UNIT 1 INTRODUCTION

Electrical fundamentals - Electronic fundamentals -Semiconductor theory - Diodes -2.3 Transistors- Digital fundamentals-Logic gates-Combinational logic systems – Mono stable devices - Bistable devices -Decoders - Encoders –Multiplexers- Bus systems-microprocessors –microcontrollers - Computers

1.Aircraft Electrical and Electronic Systems : Principles, operation and maintenance , Mike Tooley and David Wyatt ,

Chapter 1 Electrical fundamentals

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1.2 Electrostatics and capacitors
1.3 Direct current
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Electron theory

- All matter is made up of atoms or groups of atoms (**molecules**) bonded together in a particular way.
- In order to understand something about the nature of electrical charge we need to consider a simple model of the atom.
- This model, known as the Bohr model(see Fig. 1.1), shows a single atom consisting of a central nucleus with orbiting electrons.

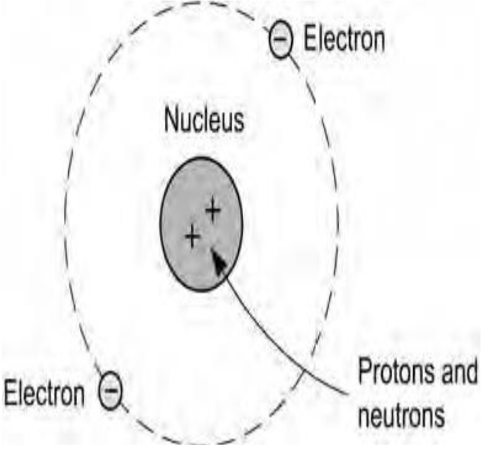


Figure 1.1 The Bohr model of the atom

- Within the nucleus there are **protons** which are positively charged and **neutrons** which, as their name implies, are electrical neutral and *have no charge* .
- Orbiting the nucleus are electrons that have a negative charge, equal in magnitude (size) to the charge on the proton. These electrons are approximately two thousand times lighter than the protons and neutrons in the nucleus.
- In a stable atom the number of protons and electrons are equal, so that overall, the atom is neutral and has no charge.
- However, if we rub two particular materials together, electrons may be transferred from one to another. This alters the stability of the atom, leaving it with a net positive or negative charge.
- When an atom within a material loses electrons it becomes positively charged and is known as a **positive ion** ,
- when an atom gains an electron it has a surplus negative charge and so is referred to as a **negative ion**
- These differences in charge can cause **electrostatic** effects.

- The electrons in all atoms sit in a particular orbit, or **shell** , dependent on their energy level Each of these shells within the atom is filled by electrons from the nucleus outwards, as shown in Fig. 1.2).

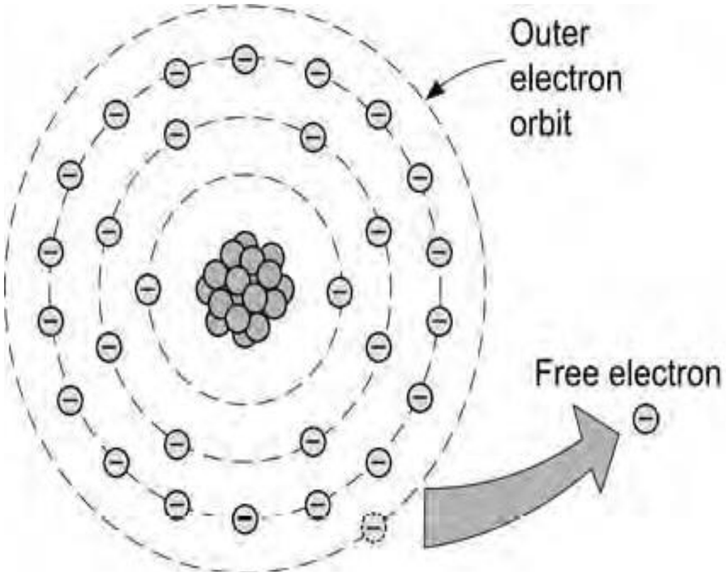


Figure 1.2 A material with a loosely bound electron in its outer shell

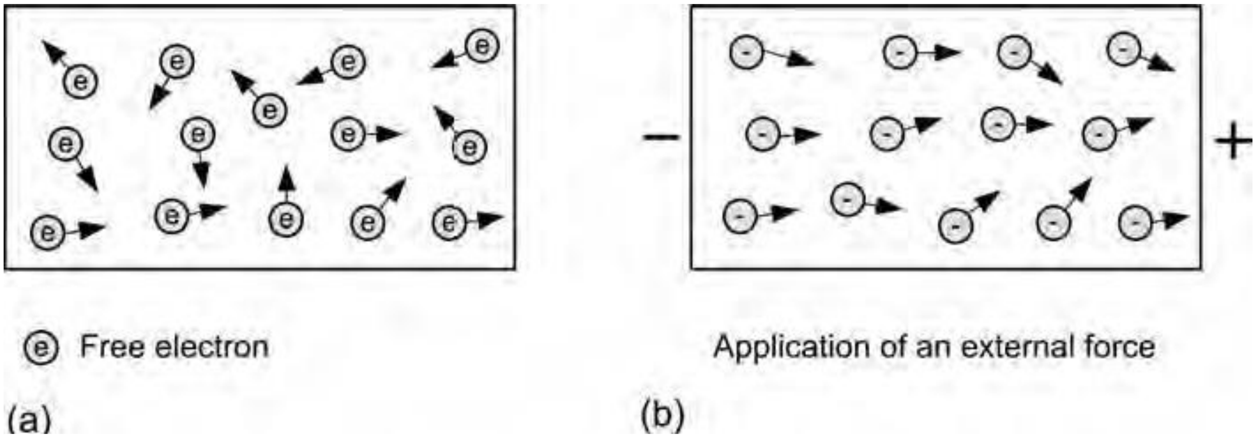
- The first, innermost, of these shells can have up to two electrons, the second shell can have up to eight and the third up to 18
- .All electrons and protons carry an electrostatic **charge** but its value is so small that a more convenient unit of charge is needed for practical use which we call the **coulomb** . One coulomb (C) is the total amount of the charge carried by 6.21 × 10^ 18 electrons .Thus a single electron has a charge of a mere 1.61 ×10 _^19 C!

CONDUCTOR .

- A material which has many free electrons available to act as charge carriers, and thus allows current to f low freely, is known as a **conductor** . Examples of good conductors include aluminum, copper, gold and iron.
- Figure 1.2 shows a material with one outer electron that can become easily detached from the parent atom. A small amount of external energy is required to overcome the attraction of the nucleus. Sources of such energy may include heat, light or electrostatic fields. The atom once detached from the atom is able to move freely around the structure of the material land is

called a **free electron** .It is these free electrons that become the **charge carriers** within a material

- Materials that have large numbers of free electrons make good **conductors** of electrical energy and heat. In a material containing free electrons their direction of motion is random, as shown in Fig. 1.3(a) ,but if an external force is applied that causes the free electrons to move in a uniform manner (Fig. 1.3(b))an electric **current** is said to flow



Metals are the best conductors, since they have a very large number of free electrons available to act as charge carriers

INSULATORS

Materials that do not conduct charge are called **insulators** ; their electrons are tightly bound to the nuclei of their atoms. Examples of insulators include plastics, glass, rubber and ceramic materials.

The effects of electric current flow can be detected by the presence of one or more of the following effects: light, heat, magnetism, chemical, pressure and friction

For example, heat is produced when an electric current is passed through a resistive heating element. Light is produced when an electric current flows through the thin filament wire in the evacuated bulb of an electric lamp.

1.2 Electrostatics and capacitors

Electric charge is all around us. Indeed, many of the everyday items that we use in the home and at work rely for their operation on the existence of electric charge and the ability to make that charge do something Useful Electric charge is also present in the natural world and anyone who has experienced an electrical storm cannot fail to have been awed by its effects

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if a conductor has a deficit of electrons, it will exhibit a net positive charge. If, on the other hand, it has a surplus of electrons ,it will exhibit a net negative charge.

An imbalance in charge can be produced by friction (removing or depositing electrons using materials such as silk and fur, respectively) or induction (by attracting or repelling electrons using a second body which is respectively positively or negatively charged)

If two bodies have charges with the same polarity (i.e. either both positively or both negatively charged)the two bodies will move apart, indicating that a force of repulsion exists between them. If, on the other hand,
the charges on the two bodies are unlike (i.e. one positively charged and one negatively charged) the two bodies will move together, indicating that a force of attraction exists between them. From this we can conclude
that like charges repel and unlike charges attract.

Static charges can be produced by friction. In this case, electrons and protons in an insulator are separated from each other by rubbing two materials together in order to produce opposite charges. These charges will remain separated for some time until they eventually leak away due to losses in the insulating **dielectric** material or in the air surrounding the materials. Note that more charge will be lost in a given time if the air is damp.

Static electricity is something that can cause particular problems in an aircraft and special measures are taken to ensure that excessive charges do not build upon the aircraft’s structure. The aim is that of equalizing the potential of all points on the aircraft’s external surfaces. The static charge that builds up during normal flight can be dissipated into the atmosphere surrounding the aircraft by means of small conductive rods connected to the aircraft’s trailing surfaces .These are known as **static dischargers** or **staticwicks**

1.2.1 Electric fields

The force exerted on a charged particle is a manifestation of the existence of an electric field. The electric

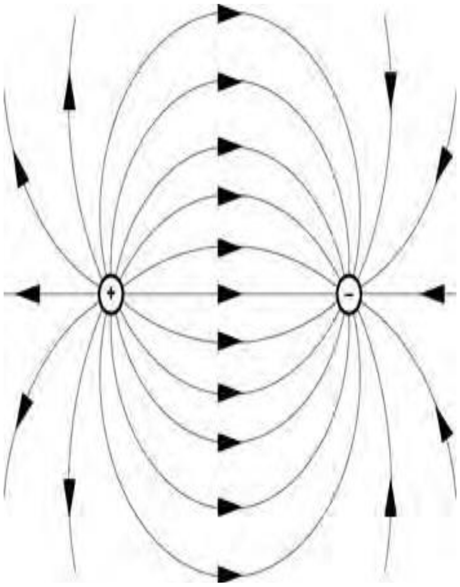


Figure 1.5 Electric field unlike charges

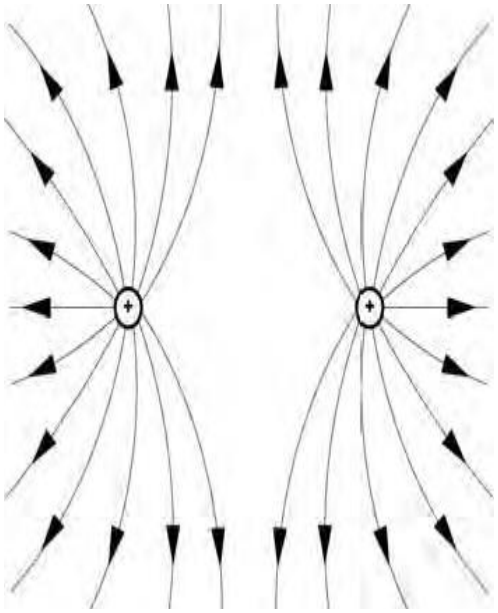


Figure 1.6 Electric field between isolated isolated like charges

field defines the direction and magnitude of a force on a charged object. The field itself is invisible to the human eye but can be drawn by constructing lines which indicate the motion of a free positive charge Within the field; the number of field lines in a particular region being used to indicate the relative strength of the field at the point in question.

Figures 1.5 and 1.6 show the electric fields between isolated unlike and like charges whilst Fig. 1.7 shows the field that exists between two charged parallel metal plates which forms a charge storage device known as a **capacitor** .

The strength of an electric field (E) is proportional to the applied **potential difference** and inversely proportional to the distance between the two conducting surfaces (see Fig. 1.8). The electric field strength is given by

$$E = \frac{V}{d}$$

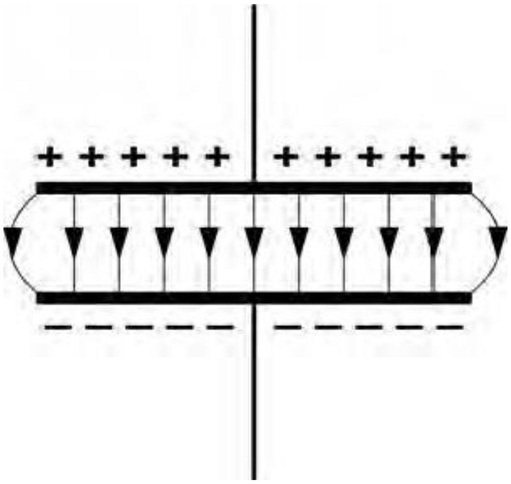
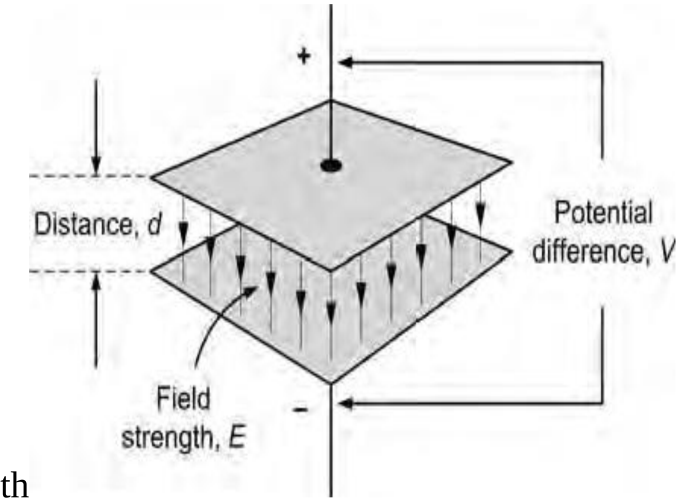


Figure 1.7 Electric field between the two Charged parallel metal plates of a capacitor



Strength

Figure 1.8 Electric field strength between two charged conducting surfaces

where *E* is the electric field strength (in V/m), *V* is the applied potential difference (in V) and *d* is the distance (in m).The amount of charge that can be stored by a capacitor is given by the relationship:

$$Q = C * V$$

where *Q* is the charge in coulomb, *C* is the capacitance in farads, F, and *V* is the voltage in volts, V. this relationship can be re-arranged to make *C* or *V* the subject as follows:

$$C = \frac{Q}{V} \text{ and } V = \frac{Q}{C}$$

1.3 Direct current

Direct current (DC) is current that flows in one direction only. DC circuits are found in every aircraft Because of their negative charge, electrons will flow from a point of negative potential to a point with more positive potential (recall that like charges attract and unlike charges repel).

However, when we indicate the direction of current in a circuit we show it as moving from a point that has the greatest positive potential to a point that has the most negative potential. We call this **conventional current** and, although it may seem odd, you just need to remember that it flows in the *opposite* direction to that of the motion of electrons The most commonly used method of generating direct current is the electrochemical cell.

A **cell** is a device that produces a charge when a chemical reaction takes place. When several cells are connected together they form a **battery.**

There are two types of cell: primary and secondary

Primary cells produce electrical energy at the expense of the chemicals from which they are made and once these chemicals are used up, no more electricity can be obtained from the cell.

In **secondary cells,** the chemical action is reversible. This means that the chemical energy is converted into electrical energy when the cell is **discharged** whereas electrical energy is converted into chemical energy when the cell is being **charged.**

1.4 Current, voltage and resistance

Current, *I,* is defined as the rate of flow of charge and its unit is the ampere, A. One ampere is equal to one coulomb C per second, or:

one ampere of current $I = \frac{Q}{t}$

Where t time in seconds

1.4.1 Potential difference (voltage)

The force that creates the flow of current (or rate of flow of charge carriers) in a circuit is known as the **electromotive force** (or **e.m.f.)** and it is measured in volts (V)

$$v = \frac{w}{Q}$$

The **potential difference** (or **p.d.)** is the voltage difference, or voltage drop between two points. One volt is the potential difference between two points if one Joule of energy is required to

1.4.2 Resistance

All materials at normal temperatures oppose the movement of electric charge through them; this opposition to the flow of the charge carriers is known as the **resistance,** *R*, of the material. This resistance is due to collisions between the charge carriers (electrons) and the atoms of the material. The unit of resistance is the **ohm,** with symbol Ω.

Note that 1 V is the electromotive force (e.m.f.) required to move 6.21 _ 10 18 electrons (1 C) through a resistance of 1 Ω in 1 second. Hence a ll materials at normal temperatures oppose the movement of electric charge through them; this opposition to the flow of the charge carriers is known as the **resistance,** *R*, of the material. This resistance is due to collisions between the charge carriers (electrons) and the atoms of the material. The unit of resistance is the **ohm,** with symbol Ω. Note that 1 V is the electromotive force (e.m.f.) required to move 6.21 * 10 18 electrons (1 C) through a resistance of 1 Ω in 1 second.

Hence: $V = \frac{Q}{t} * R$

Where *Q* = charge, *t* _ time, and *R* _ resistance. Re-arranging this equation to make *R* the subject gives: $R = \frac{V * t}{Q}$

1.4.3 Ohm’s law

The most basic DC circuit uses only two components; a cell (or battery) acting as a source of e.m.f., and a resistor (or *load)* through which a current is passing. These two components are connected together with wire conductors in order to form a completely closed circuit as shown in Fig. 1.11

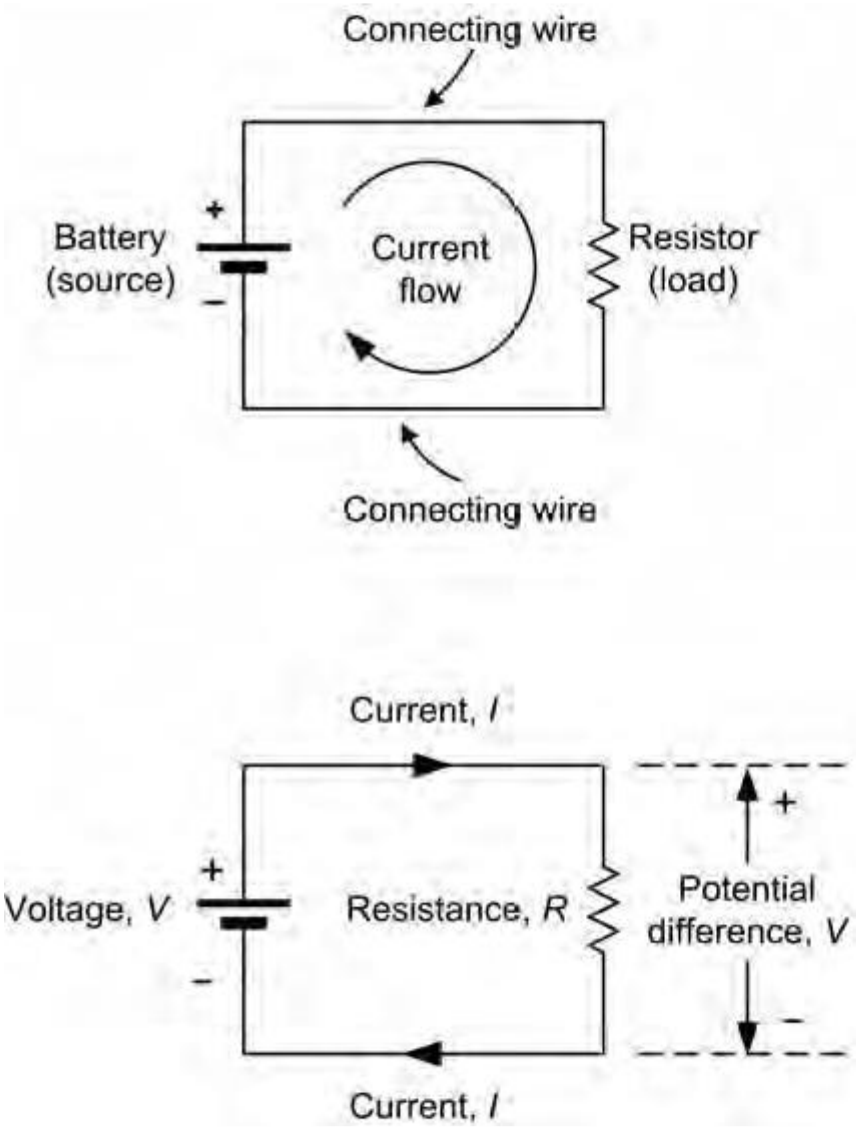


Figure 1.11 A simple DC circuit consisting of a battery (source) and resistor (load)

For any conductor, the current flowing is directly proportional to the e.m.f. applied. The current flowing will also be dependent on the physical dimensions (length and cross-sectional area) and material of which the conductor is composed. The amount of current that will flow in a conductor when a given e.m.f. is applied is inversely proportional to its resistance.

Resistance, therefore, may be thought of as an ‘opposition to current flow the higher the resistance the lower the current that will flow (assuming that the applied e.m.f. remains constant). Provided that temperature does not vary, the ratio of p.d. across the ends of a conductor to the current flowing in the conductor is a constant. This relationship is known as Ohm’s law and it leads to the relationship: $\frac{v}{I}$ = a constant= R

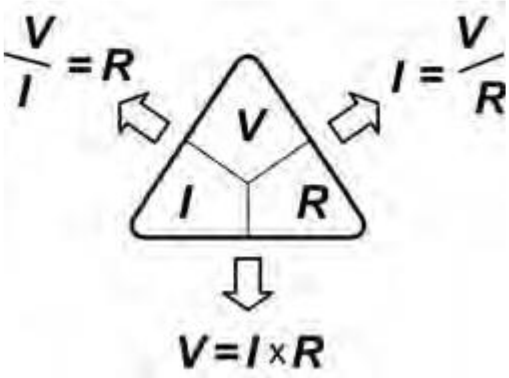


Figure 1.12 Relationship between *V*, *I* and *R*

where *V* is the potential difference (or voltage drop) in volts (V), *I* is the current in amps (A), and *R* is the resistance in ohms (Ω).This important formula may be arranged to make *V* , *I* or *R* the subject, as follows:

$$V = I \times R \quad I = \frac{V}{R} \quad R = \frac{V}{I}$$

Kirchhoff's laws

Kirchhoff's current law

Kirchhoff's current law states that the algebraic sum of the currents present at a junction (or *node) in* a circuit is zero

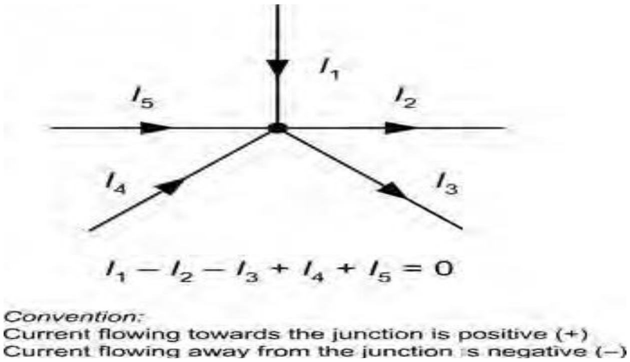
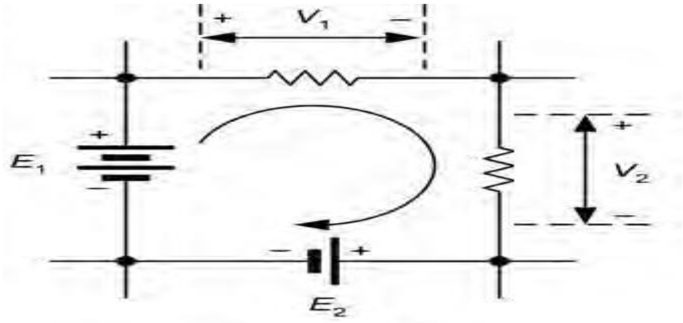


Figure 1.14 ***Kirchhoff's current law***

Kirchhoff’s voltage law

Voltage law states that the algebraic sum of the potential drops present in a closed network (or *mesh)* is zero



$$E_1 - V_1 - V_2 - E_2 = 0$$

Convention:
Move clockwise around the circuit starting with the positive terminal of the largest e.m.f.
Voltages acting in the same sense are positive (+)
Voltages acting in the opposite sense are negative (−)

Figure 1.15 ***Kirchhoff’s voltage law***

Series and parallel circuits

Ohm’s law and Kirchhoff’s laws can be combined to solve more complex series–parallel circuits

Figure 1.16 shows three circuits, each containing three resistors, *R*1, *R*2 and *R*3
In Fig. 1.16(a) the three resistors are connected one after another. We refer to this as a *series circuit.* In other words the resistors are said to be connected in *series. The same current flows through each resistor.*
In Fig. 1.16(b) the three resistors are all connected across one another. We refer to this as a *parallel* circuit. In other words the resistors are said to be connected *in parallel . the same voltage appears across each resistor* .

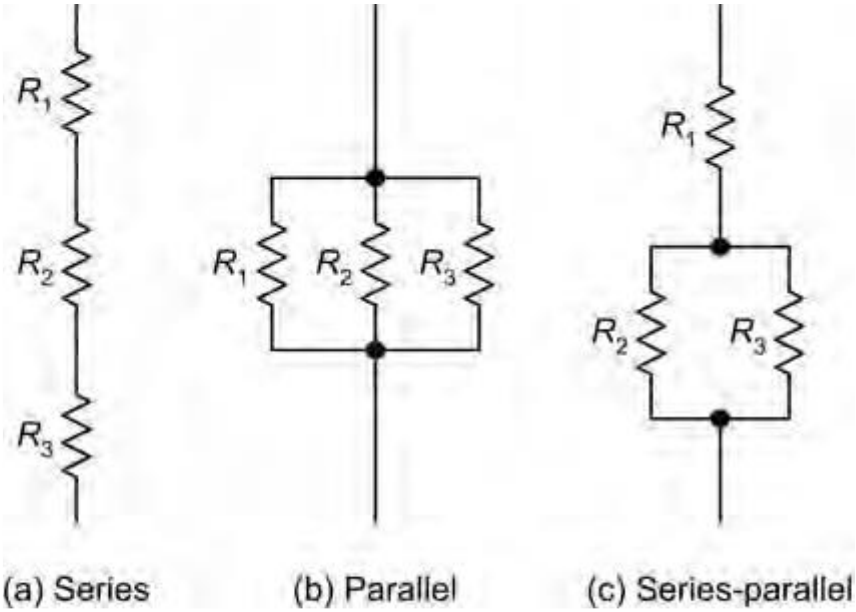


Figure 1.16 *Series and parallel circuits*

In Fig. 1.16(c) , we have shown a mixture of these two types of connection. Here we can say that *R*1 is connected in series with the parallel combination of *R*2 and *R*3 . In other words, *R*2 and*R*3 are connected *in parallel* and *R*2 is connected *in series* with the parallel combination.

1.5 Power and energy

Power, *P* , is the rate at which energy is converted from one form to another and it is measured in *watts*

1 watt = 1 joule per second

$$\text{Power, } P = \frac{\text{Energy, } W}{\text{time, } t}$$

$$P = \frac{W}{t} \text{ W}$$

Electrical energy is the capacity to do work

Energy can be converted from one form to another.

