enforcing the law. The HSE is divided into a number of specialist inspectorates or sections which operate from local offices throughout the UK. From the local offices the inspectors visit individual places of work.

The HSE inspectors have been given wide-ranging powers to assist them in the enforcement of the law. They can:

1 enter premises unannounced and carry out investigations, take measurements or photographs;
2 take statements from individuals;
3 check the records and documents required by legislation;
4 give information and advice to an employee or employer about safety in the workplace;
5 demand the dismantling or destruction of any equipment, material or substance likely to cause immediate serious injury;
6 issue an improvement notice which will require an employer to put right, within a specified period of time, a minor infringement of the legislation;
7 issue a prohibition notice which will require an employer to stop immediately any activity likely to result in serious injury, and which will be enforced until the situation is corrected;
8 prosecute all persons who fail to comply with their safety duties, including employers, employees, designers, manufacturers, suppliers and the self-employed.

Fig. 1.1 New Health and Safety Law poster. Source: HSE © Crown copyright material is reproduced with the permission of the Controller of HMSO and Her Majesty's Stationery Office, Norwich.

SAFETY DOCUMENTATION

Under the Health and Safety at Work Act, the employer is responsible for ensuring that adequate instruction and information is given to employees to make them safety-conscious. Part 1, section 3 of the Act instructs all employers to prepare a written health and safety policy statement and to bring this to the notice of all employees. Your employer must let you know who your safety representatives are and the new health and safety poster shown in Fig. 1.1 has a blank section into which the names and contact information of your specific representatives can be added. This is a large laminated poster, 595 × 415 mm suitable for wall or notice board display.

All workplaces employing five or more people must display the type of poster shown in Fig. 1.1 after 30th June 2000.

To promote adequate health and safety measures the employer must consult with the employees' safety representatives. In companies which employ more than 20 people this is normally undertaken by forming a safety committee which is made up of a safety officer and employee representatives, usually nominated by a trade union. The safety officer is usually employed full-time in that role. Small companies might employ a safety supervisor, who will have other duties within the company, or alternatively they could join a 'safety group'. The safety group then shares the cost of employing a safety adviser or safety officer, who visits each company in rotation. An employee who identifies a dangerous situation should initially report to his site safety representative. The safety representative should then bring the dangerous situation to the notice of the safety committee for action which will remove the danger. This may mean changing company policy or procedures or making modifications to equipment. All actions of the safety committee should be documented and recorded as evidence that the company takes seriously its health and safety policy.

Radioactive Substances Act 1993 (RSA)

These regulations apply to the very low ionizing radiation sources used by specialized industrial contractors. The radioactive source may be sealed or unsealed. Unsealed sources are added to a liquid in order to trace the direction or rate of flow of that liquid. Sealed radioactive sources are used in radiography for the non-destructive testing of materials or in liquid level and density gauges.

This type of work is subject to the Ionising Radiations Regulations 1999 (IRR), which impose comprehensive duties on employers to protect people at work against exposure to ionizing radiation. These regulations are enforced by the Health and Safety Executive, while the Radioactive Substances Act is enforced by the Environmental Agency.

The RSA 1993 regulates the keeping, use, accumulation and disposal of radioactive waste, while the IRR 1999 regulates the working and storage conditions when using radioactive sources. The requirements of RSA 1993 are in addition to and separate from IRR 1999 for any industry using radioactive sources. These regulations also apply to offshore installations and to work in connection with pipelines.

Dangerous Substances and Preparations and Chemicals Regulations 2000

Chemical substances that are classified as carcinogenic, mutagenic or toxic, or preparations which contain those substances, constitute a risk to the general public because they may cause cancer, genetic disorders and birth defects, respectively.

These Regulations were introduced to prohibit the supply of these dangerous drugs to the general public, to protect consumers from contracting fatal diseases through their use.

The Regulations require that new labels be attached to the containers of these drugs which identify the potential dangers and indicate that they are restricted to professional users only.

The Regulations implement Commission Directive 99/43/EC, known as the 17th Amendment, which brings the whole of Europe to an agreement that these drugs must not be sold to the general public, this being the only way of offering the highest level of protection for consumers.

The Regulations will be enforced by the Local Authority Trading Standards Department.

Noise Regulations

Before 1960 noise nuisance could only be dealt with by common law as a breach of the peace under various Acts or local by-laws. In contrast, today there are many statutes, Government circulars, British Standards and European Union Directives dealing with noise matters. Environmental noise problems have been around for many years. During the eighteenth century, in the vicinity of some London hospitals, straw was put on the roads to deaden the sound of horses' hooves and the wheels of carriages. Today we have come a long way from this self-regulatory situation.

In the context of the *Environmental Protection Act 1990*, noise or vibration is a statutory nuisance if it is prejudicial to health or is a nuisance. However, nuisance is not defined and has exercised the minds of lawyers, magistrates and judges since the concept of nuisance was first introduced in the 1936 Public Health Act. There is a wealth of case law but a good working definition might be 'A statutory nuisance must materially interfere with the enjoyment of one's dwelling. It is more than just irritating or annoying and does not take account of the undue sensitivity of the receiver'.

The line that separates nuisance from no nuisance is very fine and non-specific. Next door's intruder alarm going off at 3 a.m. for an hour or more is clearly a statutory nuisance, whereas one going off a long way from your home would not be a nuisance. Similarly, an all night party with speakers in the garden would be a nuisance, whereas an occasional party finishing at say midnight would not be a statutory nuisance.

At Stafford Crown Court on the 1st November 2004, Alton Towers, one of the country's most popular Theme Parks, was ordered by a judge to reduce noise levels from its 'white knuckle' rides. In the first judgment of its kind, the judge told the Park's owners

Fig. 1.10 Safety signs showing type of PPE to be worn.

hazards include striking the head against projections and hair becoming entangled in machinery. Typical methods of protection include helmets, light duty scalp protectors called 'bump caps' and hairnets.

The eyes are very vulnerable to liquid splashes, flying particles and light emissions such as ultraviolet light, electric arcs and lasers. Types of eye protectors include safety spectacles, safety goggles and face shields. Screen based workstations are being used increasingly in industrial and commercial locations by all types of personnel. Working with VDUs (visual display units) can cause eye strain and fatigue and, therefore, this hazard was the subject of a separate section earlier in this chapter headed VDU operation hazards.

Noise is accepted as a problem in most industries and we looked in some detail at the Noise Regulations a little earlier in this chapter under the Environmental Laws section.

Noise may be defined as any disagreeable or undesirable sound or sounds, generally of a random nature, which do not have clearly defined frequencies. The usual basis for measuring noise or sound level is the decibel scale. Whether noise of a particular level is harmful or not also depends upon the length of exposure to it. This is the basis of the widely accepted limit of 85 dB of continuous exposure to noise for 8 hours per day.

Where individuals must be subjected to some noise at work it may be reduced by ear protectors. These may be disposable ear plugs, re-usable ear plugs or ear muffs. The chosen ear protector must be suited to the user and suitable for the type of noise and individual personnel should be trained in its correct use.

Fig. 1.11 Breathing protection signs.

Breathing reasonably clean air is the right of every individual, particularly at work. Some industrial processes produce dust which may present a potentially serious hazard. The lung disease asbestosis is caused by the inhalation of asbestos dust or particles and the coal dust disease pneumoconiosis, suffered by many coal miners, has made people aware of the dangers of breathing in contaminated air.

Some people may prove to be allergic to quite innocent products such as flour dust in the food industry or wood dust in the construction industry. The main effect of inhaling dust is a measurable impairment of lung function. This can be avoided by wearing an appropriate mask, respirator or breathing apparatus as recommended by the company's health and safety policy and indicated by local safety signs such as those shown in Fig. 1.11.

A worker's body may need protection against heat or cold, bad weather, chemical or metal splash, impact or penetration and contaminated dust. Alternatively, there may be a risk of the worker's own clothes causing contamination of the product, as in the food industry. Appropriate clothing will be recommended in the company's health and safety policy. Ordinary working clothes and clothing provided for food hygiene purposes are not included in the Personal Protective Equipment at Work Regulations.

Hands and feet may need protection from abrasion, temperature extremes, cuts and punctures, impact or skin infection. Gloves or gauntlets provide protection from most industrial processes but should not be worn when operating machinery because they may become entangled in it. Care in selecting the appropriate protective device is required; for example, barrier creams provide only a limited protection against infection.

Boots or shoes with in-built toe caps can give protection against impact or falling objects and, when fitted with a mild steel sole plate, can also provide protection from sharp objects penetrating through the sole. Special slip resistant soles can also be provided for employees working in wet areas.

Whatever the hazard to health and safety at work, the employer must be able to demonstrate that he or she has carried out a risk analysis, made recommendations which will reduce that risk and communicated these recommendations to the workforce. Where there is a need for PPE to protect against personal injury and to create a safe working environment, the employer must provide that equipment and any necessary training which might be required and the employee must make full and proper use of such equipment and training.

Safety signs

The rules and regulations of the working environment are communicated to employees by written instructions, signs and symbols. All signs in the working environment are intended to inform. They should give warning of possible dangers and must be obeyed. At first there were many different safety signs but British Standard BS 5378 Part 1 (1980) and the Health and Safety (Signs and Signals) Regulations 1996 have introduced a standard system which gives health and safety information with the minimum use of words. The purpose of the regulations is to establish an internationally understood system of safety signs and colours which draw attention to equipment and situations that do, or could, affect health and safety. Text-only safety signs became illegal from 24th December 1998. From that date, all safety signs have had to contain a pictogram or symbol such as those shown in Fig. 1.12. Signs fall into four categories: prohibited activities; warnings; mandatory instructions and safe conditions.

Fig. 1.12 Text only safety signs do not comply.

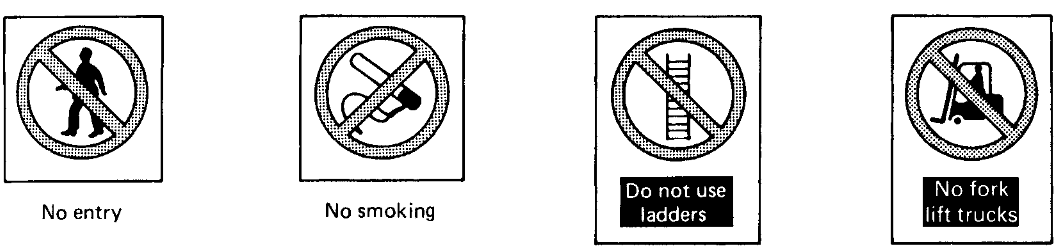


Fig. 1.13 Prohibition signs.

LIVE TESTING

The Electricity at Work Regulations 1989 at Regulation 4(3) tell us that it is preferable that supplies be made dead before work commences. However, it does acknowledge that some work, such as fault finding and testing, may require the electrical equipment to remain energized. Therefore, if the fault finding and testing can only be successfully carried out live then the person carrying out the fault diagnosis must:

- be trained so that they understand the equipment and the potential hazards of working live and can, therefore, be deemed 'competent' to carry out that activity;
- only use approved test equipment;
- set up appropriate warning notices and barriers so that the work activity does not create a situation dangerous to others.

While live testing may be required by workers in the electrotechnical industries in order to find the fault, live repair work must not be carried out. The individual circuit or piece of equipment must first be isolated before work commences in order to comply with the Electricity at Work Regulations 1989.

Permit-to-work system

The permit-to-work procedure is a type of 'safe system to work' procedure used in specialized and potentially dangerous plant process situations. The procedure was developed for the chemical industry, but the principle is equally applicable to the management of complex risk in other industries or situations. For example:

- Working on part of an assembly line process where goods move through a complex, continuous process from one machine to another (e.g. the food industry).
- Repairs to railway tracks, tippers and conveyors.
- Working in confined spaces (e.g. vats and storage containers).
- Working on or near overhead crane tracks.
- Working underground or in deep trenches.
- Working on pipelines.
- Working near live equipment or unguarded machinery.
- Roof work.
- Working in hazardous atmospheres (e.g. the petroleum industry).
- Working near or with corrosive or toxic substances.

All the above situations are high risk working situations that should be avoided unless you have received special training and will probably require the completion of a permit-to-work. Permits to work must adhere to the following eight principles:

1. Wherever possible the hazard should be eliminated so that the work can be done safely without a permit to work.
2. The Site Manager has overall responsibility for the permit to work even though he may delegate the responsibility for its issue.
3. The permit must be recognized as the master instruction, which, until it is cancelled, overrides all other instructions.
4. The permit applies to everyone on site, other trades and sub-contractors.
5. The permit must give detailed information, for example: (i) which piece of plant has been isolated and the steps by which this has been achieved (ii) what work is to be carried out (iii) the time at which the permit comes into effect.
6. The permit remains in force until the work is completed and is cancelled by the person who issued it.
7. No other work is authorized. If the planned work must be changed, the existing permit must be cancelled and a new one issued.
8. Responsibility for the plant must be clearly defined at all stages because the equipment that is taken out of service is released to those who are to carry out the work.

The people doing the work, the people to whom the permit is given, take on the responsibility of following and maintaining the safeguards set out in the permit, which will define what is to be done (no other work is permitted) and the time scale in which it is to be carried out.

The permit-to-work system must help communication between everyone involved in the process or type of work. Employers must train staff in the use of such permits and ideally, training should be designed by the company issuing the permit, so that sufficient emphasis can be given to particular hazards present and the precautions which will be required to be taken. For further details see Permit to Work @ www.hse.gov.uk

Temperature coefficient

The resistance of most materials changes with temperature. In general, conductors increase their resistance as the temperature increases and insulators decrease their resistance with a temperature increase. Therefore, an increase in temperature has a bad effect upon the electrical properties of a material.

Each material responds to temperature change in a different way, and scientists have calculated constants for each material which are called the *temperature coefficient of resistance* (symbol α – the Greek letter 'alpha'). Table 1.4 gives some typical values.

Table 1.4 Temperature coefficient values

Material	Temperature coefficient ($\Omega/\Omega°C$)
Silver	0.004
Copper	0.004
Aluminium	0.004
Brass	0.001
Iron	0.006

Using the constants for a particular material and substituting values into the following formulae the resistance of a material at different temperatures may be calculated. For a temperature increase from 0°C

$$R_t = R_0(1 + \alpha t)\ (\Omega)$$

where

R_t = the resistance at the new temperature t°C
R_0 = the resistance at 0°C
α = the temperature coefficient for the particular material.

For a temperature increase between two intermediate temperatures above 0°C

$$\frac{R_1}{R_2} = \frac{(1 + \alpha t_1)}{(1 + \alpha t_2)}$$

where

R_1 = the resistance at the original temperature
R_2 = the resistance at the final temperature
α = the temperature coefficient for the particular material.

If we take a 1 Ω resistor of, say, copper, and raise its temperature by 1°C, the resistance will increase by 0.004–1.004 Ω. This increase of 0.004 Ω is the temperature coefficient of the material.

EXAMPLE 1

The field winding of a d.c. motor has a resistance of 100 Ω at 0°C. Determine the resistance of the coil at 20°C if the temperature coefficient is 0.004 Ω/Ω°C.

$$R_t = R_0\,(1 + \alpha t)\ (\Omega)$$
$$\therefore R_t = 100\,\Omega\ (1 + 0.004\,\Omega/\Omega°C \times 20°C)$$
$$R_t = 100\,\Omega\ (1 + 0.08)$$
$$R_t = 108\,\Omega$$

EXAMPLE 2

The field winding of a shunt generator has a resistance of 150 Ω at an ambient temperature of 20°C. After running for some time the mean temperature of the generator rises to 45°C. Calculate the resistance of the winding at the higher temperature if the temperature coefficient of resistance is 0.004 Ω/Ω°C.

$$\frac{R_1}{R_2} = \frac{(1 + \alpha t_1)}{(1 + \alpha t_2)}$$

$$\frac{150\,\Omega}{R_2} = \frac{1 + 0.004\,\Omega/\Omega°C \times 20°C}{1 + 0.004\,\Omega/\Omega°C \times 45°C}$$

$$\frac{150\,\Omega}{R_2} = \frac{1.08}{1.18}$$

$$\therefore R_2 = \frac{150\,\Omega \times 1.18}{1.08} = 164\,\Omega$$

It is clear from the last two sections that the resistance of a cable is affected by length, thickness, temperature and type of material. Since Ohm's law tells us that current is inversely proportional to resistance, these factors must also influence the current carrying capacity of a cable. The tables of current ratings in Appendix 4 of the IEE Regulations and Appendix 6 of the *On Site Guide* contain correction factors so that current ratings may be accurately determined under defined installation conditions. Cable selection is considered in Chapter 2.

Resistors

In an electrical circuit resistors may be connected in series, in parallel, or in various combinations of series and parallel connections.

The current flowing through R_1 is

$$I_1 = \frac{V}{R_1}$$

$$\therefore I_1 = \frac{12\ \text{V}}{6\ \Omega} = 2\ \text{A}$$

The current flowing through R_2 is

$$I_2 = \frac{V}{R_2}$$

$$\therefore I_2 = \frac{12\ \text{V}}{6\ \Omega} = 2\ \text{A}$$

The current flowing through R_3 is

$$I_3 = \frac{V}{R_3}$$

$$\therefore I_3 = \frac{12\ \text{V}}{6\ \Omega} = 2\ \text{A}$$

SERIES AND PARALLEL COMBINATIONS

The most complex arrangement of series and parallel resistors can be simplified into a single equivalent resistor by combining the separate rules for series and parallel resistors.

EXAMPLE 1

Resolve the circuit shown in Fig. 1.29 into a single resistor and calculate the potential difference across each resistor.

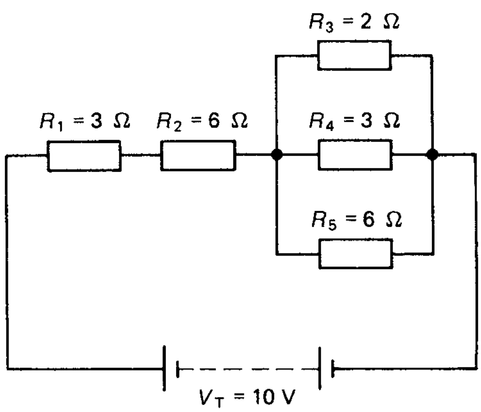


Fig. 1.29 A series/parallel circuit.

By inspection, the circuit contains a parallel group consisting of R_3, R_4 and R_5 and a series group consisting of R_1 and R_2 in series with the equivalent resistor for the parallel branch.

Consider the parallel group. We will label this group R_P. Then

$$\frac{1}{R_P} = \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$$

$$\frac{1}{R_P} = \frac{1}{2\ \Omega} + \frac{1}{3\ \Omega} + \frac{1}{6\ \Omega}$$

$$\frac{1}{R_P} = \frac{3+2+1}{6\ \Omega} = \frac{6}{6\ \Omega}$$

$$R_P = \frac{6\ \Omega}{6} = 1\ \Omega$$

Figure 1.29 may now be represented by the more simple equivalent shown in Fig. 1.30

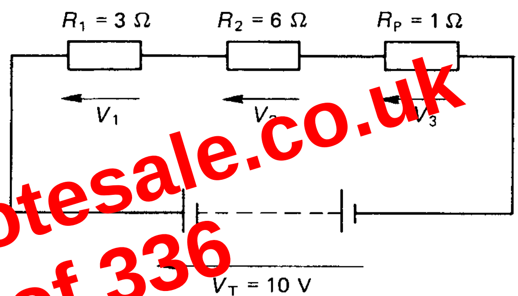


Fig. 1.30 Equivalent series circuit.

Since all resistors are now in series,

$$R_T = R_1 + R_2 + R_P$$
$$\therefore R_T = 3\ \Omega + 6\ \Omega + 1\ \Omega = 10\ \Omega$$

Thus, the circuit may be represented by a single equivalent resistor of value 10 Ω as shown in Fig. 1.31. The total current flowing in the circuit may be found by using Ohm's law

$$I_T = \frac{V_T}{R_T} + \frac{10\ \text{V}}{10\ \Omega} = 1\ \text{A}$$

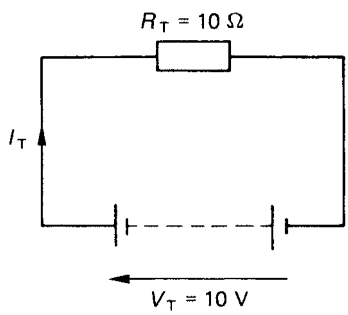


Fig. 1.31 Single equivalent resistor for Fig. 1.29.

The potential differences across the individual resistors are

$$V_1 = I \times R_1 = 1\,\text{A} \times 3\,\Omega = 3\,\text{V}$$
$$V_2 = I \times R_2 = 1\,\text{A} \times 6\,\Omega = 6\,\text{V}$$
$$V_P = I \times R_P = 1\,\text{A} \times 1\,\Omega = 1\,\text{V}$$

Since the same voltage acts across all branches of a parallel circuit the same p.d. of 1 V will exist across each resistor in the parallel branch R_3, R_4 and R_5.

EXAMPLE 2

Determine the total resistance and the current flowing through each resistor for the circuit shown in Fig. 1.32.

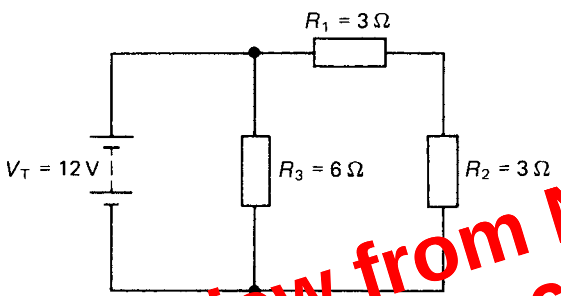


Fig. 1.32 A series/parallel circuit for Example 2.

By inspection, it can be seen that R_1 and R_2 are connected in series while R_3 is connected in parallel across R_1 and R_2. The circuit may be more easily understood if we redraw it as in Fig. 1.33.

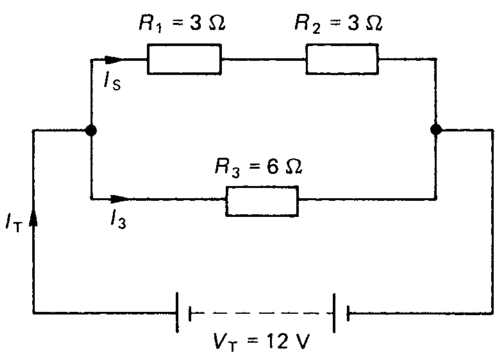


Fig. 1.33 Equivalent circuit for Example 2.

For the series branch, the equivalent resistor can be found from

$$R_S = R_1 + R_2$$
$$\therefore R_S = 3\,\Omega + 3\,\Omega = 6\,\Omega$$

Figure 1.33 may now be represented by a more simple equivalent circuit, as in Fig. 1.34.

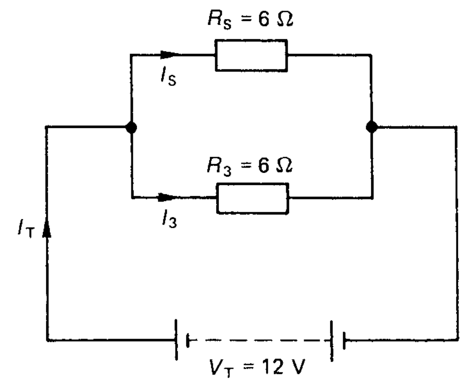


Fig. 1.34 Simplified equivalent circuit for Example 2.

Since the resistors are now in parallel, the equivalent resistance may be found from

$$\frac{1}{R_T} = \frac{1}{R_S} + \frac{1}{R_3}$$
$$\therefore \frac{1}{R_T} = \frac{1}{6\,\Omega} + \frac{1}{6\,\Omega}$$
$$\frac{1}{R_T} = \frac{1+1}{6\,\Omega} = \frac{2}{6\,\Omega}$$
$$R_T = \frac{6\,\Omega}{2} = 3\,\Omega$$

The total current is

$$I_T = \frac{V}{R_T} = \frac{12\,\text{V}}{3\,\Omega} = 4\,\text{A}$$

Let us call the current flowing through resistor R_3 I_3.

$$\therefore I_3 = \frac{V}{R_3} = \frac{12\,\text{V}}{6\,\Omega} = 2\,\text{A}$$

Let us call the current flowing through both resistors R_1 and R_2, as shown in Fig. 1.33, I_S.

$$\therefore I_S = \frac{V}{R_S} = \frac{12\,\text{V}}{6\,\Omega} = 2\,\text{A}$$

Power and energy

POWER

Power is the rate of doing work and is measured in watts.

