## Introduction

From the user's point of view the electricity service in a building consists of light switches, sockets, clock connectors, cooker control units and similar outlets. Such fittings are collectively known as accessories; this name came about because they are accessory to the wiring, which is the main substance of the installation from the designer's and installer's point of view. To them, the way the outlets are served is the major interest, but it is quite secondary to the user who is concerned only with the appearance and function of the outlet. In the complete electrical installation of a building the wiring and accessories are interdependent and neither can be fully understood without the other; a start has to be made somewhere however, and in this book it is proposed to consider accessories first.

## Switches

A switch is used to make or interrupt a circuit. Normally when one talks of switches one has in mind light switches which turn lights on and off. A complete switch consists of three parts. There is the mechanism itself, a box containing it, and a front plate over it.

The box is fixed to the wall, and the cables going to the switch are drawn into the box. After this the cables are connected to the mechanism. To carry out this operation the electrician must pull the cables away from the wall sufficiently to give himself room to work on the back of the mechanism. He then pushes the mechanism back into the box and the length of cable that he had to pull out from the wall becomes slack inside the box. It is therefore important that the box is large enough to accommodate a certain amount of slack cable at the back of the mechanism.

Standard boxes for recessing within a wall are 16, 25, 35 and 47mm deep. Sometimes the wiring is done not in the depth of the structural wall, but within the thickness of the plaster. For use with such wiring, boxes are made 16mm deep (plaster depth boxes). It is often necessary to install wiring and accessories exposed on the surface of wall. For such applications surface boxes are made which are both more robust and neater in appearance than boxes which are to be recessed in walls and made flush with the surface, although they are made to similar depth. Typical boxes of both types are shown in Figure 1.1.

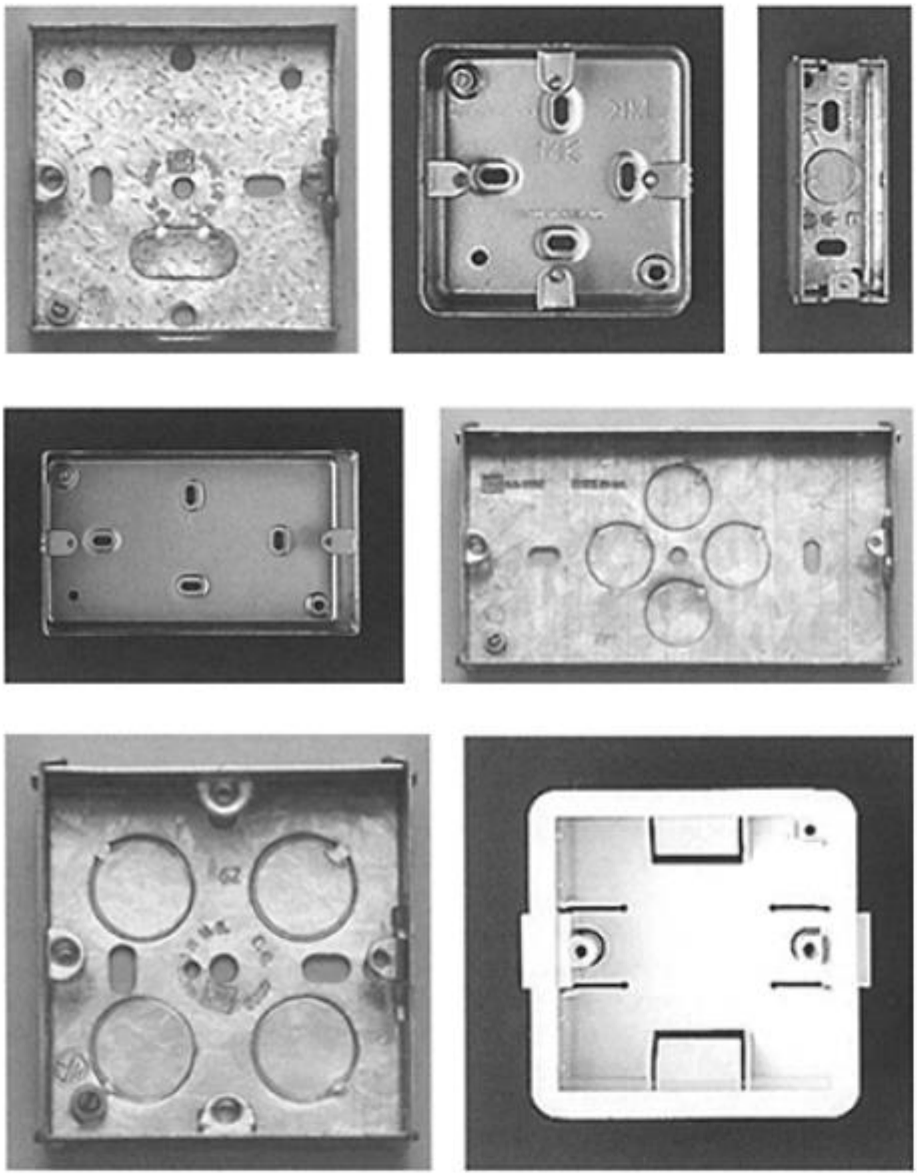


*Figure 1.1* Boxes (Courtesy of M.K. Electric Ltd)

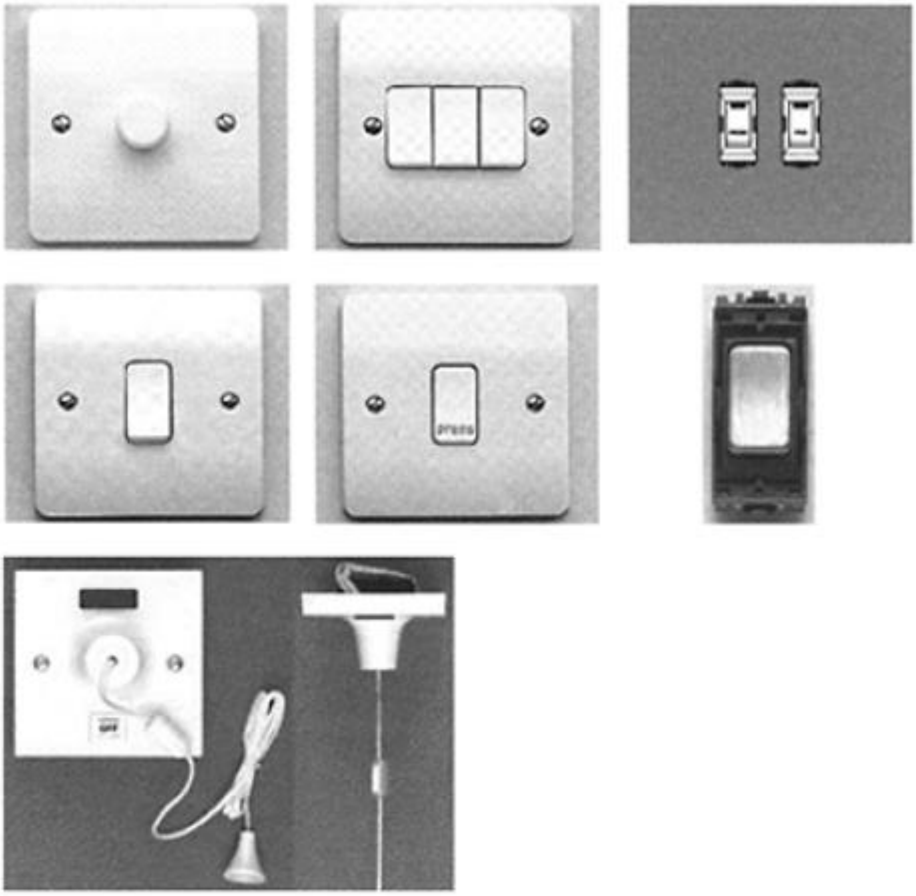


*Figure 1.3* Switches (Courtesy of M.K. Electric Ltd)


*Figure 1.4* Double pole switch

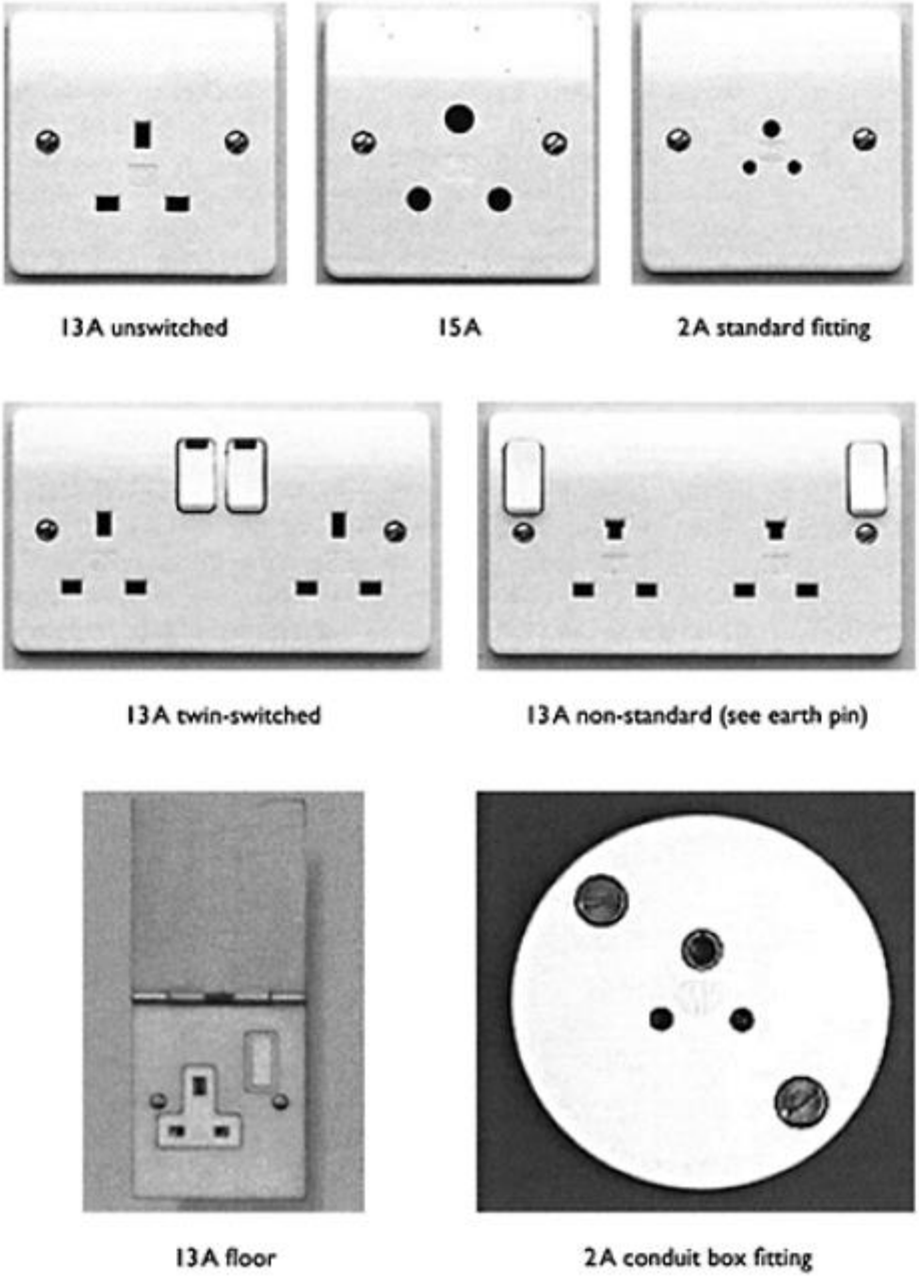



*Figure 1.5* Socket outlets (Courtesy of M.K. Electric Ltd)

Read Chapter 1—All other accessories Page 11

## Hazardous areas

There are industrial processes which involve a risk of fire or explosion. Generally, the risk arises because flammable vapours or dusts are present in the atmosphere. For example, in coal mines there is always the possibility of methane appearing in sufficient concentration to ignite or burn. In such cases any electrical equipment in the area subject to risk must be specially designed to reduce that risk.

The mere flow of electricity will not ignite a vapour unless the temperature becomes too high. The temperature can be kept low by adequate sizing of the cables so that this is not a problem as far as the installation is concerned. The surface temperature of motors, luminaires and other electrical equipment must, however, be considered. Vapour can also be ignited by a spark at a terminal or switch or as a result of mechanical damage causing a spark or local hot spot. There are various ways of designing equipment to reduce the risks in hazardous areas and these are now covered by British Standards which are harmonized with European standards if the national standards do not exactly match. If the national standards are identical, then they will be designated as a Euro-Norm EN.

1 Zone 0 (ATEX category 1G {Gas}) A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is present continuously or for long periods or frequently.
2 Zone 1 (ATEX category 2G {Gas}) A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of a gas, vapour or mist is likely to occur in normal operation occasionally.
3 Zone 2 (ATEX category 3G {Gas}) A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of a gas, vapour or mist is *not* likely to occur in normal operation but, if it does occur, will persist for a short period only.

For dusty atmospheres the following definitions apply:

1 Zone 20 (ATEX category 1D {Dust}) A place in which an explosive atmosphere in the form of a cloud of combustible dust is present continuously or for long periods or frequently.
2 Zone 21 (ATEX category 2D {Dust}) A place in which an explosive atmosphere in the form of a cloud of combustible dust in air likely to occur in normal operation occasionally.
3 Zone 22 (ATEX category 3D {Dust}) A place in which an explosive atmosphere in the form of a cloud of combustible dust in air *not* likely to occur in normal operation but, if it does occur, will persist for a short period only.

*Table 1.1* Equipment types

| *Zone* | *Type of protection* |
|---|---|
| 0 | ia |
| 1 | ia,ib,d,e,p |
| 2 | i, ia, ib, d, e, p, N |

*Table 1.2* Temperature classification

| *Class* | *Maximum surface temperature °C* |
|---|---|
| T1 | 450 |
| T2 | 300 |
| T3 | 200 |
| T4 | 135 |
| T5 | 100 |
| T6 | 85 |

| *First characteristic numeral* | *Degree of protection* |
|---|---|
| 0 | No protection of persons against contact with live or moving parts inside the enclosure.<br>No protection of equipment against ingress of solid foreign bodies. |
| 1 | Protection against accidental or inadvertent contact with live or moving parts inside the enclosure by a large surface of the human body, for example, a hand, but not protection against deliberate access to such parts.<br>Protection against ingress of large solid foreign bodies. |
| 2 | Protection against contact with live or moving parts inside the enclosure by fingers.<br>Protection against ingress of medium-size solid foreign bodies. |

| | |
|---|---|
| 3 | Protection against contact with live or moving parts inside the enclosure by tools, cables or such objects of thickness greater than 2.5mm. |
| | Protection against ingress of small solid foreign bodies. |
| 4 | Protection against contact with live or moving parts inside the enclosure by tools, cables or such objects of thickness greater than 1mm. |
| | Protection against ingress of small solid foreign bodies. |
| 5 | Complete protection against contact with live or moving parts inside the enclosure. |
| | Protection against harmful deposits of dust. The ingress of dust is not totally prevented, but dust cannot enter in an amount sufficient to interfere with satisfactory operation of the equipment enclosed. |
| 6 | Complete protection against contact with live or moving parts inside the enclosure. |
| | Protection against ingress of dust. |

*Table 1.3b* Protection of equipment against ingress of liquid

| *Second characteristic numeral* | *Degree of protection* |
|---|---|
| 0 | No protection. |
| 1 | Protection against drops of condensed water: drops of condensed water falling on the enclosure shall have no harmful effect. |
| 2 | Protection against drops of liquid: drops of falling liquid shall have no harmful effect when the enclosure is tilted at any angle up to 15° from the vertical. |
| 3 | Protection against rain: water falling in rain at an angle up to 60° with respect to the vertical shall have no harmful effect. |
| 4 | Protection against splashing: liquid splashed from any direction shall have no harmful effect. |
| 5 | Protection against water-jets: water projected by a nozzle from any direction under stated conditions shall have no harmful effect. |
| 6 | Protection against conditions on ships' decks (deck watertight equipment): water from heavy seas shall not enter the enclosure under prescribed conditions. |
| 7 | Protection against immersion in water: it must not be possible for water to enter the enclosure under stated conditions of pressure and time. |

Standards relevant to this chapter are:

| | |
|---|---|
| BS 67 | Ceiling roses |
| BS 196 | Protected-type non-reversible plugs, socket outlets, cable couplers and appliance couplers |
| BS 546 | Two-pole and earthing pin plugs, socket outlets and adaptors |
| BS 1363 | 13A plugs, socket outlets and boxes |
| BS 3535–2 | Isolating transformers and safety isolating transformers. Specification for transformers for reduced system voltage |
| BS EN 60742 | Isolating transformers, and safety isolating transformers |
| BS 3676/BS EN 60669–1 | Switches for domestic and similar purposes |
| BS 4177 | Cooker control units |
| BS EN 60309 | Industrial plugs, socket outlets and couplers |
| BS 4573 | Two-pin reversible plugs and shaver socket outlets |
| BS 4683 | Electrical apparatus for explosive atmospheres |
| BS EN 50021 | Electrical apparatus for potentially explosive atmospheres. Type of protection 'n' |
| BS 5125 | 50 A flameproof plugs and sockets |
| BS EN 60079–14 | Electrical apparatus for explosive gas atmospheres. Electrical installations in hazardous areas (other than mines) |
| BS 5419 | Air-break switches up to and including 1000V a.c. |
| BS EN 60947–3 | Specification for low-voltage switchgear and controlgear |
| BS EN 60529 | Specification for degrees of protection provided by enclosures (IP code) |
| BS EN 50014 | Electrical apparatus for potentially explosive atmospheres |
| BS 5733:1995 | General requirements for electrical accessories |
| BS 6220:1983 | Junction boxes |
| BS EN 50281–1–1,1–2 | Protection of apparatus for use in presence of combustible dusts |

IEE Wiring Regulations BS 7671 particularly applicable to this chapter are:

| | |
|---|---|
| Regulations | 412–03 |
| Regulations | 471–05 |
| Section | 476 |
| Section | 511 |

# Chapter 2
# Cable

## Introduction

Electricity is conveyed in metal conductors, which have to be insulated and which also have to be protected against mechanical damage. When the conductor is insulated to make a usable piece of equipment for carrying electricity, it becomes a cable. This nomenclature makes a convenient and logical distinction between a bare conductor and insulated cable, but in practice the terms 'conductor' and 'cable' are in fact used interchangeably and it is only the context which makes clarified what is being referred to. We shall try to avoid confusion and shall discuss conductors first and the insulation applied to them afterwards.

## Conductors

The commonest conductor used in cables is copper. The only other conductor used is aluminium. Copper was the earlier one to be used, although aluminium has the disadvantage of being much weaker than copper. Consequently BS 7671 states that the minimum permissible cross-sectional area is $16mm^2$. Aluminium's greatest assets are that it is cheaper than copper, lighter, and that its price is less liable to fluctuations.

Conductors have usually been made except for the smallest sizes, by twisting together a number of small cables, called strands, to make one larger cable. A cable made in this way is more flexible than a single cable of the same size and is consequently easier to handle. Each layer is spiralled on the cable in the direction opposite to that of the previous layer; this reduces the possibility that the strands will open under the influence of bending forces when the cable is being installed. $1mm^2$ has a solid core, $1.5mm^2$ and $2.5mm^2$ is available as solid or stranded core; sizes above these are available as stranded core only.

## Insulation

Every conductor must be insulated to keep them apart, keep the flow of current within the conductor and prevent its leaving or leaking from the conductor at random along its length. The following types of insulation are in use.

### *Thermoplastic PVC*

Polyvinyl chloride is one of the commonest materials used by man today. It is a man-made thermo-plastic which is tough, incombustible and chemically unreactive. Its chief drawback is that it softens at temperatures above about 70°C. It does not deteriorate with age and wiring carried out in PVC insulated cable should not need to be renewed in the way that wiring insulated with most of the older materials had to be. PVC insulated cable consists of cables of the types described above with a continuous layer or sleeve of PVC around them. The only restriction on this type of cable is that it should not be used in ambient temperatures higher than 70°C.

### *Thermosetting insulation*

There are plastics available as alternatives to PVC which have the advantage of being able to operate at higher temperatures. The most usual is XLPE, which is a cross linked polyethylene compound. Another alternative is hard ethylene propylene rubber compound, which is designated HEPR. These materials are normally used only in cables which have cable armouring over the insulation and an outer sheath over the armouring. The outer sheath is generally of PVC. The construction is then similar to that of the PVC wire armoured cable shown in Figure 2.3, the only difference being that the inner insulation is XLPE or HEPR instead of PVC.

### *Butyl rubber*

This insulation is used for cables which are to be subjected to high temperatures. It is, for example, used for the final connections to immersion heaters, for the control wiring of gas-fired warm-air heaters and within airing cupboards. It can safely be used for ambient temperatures up to 85°C. Butyl rubber also has greater resistance to moisture than natural rubber.

### *Silicone rubber*

This is completely resistant to moisture and is suitable for temperatures from −60°C to 150°C. It is undamaged after repeated subjection to boiling water and low pressure steam, and is therefore used on hospital equipment which has to be sterilized.

Although it is destroyed by fire, the ash is non-conductive and will continue to serve as insulation if it can be held in place. A braid or tape of glass-silicone rubber will hold it,

### *Glass*

Glass fibre has good heat-resisting properties and is therefore used for cables which are employed in high-temperature surroundings. One example is the internal wiring of electric ovens. Another application which may not at first sight seem to require heat-resisting cable lies in flexible cords for luminaires. Although the object of an incandescent lamp is to convert electrical energy into light, most of the energy is in fact dissipated as heat. Many luminaires restrict the paths available for the removal of heat and in consequence produce high local temperatures. The high temperature is transmitted to the flexible cord both by direct conduction through the lamp socket to the conductors and by an increase in the local ambient temperature. If the flexible cord is to last any length of time, it must be capable of withstanding the temperature it is subjected to.

One type of flexible cord is made from tinned copper conductors insulated with two layers of glass fibre, which is impregnated with varnish. A glass fibre braid, also impregnated with varnish, is applied over the primary insulation. This type of cord can be used at temperatures up to 155°C. If it is made with nickel-plated conductors and a silicone-based varnish, it then becomes suitable for temperatures up to 200°C.

### *Paper*

Paper-insulated cable was used for power distribution for nearly a century. It is too bulky to be used for the small cables of final circuits within buildings, or for most of the sub-mains. The smallest practicable rating is 100A, and its chief use is for the Electricity Supply Company's underground low-voltage and medium-voltage distribution.

The conductor is either stranded copper or stranded aluminium, the latter becoming increasingly popular as its price advantage increases. Whichever is used, it is heavily stranded to give good flexibility, which is important in a cable of such comparatively large size. Paper specially made for the purpose is used as an insulator. It is essential that it should have good mechanical properties to be suitable for this application. Paper itself is a hygroscopic, fibrous material, and has to be impregnated with an oily compound to make it fit for use in cables. The compound used is a heavy mineral oil mixed with resin. On its own impregnated paper, insulation would be too fragile to be used unprotected, and a lead sheath is therefore applied over the insulation. Further strengthening and protection can be applied according to the intended use of the cable and the physical wear to which it may be exposed. A very good strong protection is afforded by steel cable or tape.

Figure 2.1 shows a single-core PVC-insulated steel wire armoured PVC-covered cable. This is conventionally referred to as a PVC/SWA/PVC cable. Figure 2.2 shows a three-core PVC-insulated steel wire armoured cable with a PVC covering. The abbreviation for this is PVC/S/SWA/PVC cable. A considerable number of variations on this basic design is possible and, for any given application, a cable can only be chosen with the help of a cable manufacturer's catalogue.

PVC is now used for the larger power and sub-main cables and has superseded paper-insulated cables for these applications. The construction of such cables is similar to that of paper insulated cables, and another example is shown in Figure 2.3. This particular cable would be described as three-phase straight concentric, which would be abbreviated PCU/PVC/straight concentric/PVC cable. This type of cable is used to supply TN-C-S systems, where the armouring forms the CPC and the neutral conductor.

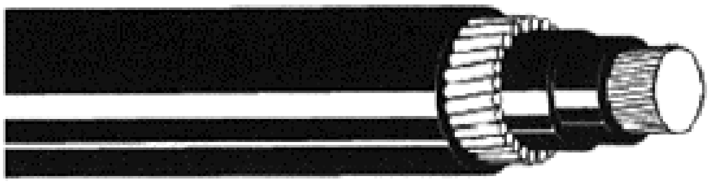


*Figure 2.1* Single-core PVC/SWA/PVC cable

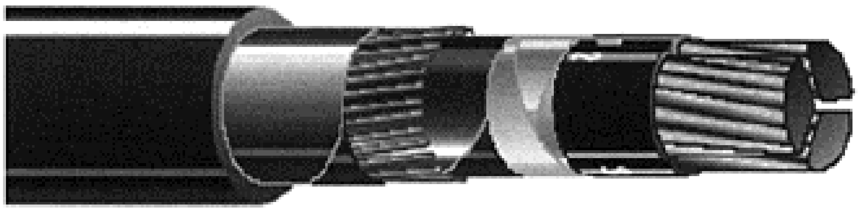


*Figure 2.2* Three-core screened and armoured cable

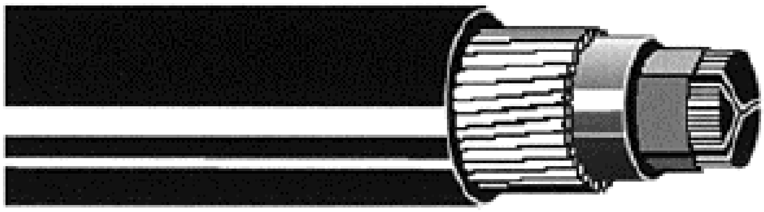


*Figure 2.3* Three-phase straight concentric cable

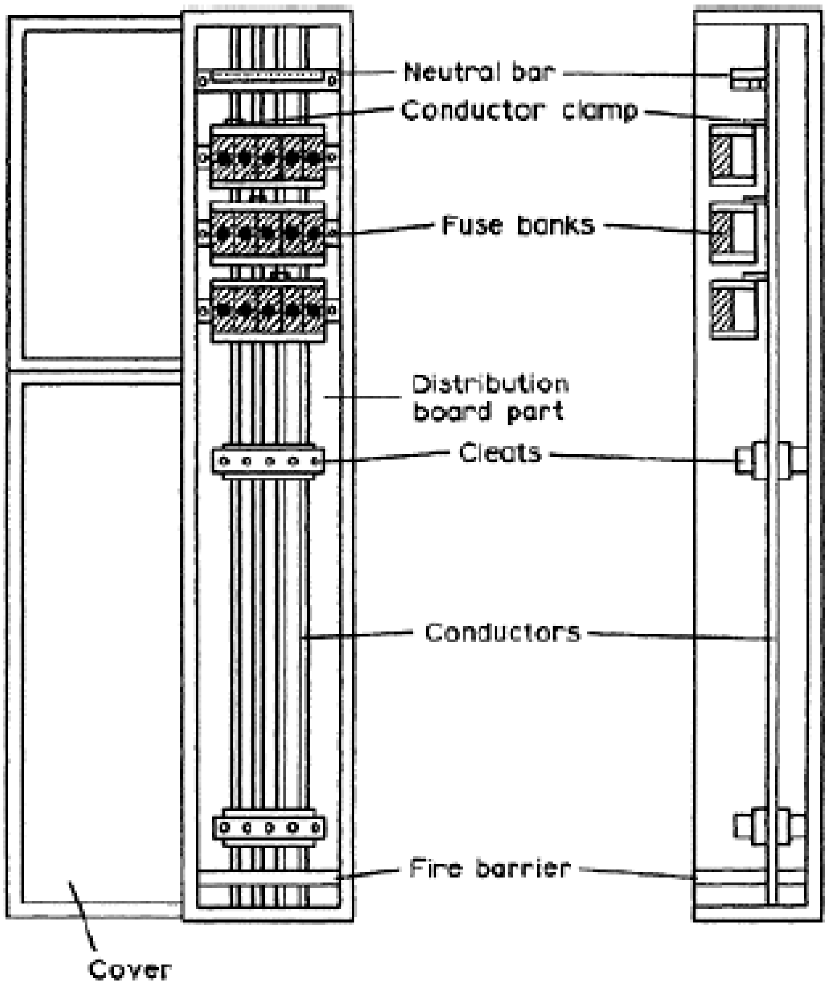



*Figure 2.4* Rising mains

where they run horizontally at high level along the walls of workshops. Plain connectors can be fixed at short intervals and short cables run from each set of connectors to a switch fuse fixed on the wall immediately below or above the trunking. The switch fuse can then be connected to serve a machine near it on the floor of the workshop.

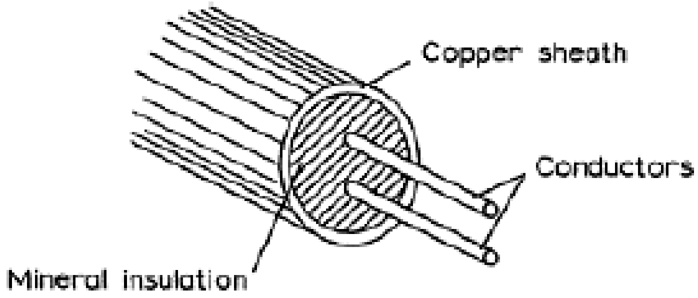



*Figure 2.5* Mineral insulated copper sheathed cable

MIMS cable is extremely robust and, when properly installed, has an indefinite life. It can be used outdoors and for such use is usually supplied with an overall covering of PVC. It is then known as MIMS PVC sheathed. Since PVC is embrittled with ultraviolet light, this PVC covered cable should not be installed where it will be exposed to direct sunlight. This is not as drastic a restriction on its use as may appear since it is probably unwise to run any cable where it is so exposed that direct sunlight can reach it. In any such situation, it would also be too vulnerable to damage by vandalism and from animals.

Because of its robustness, MIMS requires no further protection, but will not withstand being struck by sharp objects. It is, therefore, more easily built into the structure of a building than other cables, nearly all of which must have some form of enclosure around them. Because it has an indefinite life, there is no need for facilities to make it possible to rewire the installation. For both these reasons, it can often be used where no other cable would be entirely satisfactory. MIMS cable can carry a higher current than other cables with the same size conductor because the insulation can withstand a higher conductor operating temperature. However, its current carrying capacity depends on whether it is bare, PVC-covered, exposed to touch, or in contact with a combustible material. It follows that for a given current the cable can be smaller if MIMS is used than if another type of cable is used. This is a very useful property which makes it possible to conceal MIMS cable in corners which are not large enough to hide the larger cable that would have to be used with another system.

The magnesium oxide insulation is hygroscopic and will lose its insulating properties if left unprotected against the ingress of moisture from the atmosphere. To prevent this happening, MIMS cable must be terminated in special seals and glands, which are supplied for the purpose by the cable manufacturers. If the cable is cut and the ends left unsealed for any length of time, as can happen in the course of work on building sites, moisture can penetrate the insulation and render the cable useless. In most cases, however, moisture will penetrate unsealed ends for only a short distance of not more than 50mm. It is then sufficient to cut off the damaged end of the cable, after which the remainder can be used in the normal way. If the cable is carrying full rated current, it will operate at about 90°C; care must be taken that the accessory or luminaire to which the cable is connected is designed to withstand 90°C.

Read other cable notes Chapter 2 Page 29

Standards relevant to this chapter are:

| | |
|---|---|
| BS 2316 | Radio frequency cables |
| BS EN 13602 | Copper wire for the manufacture of electric cables |
| BS 6004 | Electric cables. PVC insulated, non-armoured cables for voltages up to and including 450/750V, for electric power, lighting and internal wiring |
| BS 6007 | Electric cables, single core unsheathed heat resisting |
| BS 6195 | Insulated flexible cables |
| BS 6207–3 | Mineral insulated cables |
| BS 6346 | PVC insulated cables |
| BS 6480 | Paper insulated cables |
| BS 6500 | Electric cables, flexible cords |
| BS EN 50214 | Flexible cables for lifts |

IEE Wiring Regulations particularly applicable to this chapter are:

| | |
|---|---|
| Regulation | 412–2 |
| Chapter | 52 |

# Chapter 3
# Wiring

## Introduction

To the average user the only important part of the electricity service is the outlets at which he received electricity. To the engineer concerned with designing or installing the service, the system of cables which links these outlets to each other and to the supply coming into the building is just as important and perhaps even more so. In practice, the electrical service is a complete interdependent system and the practical engineer thinks of it as a whole, but, as with the teaching of any subject, one has to break it down into parts in order to explain it in an orderly fashion which will make sense to a student with no previous knowledge of the subject.

In this chapter, we shall consider different ways in which cables can be installed in a building. The calculation of the size of particular cables we shall leave to Chapter 4 and the selection and grouping of outlets to be served by one cable we shall leave to Chapter 5. For this chapter, we assume that we know where cables are to run and discuss only how to get them into the building. This aspect of the electrical service can for convenience be called 'methods of installation'.

A method of installation consists of taking a suitable type of cable, giving it adequate protection and putting it into the building in some way. The subject can, therefore, be fairly logically considered by considering types of cable, methods of protection and methods of installation. The types of cable available and in general use have been described in Chapter 2. The protection against mechanical damage given to cable is sometimes part of the cable itself, as with PVC insulated PVC sheathed cables, and sometimes part of the method of installation, as with conduit systems. It can be more confusing than helpful to take a logical scheme of things too rigidly and, rather than deal with protection in a chapter of its own, we are dealing with it partly in the previous chapter and partly in this, according to whether it is associated with the cable or with the method of wiring.

It is probably true to say that one of the commonest methods of installing cables is still to push them into conduit and we shall devote most of our attention to this.

## Conduit

In a conduit system the cables are drawn into tubing called conduit. The conduit can be steel or plastic. Steel conduit is made in both light gauge and heavy gauge, of which heavy gauge is much more frequently used. In both cases, it can be made either by extrusion or by rolling sheet and welding it along the longitudinal joint. The latter is specified as welded conduit and the former as seamless. Seamless conduit is generally regarded as the better quality. The different sizes of conduit are identified by their nominal bore and in the case of electrical conduit the nominal bore is always the same as the outside diameter of the tube. Thus 20mm light and heavy gauge conduits both have the same outside diameter and consequently must have slightly different inside diameters. This is the opposite of the convention used for pipes for mechanical engineering in which the nominal bore usually corresponds more closely to the inside than the outside diameter. Electrical conduit is specially annealed so that it may be readily bent or set without breaking, splitting or kinking.

Heavy gauge conduit is normally joined together by screwed fittings; there is a standard electrical thread which is different from other threads of the same nominal diameter. A screwed connection between two lengths of conduit is shown in Figure 3.1. A male electrical thread is cut on the ends of both lengths of conduit to be joined and a standard coupler with a female electrical thread is screwed over them. A lock nut, which has been previously threaded well up out of the way on one of the male threads, is then wound down and tightened against the coupler. The screwed connection is relied on for continuity of the earth path and the lock nut is essential to prevent the socket working its way along the threads until it engages more on one conduit than on the other. The reason for wanting an earth path is discussed in Chapter 9. Methods of joining conduit to boxes of the kind described in Chapter 1 are shown in Figure 3.2. A bush of some sort must always be used to provide a smooth entry into the box, to avoid sharp corners which could damage the cable insulation, and in certain cases to maintain earth continuity.