The unit of energy is the *joule* (J). Then, from the definition of power

$$1 \text{ joule} = 1 \text{ watt} \times 1 \text{ second}$$

hence:

$$\text{Energy}, W = (\text{power}, P) \times (\text{time}, t)$$
$$\text{with units of (watts} \times \text{seconds)}$$

thus

$$W = Pt \text{ J}$$

Thus joules are measured in **watt-seconds** If the power was to be measured in kilowatts and the time in hours, then the unit of electrical energy would be the **kilowatt-hour** (kWh) (commonly known as a **unit of electricity**).

The power in an electrical circuit is equivalent to the product of voltage and current. Hence

$$P = I \times V$$

where P is the power in watts (W), I is the current in amps (A), and V is the voltage in volts (V).

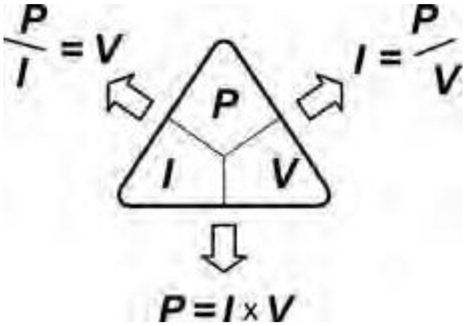


Figure 1.22 Relationships between P , I and V

$$P = I \times V \qquad I = \frac{P}{V} \qquad V = \frac{P}{I}$$

$$P = I \times V = I \times (IR) = I^2R$$

$$P = I \times V = \left(\frac{V}{R}\right) \times V = \frac{V^2}{R}$$

1.6 Electromagnetism and inductors

- Magnetism is an effect created by moving the elementary atomic particles in certain materials such as iron, nickel and cobalt

- A magnetic field of flux is the region in which the forces created by the magnet have influence. field surrounds a magnet in all directions, being strongest at the end extremities of the magnet, known as the poles
- Magnetic fields are mapped by an arrangement of lines that give an indication of strength and direction of the flux as illustrated in Fig. 1.23 .

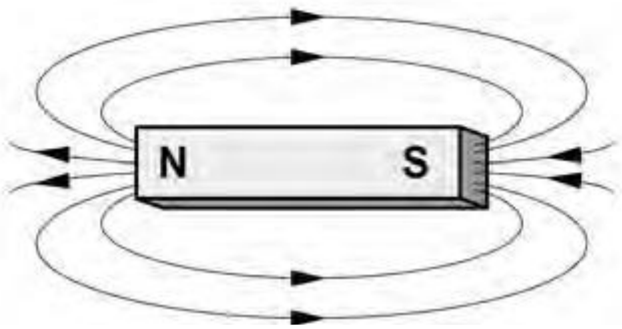


Figure 1.23 Field and flux directions for a bar magnet

- Whenever an electric current flows in a conductor a magnetic field is set up around the conductor in the form of concentric circles, as shown in Fig. 1.24
- The direction of the magnetic field is dependent on the direction of the current passing through the conductor.
- If we place a current-carrying conductor in a magnetic field, the conductor has a force exerted on it.

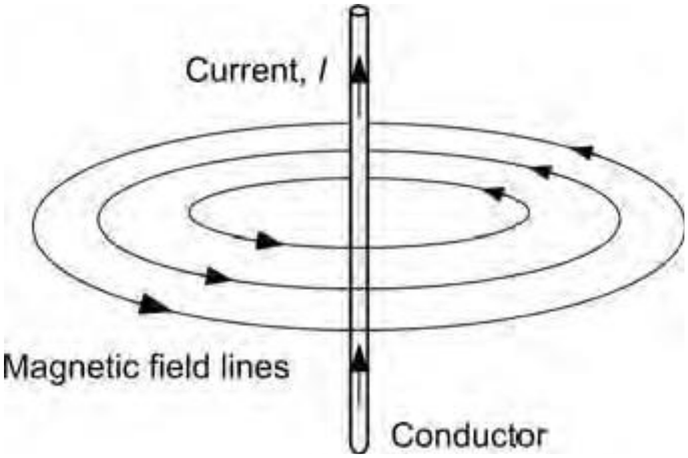


Figure 1.24 Field around a current-carrying conductor

Consider the arrangement shown in Fig. 1.25 , in which a current-carrying conductor is placed between two magnetic poles. The direction of the current passing through it is into the page going away from us. Then by the right-hand screw rule, the direction of the magnetic field, created by the current in the conductor, is clockwise, as shown.

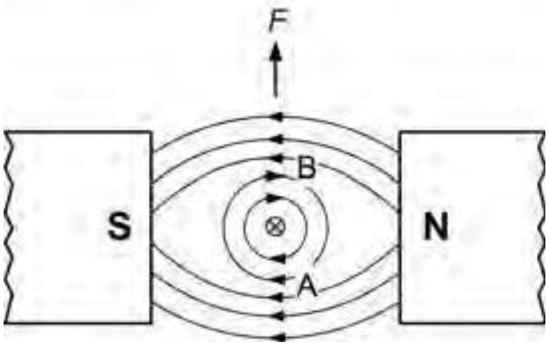


Figure 1.25 A current-carrying conductor in a magnetic field

We also know that the flux lines from the permanent magnet exit at a north pole and enter at a south pole; in other words, they travel from north to south, as indicated by the direction arrows. The net effect of the coming together of these two magnetic force fields is that at position A, they both travel in the same direction and reinforce one another. While at position B, they travel in the opposite direction and tend to cancel one another. So with a stronger force field at position A and a weaker force at position B the conductor is forced upwards out of the magnetic field. If the direction of the current was reversed, i.e. if it was to travel towards us out of the page, then the direction of the magnetic field in the current-carrying conductor would be reversed and therefore so would the direction of motion of the conductor.

The magnitude of the force acting on the conductor depends on the current flowing in the conductor, the length of the conductor in the field, and the strength of the magnetic flux (expressed in terms of its **flux density**). The size of the force will be given by the
expression:

$$F = BIl$$

where F is the force in Newton’s (N),

B is the flux density in tesla (T),
I is the current (A) and
l is the length (m).

Flux density is a term that merits a little more explanation. The total flux present in a magnetic field is a measure of the total magnetic intensity present in the field and it is measured in webers (Wb) and represented by the Greek symbol, Φ . The flux density, *B* , is simply the total flux, Φ , divided by the area over which the flux acts, *A* . Hence:

$$B = \frac{\varphi}{\mathrm{A}}$$

where *B* is the flux density (T),
Φ is the total flux present (Wb), and
A is the area (m 2).

In order to increase the strength of the field, a conductor may be shaped into a loop (Fig. 1.26) or coiled to form a **solenoid** (Fig. 1.27).

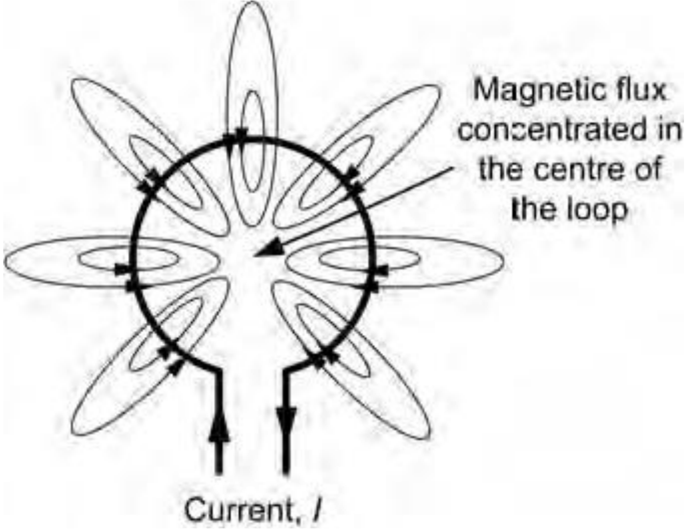


Figure 1.26 magnetic fields around a single turn loop

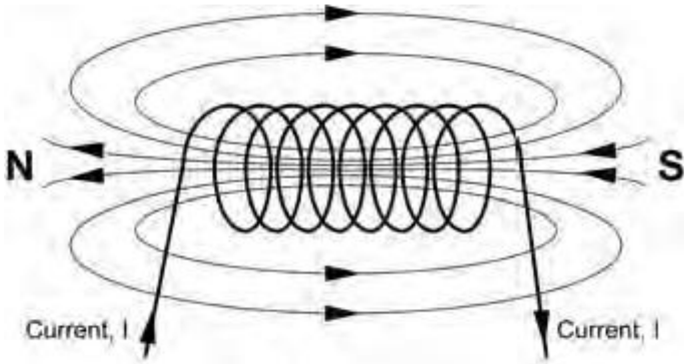


Figure 1.27 magnetic fields around a coil or solenoid

1.6.1 Electromagnetic induction

Whenever relative motion occurs between a magnetic field and a conductor acting at right angles to the field, an e.m.f. is induced, or generated in the conductor. The manner in which this e.m.f. is generated is based on the principle of electromagnetic induction

Consider Fig. 1.28 , which shows relative movement between a magnet and a closed coil of wire .An e.m.f. will be induced in the coil whenever the magnet is moved in or out of the coil (or the magnet is held stationary and the coil moved). The magnitude of the induced e.m.f., e , depends on the number of turns, N , and the rate at which the flux changes in the coil, $d\Phi/dt$.
The e.m.f., e , is given by the relationship:

$$e = -N\frac{d\varphi}{dt}$$

where N is the number of turns and
$d\Phi/dt$ is the rate of change of flux.
The minus sign indicates that the polarity of the generated e.m.f. *opposes* the change

Now the number of turns N is directly related to the length of the conductor, l , moving through a magnetic field with flux density, B . Also, the velocity with which the conductor moves through the field determines the rate at which the flux changes in the coil as it cuts the flux field. Thus the magnitude of the induced (generated) e.m.f., e , is proportional to the flux density, length of conductor and relative velocity between the field and the conductor .

The magnitude of the induced e.m.f. also depends on:

- the length of the conductor l in m
- the strength of the magnetic field, B , in tesla (T)
- the velocity of the conductor, v , in m/s.

Hence:

$$e \propto Blv$$

where B is the strength of the magnetic field (T),
l is the length of the conductor in the field (m),
and v is the velocity of the conductor (m/s).

In order to generator an e.m.f. the conductor must cut the lines of magnetic flux. If the conductor cuts the lines of flux at right angles (Fig. 1.29(a)) then the maximum e.m.f.is generated; cutting them at any other angle θ (Fig.1.29(b)), reduces this value until θ _ 0°, at which point the lines of flux are not being cut at all and no e.m.f. is induced or generated in the conductor. So the magnitude of the induced e.m.f. is also dependent on sin θ . So we may write:
$e = Blv \sin\theta$

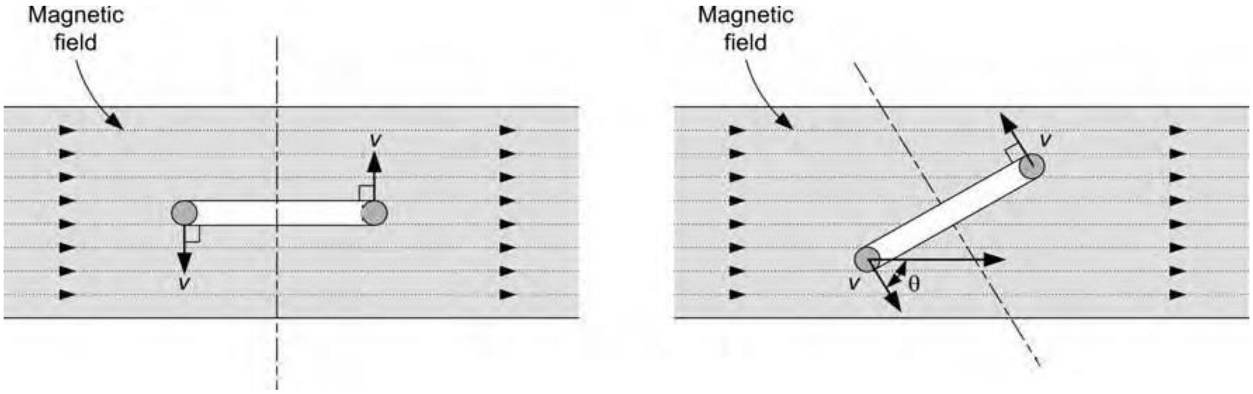


Figure 1.29 Cutting lines of flux and the e.m.f. generated: (a) cutting lines of flux at 90°, $e = Blv$; (b) cutting lines of flux at θ , $e = Blv \sin\theta$

1.6.2 Faraday's and Lenz's laws

Faraday's law also tells us that the magnitude of the induced e.m.f. is dependent on the relative velocity with which the conductor cuts the lines of magnetic flux
Lenz's law states that the current induced in a conductor opposes the changing field that produces it.It is therefore important to remember that the induced current *always* acts in such a direction so as to oppose the change in flux. This is the reason for the minus sign in the formula that we met earlier:

1.6.3 Self-inductance and mutual inductance

We have already shown how an induced e.m.f. (i.e. a **back e.m.f.**) is produced by a flux change in an inductor. The back e.m.f. is proportional to the rate of change of current (from Lenz's law), as illustrated in Fig. 1.30 .This effect is called *self-inductance* (or just *inductance*) which has the symbol L . Self-inductance is measured in henries (H) and is calculated from:

$$e = -L\frac{di}{dt}$$

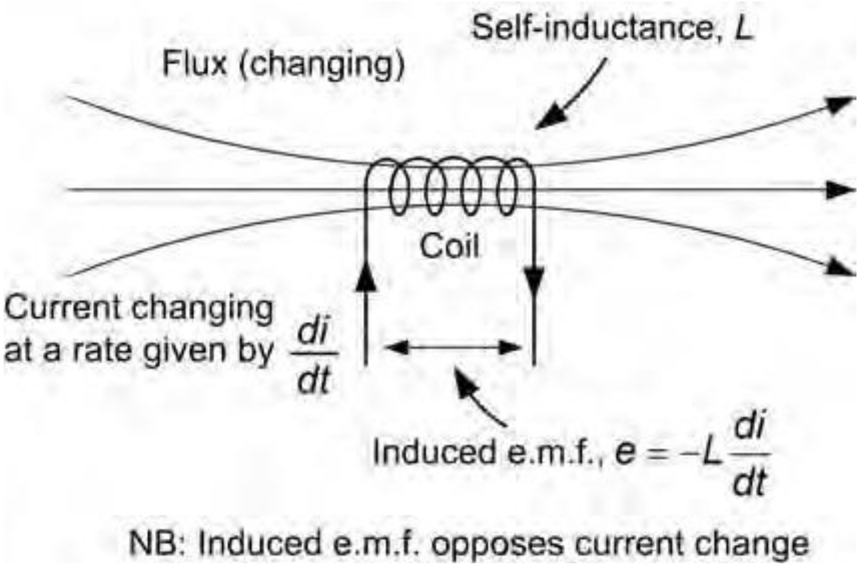


Figure1.30 Self-inductance

- where L is the self-inductance,
- di / dt is the rate of change of current and
- the minus sign indicates that the polarity of the generated e.m.f. *opposes* the change
-

The unit of inductance is the henry (H)

Finally, when two inductors are placed close to one another, the flux generated when a changing current flows in the first inductor will cut through the other inductor (see Fig. 1.31). This changing flux will, inturn, induce a current in the second inductor. This effect is known as **mutual inductance** and it occurs whenever two inductors are inductively coupled. This is the principle of a very useful component, the **transformer**

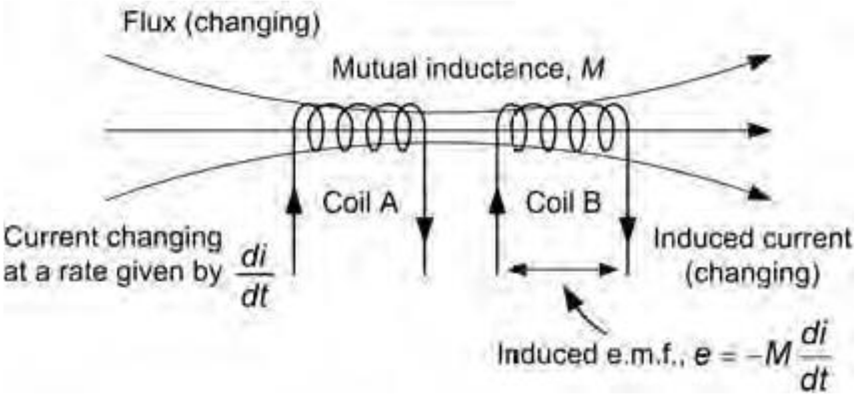


Figure 1.31 Mutual inductance

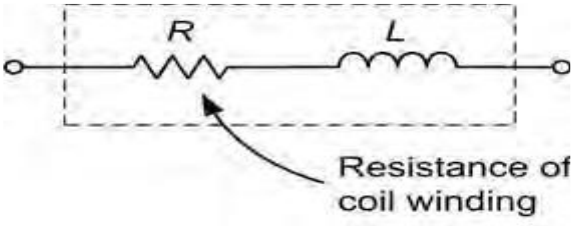


Figure 1.32 A real inductor has resistance as well as inductance

1.6.4 Inductors

Inductors provide us with a means of storing electrical energy in the form of a magnetic field. Typical applications include chokes, filters, and frequency selective circuits. In reality the inductance, L , and resistance, R , are both distributed throughout the component but it is convenient to treat the inductance and resistance as separate components in the analysis of the circuit

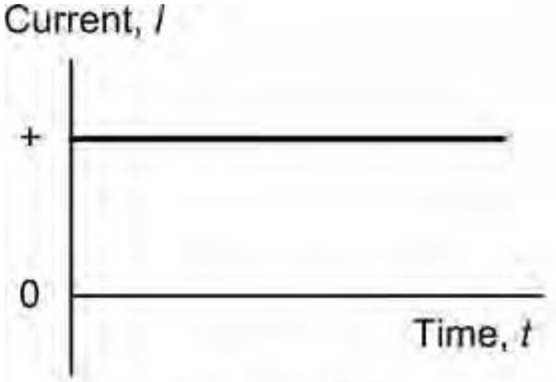
1.7 Alternating current and transformers

Direct currents

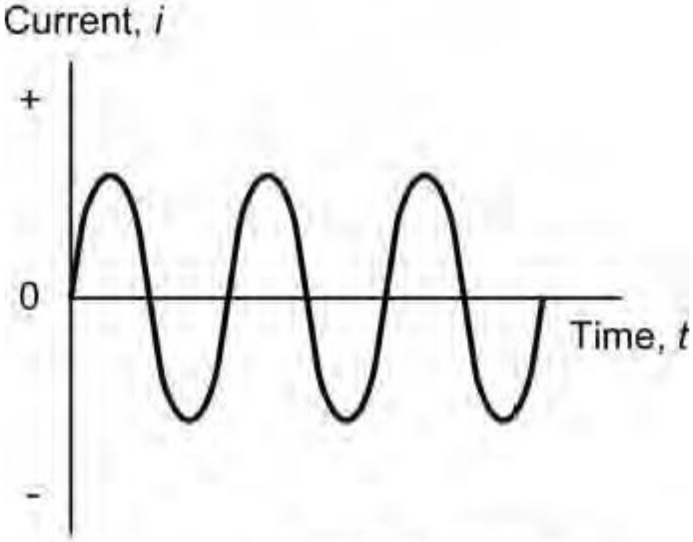
Direct currents are currents which, even though their magnitude may vary, essentially flow only in one direction. Direct currents are unidirectional.

Alternating currents, on the other hand, are bidirectional and continuously reversing their direction of flow

A graph showing the variation of voltage or current present in a circuit is known as a **waveform**



(a) Direct current



(b) Alternating current

Figure 1.34 Comparison of direct and alternating current

There are many common types of waveform encountered electrical circuits including sine (or sinusoidal),square, triangle, ramp or saw tooth (which maybe either positive or negative), and pulse. Complex waveforms like speech or music usually comprise many components at different frequencies.

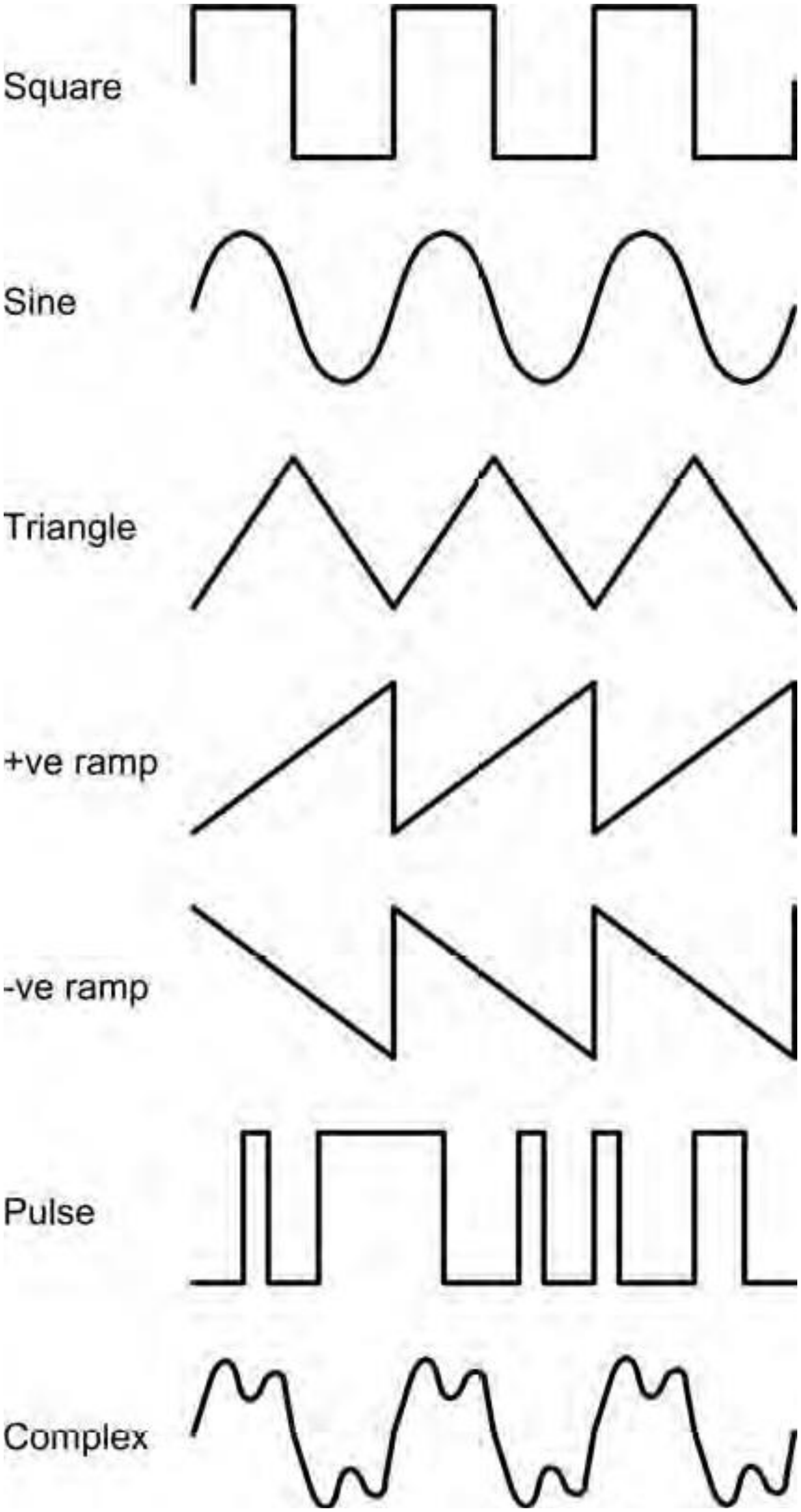


Figure 1.35 Various waveforms

1.7.1 Frequency and periodic time

The **frequency** of a repetitive waveform is the number f cycles of the waveform that occur in unit time .Frequency is expressed in **hertz** (**Hz**). A frequency of 1 Hz is equivalent to one cycle per second .

The **periodic time** (or **period**) of a waveform is the time taken for one complete cycle of the wave

The relationship between periodic time and frequency is thus:

$$t = \frac{1}{f} \qquad \text{OR} \qquad f = \frac{1}{t}$$

where *t* is the periodic time (in seconds)
and *f* is the frequency (in Hz).

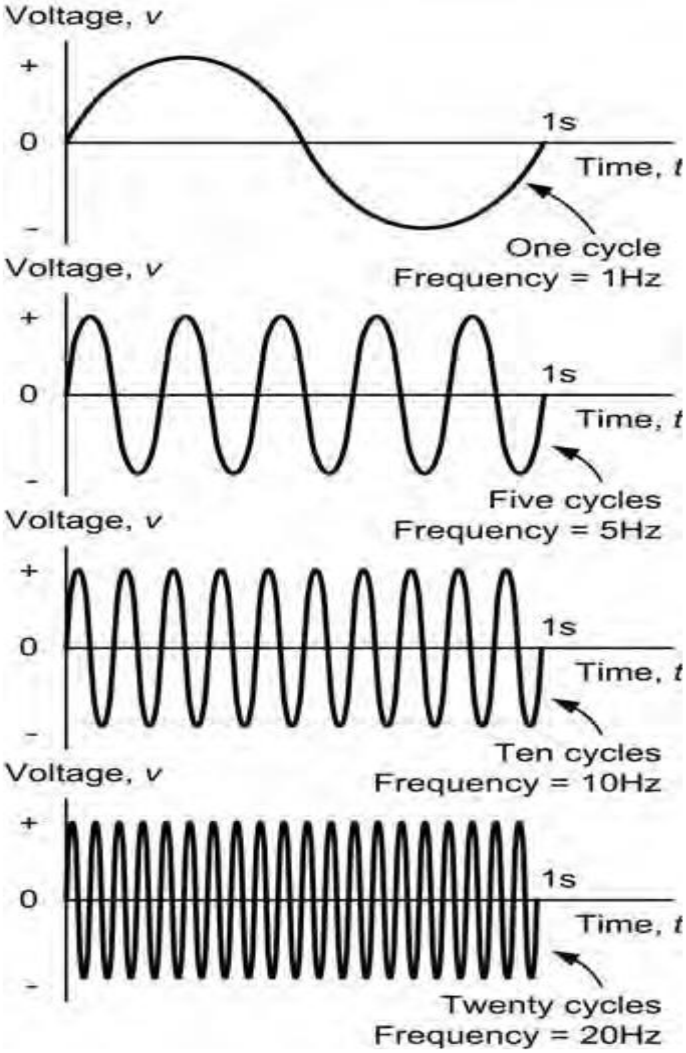


Figure 1.36 Waveforms with different frequencies

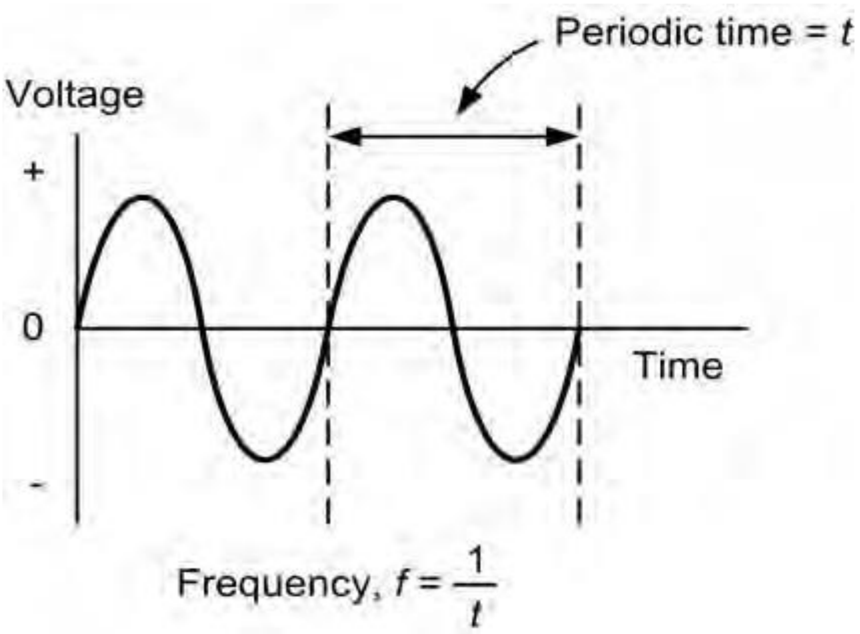


Figure 1.37 Periodic time

1.7.2 Average, peak, peak–peak, and r.m.s. values

The **average value** of an alternating current which swings symmetrically above and below zero will obviously be zero when measured over a long period of time. Hence average values of currents and voltages are invariably taken over one complete half cycle(either positive or negative) rather than over on complete full cycle (which would result in an average value of zero).

