Basics of Electrical & Electronics

Unit-IV

Diode

A semiconductor diode is simply a p–n junction which offers very low resistance when forward biased and very high resistance when reverse biased. Diodes are available in different current ratings. Low-current-rated diodes are used in switching circuits as the diode works like a switch allowing current to flow in one direction. A p–n junction with connecting leads on both sides form a p–n junction diode as shown in Fig. 11.8 (a). The symbolic representation of a p–n junction diode has been shown in Fig. 11.8 (b).

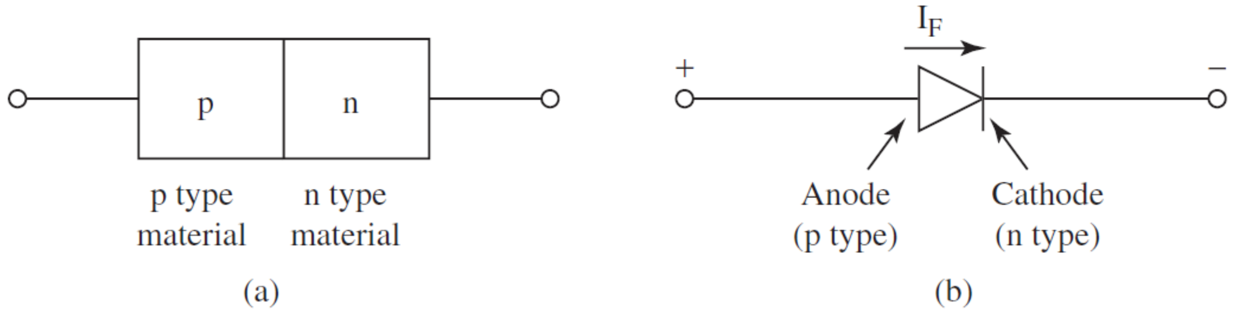


Figure 11.8 *(a) P–n junction semiconductor diode; (b) Symbolic representation of a forward-biased diode*

The p-side is connected to the positive terminal for forward bias and is called anode. The n-side is connected to the negative terminal for forward bias and is called cathode.

A very high forward current or a very high reverse voltage can destroy a diode. That is why the manufacturer, data sheet is to be consulted to note the maximum permissible forward current and maximum permissible reverse voltage. High-current power diodes are available these days which allow large forward current and considerable amount of reverse voltage.

1 Volt–Ampere Characteristic of a Diode

When a p–n junction diode is connected to a source of supply in such a way that it is forward biased, the relationship between the voltage applied and current flowing will give us a forward V–I characteristic. The connection diagram for finding the V–I characteristic has been shown in Fig. 11.9. When the applied voltage is gradually increased, at a small value of forward voltage the forward current is negligible small. At a voltage near 0.3 V, the current suddenly increases. This voltage at which the forward current starts increasing is called the cut-in voltage of the diode. The voltage drop across the diode while it is conducting remains almost constant. For the germanium semiconductor diode, the forward voltage drop is 0.3 V and for the silicon diode, the forward voltage drop is 0.7 V.

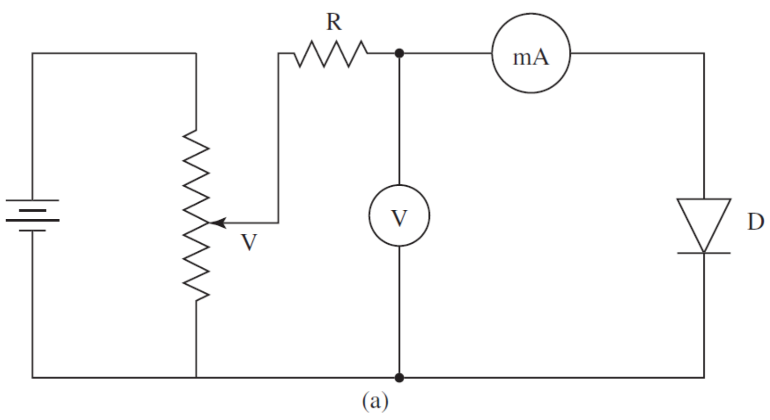


Figure 11.9 *(a) Circuit diagram*

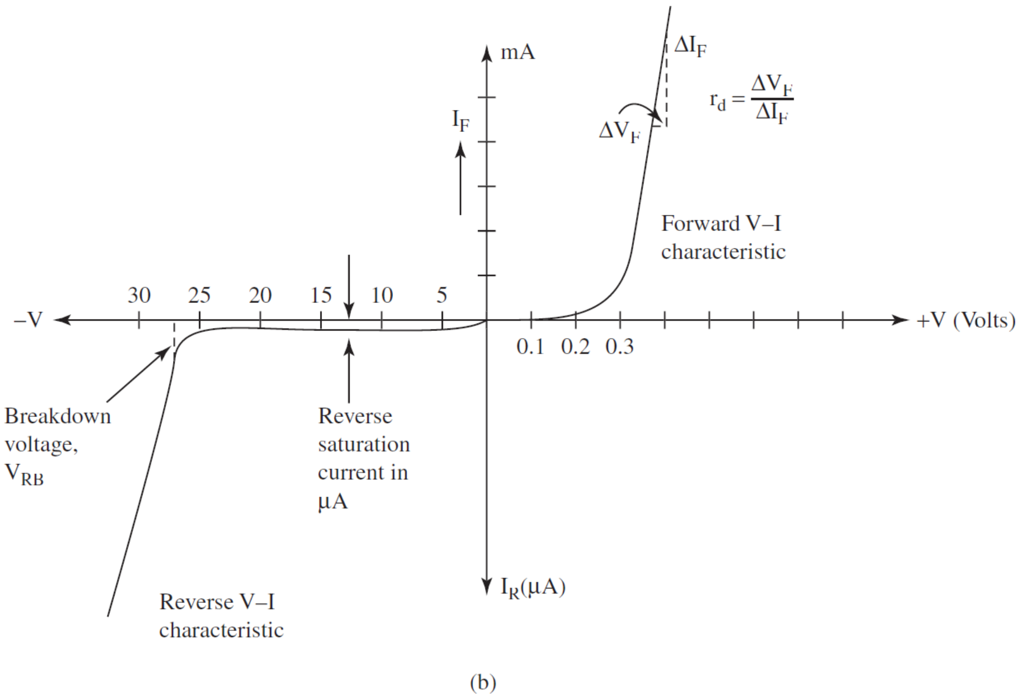


Figure 11.9 *(b) V–I characteristic*

Diode – Contd.

For determining the reverse characteristic, the supply connection has to be reversed. Under the reverse-biased condition, the junction resistance is very high and ideally no current should flow. But due to minority charge carriers, a negligibly small current of the order of microamperes will flow. This current is also called leakage current of the diode. It gets saturated to its initial value of a few microamperes or even less than that. Increase of negative biasing, i.e., increase of negative voltage across the diode does not increase this reverse current. However, if the reverse voltage is increased to a large value, at one stage, the p–n junction will break down with a sudden rise in reverse current. The reverse voltage at which the diode breaks down and a large reverse current starts flowing is called the breakdown voltage. At this reverse breakdown voltage, current continues to increase.

3 Diode Parameters and Diode Ratings

A diode is specified in terms of certain parameters. These are as follows:

(i) Forward Voltage drop, V_F

(ii) Reverse Breakdown Voltage, V_{RB}

(iii) Reverse saturation current, I_R

(iv) Dynamic resistance, r_d

(v) Maximum forward current, I_{FM}

The dynamic resistance, r_d is calculated from the slope of the forward V–I characteristic as shown in Fig. 11.9 (b)

$$r_d = \frac{\Delta V_F}{\Delta I_F} \Omega$$

Diode – Contd.

Forward voltage drop, Vf:

Any electronics device passing current will develop a resulting voltage across it and this diode characteristic is of great importance, especially for power rectification where power losses will be higher for a high forward voltage drop. Also diodes for RF designs often need a small forward voltage drop as signals may be small but still need to overcome it.

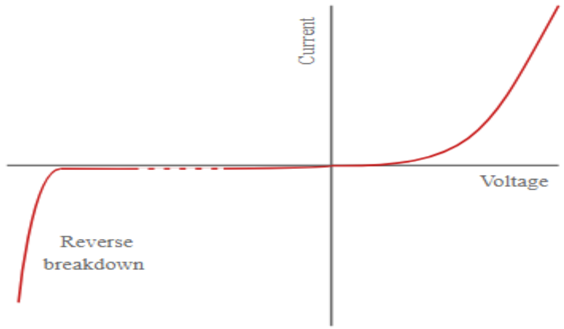
The voltage across a PN junction diode arise for two reasons. The first of the nature of the semiconductor PN junction and results from the turn-on voltage mentioned above. This voltage enables the depletion layer to be overcome and for current to flow. The second arises from the normal resistive losses in the device. As a result a figure for the forward voltage drop are a specified current level will be given. This figure is particularly important for rectifier diodes where significant levels of current may be passed.

Particularly for power rectification diodes, a graph of the forward voltage drop for various current levels is normally provided within the data sheet. This will have a band of typical figures and using this the range of voltage drop can be determined for the anticipated current levels to be carried. It is possible to then determine the power that will be dissipated into e junction area of the diode.

Reverse breakdown voltage, $V_{(BR)R}$:

This is a little different to the peak inverse voltage in that this voltage is the point at which the diode will break down.

The diode can withstand a reverse voltage up to a certain point, and then it will breakdown. In some diodes and in some circuits it will cause irreparable damage, although for Zener / voltage reference diodes the reverse breakdown scenario is what is used for the voltage reference, although the circuit must be devised to limit the current flowing, otherwise the diode can be destroyed.



PN diode IV characteristic showing the reverse breakdown

Leakage current:

If a perfect diode were available, then no current would flow when it was reverse biased. It is found that for a real PN junction diode, a very small amount of current flow in the reverse direction as a result of the minority carriers in the semiconductor. The level of leakage current is dependent upon three main factors. The reverse voltage is obviously significant. It is also temperature dependent, rising appreciably with temperature. It is also found that it is very dependent upon the type of semiconductor material used - silicon is very much better than germanium.

The leakage current characteristic or specification for a PN junction diode is specified at a certain reverse voltage and particular temperature. The specification is normally defined in terms of in microamps, μA or picoamps, pA as the levels are normally very low before reverse breakdown occurs.

Diode – Contd.

Maximum forward current:

For an electronic circuit design that passes any levels of current it is necessary to ensure that the maximum current levels for the diode are not exceeded. As the current levels rise, so additional heat is dissipated and this needs to be removed.

Sample Industrial Data sheet:

TYPICAL 1N5711 CHARACTERISTICS / SPECIFICATIONS

CHARACTERISTIC	TYPICAL VALUE	UNIT	DETAILS
Max DC Blocking Voltage, Vr	70	V	
Max forward continuous current, Ifm	15	mA	
Reverse breakdown voltage, V(BR)R	70	V	@ reverse current of 10µA
Reverse leakage current, IR	200	µA	At VR=50V
Forward voltage drop, VF	0.41 1.00	V	at IF = 1.0 mA IF=15mA
Junction capacitance, Cj	2.0	pF	VR = 0V, f=1MHz
Reverse recovery time, trr	1	nS	

Diode – Contd.

The values of these parameters are normally provided by the manufacturers in their specification sheet.

Diodes are available in low-, medium-, and high-current ratings. Diodes of low-current ratings are used in electronic switching circuits, i.e., they work as switches. Their forward current ranges from a few mA to a maximum of 100 mA. The safe reverse bias that can be applied is around 75 V. The reverse saturation current is very small, usually less than a micro-ampere.

Medium current diodes have a maximum current rating of 400 mA and reverse voltage of about 200 V.

High-current diodes are also called *power diodes*. They are rated for high current and high reverse voltage ratings. Metal heat sinks are used for dissipation of heat produced in a diode when it is conducting.

In addition to their use in switching circuits, diodes are used in rectifier circuits for half-wave and full-wave rectification.

Light Emitting Diode

We have known that when a p–n junction is forward biased, the electrons from the n-side cross over to the p-side to recombine with the holes on the p-side.

The free electrons have higher energy than the holes. When a negatively charged electron from the n-side enters the p-side and recombines with a positively charged hole, some amount of energy is emitted in the form of heat and light. Similarly, a hole from the p-side has a tendency to cross the junction and recombine with an electron on the n-side. Each recombination causes radiation of energy in the form of heat and light. If the semiconductor material is translucent, it will emit light. LEDs are made from special semiconductor materials such as arsenide phosphide or gallium phosphide.

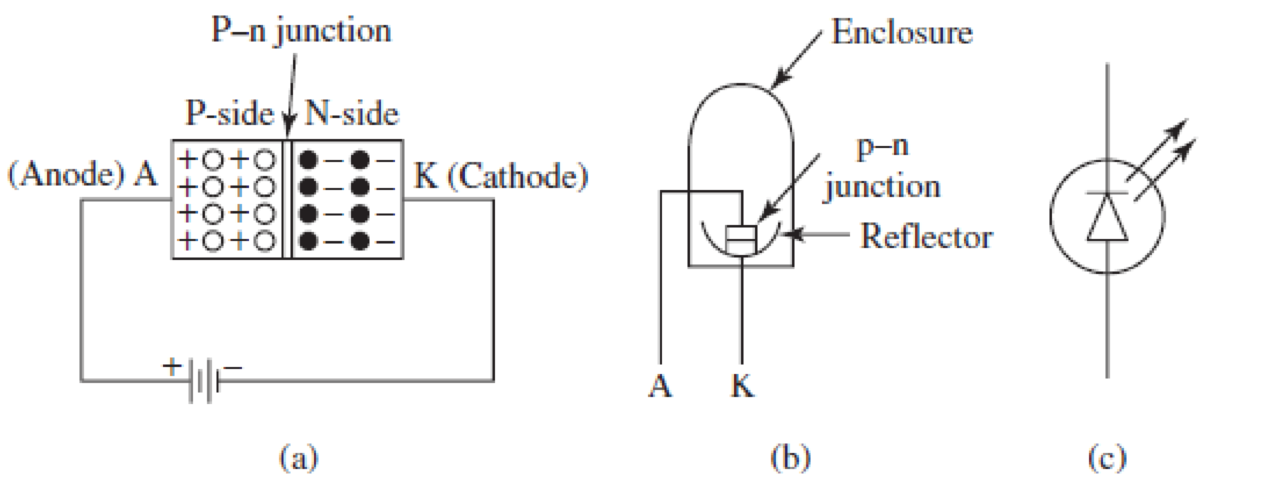
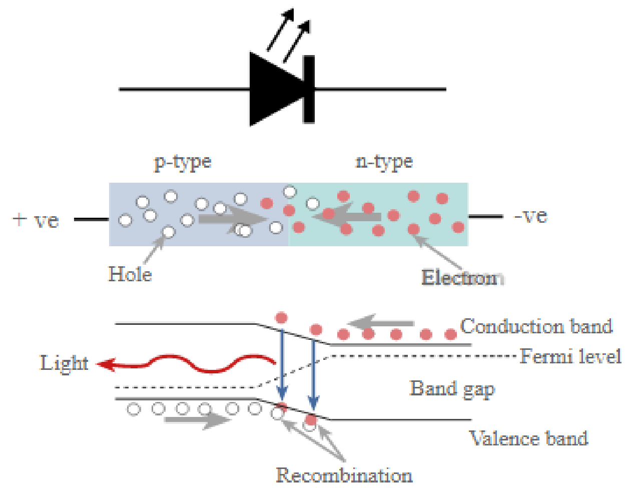


Figure 11.27 *(a) LED junction; (b) constructional details of an LED; (c) symbol of LED*



How a light emitting diode works

Light Emitting Diode

The intensity of light energy emitted from an LED will depend upon the forward voltage applied. The applied voltage is low, of the order of 1 or 2 V. An LED is a compact device which will emit a point source of light. A group of LEDs can be used to illuminate a display of numbers and alphabets. Segmented illuminated display of circuits, diagrams, photographs, etc. can be arranged with the help of an array of LEDs.

