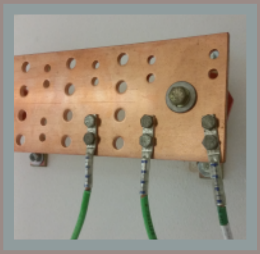
Essentials of Bonding and Grounding

Version 1.0



BICSI®

advancing the information and communications technology community

Essentials of Bonding and Grounding

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Version 1.0 published 2016
First printing May 2016
Printed in the United States of America

ISBN 978-1-928886-72-3 (Electronic)

The contents of this document are subject to revision without notice due to continued progress in bonding and grounding (earthing) methods, design, and manufacturing.

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- In general, approximate (soft) conversions are used in this document and are denoted with the approximate symbol (≈) in front of the metric number. Approximate conversions are considered reasonable and practicable; they are not precise equivalents, but are considered as "industry friendly." Example: ≈15 m (50 ft), not the hard conversion of ≈15 m (49.2 ft).

In some instances, equivalents (hard conversions) may be used when it is a:

  - Manufacturer requirement for a product (e.g., conduit, plywood sizes).
  - Standard or code requirement.
  - Safety factor.

- In general, approximate SI units of measurement are converted to an imperial unit of measurement and placed in parentheses. Exception: When the reference material from which the value is pulled is provided in imperial units only, the imperial unit is the benchmark.
- For metric conversion guidelines, refer to IEEE/ASTM SI 10, American National Standard for Metric Practice.
- Trade size is approximated for both metric and nonmetric purposes. Example: ≈100 mm (4 trade size).
- In some instances (e.g., optical fiber media specifications), the physical dimensions and operating wavelengths are designated.

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Essentials of Bonding and Grounding (Earthing)

Introduction

The purpose of bonding and grounding (earthing) in a telecommunications system is to:

- Reduce the hazard of electrical shock and damage to structures and equipment from alternating current (ac) and direct current (dc) voltages and from lightning surges.
- Abate the hazardous and damaging effects of lightning and power surge voltages and currents in telecommunications facilities.
- De-energize the power circuit quickly in the event of an accidental contact by causing operation of power circuit breakers or fuses.
- Provide paths to ground (earth) for shield currents in metallic cable shields, thereby reducing the voltages induced onto cable conductors.
- Reduce noise voltages in sensitive circuitry by providing an effective common reference point for circuit potentials to which outside induced currents can drain without disturbing circuit operation.

Grounding is achieved via mechanical connection to earth. This is done for the purpose of establishing a reference where electrical systems and equipment can be referenced at the same potential as the surrounding earth. This is also true of cable installations where the voltage differences between the cables and the surrounding earth do not exceed the insulation characteristics, thereby reducing the cables' effectiveness.

Bonding is achieved to help equalize the voltages between conductive surfaces during:

- Lightning strikes.
- ac Electrical system faults in the electrical utility or customer premises wiring.
- Electromagnetic interference (EMI).

Terminology

Distinct differences exist between the terms *bonding* and *grounding* or *earthing*. Generally speaking, grounding or earthing is the establishment of a reference for the electrical power source (ac or dc), the electrical equipment, or both. Bonding is the connection intended to safely and effectively equalize the potential differences between two metallic items (e.g., equipment rack and cable tray). In the context of this document, grounding and earthing topics are denoted as grounding (earthing).

While bonding, grounding, and earthing are all relevant to the concept of protection, in the context of this document, protection pertains to lightning and electrical surge-related topics.

Because of the criticality of bonding systems for the protection of life and equipment, efforts continue to create a consistent set of terms and definitions, applicable in all jurisdictions. In 2015, ISO published an international standard (ISO/IEC 30129) specifically for telecommunications bonding infrastructure, which included internationally accepted terminology for bonding infrastructure components. Since publication, a large number of countries, including the United States, have started the long process of updating relevant codes, standards, and other documentation to reflect these new terms.

This document uses these new terms; however, it is recognized that some of these new terms replace long established regional equivalents. Table 1 provides a listing of known regional terms and their equivalent found in standards such as ISO/IEC 30129 and TIA-607-C.

Terminology, continued

Table 1
Regional and standards terminology equivalents

ISO/IEC 30129 and TIA-607-C	Regional
backbone bonding conductor (BBC)	
	grounding equalizer (GE)*
	horizontal equalizer
primary bonding busbar (PBB)	
	building principal ground (BPG)
	CO GRD Bus
	COG
	facility ground
	main earthing terminal (MET)
	master ground bar (MGB)
	OPGPB
	PGP bus
	principal ground point (PGP) reference point 0 (RP0)
	telecommunications main grounding busbar (TMGB)*
	zero potential reference point
rack bonding busbar (RBB)	
	rack grounding busbar*
secondary bonding busbar (SBB)	
	approved floor ground
	extended reference point 0 (Extended RP0)
	floor ground bar (FGB)
	telecommunications grounding busbar (TGB)*
telecommunications bonding backbone (TBB)	
	equalizer
	equalizing conductor
	vertical equalizer
	vertical ground riser
***telecommunications bonding conductor (TBC)**	
	bonding conductor for telecommunications (BCT)

* Previously used within TIA-607-B and BICSI publications

Why Bonding and Grounding (Earthing)?

A primary responsibility of the information and communications technology (ICT) distribution designer is safeguarding personnel, property, and equipment from foreign electrical voltages and currents (foreign refers to electrical voltages or currents that normally are not carried by, or expected in, the telecommunications distribution systems).

The results of such disturbances could be:

- Death or injury due to electrical shock.
- Destruction of electronic equipment and property due to electrical fire.
- Component malfunction or degradation.
- Work or process disruption.

The ICT distribution designer must consider:

- Lightning.
- Ground potential rise (GPR).
- Contact with electrical power circuits.
- EMI.
- Radio frequency interference (RFI).
- Electromagnetic compatibility (EMC).

The bonding and grounding (earthing) infrastructure of a telecommunications installation is an essential part of an ICT distribution designer's responsibilities. This document provides some background information, design considerations, and testing verification procedures that can help the ICT distribution designer make logical, technically sound choices when confronted with a variety of telecommunications equipment or telecommunications cabling installations.

Systems and Components

The ICT distribution designer typically is responsible for the telecommunications bonding and grounding (earthing) and the telecommunications circuit protectors. The designer must also recognize that the following three subsystems constituting the bonding and grounding (earthing) system should be in place at every site:

- ac Grounding (earthing) electrode system (also known as the earthing system in some countries).
- Equipment grounding (earthing) system (also known as the equipment bonding system in some countries).
- Telecommunications bonding infrastructure.

Because the purpose of each of these subsystems is unique, one cannot be used in place of the other two.

Alternating Current (ac) Grounding (Earthing) Electrode System and Components

The purpose of the ac grounding (earthing) electrode system is to:

- Establish a 0 volt (V) reference for ac electrical power systems, whether utility-provided or customer-derived.
- Provide a path for the dissipation of currents due to lightning or accidental contact with higher-voltage systems.
- Provide a path for the dissipation of electrostatic discharge currents.

The ac grounding (earthing) electrode system consists of two main components:

- Grounding electrode conductor (GEC)—The conductor used to connect the grounding (earthing) electrode to either the equipment grounding (earthing) conductor, or to the grounded conductor of the circuit at the service equipment, or at the source of a separately derived system.
- Grounding (earthing) electrode—A conductor, usually a rod, pipe, or plate (or group of conductors), in direct contact with the earth for the purpose of providing a low-impedance connection to the earth. The grounding (earthing) electrode is a device that establishes an electrical connection to the earth.

Many types of grounding (earthing) electrodes may be utilized as an earthing reference by the ac electrical system. The electrical designer for the building makes the selection of a particular electrode. Selecting a grounding (earthing) electrode as a suitable reference can be difficult for buildings without structural steel and in geographical locations where the soil condition prohibits an effective mechanical connection.

Since the telecommunications bonding infrastructure is dependent upon its connection to the ac grounding (earthing) electrode system, the ICT distribution designer should explore the proposed or existing (if applicable) electrode system and design the telecommunications bonding infrastructure accordingly. Connections to grounding (earthing) electrodes, busbars, and associated components should be labeled with a tag in order to determine their destination or source.

Equipment Grounding (Earthing) System and Components

The primary purpose of the telecommunications equipment grounding (earthing) system is to enhance personnel safety and reduce the likelihood of a fire hazard by facilitating the operation of overcurrent devices (circuit breakers). This is achieved by reducing the amount of impedance across the equipment grounding (earthing) conductor path.

The impedance of the telecommunications equipment grounding (earthing) conductor should be as low as possible. The *National Electrical Code® (NEC®)* has not set a required impedance value. However, IEEE® 1100, *Recommended Practice for Powering and Grounding Electronic Equipment*, suggests that the recommended maximum value be 1 ohm for ac circuits of 120 V to ground and 0.8 ohms for 277 V to ground (United States) and 347 V to ground (Canada).

In addition, the equipment grounding (earthing) system is the portion of the ac electrical distribution system that:

- Maintains 0 V on all equipment enclosures during normal operations.
- Acts as the intentional path for fault current during ground fault conditions.
- Provides a voltage reference for end-user telecommunications electronic equipment power supplies.

The main component of the telecommunications equipment grounding (earthing) system is the equipment grounding (earthing) conductor, available in many forms, including:

- Bare copper conductors.
- Insulated conductors.
- Metallic conduits and the nationally recognized testing laboratory (NRTL)-listed fittings.
- ac Electrical panelboards and the NRTL-listed fittings.
- Junction boxes.
- Outlet boxes.
- Metallic raceways.

Telecommunications Bonding Infrastructure and Components

The telecommunications bonding infrastructure equalizes potentials between metallic surfaces and equipment within entrance facilities (EFs), equipment rooms (ERs), and telecommunications rooms (TRs) in the event of lightning, ac electrical system faults, electromagnetic induction, or electrostatic discharge.

Telecommunications bonding infrastructure is often grouped into small systems and large systems.