The **peak value** (or **maximum value** or **amplitude**) of a waveform is a measure of the extent of its voltage or current excursion from the resting value(usually zero). The peak-to-peak value for a wave which is symmetrical about its resting value is twice its peak value.

The **root mean square** (**r.m.s.**) or **effective value** of an alternating voltage or current is the value which would produce the same heat energy in a resistor as a direct voltage or current of the same magnitude. Since the r.m.s. value of a waveform is very much dependent upon its shape, values are only meaningful when dealing with a waveform of known shape. Where the shape of a waveform is not specified, r.m.s. values are normally assumed to refer to sinusoidal conditions.

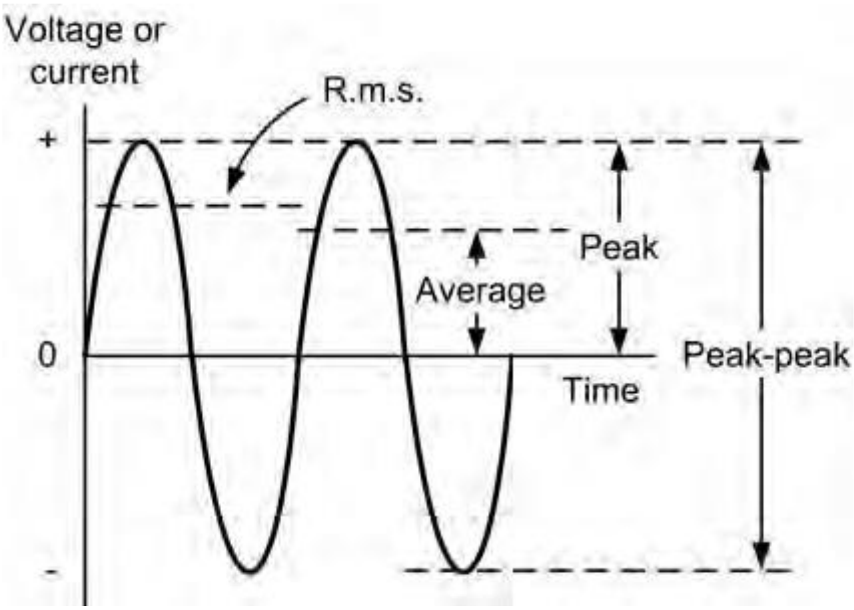


Figure 1.38 Average, r.m.s., peak and peak–peak values of a sine wave

1.7.3 Three-phase supplies

The most simple method of distributing an AC supply is a system that uses two wires. In fact, this is how AC is distributed in your home (the third wire present is simply an earth connection for any appliances that may be the most common system uses three separate voltage sources (and three wires) and is known as **three phase**

The voltages produced by the three sources are equally in time such that the angle between them is 120° (or 360°/3). The waveforms for a three phase supply are shown in Fig. 1.37 quire it for safety reasons).In many practical applications, including aircraft, it can be advantageous to use a **multiphase** supply rather than a **single-phase** supply

1.7.4 Reactance

In an AC circuit, **reactance** , like resistance, is simply the ratio of applied voltage to the current flowing. Thus:

$$I = \frac{V}{X}$$

Where X is the reactance in ohms (Ω),
V is the alternating potential difference in volts (V) and
I is the alternating current in amps (A).

In the case of **capacitive reactance** (i.e. the reactance of a capacitor) we use the suffix, C , so that the reactance equation becomes:

$$X_C = V_C \backslash I_C$$

Similarly, in the case of **inductive reactance** (i.e. the reactance of an inductor) we use the suffix, L, so that the reactance equation becomes:

$$X_L = V_L \backslash I_L$$

The voltage and current in a circuit containing pure reactance (either capacitive or inductive) will be out of phase by 90°. In the case of a circuit containing pure capacitance the current will lead the voltage by90° (alternatively we can say that the voltage lags the current by 90°). This relationship is illustrated by the waveforms shown in Fig. 1.40

In the case of a circuit containing pure inductance the voltage will lead the current by 90° (alternatively we can also say that the current lags the voltage by 90°). This relationship s illustrated by the waveforms shown in Fig. 1.41

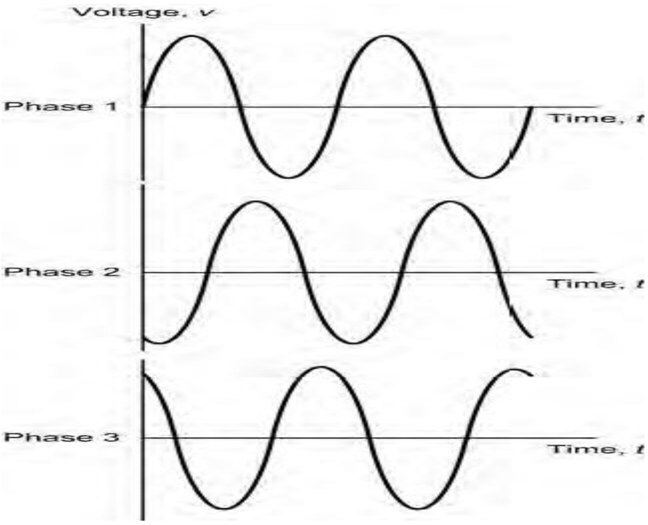


Figure 1.39 Waveforms for a three-phase AC supply

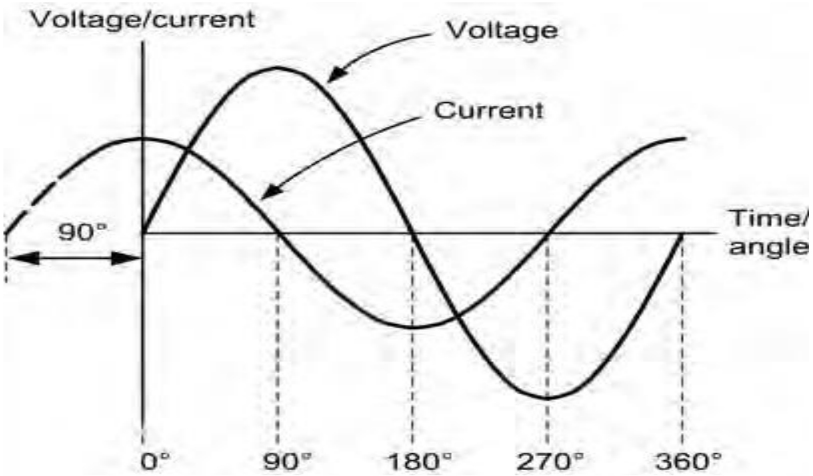


Figure 1.40 Voltage and current waveforms for a pure capacitor (the current leads the voltage by 90°)

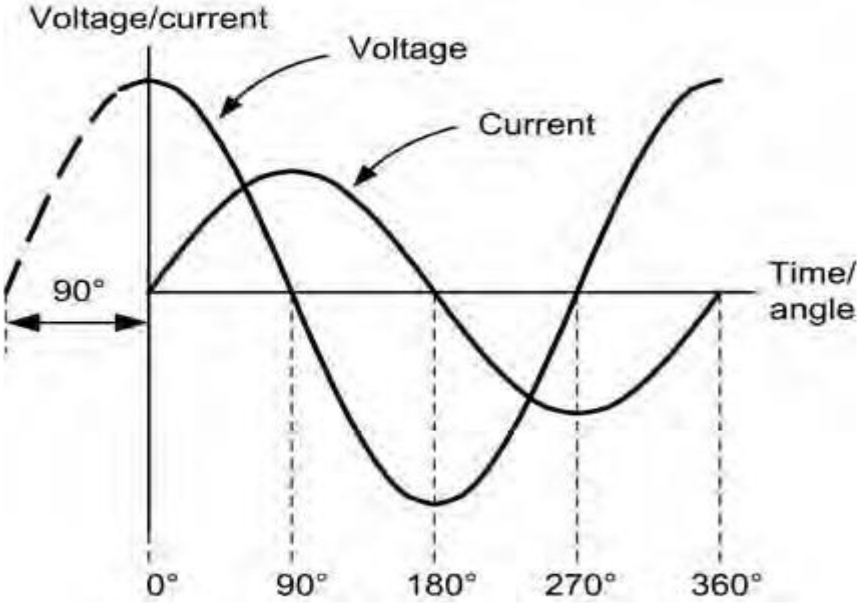


Figure 1.41 Voltage and current waveforms for a pure capacitor (the voltage leads the current by 90°)

The reactance of an inductor (**inductive reactance**)is directly proportional to the frequency of the applied alternating current and can be determined from the following formula:

$$X_L=2\pi fL$$

where X_L is the reactance in Ω ,
f is the frequency inHz, and
L is the inductance in H.

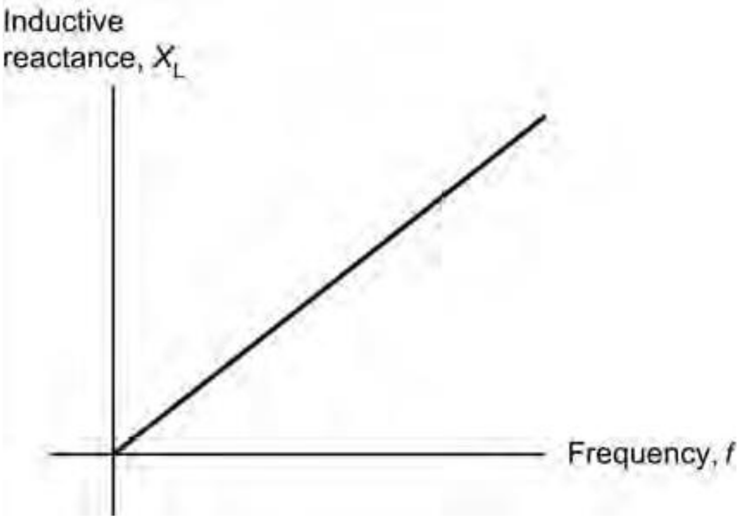


Figure 1.43 Variation of inductive reactance *X* L , with frequency, *f*

The reactance of a capacitor (**capacitive reactance**) is inversely proportional to the frequency of the applied alternating current and can be determined from the following formula:

$$XC = \frac{1}{2\pi fC}$$

where X_C is the reactance in Ω ,
f is the frequency inHz, and
C is the capacitance in F.

Since capacitive reactance is inversely proportional to frequency (*X*L =1/ *f*), the graph of inductive reactance plotted against frequency takes the form of a rectangular hyperbola (see Fig. 1.44).

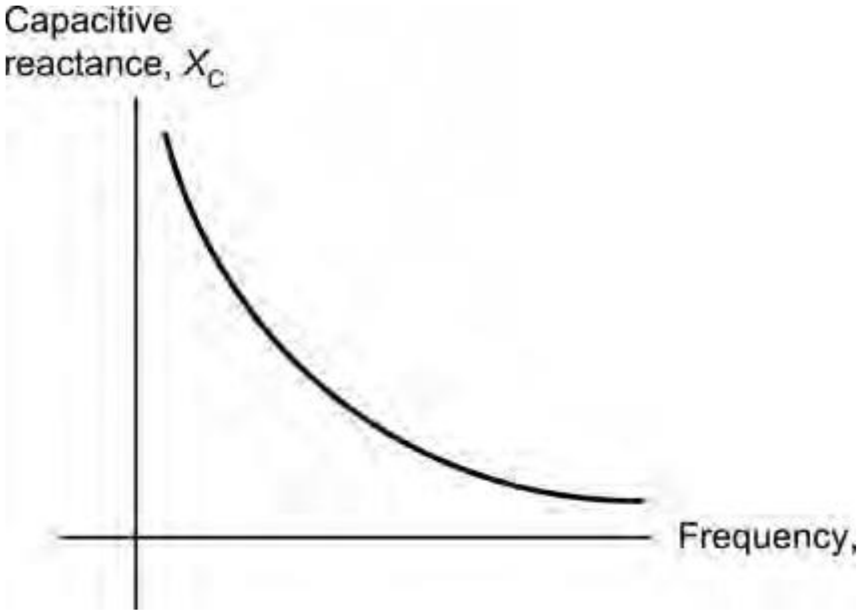


Figure 1.44 Variation of capacitive reactance, *X* C , with frequency,

1.7.5 Impedance

Circuits that contain a mixture of both resistance and reactance (either capacitive reactance or inductive reactance or both) are said to exhibit **impedance** .
Impedance, like resistance and reactance, is simply the ratio of applied voltage to the current flowing.
Thus

$$Z = \frac{V}{I}$$

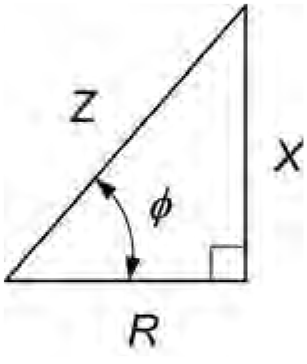


Figure 1.45 The impedance triangle

where *Z* is the impedance in ohms (Ω), *V* is the alternating potential difference in volts (V) and *I* is the alternating current in amps (A).Because the voltage and current in a pure reactance are at 90° to one another (we say that they are in **quadrature**) we can't simply add up the resistance and reactance present in a circuit in order to find its impedance. Instead, we can use the **impedance triangle** shown in Fig. 1.45 .

The impedance triangle takes into account the 90° phase angle and from it we can infer that the impedance of a series circuit (*R* in series with *X*) is given by

$$Z = \sqrt{R^2 + X^2}$$

where *Z* is the impedance (in Ω),

X is the reactance ,either capacitive or inductive (expressed in Ω), and

R is the resistance (also in Ω).

We shall be explaining the significance of the **phase angle** , φ , later on. For now you simply need to be aware that φ is the angle between the impedance ,*Z* , and the resistance, *R* . Later on we shall obtain some useful information from the fact that:

$$\sin\phi = \frac{opposite}{hypotenuse} = \frac{X}{Z} \text{ from which}$$
$$\phi = \arcsin\left(\frac{X}{Z}\right)$$

$$\cos\phi = \frac{adjacent}{hypotenuse} = \frac{R}{Z} \text{ from which}$$
$$\phi = \arccos\left(\frac{R}{Z}\right)$$

and

$$\tan\phi = \frac{opposite}{adjacent} = \frac{X}{R} \text{ from which}$$
$$\phi = \arctan\left(\frac{X}{R}\right)$$

1.7.6 Resonance

It is important to note that a special case occurs when *X*C = *X*L in which case the two equal but opposite reactance’s effectively cancel each other out. The result of this is that the circuit behaves as if only resistance, *R* , is present (in other words, the impedance of the circuit, *Z* =*R*). In this condition the circuit said to be **resonant** . The frequency at which resonance occurs is given by: is said to be **resonant** . The frequency at which resonance occurs is given by:

$$X_C = X_L$$

thus

$$\frac{1}{2\pi fC} = 2\pi fL$$

from which

$$f^2 = \frac{1}{4\pi^2 LC}$$

and thus

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

where *f* is the resonant frequency (in Hz),
L is the inductance (in H) and
C is the capacitance (in F).

POWER FACTOR

1.7.7 Power factor

The power factor in an AC circuit containing resistance and reactance is simply the ratio of true power to apparent power. Hence:

$$\text{Power factor} = \frac{\text{true power}}{\text{apparent power}}$$

The true power in an AC circuit is the power that is actually dissipated as heat in the resistive component. Thus:

$$\text{True power} = I^2R$$

where *I* is r.m.s. current and *R* is the resistance. True power is measured in watts (W).

The apparent power in an AC circuit is the power that is apparently consumed by the circuit and is the product of the supply current and supply voltage (which may not be in phase). Note that, unless the voltage and current are in phase (i.e. φ _ 0°), the apparent power *will not* be the same as the power which is actually dissipated as heat.

Hence: Apparent power = IV

$$\text{Apparent power} = IV$$

where I is r.m.s. current and V is the supply voltage. To distinguish apparent power from true power, apparent power is measured in volt-amperes (VA).

Now since $V = IZ$ we can re-arrange the apparent power equation as follows:

$$\text{Apparent power} = IV = I \times IZ = I^2Z$$

Now returning to our original equation:

$$\text{Power factor} = \frac{\text{true power}}{\text{apparent power}}$$
$$= \frac{I^2R}{IV} = \frac{I^2R}{I \times IZ} = \frac{I^2R}{I^2Z} = \frac{R}{Z}$$

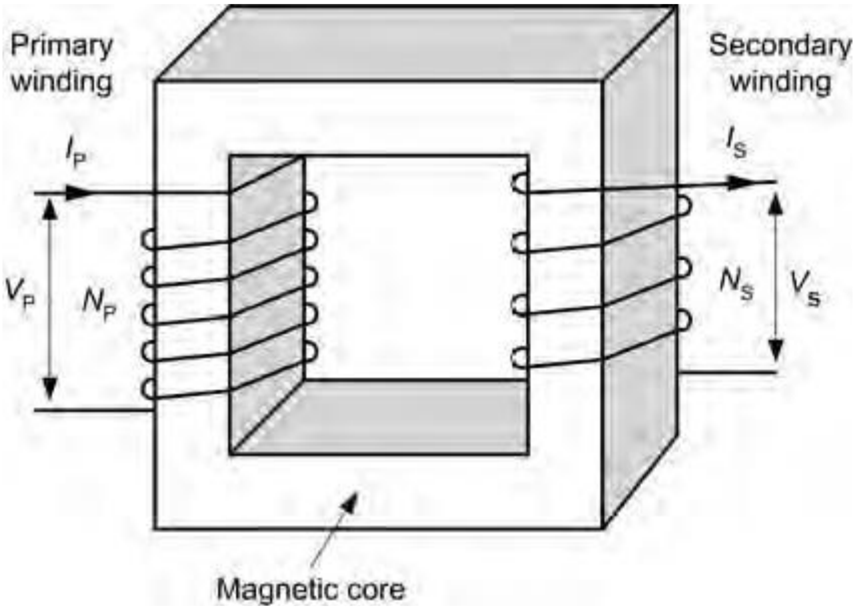
From the *impedance triangle* shown earlier in Fig. 1.43, we can infer that:

$$\text{Power factor} = \frac{R}{Z} = \cos\phi$$

1.7.8 Transformers

Transformers provide us with a means of stepping up or stepping down an AC voltage. For a **step-up transformer,** the output (or **secondary)** voltage will be greater than the input (or **primary)** whilst for a **step-down transformer** the secondary voltage will be less than the primary voltage. Since the primary and secondary power must be the same (no increase in power is possible), an increase in secondary voltage can only be achieved at the expense of a corresponding reduction in secondary current, and vice versa(in fact, the secondary power will be very slightly less than the primary power due to losses within the transformer).

The principle of the transformer is illustrated in Fig. 1.46 . The primary and secondary windings are wound on a common low-reluctance magnetic core consisting of a number of steel laminations. All of the alternating flux generated by the primary winding is therefore coupled into the secondary winding (very little flux escapes due to leakage). A sinusoidal current flowing in the primary winding produces a sinusoidal flux within the transformer core .At any instant the flux, Φ , in the transformer core is given by the equation



$$\Phi = \Phi_{max} \sin(\omega t)$$

where Φ max is the maximum value of flux (in Wb),
f is the frequency of the applied current, and
t is the time in seconds
.

The r.m.s. value of the primary voltage (*V*P) is given by:

$$V_P = 4.44 f N_P \Phi_{max}$$

Similarly, the r.m.s. value of the secondary voltage (*V*P) is given by:

$$V_S = 4.44 f N_S \Phi_{max}$$

From these two relationships (and since the same magnetic flux appears in both the primary and secondary windings) we can infer that:

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

Furthermore, assuming that no power is lost in the transformer (i.e. as long as the primary and secondary powers are the same) we can conclude that:

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$

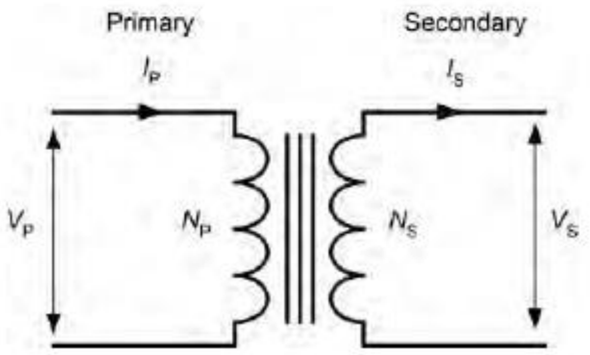


Figure 1.47 Transformer turns and voltages

The ratio of primary turns to secondary turns(*N*P / *N*S) is known as the **turns ratio** . Furthermore, since ratio of primary voltage to primary turns is the same as the ratio of secondary turns to secondary voltage, we can conclude that, for a particular transformer::

$$\text{Turns-per-volt (t.p.v.)} = \frac{V_P}{N_P} = \frac{V_S}{N_S}$$

The turns-per-volt rating can be quite useful when it comes to designing transformers with multiple secondary windings

SAFETY

When working on aircraft electrical and electronic systems, personal safety (both yours and of those around you) should be paramount in everything that you do.

Hazards can exist within many circuits –even those that, on the face of it, may appear to be totally safe.

In advertent misconnection of a supply ,incorrect earthing, reverse connection of components, and incorrect fitting can all result in serious hazards to personal safety as a consequence of fire, explosion or the generation of toxic fumes.

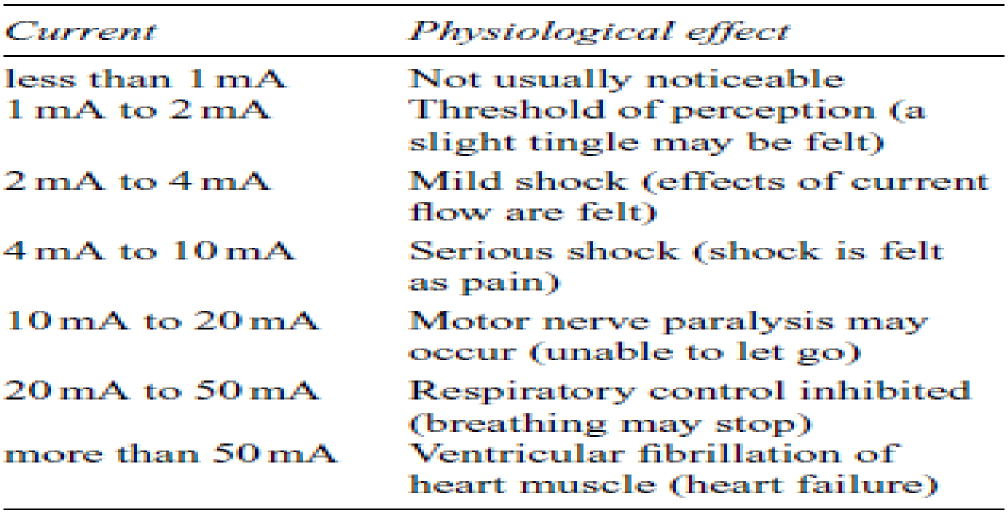
In addition, there is a need to ensure that your work will not compromise the safety and integrity of the aircraft and not endanger the passengers and crew that will fly in it.

Potential hazards can be easily recognized and it is well worth making yourself familiar with them but perhaps the most important point to make is that electricity acts very quickly and you should always think carefully before working on circuits where mains or high voltages (i.e. those over 50 V or so) are present .Failure to observe this simple precaution can result in the very real risk of electric shock.

Voltages in many items of electronic equipment, including all items which derive their power from the aircraft’s 400 Hz AC supply, are at a level which can cause sufficient current flow in the body to disrupt normal operation of the heart. The threshold will be even lower for anyone with a defective heart. Bodily contact with AC supplies and other high-voltage circuits can thus be lethal.

The most critical path for electric current within the body (i.e. the one that is most likely to stop the heart)is that which exists from one hand to the other. The hand-to-foot path is also dangerous but somewhat less dangerous than the hand-to-hand path. So, before you start to work on an item of electronic equipment, it is essential not only to switch off but to disconnect the equipment at the mains by removing the mains plug.

If you have to make measurements or carry out adjustments on a piece of working (or ‘ live ’) equipment ,a useful precaution is that of using one hand only to perform the adjustment or to make the measurement. Your ‘ spare ’ hand should be placed safely away from contact with anything metal (including the chassis of the equipment which may, or may not, be earthed).The severity of electric shock depends upon several factors including the magnitude of the current whether it is alternating or direct current, and its precise path through the body. The magnitude of the current depends upon the voltage which is applied and the resistance of the body. The electrical energy developed in the body will depend upon the time for which the current flows. The duration of contact is also crucial in determining the eventual physiological effects of the shock. As a rough guide, and assuming that the voltage applied is from the aircraft's 400 Hz AC supply, the following effects are typical:



Current	*Physiological effect*
less than 1 mA	Not usually noticeable
1 mA to 2 mA	Threshold of perception (a slight tingle may be felt)
2 mA to 4 mA	Mild shock (effects of current flow are felt)
4 mA to 10 mA	Serious shock (shock is felt as pain)
10 mA to 20 mA	Motor nerve paralysis may occur (unable to let go)
20 mA to 50 mA	Respiratory control inhibited (breathing may stop)
more than 50 mA	Ventricular fibrillation of heart muscle (heart failure)

Other hazards

Various other hazards, apart from electric shock, exist within the environment of an aircraft when work is being carried out on electrical and electronic systems.

For example, accidental movement of the aircraft's spoilers can result in injury and/or damage to equipment .Whenever power sources are changed or when switches or circuit-breakers are opened that may cause movement of spoilers it is essential to ensure that the spoilers are deactivated or that all persons and equipment are removed from the vicinity.

