ATT-TP-76416-001

Grounding and Bonding for Network Facilities – Design Fundamentals

This document reviews the concepts that influence the design of grounding and bonding systems. This is not, however, a standard for engineering and installation. For design and installation requirements, refer to ATT-TP-76416, ATT-TP-76300 and ATT-TP-76400.

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INTRODUCTION

This document reviews the concepts that influence the design of grounding and bonding systems. This document was previously numbered ATT-812-000-028, Issue 0, May 2003.

REASON FOR REISSUE

Issue	Date	Description of Changes	Author
1	02/01/2004	a) Convert ATT 812-000-028 to ATT-TP-76416-001; b) miscellaneous clarifications, revisions and additions as summarized in Annex B.	CS2416
-	-	There are no previous issues of this document.	

Table of Contents

1.0 PURPOSE

ATT-TP-76416 (Grounding and Bonding Requirements for Network Facilities) provides information about the who, what, where and how of bonding and grounding. It does not provide much information about why the requirements are specified as they are. This document is intended to address design issues that can impact the performance of bonding and grounding systems and explain, as much as possible, the derivation of our current standards.

2.0 SCOPE

The scope is the same as specified in Section 1.2 of ATT-812-000-027 (Grounding and Bonding Requirements for Network Facilities). ATT-812-000-027 is the reference for engineering and installation standards. *This document (ATT-812-000-028) is instructional in nature and not intended to specify engineering or installation requirements.*

3.0 DEFINITIONS AND ACRONYMS

See ATT-TP-76416 for definitions and acronyms that appear in this document. Network acronyms can be found in ATT-000-000-020, Network Acronyms Dictionary.

4.0 DESIGN OBJECTIVES

The bonding and grounding infrastructure within a facility containing sensitive electronic equipment is one of the most important and least understood aspects of facility design. Properly designed and maintained grounding systems are necessary to assure the safety of personnel, to protect the facility from fire and equipment malfunction, to create an environment with low levels of electrical noise and, to varying degrees, to provide protection against lightning. Bonding and grounding systems are used in telecommunications installations to accomplish the following objectives:

- **Personnel Safety** - Maintain low, equalized voltage potentials among frames, cabinets, ironwork and other conductive components. By limiting the potential differences, current flow is limited and the possibility of electrical shock due to normal operation, power faults, electrostatic discharge and lightning strikes is minimized.
- **Equipment Protection** - Provide engineered fault current paths of sufficient current carrying capacity and low impedance to allow over-current protective devices to operate in a timely manner and to eliminate excessive conductor heating.
- **Equipment Operation** - Provide a common voltage reference for connected equipment.
- **Network Reliability** - Provide a high-quality grounding infrastructure that resists deterioration, inadvertent disconnection and requires minimal maintenance.
- **Noise Mitigation** - Reduce noise and electromagnetic interference produced by the telecommunication installation.

5.0 GROUNDING COMPONENT CHARACTERISTICS

This section describes the physical construction and function of major grounding system components.

5.1 Grounding Electrodes

Grounding is a matter of bringing all of the bonded equipment to the potential of the surrounding earth. Ground potential is established by means of one or more electrodes buried in the earth and connected together.
This "ground reference" is then extended to the OPGP and throughout the network installation via a network of conductors, connectors and buses provided for the purpose. The intent is to provide a common ground reference throughout the network.

It is important to note, however, that this ground reference potential is not necessarily the same in all parts of a grounding electrode system. In a network installation, a difference of potential between different points on the ground planes is unavoidable. This is because DC power plants supply current to equipment throughout the installation and current constantly flows back to the batteries or rectifiers over ground conductors.

Depending on the impedance of the current return path and the magnitude of current flow, a difference of potential will exist between the originating and terminating points of a ground path. Under normal operating conditions, the CO GRD system is expected to maintain ground potential differential of less than one volt between any two points on the ground system.

5.2 Bus Bars

Bus bars provide a convenient means to connect multiple conductors together. They are usually made of un-tinned copper, typically ¼” thick, 4” wide and as long as necessary to accommodate anticipated terminations. Bus bars are given different names to identify how they are used. When un-tinned bus bars are used, the surface must be burnished to a bright finish and coated with an anti oxidant before terminations are made.

5.2.1 Central Office Ground (COG)

The COG bus bar is required on every equipment floor. The COG is an extension of the OPGP ground reference and associated vertical riser. The COG serves as the primary ground reference on each floor and is provided as a more convenient point of attachment (rather than bonding directly to the vertical riser). The COG bus is located on a steel column that serves as a vertical equalizer or, when a wire conductor serves as the vertical equalizer, on a column or wall that best serves the requirements of the physical design of the building. In the later case, the bond between the vertical equalizer and the COG should be as short as practical but no longer than 20 feet. All grounding conductors on each floor must have a reliable electrical path back to the COG.

The COG can serve equipment within 200 conductor feet of the vertical riser to which the COG is attached (see Figure 5.1). This 200’ restriction is a generic guideline and is based on the need to provide a low resistance fault current path for the operation of fuses and breakers. Section 6 will provide sample calculations that illustrate the correlation between this 200’ limitation and calculation of fault current.

If equipment is placed beyond 200 conductor feet from the vertical riser, a second COG should be installed on all floors that exceed this 200’ limit along with a second vertical equalizer that originates at the OPGP. The COGs are connected with a 750kcm horizontal equalizer on every third floor in order to limit the potential difference between any two grounded objects to 1/2 volt or less during normal operation.

The ideal location for the COG is in the center of the equipment floor (to maximize the area served) and near the MDF (to provide a short discharge path for protectors).

5.2.2 Main Ground Bus (MGB)

The MGB is part of the common bonding network (CBN) and provides the single connection between the CBN and the isolated bonding network (IBN). The IBN is electrically insulated from contact with any other grounded metal except at the MGB.
There are other metal conductors - normally part of the CBN - that exist within the IBN. These include anchor bolts, frames, superstructure and conduits. IBN equipment must be insulated from these conductors to prevent formation of current loops.

Figure 5.1 illustrates the distance relationships between the vertical riser, the COG, MGB and grounded equipment frames. The distances are in conductor feet and apply equally to the CBN or IBN environment. It is important to note that the physical placement of equipment will be more restrictive than the 200 conductor feet shown in Figure 5. 1. This is because grounding conductors are routed along aisles and perpendicular to aisles and results in a longer path than if a direct route ("as the crow flies") was used.

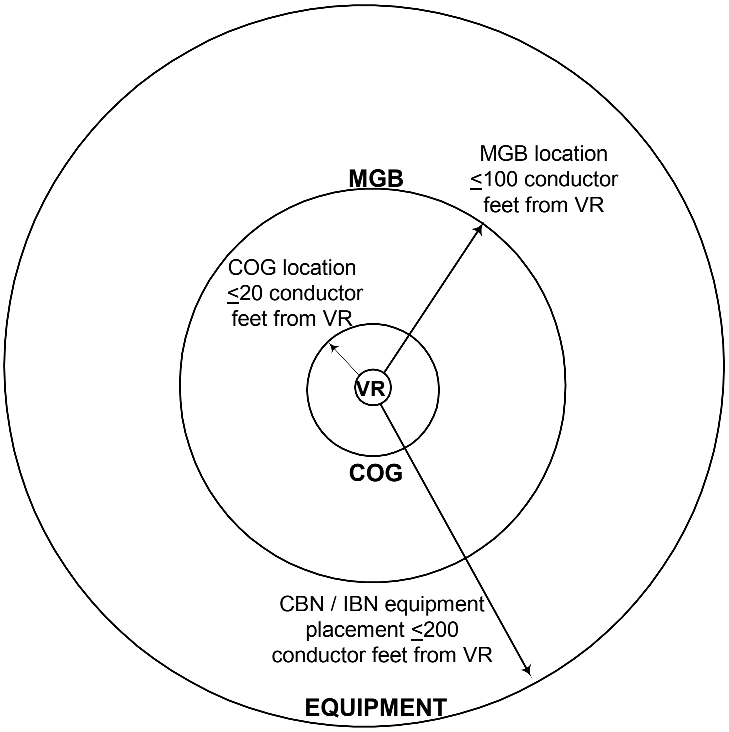


Figure 5.1
(Distance Limits of COG, MGB and Equipment Frames)

5.2.3 Office Principal Ground Point (OPGP)

The OPGP is, as the name implies, the main ground reference for the building. The OPGP is where the ground reference sources (building electrodes, AC ground reference, OSP ground reference) are tied together to provide one ground reference for the building.

5.3 Wire

Copper wire used for grounding in a central office environment is typically stranded, tinned, insulated or not insulated, will vary from #6AWG to 750kcm in size and is plated with an anti-corrosive metal. Wire smaller than #6AWG may be used to connect network elements (equipment shelves) to the CO ground system. However, as will be seen in section 6, a #6 AWG is based upon expected fault current from an equipment frame and NEC requirements. The upper limit of 750 kcm is based on physical size, weight and general availability - although occasionally a 1000 kcm will be installed.

Wire used for below ground applications is usually solid, non-insulated, #2AWG and also plated. Copper wire characteristics are described below and summarized in Table 5.1.

Aluminum is not a good grounding conductor as it forms non-conducting oxides very rapidly when exposed to air, expands more than copper when heated and has a higher galvanic reaction when bonded to steel.

5.3.1 Construction

Stranded construction consists of combining several small gauge, solid wires into a single larger gauge conductor. The first layer of strands around a center conductor is typically made of six conductors. The second layer – if used – is made of 12 additional conductors, the third layer – if used – consists of 18 additional conductors. Thus, stranded wires are composed of 7, 19, 37 stands, in continuing fixed increments.

The individual wires in a stranded conductor are usually twisted together and are not insulated from each other. Stranding makes the wire more pliable and easier to install and the space between individual strands makes the wire easier to crimp. Solid wires are not as susceptible to corrosion as stranded wires and, as a result, are more suitable for buried applications.

Figure 5.2
(Stranded & Solid Wire)

5.3.2 Plating

Bare copper conductors will oxidize from exposure to the atmosphere and will form copper oxide on the surface. Oxidation and other types of corrosion are accelerated by the presence of heat and moisture. The oxide film is a poor conducting material and must be removed from bonded surfaces to assure a good, reliable connection. To prevent corrosion and improve termination reliability, copper is coated with a metal that is less susceptible to oxidation and corrosion. Silver, nickel and tin are the most frequently used coatings with tin being the least expensive and most prevalent. Plated or tinned copper wire, lugs, connectors and bus bars will typically have a minimum 20 micro-inch coating of tin. Tinned conductors have marginally higher resistance than the equivalent non-tinned conductor. The data in Table 5.1 is for tinned conductors.

5.3.3 Gauge

An increase in the diameter or cross section of a wire decreases its resistance and increases its capacity to carry current. Two designations are used to specify conductor size, American Wire Gauge (AWG) and circular mil. AWG varies in size from 56, the smallest, to 0000 (or 4/0), the largest. AWG sizes were arbitrarily selected so the next larger size would have a cross sectional area 26% larger than the previous size.

A change in three "AWG" conductor sizes results in a doubling of cross sectional area and a halving of conductor resistance. For example, referring to column 2b and column 3 of Table 5.1, the area of a 1/0 AWG wire is half the area and twice the resistance of a 4/0 AWG wire.

A mil is 0.001 inches and a circular mil (cmil) is defined as the cross-sectional area of a conductor with a diameter of 1 mil. One thousand cmils is abbreviated “1kcmil” (or 1kcm). Column 2b gives the area of widely used grounding conductors in kcm.

Since the area of a circle ($A= \pi D^2/4$) varies according to the square of the diameter, a doubling of the wire diameter will increase the area by a factor of 4.
Wire sizes larger than a #4/0 AWG are given as kcm and generally range from 250 kcm to 1000 kcm. Kcm wire sizes get larger with larger numbers. In contrast, AWG wire sizes get smaller with larger numbers.

5.3.4 Insulation

Besides the obvious benefit of providing electrical isolation, insulation also provides physical protection for the copper wire and eliminates strand separation at locations were the wire makes a bend. Wire insulation is based on Telcordia General Requirements, GR- 347. Wire insulation adversely affects the ability of a conductor to dissipate heat. This results in lower ampacity ratings for insulated wire than for non-insulated wire used in equivalent applications.

Non-insulated wire is specified for grounding electrode applications (below ground) as it provides additional electrical contact with the earth.

Wire is first covered with a layer of Hypalon® (a polyethylene) insulation. Hypalon has good resistance to most chemicals, oil, heat and abrasion. Wire that is larger than #6 AWG is then wrapped with a polyester tape. All wires used in our grounding infrastructure (#6 AWG to 750kcm) have an outside cover of cotton braid that is saturated with a heat, moisture and flame-retardant compound and then coated with lacquer. The polyester tape helps to keep the cotton braid from gripping into the Hypalon insulation and makes it easier to strip the insulation from the conductor.

5.3.5 Impedance

Impedance is the measure of the degree to which an electric circuit resists electric-current flow when a voltage is impressed across its terminals. Impedance (Z), expressed in ohms, is the ratio of the voltage impressed across a pair of terminals to the current flow between those terminals: $Z = V/I$ and includes the effect of inductance and capacitance.

The predominant power sources in our network facilities are DC and low frequency AC (i.e., commercial AC). Most calculations of ground circuit impedance can ignore the effect of inductance and capacitance when considering DC and low frequency AC issues. However, when lightning current enters a grounding system, the very fast rise time and subsequent decay of the lightning strike requires treatment of the lightning strike as a high frequency AC current.

