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EARTHING OF FGRIs AND TGRIs

GENERAL AND TECHNICAL INFORMATION

BY COMMAND OF THE DEFENCE COUNCIL

MINISTRY OF DEFENCE

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CONTENTS

PREFACE

1 The purpose of this publication is to identify the earthing arrangements for Communications - Electronic (C-E) equipment. It describes the earthing arrangements and is a guide to ensuring that the highest possible standards of protection to personnel from the hazard of electric shock are achieved, despite the constraints of operating in a mobile or tactical environment.

2 Users of the publication should note that it does not absolve them from their individual and collective responsibilities under the current statutory Health and Safety at Work Regulations.

3 This publication is prepared to JSP 182 Specification. In order to prevent duplication of effort, users of this publication considering the submission of an Unsatisfactory Feature Report (UFR) should first contact the Radio Technical Publication Section (RTPS), by telephone, to discuss the matter. If, following the discussion, a UFR is required, the procedure outlined on the Title Page (Page (i)/(ii)) of this publication is to be followed.

LIST OF ASSOCIATED PUBLICATIONS

RAF Engineering Orders and Procedures	AP 100B-01
Inspection, Testing and Maintenance of Electrical Equipment	AP 119F-0010-5F
Precautions Against Electric Shock in Maintenance Areas	DEF-STAN 61-15
Institute of Electrical Engineers Regulations	16th Edition
HSE Memorandum of Guidance on the Electricity at Work Regulations 1989	HS(R)25

WARNINGS

HAZARDOUS SUBSTANCES

1 Before using any hazardous substance or material, the user must be conversant with the safety precautions and first aid instructions:

1.1 On the label of the container in which it was supplied.

1.2 On the material Safety Data Sheet.

1.3 In local Safety Orders and Regulations.

WARNING

ELECTRIC SHOCK. PERSONNEL MUST BE AWARE THAT RESIDUAL CURRENT DEVICES (RCDs) PROVIDE PROTECTION ONLY FROM CONTACT WITH ONE PHASE OF THE MAINS SUPPLY AND EARTH. THEY DO NOT PROVIDE PROTECTION FROM DIRECT CONTACT WITH A PHASE AND NEUTRAL SIMULTANEOUSLY.

CHAPTER 1

INTRODUCTION AND SCOPE

CONTENTS

INTRODUCTION

1 Defence Standard 61-15 (the Standard) specifies the safety requirements for the design and control of static and mobile land based Communications-Electronic (C-E) facilities, where authorised maintenance of electrical and electronic equipment takes place.

2 The Electricity at Work Regulations (the Regulations), which came into force on 1 Apr 90, require precautions to be taken against the risk of death or injury from electricity during work activities. The Regulations are made under the Health and Safety at Work Act 1974 and impose duties on employers and employees, including trainees, in respect of systems, electrical equipment and conductors, and in respect of work activities on or near electrical equipment.

3 With reference to the earthing of C-E equipment, the Regulations apply to many of the situations covered by the Standard. The Royal Air Force regulations which implement the requirement of the Standard were originally published as RAFSEE Technical Memorandum No 69310 Issue 3. This publication replaces that Memorandum and amends its original content.

4 This publication identifies and describes earthing arrangements for C-E equipment and is a guide to ensuring that the highest possible standards of protection of personnel from electric shock are achieved, despite the constraints of operating in a mobile or tactical environment.

DEFINITIONS

5 For the purpose of this publication, the following definitions shall apply:

5.1 Bonding conductor. A protective conductor providing equipotential bonding.

5.2 Circuit protective conductor. A protective conductor connecting exposed-conductive-parts of equipment to the main earthing terminal.

5.3 Direct contact. Direct contact with normally live parts which may result in electric shock.

5.4 Earth. The conductive mass of the earth, whose electric potential at any point is conventionally taken as zero.

5.5 Earth electrode. A conductor or group of conductors in intimate contact with, and providing an electrical connection to, Earth.

5.6 Earth electrode resistance. The resistance measured between an earth electrode to Earth.

5.7 Earth fault loop impedance. The impedance of the earth fault loop, starting and ending at the point of the earth fault. The impedance is denoted by the symbol Z_s.

5.8 Earth leakage current. A current which flows to Earth, or to extraneous-conductive-parts, in a circuit which is electrically sound. This current may have a capacitive component including that resulting from the deliberate use of leakage capacitors.

5.9 Earthed equipotential zone. A zone within which exposed-conductive-parts and extraneous-conductive-parts are maintained at substantially the same potential by bonding, such that, under fault conditions, the differences in potential between simultaneously accessible exposed and extraneous-conductive-parts will not cause electric shock.

5.10 Earthing. The act of connecting the exposed-conductive-parts of an installation to the main earthing terminal of an installation.

5.11 Earthing conductor. A protective conductor connecting the main earth terminal of an installation to an earth electrode or other means of earthing.

5.12 Electric shock. A dangerous physiological effect resulting from the passage of an electric current through a human body.

5.13 Electrically independent earth electrode. Earth electrodes located at such a distance from one another that the maximum current likely to flow through one of them does not significantly affect the potential of the other(s).

5.14 Equipotential bonding. Electrical connection maintaining various exposed- conductive-parts and extraneous-conductive-parts at substantially the same potential. For the purpose of this AP the term is abbreviated to 'bonding'.

5.15 Exposed-conductive-parts. A conductive part of equipment which can be touched and which is not a live part but may become live under fault conditions.

5.16 Extraneous-conductive-parts. A conductive part liable to introduce a potential, generally earth potential, and not forming part of the electrical installation.

5.17 Indirect contact. Contact with exposed-conductive-parts made live by a fault and which may result in an electric shock.

5.18 Protective conductor. A conductor used for some measure of protection against electric shock by connecting together any of the following parts:

5.18.1 Exposed-conductive-parts.

5.18.2 Extraneous-conductive-parts.

5.18.3 Earth electrode(s).

5.18.4 The main earthing terminal.

5.18.5 The earth point of the source, or an artificial neutral.

5.19 Reduced low voltage system. A system in which the nominal phase to phase voltage does not exceed 110 volts and the nominal phase to earth voltage does not exceed 63.5 volts.

5.20 Residual current. The vector sum of the instantaneous values of a current flowing through all live conductors of a circuit at a point in the circuit.

5.21 Residual current device. A mechanical switching device, or association of devices, intended to cause the opening of the supply contacts when the residual current attains a given value under specified conditions.

5.22 Resistance area (for an earth electrode only). The surface area of ground (around an earth electrode) on which a significant voltage gradient may exist.

5.23 Voltage, nominal. Voltage by which an installation is designated. The following ranges of nominal voltage (RMS values of AC) are defined.

5.23.1 Extra low. Normally not exceeding 50 VAC or 120 V ripple free DC, whether between conductors or to earth.

5.23.2 Low. Normally exceeding extra low voltage but not exceeding 1000 VAC or 1500 VDC between conductors, or 600 VAC or 900 VDC between conductors and earth.

ELECTRIC SHOCK

6 The passage of an electric current through the human body may produce effects known collectively as electric shock. These effects range from harmless or unpleasant sensations to varying degrees of physical damage, paralysis, ventricular fibrillation of the heart, cardiac arrest and ultimately, death. The involuntary recoil from electric shock may well cause physical injury through a fall or other consequential occurrence.

7 The factors which largely determine the magnitude of the electric shock and its likely effect, are the voltage and frequency of the electrical supply, the impedance of the body and any other impedance in the current path, and the duration of the shock current.

8 The human heart is frequency sensitive and alternating current supplies of 50 Hz - 60 Hz present more danger to life than other AC sources. A shock current from a 50 Hz - 60 Hz source can induce ventricular fibrillation in the heart (irregular contraction of the heart muscles) and cause it to stop beating if the fibrillation is not immediately arrested. Where other frequencies or direct current sources are involved, the physical damage and danger will depend on the magnitude and duration of the shock.

9 An electric shock is dangerous when the current through the body exceeds a certain minimum value. As stated previously, the degree of danger is dependant not only on the current but also on the time for which it flows. A low current for a long time can easily prove just as dangerous as a high current for a relatively brief period. The applied voltage is in itself important in producing this minimum current through the resistance of the body. In normal dry working conditions, supply voltages in excess of 50 VAC or 120 VDC are liable to cause dangerous levels of shock current to flow through the body. It should be noted that the shock effect is produced by the difference in voltage levels at the two points of contact with the body and does not necessarily depend on contact with earth.

10 The ohmic or electrical resistance of the human body has a negative characteristic and, instead of trying to set precise values of internal body resistance, the concept of touch voltage has been adopted. Unbroken dry skin may show a typical contact resistance of 150 kΩ, but moisture and contamination of the skin may reduce the hand to hand or hand to foot resistance to a figure as low as 500 Ω.

11 If a person with a body resistance of 500 Ω received an electric shock from a 240 VAC source, the resulting current passing through the body would be 480 mA. However, a much smaller current can be lethal. It has been estimated that 3 mA is sufficient for a shock to be felt, by a tingling sensation. Between 10 mA and 15 mA, a tightening of the muscles is experienced and there is difficulty in releasing any object gripped. Acute discomfort is felt at this current level. Between 25 mA and 30 mA the dangerous level is reached, with the extension of muscular tightening, particularly to the thoracic muscles. Over 50 mA results in fibrillation of the heart which is generally lethal if immediate specialist attention is not given.

12 The basic reason for earthing is to prevent or minimise the risk of shock to humans or animals. The reason for having properly earthed metalwork in an installation is to provide a low resistance discharge path for earth leakage current which would otherwise prove injurious or fatal to any person touching the metalwork associated with a faulty circuit.

13 Electric shock experienced due to electrostatic discharge is of a different character. Static charge is caused by the separation of electrons from neutral substances, leaving them positively charged and transferring the corresponding negative charge to the object receiving the electrons. Static charge is created primarily by contact and separation of electrically unlike substances or by friction between persons and/or materials. Examples are rubber-tyred vehicles, liquid being pumped through pipes and hoses, fuel moving about in a refueller whilst in transit, etc.

14 Since objects have a relatively small capacitance, a small flow of electrons can produce a high voltage difference at the surface on separation; the voltage is equal to the charge divided by the capacitance. Measures employed to reduce the hazards of static electricity are earthing and bonding. Earthing by a low resistance path reduces the voltage of the object by sharing the charge with the general mass of earth which has an enormous capacitance. Bonding equalizes the voltage difference between two or more objects. The generation of static electricity cannot be prevented, but the sparking hazard, which is a source of danger when it occurs in close proximity to flammable liquids and gases, can be effectively eliminated by correct bonding and earthing.

EARTH: WHAT IS IT AND WHY DO WE CONNECT TO IT?

15 The thin layer of material which covers our planet, be it rock, clay, chalk or whatever, is what we in the world of electricity call 'earth'. Earth is not a good conductor of electricity, so why do we need to connect anything to it? To understand the issue, one has to look at Potential Difference (PD). PD is exactly what it says: it is a difference in potential (volts). Hence two conductors having PDs of 50 V and 30 V have a PD of 50 - 30 = 20 V. The original PDs, 50 V and 30 V, are the PDs between 50 V and 0 V and 30 V and 0 V. So where does this 0 V or zero potential come from? The answer is the Earth.

16 The definition of earth is therefore 'the conductive mass of earth whose electrical potential at any point is conventionally taken as zero'. If a voltmeter is connected between the phase conductor of a 13 amp socket and earth, a reading of 240 V would be indicated; the phase conductor is at 240 V, the earth at zero volts. It must be remembered that we are talking about the supply industry in the United Kingdom, where, under the 1937 Electricity Supply Regulations, an Electricity Board is required, unless otherwise authorised, to earth the low voltage supply of the system at one point only. The star point (the neutral) of the secondary winding of the supply distribution transformer at the substation is usually the chosen point. By earthing the supply the whole system is tied to the potential of the general mass of earth.

17 In Fig 1, note the connection of the neutral point which makes it possible to have a complete circuit via the earth. Supply authority neutrals, as stated previously, are connected to the conductive mass of earth. This means that a person touching a live part while standing on the earth would take the place of the voltmeter at Fig 1 and could suffer a severe electric shock. The same situation would arise if a person was touching a faulty appliance and a gas or water pipe as shown in Fig 2 (overleaf).

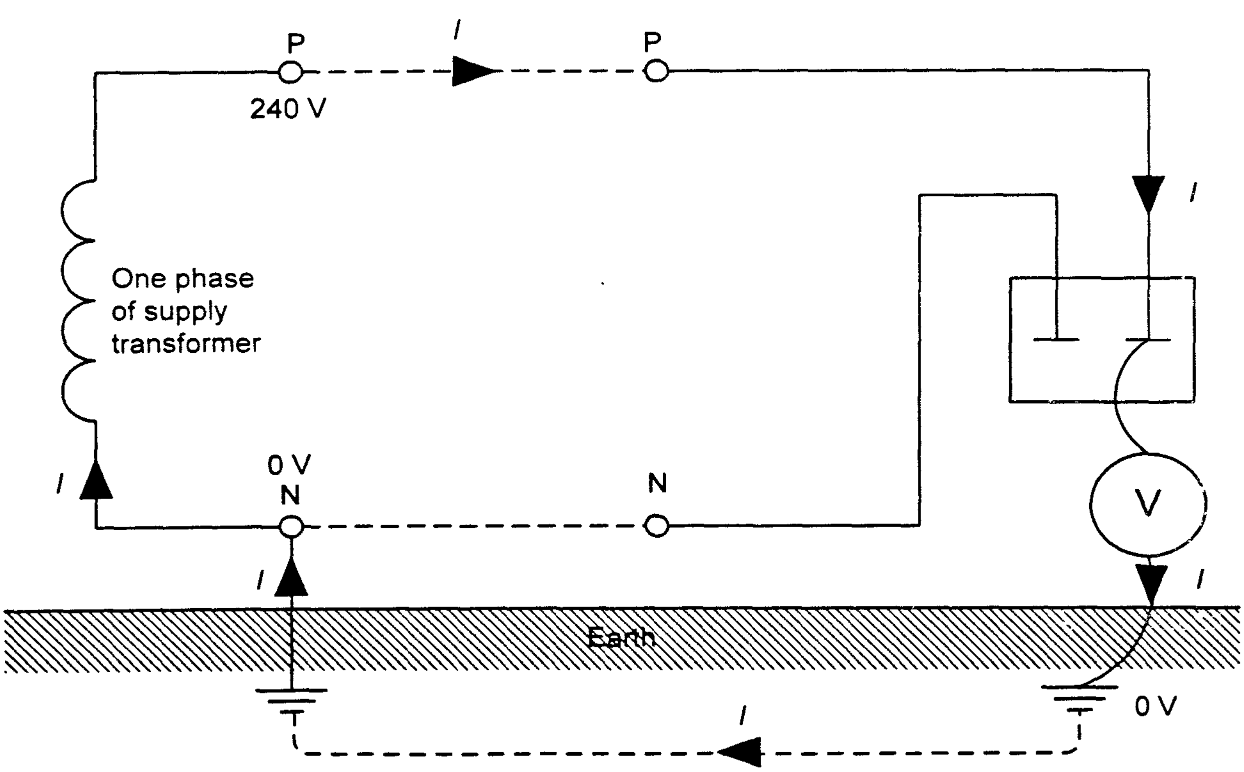

Fig 1 Voltage indication between line and earth

18 One method of providing some measure of protection against these effects is to join together (bond) all metallic parts and connect them to earth. This ensures that all metalwork in a fault free situation is at or near zero volts, and under fault conditions all metalwork will rise to the same potential. Simultaneous contact with two such metal parts would not result in a shock as there is no PD between them. This is know as earthed equipotential bonding.

19 Earth is not a good conductor unless it is wet; therefore it presents a high resistance to the flow of electric current. The earth resistance is usually enough to restrict fault current to a level well below that of the rating of the protective device (the 30 A fuse in the case of Fig 2), leaving a faulty circuit uninterrupted. Clearly this is not a healthy situation. To overcome this problem, there is a requirement at the design stage of an installation to provide a low resistance earth return path which will operate the protection devices in the event of an earth fault on the installed equipment.

