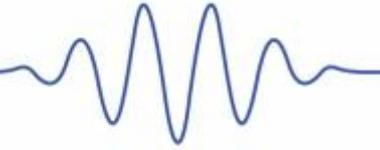




Radio Society of Great Britain

Advancing amateur radio since 1913



# Earthing and the Radio Amateur

EMC07 Advanced Leaflet

## 1 Disclaimer

*This leaflet is intended for members of the RSGB who have passed the Radio Amateur's Examination or who are studying for it. It assumes a knowledge of electrical principles and safety practice. RSGB Leaflets are made available on the understanding that any information is given in good faith and the Society cannot be held responsible for any misuse or misunderstanding. Where any doubt exists a suitably qualified electrical contractor shall be consulted*

# UK<sup>i</sup> Network Earthing Systems and RF Earthing at Amateur Radio Stations

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## 1.0 Introduction

Advice on the connection of radio equipment, antennas, coaxial cables and amateur station towers to a local earth is provided in many publications including equipment user documents. However, much of this is of a general nature only and may not fully address the specific issues that apply in the UK through the building and electrical installation regulations.

This paper is therefore intended to highlight the issues that need to be taken into account where a UK based amateur is considering the connection of radio equipment including antennas to an earth that is additional to the usual connection provided by the manufacturer using the UK standard three pin plug.

The paper is not intended to replace advice from a qualified installation electrician or electrical engineer. It is provided to advise amateurs in order that they can have informed discussions with the contractor and installation inspector. In Scotland it is an offence to undertake some wiring alterations unless you are qualified and accredited to do this work.

## 2.0 Electrical Installation Standard and Building Regulations

In UK the standard that all new electrical installations need to comply with is the 17th edition of the IET<sup>ii</sup> Wiring Regulations otherwise known as British Standard (BS) 7671<sup>1</sup>. This requirement also applies to changes or modifications to an existing electrical installation.

Building insurance normally requires that the building's electrical installation complies with the IET Wiring Regulations and that any alterations are also complaint.

In addition, in England and Wales certain work on an electrical installation has to be undertaken in accordance with Part P of the building regulations. This includes the installation of an earth electrode and changes to the property's wiring, such as the extension or modification of a ring main circuit. In Scotland and Northern Ireland separate building regulations apply, which can be found on their websites.<sup>iii</sup>

## 3.0 Domestic Property Earthing – The Different Types

In the UK most properties are now provided by the electricity distribution company with an earth connection to which the earthing pin of the UK standard three pin plug

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<sup>1</sup> The full title is the IET Wiring Regulations BS 7671: 2008 Incorporating Amendment 3: 2015

connects and to which fixed appliances also have exposed metalwork connected. This earth is primarily needed to permit the fault current from conventional protective devices to flow safely such that the fuses or circuit breakers can operate and thereby automatically disconnect the live feed to the faulty appliance. This automatic disconnection of supply (**ADS<sup>2</sup>**) is the primary purpose of the earthing system in a property.

*How does this work?*

Consider the situation in Figure 1<sup>iv</sup> where no appliance earth is provided but a cooker's metal frame becomes live through damaged or faulty wiring.