Electronic fundamentals

2.1 Semiconductor theory

1. Materials that combine some of the electrical characteristics of conductors with those of insulators are known as semiconductors
2. Common types of semiconductor material are silicon, germanium, selenium and gallium.
3. it is possible to add foreign atoms (called impurity atoms) to the semiconductor material in order to modify the properties of the semiconductor and allow it to conduct electricity
4. atom contains both negative charge carriers (electrons) and positive charge carriers (protons).
5. Electrons each carry a single unit of negative electric charge while protons each exhibit a single unit of positive charge. Since atoms normally contain an equal number of electrons and protons, the net charge present will be zero.
6. Electrons are in constant motion as they orbit around the nucleus of the atom. Electron orbits are organized into shells. The maximum number of electrons present in the first shell is two, in the second shell eight, and in the third, fourth and fifth shells it is 18, 32 and 50, respectively.
7. The movement of electrons between atoms only involves those present in the outer valence shell .
8. In its pure state, silicon is an insulator because the covalent bonding rigidly holds all of the electrons leaving no free (easily loosened) electrons to conduct current
9. If, however, an atom of a different element (i.e. an impurity) is introduced that has five electrons in its valence shell, a surplus electron will be present (see Fig. 2.2). These free electrons become available for use as charge carriers and they can be mad to move through the lattice by applying an external potential difference to the material.
10. Regardless of whether the impurity element produces surplus electrons or holes, the material will no longer behave as an insulator, neither will it have the properties that we normally associate with a metallic conductor
11. . Instead, we call the material a semiconductor – the term simply indicates that the substance is no longer a good insulator nor a good conductor but has the properties of something between the two!
12. Examples of semiconductors include germanium (Ge) and silicon (Si).
13. The process of introducing an atom of another (impurity) element into the lattice of an otherwise pure material is called doping .

14. When the pure material is doped with an impurity with five electrons in its valence shell (i.e. a pentavalent impurity) it will become an N-type (i.e. negative type) material
15. If the pure material is doped with an impurity having three electrons in its valence shell (i.e. a trivalent impurity) it will become P-type material (i.e. positive type).
16. N-type semiconductor material contains an excess of negative charge carriers, and P-type material contains an excess of positive charge carriers.

2.1.1 Temperature effects

All materials offer some resistance to current flow. In conductors the free electrons rather than passing unobstructed through the material, collide with the relatively large and solid nuclei of the atoms.

As the temperature increases, the nuclei vibrate more energetically, further obstructing the path of the free electrons, causing more frequent collisions. The result is that the resistance of a metal conductor increases with temperature.

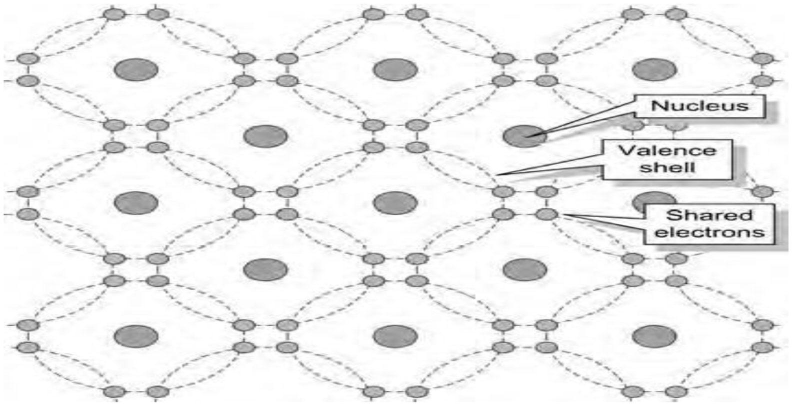


Figure 2.1 Regular lattice structure of a pure semiconductor material

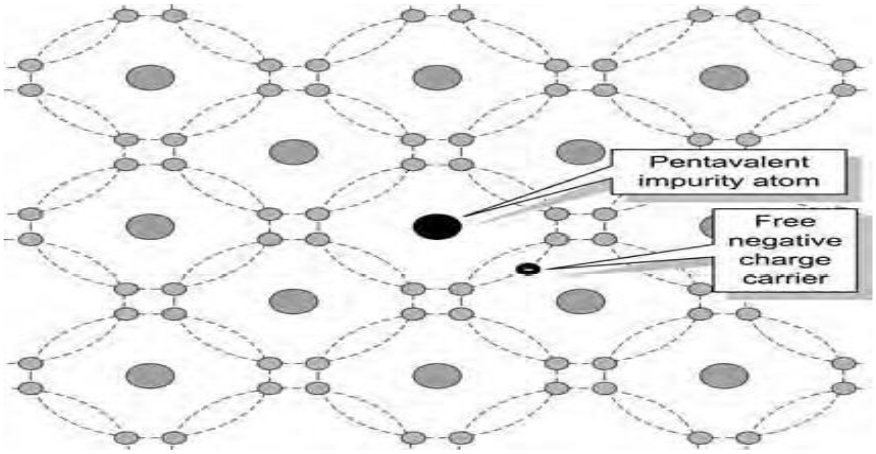


Figure 2.2 Effect of introducing a pentavalent impurity

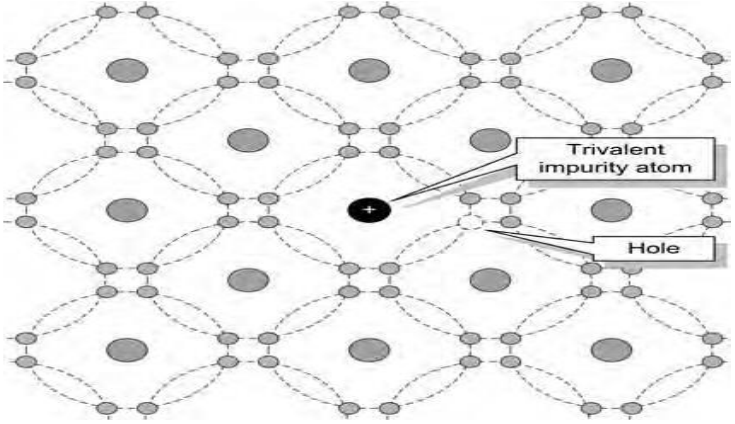


Figure 2.3 Effect of introducing a trivalent impurity

2.1.1 Temperature effects

Due to the nature of the bonding in insulators, there are no free electrons, except that when thermal energy increases as a result of a temperature increase, a few outer electrons manage to break free from their fixed positions and act as charge carriers. The result is that the resistance of an insulator decreases as temperature increases. Semiconductors behave in a similar manner to insulators .At absolute zero (273°C) both types of material act as perfect insulators. However, unlike the insulator, as temperature increases in a semiconductor large numbers of electrons break free act as charge carriers. Therefore, as temperature increases, the resistance of a semiconductor decreases rapidly

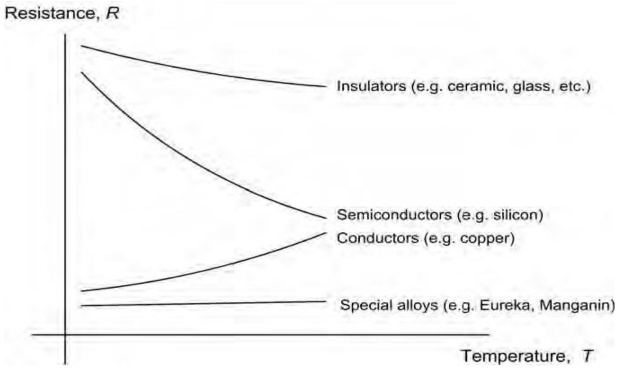


Figure 2.4 Variation of resistance with temperature for various materials

2.2 Diodes

1. When a junction is formed between N-type and P-type semiconductor materials, the resulting device is called a **diode** .
2. This component offers an extremely low resistance to current flow in one direction and an extremely high resistance to current flow in the other.
3. This characteristic allows diodes to be used in applications that require a circuit to behave differently according to the direction of current flowing in it
4. .An ideal diode would pass an infinite current in one direction and no current at all in the other direction .
5. Connections are made to each side of the diode .The connection to the P-type material is referred to as the **anode** while that to the N-type material is called the **cathode** .
6. With no externally applied potential, electrons from the N-type material will cross into the
   P-type region and fill some of the vacant holes. This action will result in the production of a region either side of the junction in which there are no free charge carriers. This zone is known as the **depletion region**
   If a positive voltage is applied to the anode(see Fig. 2.8), the free positive charge carriers in the P-type material will be repelled and they will move away from the positive potential towards the junction.
7. Likewise, the negative potential applied to the cathode will cause the free negative charge carriers in the N-type material to move away from the negative potential towards the junction
8. When the positive and negative charge carriers arrive at the junction, they will attract one another and combine (recall that that unlike charges attract)
9. .As each negative and positive charge carrier combine at the junction, a new negative and positive charge carrier will be introduced to the semiconductor material from the voltage source
10. As these new charge carriers enter the semiconductor material, they will move towards the junction and combine. Thus, current flow is established and it will continue for as long as the voltage is applied.
11. In this **forward-biased** condition the diode freely passes current. If a negative voltage is applied to the anode (see Fig. 2.9), the free positive charge carriers in the P-type material will be attracted and they will move away from the junction.
12. Likewise, the positive potential applied to the cathode will cause the free negative charge carriers in the N-type material to move away from the junction. The combined effect is that the depletion region becomes wider.

13. In this **reverse-biased** condition, the diode passes a negligible amount of current

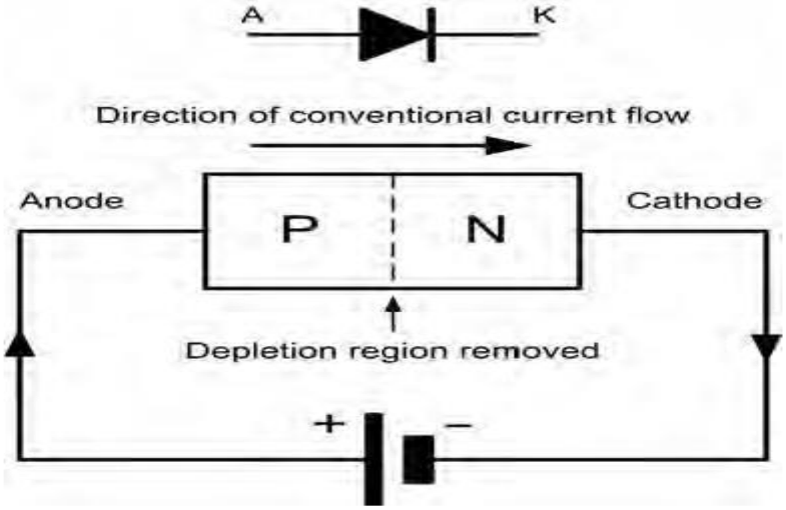


Figure 2.8 A forward-biased P-N junction Diode

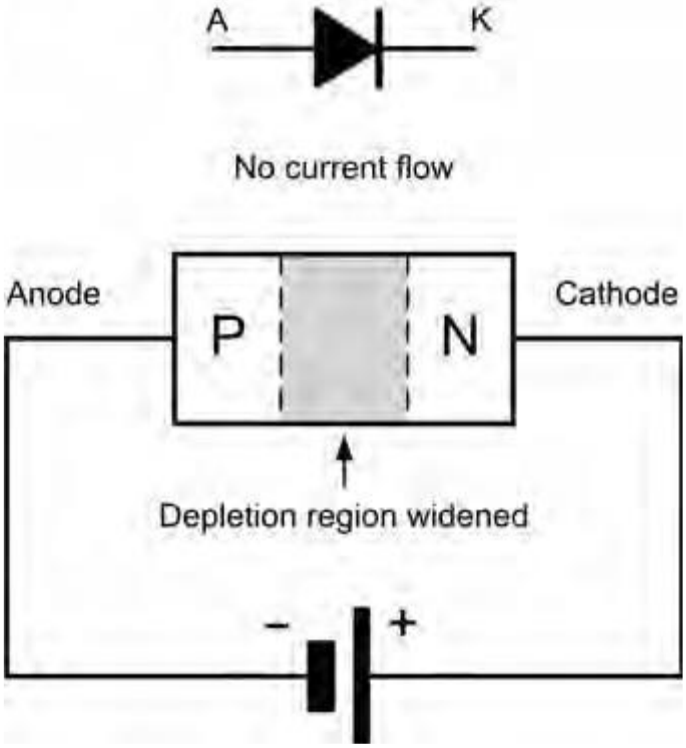


Figure 2.9 A reverse-biased P-N junction Diode

2.2.1 Diode characteristics

Typical *I* / *V* characteristics for germanium and silicon diodes are shown in Fig. 2.10 . It should be noted from these characteristics that the approximate **forward conduction voltage** for a germanium diode is 0.2 V whilst that for a silicon diode is 0.6 V.

This threshold voltage must be high enough to completely overcome the potential associated with the depletion region and force charge carriers to move across the junction.

Diodes are limited by the amount of forward current and reverse voltage they can withstand. This limit is based on the physical size and construction of the diode. In the case of a reverse biased diode, the P-type material is negatively biased relative to the N-type material.

In this case, the negative potential at the P-type material attracts the positive carriers, drawing them away from the junction. This leaves the area depleted; virtually no charge carriers exist and therefore current flow is inhibited.

If the reverse bias potential is increased above the **maximum reverse voltage** (***V*****RM**) or **peak inverse voltage** (**PIV**) quoted by the manufacturer, the depletion region may suffer an irreversible breakdown.

Typical values of maximum reverse voltage range from as low as 50 V to well over 500 V. Note that reverse breakdown voltage is usually very much higher than the forward threshold voltage.

For example, a typical general-purpose diode may be specified as having a forward threshold voltage of 0.6 V and a reverse breakdown voltage of 200 V. If the latter is exceeded, the diode may suffer irreversible Damage

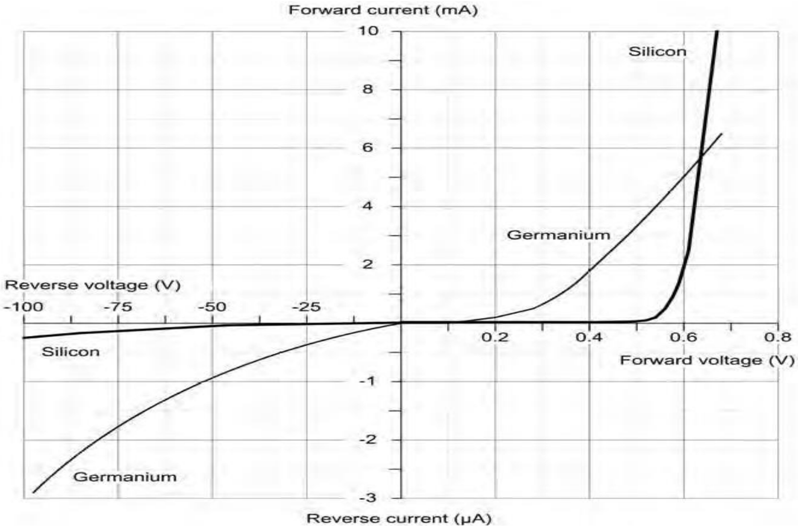


Figure 2.10 Typical *I* / *V* characteristics for germanium and silicon diodes

2.2.2 Zener diodes

Zener diodes are heavily doped silicon diodes that, unlike normal diodes, exhibit an abrupt reverse breakdown at relatively low voltages (typically less than6 V). A similar effect (avalanche) occurs in less heavily doped diodes. These avalanche diodes also exhibit a rapid breakdown with negligible current flowing below the avalanche voltage and a relatively large current flowing once the avalanche voltage has been reached.

For avalanche diodes, this breakdown voltage usually occurs at voltages above 6 V. In practice, however, both types of diode are commonly referred to as Zener diodes. The symbol for a Zener diode was shown earlier in Fig. 2.12 whilst typical Zener diode characteristics are shown in Fig. 2.13 .

Whereas reverse breakdown is a highly undesirable effect in circuits that use conventional diodes, it can be extremely useful in the case of Zener diodes where the breakdown voltage is precisely known.

When a diode is undergoing reverse breakdown and provided its maximum ratings are not exceeded the voltage appearing across it will remain substantially constant(equal to the nominal Zener voltage) regardless of the current flowing.

This property makes the Zener diode ideal for use as a **voltage regulator** .Zener diodes are available in various families(according to their general characteristics, encapsulations and power ratings) with reverse breakdown(Zener) voltages in the range 2.4 V to 91 V.

A simple **voltage regulator** is shown in Fig. 2.14 .The series resistor, *R*S is included to limit the Zenercurrent to a safe value when the load is disconnected. When a load (*R*L) is connected, the Zener current will fall as current is diverted into the load resistance(it is usual to allow a minimum current of 2 mA to 5 mA in order to ensure that the diode regulates). The output voltage will remain at the Zener voltage (*V*Z)until regulation fails at the point at which the potential divider formed by *R*S and *R*L produces a lower output voltage that is less than *V*Z . The ratio of *R*S to *R*L is thus important.

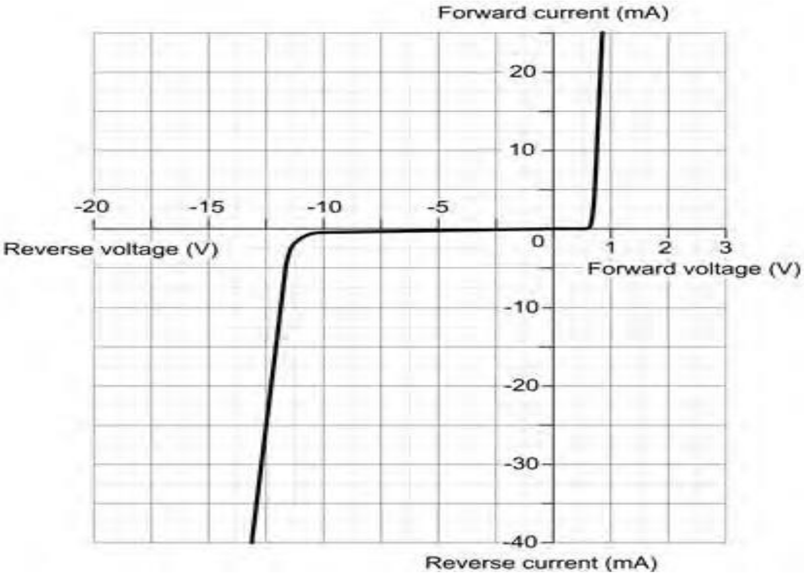


Figure 2.13 Typical Zener diode characteristic

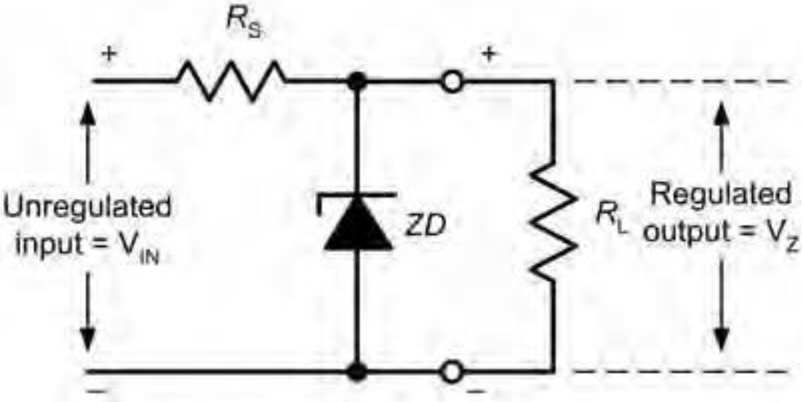


Figure 2.14 A simple Zener diode voltage Regulator

2.2.4 Light-emitting diodes

Light-emitting diodes (LED) can be used as general purpose indicators and, compared with conventional filament lamps, operate from significantly smaller voltages and currents. LEDs are also very much more reliable than filament lamps. Most LEDs will provide a reasonable level of light output when a forward current of between 5 mA and 20 mA is applied.

Light-emitting diodes are available in various formats with the round types being most popular. Round LEDs are commonly available in the 3 mm and 5 mm(0.2 inch) diameter plastic packages and also in a5 mm _ 2 mm rectangular format. The viewing angle for round LEDs tends to be in the region of 20° to40°,

whereas for rectangular types this is increased to around 100°. The symbol for an LED was shown earlier
in Fig. 2.12 .

2.3 Transistors

Typical applications for transistors in aircraft electrical and electronic systems are controlling generator field current, driving lights and warning displays, amplifying signals from sensors and transducers and for use as amplifying devices in cabin interphone and aircraft radio and navigation aids.

BJT

Conventional **bipolar junction transistors** (**BJT**)generally comprise **NPN** or **PNP** junctions of either silicon (Si) or germanium (Ge) material. The junctions are produced in a single slice of silicon by diffusing impurities through a photographically reduced mask. Silicon transistors are superior when compared with germanium transistors in the vast majority of
applications (particularly at high temperatures) and thus germanium devices are very rarely encountered in modern electronic equipment.

The construction of typical NPN and PNP BJT are shown in Figs 2.29 and 2.30 . In order to conduct the heat away from the junction (important in medium and high-power applications) the collector is often connected to the metal case of the transistor.

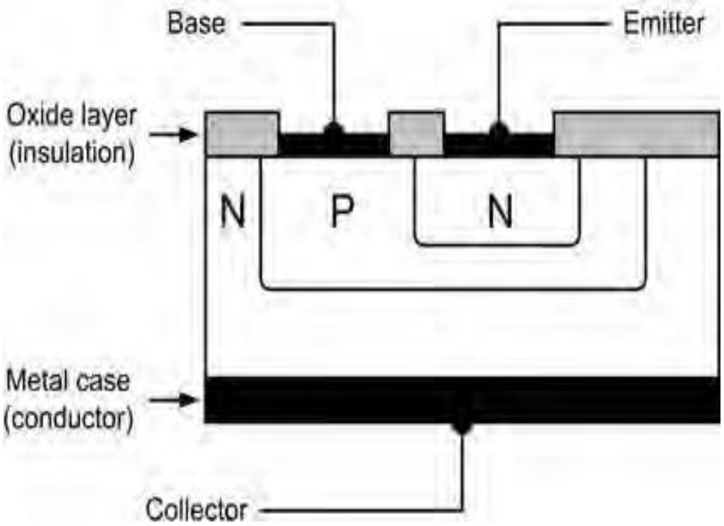


Figure 2.29 Construction of a typical NPN Transistor

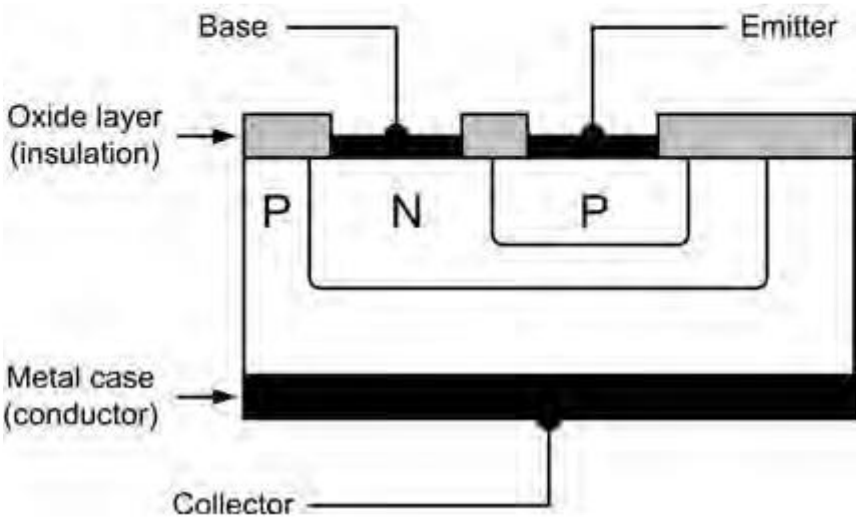
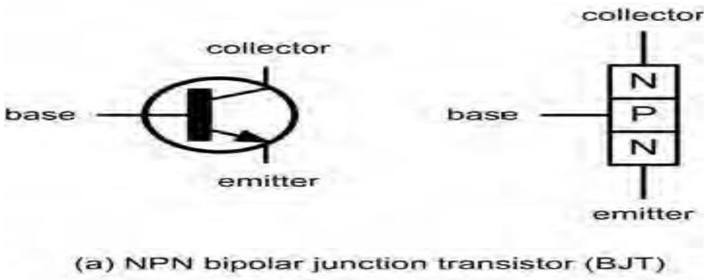
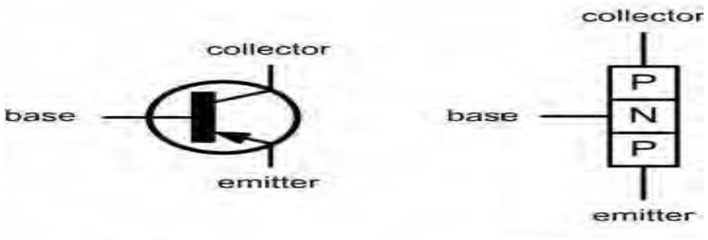


Figure 2.30 Construction of a typical PNP Transistor

The symbols and simplified junction models for NPN and PNP transistors are shown in Fig. 2.31 . It is important to note that the base region (P-type material in the case of an NPN transistor or N-type material in the case of a PNP transistor) is extremely narrow

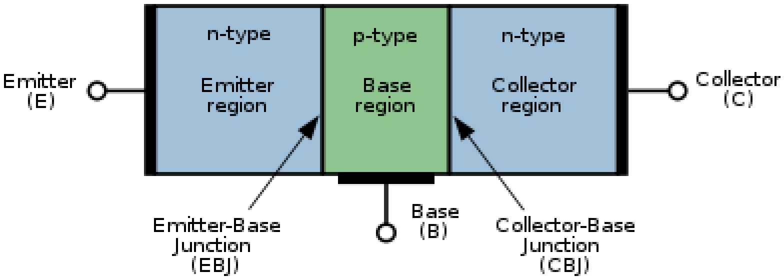


(a) NPN bipolar junction transistor (BJT)



(b) PNP bipolar junction transistor (BJT)

Figure 2.31 NPN and PNP BJT symbols and simplified junction models



WORKING

Figure shows an n-p-n transistor biased in the active region.

the BE junction is forward biased whereas the CB junction is reversed biased.

The width of the depletion region of the BE junction is small as compared to that of the CB junction.

The forward bias at the BE junction reduces the barrier potential and causes the electrons to flow from the emitter to base.

As the base is thin and lightly doped it consists of very few holes so some of the electrons from the emitter (about 2%) recombine with the holes present in the base region and flow out of the base terminal.

This constitutes the base current, it flows due to recombination of electrons and holes (Note that the direction of conventional current flow is opposite to that of flow of electrons).

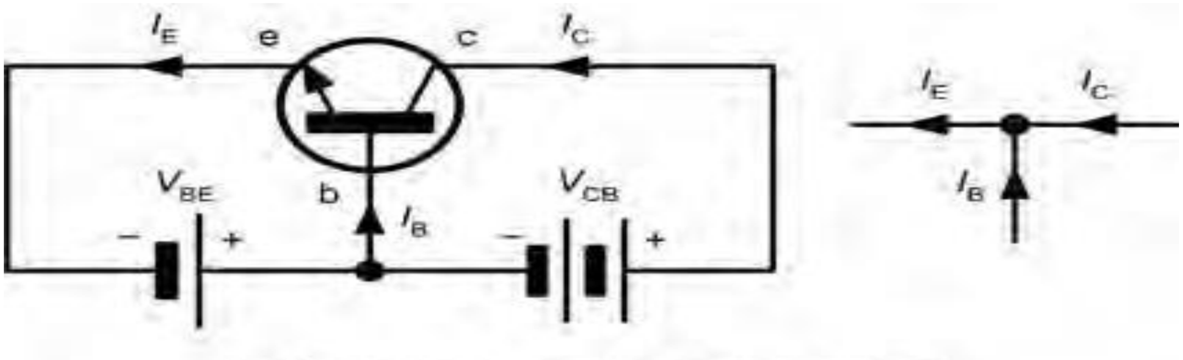
The remaining large number of electrons will cross the reverse biased collector junction to constitute the collector current.