During lightning strikes, ground circuit impedance is a function of resistance and inductive reactance, both measured in ohms. The effects of capacitive reactance can generally be ignored. To design an effective ground system, it is important to be aware of the relative effects of resistance and inductive reactance.

5.3.5.1 Resistance

In order for power board and BDFB fuses to operate in a timely manner, it is important that the DC resistance of the fault current path not exceed design limits. DC resistance is dependent on length, cross-sectional area and whether or not the conductor is tinned. Values for the DC resistance of common ground wires are shown in column 3 of Table 5.1 Fault current calculations are described more completely in section 6.

In AC circuits, resistance is dependent on the same physical characteristics as DC resistance but it is also dependent on frequency. The influence of frequency is normally not a consideration for the low frequencies of commercial power but is a consideration for the high frequency components of lightning current. See skin effect in Section 6.6.2. The AC resistance (at 1MHz) for common ground wires is shown in column 4 of Table 5.1. These values range from 5 times to 67 times the comparable DC resistance values.

5.3.5.2 Inductance

Inductance is the property of an electric circuit that opposes any change in electric current. Inductance is designated by the letter "L" and is measured by the "henry" or, more conveniently, micro henries. In CO grounding systems, inductance is a property of every grounding conductor. Sharp turns or bends should be avoided in grounding systems to minimize the inductive reactance that is introduced by lightning or other fast transient waveforms. It is common to think of inductance as being associated with a coil of wire. However, even a straight length of wire will have inductance.

This self-inductance for a single conductor can be approximated by the formula:

$$L= 2*L_c*(\ln(4L/D) - 0.75)$$

where " L" is the inductance in micro henries, "L_c" is the length of the conductor in cm, "D" is the conductor diameter in cm and "ln" is the natural logarithm. This is the formula used to estimate the inductance of wires listed in columns 5a, 5b and 5c of Table 5.1.

5.3.5.3 Inductive Reactance

The impact of inductive reactance at high frequencies can be demonstrated by comparing the DC resistance and inductive reactance for a #6 AWG wire. The DC resistance for 10 feet of #6AWG wire is 0.00427 ohms (column 3 times 10) while the inductive reactance for the same wire at 1Mhz is 24 ohms (column 6a) – over 5000 times as large. This is why there is so much emphasis on reducing inductance in our grounding infrastructure by using the shortest possible wire routes and minimizing all bends.

Inductive reactance is proportional to the applied frequency and will increase as the frequency increases.

1	2a	2b	3	4	5a	5b	5c	6a	6b	6c	7
Size	Dimensions		DC Resistance	AC Resistance (Z_L) @ 1MHz	Self Inductance (L) in microHenries for conductor lengths of 10', 100' & 200'			Inductive Reactance (Z_L) in Ohms @ 1MHz for lengths of 10', 100' & 200'			Short Circuit withstand current at 250^0C
(AWG)	Diam (in)	Area (kcm)	(milliohms/ft)	(milliohms/ft)	10	100	200	10	100	200	(amperes)
14	0.073	4.11	2.730	13.664	4.33	57.37	123.20	27	360	774	442
6	0.184	26.24	0.427	5.421	3.77	51.74	111.92	24	325	703	2823
4	0.232	41.74	0.269	4.299	3.63	50.32	109.10	23	316	685	4491
2	0.292	66.36	0.169	3.416	3.49	48.92	106.29	22	307	668	7140
1/0	0.373	105.6	0.106	2.674	3.34	47.43	103.31	21	298	649	11362
2/0	0.419	133.1	0.084	2.381	3.27	46.72	101.89	21	293	640	14320
4/0	0.528	211.6	0.052	1.889	3.13	45.31	99.07	20	285	622	22766
250kcm	0.575	250	0.043	1.735	3.08	44.79	98.03	19	281	616	26898
350kcm	0.681	350	0.032	1.465	2.97	43.76	95.97	19	275	603	37657
500kcm	0.813	500	0.022	1.227	2.86	42.68	93.81	18	268	589	53795
750kcm	0.998	750	0.015	0.999	2.74	41.43	91.31	17	260	573	80693
1000kcm	1.152	1000	0.013	0.866	2.65	40.55	89.56	17	255	562	107590

Table 5.1
(Copper Wire Characteristics)

5.4 Equipment Frames

The equipment frame is a key component of the overall grounding infrastructure. Typically, network elements consist of multiple circuit packs that are mounted in a shelf or chassis.
The ground lead or pin within the circuit pack will make a connection with the backplane of the shelf or chassis and the shelf or chassis, in turn, is bonded to the equipment frame with either a direct or indirect bond. Finally, the steel equipment frame is bonded to the grounding infrastructure with a #6 AWG or #1/0 AWG wire.

Unless a stranded bay ground lead (SBGL) is used, the steel equipment frame will be part of the grounding path. Although a steel frame is not nearly as good a conductor as copper wire, the cross sectional area of the frame uprights is approximately 6 times that of a #6 AWG copper wire. The end result is that a 7-foot vertical upright has approximately the same electrical resistance as an 8-foot, #6 AWG copper wire.

5.5 Bonds

Bonding refers to the process by which a low impedance path for the flow of current is established between two or more metallic objects. In most electronic systems, numerous interconnections between metallic objects must be made in order to provide electric power, minimize electric shock hazards, provide lightning protection, establish references for electronic signals, etc. Bonding is simply a matter of connecting all grounded electrical and metallic objects together in order to establish a single electrical potential. When everything is at the same electrical potential, no current will flow between objects. This protects both people and equipment.

Bonding is concerned with the techniques and procedures necessary to achieve a mechanically strong, low impedance interconnection between metal objects and to prevent the path from subsequent deterioration through corrosion or mechanical looseness. In terms of the results to be achieved, bonding is necessary for:

- Protection of equipment and personnel from the hazards of lightning Discharges;
- Establishment of low impedance fault current paths;
- Establishment of homogeneous and stable paths for signal currents;
- Minimization of radio frequency potentials on enclosures and housings;
- Protection of personnel from shock hazards arising from accidental power grounds, and
- Prevention of static charge accumulation.

With proper design and implementation, bonds minimize differences in potential between points within the fault protection, signal reference, shielding, and lightning protection networks of an electronic system. Poor bonds, however, lead to a variety of hazardous and interference-producing situations. Loose or high impedance joints in lightning protection networks can be particularly dangerous.

The high current of a lightning discharge may generate several thousand volts across a poor joint. Resulting arcs (flashovers) are a source of interference and damage to equipment and may cause a fire hazard. A bonding resistance of 1 milliohm or less is considered a high quality bond. There are two classifications of bonds: direct bonds and indirect bonds.

5.5.1 Direct Bonds

Direct bonding is the establishment of the desired electrical path between the interconnected members without the use of an auxiliary conductor.

Examples of direct bonds are the splices between bus bar sections, the exothermic connections between a grounding rod and a ground ring and the joining of equipment shelves to equipment racks.

Direct bonds are accomplished by direct contact of the mating surface without the use of an intervening conductor. Electrical continuity is obtained by establishing a fused metal bridge across the junction, by welding or by maintaining a high-pressure contact between the mating surfaces with threaded fasteners.

Direct bonding is preferred over indirect bonding (discussed below) because there is only one connection to install and maintain (versus two connections for indirect bonding) and direct bonding eliminates the impedance loss of the connecting wire. It can only be used when the two members can be connected together in a manner that provides a solid electrical connection while remaining free of any movement.

5.5.1.1 Welding

In terms of electrical performance, welding is the ideal method of direct bonding. The intense heat involved is sufficient to boil away contaminating films and foreign substances. A continuous metallic bridge is formed across the joint. The conductivity of this bridge typically approximates that of the bond members. The mechanical strength of the welded bond approaches or exceeds the strength of the bond members.

An effective welding technique for many bonding applications is the exothermic process. In this process, a mixture of aluminum, copper oxide and other powders is held in place around the joint with a graphite mold.
The mixture is ignited and the heat generated (in excess of 4000^o F) reduces the copper oxide to provide a homogeneous copper blanket around the junction. With the high heat of exothermic welds, copper can be bonded to steel or iron as well as to other copper materials.

Exothermic welds are often used to bond major components of the grounding infrastructure including the vertical riser, horizontal equalizer, Central Office Ground (COG), Office Principal Ground Point (OPGP), building steel and the grounding electrodes. These connections are generally considered to be permanent and may not be available for subsequent inspection (e.g., steel columns with interior finish or buried grounding electrodes). Soldering is another metal flow connection process. However, because of the low melting point of solder, solder should not be used where high currents (and high heat) may be present as this could cause the solder connection to melt and pull away.

5.5.1.2 Threaded Fasteners

Threaded fasteners include both nut and bolt combinations and thread-forming screws for joining components via direct bonding. To be effective, threaded fasteners must have adequate mating surfaces, the surfaces must allow metal-to-metal contact and the connection must be properly torqued to insure good contact between the surfaces. Proper metal-to-metal contact is insured by proper cleaning of the surfaces or by use of external-toothed lock washers that “bite” into the metal surface. Table 5.2 shows the NEMA-recommended tightening torques for silicon bronze galvanized steel and stainless steel nut and bolt combinations.

Bolt Diameter (inches)	Bolt Material (Silicon Bronze, Galvanized Steel or Stainless Steel)	
	Ft-lbs	In-lbs
3/8	20	240
½	40	480
5/8	55	660
¾	80	960

Table 5.2
(Nominal Torque Values for Bolts)

Thread-forming screws are becoming popular as a means to provide “shelf-to-rack” grounding connections as they eliminate the need for both a bolted connection to the rack and a separate grounding conductor. Relay racks have pre-drilled and tapped (threaded) holes to accept 12-24 threaded screws. The primary ground connection is through contact between the mounting ears of the network equipment and the relay rack surface (after paint removal). The contact between the screw surface and tapped hole is a secondary ground connection and should not be relied upon for grounding.

A thread–forming screw used in grounding applications typically consists of a zinc-plated, hex washer head that is assembled with a torque of 65 to 85 inch pounds. This type screw has a high resistance to vibration loosening and has been established as a standard by both GM and Ford. This type fastener is also specifically allowed by Telcordia’s GR-1089-Core (Generic Criteria for Network Telecommunications Equipment).

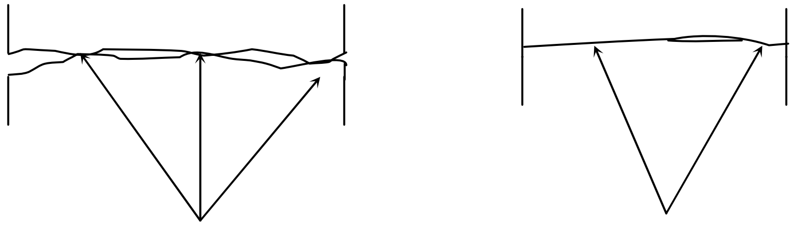
Virtually all network elements are mounted to relay racks and cabinets with thread-forming screws. However not all manufacturers provide good electrical continuity between the equipment chassis and the equipment mounting "ears." For this reason, thread-forming screws should not be relied upon for grounding unless specified by the manufacturer.

5.5.2 Indirect Bonds

The preferred method of bonding is to connect the objects together with no intervening conductor. However, operational requirements or the connection location often preclude the use of direct bonding and therefore wires (indirect bonds) become necessary to join the objects. The bonding wire can be used to connect two pieces of equipment, a piece of equipment and another wire or two wires. Before the bond is made, the wire is fitted with a compression connector.

5.5.2.1 Compression Connectors

The two types of compression connectors that are used in our central offices are compression terminals and compression taps. These connectors are sized for specific conductor gauges and fit over ends of wire (terminals and taps) or sections of wire (taps) where the insulation has been removed. A crimping die is selected for the size of the terminal/tap and placed in the crimping tool. The tool applies several tons of force to the terminal/tap and essentially fuses the connector and wire into one piece. As two surfaces are first brought together to make a joint, the microscopic peaks of each surface touch one another as in figure 5.3(a). As pressure is applied to the two surfaces, these peaks tend to flatten as in figure 5.3(b) thereby greatly increasing the contact area between the two surfaces. This compression of material also applies to the surfaces of conductors joined by properly torqued nut and bolt combinations.



(a) Poor contact before compression (b) Good contact after compression

Figure 5.3
(Effect of Compression on Copper Surfaces)

5.5.2.2 Compression Terminals

Wires that are to be terminated on an equipment frame, cabinet or bus bar will be fitted with a compression terminal. These terminals or lugs are attached to the end of the wire. The compression terminal is fastened to an equipment frame, cabinet or bus bar with a nut, bolt and external tooth lock washer assembly. The tightening torque for nuts and bolts is important to insure good contact between materials. Recommended tightening torque is shown in Figure 5.3.

5.5.2.3 Compression Taps

Wires that are to be attached to another wire are fitted with compression taps. Compression taps use the same crimping tools as are used with compression terminals/lugs except they are used to join two or more wires together instead of joining a connector to a wire. Compression taps are available in a wide assortment of sizes and shapes to accommodate various field conditions. Thin wall, cylindrically-shaped, C-taps are typically used to join conductors that are #1/0AWG and smaller in size while H-taps are more substantial in construction and are used for joining wires when 1 or more of the wires are larger than #1/0AWG. Thomas and Betts and FCI/Burndy are the two primary suppliers approved by AT&T for compression terminals and taps. More information on compression terminals and taps can be found in their respective catalogs.

5.5.3 Direction of Wire Bends

One of the design objectives of a bonding and grounding system is to minimize electrical impedance. Direct routes minimize conductor length, inductive reactance and electrical impedance. It has been widely documented and accepted that bonding and grounding conductors should be run in as direct and straight a line as possible and, when bends are necessary, to make gradual bends.