A simple on/off display using an LED is shown in Fig. 11.28. When the supply is on, the LED will get supply and will be forward biased. A resistance R is connected in series to limit the current through the LED. T is a step-down transformer. Thus, the LED will show on/off status of supply.

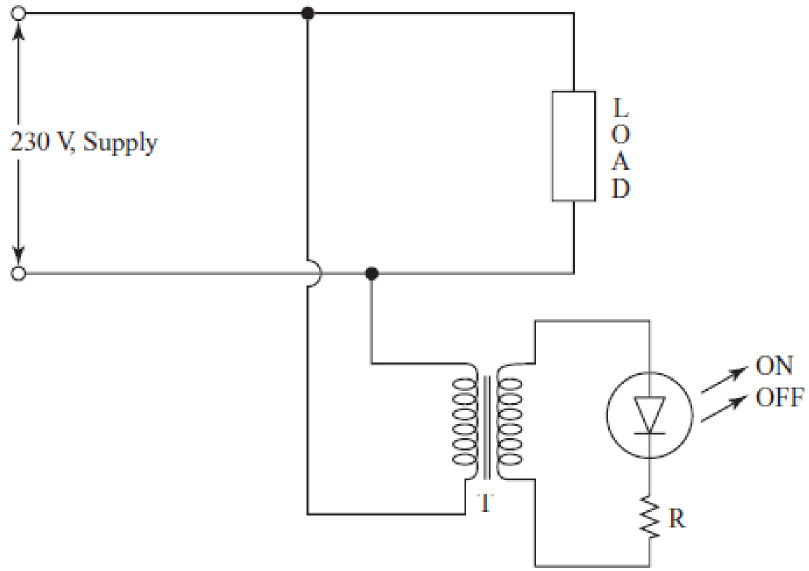


Figure 11.28 *An LED used in on/off display of power supply*

Light Emitting Diode – Contd.

There are a number of advantages of LEDs to be used in display devices. They are compact, are illuminated very quickly, light intensity in them can be controlled by varying the applied voltage, are available in different colours, are quite simple, and are cheap.

LED Industrial Data sheet Specifications:

LED colour

The colour of an LED is obviously of major importance when choosing an LED.
LEDS tend to provide what is effectively a single colour. In fact the light emission extends over a relatively narrow light spectrum.

The colour emitted by an LED is specified in terms of its peak wavelength (lpk) - i.e. the wavelength which has the peak light output. This is measured in nanometers (nm).
The colour of the LED, i.e. the peak wavelength of the emission from the LED governed mainly by the material used for the LED and also by the chip fabrication process. Variations in the process can tailor the peak wavelength variations up to figures of around ±10nm.
When choosing colours within the overall LED specification, it is worth remembering that the human eye is most sensitive to hue or colour variations around the yellow / orange area of the spectrum, i.e. between about 560 to 600 nm. Slight process variations could cause slight colour variations that could be noticeable if orange LEDs are chosen and sit next to each other on a front panel. This may affect the choice of colour, or position of LEDs if this could be a problem.

LED Industrial Data sheet Specs – Contd.

WAVELENGTH RANGE (NM)	COLOUR	VF @ 20MA	MATERIAL
< 400	Ultraviolet	3.1 - 4.4	Aluminium nitride (AlN) Aluminium gallium nitride (AlGaN) Aluminium gallium indium nitride (AlGaInN)
400 - 450	Violet	2.8 - 4.0	Indium gallium nitride (InGaN)
450 - 500	Blue	2.5 - 3.7	Indium gallium nitride (InGaN) Silicon carbide (SiC)
500 - 570	Green	1.9 - 4.0	Gallium phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP)
570 - 590	Yellow	2.1 - 2.2	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium phosphide (GaP)
590 - 610	Orange / amber	2.0 - 2.1	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaUInP) Gallium phosphide (GaP)
610 - 760	Red	1.6 - 2.0	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium phosphide (GaP)
> 760	Infrared	< 1.9	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)

LED light intensity value, Iv

The LED specification for light intensity is important. The light intensity is governed by a variety of factors including the LED chip itself (including the design, individual wafer, the materials, etc.) , the current level, encapsulation and other factors.

LED Industrial Data sheet Specs – Contd.

The LED light intensity specification is not of crucial importance for most indicator applications, but with LEDs being used for lighting, this parameter is needed to be able to specify exactly what is needed in many situations.

The light output from an LED is quantified in terms a single point, on-axis luminous intensity value (Iv). This is specified as millicandella, mcd.

The lv measurement for LEDs cannot easily be compared with the values of mean spherical candle power, MSCP used for incandescent lamps.

The luminous intensity value for an LED must be quoted for a given current. Many LEDs will operate at currents of around 20mA, but the light output of an LED increases with increasing current.

LED reverse voltage

LEDs are not tolerant to large reverse voltages. They should never be run above their stated maximum reverse voltage, which is normally quite small. If they are then permanent destruction of the device will almost certainly result.

If there is any chance of a reverse voltage appearing across the LED, then it is always best to build in protection into the circuitry to prevent this. Normally simple diode circuits can be introduced and these will adequately protect any LED.

LED angle of view specification

In view of the way in which LEDs operate, the light is only emitted over a certain angle. While this LED specification may not be important for some applications, it is of great importance for others.

LED Industrial Data sheet Specs – Contd.

The angle of view is normally defined in degrees - °. For early devices, the angle of view was normally relatively small. More recent devices may have a much wider angle of view.

LED specification for operational life

The light intensity of a LED does diminish gradually with time. This means that a LED has an operational life. This LED specification is of particular importance when a LED or LEDs are to be used for lighting applications. It is not normally as crucial when the LED is used as an indicator - here a catastrophic failure is of greater importance.

The LED specification for its operational life is generally defined in the following terms:

$L_{70\%}$ = Time to 70% of illumination (lumen maintenance)

$L_{50\%}$ = Time to 50% of illumination (lumen maintenance)

The standards state that during these times, the LED should not exhibit any major shifts in chromaticity.
The rationale behind these figures is that 70% lumen maintenance equates to a 30% reduction in light output. This is around the figure for the threshold for detecting gradual reductions in light output.
Where light output is not critical, the 50% lumen maintenance figure may be more applicable. However for applications where lights may be placed side by side any differences will be very noticeable and therefore an 80% lumen maintenance figure may be a more applicable specification.
Figures for LED operational life may be of the order of 50 000 hours or more dependent upon the lumen maintenance figure used. There is a belief that LEDs are not life'ed items, but especially where LEDs are used for lighting applications, the life of the components needs to be viewed very carefully.

LED Industrial Data sheet Specs – Contd.

These are some of the main LED specifications that are likely to be seen in the datasheets. Before choosing a particular LED it is necessary to look at all the parameters to make sure it is suitable, and allow a good margin for the spread of parameters within the specification.

BIPOLAR JUNCTION TRANSISTORS

Transistors are used in almost all electronic circuits. The ability to amplify electrical signals accounts for their wide use. The word transistor is the short form of the word "transfer resistor". The signal amplification in a transistor is achieved by transfering the signal from a region of low resistance to a region of high resistance. The concept of transfer of resistance, when viewed this way, has given the name transistor.

A bipolar junction transistor has three layers of semiconductor material. These layers are arranged either in an n–p–n sequence or in a p–n–p sequence. In an n–p–n transistor, a p-type semiconductor material is sandwiched between two n-type materials. In a p–n–p transistor, an n-type semiconductor material is sandwiched between two p-type materials.

A transistor, in general, has two p–n junctions connected back to back as shown in Fig. 11.14. As shown in the figure, the central layer is called the *base*, one of the outer layers is called the *emitter*, and the other is called the *collector*.

The basic principle of transistor operation is that a small current in the base region can control a much larger current flow through the transistor, i.e., from the emitter to the collector. A transistor can be used as current amplification or a voltage amplification device. Since a transistor combines two junction diodes, it works on the basis of p–n junction theory as has already been explained.

The symbolic representation of a transistor has also been shown. The symbol for an n–p–n or a p–n–p transistor is the same except for the direction of the arrow head. The arrow head has to be shown from p terminal to n terminal between the emitter and the base. The emitter of a transistor is heavily doped. The base is lightly doped while the collector is less heavily doped than the emitter.

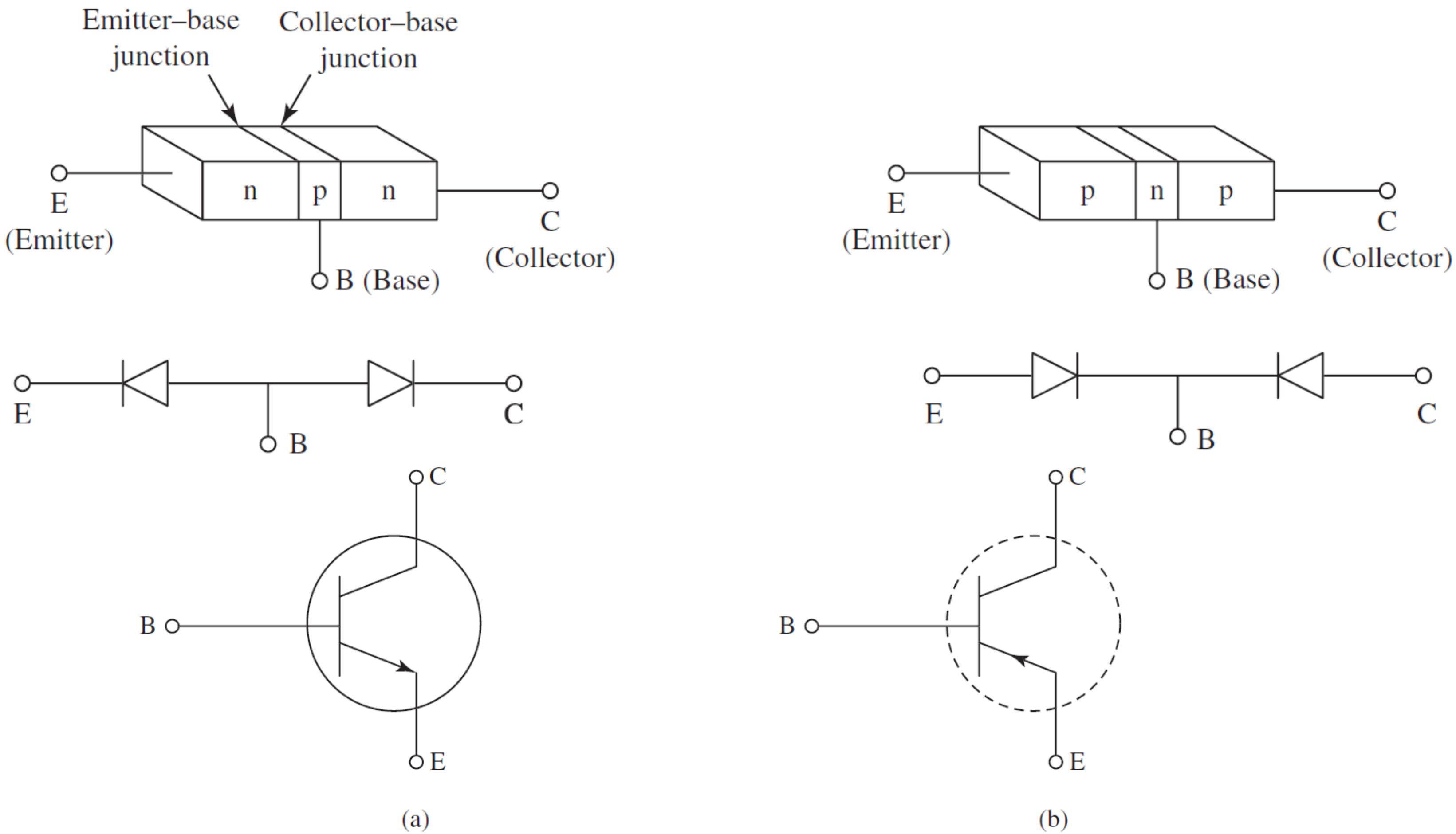


Figure 11.14 *(a) Block representation, two-diode transistor analogy, and symbol of a n–p–n transistor; (b) block representation, two-diode transistor analogy, and symbol of a p–n–p transistor*

Working of an n–p–n Transistor

For a transistor to work, it has to be biased by applying external voltage supply with proper polarity. For operation in the active region, a transistor's emitter–base junction must be forward biased while the collector base region reverse biased as shown in Fig. 11.15 (a) and (b).

The forward bias of the EB junction reduces the width of the depletion region and the barrier voltage gets reduced.

The reverse bias of the CB junction increases the width of the depletion region and the barrier voltage gets increased.

Since the EB junction is forward biased, electrons form the majority charge carriers and would flow from the emitter to the base region. Since the base is lightly doped, there will be a smaller number of holes present there. Only a small percentage of electrons from the emitter will recombine with holes in the base region. Only around two per cent of the electrons from the emitter recombine with the holes that are present in base region. The reverse bias of the CB junction causes expansion of the depletion layer. The width of the base region is thinner than the collector region. Therefore, the depletion region will penetrate deep into the base region. The electrons from the emitter region will arrive near the CB depletion region. Due to large CB bias voltage, electrons will be pulled across the CB junction by the positive terminal of the collector. The collector thus collects the 98 per cent of the electrons emitted by the emitter.