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}} \text{ (W)}$$

In an electrical circuit

$$\text{Power} = \text{Voltage} \times \text{Current (W)} \qquad (5)$$

Now from Ohm's law

$$\text{Voltage} = I \times R \text{(V)} \qquad (6)$$

$$\text{Current} = \frac{V}{R} \text{ (A)} \qquad (7)$$

Substituting Equation (6) into Equation (5), we have

$$\text{Power} = (I \times R) \times \text{Current} = I^2 \times R \text{ (W)}$$

and substituting Equation (7) into Equation (5), we have

$$\text{Power} = \text{Voltage} \times \frac{V}{R} = \frac{V^2}{R} \text{ (W)}$$

We can find the power of a circuit by using any of the three formulae

$$P = V \times I, \quad P = I^2 \times R, \quad P = \frac{V^2}{R}$$

ENERGY

Energy is a concept which engineers and scientists use to describe the ability to do work in a circuit or system

$$\begin{aligned} \text{Energy} &= \text{Power} \times \text{Time} \\ \text{but, since Power} &= \text{Voltage} \times \text{Current} \\ \text{then Energy} &= \text{Voltage} \times \text{Current} \times \text{Time} \end{aligned}$$

The SI unit of energy is the joule, where time is measured in seconds. For practical electrical installation circuits this unit is very small and therefore the kilowatt-hour (kWh) is used for domestic and commercial installations. Electricity Board meters measure 'units' of electrical energy, where each 'unit' is 1 kWh. So

$$\begin{aligned} \text{Energy in joules} &= \text{Voltage} \times \text{Current} \\ &\quad \times \text{Time in seconds} \end{aligned}$$

$$\text{Energy in kWh} = \text{kW} \times \text{Time in hours}$$

EXAMPLE 1

A domestic immersion heater is switched on for 40 minutes and takes 15 A from a 200 V supply. Calculate the energy used during this time.

$$\begin{aligned} \text{Power} &= \text{Voltage} \times \text{Current} \\ \text{Power} &= 200\text{ V} \times 15\text{ A} = 3000\text{ W or } 3\text{ kW} \\ \text{Energy} &= \text{kW} \times \text{Time in hours} \end{aligned}$$

$$\text{Energy} = 3\text{ kW} \times \frac{40\text{ min}}{60\text{ min/h}} = 2\text{ kWh}$$

This immersion heater uses 2 kWh in 40 minutes, or 2 'units' of electrical energy every 40 minutes.

EXAMPLE 2

Two 50 Ω resistors may be connected to a 200 V supply. Determine the power dissipated by the resistors when they are connected (a) in series, (b) each resistor separately connected and (c) in parallel.

For (a), the equivalent resistance when resistors are connected in series is given by

$$R_T = R_1 + R_2$$

$$\therefore R_T = 50\,\Omega + 50\,\Omega = 100\,\Omega$$

$$\text{Power} = \frac{V^2}{R_T} \text{ (W)}$$

$$\therefore \text{Power} = \frac{200\text{ V} \times 200\text{ V}}{100\,\Omega} = 400\text{ W}$$

For (b), each resistor separately connected has a resistance of 50 Ω.

$$\text{Power} = \frac{V^2}{R} \text{ (W)}$$

$$\therefore \text{Power} = \frac{200\text{ V} \times 200\text{ V}}{50\,\Omega} = 800\text{ W}$$

For (c), the equivalent resistance when resistors are connected in parallel is given by

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\therefore \frac{1}{R_T} = \frac{1}{50\,\Omega} + \frac{1}{50\,\Omega}$$

$$\frac{1}{R_T} = \frac{1+1}{50\,\Omega} = \frac{2}{50\,\Omega}$$

$$R_T = \frac{50\,\Omega}{2} = 25\,\Omega$$

of storing a quantity of electricity as an excess of electrons on one plate and a deficiency on the other.

EXAMPLE

A 100 μF capacitor is charged by a steady current of 2 mA flowing for 5 seconds. Calculate the total charge stored by the capacitor and the p.d. between the plates.

$$Q = It \text{ (C)}$$
$$\therefore Q = 2 \times 10^{-3}\,\text{A} \times 5\,\text{s} = 10\,\text{mC}$$
$$Q = CV$$
$$\therefore V = \frac{Q}{C} \text{ (V)}$$
$$V = \frac{10 \times 10^{-3}\,\text{C}}{100 \times 10^{-6}\,\text{F}} = 100\,\text{V}$$

The p.d. which may be maintained across the plates of a capacitor is determined by the type and thickness of the dielectric medium. Capacitor manufacturers usually indicate the maximum safe working voltage for their products.

Capacitors are classified by the type of dielectric material used in their construction. Figure 1.47 shows the general construction and appearance of some capacitor types to be found in installation work.

Air-dielectric capacitors

Air-dielectric capacitors are usually constructed of multiple aluminium vanes of which one section moves to make the capacitance variable. They are often used for radio tuning circuits.

Mica-dielectric capacitors

Mica-dielectric capacitors are constructed of thin aluminium foils separated by a layer of mica. They are expensive, but this dielectric is very stable and has low dielectric loss. They are often used in high-frequency electronic circuits.

Paper-dielectric capacitors

Paper-dielectric capacitors usually consist of thin aluminium foils separated by a layer of waxed paper. This

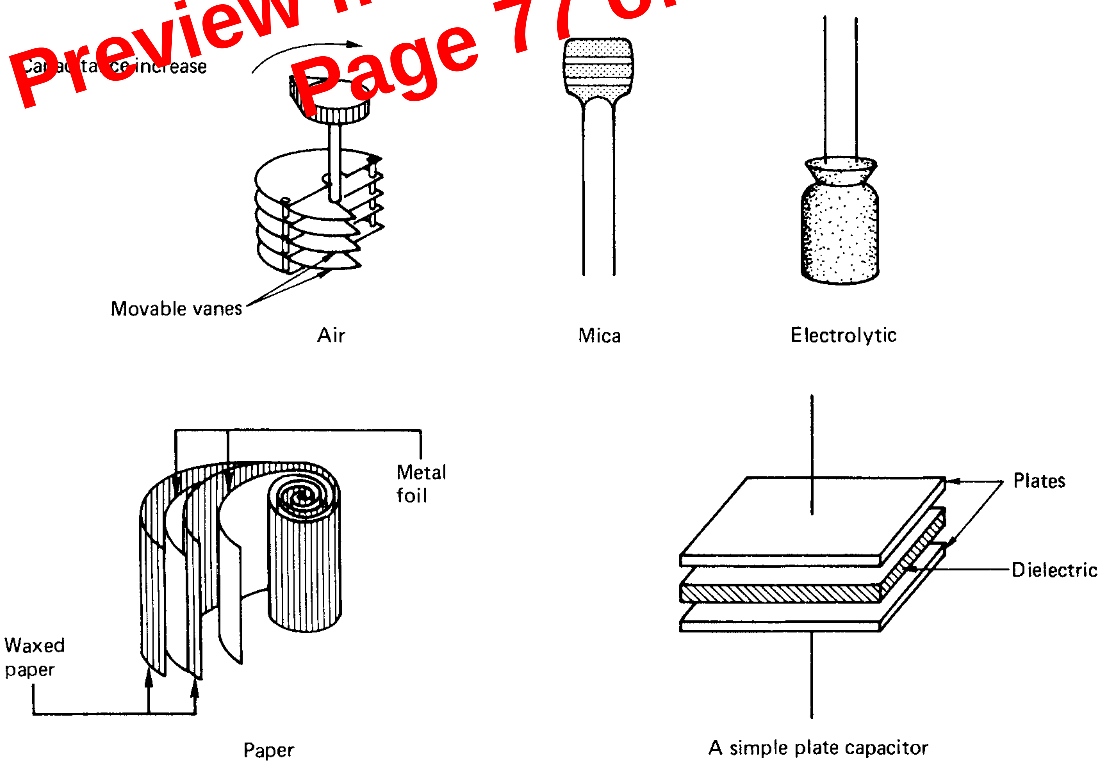


Fig. 1.47 Construction and appearance of capacitors.

paper–foil sandwich is rolled into a cylinder and usually contained in a metal cylinder. These capacitors are used in fluorescent lighting fittings and motor circuits.

Electrolytic capacitors

The construction of these is similar to that of the paper-dielectric capacitors, but the dielectric material in this case is an oxide skin formed electrolytically by the manufacturers. Since the oxide skin is very thin, a large capacitance is achieved for a small physical size, but if a voltage of the wrong polarity is applied, the oxide skin is damaged and the gas inside the sealed container explodes. For this reason electrolytic capacitors must be connected to the correct voltage polarity. They are used where a large capacitance is required from a small physical size and where the terminal voltage never reverses polarity.

CAPACITORS IN COMBINATION

Capacitors, like resistors, may be joined together in various combinations of series or parallel connections (see Fig. 1.48). The equivalent capacitance, C_T, of a number of capacitors is found by the application of similar formulae to those used for resistors and discussed earlier in this chapter. *Note* that the form of the formulae is the opposite way round to that used for series and parallel resistors.

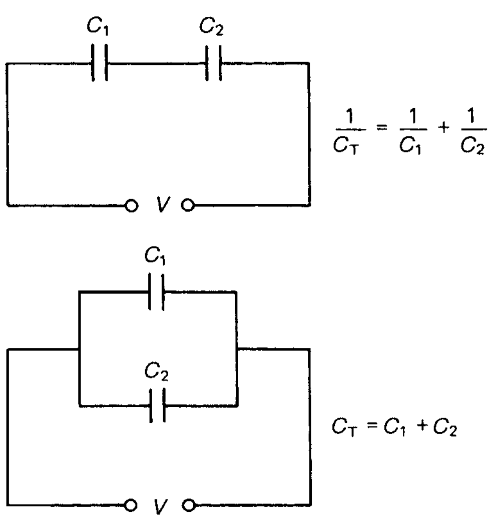


Fig. 1.48 Connection of and formulae for series and parallel capacitors.

The most complex arrangement of capacitors may be simplified into a single equivalent capacitor by applying the separate rules for series or parallel capacitors in a similar way to the simplification of resistive circuits.

EXAMPLE

Capacitors of 10 and 20 μF are connected first in series, and then in parallel, as shown in Figs 1.49 and 1.50. Calculate the effective capacitance for each connection. For connection in series,

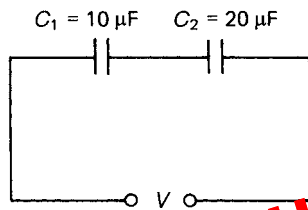


Fig. 1.49 Series capacitors.

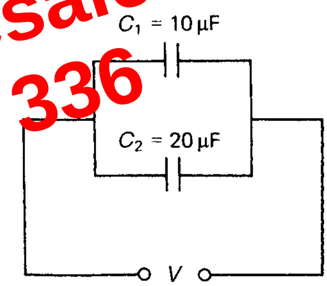


Fig. 1.50 Parallel capacitors.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\frac{1}{C_T} = \frac{1}{10\ \mu F} + \frac{1}{20\ \mu F}$$

$$\frac{1}{C_T} = \frac{2+1}{20\ \mu F} = \frac{3}{20\ \mu F}$$

$$\therefore C_T = \frac{20\ \mu F}{3} = 6.66\ \mu F$$

For connection in parallel,

$$C_T = C_1 + C_2$$

$$C_T = 10\ \mu F + 20\ \mu F = 30\ \mu F$$

Therefore, when capacitors of 10 and 20 μF are connected in series their combined effect is equivalent to a capacitor of 6.66 μF. But, when

12 Select another point G close to C along line CE and repeat the procedures 9 to 12 to draw lines GF, JH and so on as shown in Fig. 1.52.
13 Finally, join together with a smooth curving line the points OCGJ etc., and we have the exponential growth curve of the voltage across the capacitor.

Switching off the supply and discharging the capacitor through the 20 kΩ resistor will produce the exponential decay of the voltage across the capacitor which will be a mirror image of the growth curve. The decay curve can be derived graphically in the same way as the growth curve and is shown in Fig. 1.53.

SELECTING A CAPACITOR

There are two broad categories of capacitor, the non-polarized and the polarized type.

The non-polarized type is often found is electrical installation work for power-factor correction. A paper dielectric capacitor is non-polarized and can be connected either way round.

The polarized type must be connected to the polarity indicated otherwise the capacitor will explode. Electrolytic capacitors are polarized and are used where a large value of capacitance is required in a relatively small package. We therefore find polarized capacitors in electronic equipment such as smoothing or stabilized supplies, emergency lighting and alarm systems, so be careful when working on these systems.

When choosing a capacitor for a particular application, three factors must be considered: value, working voltage and leakage current.

The unit of capacitance is the *farad* (symbol F), to commemorate the name of the English scientist Michael Faraday. However, for practical purposes the farad is much too large and in electrical installation work and electronics we use fractions of a farad as follows:

$$1 \text{ microfarad} = 1\,\mu\text{F} = 1 \times 10^{-6}\,\text{F}$$
$$1 \text{ nanofarad} = 1\,\text{nF} = 1 \times 10^{-9}\,\text{F}$$
$$1 \text{ picofarad} = 1\,\text{pF} = 1 \times 10^{-12}\,\text{F}$$

The p.f. correction capacitor used in a domestic fluorescent luminaire would typically have a value of 8 μF at a working voltage of 400 V. In an electronic filter circuit a typical capacitor value might be 100 pF at 63 V.

One microfarad is 1 million times greater than one picofarad. It may be useful to remember that

$$1000\,\text{pF} = 1\,\text{nF, and } 1000\,\text{nF} = 1\,\mu\text{F}$$

The working voltage of a capacitor is the *maximum* voltage that can be applied between the plates of the capacitor without breaking down the dielectric insulating material. This is a d.c. rating and, therefore, a capacitor with a 200 V rating must only be connected across a maximum of 200 V d.c. Since a.c. voltages are usually given as rms values, a 200 V a.c. supply would

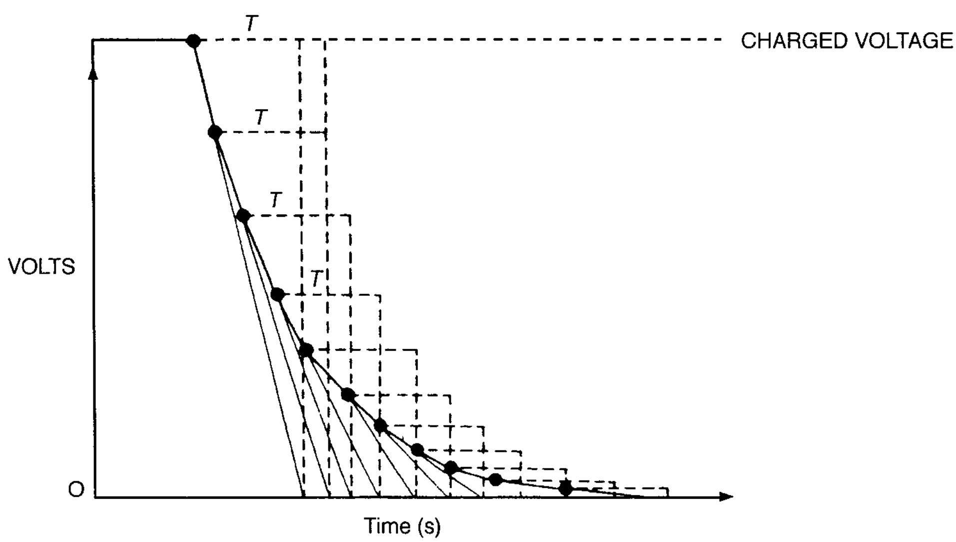


Fig. 1.53 Graphical derivation of CR decay curve.

have a maximum value of about 283 V which would damage the 200 V capacitor. When connecting a capacitor to the 230 V mains supply we must choose a working voltage of about 400 V because 230 V rms is approximately 325 V maximum. The 'factor of safety' is small and, therefore, the working voltage of the capacitor must not be exceeded.

An ideal capacitor which is isolated will remain charged for ever, but in practice no dielectric insulating material is perfect, and the charge will slowly *leak* between the plates, gradually discharging the capacitor. The loss of charge by leakage through it should be very small for a practical capacitor. However, the capacitors used in electrical installation work for power-factor correction are often fitted with a high-value discharge resistor to encourage the charge to leak away safely when not in use.

Alternating current theory

Earlier in this chapter at Figs 1.36 and 1.37 we looked at the generation of an a.c. waveform and the calculation of average and rms values. In this chapter we will first of all consider the theoretical circuits of pure resistance, inductance and capacitance acting alone in an a.c. circuit before going on to consider the practical circuits of resistance, inductance and capacitance acting together. Let us first define some of our terms of reference.

RESISTANCE

In any circuit, *resistance* is defined as opposition to current flow. From Ohm's law

$$R = \frac{V_R}{I_R}\ (\Omega)$$

However, in an a.c. circuit, resistance is only part of the opposition to current flow. The inductance and capacitance of an a.c. circuit also cause an opposition to current flow, which we call *reactance*.

Inductive reactance (X_L) is the opposition to an a.c. current in an inductive circuit. It causes the current in the circuit to lag behind the applied voltage, as shown in Fig. 1.54. It is given by the formula

$$X_L = 2\pi f L\ (\Omega)$$

where

π = 3.142 a constant
f = the frequency of the supply
L = the inductance of the circuit

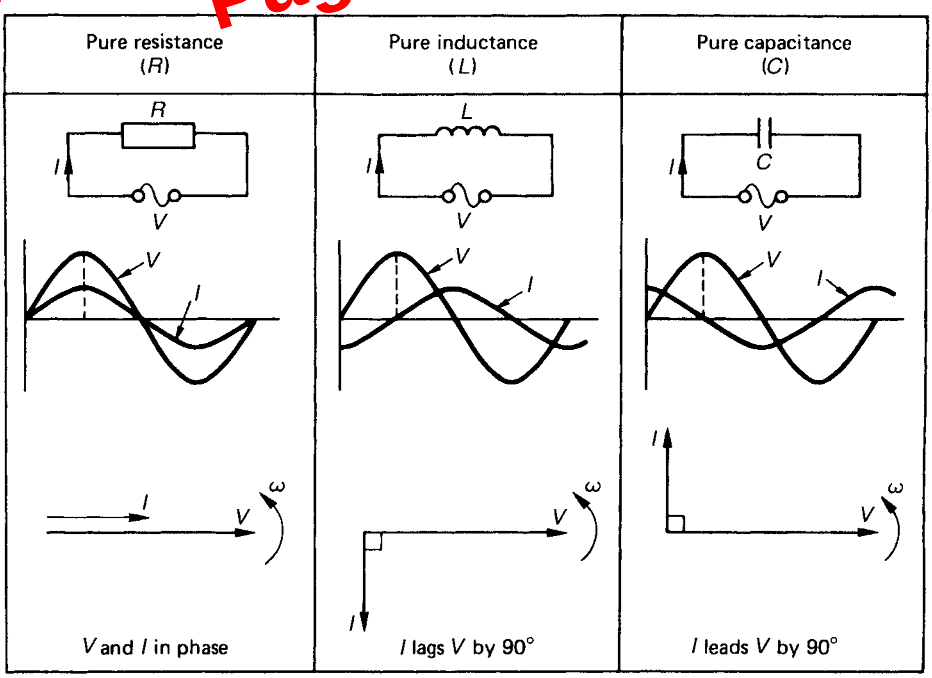


Fig. 1.54 Voltage and current relationships in resistive, capacitive and inductive circuits.

model or picture of the circuit under consideration which helps us to understand the circuit. A phasor is a straight line, having definite length and direction, which represents to scale the magnitude and direction of a quantity such as a current, voltage or impedance.

To find the combined effect of two quantities we combine their phasors by adding the beginning of the second phasor to the end of the first. The combined effect of the two quantities is shown by the resultant phasor, which is measured from the original zero position to the end of the last phasor.

EXAMPLE

Find by phasor addition the combined effect of currents *A* and *B* acting in a circuit. Current *A* has a value of 4 A, and current *B* a value of 3 A, leading *A* by 90°. We usually assume phasors to rotate anticlockwise and so the complete diagram will be as shown in Fig. 1.55. Choose a scale of, for example, 1 A = 1 cm and draw the phasors to scale, i.e. *A* = 4 cm and *B* = 3 cm, leading *A* by 90°.

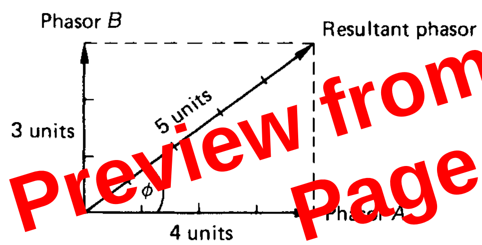


Fig. 1.55 The phasor addition of currents *A* and *B*.

The magnitude of the resultant phasor can be measured from the phasor diagram and is found to be 5 A acting at a phase angle ϕ of about 37° leading *A*. We therefore say that the combined effect of currents *A* and *B* is a current of 5 A at an angle of 37° leading *A*.

Phase angle ϕ

In an a.c. circuit containing resistance only, such as a heating circuit, the voltage and current are in phase, which means that they reach their peak and zero values together, as shown in Fig. 1.56(a).

In an a.c. circuit containing inductance, such as a motor or discharge lighting circuit, the current often reaches its maximum value after the voltage, which means that the current and voltage are out of phase with each other, as shown in Fig. 1.56(b). The phase difference, measured in degrees between the current and voltage, is called the phase angle of the circuit, and is denoted by the symbol ϕ, the lower-case Greek letter phi.

When circuits contain two or more separate elements, such as RL, RC or RLC, the phase angle between the total voltage and total current will be neither 0° nor 90° but will be determined by the relative values of resistance and reactance in the circuit. In Fig. 1.57 the phase angle between applied voltage and current is some angle ϕ.

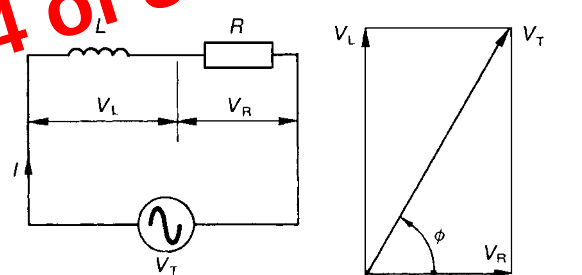


Fig. 1.57 A series RL circuit and phasor diagram.

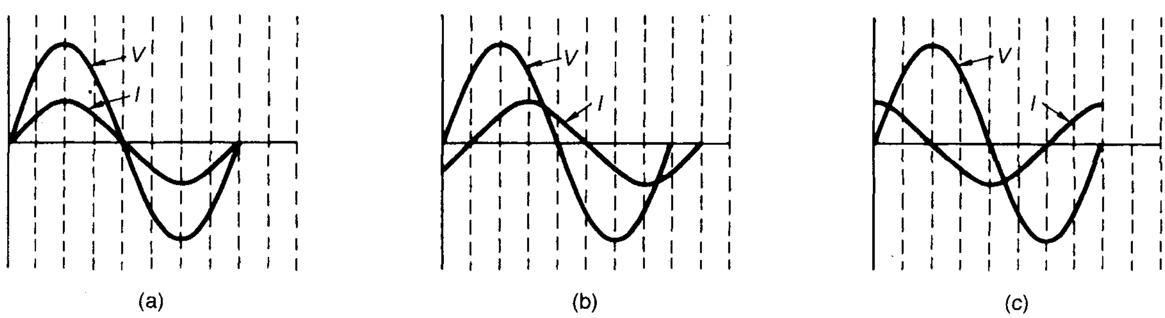


Fig. 1.56 Phase relationship of a.c. waveform: (a) *V* and *I* in phase, phase angle $\phi = 0°$ and power factor (p.f.) = $\cos\phi = 1$; (b) *V* and *I* displaced by 45°, $\phi = 45°$ and p.f. = 0.707; (c) *V* and *I* displaced by 90°, $\phi = 90°$ and p.f. = 0.

If we cancel the common factor we have

$$X_L = X_C$$
$$\therefore\ 2\pi fL = \frac{1}{2\pi fC}$$

Collecting terms,

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

Taking square roots,

$$\text{Resonant frequency} = f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}\ \text{(Hz)}$$

Note that the resonant frequency is given the symbol f_0. The derivation of the formula is not required by craft students.

At resonance the circuit is purely resistive, $Z = R$, the phase angle is zero and therefore the supply voltage and current must be in phase. These effects are shown in Fig. 1.63.

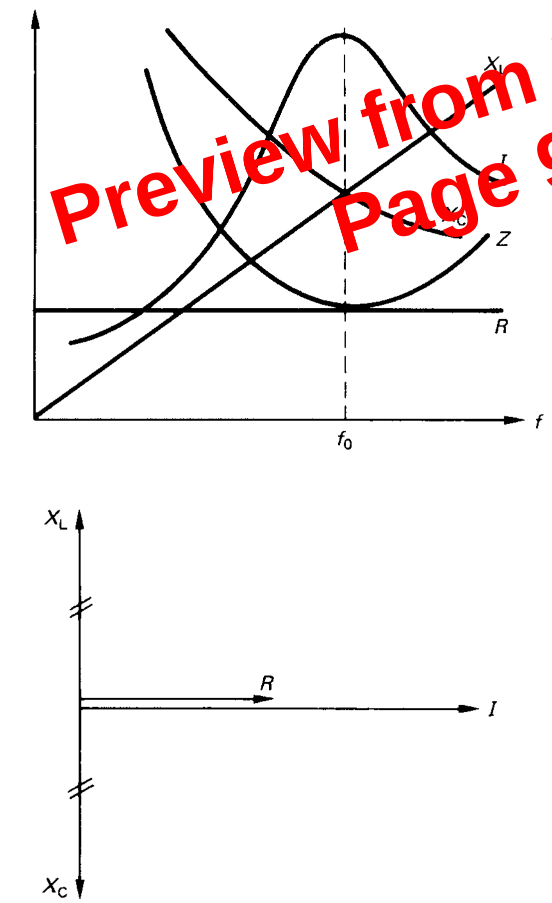


Fig. 1.63 Series resonance conditions in an RLC circuit.