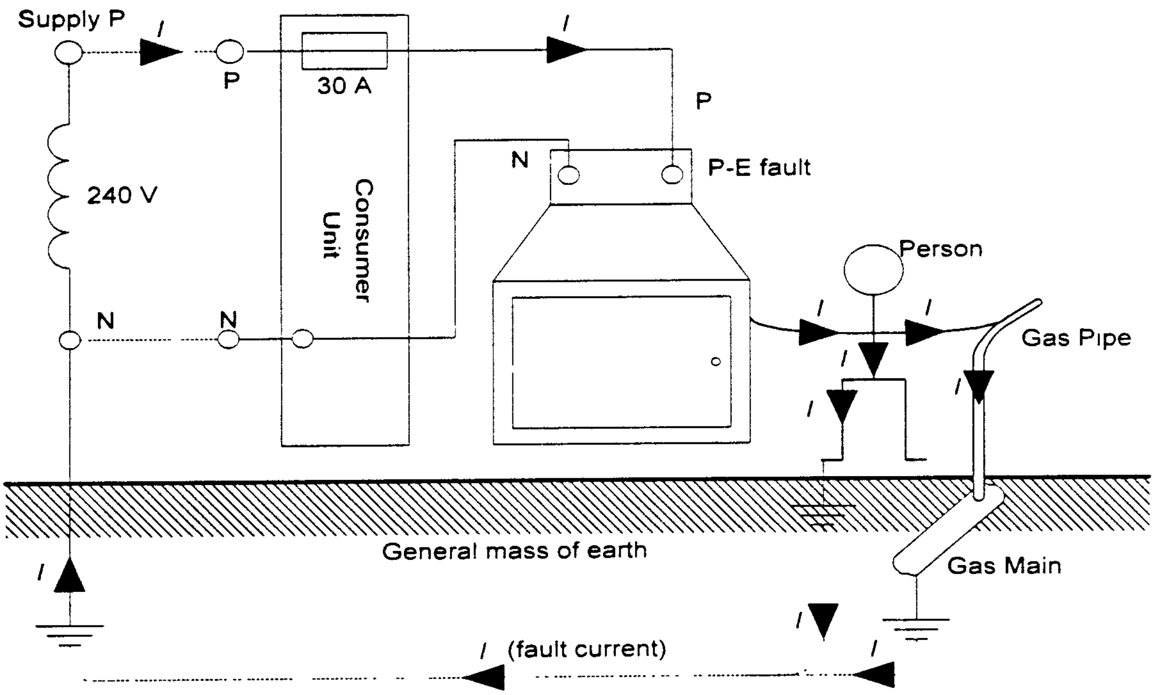

Fig 2 Fault current passing through an individual

CHAPTER 2

DESIGN CONSIDERATIONS

CONTENTS

SYSTEM EARTHING AT FIXED INSTALLATIONS

1 The system earthing depends upon the relationship between the source of the supply and of exposed-conductive-parts of the installation, to earth. System earthing is designed primarily to preserve the security of the system by ensuring that the potential on each conductor is restricted to a value consistent with the level of insulation applied. The type of system in use within a building is identified by the means of earthing that is employed, and information pertaining to the system for a particular fixed site is available from the Works Services Manager (WSM).

2 As detailed in the Institute of Electrical Engineers Wiring Regulations, five systems are available; these being TN-C, TN-S, TN-C-S, TT and IT. The systems are designated by the initials used and these initials relate to the method of earthing provided by the supply authority, the relationship between exposed-conductive-parts and earth and the arrangement of neutral and protective conductors. The letter designations are as follows:

2.1 The first letter denotes the earthing arrangements at the source of the supply and may be as follows:

2.1.1 T - Direct connection of one or more points to earth.

2.1.2 I - All live parts isolated from Earth or one point connected to earth through an impedance.

2.2 The second letter denotes the relationship between the exposed-conductive-parts of the installation and earth and may be as follows:

2.2.1 N - Direct electrical connection of the exposed-conductive-parts to the earthed point of the source of energy, which, for AC, is usually the neutral point.

2.2.2 T - Direct electrical connection of the exposed-conductive-parts to earth, independently of the earthing of any point of the source of energy.

2.3 The designation TN is further subdivided, depending on the arrangement of the neutral and protective conductors, the arrangement being denoted by a further letter or letters as follows:

2.3.1 S - Neutral and protective functions provided by separate conductors.

2.3.2 C - Neutral and protective functions combined in a single conductor.

NOTE

Figs 1 to 5 are explanatory schematic diagrams of examples of TN-C, TN-S, TN-C-S, TT and IT systems, and are not intended to represent actual installations.

3 Fig 1 shows a TN-C system in which the neutral and protective functions are combined in a single conductor throughout the system. All exposed-conductive-parts of the installation are connected to the combined protective and neutral (PEN) conductor. An example of the TN-C arrangement is earthed concentric wiring, where the conductor consists of an insulated central core surrounded by a flexible metal sheath which forms the return. This system is restricted in its use to installations not connected directly to the public supply, eg a private generating plant.

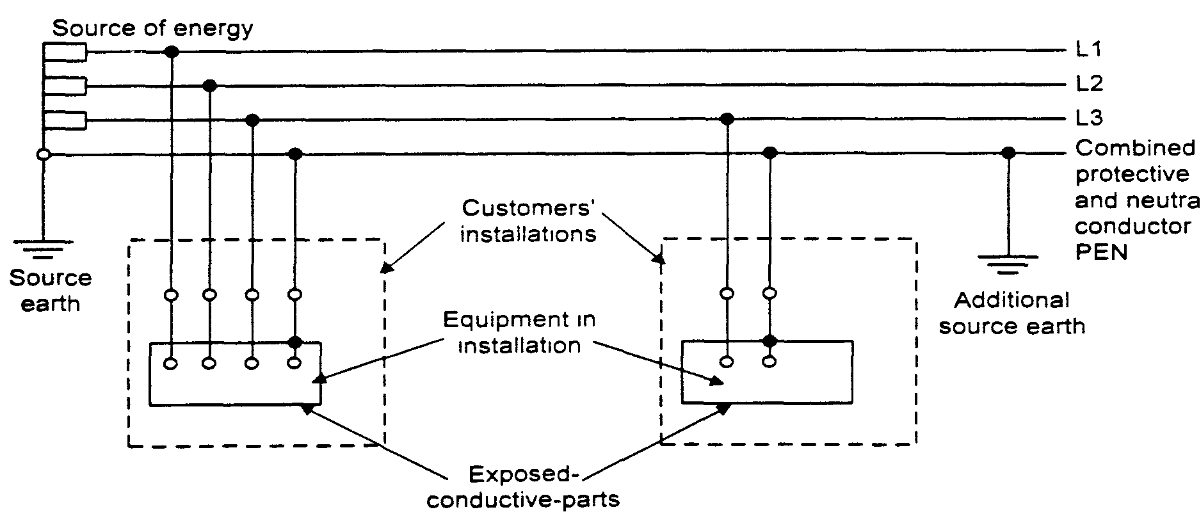

Fig 1 TN-C system

4 Fig 2 shows a TN-S system, which is in common use and has separate neutral and protective conductors. The protective conductor is either the metallic covering of the cable supplying the installation or a separate conductor. All exposed conductive parts of the installation are connected to the protective conductor via the main earthing terminal of the installation.

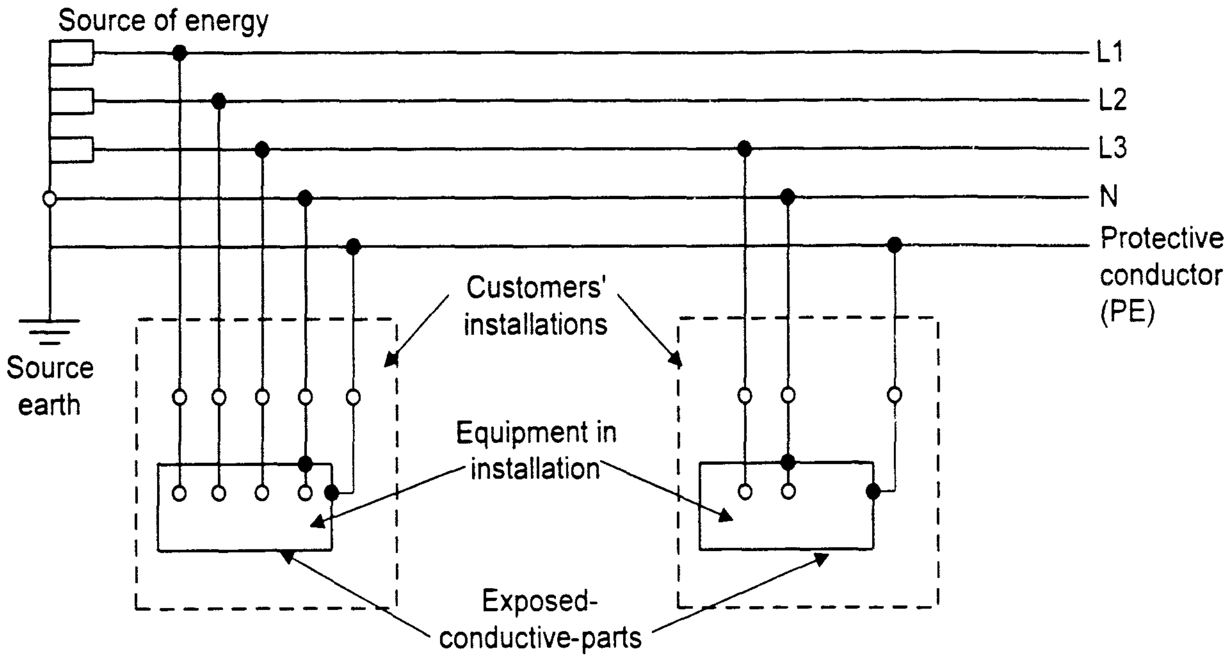

Fig 2 TN-S system

5 Fig 3 shows the usual form of a TN-C-S system, in which the neutral and protective functions are combined in a single conductor in part of the system. The supply is TN-C and the arrangement at the installation is TN-S. This type of distribution is known as Protective Multiple Earthing (PME) and the PEN conductor is referred to as the Combined Neutral and Earth (CNE) conductor. The supply PEN conductor is earthed at several points and an earth electrode may be necessary at or near the installation. All exposed-conductive-parts of the installation are connected to the PEN conductor via the main earthing terminal and the neutral terminal, these terminals being bonded together.

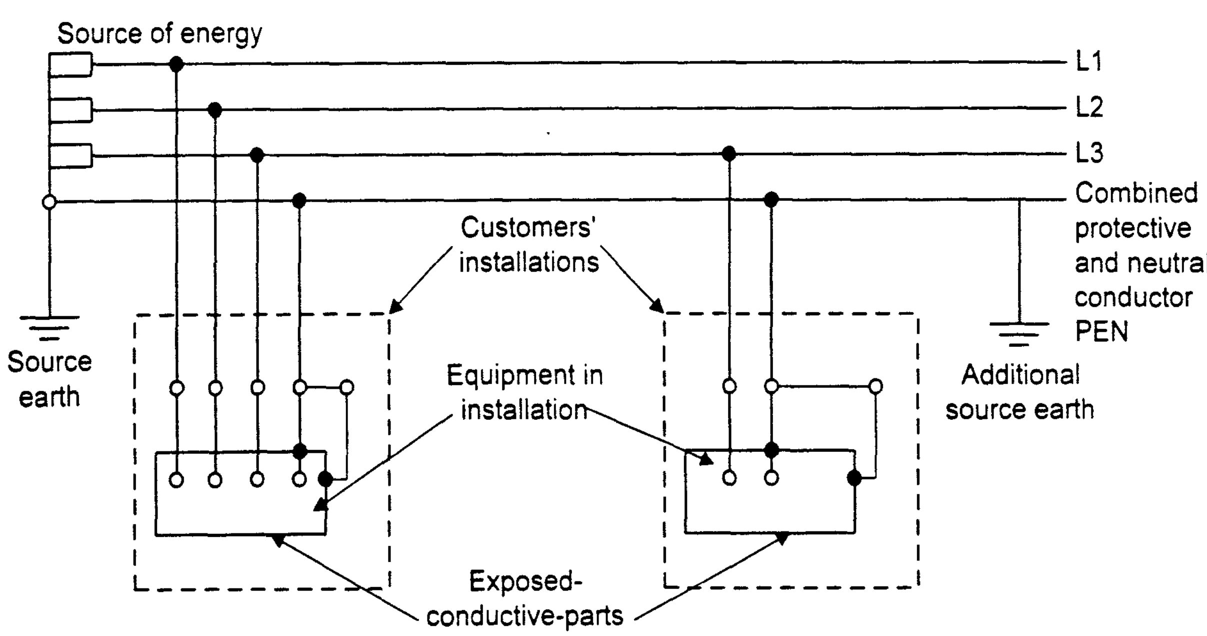

Fig 3 TN-C-S system

6 Fig 4 shows a TT system, with the neutral at the source of energy directly earthed. All exposed-conductive-parts of the installation are connected to an earth electrode which is electrically independent of the source earth. This method is commonly found in overhead supplies in rural districts.

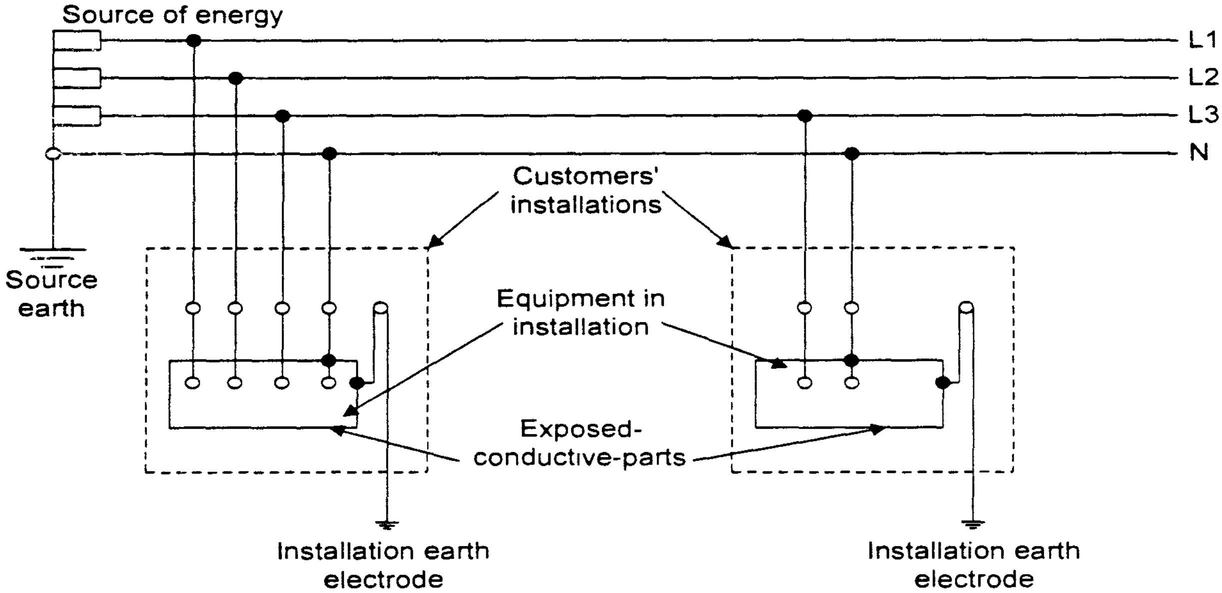

Fig 4 TT system

7 Fig 5 shows an IT system, in which all exposed-conductive-parts of the installation are connected to an earth electrode. The source is either connected to earth through a deliberately introduced earthing impedance or is isolated from earth. Under the Electricity Supply Regulations 1937, this system must not be used for public supplies.

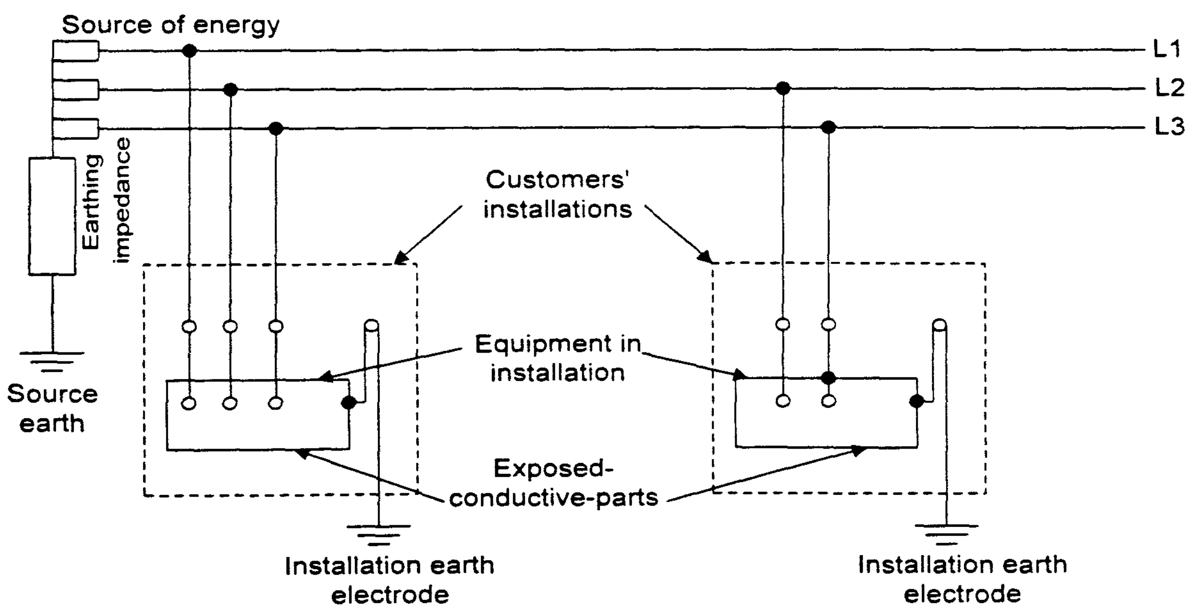

Fig 5 IT system

SYSTEM EARTHING AT TEMPORARY DEPLOYMENT LOCATIONS

8 The types of system earthing described previously are ideal for fixed installations, however, different methods are employed for temporary deployment locations where a public mains supply is not available.