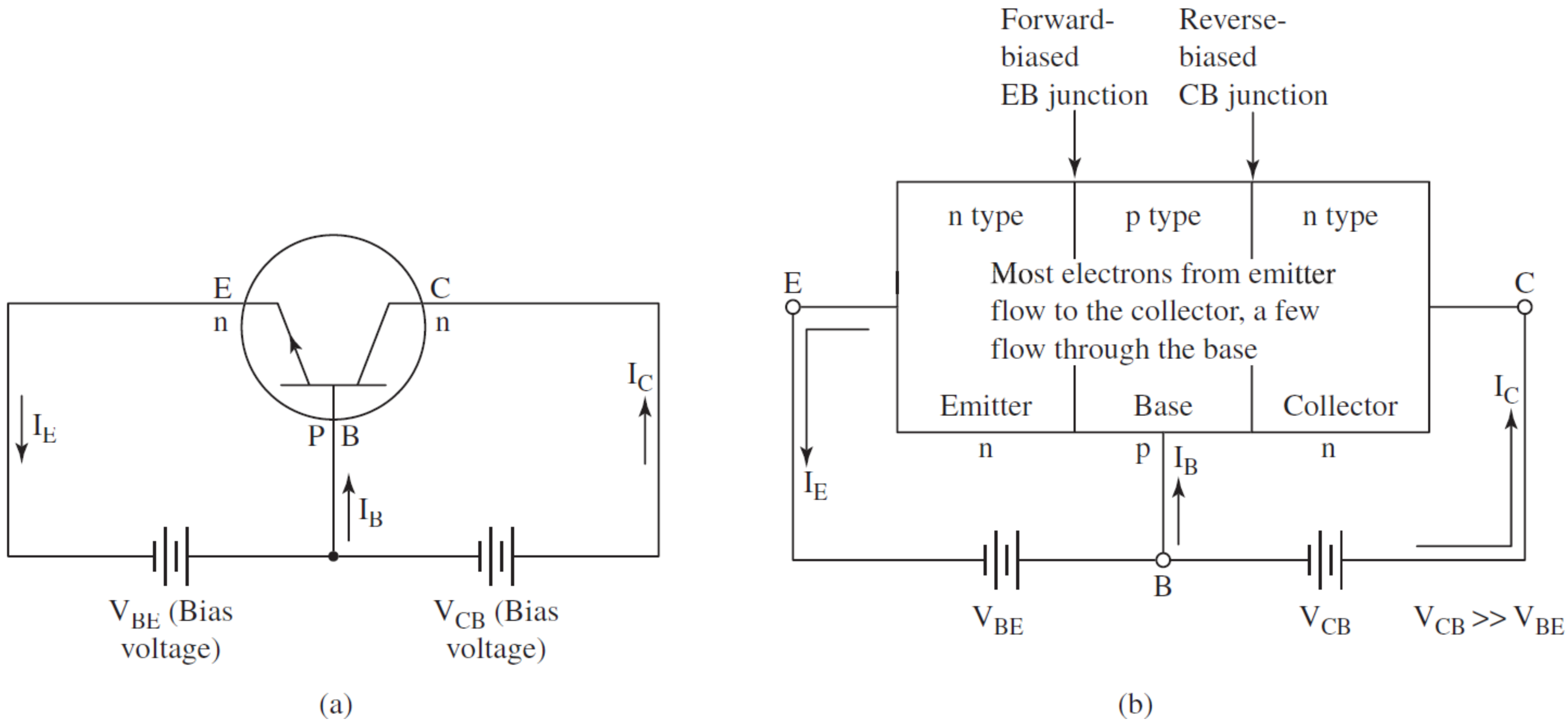


Figure 11.15 *(a) Biasing of a n–p–n transistor for normal operation; (b) operation of a n–p–n transistor*

The quantity of charge carriers crossing the emitter to the base in controlled by the base–emitter bias voltage. Thus, it can be said that emitter and collector current levels can be controlled by the base–emitter bias voltage. Note that the conventional direction of current flow i.e., the directions of emitter current, I_E, base current, I_B and collector current, I_C have been shown opposite to the direction of flow of charge carriers.

Note that for a silicon transistor, substantial current will start flowing only when the bias voltage V_{BE} is about 0.7 V and for the germanium transistor V_{BE} is 0.3 V. Beyond this voltage, a small variation of V_{BE} will control I_E and I_C, and V_{BE} has to supply only a small I_B.

To sum up, the following statements can be made for the operation of a n–p–n transistor:

(i) The outer layers of n–p–n transistors are called emitter and collector, respectively, the central layer is called the base.

(ii) The base–emitter junction, EB is forward biased and the collector–base junction is reverse biased, and V_{CB} is higher than V_{BE}.

(iii) The base section is made very thin and is lightly doped so that majority of the charge carriers (electrons in n–p–n transistor) can move from the emitter to the collector.

(iv) Most charge carriers flow from emitter to collector and only a small percentage flow through the base material.

(v) Variation of base–emitter voltage changes base, emitter, and collector currents.

Working of a p–n–p Transistor

The p–n–p transistors work the same way as n–p–n transistors except that in p–n–p transistors the majority charge carriers are holes. The biasing is same as that of a n–p–n transistor. The emitter-base junction is forward biased and the collector–base junction is reverse biased as shown in Fig. 11.16.

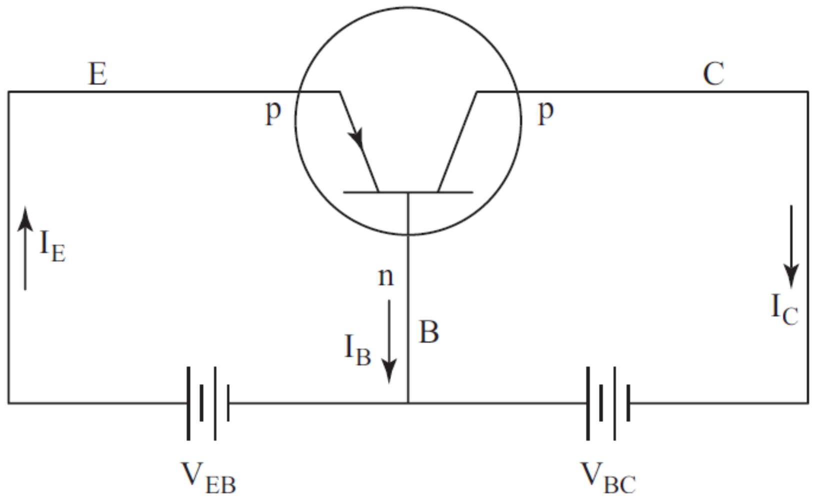


Figure 11.16 *P–n–p transistor*

The majority charge carriers from the emitter are the holes. As the base is thin and lightly doped only a small percentage of holes emanating from the emitter recombine with electrons in the base region. The rest of the holes, which are nearly 98 per cent, cross the base–collector barrier potential, because they are attracted by the negative terminal of the base–collector bias voltage.

Thus, holes are emitted from the p-type emitter across the forward-biased emitter–base junction and only a few of them find electrons in the base region to recombine with. Most of the holes get attracted to the collector side by the reverse-biased collector–base junction.

By varying the forward bias voltage at the base–emitter junction, we can control the large emitter and collector current through small variations of base current.

Both n–p–n and p–n–p type of transistors are called bipolar junction transistors, or simply BJTs because the charge carriers for both types of transistors are electrons, and holes, although for n–p–n transistors the majority charge carriers are electrons and for p–n–p transistors the majority charge carriers are the holes.

When both junctions of a transistor are reverse biased, the transistor is said to be cut off and operating in the cut-off region.

The ratio of the collector current to the emitter current of a transistor is called α_{dc} which is greater than 0.95. We can express

$$I_E = I_C + I_B \qquad \text{(i)}$$

and $$IC = \alpha_{dc}\, I_E \text{ neglecting the reverse saturation current} \qquad \text{(ii)}$$

Therefore, $$I_B = (1 - \alpha_{dc})\, I_E \qquad \text{(iii)}$$

where α_{dc} is the emitter to collector current gain.

The value of alpha dc (α_{dc}) is normally 0.95 to 0.99. As the collector–base junction is reverse biased, a small reverse saturation current flows across the junction due to minority charge carriers which are very small in number, and can be neglected.

From eqs. (i) and (ii)

$$I_C = \alpha_{dc} I_E = \alpha_{dc}\left(I_C + I_B\right)$$

or,

$$I_C(1 - \alpha_{dc}) = \alpha_{dc} I_B$$

or,

$$I_C = \frac{\alpha_{dc}}{1 - \alpha_{dc}} I_B \qquad \text{(iv)}$$

or,

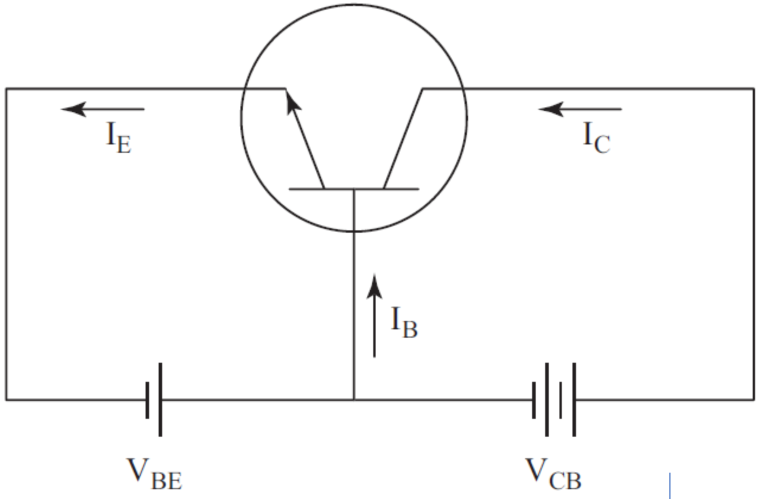
$$I_C = \beta_{dc} I_B \qquad \text{(v)}$$

where

$$\beta_{dc} = \frac{\alpha_{dc}}{1 - \alpha_{dc}}$$

Beta dc (β_{dc}) is called the base to collector current gain. This is the ratio of I_C and I_B. The value of β_{dc} varies from 25 to over 200.

Example An n–p–n transistor has been shown provided with biasing voltage V_{BE} and V_{CB}. Calculate the values of I_C and I_E if α_{dc} is 0.96 and I_B is 80 μA. Also calculate the value of β_{dc}.



Solution: Given $\alpha_{dc} = 0.96, I_B = 80\times10^{6}$ A

$$\beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}} = \frac{0.96}{1-0.96} = \frac{0.96}{.04} = 24$$

$$I_C = \frac{\alpha_{dc}}{1-\alpha_{dc}} I_B = \frac{0.96}{1-0.96}\times80\times10^{-6} = 1.92 \text{ mA}$$

Again,

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

$$I_E = \frac{I_C}{\alpha_{dc}} = \frac{1.92}{0.96}\text{mA} = 2 \text{ mA}$$

Transistor Configurations

A transistor has three terminals. For the connection of input and output, one of the transistor terminals is made common, e.g., the base terminal can be made common to both input and output terminal connections. Similarly, the emitter or the collector can be connected in common configurations. That is how we get three types of configurations, namely (i) common-base configuration; (ii) common-emitter configuration; and (iii) common-collector configuration.

These three types of connections can be made for both n–p–n and p–n–p transistors.

Each type of configuration has its advantages and disadvantages. These configurations have been illustrated in Fig. 11.18. The common emitter configuration is widely used because of its very high voltage and power gain. Discussions will therefore be restricted to the common emitter configuration of a transistor. The characteristics of a transistor in the common emitter configuration is discussed as follows.

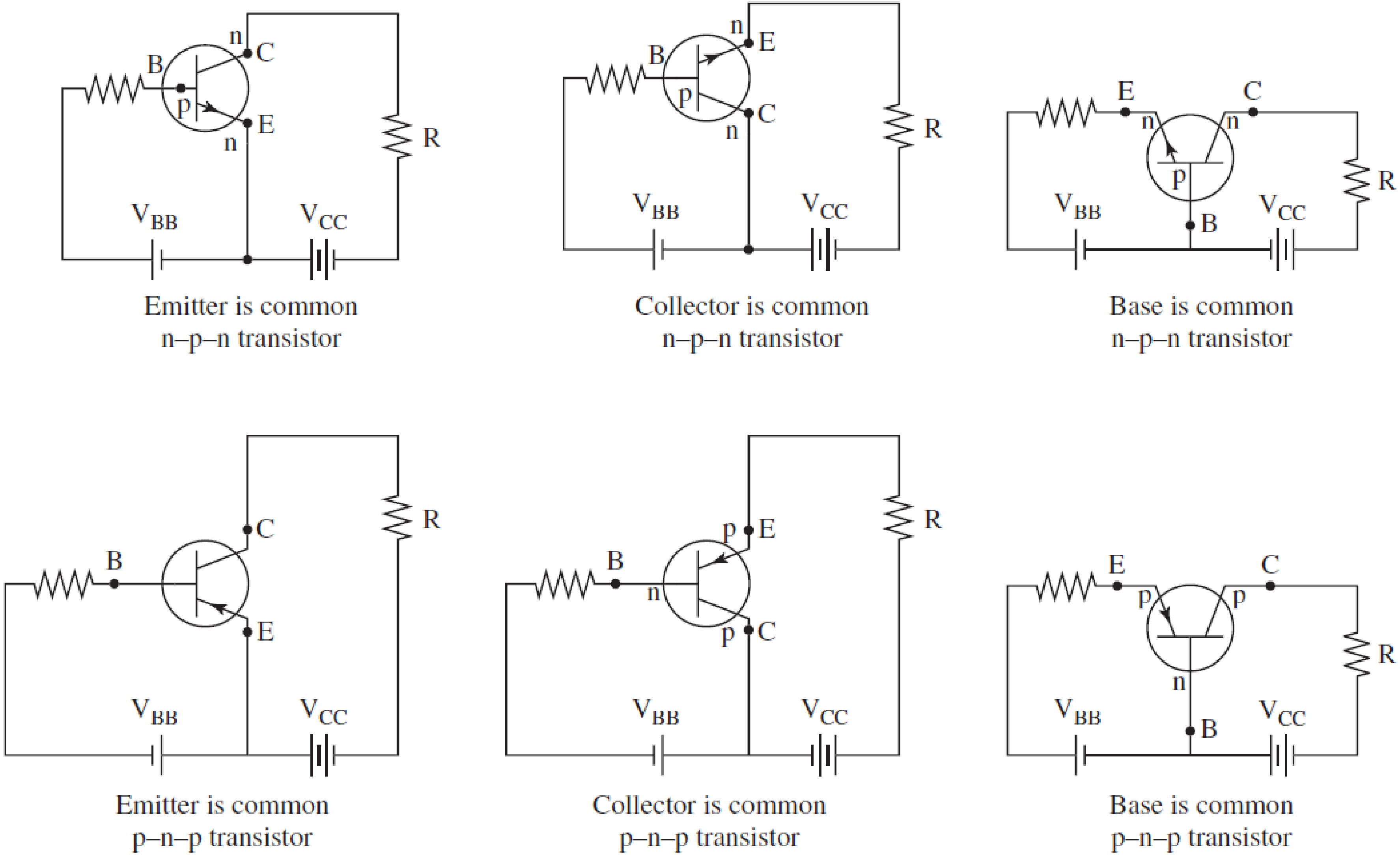


Figure 11.18 *Common-emitter, common-collector, and common-base configurations of n–p–n and p–n–p transistors*

Common-emitter transistor characteristics

The circuit diagram for determining the common-emitter transistor characteristics has been shown in Fig. 11.19. In this p–n–p transistor, input voltage is applied between the base and the emitter terminals. The output is taken from the collector and the emitter terminals as has been shown. The emitter terminal is common to both input and output. That is why this connection is called the common-emitter configuration.

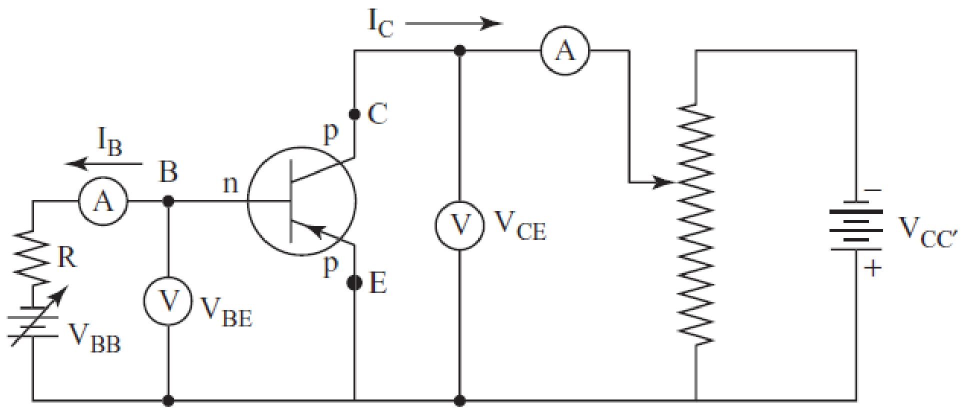


Figure 11.19 *Circuit diagram for determining the common-emitter transistor characteristics*

The input characteristic is drawn between V_{BE} and I_B. To draw the input characteristic, the voltage between the collector and the emitter, i.e., V_{CE} is kept constant at a value. By changing V_{BE} through V_{BB}, current I_B is recorded for atleast, say five readings. A plot of I_B against V_{BE} when made shows that the characteristic is similar to the characteristic of a forward-biased p–n junction. The value of I_B is very small, is of the order of several microamperes only.