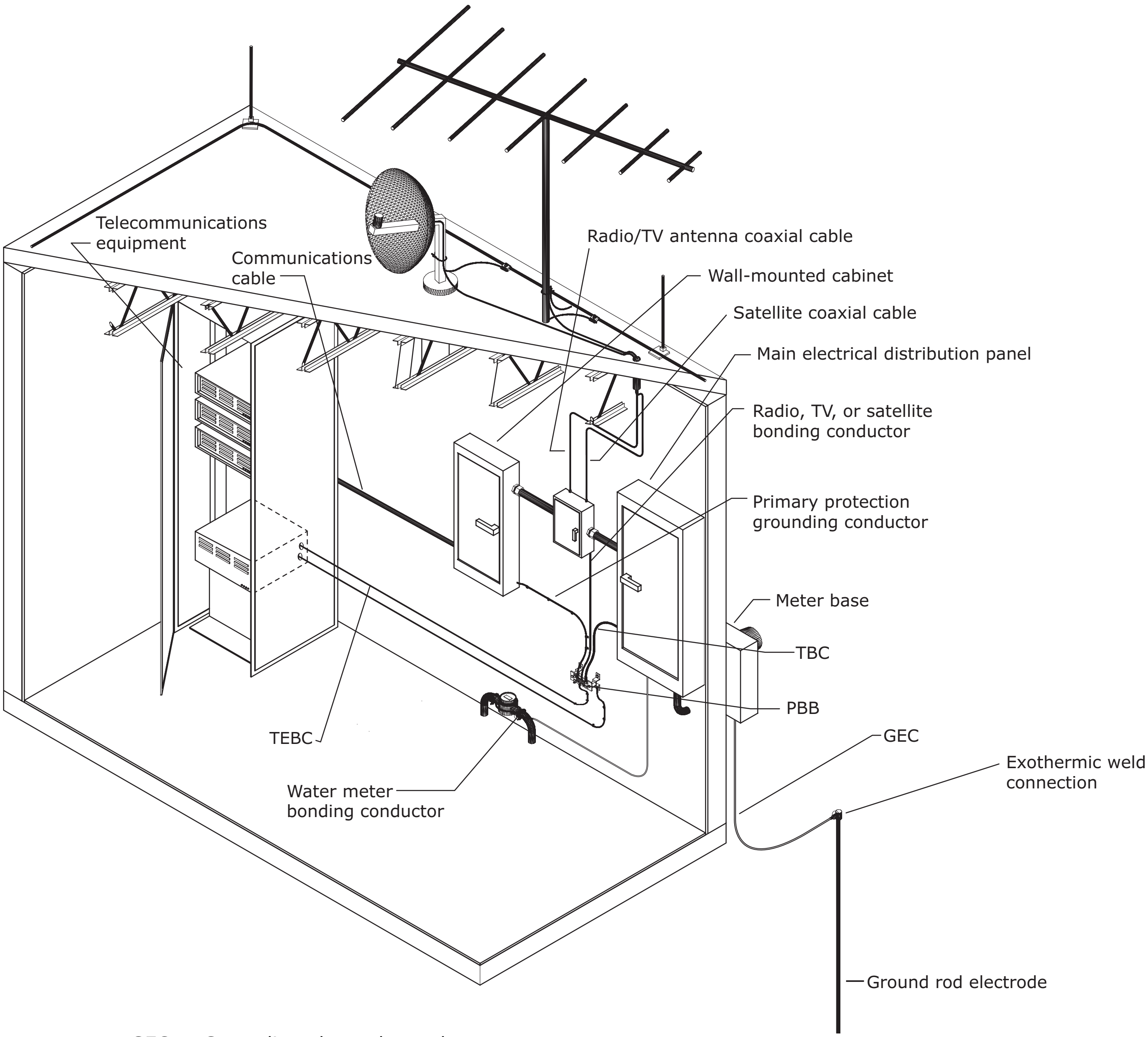
An example of a small system telecommunications bonding infrastructure is shown in Figure 1. In small ERs and EFs, the bonding and grounding begins at the primary bonding busbar (PBB), which must be connected to the building grounding (earthing) electrode.

All exposed cable must be directly terminated at the associated protectors. Any exposed cable shields are bonded directly to the closest:

- Protector.
- Protector’s ground terminal.
- Protector ground.
- Grounding (earthing) electrode connection.

Telecommunications Bonding Infrastructure and Components, continued

Figure 1
Recommended small system bonding and grounding



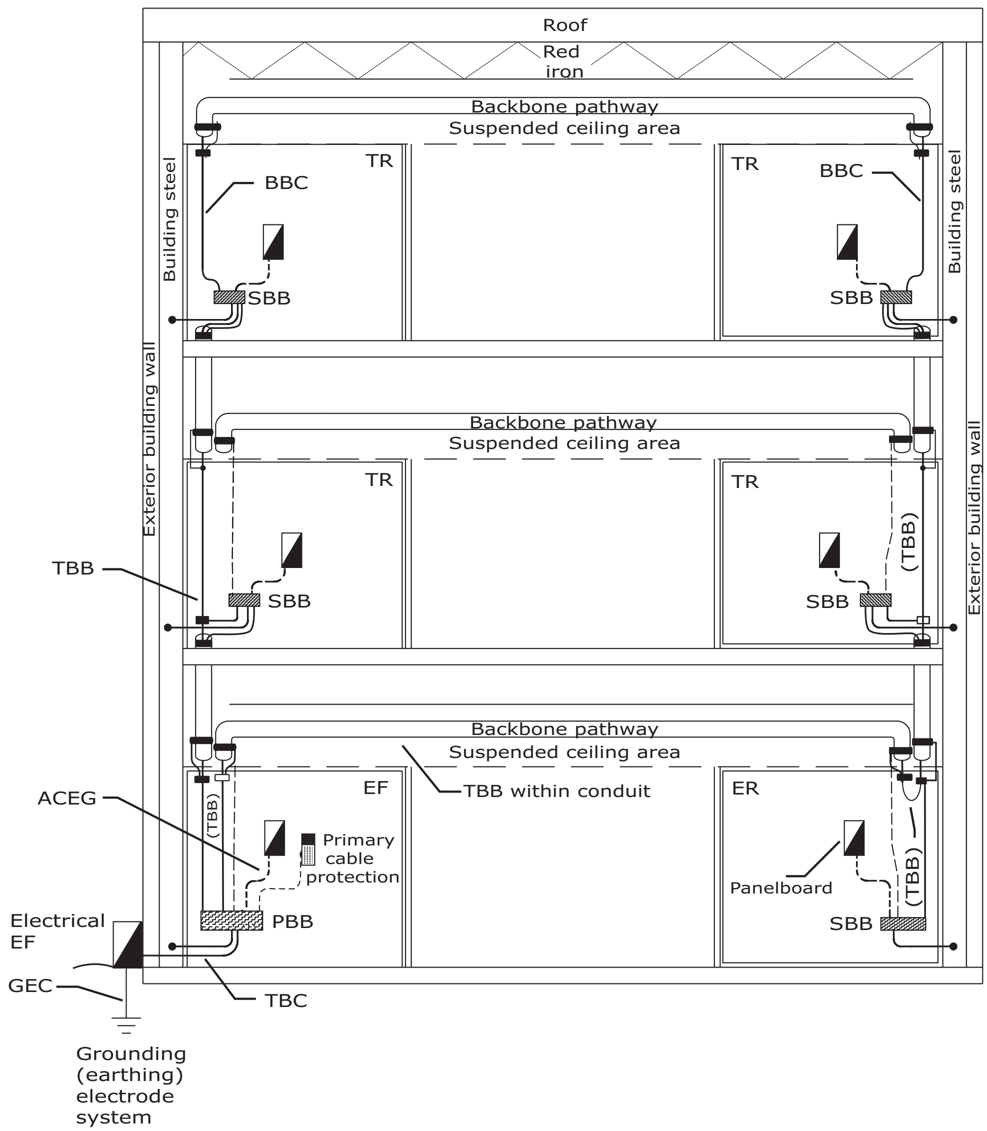
GEC = Grounding electrode conductor
PBB = Primary bonding busbar
TBC = Telecommunications bonding conductor
TEBC = Telecommunications equipment bonding conductor

An example of a large system telecommunications bonding infrastructure is shown in Figure 2. In a large system, the installation of the bonding and grounding infrastructure can be complex compared with a smaller system that only requires a few conductors to bond the limited amount of connections required. In the case of a larger building, multiple busbars are used where multiple ERs, TRs, and EFs exist.

Telecommunications Bonding Infrastructure and Components, continued

Practically speaking, each busbar must have an effective bonding connection to the building grounding (earthing) electrode and the equipment grounding system (e.g., ac branch circuit panel's equipment grounding [earthing] busbar). This will minimize voltage differences between the telecommunications bonding infrastructure and the ac grounding (earthing) systems during lightning, EMI/RFI, and ac electrical fault conditions.