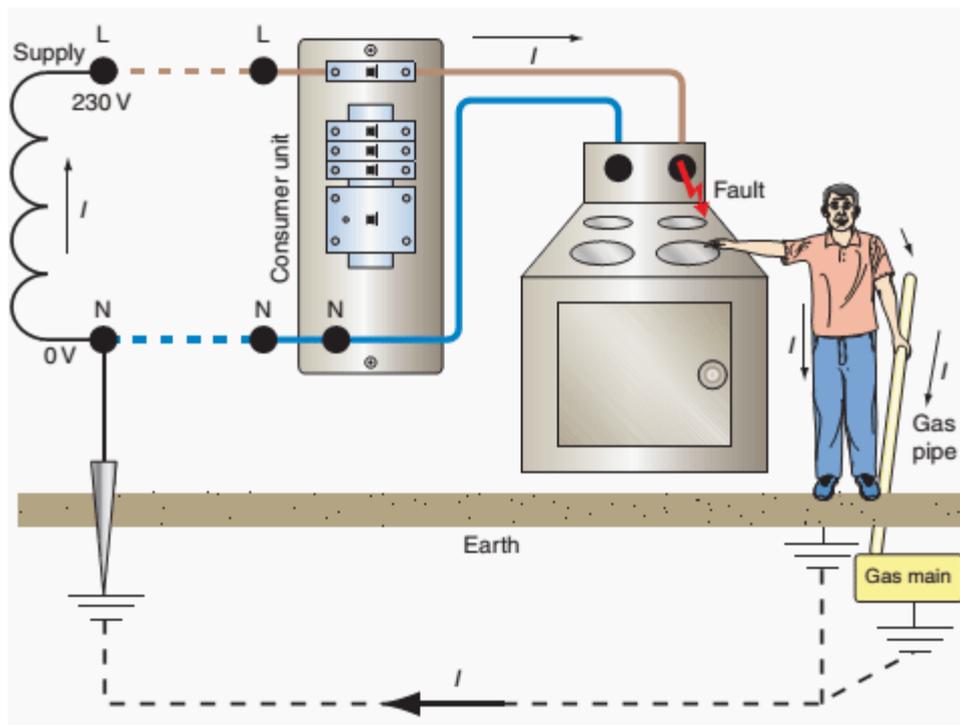


Figure 1. Risk of electrocution when a circuit earth is missing.

Fig. 1 above shows what can happen if a fault develops in an electrical appliance that does not have its metal frame connected to earth. The cooker's metal frame becomes and can remain live until in this example a person inadvertently creates the connection to earth through their body, with possible fatal consequences.

By providing a circuit earth conductor to the cooker, which then connects it to the property's installation earth, this permits the fault current to flow and operate the circuit breaker or fuse. Also with equipotential bonding to the gas pipe this minimises the risk of electric shock voltages developing between the different metalwork. This illustrates the two purposes of earthing namely to;

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<sup>2</sup> Where an abbreviation or technical term is used for the first time it is defined and shown in red to enable the reader to go back to it.

1. Provide an adequate earth return path to automatically disconnect the faulty circuit; and
2. Provide equipotential bonding to prevent dangerous touch voltages arising.

In the IET Wiring Regulations the metal frame of the cooker is called an “**exposed-conductive-part**”, meaning it is a conductive part of the appliance which can be touched and which is not normally live, but can become live under certain conditions<sup>3</sup>. The gas pipe is an “**extraneous-conductive-part**”. This is a conductive part connected to the general mass of Earth<sup>4</sup>, which itself is not forming part of the electrical installation but is importing a connection from Earth.

In the UK there are three different methods of domestic earthing. These will now be described.

### 3.1 TT System - T is the French for earth e.g. terre<sup>5</sup>.

In this situation, the electricity distribution company earths its own LV network neutral at the local substation, the source earth, but does not provide an earth connection at the property, the installation earth. This source earth is the first “Terre” reference for earth. This is shown in Fig. 3 below.

At the property the protective earth is derived from an earth stake, usually copper or copper coated, which is the responsibility of the owner of the property to install and maintain. This installation earth is the second “Terre” reference.

This is shown in Fig. 2 below at the consumer’s installation service point.

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<sup>3</sup> The reader may want to consider the conditions that could produce a live metal frame on the cooker.

<sup>4</sup> The term Earth with a capital E refers to the general mass of earth which is taken to be at or near zero volts. Different earth points in the installation can be expected on occasions to be at a measurable voltage above Earth.

<sup>5</sup> This comes from the Latin **terra**, as in “terra firma” for solid earth, or dry land, as any shipwrecked sailor will attest.