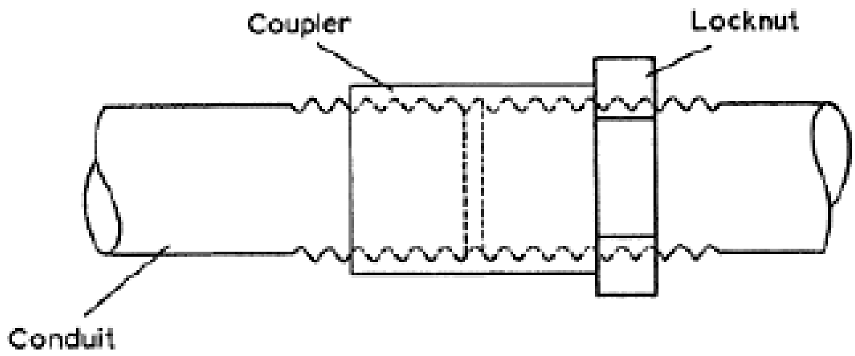



*Figure 3.1* Conduit coupling

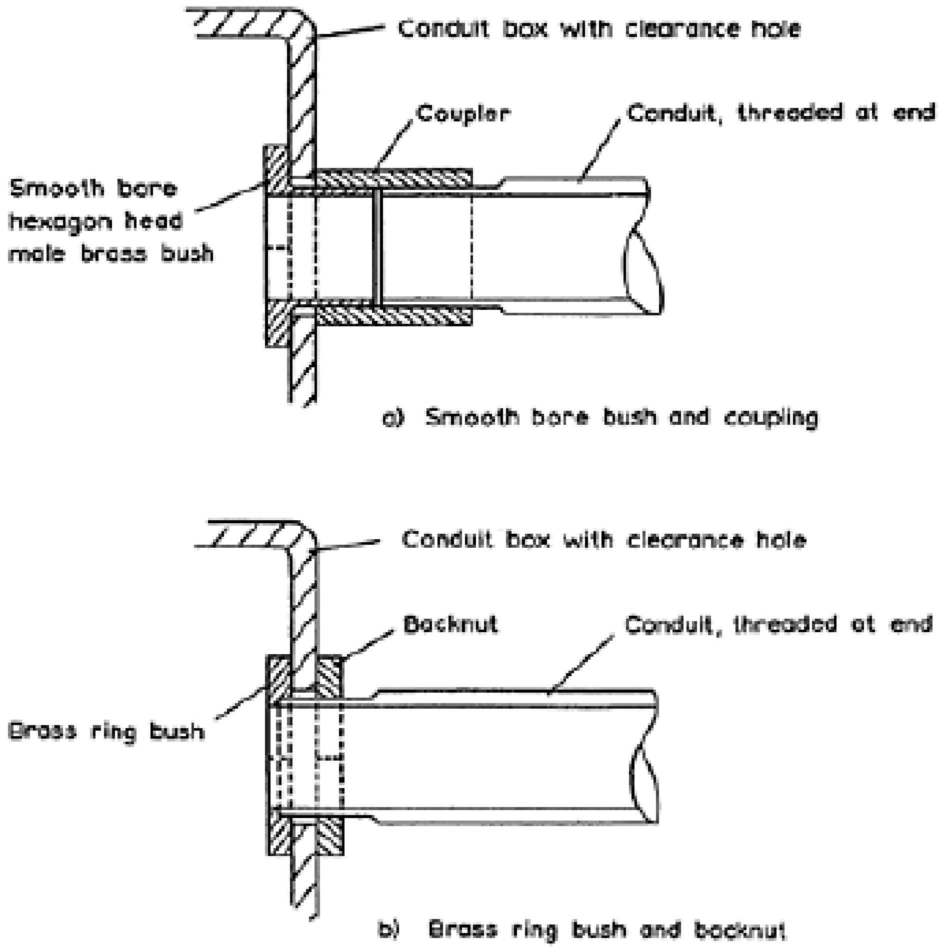
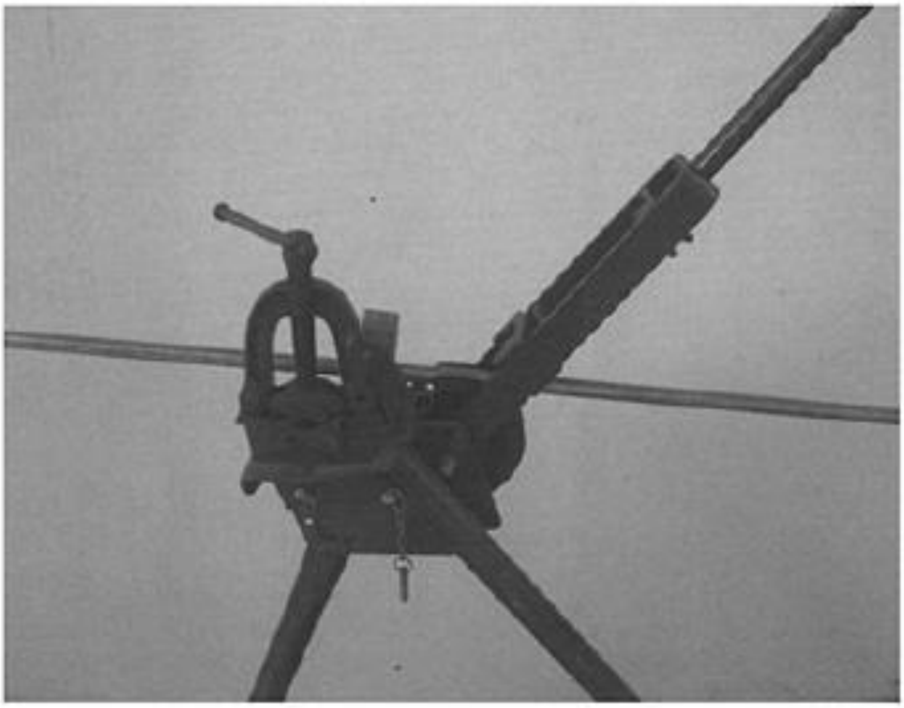



*Figure 3.2* Conduit entries into boxes

$$\frac{\text{total cross sectional area of cables}}{\text{internal cross sectional area of conduit}} \times 100$$

Note that the space factor relates to the space taken up by the cable and not the unoccupied space.

It is harder to pull several small cables together than one large cable, and when a number of cables have to go in the same conduit, it is advisable to



To avoid damage to cables as they are drawn in, burrs on cut ends of conduit must be removed with a reamer before the lengths of conduit are joined.

There are a number of positions in a building in which the conduit can be fixed. It can obviously be run on the surface of walls and ceilings, and when a building is constructed of fair-faced brick walls, surface conduit is usually the only practicable wiring system which can be adopted. If walls are plastered, the conduit can generally be concealed within the plaster. There must be at least 6mm of plaster covering the conduit if the plaster is not to crack. Since plaster-depth conduit boxes are 16mm deep, the total thickness of plaster must be at least 22mm. If the architect or builder proposes to use a lesser thickness than this, it becomes necessary to chase the conduit into the wall so that some of the total distance of 22mm between face of plaster and back of conduit is in the wall and some in the plaster. This is shown in Figure 3.8.

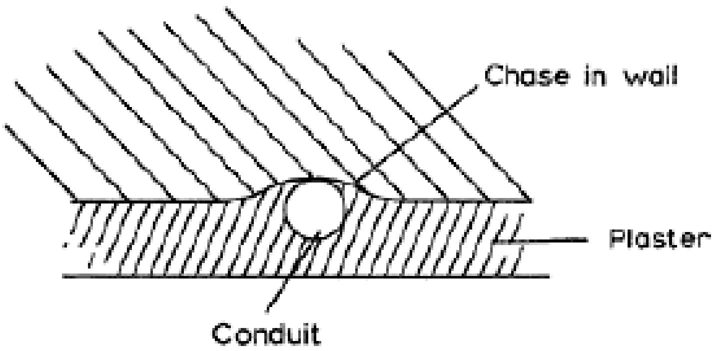



*Figure 3.8* Conduit chased into walls

In many modern buildings, internal partitions which do not carry any of the structural load are made of breeze-blocks about 75mm thick and in some cases as little as 50mm thick. If these have to be chased to take 25mm conduit, there is very little partition left. Using conduit with such partitions is a very real problem and the electrical engineer often has to abandon a conduit system in favour of one which is less robust but takes up less space.

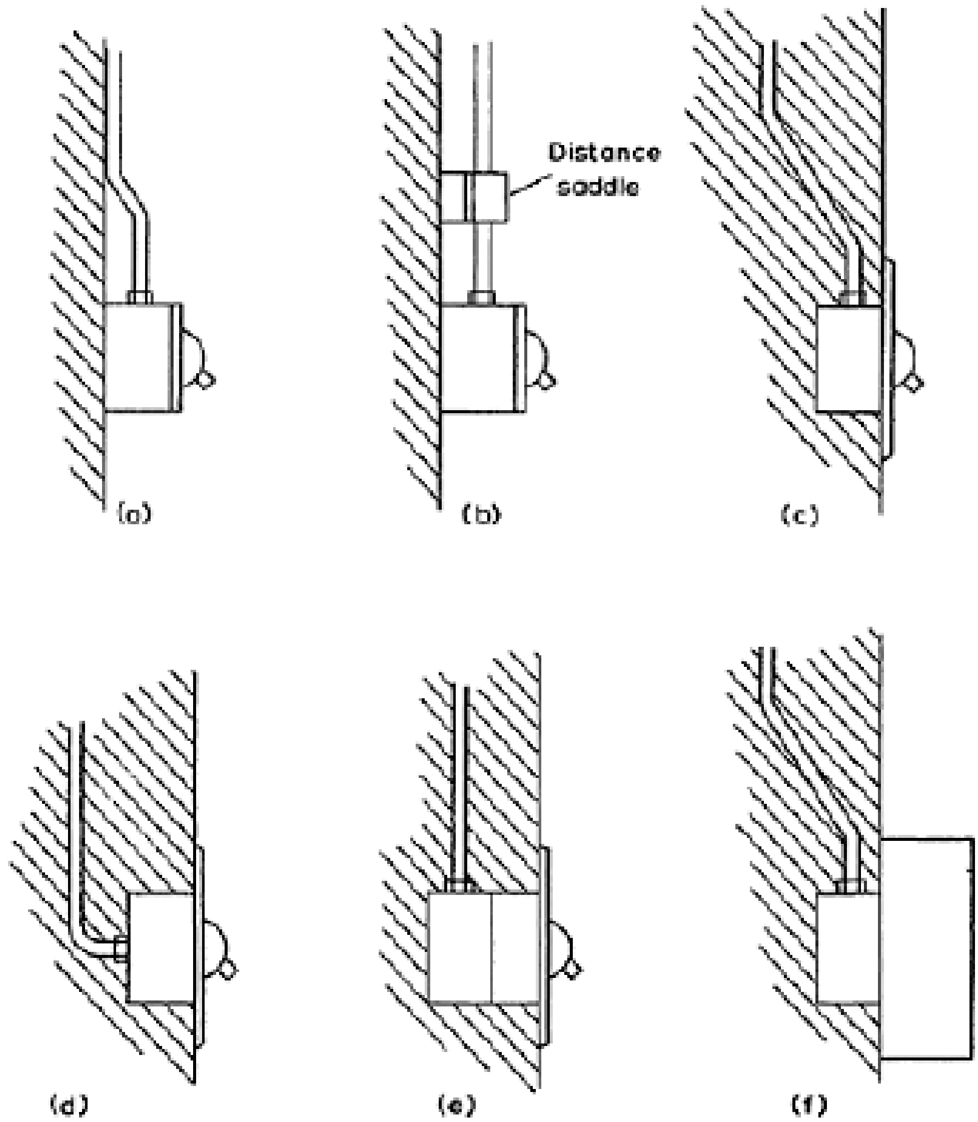



*Figure 3.9* Conduit entries to equipment

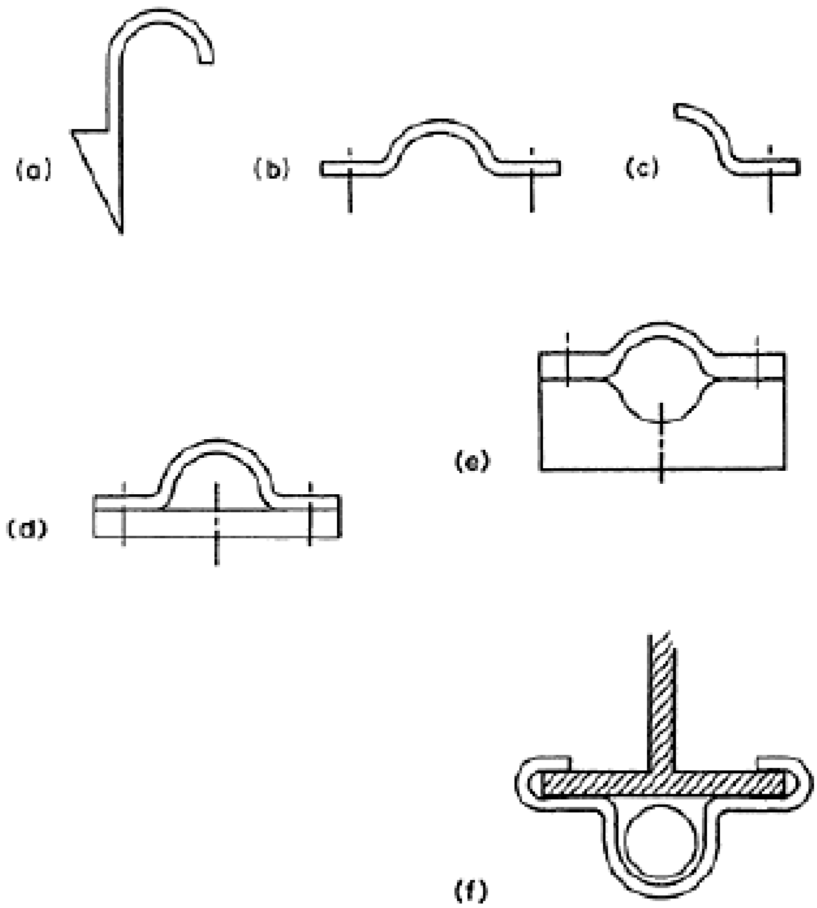



*Figure 3.10* Conduit fixings

Electrical conduit is not thick enough to support its own weight over long distances without sagging. The supports must, therefore, be at quite close intervals, and the maximum distances which should be allowed between supports are as follows:

| | Horizontal | Vertical |
|---|---|---|
| 20mm conduit | 1.75m | 2.0 |
| 25 and 32mm conduit | 2.0m | 2.5 |
| 40mm and over | 2.25m | 2.5 |

The IEE Guidance Note 1 and the IEE On-Site Guide both give guidance on the maximum spacing of conduit fastenings.

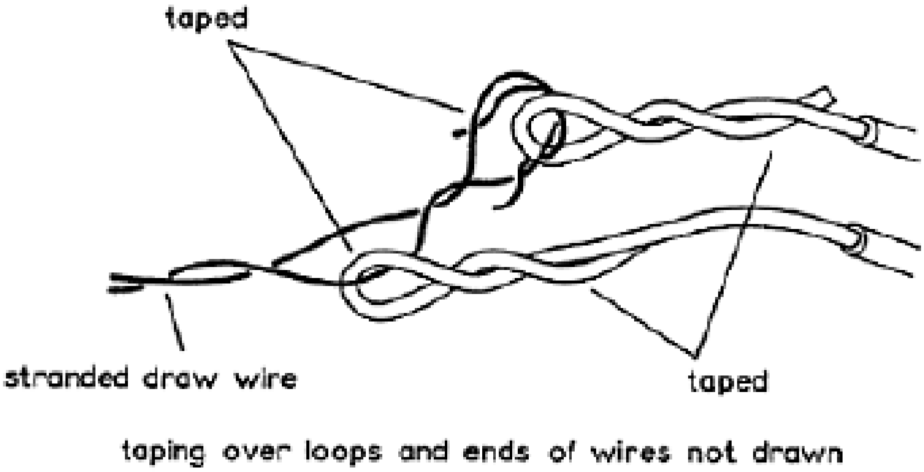



*Figure 3.11* Connection of cable to draw cable

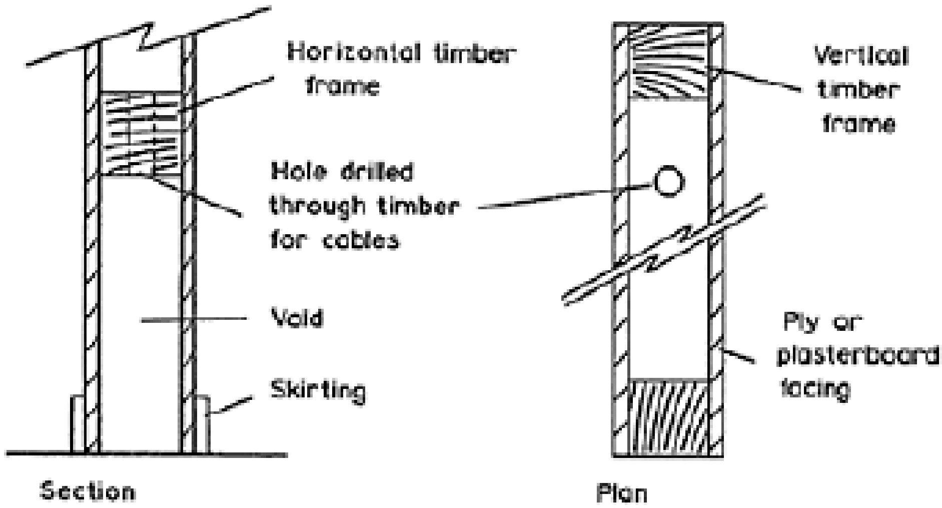



*Figure 3.12* Dry partition

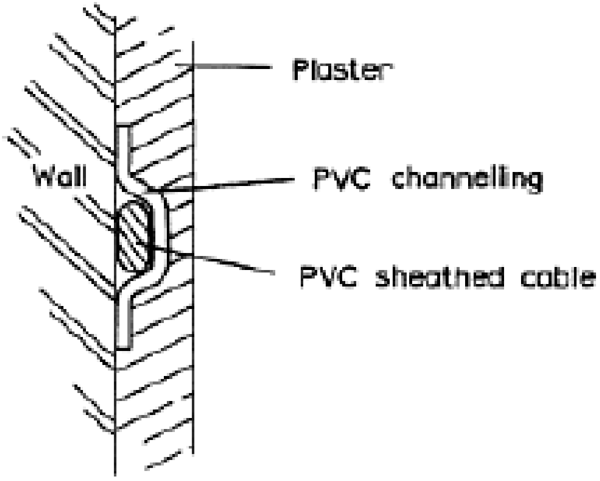



*Figure 3.13* Cable buried in plaster

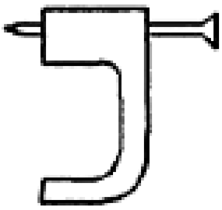


*Figure 3.14* Clip

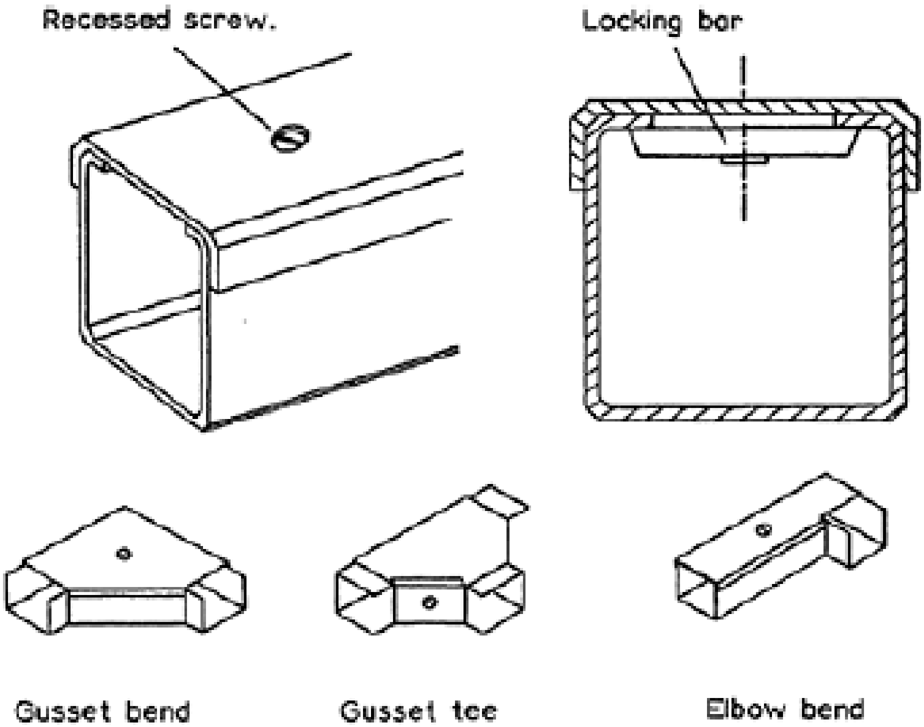



*Figure 3.15* Cable trunking

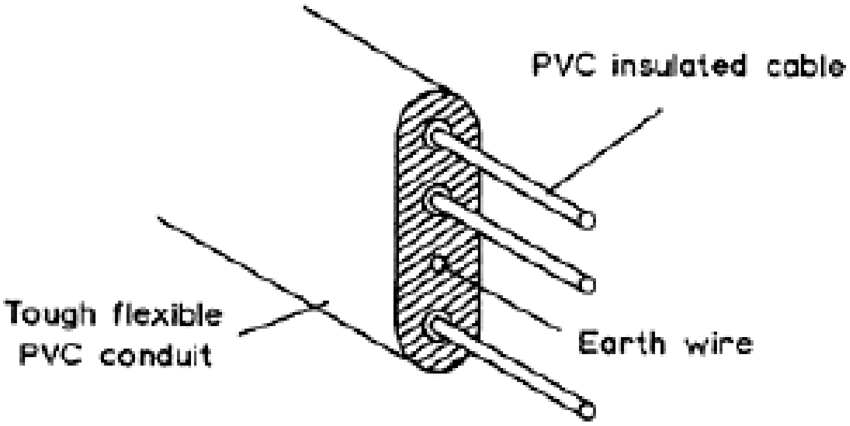



*Figure 3.17* Simplex system

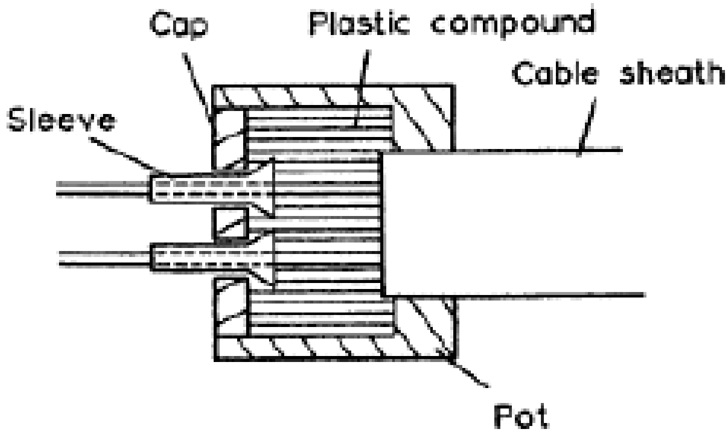



*Figure 3.18* MICC cable seal

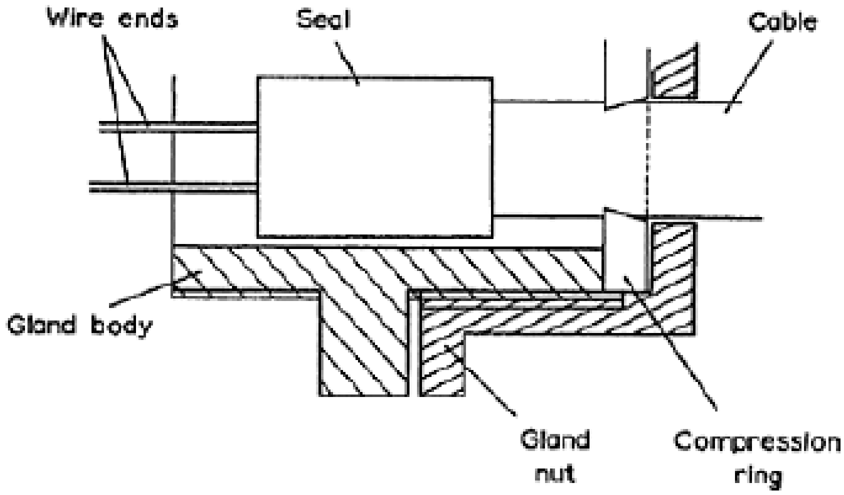



*Figure 3.19* MICC gland

### External wiring

It is sometimes necessary to run cables from one building to another. This can be done either with cables running under the ground or with overhead cables. Cables that are to be run underground can be armoured paper, armoured PVC or MICC cables. All these are strong enough to be laid directly in the ground and buried, but in order that they should have reasonable protection against damage they should be laid at least 600mm below the ground level. Since they all have metal armouring or sheathing, no protection in the ground is really necessary, but it is very usual to provide a bed of sand, and cover the cable loosely with tiles before the trench in which it has been laid is backfilled. If someone later has occasion to dig the ground near the cable they will hit the tiles first and be warned that there is something underneath them. Tiles are available for this use which have lettering on them saying 'Danger–Electric Cables'; they are known as electrical tiles. A cheaper alternative is plastic tape with the same lettering. This has almost universally superseded tiles although it may be questioned whether it will be noticed before the digging tool has gone through it and the cable. Another method is to install over ground markers showing the line of the run of the underground cable

It is also possible to bury conduit in the ground and pull cables through it in the ordinary way. Because of the danger of corrosion in the soil this is not however a good practice. It is better to use builder's polythene pipe as ducts instead of conduit, and in fact this is very often done. It is harder to provide frequent access to underground ducts than to conduit in a building, and the lengths between draw-in points can become rather large. At the same time there is plenty of room in the ground for large-diameter pipes, and it is a sound precaution never to use anything smaller than a 100mm polythene or earthenware duct.

In certain cases it is common practice to use polythene conduit underground. This happens for example when the cable from a communal TV aerial has to cross from one building to another on the same site. It is also the standard method of bringing telephone cables into a building in urban areas where the main telephone cables are in the road outside the new building. Telephone cables are quite small and can be easily pulled into 20mm conduit over considerable distances.

Buried cables rely on conduction of heat through the soil to dissipate the heat generated by the current in the resistance of the cables. If there are other services which heat the soil locally then the rate of dissipation of heat could be reduced, and the current carrying capacity of the cables would then also be reduced. The obvious example of a service which would have this effect is a district heating main. But in addition to this consideration some thought must be given to what happens when maintenance work is done on underground services. It is undesirable that workmen who may have to expose a length of buried gas or water main should have to dig near a live electric cable. There are thus two reasons why underground cables should be kept well away from other buried services. A good practical rule is to have a minimum distance apart of 2m.

## Cable entries

The entry of cables from the outside to the inside of a building sometimes causes difficulty. There must obviously be a hole in the wall which has to be tight round the cable and which has to be sealed to prevent dirt, vermin and moisture entering. Whether the cable is an armoured type laid directly in the ground or whether it is drawn into a duct, the most practicable way of making the entry into the building is by means of an earthenware duct built through the wall below ground level. When the cable has to bend up to rise on the inside face of the external wall, a duct bend can be built into the wall.

After the cable has been pulled through the polythene or earthenware duct, a seal is made round it within the duct with a bituminous mastic compound. Normally this is inserted from the inside of the building. The essential requirement is to make the seal watertight; it will be readily understood that a seal which prevents water coming through will also stop dirt and small animals. In difficult cases one can make a metal plate to overlap the earthenware duct with a hole in it of a diameter to be a push fit on the cable. The duct is filled with mastic, the metal plate is pushed over the cable to cover the end of the duct and is screwed back to the wall, and the edges of the plate are then pointed with mastic. This construction gives an effective water seal.

## Temporary installations

Temporary installations must be just as safe as permanent ones. There is therefore no reason for departing from any of the principles of design and installation which are used for permanent systems. The methods of cable sizing and schemes of distribution which are described in the following chapters apply to temporary installations as well as to permanent ones. The methods of installing cables which we have discussed in this chapter are all designed to give adequate safety and can be used on any temporary installation.

This book deals with design rather than installation, and methods of wiring have been described from this point of view. Standards relevant to this chapter are:

| | |
|---|---|
| BS 31 | Steel conduit and fittings |
| BS 731 | Flexible steel conduit |
| BS 951 | Earthing clamps |
| BS 4568 | Steel conduit and fittings with metric threads |
| BS 4607 | Non-metallic conduit and fittings |
| BS 4678 | Cable trunking |
| BS EN 60423 | Outside diameters of conduits |
| BS EN 50086–1 | Conduits for electrical installations |

IEE Wiring Regulations particularly applicable to this chapter are:

Chapter 52
*IEE Guidance Note 1*
*IEE On-Site Guide*

# Chapter 4
# Cable rating

An important part of any electrical design is the determination of the size of cables. The size of cable to be used in a given circuit is governed by the current which the circuit has to carry, so the design problem is to decide the size of cable needed to carry a known current. Two separate factors have to be taken into account in assessing this, and the size of cable chosen will depend on which factor yields the most suitable value in each particular case.

A conductor carrying a current is bound to have some losses due to its own resistance. These losses appear as heat and will raise the temperature of the insulation. The current the cable can carry is limited by the temperature to which it is safe to raise the insulation. Now the temperature reached under continuous steady state conditions is that at which the heat generated in the conductor is equal to the heat lost from the outside of the insulation. Heat loss from the surface is by radiation and conduction and depends on the closeness of other cables and on how much covering or shielding there is between the cable and the open atmosphere. Thus the heat loss and, therefore, the equilibrium temperature reached depends on how the cable is installed; that is to say whether it is in trunking, or conduit, on an exposed surface, how close to other cables, and so on. To avoid tedious calculations, tables have been prepared and published (appendix to BS 7671) which list the maximum allowable current for each type and size of cable.

The tables give a current rating for each type and size of cable for a particular method of installation and at a particular ambient temperature. For these basic conditions a cable must be chosen the rated current of which is at least equal to the working current. For other methods of installation and ambient temperatures the tables give various correction factors. The fuse or circuit breaker rating has to be divided by these to give a rated current and a cable then selected such that its tabulated current is at least equal to this nominal current.

Particular care has to be taken where cable is run in a thermally insulated space. With increasing attention to thermal insulation of walls this is likely to become a more frequently occurring situation, and BS 7671 now require a cable to be de-rated when it is used in such a situation.

$$t = \frac{k^2 S^2}{I^2}$$

where $t$=time in seconds in which protective device opens at a current of $I$A

$k$=a constant, given in the Regulations for different cables

$S$=minimum cross-sectional area of conductor in the cable, mm$^2$

$I$=short circuit current, A.

If necessary the cable size must be increased above that provisionally selected from the tables in order to satisfy this condition.

Alternatively, the cable size can be retained and a fuse or circuit breaker with a faster operating time used.

The protection must also operate if the overcurrent is not a short circuit but a comparatively small multiple of the working current, an overload. HRC fuses and circuit breakers can take up to four hours to operate at a current 1.5 times their rated current. The cable temperature will rise during this time and the working current must allow a safety margin to take account of this. The rating tables in BS 7671 include the necessary margin for HRC fuses and circuit breakers.

However, rewireable fuses (BS 3036) take longer to operate and a larger margin is therefore necessary. The rating tables therefore include a factor by which cables must be de-rated if rewireable fuses are going to be used to protect the cables.


*Figure 4.1* Device rating related to design current


*Figure 4.1* Effect of grouping cables

In other words a cable which will carry 76.92A is acceptable, but the cable must be de-rated to a factor of 0.65:

76.92×0.65=50

$$230 \times \frac{4}{100} = 9.2\text{V}$$

We now need to check that the voltage drop in the $10\text{mm}^2$ cable is within these limits.

Table 4D2B gives voltage drop in millivolts per ampere per metre. To calculate the voltage drop, multiply

$$\frac{\text{mV/amp/metre} \otimes \text{Ib} \otimes \text{Metres}}{1000}$$

$$= \frac{4.4 \times 36 \times 25}{1000} = 3.96\text{V}$$

Therefore, the minimum permissible size is $10\text{mm}^2$.

If the circuit was protected by a rewireable fuse to BS 3036, the design of the circuit would be slightly different.

Reference method 1

Design current Ib=36A. Nominal rating of the device In=45A

Cg=0.79, Ca=0.97, Ca×Cg×0.725=C, where C=combined factor to apply

C=0.79×0.97×0.725=0.555

minimum tabulated rating It=In/C 45/0.555=81A

Now look at Table 4D5A, column 4, It=85. Therefore, the minimum size with respect to current carrying capacity is $16\text{mm}^2$.

$$\frac{\text{mV/amp/metre} \times \text{Ib} \times \text{Metres}}{1000}$$

$$= \frac{2.8 \times 36 \times 25}{1000} = 2.252\text{V}$$

Therefore, the minimum permissible size is $16\text{mm}^2$ ($10\text{mm}^2$ with type-B MCB to BS EN 60898). Note that semi-enclosed fuses should be rigorously avoided these days. BS 7671 expresses a preference for cartridge-type fuses.

$$t = \frac{k^2 \times S^2}{I^2}$$

where $t$=time taken to reach the limit temperature

*K*=is a factor taken from table 43A BS 7671

*S*=cross sectional area in mm2

*I*=fault current.

For example: a motor circuit is supplied by means of 4mm$^2$ thermoplastic 70°C PVC copper cables. The protection device at the origin of the circuit is a 50A BS 88–2.1 fuse. The prospective short circuit current is 300A. The K value for thermoplastic 70°C PVC copper cables is 115. The time for the cable to reach its limit temperature is

$$t = \frac{115^2 \times 4^2}{300^2}$$
$$= 2.35\text{ s}$$

To take a typical BS 88 fuse, 300A, flowing through a 50A fuse would disconnect in about 1.2. Therefore, the fuse would operate before the cable reached its limit temperature, the cable being protected against short circuit.

Because of the cable resistance, 10m along the run the short-circuit current will be attenuated to 263A, giving a time to reach the limit temperature of above 3s. The disconnection time would, however, increase to about 2.5s. The cable is still protected.

Mention should also be made of the circuit protective conductor. The function of this is described in Chapter 9. Under normal conditions it carries no current and it conducts electricity only when an earth fault occurs and, then, only for the short time before the protective device operates. BS 7671 gives two alternative ways of determining its size. The first is by the use of the same formula as above, transposed to make S the subject of the formula, as has been quoted above, for checking the short circuit rating of the live conductor. Alternatively, the regulations give a table which relates the size of the protective conductor to the size of the phase conductor. The effect is that for circuits up to 16mm$^2$, the protective conductor minimum size must be equal to the line or phase conductor, for 25mm$^2$ and 35mm$^2$ phase conductors, the protective conductor must be at least 16mm$^2$, and for phase conductors over 35mm$^2$ the cross section of the protective conductor must be at least half the cross section of the phase conductor.

BS 7671 IEE Wiring Regulations particularly applicable to this chapter are:

| | |
|---|---|
| Section | 521–7 |
| Section | 522 |
| Section | 523 |
| Section | 524 |

| | |
|---|---|
| Section | 525 |
| Section | 543 |
| Appendix | 3 |
| Appendix | 4 |

Read Cable rating in Chapter 4 Page 69

# Chapter 5
# Circuits

The final outlets of the electrical system in a building are lighting points, socket outlets and fixed equipment. The wiring to each of these comes from an excess current protection device (fuse or circuit breaker) in a distribution board, but one fuse or CB can serve several outlets. If the circuit supplies current using equipment, wiring from one fuse or CB is known as the final circuit, and all the outlets fed from the same fuse or CB are on the same final circuit. The fuse or CB must be large enough to carry the largest steady current ever taken at any one instant by the whole of the equipment on that final circuit. Since the fuse or CB protects the cables, no cable forming part of the circuit may have a current carrying capacity less than that of the fuse, unless the characteristics of the load or supply are such that an overcurrent cannot occur. The size of both the fuse or CB and cable is, therefore, governed by the number and type of outlets on the circuit.

