and hence current increases rapidly above the breakdown point as in Fig 10.

Cut off region : In the cut off region, the emitter and collector junctions are reverse-biased. When the transistor is operated in the cut off region, it acts as an open switch, having V_{CE} = V_{cc} and I_c = 0

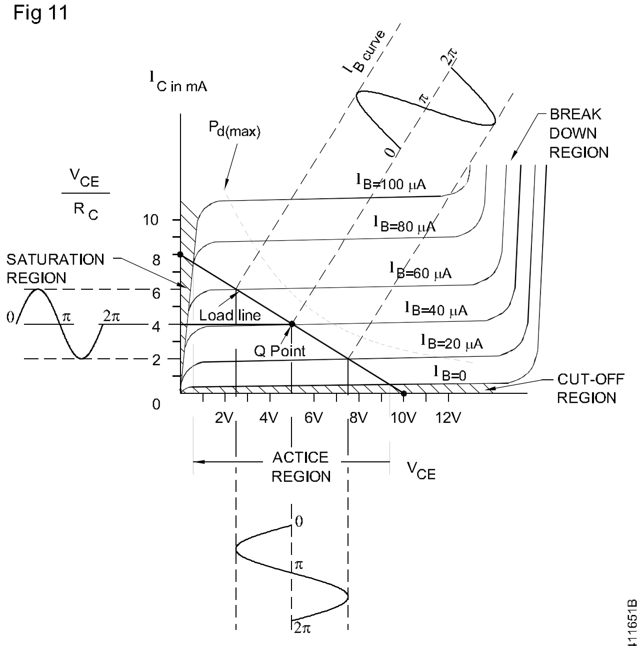
Break down region : When the collector voltage is too large, the collector diode breaks down by a rapid increase of collector current. Usually, a designer should avoid operation in the breakdown region because the excessive power dissipation may destroy the transistor.

For instance, a 2N3904 has a collector break down voltage of 40V. For normal operation, therefore, V_{CE} should be less than 40V.

Maximum power dissipation region : The maximum power dissipation ($P_{o\ max}$), defined as the product of maximum collector current $I_{c\,max}$ and maximum collector emitter voltage $V_{CE\,max}$, restricts the operation to an area on the output characteristic bounded by a hyperbola.

To understand the function of the transistor at active, cut off, saturation regions and breakdown regions, refer to Fig 11.

Fig 11



OUTPUT CHARACTERISTIC WITH LOAD LINE SUPERIMPOSED

The collector curves are very important because, from these curves the following important information required while designing an amplifier circuit using a particular type of transistor can be obtained;

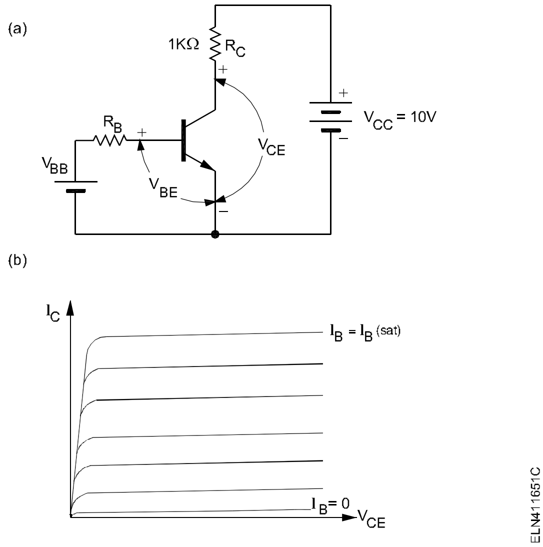
- DC current gain ß of the transistor at different set DC values of I_B and V_{CE}
- Maximum value of V_{CE} that can be applied for a set value of I_B and I_c.
- Maximum value of I_c that can be made to flow for a set value of I_B

Operation point : The position of the operating point on the DC load line determines the maximum signal that we can get from the circuit before clipping occurs. The operating point or quiescent point 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. The best position for this point is midway between cut-off and saturation point where V_{CE} = 1/2 V_{cc}.

DC load lines of transistors : To have a further insight into how a transistor works and in what region of the collector characteristics does it work better can be seen using DC load lines.

Consider a forward biased transistor as in Fig 12a. Fig 12b shows the collector characteristics of the transistor used.

Fig 12



In the circuit at Fig 12a, consider the following two situations,

– Maximum collector current, $I_{c(max)}$

– Minimum collector current, I_c

For situation (1) assume that V_{CE} is zero or collector is at short. In that case, the collector current is limited only by the collector resistor R_c.