EXAMPLE 1

A capacitor is connected in series with a coil of resistance 50 Ω and inductance 168.8 mH across a 50 Hz supply. Calculate the value of the capacitor to produce resonance in this circuit.

$$X_L = 2\pi fL\ (\Omega)$$
$$\therefore X_L = 2 \times 3.142 \times 50\ \text{Hz} \times 168.8 \times 10^{-3}\ \text{H}$$
$$X_L = 53.03\ \Omega$$

At resonance $X_L = X_C$, therefore $X_C = 53.03\ \Omega$

$$X_C = \frac{1}{2\pi fC}\ (\Omega)$$

Transporting for C

$$C = \frac{1}{2\pi f X_C}\ \text{(F)}$$
$$\therefore C = \frac{1}{2 \times 3.142 \times 50\ \text{Hz} \times 53.03\ \Omega}$$
$$C = 60\ \mu\text{F}$$

EXAMPLE 2

Calculate the resonant frequency of a circuit consisting of a 25.33 mH inductor connected in series with a 100 μF capacitor.

The resonant frequency is given by:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}\ \text{(Hz)}$$
$$\therefore f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{25.33 \times 10^{-3}\ \text{H} \times 100 \times 10^{-6}\ \text{F}}}$$
$$f_0 = 100\ \text{Hz}$$

PARALLEL CIRCUITS

In practice, most electrical installations consist of a number of circuits connected in parallel to form a network. The branches of the parallel network may consist of one component or two or more components connected in series. You should now have an appreciation of series circuits and we will now consider two branch parallel circuits. In a parallel circuit the supply voltage is applied to each of the network

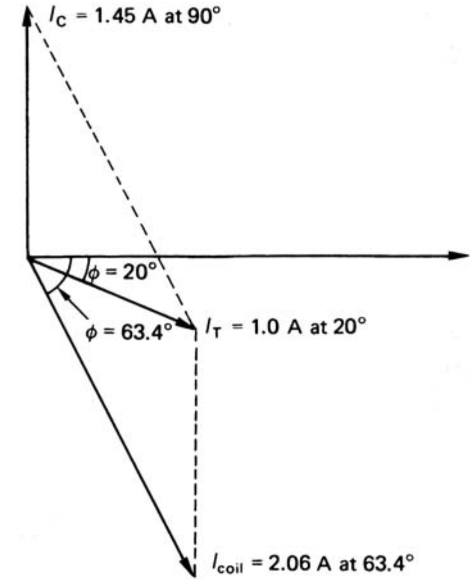


Fig. 1.67 Scale phasor diagram for Example 3.

Star and delta connections

The three phase windings may be star connected or delta connected as shown in Fig. 1.69. The important relationship between phase and line currents and voltages is also shown. The square root of 3 ($\sqrt{3}$) is simply a constant for three-phase circuits, and has a value of 1.732. The delta connection is used for electrical power transmission because only three conductors are required. Delta connection is also used to connect the windings of most three-phase motors because the phase windings are perfectly balanced and, therefore, do not require a neutral connection.

Making a star connection has the advantage that two voltages become available – a line voltage between any two phases, and a phase voltage between line and neutral which is connected to the star point.

In any star-connected system currents flow along the lines (I_L), through the load and return by the neutral conductor connected to the star point. In a *balanced* three-phase system all currents have the same value and when they are added up by phasor addition, we find the resultant current is zero. Therefore, no current flows in the neutral and the star point is at zero volts. The star point of the distribution transformer is earthed because earth is also at zero potential. A star-connected system is also called a three-phase four-wire system and allows us to connect single-phase loads to a three-phase system.

Three-phase power

We know from our single-phase theory earlier in this chapter that power can be found from the following formula:

$$\text{Power} = VI\cos\phi \text{ (W)}$$

In any balanced three-phase system, the total power is equal to three times the power in any one phase.

$$\therefore \text{ Total three-phase power} = 3V_PI_P\cos\phi \text{ (W)} \quad (1)$$

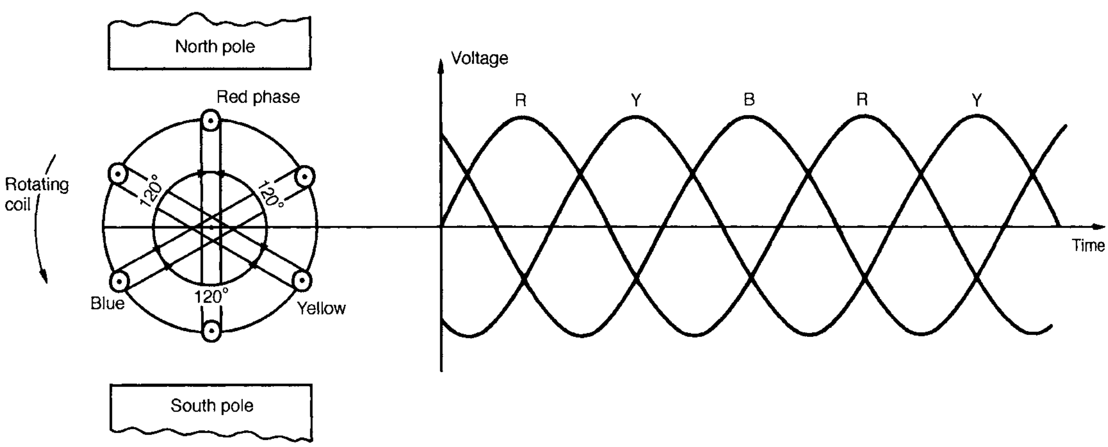


Fig. 1.68 Generation of a three-phase voltage.

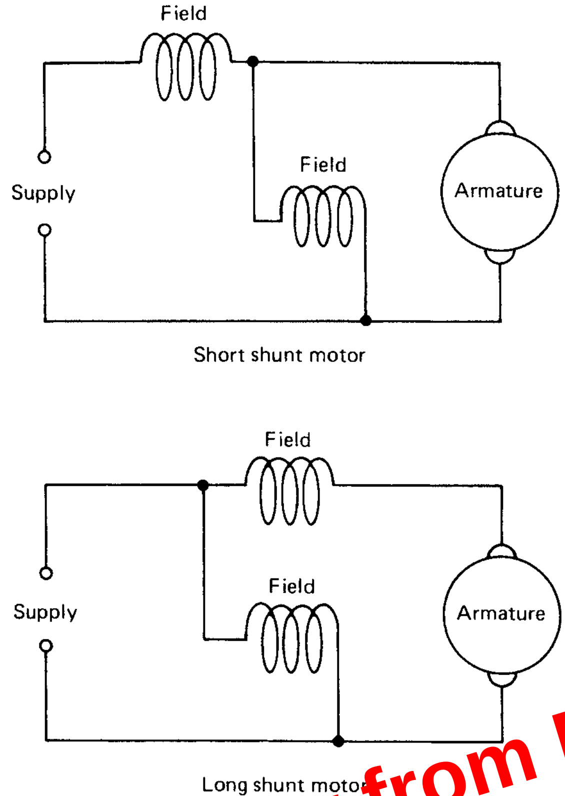


Fig. 1.74 Compound motor connections.

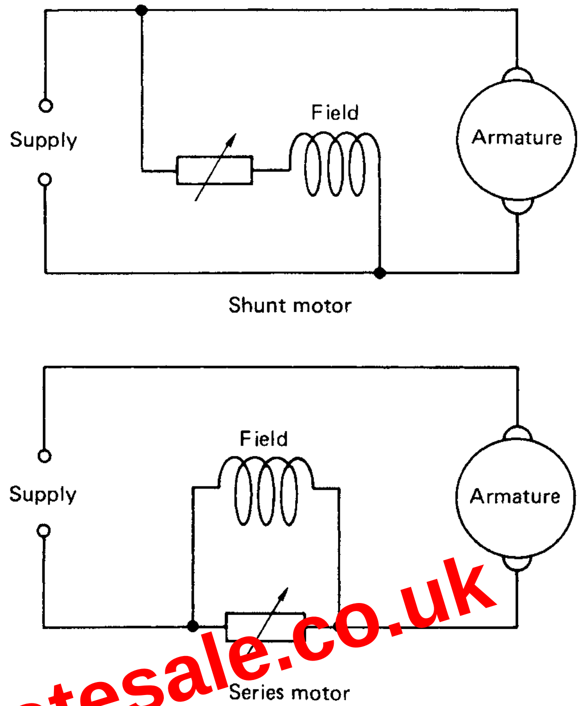


Fig. 1.75 Speed control of a d.c. motor.

SPEED CONTROL OF d.c. MACHINES

One of the advantages of a d.c. machine is the ease with which the speed may be controlled. The speed of a d.c. motor is inversely proportional to the strength of the magnetic flux in the field winding. The magnetic flux in the field winding can be controlled by the field current and, as a result, controlling the field current will control the motor speed.

A variable resistor connected into the field circuit, as shown in Fig. 1.75 provides one method of controlling the field current and the motor speed. This method has the disadvantage that much of the input energy is dissipated in the variable resistor and an alternative, when an a.c. supply is available, is to use thyristor control.

BACK emf AND MOTOR STARTING

When the armature conductors cut the magnetic flux of the main field, an emf is induced in the armature, as described earlier in this chapter at Fig. 1.43 under Inductance. This induced emf is known as the back emf, since it acts in opposition to the supply voltage. During normal running, the back emf is always a little smaller than the supply voltage, and acts as a limit to the motor current. However, when the motor is first switched on, the back emf does not exist because the conductors are stationary and so a motor starter is required to limit the starting current to a safe value. This applies to all but the very smallest of motors and is achieved by connecting a resistor in series with the armature during starting, so that the resistance can be gradually reduced as the speed builds up.

The control switch of Fig. 1.76 is moved to the start position, which connects the variable resistors in series with the motor, thereby limiting the starting current. The control switch is moved progressively over the variable resistor contacts to the run position as the motor speed builds up. A practical motor starter is designed so that the control switch returns automatically to the 'off' position whenever the motor stops, so that the starting resistors are connected when the machine is once again switched on.

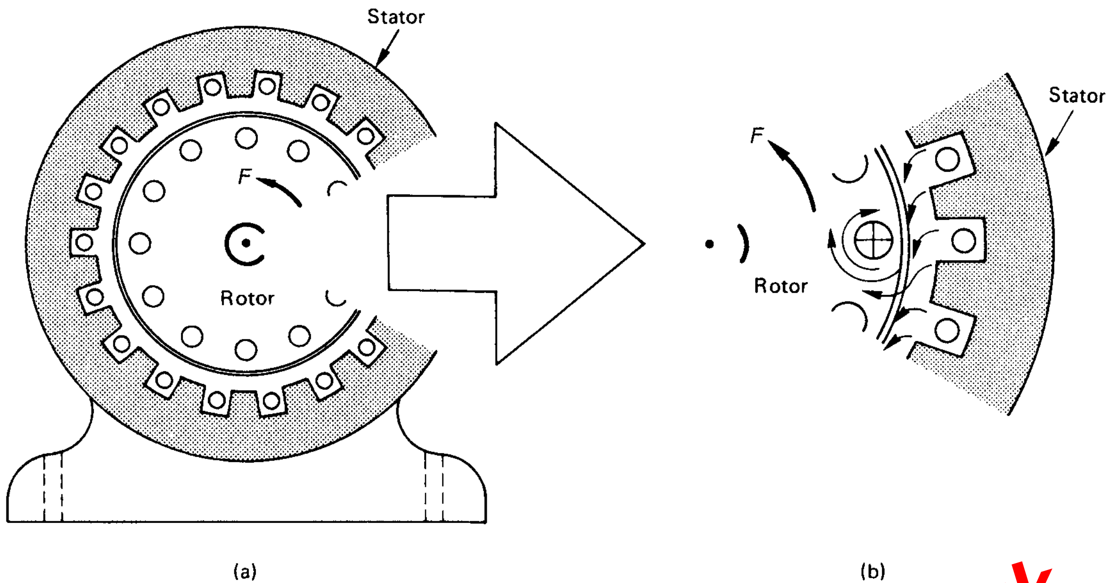


Fig. 1.78 Segment taken out of an induction motor to show turning force: (a) construction of an induction motor; (b) production of torque by magnetic fields.

conductors and the rotating field. The torque produces rotation in the same direction as the rotating magnetic field. At switch-on, the rotor speed increases until it approaches the speed of the rotating magnetic flux, that is, the synchronous speed. The faster the rotor revolves the less will be the difference in speed between the rotor and the rotating magnetic field. By Faraday's laws, this will result in less induced emf, less rotor current and less torque on the rotor. The rotor can never run at synchronous speed because, if it did so, there would be no induced emf, no current and no torque. The induction motor is called an asynchronous motor. In practice, the rotor runs at between 2% and 5% below the synchronous speed so that a torque can be maintained on the rotor which overcomes the rotor losses and the applied load.

The difference between the rotor speed and synchronous speed is called slip; the per-unit slip, denoted s, is given by

$$s = \frac{n_S - n}{n_S} = \frac{N_S - N}{N_S}$$

where

n_S = synchronous speed in revolutions per second
N_S = synchronous speed in revolutions per minute
n = rotor speed in revolutions per second
N = rotor speed in revolutions per minute.

The percentage slip is just the per-unit slip multiplied by 100.

EXAMPLE

A two-pole induction motor runs at 2880 rpm when connected to the 50 Hz mains supply. Calculate the percentage slip.

The synchronous speed is given by

$$N_S = \frac{60 \times f}{p} \text{ (rpm)}$$

$$\therefore\ N_S = \frac{60 \times 50\text{ Hz}}{1} = 3000\text{ rpm}$$

Thus the per-unit slip is

$$s = \frac{N_S - N}{N_S}$$

$$\therefore s = \frac{3000\text{ rpm} - 2880\text{ rpm}}{3000\text{ rpm}}$$

$$s = 0.04.$$

So the percentage slip is $0.04 \times 100 = 4\%$.

ROTOR CONSTRUCTION

There are two types of induction motor rotor – the wound rotor and the cage rotor. The cage rotor consists

All electric motors with a rating above 0.37 kW must be supplied from a suitable motor starter and we will now consider the more common types.

DIRECT ON LINE (d.o.l.) STARTERS

The d.o.l. starter switches the main supply directly on to the motor. Since motor starting currents can be seven or eight times greater than the running current, the d.o.l. starter is only used for small motors of less than about 5 kW rating.

When the start button is pressed current will flow from the red phase through the control circuit and contactor coil to the blue phase which energizes the contactor coil and the contacts close, connecting the three-phase supply to the motor, as can be seen in Fig. 1.83. If the start button is released the control circuit is maintained by the hold on contact. If the stop button is pressed or the overload coils operate, the control circuit is broken and the contractor drops out, breaking the supply to the load. Once the supply is interrupted the supply to the motor can only be reconnected by pressing the start button. Therefore this type of arrangement also provides no-volt protection.

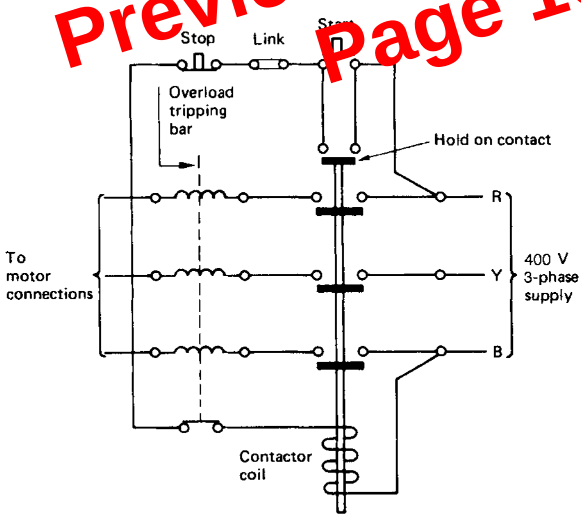


Fig. 1.83 Three-phase d.o.l. starter.

When large industrial motors have to be started, a way of reducing the excessive starting currents must be found. One method is to connect the motor to a star delta starter.

STAR DELTA STARTERS

When three loads, such as the three windings of a motor, are connected in star, the line current has only one-third of the value it has when the same load is connected in delta. A starter which can connect the motor windings in star during the initial starting period and then switch to delta connection will reduce the problems of an excessive starting current. This arrangement is shown in Fig. 1.84, where the six connections to the three stator phase windings are brought out to the starter. For starting, the motor windings are star-connected at the a–b–c end of the winding by the star making contacts. This reduces the phase voltage to about 58% of the running voltage which reduces the current and the motor's torque. Once the motor is running a double-throw switch makes the changeover from star starting to delta running, thereby achieving a minimum starting current and maximum running torque. The starter will incorporate overload and no-volt protection, but these are not shown in Fig. 1.84 in the interests of showing more clearly the principle of operation.

AUTO-TRANSFORMER STARTER

An auto-transformer motor starter provides another method of reducing the starting current by reducing the voltage during the initial starting period. Since this also reduces the starting torque, the voltage is only reduced by a sufficient amount to reduce the starting current, being permanently connected to the tapping found to be most appropriate by the installing electrician. Switching the changeover switch to the start position connects the auto-transformer windings in series with the delta-connected motor starter winding. When sufficient speed has been achieved by the motor the changeover switch is moved to the run connections which connect the three-phase supply directly on to the motor as shown in Fig. 1.85.

This starting method has the advantage of only requiring three connection conductors between the motor starter and the motor. The starter will incorporate overload and no-volt protection in addition to some method of preventing the motor being switched to the run position while the motor is stopped. These protective devices are not shown in Fig. 1.85 in order to show more clearly the principle of operation.

Collecting the information given in the question into a usable form, we have

$$V_P = 230\,\text{V}$$
$$V_S = 12\,\text{V}$$
$$N_P = 800$$

Power = 12 W
Information required: N_S, I_S and I_P
Secondary turns

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

$$\therefore N_S = \frac{800 \times 12\,\text{V}}{230\,\text{V}} = 42 \text{ turns}$$

Secondary current

$$I_S = \frac{\text{Power}}{V_S}$$

$$\therefore I_S = \frac{12\,\text{W}}{12\,\text{V}} = 1\,\text{A}$$

Primary current

$$I_P = \frac{I_S \times V_S}{V_P}$$

$$\therefore I_P = \frac{1\,\text{A} \times 12\,\text{V}}{230\,\text{V}} = 0.052\,\text{A}$$

Transformer losses

As they have no moving parts causing frictional losses, most transformers have a very high efficiency, usually better than 90%. However, the losses which do occur in a transformer can be grouped under two general headings: copper losses and iron losses.

Copper losses occur because of the small internal resistance of the windings. They are proportional to the load, increasing as the load increases because copper loss in an 'I^2R' loss.

Iron losses are made up of *hysteresis loss* and *eddy current loss*. The hysteresis loss depends upon the type of iron used to construct the core and consequently core materials are carefully chosen. Transformers will only operate on an alternating supply. Thus, the current which establishes the core flux is constantly changing from positive to negative. Each time there is a current reversal, the magnetic flux reverses and it is this build-up and collapse of magnetic flux in the core material which accounts for the hysteresis loss.

Eddy currents are circulating currents created in the core material by the changing magnetic flux. These are reduced by building up the core of thin slices or laminations of iron and insulating the separate laminations from each other. The iron loss is a constant loss consuming the same power from no load to full load.

Transformer efficiency

The efficiency of any machine is determined by the losses incurred by the machine in normal operation. The efficiency of rotating machines is usually in the region of 50–60% because they incur windage and friction losses; but the transformer has no moving parts so therefore, these losses do not occur. However, the efficiency of a transformer can be calculated in the same way as for any other machine. The efficiency of a machine is generally given by:

$$\eta = \frac{\text{Output power}}{\text{Input power}}$$

(η is the Greek letter 'eta'). However, the input to the transformer must supply the output plus any losses which occur within the transformer. We can therefore say:

$$\text{Input power} = \text{Output power} + \text{Losses}$$

Rewriting the basic formula, we have:

$$\eta = \frac{\text{Output power}}{\text{Output power} + \text{Losses}}$$

EXAMPLE

A 100 kVA power transformer feeds a load operating at a power factor of 0.8. Find the efficiency of the transformer if the combined iron and copper loss at this load is 1 kW.

$$\text{Output power} = \text{kVA} \times \text{p.f.}$$
$$\therefore \text{Output power} = 100\,\text{kVA} \times 0.8$$
$$\text{Output power} = 80\,\text{kW}$$

$$\eta = \frac{\text{Output power}}{\text{Output power} + \text{Losses}}$$

$$\eta = \frac{80\,\text{kW}}{80\,\text{kW} + 1\,\text{kW}} = 0.987$$

or, multiplying by 100 to give a percentage, the transformer has an efficiency of 98.7%.

Transformer construction

Transformers are constructed in a way which reduces the losses to a minimum. The core is usually made of silicon–iron laminations, because at fixed low frequencies silicon–iron has a small hysteresis loss and the laminations reduce the eddy current loss. The primary and secondary windings are wound close to each other on the same limb. If the windings are spread over two limbs, there will usually be half of each winding on each limb, as shown in Fig. 1.94.

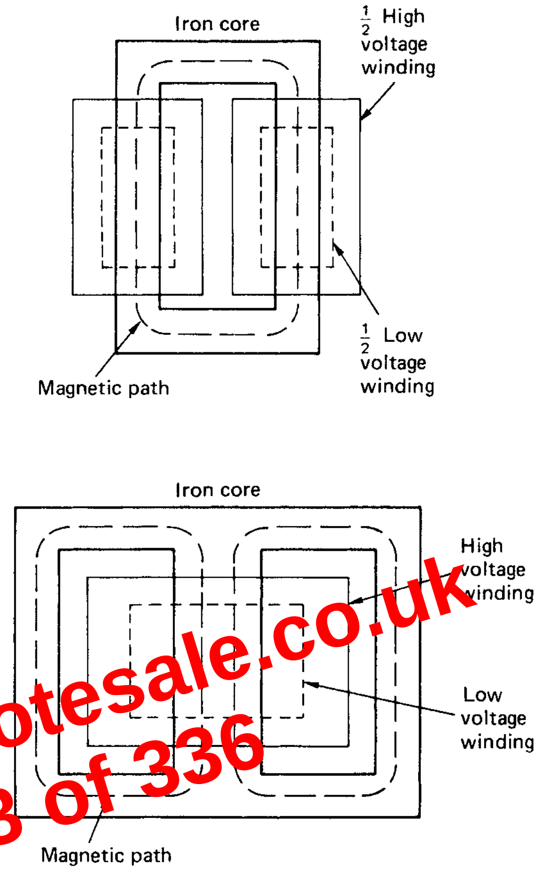


Fig. 1.94 Transformer construction.

AUTO-TRANSFORMERS

Transformers having a separate primary and secondary winding, as shown in Fig. 1.94, are called double-wound transformers, but it is possible to construct a transformer which has only one winding which is common to the primary and secondary circuits. The secondary voltage is supplied by means of a 'tapping' on the primary winding. An arrangement such as this is called an auto-transformer.

The auto-transformer is much cheaper and lighter than a double-wound transformer because less copper and iron are used in its construction. However, the primary and secondary windings are not electrically separate and a short circuit on the upper part of the winding shown in Fig. 1.95 would result in the primary voltage appearing across the secondary terminals. For this reason auto-transformers are mostly used where only a small difference is required between the primary and secondary voltages. When installing transformers, the regulations of Section 555 must be complied with, in addition to any other regulations relevant to the particular installation.

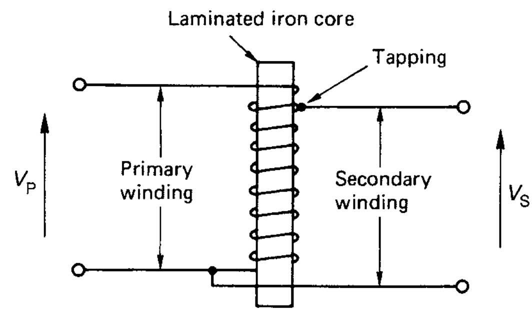


Fig. 1.95 An auto-transformer.

