APPENDIX C

Earthing and Bonding Recommendations

Note This appendix applies to the Cisco MGX switches and gateways described in this guide: MGX 8850 (PXM45/PXM1E), MGX 8850/B, MGX 8950, MGX 8830 and MGX 8830/B multiservice switches and the MGX 8880 Media Gateway.

This appendix discusses the techniques and policies that Cisco practices with regard to DC power, earthing, and bonding of Cisco equipment. It also explains why these techniques are the best practice. More specifically, this appendix describes the techniques for DC power and earth bonding for Cisco MGX switches.

The appendix also discusses the principles of mesh bonding and explains the earth return systems that are used in the Cisco MGX switch. It identifies the earthing points, shows how they are to be earthed, and how the DC power connections are to be connected to the equipment.

The earthing and powering techniques described in this appendix are extracts from Cisco internal documentation, engineering documentation, and the following standards documentation:

- ITU-T K.27, Bonding configurations and earthing inside a telecommunications building
- GR-1089-CORE, Electromagnetic compatibility and electrical safety—generic criteria for network telecommunications equipment

Scope

The bonding and earthing principles adopted by Cisco are as follows:

- Promote personal safety and reduce fire hazards
- Enable telecomm signaling with earth return
- Minimize equipment damage and service interruption
- Minimize radiated and conducted electromagnetic emissions and susceptibility
- Maximize tolerance to discharge of electrostatic energy and lightning interference

This appendix supports the principles listed above by providing information that complies with relevant safety standards on the following topics:

- Bonding and earthing of the Cisco WAN equipment at the telco sites
- Shielding provided by cabinets, cable trays, and cable shields
- Techniques for verifying and maintaining bonding and earthing networks

- Required values of voltage and resistance between different CBN bonding points

EC [3] Definitions

The following definitions apply to terminology found in IEC 50 [3]:

Earth	The conductive mass of the earth, whose electric potential at any point is conventionally taken as equal to zero. In some countries the word "ground" is used instead of "earth."
Earth electrode	A conductive part or a group of conductive parts in intimate contact with and providing an electrical connection to earth.
Earthing network	The part of an earthing installation that is restricted to the earth electrodes and their interconnections.
Main earthing terminal	A terminal or bar that is provided for the connection of protective conductors, including equipotential bonding conductors and conductors for functional earthing, if any, to the means of earthing.
Earthing conductor	A protective conductor that connects the main earthing terminal or bar to the earth electrode.
Equipotential bonding	Electrical connection putting various exposed conductive parts and extraneous conductive parts at a substantially equal potential.
Equipotential bonding conductor	A protective conductor for ensuring equipotential bonding.
Neutral conductor (N)	A conductor that is connected to the neutral point of a system and capable of contributing to the transmission of electrical energy.
Protective conductor (PE)	A conductor that is required by some measures for protection against electric shock by electrically connecting any of the following parts: • Exposed conductive parts • Extraneous conductive parts • Main earthing terminal • Earth electrode • Earthed point of the source or artificial neutral