It is unusual to have a fuse of more than 45A in a final distribution board in domestic premises, and the cables normally used for final circuits are $1.5mm^2$, $2.5mm^2$ and $6.0mm^2$, according to the nature of the circuit. Lighting is almost invariably carried out in $1.5mm^2$ cable and power circuits to socket outlets in $2.5mm^2$. $6.0mm^2$ and $10mm^2$ cable is used for circuits to cookers, instantaneous water heaters, showers, and other large current-using equipment, such as machine tools in workshops. These sizes are so usual that it is better for the designer to restrict the number of outlets on each final circuit to keep within the capacity of these cables than to specify larger cables. If he does choose the latter course there is a real danger that the site electrician will install the cables he is used to, instead of complying with the designer's specification. These considerations will not, of course, apply in a factory in which individual machines can take very heavy currents.

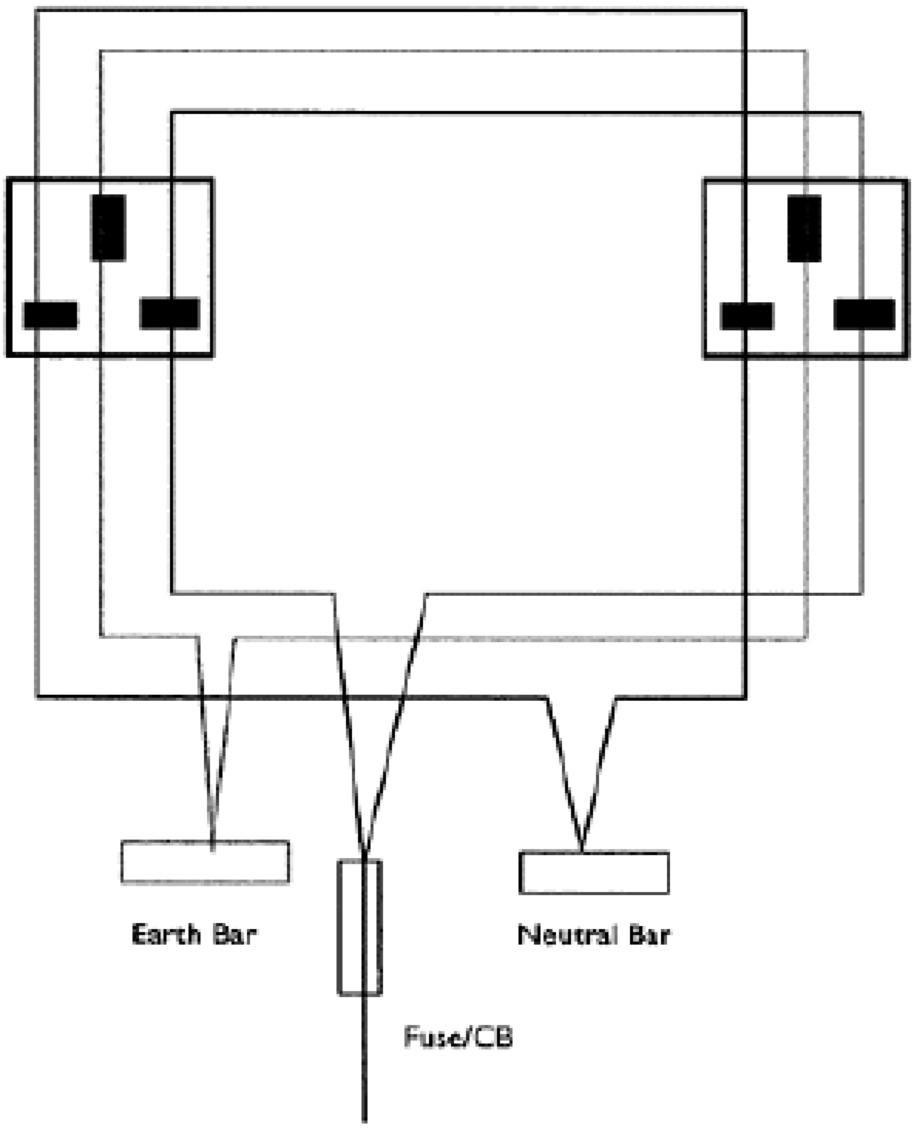
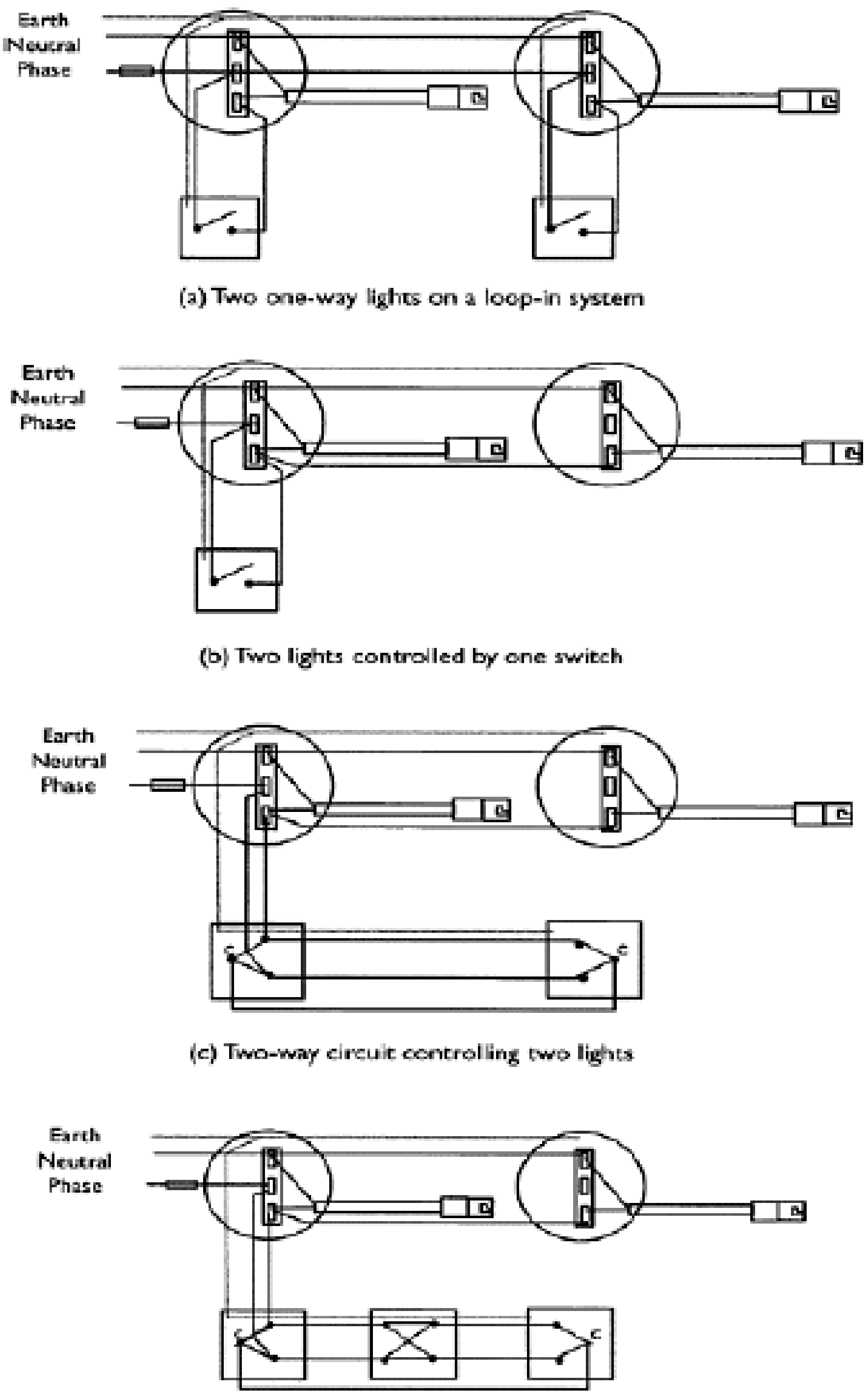



*Figure 5.1* Ring circuit




(a) Two one-way lights on a loop-in system

(b) Two lights controlled by one switch

(c) Two-way circuit controlling two lights

(d) Two-way and intermediate

*Figure 5.2* Lighting circuits

Read Circuit in Chapter 5 Page 77

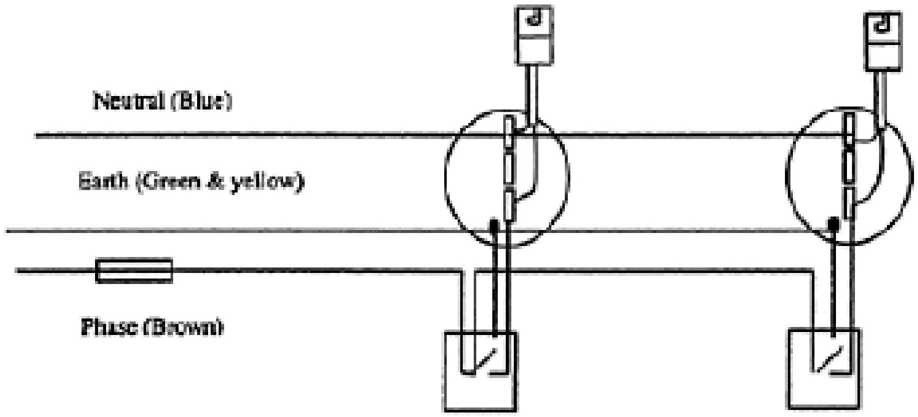



*Figure 5.3* Looping at switch

shown in Figure 5.3, but it is difficult to visualize a building in which this scheme would not require very much more cable than that of Figure 5.2.

We have described the way in which outlets are conventionally grouped and arranged in final circuits. Each of these sub-circuits is fed from a fuse on a distribution or fuseboard and the next step in describing a complete electrical system is to show from where the distribution board obtains its supply. This we shall do in the next chapter.

IEE Wiring Regulations particularly applicable to this chapter are:

| | |
|---|---|
| Section | 314 |
| Section | 463 |
| Appendix | 4 |

# Chapter 6
# **Distribution**

Electricity is supplied to a building by a supply authority; i JK this is an area electricity company, while in other countries it may be an electricity supply company or public body. The supply is provided by a cable brought from outside into a suitable point in the building which is referred to as the main intake, and from this the electricity has to be distributed to all outlets which use it. The incoming cable may be a 120 or 150mm$^2$ PVC insulated cable and the current flowing along it must be divided between a number of smaller cables to be taken to the various final destinations throughout the building. This division is the function of the distributing system.

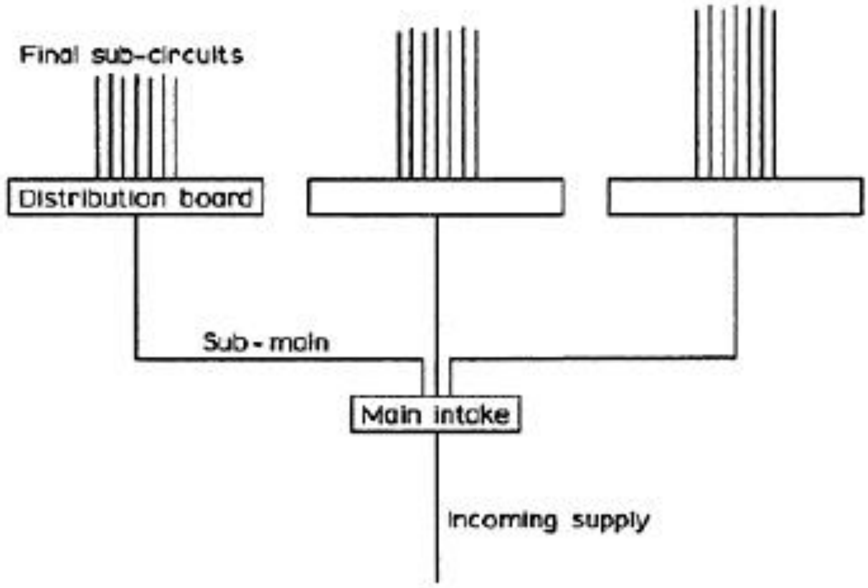



*Figure 6.1* Distribution

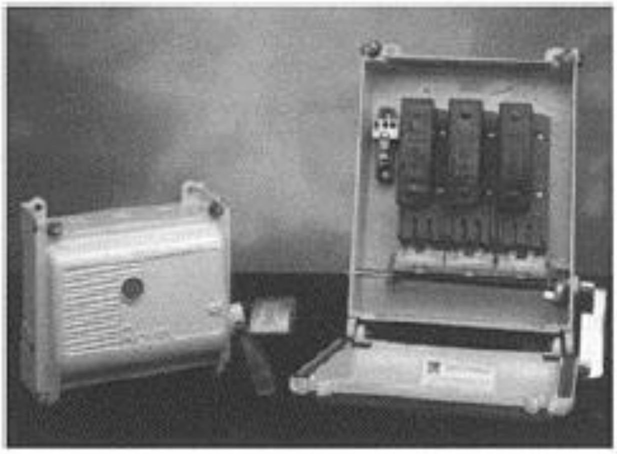


*Figure 6.2* Switch fuse (Courtesy of Eaton Electric Ltd)

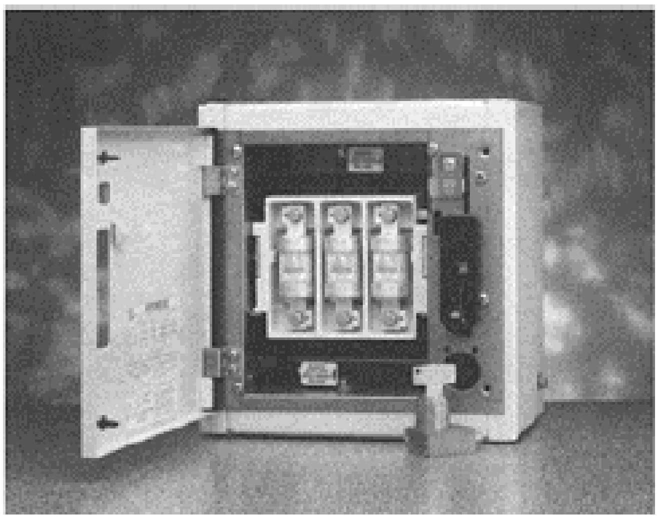
A switch fuse also includes terminals which enable the earth cables on the incoming and outgoing sides to be connected together. Under no circumstances must there be a break in this circuit as it would destroy the safety of the system. The neutral cable on the other hand can be taken through the switch fuse in one of two ways.

The more usual way is for the switch to include terminals for connecting the incoming and outgoing neutrals in the same way as the earth cables. The alternative is for it to have a switch blade in the neutral line as well as in the phase lines, thus making it a 4-pole device. In this case there is a solid link instead of a fuse in the neutral line.

A fuse switch, illustrated in Figure 6.3, is similar to a switch fuse, but in this case the fuse carriers are mounted on the moving blades of the switch.

The whole of the current going into the sub-main passes through the switch fuse which carries no current for any other part of the system.

The total incoming current must be divided to go to several switch fuses, and the simplest device for distributing current from one incoming cable to a number of outgoing ones is a busbar chamber. This consists of a number of copper bars held on insulating spacers inside a steel case. It is shown in Figure 6.4. Cables can be connected to the bars anywhere by means of cable clamps which are usually bolted to the bars. The incoming cable can be connected to the bars at one end or at some convenient point along them. Connecting the incoming cable to the centre of the busbar enables 300A



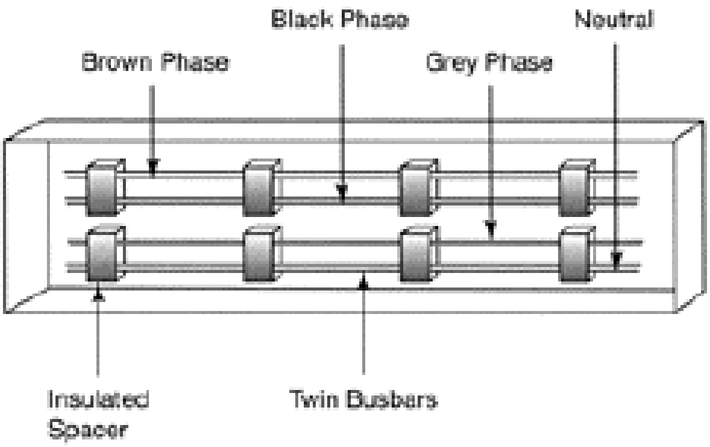



*Figure 6.4* Busbars

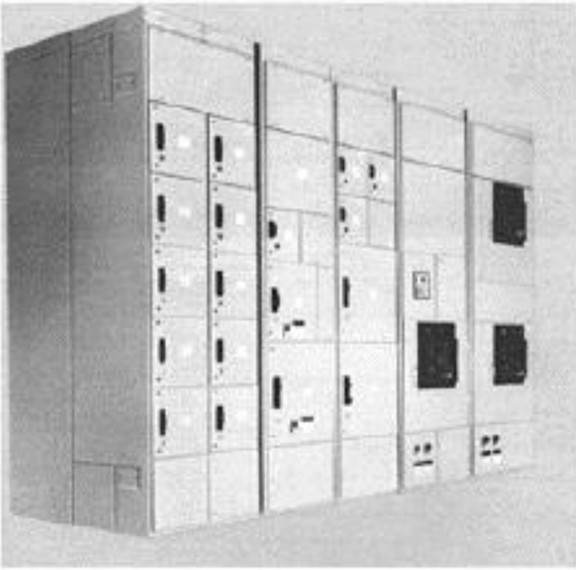


*Figure 6.5* Cubicle switchboard
(Courtesy of Eaton Electric Ltd)

*Figure 6.6* Distribution board
(Courtesy of Eaton Electric Ltd)

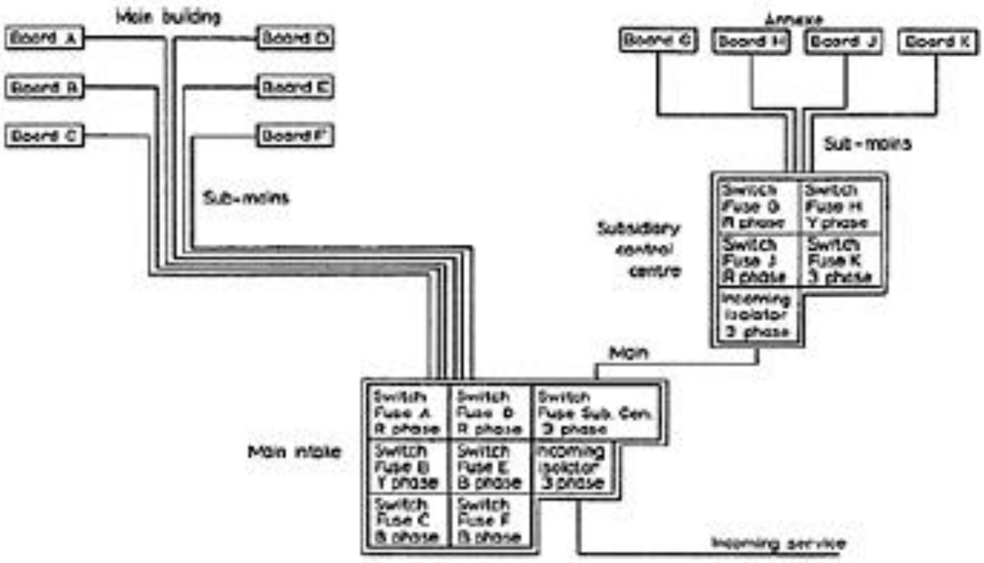



*Figure 6.7* Distribution through subsidiary centres

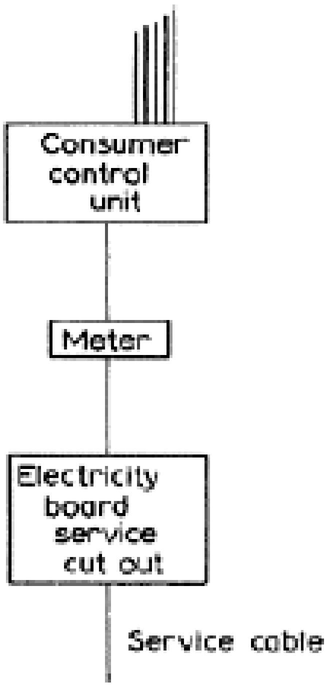



*Figure 6.8* Domestic service

| Circuits | Serving | Rating amps |
|---|---|---|
| 1 | Upstairs lights | 6 |
| 2 | Downstairs lights | 6 |
| 3 | Garage and outside lights | 6 |
| 4 | Upstairs ring main | 32 |
| 5 | Downstairs ring main | 32 |
| 6 | Immersion heater | 15 |
| 7 | Shower unit | 45 |
| 8 | Cooker | 45 |
| 8 | Spare | – |

(a)

| Circuits | Serving | Rating amps |
|---|---|---|
| 1 | Lights | 6 |
| 2 | Ring main | 32 |
| 3 | Cooker | 32 |
| 4 | Bathroom ventilation fan | 10 |
| 5 | Clothes dryer | 10 |
| 6 | Motorized valve on heating | 10 |

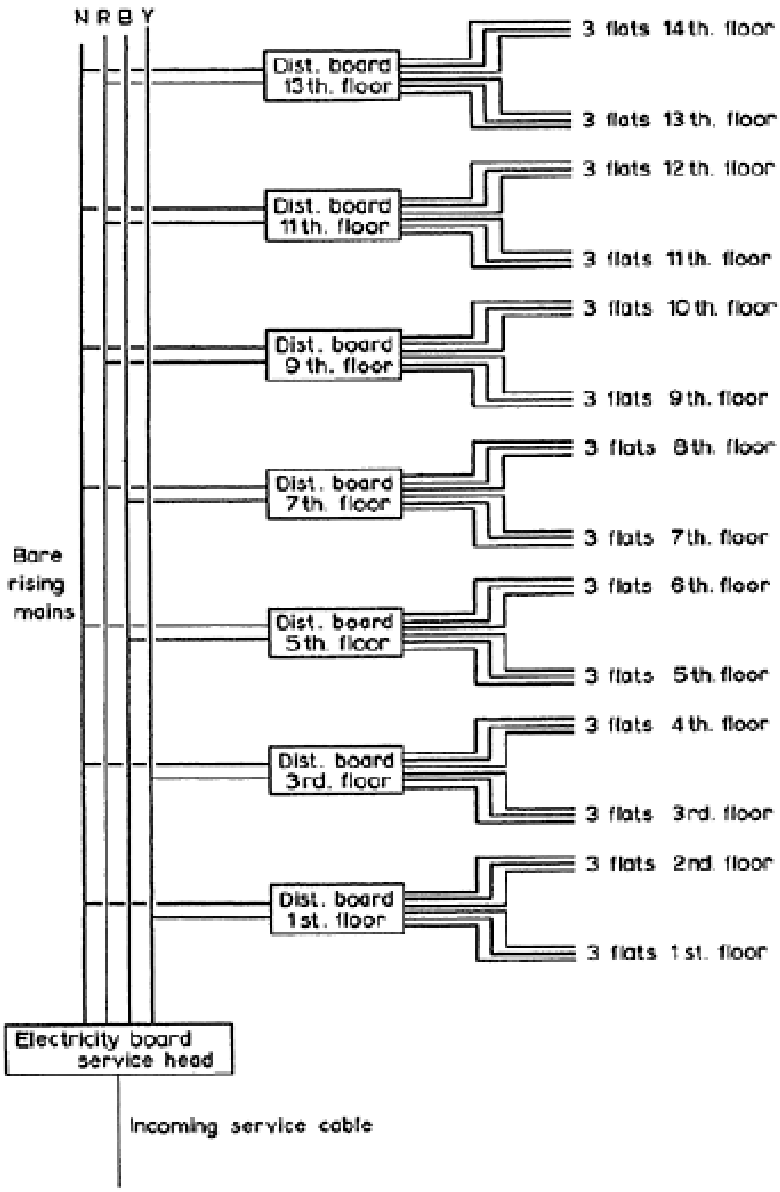



*Figure 6.9* Distribution to flats

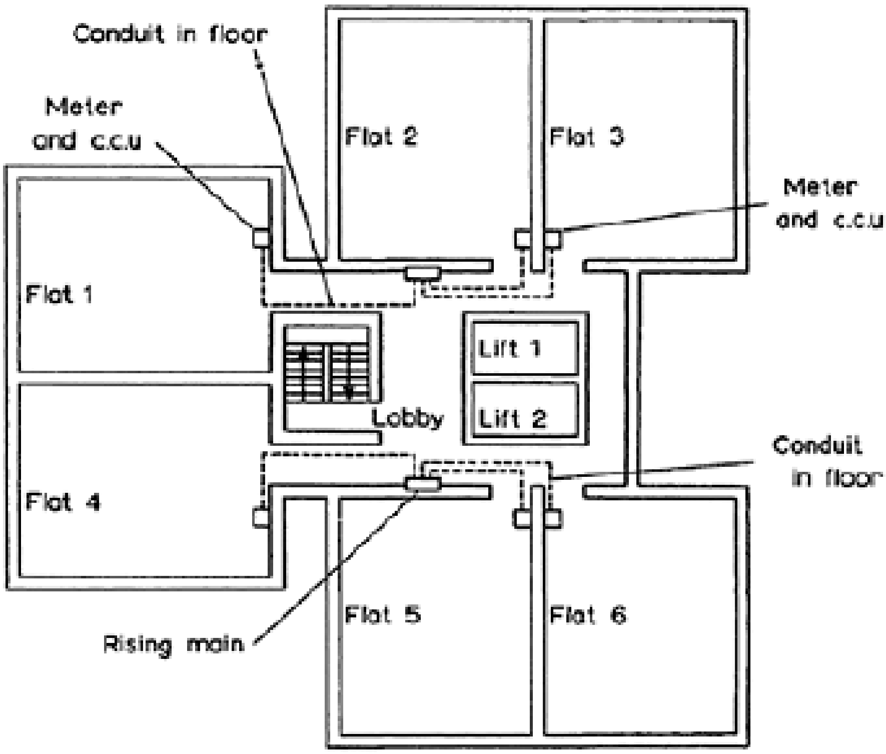



*Figure 6.10* Distribution to flats

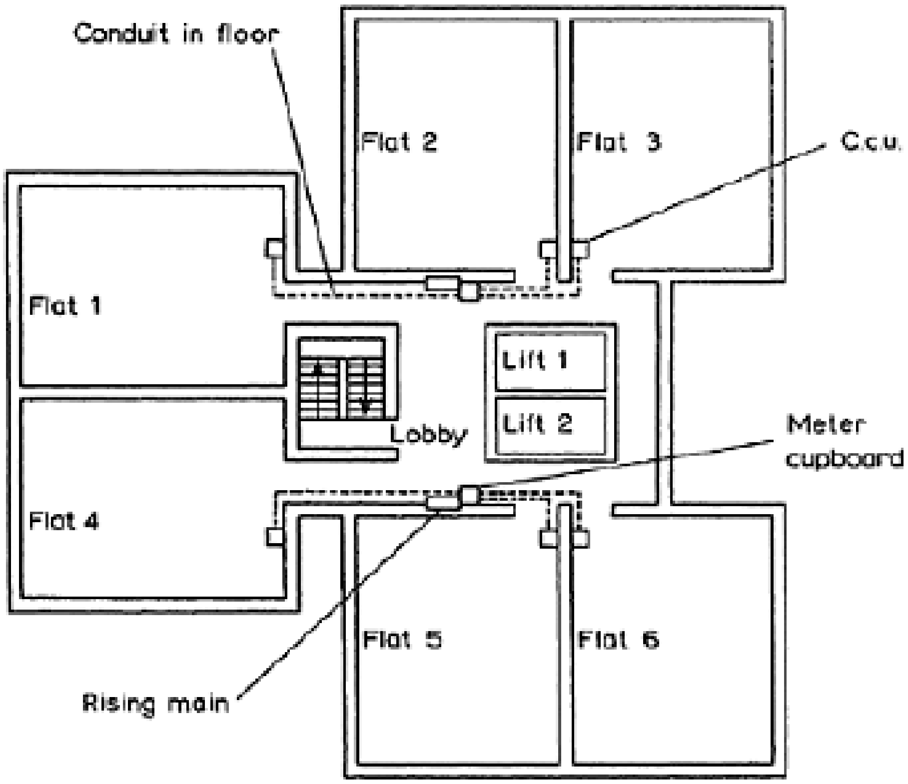



*Figure 6.11* Plan with external meter cupboards

1.5mm$^2$ cable would run in the same conduit back from the meter into the distribution board and through the side of the board into the repeater cupboard. Here it would be connected to the repeater belonging to the flat in question, and the repeater would reproduce the reading on the meter.

Standards relevant to this chapter are:

| | |
|---|---|
| BS EN 60947–2 | Specification for low voltage switchgear and controlgear |
| BS EN 60947–3 | Specification for low-voltage switchgear and controlgear |
| BS 5486 | Low voltage switchgear and controlgear |
| BS 6121 | Mechanical cable glands for elastomer and plastics insulated cables |
| BS EN 50262 | Metric cable glands for electrical installations |
| BS 6480 | Impregnated paper insulated cables for voltages up to 33000V |

IEE Wiring Regulations particularly applicable to this chapter are:

Section 537

Read Page 86 Chapter 6 Distribution

# Chapter 7
# **Lighting**

## Introduction

Illumination and the design of lighting layouts is a subject on its own. There are books dealing comprehensively with it and it is not proposed to condense the matter into a single chapter here, but once a lighting layout has been arrived at, it is necessary to design the circuits, wiring and protection for it; this is an aspect of lighting design which tends to be overlooked in books on illumination and which we propose to discuss in this chapter. The electrical requirements of a lighting system depend to a considerable extent on the kind of lamps used and we shall describe the different available types in turn.

It will be noticed that the traditional Edison screw affords slightly greater risk of accidental contact with the terminal when one is putting a bulb into

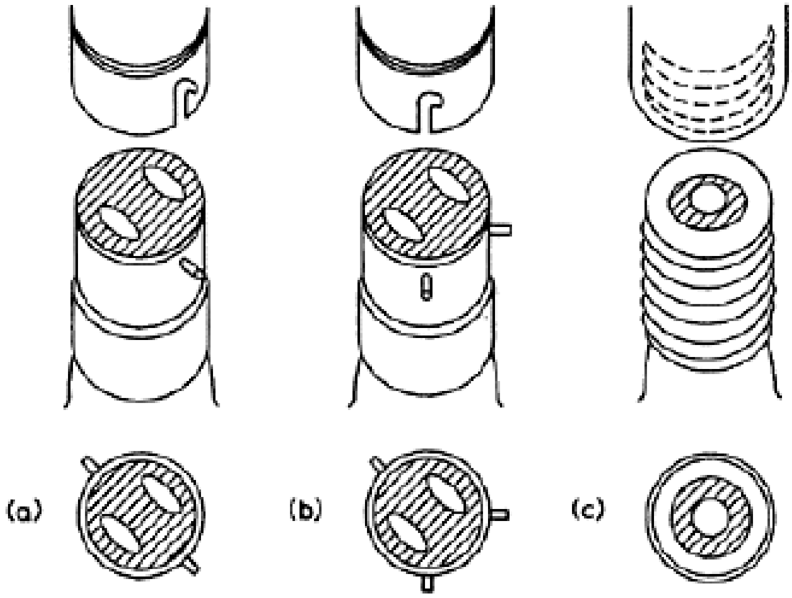



*Figure 7.1* Lamp caps

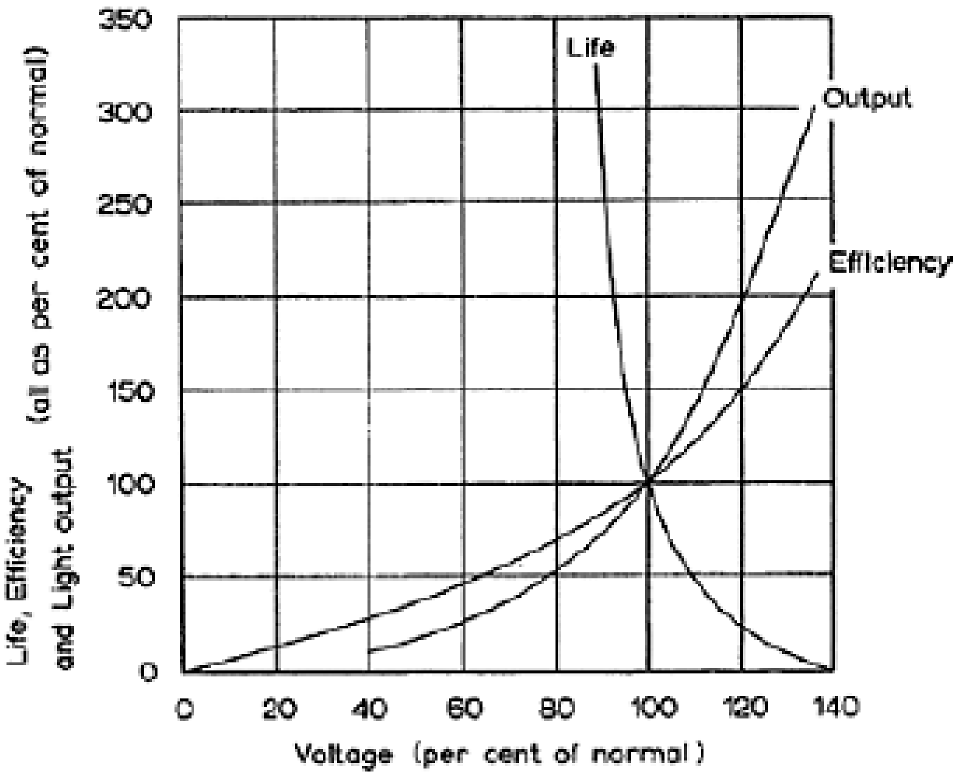



*Figure 7.2* Characteristics of incandescent lamps

Thus in the fluorescent lamp the radiation emitted by the current discharge through the mercury vapour is absorbed by the fluorescent coating which