Figure 2
Large system arrangement options



ACEG = Alternating current equipment ground
BBC = Backbone bonding conductor
EF = Entrance facility
ER = Equipment room
GEC = Grounding electrode conductor
PBB = Primary bonding busbar
SBB = Secondary bonding busbar
TBB = Telecommunications bonding backbone
TBC = Telecommunications bonding conductor
TR = Telecommunications room

Telecommunications Bonding Infrastructure and Components, continued

Primary Bonding Busbar (PBB)

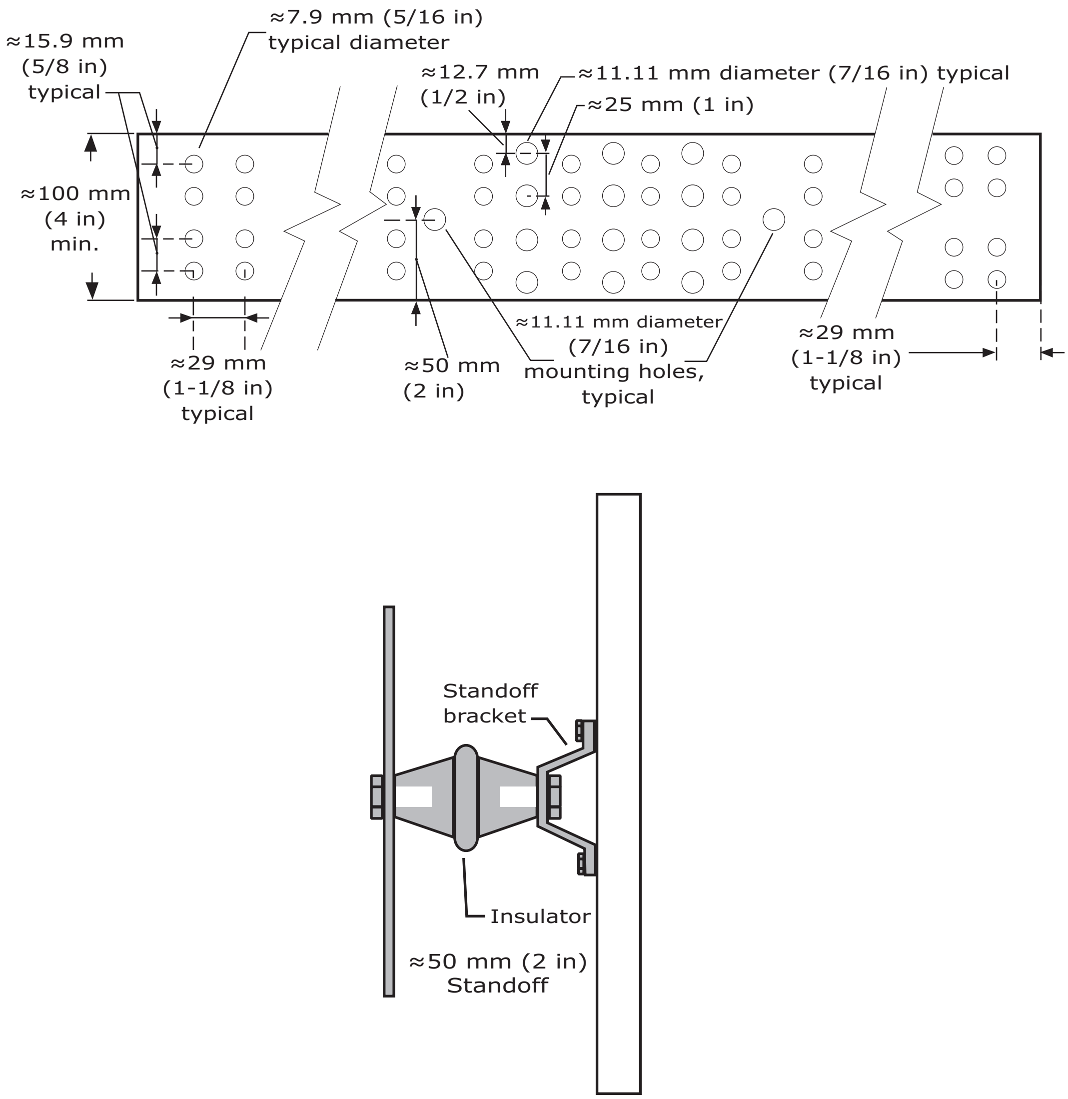
In small and large systems, the telecommunications bonding and grounding (earthing) begin at the PBB. In the case of a larger building, multiple busbars are used where multiple ERs, TRs, and EFs exist. The PBB serves as the dedicated extension of the building ac grounding (earthing) electrode system for the telecommunications infrastructure (Figure 3). It serves as the central attachment point for the telecommunications bonding backbone (TBB) and equipment.

Many different connections to the PBB can be made. These include telecommunications bonding connections to the following surfaces:

- Primary and secondary surge protectors
- Cable trays
- Ladder racks
- Equipment racks
- Branch circuit panelboards
- Power conditioning equipment
- Cable shields
- Battery racks
- Entrance conduits

Telecommunications Bonding Infrastructure and Components, continued

Figure 3
Example of primary bonding busbar (PBB)



in = inch
mm = millimeter

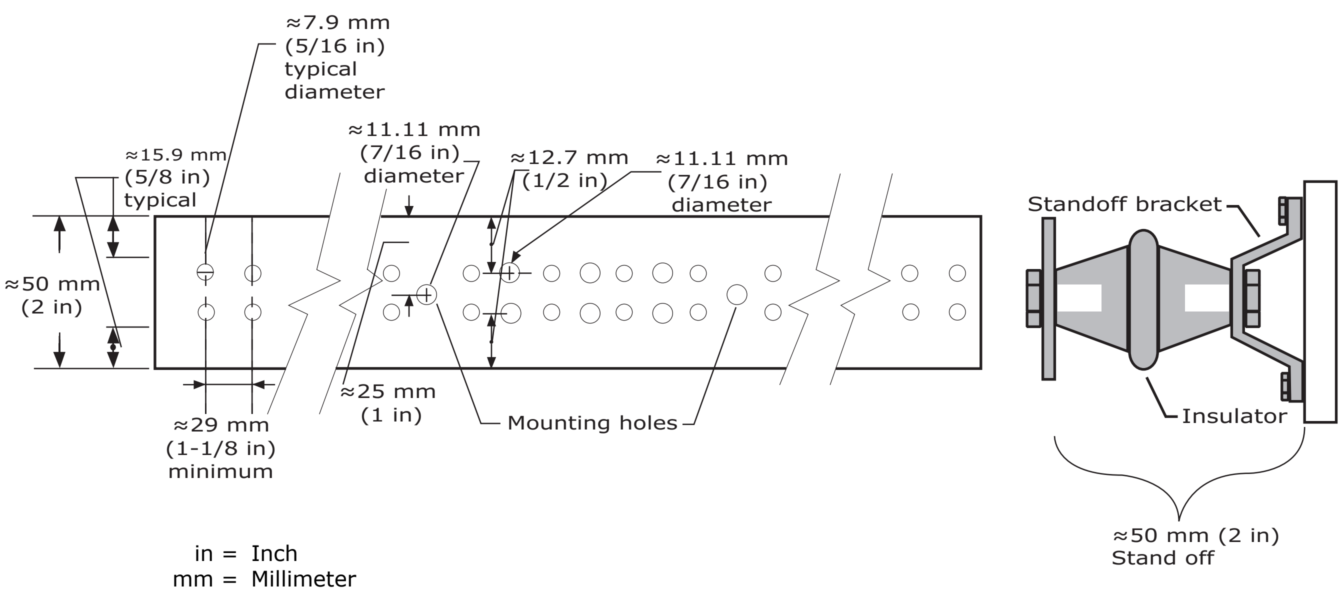
Telecommunications Bonding Infrastructure and Components, continued

Secondary Bonding Busbar (SBB)

A secondary bonding busbar (SBB) is the bonding connection point for telecommunications systems and equipment in the area served by a telecommunications space. An SBB is the grounding (earthing) connection point for telecommunications infrastructure systems (e.g., cabling, pathways) and telecommunications equipment in the area served by an ER or TR. The SBB must be a pre-drilled copper busbar with holes for use with standard-sized lugs, have minimum dimensions of ≈6 mm [millimeter (0.25 inch [in])] thick by ≈50 mm (2 in) wide, and be variable in length (see Figure 4). It must also be listed by an NRTL.

As with the PBB, the SBB should be able to accommodate bonding conductors that originate at various equipment and metallic surfaces and allow for future growth. The SBB should follow the same design and installation guidelines in the TR as the ER.

Figure 4
Example of secondary bonding busbar (SBB)



Telecommunications Bonding Infrastructure and Components, continued

Telecommunications Bonding Conductor (TBC)

The TBC bonds the electrical system's grounding (earthing) electrode system to the PBB.

Regulations, codes, and design affect the required diameter of the TBC. The effectiveness of a TBC may be affected for lengths over ≈6.1 meters [m (20 feet [ft])] because of impedance.

Telecommunications Bonding Backbone (TBB)

A TBB is a copper conductor with a minimum diameter size of 6 American wire gauge (AWG [4.1 mm (0.16 in)]) that is intended to equalize potentials between TRs on multiple floors of a building with an ultimate connection to the EF's PBB.

It should be recognized that the impedance of the TBB increases due to the length, thereby reducing its ability to equalize potentials between ERs, TRs, and EFs. This is true at low frequencies (e.g., 60 hertz [Hz] currents) but more noticeable at higher frequencies (e.g., lightning). The ICT distribution designer must consider that the TBB for a large site may be costly and may not achieve the desired result of effective bonding.

As an alternative, the ICT distribution designer can specify that the SBB in each TR be bonded to the structural steel if present and to the nearest ac electrical panelboard. Each of the bonding connections should be tested to verify that a low-resistance connection exists.

Backbone Bonding Conductor (BBC)

A BBC is an insulated, stranded copper conductor, with a minimum diameter size of 6 AWG [4.1 mm (0.16 in)] that is intended to equalize potentials between SBBs on the same floor of a structure. The bonding infrastructure design will determine if there is need for a BBC on a specific floor. Standards such as TIA-607-C recommend that a BBC be made on every third floor and the top floor of multi-story structures.

Telecommunications Equipment Bonding Conductor (TEBC)

The TEBC connects equipment cabinets and racks to the closest PBB or SBB. A TEBC typically is an insulated, stranded copper conductor with a minimum diameter size of 6 AWG [4.1 mm (0.16 in)].

The TEBC shall be exothermically welded or directly crimped to the busbar or connected using a two-hole compression or exothermic two-hole lug to the connection point on the PBB/SBB.

Testing

Alternating Current (ac) Grounding (Earthing) Electrode Testing

Typically, it is not the ICT distribution designer's responsibility to specify the type of tests or test criteria for the verification of the ac grounding (earthing) electrode system quality. This is the responsibility of a qualified electrical designer.

Most qualified electrical installers do not test the bonding and grounding (earthing) system for a building prior to its connection to the telecommunications bonding and grounding (earthing) infrastructure. However, BICSI® recommends that certain tests be performed to evaluate the bonding connection between the telecommunications busbars and the ac grounding (earthing) electrode system. This testing should be performed after the telecommunications cabling and telecommunications grounding (earthing) infrastructure are installed but prior to either the final approval of the telecommunications cabling infrastructure or end-user telecommunications equipment installation.