K.27 Definitions

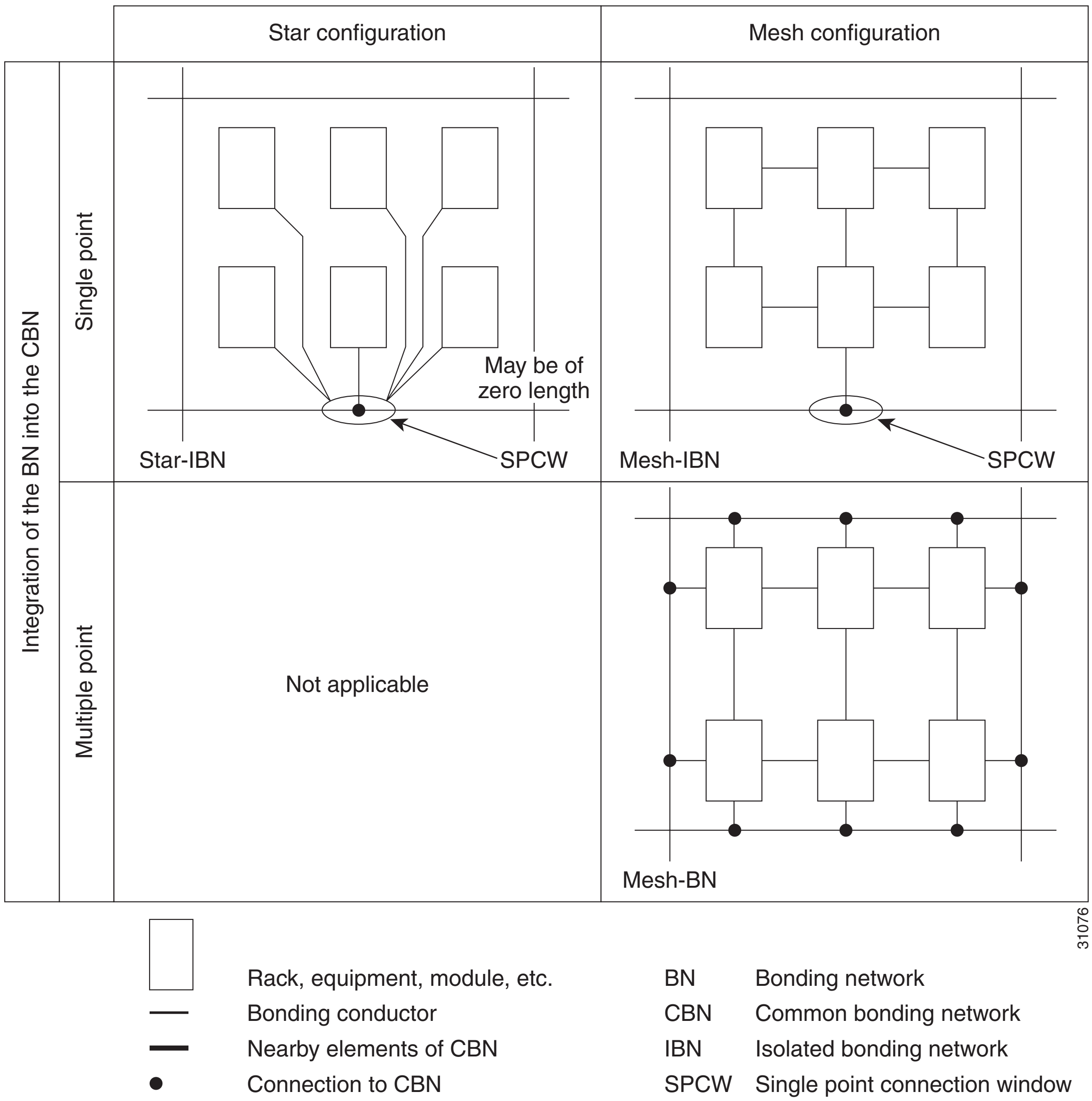
The following definitions apply to terminology found in K.27:

Bonding network (BN)	A set of interconnected conductive structures that provide an electromagnetic shield for electronic systems and personnel at frequencies from DC to low RF. The term "electromagnetic shield" denotes any structure used to divert, block, or impede electromagnetic energy. In general, a BN need not be connected to earth, but all BNs in this recommendation have an earth connection.
Common bonding network (CBN)	The CBN is the primary way to create effective bonding and earthing inside a telecommunication building. It is the set of metallic components that are intentionally or unintentionally interconnected to form the principal BN in a building. These components include: • Structural steel or reinforcing rods • Metallic plumbing • AC power conduit • PE conductors • Cable racks • Bonding conductors The CBN always has a mesh topology and is connected to the earthing network.
Mesh-BN (MBN)	A bonding network in which all associated equipment frames, racks, cabinets, and the DC power return conductor are bonded together and also bonded at multiple points to the CBN. Consequently, the mesh-BN augments the CBN.
Isolated bonding network (IBN)	A bonding network that has a single point of connection (SPC) to either the common bonding network or another isolated bonding network. All IBNs in this document have a connection to earth via the SPC.
Single point connection (SPC)	The unique location in an IBN where a connection is made to the CBN. In reality, the SPC is not a mere "point" but has sufficient size to accommodate the connection of multiple conductors. Usually, the SPC is a copper bus-bar. If cable shields or coaxial outer conductors are to be connected to the SPC, the SPC could be a frame with a grid or sheet metal structure.