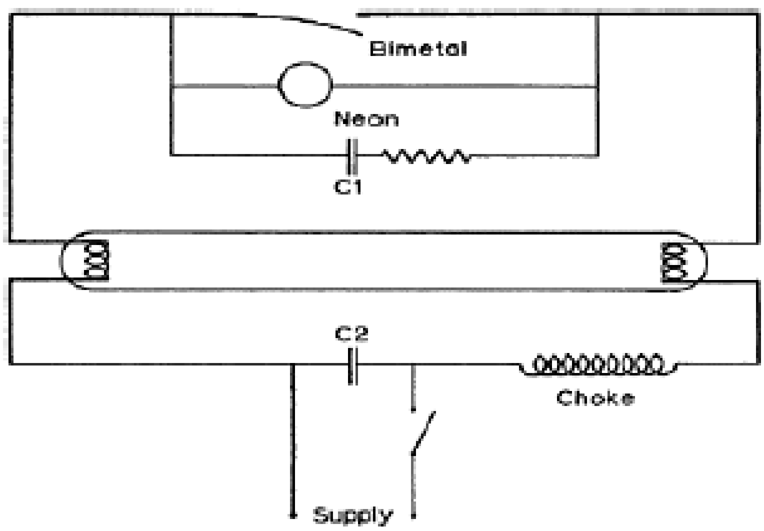



*Figure 7.3* Fluorescent lamp circuit

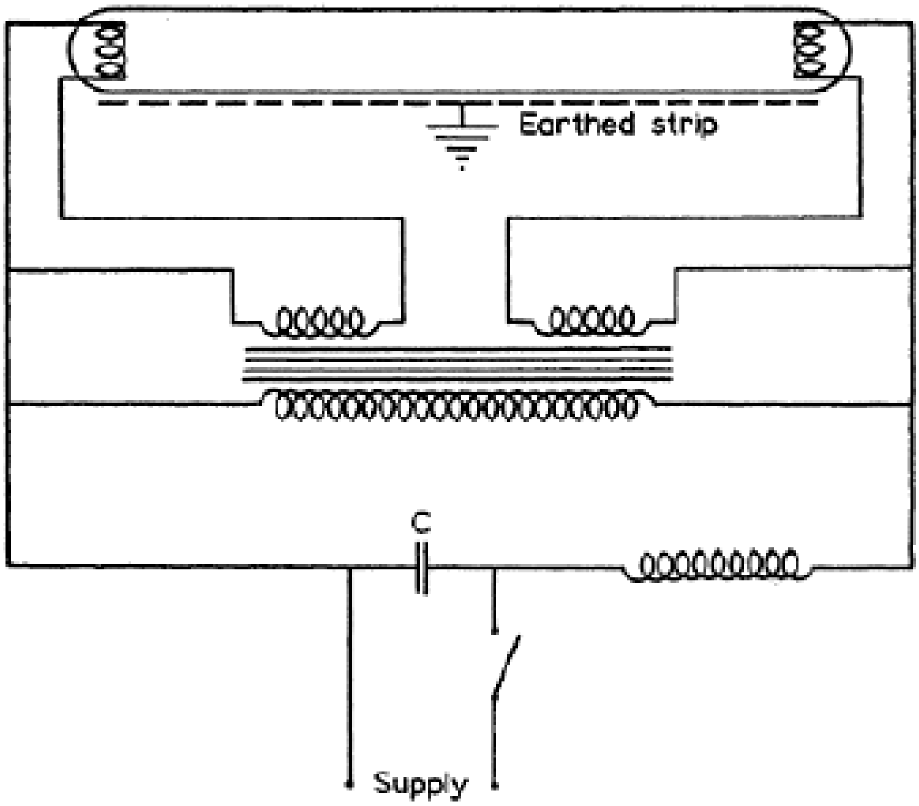



*Figure 7.4* Quick-start circuit

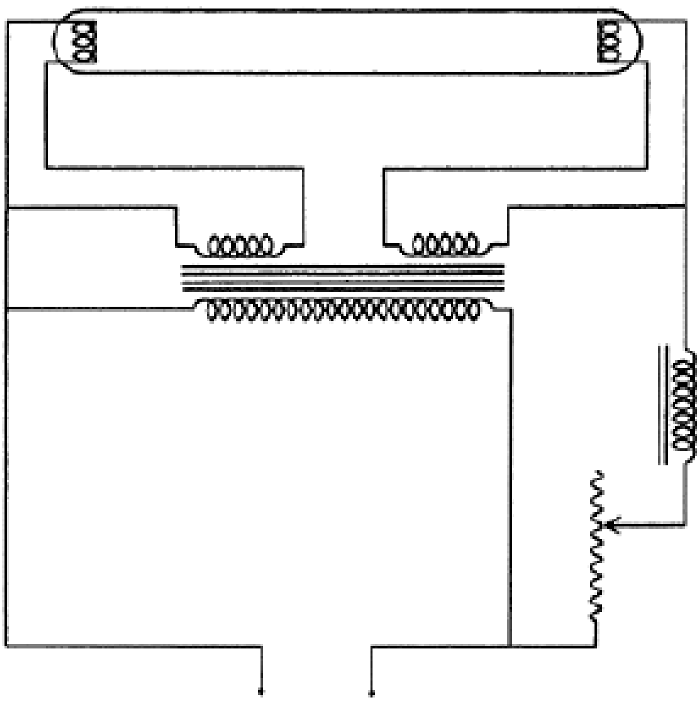


*Figure 7.5* Fluorescent dimming circuit

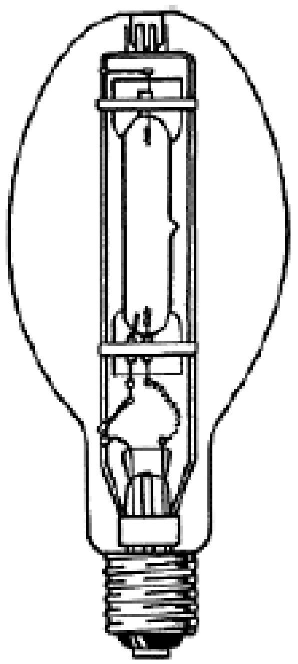


*Figure 7.6* MBF lamp

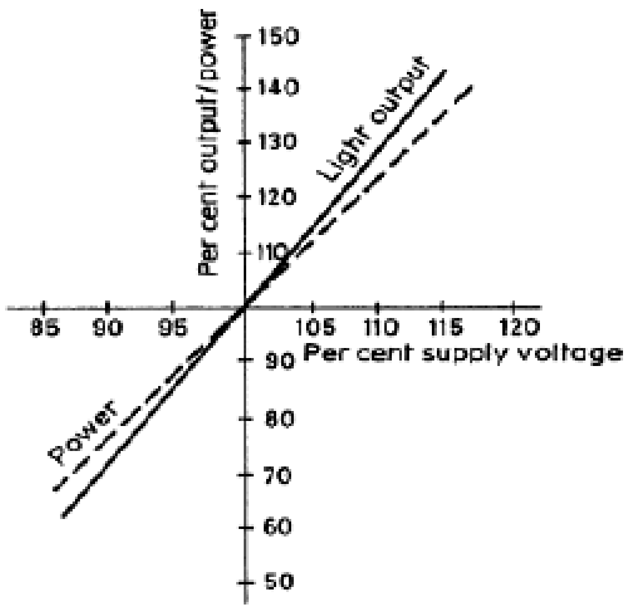



*Figure 7.7* Characteristics of MBF lamps

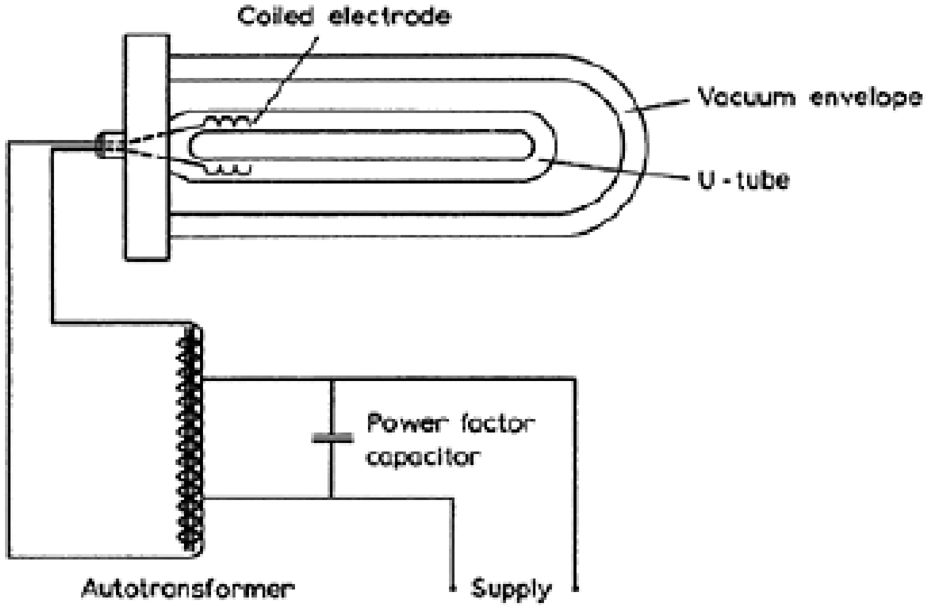



*Figure 7.8* Sodium discharge lamp

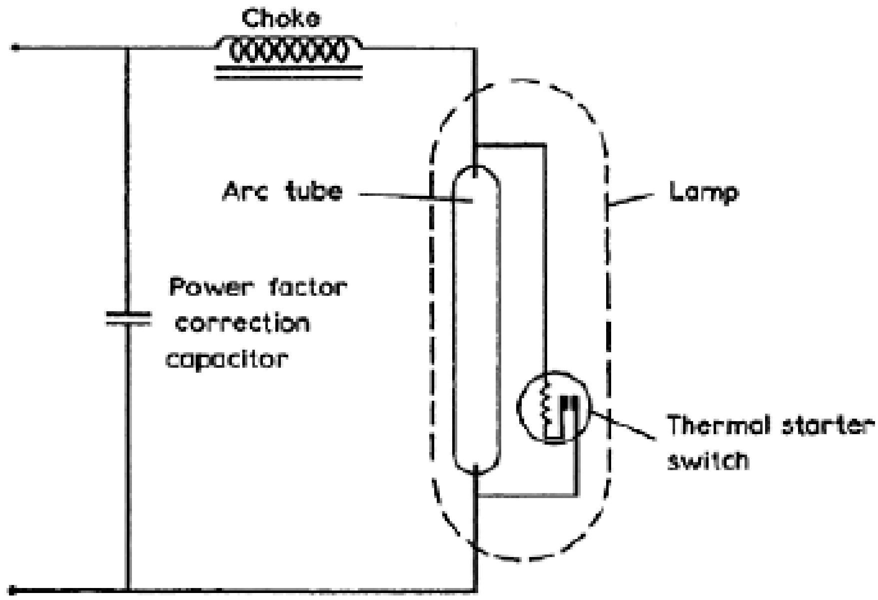



*Figure 7.9* Typical solarcolour lamp circuit

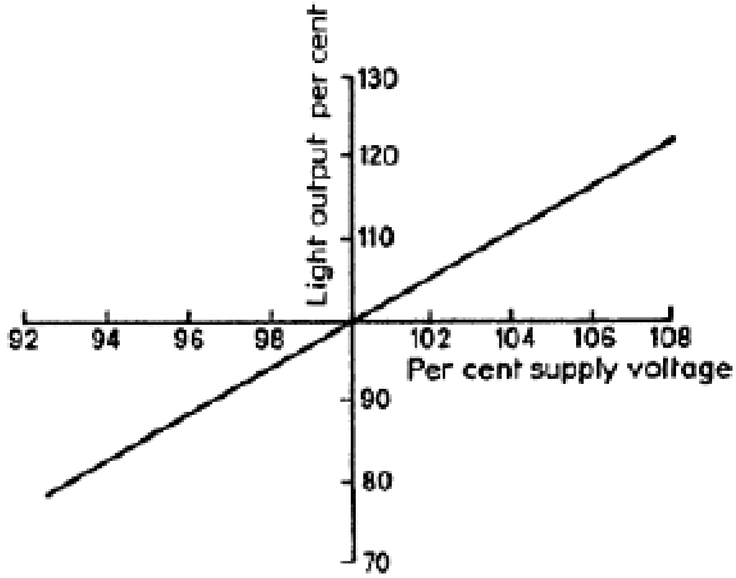



*Figure 7.10* Performance of SON lamp

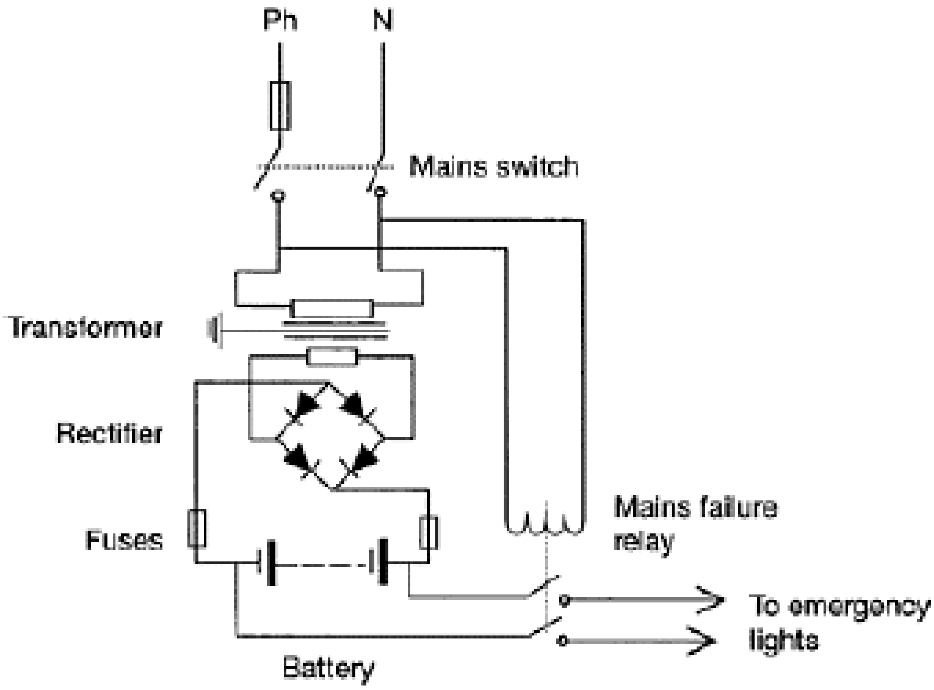



*Figure 7.14* Central emergency system

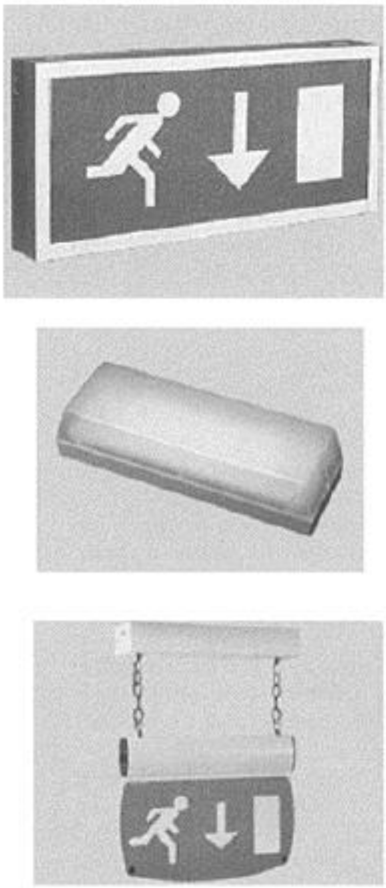


*Figure 7.15* Emergency lights
(Courtesy of Gent & Co. Ltd)

specified, it is important to make sure that the ones selected are suitable for the zone and group appropriate to the area in which they are to be fitted.

Standards relevant to this chapter are:

| | |
|---|---|
| BS 559 | Electric signs and high voltage luminous discharge tube installations |
| BS EN 60400 | Lamp holders for tubular fluorescent lamps and starter holders |
| BS 5266 | Emergency lighting |
| BS EN 1838, BS 5266–7 | Lighting applications; emergency lighting |
| BS 5499 | Exit signs |
| BS EN 60598–1 | Luminaires |
| BS EN 61184 | Bayonet lampholders |

Read Page 103 Chapter 7 Lighting

# Chapter 8
# Power

The majority of outlets to be used for power services are socket outlets of the types described in Chapter 1. The various ways in which power circuits can be arranged have been described in Chapter 5. It is usually found that as soon as more than two or three socket outlets are to be supplied, it is more economical to serve them from ring circuits than from radial ones. On ring circuits, only 13A BS 1363 socket outlets should be used in order to ensure that the plug must be of the fused type and that the appliance and flexible cable to it do not rely on the ring-circuit fuse for protection. There is little more one can add about socket outlets and it remains in this chapter to say something about connecting fixed appliances and larger equipment.

Fixed appliances of small ratings, by which we mean up to 3kW, can be served through fused connection units from the ring mains serving the socket outlets in the same area as the fixed appliance. A 3kW electric fire is one example of a fixed appliance which might be supplied in this way. If the socket outlets in the area are on radial rather than ring circuits then each fixed appliance must have a separate radial circuit of its own. It is often convenient to supply equipment such as motorized valves on hot-water heating systems, roof-mounted extractor fans in kitchens, tubular heaters in tank rooms and so on by a separate circuit for each item or group of items. There is nothing wrong technically with supplying them by a fused connection unit from an adjacent general-purpose ring main provided the permanent load they put on the ring is taken into account in assessing the number of socket outlets that can be permitted, but these items have a different function from the general-purpose socket outlets and it is logical to serve them separately. Separation by function can be an asset to maintenance; there should be no need to isolate all the socket outlets in part of a building when work has to be done to a toilet extractor fan. On the other hand, a separate circuit to one small piece of equipment may seem an extravagance. No general rule can be made, and the designer must decide each application on its particular circumstances.

Equipment larger than 3 or 4kW must in any case have a circuit for every individual item. This applies to cookers, each of which must be connected through a cooker control unit. One cooker control unit may control more than one appliance if they are in the same room. This would apply to a hob and separate oven. A cooker with four hot-plates, a grill and an oven can take 35A when everything in it is switched on, but rarely is it used in this way. Consequently the IEE Guidance Note 1 and the IEE On-Site Guide suggest a diversity factor to apply to domestic cooker circuits. In restaurant and school kitchens the cookers are likely to be in full use for the greater part of the time. Cooker control units are generally rated at 45A and if they and the cookers are to be properly protected, the circuit fuse must not be greater than 45A. It follows that the circuit cannot serve anything in addition to the cooker control unit without being overloaded.

Other large equipment is likely to consist of motors driving pumps and fans in plant rooms and machine tools in workshops and factories. In the case of plant rooms each machine is almost invariably on a circuit of its own. Having more than one motor on a circuit would make it necessary to use very heavy cable and would in general be less economic than using a larger amount of smaller cable. It would also be extremely inconvenient to have several machines put out of action if one of them blows it fuse. This is particularly the case when one machine is intended as a standby for another. Similarly in factories it is usual to have each machine on a circuit of its own. In small and medium-sized factories the most convenient wiring method is probably one using conduit and trunking. In such places there is seldom any objection to installing conduit and trunking on the surface of walls, and this is cheaper than burying it in the fabric of the building. It also makes it quite easy to alter the wiring when new machines are installed or the factory is rearranged. For the same reason, it is also better to run the wiring at high level under the ceiling and drop to the machines than to run it within the floor.

In large factories, a busbar system is often used. Bare conductors enclosed in a casing are run round the factory, preferably at high level, either on the walls or under the ceiling. A switch fuse is connected to these conductors as close as possible to each machine, and the connection from the switch fuse is taken through conduit or trunking to the machine. Each machine is thus on its own circuit, but no sub-mains other than the busbars are needed. The busbars must be protected by an adequate switch fuse at the intake. It is easy to connect a new switch fuse at any point of the busbars and the electrical installation is thus both convenient and flexible.

In small workshops, for example, metalwork and engineering rooms in secondary schools, the machines used may be small enough to make it practicable to serve a number of them from one ring circuit. Each machine is connected to the ring through a fused isolator or through a switch fuse. The fuse is necessary to protect the final connection to the machine, which is necessarily of a lower rating than the ring main, and to protect the internal wiring of the machine that will also be of smaller cable than the ring main. The cables of the ring main should be capable of carrying at least 70 per cent of the total current taken by all the machines, and it will be found that this very soon restricts the size of workshop that can be treated in this way.

It should be appreciated that everything that has been said about power circuits applies equally to three-phase and single-phase circuits. Where three-phase machines are used three or four cables, according to the system, plus an earth connection, are installed, and distribution boards, isolators and circuit breakers are of the three phase-pattern, but the general circuit arrangements are the same as for single-phase circuits.

All mechanical equipment requires maintenance, and all machines and equipment must, therefore, be installed in such a way that maintenance is possible. One of the things that has to be done before maintenance work is started is the turning off of the electricity supply, and it must be possible to isolate each machine or group of machines. It has been known to happen that an electrician has turned off an isolator in a switch room and gone to work on a machine some way from that room, that someone else has come along later, not realized that anyone was working on the machine and has turned the isolator on again. Not only has this happened, it has caused deaths. Consequently, most safety regulations, especially *The Electricity At Work Regulations,* now require that there should be an isolator within reach of the machine, or is lockable–in any case the isolation must be secure. The intention is that no one can attempt to turn the supply on without the person on the machine becoming aware of what is happening. For small machines, such as roof extractor fans, connecting the machine to the wiring through a socket and plug near the machine is a convenient and satisfactory way of providing local isolation. For larger machines, a switch or isolator or disconnector as it is now known has to be installed.

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# Chapter 9
# Protection

## Introduction

It is a truism that electricity is dangerous and can cause accidents, if not treated with respect. A large part of any system design is concerned with ensuring that accidents will not happen, or that if they do, their effects will be limited. It might be reasonably argued that these considerations are the most important part of a design engineer's task. In the previous chapters, we have spoken about choice of accessories, selection of cables and their correct sizing, the arrangement of outlets on a number of separate circuits and the proper ways of installing cables and we have pointed out the need for protecting cables against mechanical damage. If these matters are given the care they deserve, the likelihood of faults on the electrical installation will be small. Nevertheless, it is still necessary to provide protection against such faults as may happen.

The general principle of protection is that a faulty circuit should be cut off from the supply and isolated until the fault can be found and repaired. The protective device must detect that there is a fault and must then isolate the part of the installation in which it has detected the fault. One could perhaps suggest many theoretical ways of doing this, but it is also necessary that the method adopted should bear a reasonable proportion to the cost of the whole installation. Historically, the methods, which could be adopted at any time, depended on what devices could be economically manufactured at that time, but once a method has been adopted it tends to remain in use and newer products do not completely supersede it. Enthusiasts sometimes stress the advantages of a new idea while forgetting that the older method had some favourable features which the new one does not match. The result of developments is that at present there are several protective devices available and except for BS 3036 Fuses (rewireable) there appear to be no overriding grounds for preferring any one to the others.

The devices available restrict the type of protection that can be given. A logically ideal system of protection against all possible faults cannot be made economically, and the protection designed must make use of the equipment commercially available. This can lead people to argue from the available techniques to the faults to be guarded against, and in the process become so obsessed with the ease of guarding against an improbable fault that they forget the importance of protection against a more likely one. It seems more satisfactory to start by considering the faults that may happen.

When an excessive mechanical load is imposed on an electric motor it continues to run but draws a higher than normal current from the supply. The circuit supplying the motor, therefore, carries a higher current than it has been designed for, and although it is not as high as a short circuit current, it can still be high enough to be dangerous. A fault in the internal wiring of a motor can also cause an electrical overload, although if it is serious enough it is likely to amount to a short circuit.

A fault to earth occurs if through some defect the line conductor becomes connected to earthed metalwork. The effect is similar to a short circuit, but whereas a short circuit will not raise exposed metalwork, termed exposed conductive parts, above zero potential, an earth fault will. We can see this by looking at Figure 9.1 which shows diagrammatically an electric fire with an earthed metal case. Suppose the fire becomes damaged and the phase cable touches the case at point A. A current will flow through the case and circuit protective conductor to earth at point B, which would normally be the earth at the electricity distribution company's transformer.

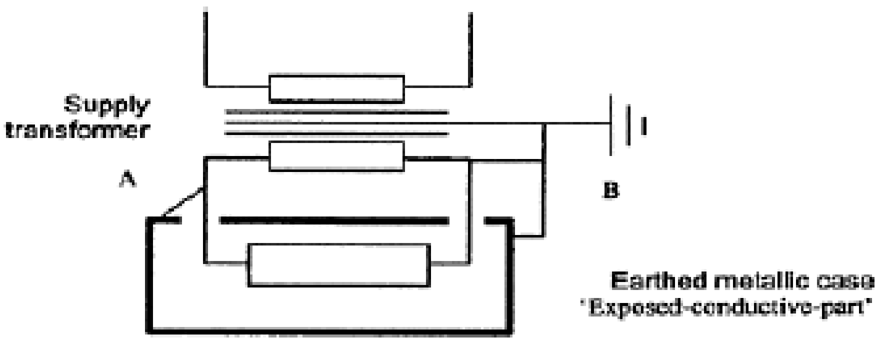


*Figure 9.1* Earth fault

Now let

$Uoc$=Open circuit supply transformer voltage

$I$=Fault current flowing

$Z_L$=total impedance from line connection of supply transformer through line conductor, fault and the circuit protective conductor to earth connection at supply transformer

$Z_e$=impedance of earth path from fault back to earth connection

$Z_s$=Total impedance of the fault circuit.

Then the current flowing will be $Uoc/Z_s$, and the voltage drop between A and B will be $IZ_e = UocZ_e/Z_s$. Now $Z_e/Z_s$ is likely to be of the order of 0.4 to 0.5, so that on a *Uoc* of 240V the metal case at A will be raised to about 100V.

We cannot explain how electrical circuits in buildings are protected against short circuits, overloads and earth faults without referring to the various protective devices which can be used. To make our account intelligible we propose first of all to describe the devices available and then go on to discuss how they are applied in practice.

## Rewirable fuses

The earliest protective device consisted of a thin fuse cable held between terminals in a porcelain or bakelite holder. It is illustrated in Figure 9.2. It is inserted in the circuit being protected and the size of fuse cable is matched to the rating of the circuit. The fuse is designed so that if the current exceeds the rated current of the circuit the fuse cable melts and interrupts the circuit. Although commonly called rewirable fuses, their correct name is semi-enclosed fuses, and it is by this name that they are referred to in *British Standard* 3036 and in the *IEE Regulations* BS 7671.

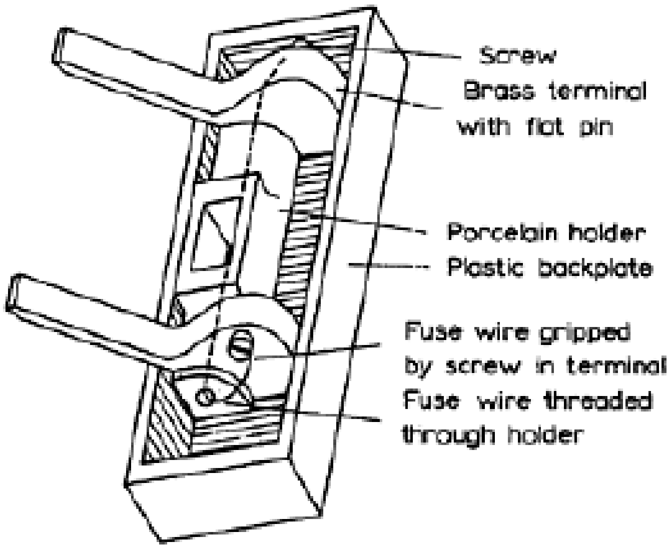


*Figure 9.2* Rewirable fuse

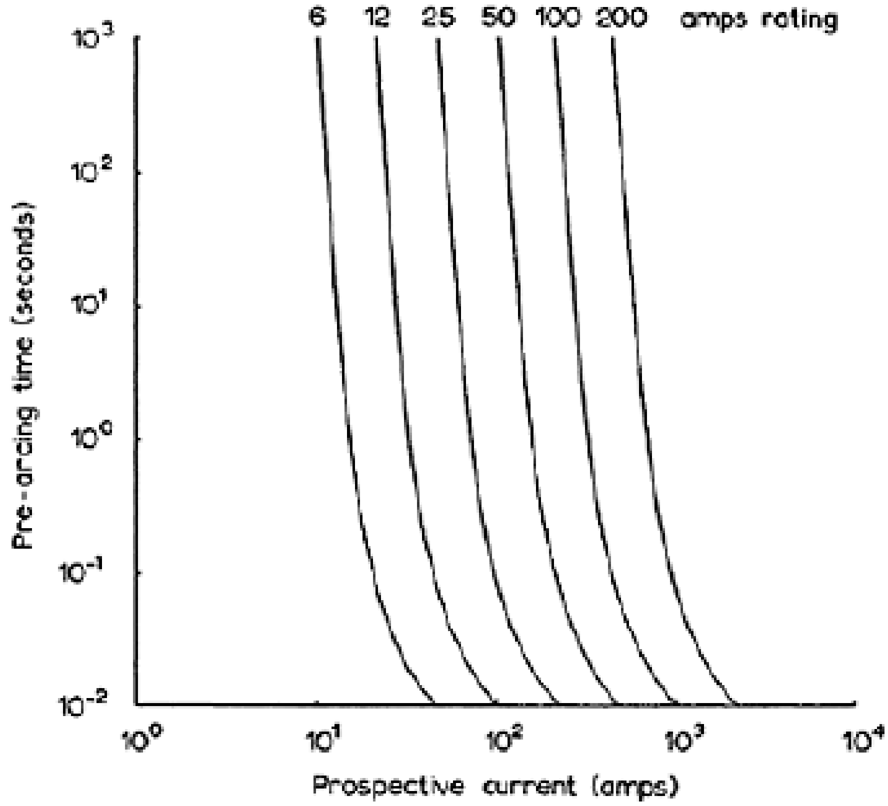


*Figure 9.4* Time-current characteristics of HRC fuses

The *minimum fusing current* is the minimum current at which a fuse will melt, that is to say the asymptotic value of the current shown on the time-current characteristics. The *current rating* is the normal current. It is the current stated by the manufacturer as the current which the fuse will carry continuously without deterioration. It is also referred to as current carrying capacity and other similar terms. The *fusing factor* is the ratio

$$\frac{\text{minimum fusing current}}{\text{current rating}}$$

When a short circuit occurs, the melting process is adiabatic and the melting energy is given by

$$W = \int_0^{t_m} i^2 R \, dt$$

where

$W$=melting energy

$i$=instantaneous current

$R$=instantaneous resistance of that part of element which melts on short circuit

$t$=time

*tm*=melting time.

*R* is assumed to vary in the same manner with *i* and *t* for all short circuits and the quantity

$$\int_0^{t_m} i^2 \, \mathrm{d}t$$

$$\int_0^{t_m} t^2 \, \mathrm{d}t$$

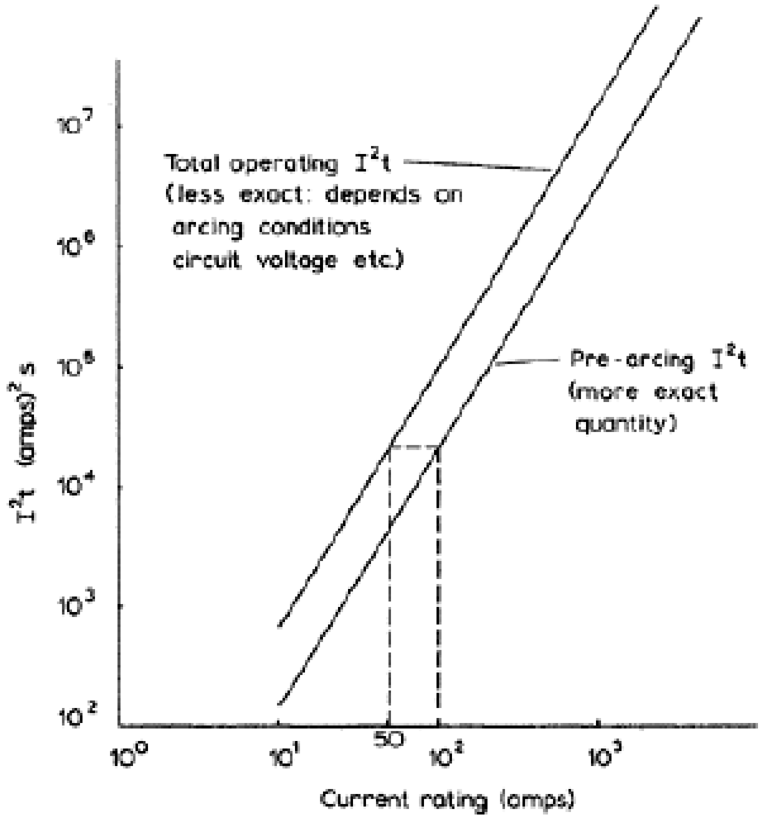


*Figure 9.5* Short circuit $I^2t$ characteristics

is approximately constant for the pre-arcing time of a fuse. It is often called the pre-arcing $I^2t$. It is this quantity which determines the amount of excess energy passing through the circuit before the circuit is broken and it is particularly important in the protection of semiconductor circuits and the reduction of overheating in power circuits. Typical $I^2t$ characteristics are shown in Figure 9.5.

Oscillograms of the operation of a fuse are shown in Figure 9.6.

