KSC-STD-E-0012
Revision H

METRIC/INCH-POUND

FACILITY GROUNDING AND LIGHTNING PROTECTION,

STANDARD FOR

June 4, 2026

Engineering Directorate

National Aeronautics and
Space Administration

John F. Kennedy Space Center

KSC FORM 16-12 (REV. 6/95) PREVIOUS EDITIONS ARE OBSOLETE (CG 11/95)
KDP-KSC-T-5407 Rev Basic

FACILITY GROUNDING AND LIGHTNING PROTECTION,

STANDARD FOR

Approved by:

//signed copy on file//

Becky Murray
Acting Director, Engineering

This Revision Supersedes All Previous Editions of This Document

June 4, 2026

JOHN F. KENNEDY SPACE CENTER, NASA

RECORD OF REVISIONS/CHANGES

REV LTR	CHG NO.	DESCRIPTION	DATE
		Basic Issue	September 29, 1969
A		General Revision	March 1, 1974
B		General Revision	October 16, 1991
C		General Revision	June 8, 1994
D		General Revision	June 7, 2000
E		General Revision	August 1, 2001
F		General Revision	January 10, 2013
G		General Revision	January 13, 2019
H		Updated to include clearer boundaries of ownership and responsibility; clarification to other systems – GSS, GSE, payload, flight – that this standard applies only to facility systems; more detailed requirements for measurements and results; updated definitions to better fit national standards and use of terms at KSC; emphasized use of national codes and standards for clarity and future adoptability; updated classification of conventional vs. non-conventional facilities; replaced "zone" classification for lightning protection systems to reflect real field conditions; replaced obsolete or unapplicable language throughout; and adopted specific materials requirements to allow for efficient decision making on system design.	June 4, 2026

Foreword

KSC-STD-E-0012 establishes overall requirements and design best practices to be used at the John F. Kennedy Space Center (KSC) for the design, analysis, installation, operation, repair, and maintenance of facility system grounding, equipment grounding, bonding, power cable shielding, and lightning protection systems. These requirements apply to projects in support of KSC facilities for which NASA or its tenant contractors have sustaining engineering responsibility. These requirements also apply to projects at the KSC Visitor Complex.

This standard applies only to facility systems. It does not apply to GSS, GSE, payload, or flight hardware grounding, bonding, shielding, or EMI requirements. The owners and users of these systems should reference their applicable standards for information and direction.

CONTENTS

FIGURES

ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
ADP	Automatic Data Processing
Al	Aluminum
ANSI	American National Standards Institute
ASCR	Aluminum Conductor Steel Reinforced
AWG	American wire gage
BCDS	Broadband Communication Distribution System
BIL	Basic Impulse Level
BS EN	British Standard/European Norm
CCSFS	Cape Canaveral Space Force Station
CFR	Code of Federal Regulations
cm	Centimeter
CRES	Corrosion-Resistant Steel
DC	Direct Current
DOD	Department of Defense
EGC	Equipment Grounding Conductor
EIA	Electronics Industries Alliance
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
ft	Feet
GSE	Ground Support Equipment
HDBK	Handbook
GSS	Ground Support System
Hz	Hertz
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
in	Inch
KDP	KSC Directive/Procedure
KNPR	KSC Procedural Requirements
KSC	John F Kennedy Space Center
kV	Kilovolt
LC-39	Launch Complex 39
LCC	Launch Control Center
L-G	Line-to-Ground
LH_2	Liquid Hydrogen
L-N	Line-to-Neutral
LO_2	Liquid Oxygen
LRA	Lightning Risk Assessment
LPS	Lightning Protection System
LSAC	Lightning Safety Assessment Committee
m	Meter
MCC	Motor Control Center
MCOV	Maximum Continuous Operating Voltage

MIL	Military
ML	Mobile Launcher
mm	Millimeter
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NGR	Neutral Ground Resistor
N-G	Neutral-to-Ground
OHGW	Overhead Ground Wire
OIS	Operational Intercom System
OSHA	Occupational Safety and Health Administration
PHSF	Payload Hazardous Servicing Facility
POL	Petroleum, Oil, and Lubricants
PTCR	Pad Terminal Connection Room
PVC	Polyvinyl Chloride
RF	Radio Frequency
RFI	Radio Frequency Interference
RPSF	Rotation, Processing, and Surge Facility
SPD	Surge Protective Device
SPFCMAN	Space Force Manual
STD	Standard
TIA	Telecommunications Industry Association
TM	Technical Manual
TO	Technical Order
UL	Underwriters Laboratories Inc.
UPS	Uninterruptible Power Supply
VAB	Vehicle Assembly Building

1. SCOPE

This standard establishes design, construction, and O&M standards for grounding, bonding, lightning protection, and surge protection for all classes of facilities at the John F. Kennedy Space Center (KSC). This standard shall be invoked by KSC contracts in support of NASA programs, program constituent elements, or the KSC Institution. The need to upgrade an existing lightning protection system (LPS) or facility grounding system to meet this standard shall be considered on an individual basis when major design modifications to a facility have been initiated, when the operational or mission use of the facility has changed, when the facility has been exposed to lightning-related damage, or when a lightning risk assessment (LRA) determines that adding a new, or modifying an existing LPS is necessary based on operational requirements. Design activities may impose additional requirements beyond the content of this standard at the discretion of the design team.

1.1 Intended Use

This standard is intended for use by all design organizations; by operating organizations having maintenance responsibility for new and existing installations; and by installation contractors as required by the contract specifications.

Compliance with Section 4.1, Requirements Applicable to All Zones, which outlines minimally feasible technical and safety requirements applicable to all systems and facilities is mandatory for all KSC design, construction, maintenance, and testing activities applicable to lightning protection systems.

1.2 Bonding and Grounding

The different types of NASA facilities located on Cape Canaveral Space Force Station (CCSFS) and KSC have varying requirements for bonding and grounding depending on location and function. Section 5.1 establishes the minimum bonding and grounding practices required at these facilities. The basic bonding and grounding objectives are presented in Appendix A.

1.2.1 Electrical/Electronic Equipment

For ground support equipment (GSE) or ground support system (GSS) equipment, bonding and grounding requirements are specified to ensure proper interfacing between the equipment and the facility ground system to which it is connected. Grounding requirements applying specifically to GSE and GSS should refer to KSC-STD-E-0022, Bonding, Grounding, Shielding, Electromagnetic Interference, Lightning and Transient Protection, Design Requirements for Ground Systems.

1.2.2 Electrical Power Systems

Bonding, grounding, surge protection, and LPS requirements for alternating current (ac) and direct current (dc) power systems are met by NFPA 70, NFPA 780, IEC 62305 and as stated in this standard.

1.2.3 Electromagnetic Compatibility Control Design

This standard deals with EMC only insofar as bonding and grounding of facilities and equipment is concerned. Additional EMC requirements applying specifically to GSE should refer to KSC-STD-E-0022.

1.3 Lightning Protection and Surge Protective Device (SPD) Systems

This standard defines the requirements for Lightning Protection Systems and Surge Protection for any KSC facility. Any facility that contains a launch-critical system, which would be considered a hazardous zone (see definitions), that could be destroyed or damaged by lightning or voltage transients, shall be given maximum protection with regards to LPS and SPD systems. Modifications to existing facilities shall not degrade the existing LPS or SPD systems. Sections 5.2 and 5.3 cover the protection of KSC and CCSFS facilities from direct lightning strikes, power surges and transients from lightning, and lightning induced effects. For further investigation into lightning induced effects reference the following documents: KSC document TM-667 and KSC-STD-E-0022.

1.4 Personnel Safety

The primary objective of an LPS is to control and disperse lightning induced energy to: (1) prevent physical damage to structures and equipment, and (2) mitigate internal electrical disruptions.

Compliance with this standard does not ensure personnel safety; however, in situations where personnel are required to continue working outdoors or within unconventional structures (e.g., platforms, decks, stands, sheds, towers, or facilities that may create large openings) during the presence of lightning activity, a Lightning Risk Assessment (LRA) must be developed by the organization responsible for the personnel performing the subject operations and processing. The LRA must quantify the risks to personnel from direct and indirect effects of a lightning strike and shall be reviewed by the Lightning Safety Assessment Committee (LSAC). The LRA is beyond the scope of this KSC standard. Refer to KNPR 8715.3, KSC Safety Procedural Requirements for more information about personnel safety with regards to lightning protection.

2. APPLICABLE DOCUMENTS

The following references form a part of this KSC standard to the extent specified herein. When this standard is used for procurement or referenced in a design, the revision of the referenced standard(s) at the time of execution of the procurement or design shall be enforced. This language shall be present in the Solicitation, Statement of Work, specification, or relevant Contract clauses. KSC organizations performing internal operations shall use the latest available issue or revision of each standard noted below in coordination with their safety organization. In the event of differences between this standard and the referenced documents, the more stringent requirements shall take precedence.

NASA facilities located on CCSFS may require adherence to additional DOD and Air/Space Force requirements that are more stringent than this standard. In this case, the more stringent DOD and Air/Space Force requirements shall take precedence over the corresponding requirements outlined in this standard.

Copies of specifications, standards, drawings, and publications required by suppliers in connection with specified procurement functions should be obtained from the procuring activity or as directed by the Contracting Officer.

2.1 Government

2.1.1 Specifications

John F. Kennedy Space Center (KSC), NASA

KSC-DE-512-SM	Ground Support Equipment and Ground Support Systems General Design Requirements
KSC-E-165	Specification for Electrical Ground Support Equipment Fabrication

Occupational Safety & Health Administration (OSHA)

29 CFR 1910	Occupational Safety and Health Standards
29 CFR 1926	Safety and Health Regulations for Construction

Federal

A-A-55804	Rods, Ground (With Attachments)

2.1.2 Standards

National Aeronautics and Space Administration

NASA-STD-8719.12	Safety Standard for Explosives, Propellants & Pyrotechnics
NASA-STD 8739.4	Crimping, Interconnecting Cables, Harnesses, and Wiring

John F. Kennedy Space Center (KSC), NASA

KSC-STD-E-0022	Bonding, Grounding, Shielding, Electromagnetic Interference, Lightning and Transient Protection, Design Requirements for Ground Systems

George C. Marshall Space Flight Center (MSFC), NASA

MSFC-STD-1800	Electrostatic Discharge (ESD) Control for Propellant and Explosive Devices

Department of Defense

MIL-HDBK-419A	Grounding, Bonding and Shielding for Electronic Equipment and Facilities Volumes I and II

2.1.3 Other Documents

John F. Kennedy Space Center (KSC), NASA

TM-667	Handbook of Design Requirements and Practices for Protection from Lightning-Induced Effects

Department of the Air Force

TO 00-25-172	Ground Servicing of Aircraft and Static Grounding/Bonding

AFI32-1065	Grounding Systems

Department of the Space Force

SPFCMAN91-710	*Range Safety User Requirements Manual Volume 6: Ground and Launch Personnel, Equipment, Sys*tems, and Material Operations Safety Requirements

2.2 Non-Governmental

Industry Publications

American National Standards Institute (ANSI)

ANSI - TIA-607-D	Generic Telecommunications Bonding and Grounding (Earthing) For Customer Premises.
ANSI/TIA-222-G	TIA Standard, Structure Standard for Antenna Supporting Structures and Antennas
ANSI/TIA/EIA-568-D.1	TIA/EIA Standard, Commercial Building Telecommunications Cabling Standard, Part 1 General Requirements

International Electrotechnical Commission

BS EN/IEC 62305 (1-4)	Protection against lightning Parts 1-4

Institute of Electrical and Electronic Engineers (IEEE)

IEEE C2	National Electrical Safety Code
IEEE C62.22	IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems
IEEE C62.41	IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits
IEEE C62.45	IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits
IEEE Std 80	IEEE Guide for Safety in AC Substation Grounding
IEEE Std 81	IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System

IEEE Std 142	Green Book Recommended Practice for Grounding of Industrial and Commercial Power Systems
IEEE Std 1100	Emerald Book Recommended Practice for Ground Electronic Equipment
IEEE Std 1410	Guide for Improving the Lightning Performance of Electric Power Overhead Distribution Lines

National Electrical Manufacturers Association (NEMA)

NEMA VE 1	Metal Cable Tray Systems
NEMA VE 2	Cable Tray Installation Guidelines

National Fire Protection Association (NFPA)

NFPA 70	National Electrical Code
NFPA 70E	Standard for Electrical Safety in the Workplace
NFPA 75	Standard for the Protection of Electronic Computer/Data Processing Equipment
NFPA 77	Recommended Practice on Static Electricity
NFPA 780	Standard for the Installation of Lightning Protection Systems

Underwriters Laboratories (UL) Inc.

UL 96	Lightning Protection Components
UL 96A	Installation Requirements for Lightning Protection Systems
UL 467	Ground and Bonding Equipment
UL 1449	Standard for Surge Protective Devices

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specified procurement functions should be obtained from the procuring activity or as directed by the Contracting Officer.)