Mesh-IBN	A type of IBN in which the components of the IBN (equipment frames) are interconnected to form a mesh-like structure. This may, for example, be achieved by multiple interconnections between cabinet rows or by connecting all equipment frames to a metallic grid (bonding mat) that extends away from beneath the equipment. The bonding mat is, of course, insulated from the adjacent CBN. If necessary the bonding mat could include vertical extensions that result in an approximation to a Faraday-cage. The spacing of the grid depends upon the frequency range of the electromagnetic environment.
Star IBN	A type of IBN comprising clustered or nested IBNs sharing a common SPC.
System block	All the equipment whose frames and associated conductive parts form a defined BN.
Isolated DC return (DC-I)	A DC power system in which the return conductor has a single point connection to a BN. More complex configurations are possible. (See the "Bonding Networks" section in this appendix.)
Common DC return (DC-C)	A DC power system in which the return conductor is connected to the surrounding BN at many locations. This BN could be either a mesh-BN (resulting in a DC-C-MBN system) or an IBN (resulting in a DC-C-IBN system). More complex configurations are possible. (See the "Bonding Networks" section in this appendix.)

Figure C-1 shows examples of star and mesh topologies.

Figure C-1 Star and Mesh Topology Examples



Bonding Networks

Bonding and earthing are accomplished through the construction and maintenance of bonding networks (BNs), which are connected and grounded to earth. In this appendix, BN refers to common bonding networks (CBNs), mesh-BNs (MBNs), and isolated bonding networks (IBNs) collectively. The acronym BN implies that a connection to earth exists.

The purpose of a BN is to shield people and equipment from the adverse effects of electromagnetic energy from DC to low RF range. Lightning and both AC and DC power faults are the energy sources that cause the greatest concern. Of less concern are quasi-steady-state sources such as AC power harmonics and function sources, such as clock signals from digital equipment.

The energy sources that cause concern are referred to as emitters. The people and equipment that can suffer adversely from these emitters are referred to as susceptors.

The coupling between an emitter and a susceptor can be characterized as a transfer function. The purpose of a BN is to reduce the magnitude of the transfer function to an acceptable level. Reducing the magnitude of the transfer function is achieved through the design of the BN; specifically, in the way that MBNs and IBNs are attached to the CBN. The practical aspects of this design are discussed below.

A BN can also function as a return conductor for signaling applications, as a connection to earth for ground return signaling, and as a path for power fault currents. A BN that can handle large currents can rapidly de-energize faulted power circuits.

Digital System Grounding

For the Cisco MGX switch, Cisco policy has been to ground the return of the 48 VDC directly to the frame at the backplane. This method of grounding prevents transient currents caused by lightning or power surges from entering the system through the backplane, upsetting system performance and possibly damaging components.

Isolating grounds like this one, using only analog methods, does not address the current high-speed digital system requirements. Digital systems today have such high speeds and large bandwidths that they now produce frequencies with harmful effects. Consequently, digital systems now require multipoint grounding.

Isolation using analog methods provides at the physical level of our interfaces and not at the power-supply end.

The bus currents and isolation parasitic capacitance that are represented by the 48 VDC side of the system create much greater threat levels to the backplane of our systems, which have embedded communication buses distributed through them. To mitigate these effects, you must bond and provide the lowest possible impedance to ground at the backplane.

Capacitors used to isolate the DC common paths are inadequate at RF frequencies outside the backplane structure. Therefore, isolation must be kept to multipoint ground the 48 VDC return to chassis and logical ground at the backplane level of the Cisco equipment.

Bellcore GR-1089, 1997 edition, speaks of these recent challenges in Chapter 9. This new thinking is the outgrowth of the ITU-T K.27 recommendations released in 1991. The bonding of meshed bonding networks and the digital high speeds dictate the eventual acceptance of this new philosophy on a universal basis.

The CE-Mark requirements for the induced effects of transient and power surge lightning cannot be met with large, high impedance (150 M ohms or greater) grounding wires. These standard grounding conductors have a very high impedance at frequencies greater than 10 MHz.