9 Fig 6 shows an example of direct earthing. With this method, the neutral point of the output supply is directly connected to earth and each cabin is equipped with an earth electrode. For this method to be effective the impedance of the earth path must be such that earth leakage currents will be of sufficient magnitude to operate the circuit over-current protective device. Conditions must also be such that the product of the earth resistance in ohms and the leakage current in amps does not exceed 50 VAC or 120 VDC. Because of the relatively high volume resistivity of soil, unless sophisticated earthing electrode systems which are incompatible with the concept of mobile equipment are used, the criteria for ensuring the protection of personnel can seldom be satisfied.

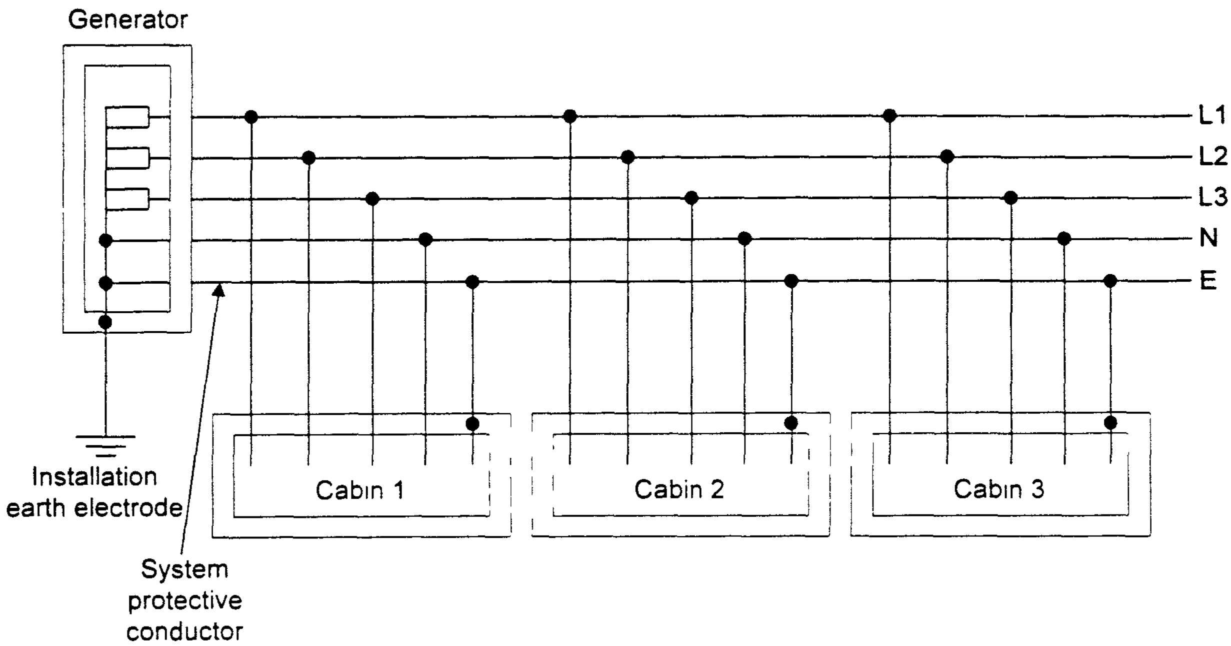

Fig 6. Direct earthing

10 Fig 7 (overleaf) illustrates a direct earthing installation where a fault condition has appeared on the exposed metalwork of the cabin. The fault condition will persist until the system protective device (fuse or circuit-breaker) operates. The actual level of the fault voltage depends on the line voltage V1, source resistance Rs, supply earth return resistance Re and the earth resistance at the installation, Rc. The fault voltage Vf between the cabin exposed metalwork and earth is determined by:

$$Vf = \frac{Rc \times V1}{Rs + Rl + Rf + Rc + Re}$$

and the earth fault current (If) is determined by:

$$If = \frac{V1}{Rs+Rl+Rf+Rc+Re}$$

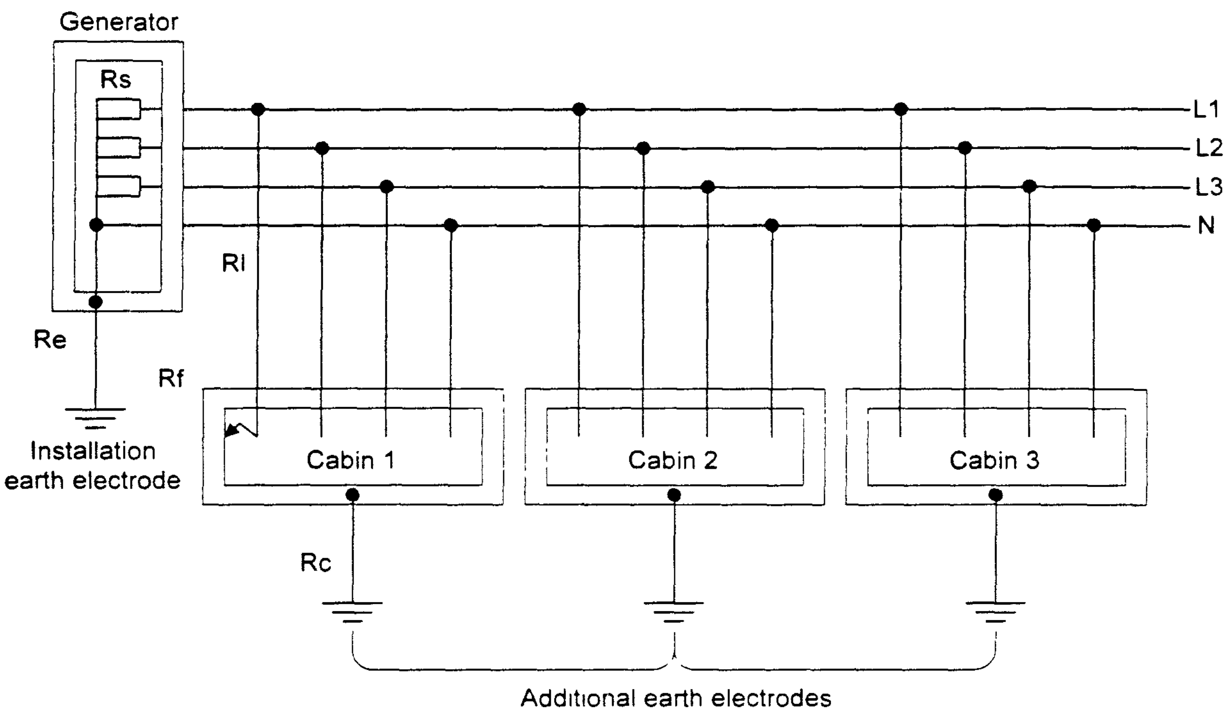

Fig 7 Direct earthing with fault condition

Typical Values:

Rs - Source resistance 0.1 Ω
Rl - Line conductor 0.05 Ω/100 m (35 mm²)
Rf - Fault resistance 0.1 Ω
Re - System main earth electrode 250 Ω
Rc - Chassis earth electrode 250 Ω

11 Substituting into the formula the typical values quoted in Fig 7 produces an earth fault current of 0.5 A and a fault voltage of 120 V on the exposed metalwork. It will be appreciated that a dangerous fault voltage has been exposed and the resulting earth fault current has not operated the over-current protection devices.

12 The previous example illustrates the principle that for temporary deployment locations, direct earthing of the installation by means of temporary earth electrodes, where protective devices are confined to the use of fuses or circuit-breakers, gives virtually no protection for personnel against electric shock.

13 Fig 8 shows an example of direct earthing to a protective conductor. In this method the system protective conductor is provided throughout the installation. The system main earth point and all the ancillary protective conductors are solidly connected to the system protective conductors. So long as the protective conductor remains intact and, under fault conditions, the volts drop in the protective conductor does not exceed that deemed as a dangerous voltage, this method is effective.

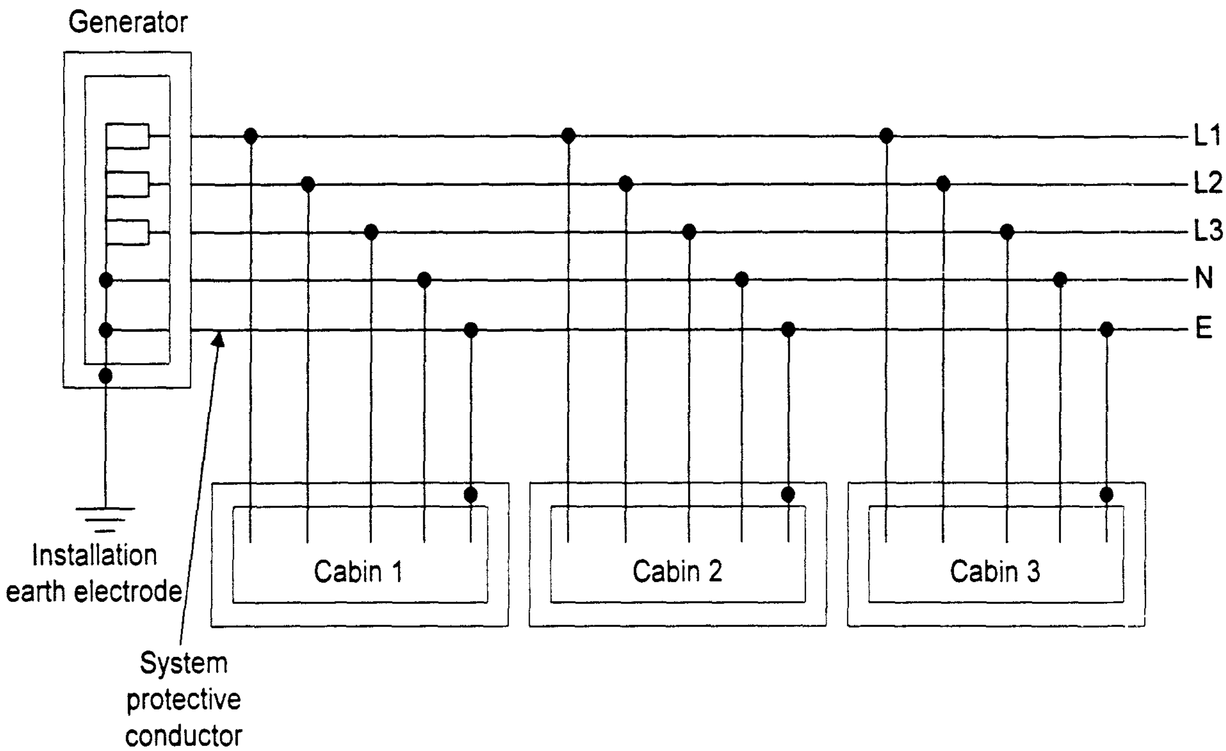

Fig 8 Direct earthing to a protective conductor

14 The only problem with the method shown in Fig 8 is the possibility of a break in the protective conductor, and then an earth fault occurring on the installation beyond the break. Under these conditions, the whole of the protective conductor and connected metal work beyond the break will assume the potential that exists at the fault. There will be no circuit for earth leakage currents, other than fortuitous earth paths, and, under these conditions, the normal over-current protective devices will usually prove ineffective. It is therefore imperative that, prior to the application of power, and at frequent intervals thereafter, a continuity check is carried out on the system protective conductor.

15 This method of installation must be further enhanced by the use of voltage or current operated residual current devices, or earth monitoring equipment.

SYSTEM MAIN EARTH POINT

16 Under the Electricity Supply Regulations 1937, it is permissible to make a permanent connection to earth at only one point on an electrical system, this being known as the system main earth point. This limitation of connecting to earth at only one point on the system is designed to prevent the passage of current through the earth under normal conditions, and thus prevent the accompanying risk of electrolysis and interference with communications equipment.

17 For mobile installations, this is normally achieved by the direct connection to earth of the neutral of a three phase supply, or one pole of a single phase supply. This connection to earth serves the purpose of system earthing and is termed the system main earth point. The point must be located adjacent to the supply transformer or generator.

18 Where installations consist of main and standby sources of supply, the WSM Supply Authority usually stipulates that the change-over system which provides power to the installation must include mechanically interlocked contactors, to prevent the neutral earth bonds of each individual supply source from being connected simultaneously to the load equipment.

19 At a fixed or prepared deployment site, the installation and maintenance of the earth system and the system main earthing will, in general, be the responsibility of the WSM. The earth system should comprise an electrode or electrodes, or earthing plates or earth mats, as approved by the WSM, and should be designed and installed to make an effective connection to the general mass of earth.

20 On installations which are not the responsibility of the WSM, the system earth and the system main earth point shall be installed and maintained in a manner approved by the Installation Design Authority (IDA) responsible for the equipment.

21 On a temporary deployment site, in the absence of a fixed earth, the installation and maintenance of the system main earth point shall be the responsibility of the Engineering Officer responsible for the deployed equipment. The system main earth point shall consist of an earth electrode or electrodes installed in such a manner that the system main earth resistance to the general mass of earth is acceptable to that installation.

POWER SUPPLIES

22 Power supplies for transportable installations fall into the following categories:

22.1 Primary power supplies derived from public mains and provided by the WSM acting as the Electrical Supply Authority, according to standards and regulations adopted by the WSM.

22.2 Primary power supplies provided under user arrangements by mobile generators. Such supplies are to have the neutral of three phase, or one pole of single phase or DC supply solidly connected to earth at source.

22.3 Secondary power supplies derived from switched mode supplies, inverters and transformers to meet user requirements. One pole of these supplies is to be connected to earth.

23 Operational equipment will often rely on a combination of the above, comprising main and standby sources of supply.

CHAPTER 3

PERSONNEL PROTECTION

CONTENTS

EQUIPMENT EARTHING

1 Equipment earthing is designed to limit the potential, with respect to the general mass of earth, of all non-current carrying metalwork (the exposed and extraneous-conductive-parts) associated with the installation. The purpose of equipment earthing is to protect personnel from the risk of electric shock by ensuring efficient and rapid operation of protective systems in the event of earth fault currents. By ensuring that the earth fault loop impedance is low enough to enable the over-current protection devices (fuses or circuit-breakers) to isolate the faulty equipment within a defined time interval of a fault developing, equipment earthing can prevent installation metalwork being maintained at a dangerous potential and thus ensure the safety of personnel.

2 For this fundamental protection system to be effective, a connection of very low impedance and adequate current carrying capacity must be provided between the supply source and the installation. Disconnection of the supply must be fast enough to ensure that a fault voltage appearing on exposed metalwork cannot persist long enough to cause a dangerous hazard to personnel. The purpose, therefore, of the system protective conductor is to provide a low impedance path which will enable over-current protection devices to operate in the event of a fault voltage in excess of 50 VAC or 120 VDC appearing on exposed metalwork.

3 The impedance between the system main earth point and any point on the protective conductor should not exceed one ohm at the frequency of the supply. Lower values of protective conductor impedance are required (as determined by the following calculation) where circuits of high current rating are used (eg 100 amps):

$$\text{Total permissible impedance of earth fault path} = \frac{\text{Phase-to-earth voltage of system}}{\text{Minimum fusing current} \times 2}$$

4 The system protective conductor forms part of the power distribution cables connecting the supply source to the load equipment. It is preferable to have the protective conductor as part of a multicore flexible cable, as the equipment cannot then be operated without the protective conductor being present. The following rules apply to protective conductors which form part of a multicore cable:

4.1 The cross-sectional area of the protective conductor shall not be less than the cross-sectional area of the largest current carrying conductor contained within the multicore cable.

4.2 Cable screens or sheaths must not be used as the protective conductor in a mobile environment.

5 For installations where it is not possible to have the system protective conductor installed as part of a multicore cable, a separate protective conductor may be employed. However, consideration should be given to the use of protective conductor monitoring, which will prevent power being applied to the installation in the absence of the protective conductor.

NOTE

The protective conductor monitor disconnects the supply if it senses a rise in the resistance of the system protective conductor above a pre-determined level.

6 The following rules are applicable to system protective conductors which do not form part of a multicore cable:

6.1 The cross-sectional area of each system protective conductor must not be less than that of the largest current carrying conductor up to a cross-sectional area of 70 mm^2.

6.2 For current carrying conductors exceeding 70 mm^2, the corresponding protective conductor must be 70 mm^2 or one half of the cross-section of the current carrying capacity, whichever is the greater.

7 Exposed conductive parts of equipment are not to form part of the protective conductors for other equipments. Flexible or pliable conduit is not to be used as a protective conductor.

8 No switching device is to be inserted in a protective conductor. However, joints that may be disconnected for test purposes, using tools, are permitted.

AUTOMATIC PROTECTION

9 Earth leakage and earth fault protection are methods of protection arranged to disconnect the supply automatically from an installation or circuit when the earth leakage or earth fault currents exceed pre-determined values. The same protection is offered when the voltage, between the protected metalwork of the installation and earth, rises above a pre-determined value. Such a system can be made to operate more rapidly and at lower values of leakage or fault current than a system dependent on over-current protective devices such as fuses or circuit-breakers. Earth leakage or earth fault protection is generally effected by means of a device known as an active device for the protection of personnel (automatic devices). There are two types; the VOELCB and the RCD. Automatic protection may also be afforded by the use of earth monitoring systems or systems which employ earth proving relays and isolating transformers.