As a guide, the recommended maximum ac current value on any bonding conductor should be less than 1 ampere (A). The recommended maximum dc current value should be less than 500 milliamperes (mA). The acceptable ac and dc current levels may change depending on the equipment needs.

If abnormally high ac current levels are present on any bonding conductor, a dangerous faulty electrical wiring condition likely exists within the room. If this is the case, a qualified electrical maintenance individual should be called immediately.

Two-point bonding measurements are performed using an earth grounding (earthing) resistance tester that is configured for a continuity test. An earth ground tester generates and tests ac current that is manufacturer-specific and less susceptible to the influences of dc current. As a result, it is more accurate than the standard volt-ohm-milliammeter (VOM).

The test is performed by connecting the meter leads between the nearest available grounding (earthing) electrode (e.g., structural steel column) and the busbar in the EF or TR. The recommended maximum value for the bonding resistance between these two points is 0.1 ohms (100 milliohms). In central office facilities, the acceptable resistance between any two points may be less than 100 milliohms, possibly 50 milliohms.

NOTE: Before performing this test, the equipment manufacturer should be consulted for detailed instrument setup and safety precautions.

Measuring the Equipment Grounding (Earthing) Conductor Impedance

The impedance of the telecommunications equipment grounding (earthing) conductor can only be accurately measured with an instrument known as a ground impedance tester. This tester is specifically designed to measure the impedance of a telecommunications equipment grounding (earthing) conductor path—whether it comprises a copper conductor, metallic conduit, or both. Most ground impedance testers may be capable of making additional measurements (e.g., ac circuit voltage, neutral conductor impedance, wiring polarity). By manipulating certain buttons on the meter, the test personnel can uncover most improper wiring conditions.

Testing the Integrity of Telecommunications Bonding Connections

Two-point bonding measurements should be performed using an earth grounding (earthing) resistance tester configured for a continuity test. The test is performed by connecting the meter leads between the nearest available grounding (earthing) electrode (e.g., structural steel column) and the busbar in the EF or TR. The recommended maximum value for the bonding resistance between these two points is 0.1 ohms (100 milliohms). Before performing this test, the test equipment manufacturer should be consulted for detailed instrument setup and safety precautions.

Bonding and Grounding (Earthing) Testing Procedures

It is essential for the installer to perform metering measurements of the bonding and grounding (earthing) topology upon completion of the installation. Metering measurements should be made for:

- Two-point bonding resistance.
- True root mean square ac current.
- The dc current.
- The ac outlet wiring polarity/conductor impedance.

The collected data is used to validate the installed components for compliance to the current design. It also is used as baseline data for comparison of retrofits, preventative maintenance, or troubleshooting.

Regulations

The information in this document does not replace international, federal, state, local, or other applicable codes, laws, or regulations. Specific applications may contain variables that are beyond the control or the scope of this document. Taking this into consideration, the application of this information cannot guarantee the desired technical results.

IMPORTANT: All design and construction for bonding and grounding (earthing) must meet or exceed applicable codes, standards, regulations, and authority having jurisdiction (AHJ) rulings.

The references to codes, standards, methods, and best practices used in this document are derived from documents such as ANSI/NECA/BICSI-607, *Telecommunications Bonding and Grounding Planning and Installation Methods for Commercial Buildings*, ANSI/TIA-607-B, *Telecommunications Grounding (Earthing) and Bonding for Customer Premises*, NFPA 70, the *NEC*®, NFPA 780, the *Standard for Installation of Lightning Protection Systems*, and publications by IEEE®.

IMPORTANT: Regions and countries have local and specific requirements relating to bonding and grounding (earthing) that differ from the contents of this document.

Sizing of Bonding Conductors

In most applications, where any bonding conductor does not exceed ≈30 m (100 ft), a minimum of a 6 AWG [4.1 mm (0.16 in)] bonding conductor is sufficient for referencing all metallic surfaces within the telecommunications environment. However, a bonding conductor that is run at distances longer than ≈30 m (100 ft) should be calculated for a size that meets the requirements of the applicable electrical code for the site.

NOTE: Standards provide additional guidance for specific bonding conductors (i.e., TBB, BBC, TBC), such as using larger conductor sizes in relation to defined lengths, and specify that the TBC and BBC are to be equivalent in size to the largest TBB.

The process for accurately sizing any TBC is as follows:

Step	Task
1.	Determine the size of the building's ac GEC for the electrical service.
2.	Using Table 2, find the short-time rating in amperes for the corresponding ac GEC.
3.	Determine the length of the desired bonding conductor.
4.	Divide 40 V by the short-time rating of the ac GEC. The result is the maximum resistance value for any conductor length.
5.	Divide the resistance value by 0.5 for ≈15 m (50 ft), 2 for ≈61 m (200 ft), 3 for ≈90 m (300 ft), and so on. Record the value.
6.	Referring to Table 2, compare the calculated resistance value with the dc resistance value per ≈30 m (100 ft). Find the conductor resistance value that does not exceed the value calculated in the step above.

Quick Determination of Bonding Conductor Size

The calculation of bonding conductor sizes may be necessary in some applications. As a general rule, the following process could be applied:

- Determine the size of the GEC for the main electrical service entrance.
- Increase the size of the bonding conductor one trade size (e.g., 4 AWG [5.2 mm (0.20 in)] to 3 AWG [5.8 mm (0.23 in)]) for every 30 m (100 ft) of travel over 30 m (100 ft).

Table 2
Basic guide to calculating bonding conductor resistance values

Grounding (Earthing) Conductor Size (AWG)	dc Resistance Per ≈30 m (100 ft) (Copper Conductor)	Short-Time Rating (A)
8	0.077800	391
6	0.049100	621
4	0.030800	988
3	0.024500	1245
2	0.019400	1571
1	0.015400	1981
1/0	0.012200	2499
2/0	0.009670	3150
3/0	0.007660	3972
4/0	0.006080	5008
kcmil		
250	0.005150	5917
300	0.004290	7101
350	0.003670	8284
400	0.003210	9467
500	0.002580	11,834

A = Ampere
AWG = American wire gauge
dc = Direct current
ft = Foot
kcmil = Thousand circular mils
m = Meter

Outside Plant (OSP) Considerations for Bonding and Grounding (Earthing)

The primary consideration for all bonding, grounding (earthing), and electrical protection designs is the safety of users and plant personnel from shock hazards and the protection of equipment from damage or destruction. The *National Electrical Safety Code® (NESC®)* requires cable shields, support strands, and other non-current-carrying metallic hardware to be effectively grounded. It is especially important to effectively ground cable shields, support strands, and non-current-carrying metallic hardware at deadends and junction points for personnel protection, power contact protection, and noise mitigation.

In the United States, the common electrical supply is 120 V 60 Hz nominally. In many other countries, the common electrical supply is 240 V 50 Hz nominally. In all cases, refer to local electrical codes and regulations.

In the United States, the OSP designer must be familiar with the definition of exposed OSP cable as defined by the *NESC* and the *NEC*. Outside the United States, the need for protection is defined in the International Electrotechnical Commission (IEC) Standard 62305, Part 2.

Protective measures are required on underground, direct-buried, and aerial cable when there is exposure to:

- Disturbances because of the presence of lightning stroke currents.
- Voltage induction (e.g., ac power) exceeding 300 V.
- Accidental contact with power conductors operating at more than 300 V to ground.
- GPR exceeding 300 V.

Exposed and Unexposed Outside Plants (OSPs)

The terms exposed and unexposed are used to describe OSP with respect to its vulnerability to the sources of current and voltage. Typical sources are lightning, contact with power conductors, and power induction.

A telecommunications system is exposed or unexposed according to whether the OSP serving it is exposed or unexposed.

NOTE: Consult the appropriate requirements and practices of applicable authorities, regulations, and codes concerning their policies with respect to exposed and unexposed plants. Frequently, the policy is to treat all locations as exposed and to protect the plant accordingly.

Grounding (Earthing) for Lightning Protection

Lightning strikes are a common source of hazardous foreign potentials. OSP cabling is classified as exposed to lightning except when located in:

- Areas having five or less thunderstorm days per year and where the ground resistivity is less than 100 ohmmeters. For example, in the continental United States, such areas are found along the Pacific coast.
- Areas where buildings are close and sufficiently high to intercept lightning.

Exposed and Unexposed Outside Plants (OSPs), continued

- Campus cabling runs that are ≈ 42 m (138 ft) or less, directly buried or in underground conduits where a continuous metallic cable shield or a continuous metallic conduit containing the cable is connected to each building's grounding electrode system.

The goal of any grounding (earthing) system is to provide a low-impedance path for fault currents until they reach the earth. When considering the grounding (earthing) conditions at any site, it is essential to test:

- Soil resistance—In general, black dirt or soils with high organic content are usually a good conductor because they tend to retain more moisture, leading to low resistivity. Sandy soils, which drain faster, tend to be less moist and are higher in resistivity. Solid rock and volcanic ash have virtually no moisture and have such high resistivity that they are useless as a grounding (earthing) material.
- Ground resistance—Applicable codes, standards, and regulations may require a single electrode consisting of a rod, pipe, or plate that has a resistance to ground of 25 ohm or less to be augmented by one additional electrode of the types listed in applicable codes, standards, and regulations. Multiple electrodes should always be installed so that they are at least ≈ 1.83 m (6 ft) apart. Spacing electrodes at distances greater than ≈ 1.83 m (6 ft) increases rod efficiency, meaning that the earth ground resistance for ground rod configuration may be lowered in value.
  - 25-Ohm ground—Lower or equal to 25 ohm ground is an *NEC* minimum resistance requirement for a single electrode. It is not an indication that the value has an impact on system performance.