The grounding of the frames and the mesh bonding network must be effective over a frequency range of 60 Hz to 100 GHz according to Bellcore requirements. 30 cm of wire represents 30 nH of inductance. This represents 2 ohms of reactance at a frequency of 30 MHz. This high impedance would be a large change from earth reference if earth were several stories below the equipment installation.

A four-story building would represent 1000 ohms above ground during a 30 MHz frequency disturbance in this example. Therefore it is required that multipoint, meshed bonding networks be used to control these excitation currents.

Equipment backplane speeds are in the category above 800 MHz. Because the design must anticipate the worst case scenario, concerns about RF damage are much greater. At 800 MHz only 10 inches of wire represents 500 ohms reactance.

For the average coaxial cable shield integrity to be maintained, the termination of the shield must see a ground reference of no more than 50 ohms. The importance of this relationship is that although the 800 MHz speed is not the data speed of E1/T1, it must mitigate frequency susceptibility issues that will upset the 800 MHz operation.

Therefore, the multipoint grounding techniques must be used as supported by the K.27 recommendations. Although K.27 is designed around lightning and transient issues, the same theory applies to the higher frequency problems; they are just smaller in scale. As frequency increases, the wave length becomes smaller, and the reactance of a fixed length of wire goes up.

The need is to multipoint ground our backplane and the 48 VDC return directly to the frame at frequent intervals that represent at least 1/20 of a wavelength. The frame, in turn, will be bonded to the isolated mesh-bonding mat. At 800 MHz, 18.8 mm represent a 20th of a wavelength, so grounding/bonding must be done at these intervals to maintain backplane-to-cabinet integrity for its full perimeter. Using capacitors to achieve the necessary bonding becomes extremely difficult at these frequencies in addition to the added cost due to the isolation breakdown voltage requirements of 2.1 kilovolts, should the old philosophy be insisted upon.

The theoretical concepts are confirmed by practical experience and lead to the general principles listed below. A consequence of applying these principles is that the number of conductors and interconnections in the CBN is increased until adequate shielding is achieved. Concerning the important issue of electric shock, the following implementation principles apply to mitigation of electric shock as well as to equipment malfunction:

1. All elements of the CBN shall be interconnected. Multiple interconnections, resulting in a three-dimensional mesh, are especially desirable. Increasing the number of CBN conductors and their interconnections increases the CBN shielding capability and extends the upper frequency limit of this capability.
2. It is desirable for the egress points for all conductors leaving the building (including the earthing conductor) to be located close together. In particular, the AC power entrance facilities, telecommunications cable entrance facilities, and the earthing conductor entry point should be close together.
3. The facility should have a main earthing terminal located as close as possible to the entrance to the AC power and telecommunications cable entrance facilities. The main earthing terminal shall connect to the following:
    - Earthing electrode(s) via a conductor of shortest length
    - One or more earthing electrodes
    - Neutral conductor of the AC power feed (in TN systems)
    - Cable shields (at the cable entrance) either directly or via arresters or capacitors if required by corrosion considerations
4. The CBN shall be connected to the main earthing terminal. Multiple conductors between the CBN and the main earthing terminal are recommended.
5. As contributors to the shielding capability of the CBN, interconnection of the following items of the CBN is important:
    - Metallic structural parts of the building including I-beams and concrete reinforcement where accessible
    - Cable supports, trays, racks, raceways, and AC power conduit

6. The coupling of surges into indoor signal or power cabling is reduced, in general, by running the cables in close proximity to CBN elements. However, in the case of external surge sources, the currents in the CBN will tend to be greater in peripheral CBN conductors. This is especially true of lightning down-conductors.

   Therefore, it is best to avoid routing cables in the periphery of the building. When this is unavoidable, metallic ducts that fully enclose the cables may be needed. In general, the shielding effect of cable trays is especially useful, and metallic ducts or conduit that fully enclose the cables provide nearly perfect shielding.

7. In steel frame high-rise buildings, the shielding effects that the steel frame provides against lightning strikes can help. For cables extending between floors, maximum shielding is obtained by locating the cables near the center of the building. However, as stated above, cables enclosed in metallic ducts may be located anywhere.