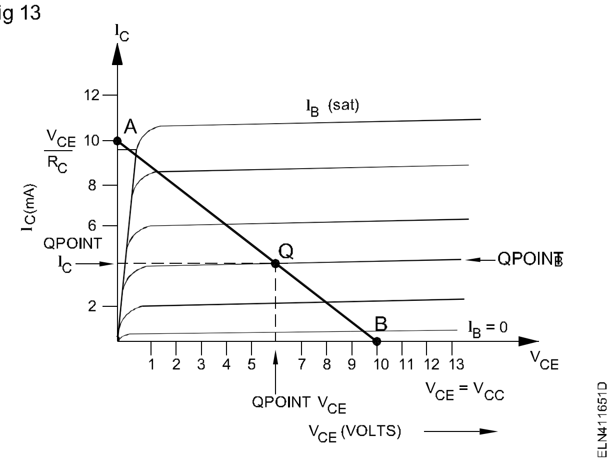
Therefore

$$I_C = \frac{V_{CC}}{R_C} \text{ at } I_{CE} = 0$$

Under such a condition for the circuit at Fig 12a I_c will be equal to 10V/kΩ = 10mA

Mark this I_c=10mA point along V_{CE}=0 on the collector characteristics of the transistor as shown in Fig 13 at point A.

Fig 13



For situation (2), assume that V_{CE} is maximum or collector emitter is open. In that case, the collector current is zero.

Therefore,

$V_{CE} = V_{cc}$ In the circuit at 6a, $V_{CE} = V_{CC}$ = 10V

Mark this point of I_C = 0 and V_{CE} = 10 V on the collector characteristics of the transistor as in Fig 13 at point B.

Connect the two marked points A and B through a straight line as shown in Fig 13. This line is called the load line.

The point at which the load line intersects the I_B = 0 is known as the cut off point. At cut off, I_B = 0; hence emitter diode is out of forward bias and the transistor action is lost.

The point at which the load line intersects $I_B = I_B$(sat) is called the saturation point. At this point the base current is maximum and the collector current is also maximum. At saturation, the collector diode comes out of the reverse bias, and hence, the normal transistor action is lost.

For a transistor to work in a normal way, i.e. as a controlled current source, it must not be made to work either in the cut off or in saturation. Therefore the ideal point would be somewhere in the middle of these extreme points on the load line. This middle point is known as Quiescent point or Q-point as in Fig 13. knowing the Q point we can fix up the value of resistors RC and RB of the circuit.

Transistor as a switch, series voltage regulator and amplifiers

Objectives: At the end of this lesson you shall be able to
- **explain the function of the transistor at cut-off and saturation condition**
- **explain the operation of a transistor as a switch and its application**
- **state the working of series voltage regulator using transistor**
- **state the classification of amplifiers.**

The function of a transistor at cut-off condition: The transistor is operated at cut–off condition when the emitter and collector junctions are both reverse-biased.

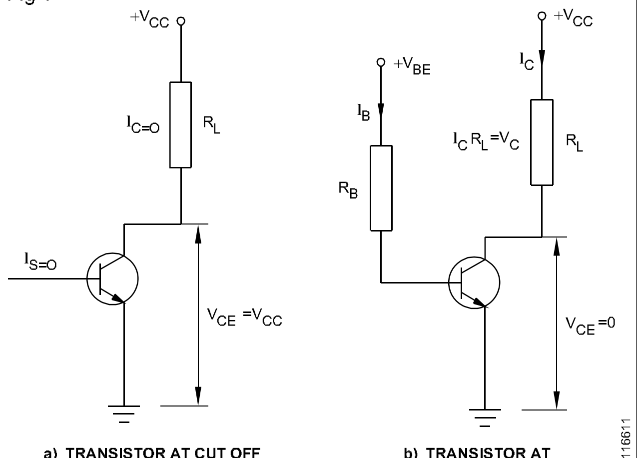
Consider the circuit in Fig 1.

$V_{CE} = V_{CC} - (I_C \times R_L)$ ..... (1)

Since, $I_B = 0$ and $I_c = 0$ $V_{CE} = V_{CC}$

The transistor is said to be cutoff for the simple reason that it does not conduct any current as in Fig 1a.This corresponds to a switch in an open state. Therefore, a transistor at cut off is said to be at open state.

Fig 1



a) TRANSISTOR AT CUT OFF CONDITION
b) TRANSISTOR AT SATURATED CONDITION

The function of a transistor at saturated condition : The transistor is operated at saturated condition when both the emitter and the collector junctions are forward biased.

In Fig 1b, if the value of R_B and R_L are such that V_{CE} tends to zero, then the transistor is said to be saturated. Putting $V_{CE} = 0$ in the equation (1) we get

$V_{CE} = 0 = V_{cc} - I_cR_L$ or $I_c = V_{cc} - R_L$

It should be noted that a transistor, when saturated, acts as closed switch of negligible resistance.