THREE-PHASE TRANSFORMERS

Most of the transformers used in industrial applications are designed for three-phase operation. In the double-wound type construction, as shown in Fig. 1.93, three separate single-phase transformers are wound onto a common laminated silicon–steel core to form the three-phase transformer. The primary and secondary windings may be either star or delta connected but in distribution transformers the primary is usually connected in delta and the secondary in star. This has the advantage of providing two secondary voltages, typically 400 V between phases and 230 V

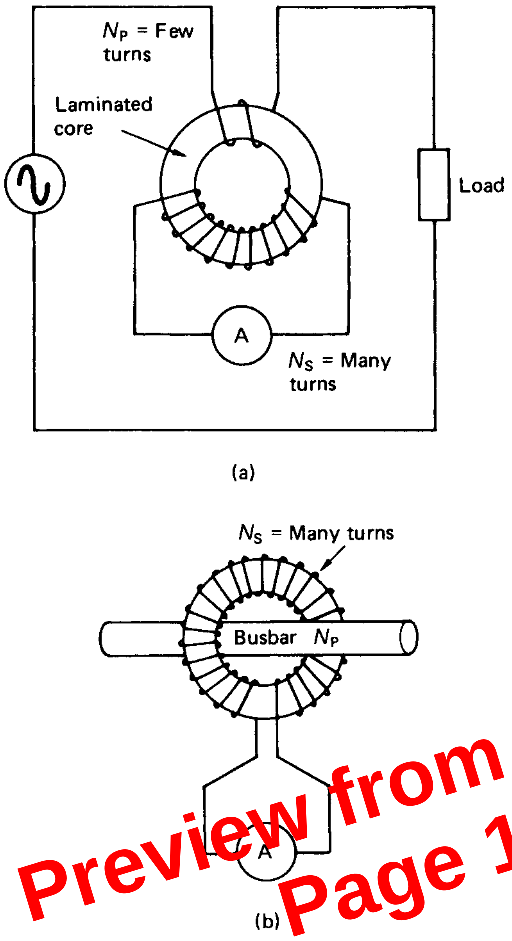


Fig. 1.99 Current transformers: (a) wound primary current transformer; (b) bar primary current transformer.

The secondary winding of the CT consists of a large number of turns connected to an ammeter as shown in Fig. 1.99 (a). The ammeter is usually standardized at 1 or 5 A and the transformer ratio chosen so that 1 or 5 A flows when the main circuit carries full load current calculated from the transformer turns ratio

$$\frac{V_P}{V_S} = \frac{I_S}{I_P}$$

The primary winding is wound with only a few turns and when heavy currents are being measured one turn on the primary may be sufficient. In this case the conductor carrying the main current or the main busbar is passed through the centre of the CT as shown in Fig. 1.99 (b). This is called a bar primary CT.

EXAMPLE 1

An ammeter having a full scale deflection of 5 A is used to measure a line current of 200 A. If the primary is wound with two turns, calculate the number of secondary turns required to give full scale deflection.

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

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

$$N_S = \frac{2 \times 200\text{ A}}{5\text{ A}} = 80\text{ turns}$$

With a power transformer a secondary load is necessary to cause a primary current to flow which maintains the magnetic flux in the core at a constant value. With a CT the primary current is the main circuit current and will flow whether the secondary is connected or not.

However, the secondary current through the ammeter is necessary to stabilize the magnetic flux in the core and if the ammeter is removed the voltage across the secondary terminals could reach a dangerously high value and cause the insulation to break down or cause excessive heating of the core. The CT must never be operated with the secondary terminals open-circuited and overload protection should not be provided in the secondary circuit (Regulation 473–01–03). If the ammeter must be removed from the CT then the terminals must first be short-circuited. This will not damage the CT and will prevent a dangerous situation arising. The rating of an instrument transformer is measured in volt amperes and is called the burden. To reduce errors, the ammeter or voltmeter connected to the CT or VT should be operated at the rated burden.

EXAMPLE 2

To determine the power taken by a single-phase motor a wattmeter is connected to the circuit through a CT and VT. The test readings obtained were:

Wattmeter reading = 300 W
Voltage transformer turns ratio = 440/110 V
Current transformer turns ratio = 150/5 A

Sketch the circuit arrangements and calculate the power taken by the motor.

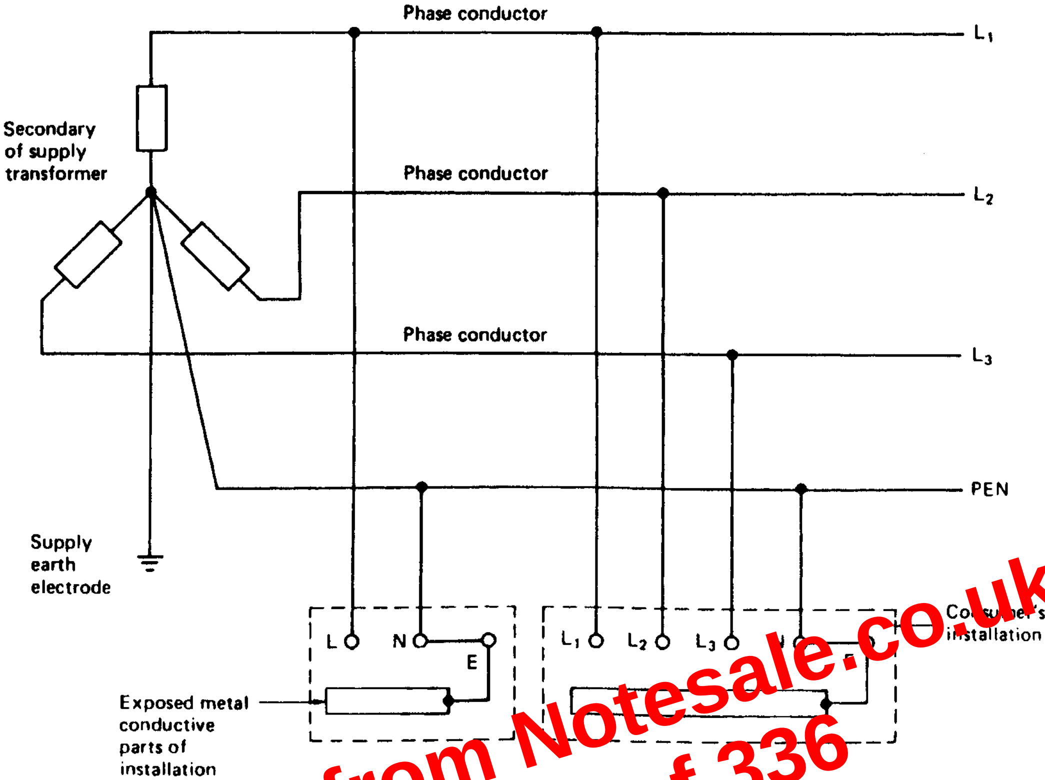


Fig. 1.108 TN-C-S system: neutral and protective functions combined in a single (PEN) conductor.

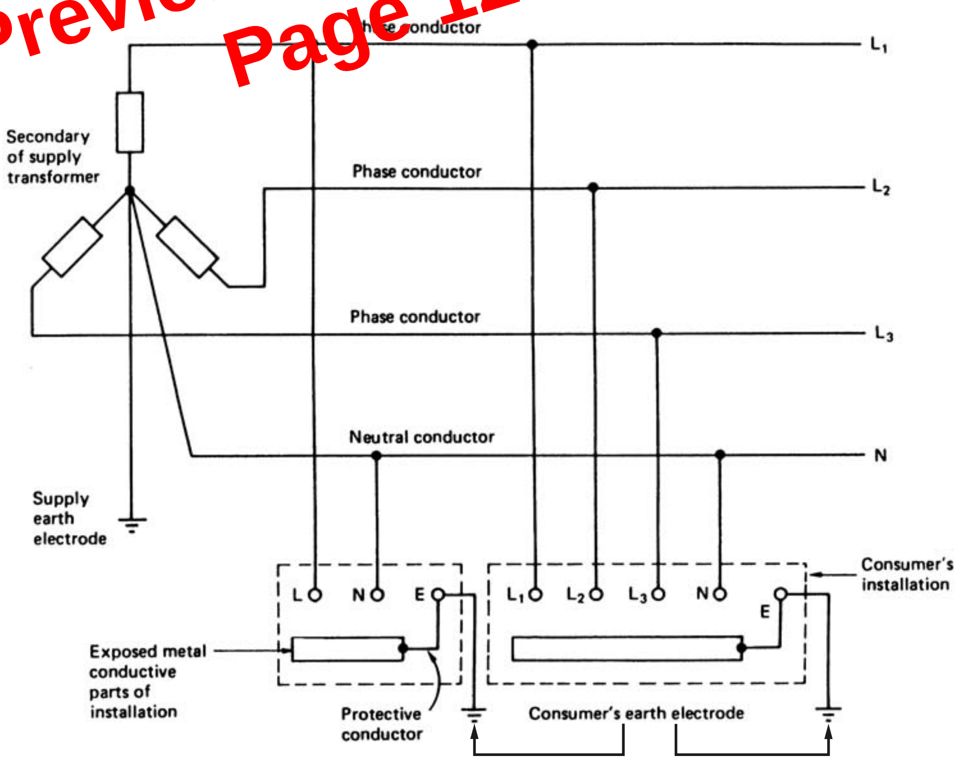


Fig. 1.109 TT systems: earthing arrangements independent of supply cable.

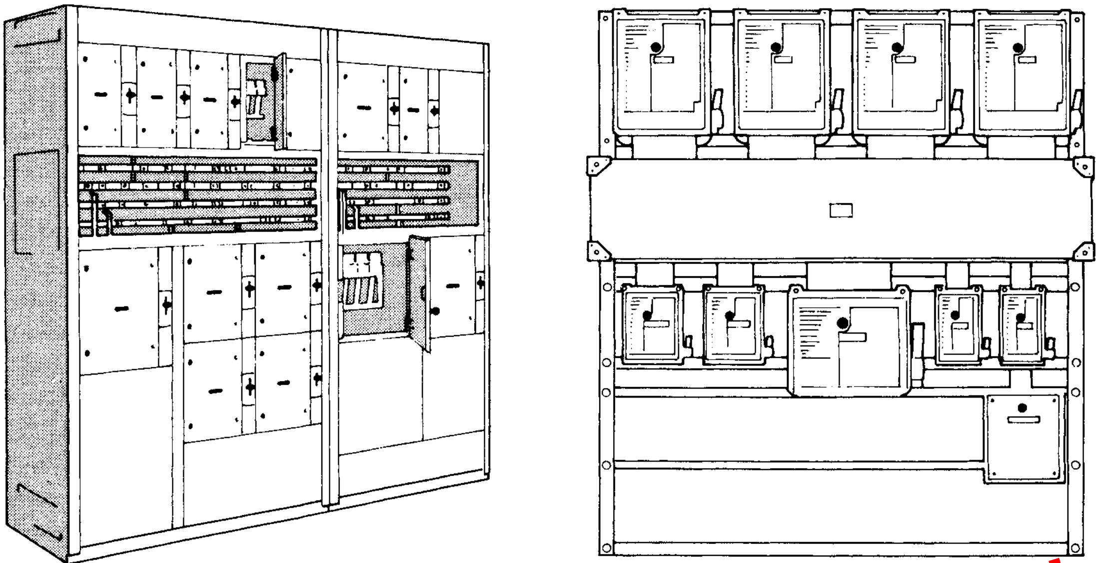


Fig. 1.111 Industrial consumer's service position equipment.

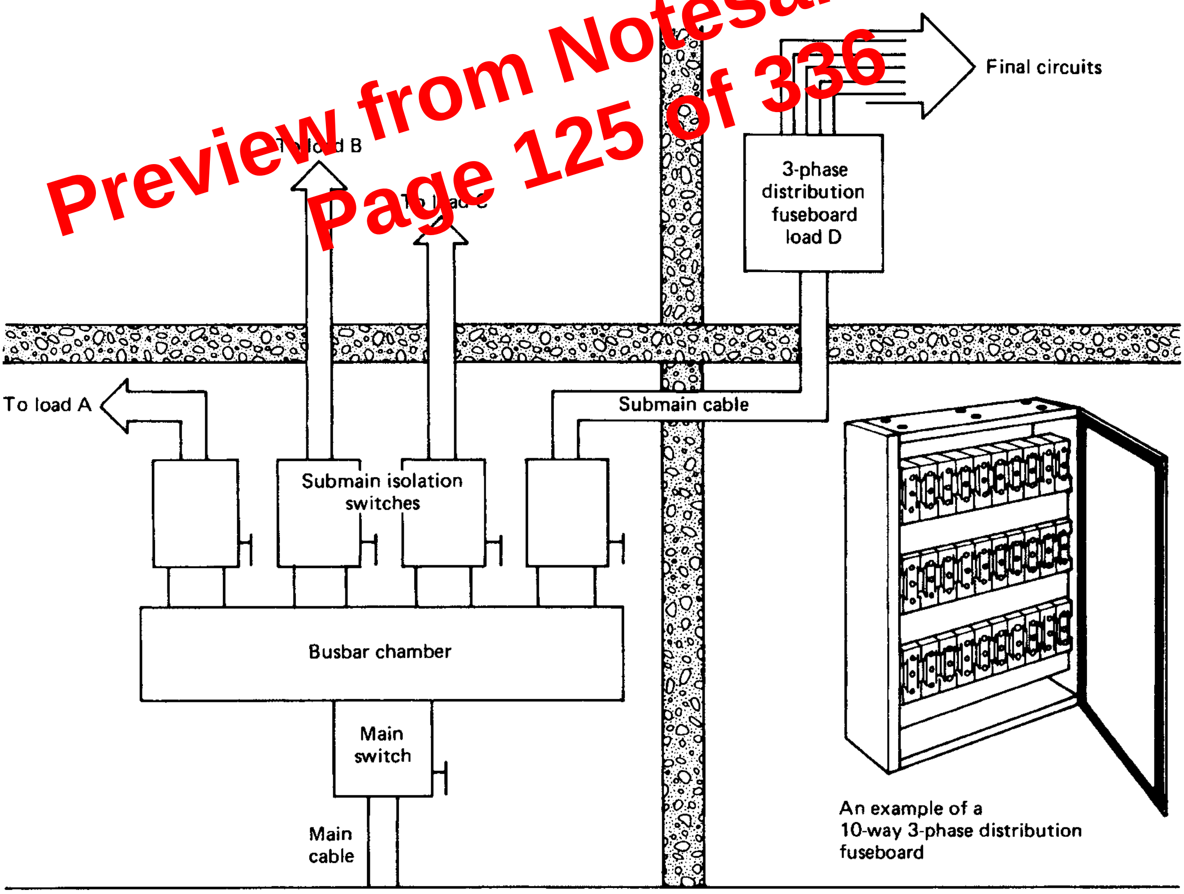


Fig. 1.112 Typical distribution in commercial or industrial building.

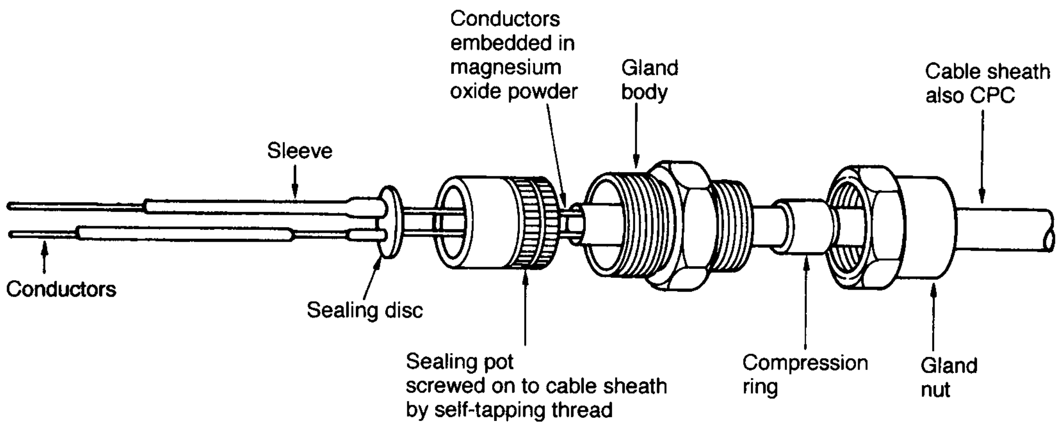


Fig. 1.116 MI cable with terminating seal and gland.

means that it readily absorbs moisture from the surrounding air, unless adequately terminated. The termination of an MI cable is a complicated process requiring the electrician to demonstrate a high level of practical skill and expertise for the termination to be successful.

FP 200 CABLE

FP 200 cable is similar in appearance to an MI cable in that it is a circular tube, or the shape of a pencil, and is available with a red or white sheath. However, it is much simpler to use and terminate than an MI cable.

The cable is available with either solid or stranded conductors that are insulated with 'insudite' a fire resistant insulation material. The conductors are then screened, by wrapping an aluminium tape around the insulated conductors, that is, between the insulated conductors and the outer sheath. This aluminium tape screen is applied metal side down and in contact with the bare circuit protective conductor.

The sheath is circular and made of a robust thermoplastic low smoke, zero halogen material.

FP 200 is available in 2, 3, 4, 7, 12 and 19 cores with a conductor size range from 1.0 mm to 4.0 mm. The core colours are: two core, red and black; three core, red, yellow and blue and four core, black, red, yellow and blue.

The cable is as easy to use as a PVC insulated and sheathed cable. No special terminations are required, the cable may be terminated through a grommet into a knock out box or terminated through a simple compression gland.

The cable is a fire resistant cable, primarily intended for use in fire alarms and emergency lighting installations or it may be embedded in plaster.

LSF CABLES

Low smoke and fume cables give off very low smoke and fumes if they are burned in a burning building. Most standard cable types are available as LSF cables.

HIGH-VOLTAGE POWER CABLES

The cables used for high-voltage power distribution require termination and installation expertise beyond the normal experience of a contracting electrician. The regulations covering high-voltage distribution are beyond the scope of the IEE Regulations for electrical installations. Operating at voltages in excess of 33 kV and delivering thousands of kilowatts, these cables are either suspended out of reach on pylons or buried in the ground in carefully constructed trenches.

HIGH-VOLTAGE OVERHEAD CABLES

Suspended from cable towers or pylons, overhead cables must be light, flexible and strong.

The cable is constructed of stranded aluminium conductors formed around a core of steel stranded conductors (see Fig. 1.117). The aluminium conductors carry the current and the steel core provides the tensile strength required to suspend the cable between pylons.

Where trunking is installed vertically, the installed conductors must be supported so that the maximum unsupported length of non-sheathed cable does not exceed 5 m. Figure 1.124(b) shows cables woven through insulated pin supports, which is one method of supporting vertical cables.

PVC insulated cables are usually drawn into an erected conduit installation or laid into an erected trunking installation. Table 5D of the *On Site Guide* only gives factors for conduits up to 32 mm in diameter, which would indicate that conduits larger than this are not in frequent or common use. Where a cable enclosure greater than 32 mm is required because of the number or size of the conductors, it is generally more economical and convenient to use trunking.

Trunking capacities

The ratio of the space occupied by all the cables in a conduit or trunking to the whole space enclosed by the conduit or trunking is known as the *space factor*. Where sizes and types of cable and trunking are not covered by the tables in Appendix 5 of the *On Site Guide* a space factor of 45% must not be exceeded. This means that the cables must not fill more than 45% of the space enclosed by the trunking. The tables of Appendix 5 take this factor into account.

To calculate the size of trunking required to enclose a number of cables:

- Identify the cable factor for the particular size of conductor (Table 5E). See Table 1.8.
- Multiply the cable factor by the number of conductors to give the sum of the cable factors.
- Consider the factors for trunking (Table 5F) and shown in Table 1.9. The correct size of trunking to accommodate the cables is that trunking which has a factor equal to or greater than the sum of the cable factors.

Table 1.8 Trunking, cable factors. Reproduced from the IEE *On Site Guide* by kind permission of the Institution of Electrical Engineers

TABLE 5E
Cable factors for trunking

Type of conductor	Conductor cross-sectional area (mm^2)	PVC, BS 6004 Cable factor	Thermosetting BS 7211 Cable factor
Solid	1.5	8.0	8.6
	2.5	11.9	11.9
Stranded	1.5	8.6	9.6
	2.5	12.6	13.9
	4	16.6	18.1
	6	21.2	22.9
	10	35.3	36.3
	16	47.8	50.3
	25	73.9	75.4

Note:
(i) These factors are for metal trunking and may be optimistic for plastic trunking where the cross-sectional area available may be significantly reduced from the nominal by the thickness of the wall material.
(ii) The provision of spare space is advisable; however, any circuits added at a later date must take into account grouping. Appendix 4, BS 7671.

EXAMPLE

Calculate the minimum size of trunking required to accommodate the following single-core PVC cables:

20 × 1.5 mm solid conductors
20 × 2.5 mm solid conductors
21 × 4.0 mm stranded conductors
16 × 6.0 mm stranded conductors

From Table 5E shown in Table 1.8, the cable factors are:

for 1.5 mm solid cable – 8.0
for 2.5 mm solid cable – 11.9
for 4.0 mm stranded cable – 16.6
for 6.0 mm stranded cable – 21.2

The sum of the cable terms is:
$(20 \times 8.0) + (20 \times 11.9) + (21 \times 16.6) + (16 \times 21.2) =$ 1085.8. From Table 5F shown in Table 1.9, 75 mm × 38 mm trunking has a factor of 1146 and, therefore, the minimum size of trunking to accommodate these cables is 75 mm × 38 mm, although a larger size, say 75 mm × 50 mm would be equally acceptable if this was more readily available as a standard stock item.

SEGREGATION OF CIRCUITS

Where an installation comprises a mixture of low-voltage and very low-voltage circuits such as mains lighting and power, fire alarm and telecommunication circuits, they must be separated or *segregated* to prevent electrical contact (IEE Regulation 528–01–01).

For the purpose of these regulations various circuits are identified by one of two bands and defined by

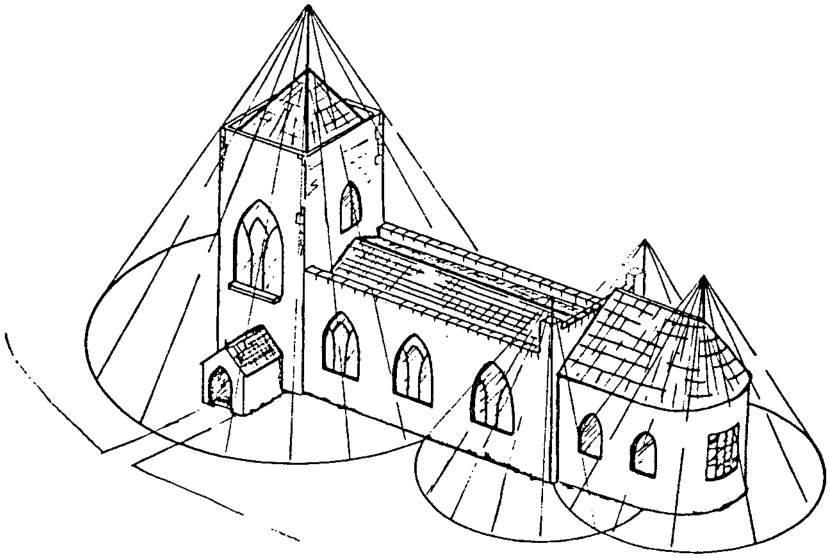


Fig. 1.127 The zone of protection for a structure is given by a cone with its apex at the highest point of the air termination.

- Structures with a base area greater than 100 m – either
  - (a) one, plus one for every 300 m in excess of the first 100 m or,
  - (b) one for every 30 m of perimeter – whichever is the smaller number.

The down conductor should be as straight as possible as shown in Figure 1.128 and it is very unwise to bend the rods to conform with architectural fancies. If a rod is struck by lightning (and this is the desired outcome) the inductance of a conductor that has been bent back on itself is higher than that of a straight one. The discharging current may take short cuts – seriously damaging masonry and endangering people's lives.

The routing of the down conductor must take account of its accessibility for inspection, testing and maintenance.

The lightning protective system should have as few joints as possible, but where necessary, these should be mechanically and electrically effective.

The cross-section of the bonds should not be less than that employed for the main conductors.

Every down conductor should be provided with a *testing joint* in such a position that, whilst not inviting unauthorized interference, is convenient for use when testing.

Earth termination There should be an earth termination to each down conductor. Each earth terminal should have a resistance to earth not exceeding $10\,\Omega \times$ the number of earth terminals. The whole lightning system should have a combined resistance to earth not exceeding $10\,\Omega$.

For example, if a system has four down conductors the maximum value for each earth terminal will be $40\,\Omega$. This gives a total resistance for the whole system of

$$\frac{1}{R_T} = \frac{1}{40} + \frac{1}{40} + \frac{1}{40} + \frac{1}{40} = \frac{1+1+1+1}{40}$$

$$\frac{1}{R_T} = \frac{4}{40} \quad \therefore R_T = \frac{40}{4} = 10\,\Omega$$

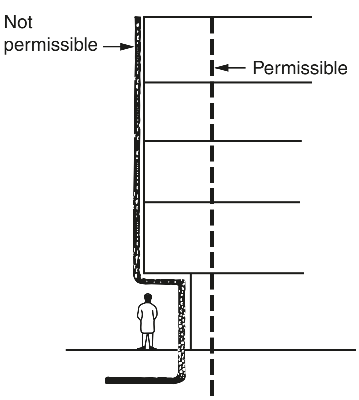


Fig. 1.128 Down conductors must always be as straight as possible to prevent flash over.

(b) 11.5 V
(c) 23 V
(d) 46 V.

37 Before an ammeter can be removed from the secondary terminals of a current transformer connected to a load, the transformer terminals must be:
(a) open-circuited
(b) short-circuited
(c) connected to the primary winding
(d) connected to earth.