8. If the facility has over-voltage primary protection on telecommunication wires, it should have a low impedance connection to the cable shield, if it exists, and to the surrounding CBN.

9. Over-voltage protectors are advisable at the AC power entrance facility if the telecommunication building is located in an area where power lines are exposed to lightning. These protectors should be bonded with low impedance to the CBN.

10. Mechanical connections in a protection path of the CBN whose electrical continuity may be insufficient shall be bypassed by jumpers that are visible to inspectors. These jumpers shall comply with IEC requirements for safety. However, for EMC applications, the jumpers should have low impedance.

11. The CBN facilitates the bonding of cable shields or outer conductors of coaxial cables at both ends by providing a low impedance path in parallel and in proximity to the cable shields and outer conductors. Thus, most of the current driven by potential differences is carried by the highly conductive members of the CBN. Disconnection of one cable shield for inspection should minimally affect the current distribution in the CBN.

The main feature of a mesh-BN is the interconnection at many points of cabinets and racks of telecommunications and other electrical equipment as well as multiple interconnections to the CBN.

Telecommunication techniques sometimes use circuits for signaling with earth return, for example, lines with ground start, three wire inter-exchange connection. Equipment interconnected by these circuits needs functional earthing.

The signaling range is normally determined by the resistance of the current path. Most of this resistance is contributed by the earth electrodes. The performance provided by the earthing network via the main earthing terminal is generally sufficient for this signaling purpose.

Bonding and Grounding the Cisco MGX System

To maintain the full EMI and EMC integrity of this equipment, the equipment must be bonded to an *integrated ground plane* or a *non-isolated ground plane* network. The purpose is to mitigate the damaging effects of electrostatic discharge or lightning.

Refer to the latest edition of ITU-T Recommendation K.27 or Bellcore GR-1089-CORE to ensure that the correct bonding and grounding procedures are followed. As recommended in these documents, a frame bonding connection is provided on the Cisco cabinet for rack-mounted systems. To see how to make a connection, see the "Ground the Frame Bonding Ground Connection for a Cisco-Supplied Rack" section on page 5-10.

Except for the AC power supply modules, every module in a rack-mount system uses the rack for grounding. Therefore, the rack must connect to protective earth ground, and the equipment must be secured to the rack so as to ensure good bonding.

A DC-powered node must have grounding conductors that connect at two separate locations:

- The grounding conductor provided with the supply source must connect to the correct terminal of the power entry module (PEM).
- A grounding conductor must connect to an appropriate terminal on a rack or the chassis of a node.

For DC-powered systems, Cisco has designed the Cisco MGX 8800 and MGX8900 series switches to connect to a *non-isolated* ground system. In contrast, routers and other LAN equipment often use an *isolated* grounding scheme.

If properly wired together through an *equalization connection* as described in ITU-T recommendation K.27, the isolated and non-isolated ground systems can form a mixed grounding system. The potential between any points in the ground system—whether or not the ground system is mixed—must not exceed 2 percent of the referenced voltage (2 percent of 48 V is 960 millivolts).

Bonding and Grounding MGX 8800 or MGX 8900 Series Chassis in a Rack

To maintain proper grounding/ bonding connections when installing an MGX 8800 or MGX 8900 series chassis in a rack, clean all paint from the surface of the rack rails that face to the unpainted surfaces of the MGX mounting flanges and apply an anti-oxidant to the unpainted surfaces. Then install the chassis.

Wiring a Mixed Ground System with Redundant Supplies

A mixed ground system appears in Figure C-2. This figure shows safety and earth grounds and the primary and redundant DC sources Battery A and Battery B. Individual ground conductors are labeled Z1, Z2, Z3, Z4, and Z5. The Z represents the impedance of the ground conductor between a chassis, for example, and a connection to the building's ground system.

The numbers 1–4 represent building ground points and indicate that an impedance can exist between different points in the ground system of the building. Each of these symbols indicates that a voltage drop may result (but must not exceed 2 percent of the referenced voltage). See Table C-1 for a definition of each Z1–Z5.