10 At a static fixed site, reliance can be placed on the system protective conductor and the over-current protective devices to ensure the safety of personnel and equipment. For mobile installations, the system protective conductor is vulnerable to damage, deterioration and corrosion, and automatic protection devices are subjected to extremes of climatic condition and vibration. Therefore, Defence Standard 61-15, covering mobile facilities, makes it mandatory for mobile installations to utilize both techniques simultaneously. These are the system protective conductor and associated over-current protective device as the primary means of personnel protection, and the inclusion of an automatic protection device as a secondary or back-up means of personnel protection.

VOLTAGE OPERATED EARTH LEAKAGE CIRCUIT-BREAKERS

11 The Institute of Electrical Engineers (IEE) no longer recognizes VOELCBs as a means of protection for installations covered by the IEE Wiring Regulations. These Regulations recognize only RCDs for this purpose, but in some circumstances standing leakage currents may preclude the use of RCDs and VOELCBs may provide an alternative form of protection.

12 VOELCBs, also known as fault operated devices, are designed to be directly responsive to fault voltages appearing on protected metalwork (vehicle and cabinet bodies). Their primary function is to provide personal protection against electric shock. The operation of the VOELCB depends not only on a fault voltage existing between the protected metalwork and the general mass of earth, but also on the resistance of the independent safety earth electrode.

13 To facilitate correct operation, VOELCBs require an independent reference earth electrode which must be situated outside the effective resistance area of any other metalwork. This requirement can be achieved by installing an earth electrode with a separation of at least 2 metres from any earthed metalwork.

14 Where a vehicle or transportable cabin is fitted with a VOELCB, a terminal, insulated from the chassis body, must be provided for connection to an independent earth electrode. The terminal must be clearly labelled SAFETY EARTH and care must be taken to ensure that the SAFETY EARTH and CHASSIS EARTH are not connected together as this would effectively short circuit the trip coil of the VOELCB, thus making the unit non-effective with no indication of its unserviceable state. An insulated cable must be used for the connection between the insulated terminal and the independent earth electrode.

15 Where a number of VOELCBs are fitted to a vehicle or transportable cabin, a separate SAFETY EARTH terminal and independent earth electrode must be provided for each unit.

16 VOELCBs are electro-mechanical devices which are connected so that their operating coils sense any voltage appearing between exposed metalwork and a reference point, usually earth, and trip if this exceeds a pre-determined level, generally 40 VAC to 50 VAC with an earth loop resistance of between 500 Ω and 4000 Ω depending on the type.

17 A simplified circuit of a VOELCB is illustrated at Fig 1 (overleaf). If an earth fault causes the vehicle or cabin to go 'live', current flows through the earth leakage trip coil to the insulated earth and operates a mechanical latch to allow the main contacts to open and disconnect the supply.

18 VOELCBs are fitted with a test button to test their electro-mechanical operation. This should be used regularly, as some devices tend to stick if not operated for a period of time. Where the device is fitted to a vehicle or a container body, the test button must be operable from the outside of the vehicle or container body without the need to touch any exposed metal work.

19 Failure of the circuit to switch off when the test button is pressed is potentially dangerous to personnel. If such an occasion arises, the safety system must be checked immediately and the fault rectified. Possible causes of failure are:

19.1 A break in the (insulated) earthing conductor.

19.2 A very high resistance path caused by poor conductivity between the earth electrode and the mass of earth.

19.3 Accidental reversal of the line and neutral conductors of the supply.

19.4 A fault in the circuit-breaker itself.

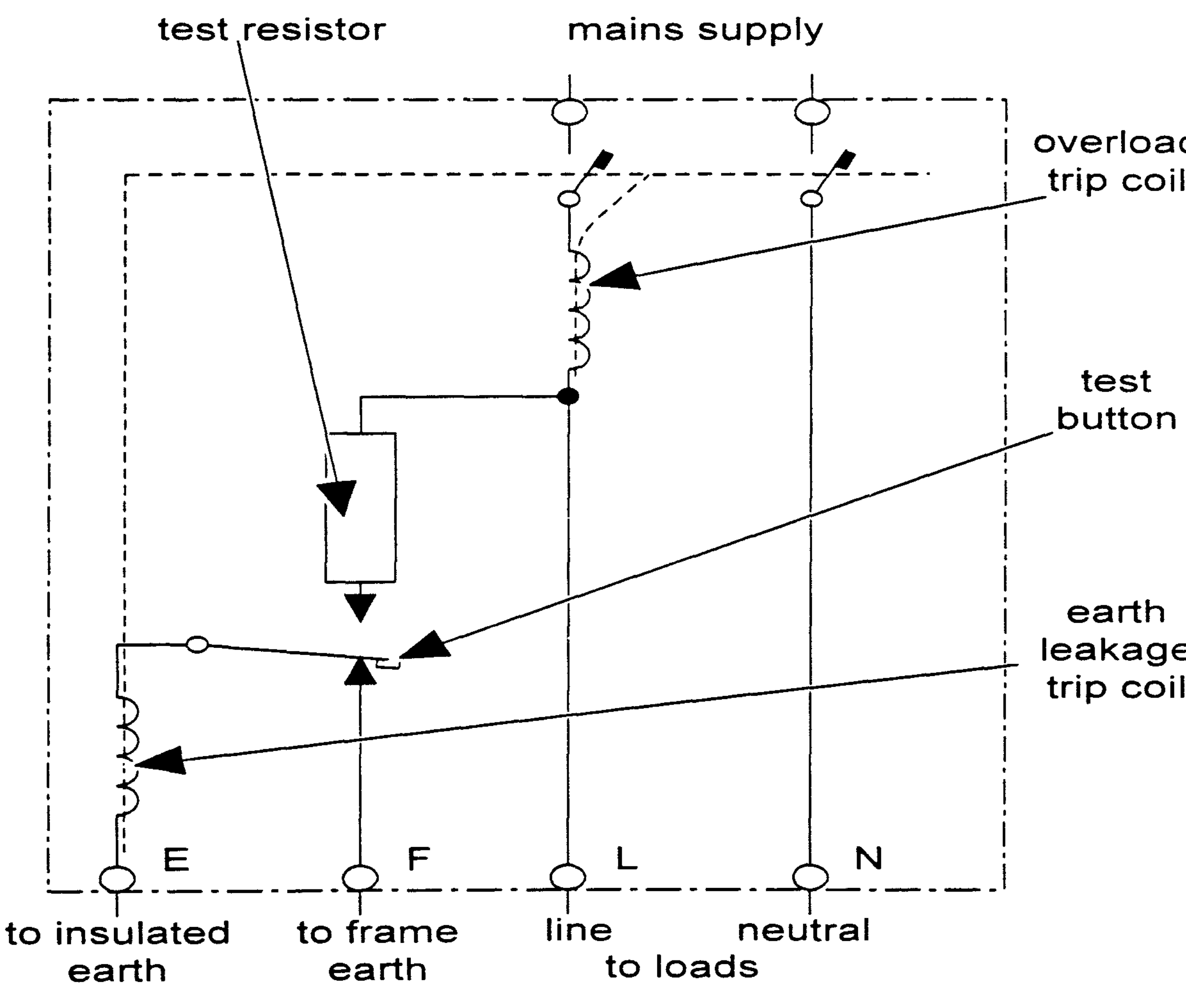

Fig 1 Simplified VOELCB circuit

20 Advantages of VOELCBs are:

20.1 They provide a suitable method of providing secondary protection for installations incorporating leakage currents caused by TEMPEST filters.

20.2 They provide effective protection with reference earth electrode resistance values up to 200 Ω and are therefore ideal for vehicles and transportable cabins.

21 The disadvantages of VOELCBs are:

21.1 A reference earth electrode is required for each VOELCB employed in a vehicle or cabin.

21.2 There is difficulty in avoiding short circuits between the SAFETY EARTH and CHASSIS EARTH terminals, which will render the unit inoperative with no indication to personnel.

RESIDUAL CURRENT DEVICE

22 This device consists of a transformer having opposed windings that carry the incoming and outgoing current of the load as shown in Fig 2.

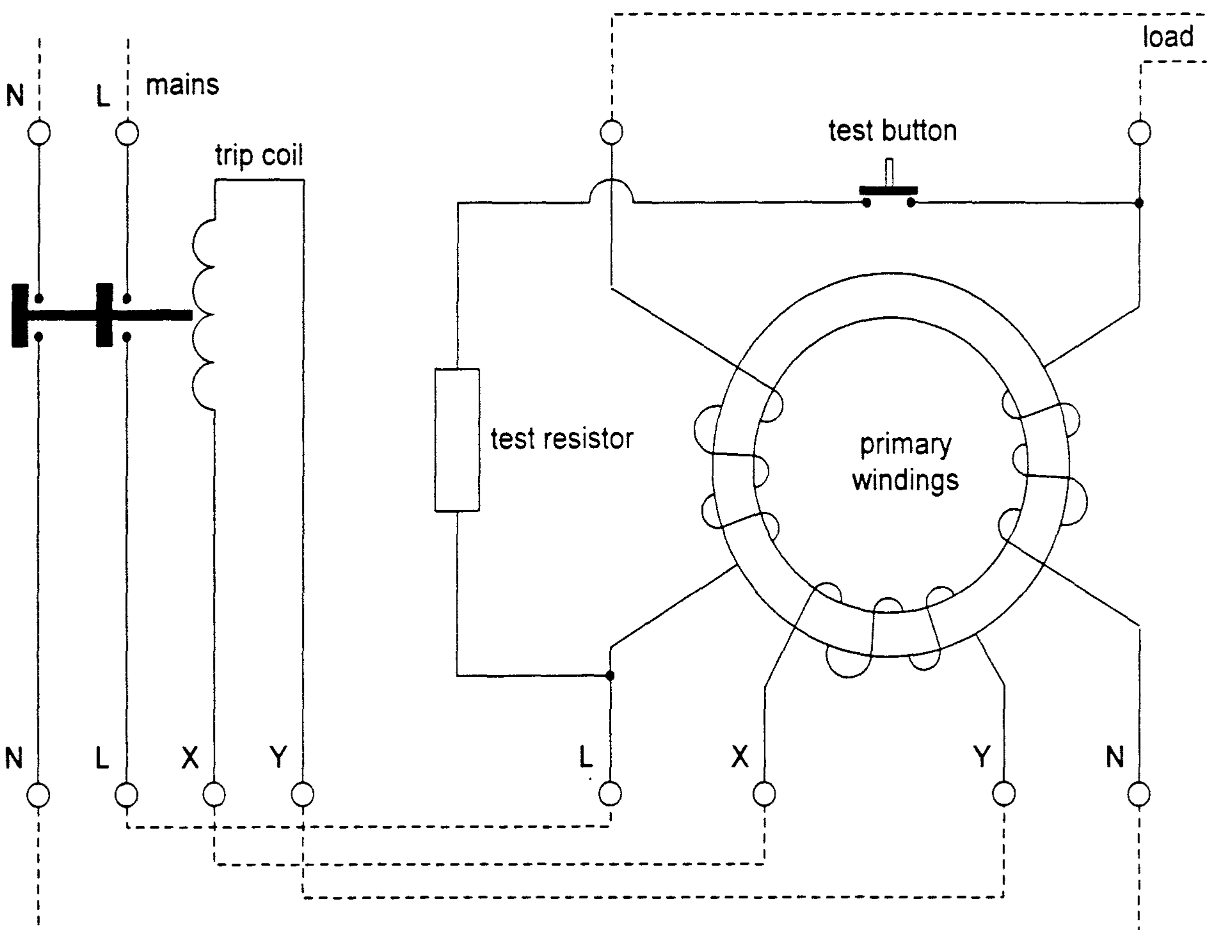

Fig 2 Residual current device circuit

23 In a healthy circuit, where the values of current in the windings are equal, the magnetic effects cancel out in the transformer core. An earth leakage fault in either the line or neutral supply will cause an out of balance circuit condition and create an effective magnetic flux in the core which links with the turns of a secondary winding and induces an EMF in it. The secondary winding is permanently connected to the trip coil of the circuit-breaker. When the circulating current in the trip coil reaches a pre-determined value, it operates the release mechanism of the circuit-breaker and opens the main contacts which are normally held closed against strong spring pressure.

24 As RCDs are current operated, the voltage appearing on the protected metalwork of a vehicle or transportable cabin, prior to the operation of the RCD, is the product of the rated tripping current of the device and the resistance of the installation to the general mass of earth. It follows that the higher the sensitivity of the RCD, the greater the value of earth resistance that can be tolerated.

25 Fig 3 shows that, to ensure that the physiological effects from an electric shock remain in the safe region of Zone 2, the residual current must be restricted to 250 mA, with a maximum exposure time of 40 ms. Hazardous voltage has been defined as 50 VAC, and this means that the product of the rated tripping current of the RCD and the earth fault loop impedance shall not exceed 50 VAC, ie:

$$\text{In} \times \text{Zs} < 50 \text{ VAC}$$

where: In = rated tripping current in amps
Zs = total earth fault loop impedance in ohms.

If the supply voltage is 240 VAC, the fault current (If) is given by:

$$\text{If} = \frac{240}{\text{Zs}} \text{ A}$$

$$\text{Therefore the ratio between If and In} = \frac{\text{If}}{\text{In}} = \frac{240/\text{Zs}}{50/\text{Zs}} = 4.8$$

This means that the fault current at 240 V is nearly five times the rated tripping current of the RCD. Therefore, to restrict the fault current to the maximum permitted 250 mA, the maximum rated tripping current for the RCD is given by:

$$\text{In} = \frac{\text{If}}{4.8} = \frac{250}{4.8} = 52 \text{ mA}$$

NOTE

The tripping current and speed of operation of the RCD are the important considerations for personal protection. In the example shown, at a fault current of 250 mA, the RCD must trip in less than 40 ms to keep the tripping characteristics within the Zone 2 area of Fig 3.

26 RCDs are manufactured in a preferred value series of rated tripping currents and the nearest lower tripping current preferred is 30 mA. Therefore, DEF STAN 61-15 states that, where an RCD is to be used as a means of providing personal protection on a mains-operated vehicle or transportable cabin, its rated tripping current shall not exceed 30 mA.

27 RCDs are fitted with a test button which tests their electro-mechanical operation. When pressed, it simulates a fault condition on one side of the primary unit and trips the unit. The magnitude of the simulated fault current is limited by the test resistor to the value of the residual operating current. This simulated test checks that the RCD is functioning correctly and at the correct level of sensitivity. However, it does not test the effectiveness of earthing, neither does it fully test the tripping characteristics.

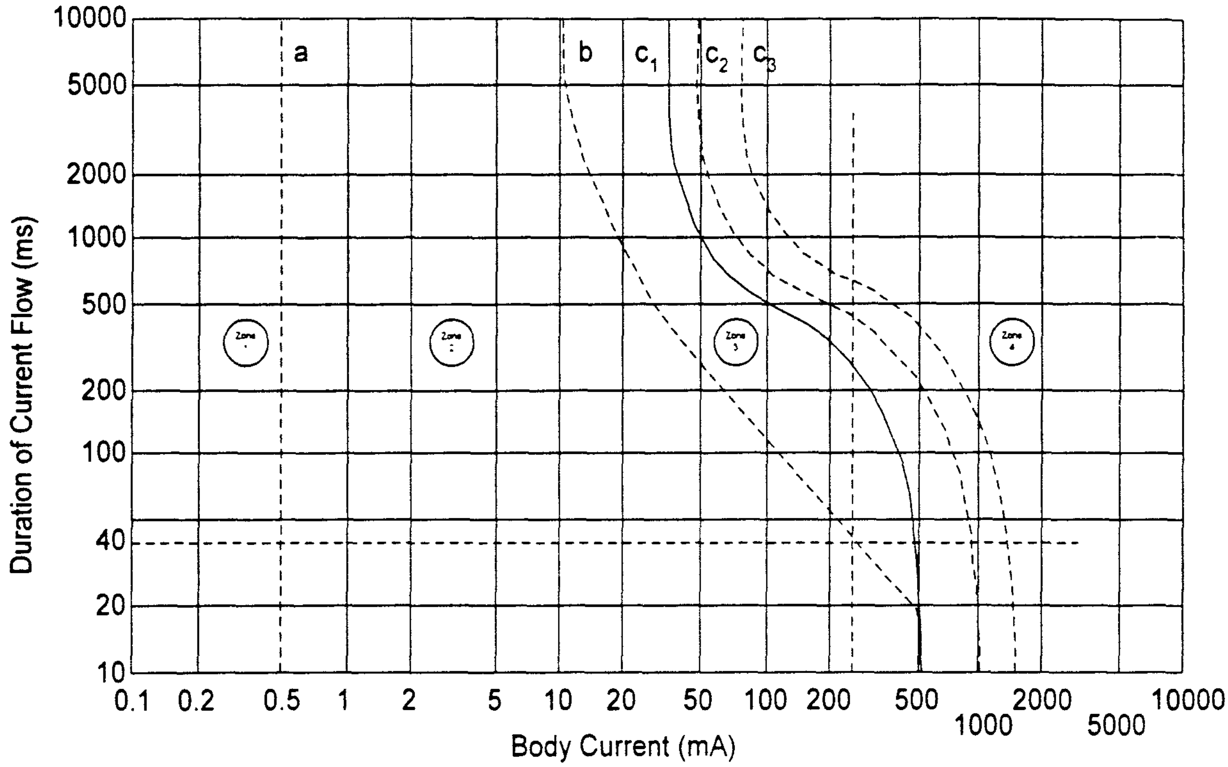

Fig 3 Time/current characteristics

28 Table 1 indicates the physiological effects that can occur.

TABLE 1 TIME CURRENT ZONES OF THE EFFECTS OF AC CURRENT ON PERSONNEL

Zones	Physiological Effects
1	Usually no reaction effects.
2	Usually no harmful physiological effects.
3	Usually no organic damage is expected. There is the likelihood of muscular contractions and difficulty in breathing, reversible disturbances of formation and conduction of impulses in the heart (including atrial fibrillation and transient cardiac arrest) without ventricular fibrillation increasing with current magnitude and time.
4	In addition to the effects of Zone 3, there is the probability of ventricular fibrillation increasing up to about 5 % (curve C_2), up to about 50 % (curve C_3) and above 50 % beyond curve C_3, increasing with magnitude and time. Pathophysiological effects such as cardiac arrest and heavy burns may occur

WARNING

> **ELECTRIC SHOCK. PERSONNEL MUST BE MADE AWARE THAT RCDs PROVIDE PROTECTION ONLY FROM CONTACT WITH ONE PHASE OF THE MAINS SUPPLY AND EARTH. THEY DO NOT PROVIDE PROTECTION FROM DIRECT CONTACT WITH A PHASE AND NEUTRAL SIMULTANEOUSLY.**

29 On transportable cabins fitted with TEMPEST or Radio Interference Filters (RIF), shunt currents will be produced between the phase and neutral to earth. An earth leakage current produced by these filters can be as high as 3 amps; thus presenting a problem when the cabin is fitted with an RCD with a residual operating current of 30 mA. It must be emphasized that the rated residual tripping current must not be raised above 30 mA to accommodate standing leakage currents. A method of substantially reducing the standing leakage currents is discussed in Chap 6. Where it is not possible to reduce these currents below 30 mA, an alternative method of protection must be considered.