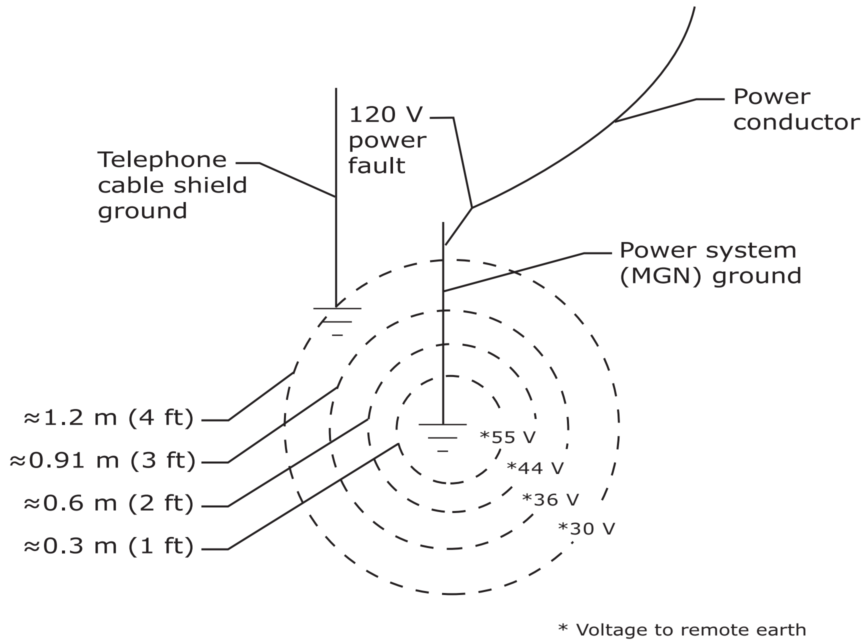
Power Induction and Ground Potential Rise (GPR)

Disturbances from electromagnetic induction (power induction) can occur wherever telecommunications and power lines run parallel for long distances. An OSP subject to power induction of more than 300 V to ground is considered exposed.

GPR can be caused by a variety of factors, including lightning, electrical system fault, and other transient conditions. In the following GPR example, the power system multi-ground neutral (MGN) system ground receives a 120 V fault (see Figure 5). This power fault induces 120 V onto the MGN ground. The voltage is dissipated through the ground, causing a GPR. Any telecommunications facilities or ground systems located in close proximity to the point of induced voltage will be influenced by that GPR. In this example, a telecommunications cable shield ground is located ≈ 1.2 m (4 ft) from the induced voltage to the MGN ground. The 120 V fault is dissipated to a 30 V GPR when it reaches the telecommunications cable shield ground.

Power Induction and Ground Potential Rise (GPR), continued

Figure 5
Example of ground potential rise (GPR)

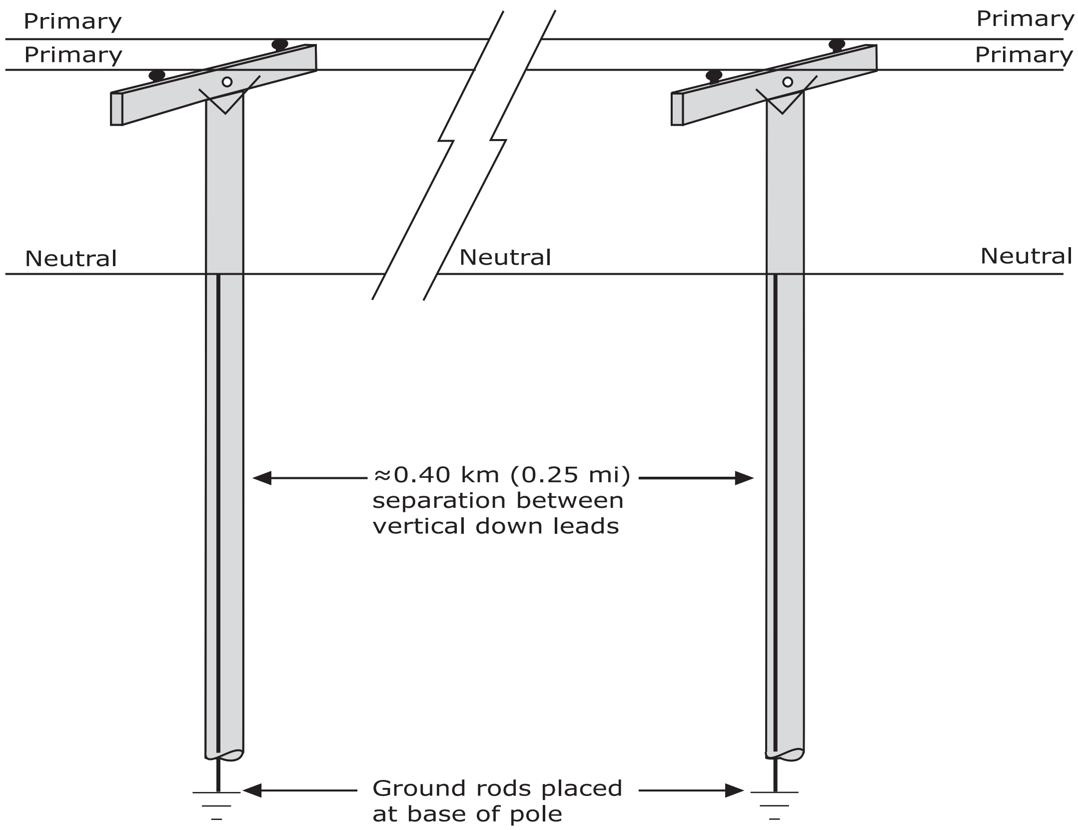


ft = Foot
m = Meter
MGN = Multi-ground neutral
V = Volt

Multi-ground Neutral (MGN) and Non-MGN Power Systems

In an MGN power system, the neutral conductor is grounded at each transformer and continues through to the secondary circuits and the customer's premises (see Figure 6).

Figure 6
Multi-ground neutral power system



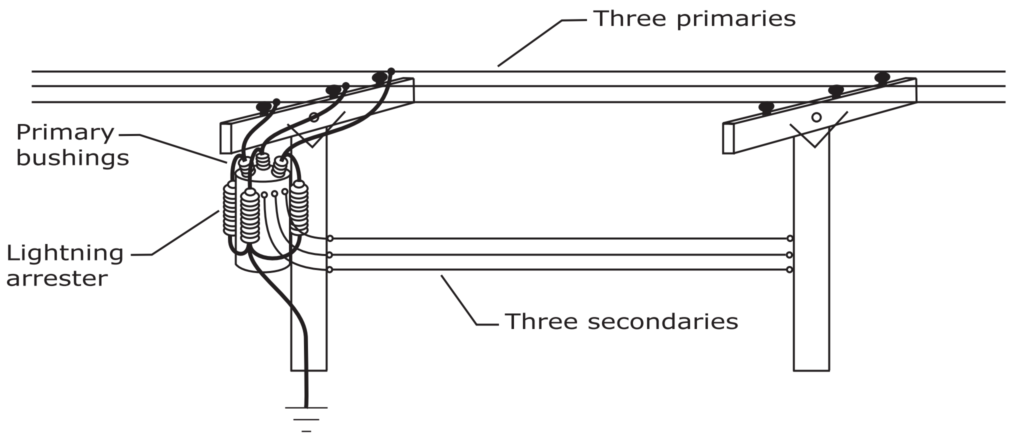
km = Kilometer
mi = Mile

At every transformer pole in an MGN power system, the neutral conductor is connected to a ground wire, a vertical down lead (VDL), which leads down to the grounding electrode at the base of the pole. Approximately every 0.40 kilometers [km (0.25 miles [mi])], even where no transformers are located, the power company runs a VDL from the ground rod to bond the primary neutral and secondary neutral for an effective ground.

The multi-grounding of this power system is more common than non-MGN systems (see Figure 7) because overcurrent devices (e.g., fuses or relay-protection systems) operate more rapidly because of low-impedance ground paths.

Multi-ground Neutral (MGN) and Non-MGN Power Systems, continued

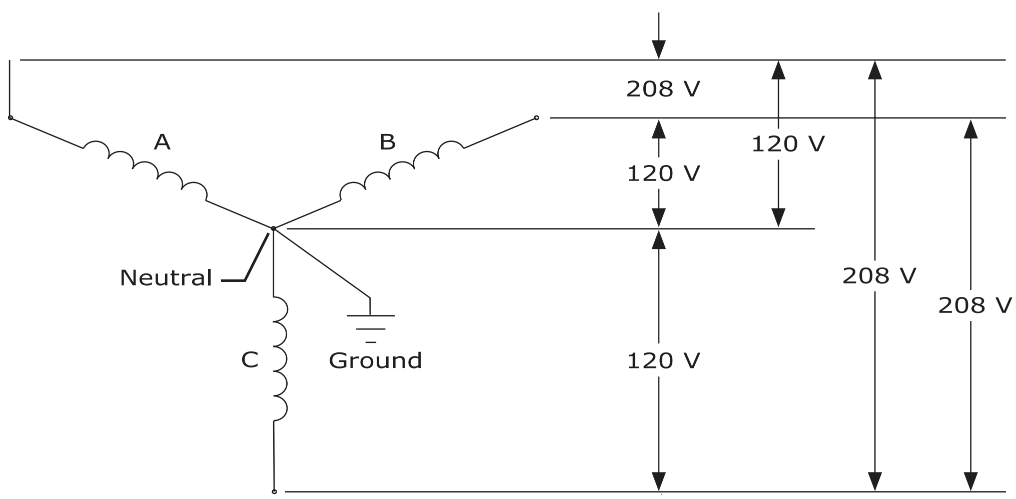
Figure 7
Non-multi-ground neutral power system



Non-MGN power systems do not utilize an MGN conductor. The two most common non-MGN are the:

- Grounded wye power system—This system has a neutral ground at a single point in the power line. Figure 8 illustrates a wye power system.