38 An a.c. series circuit has an inductive reactance of 4 Ω and a resistance of 3 Ω. The impedance of this circuit will be:
(a) 5 Ω
(b) 7 Ω
(c) 12 Ω
(d) 25 Ω.

39 An a.c. series circuit has a capacitive reactance of 12 Ω and a resistance of 9 Ω. The impedance of this circuit will be:
(a) 3 Ω
(b) 15 Ω
(c) 20 Ω
(d) 108 Ω.

40 A circuit whose resistance is 3 Ω, reactance 5 Ω and impedance 5.83 Ω will have a p.f. of:
(a) 0.515
(b) 0.600
(c) 0.858
(d) 1.666.

41 A circuit whose resistance is 5 Ω, capacitive reactance 12 Ω and inductive reactance 20 Ω will have an impedance of:
(a) 9.434 Ω
(b) 21.189 Ω
(c) 23.853 Ω
(d) 32.388 Ω.

42 The inductive reactance of a 100 mH coil when connected to 50 Hz will be:
(a) 0.5 Ω
(b) 0.0318 Ω
(c) 5.0 Ω
(d) 31.416 Ω.

43 The capacitive reactance of a 100 μF capacitor connected to a 50 Hz supply will be:
(a) 0.5 Ω
(b) 5.0 mΩ
(c) 31.83 Ω
(d) 31415.93 Ω.

44 In a series resonant circuit the:
(a) current and impedance are equal
(b) current is at a minimum and the impedance a maximum
(c) current is at a maximum and the impedance a minimum
(d) current and impedance are at a maximum.

45 In a series resonant circuit the:
(a) capacitive and inductive reactances are equal
(b) capacitive and inductive reactances are at a minimum value
(c) capacitive and inductive reactances are at a maximum value
(d) capacitive and inductive reactances are equal to the resistance of the circuit.

46 A circuit containing a 100 μF capacitor in series with a 100 mH inductor will resonate at a frequency of:
(a) 3.142 Hz
(b) 50.33 Hz
(c) 316.23 Hz
(d) 10 kHz.

47 A series circuit consisting of a 25.33 mH inductor and 100 μF capacitor will have a resonant frequency of:
(a) 2.53 Hz
(b) 79.58 Hz
(c) 90 Hz
(d) 100 Hz.

48 A capacitor is connected across the supply at a fluorescent light fitting to:
(a) increase the voltage
(b) increase the current
(c) suppress radio interference
(d) improve the power factor.

49 Capacitors of 24, 40 and 60 μF are connected in series. The equivalent capacitance will be:
(a) 12 μF
(b) 44 μF
(c) 76 μF
(d) 124 μF.

50 Capacitors of 24, 40 and 60 μF are connected in parallel. The total capacitance will be:
(a) 12 μF
(b) 44 μF
(c) 76 μF
(d) 124 μF.

51 Two a.c. voltages V_1 and V_2 have values of 20 and 30 V, respectively. If V_1 leads V_2 by 45° the

2

INSPECTION, TESTING AND COMMISSIONING

The construction industry

An electrician working for an electrical contracting company works as a part of the broader construction industry. This is a multi-million-pound industry carrying out all types of building work, from basic housing to hotels, factories, schools, shops, offices and airports. The construction industry is one of the UK's biggest employers, and carries out contracts to the value of about 10% of the UK's gross national product.

Although a major employer, the construction industry is also very fragmented. Firms vary widely in size, from the local builder employing two or three people to the big national companies employing thousands. Of the total workforce of the construction industry, 92% are employed in small firms of less than 25 people.

The yearly turnover of the construction industry is about £35 billion. Of this total sum, about 60% is spent on new building projects and the remaining 40% on maintenance, renovation or restoration of mostly housing.

In all these various construction projects the electrotechnical industries play an important role, supplying essential electrical services to meet the needs of those who will use the completed building.

The building team

The construction of a new building is a complex process which requires a team of professionals working together to produce the desired results. We can call this team of professionals the building team, and their interrelationship can be expressed by Fig. 2.1.

The client is the person or group of people with the actual need for the building, such as a new house, office or factory. The client is responsible for financing all the work and, therefore, in effect, employs the entire building team.

The architect is the client's agent and is considered to be the leader of the building team. The architect must interpret the client's requirements and produce working drawings. During the building process the architect will supervise all aspects of the work until the building is handed over to the client.

The quantity surveyor measures the quantities of labour and material necessary to complete the building work from drawings supplied by the architect.

Specialist engineers advise the architect during the design stage. They will prepare drawings and calculations on specialist areas of work.

The clerk of works is the architect's 'on-site' representative. He or she will make sure that the contractors carry out the work in accordance with the drawings and other contract documents. They can also agree general matters directly with the building contractor as the architect's representative.

The local authority will ensure that the proposed building conforms to the relevant planning and building legislation.

The health and safety inspectors will ensure that the government's legislation concerning health and safety is fully implemented by the building contractor.

The building contractor will enter into a contract with the client to carry out the construction work in

Union, which will also represent their members in any disputes. Electricians are usually paid at a rate agreed for their grade as an electrician, approved electrician or technician electrician; movements through the grades are determined by a combination of academic achievement and practical experience.

The electrical team will consist of a group of professionals and their interrelationship can be expressed as shown in Fig. 2.2.

Designing an electrical installation

The designer of an electrical installation must ensure that the design meets the requirements of the IEE Wiring Regulations for electrical installations and any other regulations which may be relevant to a particular installation. The designer may be a professional technician or engineer whose job it is to design electrical installations for a large contracting firm. In a smaller firm, the designer may also be the electrician who will carry out the installation to the customer's requirements. The designer of any electrical installation is the person who interprets the electrical requirements of the customer within the regulations, identifies the appropriate types of installation, the most suitable methods of protection and control and the size of cables to be used.

A large electrical installation may require many meetings with the customer and his professional representatives in order to identify a specification of what is required. The designer can then identify the general characteristics of the electrical installation and its compatibility with other services and equipment, as indicated in Part 3 of the Regulations. The protection and safety of the installation, and of those who will use it, must be considered, with due regard to Part 4 of the Regulations. An assessment of the frequency and quality of the maintenance to be expected (Regulation 341–01–01) will give an indication of the type of installation which is most appropriate.

The size and quantity of all the materials, cables, control equipment and accessories can then be determined. This is called a 'bill of quantities'.

It is common practice to ask a number of electrical contractors to tender or submit a price for work specified by the bill of quantities. The contractor must cost all the materials, assess the labour cost required to install the materials and add on profit and overhead costs in order to arrive at a final estimate for the work. The contractor tendering the lowest cost is usually, but not always, awarded the contract.

To complete the contract in the specified time the electrical contractor must use the management skills required by any business to ensure that men and materials are on site as and when they are required. If alterations or modifications are made to the electrical installation as the work proceeds which are outside the original specification, then a variation order must be issued so that the electrical contractor can be paid for the additional work.

The specification for the chosen wiring system will be largely determined by the building construction and the activities to be carried out in the completed building.

An industrial building, for example, will require an electrical installation which incorporates flexibility and mechanical protection. This can be achieved by a conduit, tray or trunking installation.

In a block of purpose-built flats, all the electrical connections must be accessible from one flat without intruding upon the surrounding flats. A loop-in conduit system, in which the only connections are at the light switch and outlet positions, would meet this requirement.

For a domestic electrical installation an appropriate lighting scheme and multiple socket outlets for the connection of domestic appliances, all at a reasonable cost, are important factors which can usually be met by a PVC insulated and sheathed wiring system.

The final choice of a wiring system must rest with those designing the installation and those ordering the work, but whatever system is employed, good workmanship is essential for compliance with the regulations. The necessary skills can be acquired by an electrical trainee who has the correct attitude and dedication to his craft.

Legal contracts

Before work commences, some form of legal contract should be agreed between the two parties, that is, those providing the work (e.g. the subcontracting

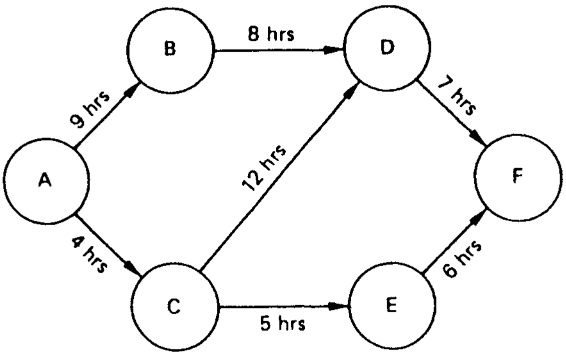


Fig. 2.4 A network diagram for Example 1.

EXAMPLE 1

Identify the three possible paths from the start event A to the finish event F for the contract shown by the network diagram in Fig. 2.4. Identify the critical path and the float time in each path.

The three possible paths are:

1 event A–B–D–F
2 event A–C–D–F
3 event A–C–E–F.

The times taken to complete these activities are:

1 path A–B–D–F = 9 + 8 + 7 = 24 hours
2 path A–C–D–F = 4 + 12 + 7 = 23 hours
3 path A–C–E–F = 4 + 5 + 6 = 15 hours.

The longest time from the start event to the finish event is 24 hours, and therefore the critical path is A–B–D–F.

The float time is given by

Float time = Critical path − Activity time

For path 1, A–B–D–F,

Float time = 24 hours − 24 hours = 0 hours

There can be no float time in any of the activities which form a part of the critical path since a delay on any of these activities would delay completion of the contract. On the other two paths some delay could occur without affecting the overall contract time. For path 2, A–C–D–F,

Float time = 24 hours − 23 hours = 1 hour

For path 3, A–C–E–F,

Float time = 24 hours − 15 hours = 9 hours

EXAMPLE 2

Identify the time taken to complete each activity in the network diagram shown in Fig. 2.5. Identify the three possible paths from the start event A to the final event G and state which path is the critical path.

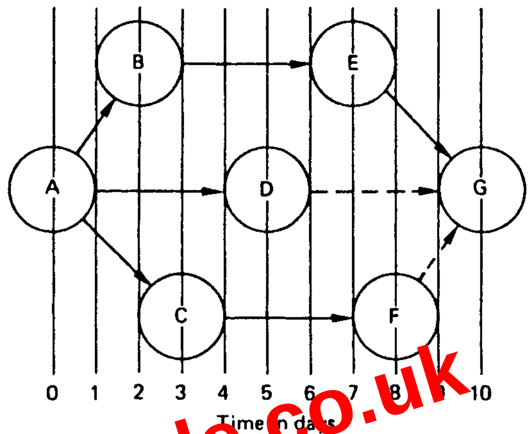


Fig. 2.5 A network diagram for Example 2.

The time taken to complete each activity using the horizontal scale is:

activity A–B = 2 days
activity A–C = 3 days
activity A–D = 5 days
activity B–E = 5 days
activity C–F = 5 days
activity E–G = 3 days
activity D–G = 0 days
activity F–G = 0 days

Activities D–G and F–G are dummy activities which take no time to complete but indicate a logical link only. This means that in this case once the activities preceding events D and F have been completed, the contract will not be held up by work associated with these particular paths and they will progress naturally to the finish event.

The three possible paths are:

1 A–B–E–G
2 A–D–G
3 A–C–F–G.

The times taken to complete the activities in each of the three paths are:

path 1, A–B–E–G = 2 + 5 + 3 = 10 days
path 2, A–D–G = 5 + 0 = 5 days
path 3, A–C–F–G = 3 + 5 + 0 = 8 days.

The critical path is path 1, A–B–E–G.

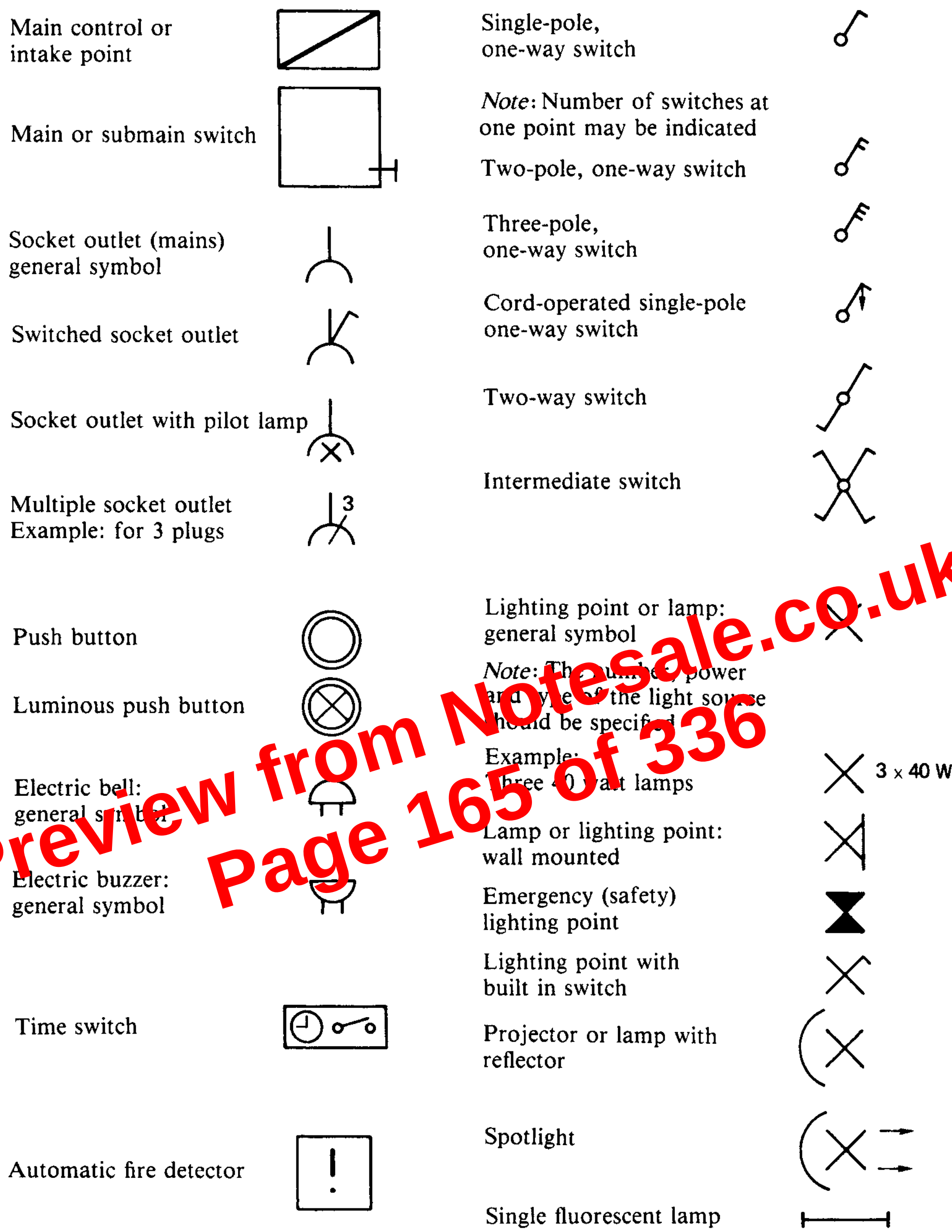


Fig. 2.7 Some BS EN 60617 installation symbols.

Schematic diagrams

A schematic diagram is a diagram in outline of, for example, a motor starter circuit. It uses graphical symbols to indicate the interrelationship of the electrical elements in a circuit. These help us to understand the working operation of the circuit.

An electrical schematic diagram looks very like a circuit diagram. A mechanical schematic diagram gives a more complex description of the individual elements in the system, indicating, for example, acceleration, velocity, position, force sensing and viscous damping.

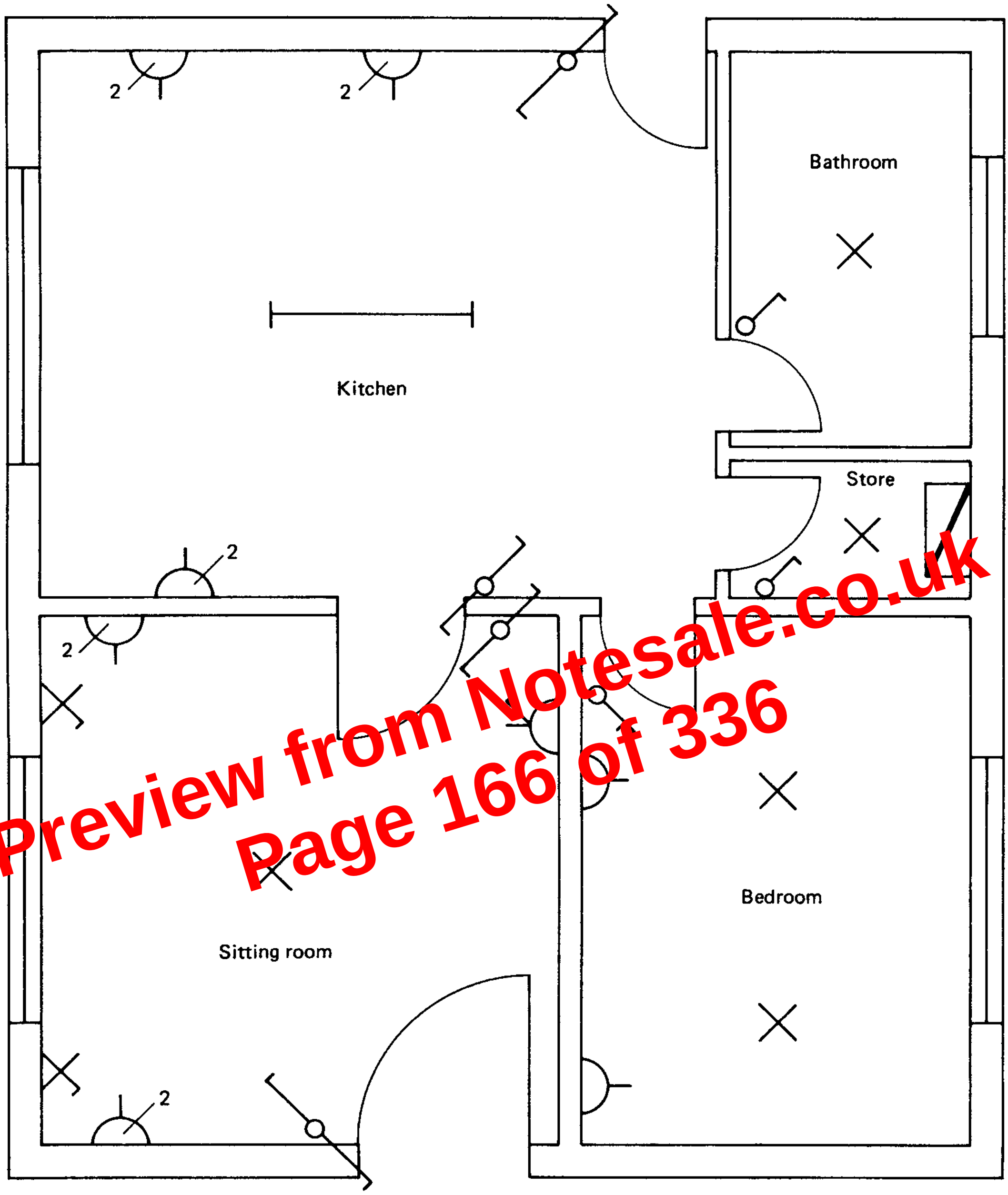


Fig. 2.8 Layout drawing for electrical installation.

Block diagrams

A block diagram is a very simple diagram in which the various items or pieces of equipment are represented by a square or rectangular box. The purpose of the block diagram is to show how the components of the circuit relate to each other and therefore the individual circuit connections are not shown. Figure 2.9 shows the block diagram of a high-voltage discharge lighting circuit.

Wiring diagrams

A wiring diagram or connection diagram shows the detailed connections between components or items of equipment. They do not indicate how a piece of the earth fault loop impedance for circuits protected by a semi-enclosed fuse to BS 3036). We will look at this again later in this chapter under the heading 'Earth Fault Loop Impedance Z_S'. Section 542 of the IEE Regulations gives details of the earthing arrangements to be incorporated in the supply system to meet these Regulations and these were described in Chapter 1 under the heading 'Low Voltage Supply Systems' and are shown in Figs 1.106 to 1.108.

Residual current protection

The IEE Regulations recognize the particular problems created when electrical equipment such as lawnmowers, hedge-trimmers, drills and lights are used outside buildings. In these circumstances the availability of an adequate earth return path is a matter of chance. The Regulations, therefore, require that any socket intended to be used to supply equipment outside a building shall have the additional protection of a residual current device (RCD), which has a rated operating current of not more than 30 milliamperes (mA).

An RCD is a type of circuit breaker that continuously compares the current in the phase and neutral conductors of the circuit. The currents in a healthy circuit will be equal, but in a circuit that develops a fault, some current will flow to earth and the phase and neutral currents will no longer balance. The RCD detects the imbalance and disconnects the circuit. Figure 2.18 shows an RCD.

Isolation and switching

Part 4 of the IEE Regulations deals with the application of protective measures for safety and Chapter 53 with

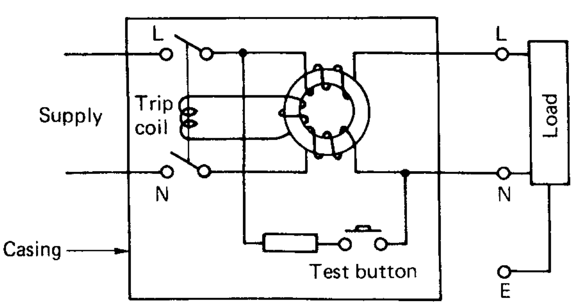


Fig. 2.18 Construction of a residual current device (RCD).

the regulations for switching devices or switchgear required for protection, isolation and switching of a consumer's installation.

The consumer's main switchgear must be readily accessible to the consumer and be able to:

- isolate the complete installation from the supply,
- protect against overcurrent,
- cut off the current in the event of a serious fault occurring.

The Regulations identify four separate types of switching: switching for isolation; switching for mechanical maintenance; emergency switching; and functional switching.

Isolation is defined as cutting off the electrical supply to a circuit or item of equipment in order to ensure the safety of those working on the equipment by making dead those parts which are live in normal service.

An isolator is a mechanical device which is operated manually and used to open or close a circuit off load. An isolator switch must be provided close to the supply point so that all equipment can be made safe for maintenance. Isolators for motor circuits must isolate the motor and the control equipment, and isolators for high-voltage discharge lighting luminaires must be an integral part of the luminaire so that it is isolated when the cover is removed (Regulations 461, 476–02 and 537–02). Devices which are suitable for isolation are isolation switches, fuse links, circuit breakers, plugs and socket outlets.

Isolation at the consumer's service position can be achieved by a double pole switch which opens or closes all conductors simultaneously. On three-phase supplies the switch need only break the live conductors with a solid link in the neutral, provided that the neutral link cannot be removed before opening the switch.

The switching for mechanical maintenance requirements is similar to those for isolation except that the control switch must be capable of switching the full load current of the circuit or piece of equipment. Switches for mechanical maintenance must not have exposed live parts when the appliance is opened, must be connected in the main electrical circuit and have a reliable on/off indication or visible contact gap (Regulations 462 and 537–03). Devices which are suitable for switching off for mechanical maintenance are switches, circuit breakers, plug and socket outlets.

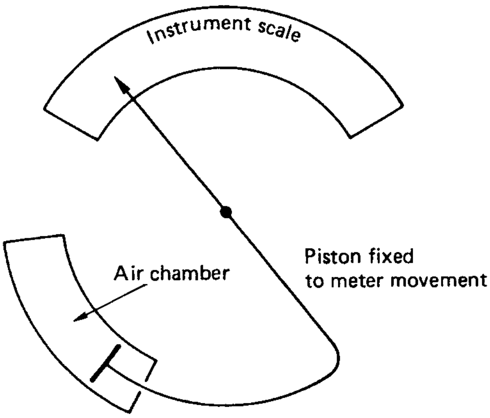


Fig. 2.36 Air piston damping.

Range extension

Moving iron instruments may be constructed to read 10, 20 or 50 A by increasing the thickness and number of solenoid conductors. However, moving coil instruments can only be constructed using a delicate lightweight coil whose maximum current carrying capacity is no more than about 75 mA. To extend the range of a moving coil instrument, shunt or series resistors are connected to it as shown in Fig. 2.37.

To extend the range of an ammeter a low-resistance shunt resistor is connected across the meter movement. This allows the majority of the circuit current to pass through the shunt and only a very small part of the current to pass through the meter movement.