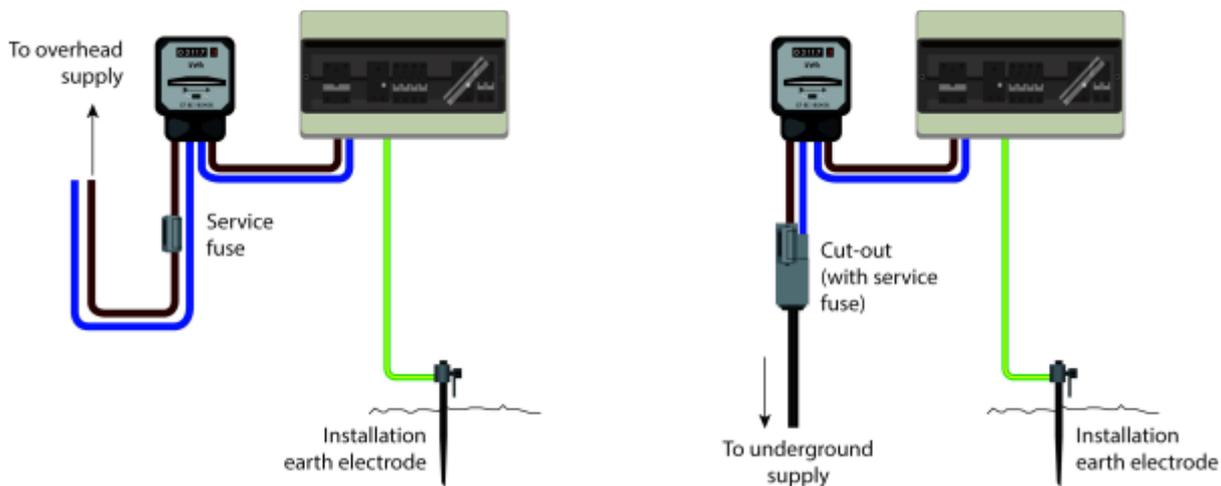


Figure 2. The typical TT system at the property's point of service.

For overhead line and under-eave networks the TT system was the main form of supply for many years.

### 3.2 TN-S System or Terre, Neutral, Separate

Under this arrangement the electricity network company provides an earth terminal, which connects to the main earth terminal (MET) in the property. Note that there is only one MET in any given property. The TN-S arrangement is shown below in Figure 3.

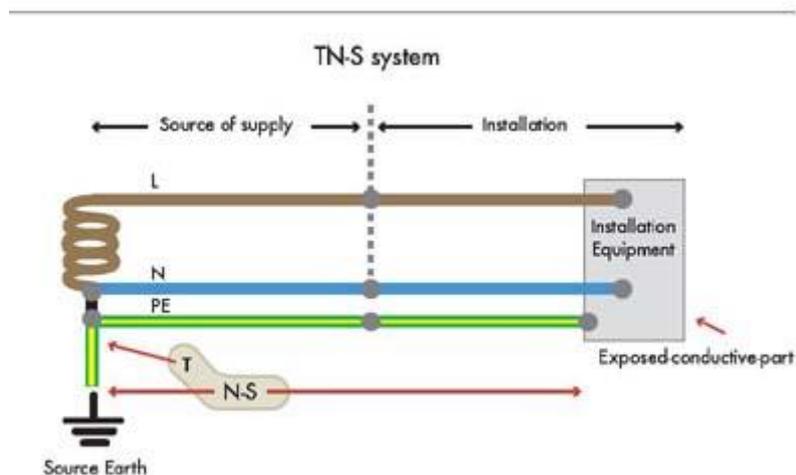


Figure 3. The TN-S (Terre, Neutral - Separate) system

The TN-S system was the main system used in the UK in most cities or large towns until the mid 1970s.

The TN-S installation is shown below in Fig. 4 at the consumer's installation service point, depending on whether it is an overhead or underground supply;

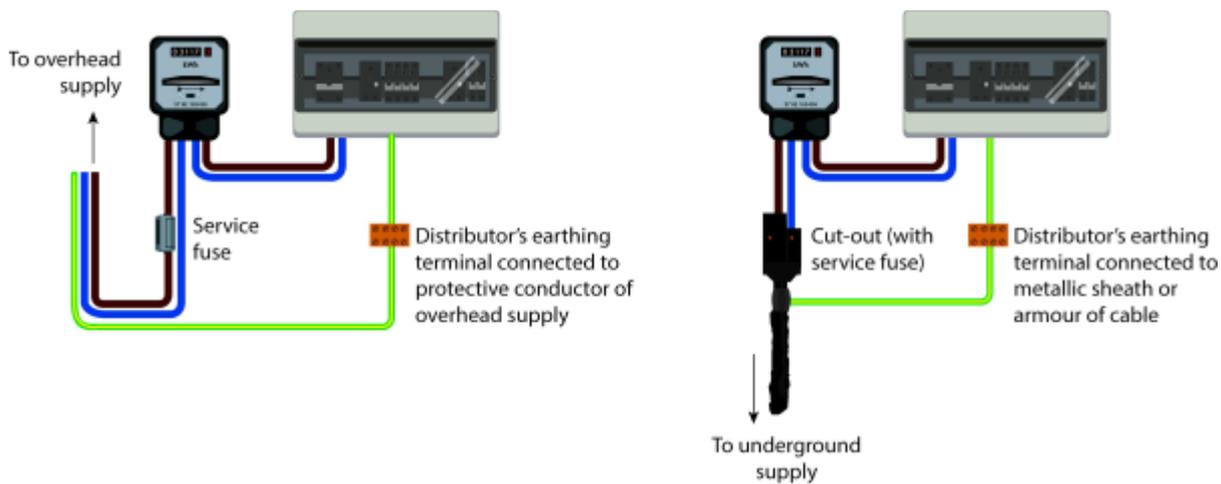


Figure 4. A typical TN-S system at the property's point of service.