The output characteristics are drawn between I_C and V_{CE} keeping I_B constant at different values. For each value of I_B, V_{CE} is adjusted in steps and the values of I_C are recorded. The values of I_C are plotted against V_{CE} for each value of I_B as shown in Fig. 11.20. Fig. 11.20 (a) shows the input characteristic and Fig. 11.20 (b) shows the output characteristics.

From the characteristics, it is seen that for a small change in base current (in μA) there is a large change (in mA) in collector current and emitter current. The *current gain* from the base to the collector can be stated as

$$\beta_{dc} = \frac{\Delta I_C}{\Delta I_B}$$

Thus, the transistor can be used as a current-amplication device.

The *voltage gain*, A_V of the transistor is defined as the ratio of output voltage to input voltage.

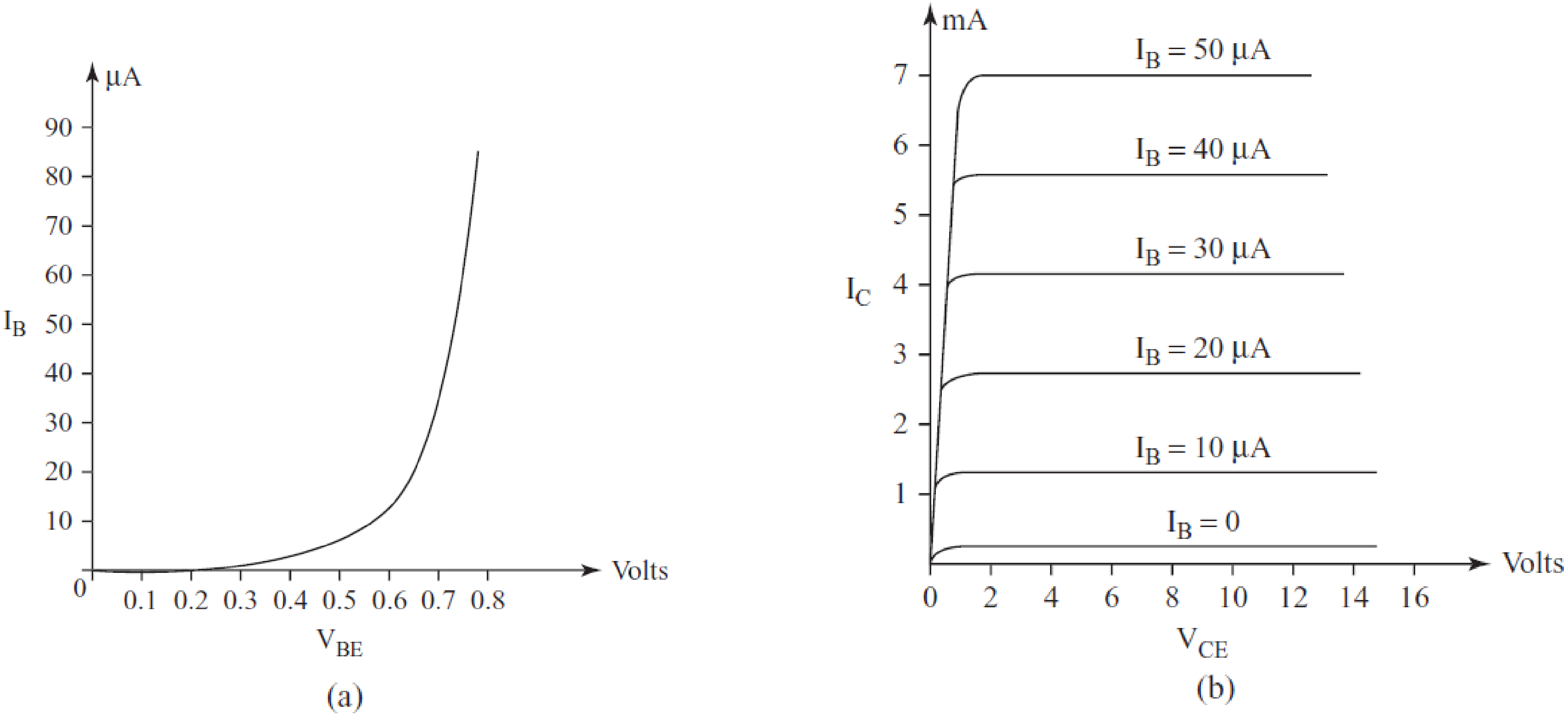


Figure 11.20 *(a) Common-emitter input characteristics; (b) common-emitter output characteristics*

Transistor as an Amplifier

In Fig. 11.21 is shown a simple transistor amplifier circuit using an n–p–n transistor connected in the common-emitter configuration. The ac signal which is to be amplified is connected to the base circuit as shown. The output is taken across a resistance, R_L in the collector circuit. The base circuit dc voltage, V_{BB} is such that the base will always remain positive irrespective of the magnitude of the input ac signal. The voltage, V_{BE} is the summation of dc voltage V_{BB} and the ac input signal, V_i. The dc voltage, V_{BB} is the bias voltage. The magnitude of V_{BB} must be higher than the maximum value of the input signal. Then, only the base will always remain positively biased in both half cycles of the input voltage. When the ac signal is applied, this becomes superimposed on the battery voltage, V_{BB} and the base current I_B will flow, which is the sum of the dc base current and the ac current. It can be observed that I_B is always positive.

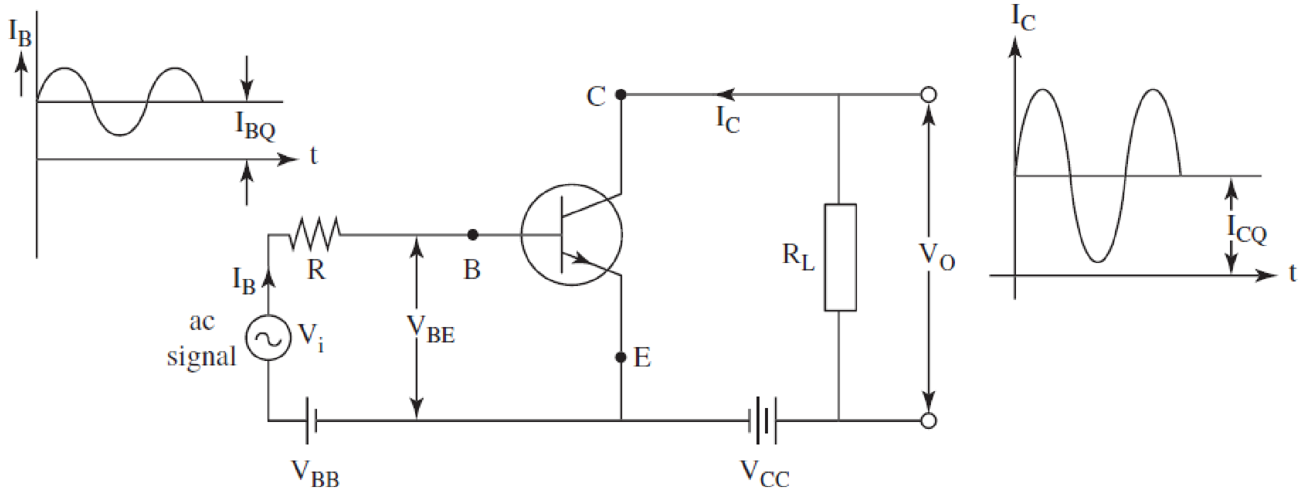


Figure 11.21 *Transistor as an amplifier*

During the positive half cycle of the input signal, the dc and ac voltages are added up and as such the base current is highly positive. During the negative half cycle, ac voltage is subtracted from the dc voltage. The net voltage is low but positive. The base current now will be positive but low.

Because of the large variation in the base current there will be a large variation in the collector current, which will flow through the load resistance. An amplified output voltage is thus available across the load. The amplified collector ac current is superimposed on the dc current, I_{CQ} which will flow through the collector when the ac input signal is not applied. It is the current when the base current is I_{BQ}.

Example In an n–p–n transistor in the common emitter configuration, an ac input signal of ±40 mV is applied as shown in Fig. 11.22. The dc current gain, β_{dc} and ac current gain β_{ac} are given as 80 and 100, respectively. Calculate the voltage amplification, A_V of the amplifier. The I_B versus V_{BE} characteristic is such that for $V_B = 0.7$ V, $I_B = 12$ μA and for $V_i = \pm 40$ mV, $I_b = \pm 4$ μA. Also calculate the dc collector voltage.

Solution:

DC base current, $I_B = 12$ μA for dc voltage, $V_{BB} = 0.7$ V and $\beta_{dc} = 80$

$$I_C = \beta_{dc} I_B = 80 \times 12\ \mu A = 0.96\ mA$$

The collector voltage V_{CE} is calculated as

$$V_{CE} = V_{CC} - I_C R_L$$
$$= 20 - 0.96 \times 10^{-3} \times 12 \times 10^3$$
$$= 20 - 11.52$$
$$= 8.48\ V$$

AC base current, $I_b = \pm 4$ μA for $V_i = \pm 40$ mV

$$I_C = \beta_{ac} I_b = 100 \times (\pm 4\ \mu A) = \pm 400\ \mu A$$

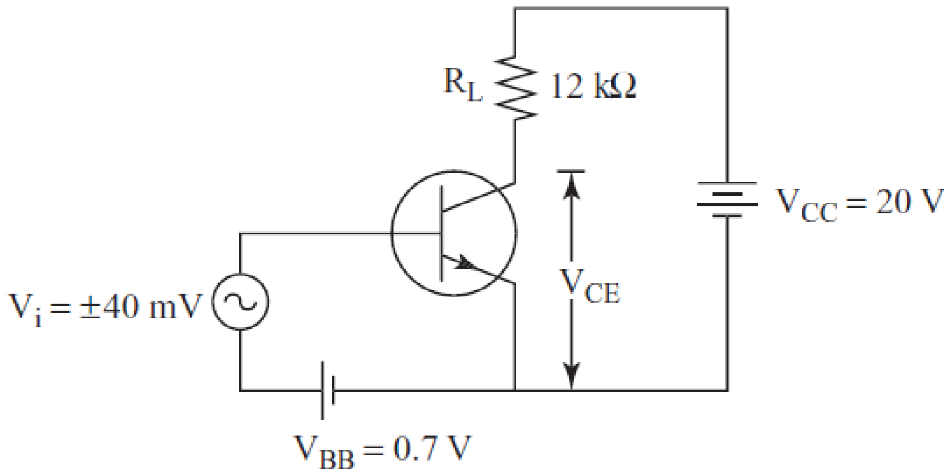


Figure 11.22 *Transistor amplifier circuit*

AC output voltage across load resistance, V_0 is calculated as

$$V_0 = I_C R_L = \pm 400 \times 10^{-6} \times 12 \times 10^3 = \pm 4.8\ \text{V}$$

AC voltage amplification factor, A_V is calculated as

$$A_v = \frac{v_0}{v_i} = \frac{\pm 4.8\ \text{V}}{\pm 40\ \text{mV}} = \frac{\pm 4.8}{\pm 40 \times 10^{-3}} = 60$$

Transistor as a Switch

A BJT can be used as an amplifier and also as a switch. A switch either closes a circuit or opens a circuit. There are two states for a switch, i.e., either there is no current flow (cut off) or the switch is closed, i.e., current flows through it with the minimum of resistance offered.

These two conditions can be created by applying a pulse wave input to the base of the BJT. In the case of an amplifier we had applied a bias voltage plus an ac signal that had to be amplified to the base circuit. In the case of switching operation, a pulse voltage of appropriate level has to be applied as shown in Fig. 11.23 (a) and (b).

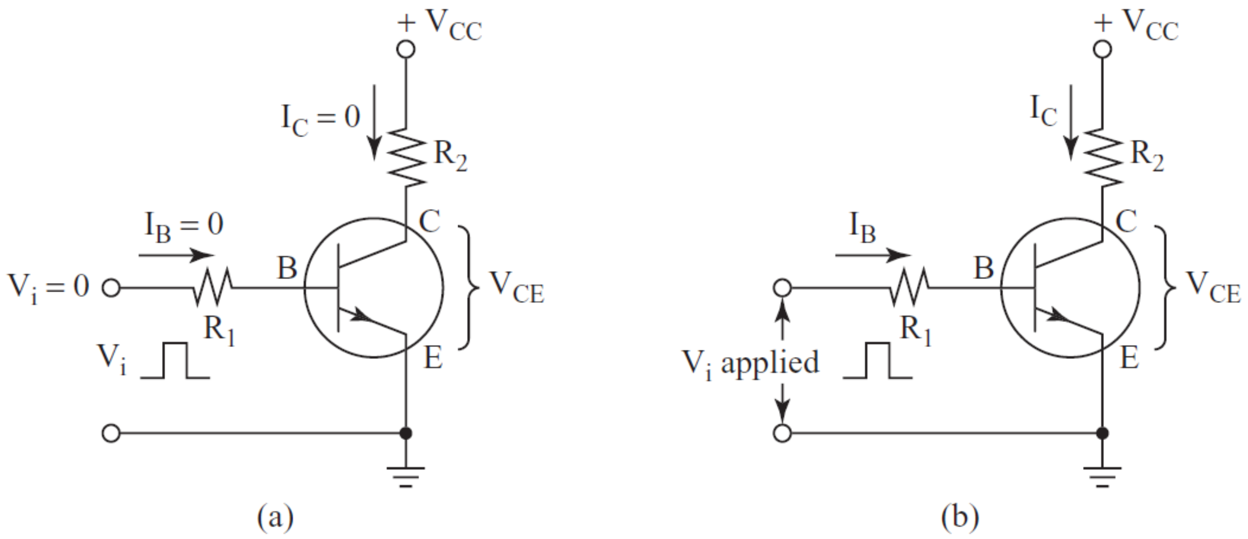


Figure 11.23 *(a) Off state of a BJT; (b) on state of a BJT*

The base voltage level is either at zero level or at an appropriate positive level. When the input voltage, V_i is at zero level, the base current is zero and there is no collector current, i.e., $I_C = 0$ as shown is Fig. 11.23 (a).

The transistor is cut off and works like an open switch.

From Fig. 11.23

V_{CE} = Supply voltage – voltage drop across R_2

$V_{CE} = V_{CC} - I_C R_2$

When the base-emitter voltage is at zero level, the transistor is not working, and hence, $I_C = 0$. Therefore,

$$V_{CE} = V_{CC}$$

When V_i is at positive level, base current, I_B will flow. If the BJT is to be used as a switching device, the level of I_B is made high enough so that the transistor is saturated. At saturated state the level of I_C will be such that $I_C R_2$ will be equal to V_{CC} for which $V_{CE} = 0$. The transistor will operate as a closed switch between the collector and emitter.

Example What minimum input voltage level is required to switch a BJT into saturation (on state) when $V_{CC} = 10$ V, $R_1 = 16$ kΩ, $R_2 = 6.2$ kΩ and $\beta_{dc} = 20$ in an n–p–n CE configuration BJT.