It is not so widely agreed, when necessary to make bends in a grounding conductor, that the bend should be in the direction of the ground reference bus bar (MGB, COG or OPGP). Listed below are three reasons that support making the bend towards the ground reference bus bar:

1. Wire loops are often used to intentionally introduce inductance into a circuit (not a good thing for grounding infrastructure). A wire with 10 loops has more inductance than a wire with 1 loop. A wire with ½ of a loop has more inductance than a wire with no loops. Referring to Figure 5.4, (from the viewpoint of current flow), connection (a) has a sharp bend of approximately 180^0 which approximates ½ of an inductive loop. Similarly, connection (b) has a 90^0 bend, which approximates ¼ of an inductive loop. Connection (c) also has a 90^0 bend but the turn is gradual and therefore adds less inductance than either (a) or (b). As a result, a conductor that bends towards the ground reference and in the direction of current flow is preferable to a conductor that does not bend or bends away from the direction of current flow.

   It is true that inductance of a ground wire is usually only of concern with alternating currents and particularly the high frequency components of lightning current. It is also true that, with only one intentional connection to the grounding infrastructure, not much lightning current is likely to flow through a ground wire connected to an equipment frame (some current would flow through the high impedance, unintentional paths to ground). However, with an increasing number of network elements being deployed that have connectivity between the equipment frame and the battery return conductor, lightning current may flow through the grounding wire to the equipment frame and (via battery return conductor) to ground. This is reason to be concerned about inductance in all ground wires.

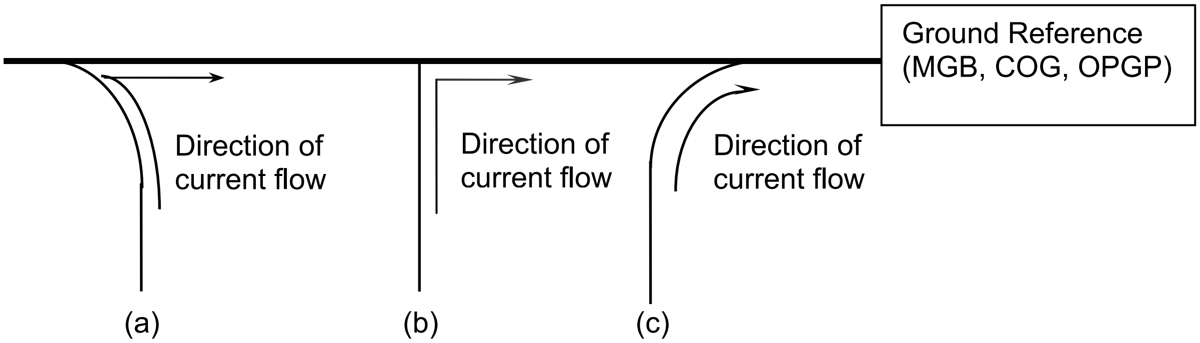


Figure 5.4
(Direction of Wire Bend and Inductance)

2. Refer to Figure 5.5. Three possible connections are shown: (a) a bend away from the ground reference, (b) a right angle connection and (c) a bend towards the ground reference. Assuming a bend radius of 1':
    - For path (a), the length of the electrical path between point "D" and point "F" is 3.57';
    - For path (b), the length of the electrical path between point "D" and point "F" is 2.00' and,
    - For path (c) the length of the electrical path between point "D" and point "F" is 1.57'.

    Consequently, it can be confirmed that a bend towards the ground reference provides a shorter electrical path with a resultant reduction in electrical impedance.

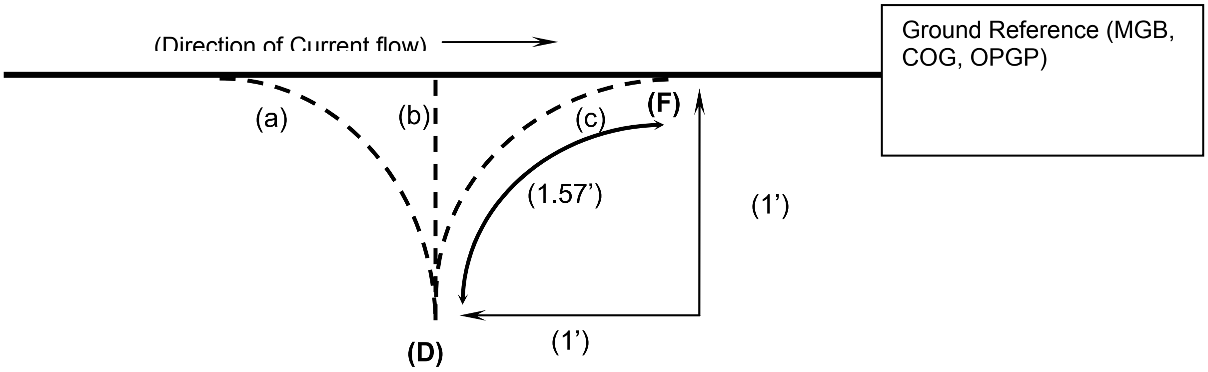


Figure 5.5
(Direction of Wire Bend on Resistance)

3. A grounding infrastructure with bends that are consistently towards the ground reference helps maintenance and engineering personnel to trace and verify ground circuit paths back to the ground reference (MGB, COG, OPGP).

6.0 GROUNDING DESIGN CONSIDERATIONS

The major grounding system components of a network facility are shown in Figures 6.1a (MGB located with the primary power distribution) and 6.1b (MGB located remote from the primary power distribution). Design considerations for each of these components are discussed later in the section and, for convenience, have been grouped into 4 functional categories:

- Establish facility ground reference
- Equalization of ground reference sources
- Distribution of ground reference
- Ground reference applications

As the entire grounding infrastructure primarily consists of interconnected grounding conductors, an overview of ground wire selection is also included.

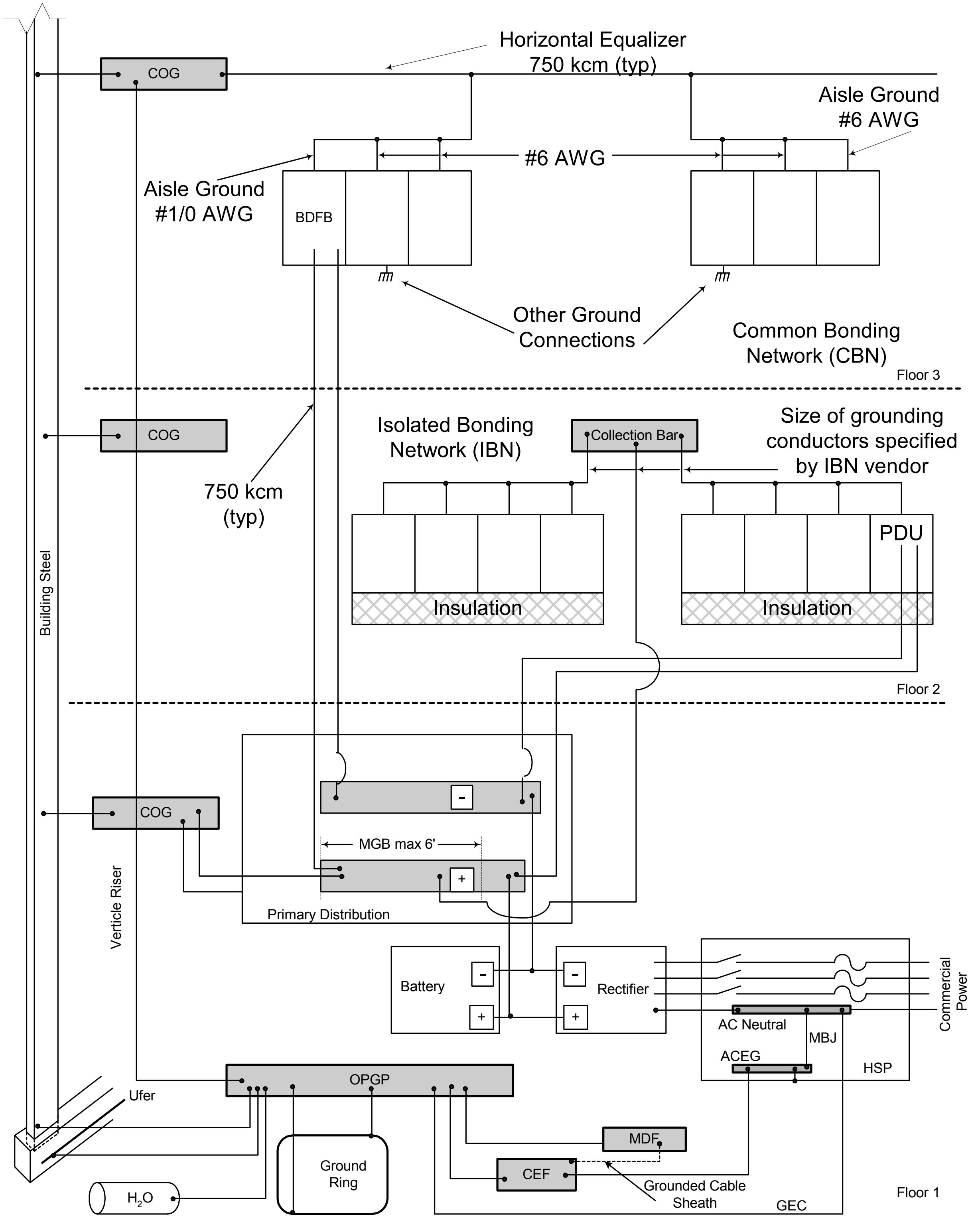


Figure 6.1a
(Grounding Infrastructure – MGB at Power Plant)

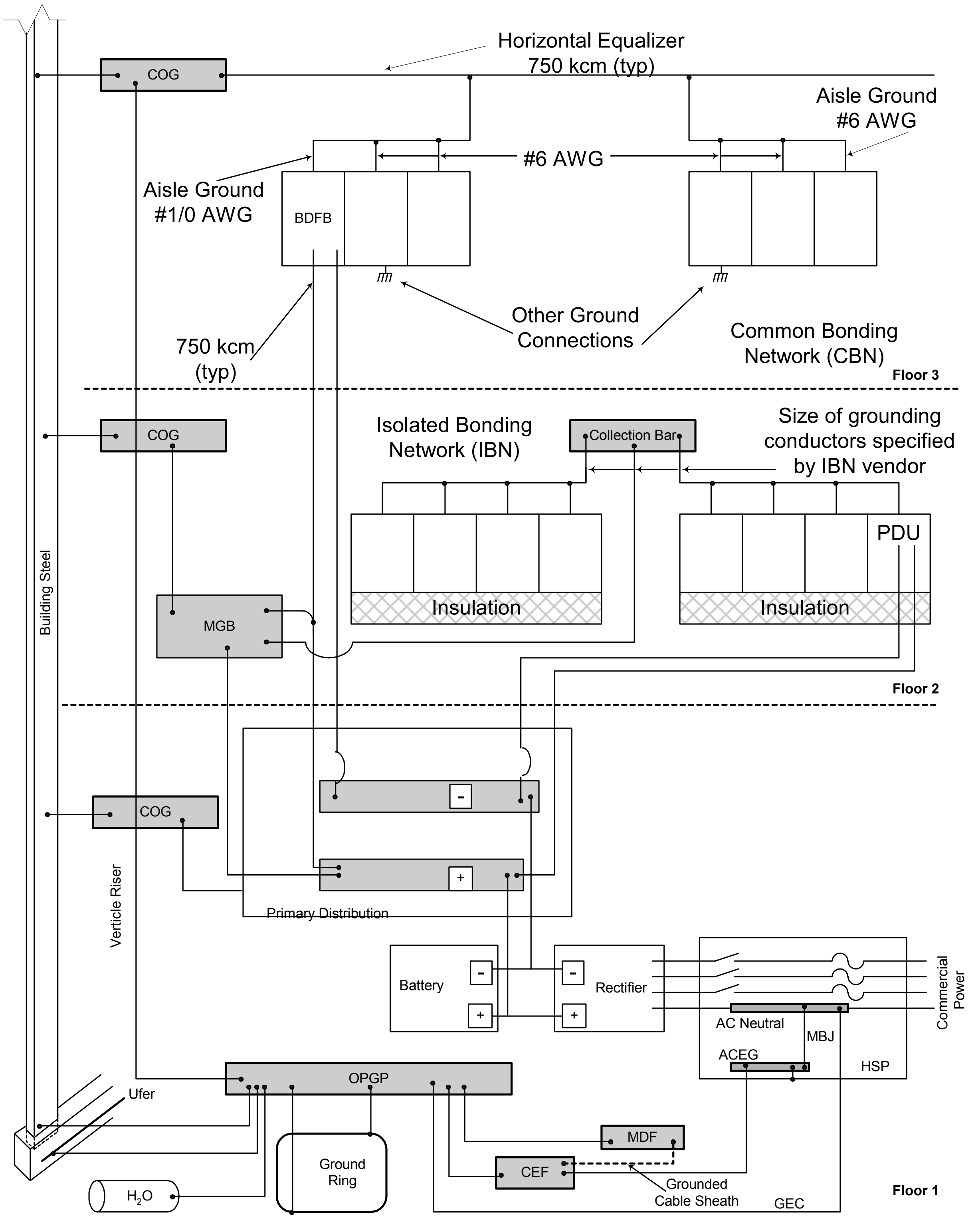


Figure 6.1b
(Grounding Infrastructure – Remote MGB)

6.1 Facility Ground Reference

All of our facility grounding systems rely on the earth as a ground reference. The earth has approximately the same number of positive and negative charges at any one time and is often considered electrically neutral or having a ground potential of zero.