3. DEFINITIONS

3.1 Definitions

For the purpose of this standard, the following definitions apply.

a. Bonding - An electrical connection between two conductive bodies to establish electrical continuity and conductivity.

b. Catenary Overhead Wire - A conductor installed above equipment or structures to intercept lightning and provide a direct, low-impedance path to ground. Numerous catenary overhead wires supported by masts or poles form a catenary shielding system that intercepts lightning and directs that current safely to ground and away from the facility.

c. Communication System - Any of a set of KSC systems which includes but is not limited to the following members – KSC Integrated Transmission System (KITS) (outside cable plant, inside communications wiring, transmission and media conversion equipment, dedicated ATXS/etc. networks); Operational Intercom System (OIS); Enterprise Physical Access Control System (EPACS); Broadband Communication Distribution System (BCDS); Imaging Systems; KSC Timing; Trunked Radio System; Conventional Radio System; Paging Area Warning System (PAWS); and Unified Communication Power System (UCPS). These systems may include their own support structures; enclosures; cable raceways; cable interconnects; internal power distribution; grounding, bonding, and shielding accommodations; and surge protection. They do not include operational RF communications interfaces to flight vehicles.

d. Conventional Facility - A facility intended for uses typical of commercial utilization such as office buildings, warehouses, machine shops, and other uses. These structures are characterized by well-established design precedents and loading conditions, whose primary function is nonhazardous, and which are not formally rated as Critical by the supported activity.

e. Counterpoise Conductor – An underground conductor that encircles a structure; and that is used to interconnect grounding electrodes, main conductors, other grounded bodies, and connects to the power system grounded conductor.

f. Earth - That portion of the earth's crust sufficiently below the surface to act as an infinite sink or source for electric charge. Earth is considered to have a zero potential level.

g. Earth Grounding Counterpoise - The complete system of counterpoise conductor(s), grounding electrodes, and metallic bodies that are interconnected to form a complete grounding system and provide for the safe dissipation of lightning current.

h. Electrical Equipment Enclosures - Conductive enclosures or structures that house, route, or protect electrical conductors and associated components.

i. Equipment Grounding Conductor (EGC) - A conductor, usually with green insulation, run with circuit conductors that provides a low impedance ground-fault current path and connects normally non–current-carrying metal parts of equipment together and to the system grounded conductor or to the system grounding electrode conductor, or both. At KSC, neither raceway nor conduit shall be used as the EGC.

j. Equipotential Signal Reference Plane - A grounding system designed to minimize voltage differences between equipment requiring a common signal reference.

k. Facility - Buildings, structures, and other real property improvements including facility systems (utility systems and collateral equipment that is integral and local to the structure). Facility systems include HVAC, 60 Hz power, potable water, elevators, lighting, shop air, etc. Facility systems may support or have interfaces with GSE.

l. Facility Ground – A ground connection, such as a grounding plate, that connects directly to the earth grounding counterpoise system of a facility. This connection may be used by GSE, GSS, or other systems to provide a ground reference or for static charge dissipation.

m. Ground - A conducting connection, whether intentional or accidental, between an electrical circuit and the earth, or to some other body that serves in place of the earth.

n. Grounded (Grounding) - Connected (connecting) to ground or to a conductive body that extends the ground connection.

o. Grounding Electrode System - The electrically conductive network, including all structures and grounding cables bonded to the earth grounding counterpoise but excluding the electrical enclosures, conduit, and raceway systems. In steel frame structures, the structural members may be bonded together and connected to the earth grounding counterpoise to form the basic network. In buildings using nonconductive structural methods and in outside facility areas such as gas, propellant, or oxidizer service facilities, the grounding electrode system consists of conductors, sized according to criteria included in this standard, bonded to an earth grounding counterpoise, and extended to all areas containing equipment to be grounded.

p. Ground Support Equipment (GSE) - Non-flight equipment, systems, or devices, portable or fixed, specifically designed and developed for a direct physical or functional interface with flight hardware. GSE may be developed or operated by a specific flight program, or by the KSC Institution as a service supporting multiple flight programs.

q. Hazardous Zones - Areas where flammable or explosive materials, explosive ordnance, or similar hazards may be present in quantities capable of producing flammable or explosive mixtures; facilities where launches or launch processing activities take place; or facilities whose operation is of such criticality that maximum protection from lightning is required to ensure mission success. Bonding and grounding of metallic conducting surfaces are required to eliminate or mitigate:

    I. Potential buildup of metal objects due to static charge accumulation
    II. Induced voltages from lightning and fault currents
    III. Arcing between metal components in fault-current paths

    Hazardous Zones include, but are not limited to, areas used for processing, storing, or handling hazardous materials; enclosed or reinforced structures designed to shield sensitive equipment; and areas where EMI suppression is inherent to operational requirements. Examples of such areas at KSC include Launch Complex 39 (LC-39), the Pad Terminal Connection Room (PTCR), the Launch Control Center (LCC), the Vehicle Assembly Building (VAB), the Mobile Launcher (ML), the Operations and Checkout (O&C) Building, and specialized payload processing facilities such as the Payload

Hazardous Servicing Facility (PHSF), Multi-Payload Processing Facility (MPPF), and Rotation Processing Support Facility (RPSF), as well as critical infrastructure such as the Kennedy Data Center (KDC).

r. Lightning Ground - A ground rod that is directly connected to the lightning protection system via a down conductor and connected to the building counterpoise.

s. Non-Hazardous Zones - Areas that do not normally contain hazardous, flammable, or explosive materials or EMI-susceptible equipment; however, bonding and grounding for protection from lightning hazards and electrical system faults are still required.

NOTE

Zone determinations will be made by the electrical design organization following consultation on requirements with users, operators, maintenance organizations, and Safety.

t. Nonconventional Facility - A facility intended for uses predominately atypical to commercial utilization. Such uses may include but are not limited to: storage or housing of flight hardware; provision of direct access to flight hardware, e.g., test stands, launch complexes, and access platforms in operational or research facilities; towers; and similar special-purpose facilities. A Nonconventional Facility may be characterized by unusual or inadequately defined conditions (launch acoustics, vibration, rocket exhaust, etc.), a lack of established design precedent, or frequent modifications due to required operational changes. A facility may also be treated as Nonconventional for the purposes herein based on formal assessment as Critical by the supported activity, or by identified hazards present.

u. Ordnance Facility Grounding and Bonding – Grounding and bonding of Ordnance Facilities shall follow the requirements of NASA STD 8719.12A and NFPA 780 chapter 8.

v. Overhead Ground Wire - At KSC the grounded conductor run above all power lines for lightning protection and personnel safety.

w. Power Ground - The connection of a power system's neutral wire (the X0 point) to the facility counterpoise. This connection serves to establish a stable reference voltage.

x. Shield Wire - When used for power systems, the shield wire is utilized for medium voltage insulated cable as a return path for faults as well as protection from lightning. When applied to communications systems, the shield wire provides lightning shielding for communications cables and associated equipment. This conductor is often a component of a larger lightning protection system designed to meet the requirements of standards such as NFPA 780.

y. Signal Ground - A connection between a signal circuit and the equipotential signal reference plane utilized for that equipment or system.

z. Static Ground - A functional term describing a connection between a conductive object and an earth grounding counterpoise for the purpose of draining static charge.

aa. Surge Protective Device (SPD) - A device intended for limiting surge voltages on equipment by diverting or limiting surge current that comprises at least one nonlinear component while remaining capable of repeating these functions.

bb. Transient – A sub cycle electrical disturbance that is evidenced by a sharp, brief discontinuity of the waveform. It can be of either polarity and can be additive to, or subtractive from, the nominal waveform.

4. GENERAL REQUIREMENTS

4.1 Requirements applicable to all Zones and Facility Types

All KSC facilities, structures, and systems shall be designed to meet the requirements of NFPA 70, NFPA 780, IEEE C2, and this standard as a minimum. Designs shall take into consideration the function, personnel operations, critical equipment, laboratory testing, and spacecraft activities by each facility, structure, or system. For personnel safety considerations, an LRA in accordance with IEC shall be developed by the organization responsible, reference Section 1.4 regarding Personnel Safety. All LPS materials specified and installed at KSC shall be class II materials as specified in NFPA 780.

4.2 Request for Waivers

The requirements set forth in this standard are intended to establish standard practice throughout KSC. There may be circumstances in which a deviation from the requirements listed herein are practical; such deviations may be allowed if they are approved in writing by a properly executed waiver. Requests to waiver any requirement of this Standard must be supported by technical justification. Deviation and waivers request shall be in accordance with KDP-KSC-P-1865, Technical and Institutional Requirement Deviation/Waiver Process"

Direct waiver request to: Engineering Directorate
Technical Performance & Integration Division, Mail-code: NE-T
John F. Kennedy Space Center, NASA
Kennedy Space Center, Florida 32899

5. DETAILED REQUIREMENTS

5.1 Bonding and Grounding Requirements

5.1.1 Facility Ground – Earth Electrode Requirements

Earth electrodes for power, communication, and lightning protection system grounding shall be in accordance with NFPA 70, NFPA 780 and the following:

a. As a minimum, a counterpoise conductor shall encircle the perimeter of the facility. The wire used for this application shall be a bare-stranded copper conductor not less than No. 2/0 AWG in size. The design shall place the counterpoise conductor outside of the structure drip line, at least 24 inches (61cm) from the building foundation but within 72 inches (183cm) of the building foundation or further if required to avoid utilities or other obstructions. The minimum burial depth shall be no less than 24 inches (61cm).

b. Ground rods shall be installed at all lightning protection down conductor connections, at ground level electrical equipment connection points, and at ground level telecommunication equipment room grounding points. All ground rods shall be interconnected in-line (dead-ends minimized) to the counterpoise system. Additional ground rods shall be installed per NFPA 70, NFPA 780, and IEC. The entire ground counterpoise system shall be designed for an overall earth ground resistance according to section 5.1.25.6 values.

c. Drawings shall show counterpoise plans and details, bonding connection provisions, ground rod locations, ground rod length, and test-well provisions.

d. New counterpoise systems shall be bonded to existing adjacent counterpoise systems within 25 feet (7.6m), all incoming power and communication service grounds, other metallic bodies within 25 feet (7.6m) and to other earth electrode grounds as required by NFPA 70.

e. At a minimum, metal frame buildings shall be directly bonded to the counterpoise system at all lightning protection down conductor locations. Down conductors are required to be run in a rigid non-metallic conduit (PVC) to prevent degradation of the building exterior. The conductor connection shall be made at lowest point on the down conductor route (e.g., point closest to earth) to minimize the length of the bonding conductor. If metallic columns are used as down-conductors, the columns shall be bonded at the lowest point to the counterpoise system, and at the highest accessible point to the roof lightning protection system conductors.

5.1.2 Medium Voltage Power Transformers

Where the service medium voltage transformer is located within the building or facility, the AC power distribution system shall be grounded to the counterpoise at one point only via the transformer Xo point for the neutral conductor. Where the medium voltage transformer is located externally to the building or facility, a counterpoise conductor shall encircle the perimeter of the voltage transformer equipment pad. The counterpoise shall be connected to the supplying duct bank ground, the service entrance equipment, the power ground on the secondary side of the supply transformer and the facility counterpoise system powered by the medium voltage transformer. Wire used for the counterpoise shall be a bare-stranded copper conductor not less than No. 2/0 AWG in size. A 20-foot (6m) ground rod shall be installed adjacent to the cable termination compartment (secondary side for pad-mounted transformers) and connected to the counterpoise conductor by exothermic weld. For medium voltage transformers the following items shall be bonded:

a. The supplying source grounded and ECG conductors, and the cable shields of the medium voltage cables via terminations.

b. The transformer secondary neutral.

c. All equipment enclosure ground pads or buses.

d. All surge arrestor ground connections.

e. All metal conduit ground bushings shall be equipped with lugs capable of connecting to No. 2/0 AWG copper cable.

5.1.3 Separately Derived Systems

Separately derived systems shall be bonded and grounded in accordance with NFPA 70 and applicable portions of this standard.

5.1.4 Uninterruptible Power Supply (UPS) Units (Including rack mounted UPS units with AC output)

a. Input and bypass circuits to UPS units shall be grounded in accordance with NFPA 70 requirements for equipment grounding.

b. Based on the source of the UPS bypass circuit, the inverter shall be grounded per NFPA 70, as per section 5.1.3 for separately derived systems as applicable, and per any specific manufacturer instructions.

c. Battery circuits shall not be grounded.

d. UPS cabinets, UPS inverter neutrals, and battery cabinets shall be grounded and bonded per NFPA 70, IEEE Std 1100 (Emeral Book), this standard, and manufacturer's recommendations based on the design philosophy for the UPS source power, bypass, output type, etc. The design shall provide and specify the necessary connection provisions in a detailed manner.

e. Transfer equipment associated with maintenance (wrap-around) bypass circuits shall include a separately switched pole for the neutral conductor where used.

5.1.5 Medium Voltage Switching Stations

Where the Switching Station - VFI, LBS, enclosed MV gear, or similar structure - is located within the building or facility, the facility ground shall be connected to the switchgear ground bus at each incoming cable termination compartment. For outdoor Switching Stations, a counterpoise conductor shall encircle the perimeter of the equipment pad. Wire used for the counterpoise conductor shall be a bare-stranded copper conductor not less than No. 2/0 AWG in size. The counterpoise shall be connected to supplying duct bank grounds and, when located within proximity (e.g., within the same site boundary), the counterpoise shall be bonded to the facility grounding system. Ground rods sized and spaced to minimize resistance to ground shall be installed adjacent to incoming cable compartments and connected to the counterpoise by exothermic welding. A minimum No. 2/0 AWG bare-stranded copper cable shall connect the switchgear ground bus to these ground rods. Additionally, any metal enclosures shall also be connected to the local counterpoise system. The switchgear ground bus shall be bonded to the following components:

a. The supplying source grounded and neutral conductors, and the cable shields on the medium voltage cables via terminations.

b. Switchgear enclosure.

c. Counterpoise of MV switch.

d. Potential transformer and control transformer neutrals.

e. Adjacent electrical equipment.

f. All surge suppressor ground connections.

g. All metal conduits.

5.1.6 Transfer Switches

Transfer equipment shall include a separately switched pole for the neutral conductor for separately derived sources. Transfer switches shall be grounded in accordance with NFPA 70 requirements for equipment grounding.

5.1.7 Generators

5.1.7.1 Permanently Installed Generators

a. A counterpoise conductor shall encircle the perimeter of the generator enclosure and other generator equipment such as fuel tanks. Wire used shall be a bare-stranded copper conductor not less than No. 2/0 AWG in size. A 20-foot (6m) ground rod shall be installed with a ground test well adjacent to the generator output and connected to the generator counterpoise conductor. The generator units shall be grounded as a separately derived system in accordance with NFPA 70. The grounding electrode conductor shall be connected directly to the generator output neutral terminal with a system bonding jumper installed to the generator enclosure. Transfer equipment connecting generator sources to facility distribution equipment shall include a separately switched pole for the neutral conductor. Contact operation on the neutral shall be make-before-break.

b. The design shall indicate the following connections to the generator counterpoise system:

   i. Generator frame.

   ii. Generator Housing.

   iii. Fuel Tanks.

   iv. Generator output duct bank ground.

   v. Any other metal bodies or auxiliary enclosures.

   vi. The facility counterpoise system served by the generator unit.

