

Guidance on Protective Conductors

including

Earthing Conductors

Circuit Protective Conductors

Main Protective & Supplementary Bonding Conductors

2008 17TH EDITION VERSION



Representing the best in electrical
engineering and building services

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Earthing and Bonding Definitions

It is essential to understand the difference between earthing and bonding.

*Earthing is defined in BS7671 as: "Connection of the **exposed**-conductive-parts of an installation to the main earthing terminal of an installation".*

Equipotential bonding is defined as: "Electrical connection maintaining various exposed-conductive-parts and extraneous-conductive-parts at substantially the same potential". (N.B. referred to as bonding throughout this document).

Both of these functions are carried out using protective conductors (as defined in the BS7671 Regulations). Protective conductors for **Earthing** are known as Circuit Protective Conductors (CPCs), protective conductors for **Bonding** are known as Bonding Conductors and may be either Main Protective or Supplementary.

The Earthing Conductor is defined as "A protective conductor connecting the Main Earthing Terminal of an installation to an earth electrode or to other means of earthing".

For a TN systems the means of earthing is either a Protective Multiple Earthing (PME) terminal or a separate conductor which may be the cable sheath. In a TT system the means of earthing is the earth electrode which must comply with the requirements of sub-section 542.2.

The definition of an extraneous-conductive-part is *"a conductive part liable to introduce a potential, generally earth potential, and not forming part of the electrical installation"*. Isolated metal door handles, shelf brackets, metal windows etc, are unlikely to be extraneous-conductive-parts.

An acceptable test to establish whether or not an item is an extraneous-conductive-part is as follows:

Using a 500 volt DC insulation tester, measure the insulation resistance between the item and the main earthing terminal. If the resistance value is 23 000 ohms or greater, and inspection confirms that the resistance is unlikely to deteriorate, then the item can reasonably be considered not to be an extraneous-conductive-part.

Selection and Sizing of CPCs and Earthing Conductors

CPCs and earthing conductors are selected in accordance with Section 543. Sub-section 543.1 deals with sizing, 543.2 with types and 543.3 with preservation of continuity.

NB A protective conductor may be common to more than one circuit (Regulation 543.1.2).

The following can be used as a protective conductor (**Regulation 543.2.2**):

- (i) A single-core cable
- (ii) A conductor in a cable
- (iii) An insulated or bare conductor in a common enclosure with insulated live conductors
- (iv) A fixed bare or insulated conductor
- (v) A metal covering, for example, the sheath, screen or armouring of a cable
- (vi) A metal conduit, metallic cable management, or other enclosure or electrically continuous support system for conductors
- (vii) **An extraneous-conductive-part complying with Regulation 543.2.6**

When sizing the CPC and earthing conductor the following must be considered:

- (i) Earth fault loop impedance requirements.
(Sub-section 411)
- (ii) Thermal constraints (i.e. the conductor does not overheat during fault conditions).
(Regulations 543.1.3 & 543.1.4).
- (iii) Additional requirements for PME supplies.
(Regulation 544.1.1).
- (iv) Additional requirements for all protective conductors where buried in the ground.
(Regulations 542.3.1 & 543.1.1).

Earth Fault Loop Impedance

$$Z_S = Z_e + R_1 + R_2$$

where:

Z_S is the earth fault loop impedance at the farthest point of the circuit.

Z_e is the earth fault loop impedance at the origin of the supply.

R_1 is the resistance of the line conductor.

R_2 is the resistance of the protective conductor.

Conductor Temperature Rise Under Fault Conditions

When evaluating measured earth fault loop impedance readings, account has to be taken of the temperature rise in conductors when carrying load currents. This has the effect of increasing the circuit earth loop impedance for the duration of the fault and delays the operation of the circuit protective device. To compensate for this condition, it is recommended that circuit earth loop impedance values of 80% of the tabulated values should be achieved when measured cool.

Thermal Constrains

Having obtained the protective conductor size and type from “Earth Fault Loop Impedance Requirements” consideration should now be given to whether the size of the conductor is sufficient to meet the thermal constraint requirements.

CPCs are sized **either** calculated as prescribed in Regulation 543.1.3 or sized using Table 54.7.

Additional Requirements

Where the CPC is also the main protective bonding conductor, it should be sized in accordance with the minimum requirements for main protective bonding.

Where Buried

Where **protective conductors** are buried directly in the ground the additional requirements of Regulations 542.3.1 and 543.3.1 must be applied.

Requirements for Main Protective Bonding Conductors

What is Main Protective Bonding?

Main protective equipotential bonding connects the main earthing terminal with the following extraneous-conductive-parts **(Regulation 413.3.1.2)**:

- (i) Water installation pipes
- (ii) Gas installation pipes
- (iii) Other installation pipes e.g. oil, compressed air-lines and ducting
- (iv) Central heating and air conditioning systems
- (v) Exposed metallic structural parts of the building
- (vi) The lightning protection system where required in accordance with BS EN 62305

Note:

- 1) Incoming plastic gas and water services pipes do not require bonding
- 2) Where an installation serves more than one building the requirements shall be applied to each building
- 3) The above list is not exhaustive

What May be Used as a Bonding Conductor?

- (i) A separate conductor
- (ii) Any CPC **complying with the requirements for sizing (Regulation 544.1.1)**
- (iii) Metal parts including conduits, trunking, tray, ducts, sheaths, screens and other metal enclosures

- (iv) Any extraneous-conductive-part except a gas or oil pipe (see Regulation 543.2.6). This is particularly useful as it allows the **use of other bonding conductors (such as structural steelwork) to be used as the bonding conductor or as part of the path of the bonding conductor to other extraneous-conductive-parts, e.g. a remote gas or water service in a steel framed building may be bonded to the structural steelwork at that remote point providing Regulations 543.2.6 and 514.13.1 are complied with.**

Size of Main Protective Bonds

In accordance with sub-section 544.1, except where protective multiple earth (PME) conditions apply and for main bonding to lightning protective systems, the main protective bonding conductors must have a cross-sectional area (CSA) of not less than half the CSA of that required of the earthing conductor of the installation, with a minimum size of 6mm². The CSA need not exceed 25mm² for copper or the equivalent for other metals.