Solution:

$$V_{CC} = I_C R_2 + V_{CE}$$

for $V_{CE} = 0$

$$I_C = \frac{V_{CC}}{R_2} = \frac{10}{6.2 \times 10^3} = 1.612 \text{ mA} = 1612\ \mu\text{A}$$

$$I_C = \beta_{dc} I_B$$

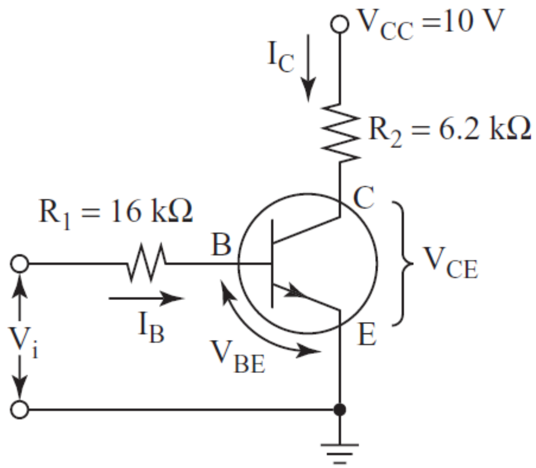


Figure 11.24

or,
$$I_B = \frac{I_C}{\beta_{dc}} = \frac{1612}{20} = 80.6\ \mu\text{A}$$

Taking $V_{BE} = 0.7$ V,
$$V_i - I_B R_1 = V_{BE}$$

or,
$$V_i = V_{BE} + I_B R_1$$
$$= 0.7\text{V} + 80.6 \times 10^{-6} \times 16 \times 10^3 \text{ V}$$
$$= (0.7 + 1.29) \text{ V} = 1.99 \text{ V}$$

Transistor specification parameters

There are a number of standard parameters with abbreviations that are used to define the performance of a transistor. The definitions of these parameters are outlined in the table below:

Type number: The type number of the device is a unique identifier given to each type of transistor. This enables the full data on its specifications to be checked on the manufacturers transistor datasheet to investigate its performance.

There are three international schemes that are widely used: European Pro-Electron scheme; US JEDEC (numbers start with 2N for transistors); and the Japanese system (numbers start with 2S).

Apart from just giving a standardised type number to the transistors, these schemes can provide information about the transistor performance. The European Pro-Electron scheme is particularly good for this as it distinguishes between different types of transistor, for example a BC109 is a silicon audio frequency low power transistor, and a BFR90 is a low power RF transistor.

Polarity: There are two types of transistor: NPN transistors and PNP transistors. It is important to choose the correct type otherwise all the circuit polarities will be wrong.

The NPN transistors are more widely used. Like for like they offer better performance than PNP transistors because electrons are the majority carriers and their mobility is higher than that of holes which are the majority carriers in PNP transistors. The basic circuits for NPN transistors also fit well with the negative earth normally used in DC systems.

Transistor specification – Contd.

Material: One key transistor specification which will be given for any transistor is the material from which t is manufactured. The main type of material used for semiconductor devices is silicon.

Although other materials like germanium and gallium arsenide are available, silicon is the most popular because it is cheaper to process and in addition to this, the processes are more advanced than for other materials. As it is used for many other semiconductor devices, there are many benefits of scale and technology available.

Silicon offers good overall performance with a base emitter junction turn on voltage of around 0.6 volts - it is 0.2 to 0.3 volts for germanium.

V_{CBO}: This parameter is the collector to base breakdown voltage of a bipolar transistor. It is the maximum collector base voltage - again it is generally measured with the emitter left open circuit. This value should not be exceeded in the operation of the circuit.

This parameter is important because some leakage current will flow between collector and base, causing the part to heat up. Alternatively excessive voltage can damage the collector base junction. As terminal damage can occur to the bipolar transistor, this rating should not be exceeded and ideally the transistor should be run with a good margin in hand.

In operation the collector-base junction is reverse biassed, and a small reverse current will flow (I_{CBO}. As the reverse voltage is increased the electric field in the depletion region of the collector base junction increases, and the reverse current starts to rise as minority carriers gain sufficient energy to generate hole electron pairs which then increase the reverse current. Eventually avalanche breakdown occurs. This limits the maximum voltage that can be applied to the transistor.

Transistor specification – Contd.

V_{CBO} is typically higher than V_{CEO} because with the base terminal of the BJT open, any leakage current will also be the same as externally applied base current, and this is amplified by the transistor. This will cause even more current to flow through the device, heating it up and for this reason, V_{CEO} is often lower than V_{CBO}.

V_{CEO}: Collector to Emitter breakdown voltage. This transistor specification is the maximum voltage that can be placed from the collector to the emitter. It is normally measured with the base open circuit - hence the letter "O" in the abbreviation. During the electronics circuit design stage it is essential to ensure that this value is not be exceeded in operation, otherwise damage may occur. Ideally the transistor should be operated with a good margin in hand.

Often the maximum voltage should only be allowed to rise to 50 or 60% of the maximum value for reliable operation. Note that for circuits using inductors in the collector circuit, the collector voltage may rise to twice the rail voltage.

If the voltage applied between the collector and emitter terminals is high, and increased number of carriers start to diffuse into the collector region from the base. This causes the base emitter diode in the bipolar transistor to start to become forward biassed, and this causes current to flow between the collector and emitter, even though no external base current has been applied. When a certain voltage, V_{CEO}, is reached the transistor can fully turn on, and in some cases this can result in terminal damage to the device.

I_C: The collector current specification of the transistor is normally defined in milliamps, but high power transistors may be quoted in amps. The important parameter is the maximum level of collector current. This figure should not be exceeded otherwise the transistor may be subject to damage.

Transistor specification – Contd.

V_{CEsat}: The collector emitter saturation voltage, i.e. the voltage across the transistor (collector to emitter) when the transistor is turned hard on. It is normally quoted for a particular base and collector current values.

Under these circumstances the voltage between the collector and emitter is smaller than that across the base emitter junction - often it is around 0.2 volts.

h_{FE} & h_{fe}: This is the current gain for a transistor expressed as an h parameter or hybrid parameter. The letter "f" indicates that it is a forward transfer characteristic, and the letter "e" indicates it is for a common emitter configuration. The value for h_{fe} is approximately the same as β.

Two versions of this parameter are seen: h_{FE} refers to the parameter measured under DC conditions, whereas h_{fe} refers to the parameter for AC signals.

FT: Frequency Transition - this transistor specification details the frequency where current gain falls to unity. The transistor should normally be operated well below this frequency.

P_{tot}: Total power dissipation for the device. It is normally quoted for an ambient external temperature of 25°C unless other wise stated. The actual dissipation across the device is the current flowing through the collector multiplied by the voltage across the device itself.

Transistor specification – Contd.

Package type: Transistors can be mounted in a variety of packages according to their applications. There are the standard leaded devices that appear in a variety of packages - these packages normally conform to JEDEC standards and start with the letters TO, standing for transistor outline. This is followed by a hyphen and a numeral which is typically up to three digits.

Popular leaded component sizes include TO5 (metal case, cap diameter of 8.1 mm), TO18 (metal case with cap diameter of the cap is 4.5-4.95mm) and TO92 (also known as SOT54, plastic case off varying sizes but straight line lead spacing of 1.27mm).

Surface mount transistors, SMD transistors are used in vast quantities because most electronics manufacture and PCB assembly is undertaken using automated techniques and surface mount technology lends itself to this. Popular sizes include the SOT-23 and SOT-223 outlines.

Transistor coding and markings schemes: Most transistors that are used have part numbers that conform to the JEDEC or Pro-Electron schemes. Numbers like BC107, BC109, 2N2222A and many more are very familiar to anyone involved in electronics design and manufacture.
However when using automated PCB assembly techniques and surface mount devices, it is found that many transistors are too small to carry the full number that might be used in a data sheet. As a result, a rather arbitrary coding system has developed, whereby the device package carries a simple two or three character identification code.

This can normally be accommodated on the small surface mount diode packages. However, identifying the manufacturers' type number of an SMD diode from the package code may not be easy at first sight. There are some useful SMD codebooks available that provide the data for these devices.

Transistor specification – Contd.

There are many different elements to transistor specifications, both both leaded and surface mount transistors. To meet the demand for electronics manufacture there is a huge variety of transistors from which to choose. However it is still relatively easy to choose a transistor when using a basic knowledge of the different transistor specifications and parameters.

For general purpose applications many transistors will suffice, but for more specialised applications it is essential to select the right type of transistor.

Industrial Data Acquisition System

- Introduction to DAS
- Objectives of a DAS
- Block diagram and explanation
- Methodology
- Hardware and software for DAS
- Merits and Demerits of DAS/DQS
- Conclusion

Introduction

- DATA ACQUISITION is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer.

- Data acquisition systems (abbreviated with the acronym DAS or DAQ) typically convert analog waveforms into digital values for easy processing.

Introduction – Contd.

- **DAQ systems capture, measure, and analyze physical phenomena from the real world.**

- **Light, temperature and pressure are examples of the different types of signals that a DAQ system can measure.**

- **Data acquisition is the process of collecting and measuring electrical signals and sending them to a computer for processing.**

- **• Electrical signals comes from Transducers.**

Components of DAS

The components of data acquisition systems include:

- Sensors that convert physical parameters to electrical signals.
- Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values.
- Analog-to-digital converters, which convert conditioned sensor signals to digital values.

Components of DAS

1. **Transducer or Sensors**: A device that converts a physical phenomenon such as light, temperature, pressure, or sound into a measurable electrical signal such as voltage or current.

2. **Signal**: The output of the transducer.

3. **Signal conditioning**: Hardware that you can connect to the DAQ device to make the signal suitable for measurement or to improve accuracy or reduce noise.

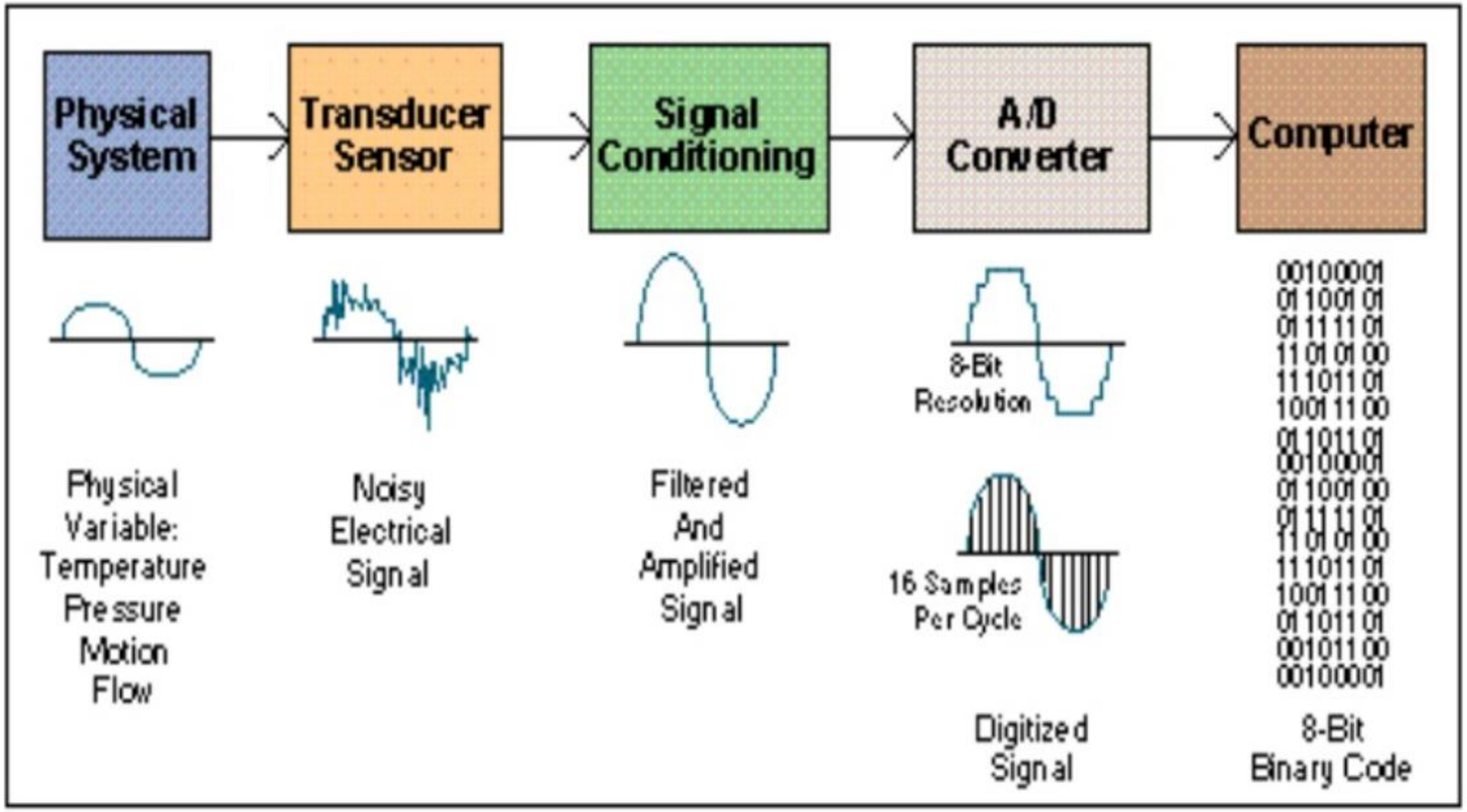
4. **DAQ hardware**: Hardware you use to acquire, measure, and analyze data.

5. **Software**: Application software is designed to help you easily design and program your measurement and control application.

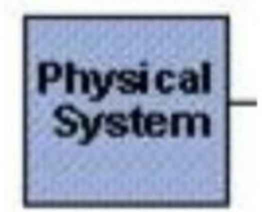
Objectives of DAS

- DAS must acquire the necessary data, at correct speed and at correct time.
- It must monitor the complete plant operation to maintain on line and safe operations.
- It must be able to collect, summarise and store data for diagnosis of operation and record purpose.
- It must be flexible and capable of being expanded for future requirements.
- It must be able to compute unit performance indices using on-line, real time data.
- It must be reliable, easy to operate and must be user friendly.

Block Diagram

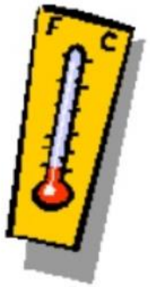


Physical Systems / Conditions



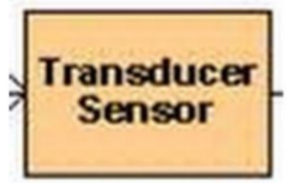
Physical condition that can be used as input of DAS or which can be represented in Digital form are as under…

- Temperature
- Pressure
- Light
- Force



- Displacement
- Level
- Electric signals
- ON/OFF switch

Transducers - Sensors



- A transducer converts temperature, pressure, level, length, position, etc. into voltage, current, frequency, pulses or other signals.
- A transducer thus converts the physical conditions in electrical waveform for easy signal processing

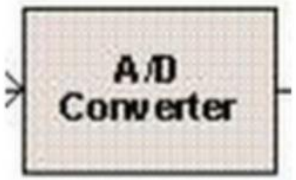
Common Transducers

Sensor	Physical Variable
Accelerometer	Acceleration
Microphone	Pressure
Pressure gauge	Pressure
Resistive temperature device (RTD)	Temperature
Strain gauge	Force
Thermocouple	Temperature

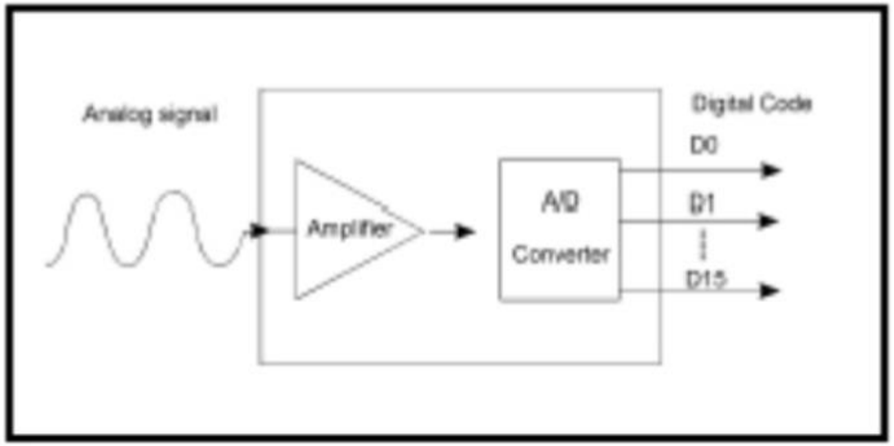
Signal Conditioning

- Signal conditioning circuits improve the quality of signals generated by transducers before they are converted into digital signals by the PC's data-acquisition hardware.
- Most common signal conditioning functions are amplification, linearization, cold-junction compensation, filtering, attenuation, excitation, common-mode rejection, and so on.
- Sensor signals are often incompatible with data acquisition hardware. To overcome this incompatibility, the sensor signal must be conditioned.