30 The advantages of RCDs are:

30.1 They provide high discriminatory protection and are thus best suited to installations comprising several subcircuits, where individual protection of the circuits is required.

30.2 They reduce the risk of fire since the sustained leakage current is reduced to a level well below that afforded by over-current protection.

31 The disadvantages of RCDs are:

31.1 On equipment fitted with RFIs or TEMPEST filters, circuit leakage currents in the order of several hundreds of mA can exist. These circuits may negate the use of RCDs due to spurious tripping caused by the leakage currents.

31.2 In the event of a break in the earth continuity loop, conditions could prevail that would cause the user equipment chassis to rise to a voltage greater than 50 VAC which may cause dangerous currents to flow if the RCD selected for use does not operate within Zone 2.

EARTH MONITORING UNITS

32 The purpose of an earth monitoring unit is to provide a continuous check on the integrity of the system protective conductor. This is achieved by generating, from a monitor unit, a test current in the order of 1 amp which is circulated in a pilot conductor-diode-system protective conductor loop. In the event of the loop impedance rising above a pre-determined level, the unit automatically disconnects the power source. Similarly, a short circuit of the pilot conductor to earth will also cause the unit to disconnect the power source.

33 Certain units have been designed to operate in the presence of earth leakage currents produced by RFI and TEMPEST filters. However, it is not practicable to manufacture a unit which is totally immune to all magnitudes and phases of leakage currents. This problem has been addressed by the introduction of a circuit which senses the potential difference across the system protective conductor between source and user. If for any reason this potential should rise above 10 VAC, the monitor unit will disconnect the power source.

CHAPTER 4

EARTH RESISTIVITY AND EARTH ELECTRODES

CONTENTS

SOIL RESISTIVITY

1 The resistance to earth of an electrode of given dimensions is dependent on the electrical resistivity of the medium in which it is installed. The soil resistivity in the area concerned is an important consideration in deciding which of the alternative methods of protection is to be adopted for a particular system or location.

2 The type of soil largely determines the resistivity, and representative values are given at Table 1 (overleaf). Earth conductivity is essentially electrolytic in nature and is affected by the moisture content of the soil and by the chemical composition and concentration of salts dissolved in the contained water. Grain size and distribution, and closeness of packing, are also contributory factors since they control the manner in which the moisture is held in the soil. Many of these vary locally and some seasonally, so that Table 1 should be taken only as a general guide. For this purpose, Column A applies to most of the British Isles, but column C is also applicable to certain areas such as marshy flats around river estuaries.

Table 1 overleaf

TABLE 1 GENERAL DATA ON EARTH RESISITIVITY

Type of Soil	Climatic Conditions			
	A		B	C
	Normal and high rainfall (eg greater than 20 in (51 cm) a year)		Low rainfall and desert conditions (eg less than 10 in (25 cm) a year)	Underground waters (saline)
	Probable Value	Range of Values Encountered	Range of Values Encountered	Range of Values Encountered
	ohm cm	ohm cm	ohm cm	ohm cm
Alluvium and lighter clays	500	*	*	100 to 500
Clays (excluding alluvium)	1000	500 to 2000	1000 to 10000	300 to 1000
Marls (eg Keuper marl)	2000	1000 to 3000	5000 to 30000	
Porous limestone (eg chalk)	5000	3000 to 10000		1000 to 3000
Porous sandstone (eg Keuper sandstone and clay shales)	10000	3000 to 30000		
Quartz, compact and crystalline limestone (eg carboniferous, marble, etc)	30000	10000 to 1000000		
Clay slates and slates and slatey shales	100000	30000 3000000	100000 upwards	3000 to 10000
Granite Fissile slates, Schists and Gneiss	100000 200000	100000 upwards		

* Depends on the water level in the locality.

3 Local values should be verified by actual measurement, and this is especially important where the soil is stratified, since, owing to the dispersion of the earth current, the effective resistivity depends not only on the surface layers but also on the underlying geological formation. Some typical values measured are given at Table 2.

4 It should also be noted that soil temperature has some effect, but is only important near and below freezing point, necessitating the installation of earth electrodes at depths to which frost will not penetrate.

TABLE 2 TYPICAL SOIL RESISTIVITIES

NOTE

Resisitivities are mean values at depths varying from 2 ft to 8 ft.

Soil	Resistivity	Place of Measurement	
Clay	2000-2700	Stowmarket, Suffolk	
Clay	500-1700	Cuffley, Herts	
Clay	400-1000	Alperton, Middlesex	
Brick clay	2600-2800	Enfield, Middlesex	
Hard clay	5000-15000	Hastings, Sussex	
Chalk	9000-14000	Thetford, Norfolk	
Chalk	6000-12000	Stevenage, Herts	
Chalk	14000-15000	Welford,	
Chalk	18000-30000	Easton,	
Chalk	9000	East Shefford,	Berks
Chalk	11000-13000	East Garston,	
Chalk	11000-40000	Belmont,	and
Chalk	26000-33000	New Barn Farm,	
Chalk	16000-20000	Balldown,	Hants
Chalk	10000	White Wall Spur	
Chalk	14000	Barrow Hill Spur	
Sand	9000-19000		
Sand	17000	Coddenham, Suffolk	
Sand	40000-45000	Blythburgh, Suffolk	
Sand	57000-68000	Wenhaston, Suffolk	
Sand	12000-18000	Reydon Mount Pleasant, Suffolk	
Sand	57000-88000	Reydon Village, Suffolk	
Sand	30000	Southwold, Suffolk	
Sand	300000-800000	Bulchamp, Suffolk	
Marsh	20-270	Newchurch Common, Cheshire	
Peat	20000	Blythburgh, Suffolk	
Rocky		North Wales	
Mountain area	100000		
Sandy gravel	30000-50000	North Wales	
		Riding Mill, Northumberland	
Measured by the Electrical Research Association			

5 While the fundamental nature and properties of the soil in a given area cannot be changed, use can be made of purely local conditions in choosing suitable electrode sites and the method of preparing the site selected to secure the optimum resistivity.

6 Where there is an option, a site should be chosen in one of the following types of soil in the order of preference indicated:

6.1 Wet marshy ground.

6.2 Clay, loamy soil, arable land, clayey soil or loam mixed with small qualities of sand.

6.3 Clay and loam mixed with varying proportions of sand, gravel and stones.

6.4 Damp and wet sand, peat.

7 Dry sand, gravel, chalk, limestone, whinstone, granite and any very stony ground should be avoided, as should all locations where virgin rock is very close to the surface.

8 A site which is not naturally well drained should be chosen. A water-logged situation is not essential, unless the soil is sand or gravel, since in general, no advantage results from an increase in moisture content above about 15 % to 20 %. Care should be taken to avoid a site kept moist by water flowing over it, as the beneficial salts may be entirely removed from the soil in such situations.

EARTH ELECTRODES

9 Effect of shape of earth electrode. With all electrodes, other than large extended systems normally used at power stations, the greater part of the fall of potential occurs in the soil within a few feet of the electrode surface, since it is here that the current density is highest. To obtain a low overall resistance, the current density should be as low as possible in the medium adjacent to the electrode, which should be so designed as to cause the current density to decrease rapidly with distance from the electrode. This requirement is met by making the dimensions in one direction large compared with those in the other two, thus a pipe, rod or strip has a much lower resistance than a plate of equal surface area.

10 Resistance of common types of earth electrode. The resistance of a pipe or rod is given by:

$$R = \frac{p}{83 \times l} \log_{10} \frac{48 \times l}{d}$$

where l = the length in feet.
d = the diameter in inches.
p = the resistivity of the soil in ohm cm (assumed uniform)

For example, for a standard 8 ft x 5/8 in. earthing rod driven into soil of 3000 ohm cm resistivity:

$$R = \frac{3000}{83 \times 8} \log_{10} \frac{48 \times 8}{0.625} = 12.6\ \Omega$$

In the previous example, if an earthing rod 4 ft x 5/8 in. was substituted, then:

$$R = \frac{3000}{83 \times 4} \log_{10} \frac{48 \times 4}{0.625} = 22.5\ \Omega$$

The curves in Fig 1 are calculated from the above equation for electrodes of 1/2 in, 1 in. and 4 in. in diameter respectively, in a soil of 10000 ohms cm resistivity. A change of diameter has a relatively minor effect, and the size of an electrode is generally governed by its resistance to bending or splitting. It is apparent that the resistance diminishes rapidly with the first few feet of driving, but less so at depths greater than 6 ft to 8 ft in soil of uniform resistivity. In cases where impenetrable strata or high resistivity soil occur at relatively small depths, considerable advantage may result from driving electrodes at an angle of about 30 ° to the horizontal, thus increasing the length installed for a given depth.

11 Additional earthing electrodes. A number of electrodes may be connected in parallel and the resistance is then proportional to the reciprocal of the number employed, as long as each is situated outside the resistance area of the other. For individual electrodes to be completely independent, they should be installed with a separation of not less than four times the length of each electrode. In practice, a mutual separation of 3 metres is acceptable, providing that the electrodes are not driven to a depth exceeding this figure. For two earth rods, this separation results in a combined resistance of 54 % of the individual earth electrode resistance.

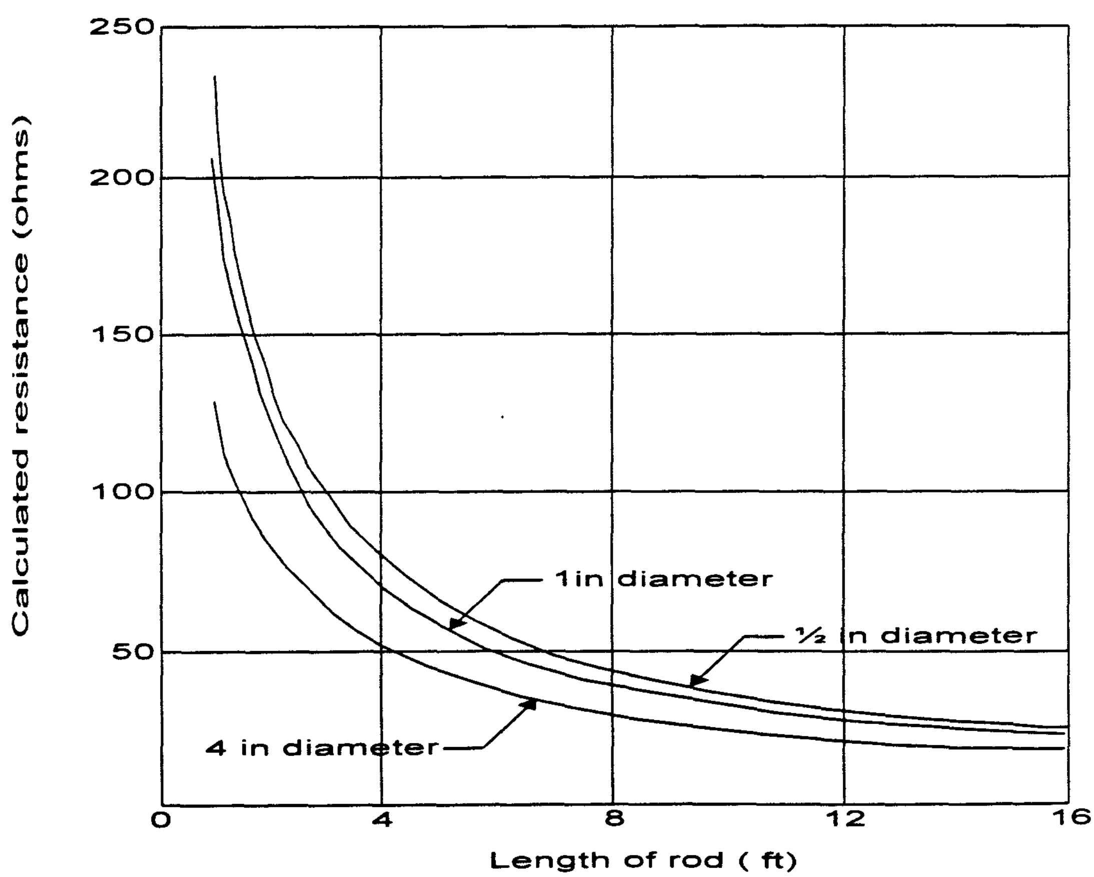

Fig 1 Calculated resistance/length of rod characteristics

12 Multiple earth electrodes. Multiple earth electrodes should be installed in a triangular, square or polygon plan where possible. In the worst case of a linear array, a separation of 3 metres between electrodes will ensure that the combined value of earth resistance does not exceed by 20 % the resistance of each rod divided by the number of electrodes employed.

13 Choice of earth electrode. Earth electrodes provided with vehicles/containers as part of the manufacturer's delivery package are often too short, and are liable to deform when driven into hard ground, owing to their all copper construction. Chilton copperweld sectional earth electrodes (4 ft x 5/8 in) have a high strength steel core, molten welded to a thick copper outer surface, providing corrosion protection and rigidity for ease of insertion in firm ground. The sectional electrodes are roll-threaded at each end to enable two or more electrodes to be connected to each other with bronze couplers.

14 Driving tool. A driving tool for inserting the electrodes into firm ground has been specially designed. The tool screws directly onto the end of the Chilton earth electrode and negates the requirement for a steel driving bolt. The tool is activated by pushing or pulling the handles up or down to insert or withdraw the electrodes. The relevant Sect/Refs and manufacturers Part No's are detailed at Table 3.

TABLE 3 EARTH ELECTRODES AND ACCESSORIES

Item	Sect/Ref	Part No.
Rod, earthing	10B/9333655	Chilton ER 458 S
Drive bolt, earth rod	10AC/9333656	Chilton DB 58
Clamp, electrical	10AR/9333657	Chilton HUC 58
Coupling, earth rod	10AC/9333658	Chilton ERS 58
Driver, earth rod	10B/9333637	N/A

15 Chemical treatment of soil. Chemical treatment of the soil around the electrode is an effective method of improving conductivity in areas of high resistivity, or where there is a low moisture content. Any of the following chemicals may be used:

15.1 Common rock salt.

15.2 Copper sulphate.

15.3 Magnesium sulphate.

15.4 Calcium chloride

15.5 Sodium carbonate.

16 Use of chemicals. Of the above chemicals, common rock salt is generally used and the addition of less than one part by weight of salt to 200 parts of soil moisture has been found to reduce the resistivity by 80%. However, there is little advantage in increasing the salt content above 3 %. The chemical should be applied in an annular trench around the earth electrode and then flooded with water to distribute it throughout the soil. In dry climates, it will be necessary to water the area around the electrode at regular intervals to keep it damp.

CHAPTER 5

VEHICLE/CONTAINER BODIES:DESIGN AND INSTALLATION

CONTENTS

GENERAL PRECAUTIONS

1 All work surfaces on which electrical/electronic equipment is repaired, serviced or tested in a live condition, exposing voltages in excess of 50 VAC or 120 VDC, shall be made of timber or other non-conductive material unless other regulations preclude their use, in which case advice should be sought from MOD specialist branches.

2 The floors of vehicle/container bodies, if not made of an insulating material, are to be covered with approved insulating material.

3 Equipment installed in vehicle/container bodies which uses voltage levels in excess of 50 VAC or 120 VDC is to display a warning plate to BS 5378, stating the highest voltage used, in a prominent, visible position on the equipment.