5.1.8 Wiring System Enclosures and Electrical Equipment Grounding

Any type of metallic electrical enclosure or related components that may come in contact with an ungrounded conductor shall be grounded; or shall be bonded to other component parts that are grounded.

5.1.8.1 Instrumentation and Communication Terminal Distributors

Grounding conductors shall be No. 6 AWG copper or larger.

5.1.9 Cable Trays

Cable trays for power, control, or communications use shall be grounded, bonded and be electrically continuous systems in accordance with NFPA 70 and the following:

a. Cable trays are permitted to be used as the equipment grounding conductor (EGC) when labeled and marked within the available cross-sectional area. If the cable tray is to be used as an EGC, see section 5.1.9.1 and examples A through D of Figure 1, unless the splice plates meet the electrical continuity requirements of NEMA VE 1. If the connectors are UL-classified, it is not necessary to use bonding jumpers or a continuous ground.

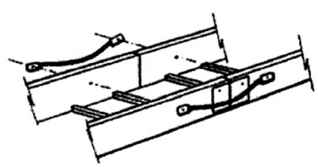
b. Connections shall be bi-metal type to prevent galvanic action between copper grounding conductors and the cable tray material, which is predominantly aluminum. Use non-oxidizing coating between different types of metals.

c. For all metal conduits housing conductors entering or leaving a cable tray system, grounding bushings with a grounding conductor connector shall be specified. Bond conduits using these grounding bushings to the cable tray (use bi-metal or other appropriate connectors), the equipment grounding within the conduit system, and the equipment grounding conductor within the cable tray system.

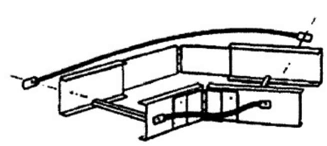
d. Where cable trays penetrate an exterior building wall, they shall be directly connected to the facility counterpoise system at this point with a minimum No. 2/0 AWG copper cable.

5.1.9.1 Cable Tray Sections

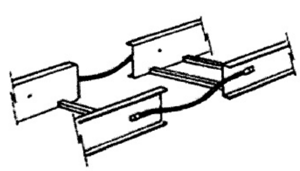
Cable tray sections, whether in single runs or in system arrangement, shall be bonded together. Cable tray sections in tandem assembly shall be considered as having electrical continuity when these sections are bonded with appropriate high-strength bolts. A jumper, consisting of a bond strap as described in this standard, shall be installed whenever expansion joints are required. The minimum jumper size shall be equivalent to a No. 3/0 aluminum or No. 1/0 copper cable in cross-sectional area. Cable tray assemblies shall be connected to the grounding electrode system with a minimum No. 2/0 AWG copper cable. Copper grounding conductors shall not be bonded directly to aluminum cable trays. To prevent galvanic action, a UL-listed copper-to- aluminum transition lug shall be used. The connections shall be made within 2 feet (0.6m) of each end and at intervals not exceeding 50 feet (15.24m) along the run. Where metal covers are used, they should be securely bolted in place. All cable trays shall be connected to grounding terminals at the point of entry into a structure.



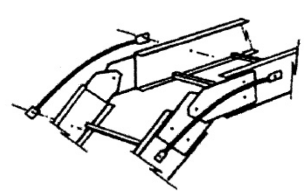
A. Expansion Splice Plates



B. Horizontal Adjustable Splice Plates



C. Discontinuous Segments



D. Cable Tray Sections
Vertical Adjustable Splice Plate

Figure 1. Installation of Cable Tray Bonding Jumpers

5.1.10 Conduit and Raceway Systems

Metal conduit, fittings, junction boxes, outlet boxes, armored and metal-sheathed cable, and other raceways shall be bonded together in accordance with NFPA 70 requirements. These bonded systems shall not serve as the equipment grounding conductor. A separate conductor shall be run in each raceway and shall serve as the equipment grounding conductor and sized per applicable code requirements.

5.1.11 Lifting, Transporting, or Portable Equipment

Portable electrical equipment shall be considered adequately grounded through the power cord ground conductor, provided a solid connection is made between the equipment case and the ground terminal of the power receptacle. All wiring enclosures and frames of electrical equipment for lifting or transporting equipment, such as elevators, cranes, trailers, crawler transporters, fuel and oxidizer handling equipment, etc., shall be grounded to the mobile equipment main metal frame in accordance with this standard. Equipment shall be grounded as follows:

a. Cranes
    i. Grounding
        1. Feed Rail and Collector Type Electrification. – A separate grounding rail shall ground the crane to the facility ground through an equipment grounding conductor.
        2. Festoon Cable or Cable Reel Type Electrification – A separate equipment grounding conductor shall ground the crane to the facility ground.
        3. Crane Hooks. – Grounding of crane hooks shall be done by a mechanical attachment in lieu of welding so as to prevent degradation of the hook material.
    ii. Bonding – Bonding of crane rail sections shall be provided by the rail clips and rail connecting plates.
b. Facility Portable Generator Connections
    i. Grounding
        1. The Generator shall be placed adjacent to the nearest location of ground rod test well as allowable by field conditions. Connections to the ground rod test well shall be made to:
            a) The facility counterpoise system.
            b) Electrical enclosures and any grounded conductor buses installed for the portable generator equipment connections to the facility.
            c) All metal conduits enclosing generator power cables; specify grounding bushing with lug capable of connecting 2/0 copper cable.

ii. Bonding - Portable generator connections to facility electrical systems shall be designed to include the isolation of generator and facility electrical system neutral conductors by using equipment that switches the neutral. Where such transfer equipment is employed, the neutral switching shall be make-before-break.

5.1.12 Electrical Manholes or Vaults

In all electrical power and communications cable system manholes, at a convenient point close to a perimeter wall, a 20-foot (6m) ground rod shall be driven (before the manhole is poured) so that the top of the rod is approximately 4 inches (10cm) above the manhole floor.

For precast concrete manholes, the top of the rod can be below the floor and a copper conductor extended from the rod into the manhole through a watertight penetration in the wall or floor. This rod or conductor shall be utilized for grounding power and communications metallic cable sheaths and all items of hardware in the manhole. All metallic hardware (including metallic enclosures, raceways, cable trays, conduits, and any other metallic items) and all exposed grounded conductors in the manhole or vault shall be bonded to the manhole ground.

Exothermic welds shall be used for bonding manhole hardware to the manhole/vault ground conductor. However, where the requirement exists for disconnecting the bond or where application of heat could jeopardize existing cables, bolted or clamp connections shall be used. A conductive corrosion inhibitor shall be applied to the mating surfaces of mechanical connectors. For large vaults, ground rods shall be installed near each corner of the vault and connected with a looping counterpoise installed within the vault.

5.1.13 Outdoor Structures

Outdoor metallic structures, such as towers, fences, railroad tracks, pole lines, etc., shall be grounded. Pole lines and railroad tracks should be grounded in accordance with those applicable requirements in section 5.2. Fences used as personnel barriers and around power substations shall be grounded as specified in sections 5.1.22 and 5.1.23 to provide protection from high-voltage hazards.

5.1.14 Metal Pipe (General)

Metal pipes shall be bonded to ground at the end terminations and at intervals of not more than 300 feet (91.4m).

5.1.15 Ground Rods

Ground rods shall be ¾-inch (19mm) diameter, 20-foot length (6m), and composed of copper-clad steel or copper-bonded steel. Ground rods shall be UL-listed/certified and compatible with soil site conditions. 10-foot (3m) lengths shall be vertically joined either by threaded brass couplings, by exothermic welding completely around both rod/coupling joints, or by threaded couplings that are welded at either rod to create a 20-foot (6m) length ground rod. Ground rods shall be driven to a depth of at least 20 feet (6m) with the top of the ground rod at a depth of 24 inches (61cm) below grade. Testing shall be in accordance with section 6.3.

5.1.16 Counterpoise Design

A counterpoise shall be installed at all KSC facilities unless waived by the Authority Having Jurisdiction (AHJ). The counterpoise design will vary in the number of ground rods, number of interconnections, etc., depending on the size and function of the facility. The following guidelines shall be used as a minimum of each design:

a. Except for straight-line counterpoises for duct banks, cable trays, etc., there shall be at least two paths between any point on the counterpoise.

b. Ground rods shall be installed so any point on the counterpoise is within 50 feet (15.24m) of a ground rod. Spacing between ground rods shall be as uniform as practicable throughout the counterpoise, however, minimum spacing between ground rods shall not be less than the total driven depth of one ground rod.

c. Wire used for interconnecting ground rods shall be bare-stranded copper conductors not less than No. 2/0 AWG in size.

d. Ground rods shall be located not less than 24 inches (61cm) from structure foundations as practical or outside the drip line of the facility. Ground rods shall be driven to a depth such that the tops of the rods are 24 inches (61cm) below grade level.

e. The facility counterpoise shall meet the following requirements:

    i. Be installed within the excavation for curtain wall and column footings.

    ii. Be located no more than 72 inches (183cm) from the building foundation unless site conditions require otherwise.

    iii. Be buried 24 inches (61cm) below grade level.

f. Wire connections to ground rods and riser connections to counterpoise wires shall be made by exothermic welding only. The wires or the wire and rod shall be placed in parallel contact and continuously welded for a distance of at least 2 inches (50mm).

g. Facility counterpoise systems shall have test well(s) or test point locations to allow for the ease of periodic testing of the counterpoise ground resistance. Test well connections shall be mechanical to aid in necessary maintenance and testing

h. New counterpoise systems shall be bonded to existing adjacent counterpoise systems within 25 feet (7.6m), all incoming power and communication service grounds, other metallic bodies within 25 feet (7.6m) and to other earth electrode grounds as required by NFPA 70.

5.1.17 Grounding System Requirements

The design of a grounding system must be tailored to the characteristics and operational needs of the systems it supports. Individual ground planes may consist of a flat conductive surface, tubular conductors, solid or stranded wire, or combinations thereof. The design of ground systems shall be in accordance with the general guidelines stated below and in appendix A, A.2.4. The grounding schemes that may be used are as follows:

a. Structural Steel as a System Ground Point — A grounding method that uses the building's structural steel as the primary grounding reference for the facility. Individual electronic equipment and communication system reference planes are single-point bonded to the building steel using a minimum of No. 2/0 insulated copper ground wire which provides a system ground point. Where an electronic system consists of a number of subsystems, the ground connections from each subsystem may be connected to a common point and this point connected to the building steel using a minimum of No. 2/0 insulated copper ground wire. Structural steel columns shall be bonded to the facility counterpoise at each outer column or selected outer columns, so that the spacing between connections to the counterpoise system does not exceed 100-ft (30.5m). Note that the structural steel of the facility shall be electrically continuous.

b. Use of Structural Steel for Multiple Grounds

   i. Multiple Grounds (for High Frequencies). – The multiple ground configuration is used for high frequency electronic equipment and computer grounding systems. In this method, many conductive paths from the electronic equipment within the facility to the facility ground or earth-grounded building steel system may be established such that the systems are interconnected to each other and to building steel at multiple locations.

   ii. Raised Floors –Metallic components of raised floors shall be bonded together to form an equipotential plane on which automatic data processing, computer, and other electronic equipment, susceptible to high-frequency noise, can be installed. Raised floor parts must be bonded together and must be bonded to the grounding counterpoise. The designer may use single-point or multipoint grounding for the equipotential plane as required by the noise frequencies and the network size. Raised floor pedestals, stringers, space assembly blocks, springs, and spring isolation assemblies may be grounded via grounding system conductors to the earth electrode system. The lateral stringers (supporting braces installed between supporting pedestals) must be bolted down. Only bolted-grid (stringer) or rigid-grid systems are acceptable as equipotential planes. Members must be suitably plated (tin or zinc) so that low-resistance pressure connections can be made as shown in figure 2 along with EMI bonds. See section 5.1.25.9 for test resistance values.

   Note that if the structural steel is used for multiple grounds, the facility structural steel shall be electrically continuous and bonded to the facility counterpoise system as de-scribed in (a) above.

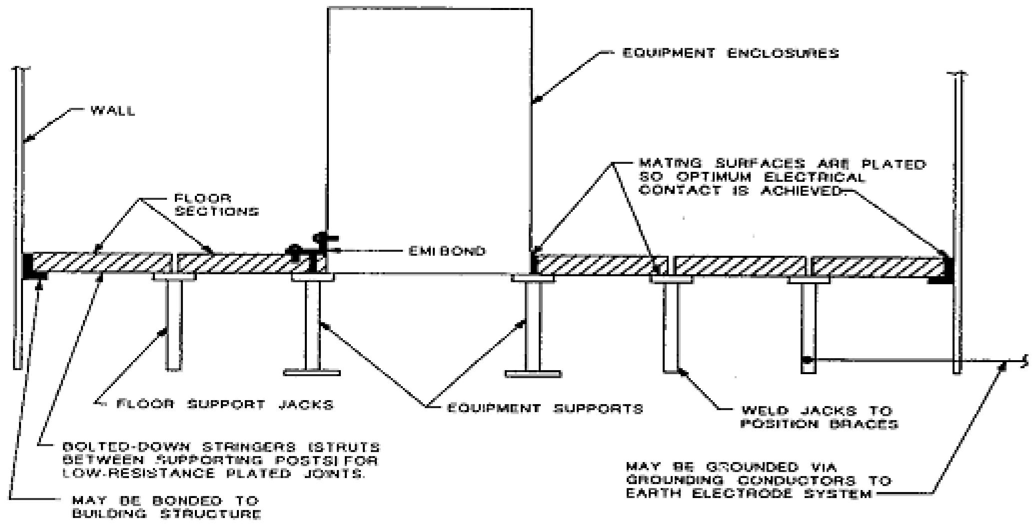


Figure 2. Grounded Raised Floor

5.1.18 Critical Instrumentation, Control, Communication, and Data Cable Shields

The following requirements shall apply.

a. Shield shall have a minimum optical coverage of 98 percent.

b. Overall cable shields shall be grounded at both ends of the cable and at every interface where connections are made (if any).

c. Termination of overall shields shall be made along a 360-degree periphery of the connector shell.

d. The connector shall be grounded in a 360-degree manner to the surface upon which it is mounted.

e. Termination and grounding of overall shields at such surfaces with pigtails or single pins shall not be acceptable.

f. Termination and grounding shields shall be installed in accordance with NASA STD 8739.4 and KSC-E-165.

g. Shielding and bonding design practices shall also comply with the design and EMI requirements of KSC-STD-E-0022.