Thus by KCL, $I_E = I_B + I_C$

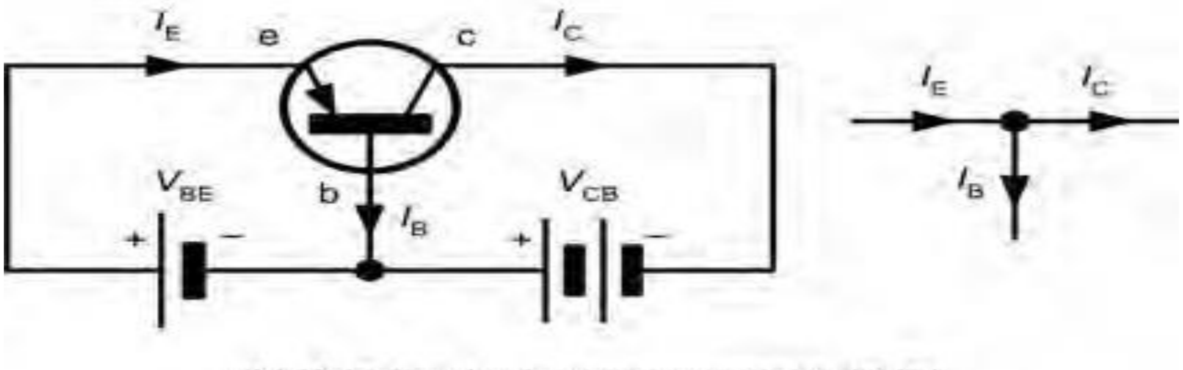
The base current is very small as compared to emitter and collector current. $Therefore,\ I_E \sim I_C$

2.3.1 Bias and current flow

In normal operation (i.e. for operation as a linear amplifier) the base-emitter junction of a transistor is forward biased and the collector base junction is reverse biased. The base region is, however, made very narrow so that carriers are swept across it from emitter to collector so that only a relatively small current flows in the base. To put this into context, the current flowing in the emitter circuit is typically 100 times greater than that flowing in the base. The direction of conventional current flow is from emitter to collector in the case of a PNP transistor, and collector to emitter in the case of an NPN device, as shown in Fig. 2.32 .



(a) NPN bipolar junction transistor (BJT)



(b) PNP bipolar junction transistor (BJT)

Figure 2.32 Bias voltages and current flow in NPN and PNP bipolar junction transistors The equation (based on Kirchhoff 's current law)that relates current flow in the collector, base, and emitter of a transistor (see Fig. 2.32) is:

$$I_E = I_B + I_C$$

where IE is the emitter current,
IB is the base current, and
IC is the collector current (all expressed in the same units)

2.3.2 Transistor characteristics

The characteristics of a bipolar junction transistor are usually presented in the form of a set of graphs relating voltage and current present at the transistors terminals. Figure 2.33 shows a typical **input characteristic** (IB plotted against VBE) for an NPN bipolar junction transistor operating in **common-emitter mode** . In this mode, the input current is applied to the

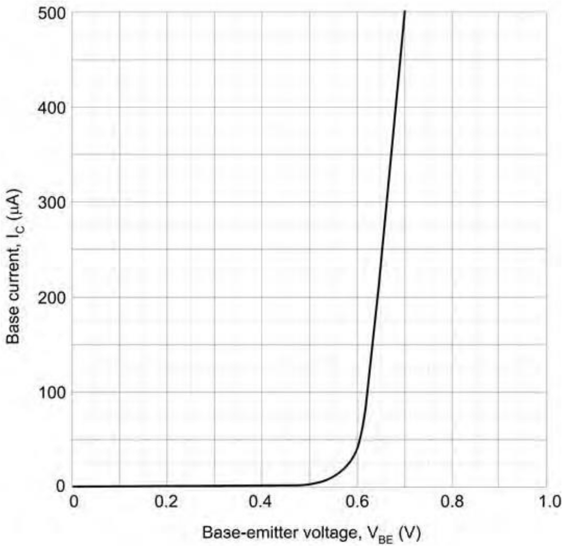


Figure 2.33 Input characteristic (I B / V BE) for an NPN bipolar junction transistor

base and the output current appears in the collector(the emitter is effectively common to both the input and output circuits). The input characteristic shows that very little base current flows until the base emitter voltage *V*BE exceeds0.6 V. Thereafter, the base current increases rapidly (this characteristic bears a close resemblance to the forward part of the characteristic for a silicon diode).

Figure 2.34 shows a typical set of **output (collector) characteristics** (*I*C plotted against *V*CE) for an NPN bipolar transistor. Each curve corresponds to a different value of base current. Note the ' knee ' in the characteristic below *V*CE _ 2 V. Also note that the curves are quite fl at. For this reason (i.e. since the collector current does not change very much as the collector-emitter voltage changes) we often refer to this as a *constant current characteristic*

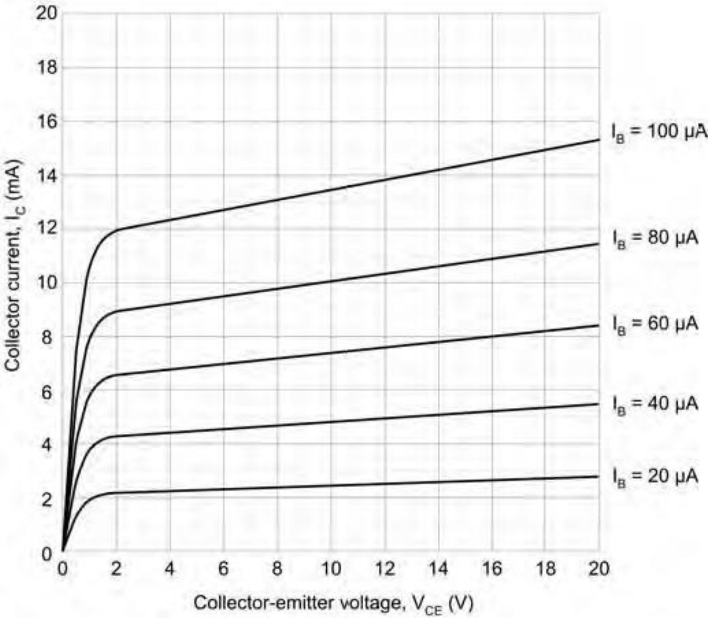
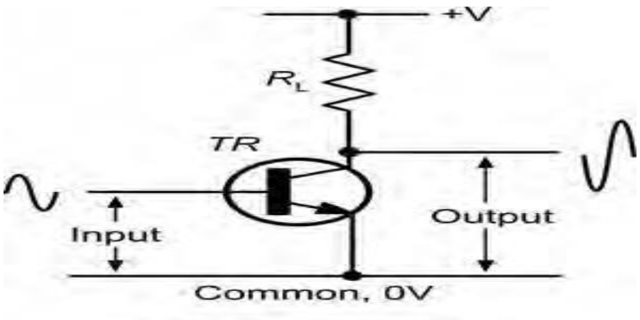


Figure 2.34 Output characteristic (*I* C / *V* CE) for an NPN bipolar junction transistor

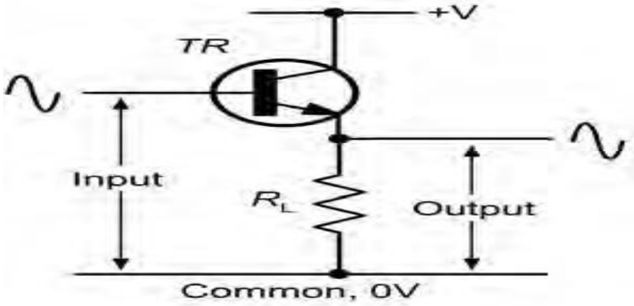
2.3.3 Transistor operating configurations

Three basic circuit arrangements are used for transistor **amplifiers** and these are based on the three circuit configurations that we met earlier (i.e. they depend upon which one of the three transistor connections is made common to both the input and the output). In the case of bipolar transistors, the configurations are known as **common emitter** , **common collector** (or emitter follower) and **common base** . Where field effect transistors are used, the corresponding configurations are common source, common drain (or source follower) and common gate.

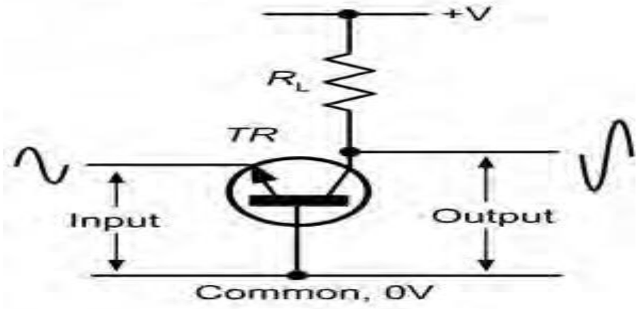
Aircraft logic systems follow the same conventions and standards as those used in other electronic applications. In particular, the MIL/ANSI standard logic symbols are invariably used and the logic elements that they represent operate in exactly the same way as those used in non-aircraft applications. MIL/ANSI standard symbols for the most common logic gates are shown together with their truth tables in Fig. 3.1



(a) Common emitter



(b) Common collector



(c) Common base

Figure 2.38 BJT circuit configurations

3.1 Logic gates

.

3.1.1 Buffers

Buffers do not affect the logical state of a digital signal (i.e. a logic 1 input results in a logic 1 output whereas a logic 0 input results in a logic 0 output).Buffers are normally used to provide extra current drive at the output but can also be used to regularize the logic levels present at an interface.

Inverters are used to complement the logical state (i.e. a logic 1 input results in a logic 0 output and vice versa). Inverters also provide extra current drive and, like buffers, are used in interfacing applications where they provide a means of regularizing logic levels present at the input or output of a digital system.

3.1.2 AND logic

AND gates will only produce a logic 1 output when all inputs are simultaneously at logic 1. Any other input combination results in a logic 0 output.

3.1.3 OR logic

OR gates will produce a logic 1 output whenever any one, or more, inputs are at logic 1. Putting this another way, an OR gate will only produce a logic 0output whenever all of its inputs are simultaneously at logic 0.

3.1.4 NAND logic

NAND (i.e. NOT-AND) gates will only produce a logic 0 output when all inputs are simultaneously at logic 1. Any other input combination will produce a logic 1 output. A NAND gate, therefore, is nothing more than an AND gate with its output inverted .The circle shown at the output of the gate denotes this inversion.

3.1.5 NOR logic

NOR (i.e. NOT-OR) gates will only produce a logic 1output when all inputs are simultaneously at logic 0.Any other input combination will produce a logic 0 output. A NOR gate, therefore, is simply an OR gate with its output inverted. A circle is again used to indicate inversion.

3.1.6 Exclusive-OR logic

Exclusive-OR gates will produce a logic 1 output whenever either one of the two inputs is at logic 1 and the other is at logic 0. Exclusive-OR gates produce a logic 0 output whenever both inputs have the same logical state (i.e. when both are at logic 0 or both are at logic 1).

3.1.7 Exclusive-NOR logic

Exclusive-NOR gates will produce a logic 0 output whenever either one of the two inputs is at logic 1 and the other is at logic 0. Exclusive-NOR gates produce a logic 1 output whenever both inputs have the same logical state (i.e. when both are at logic 0 or both are at logic 1).

3.1.8 Inverted inputs and outputs

The NAND and NOR gates that we have just met are said to have inverted outputs. In other words, they are respectively equivalent to AND and OR gates with their outputs passed through an inverter (or NOT gate) as shown in Fig. 3.2(a) and (b). As well as inverted outputs, aircraft logic systems also tend to show logic gates in which one or more of the inputs are inverted. In Fig. 3.2(c) an AND gate is shown with one input inverted. This is equivalent to an inverter (NOT gate) connected to one input of the AND gate, as shown. In Fig. 3.2(d) an OR gate is shown with one input inverted. This is equivalent to an inverter (NOT gate) connected to one input of the OR gate, as shown .Two further circuits with inverted inputs are shown in Fig. 3.2. In Fig. 3.2(e) both inputs of an AND gate are shown inverted. This

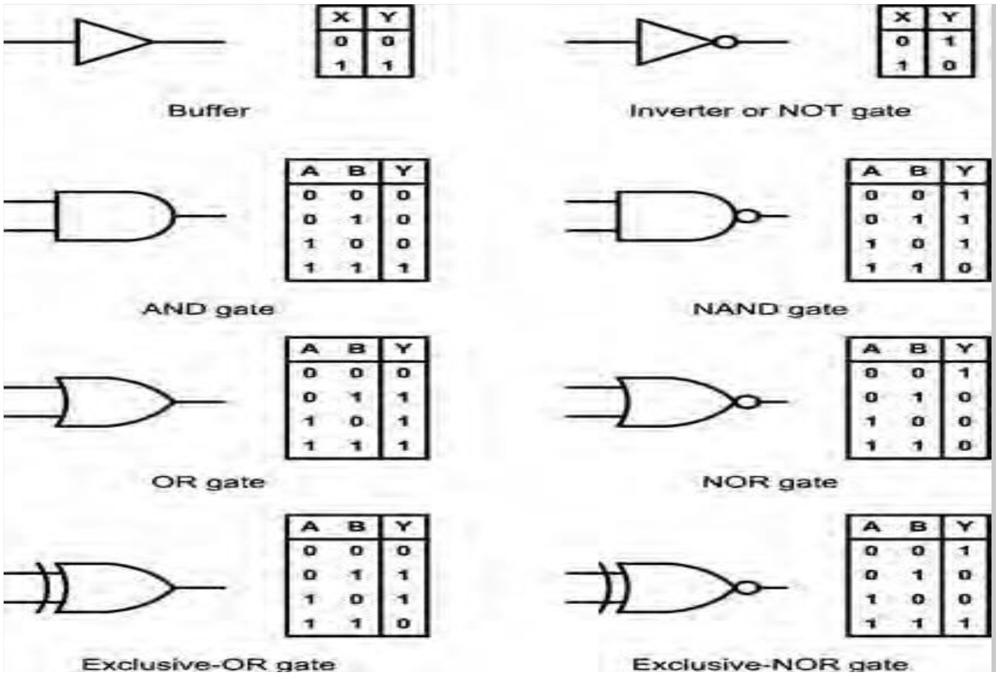


Figure 3.1 MIL/ANSI symbols for standard logic gates together with truth tables

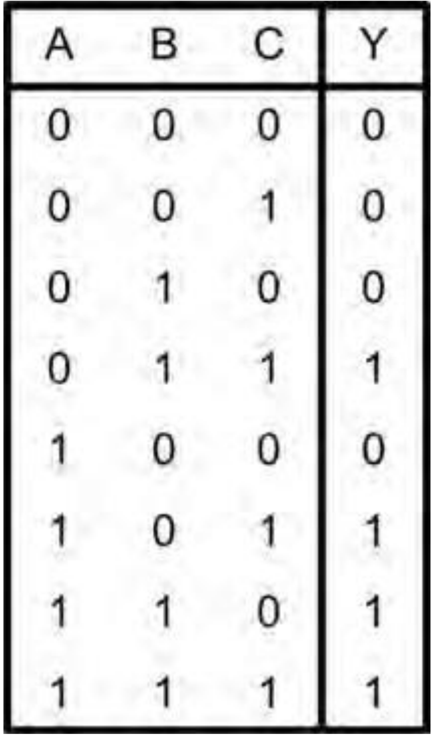
arrangement is equivalent to the two-input NOR gate shown. In Fig. 3.2(f) ,both inputs of an OR gate are shown inverted. This arrangement is equivalent to the two-input NAND gate shown.

3.2 Combinational logic systems

By using a standard range of logic levels (i.e. voltage levels used to represent the logic 1 and logic 0 states) logic circuits can be combined together in order to solve more complex logic functions. As an example, assume that a logic circuit is to be constructed that will produce a logic 1 output whenever two or more of its three inputs are at logic 1. This circuit is referred to as a majority vote circuit and its truth table is shown in Fig. 3.3. Figure 3.4 shows the logic circuitry required to satisfy the truth table

3.2.1 Landing gear warning logic

Now let’s look at a more practical example of the use of logic in the typical aircraft system shown in Fig.3.5. The inputs to this logic system consist of five switches that detect whether or not the respective landing gear door is open. The output from the logic system is used to drive six warning indicators. Four of these are located on the overhead display panel and show which door (or doors) are left open whilst an whilst an indicator located on the pilot’s instrument panel provides a master landing gear door warning. A switch is also provided in order to enable or disable the five door warning indicators



A	B	C	Y
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

Figure 3.3 The majority vote truth table The landing gear warning logic primary module consists of the following integrated circuit devices:

A1 Regulated power supply for A5
A2 Regulated power supply for A7 and A11
A5 Ten inverting (NOT) gates
A7 Five-input NAND gate
A11 Six inverting (NOT) gates

Note that the power supply for A1 and A2 is derived from the essential services DC bus. This is a 28 V DC bus which is maintained in the event of an aircraft power failure. Note also that the indicators are **active-low** devices (in other words, they require a logic 0 input in order to become illuminated).

In order to understand how the landing gear warning logic works it is simple a matter of tracing logic0 and logic 1 states through the logic diagram.

When all of the landing gear doors are closed (normal flight condition) all the inputs to A5 are taken to logic 0 and) all the output from A5 are at logic 0 as is the output from A7 . this , in turn, results in logic 1 input to the indicatorswhich remain in the off (non-illuminated state)

In Fig 3.8 the nose landing gear door is open, in this condition the output of A7 goes to logic 1 and the master warning becomes illuminated on the pilot 's panel . at the same time the nose door open warning becomes illuminated
In fig 3.9 both the left wing and the nose landing gear doors are open . in this condition the output of A7 goes to logic 1 and the master warning becomes illuminated as before. This time however ,both the nose door open and left wing door open warnings become illuminated

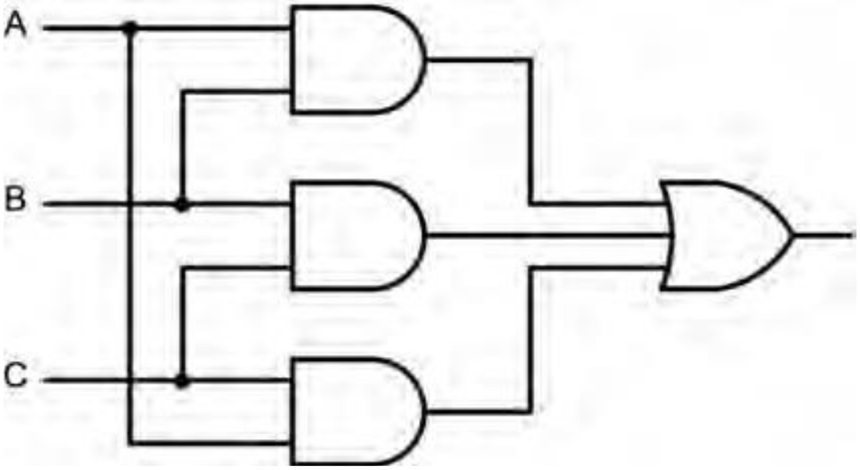


Figure 3.4 The majority vote logic

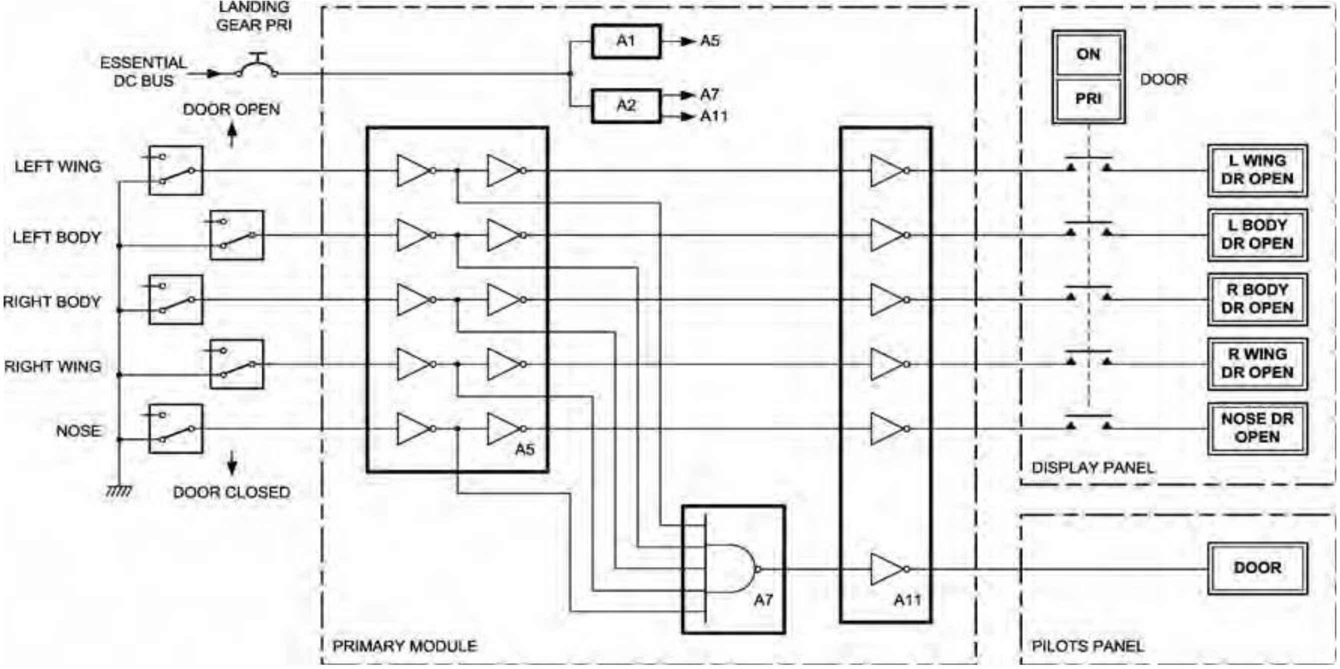


Figure 3.5 Landing gear warning logic

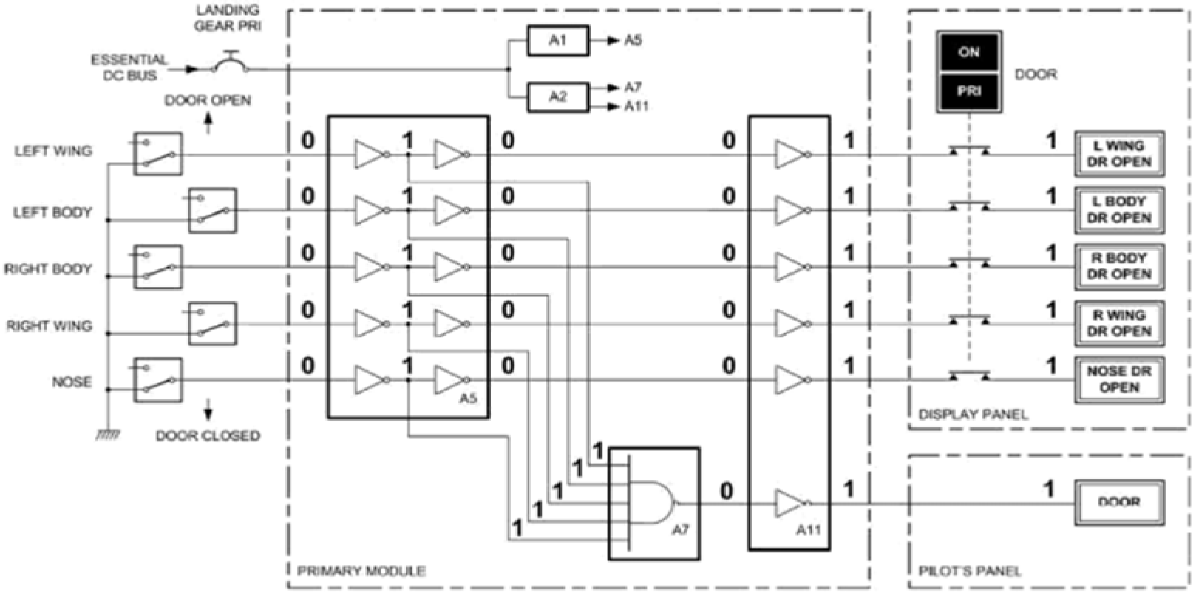


Figure 3.7 Landing gear warning logic with all doors closed (normal in flight condition)

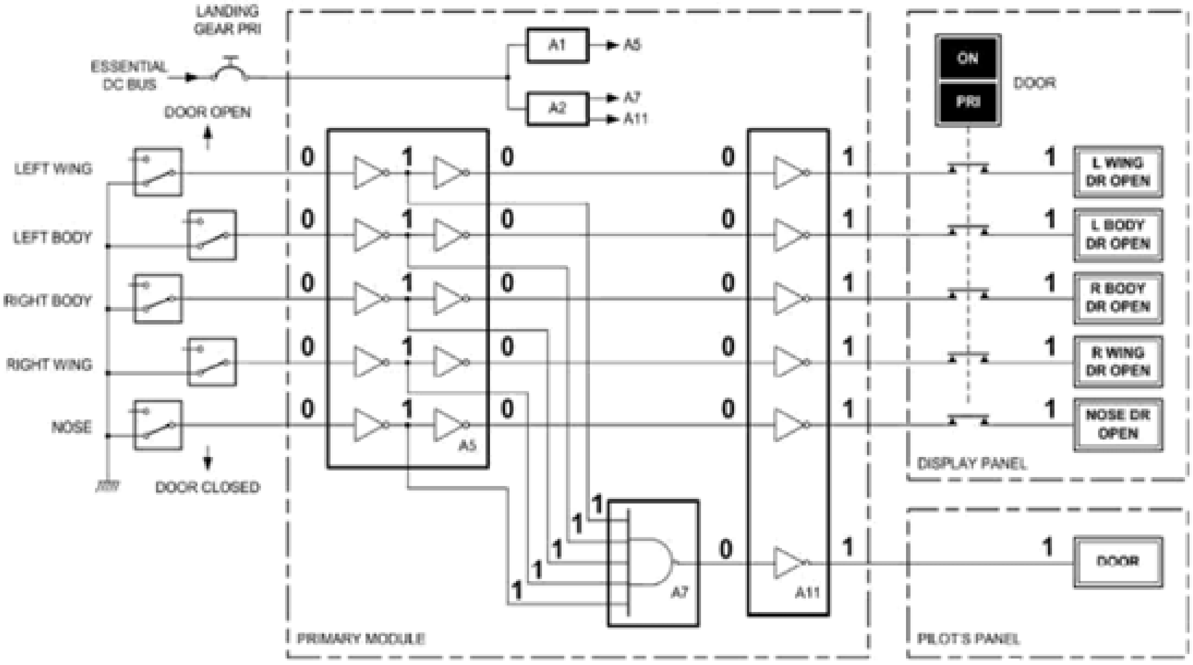


Figure 3.7 Landing gear warning logic with nose door open

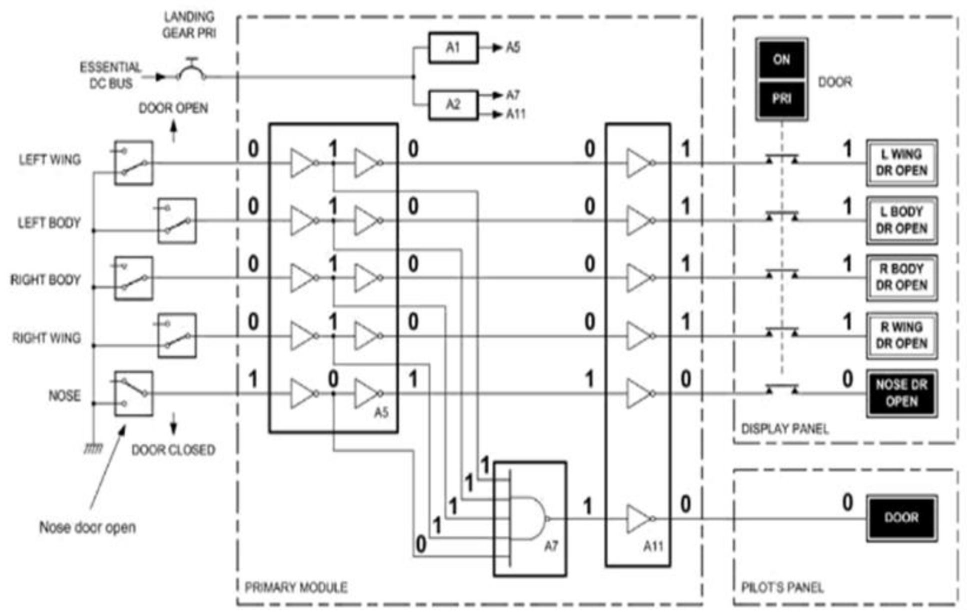


Figure 3.8 Landing gear warning logic with nose and left wing door open

3.3 Monostable devices

Monostable (or one-shot) devices provide us with a means of generating precise time delays. Such delays become important in many logic applications where logic states are not static but change with time. The action of a monostable is quite simple – its output is initially logic 0 until a change of state occurs at its trigger input. The level change can be from 0 to1 (positive edge trigger) or 1 to 0 (negative edge trigger). Immediately the trigger pulse arrives, the output of the monostable changes state to logic 1. The output then remains at logic 1 for a pre-determined period before reverting back to logic 0

3.3.1 APU starter logic

An example of the use of a monostable is shown in the auxiliary power unit (APU) starter logic shown in Fig. 3.9 . This arrangement has three inputs (APUSTART, APU SHUTDOWN, and APU RUNNING)and one output (APU STARTER

MOTOR). The inputs are all active-high (in other words, a logic 1 is generated when the pilot operates the APU START switch, and so on). The output of the APU starter motor control logic goes to logic 1 in order to apply power to the starter motor via a large relay.