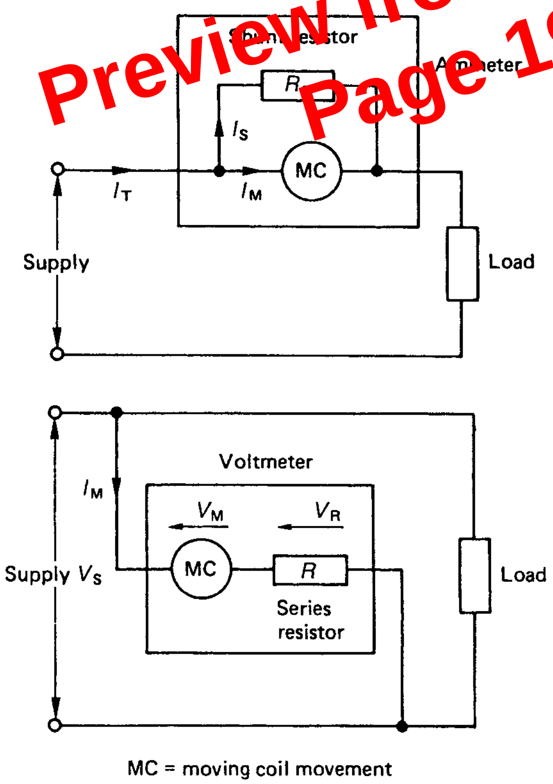


Fig. 2.37 Range extension of moving coil movement.

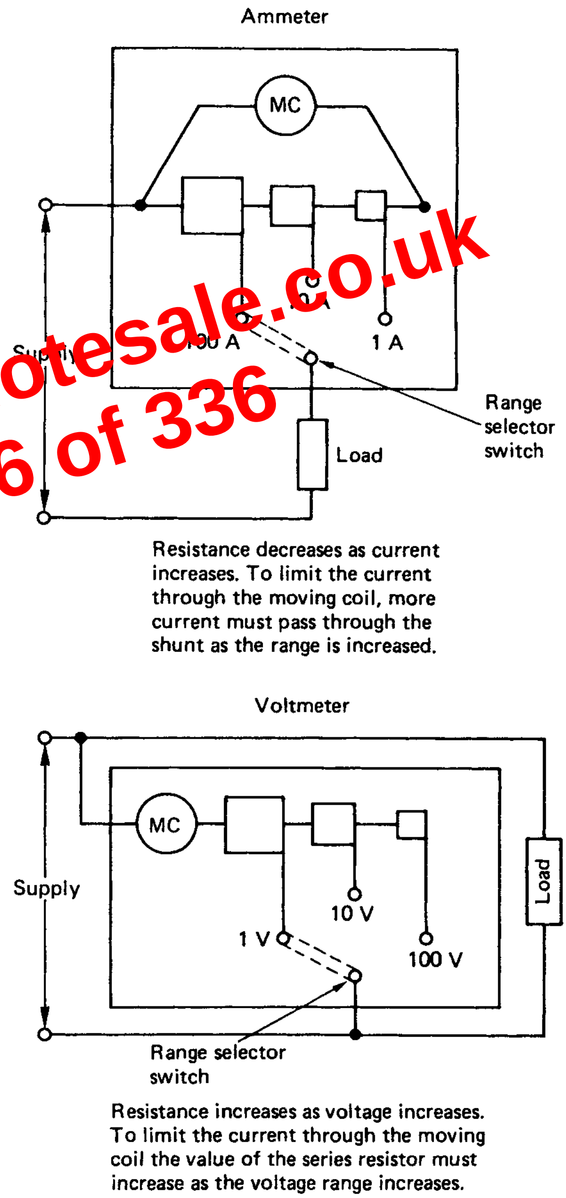


Fig. 2.38 The resistor and coil arrangements in a multirange instrument.

2 The probe tip must not protrude more than 2 mm, and preferably only 1 mm, be spring-loaded and screened.
3 The lead must be adequately insulated and coloured so that one lead is readily distinguished from the other.
4 The lead must be flexible and sufficiently robust.
5 The lead must be long enough to serve its purpose but not too long.
6 The lead must not have accessible exposed conductors even if it becomes detached from the probe or from the instrument.
7 Where the leads are to be used in conjunction with a voltage detector they must be protected by a fuse.

A suitable probe and lead is shown in Fig. 2.47.

GS 38 also tells us that where the test is being made simply to establish the presence or absence of a voltage, the preferred method is to use a proprietary test lamp or voltage indicator which is suitable for the working voltage, rather than a multimeter. Accident history has shown that incorrectly set multimeters or makeshift devices for voltage detection have frequently caused accidents. Figure 2.48 shows a suitable voltage indicator. Test lamps and voltage indicators are not fail-safe, and therefore GS 38 recommends that they should be regularly proved, preferably before and after use, as described in the flowchart for a safe isolation procedure.

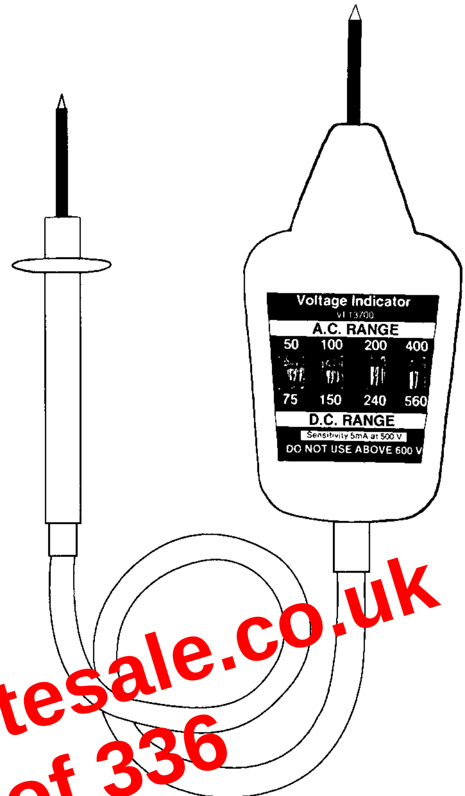


Fig. 2.48 Typical voltage indicator.

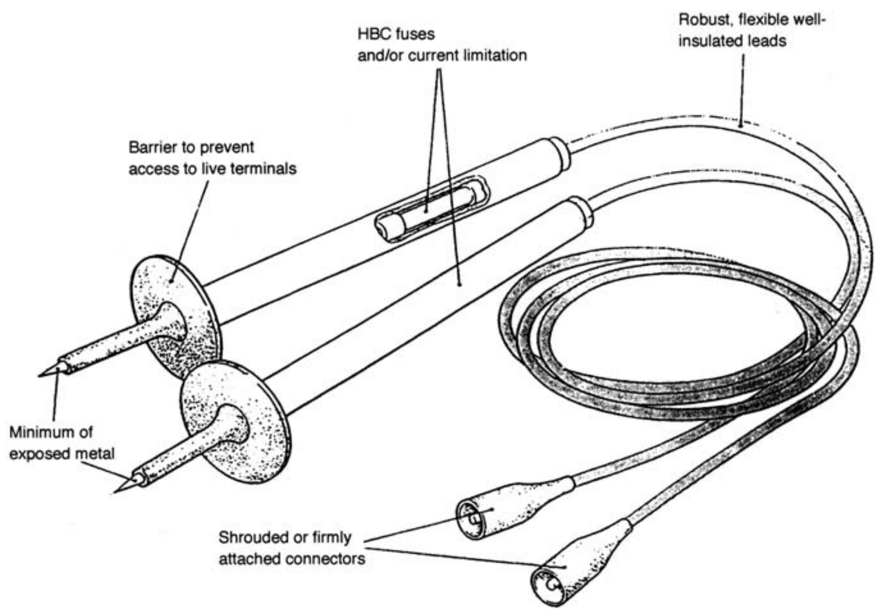


Fig. 2.47 Recommended type of test probe and leads.

Test procedures

1 The circuits must be isolated using a 'safe isolation procedure', such as that described below, before beginning to test.
2 All test equipment must be 'approved' and connected to the test circuits by recommended test probes as described by the HSE Guidance Notes GS 38. The test equipment used must also be 'proved' on a known supply or by means of a proving unit such as that shown in Fig. 2.49.
3 Isolation devices must be 'secured' in the 'off' position as shown in Fig. 2.50.
4 Warning notices must be posted.
5 All relevant safety and functional tests must be completed before restoring the supply.

Fig. 2.49 Voltage proving unit.

EXAMPLE

The total resistance of the complete earth path of an electrical installation supplied by a TT system is 20 Ω including the resistance of the consumer's earth electrode. Calculate the earth fault current which would flow if the supply voltage was 230 V.

$$I = \frac{V}{R}\,(\mathrm{A})$$

$$\therefore\ I = \frac{230\ \mathrm{V}}{20\ \Omega} = 11.5\ \mathrm{A}$$

Under earth fault conditions only 11.5 A will flow which would not be sufficient to operate, for example, a 30 A ring main fuse, but would be sufficient to kill someone since 50 mA can be fatal.

To operate a 30 A protective device effectively would require an earth electrode resistance of about 0.5 Ω. For this reason Regulation 471–08–06 recommends that socket outlets on a TT system be protected by an RCD. Regulation 413–02–16 states that the product of the earth loop impedance and the operating current of the RCD should be less than 50.

If the electrode under test forms part of the earth return for a TT installation in conjunction with a residual current device, Section 10.3.5 of the *On Site Guide* describes the following method:

1 Disconnect the installation equipotential bonding from the earth electrode to ensure that the test current passes only through the earth electrode.
2 Switch off the consumer's unit to isolate the installation.
3 Using a phase earth loop impedance tester, test between the incoming phase conductor and the earth electrode.

Record the result on an installation schedule such as that given in Appendix 7 of the *On Site Guide*.

Section 10.3.5 of the *On Site Guide* tells us that the recommended maximum value of the earth fault loop impedance for a TT installation is 220 Ω.

Since most of the circuit impedance will be made up of the earth electrode resistance, we can say that an acceptable value for the measurement of the earth electrode resistance would be less than about 200 Ω.

Providing the first five tests were satisfactory, the supply may now be switched on and the final tests completed with the supply connected.

6 TESTING POLARITY – SUPPLY CONNECTED

Using an approved voltage indicator such as that shown at Fig. 2.48 or test lamp and probes which comply with the HSE Guidance Note GS 38, again carry out a polarity test to verify that all fuses, circuit breakers and switches are connected in the live conductor. Test from the common terminal of switches to earth, the live pin of each socket outlet to earth and the centre pin of any Edison screw lampholders to earth. In each case the voltmeter or test lamp should indicate the supply voltage for a satisfactory result.

7 TESTING EARTH FAULT LOOP IMPEDANCE (SUPPLY CONNECTED) (713–11)

The object of this test is to verify that the impedance of the whole earth fault current loop phase to earth is low enough to allow the overcurrent protective device to operate within the disconnection time requirements of Regulations 413–02–08 and 09, should an earth fault occur.

The whole earth fault current loop examined by this test is comprised of all the installation protective conductors, the earthing terminal and earth conductors, the earthed neutral point and the secondary winding of the supply transformer and the phase conductor from the transformer to the point of the fault in the installation.

The test will, in most cases, be done with a purpose-made phase earth loop impedance tester which circulates a current in excess of 10 A around the loop for a very short time, so reducing the danger of a faulty circuit. The test is made with the supply switched on, from the furthest point of *every* final circuit, including lighting, socket outlets and any fixed appliances. Record the results on an installation schedule.

Purpose-built testers give a readout in ohms and a satisfactory result is obtained when the loop impedance does not exceed the appropriate values given in Tables 2A, 2B and 2C of Appendix 2 of the *On Site Guide* or Table 41B1 and 41B2 or Table 604B2, 605B1 and 605B2 of the IEE Regulations.

(Note Table 2A of the *On Site Guide* was shown earlier in this chapter as Table 2.3).

8 FUNCTIONAL TESTING OF RCD – SUPPLY CONNECTED (712–12)

The object of the test is to verify the effectiveness of the residual current device, that it is operating with dangers to look for are as follows:

- Damage to the power cable or lead which exposes the colours of the internal conductors, which are brown, blue and green with a yellow stripe.
- Damage to the plug top itself. The plug top pushes into the wall socket, usually a square pin 13A socket in the UK, to make an electrical connection. With the plug top removed from the socket the equipment is usually electrically 'dead'. If the bakelite plastic casing of the plug top is cracked, broken or burned, or the contact pins are bent, do not use it.
- Non-standard joints in the power cable, such as taped joints.
- Poor cable retention. The outer sheath of the power cable must be secure and enter the plug top at one end and the equipment at the other. The coloured internal conductors must not be visible at either end.
- Damage to the casing of the equipment such as cracks, pieces missing, loose or missing screws or signs of melted plastic, burning, scorching or discolouration.
- Equipment which has previously been used in unsuitable conditions such as a wet or dusty environment.

If any of the above dangers are present, the equipment should not be used until the person appointed by the company to make a 'visual inspection' has had an opportunity to do so.

A **visual inspection** will be carried out by an appointed person within a company, such person having been trained to carry out this task. In addition to the user checks described above, an inspection could include the removal of the plug top cover to check that:

- a fuse of the correct rating is being used and also that a proper cartridge fuse is being used and not a piece of wire, a nail or silver paper;
- the cord grip is holding the sheath of the cable and not the coloured conductors;
- the wires (conductors) are connected to the correct terminals of the plug top as shown in Fig. 2.62;
- the coloured insulation of each conductor wire goes right up to the terminal so that no bare wire is visible;

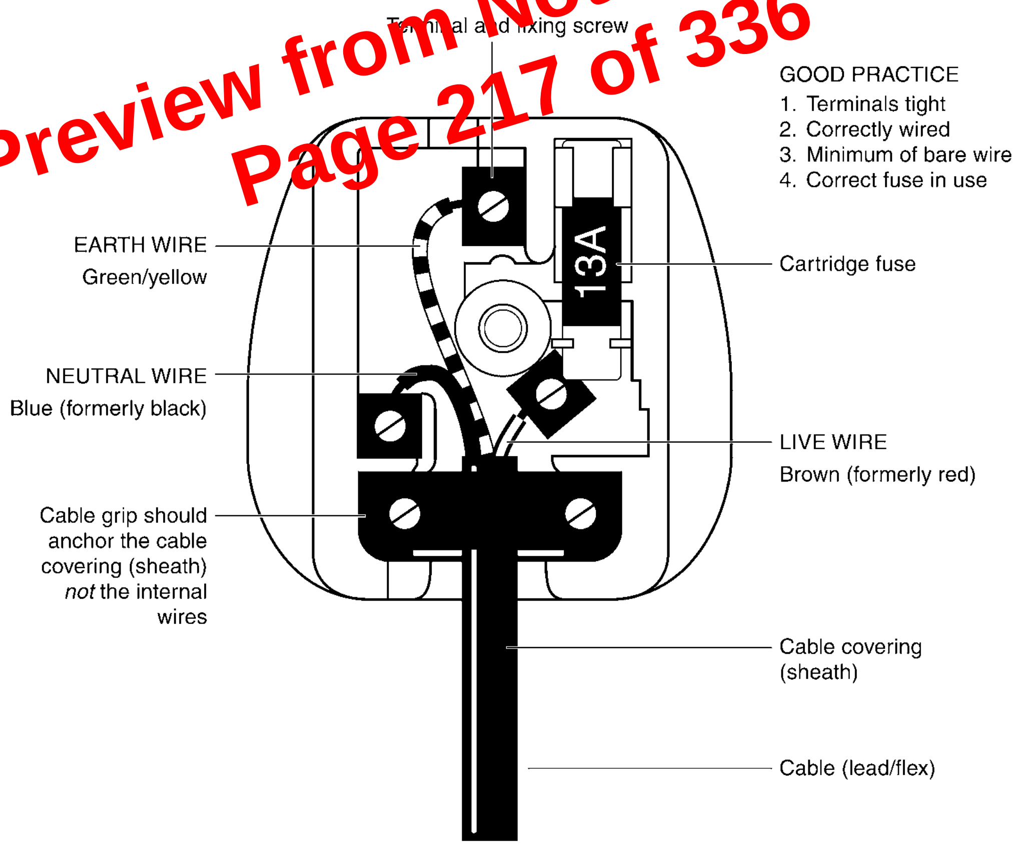


Fig. 2.62 Correct connection of plug top.

Table 2.9 HSE suggested intervals for checking, inspecting and testing of portable appliances in offices and other low risk environments

Equipment/environment	User checks	Formal visual inspection	Combined visual inspection and electrical testing
Battery-operated: (less than 20 V)	No	No	No
Extra low voltage: (less than 50 V a.c.) e.g. telephone equipment, low voltage desk lights	No	No	No
Information technology: e.g. desktop computers, VDU screens	No	Yes, 2–4 years	No if double insulated – otherwise up to 5 years
Photocopiers, fax machines: *not* hand-held, rarely moved	No	Yes, 2–4 years	No if double insulated – otherwise up to 5 years
Double insulated equipment: *not* hand-held, moved occasionally, e.g. fans, table lamps, slide projectors	No	Yes, 2–4 years	No
Double insulated equipment: *hand-held*, e.g. power tools	Yes	Yes, 6 months–1 year	No
Earthed equipment (Class 1): e.g. electric kettles, some floor cleaners, power tools	Yes	Yes, 6 months–1 year	Yes, 1–2 years
Cables (leads) and plugs connected to the above. Extension leads (mains voltage)	Yes	Yes, 6 months–4 years depending on the type of equipment it is connected to	Yes, 1–5 years depending on the type of equipment it is connected to

does not need to be an electrician or electronics service engineer. Any sensible member of staff who has received training can carry out this duty. They will need to know what to look for and what to do, but more importantly, they will need to be able to avoid danger to themselves and to others. The HSE recommend that the appointed person follow a simple written procedure for each visual inspection. A simple tick sheet would meet this requirement. For example:

1 Is the correct fuse fitted? Yes/No
2 Is the cord grip holding the cable sheath? Yes/No

The tick sheet should incorporate all the appropriate visual checks and inspections described earlier.

Testing and inspection require a much greater knowledge than is required for simple checks and visual inspections. This more complex task need not necessarily be carried out by a qualified electrician or electronics service engineer. However, the person carrying out the test must be trained to use the equipment and to interpret the results. Also, greater knowledge will be required for the inspection of the range of portable appliances which might be tested.

KEEPING RECORDS

Records of the inspecting and testing of portable appliances are not required by law but within the Electricity at Work Regulations 1989, it is generally accepted that some form of recording of results is required to implement a quality control system. The control system should:

- ensure that someone is nominated to have responsibility for portable appliance inspection and testing;
- maintain a log or register of all portable appliance test results to ensure that equipment is inspected and tested when it is due;
- label tested equipment with the due date for its next inspection and test as shown in Fig. 2.63.

Any piece of equipment which fails a PAT Test should be disabled and taken out of service (usually by

Fig. 2.63 Typical PAT Test labels.

7 To reduce errors when testing electronic circuits, the test instrument should:
(a) have a very low impedance
(b) have a very high impedance
(c) have a resistance equal to the circuit impedance
(d) have a resistance approximately equal to the circuit current.

8 The two-wattmeter method is used to measure the power in a three-phase, three-wire system. The two readings obtained are 100 and 50 W and, therefore, the total power in the system is:
(a) 50 W
(b) 75 W
(c) 150 W
(d) 5 kW.

9 An acceptable earth electrode resistance test on a lightning conductor earth electrode must reveal a maximum value of:
(a) 10 Ω
(b) 100 Ω
(c) 0.5 MΩ
(d) 1 MΩ.

10 The test required by the Regulations to ascertain that the circuit protective conductor is correctly connected is:
(a) continuity of ring final circuit conductors
(b) continuity of protective conductors
(c) earth electrode resistance
(d) protection by electrical separation.

11 One objective of the polarity test is to verify that:
(a) lampholders are correctly earthed
(b) final circuits are correctly fused
(c) the CPC is continuous throughout the installation
(d) the protective devices are connected in the live conductor.

12 When testing a 230 V installation an insulation resistance tester must supply a voltage of:
(a) less than 50 V
(b) 500 V
(c) less than 500 V
(d) greater than twice the supply voltage but less than 1000 V.

13 The value of a satisfactory insulation resistance test on each final circuit of a 230 V installation must be:
(a) less than 1 Ω
(b) less than 0.5 MΩ
(c) not less than 0.5 MΩ
(d) not less than 1 MΩ.

14 The value of a satisfactory insulation resistance test on a disconnected piece of equipment is:
(a) less than 1 Ω
(b) less than 0.5 MΩ
(c) not less than 0.5 MΩ
(d) not less than 1 MΩ.

15 The maximum inspection and retest period for a general electrical installation is:
(a) 3 months
(b) 3 years
(c) 5 years
(d) 10 years.

16 A visual inspection of a new installation must be carried out:
(a) during the erection period
(b) during testing upon completion
(c) after testing upon completion
(d) before testing upon completion.

17 'To ensure that all the systems within a building work as they were intended to work' is one definition of the purpose of:
(a) testing electrical systems
(b) inspecting electrical systems
(c) commissioning electrical systems
(d) isolating electrical systems.

18 The person responsible for financing the building team is the:
(a) main contractor
(b) subcontractor
(c) client
(d) architect.

19 The person responsible for interpreting the client's requirements to the building team is the:
(a) main contractor
(b) subcontractor
(c) client
(d) architect.

20 The building contractor is also called the:
(a) main contractor
(b) subcontractor
(c) client
(d) architect.

21 The electrical contractor is also called the:
(a) main contractor
(b) subcontractor

(c) 1.20 Ω
(d) 2.0 Ω.

33 The $(R_1 + R_2)$ resistance of 1000 m of PVC insulated copper cable having a 4.0 mm² phase conductor and 2.5 mm² protective conductor will be found from Table 9A of the *On Site Guide* to be:
(a) 4.61 Ω
(b) 9.22 Ω
(c) 12.02 Ω
(d) 16.71 Ω.

34 The $(R_1 + R_2)$ resistance of 176 m of PVC insulated copper cable having a 2.5 mm² phase and protective conductor is:
(a) 2.608 Ω
(b) 7.41 Ω
(c) 14.82 Ω
(d) 19.51 Ω.

35 The value of the earth fault loop impedance Z_S of a circuit fed by 40 m of PVC insulated copper cable having a 2.5 mm² phase conductor and 1.5 mm² protective conductor connected to a supply having an impedance Z_E of 0.5 Ω under fault conditions will be
(a) 1.436 Ω
(b) 9.755 Ω
(c) 20.01 Ω
(d) 780.4 mΩ.

36 The time/current characteristics shown in Fig. 3.20 indicate that a fault current of 300 A will cause a 30 A semi-enclosed fuse to BS 3036 to operate in
(a) 0.01 s
(b) 0.1 s
(c) 0.2 s
(d) 2.0 s.

37 The time/current characteristics shown in Fig. 3.20 indicate that a fault current of 30 A will cause a 10 A type 2 MCB to BS 3871 to operate in
(a) 0.02 s
(b) 8 s
(c) 30 s
(d) 200 s.

38 'Under fault conditions the protective device nearest to the fault should operate leaving other healthy circuits unaffected'. This is one definition of:
(a) fusing factor
(b) effective discrimination
(c) a miniature circuit breaker
(d) a circuit protective conductor.

39 The overcurrent protective device protecting socket outlet circuits and any fixed equipment in bathrooms must operate within:
(a) 0.02 s
(b) 0.4 s
(c) 5 s
(d) 45 s.

40 The overcurrent protective device protecting fixed equipment in rooms other than bathrooms must operate within
(a) 0.02 s
(b) 0.4 s
(c) 5 s
(d) 45 s.

41 Explain why the maximum values of earth fault loop impedance Z_S specified by the IEE Regulations and given in Tables 41B1 and 41B2 should not be exceeded.

42 By referring to the tables in the IEE Regulations (Tables 41B1, 41B2 and 41D), determine the maximum permitted earth fault loop impedance Z_S for the following circuits:
(a) a ring main of 13 A socket outlets protected by a 30 A semi-enclosed fuse to BS 3036
(b) a ring main of 13 A socket outlets protected by a 30 A cartridge fuse to BS 1361
(c) a single socket outlet protected by a 15 A type 1 MCB to BS 3871
(d) a water heating circuit protected by a 15 A semi-enclosed fuse to BS 3036
(e) a lighting circuit protected by a 6 A HBC fuse to BS 88 Part 2
(f) a lighting circuit protected by a 5 A semi-enclosed fuse to BS 3036.

43 10 mm² cables with PVC insulated copper conductors feed a commercial cooker connected to a 400 V supply. An earth loop impedance test indicates that Z_S has a value of 1.5 Ω. Calculate the minimum size of the protective conductor.

44 It is proposed to protect the commercial cooker circuit described in Exercise 43 with 30 A
(a) semi-enclosed fuses to BS 3036
(b) type 2 MCBs to BS 3871.
Determine the time taken for each protection device to clear an earth fault on this circuit by referring to the characteristics of Fig. 3.20.

45 A 2.5 mm² PVC insulated and sheathed cable is used to feed a single 13 A socket outlet from a 15 A instrument to be used and the values of a satisfactory test.

63 State eight separate tasks carried out by the electrical design team.

64 State seven separate tasks carried out by the electrical installation team.

65 State the purpose of a 'variation' order.

66 State the advantages of a written legal contract as compared to a verbal contract.

67 A particular contract is made up of activities A to I as follows: Activity A takes 3 weeks commencing in week 1. Activity B takes 1 week commencing in week 1. Activity C takes 5 weeks commencing in week 2. Activity D takes 4 weeks commencing in week 7. Activity E takes 3 weeks commencing in week 3. Activity F takes 5 weeks commencing in week 4. Activity G takes 4 weeks commencing in week 9. Activity H takes 4 weeks commencing in week 6. Activity I takes 10 weeks commencing in week 3.