5.1.19 Ground Connections (General)

All ground connections shall be made in accordance with the applicable requirements of section 5.1.20. Unless otherwise directed, grounding conductors shall be Class B stranded copper of a size sufficient to meet the grounding resistance requirements specified herein. Exothermic Welding is the accepted method of connecting grounding conductors, and this method shall be employed in all cases. When welding is unsafe or at the direction of the Authority Having Jurisdiction (AHJ) then bolted, compression, or clamp type connections may be used.

5.1.20 Types of Bonds

Unless otherwise specified herein, bonding of metal surfaces shall be accomplished by (1) brazing, (2) welding, (3) clamping, (4) high compression connectors listed for that purpose, or (5) structural joining methods. Section (6) below details cleaning methods for surfaces to be bonded.

5.1.20.1 Brazing

Brazing solder shall conform to specifications in KSC-DE-512-SM.

5.1.20.2 Exothermic Welding

Welding shall be by the exothermic process in which the conductors are permanently joined by approved methods. The welding procedure shall include the proper mold and powder charge and shall conform to the manufacturer's recommendations.

5.1.20.3 Clamping

In external locations, clamping shall be used only where a disconnect type of connection is required or as specified by this standard. The connection device may utilize either spring-loaded jaws or threaded fasteners. The device shall be constructed so that positive contact pressure is always maintained. This method includes the use of machine bolts with tooth-type or spring-type lock washers. A conductive corrosion inhibitor shall be applied to all mating surfaces before connection is made.

5.1.20.4 Compression (Pressure) Connector (irreversible)

A compression connection is a technique where connection between two or more conductors or between one or more conductors and a terminal is achieved by means of mechanical pressure and without the use of solder. Conductors of dissimilar metals shall not be intermixed in a terminal or splicing connector where physical contact occurs between dissimilar conductors, unless the device is identified for the purpose and conditions of use. The connection is essentially irreversible without destroying the original connection.

5.1.20.5 Structural Joining Methods

Joints made with high-strength structural bolts and clean unpainted faying surfaces shall be considered as sufficiently bonded to meet the electrical requirements of this standard. The term “clean” as used herein shall mean that faying surfaces on new steel shall have been cleaned to bare metal. Where this condition does not exist, a jumper in the form of a No. 4 AWG bare copper wire exothermally welded at each end to the surfaces involved spanning the connection, or a bond weld defined as a ¼-inch (6.4mm) or larger fillet weld with a 2-inch (50mm) minimum length across the connection would meet the requirements of this standard. Wire jumpers shall be used across joints employing miscellaneous machine bolts such as those used in stairway construction.

5.1.20.6 Cleaning of Bonded Surfaces

Before joining, all surfaces that comprise a bond shall be thoroughly cleaned to remove paint, oxides, and other resistance films from the mating surfaces. Gentle and uniform pressure and an appropriate abrasive shall be used to ensure a smooth, uniform surface without point contacts. Excessive metal shall not be removed from the surface. Clad metals shall be cleaned with a fine steel wool or grit in such a manner that the cladding material is not penetrated by the cleaning process. Bare metal shall then be cleaned with a solvent-moistened cheese cloth. Grease, oil, dirt, corrosive preventatives, and other contaminants shall also be removed using this same method. This cleaned area shall be allowed to air dry before connection of the bond. The bond shall be attached within 1 hour after cleaning. The joints shall be sealed, and the exposed surfaces shall be refinished within 2 hours to prevent oxidation. If additional time is required, a corrosion preventative shall be applied until the area can be refinished.

5.1.20.7 Corrosion Inhibitor

All bonds made using compression or bolted connectors shall be prepared as described in section 5.1.20.6. A conductive corrosion inhibitor shall be applied to the connector mating surfaces before the connection is made.

5.1.20.8 Bonding Straps and Jumpers

Unless otherwise specified, bonding straps and jumpers shall be copper and shall have a cross-sectional area of not less than that of No. 6 AWG copper wire. Bonding straps and jumpers for shock-mounted devices (pivot, hinged, or swivel joints) shall be made of flat-tinned copper woven wire braid or flexible stranded wire. Vibration of the strap or jumper by the shock-mounted device shall not change its electrical characteristics. Bonding jumper installation shall conform to the following:

a. Bonds shall be accomplished by brazing or welding in outdoor locations unless a disconnect type of connection is required, in which case clamping with bolts shall be used. For each bolt, a tooth-type lock washer shall be inserted between the strap and metallic member.

b. The straps shall be bonded directly to the basic structure rather than through any adjacent parts.

c. When installed, the straps shall be unaffected electrically by motion or vibration.

d. The straps shall be installed in an area that is accessible for maintenance.

e. Single straps shall be used; two or more straps shall not be connected in series.

f. Straps shall be installed so they will not restrict movement of structure members.

g. Straps shall be installed so they will not weaken structure members to which they are attached.

5.1.21 Ground Plate and Ground Point Identification

Where required in the design, equipment grounding plates and grounding points shall be made easily identifiable. An Operational Check sticker (see figure 3) shall be affixed to the ground plate or ground point identifying the date checked for new construction. The next check due date will be established by operations and maintenance (O&M).

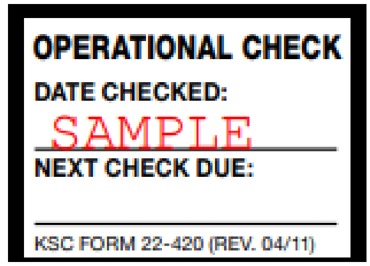


Figure 3. Operational Check Sticker for Ground Plate

5.1.22 Metallic Fences Used as Personnel Barriers

All gates, gate posts and corner posts should be grounded. Fences shall be grounded at intervals not to exceed 1000 feet (305m). In addition, fences shall be grounded at 150 feet (46.3m) on either side of a point where power lines and/or communication lines cross the fence. Fences within 10 feet (3m) of a lightning-protected structure shall be grounded to the structure counterpoise.

5.1.23 Metallic Fences for Electrical Substations

Substation fences shall be bonded to the station counterpoise at intervals not exceeding 100 feet (30.5m). Each fence side shall have at least one bonded connection to the counterpoise regardless of length (a minimum of four bonded connections for a square or rectangular fence). Each gate post shall be bonded to the counterpoise. The top rail and posts shall be grounded with No. 2/0 AWG bare copper wire and connected to substation grounding grid. The ground grid shall be connected to the nearest metallic water main and complex grounding counterpoise, if available (see figures 4 & 5).

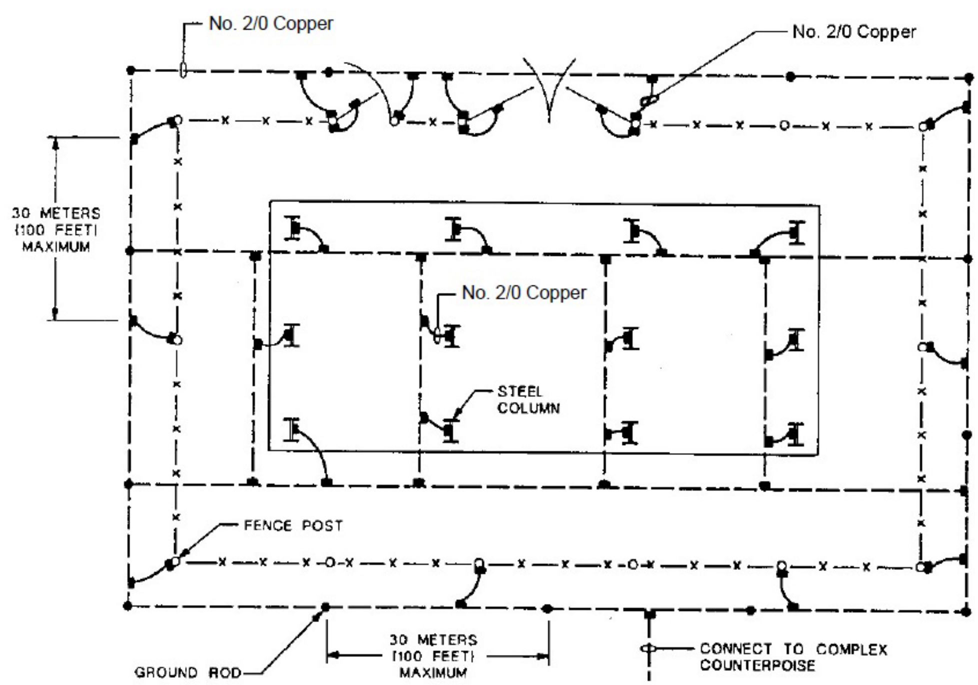


Figure 4. Connection of Substation Fence and Structural Steel

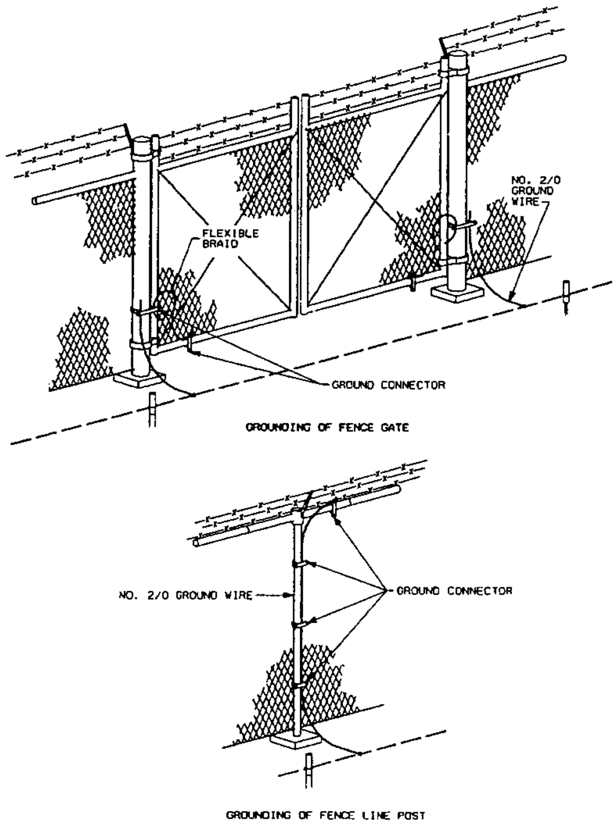


Figure 5. Substation Fence Detail

5.1.24 Additional Requirements for Hazardous Zones

In addition to the general Non-Hazardous Zones requirements specified above, areas classified as Hazardous Zones (see section 3 for zone definitions) shall comply with the requirements of section 5.1.24.1. Additionally, for each designated Hazardous Zone, the design basis shall explicitly identify the specific hazard types present (e.g., flammable/explosive atmospheres, launch/processing hazards, EMI-sensitive environments, mission-critical operational requirements, personnel-exposure-driven hazards, or combinations thereof).

Facilities and areas used for storage, transfer, handling, venting, or processing of fuel, propellants, oxidizers, POL, flammable gases, or liquids capable of producing flammable vapors shall be designed to minimize ignition probability due to direct lightning attachment, side flash, upward leaders, sparking, touch voltage, transferred potentials, static discharge, and lightning-induced transients. The design shall identify vent locations, vapor-release zones, tanks, piping, loading/unloading interfaces, instrumentation, control wiring, electrical equipment, cable shields, metallic structures, and conductive services that require bonding, shielding, separation, surge protection, or direct-strike protection.

Vent outlets, vapor-release locations, tanks, piping systems, loading/unloading interfaces, and exposed conductive features shall be located within an appropriate protected volume where practicable or otherwise evaluated by engineering analysis. Lightning protection for these areas shall include attachment control, bonding of metallic piping and structures, control of side-flash/separation distance, avoidance of ignition-capable sparking, use of SPDs and electrical components suitable for the classified/hazardous location and circuit type, and post-event inspection criteria following known or suspected direct attachment or recurrent lightning-related anomalies.

5.1.24.1 Hazardous Zone Requirements

a. Metal Objects – All outdoor exposed metal objects exceeding 48 inches (122cm) in any dimension shall be bonded to ground. Fuel and oxidizer handling equipment shall be bonded to ground.

b. Structure Metals - In structures housing explosives or hazardous materials, all reinforcing steel (concrete construction) and all enclosing metal coverings (walls, roofs, floors, and interior partitions) shall be bonded together and grounded. Objects less than 24 inches (61cm) in their largest dimensions are exempted.

c. Heating, Ventilating, and Air-Conditioning Systems – Metallic heating, ventilating, and air-conditioning ducts shall be bonded together and grounded on each end as a minimum. Jumpers shall be used across flexible connections and shall be bonded to the flanges by brazing or welding. Regular slip joints between duct sections consisting of locking devices or sheet metal screws are considered adequately bonded and require no additional bond straps.

d. Metal Piping (non-electrical) - Metal pipe shall be bonded to ground at the end terminations and at intervals of not more than 100 feet (30.5m). For internal locations, bonding can be by clamping methods if continuous pressure follow-up is provided with serrated or spring washers. External locations shall have brazed or welded bonds, except stainless-steel clamps can be used to bond stainless steel pipe to ground if the restrictions of dissimilar metals as presented in this standard are considered. Threaded joints that have a tapered thread are acceptable if they are drawn up tightly with a corrosion-inhibiting compound applied on both the internal and the external threads to ensure an adequate bond across the joint. Tubing sections joined with fittings that seat metal-to-metal are considered adequately bonded. Flanged joints are acceptable if the flanges are stainless steel or the flanged areas are in contact with the bolt heads and the washers are clean and bright. Bolts and nuts shall be maintained tight. Serrated or spring washers may be used with bolts and nuts to maintain tightness. Flanged joints used in liquid hydrogen (LH_2) systems shall be bonded in accordance with 76K04932. Flanged joints used in LO_2 systems shall be bonded in accordance with 76K04892.

e. Exotic Piping - Bimetallic and vacuum-jacketed piping shall be bonded by clamps or attached grounding lugs and pigtails of compatible material.

f. Special Structures – Bonding and grounding required to incorporate any special shielding enclosures or other special equipment shall be performed as specified by the designers of such hardware. The methods employed in implementing these requirements shall not conflict with any provision of this standard.

g. Reinforced Concrete - As illustrated in figure 6, each vertical reinforcing bar shall be brazed or welded to two adjacent transverse reinforcing bars consecutively changing bonding point on successive vertical bars, making all bars electrically continuous. A bonding jumper shall be installed from this plane to ground (as shown, building structural steel) at maximum intervals of 50 feet (15.3m). Welded wire fabric shall be brazed or welded together at the edges on 4-foot (122cm) centers and connected to reinforcing steel on 4-foot (122cm) centers.