Figure 8
Wye power system

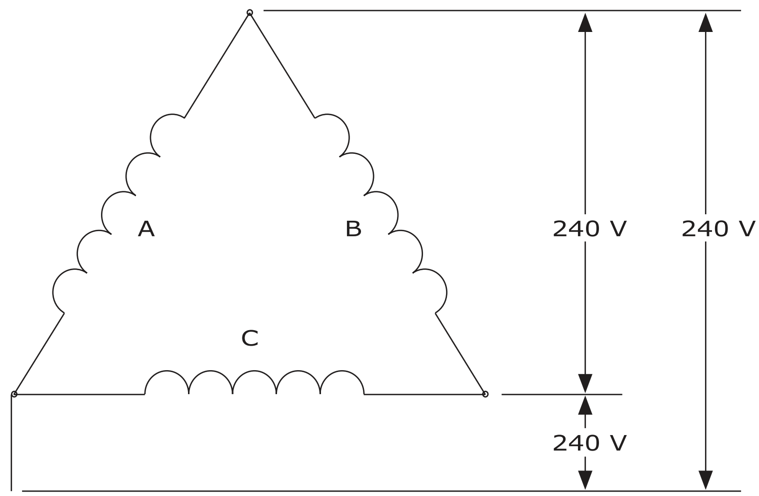


V = Volt

- Three-phase, ungrounded delta power system—A delta power system is a three-legged, ungrounded configuration with an equal potential among the phases of the transformer. Figure 9 illustrates a delta power system.

Multi-ground Neutral (MGN) and Non-MGN Power Systems, continued

Figure 9
Delta power system



V = Volt

Bonding Telecommunications and Power Grounds

A bond between power and telecommunications plants must be established using at least a 6 AWG [4.1 mm (0.16 in)] bonding conductor per the *NEC*.

Bonding Requirements

Underground Cable Bonding Requirements

Telecommunications and power facilities occupy separate structures in an underground plant; therefore, underground metallic conductor cables are not exposed to power contact.

Bonding cables equalizes the potential between the cables. Equalizing the potential between cables protects personnel by reducing the possibility of shock hazards and minimizes plant damage.

Cables used in the underground conduit system have either an outer metallic sheath or a plastic sheath. Generally, cables with an outer metallic sheath are bonded at each maintenance hole (MH) while cables with an outer plastic sheath are bonded at MHs where a splice is made.

In some instances, when cables are exposed because of aerial to underground OSP (e.g., cable dip) extensions, the following guidelines should be applied:

- Establish and maintain continuity of all metallic cable elements (e.g., metallic sheaths, armor, strength members).
- Non-metallic splice case bonding connections as well as lead sleeves and metallic splice cases should be connected to the MH grounding (earthing) system at every MH.
- Plastic sheath cables do not need to be bonded at pull-through MHs.

Direct-Buried Cable Bonding Requirements

Bonds must be made using minimum 6 AWG [4.1 mm (0.16 in)] solid copper wire and listed clamps. Convenient bonding locations should be chosen to minimize the length of the bonding conductor.

Maintain cable shield continuity of all telecommunications plants.

Direct-Buried Plant Exposed to Power

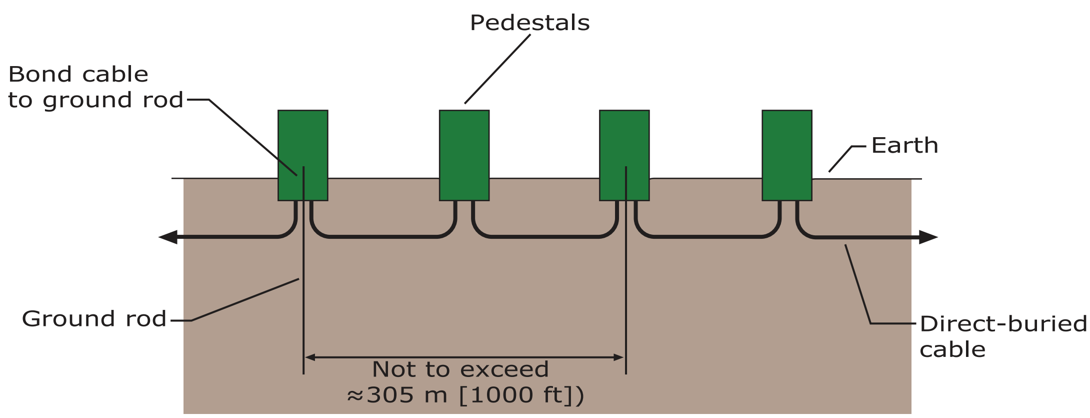
The following methods should be used to protect telecommunications cable direct-buried near power conductors. Protection requirements are based on the distances between the two systems:

- Less than ≈ 1 m (3.28 ft) separation—To maintain shield continuity through terminals and splice closures, direct-buried telecommunications cable shields and metal components other than conductors must be bonded common with power neutral when they are located less than ≈ 1 m (3.28 ft) from a power cable. Bonding must be performed regardless of whether the cables are in the same or separate trenches.

Direct-Buried Cable Bonding Requirements, continued

- Additionally:
  - Telecommunications cable shields should be bonded to the power neutral or to the power apparatus at all above-ground telecommunications terminals, pedestals, apparatus cases, and direct-buried cable closures located within ≈ 1.83 m (6 ft) of any above-ground power apparatus.
  - For every terminal located near a power transformer, provide a bonding conductor for connection to either the transformer housing, primary neutral, secondary neutral, or secondary pedestal served from the transformer. This connection must be installed by power company personnel.
  - Grounding (earthing) should be performed at every other pedestal if no transformer is present (see Figure 10).
  - The connection to ground shall not be omitted on any two adjacent terminals.
  - The distance between grounding (earthing) locations shall not exceed ≈ 305 m (1000 ft).
  - No exposed point of the telecommunications cable should be more than ≈ 152 m (500 ft) from a grounded connection.

Figure 10
Grounding (earthing) without access to transformers



ft = Foot
m = Meter

- More than ≈ 1 m (3.28 ft) separation—When direct-buried telecommunications cable and power cable are separated by more than ≈ 1 m (3.28 ft), only bonding is required.

Where direct-buried telecommunications cable is separated from direct-buried power cable with more than ≈ 0.91 m (3 ft) of well-tamped earth, the chance for accidental contact with power conductors is minimal.

Direct-Buried Cable Bonding Requirements, continued

Joint Random Direct-Buried Plant

A joint random direct-buried plant is a plant directly buried in the same trench as power conductors where a minimum ≈305 mm (12 in) separation has not been maintained. Joint random spacing is limited to distribution cable that is joint buried. Applicable codes, standards, and regulations (e.g., *NESC*, Section 35, Rule 354) may specify the voltage limitations in the joint random construction.

In addition to voltage limitations in joint random construction, applicable codes, standards, and regulations (e.g., *NESC*) may specify that the power conductors include a bare or semiconducting, jacketed, grounded conductor in continuous contact with the earth. An overall insulating jacket with a copper concentric conductor that is grounded a minimum of eight times per ≈ 1.6 km (1 mi) in each random direct-buried section may be required.

Aerial Cable Bonding Requirements

It is important to maintain the electrical continuity of aerial cable shields. Bond all connecting underground or direct-buried cable shields to provide:

- An effective reference for lightning and power currents.
- RFI mitigation.
- EMI mitigation.

Metallic Conductors

The required intervals for bonding the telecommunications support strand to the power system MGN depend on the power voltages involved.

NOTE: The bonding and grounding (earthing) requirements should be reviewed with the power and access provider if it is a jointly used pole line.

All connectors and clamps must be listed, rated for outside use, and properly sized to accept the wire and strand size.

The bonding of telecommunications hardware to power company facilities on an aerial plant shall be performed:

- Only by ICT personnel on a telecommunications cable plant.
- In or below the telecommunications pole space.
- Only when authorized by the power company.

ICT personnel shall not perform any work within nor climb into the power space on a pole. Where the connection to the MGN must be made above the telecommunications space, sufficient wire should be coiled and temporarily attached to the pole for later connection by power company personnel.

NOTE: The TBC should only be connected to the power utility MGN by the power utility. This requires the submittal of information to the power utility on a pre-approved or other negotiated form or document.

Aerial Cable Bonding Requirements, continued

Bonding Support Strands to Ground

Suspension strands are bonded to reduce the possibility of electrical shock and to minimize plant damage.

Bonding and grounding (earthing) of the suspension strand will:

- Limit the voltage on the strand in the event of an accidental contact with energized power conductors.
- De-energize the power circuit quickly in the event of an accidental contact by causing operation of power circuit breakers or fuses.
- Minimize induced voltages that may be on the strand.
- Establish and maintain shield continuity of the cable, terminals, and splices.
- Bond the strands of separate cables or wires together:
  - Every ≈ 0.40 km (0.25 mi).
  - At each crossover.
  - At each branch.
  - At the beginning and end of an aerial section.

Aerial Cable Bonding Requirements, continued

Bonding Cable Shields to Support Strands

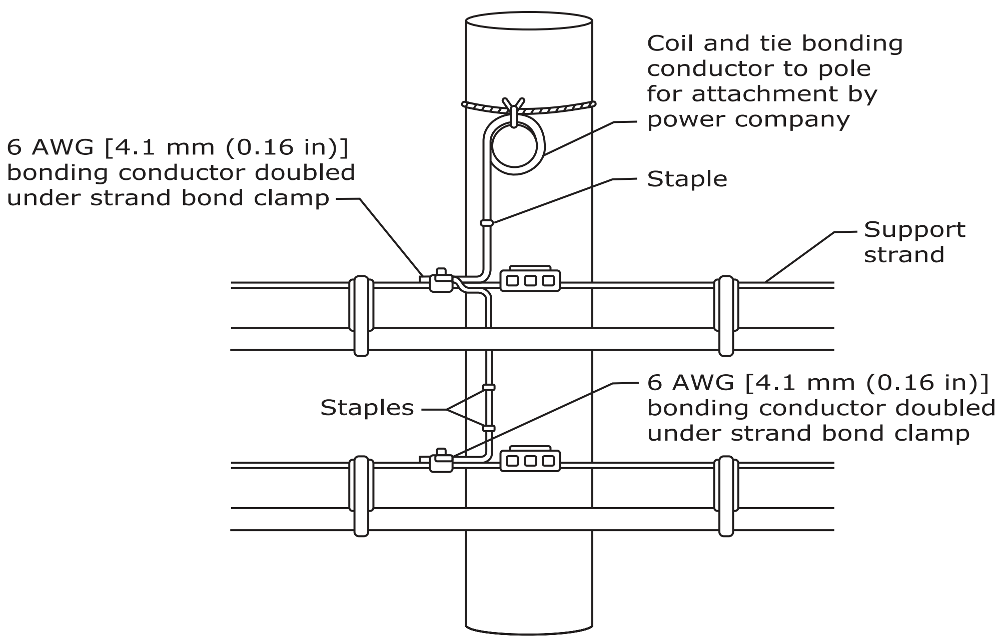
Cable shields should be bonded to support strands at frequent intervals to prevent arcing and to provide a low-impedance ground for power contact or lightning-related surge currents.