In reality, there are subtle and continuous variations of ground potential due to widely varying soil composition, moisture content, and general electrical activity in any one area. However, the earth does provide a convenient frame of reference for voltage measurements and the enormous size of the earth allows it to absorb virtually an unlimited electrical charge from any source.

A ground, as defined in this document (and by the NEC) is: "***A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth***". A facility ground reference provides three primary functions:

- Dissipate lightning current
- Dissipate static discharge current
- Provide a voltage reference for CO equipment

A ground reference is established by connection to one or more grounding electrodes. When connected together, the various grounding electrodes make up the grounding electrode system that provides the ground reference for the facility. The grounding electrode system is not intended to clear ground faults.

6.1.1 Underground Water Pipe Electrode

To qualify as an acceptable grounding electrode, an underground water pipe must be in contact with the earth for at least 10' and connection to the pipe must be made within 5' of where the pipe enters the building. Whether or not a water pipe is qualified as a grounding electrode, the water pipe – as well as all other metallic pipe systems – must be bonded to the OPGP.

Due to the increased use of plastic pipe for municipal water systems, a cold water system should never be considered for an exclusive grounding electrode and must always be supplemented with another type of grounding electrode. The connection between the cold water pipe and the OPGP is sized according to Table 250.66 of the NEC.

6.1.2 Building Steel Electrode

Building steel can be connected to the earth by bolted or welded connection to reinforcing steel in foundations or footings that are, in turn, encased in concrete. To be an effective grounding electrode, the metal frame of the building must have low impedance contact with earth. Corporate Real Estate should verify the adequacy of the building columns for use as a grounding electrode.

When qualified as a grounding electrode, the connection between the building steel and the OPGP is sized according to Table 250.66 of the NEC.

6.1.3 Concrete Encased Electrode

The widespread use of steel reinforcing bars (rebar) and / or copper conductors in concrete foundations and footings provides a ready-made supply of grounding electrodes at structures utilizing this type of construction. In order to qualify as a grounding electrode, the rebar must be at least ½ inch in diameter or the bare copper conductor must be a #4 AWG or larger diameter and both must be continuous for 20'. Steel tie wires are permitted to join sections of rebar in order to qualify for the 20' requirement. Corporate Real Estate should verify the adequacy of concrete encased electrodes for use as a grounding electrode.

Bonding conductors between the concrete encased electrode and the OPGP are not required by the NEC to be larger than #4 AWG but no minimum size is given. AT&T recommends a minimum # 6AWG.

6.1.4 Ground Rod Electrode

Ground rods are made of iron or steel, are 8' or 10' in length, 5/8" in diameter and have a copper cladding to inhibit corrosion. When used as a supplement to an underground water pipe electrode or as a stand-alone electrode, ground rods have an NEC requirement that the resistance to earth for a single ground rod be 25 ohms or less. This is the only grounding electrode described in this section that has a resistance requirement.

It is important to note that the NEC requires that a single ground rod electrode that does not meet the 25-ohm requirement be augmented with a second electrode – usually a second ground rod. The NEC does not require that the resultant ground (initial ground rod plus augmented electrode) be 25 ohms or less.

Bonding conductors between the ground rod(s) electrode and the OPGP are not required by the NEC to be larger than #4 AWG but no minimum size is given. As seen below for AT&T's version of a ground ring electrode, a minimum #2 AWG (solid tinned) is usually specified.

6.1.5 Ground Ring Electrode

A bare copper conductor buried in the earth and that encircles a building or structure may be used as a grounding electrode. The ring must be at least 20' long using a bare #2 AWG or larger wire and buried at least 30" below the surface. The bonding conductor connecting the ring to the OPGP should also be a bare #2 AWG (solid, tinned) wire.

6.1.6 Ground Ring Electrode (AT&T)

AT&T's version of a ground ring combines the ground rod and ground ring electrodes described above. The minimum requirement for all AT&T facilities is that a ground ring electrode be installed for all network facilities – from central office to OSP pad. AT&T's ground ring electrode consists of 2 or more ground rods that are driven into the ground around the perimeter of the network facility. Frozen ground can increase the resistivity of earth by 100% or more. To be effective, ground rods that make up a ground ring and the interconnecting #2 AWG wire must be installed below the frost line. Generally, a placement 30" below the surface will protect against both frost and incidental earth disturbances.

Ground rods should be driven into undisturbed earth (as opposed to being placed in predrilled holes) in order to improve the contact between the rod and the earth and thereby minimizing the contact resistance. Generally speaking, the more ground rods in a ring, the lower the overall resistance will be. However, tests have shown that there is little improvement when ground rods are placed closer to one another than the length of the individual rods. This is because, if spaced too close to each other, the rods will be discharging current into the same volume of earth and will be less effective than if spaced further apart. Ground rods in a ring should be spaced approximately twice the length of the ground rod or approximately 16' for an 8' rod.

The bare, solid, tinned, #2 AWG conductor that connects the ground rods to the OPGP also provides additional contact with earth. Ground rods should be placed around a building or OSP pad at a location most likely to receive precipitation. This location within the drip line is usually 2' to 6' from the foundation of a building and 6" to 2' for a pad. Moisture in the soil greatly improves the ability of the soil to discharge current.

A solid #2 AWG conductor is used for below ground connections as it is more immune to corrosion than a stranded conductor and a #2 AWG conductor is capable of carrying current that is characteristic of lightning currents (very high magnitudes for a short period of time). A #2 AWG conductor is capable of carrying lightning current of up to a half million amperes for 350 micro seconds before the conductor fuses open.

The ground ring electrode must be connected to other "available" electrodes described above where the electrodes exist and are qualified. All connections must be made with exothermic or listed mechanical connectors.

6.1.7 Lightning Protection Electrode

In areas that have a high incidence of lightning and where the buildings are subject to direct lightning strikes, grounding electrodes may be established specifically for lightning protection. Grounding electrode systems for lightning protection consist of air terminals on top of the building, "down" conductors and grounding electrodes that are also connected to the grounding electrode system discussed above. The need for building lightning protection should be evaluated in conjunction with the Corporate Real Estate group and should be designed consistent with the requirements of NFPA 780. Implementation is the responsibility of Corporate Real Estate.

6.2 Ground Reference Equalization

As important as it is to establish a reliable, low resistance facility ground reference through the grounding electrode system discussed in section 6.1, it is perhaps more important to provide equalization of voltage potentials such that all non-current carrying conductive objects rise and fall in potential as a single unit. Ground reference equalization ensures that all metallic supply lines entering a network facility (and that may have a ground reference different from the grounding electrode system) are connected to the facility grounding electrode system.

This insures that there is only one ground reference within the building and that all conductors connected to this reference will be at the same voltage potential. Supply lines that may enter a network facility include but are not limited to power lines, outside plant (OSP) cables, community antenna television (CATV) cables or radio system wave guides.

The neutral conductors of power utility distribution systems are typically grounded via a grounding electrode at four locations per mile. OSP cable sheath is also grounded and/or bonded along its length (grounding specifics are dependent on buried or aerial construction and proximity to power distribution) and may or may not be at the same earth potential as the power system. What is important to recognize is that the power system neutral, the OSP sheath conductor, CATV sheath conductor, wave guide and the grounding electrode system of the facility may all have different ground reference potentials.

Without equalization, personnel or equipment that are in contact with any two of these ground references would likely experience a difference of potential during normal day-to-day activity and especially during lightning activity. Therefore, it is critically important that these ground references be connected to one another immediately after the conductors enter the building in order to provide a common ground potential for all conductive objects within the building. This equalization is important enough to be required by the NEC.

The previous section described how to establish a ground reference for a building (network facility). Most network facilities will also have AC power and OSP cable.

The AC neutral and OSP cable sheath will have their own ground reference established outside of the network facility and that may be different than the ground reference established for the building through the grounding electrode system. By connecting the AC neutral bus, cable entrance facility bus and the OPGP, all ground references within the network facility are tied together (equalized).

The connections between these components are deemed important enough to provide two connections from each component to other components.

6.2.1 OPGP

The Office Principal Ground Point (OPGP), as the name implies, is at the heart of the facility bonding and grounding system. The OPGP is nothing more than a copper bus bar that provides a convenient point to terminate connections to various grounding electrodes and to other major components of the facility grounding infrastructure (see Figure 6.1). The OPGP should be centrally located to the AC service, the grounding electrode system and the cable entrance ground bar. Voltage differences between these systems are minimized if the lengths of bond wires that conduct surge currents are kept as short as practical. Connections to the OPGP should be made using exothermic welds or with two-bolt terminals/lugs.

6.2.2 AC Power

Virtually every network facility has commercial AC service although there may be a wide variety of additional power service arrangements. It is beyond the scope of this document to review all variations of AC service that may be encountered. Therefore, the most frequently deployed service arrangement in network facilities is depicted in Figure 6.2 with primary components including the ungrounded service conductors, breakers, grounded service conductor (neutral), neutral bus, AC equipment ground bus, main bonding jumper (MBJ) and grounding electrode conductor (GEC). Of these components, the neutral bus, AC equipment ground bus, MBJ and GEC are part of the bonding and grounding system and are described below.

The National Electric Code dictates most of the bonding and grounding requirements for AC service in our facilities. This work is generally coordinated through the Corporate Real Estate group.

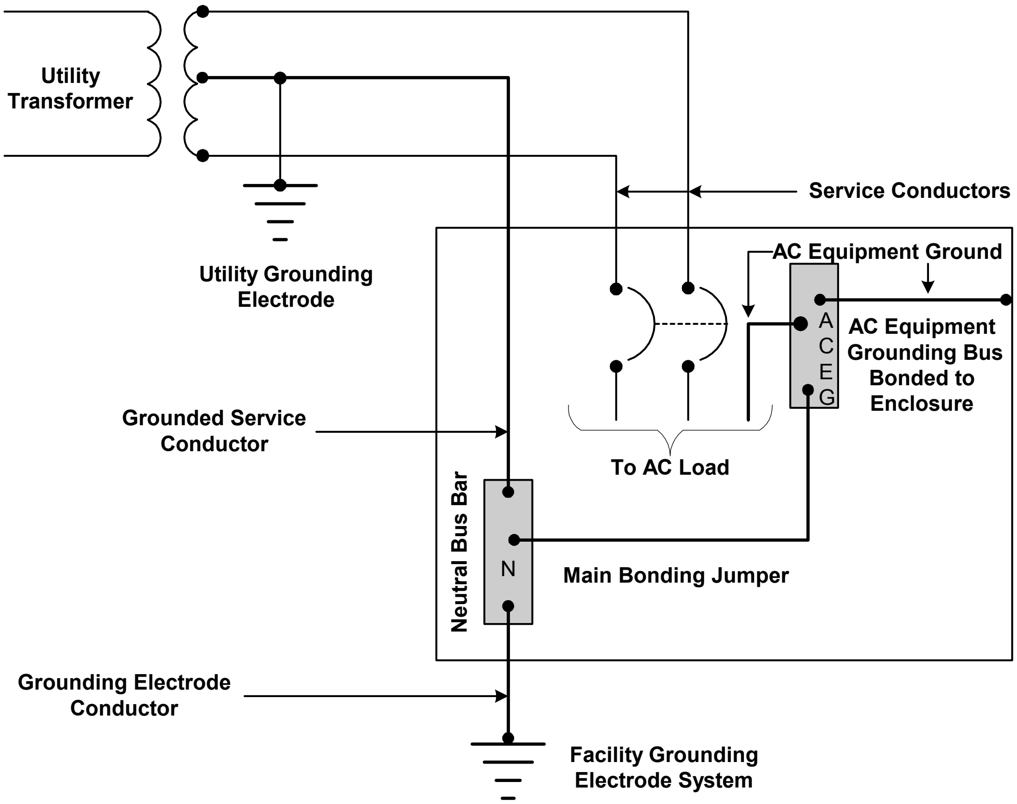


Figure 6.2
(Typical Single Phase, 3-Wire AC Service)

6.2.2.1 AC Neutral Bus

Where the transformer supplying service is located outside the network facility, the grounded service conductor is connected to the neutral of the transformer and is often referred to simply as the "neutral". The neutral provides two functions. First, it allows utilization of power at "line-to-neutral" voltage and, in that capacity, will be a current-carrying conductor. Secondly, since AC or DC fault currents return to their source, the neutral provides a low impedance path for AC fault currents back to the source (the utility transformer) and facilitate the operation of over-current devices. A fault between a service conductor and an equipment housing would cause current to flow over the AC Equipment Ground to the AC Equipment Ground Bus, through the Main Bonding Jumper to the neutral and back to the source. This low impedance, high-current path will cause circuit breakers to activate. It is important to note that the grounding electrode system is not a part of the normal fault-clearing path.

Within the service disconnect enclosure, the neutral bus and grounding electrode conductor serve as a means to connect the AC ground reference to other ground reference components that perform the "ground reference" function.

6.2.2.2 AC Equipment Ground Bus (ACEG bus)

All equipment served by AC service has an equipment grounding conductor that terminates at the equipment on one end and at the AC Equipment Ground Bus at the other end. This bus provides a ground reference for these conductors as well as a fault current path back to the AC source via the MBJ.

6.2.2.3 Main Bonding Jumper

The MBJ is one of the most critical elements in the safety grounding system. This conductor is the link between the grounded service conductor (neutral) and the equipment grounding conductor (via ACEG bus). Since the MBJ must carry ground fault current back to the grounded service conductor, its size must relate to the rating of the service conductors, which supply the service. Table 250.66 of the NEC can be used to size MBJ conductors. Although these conductors are designed to carry the same current as service conductors under fault conditions, they are generally smaller than service conductors because they are intended to carry fault current only for a short period of time.