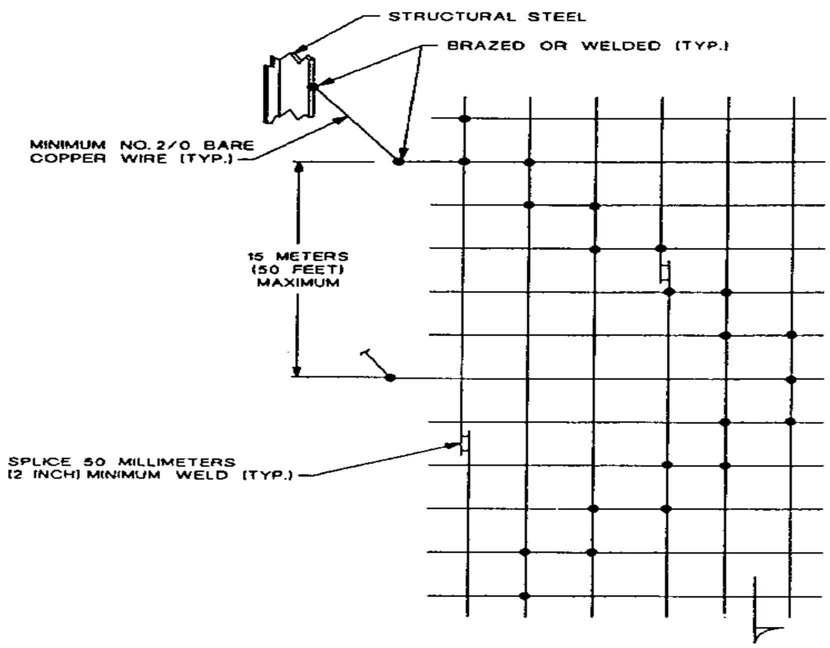


Figure 6. Bonding and Grounding of Reinforced Concrete

5.1.25 Resistance Values

The following resistance values represent the maximum allowable resistance values needed to achieve the requirements of this standard for facility grounding and lightning protection. The designer shall incorporate sufficient details within the design to ensure these values are met. Refer to KSC-STD-E-0022 for bonding and grounding requirements and resistance values for GSE and GSS.

Resistance values in this section shall be verified using measurement methods appropriate to the parameter being measured. Earth resistance values for ground rods and counterpoise systems shall be measured using IEEE Std 81 methods where practicable. Metallic path resistance and bond resistance measurements at milliohm levels shall be performed using a calibrated low-resistance ohmmeter with a four-wire Kelvin test configuration, or another AHJ-approved method capable of resolving the specified resistance value with documented lead compensation, calibration status, and test-current adequacy. The test procedure shall identify whether the circuit is isolated or measured in the installed condition with parallel paths present and shall include appropriate safety controls for energized or operational facilities.

5.1.25.1 Facility Equipment to Counterpoise

The total resistance from any point on the building structure, equipment enclosure, facility ground plate, or any other grounded equipment to the counterpoise shall not exceed 50 milliohms.

5.1.25.2 Power Ground

The total resistance from the neutral (e.g., Xo point of a three-phase transformer) of the power source through the connection (e.g., grounding electrode conductor) to the counterpoise ground shall not exceed 20 milliohms.

5.1.25.3 Electrical Equipment Enclosures

The total resistance from each electrical equipment enclosure to the earth grounding counterpoise shall not exceed 50 milliohms.

5.1.25.4 Lightning Protection System to Counterpoise

The conductive path from each air terminal, catenary support, mast, down conductor, structural steel down path, or other strike-termination component to the counterpoise shall be electrically continuous and shall be verified by an approved low-resistance measurement method. The total resistance between the conductive path of each air terminal and the counterpoise shall not exceed 10 milliohms if copper, and not greater than 200 milliohms (NFPA 780) if aluminum.

5.1.25.5 Static Grounds Resistance to Counterpoise

Low resistance is not required for static grounds. At KSC, resistances from 0.1 to 1 megaohm are used to provide static grounds between the grounded object and the counterpoise. These series resistors may be installed in wrist stats and leg stats (refer to A.2.2 in appendix A).

5.1.25.6 Ground Rod & Counterpoise to Earth

The maximum resistance from a single ground rod to the earth shall not exceed 25 ohms. The resistance from the complete counterpoise system to earth shall not exceed 5 ohms and shall be measured from a test well or other accessible location for testing. See section 6 for testing and recording requirements.

5.1.25.7 Bond Resistance

The resistance of any bond connection shall not exceed 2.5 milliohms, unless stainless steel wire ropes are used. When stainless steel wire ropes are used, the resistance of any bond connection shall not exceed 10 milliohms. During construction, bonds shall be tested as they are created. Bond resistance shall be tested using the 4-wire Kelvin method or other method approved by the government.

5.1.25.8 End-Device-to-Counterpoise Resistance

The resistance between the end device (such as a receptacle ground connection) and the counterpoise shall not exceed 1 ohm.

5.1.25.9 Raised Floor Resistance to Counterpoise

Raised floors used as an equipotential plane for automatic data processing, computer, and other electronic equipment shall have test resistance value of 20 milliohms or less measured from selected points on the floor grid system to the counterpoise.

5. 2 Lightning Protection Requirements

5.2.1 General

All facilities shall be evaluated using the Risk Assessment framework from IEC
and protected accordingly. A lightning protection system shall "safeguard the facility from hazards arising from exposure to lightning" (NFPA 780) and shall provide a zone of protection, as defined in NFPA 780, appropriate for the facility and its intended use. The method of bonding, lightning protection, power, control, and communication system grounds shall be evident on the design drawings.
KSC only recognizes lightning protection systems as defined by NFPA 780, UL 96, and IEC. Unconventional systems, such as Early Streamer Emitters (ESE), Dissipation Array Systems (DAS), Charge Transfer Systems (CTS), Dissipation Devices, Lightning Suppressor, Streamer Retarding Air Terminals, Dissipation Devices, or any other type of lightning elimination or dissipation device shall not be used in any NASA facility or structure at KSC and CCSFS.

A facility equipped with a compliant LPS reduces the risk of physical damage and fire from direct lightning strikes by providing intended strike-termination, bonding, and current-conduction paths. Internal electrical/electronic systems, exterior circuits, conductive services, SPDs, shielding, bonding, and post-event verification must be addressed separately to control lightning-induced effects and residual risk. For buildings where explosives, solid propellants, toxic or flammable liquids and gases, or petroleum, oils, and lubricants (POL) are handled or stored, the lightning protection system shall be designed in accordance with NFPA 780, Chapters 7 and 8. Grounding systems associated with lightning protection systems shall be in accordance with the requirements of section 5.1 of this standard. Resistance values for all lightning protection system connections and components shall meet the requirements of section 5.1.25

When bonding roof conductors or air terminals to structural steel or routing down conductors inside the facility, through-roof connections shall be made in such a way that a clamp on loop resistance meter can be used to verify bonding of the roof conductor to down conductor or structural steel.

5.2.2 Materials

The minimum materials requirements to be used in lightning protection system design for all KSC facilities shall be class II materials as defined in NFPA 780. For lightning protection systems, copper shall be specified and utilized for all system components. Areas within one mile of salt or brackish water or other installations with specific corrosion concerns shall specify copper materials. Where building construction causes concern with the use of copper, aluminum materials may be used on a case-by-case and approved basis. Aluminum down conductors shall transition to copper, using approved connection hardware, above grade using bi-metallic connectors listed and approved for the purpose. Design shall require these bi-metallic connectors to be within 3-6 feet (0.9-1.8m) of ground level as to be accessible without the use of ladders or lift equipment.

For metal roof or other conductive roof assemblies, lightning protection conductors shall be installed so that direct contact with roof surfaces is avoided to prevent corrosion. Where conductors are routed across metal roof panels, a continuous protective isolation layer such as a

35-mil single-ply peel-and-stick membrane, 12 inches (30cm) wide or equivalent, shall be installed beneath the conductor along its entire run. This requirement applies to adhered air terminals and conductor routing on metal roof systems. When protective isolation layer is utilized, roofing manufacturer approval and compatibility with roof membrane, warranty, and environmental exposure will be required.

5.2.2.1 Overhead Ground Wire (OHGW) Systems

Materials recommended for OHGW systems are specified in section 5.2.3 and in Table B.1 of Appendix B.

5.2.3 Grounded Masts and Catenary Wire System

5.2.3.1 Protected Area

Catenary wire LPS shall be designed so protected components are within the calculated zone/protected volume, with direct-attachment exposure minimized or eliminated to the extent required by the hazard and mission analysis. The catenary wire LPS shall be used for facilities that launch or process spacecraft, facilities located within other hazardous zones, and facilities or structures housing explosive or flammable materials, to ensure that no component is exposed to a direct lightning strike. This also applies to testing areas utilizing explosive fuels or materials. Launch Pad Lightning Protection Systems require special analysis to determine dimensioning of insulating masts, safety distances, etc. Designers shall meet the requirements of NFPA 780, Chapter 8, and IEC.

5.2.3.2 Clearance Between Conductive Mast and Protected Structure

For structures not over 50 feet (15.2m) in height, clearance for conductive masts or wood masts with down conductor cables shall not be less than 6 feet (1.8m) from the protected structure in order to prevent side flash from the down conductor to the structure. The clearance shall be increased by 1-foot (30cm) for every 10 feet (3m) of structure height above 50 feet (15.2m). All masts shall be grounded and connected at ground level to the grounding system of the protected structure.

5.2.3.3 Clearance Between Catenary Wire and Protected Structure

The minimum clearance between a catenary wire and the highest point on the protected structure shall be based on project-specific engineering analysis for launch pad, spacecraft processing, hazardous, and nonconventional facilities. Catenary wire ground conductors shall be bonded with the grounding system of the protected structure.

5.2.3.4 Rooftop Antenna Protection

Rooftop antenna installations at KSC and CCSFS that require lightning protection, such as microwave dishes and helical or Yagi antennas, shall be protected from direct strikes by catenary wire, which is insulated from the antenna and grounded to the building structure or lightning protection conductors (see figure 7). Other antennas mounted on elevated platforms shall be protected in a similar manner. Antenna hardware shall be separately bonded to the building structure or to the lightning protection system. If antennas do not require protection from direct strikes, they shall be grounded and bonded in accordance with TIA-222-I. In addition, the metal bases of helical and Yagi antennas and the supporting pedestals of microwave dishes shall be bonded to the building structure or lightning protection conductors.

All rooftop antennas, television cameras, lights, and other installations that have cabling entering the building structure shall be shielded and properly protected from lightning. The designs, installation, maintenance plan, and configuration control plan shall be reviewed by the KSC Lightning Safety Assessment Committee (ksc-lightning-safety@mail.nasa.gov).

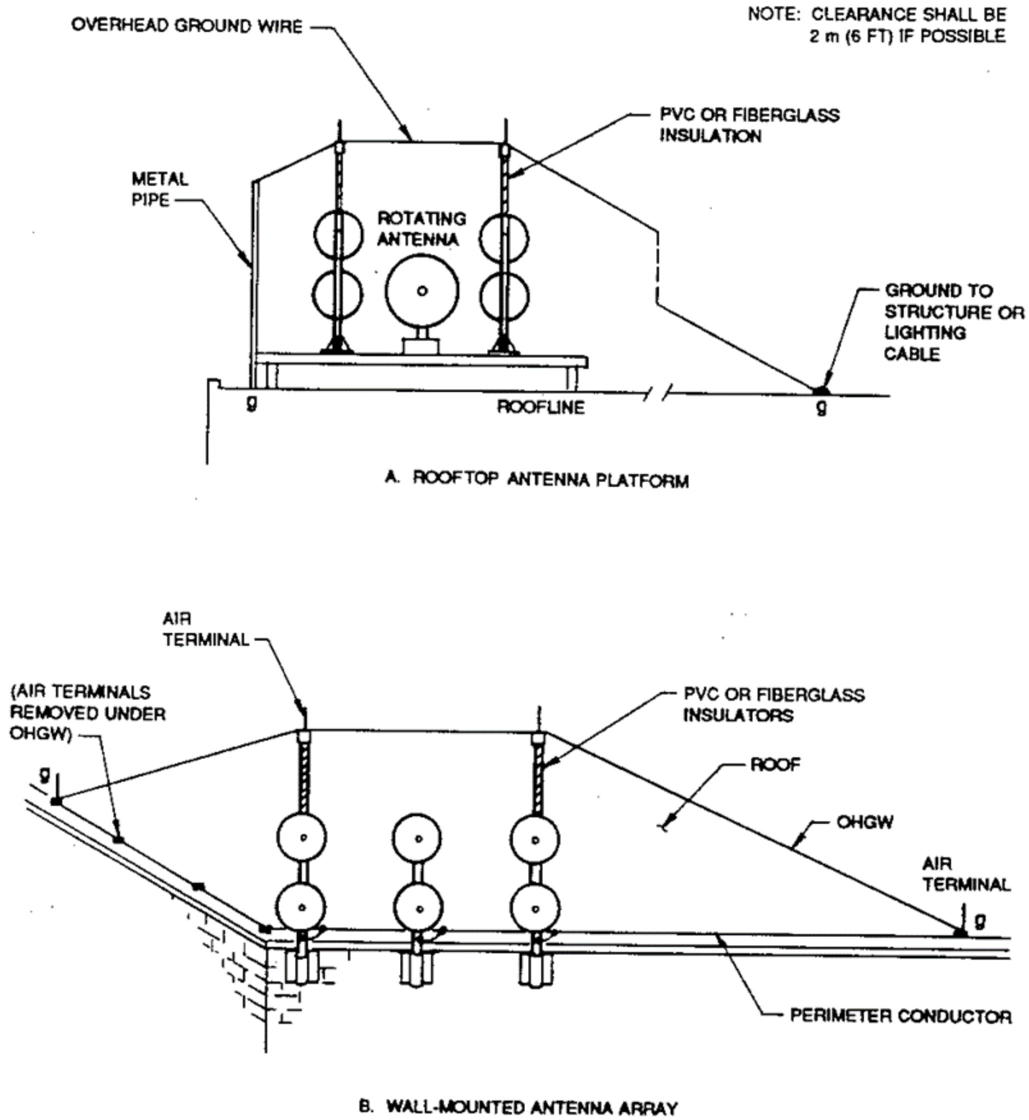


Figure 7. Rooftop Antenna Lightning Protection

5.2.3.5 Environmental Design Criteria for OHGW Installations

IEEE C2 defines the loading requirements for extreme winds on structures exceeding 60 feet (18.3m) above ground or water level, including OHGW's, towers, and poles. Criteria in IEEE C2 shall be used in the design of all affected OHGW systems.