Shielded cables should be bonded between the shield and support strand at all splices, terminals, load points, and repeaters. The method used to bond the shield to the support strand depends on the types of enclosures.

If a shielded cable is exposed to lightning, the shield should be bonded to the strand every ≈ 0.40 km (0.25 mi), usually at splices and terminals.

An example of bonding and grounding (earthing) the telecommunications support strand is shown in Figure 11.

Figure 11
Ground connection on a pole (multi-ground neutral system)



AWG = American wire gauge
in = Inch
mm = Millimeter

Aerial Cable Bonding Requirements, continued

Bonding at Power Crossings

Where possible, aerial telecommunications cable and electrical distribution lines should be crossed on jointly used or occupied poles rather than midspan. At joint pole crossings with MGN-type power lines, the cable support strand should be connected to the MGN via VDL.

Span crossings may be used where it is not feasible to have:

- Joint-pole crossings with electrical distribution lines.
- Underground or direct-buried dip section of plant.

Bonding in Joint Use or Joint Occupancy

Where the same poles used for MGN electrical supply circuits support a telecommunications cable, the cable shield and support strand should be bonded to the MGN. Bonding connections should be made:

- Where the joint use or joint occupancy arrangement begins and ends.
- On every electrical supply pole that carries a VDL to which the following are connected:
  - Transformers.
  - Capacitors.
  - Other types of power equipment that draw load current under normal conditions.
- If the joint use or joint occupancy section is longer than ≈0.8 km (0.5 mi), these bonds should be made to the MGN every ≈ 0.40 km (0.25 mi).
- Applicable codes, standards, and regulations (e.g., *NESC*) may require additional grounding (earthing) considerations for certain support strand sizes where the support strands are exposed to possible power contacts, power induction, or lightning. If the ampacity of the support strands is not adequate for system grounding (earthing) conductors, additional bonds must be made at intervals of ≈ 0.20 km (0.12 mi).

Where the same poles used for non-MGN electrical supply circuits support a telecommunications cable, shields should be grounded by bonding them to a telecommunications ground system.

Under certain conditions, it may be necessary to use an additional telecommunications grounding (earthing) system with ground rods connected to the support strand and cable sheath.

VDL on utility poles interconnected to transformers or capacitor banks should be designed by power company engineers for direct bonding to the power system neutral. At such locations, visual inspections from the ground should be made before climbing the pole to determine if the VDL is actually connected to the neutral.

WARNING: If the VDL is not connected to the neutral, the power company should be informed and the wire regarded as energized. Telecommunications line workers should not touch or climb the pole until the power company reconnects the VDL to the neutral.

Aerial Cable Bonding Requirements, continued

Where bonding of the support strand and MGN is recommended, the bond should be accomplished by the appropriate method for the conditions prevailing at the pole as listed below:

- If the pole already has a VDL connected to the MGN, then a bonding conductor should be installed by power company personnel.
- A bonding conductor should be left with sufficient slack to connect it to the MGN.

Connection of the bonding conductor to the MGN should be made only by the power company. For recommended intermediate bonds, a pole already equipped with a VDL should be selected and a bonding conductor installed.

In most instances, bonding the cable shield to the MGN will reduce noise levels in the telecommunications cable.

Underground/Direct-Buried Cable Dips in Aerial Cable Runs

Special protection may be required at junctions of aerial cable less than ≈ 42 m (138 ft) in short underground or direct-buried plastic-sheathed cable dips in aerial cable runs.

Aerial Inserts

Aerial inserts consist of short sections of lashed or self-supporting OSP cable or wire that are placed within an underground or direct-buried cable route to avoid obstructions and interferences such as river or creek crossings.

The support strand (messenger) of aerial inserts must be grounded in accordance with the *NESC* at four or eight times 1.6 km (1 mi), depending on the conductivity of the support strand (messenger). Steel strand messengers of ≈ 6.3 mm (1/4 in [6M]) and ≈ 7.9 mm (5/16 in [6.6M]) must be grounded eight times every ≈ 1.6 km (1 mi), whereas ≈ 9.5 mm (3/8 in [10M]) and ≈ 11 mm (7/16 in [16 M]) must be grounded four times every ≈ 1.6 km (1 mi).

NOTE: 6M, 6.6M, 10M, and 16M are designations that refer to the breaking strength of a strand.

Aerial Cable Bonding Requirements, continued

The conductors of exposed aerial inserts must be isolated from the direct-buried or underground portions of the cable route on both sides of the insert to maintain the unexposed status of the direct-buried or underground cable plant. Isolation of the conductors of exposed aerial inserts is necessary so that fuseless-type station/premises protectors may be used and isolation may be accomplished by any of the following procedures:

- If the conductors of the direct-buried or underground cable plant on both sides of the aerial insert are 24 AWG [0.51 mm (0.020 in)] copper or smaller, no fuse links are required.
- If the conductors of the direct-buried or underground cable plant are larger than 24 AWG [0.51 mm (0.020 in)] copper, it is recommended that 24 AWG [0.51 mm (0.020 in)] cable be installed as the aerial insert. If the aerial insert extends for more than a few spans, the effect of using 24 AWG [0.51 mm (0.020 in)] on transmission should be checked.
- If the conductors of both the direct-buried plant and the aerial insert are larger than 24 AWG [0.51 mm (0.020 in)], the exposed aerial insert must be isolated by providing 24 AWG [0.51 mm (0.020 in)] copper fuse links between the aerial insert and the underground or direct-buried portions of the cable. These fuse links must be applied at both ends of the exposed insert. The 24 AWG [0.51 mm (0.020 in)] links should usually be installed in terminal housings that are required for other purposes at points nearest to each end of the aerial insert. Color-coded 24 AWG [0.51 mm (0.020 in)] leads at least 203 mm (8 in) long must be spliced in series with each conductor of the cable between the end of the direct-buried or underground portion of the cable and the adjoining end of the aerial insert. The color code should be preserved. If direct-buried service wires or underground/direct- buried branch cables are distributed from the terminal housings involved, the leads must be connected to the unexposed side of the fuse link. Exposed aerial drop or distribution wires must be connected to the exposed side of the fuse links.
- The shields of all cables or wires in the terminal housings must be bonded together and grounded to the same grounding electrode to which the support strand (messenger) is grounded.

Aerial—Underground Transitions

If an aerial cable exposed to lightning is connected to a single underground cable that extends for ≈ 305 m (1000 ft) or more before paralleling other cables, ground the aerial cable shield at the last pole. The shield and supporting strand should be bonded to an MGN VDL or, alternatively, a telecommunications grounding electrode.

Installation Considerations for Bonding and Grounding (Earthing)

Preforming and verifying connections to the telecommunications bonding infrastructure is an essential part of an ICT systems cabling installer's responsibilities. Although installers are not responsible for engineering the portions of the electrical system related to ac electrical ground faults, structural lightning protection systems, or surge protective devices, they must be familiar with the basic components and the functions of these systems. In many cases, installers must incorporate effective bonding, grounding, and installation procedures for a building or structure that has been in place for years.

Primary Bonding Busbar (PBB)

A PBB is bonded to the ac electrical ground system, usually at the electrical service equipment ground, through the use of the TBC.

In addition to the TBC, the installer may be required to make two supplemental bonding connections:

- Where building steel is available in the EF, the PBB may be bonded to the nearest structural steel column provided that its bonding effectiveness has been verified via two-point bonding testing.
- A bonding conductor may be provided between the PBB and the nearest effective grounded ac electrical branch circuit panelboard within the room. A low ground impedance of the panelboard shall be verified with a ground impedance tester.

WARNING: Connections to an ac panel ground should be installed by qualified electrical personnel.

The PBB should:

- Be located in the telecommunications EF but shall be placed to minimize the length of the TBC that bonds the PBB to the building's grounding (earthing) electrode system.
- Be located in the EF for the bonding of protector terminals and cables with metallic shields.
- Be positioned adjacent to the telecommunications circuit protectors and directly between the telecommunications circuit protectors and the building ground for protector operation.
- Be designated for telecommunications circuit protectors and must safely carry lightning and power fault currents.
- Be located to minimize bonding conductor lengths.
- Serve equipment within the same room or space.
- Have a minimum of ≈50 mm (2 in) clearance behind the busbar when mounted for the ability to double-wrench tighten the required lug bolts.
- Have an isolated mount.

Secondary Bonding Busbar (SBB)

As with the PBB, the SBB should be sized to accommodate all bonding conductors to various equipment and metallic surfaces and allow for future growth.

The SBB should be mounted providing a minimum of ≈50 mm (2 in) clearance in order to access the rear of the busbar to double-wrench tighten the required lug bolts.

Installing Bonding Connections

The bonding or grounding conductor shall be connected to the grounding (earthing) electrode by exothermic welding, listed lugs, listed pressure connectors, listed clamps, or other listed alternatives. The necessary bonding connections shall be positioned in an accessible location. Unnecessary connections or splices in bonding conductors should be avoided.

All bonding connections should follow the manufacturer's installation guidelines. For most connectors, the conductor will be fully seated inside the connector barrel or extended ≈3 mm (0.12 in) beyond if the connector is a pass-through style setscrew. Some crimp style connectors have inspection holes that are used to visually ensure that the conductor is fully inserted into the connector during assembly and later during subsequent inspections.

IMPORTANT: Care must be taken not to nick the conductors when preparing them for termination. High-voltage faults will arc across nicked conductors and may cause a fire. Nicked conductors are also subject to breakage when the conductor is flexed at the nicked location.