6.2.2.4 Grounding Electrode Conductor

The grounding electrode conductor (GEC) is the sole connection between the grounding electrode system and the grounded service conductor (service neutral). The size of the GEC is based on Table 250.66 of the NEC. The GEC is generally smaller than a service conductor as a service conductor carries current on a steady basis whereas the GEC only carries current during a fault condition.

6.2.3 Cable Entrance Facility (CEF)

The CEF is the interface linking the outside plant cables to the main distributing frame in the central office. The metallic sheaths of OSP cables, the outer conductor of coaxial cables and the metallic strength member of some optical cables are all sources of surge currents into the CO. Connection of these components to the grounding electrode system and to the neutral of the AC power system (via the ACEG) helps to:

- Divert surge current that may appear on these metallic components away from sensitive electronic equipment and into the earth
- Equalize voltage potentials
- Reduce impedance to ground

Voltage differences between the cable sheaths entering the CO, the AC neutral and the grounding electrode system are minimized if the lengths of bond wires that conduct surge currents between the CEF, neutral conductor of the AC power service and CO grounding electrode are as short as practical.

Cable sheaths are bonded to the cable entrance facility ground bar (CEF) with a #6AWG conductor when individual bonds are made. This size conductor is common in the outside plant and is based on requirements of the National Electric Safety Code. To reduce the number of individual connections to the CEF, the #6 AWG sheath bonds are usually terminated to a #1/0 AWG conductor that extends the length of the cable vault and that, in turn, is connected to the CEF. Tip cables (or stub cables) extend from the cable entrance to the MDF. The sheaths of these cables are bonded to OSP cable sheaths and the MDF. This is shown as a dotted connection in Figure 6.1.

The CEF is connected to the OPGP and to the AC neutral (via the ACEG bus). Both conductors should be a #1/0 AWG. The industry has standardized on a #1/0 AWG for the connection between the CEF and the OPGP/AC neutral. This size insures that, if a power service fault is not cleared as designed, the grounding path will fuse open at the OSP fusible link, the #6 AWG sheath ground or at the cable sheath and not within the CO.

There is an exception to the practice of bonding the OSP cable sheaths to the OPGP. The low resistance of the CO grounding electrode system can conduct stray DC current from other sources such as public transit systems or large welding establishments.

This current may be conducted through the OPGP and on to the cable sheaths until it returns to the earth at a remote location where the cable sheath is grounded. This current can cause corrosion at the remote location.

Breaking the continuity of the cable sheath within the cable entrance facility can prevent this undesirable current. A gap of ¾" is sufficient. The cable sheath on the field side of the gap is insulated from the CO grounding infrastructure while the cable sheath on the CO side is bonded as before. In addition, a capacitor is placed across the gap to allow AC current flow (and lightning surges) while blocking DC current. For more information on this topic refer to 876-230-100 and the 877-xxx-xxx series of practices.

6.3 Ground Reference Distribution

Section 6.1 discussed the importance of establishing a good ground reference (grounding electrode system) and section 6.2 discussed how to equalize the voltage between the grounding electrode system and the ground references associated with the OSP and AC service.

The next step in designing a facility grounding system is to distribute the ground reference throughout the facility. This is accomplished with a vertical riser, central office ground bar (COG) and horizontal equalizer.

6.3.1 Vertical Riser

The vertical riser, as the name implies, is a low impedance conductor that is connected to the OPGP and extended in a continuous run to all floors of a building that have network equipment. The industry standard size for this conductor is a #750kcm. Although this conductor may carry lightning current (via connections to building steel), the low impedance design is based on an objective of providing a low impedance path for AC and DC fault current – not for lightning current. Large conductors (beyond a #2/0 AWG) are not required for lightning current.

The vertical riser is bonded directly to a COG on each floor. If the COG cannot be conveniently located at the vertical riser, it can be offset up to 20 conductor feet from the vertical riser as depicted in Figure 5.1. In this case, a conductor equal in size to that of the vertical riser is used to bond the two together.

When approved by Corporate Real Estate, the building structural steel may be used as a vertical riser or as a down conductor for building lightning protection. When a steel building column consists of an "I" beam or other substantial configuration and is made electrically continuous by welding a bond across butt joints, the column steel may by utilized as the vertical riser and the riser may be eliminated.

Although steel is not as good a conductor as copper, the volume of most steel beams is such that the resistance per foot is actually less than that of a # 750kcm copper conductor. The steel columns that provide structural support for network facilities are often overlooked as a resource for grounding.

6.3.2 COG

In multi-floor buildings, the ground reference (at the OPGP) is distributed to other floors by connecting a low impedance conductor (vertical riser) to the OPGP and extending the conductor to the other floors.

At each floor, a central office ground bus (COG) is connected to the vertical riser and this COG bus then becomes an appearance of the OPGP for that floor. The COG must be within 20 conductor feet of the vertical riser.

All grounding conductors on each floor are then connected back to the COG serving that floor. When the floor area is so large that all equipment is not within 200 conductor feet of the vertical riser, a second vertical riser is installed.

For single floor buildings, a vertical riser is not required although a COG may still be installed in order to provide a more convenient and cost-effective location to terminate equipment grounding conductors (rather than running all cables back to the OPGP). In this case, the COG is connected to the OPGP with a low impedance conductor, usually a #750kcm.

6.3.3 Horizontal Equalizer

As stated above, the COG is simply an extension of the OPGP. In a similar fashion, the horizontal equalizer is a ground wire that extends the COG reference voltage to the equipment floor area. The horizontal equalizer is a low resistance wire, usually a 750kcm. If two vertical risers are required to meet the 200’ distance limitation as described above, a horizontal equalizer should connect the two vertical risers on every third floor. This helps to further equalize ground references in larger COs. In either case (single or multiple vertical risers), smaller gauge bonds from equipment lineups and other grounded objects are connected to the horizontal equalizer with H-tap connectors.

Equipment lineup conductors are limited to 50’ for two reasons. First, fire codes require that personnel have reasonable access to fire exit routes and have placed a 50’ restriction on equipment lineups. Secondly, the resistance of #6 AWG or #1/0 AWG wire is relatively high compared to 750kcm wire. This higher resistance has an adverse impact on the fault current path and limiting lineup conductors to 50’ helps to insure there will not be excessive lengths of high resistance wire in the fault current path. Section 6.5 goes into more detail on determining the size of ground wires.

6.3.4 Grounding vs Bonding

Within a CO, grounding conductors are often thought of as the collection of wires that are purposely designed and installed to provide connection to a grounding electrode and - subsequently – to ground (or earth). These conductors distribute the ground reference throughout a network facility and generally consist of the vertical riser, horizontal equalizer and grounding electrode conductor.

Bonding conductors, on the other hand, provide the path between the metallic components that require a ground reference (e.g., equipment frames) and the grounding conductors. It is a subtle distinction and the two terms are often used interchangeably without adverse impact.

6.4 Ground Reference Applications

With the grounding electrode system established, all ground references connected together and equalized and the ground reference distributed to network equipment areas, it is now possible to connect network equipment (that requires grounding) to the ground reference. The three applications that utilize this ground reference are the common bonding network, the isolated bonding network and power supplies.

6.4.1 CBN

All of the ground reference, ground equalization and ground distribution systems that have been discussed above are part of the CBN. Every conductive object that is grounded and not explicitly identified as part of the IBN is, by default, part of the CBN. Each of these conductive objects will have an engineered ground wire connection to the CBN as well as any number of “incidental” or unplanned ground connections.

For example, an equipment frame may have a #6 AWG wire connecting the frame to the CBN but also have incidental ground connections through contact with adjoining frames, the concrete equipment floor, auxiliary framing, AC power conduit, DC battery return conductors, air conditioning duct, etc.

In Figure 6.3, the wire connections between the conduit, cable tray, equipment frames, battery return and the COG are placed intentionally and are sized according to design objectives. The contact between the conduit, cable tray and equipment frames as well as the contact between the equipment frames and the floor is incidental (no intentional wire connections) in nature. The quantity and quality of these contacts is generally unknown.

6.4.1.1 CBN Battery Return Current

It is worth noting the connection between the battery return and the equipment frame (a short connection to the left of the load on the CBN equipment lineup of Figure 6.3).

There is a common misperception that there is no current flow between the battery return and equipment grounding conductors. However, within the CBN, there are at least three sources for this type of current:

Older style Battery Distribution Fuse Bays (BDFBs) had the battery return of the BDFB directly mounted on the equipment frame. Although these type BDFBs have largely been replaced, they still exist in our network and can be a source of current flow on grounding conductors.
Industry standards specify that all DC-DC converters (that convert 48 volts to the 12V, 5V or 3V used by network elements) rated at 150 watts or above and that do not have current limiting capabilities, must have the output (battery return) grounded – another source of current flow on grounding conductors. Also, there is no restriction on volunteer grounding of the outputs – whether above or below 150 watts.
An increasing number of network equipment vendors are choosing to connect the battery return to the equipment frame, purportedly to reduce the levels of electromagnetic interference. This configuration is an obvious source of current flow on grounding conductors.

It is important to be aware that current flow on grounding conductors is relatively common and not generally a source of alarm unless the level of current exceeds the full time rating of the ground wire.

6.4.1.2 CBN Lightning Current

When lightning current does enter the facility (direct hit to the building or through AC service or OSP conductors), the current will seek the path of least resistance to earth. Hopefully, this path is through the grounding infrastructure provided for the purpose (via the OPGP to the grounding electrode system). Some current, however, will flow through incidental connections to ground shown in Figure 6.3. This brings disruptive lightning current close to sensitive network elements and led to the introduction of the Isolated Bonding Network.

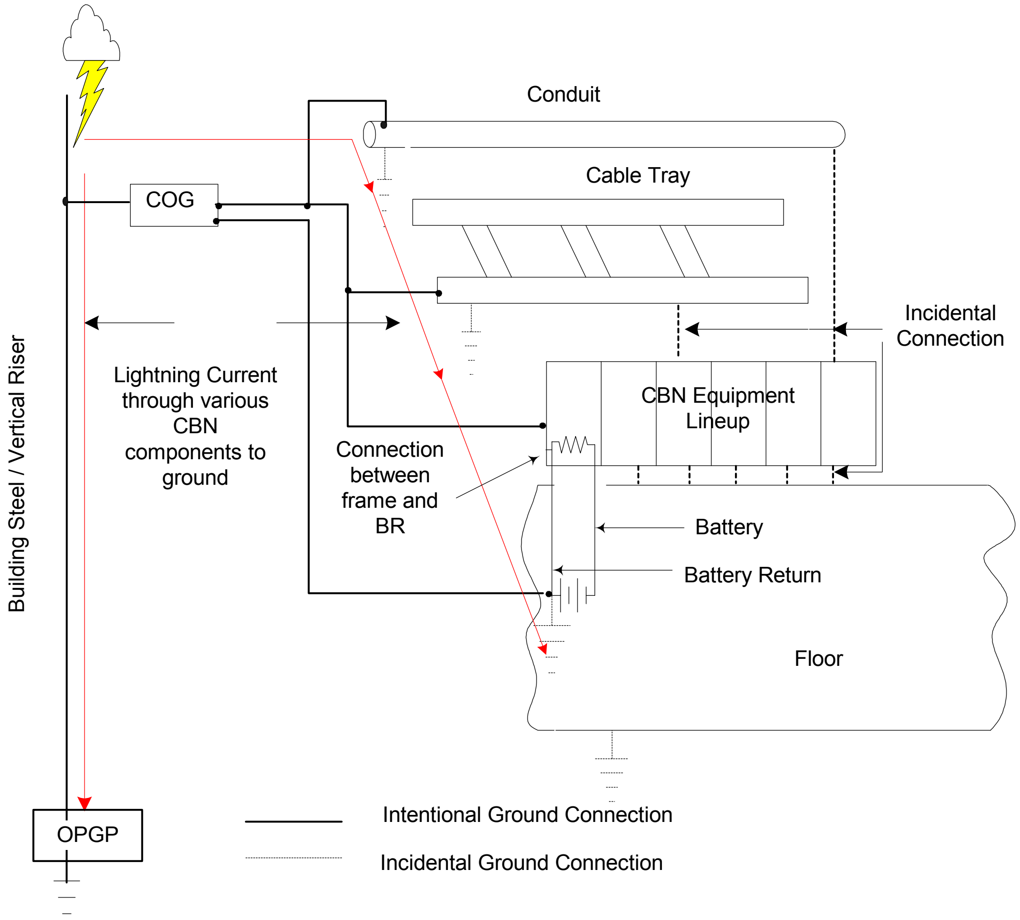


Figure 6.3
(CBN Grounding)

6.4.2 IBN

With the evolution from electromechanical switches to electronic switches, manufacturers devised a method to isolate sensitive electronic switch components from the effects of lightning current and fault currents originating in the CBN. An IBN is simply a subset of equipment frames that exist within the CBN and that are electrically isolated from the CBN except for a single point. As shown in Figure 6.4, IBN equipment is electrically insulated from the floor, conduit, cable trays and other conductive objects that are part of the CBN.

While equipment within the CBN may have a variety of intentional and incidental grounding connections at multiple points, equipment within the IBN has grounding connections to the CBN at a single point only (actually, a single area) called the Main Ground Bus (MGB).