5.2.4 Towers Located Near Structures

Towers supporting antennas and other sensors are often located near structures containing equipment and systems connected to the antennas and sensors mounted on the tower. When the towers are struck by lightning, part of the current is conducted inside the structure to the equipment via the connecting cables. To prevent damage and sparking inside the structure, the tower shall be grounded by at least two 20-foot (6m) ground rods. All cables from the tower to the structure shall have an overall shield of at least 98 percent optical coverage or be enclosed in a covered metal cable tray. Where 98 percent shield coverage is not practical, equivalent shielding/bonding/transient protection shall be utilized. The cable shields or covered tray shall be connected, using 360-degree coverage, to an external grounded metal plate or box. For structures with grounded external metal siding, the plate or box shall be connected to the external siding of the structure with 360-degree coverage. For other structures, the interface plate or box shall be grounded by connection to the building counterpoise and to at least one 20-foot (6m) ground rod at the interface.

Where power cables are routed between towers and adjacent structures, suitably rated lightning arresters or SPD devices shall be applied for protection.

5.2.5 Material Corrosion-Resistance, Compatibility, and Suitability

Cables and hardware selected for OHGW or catenary overhead wire systems shall be composed of materials that are noncorrosive for conditions at the site, galvanically compatible, and sized to carry the lightning current dictated by operational lightning protection requirements. Recommended cables are listed in Appendix B.

5.2.6 Railroads

Loading and unloading operations from ungrounded tank cars are not permitted at KSC facilities. Railroad tracks in hazardous areas, fuel transfer locations, or flight hardware transfer locations, shall be grounded for lightning protection as shown in figures 8 and 9 and as referenced in NFPA 780 section 8.5.7. This requirement also applies to service carts and flame-deflector tracks. Railroad tracks located within 50 feet (15.2m) of a building shall be bonded to the facility counterpoise system as shown in figure 8.

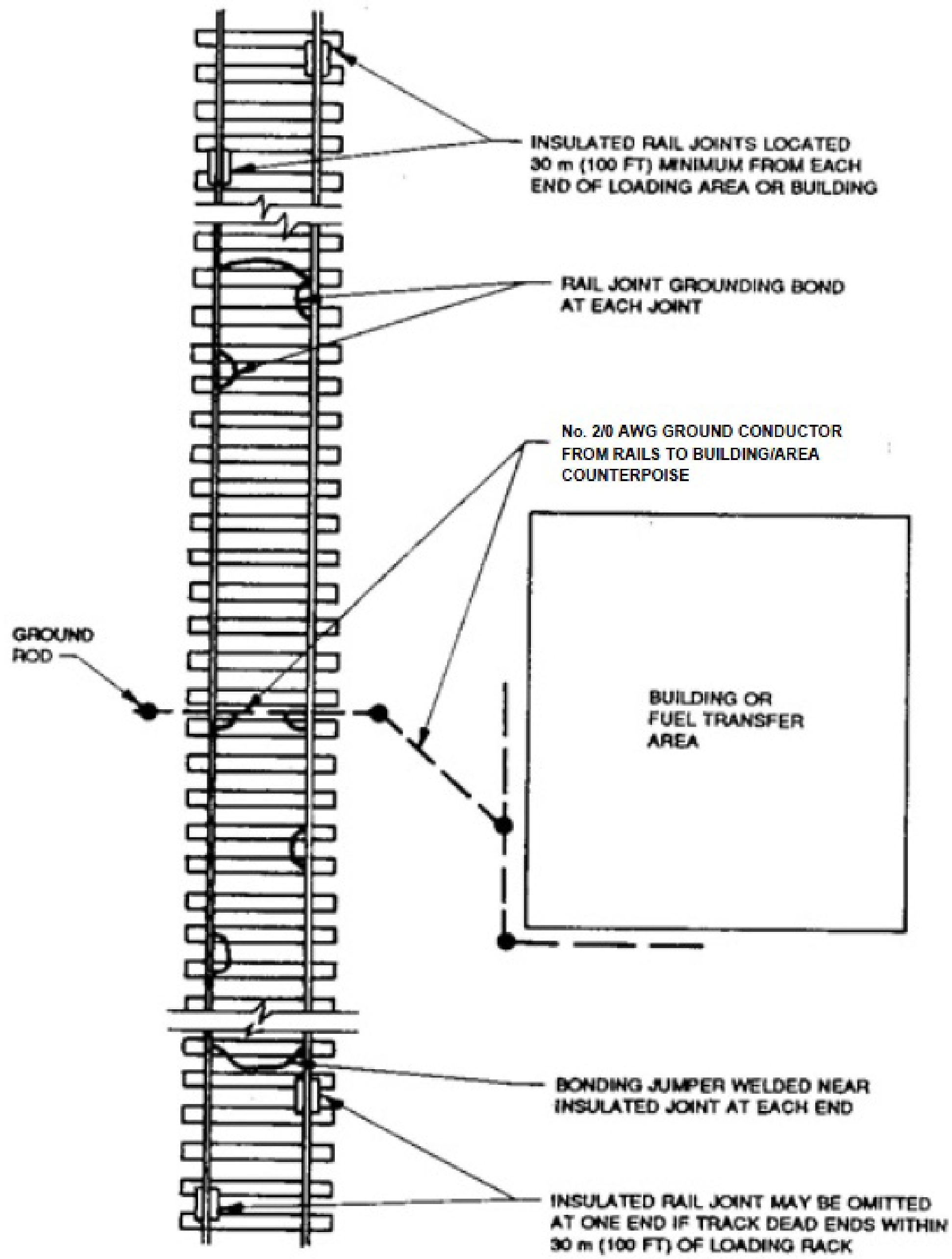
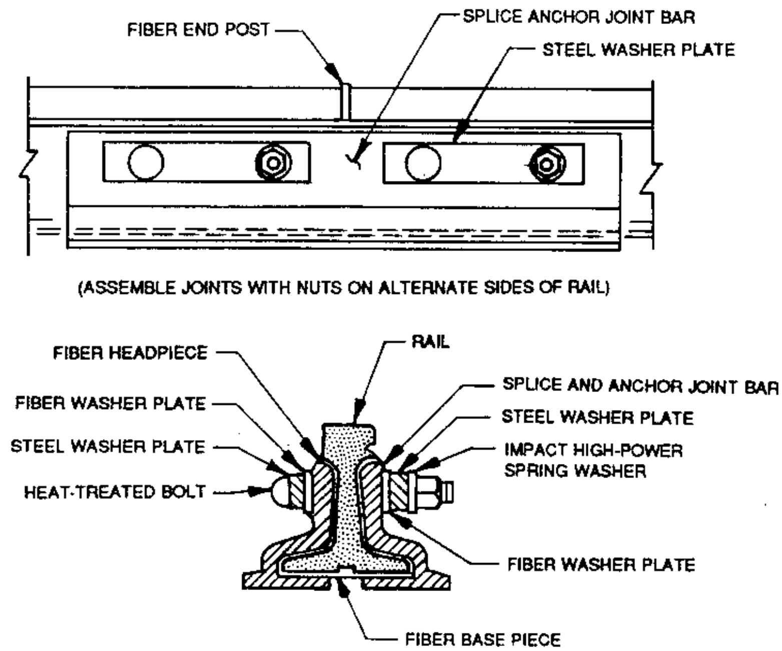
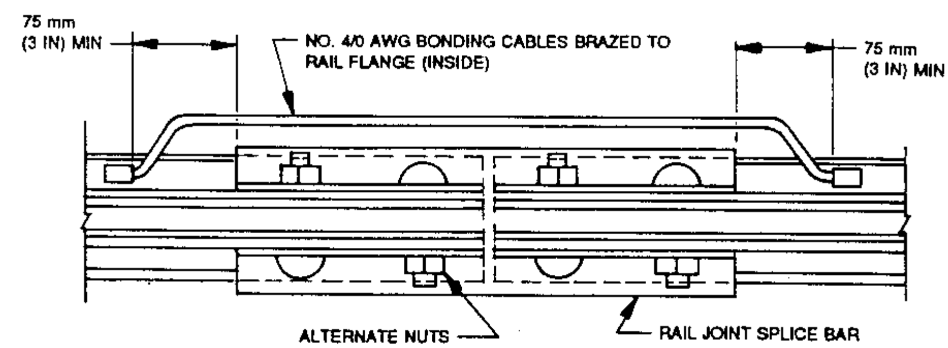


Figure 8. Lightning Protection Requirements for Railroads



5(a) SIDE AND SECTION VIEWS OF A TYPICAL INSULATED JOINT



5(b) TOP VIEW OF A TYPICAL BONDED RAIL JOINT [USED WITHIN 15 m (50 FT) OF STRUCTURE]

Figure 9. Railroad Track Details for Lightning Protection

5.2.7 Medium Voltage (MV) Pad-Mounted Transformers, Underground Cables, and Unit Substations/Switching Stations

5.2.7.1 MV Surge Arresters

Medium-voltage surge arresters shall be applied as specified in the following paragraphs and shall comply with IEEE C62.22. Because KSC employs neutral grounding resistors for maintenance activities on medium-voltage circuits, surge arresters installed on 13.2kV or 13.8kV systems shall be rated 15kV duty cycle with a Maximum Continuous Operating Voltage (MCOV) of 12.7 kV. If neutral grounding resistors are not present in the medium-voltage circuit, IEEE C62.22 application guidance applies.

5.2.7.2 MV Pad-Mounted Power Transformers

Power transformer insulation shall be protected from the voltage surge of the traveling wave coming in on the lines. This protection shall be accomplished by means of lightning arresters located as close as possible to the equipment to be protected on each primary bushing. An arrester shall be chosen whose discharge voltage is lower than the basic impulse level (BIL) rating of the transformer insulation.

5.2.7.3 MV Underground Cables

Underground feeder cables radiating from a substation bus shall have lightning arresters installed to protect the cable. The arresters shall be connected directly to open terminals of the cable pothead.

5.2.7.4 MV Switching Stations

Medium voltage switching substations are defined as a line-up of 5kV or 15kV class metal-clad Switchgear, Motor Control Center (MCC), VFI, or LBS installed within a facility or outdoors in a weather-proof enclosure. Switching stations shall incorporate surge protection using arresters that may be located on the bushings of a spare switch way or cabinet. The surge arrester grounding wires, concentric neutral shields, and other supplying source ground conductors shall be directly connected to the equipment ground pads, metal conduits enclosing the conductors, and all other local earth ground systems associated with the equipment.

5.2.8 Aboveground Cable Trays

Cable tray lightning protection systems shall be as depicted in figure 10.

Specifically:

a. An overhead ground wire (minimum 2/0 AWG bare copper wire) shall be run parallel to the cable tray supported by metallic support posts with as minimum sag as possible. The overhead ground wire shall be electrically bonded to the metallic support post at each post.

b. The metal support posts shall be insulated from the tray support posts by air or post insulators. The metallic support posts shall be installed so they align with the cable tray support posts.

c. Each tray support post shall have a ground rod installed next to it. The metallic support post and the cable tray bonding cable shall be electrically bonded at ground level where the grounding rod is located; the No. 2 AWG (minimum) copper conductors, running down to the ground rod, shall be insulated and protected with suitable cable guards to prevent physical damage or displacement.

d. A counterpoise shall run parallel to the cable tray and be electrically connected to each grounding rod. The counterpoise shall extend for the length of the cable tray and shall be electrically bonded to the facility lightning protection system at each end.

e. Cable tray sections shall be electrically bonded by exothermic weld of bonding wires to ensure electrical continuity. Cable tray metallic covers shall be electrically bonded to the cable tray.

The height of the supporting metallic poles and overhead ground wire shall be such that the cable tray lays in its entirety underneath the area of protection.