ELECTRICAL PRECAUTIONS

4 All vehicle/container bodies shall be provided with a means of earthing the chassis when the vehicle/container is stationary. This earthing point shall be clearly marked, CHASSIS EARTH. Any insulated earthing point provided for a fault-voltage-operated automatic protective device shall be clearly marked, SAFETY EARTH. When using a fault operated protective device, care should be taken to ensure that the CHASSIS EARTH and the SAFETY EARTH are not connected together as this will effectively short circuit the trip coil of the protective device. Separate earth electrodes are to be connected to the CHASSIS EARTH and the SAFETY EARTH and are to be separated by a minimum of 1.8 metres.

5 Suitable earth electrodes, see Chap 4, shall be provided. Instructions and guidance on the correct use of these items are to be carried on the vehicle/container body.

6 All exposed and extraneous-conductive-parts are to be connected to CHASSIS EARTH via protective conductors. The maximum permissible resistance between the exposed and extraneous parts and CHASSIS EARTH shall be 0.1 Ω.

7 Power outlets must be clearly marked to indicate their voltage and frequency. In addition, they must be suitably protected and of such design that only the correct voltage and frequency plug can be inserted.

8 Auxiliary bench lighting, soldering irons, etc are to be operated at extra low voltages and supplied either from isolating transformers to BS 3535 or from DC power supplies. The secondary windings of the isolating transformers and associated metalwork are to be isolated from earth. If there is a requirement to provide power to an anti-static environment or explosive area, then the relevant Service Department Regulations must be observed.

9 The power supply feeding the working area of a vehicle/container should incorporate a personnel automatic protection device to DEF STAN 61-15. A Residual Current Device (RCD) is to be connected to the power cables immediately preceding the supply input and is to be physically located on the outside of the vehicle/container. Protective conductor monitoring devices are to be fitted to the power source, to continually monitor the integrity of the protective conductors.

10 The preferred position for a protective device is on the external surface of the vehicle/ container. Devices fitted externally must meet fully the environmental conditions specified for the intended application.

11 The test button for the protective device must be accessible, and the indication of system status visible from outside the vehicle/container. On deployment, it must be possible to apply power to the equipment container and test for satisfactory operation of the protective device before making contact with the vehicle/container.

12 Protective devices must be tested on initial deployment and at regular intervals not exceeding three months during routine operation.

13 In specifying automatic devices for the protection of personnel, it is important to ensure that the device is suitable for the voltage and frequency of the supply.

14 Power sockets fitted to the exterior surface of a vehicle/container, for use with power tools or other equipment operated remotely from the container chassis, must be protected by means of an RCD having a rated residual tripping current not exceeding 30 mA.

15 Where there is a possibility of a vehicle/container being shut down or held in storage for extended periods, the installed equipment may suffer from deterioration due to dampness and condensation. Such equipment is normally protected by preservation heaters.

16 A dedicated circuit is required for preservation heaters. For the protection of personnel, this circuit shall be fitted with an isolator, an indicator lamp external to the container and an RCD having a rated residual tripping current not exceeding 30 mA.

CHAPTER 6

FILTERS

CONTENTS

TEMPEST

1 Transportable containers equipped with communications equipment containing data encryption systems have Radio Frequency Interference (RFI) or TEMPEST filters fitted to the mains inputs. These filters produce shunt currents, from live and neutral to earth, of up to 3 amps, and as currents as low as 3 mA are sufficient for an electric shock to be felt, there is a considerable safety hazard to personnel.

2 For a hazardous situation to develop on an installation under normal circumstances, two simultaneous fault conditions are required:

2.1 Failure of the system protective conductor.

2.2 An equipment fault causing metalwork to rise to a hazardous potential.

3 In the event of such an occurrence, the point at which the mains supply is isolated, making the system safe, will depend on which method of secondary protection has been installed. If the system is not fitted with leakage filters, then a current operated Residual Current Device (RCD), with a trip value of 30 mA, will satisfy all safety aspects. With installations incorporating TEMPEST filters, there is a permanent condition of insulation breakdown with a dangerous current flowing in the system protective conductor. It is therefore essential that the method of secondary protection used on the installation complies with precise standards of design and installation practice.

4 Equipment containers producing a continuous leakage current in excess of 5 mA, due to RFI filters, are to display prominently the following warning label:

WARNING - MAINS FILTER FITTED. DANGEROUS HAZARD EXISTS IF THIS EQUIPMENT IS NOT EARTHED.

TEMPEST EARTH ELECTRODES

5 The TEMPEST equivalent circuit of the power distribution system of a transportable equipment is shown at Fig 1. From TEMPEST considerations it is essential to eliminate radiation from secure information. In order to achieve this aim, impedance Z3 in the diagram must be as low as possible, ideally zero, at the radio frequency under consideration.

6 NATO TEMPEST criteria stipulate that the resistance of this TEMPEST earth electrode must not exceed 5 Ω to the general mass of earth.

7 TEMPEST earth electrodes for prepared deployment sites must have a resistance to the general mass of earth of less than 5 Ω . These TEMPEST earth points are to be located so that connections to TEMPEST EARTH or CHASSIS EARTH terminals are as short and direct as possible.

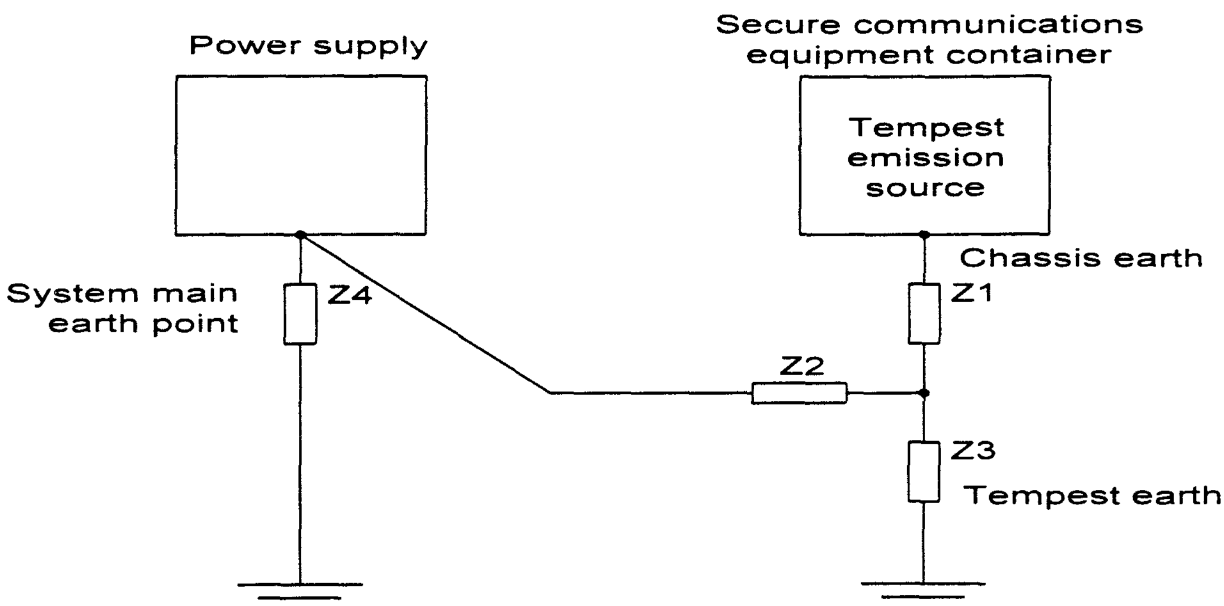

Fig 1 TEMPEST equivalent circuit of a power distribution system

8 At temporary deployment locations, it may not be feasible to obtain this 5 Ω criteria due to high soil resistivity. Therefore, the lowest resistance will have to be accepted or an elaborate earthing system will have to be incorporated.

9 In a current distribution system incorporating TEMPEST protection by both TEMPEST earths adjacent to protected containers and a system protective conductor connected back to the source of the supply, it is apparent that, at the power supply frequencies, the vast majority of the leakage current will flow in the system protective conductor. Therefore, the drying out of TEMPEST earth electrodes should present no safety implications. For example, an installation having a system protective conductor resistance of 0.05 ohms, (corresponding to a length of approx 100 metres) and having TEMPEST earths and system main earth points of 5 Ω to the general mass of earth, will have 99.5 % of the leakage currents flowing in the system protective conductor. At radio frequencies, the inductance of the system protective conductor will result in RF currents being fed via the TEMPEST earth.

LOW LEAKAGE FILTERS

10 TEMPEST filters which produce large values of leakage current can now be replaced with filters which produce lower leakage currents. These filters are available in equivalent case sizes so that existing filters can be substituted in present designs without the need for extensive modifications.

11 RCD protective devices that have 30 mA residual tripping current are incompatible with conventional power filters due to:

11.1 The steady value of leakage current to earth through the shunt capacitors between the phase lines and earth.

11.2 The imbalance in rush transient current, due to the capacitors in the filter, when the circuit is switched on.

12 The solution to this incompatibility lies in the use of the following components:

12.1 Low leakage current power filters.

12.2 An RCD protective device with an accessible toroidal sensing core and sufficient space to pass an additional cable through the core.

12.3 A compensating capacitor to feed a current through the sensing device equal to that lost to earth in the filter. The value of this compensating capacitor needs to match the value of the capacitance of the filter to within 10 %.

13 Fig 2 shows a simplified circuit of a conventional TEMPEST filter in which the leakage current arises due to dielectric leakage of the capacitor placed between the phase line and earth. The filter is seen to attenuate both symmetric and asymmetric voltage sources. A corresponding diagram of the low leakage filter is also shown at Fig 3 (overleaf) with the capacitor values scaled down to maintain the same performance. As the neutral line is close to earth potential, it follows that the standing leakage current is much smaller than in the previous case.

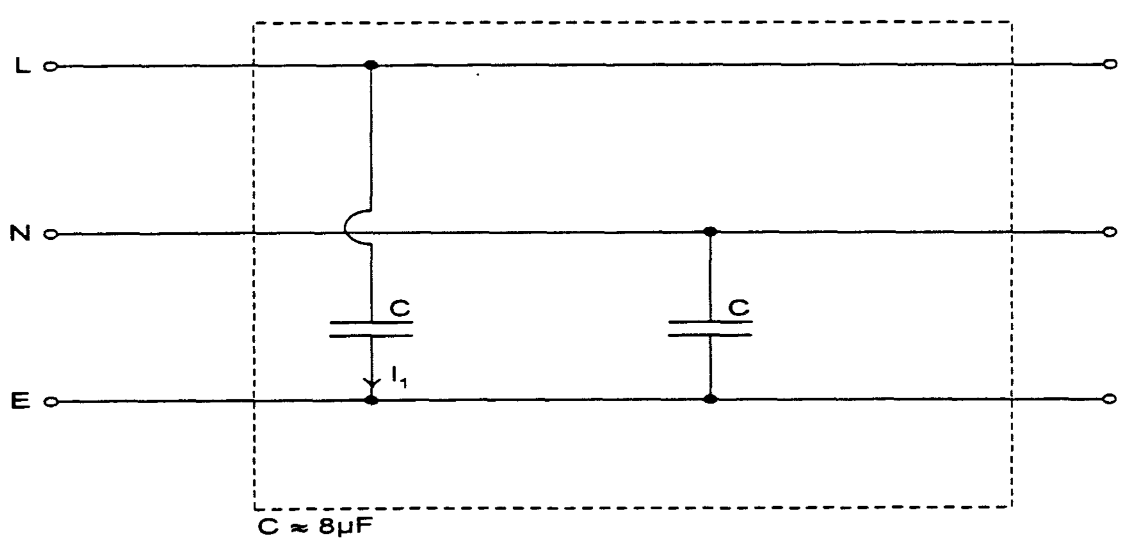

Fig 2 Simplified circuit of conventional TEMPEST filter

14 Filters may be divided into the following categories:

14.1 System power filters of two line or four line construction, classed as 'High Performance' or 'Very High Performance' and used in TEMPEST applications where the highest degree of protection is required to obtain maximum security. These filters produce leakage currents in the range 200 mA to 3 A.

14.2 'Feed Through' filters for the power cable entry panels of TEMPEST shielded enclosures. A separate filter is required for each current carrying conductor. The leakage current is typically 150 mA per line.

14.3 General purpose RFI filters for equipment racks. These filters produce leakage currents of approx 15 mA.

15 Low leakage equivalent filters are available for all of those applications in Para 14 and produce identical insertion loss. These filters typically produce a leakage current of 30 mA per volt potential difference between the neutral and protective conductors at the filter input terminals. In mobile applications, neutral is bonded to earth at the supply source and hence this voltage differential depends on the voltage drop in the neutral conductor. This voltage drop will therefore normally be small, especially with balanced three phase loads. The adoption of low leakage filters will normally reduce the system leakage current to the extent where secondary protection can be provided by means of RCD protection devices ie the preferred means of secondary protection.

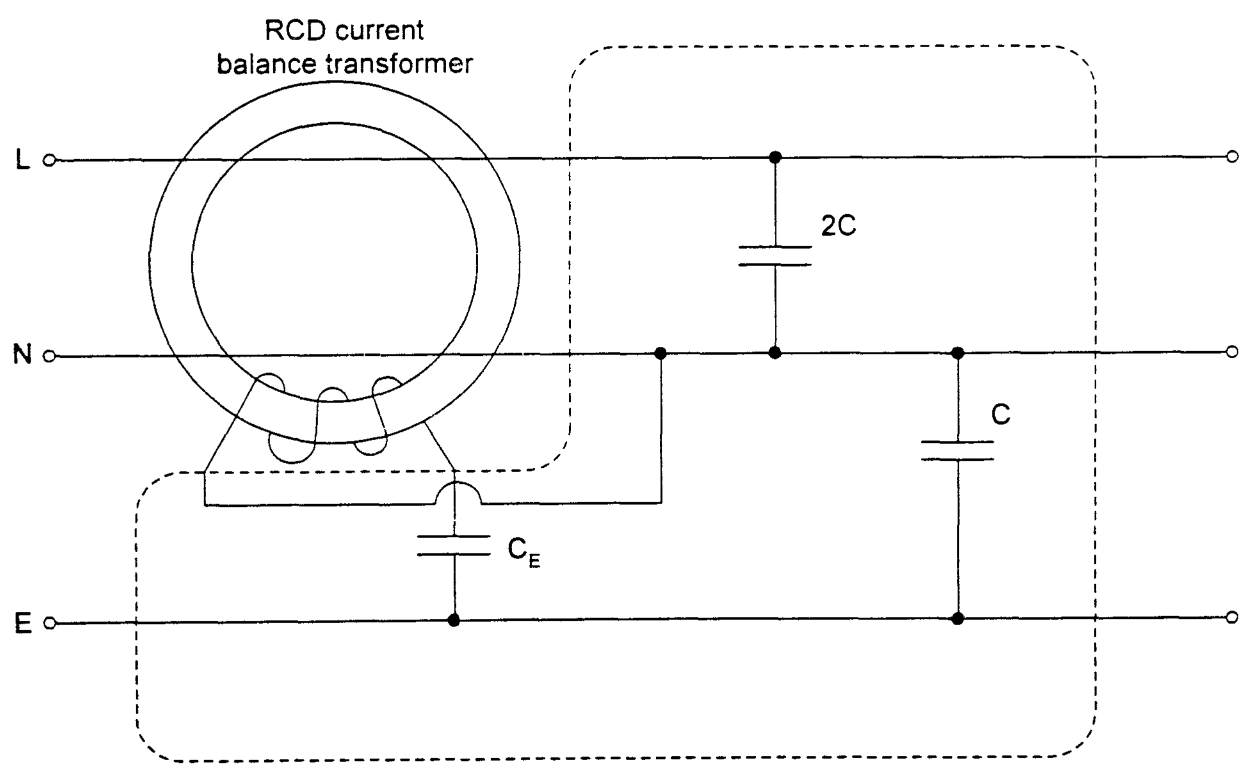

Fig 3 Equivalent low leakage filter with compensating capacitor for RCD protection

CHAPTER 7

BONDING

CONTENTS

DEFINITION

1 Bonding is the electrical interconnection of normally non-current carrying metal parts of an equipment or system to ensure that those parts are at a common potential.

EQUIPOTENTIAL BONDING

2 The purpose of the protective conductors is to provide a path for earth fault current, so that the installed protective devices will operate to remove any dangerous potential differences appearing under fault conditions, before an electric shock can be delivered.

3 Equipotential bonding ensures that the earthed metalwork (exposed-conductive-parts) of a container/vehicle is connected to any other metalwork installed in the cabin/container (extraneous-conductive-parts), thus preventing dangerous potential differences. Efficient bonding also prevents the accumulation of dangerous electrostatic charges and, in certain cases, helps minimise the fire risk (eg where flammable gases or vapours are likely to accumulate).

4 Where a container houses equipment racks, frames and panels, the frame shall not be relied upon as the bonding connection between itself, the racks and the panels. A direct connection shall be provided between the frame, racks and panels. A direct connection must also be made between the frame and CHASSIS EARTH via protective conductors.