6.4.2.1 MGB

Referring again to Figure 6.4, lightning current will still flow through the CBN and the incidental connections to ground. However, since the conduit, cable tray and floor are all electrically insulated from the IBN equipment, no current will flow between the CBN and the IBN. Furthermore, since the only ground reference point serving the IBN is the MGB, all grounding wire connections at the MGB will be at the same reference potential. With no difference in potential between ground wires connected to the IBN, no current will flow between these conductors and, consequently, there is no current flow in the IBN.

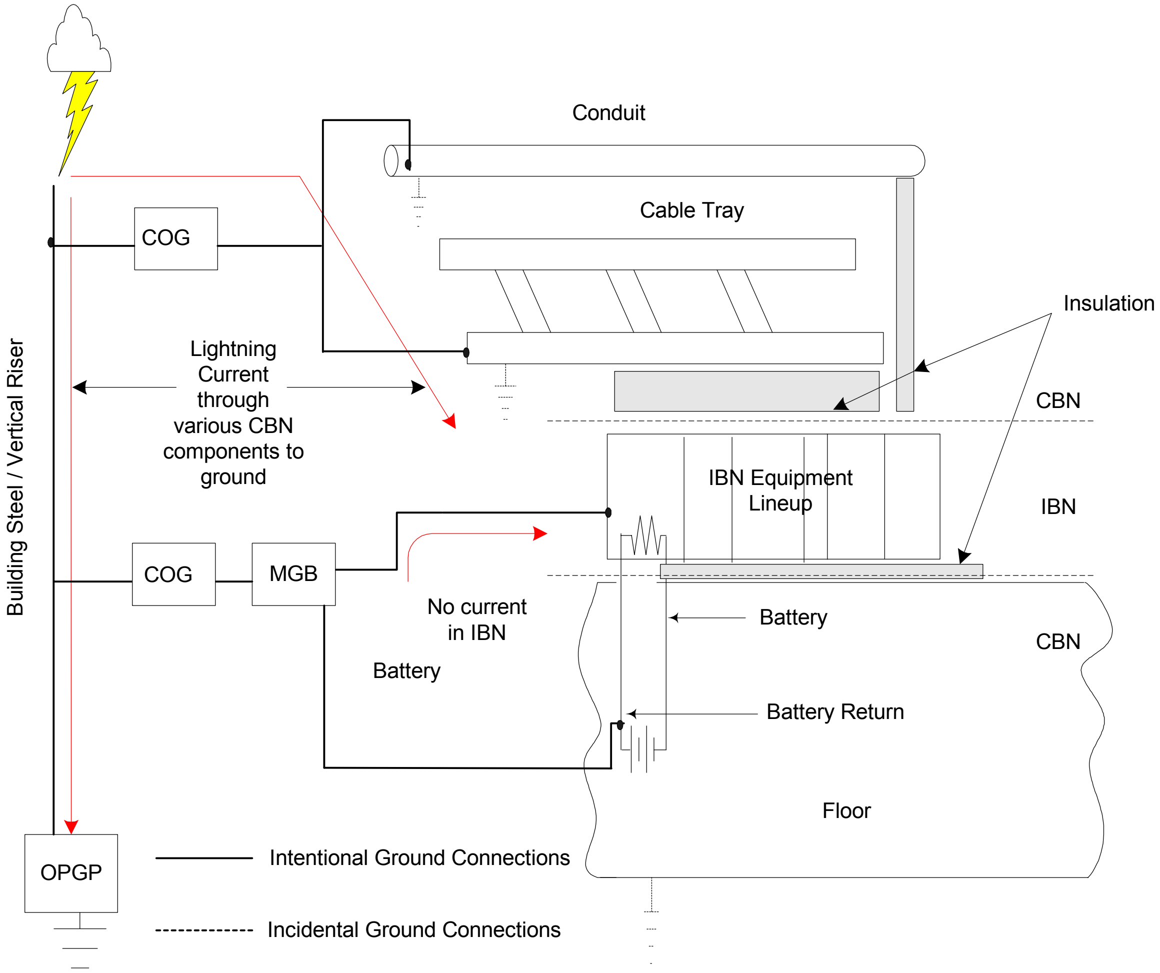


Figure 6.4
(IBN Grounding with Remote MGB)

Figure 6.4 illustrates a specialized implementation of an IBN where the conduit and cable tray do not make physical contact with the IBN equipment frames. More often, the conduit, cable tray and battery return will all make contact with both IBN and CBN components. Without additional installation safeguards, this contact would violate the integrity of the IBN.

For example, referring to Figure 6.4, if the conduit shown were not insulated from the IBN equipment and, instead, made physical contact with IBN equipment, then lightning current could flow through the COG, along the conduit (and along the ACEG conductor within the conduit) through the IBN equipment to the MGB and on to the COG/OPGP. This would bring lightning current into the IBN and is contrary to the design objective of an IBN.

To circumvent this condition, all conduit, cable tray, cable conductors and battery return conductors that are grounded in both the CBN and IBN, must be routed near the MGB, be bonded to the MGB with a bond no more than 3' in length and make no subsequent contact with CBN components.

Figure 6.5 shows an AC conduit grounded at the House Service Panel (HSP) that is part of the CBN. This conduit provides AC service to IBN network equipment and is also bonded to the IBN. In order to prevent lightning current from flowing along the conduit to the IBN, the conduit is routed past and bonded to the MGB and then isolated from further contact with the CBN.

Since both the conduit and IBN equipment have the same ground reference at the MGB, no current will flow between the two.

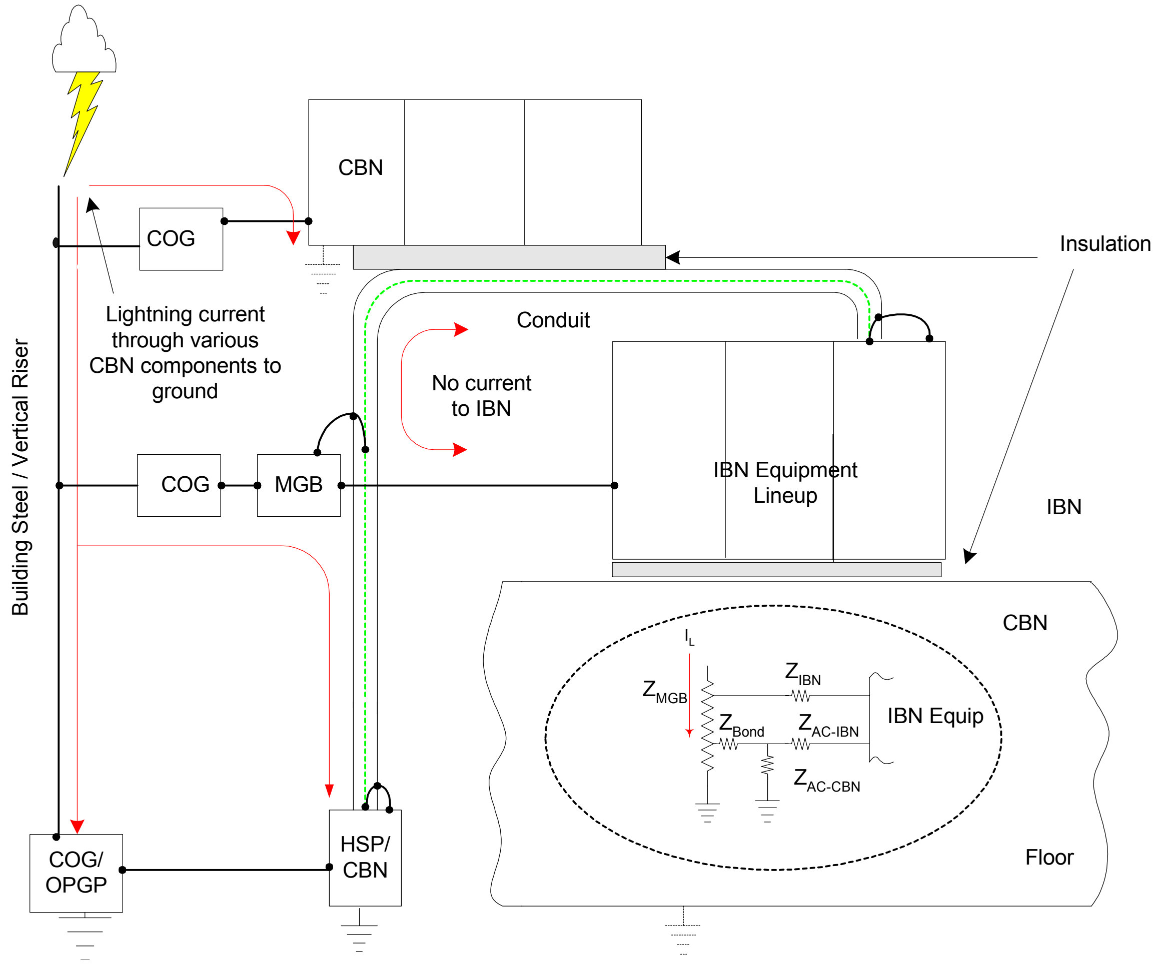


Figure 6.5
(Conductors in CBN and IBN)

While the MGB is physically nothing more than a copper bus, there are two important attributes that govern how connections are made to the MGB.

First, all connections to the MGB should be made within 6 conductor feet of one another. The MGB is usually a straight bar but can be formed in the shape of an “L”, “E”, “C” or other shape to meet site-specific requirements. Although the electrical impedance of a copper bar is very low, when high currents associated with lightning flow through the bar, there will be a voltage gradient along he length of the bar. By keeping the MGB to 6’ or less, the difference in voltage between any two conductors on the bar is kept to a minimum. The 6’ length still allows a reasonable amount of physical space for termination of conductors on the bus.

Secondly, when a conductor has connections to both the CBN and IBN (as the AC conduit in Figure 6.5), the conductor must be referenced to ground at the MGB via a connection of 3’ or less. Keeping the connection to 3’ or less helps to minimize any lightning current flow towards the IBN. This can be illustrated by referring to the inset in Figure 6.5 that shows the equivalent circuit for bonding of the AC conduit shown in Figure 6.5 where:

$\mathbf{I_L}$ – Lightning current
$\mathbf{Z_{MGB}}$ – Impedance of the MGB
$\mathbf{Z_{IBN}}$ – Impedance of the grounding conductor between the MGB and IBN
$\mathbf{Z_{Bond}}$ – Impedance of the bonding conductor between the MGB and AC conduit
$\mathbf{Z_{AC\text{-}IBN}}$ – Impedance of the conduit between the MGB and IBN
$\mathbf{Z_{AC\text{-}CBN}}$ – Impedance of the conduit between the MGB and the HSP / CBN

It can be seen that, if Z_{Bond} is large or non-existent (an open), then current at the MGB will also flow through $Z_{IBN,}$ through the IBN equipment frame, along the AC conduit and on to the CBN ground. This would defeat the purpose of an IBN. On the other hand, if Z_{Bond} is kept small (relative to the sum of Z_{IBN} and $Z_{AC\text{-}IBN}$), then there will be minimal current flow through the IBN. This is the rationale behind short bonding conductors.

6.4.2.2 Ground Window

Any discussion of an IBN seems to require a discussion of a “ground window”. A ground window is an imaginary spherical volume having a radius of 3 feet and is the opening where conductors having a ground reference in the CBN and also serving isolated bonding network equipment are connected to a common ground reference. If this description of a ground window sounds a lot like an MGB it is because the two terms are often used interchangeably. The very important difference is that a ground window is an imaginary sphere and an MGB is a physical bus bar as described above. For that reason, all reference in this document is to the MGB and not the ground window.

6.4.2.3 Termination Sequence at the MGB

Telcordia document TR-NWT-000295 is a standard developed for the industry to specify how IBN networks should be configured. This document goes in to considerable detail on what sequence to be followed for terminating conductors on the MGB without giving any justification for the sequence.

Every conductor that terminates on the MGB, except the IBN frame grounds, may carry lightning or fault current into or away from the MGB. It probably does not make a lot of sense to spend an inordinate amount of time fine tuning the sequence of these terminations on the MGB. Since the whole idea of an IBN is to protect sensitive digital switches, it is worth noting that neither Lucent nor Nortel have any installation requirements that specify a particular sequence for termination of conductors on the MGB. None-the-less, there may be benefit to the following arrangement of conductors at the MGB:

- Terminate all IBN frame and logic grounds together at one end of the MGB. This may help isolate IBN conductors form conductive and inductive disturbances.
- Terminate all CBN conductors together. This will shorten the electrical path between the source of the lightning or fault current and the sink (path to ground).

- Terminate conductors that have the same function adjacent to one another (for example, terminate all CBN battery return conductors together (for general administration and aesthetics only).

- Provide a reasonable amount of area for future terminations (most likely future CBN battery return conductors).

- For MGBs that are collocated with the power plant battery return, keep in mind that the battery return conductors serving IBN loads are not terminated within the MGB.

Consequently, an IBN battery return termination will define one boundary of the MGB.

Many AT&T employees refer to Telcordia document TR-NWT-000295 (Isolated Ground Planes: Definition and Application to Telephone Central Offices) for direction on bonding and grounding. Be aware that Figure 5-7 shows connections to the isolated ground plane frames as being outside the ground window (MGB). This is an error that has been brought to Telcordia's attention (the connection should be within the ground window depicted in the Figure).

6.4.2.4 Foreign Objects

The location of IBN equipment is limited to the same floor or floor above and below the MGB. This is done to limit the voltage potential difference between IBN and CBN components during a lightning strike (keep in mind that IBN equipment gets a ground reference from the MGB that may be one floor away from CBN components that get a ground reference from the COG on the same floor as the equipment).