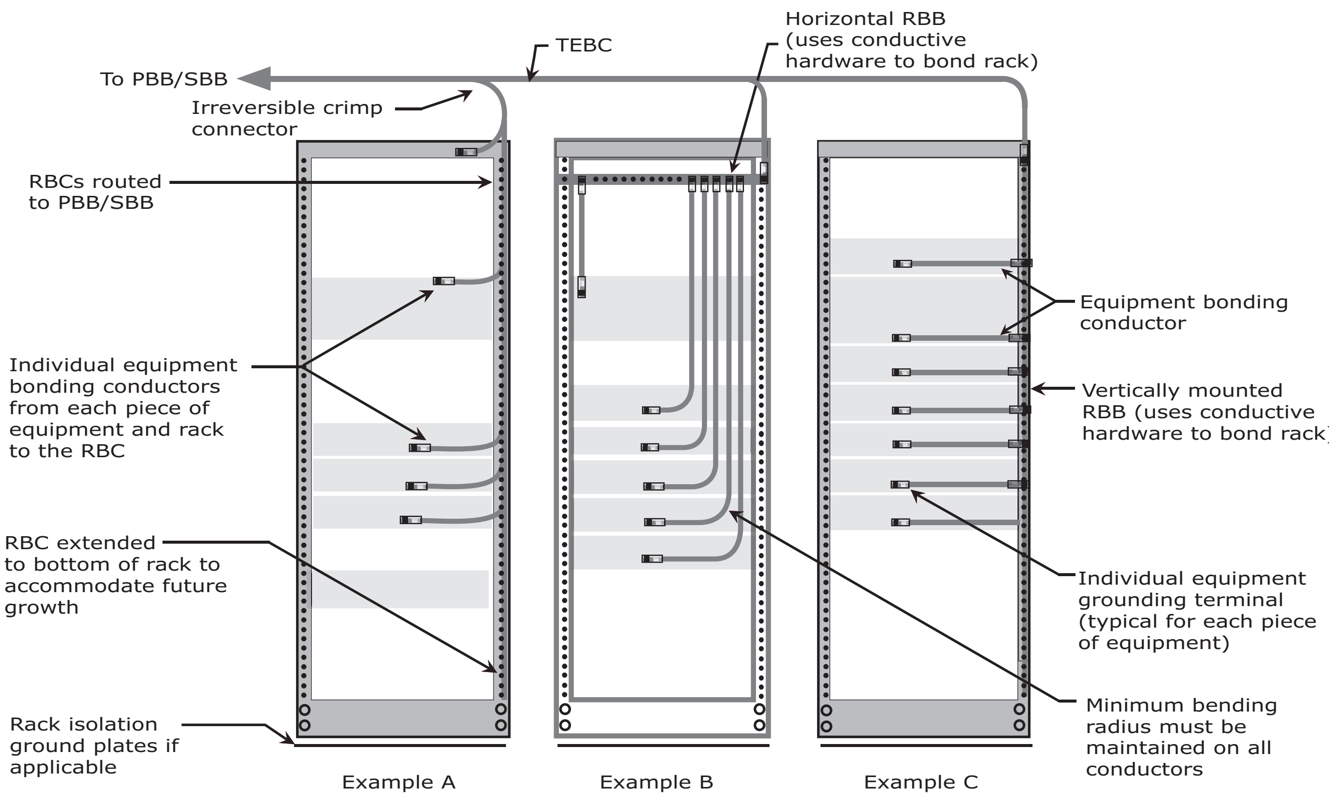
When connecting an insulated conductor, the insulation should be removed using an appropriate tool. This will ensure that the conductor is not nicked and the edge of the insulation is neat and close to the barrel of the connector where the conductor enters the lug. The insulation should be flush with the connector. This provides a uniform installation that maintains the aesthetics of a professional installation.

All metal pathways must be bonded at both ends regardless of length when containing a bonding conductor.

Bonding Equipment Cabinets and Racks

In lieu of relying on the mechanical integrity of the cable trays, racks, and other conductive surfaces, there are three optional methods to bond the equipment located in the equipment cabinet or rack to the telecommunications bonding system (see Figure 12).

Figure 12
Example of three methods for bonding rack-mounted equipment to the bonding system



PBB = Primary bonding busbar
RBB = Rack bonding busbar
RBC = Rack bonding conductor
SBB = Secondary bonding busbar
TEBC = Telecommunications equipment bonding conductor

Bonding Equipment Cabinets and Racks, continued

Example A

Example A attaches the equipment to a rack bonding conductor (RBC) that extends from the equipment cabinet or rack to the TEBC using an irreversible compression connector sized to match the conductor gauges or a NRTL-listed grounding block.

The TEBC is then bonded directly to the PBB/SBB. This example illustrates that there is multiple cutting and stripping of the RBC as well as the addition of multiple irreversible compression connections. The removal of paint on the rack surface also may be necessary.

Example B

Example B utilizes a horizontal rack bonding busbar (RBB) located at the top or bottom of the equipment cabinet or rack. Each piece of equipment in the cabinet or rack is bonded directly to the horizontal RBB through a unit-bonding conductor. The horizontal RBB is then bonded to the TEBC through an RBC using an irreversible compression connector sized to match the conductor gauges.

The TEBC is then bonded directly to the PBB/SBB. This example illustrates that unit-bonding conductors may be longer and add to the complexity of cable management. A risk of this installation is that conductors of varying lengths along equipment frames will exhibit voltage drops during transient conditions such as lightning and EMI/RFI.

Example C

Example C utilizes a vertical RBB that runs almost the entire length of the cabinet or rack. The equipment is then bonded to the vertical RBB via a short unit-bonding conductor. The vertical RBB is then bonded to the TEBC via an RBC using an irreversible compression connector sized to match the conductor gauge.

The TEBC is then bonded directly to the PBB/SBB. This example illustrates that unit-bonding conductors can be short, and the connection to the grounding busbar does not require stripping of insulation and the use of irreversible compression connections. However, the busbar would need to make metal-to-metal contact across its entire length to be effective, thus concluding that the paint along the surface of the rack would need to be removed. It would be advantageous to install the bonding conductors in the manner shown in Example C but omit the installation of the busbar along the rack's frame.

NOTE: In a single rack environment, an RBC is not required; the TEBC will serve this purpose.

Primary Protectors

Primary protectors are typically fused or fuseless. In the event of extended overcurrent situations, the exposed side must fuse open without damaging the ground conductor or indoor circuit. Primary protectors include:

- Carbon Blocks (Legacy)—Carbon blocks are the original protectors. An air gap between carbon elements is set to arc at about 300 V to 1000 V and conducts the surge current to a grounding conductor. When the surge current drops low enough, the arc stops and the protector resumes its normal isolation of ground. These devices have relatively slow reaction times, usually in excess of 15 nanoseconds (ns).
- Gas Tubes (Typical)—Gas tubes are arresters that operate the same as legacy carbon blocks, arcing over a gap to a grounding conductor. They have a wider gap because of special gas and therefore a higher reliability. They have tighter tolerances on arc breakdown voltage and typically are set to arc at a lower voltage, providing better protection than legacy carbon blocks. Gas tubes have reaction times of 10 to 15 ns.
- Solid State (Typical)—Solid-state arresters rely on high-power semiconductor technology. They are fast acting and well balanced and do not deteriorate with age below a rated maximum surge current. Reaction times for these types of units are 3 to 5 ns with clamping voltages of 150 V to 300 V.

Primary Protector Terminal Installation Design Considerations

Important installation considerations include the following:

- Primary protectors must be installed immediately adjacent to the exposed cable's point of entry. The associated grounding conductor must be bonded directly to the PBB or nearest point on the grounding electrode system.
- A non-corrosive atmosphere is required for long-term reliability.
- When a protector is installed in a metal box, bond the box with a listed bonding conductor directly to the protector ground.

WARNING: Do not locate primary protectors near any hazardous or easily ignitable material.

Exceptions to the minimum 6 AWG [4.1 mm (0.16 in)] bonding conductor are smaller EFs.

The size of an EF determines the minimum-size conductor for the protection unit based on the anticipated current flow from the number of conductor pairs and the distance of the protector terminal from the ground source.

The conductor sizes in Table 3 are based on the assumption that the protector terminals will be located up to ≈6.1 m (20 ft) away from the electrodes.

Primary Protectors, continued

Table 3
Copper grounding conductor capacity

Number of Pairs	Minimum Capacity
1–2	12 AWG [2.05 mm (0.081 in)]
3–6	10 AWG [2.6 mm (0.10 in)]
> 6	6 AWG [4.1 mm (0.16 in)]

AWG = American wire gauge
in = Inch
mm = Millimeter

NOTE: Some codes (e.g., *NEC*) allow the conductor to be as small as 14 AWG [1.63 mm (0.064 in)]. The installer may consider using 12, 10, and 6 AWG, as outlined in Table 3, when installing protection terminals in order to reduce the resistance of the conductor path.

Aside from the concern for the size of the protector ground conductor, the installer also must consider the variables that may affect the conductor's impedance when exposed to ac transient events (e.g., lightning). The variables include the:

- Tightness of the connections.
- Length of the conductor.
- Bend radius of the conductor.
- Number of bends in the conductor path.

Secondary Protectors

Secondary protectors are required to coordinate with lightning transient and power-fault requirements of primary protectors. In some cases, secondary protectors may include one of the previously described arrester components. For this reason, cost-effective secondary protection is typically available as an option on primary protectors. Secondary protectors must handle sneak currents. The components for sneak currents are different from those used for primary protection. Secondary protectors include:

- Heat Coil (Legacy)—The coils detect sustained low-level current by heat. The heat melts a spring-loaded shorting contact that permanently shorts the line to ground, requiring manual inspection and replacement.
- Sneak Current Fuse—A sneak current fuse opens the station circuit wiring under sustained low-level current, requiring manual inspection and replacement. This fusing is on the station side of the arresters and should not be confused with the primary protector line fusing.
- Positive Temperature Coefficient Resistors—Positive temperature coefficient resistors are used in place of a sneak current fuse and will limit sustained current as they heat. They do not require replacement after the sneak current fault is cleared.

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