Note that the earth connection from an overhead line was only provided by a few distribution companies or Area Boards as they were then called.

### 3.3 The TN-C-S System – Terre Neutral –Combined (then)- Separate

In this arrangement the electricity network company provides an earth connection to the MET. This is derived from a cable containing line (phase) and a combined neutral/earth conductor, or from the neutral conductor of an LV overhead line. This is the TN-C part of the reference. At the property the neutral and earth conductors are then separated and remain so within the domestic installation, which is the S part of TN-C-S term.

This is shown below in Figure 4. The neutral and earth are combined outside the premises and then separated inside the building. Hence the condition of TN-Combined then TN-Separate.

This system is used on most distribution networks installed since the mid-1970s and on most network or service alterations made since then to the older systems.

The purpose of this change is to save money on the network costs and also provide a free consumer earth terminal from the distribution network including overhead networks.

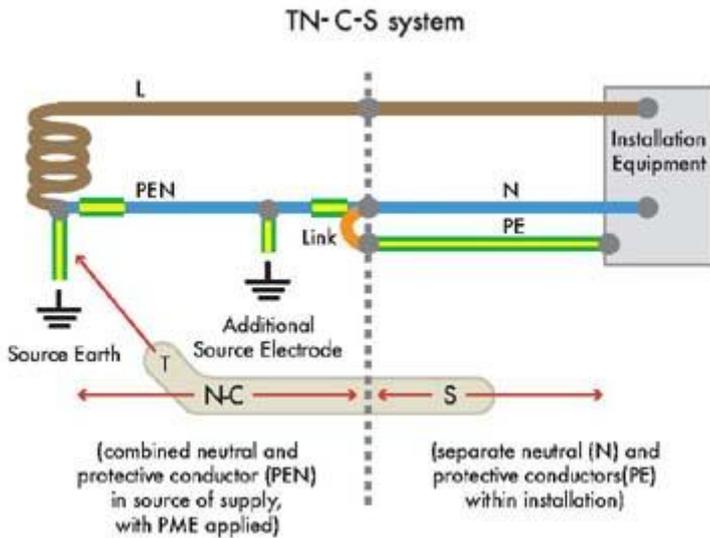


Figure 5. The TN-C-S system

In Fig. 5 we have introduced the term **PME**. This stands for protective multiple earthing. This refers to the distribution network but requires properties to have an installation that complies with PME requirements regarding for example adequate cross bonding of metalwork. You will recall the example of the metal gas pipe in Figure 1; this is an example of metalwork that requires cross bonding. Another new term in Figure 5 is **PEN** which means a protective earth-neutral conductor or combined neutral earth conductor. It should be noted that a PEN conductor cannot be used within a domestic wiring installation.

With PME systems additional earth rods are connected to the local distribution network PEN conductor for safety reasons. Hence the term protective multiple earthing, which means the local distribution network has multiple earth connections on its neutral.<sup>6</sup>

Many properties and virtually all new properties will have a PME system connection. This means the property has the TN-C-S system and requires that exposed metalwork within the property is bonded.

The TN-C-S system looks like this at the property's service position, depending on the type of supply;

<sup>6</sup> In the early years of electricity supply the Post Master General had to be consulted over the earthing of the distribution network and PME was not possible until the rules were relaxed on the amount of neutral earths permitted.