To provide further protection to personnel during lightning strikes, CBN components that are within 7' (the maximum likely "wingspan" of a human) of IBN components are also grounded at the MGB. Grounding of these "foreign objects" provides additional safety to personnel who may be in physical contact with both IBN and CBN components during a lightning strike. With both IBN and CBN components grounded at the same reference (the MGB) there will be no difference of potential between the two components (and consequently no current flow) during lightning activity.

The foreign object bonding system is not part of the fault current path used to operate over current devices protecting ac or dc circuits. These bonds are intended to mitigate the effects of transients that may be of very high amplitude, but very short duration. Thus, foreign object bonding conductors need be no larger than #6 AWG.

6.4.3 DC Power

Within AT&T network facilities, the "+" side (battery return) of the DC battery supply is connected to ground. This provides a path for fault currents and enables over-current protective devices to operate. Referring to Figure 6.6, it can be seen that, without a connection between the battery return and the COG, there would be no fault current path. Connection of the battery return to a facility ground reference also provides network elements with a uniform reference point for DC power.

6.5 Wire Selection

The size of wire used for grounding conductors is based on four requirements. The first is that the conductor must be sized according to the minimum requirements of the National Electric Code. The second requirement is that the overall path for grounding conductors must provide sufficiently low resistance to operate over-current protection devices. The third is that grounding conductors should be adequate to carry fault current without any damage to wire insulation. Finally, for lightning protection, grounding conductors should be sized to carry anticipated lightning current.

6.5.1 NEC

In today's environment, the maximum size fuse that would be placed at a BDFB is 150 amperes. If the –48V conductor that carries this current to an equipment frame were to make contact with the equipment frame, the grounding conductors must safely carry this current. This type of "fault" is shown by an "**X**" on the CBN network equipment of Figure 6.6. Looking at Table 250.122 of the NEC, it can be seen that there is no entry for 150 amperes; therefore the next larger capacity requirement (200 amperes) is selected.

From this, it can be determined that a #6 AWG is the minimum size required to safely carry currents up to 200 amperes. Although few, if any, network elements require 150-ampere fuses, such equipment may be added in the future. Therefore, a #6 AWG wire is chosen as the minimum wire size for our grounding infrastructure.

Equipment lineups with a BDFB in the lineup may have over-current protection requirements up to 600 amperes. Again referring to Table 250.122 of the NEC it can be determined that a minimum #1 AWG is required. Since this is a non-standard wire size, the next larger size, is used. Therefore, any lineup with a BDFB should be grounded with a minimum # 1/0 AWG conductor.

6.5.2 Fault Current

As stated in Section 4, one of the design objectives for a grounding system is to: "Provide engineered fault current paths of sufficient current carrying capacity and low impedance to allow over-current protective devices to operate in a timely manner and to eliminate excessive conductor heating." The previous section identified the minimum current carrying capacity requirements for ground wire. This section will review capacity requirements for the fault current path.

Figure 6.6 shows the fault current path associated with a representative fault between the power feed and a BDFB equipment frame.

Fault current returns to its source. For DC current, that source is the battery or rectifier. For AC current, the source is the commercial power transformer or AC generator and for lightning current, the source is earth.

The primary objective in the design of a fault current path is to insure the path allows the high current necessary to operate the over-current protection device (fuse) in a timely manner. A good place to start is to determine how fast the fuse should operate. Since no industry benchmarks have been identified that specify how quickly a fuse should operate, a minimum objective time frame of 0.5 seconds will be used for this example.

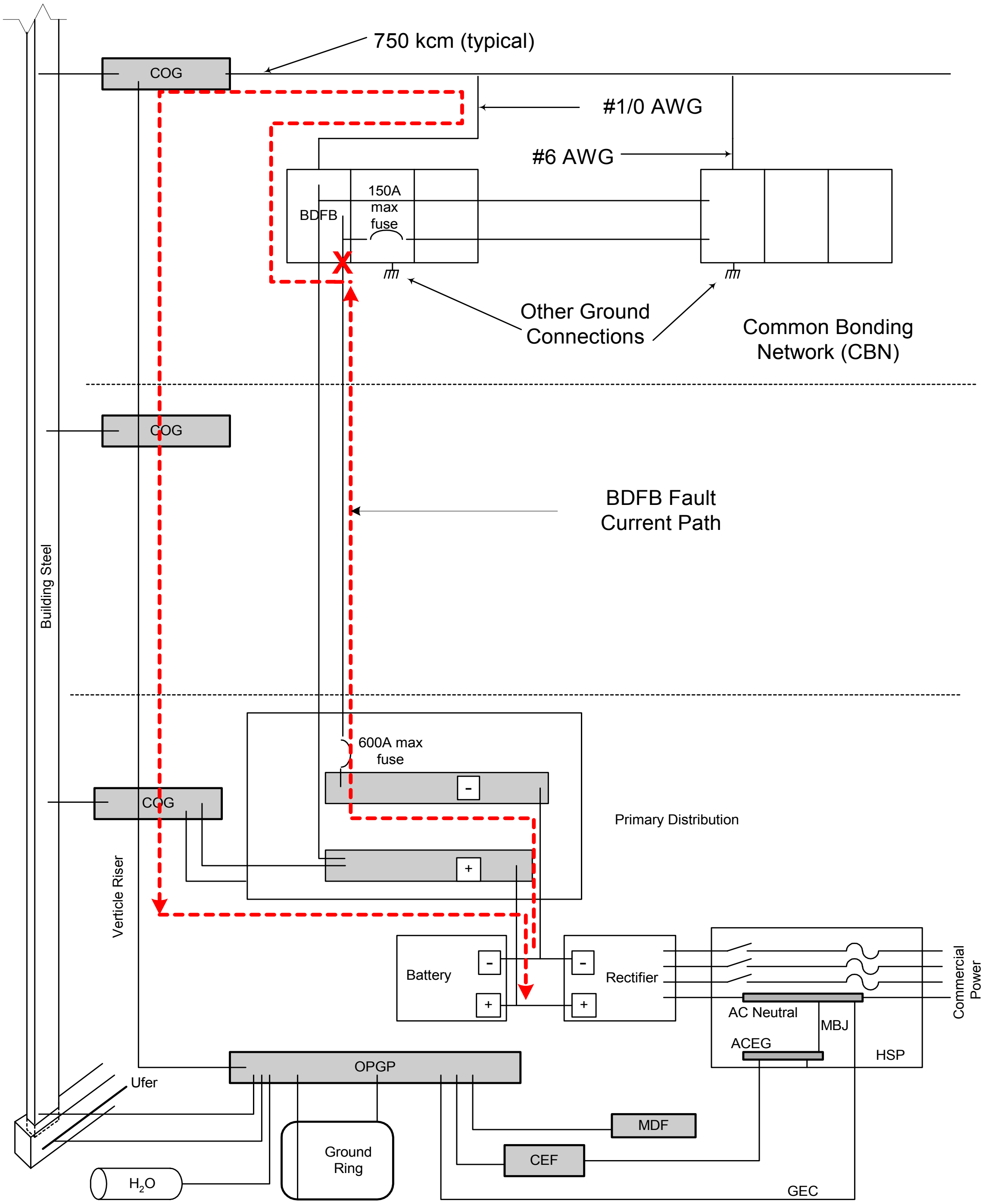


Figure 6.6
(Fault Current Path)

Figures 6.7 and 6.8 show the time-current characteristic curves for two types of fuses used in AT&T power distribution. It can be seen that the more current that flows through the fuse, the faster the fuse will operate.

Furthermore, the current required to operate a TPL fuse within 0.5 seconds varies from 2.6 to 3.7 times the current rating of the individual fuses (2.6 for the TPL-BA fuse and 3.7 for the TPL-CZ fuse) and for a TPS fuse the range is from 1.7 to 4.7 times the fuse current rating (1.7 for the TPS-1 fuse and 4.7 for the TPS-70 fuse).

To be on the safe side, an arbitrary fault current value of 6 times the current rating of the fuse will be used as a design objective for a fault current path. In other words, the design objective is to have a low enough resistance in the fault current path, under worst case operating conditions, to allow 6X the current necessary to operate the fuse in the fault current path. This should allow all fuses to operate in less than 0.5 seconds.

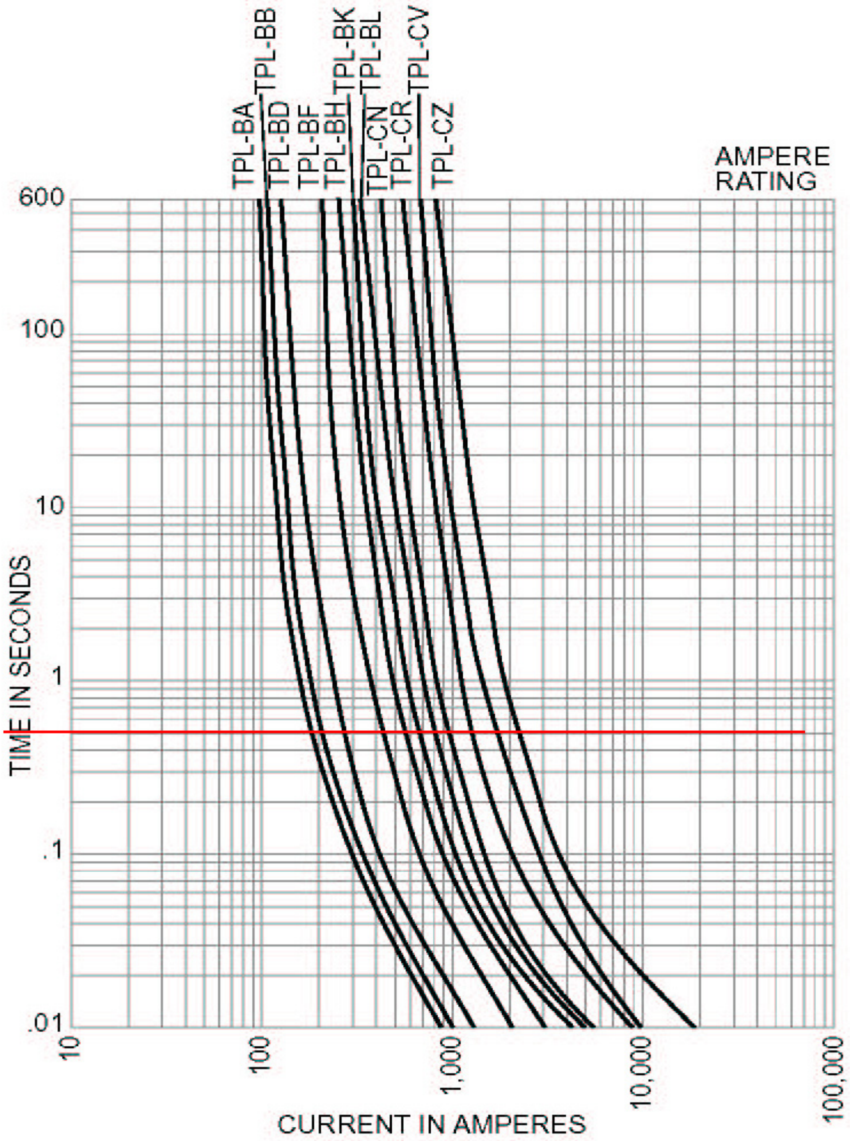


Figure 6.7
(Bussman Time-Current Curves for TPL Fuses)

The fault depicted in Figure 6.6 has a 600-ampere TPL–CZ fuse. The fault current path should have sufficiently low resistance to allow 6 x 600 amperes (or 3600 amperes) of current at the operating voltage. This would allow the fuse to operate in approximately 0.07 seconds.

From Ohm’s law and DC circuits, we know that:

$$R = V/I$$

where “R” is circuit resistance, “V” is voltage and “I” is current. Normal operating or “float” voltage is around 52 volts. Using Ohm’s law, this would give us a fault current path objective of (52V/3600A) = 0.014 Ohms. However, during battery discharge conditions, this operating voltage is allowed to drop to 44.64 volts and since current faults may occur at any time, the 44.64V value should be used as it leads to a more stringent design requirement. Therefore our fault current path (for 600A fuses) is based on (44.64V / (600 x 6) or 0.0124 ohms.