Analog / Digital Converter



- Analog to digital (A/D) conversion changes analog voltage or current levels into digital information. The conversion is necessary to enable the computer to process or store the signals.



What type of device to be used?

- The trade-off usually falls between

  1- Resolution (bits)

  2- Sampling rate (samples/second)

  3- Number of channels, and data transfer rate (usually limited by “bus” type: USB, PCI, PXI, etc.)

Resolution

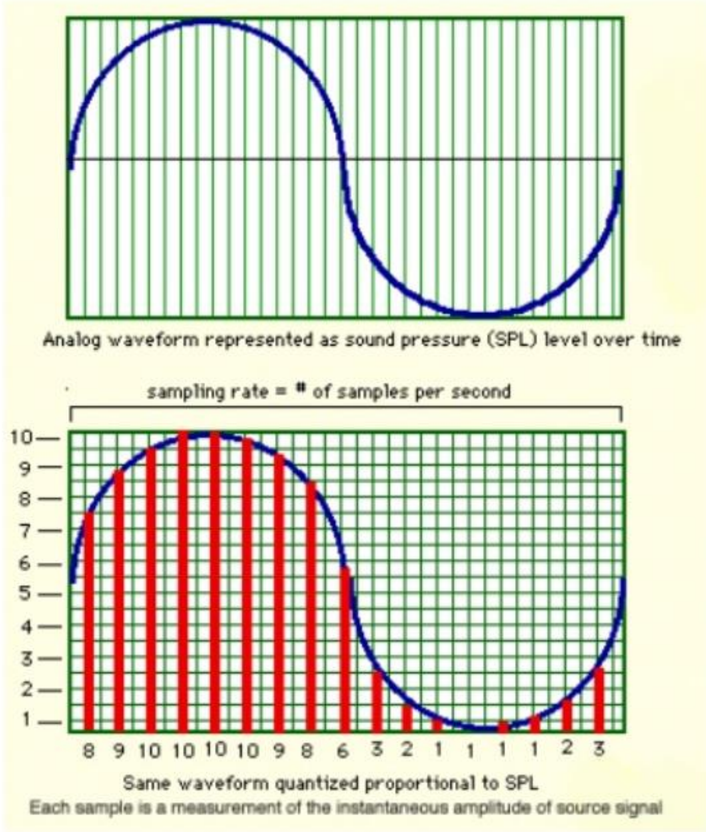
- Precision of the analog to digital conversion process is dependent upon the number (n) of bits the ADC of the DAQ uses.

- The higher the resolution, the higher the number of divisions the voltage range is broken into (2^n), and therefore, the smaller the detectable voltage changes.

- An 8 bit ADC gives 256 levels (2^8) compared to a 12 bit ADC that has 4096 levels (2^{12}).

Sampling Rate

- The data is acquired by an ADC using a process called sampling.
- Sampling an analog signal occurs at discrete time intervals.
- The rate at which the signal is sampled is known as the sampling frequency.



Methodology

- DAS begins with the physical property to be measured. Examples of this include temperature, light intensity, gas pressure, fluid flow, force etc.
- A sensor, which is a type of transducer converts a physical property into a corresponding electrical signal
- Signal conditioning may be necessary if the signal from the transducer is not suitable for the DAQ hardware being used.
- After signal conditioning the analog wave output is converted into digital form using A/D converter.
- Once digitized, the signal can be encoded to reduce and correct transmission errors.
- This whole process is called as DATA ACQUISITION SYSTEM

Data Acquisition Hardware

➢DAQ hardware interfaces the signal and a PC. It could be in the form of modules that can be connected to the computer's ports or cards connected to slots in the motherboard. Following are some hardware's….

- CAMAC - Computer Automated Measurement and Control
- Industrial Ethernet
- Industrial USB
- LAN eXtensions for Instrumentation
- NIM
- PowerLab
- VME bus
- VXI

Data Acquisition Software

- DAQ software is needed in order for the DAQ hardware to work with a PC.
- Involves the use of a programming language, such as:
  - C++, visual C++
  - BASIC, Visual Basic + Add-on tools (such as Visual lab with VTX)
  - Fortran
  - Pascal
  - Ladder logic
  - Lab view

Merits / Advantages

- Reduced data redundancy
- Reduced updating errors and increased consistency
- Greater data integrity and independence from applications programs
- Improved data access to users through use of host and query languages
- Improved data security
- Reduced data entry, storage, and retrieval costs
- Facilitated development of new applications program

Demerits / Disadvantages

- Database systems are complex, difficult, and time-consuming to design
- Substantial hardware and software start-up costs
- Damage to database affects virtually all applications programs
- Extensive conversion costs in moving form a file-based system to a database system
- Initial training required for all programmers and users

Conclusion

- Data acquisition systems typically convert analog Physical condition into digital values for easy processing.
- DAS is advantageous as we can store a lot of physical condition data in digitized form
- DAS helps in easy processing of data as well as easy comparison can be done.
- Today DAS is used in almost every field,industry and companies.

Logic Gates

Definition of a Logic Gate

A logic gate is an electronic circuit **which makes logic decisions**. It has one output and one or more inputs. The output signal appears only for certain combinations of input signals. Logic gates are the basic building blocks from which most of the digital systems are built up. They implement the hardware logic function based on the logical algebra developed by George Boole which is called Boolean algebra in his honour. A unique characteristic of the Boolean algebra is that variables used in it **can assume only one of the two values** *i.e*. either 0 or 1. Hence, every variable is either a 0 or a 1.

These gates are available today in the form of various IC families. The most popular families are: transistor-transistor logic (*TTL*), emitter-coupled logic (*ECL*), metal-oxide-semiconductor (*MOS*) and complementary metal-oxide-semiconductor (*CMOS*).

In this chapter, we will consider the *OR*, *AND*, *NOT*, *NOR*, *NAND*, exclusive *OR* (*XOR*) and exclusive *NOR* (*XNOR*) gates along with their truth tables.

Positive and Negative Logic

In computing systems, the number symbols 0 and 1 represent two possible states of a circuit or device. It makes no difference if these two states are referred to as *ON* and *OFF*, *CLOSED* and *OPEN*, *HIGH* and *LOW PLUS* and *MINUS* or *TRUE* and *FALSE* depending on the circumstances. Main point is that **they must be symbolized by two opposite conditions**.

In positive logic, a 1 represents

1. an *ON* circuit **2.** a *CLOSED* switch **3.** a *HIGH* voltage

4. a *PLUS* sign **5.** a *TRUE* statement

Consequently, a 0 represents

1. an *OFF* circuit **2.** an *OPEN* switch **3.** a *LOW* voltage **4.** a *MINUS* sign **5.** a *FALSE* statement.

In negative logic, just opposite conditions prevail.

Suppose, a digital system has two voltage levels of 0V and 5V. If we say that symbol 1 stands for 5V and symbol 0 for 0V, then we have positive logic system. If, on other hand, we decide that a 1 should represent 0 V and 0 should represent 5V, then we will get negative logic system.

Main point is that in ***positive logic***, **the more positive** of the two voltage levels represents the 1 while in negative logic, **the more negative** voltage represents the 1. Moreover, it is not essential that a 0 has to be represented by 0V although in some cases the two may coincide. Suppose, in a circuit, the two voltage levels are 2V and 10V. Then for positive logic, the 1 represents 10V and the 0 represents 2V (*i.e.* lesser of the two voltages). If the voltage levels are – 2V and – 8V, then, in positive logic, the 1 represents – 2V and the 0 represents – 8V (*i.e.* lesser of the two voltages).

Unless stated otherwise, we will be using only ***positive logic*** in this chapter.

The OR Gate

The electronic symbol for a two-input *OR* gate is shown in Fig. 70.1 (*a*) and its equivalent switching circuit in Fig. 70.1 (*b*). The two inputs have been marked as *A* and *B* and the output as *X*. It is worth reminding the reader that as per Boolean algebra, the three variables *A*, *B* and *X* can have only one of the two values *i.e.* either 0 or 1.

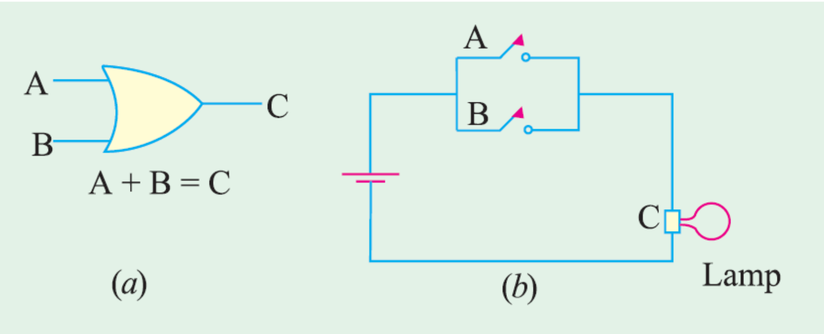


Fig. 70.1

Logic Operation

The *OR* gate has an **output of 1 when either A or B or both are 1**.

In other words, it is an **any-or-all** gate because an output occurs when any or all the inputs are present.

As seen from Fig. 70.1 (*b*), the lamp will light up (logic 1) when either switch *A* or *B* or both are closed.

Obviously, the output would be 0 **if and only if both its inputs are 0**. In terms of the switching conditions, it means that lamp would be *OFF* (logic 0) only when both switches *A* and *B* are *OFF*.

The *OR* gate represents the Boolean equation $A + B = X$

The meaning of this equation is that *X* is true when either *A* is true or *B* is true or both are true. Alternatively, it means that output *X* is 1 when either *A* or *B* or both are 1.

Table 70.1

A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

Fig. 70.2

The above logic operation of the *OR* gate can be summarised with the help of the truth table given in Fig. 70.2. A truth table may be defined as a table which ***gives the output state for all possible input combinations.*** The *OR* Table 70.1 gives outputs for all possible *A B* inputs of 00, 01, 10 and 11.

We may interpret the truth table as follows:

When both inputs are 0 (switches are *OPEN*), output *X* is 0 (lamp is *OFF*). When *A* is in logic state 0 (switch *A* is *OPEN*) but *B* is in logic state 1 (switch *B* is *CLOSED*), the output *X* is logic state 1 (lamp is *ON*). Lamp would be also *ON* when *A* is *CLOSED* and *B* is *OPEN*. Of course, lamp would be *ON* when both switched are *CLOSED*. It is so because an *OR* gate is equivalent to a **parallel** ***circuit in its logic function.***

Another point worth remembering is that the above *OR* gate is called **inclusive** *OR* gate because **it includes the case when both inputs are true**.

Diode OR Gate

Fig. 70.4. shows the diode *OR* gate consisting of two ideal diodes D_1 and D_2 connected in parallel across the output X.

1. When A is at +5V, D_1 is forward-biased and hence conducts. The circuit current flows *via* R dropping 5V across it. In this way, point X achieves potential of +5 V.
2. When + 5V is applied to B, D_2 conducts causing point X to go to +5 V.
3. When both A and B are +5V, the drop across R is 5V because voltages of A and B ***are in parallel.***

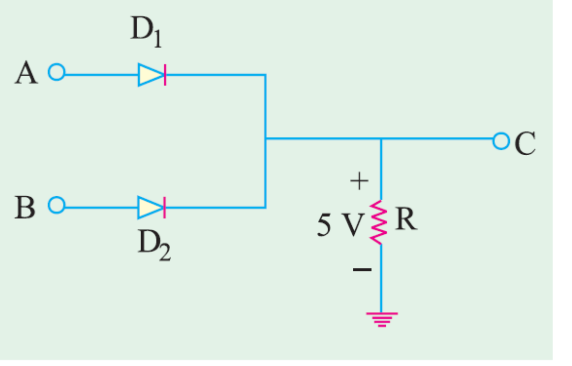


Fig. 70.4

Again, point X is driven to +5 V.

4. Obviously, when there is no voltage either at A or B, output X remains 0.

OR Gate Symbolizes Logic Addition

According to Boolean algebra, *OR* gate performs **logical addition**. Its truth table can be written as given below:

0 + 0	= 0
0 + 1	= 1
1 + 0	= 1
1 + 1	= 1

It must be clearly understood that '+' sign in Boolean algebra **does not stand for the addition** as understood in the ordinary or numerical algebra. In symbolic logic, the '+' sign indicates **OR** operation whose rules are given above. In logic algebra, $A + B = X$ means that if A is true *OR* B is true, then X will be true. ***It does not mean here that sum of A and B equals X.*** The other symbols used for '+' sign are U and V. Hence, the above equation could also be written as $A\,U\,B = X$ or $A\,V\,B = X$.

The AND Gate

The electronic (or logic) symbol for a 2-input *AND* gate is shown in Fig. 70.12 (*a*) and its equivalent switching circuit in Fig. 70.12 (*b*). It is worth reminding the readers once again that the three variables A, B, C can have a **value of either 0 or 1**.

Logic Operation

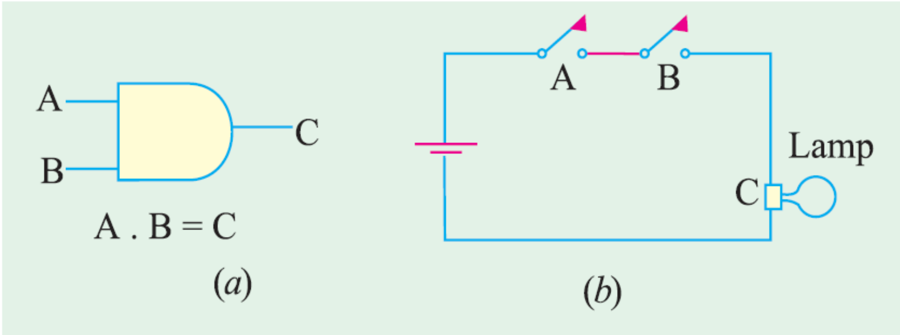


Fig. 70.12

1. The *AND* gate gives an output only **when all its inputs are present**.
2. The *AND* gate has a 1 output when both A **and** B are 1. Hence, this gate is an **all-or-nothing** gate whose output occurs only when all its inputs are present.
3. In True/False terminology, the output of an *AND* gate will be **true** only if **all its inputs are true**. Its output would be false if **any *of its inputs is false*.**

The *AND* gate works on the Boolean algebra

$$A \times B = X \quad \text{or} \quad A \,.\, B = X \quad \text{or} \quad AB = X$$

It is a **logical** multiplication and is different from the **arithmetic** multiplication. Often the sign '×' is replaced by a dot which itself is generally omitted as shown above. The logical meaning of the above equation is that

The AND Gate

1. output X is 1 only when both A *and* B are 1.
2. output X is true only when both A *and* B are true.