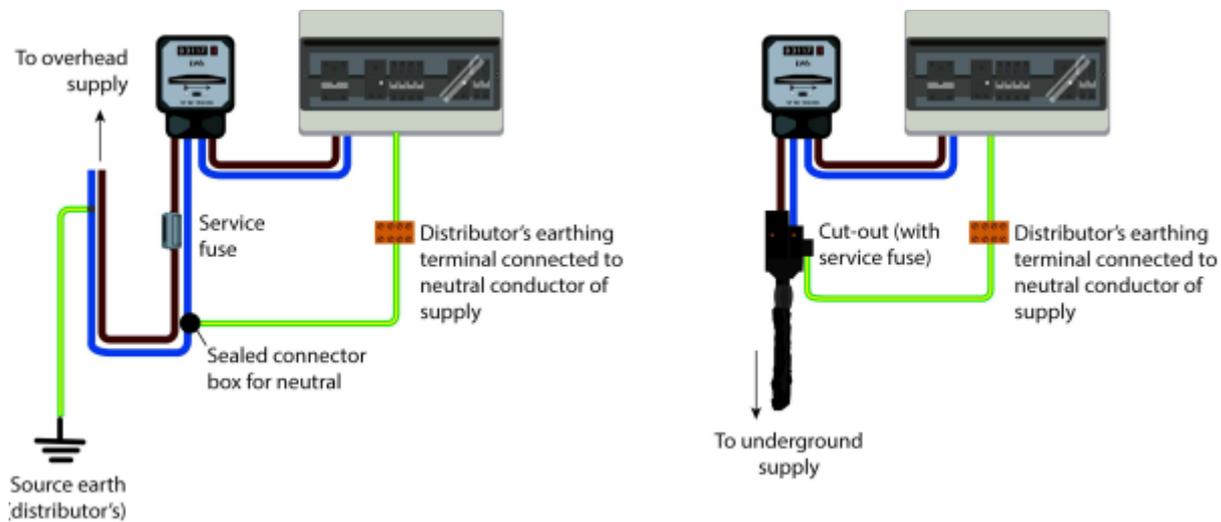


Figure 6. A typical TN-C-S system at the property's point of service.

### 3.4 The Fourth System

There is another earthing system called the IT system. This is not used in the public distribution networks in the UK. This typically has a high impedance inserted in the neutral earth at the source of the supply to the LV Network. It is shown below in Fig. 7 for information only.

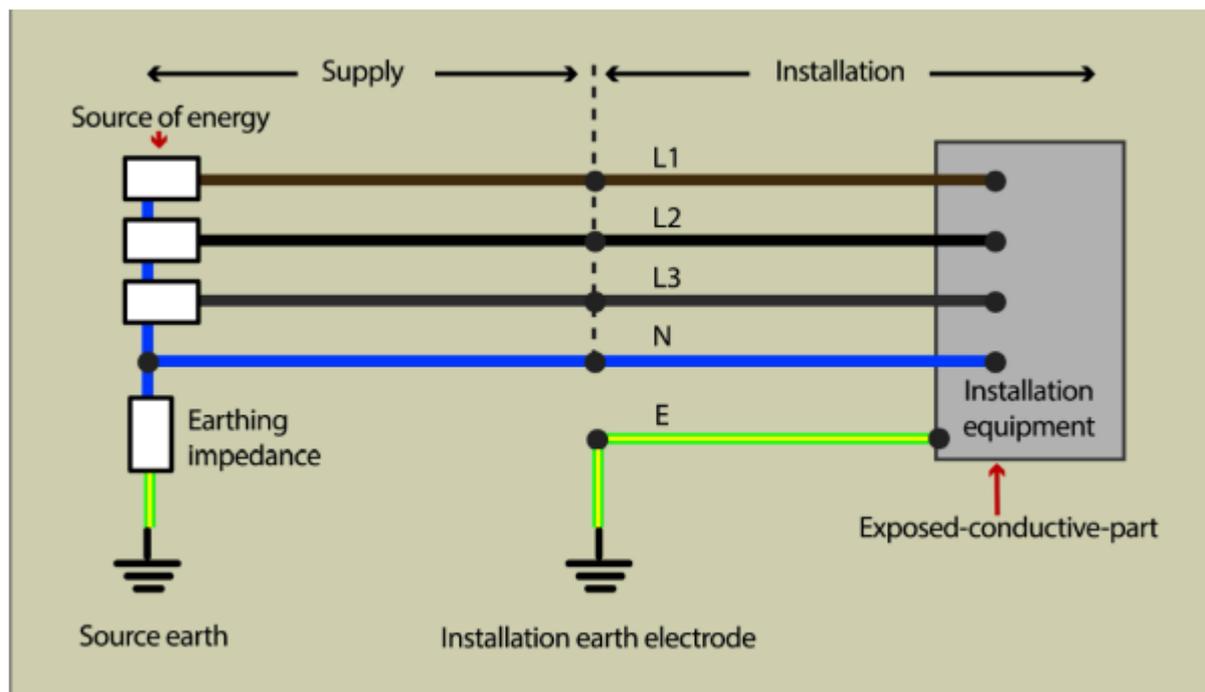


Figure 7. The IT system – not used in domestic property.