Table 54.8

Minimum CSA of the main Protective bonding conductor in relation to the neutral of the supply

Copper equivalent cross-sectional area of the supply neutral conductor	Minimum copper equivalent cross sectional area of the main protective bonding conductor
35 mm ² or less	10 mm ²
over 35 mm ² up to 50 mm ²	16 mm ²
over 50 mm ² up to 95 mm ²	25 mm ²
over 95 mm ² up to 150 mm ²	35 mm ²
over 150 mm ²	50 mm ²

Where PME conditions do apply the main protective bonding conductors must be sized in accordance with the supply neutral conductor and be selected in accordance with Table 54.8 above.

Location of Main Protective Bonding Connections

Main bonding connections should be located as **near as practicable** (preferably within 600mm) to the point of entry into the building of water, gas or other services as required by Regulation 544.1.2. Connections must be on the consumer's side of any insulating insert, before any branch pipework and on hard metal, i.e. not on flexible meter hose.

BS 7671 does not specify where main protective bonding conductors should be connected to central heating pipes or air conditioning systems etc. but it would seem sensible to make these connections so that in the event of any subsequent alterations the connections would remain in place. BS EN 62305 Protection Against Lightning requires the connection to be made to the lightning conductor above the test clamp, so that when testing the lightning system earth it is disconnected from the electrical installation earth.

Supplementary and Additional Bonding

Supplementary bonding may be necessary in the following circumstances:

- (i) where automatic disconnection cannot be achieved in the required time regulation 411.3.2.6
- (ii) protection by earth-free local equipotential bonding regulation 418.2

Where Automatic Disconnection Cannot Be Achieved in the Required Time

Regulation 411.3.2.6 requires the installation of supplementary bonding where the required disconnection time cannot be achieved. The supplementary bonding shall connect together all exposed and extraneous conductive parts in the area of the circuit(s) concerned.

Where this method is used, consideration needs to be given to the need to disconnect for thermal protection purposes using the adiabatic equation in Regulation 434.5.2.

Protection By Earth-Free Local Equipotential Bonding

This method of protection shall only be used in special circumstances and must be supervised to ensure the environment remains earth free.

Where this method is used, supplementary bonding is required to connect together all simultaneously accessible exposed and extraneous conductive parts, Regulation 418.2.2.

Earthing and Bonding Requirements for Special Installations or Locations

Section 701 Location Containing a Bath or Shower

Supplementary bonding is not required in new installations as an RCD is always required for both domestic and commercial installations.

Section 702 Swimming Pools and Fountains

Regulation 702.411.3.3 requires local supplementary bonding between all extraneous-conductive-parts in Zones 0, 1 and 2 and the CPCs of all exposed-conductive-parts in these zones. Where the supply is TN-C-S it is recommended that an earth mat or electrode of resistance less than 20 ohms is installed and connected to the main protective bonding.

Section 705 Agricultural and Horticultural Premises

For **these premises**, where livestock is kept, the requirements of Regulation, 705.415.2.1 should be noted i.e. supplementary bonding shall connect together all exposed conductive-parts and extraneous-conductive-parts which can be touched by livestock. If there is a metallic grid laid in the floor it should be supplementary bonded.

Section 706 Conducting Locations with Restricted Movement

Where automatic disconnection is used for protection against electric shock, Regulation 706.410.3.5 (iii) requires supplementary equipotential bonding.

Section 711 Exhibitions, Shows and Stands

Structural metallic parts, which are accessible from within the unit, shall be connected to the main earth terminal **within** the unit.

Section 712 Solar Photovoltaic (PV) Power Supply Systems

Where protective bonding conductors are installed, these shall be run parallel and in close contact with the dc and ac cables (Regulation 712.54).

Section 717 Mobile or Transportable Units

Regulation 717.411.3.1.2 requires main protective bonding to the accessible conductive parts such as the chassis.

Section 721 Caravans and Motor Caravans

Regulation 721.411.3.1 calls for additional bonding of extraneous-conductive-parts within the Caravan and Motor Caravan.

Section 740 Temporary Electrical Installations for Structures, Amusement Devices and Booths at Fairgrounds, Amusement Parks and Circuses

Locations intended for livestock require supplementary Bonding (Regulation 740.415.2.1) see Section 705.

Labelling Requirements for Earthing and Bonding Conductors

Under Regulation 514.13.1 it is a requirement that a durable label marked 'Safety Electrical Connection - do not Remove' should be permanently fixed in a visible position at or near:

- (i) the point of connection of every earthing conductor to an earth electrode; and
- (ii) the point of connection of every bonding conductor to an extraneous-conductive-part; and
- (iii) the main earth terminal, where separated from the main switch gear.

Additional Information

Regulation 544.2.5 now allows **for part of the bonding path to** an appliance to be via the CPC of the flex. This is particularly useful for bathrooms with electric towel rails etc.

However supplementary bonding shall be applied to the CPC of that circuit unless all circuits within the location are protected by a 30mA RCD.

Under Regulation 559.10.3.1 (v) metallic structures not connected to or part of street furniture do not require bonding.

Regulation sub-section 543.7 has additional requirements for CPCs in areas containing equipment with High Protective Conductor connections i.e. computers.



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