There are a few things to note about the logic arrangement shown in Fig. 3.9 :

1. When the APU runs on its own we need to disengage the starter motor. In this condition theAPU MOTOR signal needs to become in active(i.e. it needs to revert to logic 0).

2. We need to avoid the situation that might occur if the APU does not start but the starter motor runs continuously (as this will drain the aircraft batteries). Instead, we should run the starter motor for a reasonable time (say, 60 seconds)before disengaging the starter motor. The 60 second timing is provided by means of a positive edge triggered monostable device. This device is triggered from the APU START signal.

3. Since the pilot is only required to momentarily press the APU START switch, we need to hold the condition until such time as the engine starts or times out (i.e. at the end of the 60 second period).

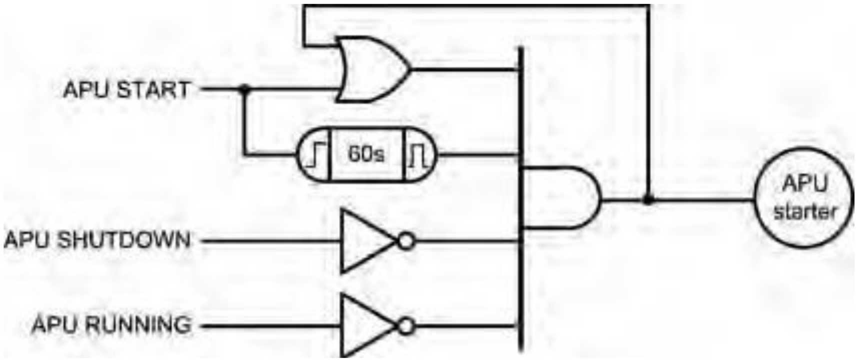


Figure 3.9 APU starter logic

We can achieve this by OR' ing the momentary APU START signal with the APU STARTER MOTOR signal.

4. We need to provide a signal that the pilot can use to shut down the APU (for example, when the
aircraft's main engines are running or perhaps in the event of a fault condition).In order to understand the operation of the APU starter motor logic system we can once again trace through the logic system using 1's and 0's to represent the logical condition at each point (just as we did for the landing gear door warning logic).

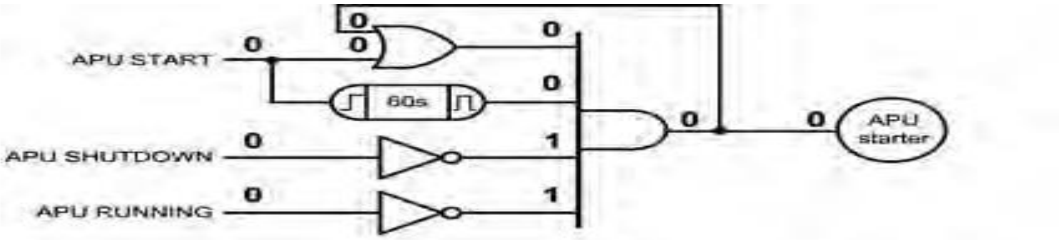
In Fig. 3.10(a) the APU is in normal flight and the APU is not running. In this condition the main engines are providing the aircraft's electrical power.

In Fig. 3.10(b) the pilot is operating the APUSTART switch. The monostable is triggered and output of the OR and AND gates both go to logic 1 in order to assert the APU STARTER MOTOR signal.

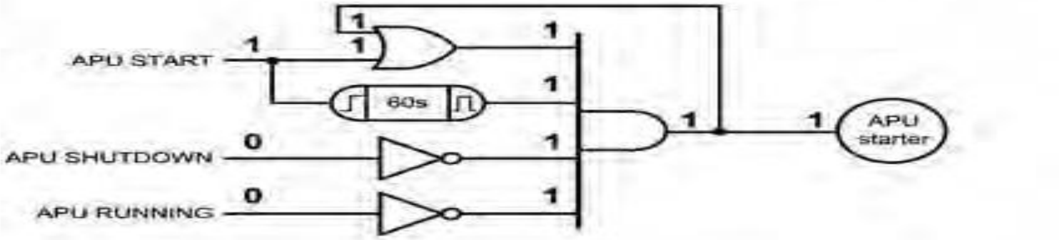
In Fig. 3.10(c) the APU START signal is removed but the output of the AND gate is held at logic 1 by feeding back its logical state via the OR gate. The monostable remains triggered and continues to produce a logic 1 output for its 60 second period.

In Fig. 3.10(d) the APU is now running and the APU RUNNING signal has gone to logic 1 in order to signal this conditions. This results in the output of the AND gate going to logic 0 and the APU STARTERMOTOR signal is no longer made active. The starter motor is therefore disengaged.

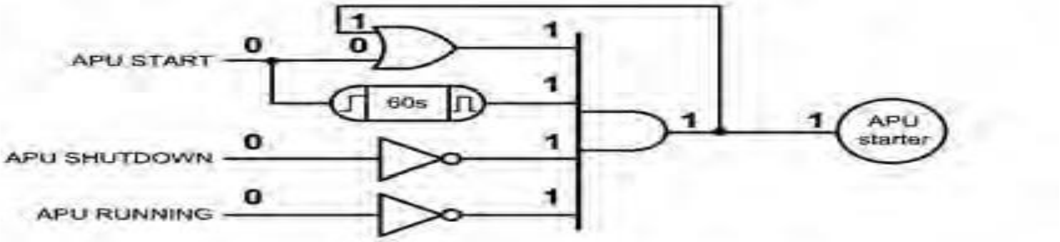
In Fig. 3.10(e) the APU has failed to run during the60 second monostable period. In this timed out condition the output of the AND gate goes to logic 0 and the APU STARTER MOTOR signal becomes in active. The system then waits for the pilot to operate the APU START button for a further attempt at starting!



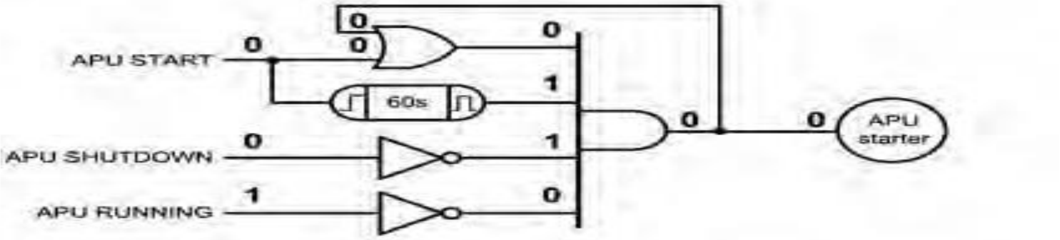
(a) Normal flight; engine power generation; APU not running



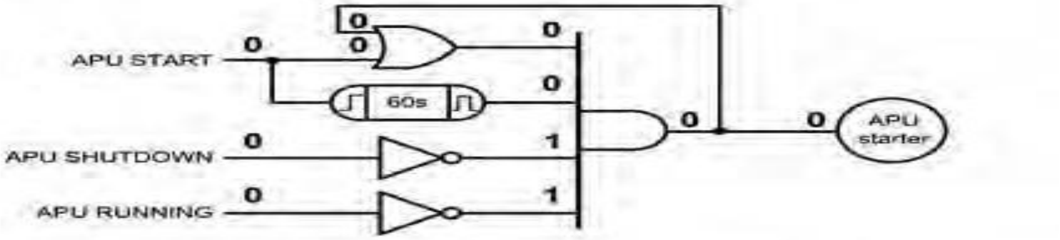
(b) APU starter switch operated; APU starter motor begins to run



(c) APU starter motor continues to run for up to 60s



(d) APU runs before 60s timeout; starter motor stops when APU runs



(e) APU fails to run during 60s period; further APU START signal awaited

Figure 3.10 APU starter operation

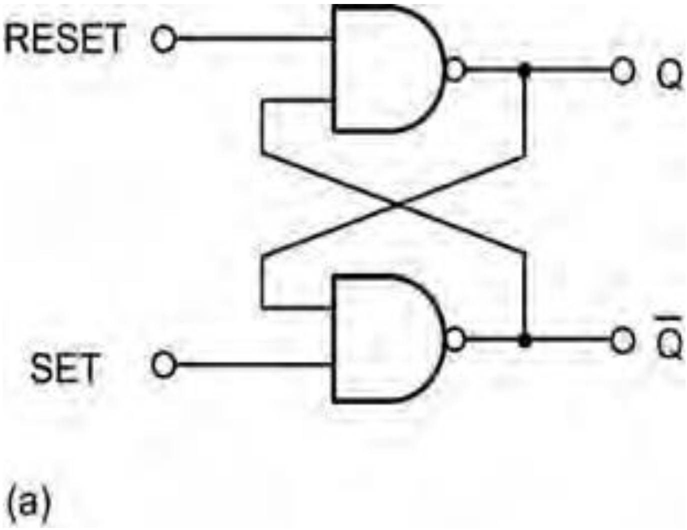
3.4 Bistable devices

A bistable device is a logic arrangement that is capable of ‘ remembering ’ a transient logic state such as a key press or a momentary overload condition. The output of a bistable circuit has two stables states (logic 0 or logic

1). Once **set** in one or other of these states, the output of a bistable will remain at a particular logic level for an indefinite period until **reset** . A bistable thus forms a simple form of memory as it remains in its latched state(either **set** or **reset**) until a signal is applied to it in order to change its state (or until the supply is disconnected).

The simplest form of bistable is the **R-S bistable** . This device has two inputs, SET and RESET, and complementary outputs, Q and /Q. A logic 1 applied to the SET input will cause the Q output to become(or remain at) logic 1 while a logic 1 applied to the RESET input will cause the Q output to become (or remain at) logic 0. In either case, the bistable will remain in its SET or RESET state until an input is applied in such a sense as to change the state.

Two simple forms of R-S bistable based on cross coupled logic gates are shown in Fig. 3.12 . Figure3.12(a) is based on cross-coupled two-input NAND gates while Fig. 3.12(b) is based on cross-coupledtwo-input NOR gates.



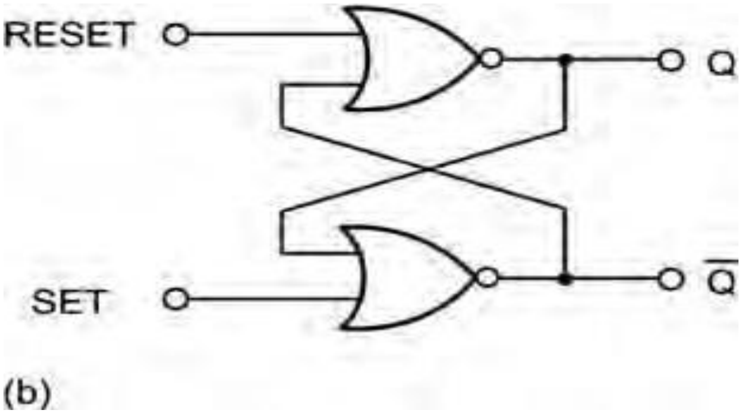


Figure 3.12 Simple R-S bistables based on: (a) NAND gates and (b) NOR gates

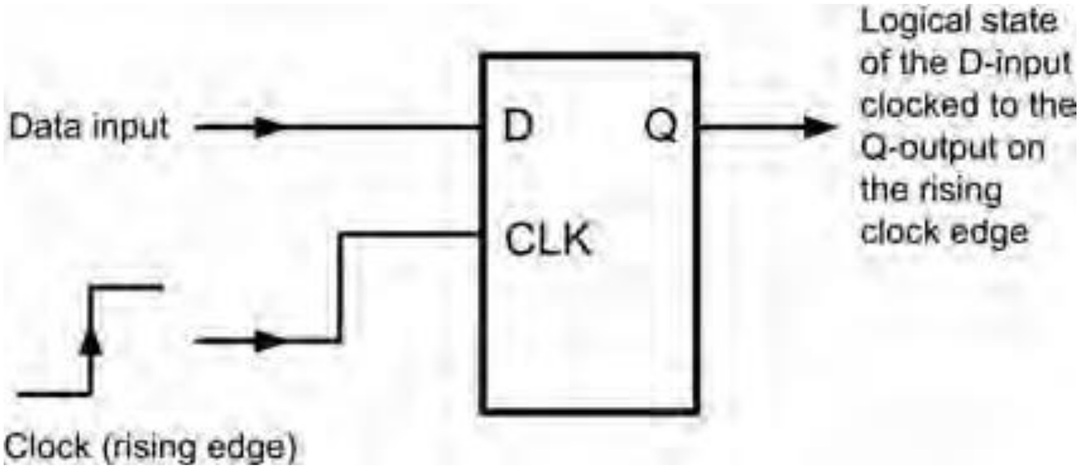


Figure 3.13 D-type bistable

Unfortunately, the simple cross-coupled logic gate bistable has a number of serious shortcomings (consider what would happen if a logic 1 was simultaneously present on both the SET and RESET inputs!)and practical forms of bistable make use of much improved purpose-designed logic circuits such as D-type and J-K bistables.

The **D-type bistable** has two inputs: D (standing variously for ‘ data ’ or ‘ delay ’) and CLOCK (CLK).The data input (logic 0 or logic 1) is clocked into the bistable such that the output state only changes when the clock changes state. Operation is thus said to be synchronous. Additional subsidiary inputs (which are invariably active low) are provided which can be used to directly set or reset the bistable. These are usually called PRESET (PR) and CLEAR (CLR).

D-type bistables are used both as latches (a simple form of memory) and as binary dividers. The simple circuit arrangement in Fig. 3.13 together with the **timing diagram** shown in Fig. 3.14 illustrate the operation, of D-type bistables.

J-K bistables (see Fig. 3.15) have two clocked inputs (J and K), two direct inputs (PRESET and CLEAR), a CLOCK (CK) input, and complementary outputs (And /Q). As with R-S bitable, the two outputs are Complementary (i.e. when one is 0 the other is 1, and vice versa). Similarly, the PRESET and CLEAR inputs are invariably both active low (i.e. a 0 on the PRESET input will set the Q output to 1 whereas a 0 on the CLEAR input will set the Q output to 0). Figure 3.16summarizes the input and corresponding output states of a J-K bistable for various input states. J-K bistables are the most sophisticated and flexible of the bistable types and they can be configured in various ways for use in binary dividers, shift registers, and latches.

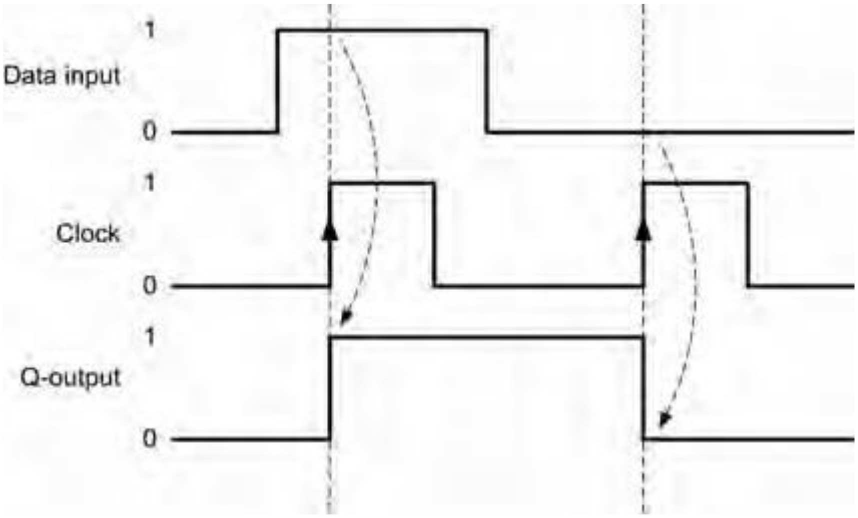
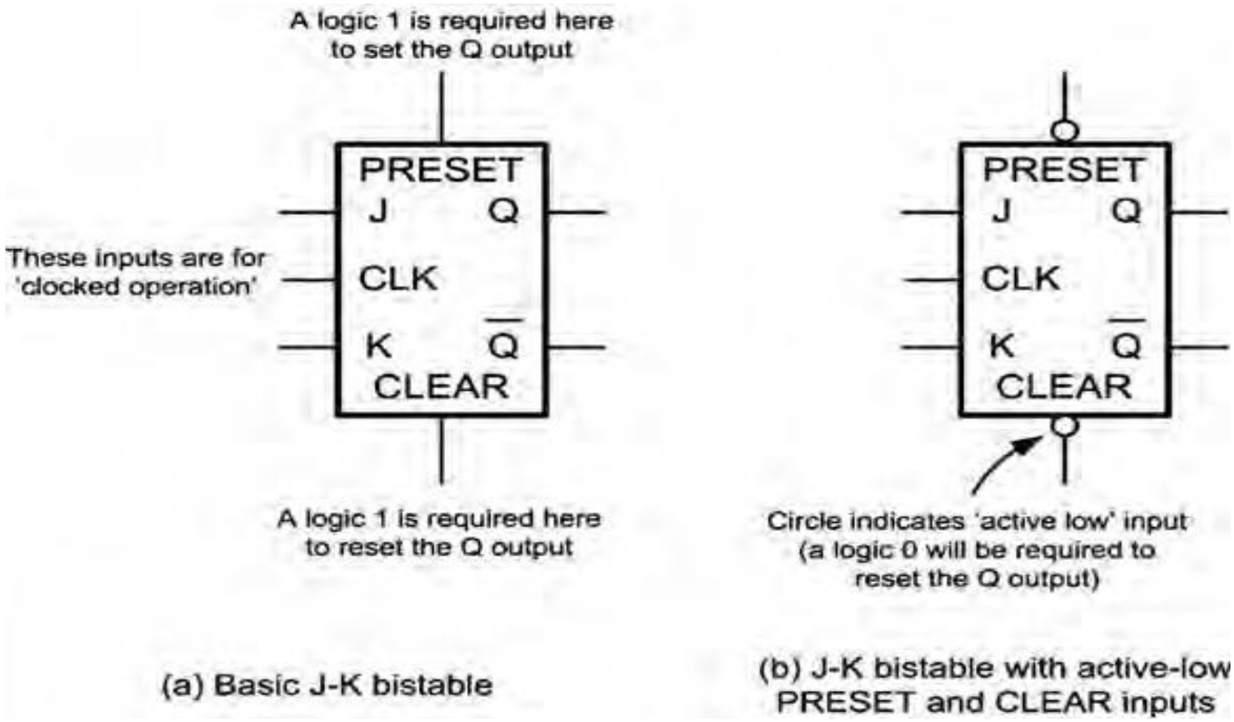


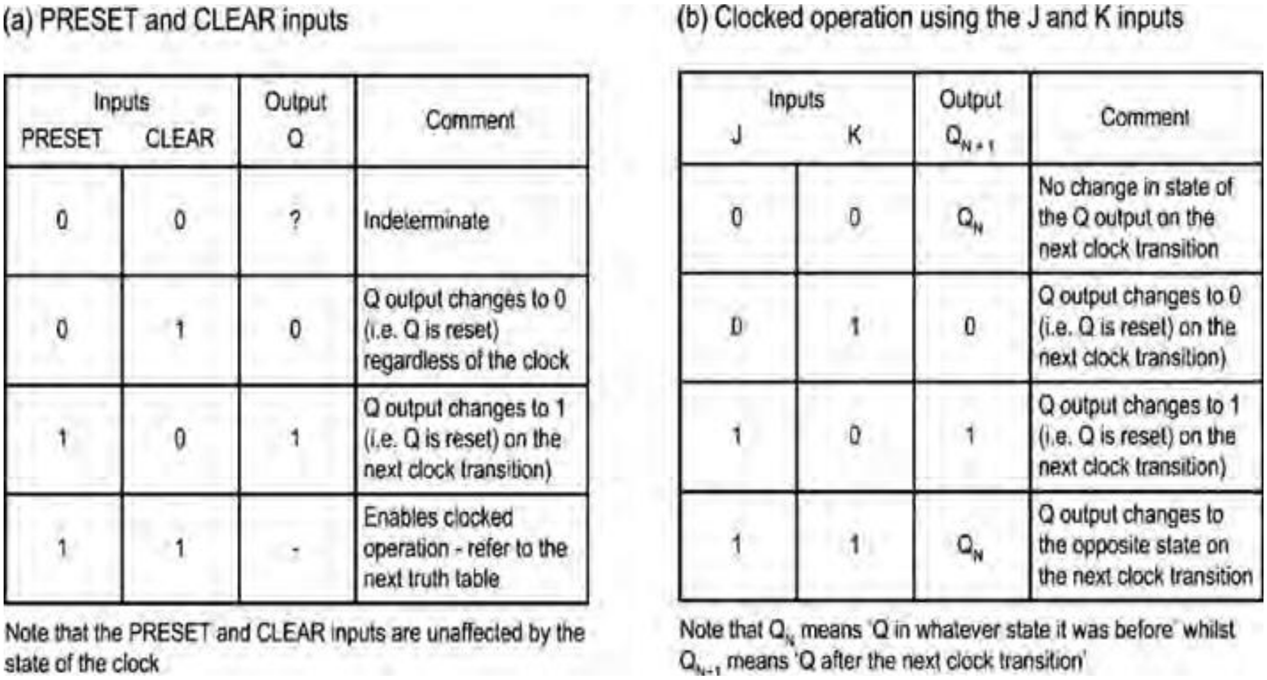
Figure 3.14 Timing diagram for the D-type Bistable



(a) Basic J-K bistable

(b) J-K bistable with active-low PRESET and CLEAR inputs

Figure 3.15 J-K bistable symbols



(a) PRESET and CLEAR inputs

Inputs PRESET	 CLEAR	Output Q	Comment
0	0	?	Indeterminate
0	1	0	Q output changes to 0 (i.e. Q is reset) regardless of the clock
1	0	1	Q output changes to 1 (i.e. Q is reset) on the next clock transition)
1	1	-	Enables clocked operation - refer to the next truth table

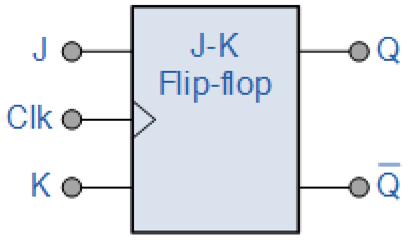
Note that the PRESET and CLEAR inputs are unaffected by the state of the clock

(b) Clocked operation using the J and K inputs

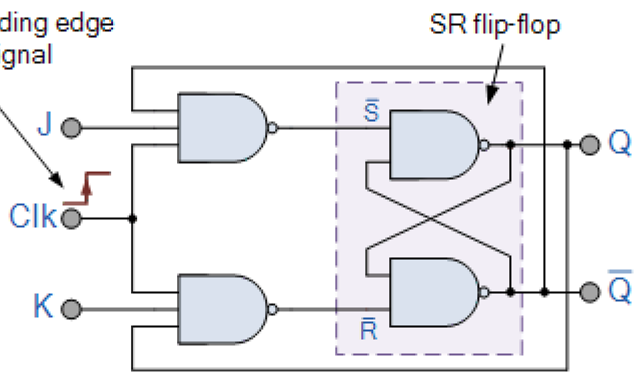
Inputs J	 K	Output Q_{N+1}	Comment
0	0	Q_N	No change in state of the Q output on the next clock transition
0	1	0	Q output changes to 0 (i.e. Q is reset) on the next clock transition)
1	0	1	Q output changes to 1 (i.e. Q is reset) on the next clock transition)
1	1	Q_N	Q output changes to the opposite state on the next clock transition

Note that Q_N means 'Q in whatever state it was before' whilst Q_{N+1} means 'Q after the next clock transition'

Figure 3.16 Truth tables for the J-K bistable



Symbol



Circuit

Truth Table

Trigger	Inputs		Output				Inference
			Present State		Next State		
CLK	J	K	Q	$\bar{Q}$	Q	$\bar{Q}$	
✗	x	x	-		-		Latched
↑	0	0	0	1	0	1	No Change
↑			1	0	1	0	
↑	0	1	0	1	0	1	Reset
↑			1	0	0	1	
↑	1	0	0	1	1	0	Set
↑			1	0	1	0	
↑	1	1	0	1	1	0	Toggles
↑			1	0	0	1	

Table I Truth table for positive-edge triggered JK flip-flop

J = K = 0, Q = 1 and $\bar{Q}$ = 0, then s = R= 0 which results in Q = 1 and $\bar{Q}$ = 0. This indicates that the state of flip-flop outputs Q and $\bar{Q}$ remains unchanged for the case of J = K = 0.