### 3.5 What is bonding?

In a property all the metallic services, i.e. gas, water, oil, etc. must be bonded back to the MET by means of a bonding earth connection. This is called in the IET Wiring Regulations “**equipotential bonding**”, which means an electrical connection maintaining exposed-conductive-parts and extraneous-conductive-parts at substantially the same potential.

Bonding is required to prevent dangerous touch voltages developing between different conducting surfaces, as shown occurring in Figure 1.

The different types of bonding are shown in Fig. 8 below. These are main protective bonding and supplementary bonding. It is important to remember that the automatic disconnection of supply (ADS) is the most commonly used measure for protection against electric shock. A prerequisite for this measure to be effective is that the installation is required to be earthed, as well as having protective equipotential bonding. During an earth fault, the earthing system permits an earth fault current to flow and to be detected by an ADS device (e.g. an overcurrent protective device or a residual current device). This limits the duration of the earth fault and removes the risk of thermal damage to the installation. Additionally, the protective equipotential bonding minimises the touch voltages that may appear between exposed-conductive-parts and extraneous-conductive-parts, thereby together with the ADS preventing the occurrence of dangerous voltages and the risk of fire.

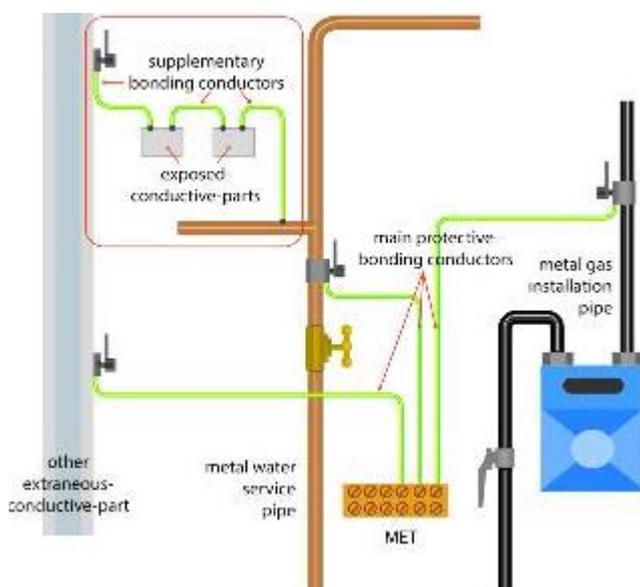


Figure 8. The two different types of bonding.

It used to be the case that all extraneous-conductive-parts in a house with TN-C-S needed to be bonded, but with the recent changes to the IET Wiring Regs if you have a supply totally fed from RCD<sup>7</sup> or RCBO<sup>8</sup> protection devices, this requirement is no longer mandatory. However, the impact of a lost network neutral still needs to be considered with respect to conductive path bonding if a better earth (i.e. lower impedance connection to Earth) is imported by say a radio mast's earthing system, since this will not be interrupted by RCD or RCBO protection<sup>9</sup>.

<sup>7</sup> RCDs are residual current circuit breakers. These detect small current leakages from a circuit.

<sup>8</sup> RCBOs are devices that provide RCD protection, for example 30mA and also circuit thermal fault protection normally provided by fuses or miniature circuit breakers (MCBs).

<sup>9</sup> The reader may want to reflect on why an RCD or RCBO does not monitor current in a neutral conductor.

## 4.0 TN-C-S and the Amateur

In a TN-C-S situation if the local distribution network has a neutral failure between the amateur's property and the substation then a well grounded RF earth connection at the property, such as the earth on a radio tower, will act as the new neutral earth for all properties upstream of the supply, The RF earth will become the new load side network neutral/earth return point and if this happens the RF earth will need to carry all the local load current on that part of the street –which may include shops and light industry. If poorly designed or inadequately installed this could cause a fire and destroy your shack and its equipment. It has happened!

Additionally, if a TN-C-S system has a fault on it all of the earth metalwork connected to the system will rise to the neutral fault voltage level, which can be a few volts through to hundreds of volts above true Earth, in extreme but rare cases. In the event that an operator has contact with equipment say with RF earth that is not cross bonded to the MET and other metalwork, say a central heating radiator, which is bonded to the MET then an electric shock risk will arise. Note that potentials as low as 50 Volts with mains current behind it can electrocute a person<sup>10</sup>.