It is obvious that under saturation conditions,

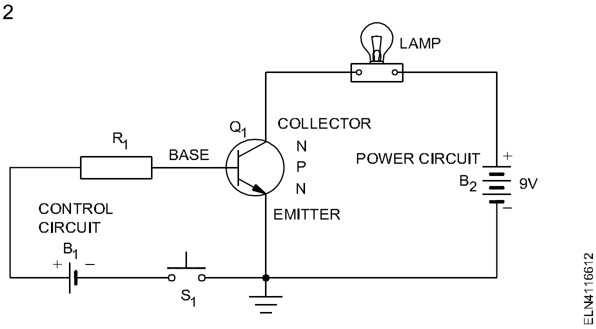
- the whole of V_{cc} drops across R_L
- the collector current has maximum possible value called $I_{C(SAT)}$

The operation of transistor as switch: The switching action for Q_1 in Fig 2 illustrates how the output current can be controlled at the input. Note the following important operating characteristics.

- The transistor is normally off, without any output current unless forward voltage is applied in the base-emitter circuit.
- The forward voltage controlling the base current determines the amount of output current.

In Fig 2 the control circuit of the input determines the base current. For the power circuit, the output is the collector current. An NPN transistor is used for Q_1. This type requires positive V_{BE} forward voltage. The emitter is common to both (a) the control circuit at the input and (b) the power output circuit.

Fig 2



The base emitter junction of Q_1, in Fig 2 can be forward biased by the battery B_1. Switch S_1 must be closed to apply the forward voltage. Reverse voltage for the collector of Q_1 is supplied by B_2.The reverse polarity means that the N collector is more positive than the base. With switch S_1 open, no current flows in the base-emitter (or control) circuit.

The reason is that the forward voltage is not applied. Therefore, the resistance from the emitter to the collector of the transistor is very high. No current flows in the power circuit, and the lamp does not light.

Next, assume that switch S_1 is closed. This causes a small current to flow in the control circuit. R_1 is a current limiting resistor for the base circuit. Therefore, the resistance from the emitter to the collector of the transistor drops.

Consequently, a large current flows in the power circuit, causing the lamp to light.

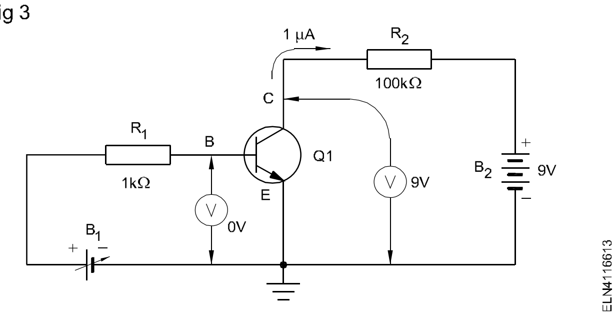
Finally, the opening of the switch S_1 in the control circuit cause the lamp in the power circuit to go out. This is because the resistance from the emitter(E) to the collector (C) of Q_1 has again increased to near infinity.

In summary, a small current in the control circuit causes a large current to flow in the power circuit. With no current in the control circuit, the transistor acts like an open switch. With some current in the control circuit, the transistor acts like a closed switch.

Operation of transistor switching circuit : The schematic circuit in Fig 3 shows the measured voltages and collector current I_c in the 'transistor off' circuit. Note that only a tiny leakage current of 1micro amp flows from the emitter to the collector. The resistance from E to C is calculated as

$$R = \frac{V}{I} = \frac{9\ V}{0.000001\ A} = 9\ \text{megohm}$$

Fig 3

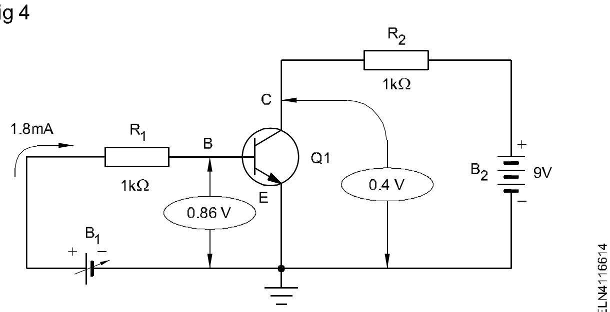


The transistor has a resistance of 9 Megohm, which is like the open or off condition of a switch.