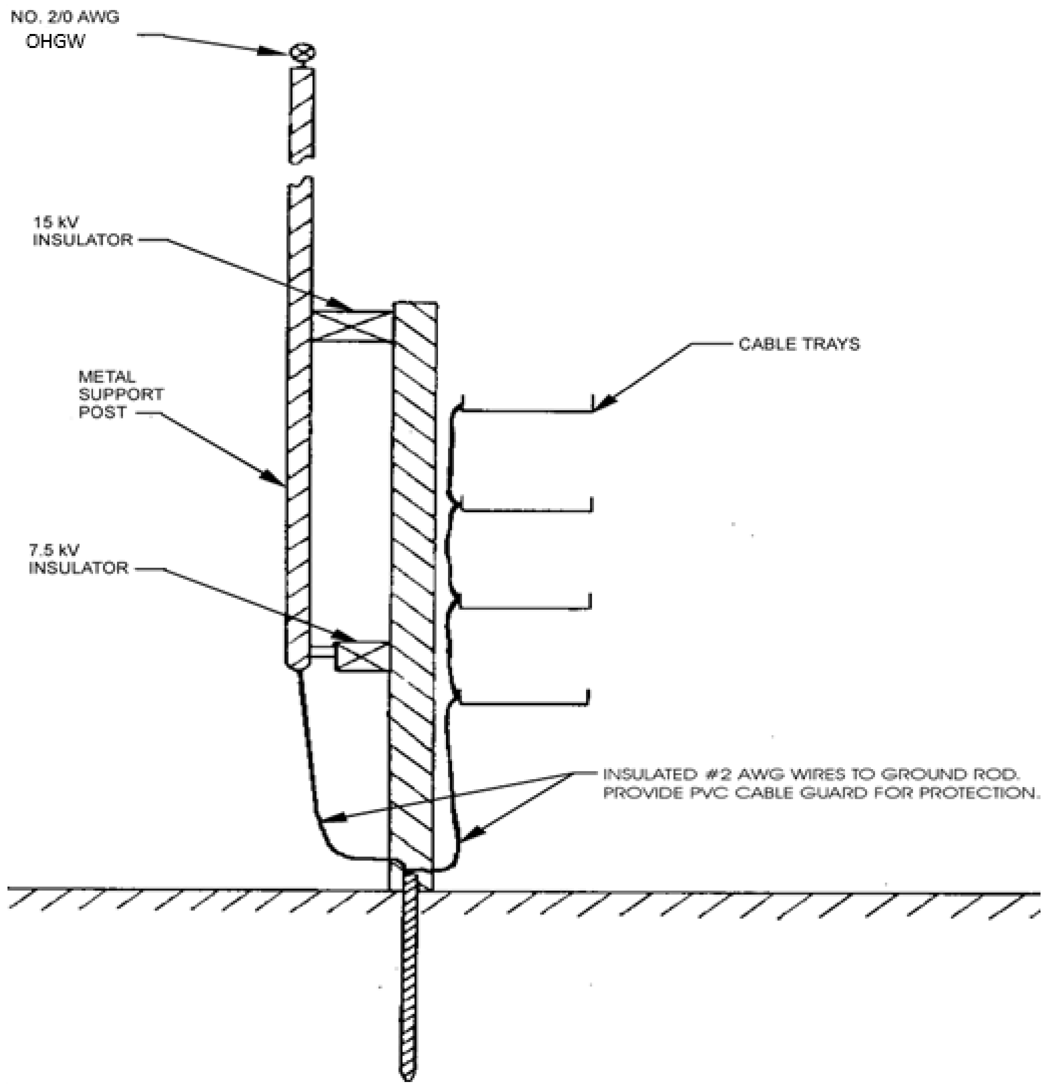


Figure 10. Lightning Protection for Cross-Country Cable Trays (60-Hertz, 15-KV Rating)

5.2.9 Overhead Distribution Lines

Overhead distribution lines (open wire or aerial cable) may consist of either high-voltage primary or low voltage secondary circuits, or both. These circuits are normally carried on wood or concrete poles. They shall be protected against direct lightning strikes with an overhead ground wire mounted on insulators above the conductors. The height of the OHGW wire above the phase conductors shall be governed by IEEE 1410 requirements (See figure 11). In addition, the following requirement shall apply:

a. The OHGW wire shall be bonded to the underground supplying circuit concentric neutral and duct bank ground using jumpers equal in size to the OHGW wire. The metallic conduit enclosing the underground conductors shall also be bonded to this ground.

b. All pole line insulators and hardware shall be rated for ocean salt spray. All insulators and hardware shall be designed specifically for pole-line use.

c. Minimum OHGW wire size shall be #1/0 All-Aluminum Alloy Conductor (AAAC); ASCR conductor is not acceptable.

d. Ground rods shall be installed to obtain less than 10 Ohms Earth resistance at each pole and shall be connected to the overhead grounded OHGW wire. Minimum bonding wire size shall be No. 6 copper. All metallic bodies on the pole including primary attachment hardware, lighting, concrete pole internal ground shall be bonded to the pole ground.

e. Pole distribution transformers shall be connected line to line only. Transformer secondary neutral shall be connected directly to both the system neutral and pole ground.

f. Surge arresters shall be installed on all phases and spaced approximately every 400 feet (122m) or every other pole based on design arrangement. Specification and application of the surge arrester shall be in accordance with IEEE C62.22. Surge arresters shall also be installed:
    i. At all dead-end poles.
    ii. At all poles with underground riser connections.
    iii. At all poles with mounted equipment such as transformers.

Overhead distribution lines shall be designed using IEEE Std 1410 methods to improve lightning performance. The preferred configuration for new or substantially modified KSC overhead distribution lines shall place the overhead ground wire above the phase conductors with shielding geometry selected to reduce shielding failures, backflashover probability, and lightning-related flashovers. The OHGW shall be electrically bonded to the pole grounding system at each pole unless an approved engineering analysis specifies another grounding interval. Surge arresters shall be applied at dead-ends, riser poles, equipment poles, transformer poles, and at intervals determined by the line configuration, grounding resistance, BIL, exposure, and IEEE Std 1410 analysis. Drawings shall show arrester locations, grounding details, downlead routing, and BIL assumptions.

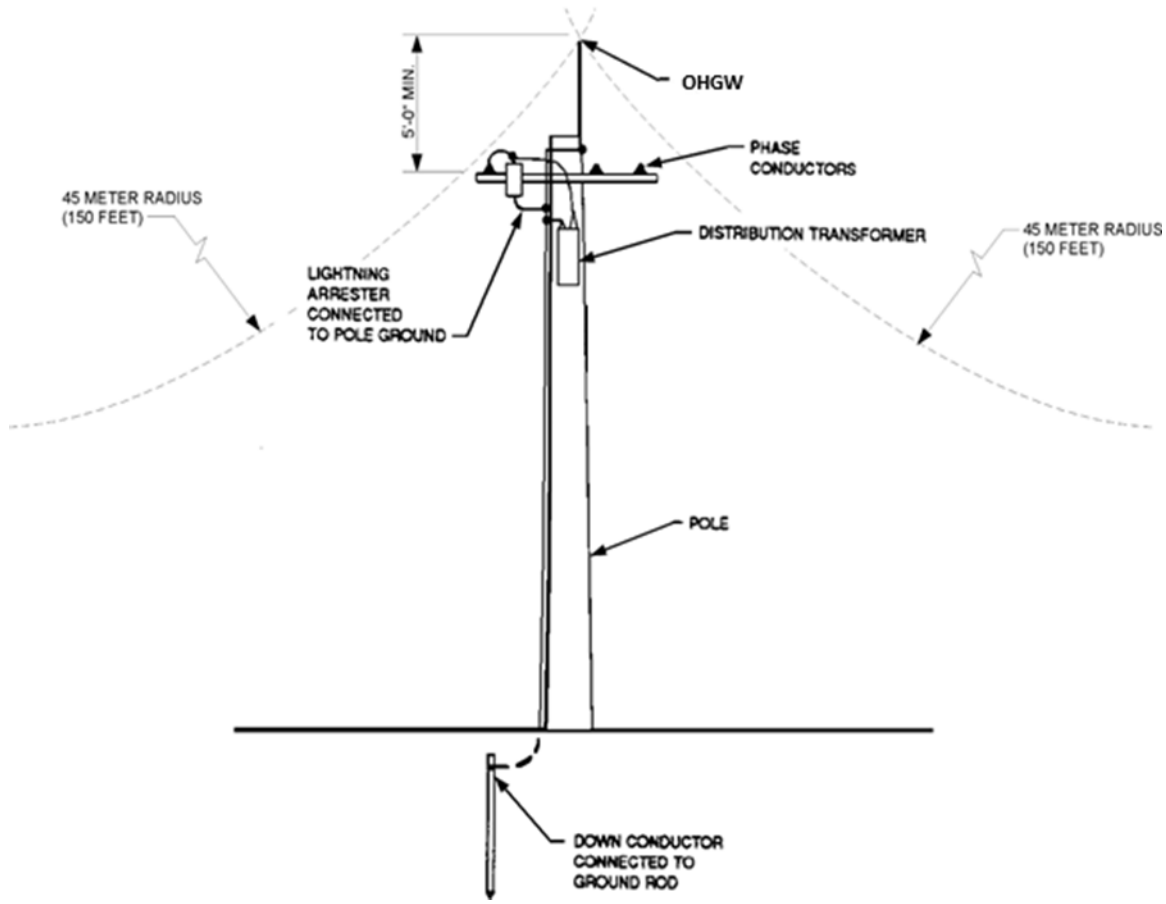


Figure 11. OHGW Wire and Lightning Arrester Typical Installation

5.2.10 Outdoor Communications and Instrumentation Equipment

5.2.10.1 Outdoor Equipment

Exposed communications and instrument equipment and terminal facilities shall be protected against direct lightning strikes. The methods employed may consist of catenary wire, grounded masts, or lightning systems placed on adjacent structures. Pole-mounted circuits shall be protected by overhead OHGW wires.

5.2.10.2 Lightning Surge Protection

Communication and instrumentation cables shall be provided with protection against induced high-voltage surges. This protection shall be afforded through the judicious use and application of lightning arresters, spark gaps, and shielding and grounding techniques. Any critical facility electronic equipment that has interconnecting cables, power, or data that extend outside the facility lightning protection system shall be protected by surge protective devices, as discussed in section 5.3.5; where possible, fiber-optic-based cable systems, with nonconductive cable sheaths, should be considered for use.

5.2.11 Underground Duct Banks

Designs for communication, instrumentation, and power cable duct banks shall include the following features (see figure 12)

a. A buried minimum No. 2/0 AWG bare copper counterpoise whose spacing above the duct bank is not less than 10 inches (25cm). Duct banks less than 36 inches (1m) wide require only one counterpoise wire. Duct banks wider than 36 inches (1m) may require two counterpoise wires and the spacing shall be as referenced in NFPA 780 (figure 11.4.3.1).

b. The subterranean configuration of the counterpoise cables to the duct bank tubes shall be maintained when the items are exposed above ground, such as at ditch crossings.

c. The counterpoise shall be connected to ground rods driven at intervals not to exceed 100 feet (30.5m) and at manholes.

d. New counterpoise systems shall be bonded to existing adjacent counterpoise systems. Where raceways are installed by directional bore, jack and bore, or other drilling methods, the counterpoise conductor shall be permitted to be installed concurrently with the drilling method raceway, external to the raceway or sleeve in accordance with NFPA 780.

e. The installation method described in paragraph (d) shall be used primarily where existing pavement cannot be cut. While this process may result in the counterpoise conductor being wrapped around the raceway in an unknown position, the installation is required to maintain the equipotential bonding of the overall lightning protection system.

f. Where multiple directional bores are necessary, each end of the counterpoise conductor shall be dedicated to its respective directional bore.

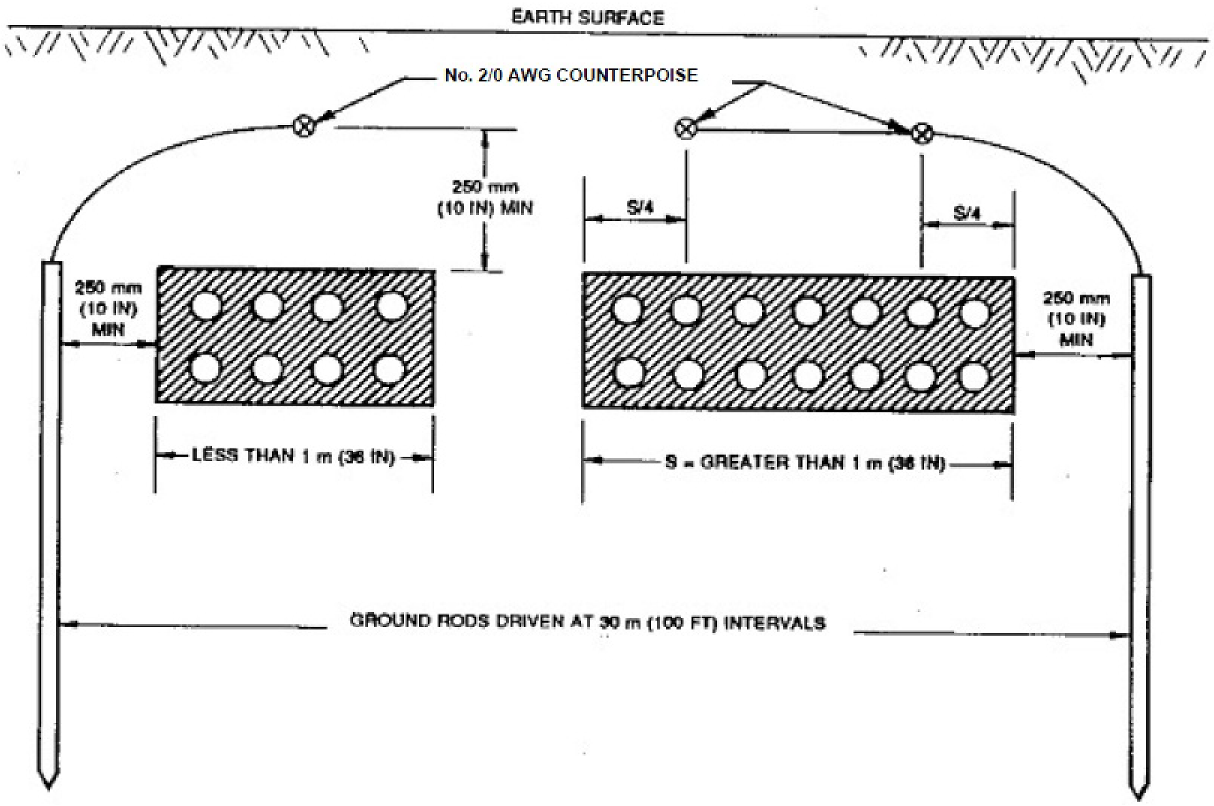


Figure 12. Lightning Protection for Underground Duct Banks

5.2.12 Guard Stations and Gates

Guard stations and guard gate lightning protection systems shall be designed in accordance with NFPA 780 and NFPA 70. Since methods of construction are not uniform, lightning protection requirements must be tailored to each installation. The design shall specifically indicate how all lightning protection, facility grounds, system grounds, and metallic bodies are bonded. The following design guidelines shall be considered:

a. Lightning mast poles with catenary systems, and lightning poles shall be utilized as part of the lightning protection system to help divert any lightning from directly striking guard house or gate structures.

b. Light poles located near guard facilities must be made part of the lightning protection system.

c. Communications antennas should not be located on roofs or poles without adequate consideration of lightning protection.

d. Provide surge protection for all conductors entering or exiting the lightning protected area, including telephone, ethernet and power cables. Antennas and connecting conductors shall be protected with the design and application of Surge Protective Devices (SPD) per section 5.3.

e. Provide for the necessary accessible test points and test wells.