Due to the availability of men and materials some activities must be completed before others can commence, as follows. Activity C can only commence when B is completed. Activity D can only commence when C is completed. Activity F can only commence when A is completed. Activity G can only commence when F is completed. Activity H can only commence when E is completed. Activity I does not restrict any other activity.

(a) Draw up a bar chart to show the various activities.
(b) Assemble a network diagram for the contract.
(c) Identify the critical path.
(d) Find the time required to complete the contract.
(e) State the float time in activity F.
(f) State the float time in activity D.

68 Sketch the BS EN 60617 graphical symbols for the following equipment:
(a) a single socket outlet
(b) a double socket outlet
(c) a switched double socket outlet
(d) an electric bell
(e) a single-pole one-way switch
(f) a cord-operated single-pole one-way switch
(g) a wall-mounted lighting point
(h) a double fluorescent lamp
(i) an emergency lighting point.

69 State the requirements of the Electricity at Work Act with regard to
(a) 'live' testing and 'fault diagnosis'
(b) 'live working' to repair a fault.

70 Define 'isolation' with respect to an electrical circuit or item of equipment.

71 List a logical procedure for the isolation of an electrical circuit. Start from the point at which you choose the voltage indicating device and finish with the point at which you begin to work on the circuit.

72 Use a sketch to describe the construction of a test lead approved to HSE GS 38.

73 Describe eddy current damping.

74 Describe air vane and air piston damping.

75 Use a labelled sketch to describe the construction and operation of an energy meter.

76 Use a labelled sketch to describe the construction and operation of a tong tester.

77 Describe the construction and use of a phase sequence tester.

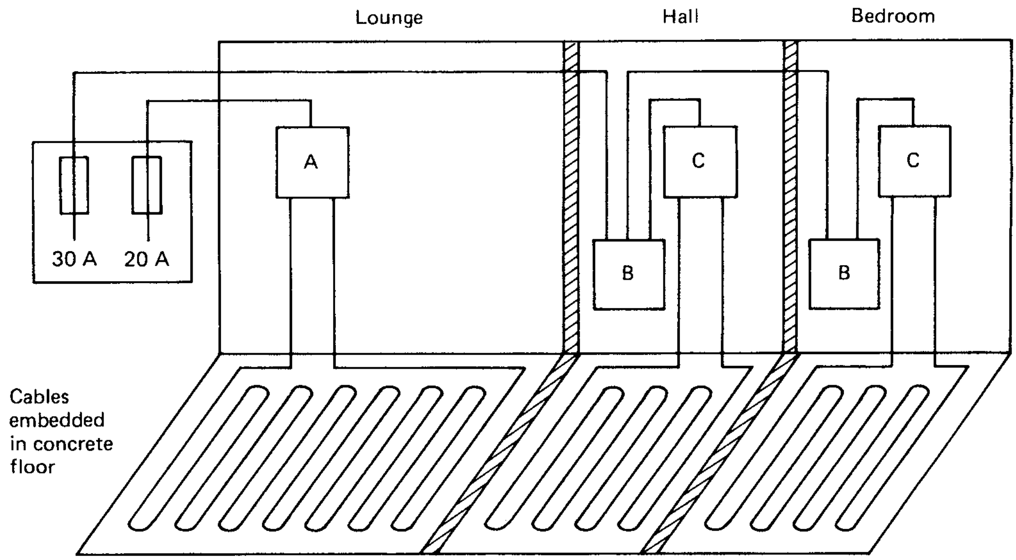
78 Use sketches to describe the operation of the deflection system in a moving coil instrument.

79 Explain how the basic moving coil system is modified so that a test instrument can be used on a.c. circuits.

80 Describe what is meant by damping of a system. Sketch a graph to show an overdamped, underdamped and critically damped system.

81 Describe the construction and operation of a dynamometer wattmeter.

82 Explain with the aid of a diagram how a single wattmeter can be used to measure the total power in
(a) a balanced three-phase load
(b) an unbalanced three-phase load.



A = Thermostat incorporating DP switch fed by 2.5 mm PVC/copper
B = DP switch fuse fed by 4.0 mm PVC/copper
C = Thermostat fed by 2.5 mm PVC/copper

Fig. 3.13 Floor warming installations.

current is passed through the cables they become heated, the concrete absorbs this heat and radiates it into the room. The wiring arrangements are shown in Fig. 3.13. Once heated, the concrete will give off heat for a long time after the supply is switched off and is, therefore, suitable for connection to an off-peak supply.

Underfloor heating cables installed in bathrooms or shower rooms must incorporate an earthed metallic sheath or be covered by an earthed metallic grid connected to the supplementary bonding (Regulation 601–12–02).

COOKER CIRCUIT

A cooker with a rating above 3 kW must be supplied on its own circuit but since it is unlikely that in normal use every heating element will be switched on at the same time, a diversity factor may be applied in calculating the cable size, as detailed in Table 1A in Appendix 1 of the *On Site Guide.*

Consider, as an example, a cooker with the following elements fed from a cooker control unit incorporating a 13 A socket:

$$4 \times 2\,\text{kW fast boiling rings} = 8000\,\text{W}$$
$$1 \times 2\,\text{kW grill} = 2000\,\text{W}$$
$$1 \times 2\,\text{kW oven} = 2000\,\text{W}$$
$$\text{Total loading} = 12\,000\,\text{W}$$

When connected to 250 V

$$\text{Current rating} = \frac{12\,000}{250} = 48\,\text{A}.$$

Applying the diversity factor of Table 1A,

$$\text{Total current rating} = 48\,\text{A}$$
$$\text{First 10 amperes} = 10\,\text{A}$$
$$30\%\ \text{of}\ 38\,\text{A} = 11.4\,\text{A}$$
$$\text{Socket outlet} = 5\,\text{A}$$
$$\text{Assessed current demand} = 10 + 11.4 + 5 = 26.4\,\text{A}$$

Therefore, a cable capable of carrying 26.4 A may be used safely rather than a 48 A cable.

A cooking appliance must be controlled by a switch separate from the cooker but in a readily accessible position (Regulation 476–03–04). Where two cooking appliances are installed in one room, such as split-level cookers, one switch may be used to control both appliances provided that neither appliance is more than 2 m from the switch (*On Site Guide*, Appendix 8).

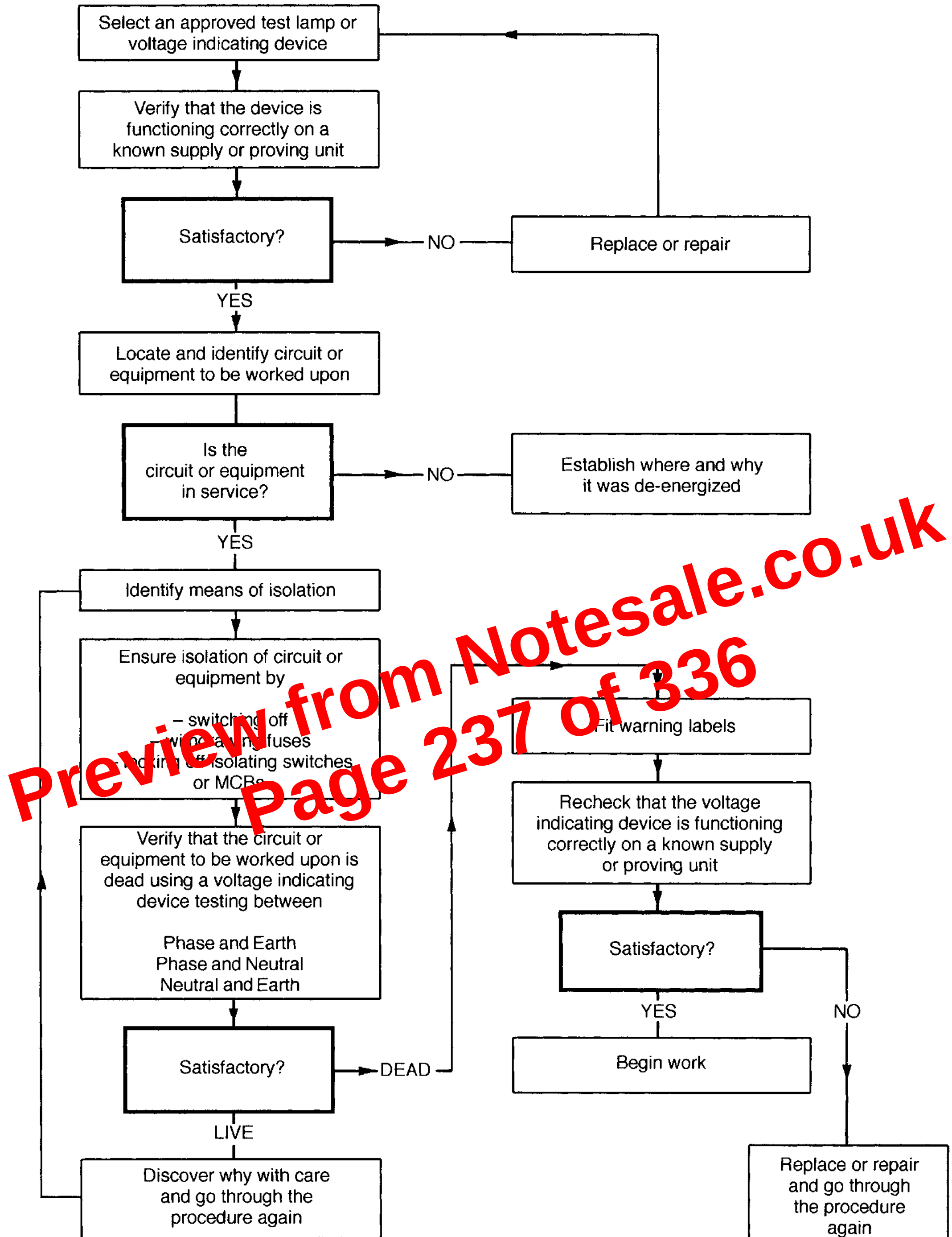


Fig. 3.14 Flowchart for a secure isolation procedure.

purpose must itself be proved immediately before and immediately after testing the conductors. To isolate an individual circuit or item of equipment successfully, competently and safely we must follow a procedure such as that given by the flow diagram in Fig. 3.14. Start at the top and work your way down the flowchart. When you get to the heavy-outlined boxes, pause and ask yourself whether everything is satisfactory up to this point. If the answer is yes, move on. If no, go back as indicated by the diagram.

Faulty equipment: to repair or replace?

Having successfully diagnosed the cause of the fault we have to decide if we are to repair or replace the faulty component or piece of equipment.

In many cases the answer will be straightforward and obvious, but in some circumstances the solution will need to be discussed with the customer. Some of the issues which may be discussed are as follows:

- What is the cost of replacement? Will the replacement cost be prohibitive? Is it possible to replace only some of the components? Will the labour costs of the repair be more expensive than a replacement? Do you have the skills necessary to carry out the repair? Would the repaired piece of equipment be as reliable as a replacement?
- Is a suitable replacement available within an acceptable time? These days, manufacturers carry small stocks to keep cost down.
- Can the circuit or system be shut down to facilitate a repair or replacement?
- Can alternative or temporary supplies and services be provided while replacements or repairs are carried out?

Selecting test equipment

The Health and Safety Executive has published Guidance Notes (GS 38) which advise electricians and other electrically competent people on the selection of suitable test probes, voltage indicating devices and measuring instruments. This is because they consider suitably constructed test equipment to be as vital for personal safety as the training and practical skills of the electrician. In the past, unsatisfactory test probes and voltage indicators have frequently been the cause of accidents, and therefore all test probes must now incorporate the following features:

1 The probes must have finger barriers or be shaped so that the hand or fingers cannot make contact with the live conductors under test.
2 The probe tip must not protrude more than 2 mm, and preferably only 1 mm, be spring-loaded and screened.
3 The lead must be adequately insulated and coloured so that one lead is readily distinguished from the other.
4 The lead must be flexible and sufficiently robust.
5 The lead must be long enough to serve its purpose but not too long.
6 The lead must not have accessible exposed conductors even if it becomes detached from the probe or from the instrument.
7 Where the leads are to be used in conjunction with a voltage detector they must be protected by a fuse.

A suitable probe and lead is shown in Fig. 2.47.

GS 38 also tells us that where the test is being made simply to establish the presence or absence of a voltage, the preferred method is to use a proprietary test lamp or voltage indicator which is suitable for the working voltage, rather than a multimeter. Accident history has shown that incorrectly set multimeters or makeshift devices for voltage detection have frequently caused accidents. Figure 2.48 shows a suitable voltage indicator. Test lamps and voltage indicators are not fail-safe, and therefore GS 38 recommends that they should be regularly proved, preferably before and after use, as described previously in the flowchart for a safe isolation procedure.

The IEE Regulations (BS 7671) also specify the test voltage or current required to carry out particular tests satisfactorily. All testing must, therefore, be carried out using an 'approved' test instrument if the test results are to be valid. The test instrument must also carry a calibration certificate, otherwise the recorded results may be void. Calibration certificates usually last for a year. Test instruments must, therefore, be tested and recalibrated each year by an approved supplier. This will maintain the accuracy of the instrument to an acceptable level, usually within 2% of the true value.

Modern digital test instruments are reasonably robust, but to maintain them in good working order they must be treated with care. An approved test instrument costs equally as much as a good-quality camera; it should, therefore, receive the same care and consideration.

CONTINUITY TESTER

To measure accurately the resistance of the conductors in an electrical installation we must use an instrument which is capable of producing an open circuit voltage of between 4 and 24 V a.c. or d.c., and deliver a short-circuit current of not less than 200 mA (Regulation 713–02). The functions of continuity testing and insulation resistance testing are usually combined in one test instrument.

INSULATION RESISTANCE TESTER

The test instrument must be capable of detecting insulation leakage between live conductors and between live conductors and earth. To do this and comply with Regulation 713–04 the test instrument must be capable of producing a test voltage of 250, 500 or 1000 V and deliver an output current of not less than 1 mA at its normal voltage.

EARTH FAULT LOOP IMPEDANCE TESTER

The test instrument must be capable of delivering fault currents as high as 25 A for up to 40 ms using the supply voltage. During the test, the instrument does an Ohm's law calculation and displays the test result as a resistance reading.

RCD TESTER

Where circuits are protected by a residual current device we must carry out a test to ensure that the device will operate very quickly under fault conditions and within the time limits set by the IEE Regulations. The instrument must, therefore, simulate a fault and measure the time taken for the RCD to operate. The instrument is, therefore, calibrated to give a reading measured in milliseconds to an in-service accuracy of 10%.

If you purchase good-quality 'approved' test instruments and leads from specialist manufacturers they will meet all the Regulations and Standards and therefore give valid test results. However, to carry out all the tests required by the IEE Regulations will require a number of test instruments and this will represent a major capital investment in the region of £1000.

The specific tests required by the IEE Regulations: BS 7671 are described in detail in Chapter 2 of this book under the sub-heading 'Inspection and Testing Techniques.'

Electrical installation circuits usually carry in excess of 1 A and often carry hundreds of amperes. Electronic circuits operate in the milliampere or even microampere range. The test instruments used on electronic circuits must have a *high impedance* so that they do not damage the circuit when connected to take readings. All instruments cause some disturbance when connected into a circuit because they consume some power in order to provide the torque required to move the pointer. In power applications these small disturbances seldom give rise to obvious errors, but in electronic circuits, a small disturbance can completely invalidate any readings taken. We must, therefore, choose our electronic test equipment with great care.

This is described in detail in Chapter 4 of this book under the sub-heading 'Electronic Test Equipment' and suitable test instruments are shown in Figs 4.74–4.76.

So far in this chapter, I have been considering standard electrical installation circuits wired in conductors and cables using standard wiring systems. However, you may be asked to diagnose and repair a fault on a system that is unfamiliar to you or outside your experience and training. If this happens to you I would suggest that you immediately tell the person ordering the work that it is beyond your knowledge and experience. I have said earlier that fault diagnosis can only be carried out successfully by someone with a broad range of experience and a thorough knowledge of the installation or equipment that is malfunctioning. The person ordering the work will not think you a fool for saying straightaway that the work is outside your experience. It is better to be respected for your honesty than to attempt something that is beyond you at the present time and which could create bigger problems and waste valuable repair time.

Let us now consider some situations where special precautions or additional skills and knowledge may need to be applied.

Special situations

OPTICAL FIBRE CABLES

The introduction of fibre-optic cable systems and digital transmissions will undoubtedly affect future cabling arrangements and the work of the electrician. Networks based on the digital technology currently conscientiously and neatly, keeping passageways clear and regularly tidying up the workplace is the sign of a good and competent craftsman. But what do you do with the rubbish that the working environment produces? Well, all the packaging material for electrical fittings and accessories usually goes into either your employer's skip or the skip on site designated for that purpose. All the off-cuts of conduit, trunking and tray also go into the skip. In fact, most of the general site debris will probably go into the skip and the waste disposal company will take the skip contents to a designated local council land fill area for safe disposal.

The part coils of cable and any other re-useable leftover lengths of conduit, trunking or tray will be taken back to your employer's stores area. Here it will be stored for future use and the returned quantities deducted from the costs allocated to that job.

What goes into the skip for normal disposal into a land fill site is usually a matter of common sense. However, some substances require special consideration and disposal. We will now look at asbestos and large quantities of used fluorescent tubes which are classified as 'Special waste'.

Asbestos is a mineral found in many rock formations. When separated it becomes a fluffy, fibrous material with many uses. It was used extensively in the construction industry during the 1960s and 70's for roofing material, ceiling and floor tiles, fire resistant board for doors and partitions, for thermal insulation and commercial and industrial pipe lagging.

In the buildings where it was installed some 40 years ago, when left alone, it does not represent a health hazard, but those buildings are increasingly becoming in need of renovation and modernisation. It is in the dismantling and breaking up of these asbestos materials that the health hazard increases. Asbestos is a serious health hazard if the dust is inhaled. The tiny asbestos particles find their way into delicate lung tissue and remain embedded for life, causing constant irritation and eventually, serious lung disease.

Working with asbestos materials is not a job for anyone in the electrotechnical industry. If asbestos is present in situations or buildings where you are expected to work, it should be removed by a specialist contractor before your work commences. Specialist contractors, who will wear fully protective suits and use breathing apparatus, are the only people who can safely and responsibly carry out the removal of asbestos. They will wrap the asbestos in thick plastic bags and store them temporarily in a covered and locked skip. This material is then disposed of in a special land fill site with other toxic industrial waste materials and the site monitored by the local authority for the foreseeable future.

There is a lot of work for electrical contractors in my part of the country, updating and improving the lighting in government buildings and schools. This work often involves removing the old fluorescent fittings, hanging on chains or fixed to beams and installing a suspended ceiling and an appropriate number of recessed modular fluorescent fittings. So what do we do with the old fittings? Well, the fittings are made of sheet steel, a couple of plastic lampholders, a little cable, a starter and ballast. All of these materials can go into the ordinary skip. However, the fluorescent tubes contain a little mercury and fluorescent powder with toxic elements, which cannot be disposed of in the normal land fill sites. The responsible way to dispose of fluorescent tubes is by grinding them up into small pieces using a 'lamp crusher', which looks very much like a garden waste shredder. The crushed lamp contents falls into a heavy duty plastic bag which is sealed and disposed of along with the asbestos, material and other industrial waste in special land fill sites.

The COSHH Regulations and the Controlled Waste Regulations 1998 have encouraged specialist companies to set up businesses dealing with the responsible disposal of toxic waste material. Specialist companies have systems and procedures, which meet the relevant regulation, and they would usually give an electrical company a certificate to say that they had disposed of a particular waste material responsibly. The system is called 'Waste Transfer Notes'. The notes will identify the type of waste taken by whom and its final place of disposal. The person handing over the waste material to the waste disposal company will be given a copy of the notes and this must be filed in a safe place, probably in the job file or a dedicated file. It is the proof that your company has carried out its duty of care to dispose of the waste responsibly. The cost of this service is then passed on to the customer. These days, large employers and local authorities insist that waste is disposed of properly.

The Environmental Health Officer at your local Council Offices will always give advice and point you in the direction of specialist companies dealing with toxic waste disposal.

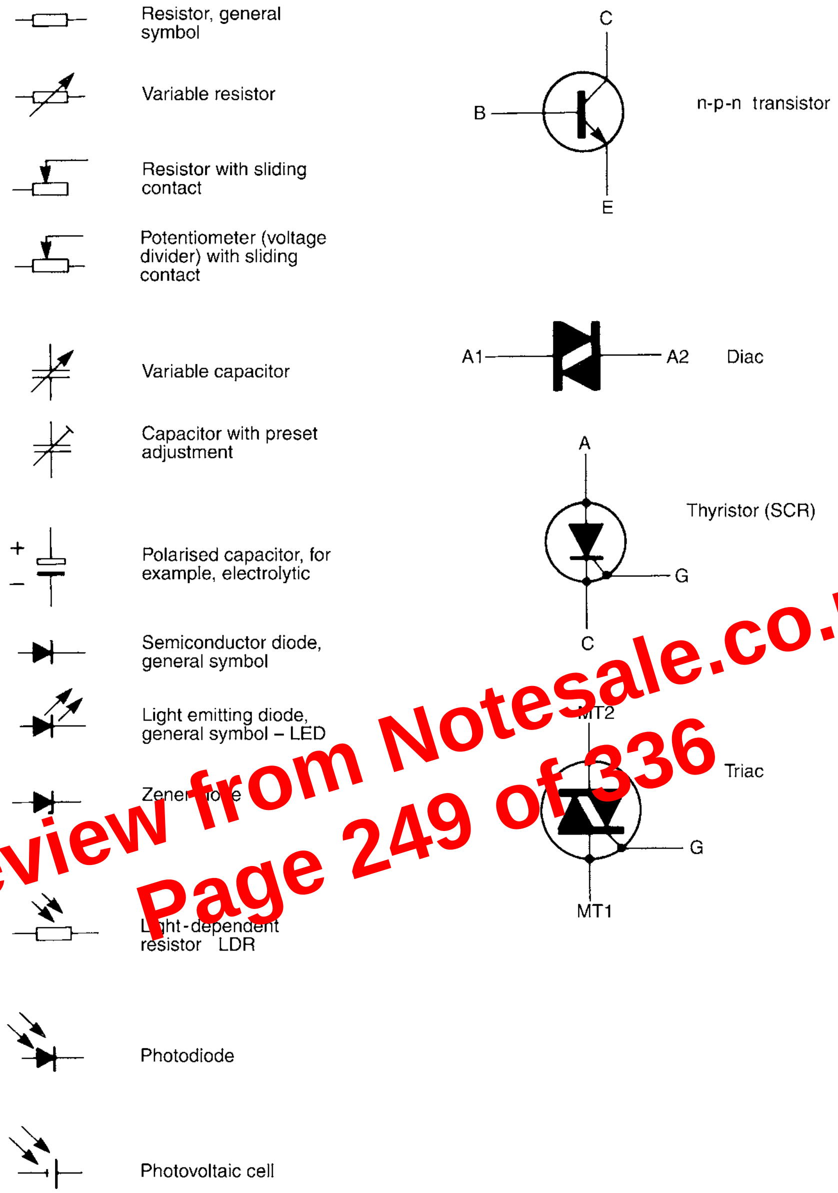


Fig. 4.1 Some BS EN 60617 graphical symbols used in electronics.

Fig. 4.3. Variable resistors are also known as potentiometers because they can be used to adjust the potential difference (voltage) in a circuit. The variation in resistance can be to either a logarithmic or a linear scale.

The value of the resistor and the tolerance may be marked on the body of the component either by direct numerical indication or by using a standard colour code. The method used will depend upon the type, physical size and manufacturer's preference, but in general the larger components have values marked directly on the body and the smaller components use the standard resistor colour code.

ABBREVIATIONS USED IN ELECTRONICS

Where the numerical value of a component includes a decimal point, it is standard practice to include the prefix for the multiplication factor in place of the diode will break down if the current rating is exceeded, because excessive heat will be generated. Manufacturer's information therefore gives maximum voltage and current ratings for individual diodes which must not be exceeded. However, it is possible to connect a number of standard diodes in series or parallel, thereby sharing current or voltage, as shown in Fig. 4.16, so that the manufacturers' maximum values are not exceeded by the circuit.

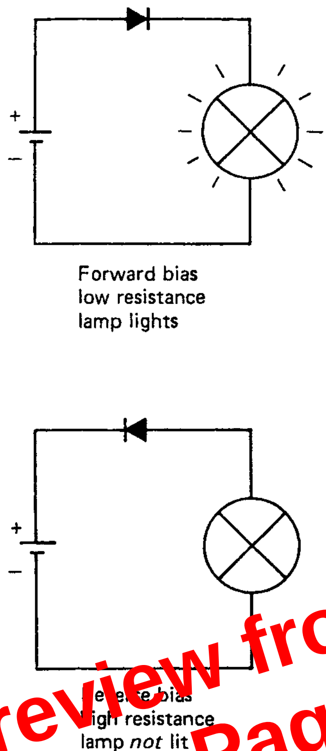


Fig. 4.14 Forward and reverse bias of a diode.