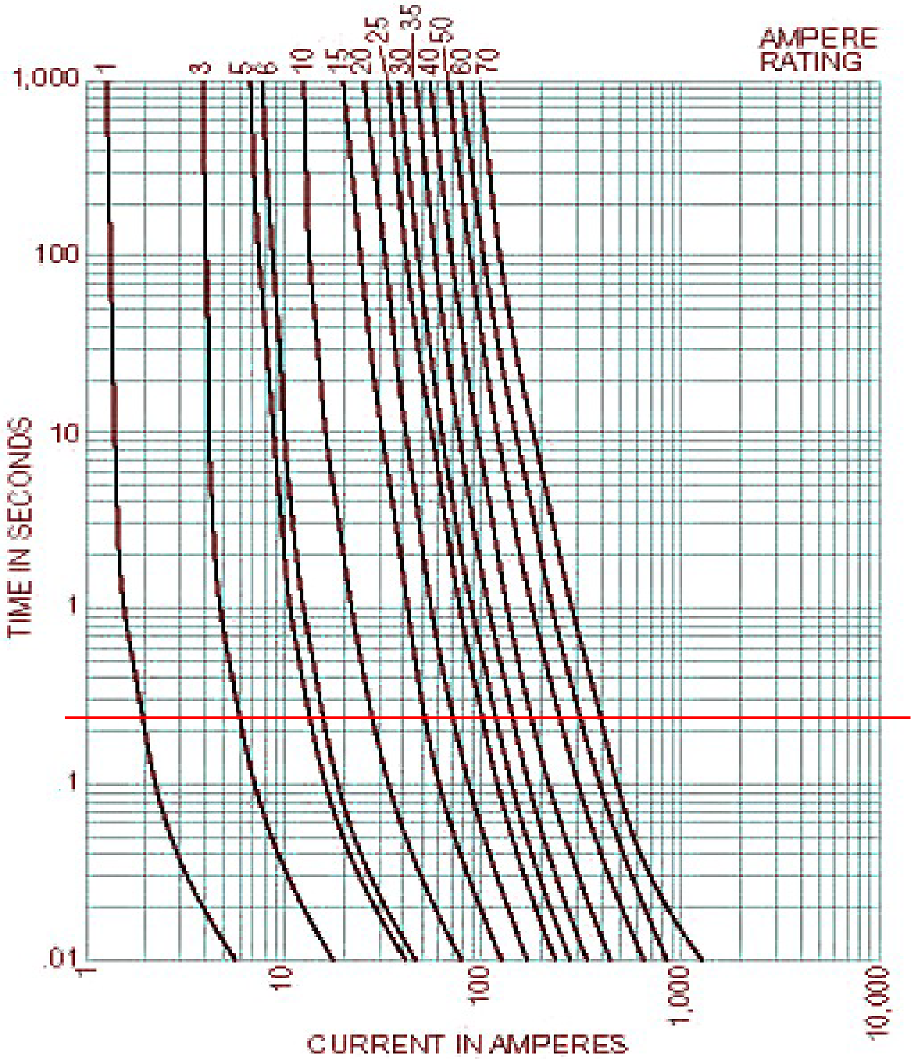


Figure 6.8
(Bussman Time-Current Curves for TPS Fuses)

Referring to Figure 6.6 and the red dotted line of the fault current path, the combined resistance of the fault current path includes the power feed conductor from the battery / rectifier to the BDFB, the steel equipment frame, the #1/0 AWG rack and lineup grounding conductor, the 750 kcm horizontal equalizer, the 750 kcm vertical riser and the 750 kcm battery ground. This resistance should not exceed 0.0124 Ohms. This is not very much resistance. Referring to Table 5.1, it amounts to about 117' of #1/0 AWG wire.

Continuing with the example and using the following representative distances for the fault current path and DC resistance values from Table 5.1, the fault current resistance for this example can be estimated as follows:

Power feed conductor	75' of 750kcm x 2	0.0006 Ohms
Equipment frame	5' of 1/0 AWG (equiv)	0.0005
Rack ground	5' of 1/0 AWG	0.0005
Line up conductor	50' of 1/0 AWG	0.0050
Horizontal equalizer	100' of 750 kcm	0.0015
Vertical riser (to last COG)	30' of 750 kcm	0.0005
Battery ground	30' of 750 kcm	0.0005
TOTAL		0.0091 Ohms

This value is within our design objective of 0.0124 Ohms. The calculated resistance is for the intentionally designed path. There will likely be other unintentional paths to ground that are in parallel with the designed path that will tend to improve the overall performance (i.e., reduce the overall resistance).

If the fault had occurred in an equipment lineup without a BDFB, the maximum over-current fuse would be 150 amperes and the resistance design would be based on a current flow of 6 x 150 amperes or 900 amperes. This would allow the fuse (TPL-BF) to operate in approximately 0.05 seconds. Following the same process as before, the maximum fault current resistance would be (44.64V / (6 x 150A) or 0.0496 Ohms.

Using the same representative distances as before and the associated resistance values, the fault current resistance can be estimated as follows:

Power feed conductor	75' of 750kcm x 2	0.0006 Ohms
Equipment frame	5' of 1/0 AWG (equiv)	0.0005
Rack ground	5' of 6 AWG	0.0020
Line up conductor	50' of 6 AWG	0.0200
Horizontal equalizer	100' of 750 kcm	0.0015
Vertical riser (to last COG)	30' of 750 kcm	0.0005
Battery ground	30' of 750 kcm	0.0005
TOTAL		0.0256 Ohms

Once again, this value is within the design objective of 0.0496 Ohms. If it wasn't already clear, this design exercise helps to illustrate the need for having low resistance wire (like 750kcm) in our grounding infrastructure in order to meet fault current design objectives.

6.5.3 Withstand Current

Withstand rating is defined as the maximum current an unprotected electrical component can sustain for a specified period of time without the occurrence of extensive damage. For ground wire, it is important to evaluate grounding conductors during fault current conditions to insure wire insulation is not damaged. Figure 6.9 is a graph showing the amount and duration of current allowed by thermoplastic insulated copper wire before damage occurs. AT&T uses Hypalon ® insulation that has a T_2 value of 250^0 C. This "withstand current" has been calculated for associated wire sizes and is shown in column 7 of Table 5.1. For the fault current examples above, it can be seen that the withstand rating for a #6 and #1/0 AWG are both higher than the expected fault current.

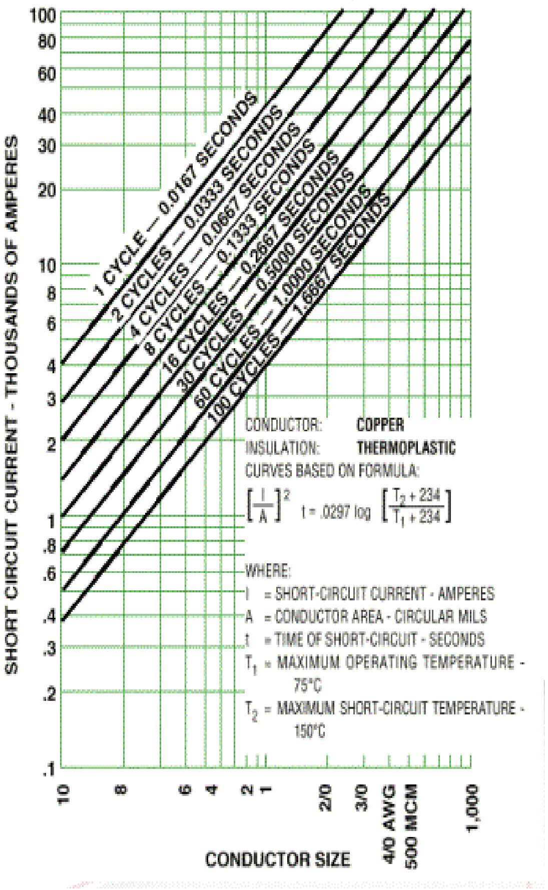


Figure 6.9
(Withstand Current)

6.5.4 Lightning Current

The majority of cloud to ground lightning strikes produce current in the range of 10,000 to 40,000 amperes with maximum current in the range of 100,000 amperes. Although direct strikes to COs do occur, most often lightning will enter COs through OSP cable sheaths or through commercial AC conductors. Lightning current will typically reach a peak value in a few microseconds and, with a good path to ground, will dissipate to 50% of its peak value in 50 microseconds or less.

There is a natural tendency to think that conductors must be large to carry this high lightning current. However, referring to Figure 6.9, it can be seen that a #2/0 AWG wire can handle nearly 100,000 amperes for 1/60 of a second (hundreds of times longer than a lightning strike) without damage to the insulation. As was demonstrated in section 6.5.2, the large (750kcm) CO ground conductors are needed for proper fault current design and not necessarily for lightning current.

Generally, Network Engineering will have responsibility for the design and implementation of bonding and grounding facilities required to mitigate the adverse effects of lightning current that enters a CO via cable sheaths, commercial AC, wave guides or other network infrastructure. Network Engineering will work jointly with Corporate Real Estate to design lightning protection for CO buildings and radio sites.

With the exception of radio sites, lightning protection for a building will more likely be required in the Midwest than in the far west. The National Fire Protection Association, the same organization that publishes the National Electric Code, also publishes NFPA 780, the Standard for the Installation of Lightning Protection Systems for building structures.

6.6 Other Considerations

Although they don't normally come into play during the design of a grounding infrastructure, it is worth being aware of three other characteristics of wire conductors: fuse open current, skin effect and flash over.

6.6.1 Fuse Open Current

There is a limit to how much fault current or lightning current any conductor can carry before the heat generated by the current flow causes the conductor to melt and for the conducting path to open. This fusing current is a function of the conductor cross-sectional area, the melting temperature of the material, ambient temperature and the length of time the current is applied. This fuse current can be approximated (for current durations of up to 10 seconds) by the following equation:

$$I = A\left[\frac{\log\left(\frac{T_c - T_a}{234+T_a} + 1\right)}{33d}\right]^{1/2}$$

where I= current in amperes, A = conductor area in circular mils, d= the duration of time that current is applied, T_c = melting point of copper in degrees C and T_a = the ambient temperature in degrees C.

With the melting point of copper at 1083 degrees C and assuming the ambient temperature to be 25 degrees C, the equation can be reduced to:

$$I = 0.1463A(1/d)^{1/2}$$

As an example, a current of 5429 amperes will cause a #6AWG wire to fuse open in 0.5 seconds. This compares to a current of 2823 amperes that will cause insulation damage.

6.6.2 Skin Effect

Skin effect is the tendency of a high-frequency alternating current to flow near the surface of a conductor, thereby restricting the current to a small part of the total cross-sectional area and increasing the resistance to the flow of current. The skin effect is caused by the self-inductance of the conductor, which causes an increase in the inductive reactance at high frequencies, thus forcing the carriers, i.e., electrons, toward the surface of the conductor. For a copper conductor in free space, the resistance can be determined from the following equation:

$$Z_R = 2.61\text{x}10^{-7}\,(f)^{1/2}\,(L/\pi D)$$

where f = frequency, L is the length of the conductor and D is the diameter of the conductor. Column 5 of Table 5.1 shows the DC resistance of copper wire and column 6 shows the resistance of the same wire at 1MHz.

Although the resistance of wire due to skin effect at 1MHz is 5 to 50 times greater than the corresponding DC resistance, it is still much less than the effect of inductance on the same wire at the same frequency (column 6 of Table 5.1).

6.6.3 Flash Over

Because of the high magnitude of lightning current (with a mean value of 30,000± amperes for direct strokes), conductors of lightning current can rise to several hundred thousand volts or more during a strike. Flash over (when no insulation is present) can occur at approximately 13kv/inch in air. Depending on the proximity of other conductors, their ground potential, ambient air conditions and conductor insulation, it is possible for lightning current to arc or "flash over" to other conductors.

Conductors that are expected to carry high current should be routed a minimum of 3’ from other conductors to guard against flash over and electromagnetic interference.

Annex A
Reference Documents and Information

The documents listed below contain a wide variety of information on the subject of grounding. The first group, labeled *Public Domain Documents*, should be readily available to anyone. The second group *Operating Company Documents*, contains documents that may not be available to non-employees because of proprietary information agreements.

MIL-HDBK-419A is particularly good. This 600-page reference is divided into two sections, one on Theory and one on Applications.

A.1 Public Domain Documents

ANSI/IEEE Std 142-1991 IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems

FAA-STD-019b – Lightning Protection, Grounding, Bonding and Shielding Requirements for Facilities

FIPS PUB 94 Federal Information Processing Standards - Guideline on Electrical Power for Automated Data Processing Installations

The IAEI Soares Book on Grounding (International Association of Electrical Inspectors)

MIL-HDBK 419A – Grounding, Bonding and Shielding for Electronic Equipments and Facilities
http://www.uscg.mil/hq/tcpet/tpf/etsms/Mil-STDs/MILHDBK419.pdf

MIL-HDBK 1857 – Grounding, Bonding, and Shielding Design Practices

MIL-HDBK 1004/6 – Lightning Protection

MIL-STD-188-124B – Grounding, Bonding and Shielding for Common Long Haul/Tactical Communications Systems Including Ground Based Communications-Electronics Facilities and Equipments

NFPA 70	National Electrical Code
NFPA 75	Standard for Protection of Electronic Computer/Data Processing Equipment
NFPA 780	Lightning Protection Code

Section 802 Rural Electrification Administration (REA) Electrical Protection Grounding Fundamentals

TR-NWT-000295 Isolated Ground Planes - Definition and Application to Telephone Central Offices (Telcordia)

GR-1089-CORE Electromagnetic Compatibility and Electrical Safety Generic Criteria for Network Telecommunication Equipment (Telcordia)

A.2 Operating Company Documents

PBS-005-300PT	Electrostatic Discharge Control
BSP 760-150-155	Building Planning for Operations Support Systems
BSP 760-400-510	Building Electrical Systems Grounding
BSP 790-100-660	AC Power for Telecommunication Equipment
BSP 876-000-000	Index, Electrical Protection and Bonding
BSP 876-100-100	Principles of Electrical Protection - Engineering Considerations
BSP 876-101-130MP	Electrical Protection Grounding
BSP 876-200-100	Electrical Protection - Central Offices
BSP 876-210-100	Electrical Protection of Radio Stations
BSP 876-300-100MP	Electrical Protection at the Customer Premises
BSP 876-700-100	Measurements of Ground
BSP 876-701-100	Earth Resistivity Measurements

Annex B
Revisions to Text and Figures

Affected sections refer to new section numbers of ATT-TP-76416-001

Affected Sections	**Type of Change**
All	Document number changed from ATT-812-000-027
All	Typos, Spelling and Grammar
5.2	Clarification
Figure 5-1	Clarification
5.3.5.1	Clarification
5.5.2.2	Clarification
6.0	Revised
Figure 6-1a	New
Figure 6-1b	New
6.1.1	Correction
6.1.5	Clarification
6.3.4	New
6.5.2	Clarification
6.6.1	Clarification
7.0	Moved to ATT-TP-76416

Annex C
INDEX TO FIGURES AND TABLES