5 The maximum permissible resistance between any exposed or extraneous-conductive-part shall not exceed 0.1 Ω.

6 Electrical bonding between exposed-conductive-parts and extraneous-conductive-parts is to be made using conductors with a minimum cross sectional area of 2.5 mm^2 for protected conductors. The minimum cross sectional area for unprotected conductors is 4.0 mm^2. The bonding cable must be at least half the cross sectional area of the equipment earth conductor, with a minimum of 6.0 mm^2.

7 Rigid aluminium bonding conductors are to be greater than 16 mm^2 and copper conductors are to be greater than 10 mm^2.

EARTH BONDING TESTER (10S/1222371)

8 The Earth Bonding Tester is a small portable instrument that enables the accurate measurement of low resistance. It employs four-wire resistance measurement techniques and is designed to provide immunity from thermal EMFs and contact potentials. The tester can be easily operated from its protective case.

9 The tester utilizes a low frequency AC measurement principle. The AC signal is applied to the resistance under test by two source wires and is monitored by two sense wires which feed an amplifier. After amplification, the signal is filtered and rectified before being fed to a LCD display. Power to the test set is provided by 4 x AA size batteries, and a low battery annunciator is fitted, indicating when 90 % of the battery life has been used. The instrument is activated by a push button ON switch which incorporates a timer circuit that automatically switches it off after 4 minutes. Backlighting for the LCD display is provided.

10 The tester is supplied with a 50 m accessory lead (10S/9730399) and zero adjustment is provided to trim off the lead impedance, which can be up to 4 mΩ. The ranges of the instrument are:

10.1 000.0 to 199.9 Ω - resolution 0.1 Ω.

10.2 00.00 to 19.99 Ω - resolution 0.01 Ω.

10.3 0.000 to 1.999 Ω - resolution 0.001 Ω.

10.4 000.0 to 199.9 mΩ - resolution 0.1 mΩ.

CHAPTER 8

INSPECTION AND TESTING

CONTENTS

INTRODUCTION

1 No electrical installation, however carefully designed and installed, can be expected to last forever; deterioration will take place as well as normal wear and tear. This is particularly true for temporary installations where equipment and power distribution cables may be subject to changes of location in varying environments over a short period of time. Therefore, the need to examine and test those items comprising the installation (containers, vehicles etc), is of great importance.

2 Prior to the application of power, and before testing, it is important that a full visual examination of an installation is carried out to verify that:

2.1 Installed equipment is not obviously damaged or defective so that the safety of personnel or equipment is impaired.

2.2 Mechanical protection is provided for cable runs and they are routed in safe zones.

2.3 All cables are free from damage and deterioration.

2.4 The correct settings of devices for protection against indirect contact and over-current are provided.

2.5 Where a three phase installation is in use, the input/output cables are suitably codified to prevent the possibility of incorrect phase rotation.

2.6 Where a system main earth point has not been provided, an earth electrode has been installed and the system protective conductor has been connected to it.

2.7 Where a container/vehicle is fitted with a VOELCB, an earth electrode is fitted and connected via insulated cable.

TESTING SEQUENCE

3 Testing can be hazardous, both to the person carrying out the tests and to others who are within the area of the installation during the tests. It is therefore imperative that, during testing that requires power to be on, personnel not involved with the testing process are not permitted within the installation area (containers, vehicles under test).

4 The danger is compounded if the tests are not carried out in the correct sequence. For example, it is of great importance that the continuity, and hence the effectiveness, of protective conductors is confirmed before the insulation resistance test is carried out. The high voltage used for insulation testing could appear on all extraneous metalwork associated with the installation in the event of an open-circuit protective conductor, if the insulation resistance is very low.

5 Tests are to be carried out in the following sequence:

WARNING

PARAS 5.1 TO 5.6 MUST BE CARRIED OUT WITH THE POWER SOURCE ISOLATED.

5.1 Soil resistivity.

5.2 Earth electrode resistance.

5.3 Continuity of protective conductors.

5.4 Verification of polarity.

5.5 Installation insulation resistance.

5.6 Earth-fault loop impedance.

5.7 Correct operation of RCDs, VOELCBs and EMERGENCY OFF switches (if fitted).

EARTH TESTER (NULL BALANCE)

6 The earth tester (null balance) (5G/1060648 or 5G/7556108) is designed to test the resistance of earth electrodes and to measure soil resistivity. It may also be used to carry out continuity checks and the earth loop impedance test.

7 The tester contains a hand driven generator which passes current from terminal C1, through the resistance under test (soil, electrode etc) to terminal C2. A potential difference is developed across the test resistance which is applied across terminals P1 and P2 causing the galvanometer pointer to move from the zero setting. Using the Wheatstone Bridge principle, the potential P1/P2 is balanced against an opposite potential produced across the switched resistors in the tester. On the tester, the resistors are switched until the galvanometer indicates zero, whereupon the resistance under test is indicated on the front panel. Resistances of earth electrodes of a similar construction do not affect the measured values because most of the resistance is eliminated in the balancing effect. Stray currents produced in the soil cause random movement of the tester pointer. However, this random movement disappears when the generator is operated at a higher current (160 rev/min).

8 The tester is operated as follows:

8.1 Set the range switch to X 0.01 and the balancing resistor dials to 999 ohms.

8.2 Turn the handle slowly and note the galvanometer deflection. If the deflection is (+), increase the range factor to X 0.1 (or higher) until the deflection becomes (-).

8.3 When the deflection is (-), decrease the value of resistance digit by digit, starting with the left dial, then the centre and finally the right dial, until the galvanometer pointer is central.

8.4 Resistance under test = dial reading x range factor.

SOIL RESISTIVITY

9 Prior to inserting an earth electrode, it is desirable to ascertain the resistivity of the surrounding soil using the earth tester (null balance). Four test electrodes are driven to a depth of, but not exceeding, 1/20 of 'a' (distance between electrodes) and connected to the earth tester as shown in Fig 1.

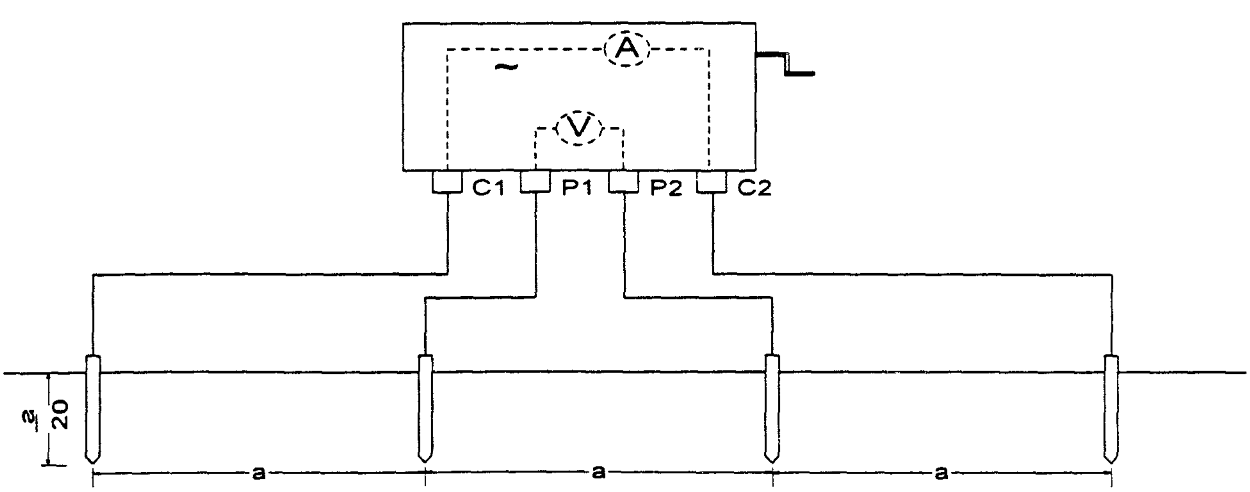

Fig 1 Connections for measuring earth resistivity

10 The soil resistivity is calculated using the following formula:

$$p = 2\pi \times a \times r$$

where: p = soil resistivity in Ω/m.
a = distance between electrodes.
r = resistance recorded on earth tester.

For example, if the electrodes were driven to a depth of 200 cm and separated by 4 m, and the test resulted in a reading of 1.8 on the earth tester, the soil resistivity would be:

$$p = 2\pi\,(4 \times 10^2) \times 1.8$$
$$= 45.25\ \Omega/\text{m}.$$

11 Table 1 shows the results of a series of tests carried out with electrodes driven to a depth of 1/20 of 'a'.

TABLE 1 TEST RESULTS OF ELECTRODES DRIVEN TO DEPTH OF a/20

Depth (m)	Resitance (Ω)	Resistivity (average)
1.5	3.8	35.8 Ω/m
3.0	2.0	37.7 Ω/m
4.0	1.8	42.5 Ω/m
5.0	2.3	77.3 Ω/m

12 From the above results it can be seen that:

12.1 Soil resistivity is reasonably constant down to a depth of 3 m.

12.2 Between 3 m and 4 m the soil resistivity increases.

12.3 Below 4 m the soil resistivity increases considerably.

Thus it can be assumed that the soil is reasonably homogenous down to approximately 3 m with an underlying high resistivity layer. Personnel should aim to achieve a figure of below 35 Ω/m for the system main earth point and reference earth points. If this figure cannot be achieved refer to Chap 4.

EARTH ELECTRODE RESISTANCE CALCULATION

13 Once the soil resistivity is known, it is possible to calculate the earth electrode resistance using the following formula:

$$R = \frac{p}{83 \times l} \log_{10} \frac{48 \times l}{d}$$

where: l = the length in feet.
d = the diameter in inches.
p = the soil resistivity in Ω/m.

For example, an earth electrode of 4 ft x 5/8 in. diameter driven into soil of 30 Ω/m gives an earth electrode resistance of:

$$R = \frac{30}{83 \times 4} \log_{10} \frac{48 \times 4}{0.625} = 22.5\ \Omega$$

14 The earth electrode resistance for electrodes of metric dimensions can be measured using the following formula:

$$R = \frac{p}{272 \times l} \log_{10} \frac{40 \times l}{d}$$

where: l = the length in metres.
d = the diameter in millimetres.
p = the soil resistivity in Ω/m.

For example an earth electrode of 1.2 m x 16 mm in diameter driven into soil of 30 Ω/m gives an earth electrode resistance of:

$$R = \frac{30}{272 \times 1.2} \log_{10} \frac{40 \times 1.2}{16} = 22.76\ \Omega$$

15 To assist in bringing the earth electrode resistance down to an acceptable level, Table 2 shows the probable earth resistance in ohms for 16 mm diameter copper sheathed electrodes in soil of 10 Ω/m resistivity.

TABLE 2 RESISTANCE OF EARTH ELECTRODES

Driven Depth	Number of Rods in Parallel			
	1	2	3	4
2.4 m	4.2	2.31	1.68	1.26
3.6 m	3.0	1.65	1.2	0.9
4.8 m	2.3	1.26	0.92	0.69
6.0 m	1.9	1.05	0.76	0.57
7.2 m	1.6	0.87	0.61	0.48

For soils of other resistivities the quoted figures should be multiplied by:

$$\frac{\text{Resistivity}}{10}$$

EXAMPLE 1: It is required to install a system main earth point, maximum resistance 5 Ω using earth electrodes, in soil which has an average resistivity over 3 m depth of 20 Ω/m. Using the figures given at Table 2:

$$1 \times 2.4 \text{ m electrode} = 4.2 \times \frac{20}{10} = 8.4\ \Omega$$

$$2 \times 2.4 \text{ m electrodes} = 2.31 \times \frac{20}{10} = 4.62\ \Omega$$

EXAMPLE 2: It is required to install a system main earth point, maximum resistance 5 Ω, using earth electrodes, in soil which has an average resistivity of 3.77 Ω/m. Using the figures given at Table 2 for 2.4 m x 16 mm electrodes:

Resistance of: 1 electrode = 4.2 x 3.77 = 15.8 Ω
2 electrodes = 2.31 x 3.77 = 8.71 Ω
3 electrodes = 1.68 x 3.77 = 6.33 Ω
4 electrodes = 1.26 x 3.77 = 4.75 Ω

Thus to obtain the required resistance of 5 Ω, 4 x 2.4 m electrodes connected in parallel will be required.

It can be seen from the above examples that investigating the soil resistivity prior to installing earth electrodes will save valuable time and produce satisfactory earth electrode resistance for use at deployed sites.

NOTE

The above examples give 'probable' earth electrode resistances but this is only a guide and the readings obtained must be confirmed by carrying out the test detailed at Paras 16 to 20.

EARTH ELECTRODE RESISTANCE TEST

16 The measurement of an earth electrode resistance is not a simple matter since the requirement is to measure the resistance between the electrode and 'true' earth. A connection to the electrode under test is easy but the problem is in connecting to 'true' earth. If a test electrode is driven into the surrounding soil and a resistance measurement taken, the result will be the total resistance of the electrode under test and the surrounding soil. However, the problem is simplified if a second 'test' electrode is installed and, as shown at Fig 2, the ammeter indicates the total circuit current while the voltmeter indicates the voltage drop across the electrode under test.

17 The earth electrode resistance is defined as that body of earth in close proximity to the surface area of the electrode. This area is called the 'resistance area'.

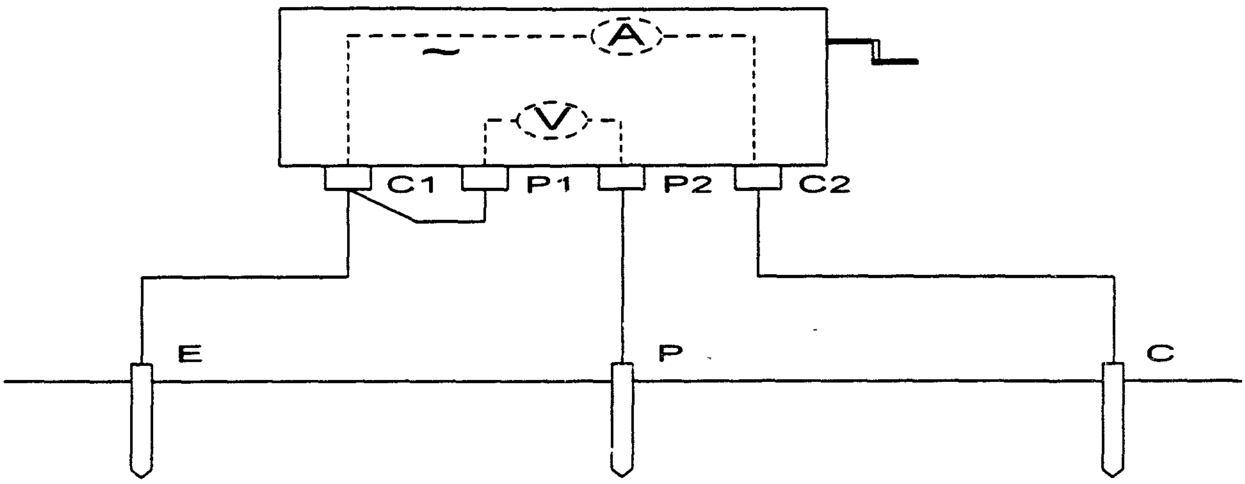

Fig 2 Electrode resistance testing connections

NOTES

(1) E - electrode under test
P - test potential electrode
C - test current electrode

(2) P and C are usually driven to a depth of 0.3 m to 1.0 m.

18 When measuring the earth electrode resistance, the electrodes E, P and C are positioned between 20 metres and 25 metres apart to ensure no overlapping of resistance areas. A resistance measurement is taken at the first siting of the three electrodes, and a further two measurements are taken with electrode P positioned 5 metres closer to E and then P moved 5 metres closer to C. If the three measurements are stable, then the average can be taken as the correct resistance of the electrode under test. If the three measurements are not stable, then the process must be repeated using larger electrode separations.

19 To achieve accurate resistance measurements, the tester is to be positioned as close as possible to the electrode under test and the resistance of the test leads is to be deducted from the result.

20 The earth resistance varies throughout the year depending on the climatic conditions, therefore this test is to be repeated at intervals not exceeding 3 months.

CONTINUITY OF PROTECTIVE CONDUCTOR

21 All protective and bonding conductors must be tested to ensure that they are electrically safe and correctly connected. Where earth-fault loop impedance measurement of the installation is carried out, this will remove the requirement for protective conductor tests because the conductor forms part of the loop. However, the loop test cannot be carried out until the supply is connected, so testing of the protective system is necessary before supply connection. Connection of the supply to an installation with a faulty protective system could lead to danger.

22 There are two methods of testing the continuity of the protective conductor:

22.1 Using the neutral conductor as the return lead.

22.2 Using a long return lead.

23 When using the neutral conductor as the return lead (neutral and earth are connected at source), the tester is connected across the neutral and earth at the furthest point from the system main earth point. If the test instrument is the Earth Tester (Null Balance), terminals C1 and C2 should be used. The figure obtained will be the combined resistance of the neutral and protective conductors. The resistance of the protective conductor can be calculated from:

$$Rp = R \times \frac{An}{An + Ap}$$

where: Rp = the resistance of the protective conductor

R = the resistance reading taken

An = the cross-sectional area of the neutral conductor

Ap = the cross-sectional area of the protective conductor

24 When using a long return lead, its length must be sufficient to stretch from the system main earth point to every point on the installation. The resistance of this return lead is measured and then one end is connected to the system main earth point and the other end to terminal C1 of the meter. C2 is connected the protective conductor, via one of the tester leads, at the furthest point from the system main earth point. The resistance of the protective conductor can be calculated from:

$$Rp = R - R1$$

where: Rp = the resistance of the protective conductor
R = the resistance reading taken
Rl = the resistance of the long lead

25 Using either of the two methods, the maximum resistance of the protective conductor measured at any point along its length must not exceed 1 Ω.