Now assume that J = 0, K = 1 For the same case if Q and $\bar{Q}$ were 1 and 0, respectively, then S= 1 and R = 0 which would result in Q = 0 (and hence $\bar{Q}$ = 1). This implies that if J = 0 and K = 1, then the flip-flop resets (Q = 0 and $\bar{Q}$ = 1

Next if J = 1, K = 0, Q = 1 and $\overline{Q}$ = 0, then $X_1 = X_2 = 0$ which results in Q = 1 (and thus $\overline{Q}$ = 0). this means that for the case of J = 1 and K = 0, flip-flop output will always be set i.e. Q = 1 and $\overline{Q}$ = 0.
Similarly for J = 1, K = 1, Q = 1 and $\overline{Q}$ = 0 one gets X_1 = 1, X_2 = 0 and Q = 0 (and hence $\overline{Q}$ = 1); and if Q changes to 0 and $\overline{Q}$ to 1, then X_1 = 0, X_2 = 1 which forces $\overline{Q}$ to 0 and hence Q to 1. This indicates that for J = K = 1, flip-flop outputs toggle meaning which Q changes from 0 to 1 or from 1 to 0, and these changes are reflected at the output pin $\overline{Q}$ accordingly.

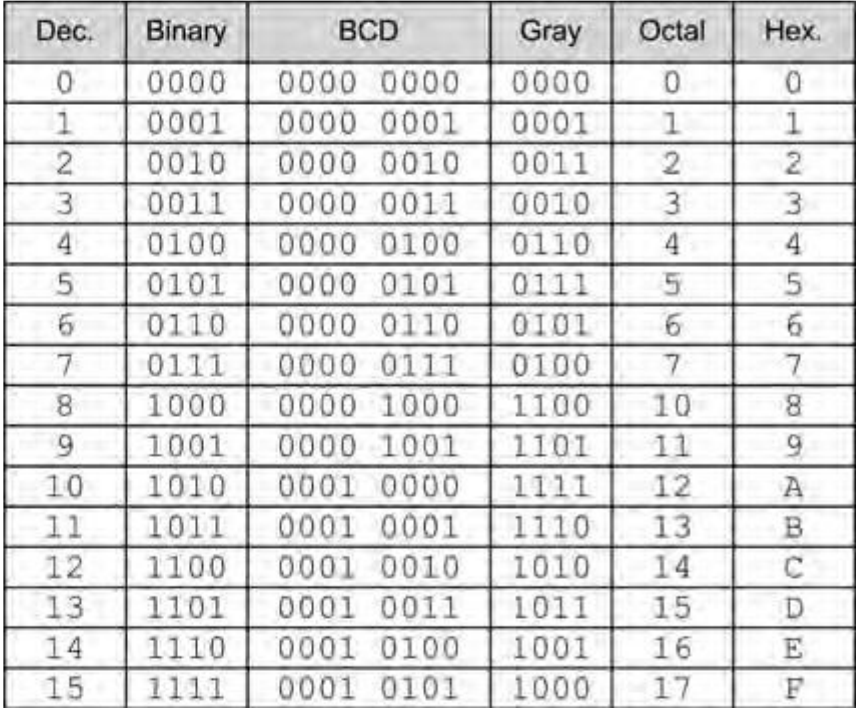
3.5 Decoders

A variety of different coding schemes are used to represent numerical data in avionic systems. They include binary (or, more correctly, **natural binary**), **binary coded decimal** (**BCD**), **Gray code** , **octal** (base 8), and **hexadecimal** (base 16) as shown in Fig. 3.17

BCD uses four digits to represent each numerical character. Thus decimal 11 is represented by 00010001 (or just 10001 omitting the three leading zeros).Gray code is an important code because only one digit changes at a time. This property assists with error correction. Notice also how the least significant three bits of each Gray coded number become reflected after a decimal count of seven. Because of this, Gray code is often referred to as a **reflected code**

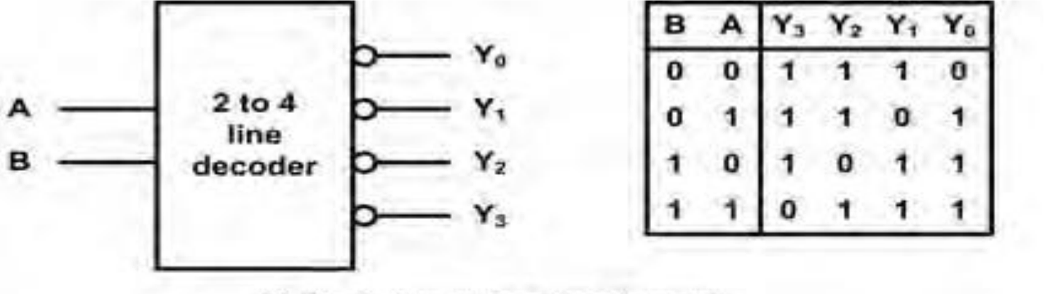
Decoders are used to convert information from one number system to another, such as binary to octal or binary to decimal. A simple two to four line decoder is shown in Fig. 3.18 . In this arrangement there are two inputs, A and B, and four outputs, Y 0 , Y 1 , Y 2 and Y 3 .The binary code appearing on A and B is decoded into one of the four possible states and corresponding output appears on the four output lines with Y 3 being the most significant. Because two to four and three to eight line decoders are frequently used as address decoders in computer systems (where memory and I/O devices are invariably enabled by a low rather than a high state), the outputs are active-low, as indicated by the circles on the logic diagrams.

The internal logic arrangement of a two to four line decoder is shown in Fig. 3.19 . This arrangement uses two inverters and three two-input NAND gates. All four outputs are active-low; Y 0 will go low when A and B are both at logic 0, Y 1 will go low when A is at logic 0 and B is at logic 1, Y 2 will go low when A is at logic 1 and B is at logic 0, and Y 3 will go low when both A and B are at logic 1.



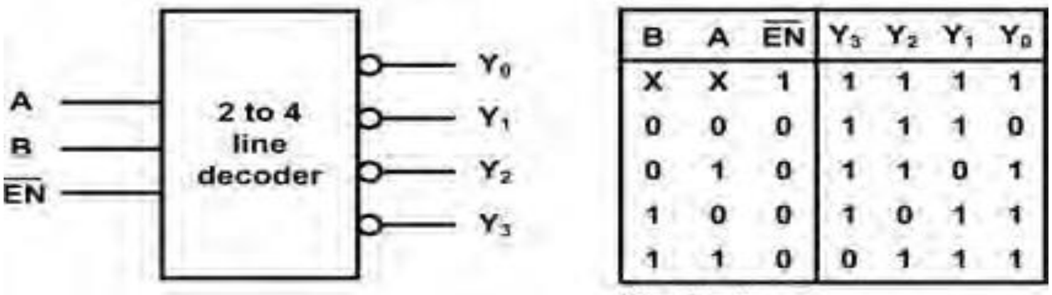
Dec.	Binary	BCD	Gray	Octal	Hex.
0	0000	0000 0000	0000	0	0
1	0001	0000 0001	0001	1	1
2	0010	0000 0010	0011	2	2
3	0011	0000 0011	0010	3	3
4	0100	0000 0100	0110	4	4
5	0101	0000 0101	0111	5	5
6	0110	0000 0110	0101	6	6
7	0111	0000 0111	0100	7	7
8	1000	0000 1000	1100	10	8
9	1001	0000 1001	1101	11	9
10	1010	0001 0000	1111	12	A
11	1011	0001 0001	1110	13	B
12	1100	0001 0010	1010	14	C
13	1101	0001 0011	1011	15	D
14	1110	0001 0100	1001	16	E
15	1111	0001 0101	1000	17	F

Figure 3.17 Various coding schemes for numerical data



B	A	Y_3	Y_2	Y_1	Y_0
0	0	1	1	1	0
0	1	1	1	0	1
1	0	1	0	1	1
1	1	0	1	1	1

(a) Basic two to four line decoder



B	A	$\overline{EN}$	Y_3	Y_2	Y_1	Y_0
X	X	1	1	1	1	1
0	0	0	1	1	1	0
0	1	0	1	1	0	1
1	0	0	1	0	1	1
1	1	0	0	1	1	1

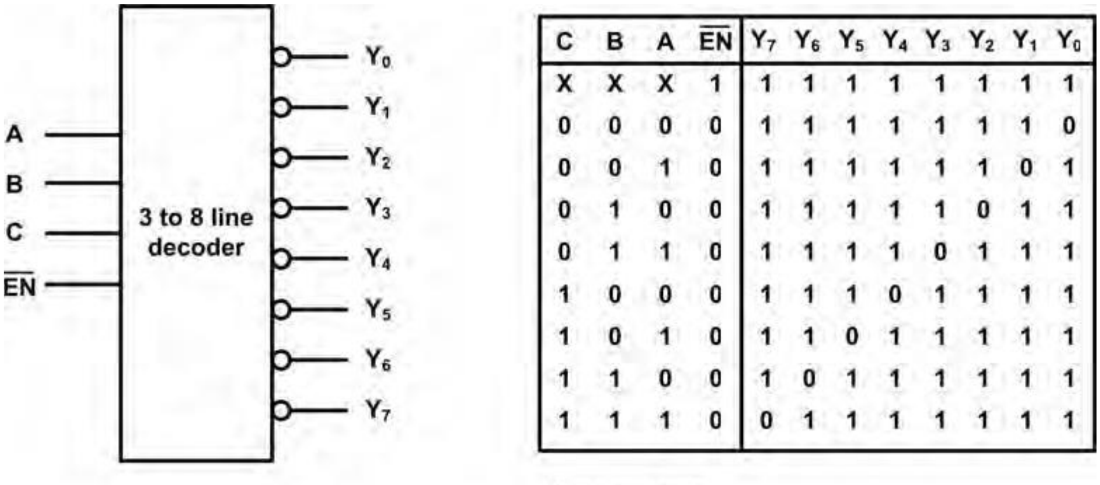
X = don't care

(b) Two to four line decoder with enable input

Figure 3.18 Two to four line decoders and their corresponding truth tables. The arrangement shown in (b) has a separate active-low enable input (when this input is high all of the outputs remain in the high state regardless of the A and B inputs)

3.6 Encoders

Encoders provide the reverse function to that of a decoder. In other words, they accept a number of inputs and then generate a binary code corresponding to the state of those inputs. Typical applications for encoders include generating a binary code corresponding to the state of a keyboard/keypad or generating BCD from a decade (ten-position) rotary switch. A particularly useful form of encoder is one that can determine the priority of its inputs. This device is known as a **priority encoder** and its inputs are arranged in priority order, from lowest to highest priority. If more than one input becomes active, the input with the highest priority will be encoded and its binary coded value will appear on the outputs. The state of the other (lower priority) inputs will be ignored Figure 3.21 shows an eight to three line priority encoder together with its corresponding truth table .Note that this device has active-low inputs as well as active-low outputs.



C	B	A	$\overline{EN}$	Y_7	Y_6	Y_5	Y_4	Y_3	Y_2	Y_1	Y_0
X	X	X	1	1	1	1	1	1	1	1	1
0	0	0	0	1	1	1	1	1	1	1	0
0	0	1	0	1	1	1	1	1	1	0	1
0	1	0	0	1	1	1	1	1	0	1	1
0	1	1	0	1	1	1	1	0	1	1	1
1	0	0	0	1	1	1	0	1	1	1	1
1	0	1	0	1	1	0	1	1	1	1	1
1	1	0	0	1	0	1	1	1	1	1	1
1	1	1	0	0	1	1	1	1	1	1	1

X = don't care

Figure 3.21 An eight to three line priority encoder and its corresponding truth table. Note that the enable (EN) input is active-low

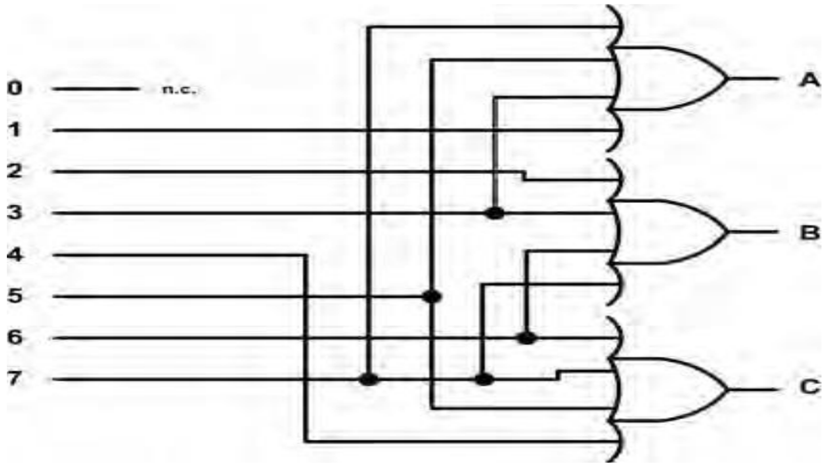
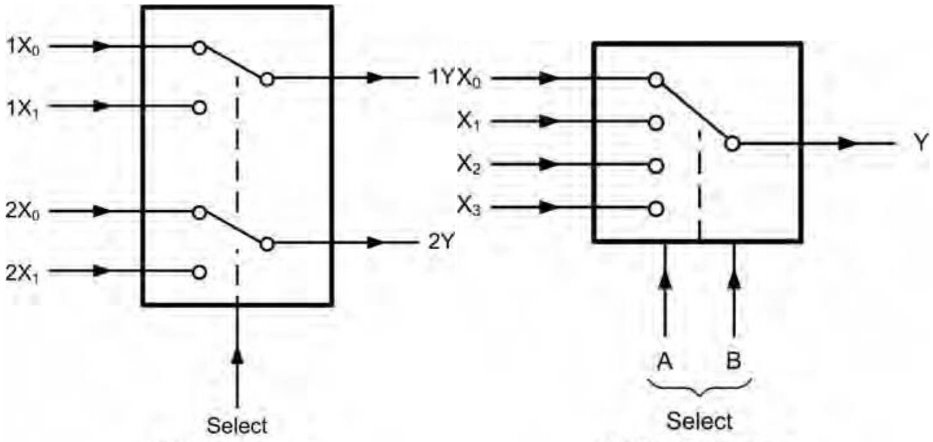


Figure 3.22 An octal to binary encoder

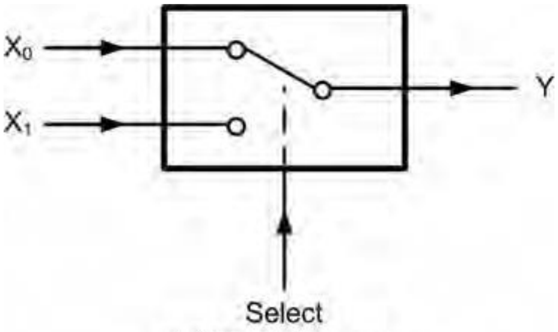
3.7 Multiplexers

- Like encoders, multiplexers have several inputs. However, unlike encoders, they have only one output.
- Multiplexers provide a means of selecting data from one of several sources. Because of this, they are often referred to as **data selectors** . Switch equivalent circuits of some common types of multiplexer are shown in Fig. 3.23 .
- The single two-way multiplexer in Fig. 3.23(a) is equivalent to a simple SPDT (changeover) switch. Thedual two-way multiplexer shown in Fig. 3.23(b) performs the same function but two independent circuits
  are controlled from the same select signal. A single four-way multiplexer is shown in Fig. 3.23(c) .
  Note that two digital select inputs are required, A and B, in order to place the switch in its four different states.
- Block schematic symbols, truth tables and simplified logic circuits for two to one and four to one multiplexers are shown in Figs 3.24 to 3.27 .



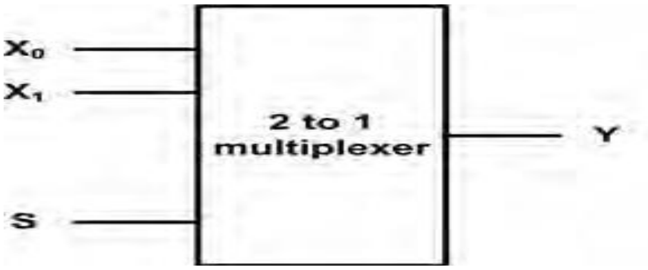
(b) Dual two way

(c) Single four way



(a) Single two way

Figure 3.23 Switch equivalent circuits for some common types of multiplexer or data selector



S	Y
0	X_0
1	X_1

Figure 3.24 A basic two to one multiplexer arrangement with its corresponding truth table

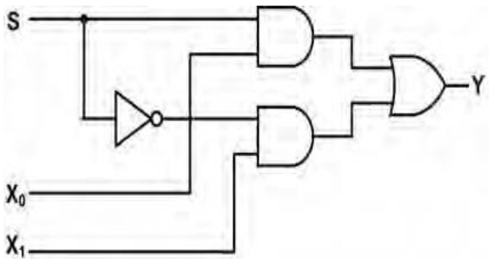
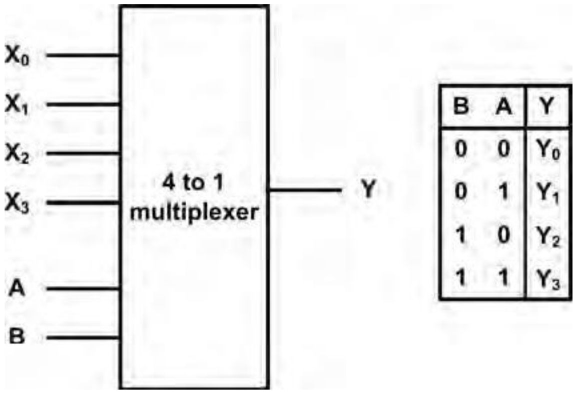


Figure 3.25 Logic circuit arrangement for the basic two to one multiplexer



B	A	Y
0	0	Y_0
0	1	Y_1
1	0	Y_2
1	1	Y_3

Figure 3.26 A four to one multiplexer. The logic state of the A and B inputs determines which of the four logic inputs (X 0 to X 3) appears at the output

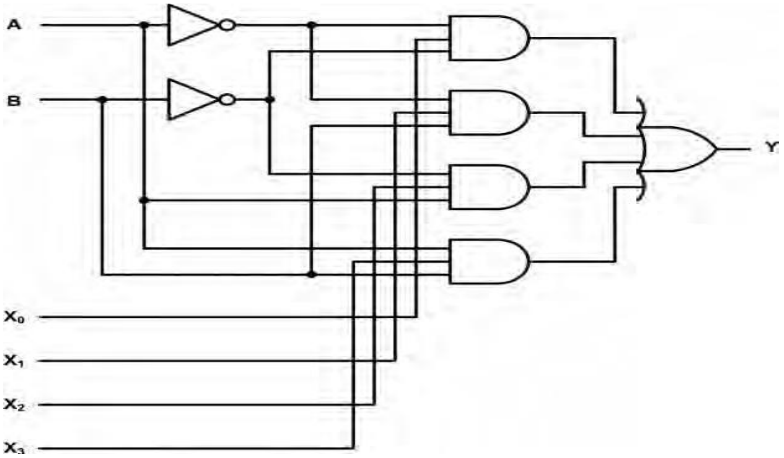


Figure 3.27 Logic gate arrangement for the four to one multiplexer

3.8 Bus systems

Aircraft data bus systems allow a wide variety of avionics equipment to communicate with one another and exchange data. Bus systems can be either **bidirectional** (one way) or **unidirectional** (two way), as shown in Fig. 3.28 . They can also be serial (one bit of data transmitted at a time) or **parallel** (where often 8,16 or 32 bits of data appear as a group on a number of data lines at the same time). Because of the constraints imposed by conductor length and weight, all practical aircraft bus systems are based on serial (rather than parallel) data transfer. Bus systems provide an efficient means of exchanging data between the diverse avionic systems found in a modern aircraft (see Fig. 3.29). Individual **line replaceable units** (**LRU**), such as the engine data interface or flap/slat electronics units shown in Fig. 3.29 , are each connected to the bus by means of a dedicated **bus coupler** and **serial interface module**(not shown in Fig. 3.29). Within the LRU, the dedicated digital logic and microprocessor systems that process data locally each make use of their own **local bus** system. These local bus systems invariably use parallel data transfer which is ideal for moving large amounts of data very quickly but only over short distances.

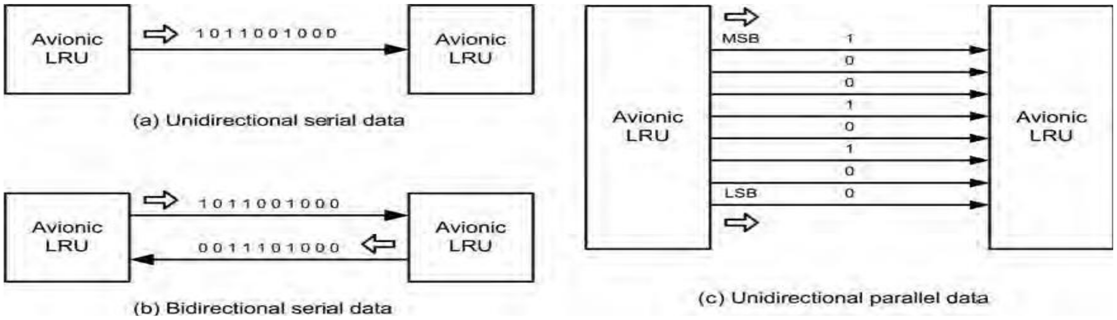


Figure 3.28 Unidirectional and bidirectional serial and parallel data

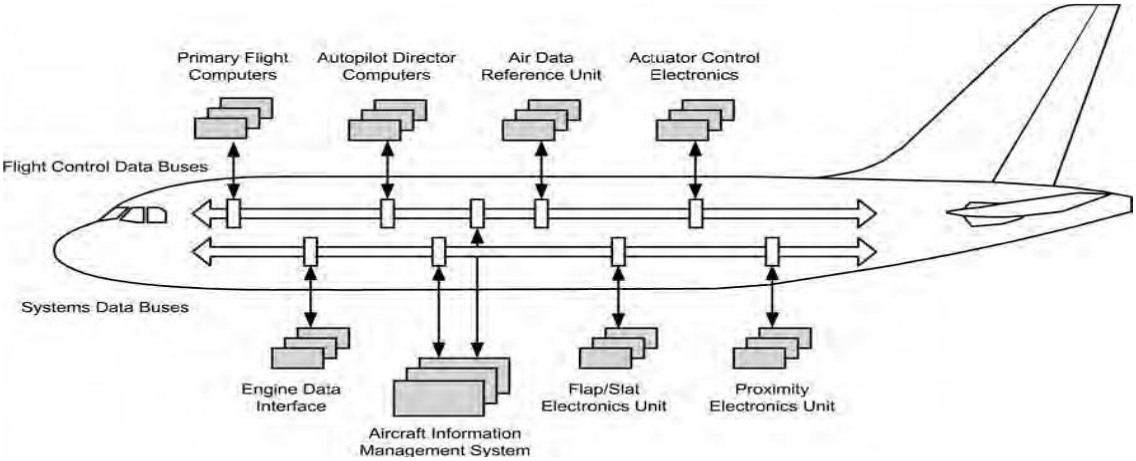


Figure 3.29 Bus systems implemented on a modern passenger aircraft

3.8.1 Serial bus principles

A simple system for serial data transfer between two line replaceable units, each of which comprises an avionic system in its own right, is shown in Fig. 3.30 .Within the LRU data is transferred using an internal
parallel data bus (either 8, 16, 32 or 64 bits wide).The link between the two LRUs is made using a simple serial cable (often with only two, four or six conductors).The required parallel-to-serial and serial-to-parallel data conversion is carried out by a bus interface (often this is a single card or module within the LRU). The data to be transferred can be **synchronous** (using clock signals generated locally within each LRU) or it may be **asynchronous**(i.e. self-clocking).

The system shown in Fig. 3.30 has the obvious limitation that data can only be exchanged between two devices. In practice we need to share the data between many LRU/avionic units. This can be achieved by the bus system illustrated in Fig. 3.31 .

In this system, data is transferred using a **shielded twisted pair** (**STP**) **bus cable** with a number of **coupler panels** that are located at appropriate points in the aircraft (e.g. the flight deck, avionics bay, etc.). Each coupler panel allows a number of avionic units to be connected to the bus using a **stub cable** .

In order to optimize the speed of data transfer and minimize problems associated with reflection and mismatch, the bus cable must be terminated at each end using a matched **bus terminator** Bus couplers are produced as either **voltage mode** or **current mode** units depending upon whether they use voltage or current sensing devices. Within each LRU/avionics unit, an interface is provided that performs the required serial-to-parallel or parallel-to serial data conversion, as shown in Fig. 3.32 .

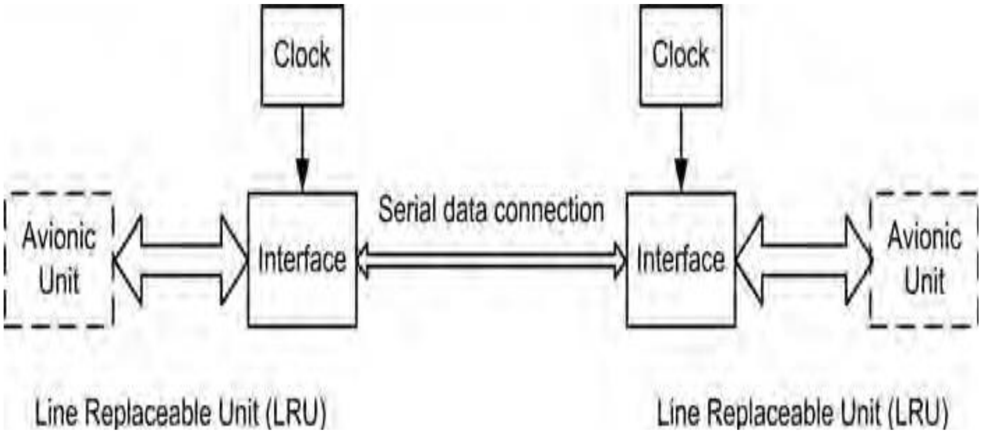


Figure 3.30 A simple system for serial data transfer between two avionic systems

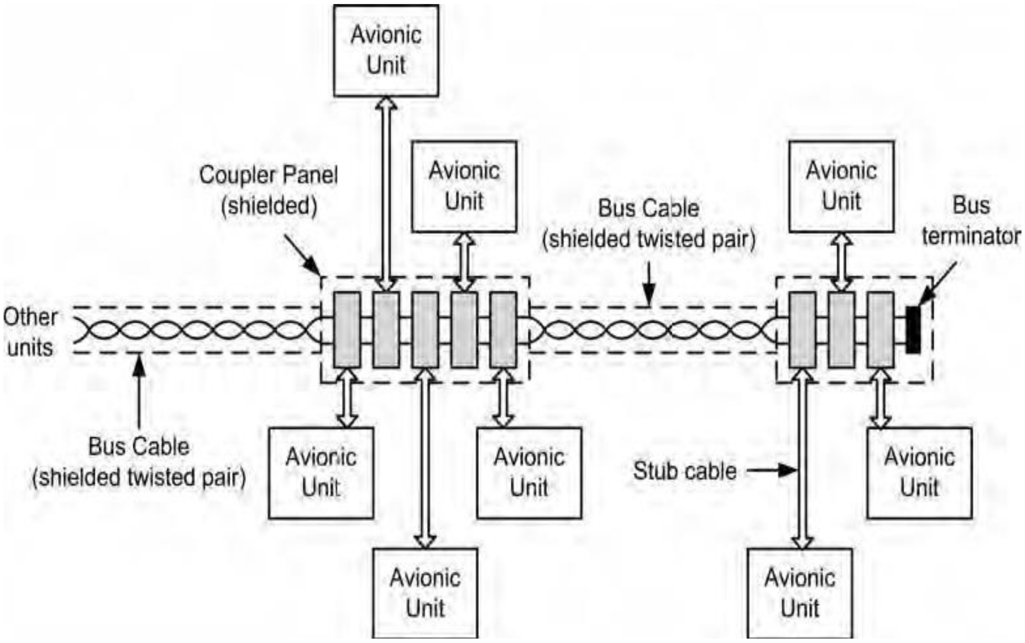


Figure 3.31 A practical aircraft data bus

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3.9 Computers

Modern aircraft use increasingly sophisticated avionic systems which involve the use of microprocessor based computer systems. These systems combine hardware and software and are capable of processing large amounts of data in a very small time.