Figure C-2 Mixed Grounding System

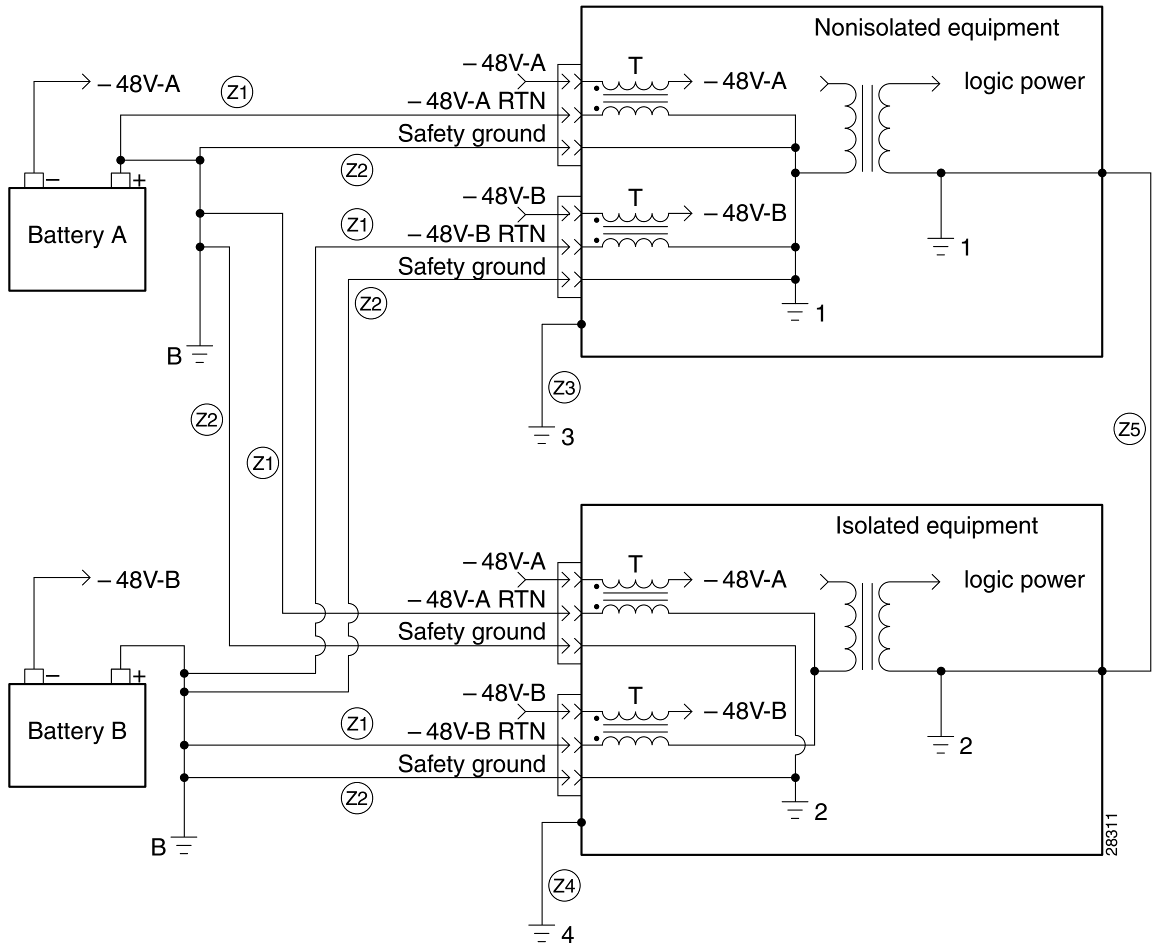


Table C-1 Ground Point Descriptions for Mixed Grounding

Connection	Description
Z1	–48 VDC return.
Z2	Protective earth or safety ground (green/yellow).
Z3	Equipment ground for non-isolated equipment.
Z4	Equipment ground for isolated equipment.
Z5	Equalizing frame ground. This ground creates low-impedance equalization between frames.
B	Battery ground.
1, 2, 3, 4	Connection points to the building's ground system: a potential can exist between these points within the ground system.
T	Common-mode EMI filters.

As Figure C-2 shows, the non-isolated system has a 48-VDC return that internally connects to the backplane. (This design calls for a hard-wired return and so does not allow for an *optional* or alternate ground connection.) The internal connection provides a low-impedance connection between 48-VDC return and frame ground. This grounding scheme protects the signals on the backplane from corruption by transients that can result from lightning or electrostatic discharge.