26 Tests which give no quantitive results (bell or cell tests) must never be used to prove the adequacy of protective conductors.

VERIFICATION OF POLARITY

27 On the container/vehicle, and at the power source, a visual examination of all input/output plugs and sockets is carried out. To limit the possibility of incorrect polarity connections, the plugs/sockets at both ends of the cables are checked for correct indentification, using the colour code or numbering method. Where the polarity is uncertain, a cross-check with the installation diagrams is carried out, supplemented by continuity checks.

INSTALLATION INSULATION CHECK

28 A low resistance between phase and neutral conductors, or between live conductors to earth, will result in a leakage current. This current could cause deterioration of the installation and present a danger for personnel. Thus the resistance between poles or to earth must never be less than 2 MΩ.

NOTE

> The minimum insulation resistance required by the 16th edition of the Institute of Electrical Engineers Regulations for voltages of up to 500 V is 0.5 MΩ. However, the minimum figure required by the Health and Safety Executive is 2 MΩ.

29 In addition to the leakage current resulting from low insulation resistance, there are further leakage currents due to the reactance of the insulation which acts like a dielectric of a capacitor. These currents dissipate no energy and are not harmful, but as accurate insulation measurements are required, a direct high voltage is applied to reduce the reactive effect. Some insulating materials indicate high resistance under low voltage testing but 'break-down' when higher voltages are applied. Therefore, on systems using voltages in excess of 240 V, 500 V testers are to be used.

30 On a large installation, where there are many earth paths in parallel, the reading may be lower than expected. In such cases, the installation is to be subdivided and retested, when each part must meet the minimum requirement of 2 MΩ.

CAUTION

> **EQUIPMENT DAMAGE. Electronic components may be damaged if not disconnected prior to test.**

31 Prior to carrying out an insulation test it is important that electronic equipment which could be damaged by the application of the high test voltage is identified and disconnected or isolated from the test circuit. Included, in this category are the controllers on certain air conditioning units, mains and tempest filters, power controllers and delay timers.

EARTH FAULT LOOP IMPEDANCE

32 The current which will flow under earth fault conditions, and will thus be available to operate the overload and earth fault protection circuits, depends upon the impedance of the earth return loop. This includes the line conductor, the fault, the earth continuity conductor and earthing lead (if applicable), and the system main earth point and earth electrodes. Except where the system is earthed by protective multiple earthing, it is permissible to test the neutral-earth loop instead of the line-earth loop.

33 The neutral-earth loop test, as shown in Fig 3, should be carried out, and, if necessary, the line-earth loop test as shown in Fig 4 (overleaf). The results of the loop tests should conform to Tables 3 or 4.

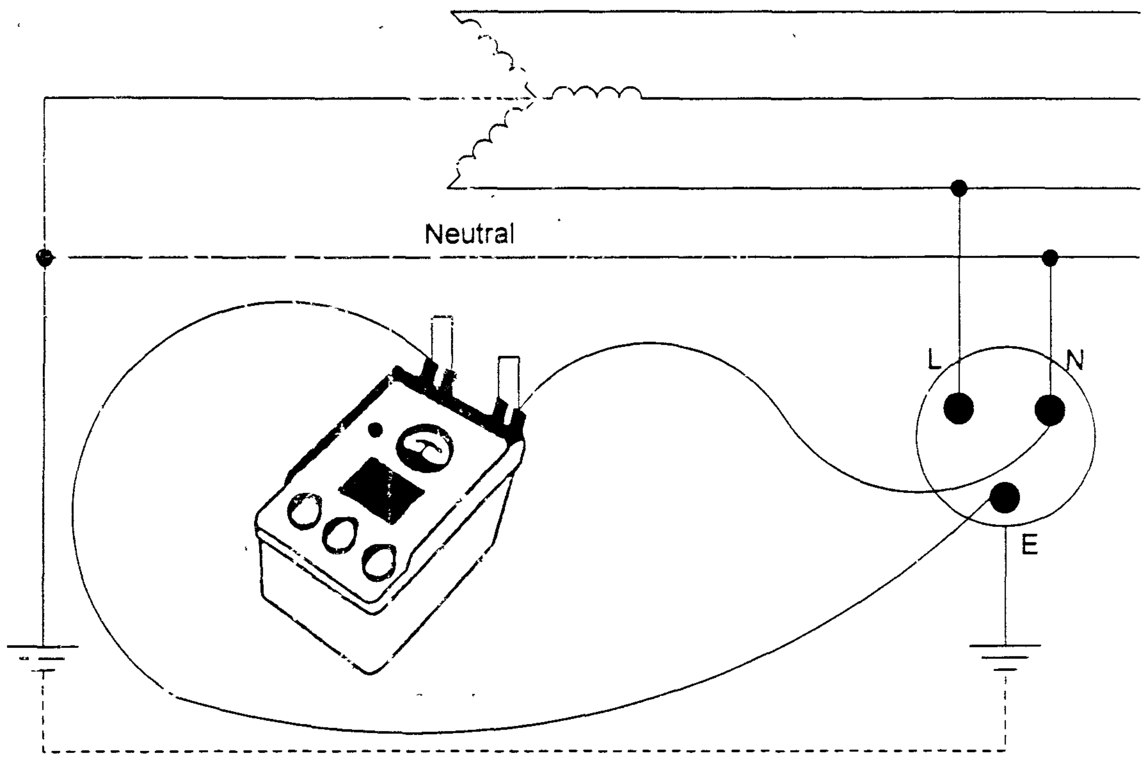

Fig 3 Method of carrying out a neutral-earth loop test

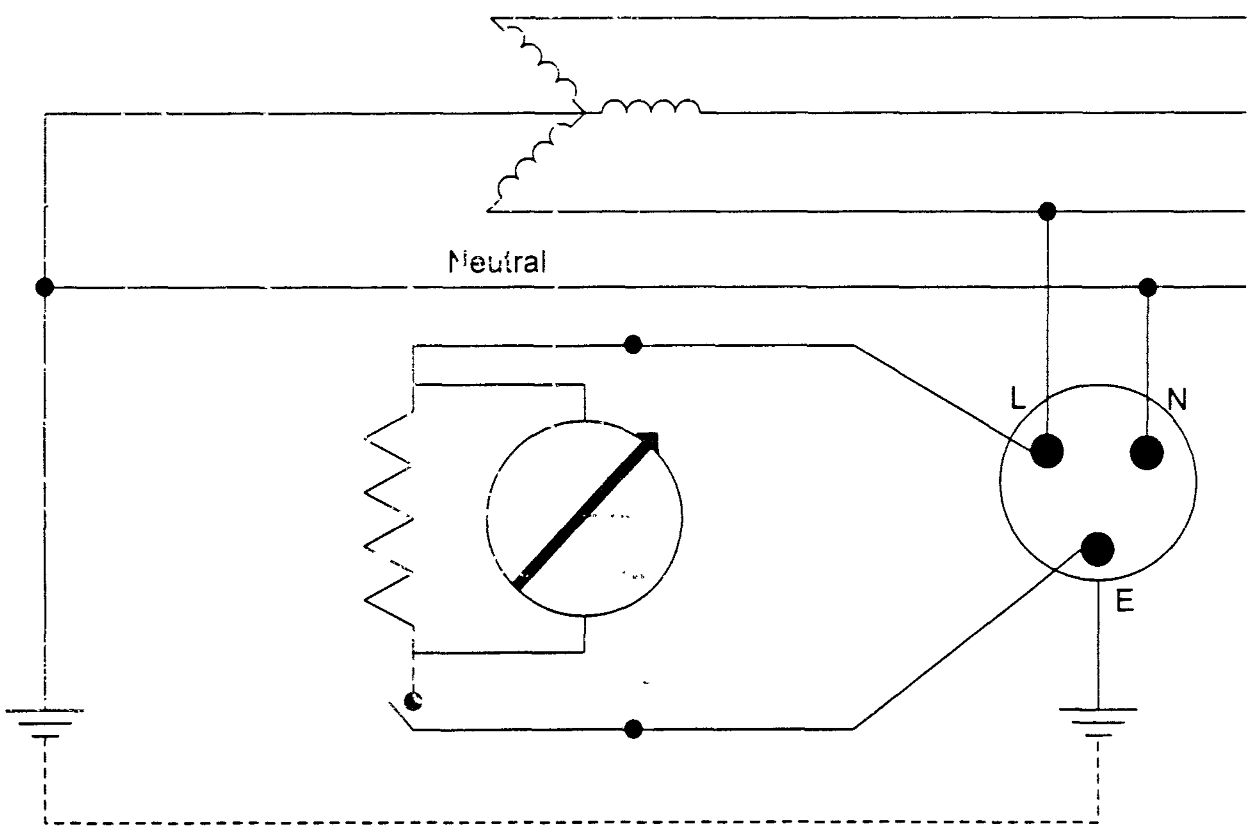

Fig 4 Method of carrying out a line-earth loop test

TABLE 3 MAX EARTH LOOP IMPEDANCE FOR EARTH LEAKAGE PROTECTION BY SEMI-ENCLOSED FUSES OR CARTRIDGE FUSES MAKING A FUSING FACTOR EXCEEDING 1.5

Current Rating of Fuse (amperes)	Impedance in Ohms when Voltage is					
	200 V	210 V	220 V	230 V	240 V	250 V
5	13.33	14.00	14.65	15.85	16.00	16.65
10	6.68	7.00	7.33	7.66	8.0	8.33
15	4.45	4.67	4.88	5.11	5.33	5.56
20	3.32	3.50	3.67	3.83	4.00	4.17
30	2.22	2.34	2.44	2.56	2.70	2.78
60	1.11	1.17	1.22	1.28	1.35	1.39
100	0.668	0.7000	0.735	0.768	0.80	0.835

TABLE 4 MAX EARTH LOOP IMPEDANCE FOR EARTH LEAKAGE PROTECTION BY CIRCUIT-BREAKERS

Current Rating of Fuse (amperes)	Impedance in Ohms when Voltage is					
	200 V	210 V	220 V	230 V	240 V	250 V
5	29.66	28.00	29.30	30.70	32.00	33.35
10	13.39	14.00	14.65	15.35	16.00	16.67
15	8.88	9.34	9.76	10.22	10.66	11.12
20	6.68	7.00	7.33	7.66	8.00	8.34
30	4.44	4.67	4.88	5.11	5.33	2.56
60	2.22	2.34	2.44	2.56	2.66	2.78
100	1.33	1.40	1.46	1.53	1.60	1.66

TESTING PERSONAL PROTECTION RESIDUAL CURRENT DEVICES (RCDs)

34 Residual current devices are provided with a built-in self test system which is intended to be operated by the user at intervals not exceeding 3 months, in accordance with the Institute of Electrical Engineers Regulations. However, this test is not conclusive as it does not determine the time taken for the RCD to trip.

35 RCDs are to be tested using the Martindales residual current detector tester 5A/ 1728043. The tester is designed to check standard trip current ratings from 15 mA to 500 mA at 0 ° and 180 ° on the sine wave, to indicate faulty circuit wiring and to handle both single phase and three phase four wire installations.

36 The dual test facility of the Martindale tester is necessary to determine the true efficiency of the unit under test. An RCD's response time can vary up to 10 ms within the cycle of the sine wave depending upon the time when the simulated earth fault is injected. Conventional analogue testers inject an earth fault arbitrarily, thus creating a possible inaccuracy. The dual test at 0 ° and180 ° offered by the Martindale tester eliminates the possibility of error and ensures that the maximum disconnection time is measured. The Martindale tester comes complete with a full set of operating instructions.

TESTING VOLTAGE OPERATED EARTH LEAKAGE CIRCUIT-BREAKERS (VOELCBs)

37 A large number of cabins/vehicles in service are fitted with VOELCBs. Although this publication does not endorse the use of this device for new installations, it has given reliable protection over many years, and it has not yet been considered appropriate to engage in a large scale replacement programme for existing installations.

38 To test the VOELCB, all loads on the output side of the VOELCB are isolated. The VOELCB test button is pressed and the unit must trip immediately. If the unit trips with reluctance after a delay of one second or more, and makes a buzzing sound, it is indicative of excessive reference electrode resistance. The test should be halted at this stage and the electrode resistance measured in accordance with Paras 16 to 20.

39 The reference earth electrode insulated cable is disconnected at the SAFETY EARTH terminal and the resistance between the insulated SAFETY EARTH terminal and the CHASSIS EARTH terminal is measured. This test measures the DC resistance of the earth leakage trip coil and checks that the normally closed contact of the test switch is serviceable. The indication should be 175 ± 25 Ω. A high indication or open circuit indicates deterioration of the test button switch contact resistance or a faulty trip coil, and will require a replacement device to be fitted. A short circuit reading indicates a faulty coil or incorrect installation of the unit which would render the VOELCB inoperative, even though it appears to pass the test button check.

40 Operating the test button does not test the VOELCB under fault conditions. It should be tested fully using the test circuit at Fig 5 and the instructions detailed in AP 119F-00010-5F.

NOTE

> The earth continuity conductor must be disconnected at point F. The test lead should then be connected at point F and the test carried out On satisfactory completion, the earth continuity conductor must then be reconnected at point F.

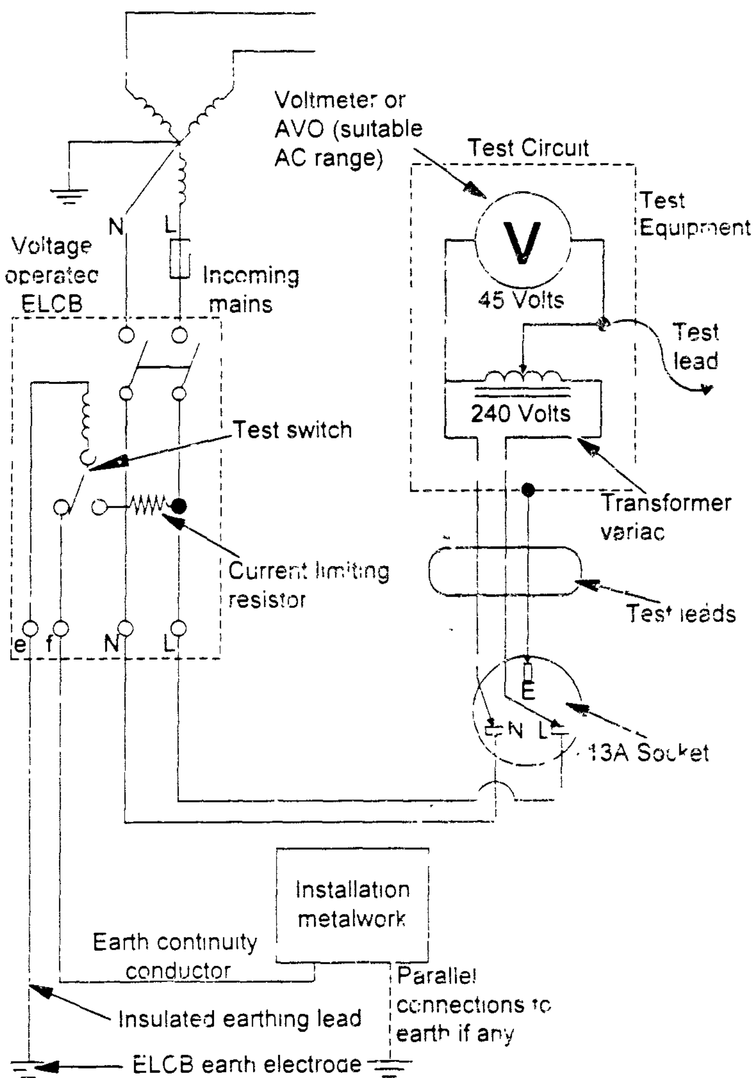

Fig 5 VOELCB test circuit

FREQUENCY OF TESTS

41 It is recommended that when a cabin/vehicle utilizing voltages in excess of 50 VAC or 120 VDC is used in a deployed mode, the following checks are implemented at the periodicities indicated:

41.1 Visual examination of all exposed cables - Daily.

41.2 Resistance measurement of all earth leads and protective conductor - maximum resistance 1 Ω - on initial set up and at monthly intervals.

41.3 Soil resistivity - on initial set up and at 3 monthly intervals.

41.4 Earth electrode resistance - on initial set up and at 3 monthly intervals.

41.5 Installation insulation test - on initial set up and at 3 monthly intervals.

41.6 Earth loop impedance test - on initial set up and at 6 monthly intervals.

41.7 Bonding checks, maximum resistance 0.1 Ω - 6 monthly intervals.

41.8 RCD and FVELCB electro-mechanical checks - on initial set up and at 3 monthly - intervals.

41.9 Emergency off buttons, if fitted - 3 monthly intervals.

41.10 Verification of polarity - on initial set up.

41.11 RCD and VOELCB, using external test equipment - 12 monthly intervals.