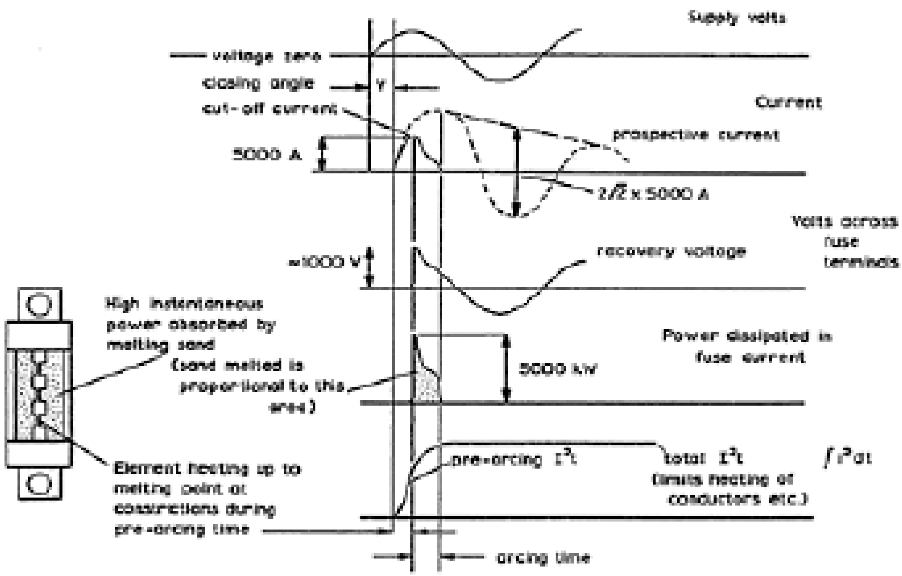


*Figure 9.6* Oscillograms of fuse operation

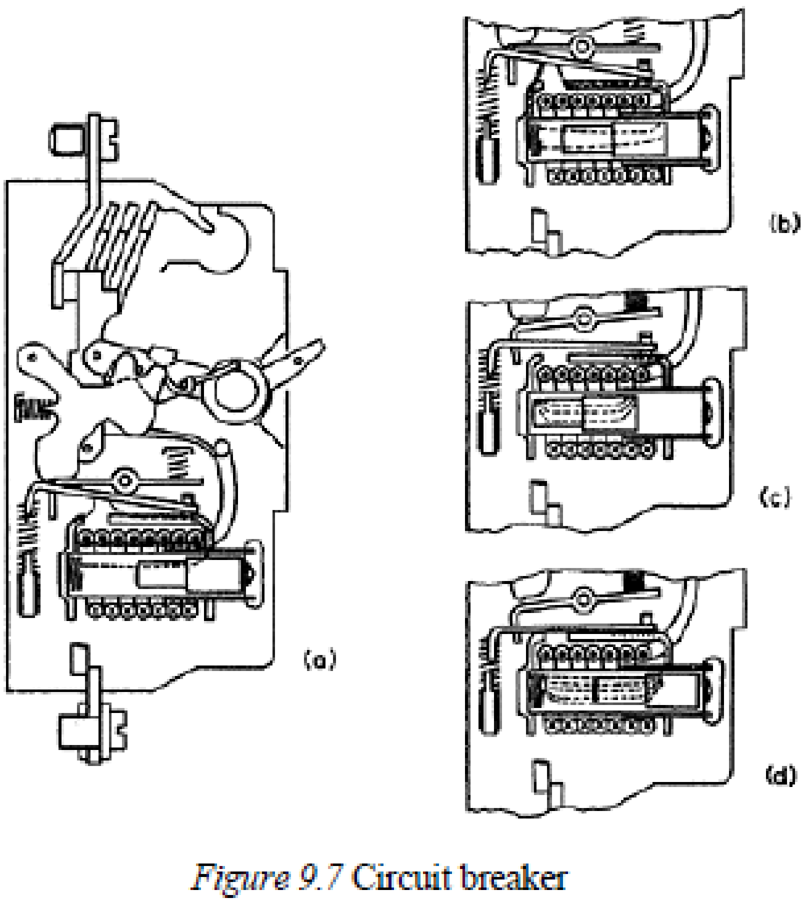


*Figure 9.7* Circuit breaker

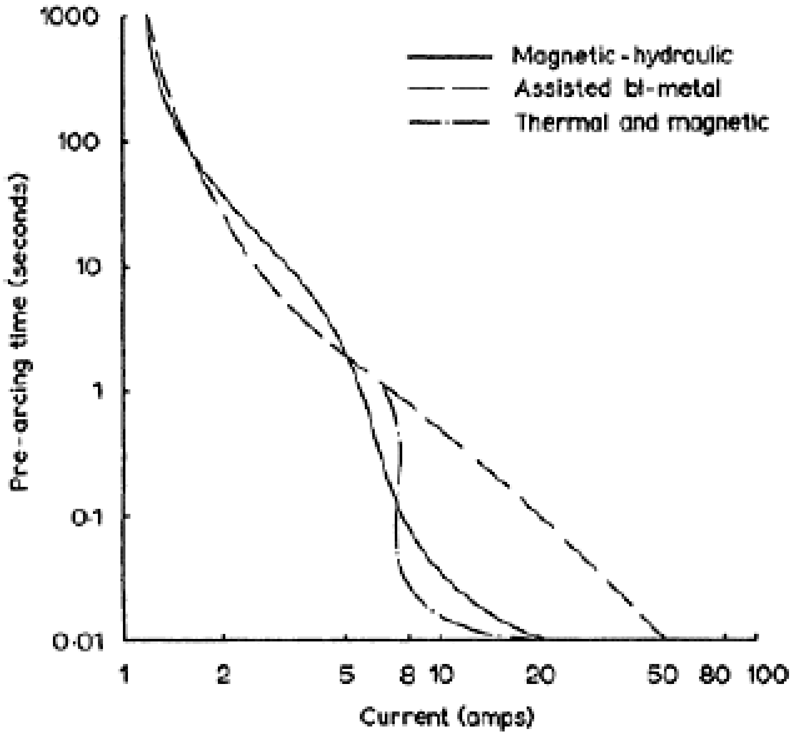


*Figure 9.8* Time-current curves for CBs

breaker, and the CB is reset by the same switch. CBs can, therefore, combine the functions of switch and fuse, and in some cases this is a very useful and economic procedure. In a factory or store, for example, one may want to control the lights for a large area from a bank of switches at a single point. If a distribution board with CBs is placed at this point, it is possible to dispense with a separate bank of switches.

## RCD

Another device frequently used is the residual current device (RCD). This is a circuit breaker which detects a current leaking to earth and uses this leakage current to operate the tripping mechanism. The leakage current is a residual current and gives the device its name. It should be noted here that this device will not protect against short circuit and overload. Residual current devices which do incorporate overcurrent protection are referred to as RCBOs.

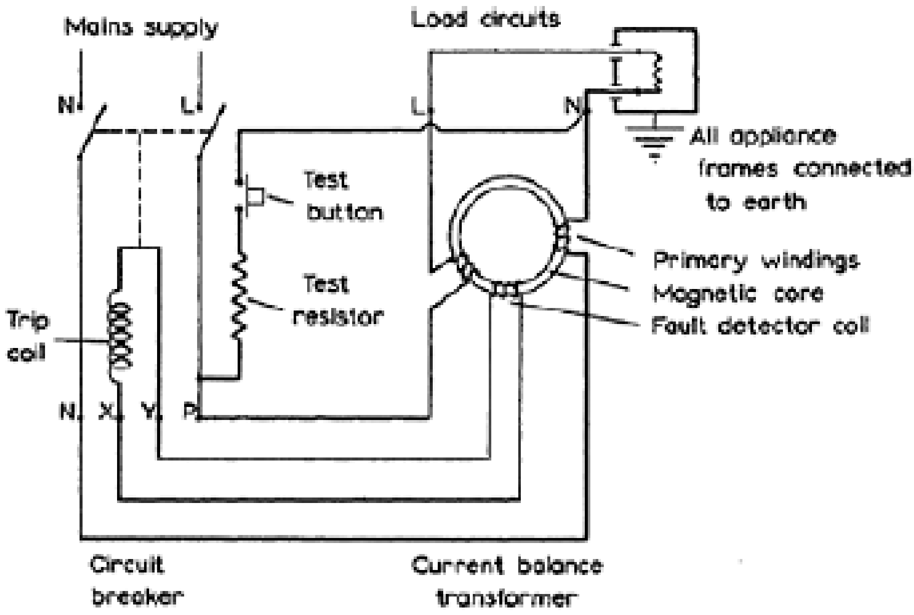


*Figure 9.9* Residual current device

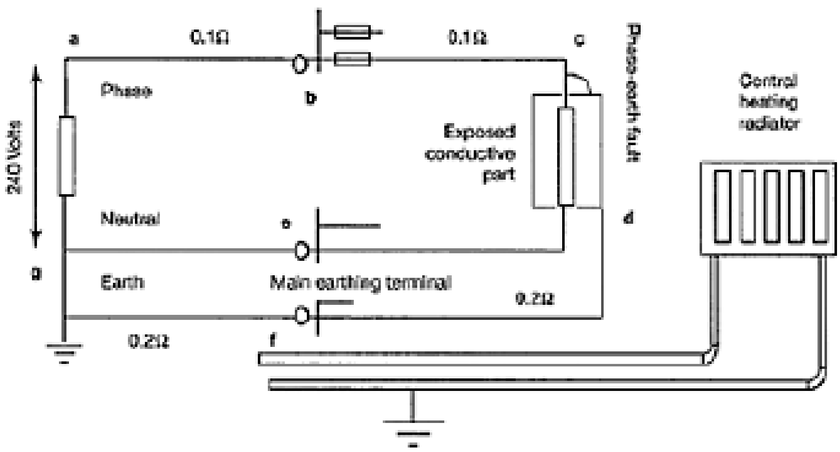


*Figure 9.12a* Fault currents

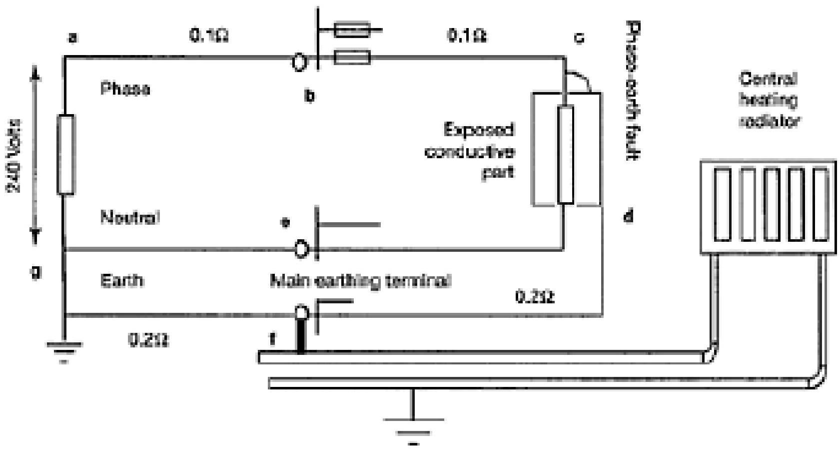


*Figure 9.12b* Fault currents

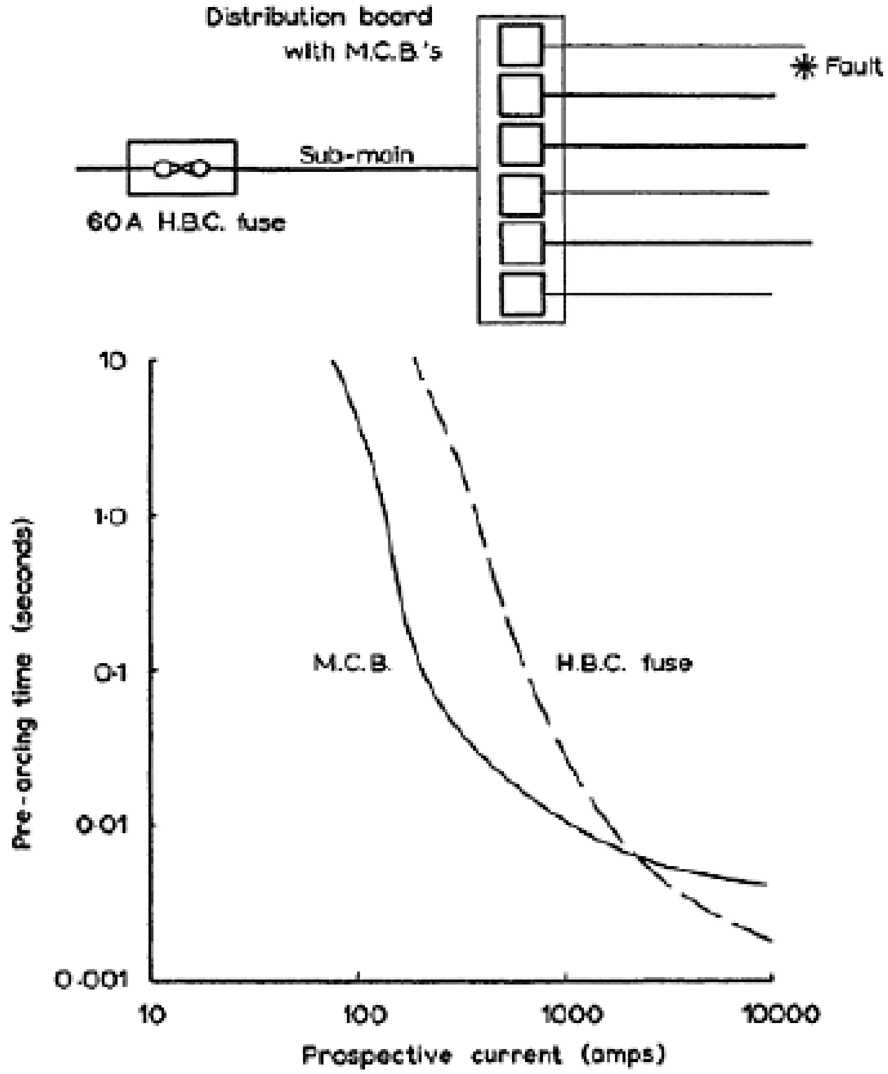


*Figure 9.13* Discrimination

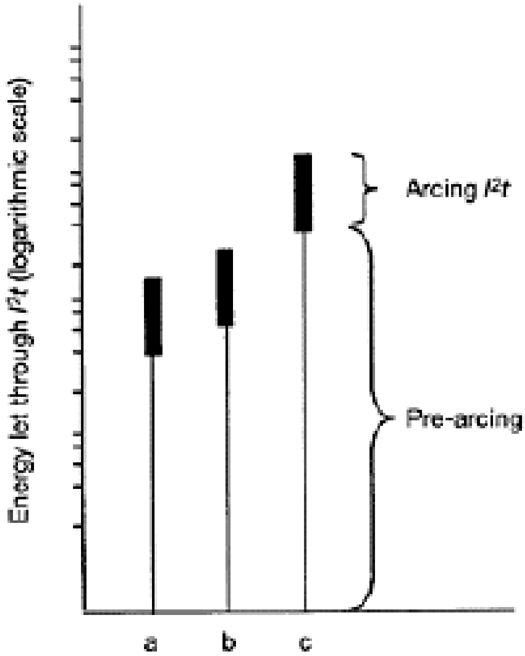


*Figure 9.14* Lollipop graph

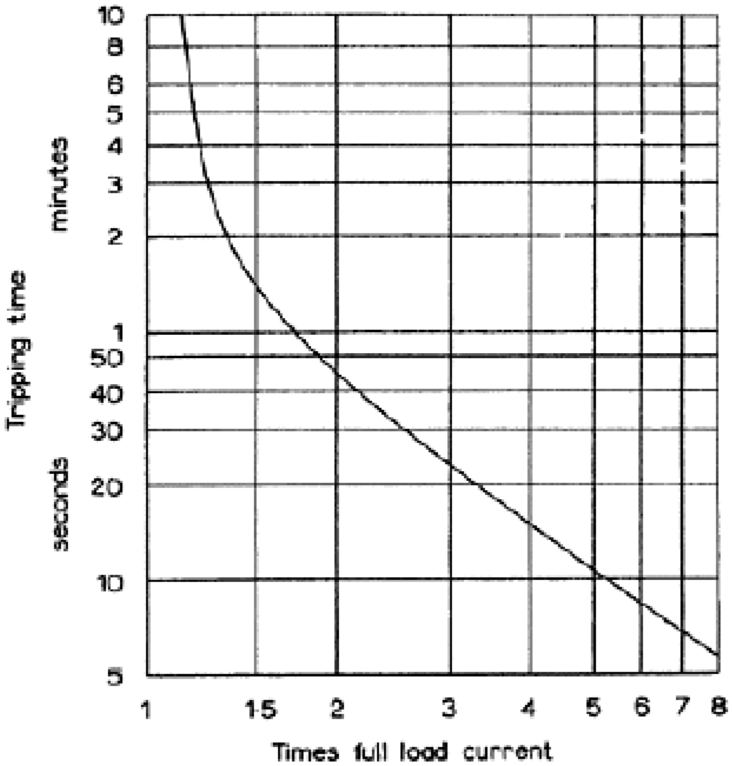


*Figure 9.15* Motor starter characteristics

*Table 9.1* Fuse ratings for motor circuits

| *Type of starter* | *Overload release rating-amps* | *Fusing rating amps* |
|---|---|---|
| Direct on | 0.6 to 1.2 | 5 |
| | 1.0 to 2.0 | 10 |
| | 1.5 to 3.0 | 10 |
| | 2.0 to 4.0 | 15 |
| | 3.0 to 6.0 | 20 |
| | 5.6 to 10.0 | 30 |
| | 9.0 to 15.0 | 40 |
| | 13.0 to 17.0 | 50 |
| Star-delta | 4.0 to 7.0 | 15 |
| | 6.0 to 10.0 | 20 |
| | 9.0 to 17.0 | 30 |
| | 1 6.0 to 26.0 | 40 |
| | 22.0 to 28.0 | 50 |

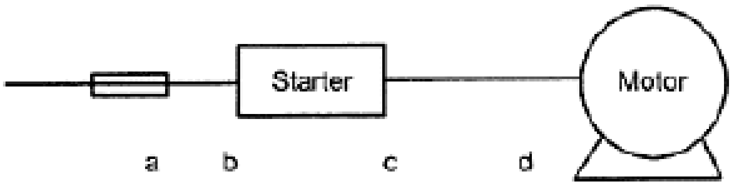


*Figure 9.16* Motor protection

$$\frac{\text{impedance of abc}}{\text{impedance of abcdega}} \times \text{line voltage}$$

and depending on the relative impedances of the various parts of the earth fault loop impedance path, this could be anything up to almost full line voltage.

We refer yet again to Figure 9.12a. If we assume that the impedance of the transformer winding is negligible, the value of the earth fault loop path Zs, is 0.1+0.1+0.2+0.2=0.6Ω.

$I_f = Uoc/Z_s$

where *Uoc* is the open circuit voltage of the transformer, the fault current would be

$I_f = 240/0.6 = 400\text{A}$

and the potential drop from a to c is

$Ua{-}c = I_f \times Za{-}c$

$Ua{-}c = 400 \times (0.1+0.1) = 80\text{V}$

The voltage of the exposed conductive part will be

240–80=160V above earth

If the faulted piece of equipment is touched by a person simultaneously with the central heating radiator, the person would receive a 160V shock.

Now consider Figure 9.12b, with the main equipotential bonding in place. Assuming the earth fault current remained the same as without bonding, the volts drop d-f would be

$Ud{-}f = I_f \times Zd{-}f$

$Ud{-}f = 400 \times 0.2 = 80\text{V}$

The potential of the main earthing terminal will be

$Uoc - (Ua{-}c + Ud{-}f)$

240−(80+80)=80V above earth potential

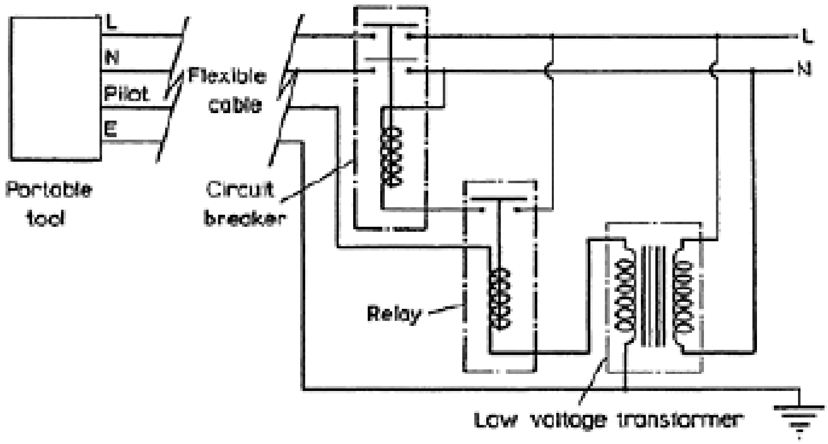


*Figure 9.17* Monitored earth leakage protection

the main circuit and cuts off the supply to the appliance. It will be noticed that this monitoring circuit merely checks that the earth continuity conductor is sound; it does not add to the basic earth leakage protection.

## Earth electrodes

In normal earthing, the earth and the neutral are quite separate. The load current flowing through the neutral must cause a potential difference between the two ends of the neutral. Since the end at the supply transformer is earthed, the end at the consumer's service terminal must inevitably be at some potential above earth. It cannot, therefore, be used as an earth point.

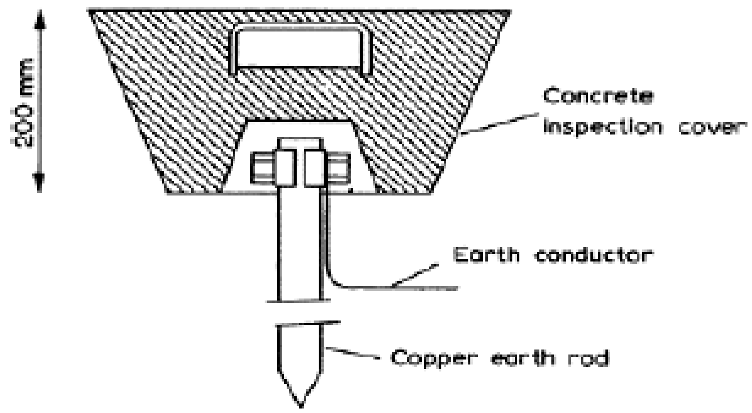


*Figure 9.18* Copper rod electrode

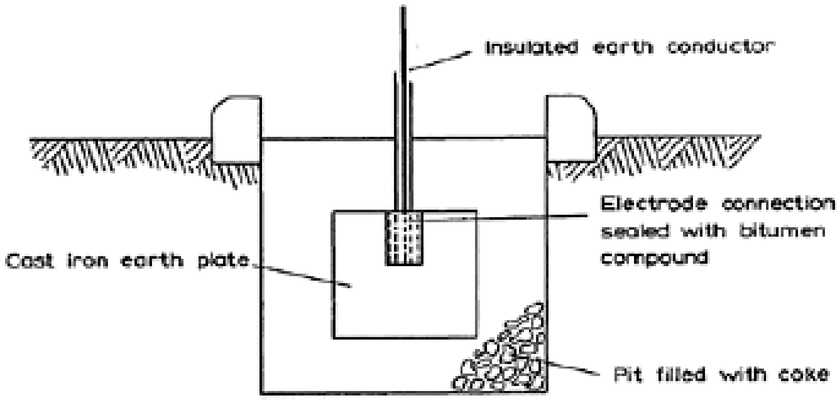


*Figure 9.19* Cast iron plate electrode

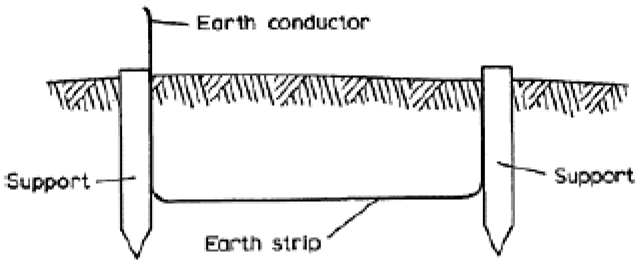


*Figure 9.20* Copper strip electrode

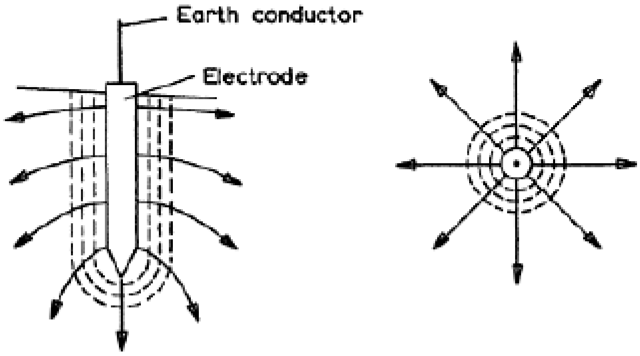


*Figure 9.21* Current from electrode into earth

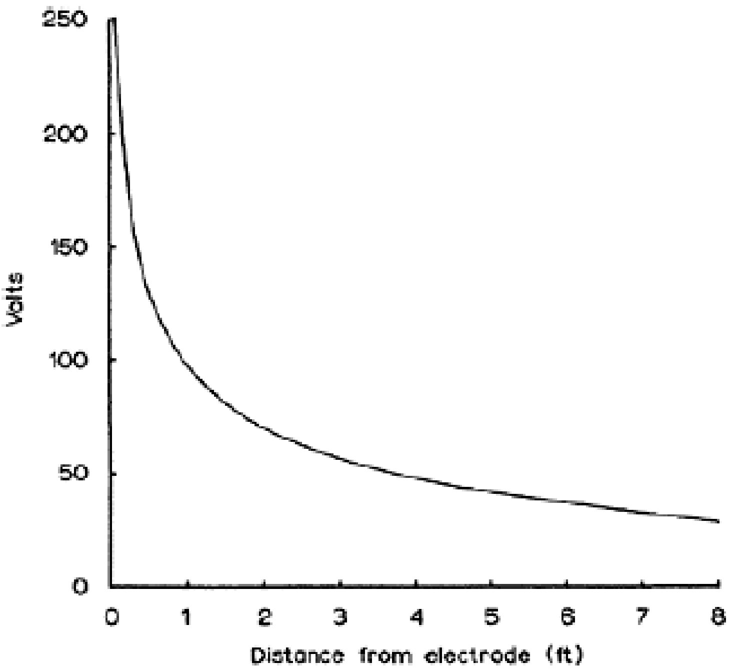


*Figure 9.22* Voltage at surface of ground due to rod electrode

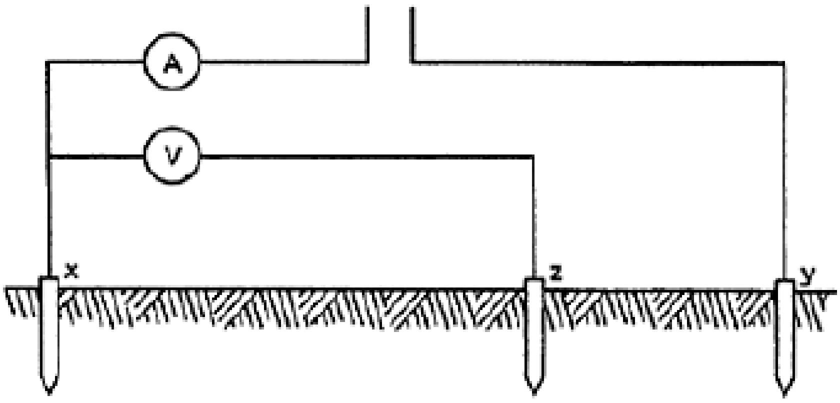


*Figure 9.23* Earth electrode resistance test

accepted only if all three readings are substantially the same. If they are not, the test must be repeated with a greater distance between X and Y.

## Protective multiple earthing

This is an alternative method of earthing in which the neutral of the incoming supply also forms the earth return path. In other words, instead of the neutral and earth of the incoming supply being separate, they are combined to form a TN-C-S system (definitions in BS 7671 explains the systems in use). The supply authority is required to maintain the resistance between the neutral conductor and earth to a maximum of 10Ω To do this the supply authority earth the supply neutral at various multiple points, protective multiple earthing (PME).

The installation within the building is carried out in exactly the same way as for any other system, and separate earth continuity conductors are used. The main earthing terminal at the intake is not, however, connected to a separate earth return, but connected to the neutral of the incoming service cable.

Because with this system the neutral is relied on as the earth, there must be no fuses, cut-outs, circuit breakers or switches anywhere in the neutral. In the UK an area electricity company may not adopt PME without the permission of the Secretary of State for the Environment, and stringent requirements are made to ensure that the neutral conductor is adequate to carry earth fault currents, that it is truly kept at earth potential and that it is protected against breaks in continuity. The permission of British Telecom is also required. This is because the currents into and through the ground at the points of multiple earthing could cause interference to adjacent telephone and telegraph cables in the ground.

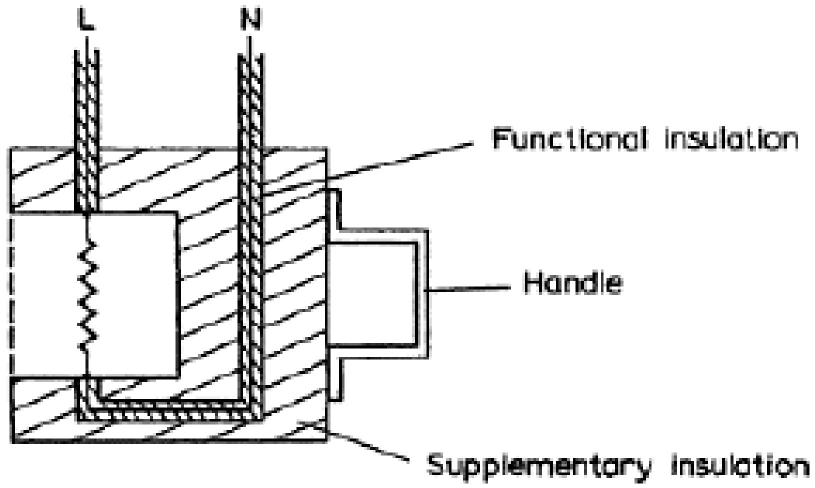


*Figure 9.24* Double insulation

| | |
|---|---|
| BS 88 | Cartridge fuses for voltages up to and including 1000V a.c. and 1500V d.c. |
| BS 2950 | Specification for cartridge fuse links for telecommunications and light current applications |
| BS 1361 | Cartridge fuses for a.c. circuits in domestic and similar premises |
| BS 1362 | General purpose fuse links for domestic and similar purposes (primarily for use in plugs) |
| BS 3036 | Semi-enclosed electric fuses (ratings up to 100A and 240V) |
| BS 3535/BS EN 60742 | Safety isolating transformers |
| BS 4293/BS EN 61008–1 | Residual current operated circuit breakers |
| BS 4752 | Switchgear and controlgear up to 1000V a.c. and 1200V d.c. |
| BS 5486 | Factory built assemblies of switchgear and controlgear |

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# Chapter 10
# Fire alarms

## Introduction

A fire alarm circuit, as its name implies, sounds an alarm in the event of a fire. There can be one or several alarms throughout a building, and there can be several alarm points which activate the warning. The alarm points can be operated manually or automatically; in the latter case they may be sensitive to heat, smoke or ionization. There are clearly many combinations possible, and we shall try in this chapter to give some systematic account of the way they are built up. The external circuitry is similar whether the control panel consists of electronic components or electromechanical relays.

## Circuits

The simplest scheme is shown in Figure 10.1. Several alarm points are connected in parallel, and whenever one of them is actuated the circuit is completed and the alarm sounds. This is described as an open circuit, and it will be seen that it is not fail-safe, because if there is a failure of supply, the fire alarm cannot work. Another characteristic of this circuit is that every

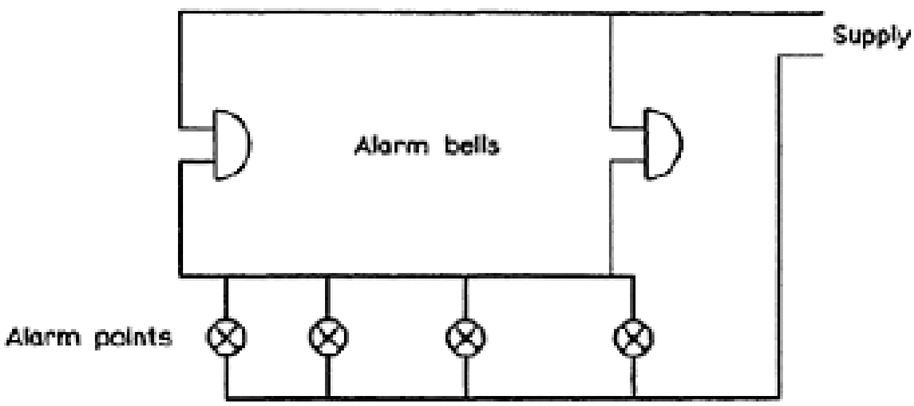



*Figure 10.1* Fire alarm open circuit

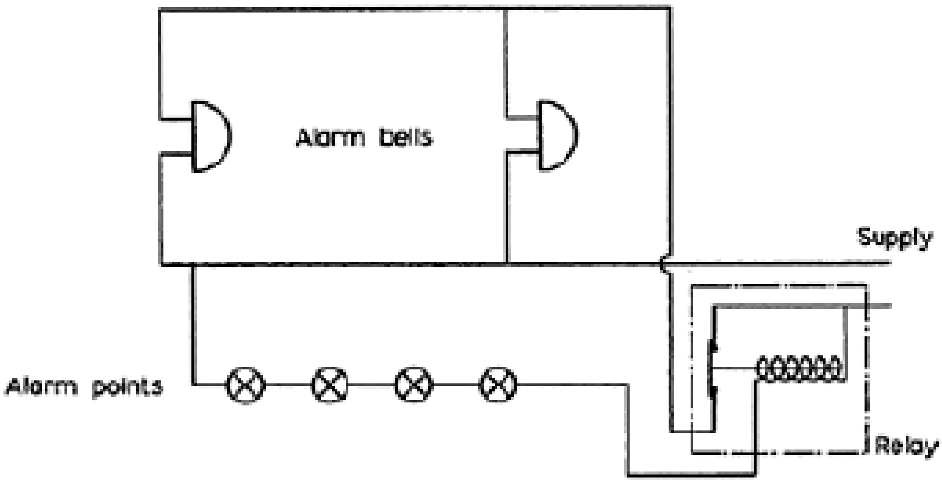



*Figure 10.2* Fire alarm closed circuit

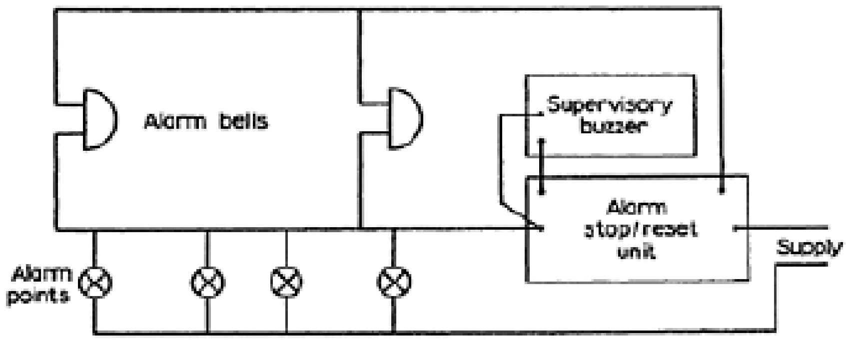



*Figure 10.3* Fire alarm with relay unit

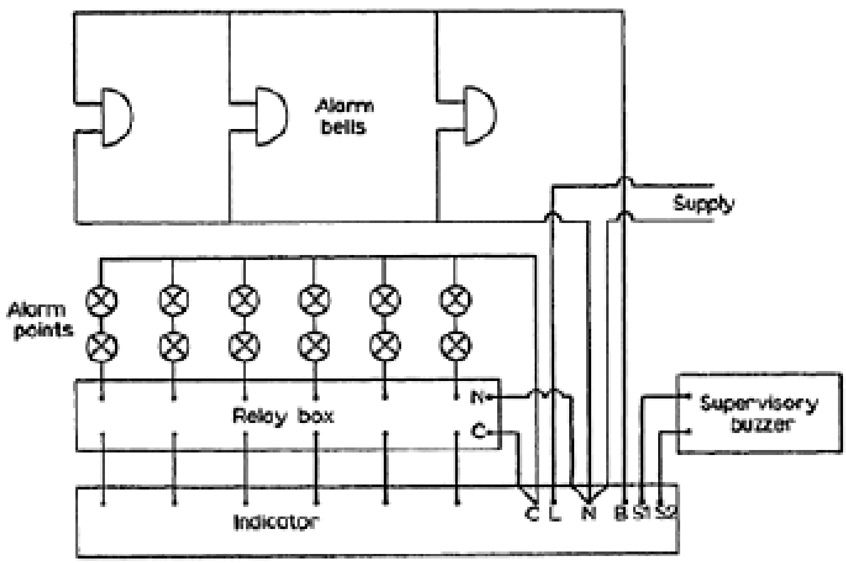



*Figure 10.4* Fire alarm with indicator

## Wiring

The wiring of a fire alarm installation follows exactly the same principles as any other wiring, but greater consideration has to be given to the protection of the cables and to their ability to withstand fire damage. Cables used in fire alarm systems fall into two general categories. In group 1, cables are not required to operate after the fire has been detected; in group 2, cables are required to operate after the fire has been detected. It is obviously necessary for a fire alarm to go on working for quite some time after a fire has started. The wiring of group 2 must, therefore, be entirely separate from any other wiring. In conduit or trunking systems, it should be segregated from all other services and run in conduit or trunking of its own. It must be able to withstand high temperature, which in practice means that it is MICC to BS 6207 part 1, to BS 6387 categories AWX, SWX, A or S. Other types of cable may be used if they are embedded in 12mm of plaster or equivalent, protecting them from significant fire risk for half-an-hour. In any case, BS 5839 specifies a number of requirements on the cables used in fire-alarm circuits. For electronic systems the cable may need to be a coaxial or screened type, and the manufacturer's requirements must be checked to ascertain this. The supply to the fire alarm must also be separate from any other supply, and this at the very least means that it must be fed from its own circuit breaker or switch at the main service entry into the building. Some authorities go further and think that the fire-alarm system should be at extra low voltage, and to satisfy this requirement fire alarm equipment is made for 24V a.c. and 12, 24 or 48V d.c. operation as well as for mains voltage operation. BS 5839 requires that a risk formal assessment forms the basis of design.