The schematic in Fig 4, shows the measured voltages and currents in the 'transistor on' circuit. First, the voltage from the emitter to the base has been increased by adjusting B_1. The forward-biased voltage of 0,86V at the emitter-base junction of the transistor causes 1.8 mA to flow in the control circuit. This current in turn causes the resistance of the transistor from E to C to drop. The effect is that a large current of 85mA flows from the collector of the transistor. The resistance from E to C in Fig 4 is calculated as

$$R = \frac{V}{I} = \frac{0.4\ V}{0.085A} = 4.7\ \text{ohm}$$

Fig 4



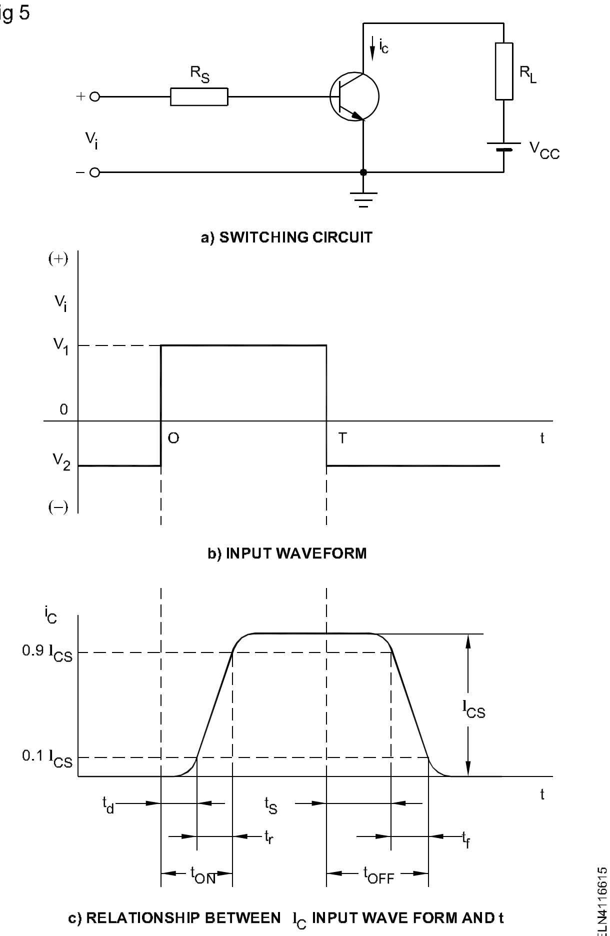
The resistance of the transistor from E to C has dropped from its previous high value of 9 megohm to a low value of 4.7 ohm. As a result, the transistor is acting like a closed switch.

The transistor in Fig 3 is said to be at cut off position. It has reached its maximum resistance from E to C and has cut off the current. The very tiny current still flowing is due to minority current carriers in the transistor, which is the leakage current.

The transistor in Fig 4 is said to be at saturation. It has reached its minimum resistance from E to C, which produces the maximum collector current. When used as a switch, the transistor is driven to cut off or to saturation by the base current caused by the emitter-base voltage.

Transistor switching times : Now let us pay attention to the behaviour of the transistor as it makes a transition from one state to the other. Consider the transistor circuit in Fig 5a, driven by the pulse wave-form in Fig 5b. This wave-form makes transitions between the voltage levels V_2 and V_1. At V_2 the transistor is at cut off, and at V_1 is applied between the base and the emitter through a resistor R_1 which may be included explicitly in the circuit or may represent the output impedance of the source in the wave-form Fig 5b.

Fig 5



The response of the collector current I_c to the input waveform, together with its time relationship to that waveform, is in Fig 5c. The current does not immediately respond to the input signal. Instead, there is a delay, and the time that elapses during this delay, together with the time required for the current to rise to 10 percent of its maximum (saturation) value $I_{CS} = V_{cc}/R_L$, is called the delay time t_d. The current waveform has a nonzero rise time tr which is the time required for the current to rise from 10 to 90 percent of I_{CS}. The total turn-on time t_{ON} is the sum of the delay and rise time,

$$t_{ON} = t_d + t_r$$

When the input signal returns to its initial state at t = T (Fig 5b), the current again fails to respond immediately. The interval which elapses between the transition of the input waveform and the time when i_c has dropped to 90 percent of ICS is called the storage time t_s. The storage interval is followed by the fall time tt, which is the time required for i_c to fall from 90 to 10 percent of I_{CS}. The turn off time to t_{OFF} is defined as the sum of the storage and fall times,

$$t_{OFF} = t_s + t_F$$

The application of transistor switch: The transistor switch is used

- as an electronic ON and OFF switch
- in the stable, mono-stable and bi-stable or filp-flop multi-vibrator circuits
- in the counter and pulse generator circuit
- in the clipping circuits
- as a sweep starting switch in the cathode ray oscilloscope equipment
- as a relay, but unlike the mechanical relay, the transistor has no moving mechanical parts.