To improve protection against transients, the loop area (and resultant loop impedance) should be made as small as possible by locating the –48-VDC supply, 48-VDC return, and protective earth conductors as close to each other as possible.

As recommended in ITU-T K.27, the multipoint grounding in a mesh bonding network provides the best protection for equipment by providing the lowest impedance in the ground system. For more detailed information, refer to the recommendation itself.

Conductor Characteristics for Carrying Current and Ensuring Low Voltage Drops

For signal degradation to be averted, a conductor must be large enough to prevent its impedance from creating a voltage drop equal to 2 percent of the reference voltage. Also, the protective earth conductor must be large enough to carry all the current if the 48 VDC return fails. This latter requirement is for safety. Full fault redundancy is achieved by having equal size conductors for the protective earth ground and the 48 VDC return of the switch.

For wire gauges that prevent unacceptable voltage drops over different lengths of copper wire, see Table C-2. For the resistance of 1000 feet of copper wire for each gauge of wire, see Table C-3. These references are for planning purposes and might be further subject to local laws and practices.

Note Table C-2 is for reference. It is recommended that you use 50-A or greater.

Table C-2 Wire Gauge for Current Loads over Copper Wire Lengths

DC Current	Distance in Feet						
	25 feet	**50 feet**	**75 feet**	**100 feet**	**150 feet**	**200 feet**	**400 feet**
5 A	18 gauge	14 gauge	14 gauge	12 gauge	10 gauge	8 gauge	6 gauge
10 A	14 gauge	12 gauge	10 gauge	8 gauge	8 gauge	6 gauge	2 gauge
15 A	14 gauge	10 gauge	8 gauge	8 gauge	6 gauge	4 gauge	2 gauge
20 A	12 gauge	8 gauge	8 gauge	6 gauge	4 gauge	2 gauge	0 gauge
25 A	12 gauge	8 gauge	6 gauge	4 gauge	4 gauge	2 gauge	0 gauge
30 A	10 gauge	8 gauge	6 gauge	4 gauge	2 gauge	2 gauge	00 gauge
35 A	10 gauge	6 gauge	4 gauge	2 gauge	2 gauge	1 gauge	000 gauge
40 A	8 gauge	6 gauge	2 gauge	2 gauge	2 gauge	0 gauge	000 gauge
45 A	8 gauge	6 gauge	4 gauge	2 gauge	1 gauge	0 gauge	0000 gauge
50 A	8 gauge	4 gauge	4 gauge	2 gauge	1 gauge	00 gauge	—
55 A	8 gauge	4 gauge	2 gauge	2 gauge	0 gauge	00 gauge	—
60 A	8 gauge	4 gauge	2 gauge	2 gauge	0 gauge	00 gauge	—
65 A	6 gauge	4 gauge	2 gauge	1 gauge	0 gauge	000 gauge	—

Table C-2 Wire Gauge for Current Loads over Copper Wire Lengths (continued)

DC Current	Distance in Feet						
	25 feet	50 feet	75 feet	100 feet	150 feet	200 feet	400 feet
70 A	6 gauge	4 gauge	2 gauge	1 gauge	00 gauge	000 gauge	—
75 A	6 gauge	4 gauge	2 gauge	1 gauge	00 gauge	000 gauge	—
100 A	4 gauge	2 gauge	1 gauge	00 gauge	000 gauge	—	—

Note Table C-3 is for reference, it is recommended that you use 6 gauge or greater.

Table C-3 Resistance for Each Gauge of Copper Wire

Gauge	Ohms per 1000 Feet	Gauge	Ohms per 1000 Feet
0000	0.0489	10	0.9968
000	0.0617	11	1.257
00	0.0778	12	1.5849
0	0.098	13	1.9987
1	0.1237	14	2.5206
2	0.156	15	3.1778
3	0.1967	16	4.0075
4	0.248	17	5.0526
5	0.3128	18	6.3728
6	0.3944	19	8.0351
7	0.4971	20	10.1327
8	0.6268	21	12.7782
9	0.7908	22	16.1059