### 4.1 How to minimise these risks ?

- Use earth free antennas (balanced feed) and use trees or fiberglass masts for support. If you use a vertical dipole then choose one which is mounted free from earth.
- Some verticals can be installed with radials suspended in the air. The RSGB “Successful Wire Antennas” book provides more detail.
- Next, if you have a TN-C-S supply and must have that metal tower (with good tower grounding against lightning/static) and provided you have the space, then consider separating your shack from the TN-C-S system neutral-earth. If your shack is in an outbuilding or separate garage or similar, convert it to a TT system, with its own dedicated earth. Otherwise you have to cross bond the tower to the MET – and import the noisy mains earth with all that conducted interference possibly adding a couple of S points or more of background noise.
- If you have the funds, convert the whole house to TT. However, this is only possible if you have dedicated services to the property. If you have a flat, maisonette or terraced property the distribution network company may not let you convert your property due to the presence of shared services with your neighbors.
- Convert a room to TT. However, if you do this all forms of earthing in that room, must be separate from the house earth or electrically insulated. This includes radiators, pipes, exposed structural steel etc. It may be that an electrical storage radiator connected to the TT supply could be used to replace a metal water heating radiator, with its water bonding and gas bonded to the TN-S-C system.

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<sup>10</sup> See <http://www.hse.gov.uk/electricity/injuries.htm#shock> for more information.

## 5.0 Part P Building Regulations in England and Wales<sup>v</sup>

The above work involving earthing or changes to earthing, require in England and Wales support from a Part P approved electrician since they are reportable works under Part P and require inspection, testing and certification. If an amateur has the experience, say as a former contract electrician, then a Part P approved electrician can review the plan, report the works and then test and certify it. Scotland and Northern Ireland have similar arrangements.

Where a TN-S system is involved and the property is not in a cul-de-sac or similar location, then it may be possible to confirm that the network neutral is suitably linked to adequate earth clusters and or back to another substation to make the loss of neutral no longer a major risk of fire and radio equipment damage. In this case any additional earth electrodes for the tower and/or antenna earth will need to be cross bonded to the property's MET. The size and type of bonding conductor are subject to a number of factors and again a Part P electrician should be consulted before any work is commenced. Usually when the property service conductor is 35mm or less a 10mm Earth cable will suffice, but if you are in a cul-de-sac or on a similar network you may have to use the same size cross as the service cable neutral conductor for cross bonding. For a 25 sq mm copper service cable this means a 25 sq mm cross bonding connection is required.

The earth rods need to comply with BS7671. These rods should have an approved termination cover and not be left open to the elements and be labelled as shown in Fig. 9 below.



Figure 9. Essential earth electrode labelling.

The shack earth bar or terminal should then go to this earth rod also using the 10mm cable (or larger if specified by the distribution network company). The individual equipment earths should also be 10mm, but earth braid of this cross section area will be easier to use than 10mm earth cable.

The connections to the earth stake should be made with approved connections and crimped ring termination used on the ends of the earth cable with the notice shown in Fig. 9 attached.

Again this requires the input of a registered Part P electrician. Additional earth stakes should be recorded and the resistance measured under Part P guidelines

However, if you do not have a metal tower to connect to earth and if your antenna is installed without the use of any direct connections to earth, you will avoid the need for a Part P approved electrician.

#### 6.0 Note on CE marks

Electrical equipment supplied in UK since 1995 is required to have the CE, or European Conformity mark, to show it conforms with the EMC Directive on electromagnetic compatibility and also the Low Voltage Directive and other appropriate European standards. Transceivers and other equipment that have not been marked with the CE mark need to be treated with caution as they may have inadequate electrical safety features. Earlier manufactured equipment may need to be checked through the operating manual to determine if its basic insulation, basic protection and earth bonding conductors are adequately sized particularly for PME systems.

#### 7.0 The Electricity Safety, Quality and Continuity Regulations (ESQCR) requirements

The electricity distribution operator shall on request provide the following information for the property;

- (a) the number of phases;
- (b) the frequency; and
- (c) the voltage;

and, on request, (regulation 28) provide the following information:

- (d) the maximum prospective short-circuit current at the supply terminals;
- (e) for low voltage connections, the maximum earth loop impedance of the earth fault path outside the installation;
- (f) the type and rating of the distributor's protective device or devices nearest to the supply terminals;
- (g) the type of earthing system applicable to the connection; and
- (h) requirements for cross-sectional area and maximum length of meter tails.

Thus when an amateur is uncertain of the supply installation he/she can ask the distribution company that services the property. Item (e.) will give a good indication of the likely issues with poor earthing on the distribution company's network. A request for a copy of the plan showing the LV cables in the street should reveal where neutral earths are located, or missing. Where in doubt it is best to employ a qualified electrical contractor to carry out an installation check and advise on the condition of the Property's earthing system including its earth loop impedance.