Classification of the Switching Transistor: Transistor switches are used very often as they are small and are of light weight, and they consume low power. The important specifications of a switching transistor are the numerical values of delay time, rise time, storage time and fall time. For the TEXAS INSTRUMENTS n-p-n silicon transistor 2N3830, under specified conditions can be as low as t_d = 10 nsec, t_r = 50 nsec, t_s = 40 nsec and t_f = 30 nsec.

Series voltage regulator

Voltage regulated power supply using zener diode is the simplest form of voltage regulator. But, zener voltage regulators have two main disadvantages:

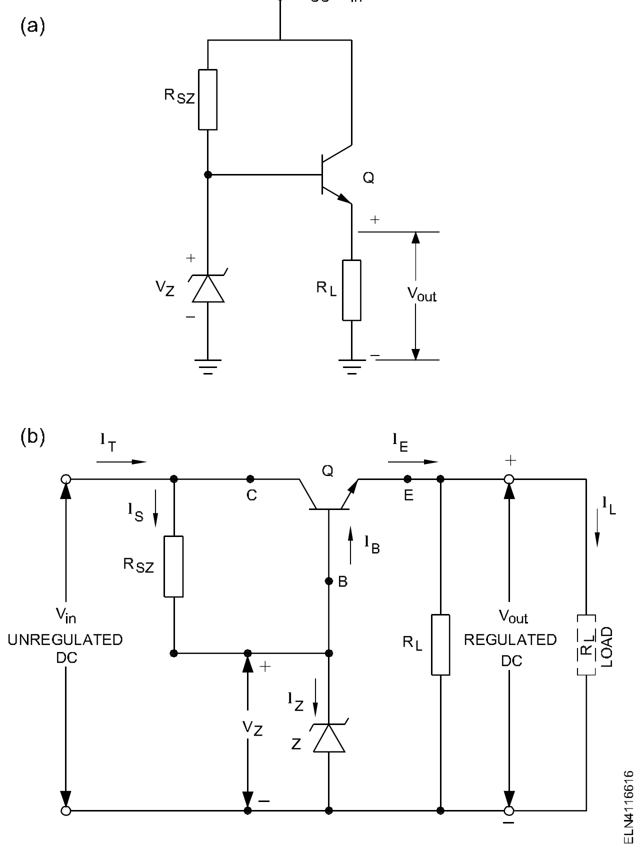
1 When the load current requirement is higher, say of the order of a few amperes, the zener regulator requires a very high wattage zener diode capable of handling high current.

2 In a zener regulator, the load resistor sees an output impedance of approximately the zener impedance, R_Z which ranges from a few ohms to a few tens of ohms (typically 5Ω to 25Ω). This is a considerably high output impedance because the output impedance of a ideal power supply should be zero ohms.

These two disadvantages of zener regulators are overcome in a simple series regulator shown in Fig 6.

The simple series regulator is in Fig 6a, redrawn in Fig 6b is nothing but a zener regulator followed by an emitter follower. A circuit like this can hold the load voltage almost constant, thus working as a voltage regulator.

Fig 6



The advantages of this circuit are listed below;

1 Less load on the zener diode

Current through R_Z is the sum of current just required to keep the zener fired and the small base current I_B.

$$I_B = \frac{\text{emitter curent}}{\beta_{dc} \text{ of transistor}} = \frac{I_E}{\beta_{dc}} = \frac{I_L}{\beta_{dc}}$$

Since the base current is very much smaller than the emitter current or the load current, a very small wattage zener diode itself is sufficient.

For instance for a load of say 1 amp, if the β_{dc} of the transistor is 100, then the zener diode need to handle only,

$$I_Z = I_{Z(min)} + \frac{I_L}{\beta_{dc}} = I_{Z(min)} + \frac{1Amp}{100}$$

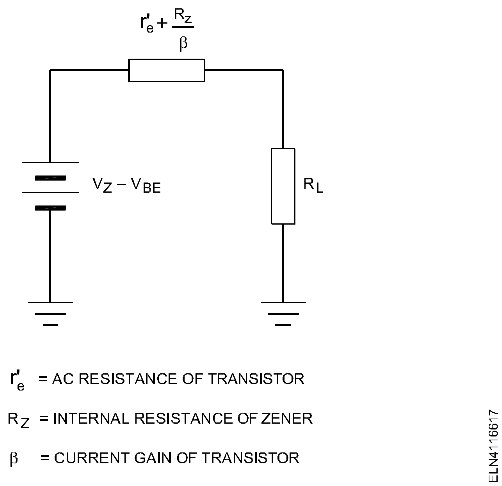
Since $I_{Z(min)}$ will generally be in the range of 5 to 10mA, I_Z = 10mA + 10mA = 20mA.