The basic components of a computer system are shown in Fig. 3.33 . The main components are:
(a) a central processing unit (CPU)
(b) a memory, comprising both ‘ read/write ’ and ‘ read only ’ devices (commonly called RAM and ROM respectively)
(c) a means of providing input and output (I/O). For example, a keypad for input and a display for output.

In a microprocessor system the functions of the CPU are provided by a single very large scale integrated(VLSI) microprocessor chip. This chip is equivalent to many thousands of individual transistors. Semiconductor devices are also used to provide the read/write and read-only memory. Strictly speaking,
both types of memory permit ‘ random access ’ since any item of data can be retrieved with equal easer regardless of its actual location within the memory.

Despite this, the term ' RAM ' has become synonymous with semiconductor read/write memory.

The basic components of the system (CPU, RAM,ROM and I/O) are linked together using a multiple wire connecting system know as a **bus** (see Fig. 3.33).Three different buses are present, these are:
(a) the **address bus** used to specify memory locations;
(b) the **data bus** on which data is transferred between devices; and

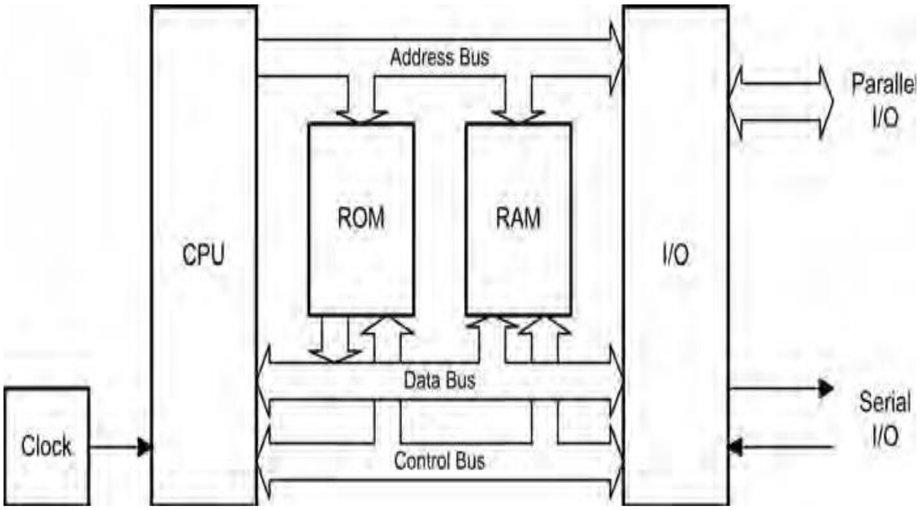


Figure 3.33 Basic components of a computer system

(c) the **control bus** which provides timing and control signals throughout the system. The number of individual lines present within the address bus and data bus depends upon the particular microprocessor employed. Signals on all lines, no matter whether they are used for address, data ,or control, can exist in only two basic states: logic 0(**low**) or logic 1 (**high**). Data and addresses are represented by **binary numbers** (a sequence of 1 s and 0 s) that appear respectively on the data and address bus.

Some basic microprocessors designed for control and instrumentation applications have an 8-bit data bus and a 16-bit address bus. More sophisticated processors can operate with as many as 64 or 128 bits at a time. The largest binary number that can appear on an8-bit data bus corresponds to the condition when all eight lines are at logic 1. Therefore the largest value of data that can be present on the bus at any instant of time is equivalent to the binary number 11111111 (or 255). Similarly, most the highest address that can appear on a 16-bit address bus is 1111111111111111(or 65,535). The full range of data values and addresses for a simple microprocessor of this type is thus

Data	From	00000000
	To	11111111
Addresses	From	0000000000000000
	To	1111111111111111

Finally, a locally generated clock signal provides a time reference for controlling the transfer of synchronous data within the system. The clock signal usually consists of a high-frequency square wave pulse train derived from an accurate quartz crystal controlled oscillator .

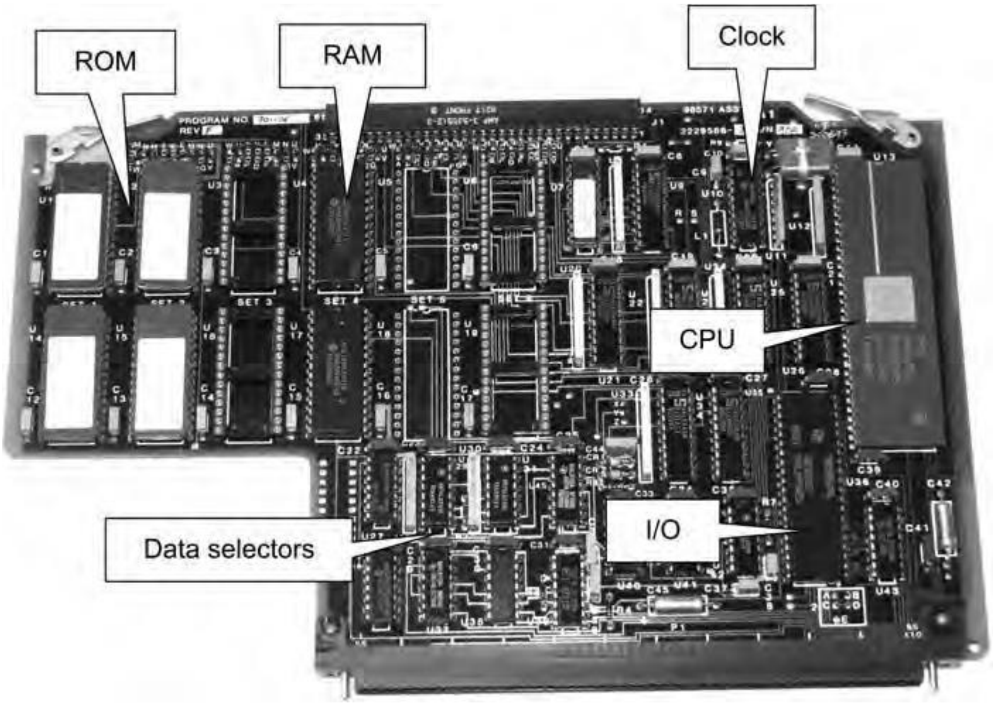


Figure 3.34 A typical aircraft computer system

3.10 Microprocessor

Microprocessor is a tiny programmable integrated electronic device that has computing and decision making capability. It is similar to the central processing unit of a computer.

The microprocessor is a digital device that communicates and operates in the binary numbers0 and 1. It processes the information according to a stored program, and output information in the form of digital signals. Each microprocessor has a fixed set of instructions in the form of binary patterns known as a machine language.

It is basically single (large scaleintegration) LSI chip. It consists of tens of thousands of transistors on a silicon chip as small as a fingernail. The device is often called a “computer on a chip”. Sometimes, thiscombination may include a small sized memory on the same chip.The word CPU usually identifies that part of a computer system that actually computes. The rest of the computer system provides an interface between human operators and the computer. Thus, the CPU may be visualized as the “brains” of the computer system.A microprocessor is a central processing unit (CPU) which is usually implemented in oneor several IC packages. When the microprocessor is combined with memory and input/output devices

What is a Microprocessor?

The microprocessor is a programmable device that takes in numbers, performs on them arithmetic or logical operations according to the program stored in memory and then produces other numbers as a result.

Programmable device: The microprocessor can perform different sets of operations on the data it receives depending on the sequence of instructions supplied in the given program. By changing the program, the microprocessor manipulates the data in different ways.

Instructions: Each microprocessor is designed to execute a specific group of operations. This group of operations is called an instruction set. This instruction set defines what the microprocessor can and cannot do.
Takes in: The data that the microprocessor manipulates must come from somewhere. • It comes from what is called “input devices”. • These are devices that bring data into the system from the outside world. • These represent devices such as a keyboard, a mouse, switches, and the like

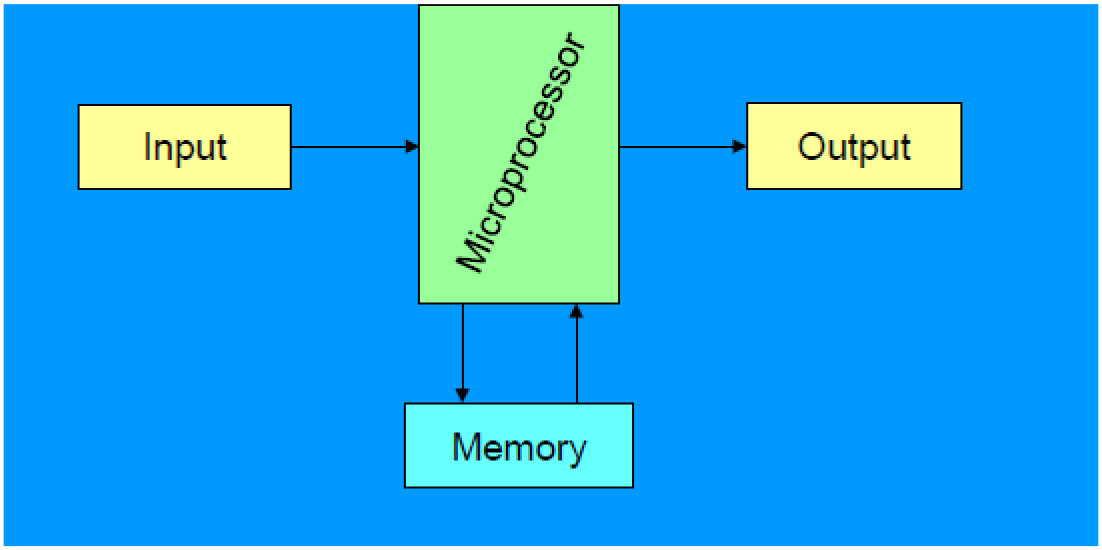
Numbers: The microprocessor has a very narrow view on life. It only understands binary numbers. A binary digit is called a bit (which comes from binary digit). The microprocessor recognizes and processes a group of bits together. This group of bits is called a “word”. The number of bits in a Microprocessor’s word, is a measure of its “abilities”.
Words, Bytes, etc. • The earliest microprocessor (the Intel 8088 and Motorola’s 6800) recognized 8-bit words. – They processed information 8-bits at a time. That’s why they are called “8-bit processors”. They can handle large numbers, but in order to process these numbers, they broke them into 8-bit pieces and processed each group of 8-bits separately. • Later microprocessors (8086 and 68000) were designed with 16-bit words. – A group of 8-bits were referred to as a “half-word” or “byte”. – A group of 4 bits is called a “nibble”. – Also, 32 bit groups were given the name “long word”. • Today, all processors manipulate at least 32 bits at a time and there exists microprocessors that can process 64, 80, 128 bits

Arithmetic and Logic Operations: • Every microprocessor has arithmetic operations such as add and subtract as part of its instruction set. – Most microprocessors will have operations such as multiply and divide. – Some of the newer ones will have complex operations such as square root. • In addition, microprocessors have logic operations as well. Such as AND, OR, XOR, shift left, shift right, etc. • Again, the number and types of operations define the microprocessor’s instruction set and depends on the specific microprocessor
Stored in memory : • First, what is memory? – Memory is the location where information is kept while not in current use. – Memory is a collection of storage devices. Usually, each storage device holds one bit. Also, in most kinds of memory, these storage devices are grouped into groups of 8. These 8 storage locations can only be accessed together. So, one can only read or write in terms of

bytes to and form memory. – Memory is usually measured by the number of bytes it can hold. It is measured in Kilos, Megas and lately Gigas. A Kilo in computer language is 210 =1024. So, a KB (KiloByte) is 1024 bytes. Mega is 1024 Kilos and Giga is 1024 Mega.

Stored in memory: • When a program is entered into a computer, it is stored in memory. Then as the microprocessor starts to execute the instructions, it brings the instructions from memory one at a time. • Memory is also used to hold the data. – The microprocessor reads (brings in) the data from memory when it needs it and writes (stores) the results into memory when it is done.

– **Produces:** For the user to see the result of the execution of the program, the results must be presented in a human readable form. • The results must be presented on an output device. • This can be the monitor, a paper from the printer, a simple LED or many other forms



Inside TheMicroprocessor

Internally, the microprocessor is made up of 3 main units.

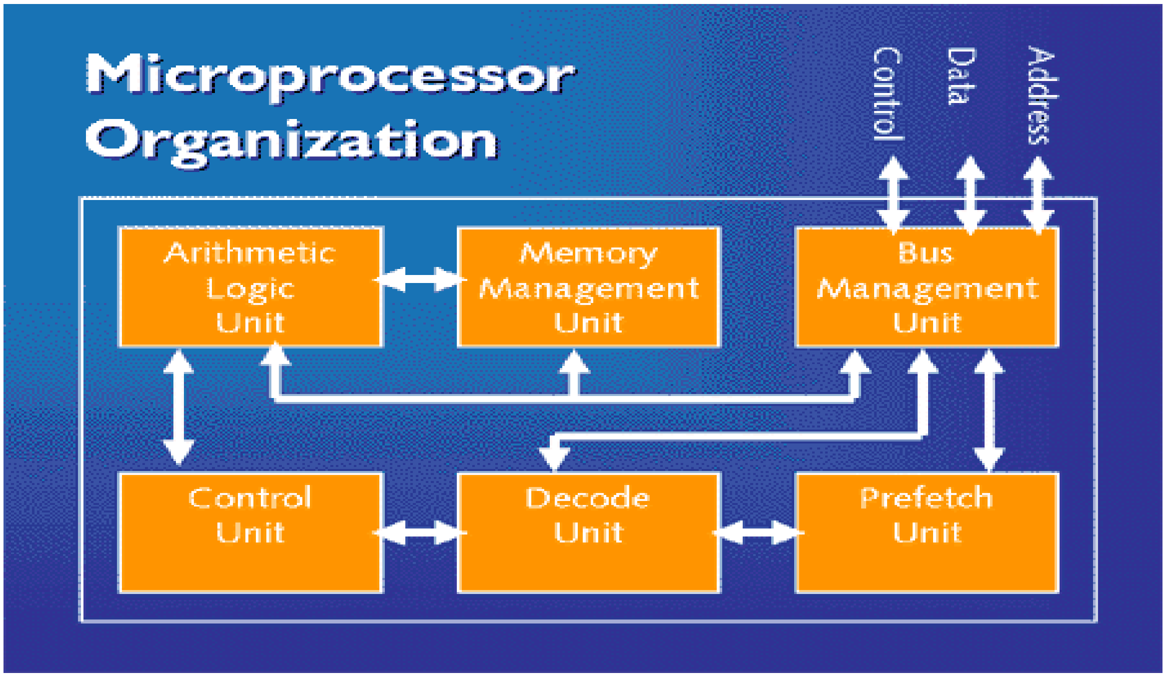
The Arithmetic/Logic Unit (ALU)

The Control Unit.

An array of registers for holding data while it is being manipulated.

Organization of a microprocessor based system

Although microprocessors are becoming increasingly complex, at root its operation can be summed up as the repeated sequence of simple tasks: Fetch an instruction; Decode the instruction; Execute the instruction



Each microprocessor recognizes a unique set of binary instructions which have been predefined and stored permanently in the chip. When the CPU receives an instruction it passes it to a unit known as the Decode unit which contains a sequence of operations which must be performed to complete the operation. The Decode unit passes the sequence of instructions to the Control Unit which holds tiny programs known as microcode for each operation the microprocessor had been designed to carry out.

The actual work of the microprocessor is carried out in the Arithmetic Logic Unit. Most of these operations are in fact performed by addition. To perform subtraction, the CPU first finds the complement of the number to be subtracted and then adds the two numbers. Multiplication and division can be performed by carrying out multiple addition or subtraction operations. To compare two numbers, the CPU will subtract them and then check to see if there is a remainder, and so on.

In order to carry out its operations, the processor has storage locations, called registers, for the numbers and instructions it is operating on. For example, to add two numbers, the first number mign be loaded into Register A, the second into Register B and the result stored in Register C. To speed up the operations of the processor, the Prefetch unit looks ahead in the program to find the next instructions and preloads them into registers, to cut down on time wasted waiting for the next instruction.

The microprocessor connects to the external components of the computer via "buses": sets of parallel conductors used to move data in the form of electrical pulses. There are three types of buses: the *data bus* carries the binary-coded information and instructions; the *address bus* carries binary-coded numbers which identify storage locations in main memory, much like the postal code on a letter; the *control bus* carries timing signals, read-write signals, interrupt requests and similar signals between the microprocessor and external devices.

To manage the flow of data into and out of the CPU, two other units are required: the Memory Management Unit, and the Bus Management Unit. To summarize, the essential sections of a microprocessor are:

- **Arithmetic Logic Unit:** executes all logic and arithmetic operations as specified by the instruction set
- **Control Unit:** contains the microcode that tells the ALU how to function.
- **Decode Unit:** translates instruction into control signals and microcode directions then queues them until requested by the Control Unit.
- **Prefetch Unit:** queues instruction to assure that the microprocessor is in continuous operation.
- **Memory Management Unit**: converts internal logic addresses into external memory addresses.
- **Bus Management Unit:** manages the flow of information between the microprocessor and data storage locations (main disk, CD-ROM, etc.) and peripherals (printer, monitor, etc.)

A Microcontroller is a programmable digital processor with necessary peripherals. Both microcontrollers and microprocessors are complex sequential digital circuits meant to carry out job according to the program / instructions. Sometimes analog input/output interface makes a part of microcontroller circuit of mixed mode(both analog and digital nature).

Some of the benefits of microcontrollers include the following

Cost advantage: The biggest advantage of **microcontrollers**against larger microprocessors is that the design and hardware costs are much lesser and can be kept to a minimum. A microcontroller is cheap to replace, while microprocessors are ten times more expensive.

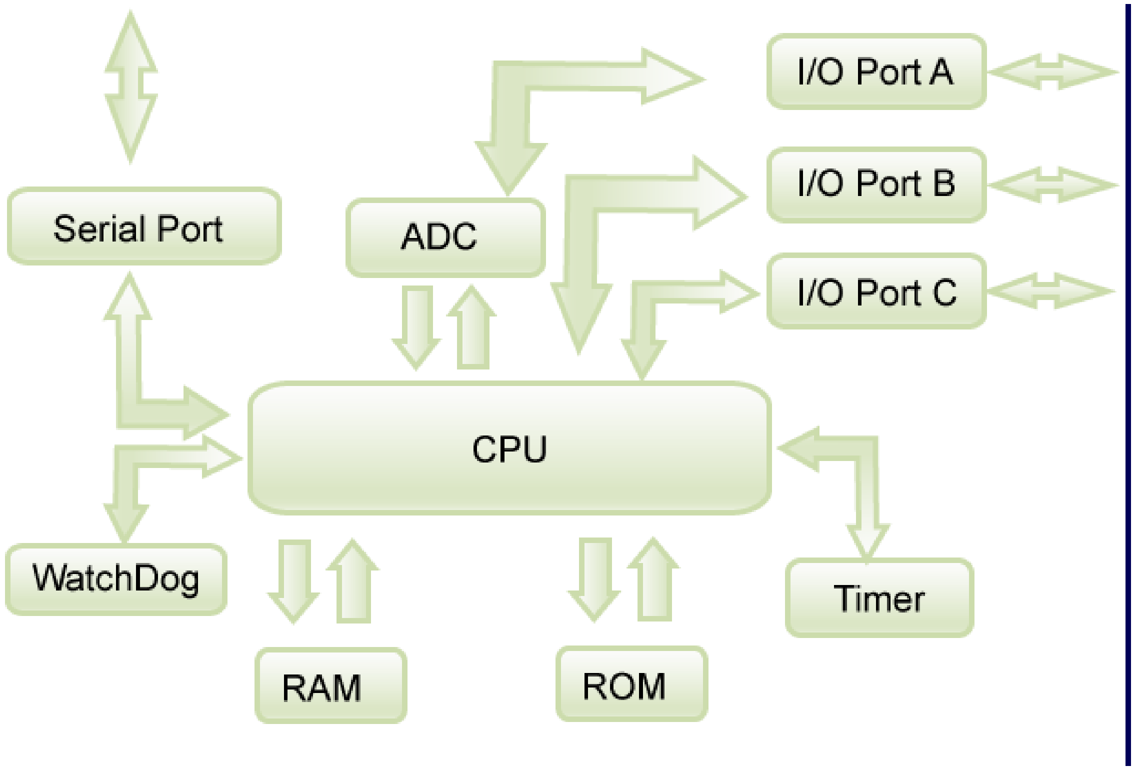
- **Lesser power usage:** Microcontrollers are generally built using a technology known as Complementary Metal Oxide Semiconductor (CMOS). This technology is a competent fabrication system that uses less power and is more immune to power spikes than other techniques.

- **All-in-one:** A microcontroller usually comprises of a CPU, ROM, RAM and I/O ports, built within it to execute a single and dedicated task. On the other hand, a microprocessor generally does not have a RAM, ROM or IO pins and generally uses its pins as a bus to interface to peripherals such as RAM, ROM, serial ports, digital and analog IO

How does a Microcontroller work?

Microcontroller has an input device in order to get the input and an output device (such as LED or LCD Display) to exhibit the final process. Let us look into the illustration of how a microcontroller works in a Television.

The Television has a remote control as an Input device and the TV screen as the output device. The signal sent from the remote control is captured by the microcontroller. The microcontroller controls the channel selection, the amplifier system and picture tube adjustments such as hue, brightness, contrast etc



The architecture of a typical microcontroller is complex and may include the following:

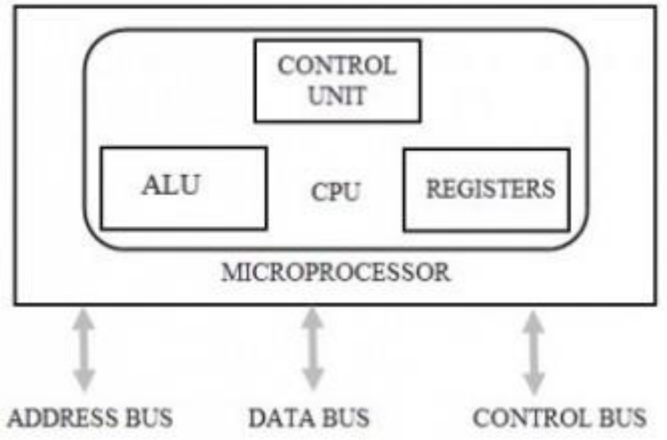
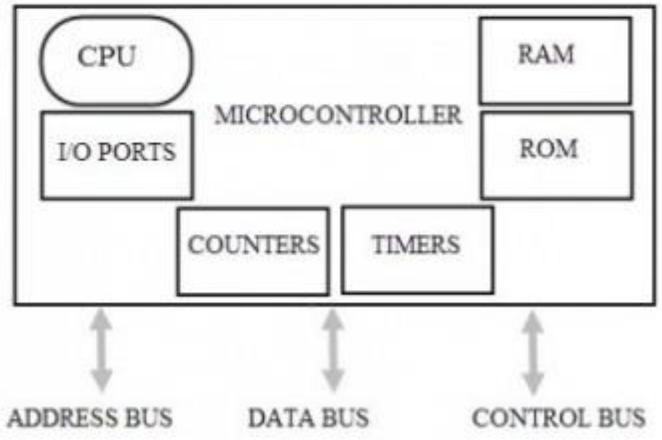
1. A CPU, ranging from simple 4-bit to complex 64-bit processers.
2. Peripherals such as timers, event counters and watchdog.
3. RAM (volatile memory) for data storage. The data is stored in the form of registers, and the general-purpose registers store information that interacts with the arithmetic logical unit (ALU).
4. ROM, EPROM, EEPROM or flash memory for program and operating parameter storage.
5. Programming capabilities.
6. Serial input/output such as serial ports.
7. A clock generator for resonator, quartz timing crystal or RC circuit.
8. Analog-to-digital convertors.
9. Serial ports.
10. Data bus to carry information.

Microcontrollers Vs Microprocessors

1. A microprocessor requires an external memory for program/data storage. Instruction execution requires movement of data from the external memory to the microprocessor or vice versa. Usually, microprocessors have good computing power and they have higher clock speed to

facilitate faster computation.

2. A microcontroller has required on-chip memory with associated peripherals. A microcontroller can be thought of a microprocessor with inbuilt peripherals.
3. A microcontroller does not require much additional interfacing ICs for operation and it functions as a stand alone system. The operation of a microcontroller is multipurpose, just like a Swiss knife.
4. Microcontrollers are also called embedded controllers. A microcontroller clock speed is limited only to a few tens of MHz. Microcontrollers are numerous and many of them are application specific

Microprocessors	**Microcontrollers**
	
Microprocessor assimilates the function of a central processing unit (CPU) on to a single integrated circuit (IC).	Microcontroller can be considered as a small computer which has a processor and some other components in order to make it a computer.
Microprocessors are mainly used in designing general purpose systems from	Microcontrollers are

small to large and complex systems like super computers.	used in automatically controlled devices.
Microprocessors are basic components of personal computers.	Microcontrollers are generally used in embedded systems
Computational capacity of microprocessor is very high. Hence can perform complex tasks.	Less computational capacity when compared to microprocessors. Usually used for simpler tasks.
A microprocessor based system can perform numerous tasks.	A microcontroller based system can perform single or very few tasks.
Microprocessors have integrated Math Coprocessor. Complex mathematical calculations which involve floating point can be performed with great ease.	Microcontrollers do not have math coprocessors. They use software to perform floating point

	calculations which slows down the device.
The main task of microprocessor is to perform the instruction cycle repeatedly. This includes fetch, decode and execute.	In addition to performing the tasks of fetch, decode and execute, a microcontroller also controls its environment based on the output of the instruction cycle.
In order to build or design a system (computer), a microprocessor has to be connected externally to some other components like Memory (RAM and ROM) and Input / Output ports.	The IC of a microcontroller has memory (both RAM and ROM) integrated on it along with some other components like I / O devices and timers.
The overall cost of a system built using a microprocessor is high. This is because of the requirement of external components.	Cost of a system built using a microcontroller is less as all the

	components are readily available.
Generally power consumption and dissipation is high because of the external devices. Hence it requires external cooling system.	Power consumption is less.
The clock frequency is very high usually in the order of Giga Hertz.	Clock frequency is less usually in the order of Mega Hertz.
Instruction throughput is given higher priority than interrupt latency.	In contrast, microcontrollers are designed to optimize interrupt latency.
Have few bit manipulation instructions	Bit manipulation is powerful and widely used feature in microcontrollers. They have numerous bit manipulation instructions.

Generally microprocessors are not used in real time systems as they are severely dependent on several other components.	Microcontrollers are used to handle real time tasks as they are single programmed, self sufficient and task oriented devices\