Table 70.4

A	B	X
0	0	0
0	1	0
1	0	0
1	1	1

Fig. 70.13

Table 70.5

A	B	C	X
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

ABC = X

Fig. 70.14

As seen from Fig. 70.12 (*b*), the lamp would be *ON* when both switches A and B are closed. Even when one switch is open, the lamp would be *OFF*. Obviously, an *AND* gate is equivalent to a **series switching circuit.**

Truth Table Fig. 70.13 shows truth table for a 2-input *AND* gate and Fig. 70.14 gives the same for a 3-input *AND* gate.

As seen, X is at logic 1 only when *all* inputs are at logic 1, not otherwise. The procedure for writing down the first three columns is the same as explained in Art. 70.8 earlier.

Diode AND Gate

It is shown in Fig. 70.16. Its logical operation is as under :

1. When A is at 0 V, diode D_1 conducts and the supply voltage of +5 V drops across R. Consequently, point N and hence point X are driven to 0 V. Therefore, the output C is 0.

2. Similarly, when B is at 0 V, D_2 conducts thereby driving N and hence X to ground.

3. Obviously, when both A and B are at 0 V, both diodes conduct and, again, the output X is 0.

4. There is no supply current and hence no drop across R ***only when both A and B are at +5 V.*** Only in that case, the output X goes to supply voltage of +5 V.

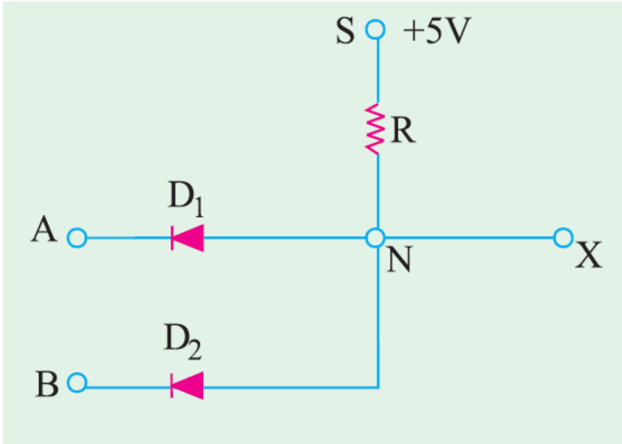
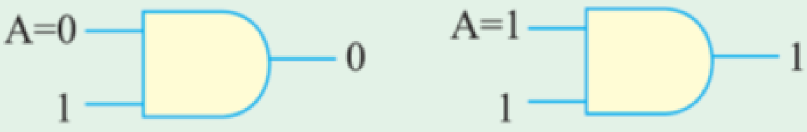
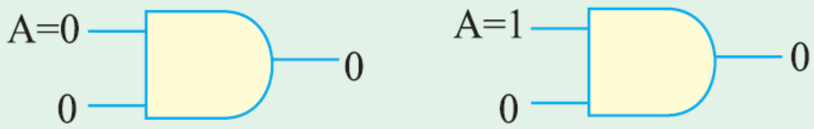


Fig. 70.16

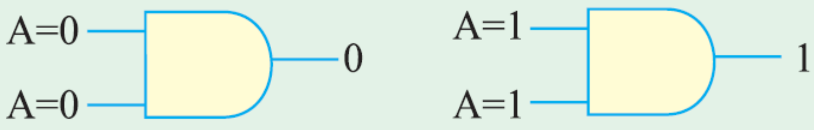
AND Gate Symbolizes Logic Multiplication



A.1 = A



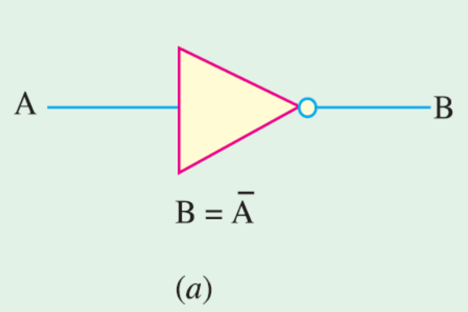
A.0 = 0



A.A = A

The NOT Gate

It is so called because *its output is NOT the* ***same as its input***. It is also called an ***inverter*** because it inverts the input signal. It has **one** input and **one** output as shown in Fig. 70.21 (*a*). All it does is to invert (or complement) the input as seen from its truth table of Fig. 70.21 (*b*).



A	B
0	1
1	0

(*b*)

Fig. 70.21

The schematic symbol for inversion is a small circle as shown in Fig. 70.21 (*a*). The logical symbol for inversion or negation or complementation is a bar over the function to indicate the opposite state.

Sometimes, a prime is also used as A'. For example, $\overline{A}$ means not-A. Similarly, $\overline{(A + B)}$ means the complement of $(A + B)$.

The NOT Operation

It is a ***complementation*** operation and its symbol is an **overbar**. It can be defined as under:

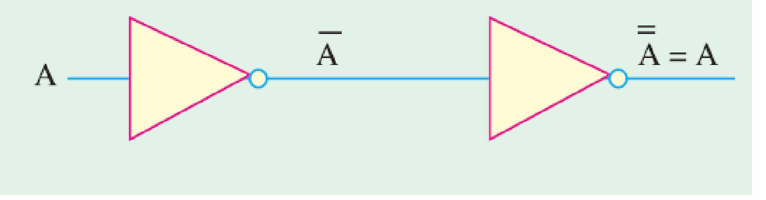


Fig. 70.23

As stated earlier, $\overline{0}$ means taking the negation or complement of 0 which is 1.

$$\overline{0} = 1$$

$$\overline{1} = 0$$

It should also be noted that complement of a value can be taken repeatedly. For example,

$$\overline{\overline{1}} = \overline{0} = 1 \quad \text{or} \quad \overline{\overline{0}} = \overline{1} = 0$$

As seen double complementation gives the original value as shown in Fig. 70.23.

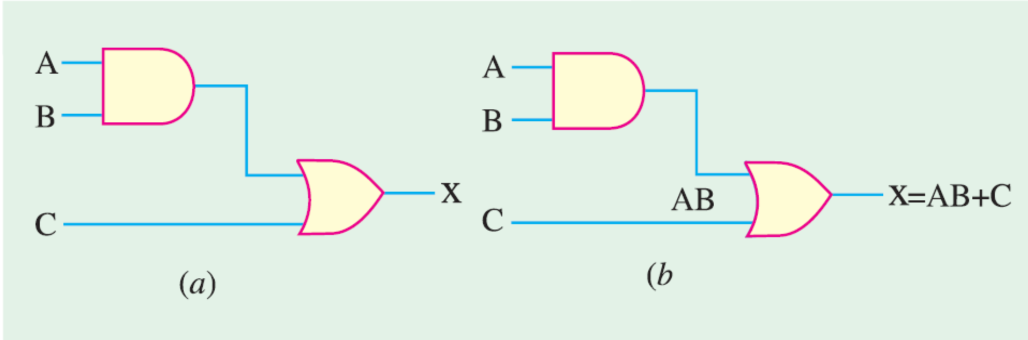


Fig. 70.24

Bubbled Gates

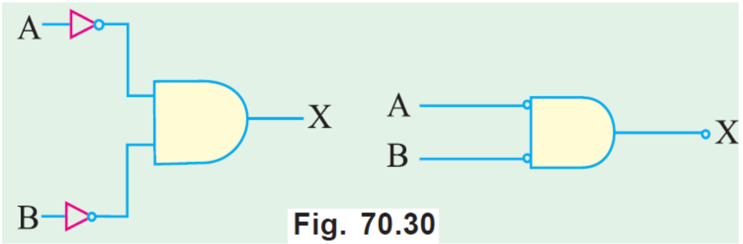


Fig. 70.30

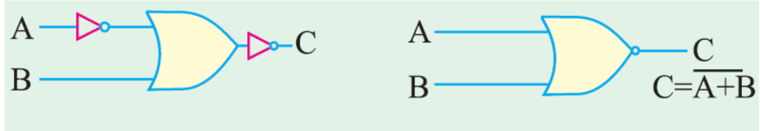
A bubbled gate is one whose inputs are *NOT*ed or inverted *i.e.* it is a negated gate. Fig. 70.30 (*a*) shows an *AND* gate whose both input are inverted.

In practice, instead of this logic symbol, the one shown in Fig. 70.30 (*b*) is widely used. As seen, the inverter triangles have been eliminated and the two small circles or bubbles have been moved to the inputs of the gate. Such a gate is called a ***bubbled AND*** gate, the bubbles acting as a reminder of the inversion or complementation that takes place before *AND*ing the inputs.

It would be shown later that a bubbled *AND* gate is equivalent to a *NOR* gate.

The NOR Gate

In fact, it is a *NOT-OR* gate. It can be made out of an *OR* gate by connecting an inverter in its output as shown in Fig. 70.31 (*a*).



(*a*) Fig. 70.31 (*b*)

The output equation is given by

$$X = \overline{A + B}$$

A *NOR* function is just the reverse of the *OR* function.

Logic Operation

A *NOR* gate will have an output of 1 **only when all its inputs are 0**. Obviously, if any input is **1**, the output will be 0. Alternatively, in a *NOR* gate, output is **true** only **when all inputs are false**.

The truth table for a 2-input *NOR* gate is shown in Fig. 70.32. It will be observed that the output *X* is just the reverse of that shown in Fig. 70.2.

The equivalent relay circuit for a *NOR* gate is shown in Fig. 70.33.

It is seen that the lamp glows under 00 input condition only but not under 01, 10, 11 input conditions.

Table 70.6

A	B	X
0	0	1
0	1	0
1	0	0
1	1	0

Fig. 70.32

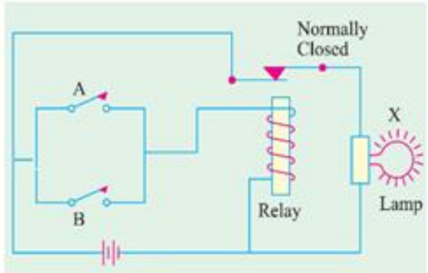


Fig. 70.33

NOR Gate is a Universal Gate

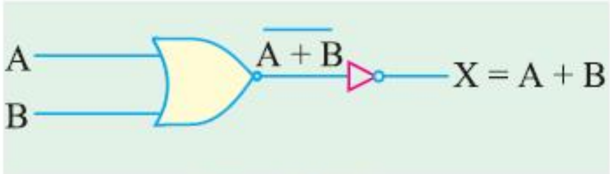


Fig. 70.35

It is interesting to note that a *NOR* gate can be used to realize the basic logic functions : *OR*, *AND* and *NOT*. That is why it is often referred to as a ***universal*** gate. Examples are given below:

1. As OR Gate

As shown in Fig. 70.35, the output from *NOR* gate is $A + B$. By using another inverter in the output, the final output is inverted and is given by $X = A + B$ which is the logic function of a normal *OR* gate.

2. As AND Gate

Here, two inverters have been used, one for each input (Fig. 70.36). The inputs have, thus, been **inverted before they are applied** to the *NOR* gate.

The output is $\overline{A} + \overline{B}$ which can be proved (with the help of De Morgan's theorem) to be equal to AB.

Incidentally, we could have used a bubbled *NOR* gate for the above purpose.

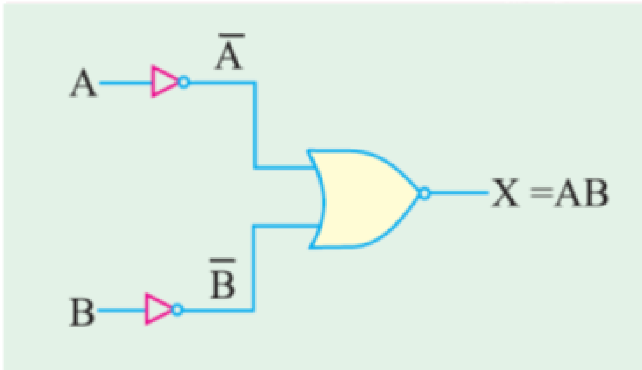
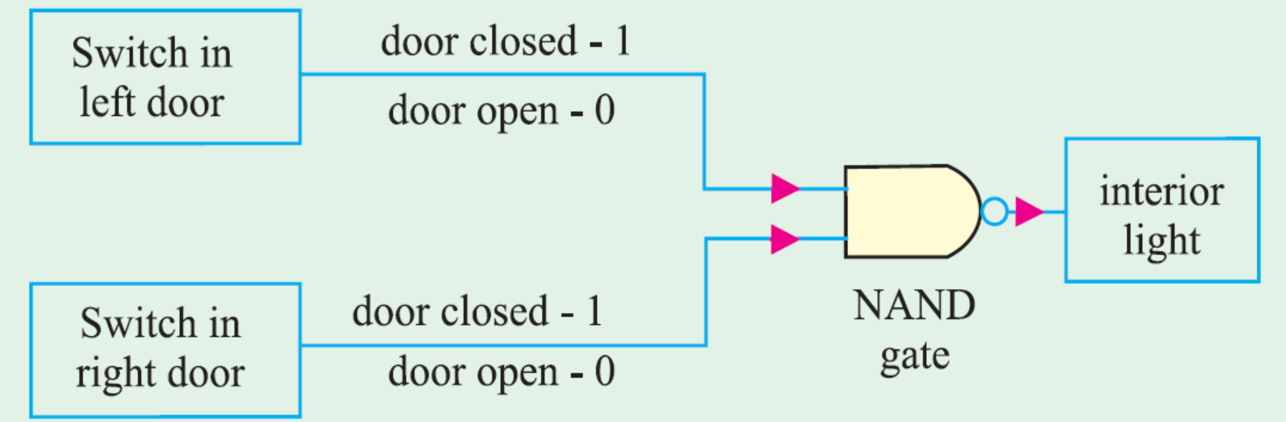


Fig. 70.36

3. As NOT Gate



The NAND gate is used to design an interior lighting system of a car such that the light is switched off only when both doors are shut

The two inputs have been tied together as shown in Fig. 70.37 (*a*). The output is $\overline{A} + \overline{A}$ which can be proved to be equal to A with the help of De Morgan's theorem. Instead of the first symbol, the second symbol shown in Fig. 70.37 (*b*) is widely used where only single input has been used.

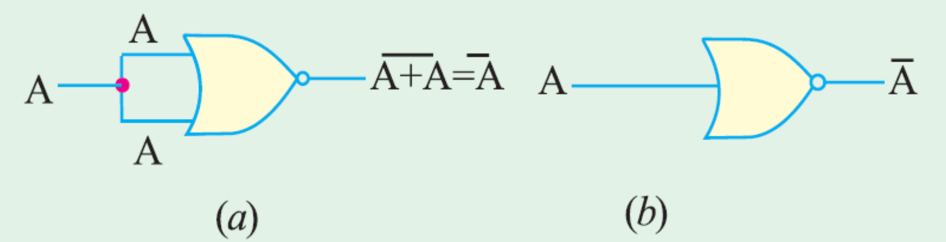


Fig. 70.37

Here is a different way of making *OR* and *AND* gates. Fig. 70.38 (*a*) shows how we can use *NOR* gates to produce an *OR* gate. Similarly, Fig. 70.38 (*b*) shows the formation of an *AND* gate from three *NOR* gates. Knowledge of De Morgan's theorem is needed to understand their logic operation.

The NAND Gate

It is, in fact, a *NOT-AND* gate. It can be obtained by connecting a NOT gate in the output of an AND gate as shown in Fig. 70.39. Its output is given by the Boolean equation.