2 Lower output impedance

If the zener resistance, R_Z is say 7Ω, then, in a zener regulator discussed in unit 9, the output impedance of the power supply will be approximately equal to R_Z = 7Ω.

Fig 7 shows the output equivalent circuit of the series regulator at Fig 6. As in Fig 7, the output impedance of the power supply will be,

Fig 7



$$Z_{out} = r'e + \frac{R_Z}{\beta}$$

Since I_E is very large (load current), r^{l}_{e} will be comparatively small, hence the term r^{l}_{e} can be neglected. Therefore, in Fig 6 the output impedance will be,

$$Z_{out} \cong \frac{R_Z}{\beta} = \frac{7}{100} = 0.07\Omega$$

This low output impedance of 0.07Ω is close to the ideal output impedance of zero required for a power supply.

Working of a simple series regulator

In Fig 6b, the current through R_{SZ} should be atleast equal to zener breakdown current, plus, base current for the transistor Q.

The voltage across the zener, V_Z drives the base of the emitter follower. Therefore, the DC output voltage is bootstrapped to within one V_{BE} drop of the zener voltage. The regulated dc output voltage will be,

$V_{out} = V_Z - V_{BE}$ ....[1]

The collector - emitter voltage across the transistor will be the difference in the voltage between the input and output.

$V_{CE} = V_{in} - V_{out}$

If the input voltage V_{in} increases, the output voltage V_{out} remains constant due to the bootstrapped zener voltage. Therefore, the drop across the collector-emitter, V_{CE} of the transistor increases compensating the rise in the input voltage V_i.

For example, in the series regulator shown in Fig 6, if V_{in} is 15 V and V_{out} is 12 volts, then, V_{CE} will be,

$V_{CE} = V_{in} - V_{out}$ = 15-12 = 3 V.

If V_{in} increases to say 20 V, then V_{CE} increases to 20-12=8 V, thus keeping the output voltage unaltered at 12 volts. Since the collector and emitter of the transistor in Fig 6 is in series with the input and output terminals, this type of regulators are known as series voltage regulators.

Because the transistor is in series, all the load current must pass through the transistor. Hence the transistor is referred to as the pass transistor.

Because of the fact, that all the load current must flow through the pass transistor and that the value of V_{CE} increases when V_{in} increases, the wattage rating of the pass transistor should be high enough to handle the dissipation.

For instance, while supplying a load current of 300 mA, with V_{in} at 20 V and V_{out} at 12V, V_{CE} will be 8 V. Therefore, the dissipation at the transistor will be,

$P_D = V_{CE} \times I_L$ = 8 x 300 mA = 2400 mw = 2.4 watts

To accommodate this, the wattage rating of the chosen pass transistor should be greater than 2.4 watts.

TIP: Allow at least 20% higher rating. For the example above, choose a transistor of rating 2.4 + 0.48 watts= 3 watts.

Because there will be quite a high dissipation depending on load current requirement, medium to high power transistors are used as pass transistors.

Temperature effect on output voltage

When temperature increases, V_{BE} decreases. Therefore, V_{out} decreases by the change of current in V_{BE}.

Data sheets of transistors usually give information about how much V_{BE} changes with temperature.

For all practical purposes, an approximate of 2 mV decreases in V_{BE} for each degree rise in temperature. For instance when the temperature of the transistor rises from 25°C (room temperature) to 75°C (due to power dissipation at the transistor), V_{BE} decreases approximately 100 mV. Hence, the output will increases by 100 mV. This is relatively small, and hence, can be neglected.

Temperature also has an effect on the voltage across the zener. Any increase or decrease in the voltage across the zener is reflected at the output. Hence, while choosing the zener, it is equally important to know the temperature coefficient of the zener, specially when the power supply is connected to higher loads of the order of a few amperes.

Classifications of amplifiers : An amplifier is an electronic circuit which is used to amplify or increase the level of weak input signals into very high output signals. Transistors are used as amplifiers in most circuits. In addition, resistors, capacitors and a biasing battery are required to form complete amplifier circuits.

Almost all electronic systems work with amplifiers. We are able to hear the news or other programmes on our radio, simply because the amplifier in the radio amplifiers the weak signals received by its antenna.