5.2.12.1 Personnel Safety Requirements

The following shall be addressed when designing guard stations where personnel are required to perform their duties outside during the presence of lightning activity:

Equipotential ground planes and ground grids may reduce step-potential hazards but shall not be considered sufficient by themselves to make outdoor personnel safe during lightning activity. Outdoor personnel may remain exposed to direct lightning attachment, upward leaders, side flash, touch voltage, transferred potentials, nearby strike effects, and induced effects on conductive systems.

Where personnel are required to perform duties outdoors during lightning activity or lightning warning conditions, the organization responsible shall develop a personnel lightning risk assessment for LSAC review. The assessment shall address direct and indirect lightning effects, step and touch voltage, transferred potentials, conductive gates/fences/controls, nearby masts/light poles, communication and power conductors, safe work positions, operational constraints, warning criteria, and emergency procedures. Equipotential planes, ground grids, shelters, remote operation, procedural controls, and operational restrictions shall be selected based on that assessment.

5.2.12.2 Unoccupied Facilities Requirements

For guard gates or stations where personnel are not required to be outdoors during the presence of lightning activity, the requirements of section 5.2.12.1 may be waived, provided the following conditions are met:

a. All electronic controls, sensors, and motor operators are designed with full lightning and surge protection per section 5.2.12 paragraph (d).

b. The facility is clearly marked to prohibit personnel entry or operation during lightning events.

5.3 Surge Protective Device (SPD)

5.3.1 General

Designs for all buildings and structures at KSC and CCSFS shall include surge protective devices (SPD). The devices shall be placed at all main facility service entrance equipment, AC panels or switchboards, AC subpanels and on all branch circuits supplying: telecommunication room loads, data processing room loads, or critical or sensitive loads. In addition, any panel supplying exterior circuits (light poles, lift stations, etc.) and any distribution panel supplied by an exterior circuit shall be equipped with surge protection. All SPD devices specified shall be manufactured, tested, and listed in accordance with UL 1449 and applied in accordance with IEEE C62.41 for high exposure locations. Designs shall indicate the locations of all SPD's and incorporate specific provision for connection and over-current protection. SPD devices connected to power equipment shall be indicated on the one-line diagrams and panel schedules.

5.3.2 Purpose

This paragraph provides recommended criteria for the selection of surge protective devices for the protection of all AC electrical circuits from the effects of lightning-induced currents, substation switching transients, and internally generated transients resulting from inductive or capacitive load switching. Note that the application of SPD protection, as described in this section, is based on the requirement that SPD devices be applied on indicated AC supply panels in a coordinated manner starting with the main service entrance AC panel or switchboard, then to the lower voltage distribution or subpanels, and finally to specific electric or electronic equipment to be protected.

5.3.3 SPD Protection Requirements for Power Systems

The SPD shall be parallel connected and designed, rated, selected, and permanently connected for main entrance panel (service entrance) protection, based on the entrance panel current and voltage ratings. The service entrance SPD is to be tested in accordance with IEEE C62.45 and rated for application High Exposure Location, Category C3, as defined in IEEE C62.41. SPD's specified shall be listed and labeled in accordance with UL 1449 and approved for the location in which they are to be installed. For 3-phase, 4-wire Wye configurations, suppressors, as a minimum, shall provide suppression elements between each line and neutral (L-N), each line and ground (L-G), and neutral and ground (N-G) for a minimum of seven modes of protection. For Delta-configured systems, the device must have suppression elements connected L-L and L-G, providing a total of six modes of protection.

5.3.4 SPD Protection Low-Voltage Signal Equipment

This paragraph provides recommended criteria for the selection of SPD for the protection of electronic equipment low-voltage signal conductors. System design shall protect sensitive electronic devices against the effects of surges, transients, and electrical line noise. Note that the intent of the section is to only make general recommendations with respect to SPD selection for sensitive equipment applications. The protection system designer shall set more specific criteria based on knowledge of the specific requirements of the equipment to be protected. General protection requirements for all systems such as telecommunication systems, temperature control panels, security systems, TV antenna distribution systems, fire alarm systems, sound distribution systems, paging systems, intrusion detection and alarm systems, energy management systems, scoreboards, control systems, surveillance TV systems, and all other systems that communicate by wire are covered by this paragraph.

The system parameters of the electronic system requiring protection shall be reviewed by the surge protection system design engineer for the proper selection of SPD components. The system parameters to be considered in the design shall include but are not limited to:

a. Conductor size.

b. Maximum conductor length.

c. Signal speed of transmission and signal type.

d. Peak-to-peak voltages with relation to ground.

e. Shielding requirements, if any, of the cable at both ends of the equipment.

f. Expected EMI/RFI exposure of sensitive electronic equipment. External filtering components should be considered for use at the equipment location where required to minimize noise from known external sources. Filters should also be considered for application at the source of the noise or RF interference.

g. Maximum operating voltage and maximum operating current.

Electronic system low-voltage signal conductors shall be protected by surge protective devices (SPDs) listed, recognized, or otherwise suitable for the specific circuit type, signal level, bandwidth, installation environment, and exposure. Protection is acceptable only when SPD type, rating, location, bonding, coordination, shielding, and installation are compatible with the protected circuit and exposure.

6. QUALITY ASSURANCE PROVISIONS

6.1 New Installations and Modifications to Existing Installations

Designers preparing designs for new installations or modifications to existing installations shall ensure that grounding, bonding, lightning protection, and surge suppression device systems conform to all applicable requirements of this standard.

6.2 Existing Installations

Responsible operating and maintenance organizations are required to implement adequate testing and inspection programs to ensure the facilities and equipment under their responsibility conform to the applicable requirements of this standard and in accordance with NFPA 780.

6.3 Acceptance Tests

The following tests shall be performed by the contractor for all new installations and modifications to existing installations. The Government reserves the right to witness the test performed by the contractor in this chapter.

6.3.1 Ground Rod & Counterpoise Resistance Test

The resistance of ground rods or counterpoise systems to earth shall be measured using the fall-of-potential test method as described in IEEE Std 81. The measured rod-to-earth and counterpoise-to-earth resistance values shall meet those stated in section 5.1.25.6. Recording shall be per specific contract requirements of user, operator, or installer.

6.3.2 Continuity Tests

Continuity tests shall be performed on all power receptacles to ensure the ground terminals are connected to the facility counterpoise. The continuity test values shall meet those stated in section 5.1.25.8.

6.3.3 Visual and Mechanical Checks

The organization responsible shall inspect all system components for mechanical integrity as referenced in section 5.1.20. Any items found loose, damaged, or corroded shall be replaced to ensure full system integrity.

Verification of bond and ground connection as referenced in 5.1.20 shall include the following:

a. Inspection of connections and conductors for looseness or damage.

b. Replace, repair, or tighten conductors or connections that are mechanically damaged, or loose.

c. Inspect air terminals and lightning arresters for visible defects.

d. Inspect, repair, or replace equipment surge protective devices found to be defective.

6.3.4 Resistance Tests

The designer shall specify any additional tests to verify conformance with the design as well as the usage and general configuration of the facility. The resistance values given in section 5.1.25 shall be used as a reference.

Custodian:

NASA – John F. Kennedy Space Center
Kenndy Space Center, FL 32899

Preparing Activity:

John F. Kennedy Space Center
Engineering Directorate
Technical Performance & Integration, NE-T

APPENDIX A. BONDING AND GROUNDING OBJECTIVES

A.1 Applicability

Bonding and grounding of conductive materials may be required for any of the following reasons:

a. To provide a low-impedance path to earth for electrical currents resulting from lightning discharges or electrical power system faults to minimize abnormal voltage rises that might injure personnel or damage equipment.

b. To provide a discharge path between metal objects and earth to prevent the buildup of static electricity.

c. To reduce electromagnetic interference that could disrupt sensitive communications or electronic equipment.

d. To incorporate structural metals into an electrically continuous mass that will afford electromagnetic shielding.

e. To provide a conductive equipotential surface to serve as a zero-signal reference plane for electrical/electronic systems or subsystems.

A.2 Design Considerations

Various factors to be considered in designing bonding and grounding schemes are presented in the following subsections.

A.2.1 Lightning Protection

For effective protection of structures and personnel and equipment housed therein from harmful effects from lightning, any part of a structure or air terminal arrays sheltering a structure that may sustain lightning strikes should be electrically connected to earth through a low-impedance path. On nonmetallic structures, air terminals are provided to intercept any lightning strikes to the structure and these air terminals must be solidly connected to an earth grounding counterpoise through down conductors in order to dissipate lightning discharge currents. Large, well-bonded metal structures can naturally withstand direct lightning strikes and often function as their own strike-termination means. However, at KSC we require protection systems for all facilities. Even when the structure itself can generally withstand the lightning current, proper grounding, bonding, and surge-protection measures are still required to ensure safety and compliance and must be integrated into a lightning protection system. Since such currents can reach several hundred thousand amperes, the electrical impedance of the structure must be extremely low to prevent dangerous differences in electrical potential from developing between different paths of the structure. A low-impedance path through the structure is attained by bonding all structural members together and bonding the structure to an earth grounding counterpoise. This practice also serves to minimize potential rises in any part of the structure due to electrostatic or magnetic induction effects from discharge currents in the structure.

A.2.2 Static Grounding

The generation, accumulation, and effects of static electricity are rather complex processes, and ANSI/NFPA 77 should be consulted for a detailed treatment of the subject. The process, insofar as this standard is concerned, consists of electric charge displacement between ungrounded metal objects and their environment (including earth) so that a difference of electrical potential is developed due to the accumulation of electric charge on the ungrounded objects. This buildup in potential difference produces the possibility of arcing, which may constitute a safety hazard if the charged objects are in an environment containing highly flammable or explosive materials. It must be assumed that some of many processes that produce electric charge displacement are present in practically all areas. Therefore, bonding and grounding practices for minimizing static electricity shall be followed in all areas of KSC where highly flammable or explosive materials may be located. The dimensional limitations specified elsewhere in this standard are based on the relationships between minimum ignition energies of hydrocarbon gaseous mixtures and ungrounded structure sizes given in ANSI/NFPA 77 and are considered adequate to minimize hazards from static arcing.

A.2.3 Structural Shielding

Enclosed metal and reinforced concrete structures will provide effective electromagnetic shielding between interior and exterior if all peripheral metal is bonded together and grounded. This practice should be followed in all structures that may contain equipment susceptible to EMI. Isolation of interior areas from the external electromagnetic environment may significantly reduce the EMI suppression measures required for the systems and equipment therein. Particular attention should be given to this consideration when establishing bonding and grounding requirements for new facilities, since bonding and grounding of peripheral metals may not be required for any other reason.

A.2.4 Ground Network Requirements

The physical configuration of special grounding systems for sensitive electrical/electronic systems and equipment depends on the physical and electrical characteristics of the system or equipment to be grounded. The overall design objectives of all such grounding systems are common. The objectives are:

a. To provide a ground connection to earth in a manner that will not introduce EMI into the system or equipment
b. To provide an equipotential signal reference plane for the system or equipment
c. Additional requirements for electronic equipment grounding and EMI control shall be applied as specified in KSC-STD-E-0022, when applicable.

For additional technical guidance on grounding practices, including low-frequency loop control, signal-reference grounding, and single- versus multipoint grounding methods, designers should consult the applicable industry standards. References include IEEE Std 1100 (electronic equipment grounding) and IEEE Std 142 (power system grounding).

APPENDIX B. HARDWARE AND MATERIALS

B.1 Overhead Power Conductor Cables and OHGW requirements

Two types of stranded-steel cables are recommended for overhead ground wires: aluminum-clad steel (alum weld or equivalent) and type 316 corrosion-resistant steel (CRES). The CRES cable is recommended only where a corrosive atmosphere could not be tolerated by aluminum or where an extra-high-strength cable is required.

Three sizes of each type of cable are listed in table B1; these are the minimum, average, and maximum size cables required to tension it to the desired sag and to provide the maximum wind load, the interconnections made in the OHGW system, the size and number of down conductors, and the current-carrying requirements of the system. Initial cable tension shall not exceed recommendations based on the cable rated breaking strength (ultimate tensile strength), manufacturer's specified outside air temperature, and the length of the ruling space.

B.2 LPS Hardware

Cables, connectors, clamps, and air terminal point bases shall be galvanically compatible with the building roofing or structure material. Bimetal connectors or fused bimetal shim stock shall be used for interconnection of copper- and aluminum-clad cables.

Table B1. Cable Strand and Wire Data

Wire Type	Size Diameter		Stranding mm (in)	Cross-Sectional Area		Type/ Grade	Ultimate Breaking Strength		Weight			
	mm	in		mm^2	circular mil		Kilo-newton (kN)	Pound (lb)	kilo-gram (kg)/ m	m/kg	lb/ft	ft/lb
CRES	6.35	0.25	3 x 3.05 (0.12)	21.88	43,200	316	33.36	7,500	0.176	5.69	0.118	8.475
	9.614	0.3785	7 x 3.05 (0.12)	51.08	100,800	316	72.06	16,200	0.42	2.381	0.282	3.546
	12.7	0.5	7 x 4.24 (0.167)	98.92	195,223	315	134.33	30,200	0.797	1.255	0.535	1.869
Aluminum Clad Steel	7.938	0.3125	3 No. 7 AWG	31.65	62,467		38.35	8,621	0.21	4.755	0.1412	7.082
	9.614	0.3785	7 No. 8 AWG	58.57	115,586		70.86	15,930	0.39	2.565	0.2618	3.82
	12.7	0.5	19 No. 10 AWG	99.97	197,289		120.94	27,190	0.668	1.496	0.4487	2.229