## 8.0 Earth Rod Testing

There are several methods of testing an earth rod. The most widely used on new construction projects is by using a propriety earth tester, which uses two additional temporary earth stakes plus the one under test. This method is normally used when no power is available. However, this method cannot be used where there are imported substances, such as tarmac, concrete or hardcore in the intervening ground as the test needs to be conducted with typical local ground situated between the test rods.

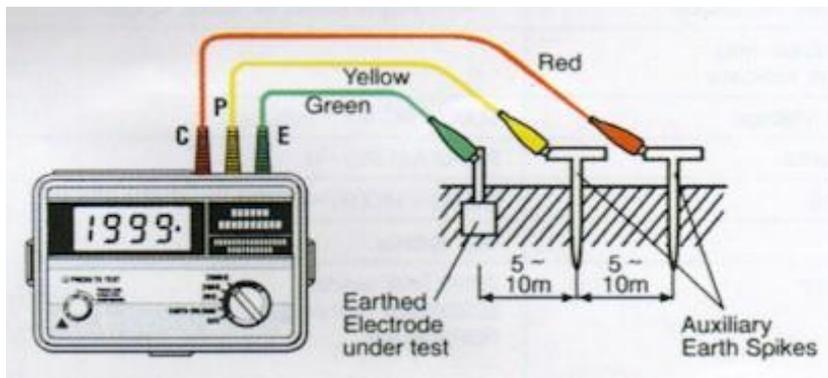


Figure 10. The twin earth spike test method

Another method is by using an earth loop impedance tester. This is normally used to measure the earth loop of a wiring installation, but can be used to measure earth rods by disconnecting the MET earth and then using the earth rod as the means of earth.

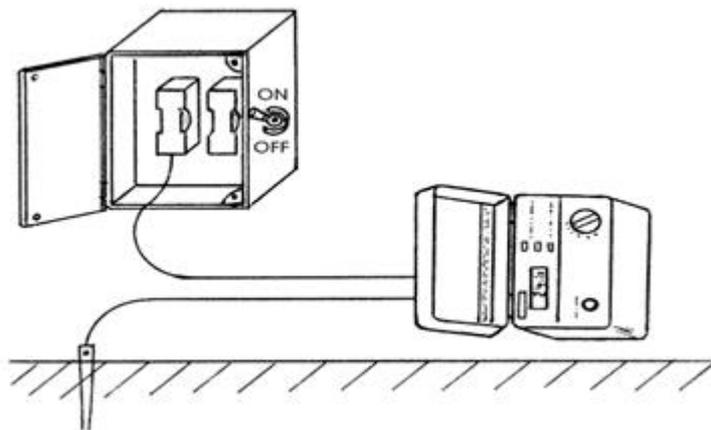


Figure 11. The earth loop impedance tester method.

A third method is to test by a clamp on meter that measures the earth rod resistance directly. An example of this is made by Fluke, which can be seen on YouTube at “The Fluke 1630 Earth Ground Clamp Meter”. It is being used in Australia where the standards are similar to UK’s. This shows that this meter can be used to carry out tests on a live system without disconnecting any of the earth rods. An alternative video is for Megger’s digital earth tester clamp on meters, which can be seen at “The Megger DET14C and DET24C Clamp on Meters” on YouTube.

Note that most American electrical installation YouTube videos are not compatible with UK regulations because of differences in design philosophy, voltage, frequency, ADS and earthing system.

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<sup>i</sup> Note that this paper only applies to electrical installations in UK. For other jurisdictions a locally accredited and qualified electrical engineer should be consulted.

<sup>ii</sup> The IET or Institution of Engineering and Technology was formerly known as the IEE or Institution of Electrical Engineers

<sup>iii</sup> At the time of writing the Scottish Government's building regs site was [www.scotland.gov.uk/bsd](http://www.scotland.gov.uk/bsd) and Northern Ireland's was [www.buildingcontrol-ni.com](http://www.buildingcontrol-ni.com)

<sup>iv</sup> Note that diagrams and figures used in this document are for self-study purposes only and shall not be used for commercial purposes without consent from the copywriter holder.

<sup>v</sup> Welsh Ministers may introduce additional requirements but at present the Part P requirements as contained in [www.planningportal.gov.uk](http://www.planningportal.gov.uk) apply.