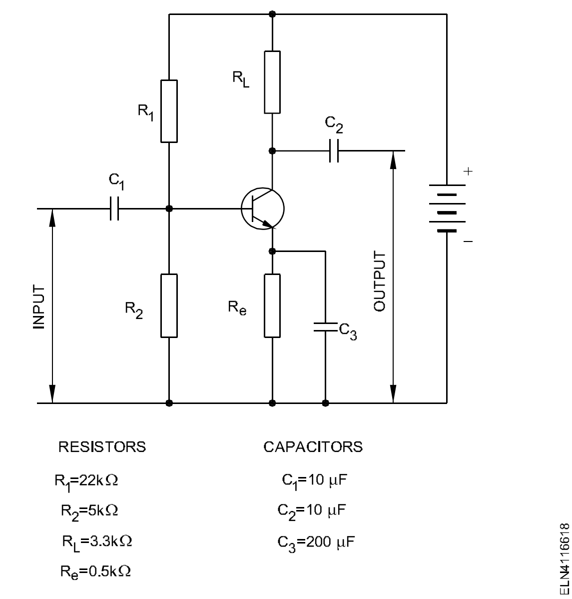
Classification of amplifiers: Linear amplifiers are classified according to their mode of operation, i.e. the way they operate according to a predetermined set of values. Various amplifier descriptions are based on the following factors.

1 Based on the transistor configuration
   a common emitter (CE) amplifier
   b common collector (CC) amplifier
   c common Base (CB) amplifier
2 Based on the output
   a voltage amplifier
   b current amplifier
   c power amplifier
3 Based on the input
   a small signal amplifier
   b large signal amplifier
4 Based on the coupling
   a RC coupled amplifier
   b transformer coupled amplifier
   c impedance coupled amplifier
   d direct coupled amplifier
5 Based on the frequency response
   a audio frequency (AF) amplifier
   b intermediate frequency (IF) amplifier
   c radio frequency (RF) amplifier
   d VHF and UHF amplifiers
6 Based on the feedback
   a current series feedback amplifier
   b current parallel feedback amplifier
   c voltage series feedback amplifier
   d voltage parallel feedback amplifier
7 Based on the biasing conditions
   a Class A power amplifier
   b Class B power amplifier
   c Class AB power amplifier
   d Class C power amplifier

Of the above mentioned, serial numbers one and two are explained at this state. Some of the amplifiers dealt in this book for detailed study the students can refer to any standard books for the remaining portions depending on their special interest.

Common-emitter amplifier: This type of circuit is by far the most frequently used. It has the greatest power gain, substantial current and voltage gains, and is specially advantageous in multistage application when a high gain is a primary requirement. A common-emitter amplifier stage with biasing from a single D.C supply battery is in Figure 8.

Fig 8



The A.C. signal is applied between the base and the emitter and the output is taken from the collector. For the transistor to operate, the emitter base junction must be forward-biased, the resistors R_1 and R_2 setting the base voltage so that the emitter is forward-biased. The collector current flows through the load resistors R_L and R_e and the voltage developed by R_L at the collector is the output.

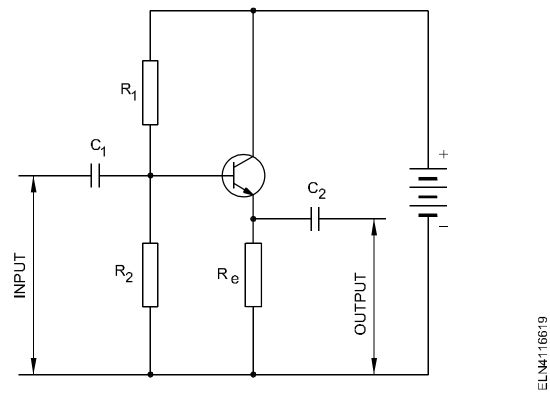
The voltage gain of a transistor is largely determined by the value of this particular resistor since the voltage developed across it due to change in the collector current is far greater than that developed across the base resistor from the input signal.

Resistor R_e is included to minimise the effect of temperature changes in the collector current. To prevent R_e from reducing the signal gain by current feedback, a capacitor C_3 may be included in parallel with R_e.

The capacitors C_1 and C_2 are provided to prevent (block) the flow of direct current so that the D.C. bias conditions are in no ways affected by the signal circuit. In this way, the D.C. conditions at one stage are prevented from affecting the following stage, so that only D.C. signals are passed from one stage to the next one.

Common-collector amplifier : In this configuration, the collector is the common point for the input and output circuits, the input signal being applied between the base and collector and taken off between the emitter and collector, Fig 9. The notable feature is the large input impedance virtually equal to that of the parallel circuit of R_1 and R_2. The output resistance is, however, low and, hence it follows that the voltage gain is low, but a high current amplification can be obtained.