A system working on 24V a.c. has to be fed from a transformer. The primary of the transformer is fed from its own circuit breaker or switch at the main service entry. D.c. systems are fed from batteries of the accumulator type, which are kept charged by a charger unit connected to the mains. As the battery will operate the system for a considerable period before losing all its charge, this method provides a fire alarm which is independent not only of the mains within the building, but also of all electrical services into the building. For this reason, some factory inspectors and fire-pevention officers insist that a battery system be used. However, when the system voltage is low the currents required to operate the equipment are higher and the voltage drops which can be tolerated are much smaller. We can see this by reflecting that a motor wound for 240V will work without noticeable diminution of speed or performance if the voltage at its terminals drops by 6V to 234V, which is a reduction of 21.5 per cent, whereas a 24V bell may not sound at all if a potential of 18V is applied to it. In this case a drop of 6V in the line is a reduction of 25 per cent. At the same time for a given sound output a 24V bell needs ten times the current that a 240V bell does.

Thus voltage drop becomes a very serious factor in the design of any extra-low voltage system. The equipment to be used must be carefully checked to see what voltage drop it can accept and the cables sized to keep the drops very low. This usually results in large cables having to be used. There is a great deal to be said for obviating these difficulties as far as possible by not using systems at less than 48V. Electronic systems operate with much smaller currents so that for most of the system, voltage drop is not a critical consideration. But the bells or horns still require appreciable power and voltage drop should not be overlooked, particularly in discussion with electronics specialists who are not normally concerned with it.

In the author's opinion, there is very little to be said for a 24V transformer system. It has all the voltage drop problems of a d.c. system without the independence of the incoming service that batteries give. In other words it appears to have the disadvantages of both mains and battery systems without the advantage of either.

The current carrying capacity of each component has to be taken into account in the design and layout of the installation. It may happen, for example, that the total current of all the alarm signals sounding together exceeds the current which can be taken by the contacts of the alarm initiating points. The closed circuit of the type shown in Figure 10.2 overcomes this problem because the current to the alarm bells does not go through the initiating points. This is a considerable advantage of the closed system, and can be a deciding factor in choosing it in preference to the open system. Even with closed systems, however, the total current of the alarm signals may exceed the capacity of the contacts in the indicator panel. If this happens, a further relay must be interposed between the indicator and the alarm signals.

## Fire-alarm points

A typical manually operated fire-alarm point is shown in Figure 10.6. It is contained in a robust red plastic case with a glass cover. The material is chosen for its fire-resisting properties. The case has knock-outs for conduit entries at top and bottom but the material can be sufficiently easily cut for the site electrician to make an entry in the back if needed. Alternative terminals are provided for circuits in which the contacts have to close when the glass is smashed (as in Figure 10.1) and for circuits in which the contacts have to open when the glass is smashed (as in Figure 10.2). In the former case, there is a test switch which can be reached when the whole front is opened with an Allen Key. In the latter case, the test push is omitted because the circuit is in any case of the fail-safe type.

The alarm point illustrated is suitable for surface mounting. Similar ones are available for flush fixing and in weatherproof versions. The current carrying capacity of the contacts should always be checked with the maker's catalogue.

Automatic detectors can respond to heat, smoke or ionization, and in the first case they can respond either at a fixed temperature or to a given rate of rise in temperature. A thermally operated detector for use with power-type systems is shown in Figure 10.7. It consists of a bi-metal strip which deflects


*Figure 10.6* Fire alarm point (Courtesy


*Figure 10.7* Heat detector (Courtesy of Gent & Co. Ltd)

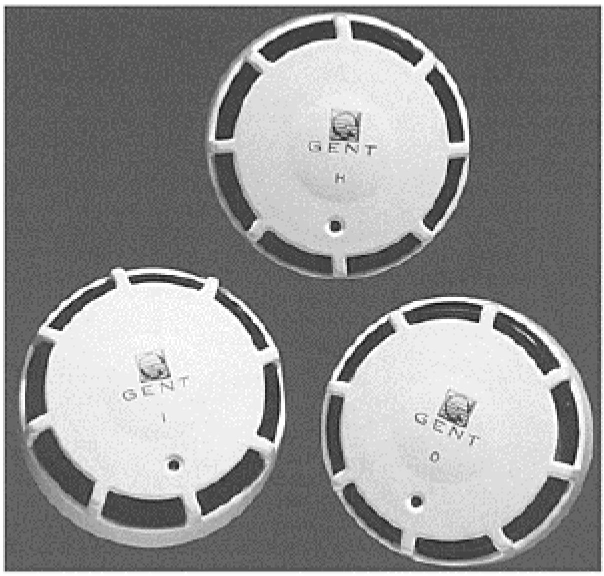



*Figure 10.8* Automatic fire detectors
(Courtesy of Gent & Co. Ltd)

### Horns

A horn is an alternative to both bell and siren, and because of its penetrating, raucous note it is particularly suitable where a distinctive sound is needed. Its volume is easily adjustable and its power consumption is intermediate between that of a bell and that of a siren.

The manufacturers of fire-alarm equipment also provide standard indicators, relays and reset units for use with the various circuits which we have described in this chapter. Typical indicators for use with power systems are illustrated in Figure 10.9. The appropriate indicator light is illuminated, or


*Figure 10.9* Fire alarm indicators
(Courtesy of Gent & Co. Ltd)

| | |
|---|---|
| BS 2740 | Simple smoke alarms and alarm metering devices |
| BS EN 54–1 | Fire detection and fire-alarm systems; introduction |
| BS EN 54–2 | Fire detection and fire-alarm systems; control and indicating equipment |
| BS EN 54–4 | Fire detection and fire-alarm systems; power supply equipment |
| BS 5446–1 | Fire detection and fire-alarm devices for dwellings; spec. for smoke/heat alarms |
| BS 5839 | Fire detection and alarm systems in buildings CoP for system design, installation, commissioning and maintenance |
| BS 6387 | Specification for performance requirements for cables required to maintain circuit integrity under fire conditions |
| BS 6004 | Electric cables; single-core unsheathed heat-resisting cables for voltages up to and including 450/750V, for internal wiring |
| BS 6007 | Electric cables; single-core unsheathed heat-resisting cables for voltages up to and including 450/750V, for internal wiring |
| BS 6346 | Specification for 600/1000V and 1900/3300V armoured electric cables having PVC insulation |
| BS 5467 | Specification for 600/1000V and 1900/3300V armoured electric cables having thermosetting insulation |
| BS 2316 | Specification for radio-frequency cables; general requirements and tests; British Government Services requirements |

IEE Wiring Regulations particularly applicable to this chapter are:

| | |
|---|---|
| Part | 4 |
| Section | 531 |
| Section | 533 |
| Section | 537 |
| Chapter | 54 |
| Appendix | 3 |

Read Page 164 Fire Alarms

# Chapter 11
# Call and computer systems, telephone and public address systems

## Introduction

In many buildings, it is necessary to have a system of calling staff who are on duty in an office or staff room to go to rooms elsewhere in the building. This happens, for example, in hotels, hospitals and retirement homes. In the case of hospitals, patients wish to call a nurse who is in the ward office to their own beds, and in hotels guests may wish to call staff to their rooms. In retirement homes, a resident may wish to summon either domestic or nursing staff. All such systems can be arranged electrically and form part of the electrical services in a building.

## Hospital call systems

In hospitals, it is desirable for each patient to be able to call a nurse to his/her bed. Figure 11.1 is a wiring diagram of a simple circuit for achieving this. There is a call unit at each bed which contains a push button, a relay and an illuminated reset lamp push. When the patient pushes the button, the relay is energized and holds itself in until it is released by the reset lamp push. While the relay is energized, a lamp is illuminated; it can be either next to the patient's bed or over the door of the room. At the same time, a buzzer and light are operated in the ward office or wherever else the nurse is to be called from. The buzzer can be silenced by a muting switch, but the light can only be cancelled by the resetting push on the patient's unit. Secondary or pilot lamps and buzzers can be placed elsewhere so that a nurse's attention can be attracted in more than one place or so that a nurse can supervise the activity of his/her staff.

When the call is made, the duty nurse has no indication from where it is coming and must, therefore, walk around all the places on the system until s/he sees the individual lamp which has been illuminated. The system is therefore limited to small areas. An extended version which does not have such a limitation is shown in Figure 11.2. A call unit is provided at each bed and also in each toilet; the toilet unit differs from the bed unit by being

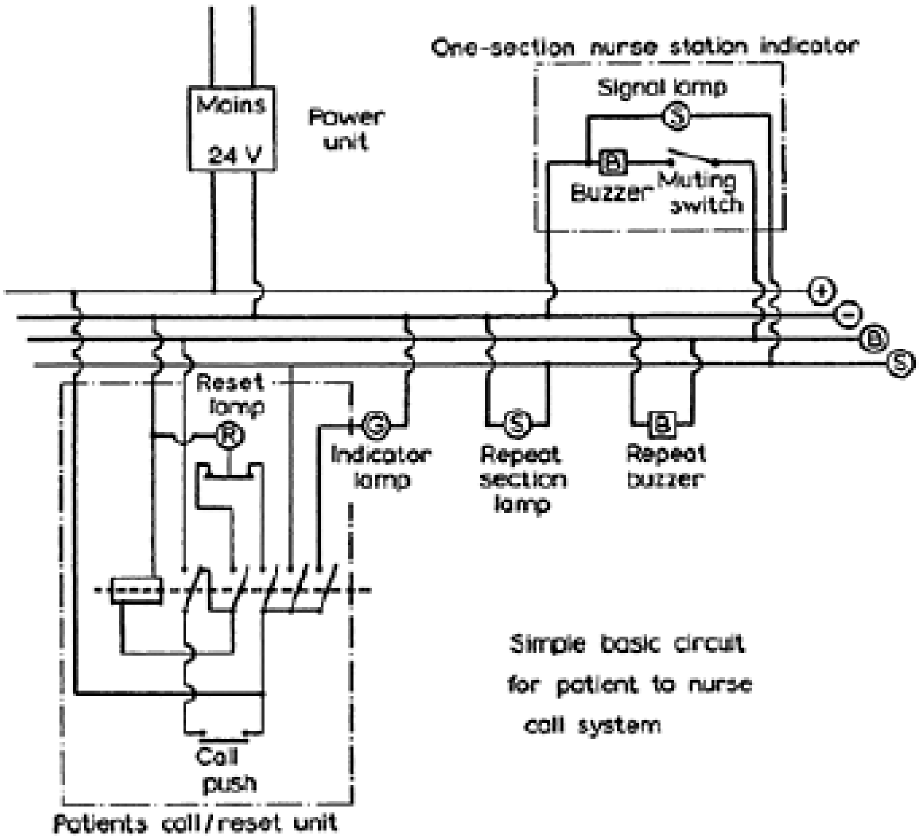



*Figure 11.1* Hospital call system

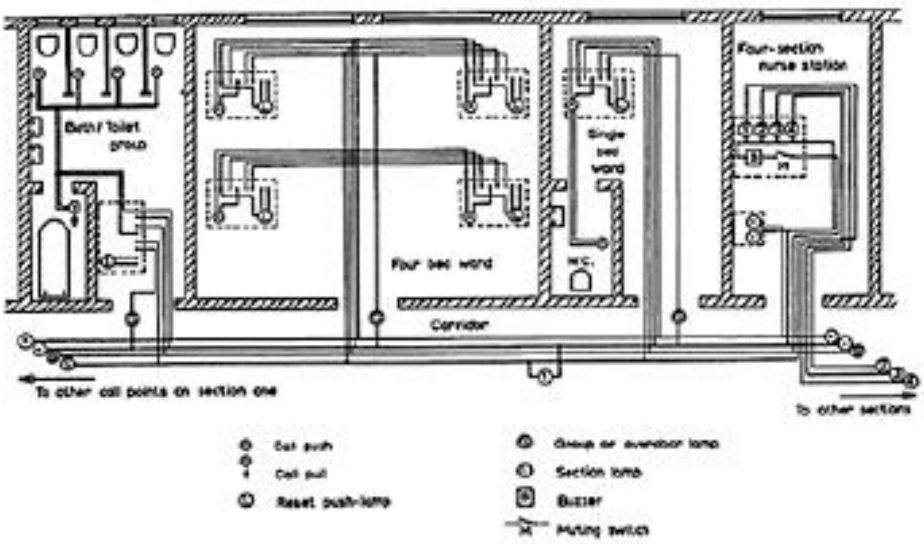



*Figure 11.2* Hospital call system

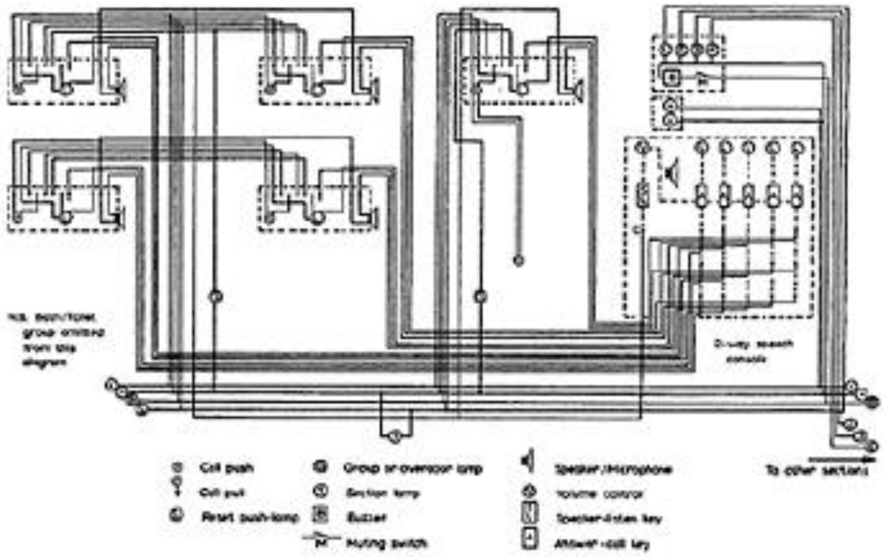



*Figure 11.3* Call system with speech facility

*Figure 11.4* Alarm indicator (Courtesy of Gent & Co. Ltd)

*Figure 11.5* Indicator lamp (Courtesy of Edison Telecom Ltd)

*Figure 11.6* Call button (Courtesy of Edison Telecom Ltd)

*Figure 11.7* Call unit (Courtesy of Edison Telecom Ltd)

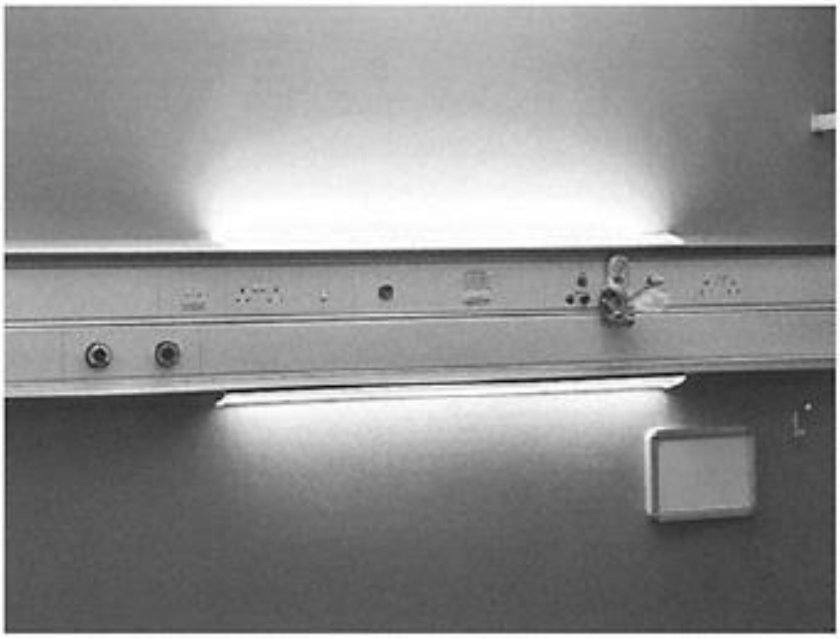


*Figure 11.8* Bedhead trunking (Courtesy of Cableflow Ltd)

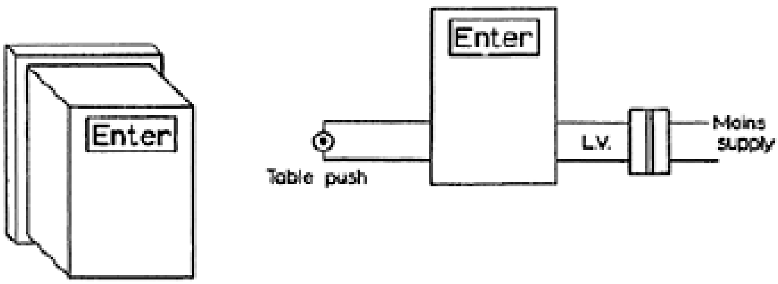



*Figure 11.9* Door sign

## Telephone systems

The design of telephone systems is beyond the scope of this book, but we must consider the provision that has to be made for them within a building. In many cases all that is needed is a route by which the public telephone service, which in the UK is British Telecom, can bring a telephone cable to an instrument. British Telecom telephones are operated by batteries at the telephone exchanges and need no source of power within the buildings they serve. Telephone cable is quite small and if the position of the outlet for the telephone receiver is known it is sufficient to install a 20mm conduit from outside the building to the outlet, with the same number and spacing of draw-in points as are used for any other conduit system. It is usual for the electrical installer to fix the conduit and leave draw cable in it, which the telephone engineers subsequently use for pulling their cable in after the building is finished and occupied.

## Public address systems

Public address and loudspeaker systems are somewhat similar to telephones. The details of the equipment to be used can be settled only with manufacturers' catalogues and by discussion with the manufacturers. Once the equipment and its location have been selected, provision must be made for running cables from the announcing station to the loudspeakers. Because these cables are likely to be put in after all other building work is finished a conduit system is the almost inevitable choice. Loudspeaker cables are like telephone cables in that they are small and do not have an outer sheath; this also makes it difficult to find any alternative to putting them inside conduit.

## Closed-circuit television systems

There is no real technical difference between the pictures we see at home on television, and those delivered by a CCTV camera and monitor. The real difference is in the cost of the equipment. Therefore we cannot expect to have the same quality of picture from equipment bought for the sums of money a client is prepared to spend, compared with broadcasting company equipment.

Closed-circuit television is used in many circumstances, including surveillance of vehicular, and people traffic, entering and leaving a premises. The CCTV standard is phase alternate line (PAL), also used in normal TV transmissions in Europe with the exception of France, who use PAL only for CCTV.

The typical types of cable are: (a) coaxial, which is unbalanced, meaning that the signal is a voltage with reference to ground. The video signal is between 0.3 to 1.0V above ground; (b) twisted pair balanced, meaning that the video signal has been converted for transmission along a medium other than coaxial. The signal level is the voltage difference between each conductor; (c) fibre optics, which are immune to outside interference and signals without needing amplification.

External interference is picked up en route by all types of cable, with the exception of fibre optics. Unless suitably screened, power and signal cables should be kept well apart. The longer the length of cables, the greater the losses. Unlike fibre cables, copper cables will have a voltage drop over the length resulting in a lower signal level at the receiving end than that processed by the camera. Provision of cable routes for CCTV is similar to that discussed in telephone systems.

## Computer systems

Computer networks are used extensively in organisations to utilise the storage space of a server. To connect the workstations to the server, a network is used. The network wiring provides a transmission path between the workstations and the server. Copper cable can meet most demands at a relatively low cost. The data is transmitted in the form of low-voltage electrical signals, which are unfortunately subject to interference. '

Standards relevant to this chapter are:

| | |
|---|---|
| BS EN 50134–7 | Social alarm systems |
| BS 5839 | Fire detection and alarm systems in buildings |
| BS 6259 | Code of practice for sound systems |
| BS EN 50132–7 | Alarm systems; CCTV surveillance systems for use in security applications |
| BS 8220 | Guide for security of buildings against crime |
| BS 7671 | Section 607 |

# Chapter 12
# Reduced-voltage systems

The use of extra-low-voltage wiring for fire alarms and call systems has been discussed in the previous two chapters. Other applications occur in laboratories, where permanently installed reduced-voltage outlets are required for various experiments. Permanent outlets are easier for the staff than the use of accumulator batteries which have to be carried from preparation room stores and set up on the laboratory benches for each experiment. Reduced-voltage supplies are also needed for microscopes which have a built-in light for illuminating the slide.

It would be possible to take the secondary of the transformer to a reduced-voltage distribution board and split there to several reduced-voltage circuits. The cable from the transformer to the distribution board would, however, be very large to take the necessary current, and it is better to use a separate transformer for each secondary circuit. The kVA rating required is calculated from the secondary voltage and total output power needed. As usual in this kind of design, it is advisable to allow ample spare capacity so that the transformer rating should be somewhat above the calculated requirement.

The voltage on the primary of the transformer is known, being the ordinary mains supply voltage in the building, and this determines the transformer ratio. The ratio determines the primary current and thus provides all the information necessary to design the mains circuit feeding the transformer. A fuse can, if desired, be provided on the secondary of the transformer, but an overload on the secondary would draw an overload on the primary so that the fuse in the supply to the transformer will also protect the secondary. This will not, however, be the case if the primary has been oversized while the secondary has not. The exact carrying capacities of the primary and secondary sides should be carefully compared before the fusing arrangements are finally decided on.

*Figure 12.1* Reduced-voltage unit

## Intrinsically safe circuits

Equipment for hazardous areas is discussed in Chapter 1. One technique in areas where there is a risk of fire is the use of intrinsically safe circuits. The principle of these is that the energy of any spark which occurs shall be limited so that it is not sufficient to ignite the vapour. This is achieved by using reduced voltages and equipment which does not take high currents at these voltages. The power in the circuit is thus low and there is not enough energy available to initiate combustion.

Not all equipment can be designed on this basis, but it is often possible to have intrinsically safe circuits within a hazardous area operating relays which control normal equipment outside the danger zone. This may be cheaper than installing flameproof equipment within the zone.

Standards relevant to this chapter are:

BS 1259 Intrinsically safe electrical apparatus and circuits

IEE Wiring Regulations particularly applicable to this chapter are:

| | |
|---|---|
| Section | 411 |
| Regulation | 553–3 |

Read Page 185 Chapter 12 Reduced voltage system

*Table 13.1* Frequency bands

| *Designation* | *Abbreviation* | *Frequency range* |
|---|---|---|
| Low frequency | LF | 30kHz–300kHz |
| Medium frequency | MF | 300mHz–3MHz |
| High frequency | HF | 3MHz–30MHz |
| Very high frequency | VHF | 30MHz–300MHz |
| Ultra high frequency | UHF | 300MHz–3000MHz |
| Super high frequency | SHF | 3000MHz–30000MHz |

*Table 13.2* Broadcasting services

| *Range* | *Band* | *Channel numbers* | *Frequency* | *Service* |
|---|---|---|---|---|
| LF | – | – | 150–285kHz | AM sound long wave |
| MF | – | – | 535–1605kHz | AM sound medium wave |
| HF | – | – | 2.3–26.1MHz | AM sound short wave |
| VHF | I | 1–5 | 41–68MHz | TV Band I |
| | II | – | 87.5–100MHz | FM sound (VHF) |
| | III | 6–13 | 175–215MHz | TV band III |
| UHF | IV | 21–34 | 470–582MHz | TV band IV |
| | V | 39–68 | 614–854MHz | TV band V |

## Aerials

If an e.m.f. is placed in the centre of a short cable (Figure 13.1), the two halves of the cable act as capacitor plates, one becoming positively charged and the other negatively. Each charge produces an electric field. Suppose now that the e.m.f. is alternating; there is then an alternating charging current in the cable. When the current is a maximum the positive and negative charges occupy the same place and produce equal and opposite fields. When the current is zero the positive and negative charges are at opposite ends of the cable and produce a resultant electric field. Thus there is an electric field which alternates with the charging current in the cable.

The current also produces a magnetic field which spreads out from the cable with the velocity of light. The motion of this magnetic field induces a further electric field.

Now the oscillating charges in the cable have not only a velocity, but also an acceleration. This acceleration is propagated outwards in the electric field at a finite velocity and, therefore, the field further out is moving with a lower velocity than that closer in. Since the charges oscillate the acceleration is alternately forward and backward, and the result is that the complete field radiated forms closed loops which travel out from the cable and expand (Figure 13.2). It can be shown that this radiated field is appreciable only if the length of the cable is of the same order as the wavelength.

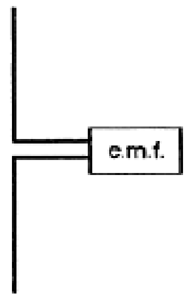



*Figure 13.1* Principle of dipole

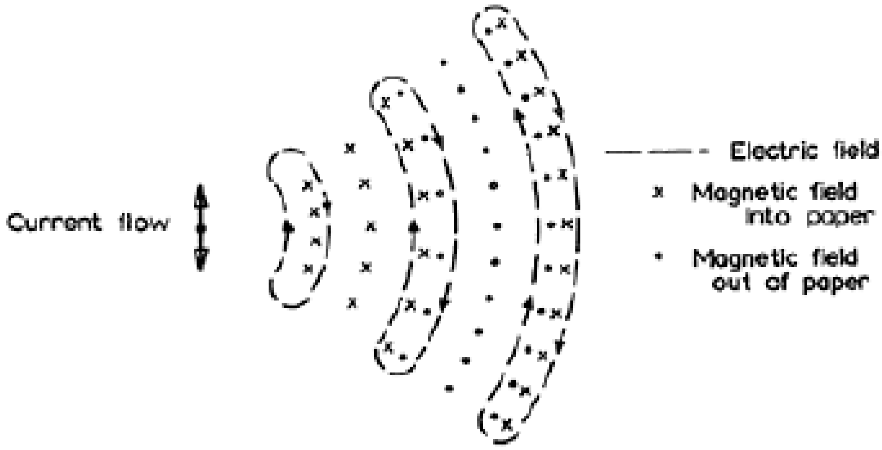



*Figure 13.2* Radiated field

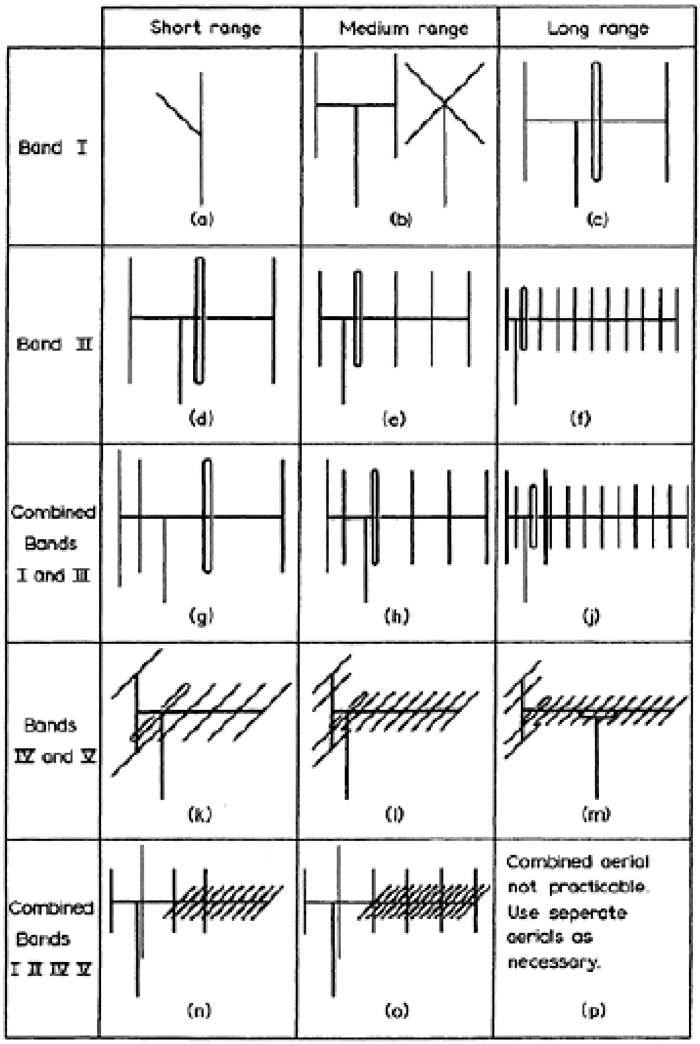



*Figure 13.3* TV aerials

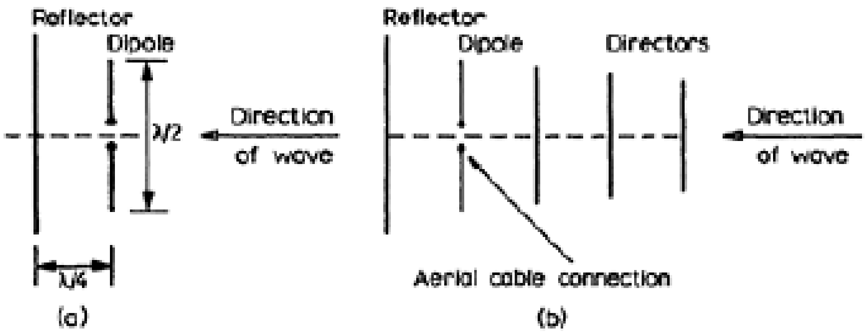



*Figure 13.4* Strengthening elements

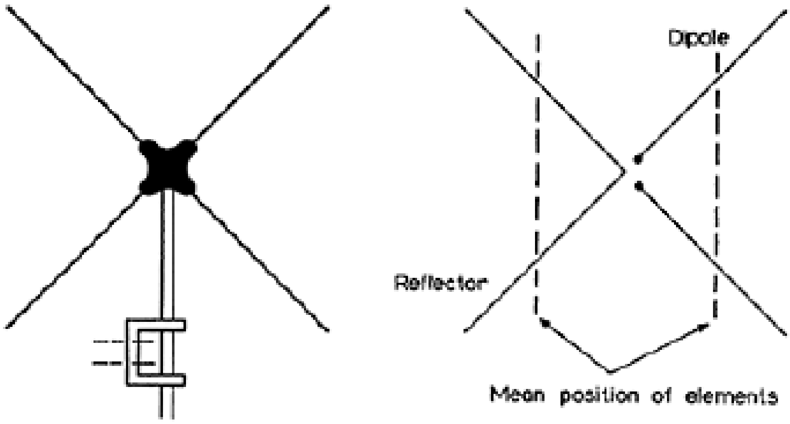



*Figure 13.5* Aerial


*Figure 13.6* Folded dipole

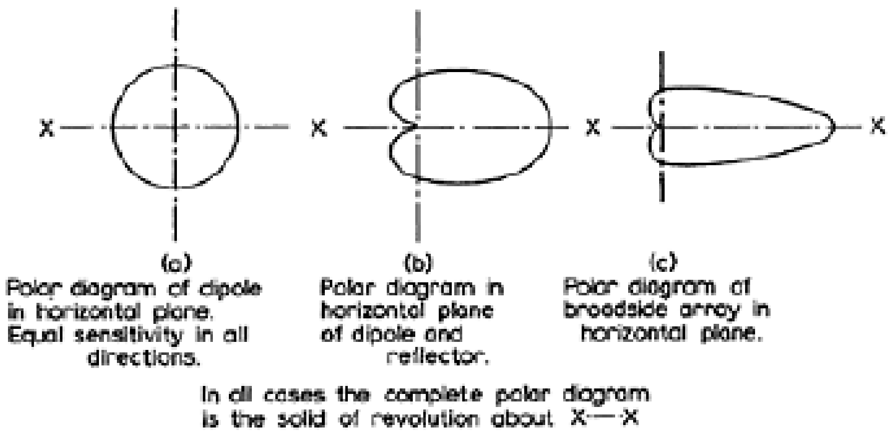



*Figure 13.7* Polar diagrams

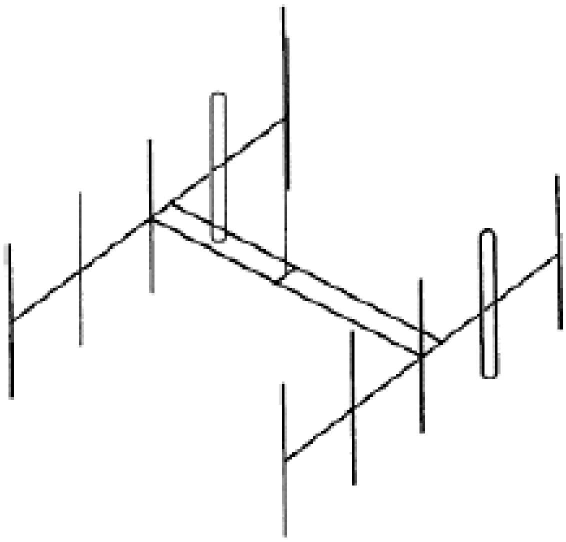


*Figure 13.8* Twin arrays

$$\text{Log}_{10}\left(\frac{P_s}{P_r}\right) = 10\ \log_{10}\left(\frac{P_s}{P_r}\right)\ \text{decibels}$$

The decibel is convenient because of the very large losses and amplifications encountered in communications engineering; for example, if an amplifier has an output 10000 times the input it is more convenient to say that is has a gain of 40dB. Since the gain, or loss, in decibels is a ratio, the input level should also be stated.

Power ratios are proportional to the square of the voltage or current ratios. Therefore:

$$\log 10\left(\frac{P_s}{P_r}\right) = 2\ \log_{10}\left(\frac{V_s}{V_r}\right) = 2\ \log_{10}\left(\frac{I_s}{I_r}\right)$$

Thus when measurements are made in volts or amps the loss is

$$20\ \log_{10}\left(\frac{V_s}{V_r}\right)\text{dB or }\log_{10}\left(\frac{I_s}{I_r}\right)\text{dB}$$

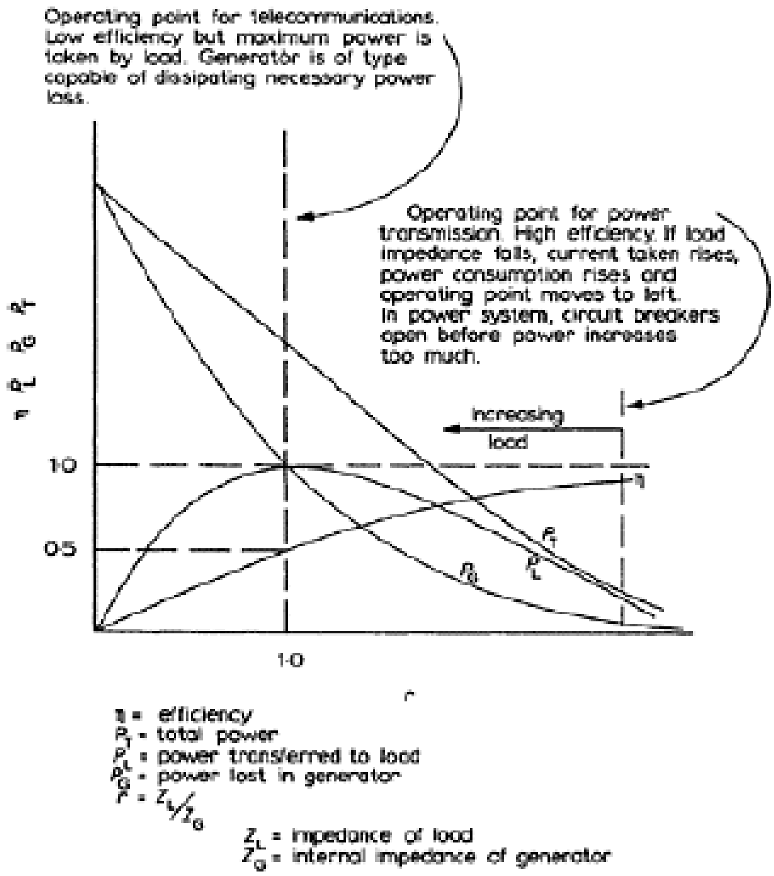



*Figure 13.9* Operating points of transmission lines

Let

$I_s$=current at sending end

$I_l$=current one kilometre down line

Then $\frac{I_l}{I_s} = e^{-y}$ where $y$=propagation constant per kilometre of line.