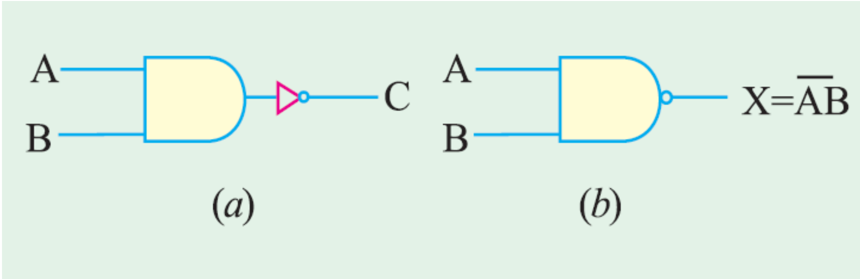


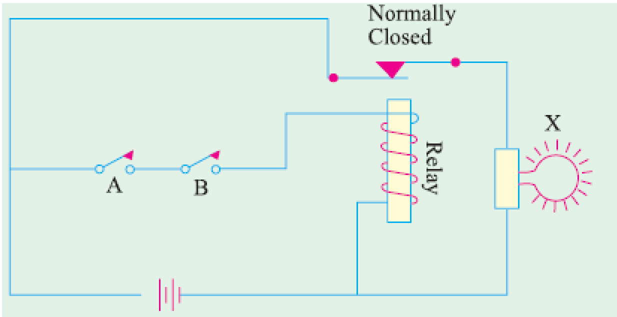
Fig. 70.39

This gate gives an output of 1 if its ***both inputs are* not 1**. In other words, it gives an output 1 if **either A or B or both are 0**.

The truth table for a 2-input *NAND* gate is given in Fig. 70.40. It is just the opposite of the truth for *AND* gate. It is so because *NAND* gate performs reverse function of an *AND* gate.

The equivalent relay circuit of a *NAND* gate is shown in Fig. 70.41.

A	B	X
0	0	1
0	1	1
1	0	1
1	1	0



NAND Gate is a Universal Gate

NAND gate is also called universal gate because it can perform all the three logic functions of an *OR* gate, *AND* gate and inverter as shown below.

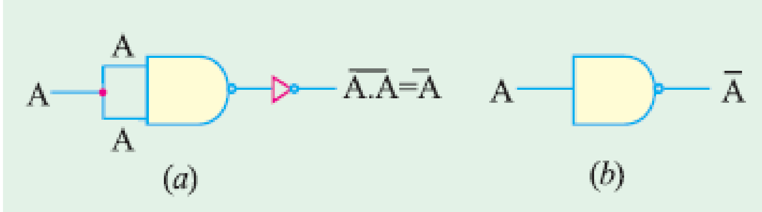


Fig. 70.43

As shown in Fig. 70.43 (*a*), a *NOT* gate can be made out of a *NAND* gate by connecting its two inputs together. When a *NAND* gate is used as a *NOT* gate, the logic symbol of Fig. 70.43 (*b*) is employed instead.

The use of two *NAND* gates to produce an *AND* gate is shown in Fig. 70.44 (*a*).

Similarly, Fig. 70.44 (*b*) shows how *OR* gate can be made out of three *NAND* gates. The *OR* function may not be clear from the figure because we need De Morgan's theorem to prove that $\overline{A}\ \overline{B} = A + B$.

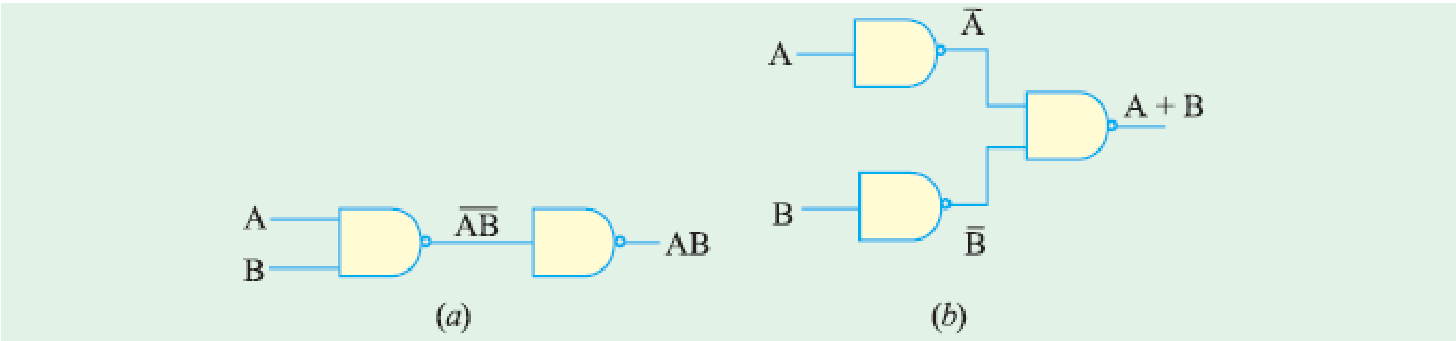


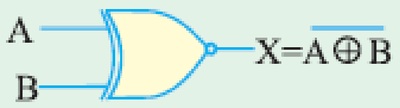
Fig. 70.44

The XNOR Gate

It is known as a not-*XOR* gate *i.e.* $\overline{XOR}$ gate. Its logic symbol and truth table are shown in Fig. 70.45.

Its logic function and truth table are ***just the reverse of those for XOR gate*** (Art 70.9).

This gate has an output 1 if **its both inputs are either 0 or 1**. In other words, for getting an output, its both inputs should be ***at the same logic level*** of either 0 or 1. Obviously, it produces **no** output if its two inputs are at the **opposite** logic level.



A	B	X
0	0	1
0	1	0
1	0	0
1	1	1

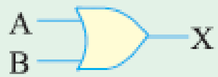
Fig. 70.45

Logic Gates at a Glance

In Fig. 70.46 is shown the summary of all the 2-output logic gates considered so far along with their truth tables.

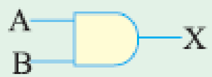
Following points should prove helpful when writing these truth tables:

1. In first column A, logic values alternate between 0 and 1 every two rows
2. In second column B, logic values alternate every other row
3. Column X is filled up as per the logic function it performs
4. Truth tables for *NOR*, *NAND* and *XNOR* (or $\overline{XOR}$) gates are *just the opposite* of those for *OR*, *AND* and *XOR* gates.



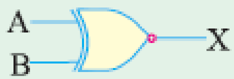
$A + B = X$

A	B	X
0	0	0
0	1	1
1	0	1
1	1	1



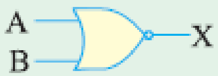
$AB = X$

A	B	X
0	0	0
0	1	0
1	0	0
1	1	1



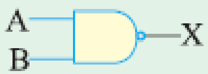
$A \oplus B = X$

A	B	X
0	0	0
0	1	1
1	0	1
1	1	0



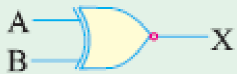
$\overline{A + B} = X$

A	B	X
0	0	1
0	1	0
1	0	0
1	1	0



$\overline{AB} = X$

A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

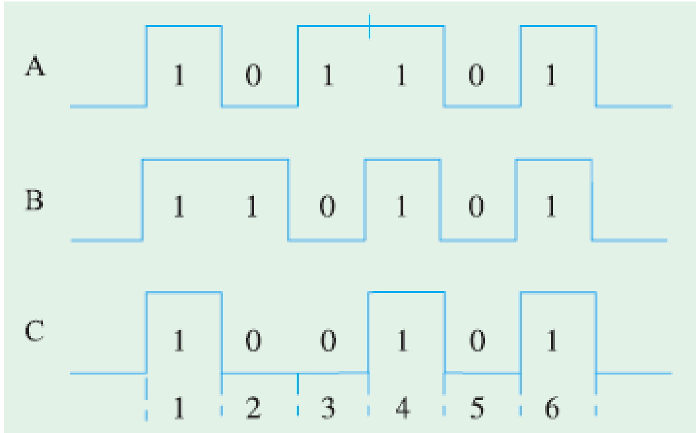


$\overline{A \oplus B} = X$

A	B	X
0	0	1
0	1	0
1	0	0
1	1	1

Fig. 70.46

Example *Two electrical signals represented by A = 101101 and B = 110101 are applied to a 2-input AND gate. Sketch the output signal and the binary number it represents.*



Solution. The pulse trains corresponding to A and B are shown in Fig. 70.49.

Remember that in an AND gate, C is 1 only when both A and B are 1. It is an *all-or-nothing gate*. The output can be found in different time intervals as under :

1. 1st interval : $1 + 1 = 1$
2. 2nd interval : $0 + 1 = 0$
3. 3rd interval : $1 + 0 = 0$
4. 4th interval : $1 + 1 = 1$
5. 5th interval : $0 + 0 = 0$
6. 6th interval : $1 + 1 = 1$

Hence, ouput of the AND gate is 100101_2. It is sketched in Fig. 70.49.

Example . *Design a logic circuit whose output is given by the Boolean expression* $(A + B). \overline{AB}$.

Solution. Working from output to input, we find that the output gate has to be a 2-input *AND* gate with inputs of $(A + B)$ and $\overline{AB}$. The first step of the circuit design is shown in Fig. 70.52 (*a*). It is also seen that the input to the entire circuit consists of A and B only.

The input of $(A + B)$ has been obtained with the help of an *OR* gate as shown in Fig. 70.52 (*b*).

Finally, a *NAND* gate is connected **in parallel** with the *OR* gate for getting its inputs of A and B and thereafter for supplying an output of $\overline{AB}$. The complete circuit is shown in Fig. 70.52 (*c*).

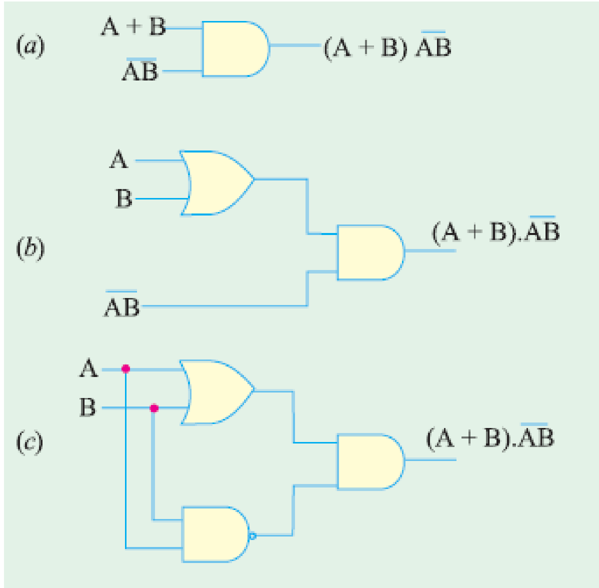


Fig. 70.52

Introduction: Analog & Digital Signals

The two major categories in which a signal is classified is analog and digital. The crucial difference between Analog and Digital Signal is that an analog signal is a continuous signal which is defined for every particular instant of time. On the contrary, a digital signal is of non-continuous nature, defined discretely at some specific time instants.

Due to the different nature of the two signals, these find applications in different fields.

What is Signal?

In electronics and field of signal processing, a signal is defined as an electric current or energy that carries information. A quantity that varies in space and time is utilized as a signal in order to transmit the data from one point to another. So, basically, the type of information carried out by the signal leads to its classification as analog and digital.

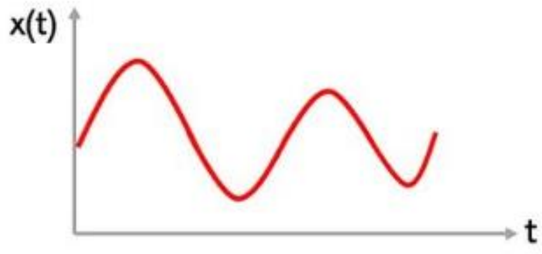
Comparison Chart

Basis for Comparison	Analog Signal	Digital Signal
Nature	Continuous with time.	Discrete sets at specific time.
Type of Waveform	Sinusoidal waves	Square waves
Representation		
Information carried	Continuous range of values.	Discrete value i.e., 0 and 1.
Noise Susceptibility	More	Comparatively less
Processing offered	Easy	Quite complex
Signal polarity	Positive as well as negative	Only positive
Signal encryption	Not required	Required
Bandwidth	Low	Comparatively high

Basis for Comparison	Analog Signal	Digital Signal
Signal polarity	Positive as well as negative	Only positive
Signal encryption	Not required	Required
Bandwidth	Low	Comparatively high
Power required for transmission	More	Less in comparison to analog signal
Rate of data transmission	Slow	Quite fast
Parameters associated	Amplitude, frequency, phase, etc.	Bit rate, bit interval, etc.
Accuracy of information	More	Comparatively less
Examples	Human voice, vision.	Computer data transmission and reception, transmission of signals through cables like telephone.

Definition of Analog Signal

Analog signal is continuous in nature as it is well defined for every specific time. More specifically, it is the one defined continuously for a range of values with time. These are represented as a **sinusoidal waveform**. The figure below represents an analog signal:

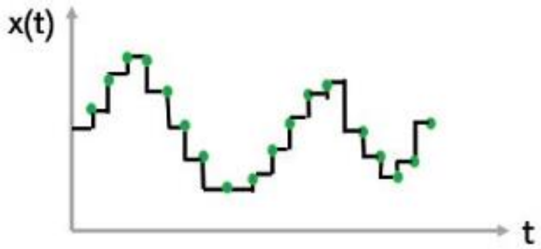


As we can see here that the signal is continuous in nature as its every value is specified for each particular interval of time, thus, is referred as the **continuous-time signal**. For the purpose of recording the analog signals, the actual signal must be preserved as only in that case we can record the accurate analog signal.

However, whenever in any application there arises a need to change an analog signal into a digital one then through sampling this can be achieved. In the sampling technique, this signal is sampled at certain fixed time intervals and the sampled voltage is converted into digital values.

Definition of Digital Signal

A type of signal which is non-continuous in nature as it is defined only for a set of discrete times is known as a **digital signal**. More simply, we can say, it is specified at some particular time instants only. Thus, here the information is represented as a set of discrete values. The figure given below shows the signal representation in digital form:



Here it is clear that the data is discretely positioned in time axis thus is shown in the form of bits i.e., **0** and **1**. This means that here the signal performs the sudden transition between 0 and 1 where these two values correspond to the two voltage levels. For the purpose of recording the signals, in the digital one, only the samples of the actual signal are taken and not the whole signal.

Key Differences Between Analog and Digital Signal

1. Analog and digital signals are differentiated mainly on the basis of their **way to carry the information**. Analog signals represent the information as a continuous function of time. As against, digital signals are represented discretely at specific time intervals.
2. Analog signals deteriorate more easily than digital one as their **susceptibility** towards noise is higher.
3. The devices that operate on an analog signal need more power for transmission and reception than the devices that work on the digital signal.
4. The **information** represented by the analog signal is comparatively more accurate than the digital signal due to its continuous range of values.
5. Analog signals are transmitted at a slower rate than digital signals as the information holds more values thus is precise.
6. An analog signal is defined by the amplitude, phase, frequency, etc. While the digital signal is mainly associated with bit rate, bit intervals, etc.
7. The sinusoidal representation of the analog signal makes it difficult to understand or get decoded thus **encryption** is not required in analog signals. But as the digital signals are in the form of square waves, thus, it can be decoded easily hence need to be encrypted for secured communication.
8. On the basis of processing, it is said that the continuous nature of the signal offers easy **processing** of the analog signal. However, the discrete nature of the signal offers difficultly in the processing of the digital signal.

Conclusion

Thus, the above discussion concludes that due to the way of representing the signal, the two are differentiated. And because of this, the two types of signals possess different properties and are used in different applications. Like analog signals are used in radio wave transmission and reception whereas digital signals are used in the field of digital electronics.