Fig 9



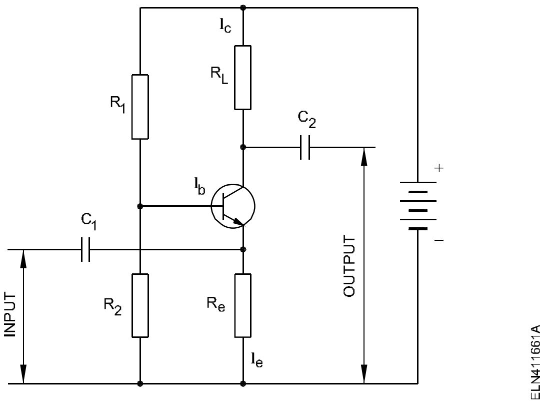
The functions of the capacitors C_1 and C_2 are the same as for the common-emitter stage, as the potential networks R_1 and R_2 which provide forward bias for the emitter-base junction. The main advantage of the common-collector circuit is the readiness with which it may be directly coupled to any point in a circuit regardless of voltage.

The circuit is often called the emitter-follower because the emitter voltage tends to follow the input voltage, the difference between the two being only the AC voltage across the base-emitter junction of the transistor which is quite small. Hence the output gain is less than 1.The current gain 50 to 500 is, however, high, being approximately equal to that of the common-emitter circuit. The output resistance is very low (less than 100 ohms) since the emitter-to-collector resistance is low and there is not resistance in the collector circuit.

The external resistance of the collector circuit, that is, the impedance presented by the transistor to the load is, however, very high (300 KΩ) and hence the emitter follower, circuit, transforms a very high input impedance into a low output impedance; it is in fact an impedance transformer. Hence its main application is as a buffer, i.e. an impedance matching device in which it can be connected between a high impedance source and a low impedance load without excessive loss of power due to mismatching or not suitable.

Common-base amplifier: In this circuit the base is the common terminal between the emitter terminal and the collector terminal. The emitter current I_c is the input current and the collector current I_c is the output current. (Fig 10) Since $I_e = I_b + I_c$ and since in this circuit Ie is greater than I_c, by the value of I_b, the current gain I_c/I_e will always be slightly less than one. Therefore, there can be no current gain in a common-base circuit. However, because of the low impedance of the forward-biased emitter-base junction and the high impedance of the reverse-biased collector-base junction a sizable voltage gain is obtained.

Fig 10



For instance, if we assume that input resistance of 200Ω, a load resistance of 50K and a current gain of 0.98, the voltage gain is 0.98 x 50k/200 = 245

The common-base circuit is not suitable for multi-stage amplification because its current and power gain are low when compared with the common-emitter. Also its low input impedance shunts the load resistance of any previous stage, thereby reducing the output voltage from that stage causing a corresponding fall in overall gain.

However, its ability to operate at high frequencies makes it useful in v.h.f. amplifiers. At such frequencies this circuit is more stable than the common-emitter amplifiers because of the very small capacitance linking input and output circuits (the emitter-collector capacitance).

Voltage amplifier: An amplifier is a circuit that incorporates one or more transistors and is designed to increase an alternating signal applied to the input terminals. It is called a voltage amplifier. If the size or magnitude of the output voltage is considerably greater than the input voltage, it is called the voltage gain of the amplifier.

The main function of a voltage amplifier is to produce a given gain with the minimum of distortion, i.e. the output voltages should have the same wave-form as the input wave-form, but should of course be much higher in magnitude. Examples for the voltage amplifier are the common base and the common emitter amplifiers.

Current amplifier: The function of the current amplifier is when the current injected in the base, load can influence to much greater current to flow in the emitter-collector circuit.

The remarkable result is that, if the base current is increased by a certain proportion, the base current in the collector current gives rise to a corresponding, but much larger changes in the collector current. We have achieved current amplification. The ratio of the output current to the input current is called the current gain of the amplifier.

An example for the current amplifier is the common-emitter, common-collector amplifier. The current gain of common-emitter amplifier is 50 to 300 and that of the common-collector amplifier is 50 to 500.

Power amplifier : Power amplifiers are used to drive the output mechanism, e.g. a loudspeaker, a pair of earphones, a moving coil meter or some other type of indicating device. The main function of a power amplifier is to deliver a good deal of undistorted power into the output device or load circuit. Examples for the power amplifiers are class A, class B, class AB and class C.

Fig 11 shows the complementary symmetry Class B push-pull power amplifier circuit. In a complementary pair of power amplifiers, one of them is an NPN type and the other a PNP type. With no input signal, neither transistor conducts and the output is zero. When the input signal is positive going, the NPN transistor T_1 conducts and the PNP transistor T_2 is cut off. When the signal is negative going, T_1 is tuned of while T_2 conductors. The maximum efficiency of this circuit is about 78%.

Fig 11