$y$ is a complex quantity so that $I_l$ is both less than $I_s$ and also different in phase. In general,

$I_n=I_se^{-ny}$ where $I_n$=current $n$ kilometres along the line.

Similarly, $E_n=E_se^{-ny}$

$y$ is a complex quantity which can be written $y=\alpha+j\beta$ where $\alpha$ is the attenuation constant and $\beta$ is the phase constant.

The four quantities:

$Z_0$=characteristic impedance

$y$=propagation constant

$\alpha$=attenuation constant

$\beta$=phase constant

are characteristic of the particular cable being used. They are known as the secondary line constants and can be calculated theoretically from the four primary line constants which are

$R$=resistance per kilometre (ohms)

$G$=leakage per kilometre (mhos)

$L$=inductance per kilometre (henries)

$C$=capacitance per kilometre (farads)

Whilst the primary constants are independent of frequency the secondary constants in general vary with frequency.

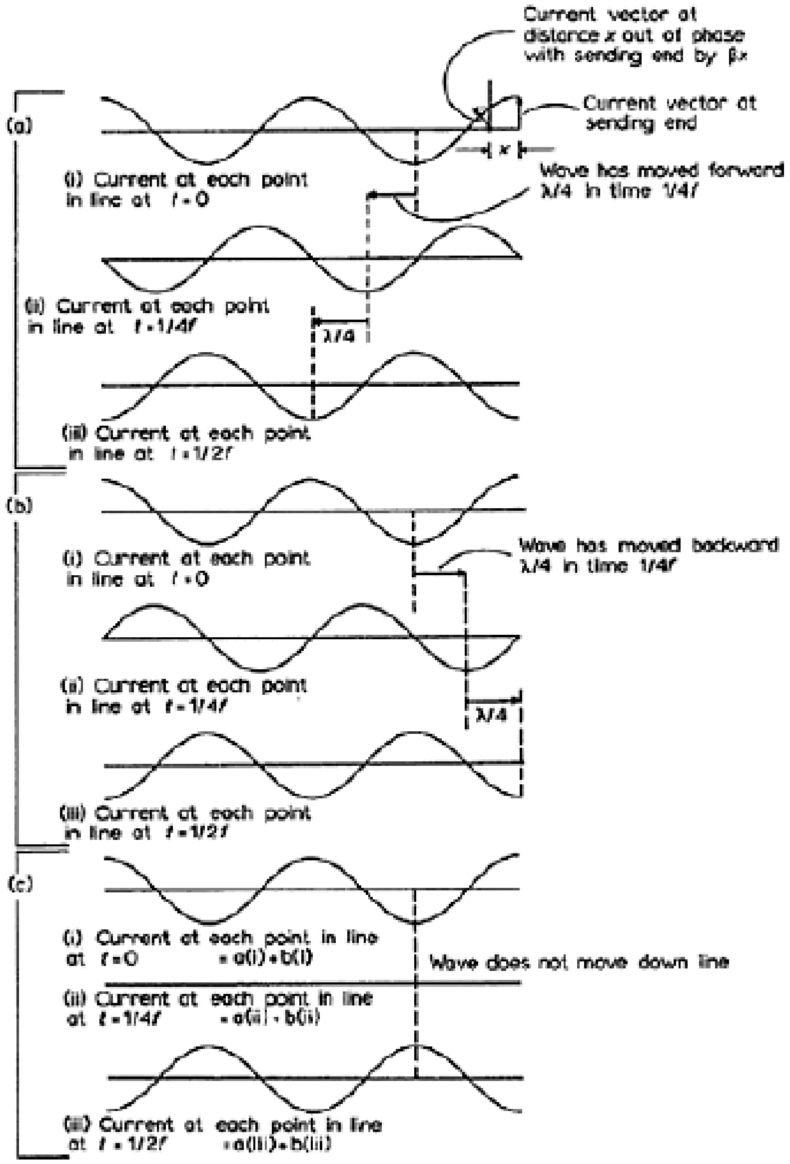



*Figure 13.10* Travelling and standing waves

$$\therefore \beta\lambda = 2\pi$$

$$\therefore \lambda = 2\frac{\pi}{\beta}$$

Since velocity=frequency×wavelength

$$v = f\lambda$$

$$= f, 2\frac{\pi}{\beta} = 2\frac{\pi}{\beta}$$

$$= w\beta$$


*Figure 13.11* Impedance transformer

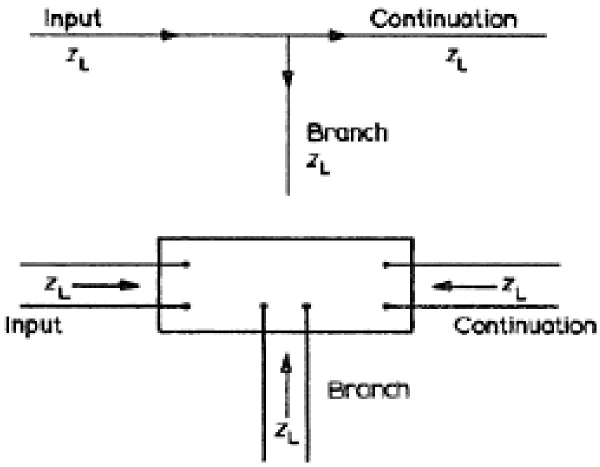



*Figure 13.12* Branch network

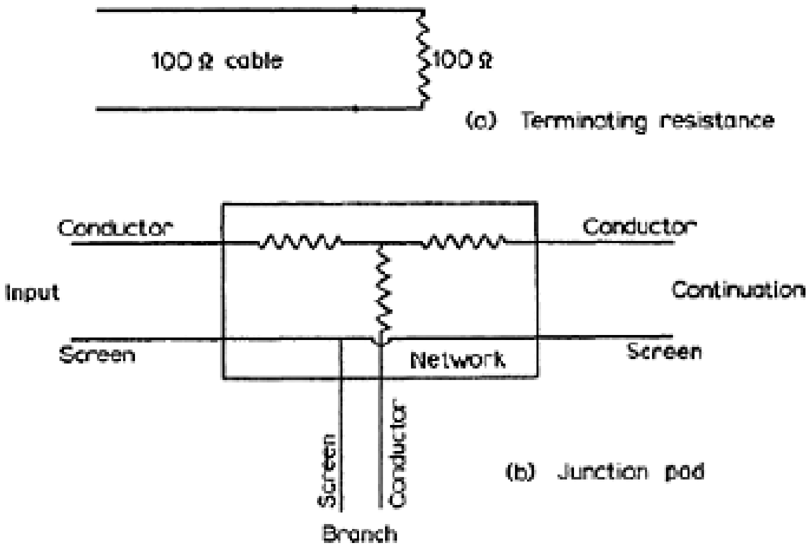



*Figure 13.13* Junction box

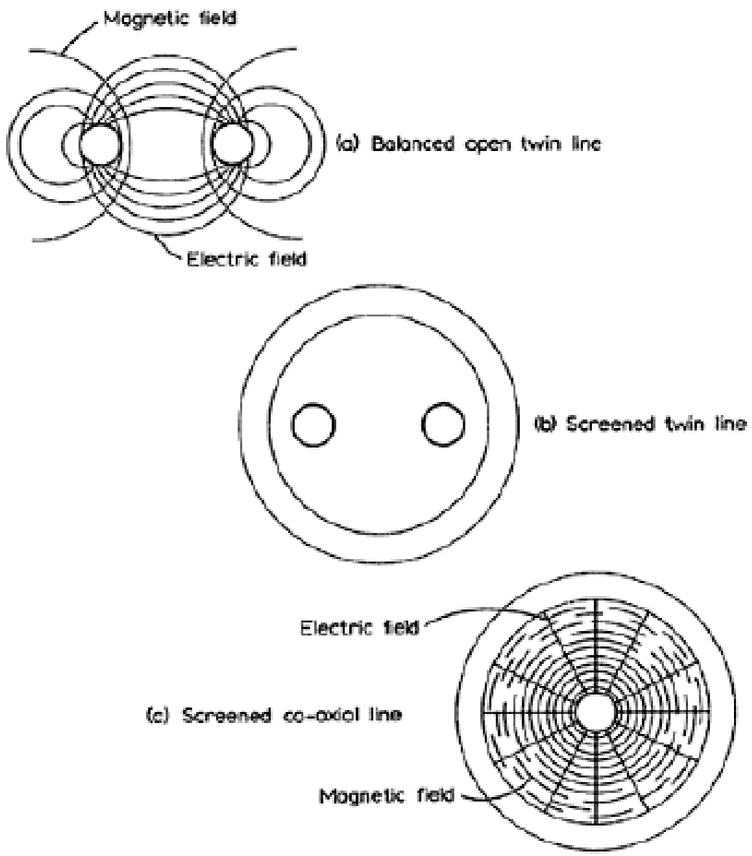



*Figure 13.14* TV cables

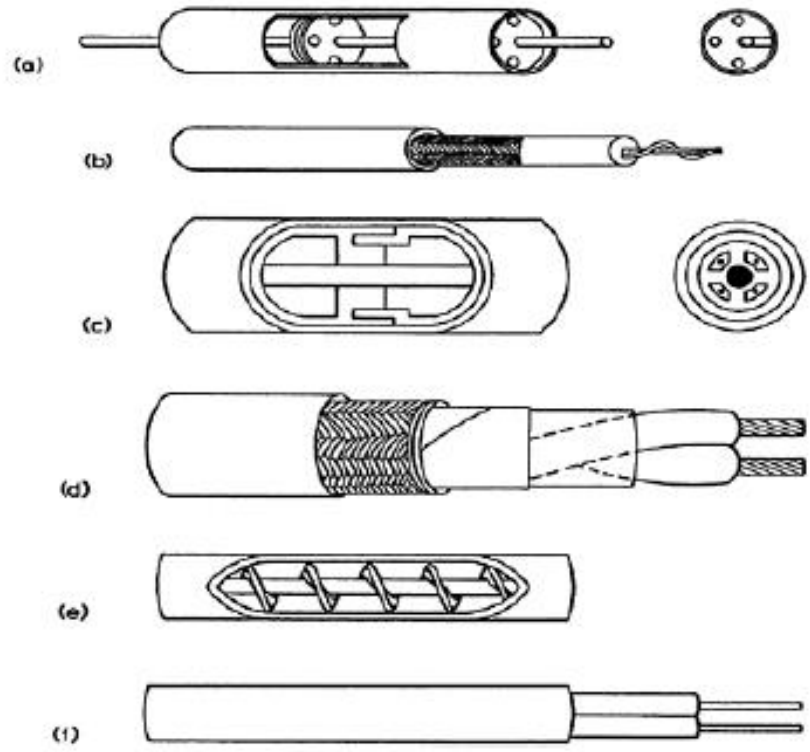



*Figure 13.15* Radio frequency cables

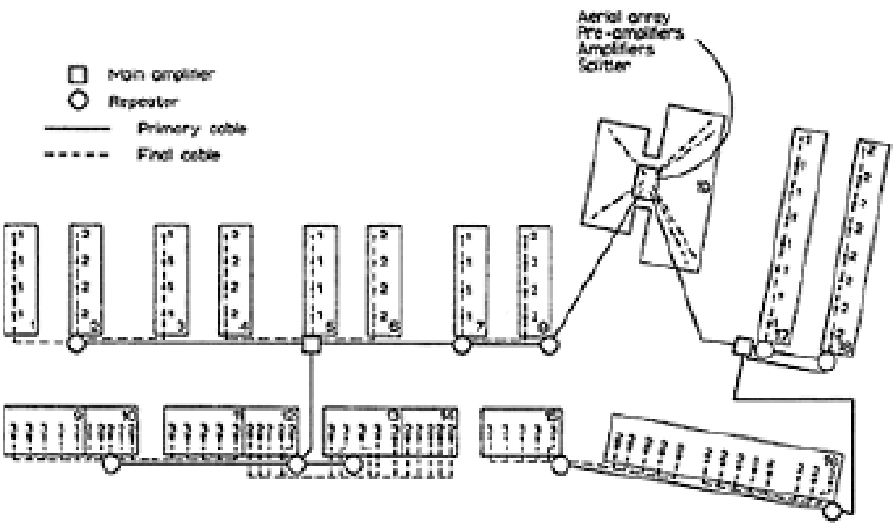



*Figure 13.18* Typical scheme

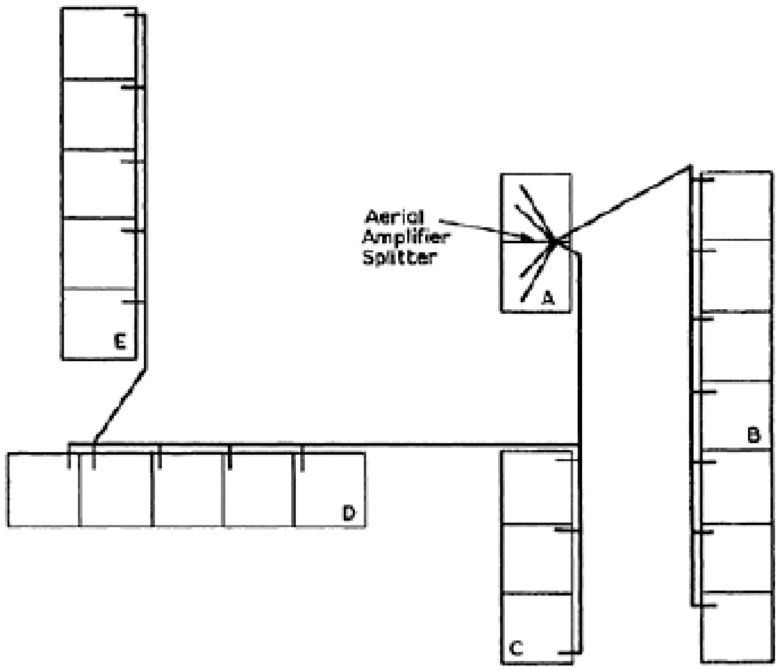



*Figure 13.19* Small scheme

box in the wall of each house from which a short stub aerial cable ran in conduit to the outlet in the living room. The longest cable on this scheme served only 13 dwellings and it was therefore possible to avoid the use of repeater amplifiers altogether. On a small scheme it is better to have a splitter at the masthead with several distributing cables than to run a single cable round the whole site with several repeater amplifiers along it.

Standards relevant to this chapter are:

| | |
|---|---|
| BS 3041 | Radio frequency connectors |
| BS 6259 | Code of practice for the design, planning, installation, testing and maintenance of sound systems |
| BS 6330 | Code of practice for reception of sound and television broadcasting |

Read Page 188 Communal and closed TV system

# Chapter 14
# Lightning protection

Lightning strokes can be of two kinds. In the first, a charged cloud induces a charge of opposite sign in nearby tall objects, such as towers, chimneys and trees. The electrostatic stress at the upper ends of these objects is sufficiently great to ionize the air in the immediate neighbourhood, which lowers the resistance of the path between the cloud and the object. Ultimately, the resistance is lowered sufficiently for a disruptive discharge to occur between them. This type of discharge is characterized by the time taken to produce it, and by the fact that it usually strikes against the highest and most pointed object in the area.

The second kind of stroke is a discharge which occurs suddenly when a potential difference between a cloud and the earth is established almost instantly. It is generally induced by a previous stroke of the first kind; thus if a stroke of this kind takes place between clouds 1 and 2 (Figure 14.1), cloud 3 may be suddenly left with a greater potential gradient immediately adjacent to it than the air can withstand, and a stroke to earth suddenly occurs. This type of stroke occurs suddenly and is not necessarily directed to tall sharp objects like the first kind of stroke. It may miss tall objects and strike the ground nearby. Figure 14.2 shows other ways in which this. kind of stroke may be induced. In each case, A is a stroke of the first kind and B is the second type of stroke induced by A. In each case the first stroke from cloud 1 changes the potential gradient at cloud 2 and thus produces the second stroke.

The current in a discharge is uni-directional and consists of impulses with very steep wave fronts. The equivalent frequency of these impulses varies from 10kHz to 100kHz. While some lightning discharges consist of a single stroke, others consist of a series of strokes following each other along the same path in rapid succession. The current in a single stroke can vary from about 2000A to a maximum of about 200000A, with a statistical average of 20000A. It rises to a peak value in a few microseconds. When a discharge consists of several successive strokes, each stroke rises and falls in a time and to an amplitude of this order so that the whole discharge can last up to a second.

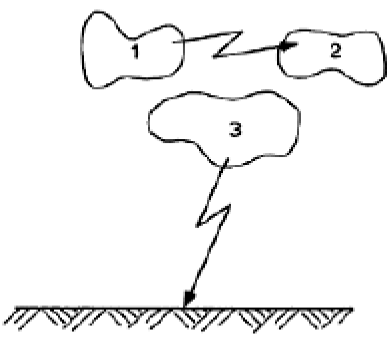



*Figure 14.1* Induced lightning stroke

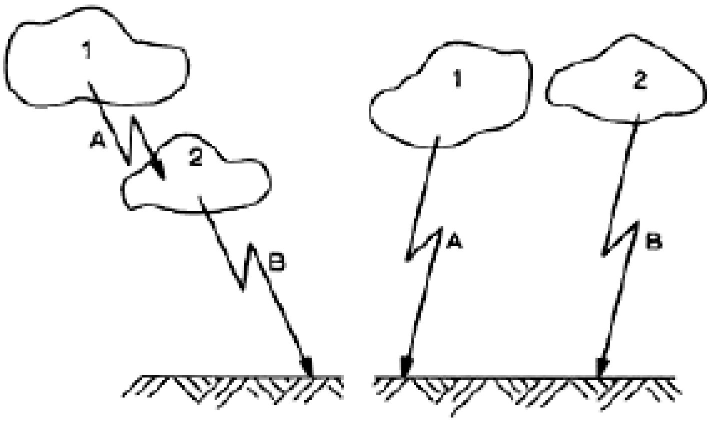



*Figure 14.2* Induced lightning strokes

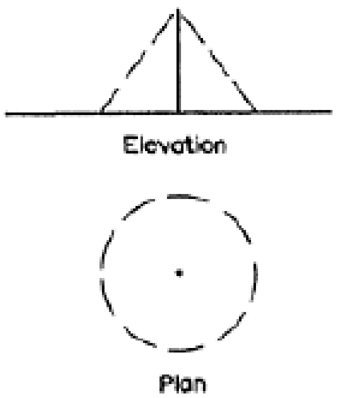



*Figure 14.3* Protected zone

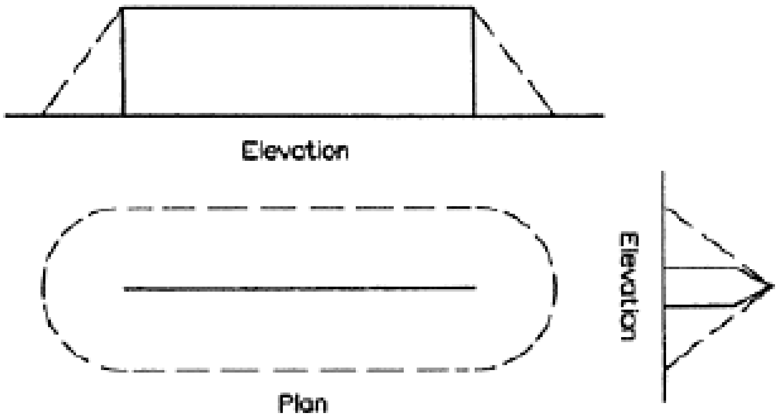



*Figure 14.4* Protected zone—horizontal conductor

Whether or not a building needs protection against lightning is a matter of judgement. It obviously depends on the risk of a lightning stroke and also on the consequence of a stroke. Thus a higher risk of a strike can probably be accepted for an isolated small bungalow than for, say, a children's hospital. While no exact rules can be laid down that would eliminate the designer's judgement entirely, some steps can be taken to objectify the assessment of risk and of the magnitude of the consequences. The method recommended in BS 6651:1999 is to determine the probable number of strikes per year, apply a weighting factor to this, and see if the result is more or less than an acceptable level of risk. The weighting factor is the product of individual factors which take into account the use of the structure, the type of construction, the consequential effects of a strike, the degree of isolation and the type of country.

The probable number of strikes is given by

$$P = A_c \times N_g \times 10^{-16}$$

where

$P$=probable number of strikes per year

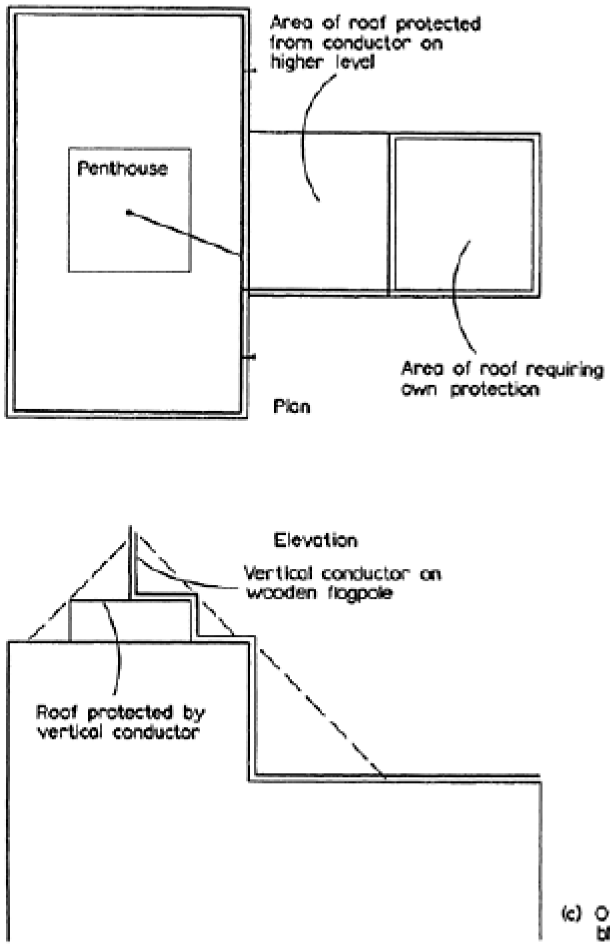
$A_c$=area protected by conductor, m$^2$

$N_g$=*lightning* flash density, i.e. the number of flashes to ground per km$^2$ per year.

A map showing values of $N_g$ for different parts of the UK is shown in Figure 14.5. This and other extracts from BS 6651 are reproduced here by permission of the British

*Table 14.1* Need for lightning protection

| *Weighting factor* | *Factor* |
| --- | --- |
| *A Use of structure* | |
| Houses and similar buildings | 0.3 |
| Houses and similar buildings with outside aerial | 0.7 |
| Factories, workshops, laboratories | 1.0 |
| Offices, hotels, blocks of flats | 1.2 |
| Places of assembly, churches, halls, theatres, museums, department stores, post offices, stations, airports, stadiums | 1.3 |
| Schools, hospitals, children's and other homes | 1.7 |
| *B Type of construction* | |
| Steel framed encased with non-metal roof | 0.2 |
| Reinforced concrete with non-metal roof | 0.4 |
| Steel framed encased or reinforced concrete with metal roof | 0.8 |
| Brick, plain concrete, or masonry with non-metal roof | 1.0 |
| Timber framed or clad with roof other than metal or thatch | 1.4 |
| Brick, plain concrete masonry, timber framed, with metal roof | 1.7 |
| Any building with a thatched roof | 2.0 |
| *C Contents or effects* | |
| *Contents or type of building* | |
| Ordinary domestic or office building, factories and workshops not containing valuable materials | 0.3 |
| Industrial and agricultural buildings with specially susceptible contents | 0.8 |
| Power stations, gas installations, telephone exchanges, radio stations | 1.0 |
| Industrial key plants, ancient monuments, historic buildings, museums, art galleries | 1.3 |
| Schools, hospitals, children's and other homes, places of assembly | 1.7 |
| *D Degree of isolation* | |
| Structure in a large area of structures or trees of same height or greater height, e.g. town or forest | 0.4 |
| Structure in area with few other structures or trees of similar height | 1.0 |
| Structure completely isolated or twice the height of surrounding structures of trees | 2.0 |
| *E Type of country* | |
| Flat country at any level | 0.3 |




(c) Office
block

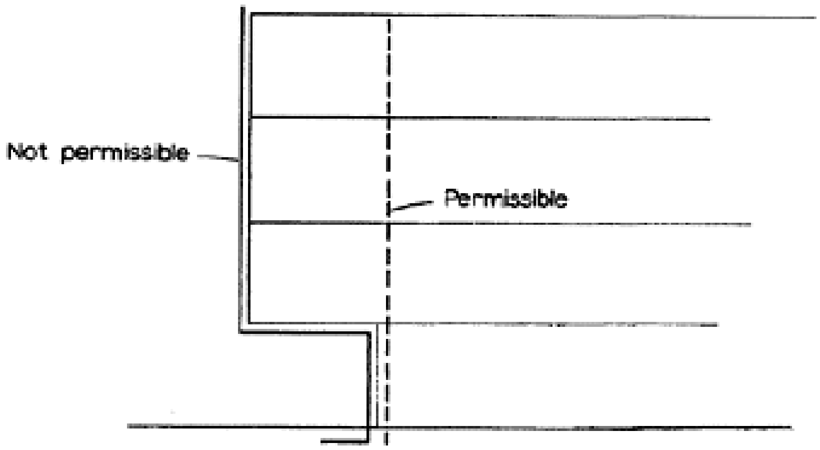



*Figure 14.9* Cantilevered building

*Table 14.2* Lightning conductors

| *Components* | *Minimum dimensions* |
|---|---|
| *Air terminations* | *mm* |
| Aluminium and copper strip | 20×3 |
| Aluminium, aluminium alloy, copper and phosphor bronze rods | 10 diam. |
| Stranded aluminium conductors | 19/2.50 |
| Stranded copper conductors | 19/1.80 |
| *Down conductors* | |
| Aluminium and copper strip | 20×3 |
| Aluminium, aluminium alloy and copper rods | 10 diam. |
| *Earth terminations* | |

$$M_T = 0.46 \log_{10} \frac{S}{r_e}$$

where

$M_T$=transfer inductance, μH $m^{-1}$

$S$=distance between centre of down conductor and centre of nearest vertical metal component, m

$r_e$=equivalent radius of down conductor, m.

For a circular down conductor $r_e$ is the actual radius. For the more usual case of a rectangular strip down conductor,

$$r_e \frac{w+t}{3.5}$$

where

$w$=width, m

$t$=thickness, m.

The inductive voltage is proportional to the rate of change of current, and for design purposes this must be taken as the maximum likely to occur, which is 200kA $s^{-1}$. The voltage is therefore calculated from the formula

$$V_L = 200 \frac{lM_T}{n}$$

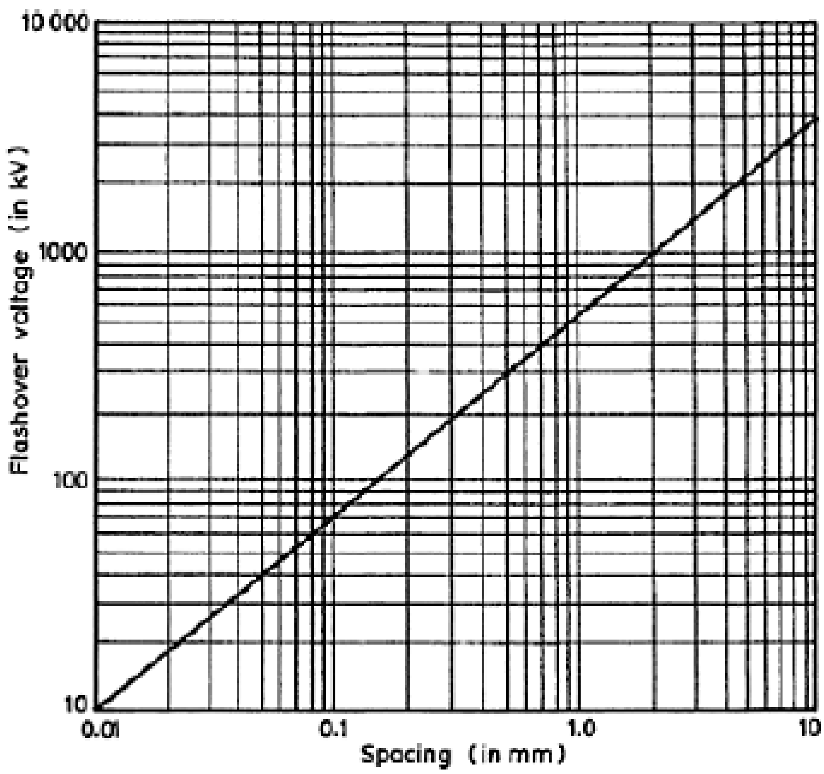
where

$V_L$=inductive voltage, kV

$l$=length of inductive loop, m

$M_T$=transfer inductance μH $m^{-1}$

$n$=number of down conductors.




Read Page 212 Lightning Protection

# Chapter 15
# Emergency supplies

## Introduction

There are rare occasions when the public electricity supply fails and a building is left without electricity. In some buildings, the risk of being totally without electricity cannot be taken, and some provision must be made for an alternative supply to be used in an emergency. What form this provision should take is an economic matter which depends on the magnitude of the risk of failure and the seriousness of the consequences of failure. In this chapter, we shall say something about the available methods of providing an alternative supply.

## Standby service cable

The Electricity Supply Authority can be asked to bring two separate service cables into the building. They will normally make a charge for this, but it provides security against a fault in one of the cables. It does not, of course, give security against a failure of the public supply altogether.

In heavily built up areas, such as London and other large cities, the public distribution system is in the form of a network and each distribution cable in the streets is fed from a sub-station at each end. The supply system itself thus contains its own standby provision. The only addition the building developer can make is to duplicate the short length of cable from the distributor in the road into the building, and it may be doubted whether the risk of this cable failing is sufficiently great to justify the cost of duplicating it. In rural areas the service cable to individual buildings may be quite long, and may take the form of an overhead line rather than an underground cable. The risk of damage is thus greater than in urban areas and there is much more reason for installing a duplicate cable.

## Battery systems

Central battery and individual battery systems have been discussed in Chapter 7 as means of providing emergency lighting. A central battery system can also provide d.c. power. An alternative is for the battery to feed a thyristor inverter which then gives a.c. power.

## Standby generators

A diesel or gas turbine generator set can be installed in a building to provide electricity when the public supply fails. This is a complete form of protection against all possible interruptions of the main supply. The generator can be large enough to supply all the needs of the building and its output can be connected to the ordinary mains immediately after the supply authority's meters and it then provides standby facilities for the entire building. It is cheaper, and may be adequate for the risk to be guarded against, to have a smaller generator serving only the more important outlets. In this case, the distribution must be arranged so that these outlets can be switched from main to emergency supply at one point and so that there is no unintentional path from the emergency generator to outlets not meant to be served by it. In effect the building is divided at the main intake into two distribution systems and only one of them is connected to the emergency changeover switch. It is also possible to install a completely separate system of wiring from the emergency generator to outlets quite distinct from the normal ones. This may be the simplest thing to do in a small building or when the emergency supply is required to serve only one or two outlets. It has the disadvantage that individual pieces of equipment have to be disconnected from one outlet and reconnected to another. Whilst this may not be acceptable in a hospital it may be quite in order in a large residence or hostel to have one or two emergency power points into which vacuum cleaners and other domestic equipment can be plugged when the main power supply is interrupted.

Buildings in which standby generators have been installed include poultry farms, chemical process plants, hospitals, telephone exchanges, computer rooms and prisons.

An emergency generator can be started either manually or automatically. A manual start is simple, but it involves a delay during which the building is without power. This delay can be avoided by automatic starting, initiated by a sensing unit which detects a drop in the mains voltage. Figure 15.1 shows the circuit of a typical mains failure control panel.

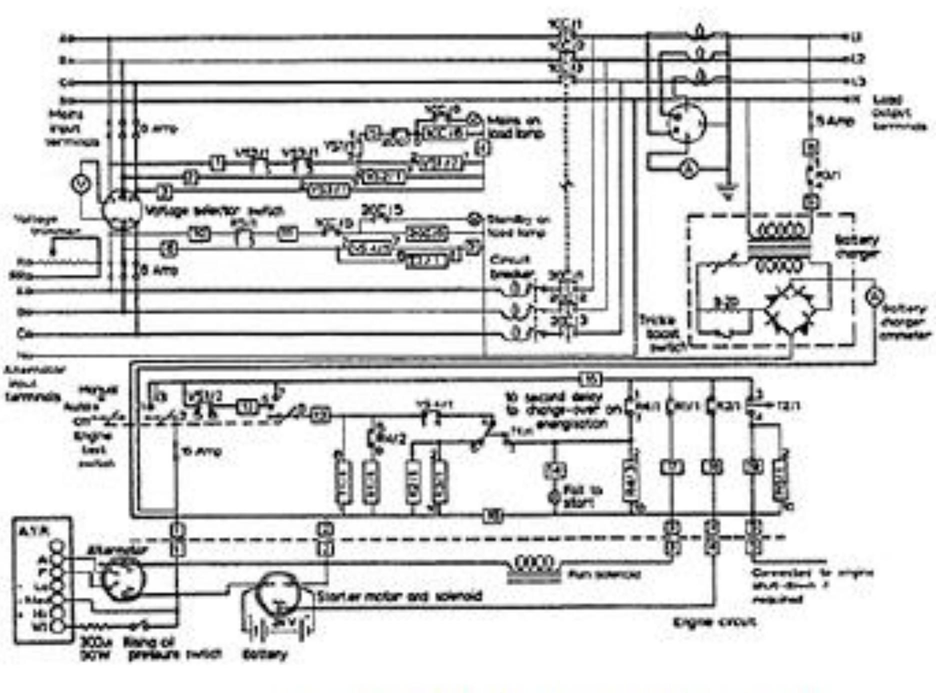



*Figure 15.1* Automatic starting circuit

**Uninterruptible power supplies**

The requirements of computers have led to the development of uninterruptible power supply units, generally referred to as UPS. In essence they

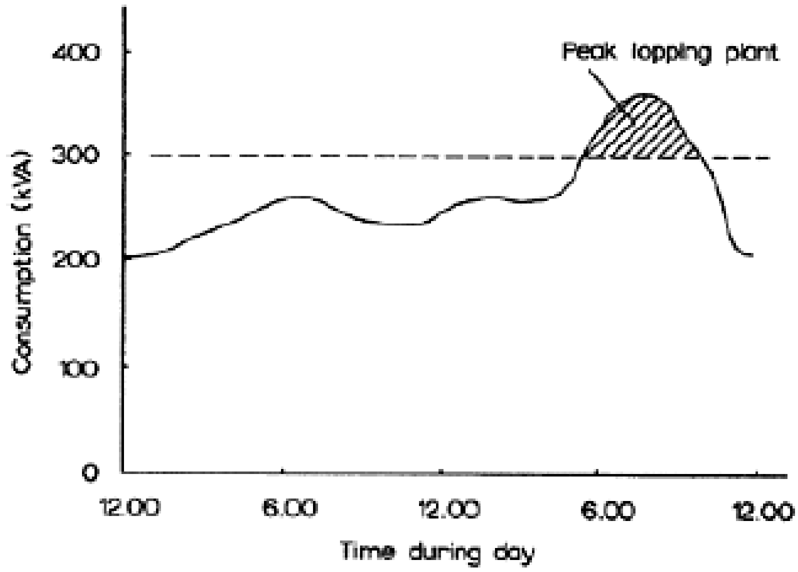



*Figure 15.3* Load diagram

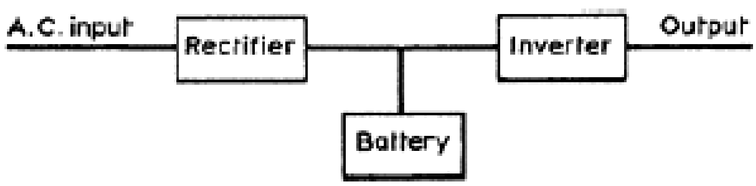



*Figure 15.4* Scheme of UPS unit

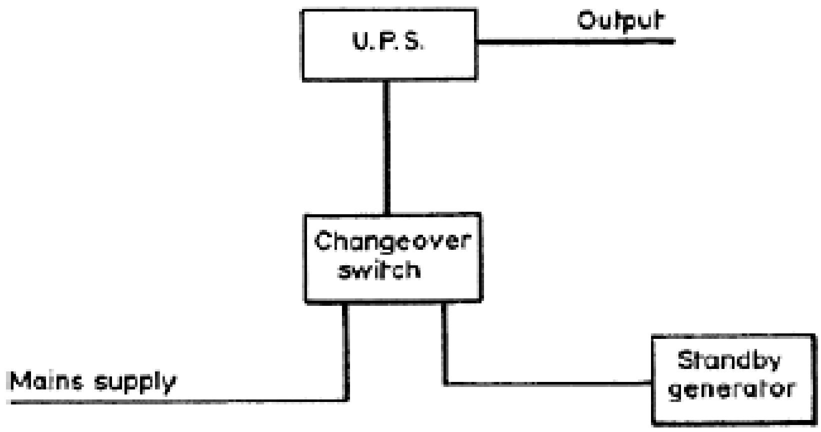



*Figure 15.5* Standby system

Read Page 228 Emergency Supply

# Chapter 16
# Lifts, escalators and paternosters

## Introduction

The general design of lifts is very well established, and in this country at least, nearly all the reputable lift manufacturers will design and supply a satisfactory lift as a matter of routine if given the details and the size of building. Nevertheless, the designer of the building electrical services must be able to advise the client about the lifts, to negotiate with the lift suppliers and to compare competing tenders. The designer must, therefore, know something about the technical details of lifts and we shall accordingly devote this chapter to a brief outline of the subject.