DIODE TESTING

The p–n junction of the diode has a low resistance in one direction and a very high resistance in the reverse direction.

Connecting an ohmmeter, as shown in Fig. 4.76 with the red positive lead to the anode of the junction diode and the black negative lead to the cathode, would give a very low reading. Reversing the lead connections would give a high resistance reading in a 'good' component.

ZENER DIODE

A Zener diode is a silicon junction diode but with a different characteristic than the semiconductor diode considered previously. It is a special diode with a predetermined reverse breakdown voltage, the mechanism for which was discovered by Carl Zener in 1934. Its symbol and general appearance are shown in Fig. 4.17. In its forward bias mode, that is, when the

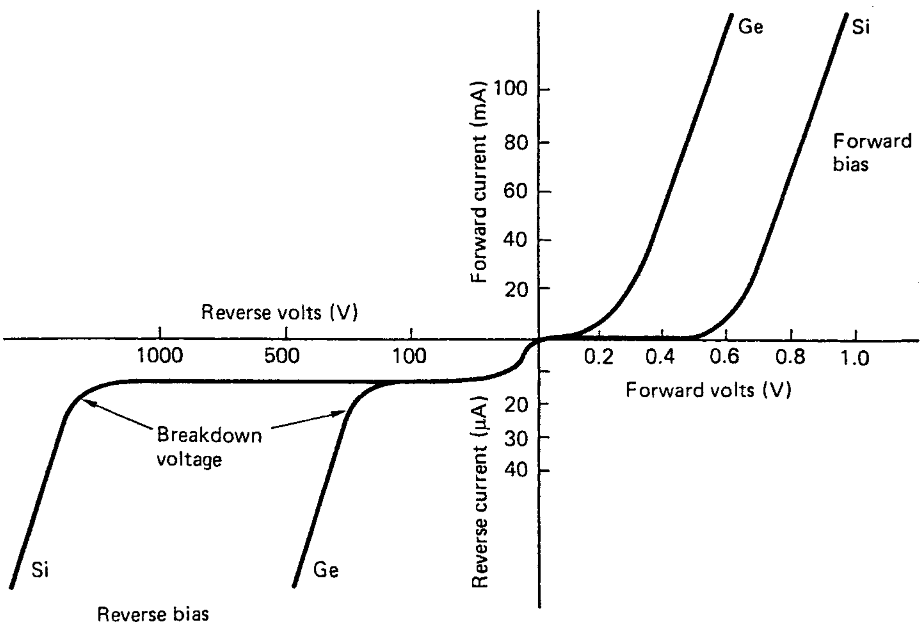


Fig. 4.15 Forward and reverse bias characteristic of silicon and germanium.

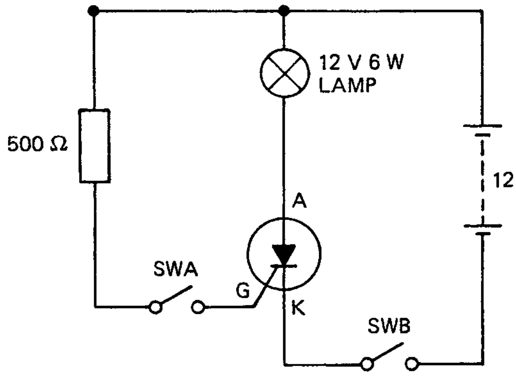


Fig. 4.34 Thyristor test circuit.

current flow through the device. The door is opened – we say the thyristor is triggered – to a conducting state by applying a pulse voltage to the gate connection. Once the thyristor is in the conducting state, the gate loses all control over the devices. The only way to bring the thyristor back to a non-conducting state is to reduce the voltage across the anode and cathode to zero or apply reverse voltage across the anode and cathode.

We can understand the operation of a thyristor by considering the circuit shown in Fig. 4.34. This circuit can also be used to test suspected faulty components.

When SWB only is closed the lamp will not light, but when SWA is also closed, the lamp lights to full brilliance. The lamp will remain illuminated even when SWA is opened. This shows that the thyristor is operating correctly. Once a voltage has been applied to the gate the thyristor becomes forward conducting, like a diode, and the gate loses control.

A thyristor may also be tested using an ohmmeter as described in Table 4.6, assuming that the red lead of the ohmmeter is positive as described in Chapter 12.

The thyristor has no moving parts and operates without arcing. It can operate at extremely high speeds, and

Table 4.6 Thyristor testing using an ohmmeter

A 'good' thyristor will give the following readings:
Black to cathode and red on gate = low resistance Red to cathode and black on gate = a higher resistance value
The value of the second reading will depend upon the thyristor, and may vary from only slightly greater to very much greater.
Connecting the test instrument leads from cathode to anode will result in a very high resistance reading, whatever polarity is used.

the currents used to operate the gate are very small. The most common application for the thyristor is to control the power supply to a load, for example, lighting dimmers and motor speed control.

The power available to an a.c. load can be controlled by allowing current to be supplied to the load during only a part of each cycle. This can be achieved by supplying a gate pulse automatically at a chosen

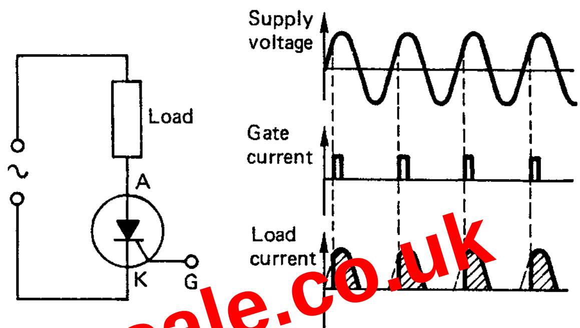


Fig. 4.35 Waveforms to show the control effect of a thyristor.

point in each cycle, as shown by Fig. 4.35. Power is reduced by triggering the gate later in the cycle.

The thyristor is only a half-wave device (like a diode) allowing control of only half the available power in an a.c. circuit. This is very uneconomical, and a further development of this device has been the triac which is considered next.

THE TRIAC

The triac was developed following the practical problems experienced in connecting two thyristors in parallel, to obtain full wave control, and in providing two separate gate pulses to trigger the two devices.

The triac is a single device containing a back-to-back, two-directional thyristor which is triggered on both halves of each cycle of the a.c. supply by the same gate signal. The power available to the load can, therefore, be varied between zero and full load.

Its symbol and general appearance are shown in Fig. 4.36. Power to the load is reduced by triggering the gate later in the cycle, as shown by the waveforms of Fig. 4.37.

The triac is a three-terminal device, just like the thyristor, but the terms anode and cathode have no

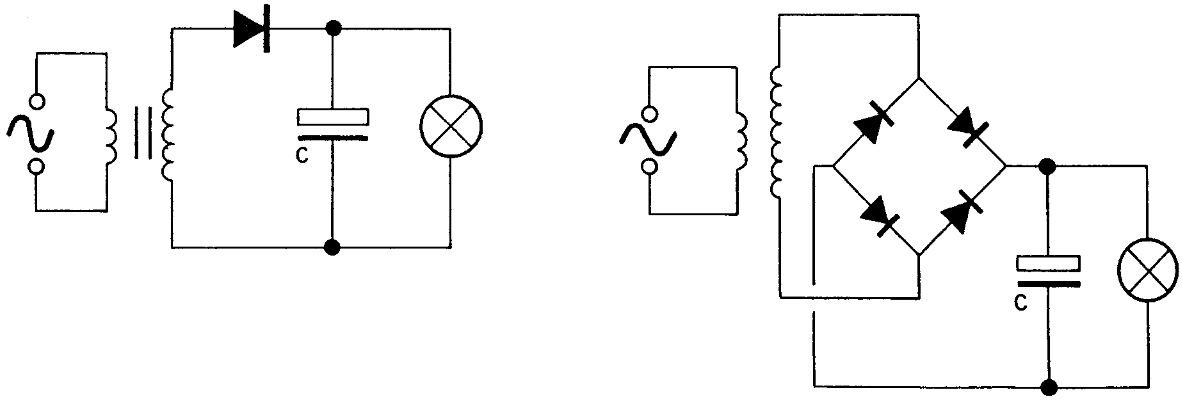


Fig. 4.45 Rectified a.c. with smoothing capacitor connected.

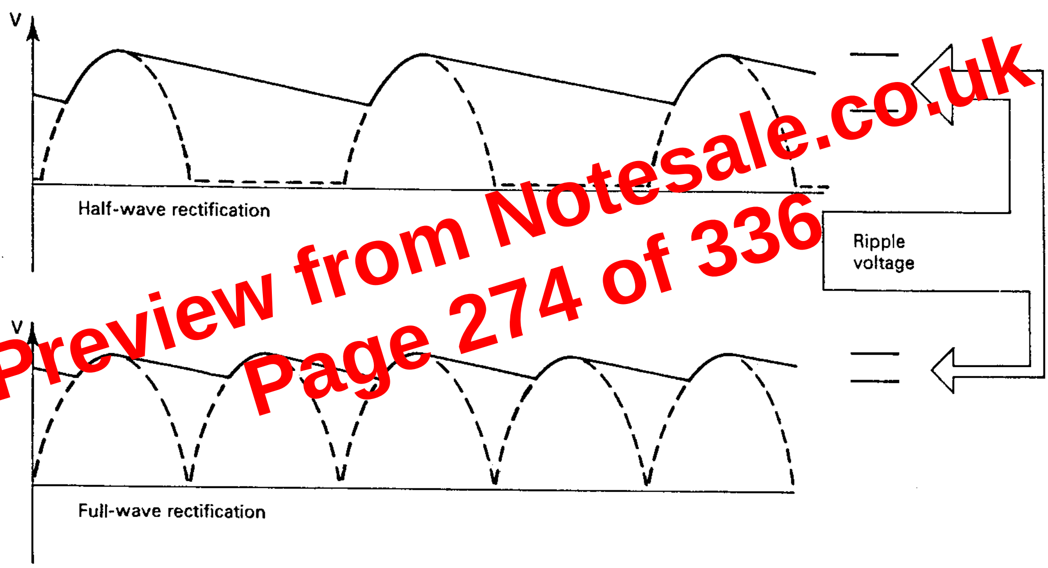


Fig. 4.46 Output waveforms with smoothing showing reduced ripple with full wave.

circuit and, therefore, the output ripple on the full-wave circuit is smaller, giving better smoothing. Increasing the current drawn from the supply increases the size of the ripple. Increasing the size of the capacitor reduces the amount of ripple.

LOW-PASS FILTER

The ripple voltage of the rectified and smoothed circuit shown in Fig. 4.45 can be further reduced by adding a low-pass filter, as shown in Fig. 4.47. A low-pass filter allows low frequencies to pass while blocking higher frequencies. Direct current has a frequency of zero hertz, while the ripple voltage of a full-wave rectifier has a frequency of 100 Hz. Connecting the low-pass filter will allow the d.c. to pass while blocking the ripple voltage, resulting in a smoother output voltage.

The low-pass filter shown in Fig. 4.47 does, however, increase the output resistance, which encourages the voltage to fall as the load current increases. This can be reduced if the resistor is replaced by a choke, which has a high impedance to the ripple voltage but a low resistance, which reduces the output ripple without increasing the output resistance.

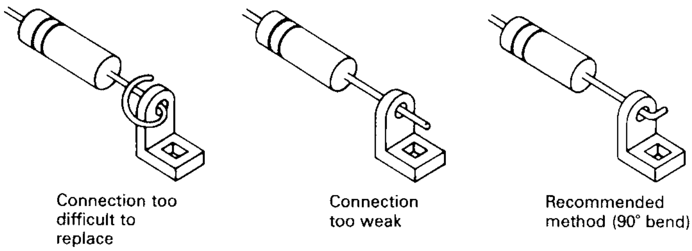


Fig. 4.56 Shaping conductors to give strength to electrical connections to tag terminals.

cut after soldering, cutters with a shearing action should be used, as shown in Fig. 4.59. Side cutters have a pinching action and the shock of the final pinch-through, identified by a sharp click, may fracture the soldered joint or damage the component.

Most electronic components are very sensitive and are easily damaged by excess heat. Soldered joints must not, therefore, be made close to the body of the component or the heat transferred from the joint may cause some damage. When components are being soldered into a circuit the heat from the soldering iron at the connection must be diverted or 'shunted' away from the body of the component. This can be done by placing a pair of long-nosed pliers or a crocodile clip

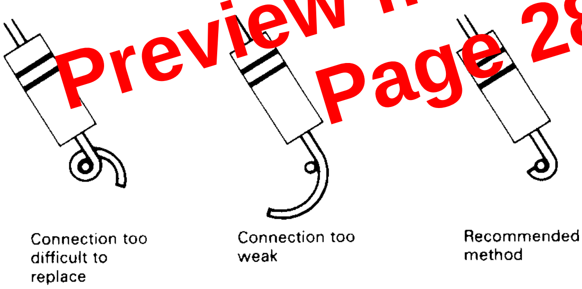


Fig. 4.57 Shaping conductors to give strength to electrical connections to pin terminals (plan view).

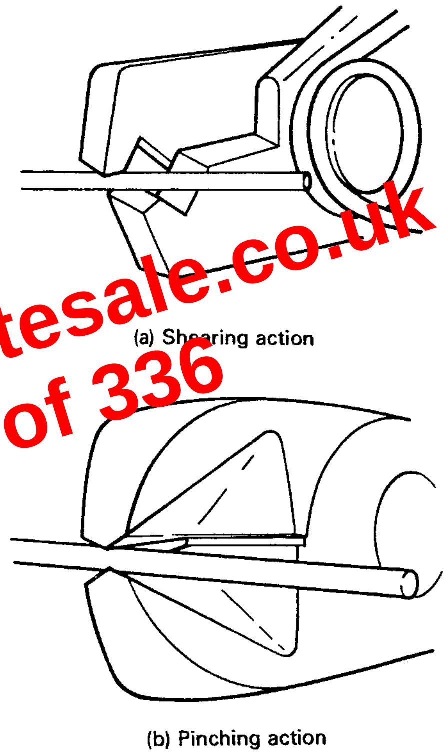


Fig. 4.59 Wire cutting.

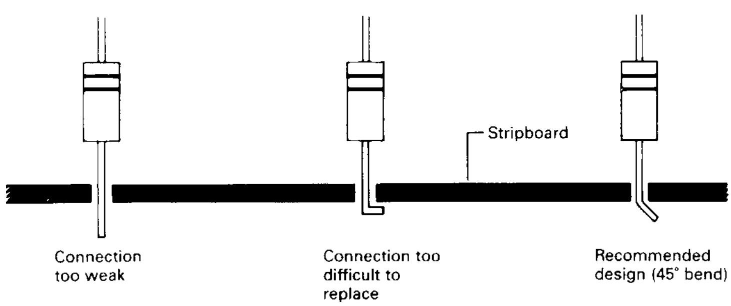


Fig. 4.58 Shaping conductors to give strength to electrical connections to stripboard.

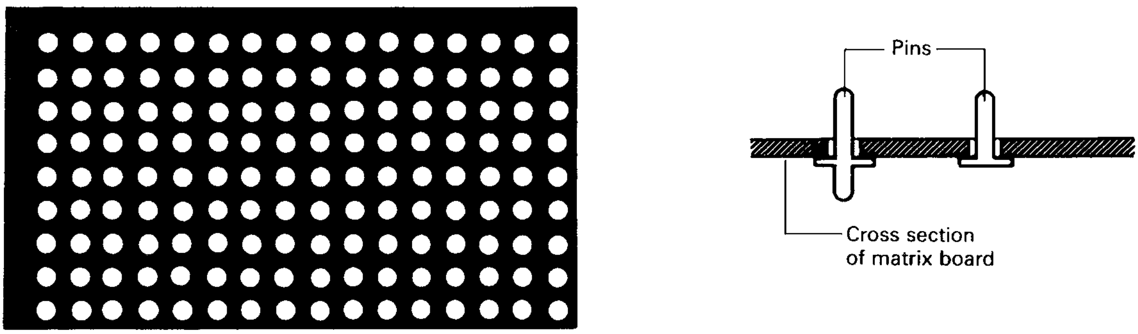


Fig. 4.63 Matrix board and double-sided and single-sided pin inserts.

various sizes: the 149 × 114 mm board is pierced with 58 × 42 holes and the 104 × 65 mm board has 39 × 25 holes. Matrix pins press into any of the holes in the board and provide a terminal post to which components and connecting wires can be soldered. Single-sided or double-sided matrix pins are available. Double-sided pins have the advantage that connections can be made on the underside of the board as well as on the top. The hole spacing of 0.1 inch makes the board compatible with many electronic components. Plug-in relays, DIL integrated circuits and many sockets and connectors all use 0.1 inch spacing at their connections.

Matrix board is probably the easiest and cheapest way to build simple electronic circuits. It is recommended that inexperienced circuit builders construct the circuit on the matrix board using a layout which is very similar to the circuit diagram to reduce the possibility of mistakes.

Suppose, for example, that we intend to build the very simple circuit shown in Fig. 4.64. First we would insert four pins into the matrix board as shown. The diode would then be connected between pins A and B, taking care that the anode was connected to pin A. The resistor would be connected between pins B and C and a wire linked between pins C and D. The a.c. supply from a signal generator would be connected to pins A and D by 'flying' leads and the oscilloscope leads to pins B and C. This circuit would show half-wave rectification. When planning the conversion of circuit diagrams into a matrix board layout it helps to have a positional reference system so that we know where to push the pins in the matrix board.

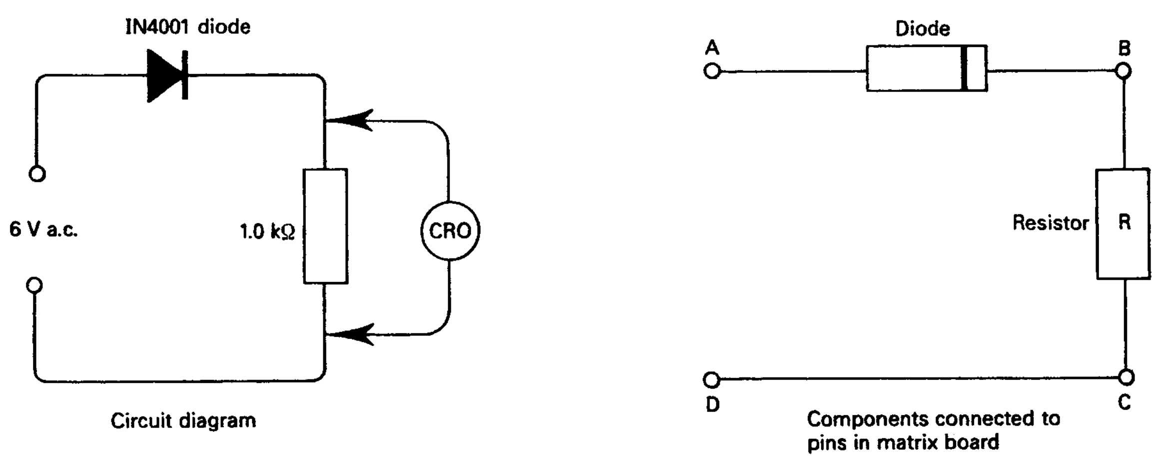


Fig. 4.64 Circuit diagram converted to a component layout.

APPENDICES

Appendix A: Obtaining information and electronic components

For local suppliers, you should consult your local telephone directory. However, the following companies distribute electrical and electronic components throughout the UK. In most cases, telephone orders received before 5 p.m. can be dispatched the same day.

Electromail (R.S. mail order business), P.O. Box 33, Corby, Northants NN17 9EL, Telephone: 011536 204555. Website: RS www.com

Farnell Electronic Components, Canal Road, Leeds LS12 2TU, Telephone: 0113 636311. Email: Sale@farnellinone.co.uk

Maplin Electronics, Valley Road. Wombwell S73 OBS, Telephone: 01226 751155. Website: www.maplin.co.uk

Rapid Electronics Ltd, Heckworth Close, Severalls Industrial Estate, Colchester, Essex CO4 4TB, Telephone: 01206 751166. Fax: 01206 751188. Email: sales@rapidelec.co.uk

R.S. Components Ltd, P.O. Box 99, Corby, Northants NN17 9RS, Telephone: 01536 201234. Website: RS www.com

Verospeed Electronic Components, Boyatt Wood, Eastleigh, Hants SO5 4ZY, Telephone: 02380 644555.

Appendix B: Abbreviations, symbols and codes

Abbreviations used in electronics for multiples and sub-multiples

T	tera	10^{12}
G	giga	10^{9}
M	mega or meg	10^{6}
k	kilo	10^{3}
d	deci	10^{-1}
c	centi	10^{-2}
m	milli	10^{-3}
μ	micro	10^{-6}
n	nano	10^{-9}
p	pico	10^{-12}

Terms and symbols used in electronics

Term	Symbol
Approximately equal to	$\simeq$
Proportional to	$\propto$
Infinity	∞
Sum of	Σ
Greater than	$>$
Less than	$<$
Much greater than	$\gg$
Much less than	$\ll$
Base of natural logarithms	e
Common logarithms of x	$\log x$
Temperature	θ
Time constant	T
Efficiency	η
Per unit	p.u.

9.1 V	BZX79C9V1	BZX55C9V1	BZX85C9V1	BZV85C9V1	BZX70C9V1	BZT03C9V1	1N5346B		BZY93C9V1#	
10 V	BZX79C10	BZX55C10	BZX85C10	BZV85C10	BZX70C10	BZT03C10	1N5347B	BZW03-C10 NEW	BZY93C 10#	BZY91C10
11 V	BZX79C11	BZX55C11	BZX85C11	BZV85C11	BZX70C11	BZT03C11	1N5348B		BZY93C11	
12 V	BZX79C12	BZX55C12	BZX85C12	BZV85C12	BZX70C12	BZT03C12	1N5349B	BZW03-C12 NEW	BZY93C12#	BZY91C12
13 V	BZX79C13	BZX55C13	BZX85C13	BZV85C13	BZX70C13	BZT03C13	1N5350B		BZY93C13#	
15 V	BZX79C15	BZX55C15	BZX85C15	BZV85C15	BZX70C15	BZT03C15	1N5352B		BZY93C15#	BZY91C15#
16 V	BZX79C16	BZX55C16	BZX85C16	BZV85C16	BZX70C16	BZT03C16	1N5353B		BZY93C16#	
18 V	BZX79C18	BZX55C18	BZX85C18	BZV85C18	BZX70C18	BZT03C18	1N5355B		BZY93C18#	BZY91C18#
20 V	BZX79C20	BZX55C20	BZX85C20	BZV85C20	BZX70C20	BZT03C20	1N5357B		BZY93C20#	BZY91C20
22 V	BZX79C22	BZX55C22	BZX85C22	BZV85C22	BZX70C22	BZT03C22	1N5358B		BZY93C22	
24 V	BZX79C24	BZX55C24	BZX85C24	BZV85C24	BZX70C24	BZT03C24	1N5359B	BZW03-C24 NEW	BZY93C24#	BZY91C24
27 V	BZX79C27	BZX55C27	BZX85C27	BZV85C27	BZX70C27	BZT03C27	1N5361B	BZW03-C27 NEW	BZY93C27#	BZY91C27
30 V	BZX79C30	BZX55C30	BZX85C30	BZV85C30	BZX70C30	BZT03C30	1N5363B		BZY93C30#	BZY91C30
33 V	BZX79C33	BZX55C33	BZX85C33	BZV85C33	BZX70C33	BZT03C33	1N5364B		BZY93C33#	BZY91C33
36 V	BZX79C36	BZX55C36	BZX85C36	BZV85C36	BZX70C36	BZT03C36	1N5365B	BZW03-C36 NEW	BZY93C36	BZY91C36
39 V	BZX79C39	BZX55C39	BZX85C39	BZV85C39	BZX70C39	BZT03C39	1N5366B		BZY93C39#	
43 V	BZX79C43	BZX55C43	BZX85C43	BZV85C43	BZX70C43	BZT03C43	1N5367B		BZY93C43	BZY91C43
47 V	BZX79C47	BZX55C47	BZX85C47	BZV85C47	BZX70C47	BZT03C47	1N5368B	BZW03-C47 NEW	BZY93C47	BZY91C47
51 V	BZX79C51	BZX55C51	BZX85C51	BZV85C51	BZX70C51	BZT03C51	1N5369B	BZW03-C51 NEW	BZY93C51	BZY91C51
56 V	BZX79C56	BZX55C56	BZX85C56	BZV85C56	BZX70C56	BZT03C56	1N5370B		BZY93C56	
62 V	BZX79C62	BZX55C62	BZX85C62	BZV85C62	BZX70C62	BZT03C62	1N5372B		BZY93C62	BZY91C62
68 V	BZX79C68	BZX55C68	BZX85C68	BZV85C68	BZX70C68	BZT03C68	1N5373B		BZY93C68	BZY91C68
75 V	BZX79C75	BZX55C75	BZX85C75	BZV85C75	BZX70C75	BZT03C75	1N5374B	BZW03-C75 NEW	BZY93C75#	BZY91C75
82 V		BZX55C82	BZX85C82			BZT03C82	1N5375B	BZW03-C82 NEW		