First, we can note that there are three categories of lifts. Passenger lifts are designed primarily for passenger use; goods lifts are mainly for goods but can on occasion carry passengers; and service lifts are for goods only and are of such a size that passengers cannot enter into the car. Lift speeds are determined by the number of floors served and the quality of service required. They vary from $0.5ms^{-1}$ to $10ms^{-1}$ in high office blocks.

In deciding the size of car one can allow $0.2m^2$ for each passenger, and when determining the load the average weight of a passenger can be taken as 75kg. It must, however, be remembered that in many buildings the lift will be used for moving in furniture and the car must be big enough for the bulkiest piece of furniture likely to be needed. The author has made measurements of domestic furniture and has concluded that the most awkward item to manoeuvre is a double bed, which can be up to 1670mm wide by 1900mm long and 360mm high. In flats it is unfortunately also necessary to make sure that stretchers and coffins can be carried in the lift. To accommodate these, a depth of 2.5m is required. The whole car can be made this depth or it can be shallower but have a collapsible extension which can be opened out at the back when the need arises. The lift well must, of course, be deep enough to allow the extension to be opened. In hospitals some of the lifts must take stretchers on trolleys and also hospital beds and these lifts must be the full depth of a complete bed.

The use of a building will often enable a designer to estimate the probable number of stops during each trip. If this is difficult, then a formula can be developed by probability theory, and is:

$$S_n = n - \left[\left(\frac{P - P_a}{P}\right)^N + \left(\frac{P - P_b}{P}\right)^N + \ldots + \left(\frac{P - P_n}{P}\right)^N\right]$$

where

$S_n$=probable number of stops

$n$=number of floors served above ground floor

$N$=number of passengers entering lift at ground floor on each trip

P=total population on all floors

$P_a$, $P_b$,…$p_n$=population on 1st, 2nd…$n$th floor.

Three to four seconds must be allowed for opening and closing the doors at each stop. A further 1 to 11.5s have to be allowed for each passenger to enter the lift and 1 to 2s for each passenger to leave.

The travelling time is made up of periods of acceleration, constant speed and retardation. Figure 16.1 gives the time versus distance curves for the acceleration normally associated with various lift speeds. On each curve, the point marked X indicates the end of acceleration and start of constant velocity. The retardation is generally taken to be equal in magnitude to the acceleration. Providing the distance between stops is long enough for the lift to reach steady speed before starting to slow, the total travelling time of a round trip is given by:

$$t = \frac{2}{V}(dS_n + D + d)$$

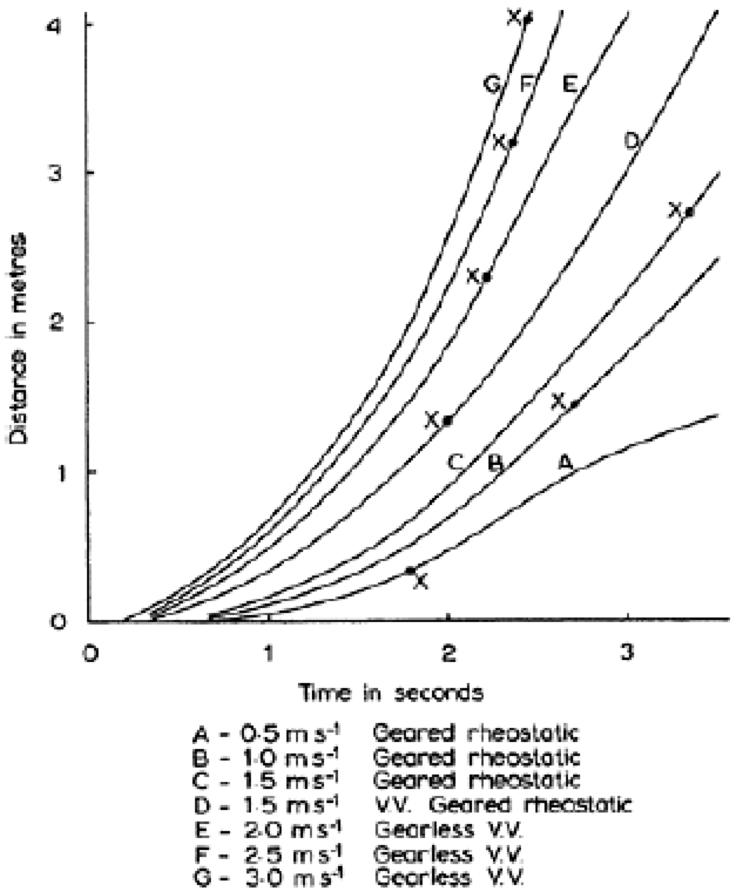



*Figure 16.1* Acceleration curves for lifts

where

$t$=total travelling time

$d$=distance during which acceleration takes place

$D$=distance between ground and top floors

$S_n$=number of stops between ground and top floors

$V$=lift speed.

*Table 16.1* Lift service comparison

| | *A* | *B* | *C* | *D* |
|---|---|---|---|---|
| Load persons | 10 | 20 | 10 | 15 |
| Speed $ms^{-1}$ | 1.5 | 1.5 | 2.0 | 2.0 |
| Probable no. of stops per trip ($S_n$) | 5.23 | 6.35 | 5.23 | 5.99 |
| Accelerating distance *(d)* m | 2.60 | 2.60 | 2.20 | 2.20 |
| $d \times S_n$ | 13.60 | 16.50 | 11.50 | 13.20 |
| Distance between ground and top floors *(D)* m | 25.00 | 25.00 | 25.00 | 25.00 |
| $(dS_n+D+d)$ | 41.20 | 44.10 | 38.70 | 40.40 |
| $\frac{2(dS_n+D+d)}{2\times \text{speed}}$ = travelling time (s) | 55.00 | 59.00 | 38.00 | 40.00 |
| Door opening time (s) | 21.00 | 28.00 | 21.00 | 24.00 |
| Passengers entering and leaving (s) | 25.00 | 50.00 | 25.00 | 37.00 |
| Total travelling time | 101 | 137 | 84 | 101 |
| 10% margin | 10 | 13 | 8 | 10 |
| RTT(s) | 111 | 150 | 92 | 111 |
| No. of lifts | 4 | 3 | 4 | 3 |
| No. of trips per lift in 30min | 16 | 12 | 19 | 16 |
| No. of persons per lift in 30min | 160 | 240 | 190 | 240 |
| Total no. of persons carried in 30min | 640 | 720 | 760 | 720 |
| WI(s) | 28 | 50 | 23 | 37 |
| $\frac{WI}{4}(2+N)$ | 42 | 62 | 35 | 46 |
| Grade of service | Excellent | Fair | Excellent | Good |

*Calculation of $S_n$*

$$S_n = n - \sum_{i=2}^{i=6}\left(\frac{P-P_i}{P}\right)^N$$

*P*=662
*n*=7

| *i* | *Pi* | *P−Pi* | $\left(\frac{P=P_i}{P}\right)$ | $\left(\frac{P=P_i}{P}\right)^{10}$ | $\left(\frac{P=P_i}{P}\right)^{15}$ | $\left(\frac{P=P_i}{P}\right)^{20}$ |
|---|---|---|---|---|---|---|
| 2 | 36 | 626 | 0.95 | 0.60 | 0.46 | 0.36 |
| 3 | 93 | 569 | 0.86 | 0.22 | 0.10 | 0.05 |
| 4 | 160 | 502 | 0.76 | 0.06 | 0.01 | 0.00 |
| 5 | 85 | 577 | 0.58 | 0.22 | 0.10 | 0.05 |

*Table 16.2* Lift dimensions

Passenger lifts

| | | *Well* | | *Machine room* | | | | |
|---|---|---|---|---|---|---|---|---|
| *Load persons* | *Speed ($ms^{-1}$)* | *Width (m)* | *Depth (m)* | *Width (m)* | *Length (m)* | *Height (m)* | *Top landing to MIC room floor (m)* | *Pit depth (m)* |
| *General purpose passenger lifts* | | | | | | | | |
| 8 | 1.0 | 1.80 | 1.90 | 3.10 | 4.80 | 2.60 | 4.00 | 1.60 |
| 10 | 0.75 | 2.00 | 1.90 | 3.10 | 5.00 | 2.60 | 4.00 | 1.60 |
| 10 | 1.0 | 2.00 | 1.90 | 3.10 | 5.00 | 2.60 | 4.00 | 1.70 |
| 10 | 1.5 | 2.00 | 1.90 | 3.10 | 5.00 | 2.60 | 4.20 | 1.70 |
| 16 | 0.75 | 2.60 | 2.20 | 3.50 | 5.30 | 2.70 | 4.10 | 1.70 |
| 16 | 1.00 | 2.60 | 2.20 | 3.50 | 5.30 | 2.70 | 4.20 | 1.90 |
| 16 | 1.50 | 2.60 | 2.20 | 3.50 | 5.30 | 2.70 | 4.30 | 1.90 |
| 20 | 0.75 | 2.60 | 2.50 | 3.50 | 5.60 | 2.70 | 4.10 | 1.70 |
| 20 | 1.00 | 2.60 | 2.50 | 3.50 | 5.60 | 2.70 | 4.20 | 1.90 |
| 20 | 1.50 | 2.60 | 2.50 | 3.50 | 5.60 | 2.70 | 4.30 | 1.90 |
| *High speed passenger lifts* | | | | | | | | |
| 12 | 2.5 | 2.20 | 2.20 | 3.20 | 7.50 | 2.70 | 6.80 | 2.80 |
| 16 | 2.5 | 2.60 | 2.30 | 3.20 | 8.00 | 2.70 | 6.80 | 2.80 |
| 16 | 3.5 | 2.60 | 2.30 | 3.20 | 8.00 | 3.50 | 6.90 | 3.40 |
| 20 | 2.5 | 2.60 | 2.60 | 3.20 | 8.30 | 3.50 | 6.20 | 2.80 |
| 20 | 3.5 | 2.60 | 2.60 | 3.20 | 8.30 | 3.50 | 7.10 | 3.40 |
| 20 | 5.0 | 2.60 | 2.60 | 3.20 | 8.30 | 3.50 | 8.20 | 5.10 |

Goods lifts

| | | *Well* | | *Machine room* | | | | |
|---|---|---|---|---|---|---|---|---|
| *Load (kg)* | *Speed ($ms^{-1}$)* | *Width (m)* | *Depth (m)* | *Width (m)* | *Length (m)* | *Height (m)* | *Top landing to M/C room floor (m)* | *Pit depth (m)* |
| *General purpose goods lifts* | | | | | | | | |

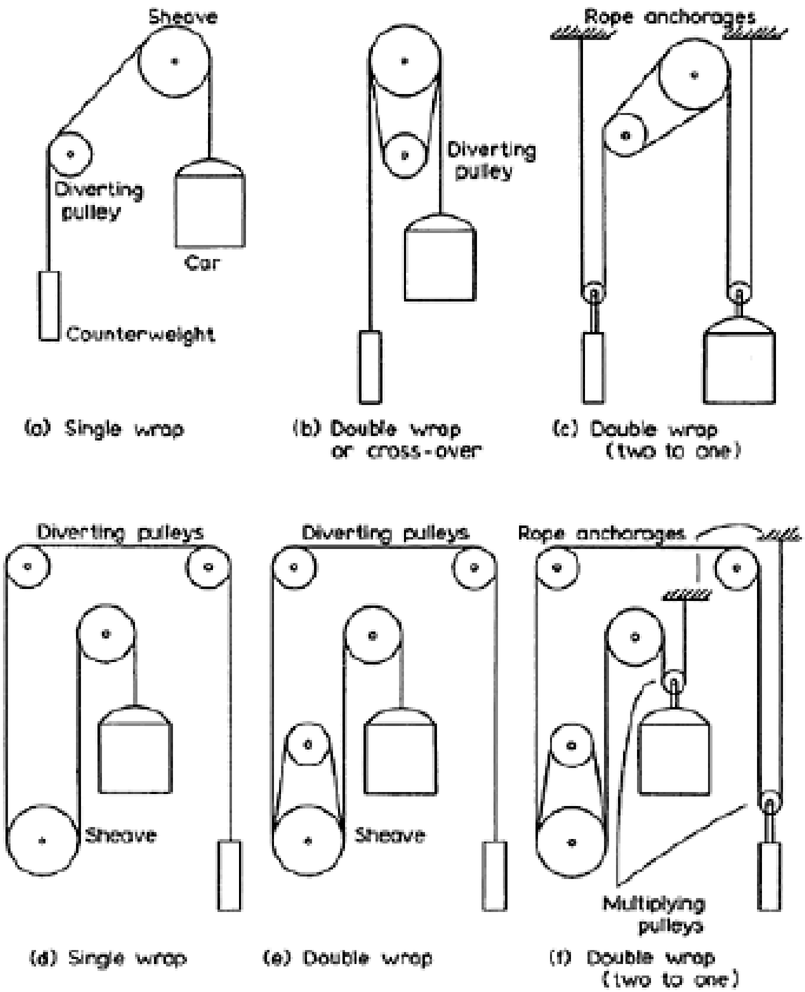



*Figure 16.3* Roping systems

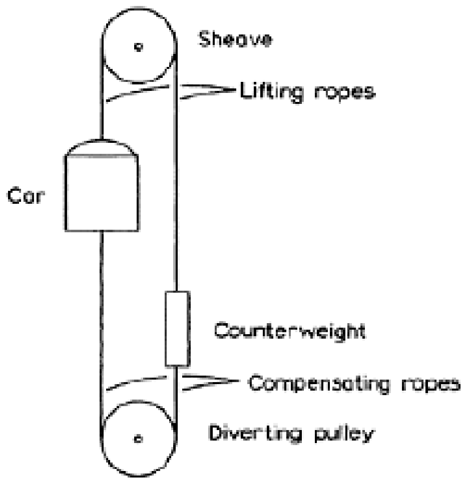



*Figure 16.4* Compensating ropes

### *DC silicon-controlled rectifier (SCR)*

Using power electronics, a DC motor can be used to vary the speed of the lift by varying the armature voltage. This method is the most widely used in DC drives, in the form of a controlled three-phase rectifier. This can be implemented in two forms. One form is a fully controlled bridge rectifier, which allows two-quadrant operation.

The other form uses two bridges in parallel, each connected to drive the motor in the opposite direction of the other. By using both bridges, the motor can be operated in both driving and braking modes, in forward and reverse directions (i.e. four-quadrant operation).

### *AC variable voltage (ACVV)*

These systems were widely used in the mid-1980s and early 1990s. They are very simple in the method of operation. They rely on three pairs of back-to-back thyristors for varying the stator AC voltage on a double-cage squirrel cage motor. By varying the firing angle, the stator voltage is varied and a new speed torque curve results.

### *Variable voltage variable frequency (VVVF)*

The most widely used system today is the VVVF system, usually referred to as an inverter drive. The principle of operation relies on a rectifier to produce DC into the so-called DC link and an inverter, which produces sinusoidal current into the windings. By changing the frequency of the inverted signal, the synchronous frequency and hence the speed torque curve is moved to the desired profile. The supply is fed to a servo motor.

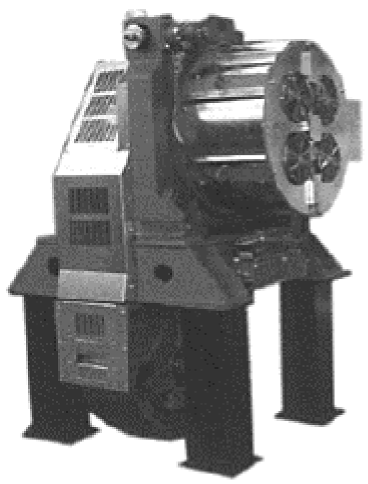


*Figure 16.5* Gearless drive unit
(Courtesy of Schindler Lifts Ltd)

**Brakes**

Lift brakes are usually electromagnetic. In the majority of cases, they are placed between the motor and the gearbox; in a gearless machine the brake is keyed to the sheave. The shoes are cperated by springs and released by an electromagnet the armature of which acts either directly or through a system of links. A typical brake is shown in Figure 16.6. The brake is used only when the car is parked. To slow the car down, several methods are employed. Plugging is reversing the phase sequence as the motor is running; the synchronous magnetic field reverses direction, causing the motor to slow

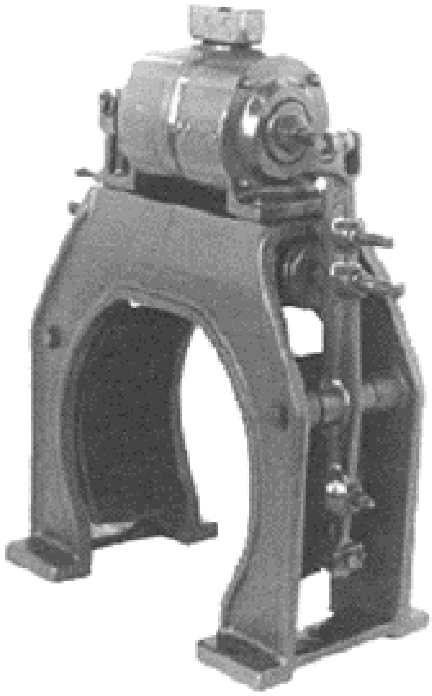


*Figure 16.6* Lift brake

## Lift cars

Passenger cars should be at least 2.00m high, and preferably 2.15m or more. They can be made to almost any specification, but most manufacturers have certain standard finishes from which the client should choose.

Lift cars consist of two separate units, namely the sling and the car proper. The sling is constructed of steel angles or channels and the car is held within the sling. The sling also carries the guide shoes and the safety gear. The car is sometimes insulated from the sling frame by anti-vibration mountings. Goods cars are of rougher construction than passenger cars but otherwise follow the same principles.

Except for very small installations it is now almost universal practice to have an emergency telephone in the car. It can be connected either as a direct line to the public telephone network or as an extension of the private branch exchange in the building. It is generally fitted in a recess in the wall of the car with a hinged door over it.

All electrical connections to a car are made through a multi-core hanging flexible cable. One end of this is connected to a terminal box under the car, and the other end to a terminal box on the wall of the well approximately half-way down. A separate hanging cable may be needed for the telephone.

## Counterweights

A counterweight is provided to balance the load being carried. As the load carried varies, the counterweight cannot always balance it exactly; it is usual for the counterweight to balance the weight of the car plus 50 per cent of the maximum load to be taken in the car. A typical counterweight frame is shown in Figure 16.7. It contains cast-iron sections held in the steel framework and rigidly bolted together by tie rods. The lifting ropes are attached to eye bolts which pass through the top piece of the frame.

## Guides

Both the car and the counterweight must be guided in the well so that they do not swing about as they travel up and down. Continuous vertical guides are provided for this purpose. They are most commonly made of steel tees,

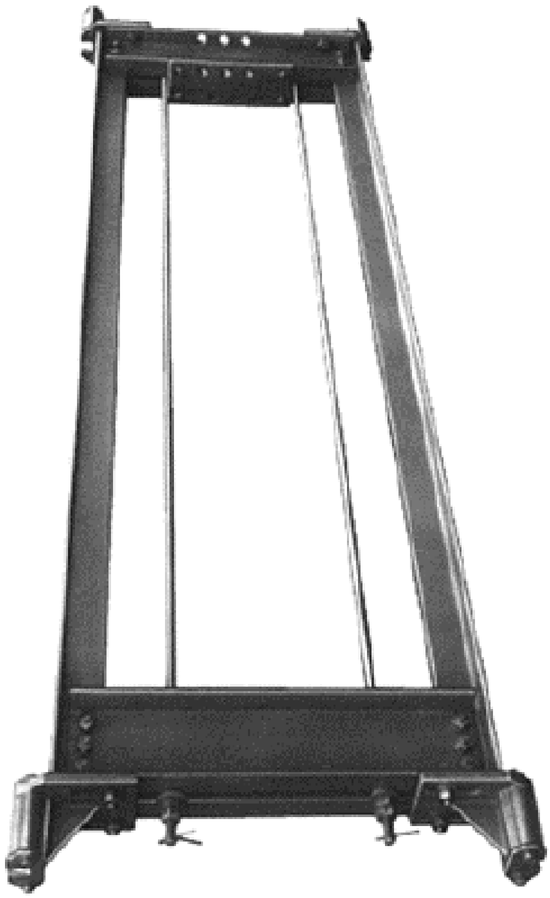


*Figure 16.7* Counterweight frame

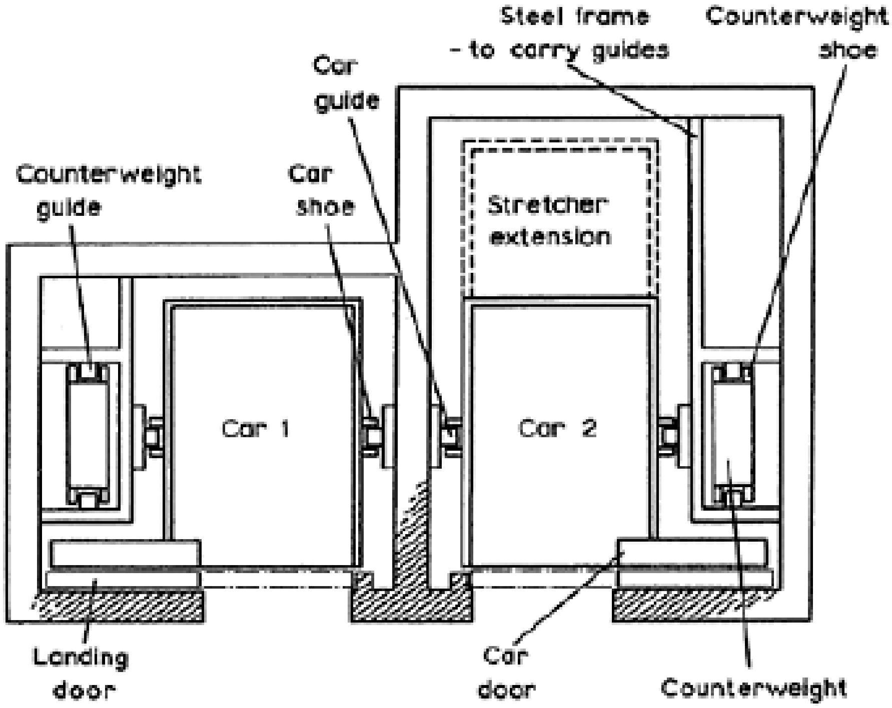



*Figure 16.9* Plan of typical lift arrangement

### Indicators

Indicators are available for showing when the car is in motion, the direction of travel and the position of the car in the well. A position indicator may be installed in the car, and in many cases also at each landing. Direction indicators are provided at the landings, and a common arrangement is to have a position an direction indicator in the car and at the ground floor with direction indicators at the other landings.

For lifts at higher speeds, gradual wedge clamp safety gear is used. This also works by clamping the car to the guides, but the clamps are forced against the guides gradually and so bring the car to rest more smoothly. The clamps can be brought into play by screw motion or by a spring.

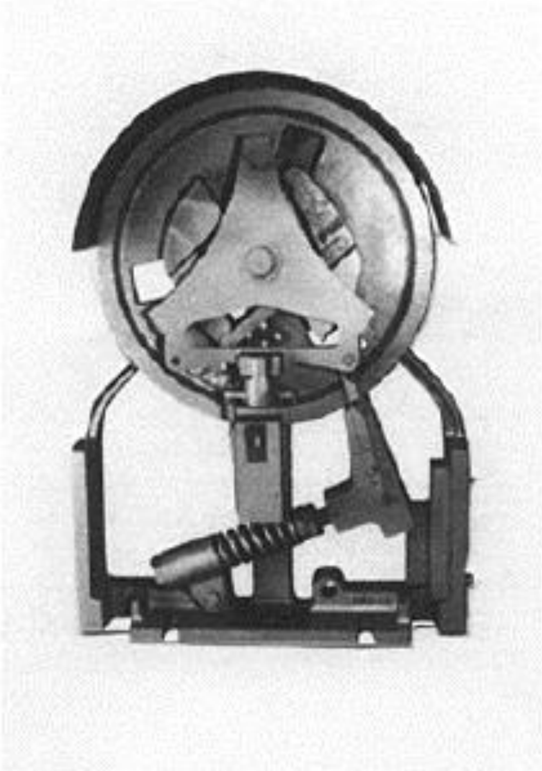


*Figure 16.10* Lift governor

Table 16.4 Lift clearances

| *Lift speed* ($ms^{-1}$) | *Bottom clearance (m)* | *Top clearance (m)* |
|---|---|---|
| 0–0.5 | 0.330 | 0.455 |
| 0.5–1.0 | 0.410 | 0.610 |
| 1.0–1.5 | 0.510 | 0.760 |

### Landing

As it stops, the car must be brought to the exact level of the landing. With an automatic lift, this depends on the accuracy with which the slowing and stopping devices cut off the motor current and apply the brake. Levelling is affected by the load being carried; a full load travels further than a light load when coming to rest from a given speed on the downward trip and less far on the upward trip. To overcome this, it is desirable that the car should travel faster when carrying a full load up than when travelling up empty. A motor with a rising characteristic would be unstable, but the desired effect can be easily achieved with variable voltage control. The rising characteristic is needed only at the levelling speed, which is from about 1/6 to 1/20 of the maximum speed.

### Type of control

An automatic control system has a single call button at each landing and a button for each floor in the car. A passenger presses the car button for the desired floor and the lift automatically travels there. Calls made from landings while the car is in motion are stored in the controller memory. With Automatic Collective Control, each landing has both an UP and a DOWN button, and there is a set of floor buttons in the car. Every button pressed registers a call, and up and down calls are answered during up and down journeys respectively, in the order in which the floors are reached. The order in which the buttons are pressed does not affect the sequence in which the car stops at the various floors, and all calls made are stored in the system until they have been answered. Down calls made while the lift is travelling up are kept until after the up journey is finished, and up calls made while the lift is moving down are similarly kept until that trip is finished.

The system can be modified to work as a collective system in the down direction and as a simple automatic system in the up direction. It is then known as Down Collective. This version is sometimes used in blocks of flats and is based on the assumption that occupants and their visitors travelling up like to go straight to their own floors, but that everyone going down wants to get off at the ground floor. Thus upward travellers should be able to go straight to their own floor without interference, while downward travellers are less likely to be irritated by intermediate stops to pick up other passengers going to the same destination. This reasoning ignores milkmen, postmen and other delivery workers, and the author of this book finds it unconvincing. Nevertheless, it appears to be popular with many authorities.

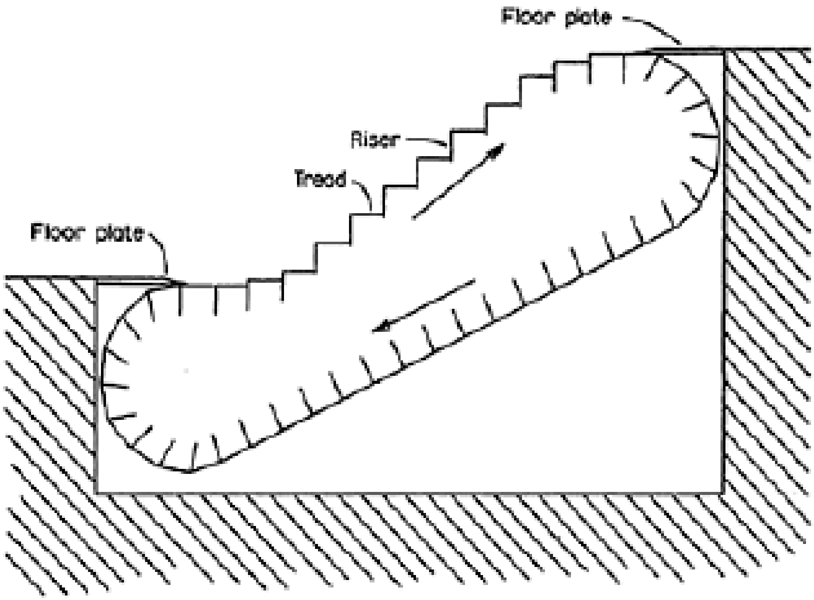



*Figure 16.12* Escalator

The drive and transmission have to carry the total load on the escalator. Since people do not stand at even and regular intervals on the whole staircase the load averaged over the whole length of the escalator is less than the maximum load on individual treads. The peak load on each tread is of concern to the structural designer but the electrical engineer concerned with the power requirements can use the average passenger load taken over the total area of exposed treads. This average can be taken as $290\text{kgm}^{-2}$.

An escalator must have a brake which has to fail safe if there is an interruption to the electrical supply. The brake is therefore applied by a spring or a hydraulic force and is held off against the mechanical force by an electrically energized solenoid. As is the case with lifts, there is also provision for releasing the brake manually and handwinding the escalator.

## Paternosters

Whilst paternosters are a type of lift they also have similarities with escalators and it is more convenient to discuss them after the latter. A paternoster is a lift which has a series of. small cars running continuously in a closed loop. It is difficult to explain this clearly in words but it should be clear from Figure 16.13. The cars are open at the front and move slowly enough for people to step in and out of them whilst they are in motion, just as they step on and off an escalator. In fact a paternoster can perhaps be thought of as a vertical escalator. To make it safe for people to get on and off whilst the cars are in motion the speed must be less than $0.4ms^{-1}$.

The cars are constructed in the same way as ordinary lift cars but do not have doors and are not large enough to take more than one person each. In practice this means that the cars are less than $1.0m\times1.0m$ in plan. They must of course be of normal height. The front of the floor of each car is made as a hinged flap. This ensures that if a person has one foot in the car and one on the landing he will not be thrown off balance as the car moves up. Since the cars move in a continuous loop they provide their own counterweight and no additional counterweight is needed. Rigid guides are provided for the cars which have shoes similar to those of ordinary lift cars.

In the space between cars there is a protective screen level with the front of the cars. This prevents people stepping into the shaft in between cars. It is still necessary to make sure that the landings and entrances are well illuminated. The cars are carried on a continuous steel link chain. The driving machinery is similar to that of an escalator and is always placed above the well. It includes a brake which is applied mechanically and held off electrically, so that the paternoster is braked if the electrical supply fails. As in the case of both lifts and escalators there is provision for handwinding.

A paternoster is started by a key-operated switch, either at the ground floor or at the main floor if this is other than the ground floor. There are emergency stop buttons at each floor, in the pit and in the machinery space.

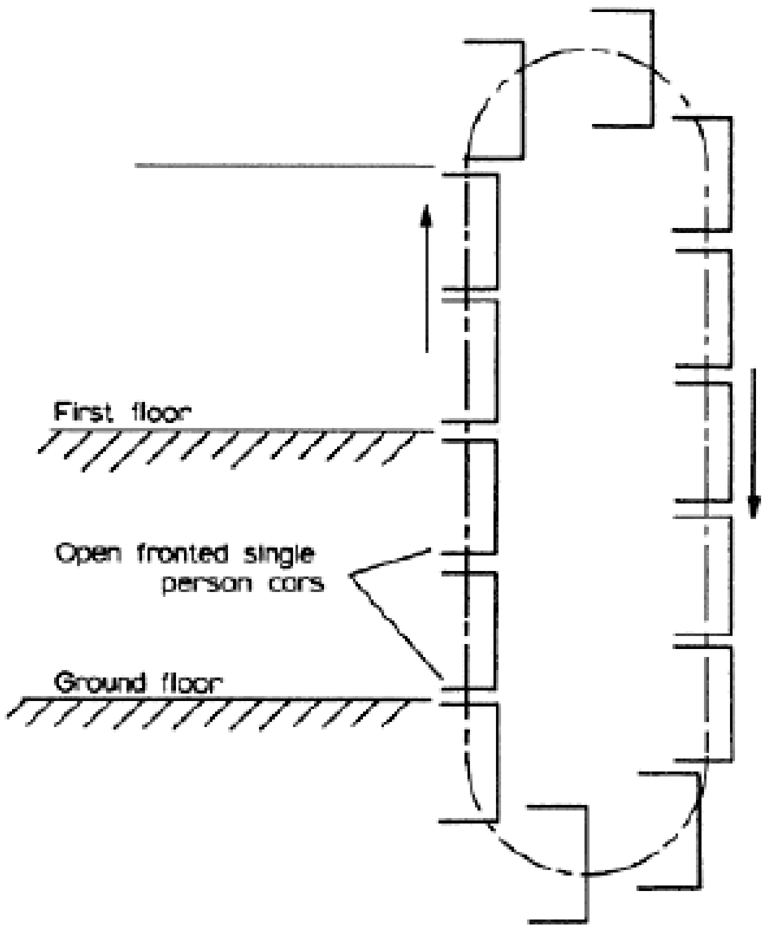



*Figure 16.13* Paternoster

| | |
|---|---|
| BS 2655 | Lifts, escalators and paternosters |
| BS 5655 | Lifts and service lifts |
| BS 5656 | Safety rules for escalators and passenger conveyors |

Read Page 235 Lift, Escalators, Parternosters

Read Page 262 to 318 Chapter 17 Regulations and Chapter 18 Design Examples.