KSC-STD-E-0012E
August 1, 2001

FACILITY GROUNDING AND LIGHTNING PROTECTION, STANDARD FOR

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KSC-STD-E-0012E
August 1, 2001

FACILITY GROUNDING AND LIGHTNING PROTECTION, STANDARD FOR

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JOHN F. KENNEDY SPACE CENTER, NASA

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ABBREVIATIONS AND ACRONYMS

ac	alternating current
ADP	automatic data processing
AFR	Air Force regulation
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
AWG	American wire gage
BIL	basic impulse level
CCAFS	Cape Canaveral Air Force Station
CIF	Central Instrumentation Facility
CRES	corrosion-resistant steel
dc	direct current
DOD	Department of Defense
EMC	electromagnetic compatibility
EMI	Electromagnetic interference
ESD	electrostatic discharge
ft	feet
GP	General Publication
GSE	ground support equipment
HDBK	handbook
Hz	hertz
IEEE	Institute of Electrical and Electronic Engineers
in	inch
kA	kiloampere
kg	kilogram
KHB	Kennedy Handbook
kN	kilonewton
KSC	John F. Kennedy Space Center
kV	kilovolt
lb	pound
LC-39	Launch Complex 39
LCC	Launch Control Center
L-G	line and ground
LH_2	liquid hydrogen
L-N	line and neutral
m	meter
MCOV	maximum continuous operating voltage
MIL	military
min	minimum
MLP	Mobile Launcher Platform
mm	millimeter
MOV	metal oxide varistor

ABBREVIATIONS AND ACRONYMS (cont)

MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NFPA	National Fire Protection Association
N-G	neutral and ground
NHB	NASA Handbook
NSTS	National Space Transportation System
O&M	Operations and Maintenance
OHGW	overhead ground wire
PHSF	Payload Hazardous Servicing Facility
POL	petroleum, oil, and lubricants
PTCR	Pad Terminal Connection Room
PVC	Polyvinyl Chloride
RBS	rated breaking strength
RF	radio frequency
RFI	radio frequency interference
RMS	root mean square
RPSF	Rotation, Processing, and Surge Facility
SPEC	specification
STD	standard
SVR	suppression voltage rating
TM	technical manual
TVSS	Transient Voltage Surge Suppression
UHF	ultrahigh frequency
UL	Underwriters Laboratories Inc.
V	volt
VAB	Vehicle Assembly Building
VPF	Vertical Processing Facility
μs	microsecond

FACILITY GROUNDING AND LIGHTNING PROTECTION, STANDARD FOR

1. SCOPE

This standard establishes the minimum design requirements for grounding and lightning protection systems for NASA facilities at the John F. Kennedy Space Center (KSC) and for Cape Canaveral Air Force Station (CCAFS). This standard replaces and changes the title of KSC-STD-E-0012C, Bonding and Grounding, and replaces KSC-STD-E-0013D, Facility Lightning Protection Design. It is not the intent of this document to require that all existing facilities at KSC be modified to meet the requirements contained herein. It is intended that existing facilities be considered on an individual basis and modifications be made only when a significant improvement in the level of protection can be achieved.

1.1 General. - This standard is broken into two separate areas of concern: (1) grounding and bonding issues, and (2) lightning and surge protection. Where appropriate, requirements for both have been combined.

1.2 Bonding and Grounding. - The different types of facilities at KSC and CCAFS require varying degrees of bonding and grounding, depending on location and function. Paragraph 3.2 establishes the minimum bonding and grounding practices required at these facilities. The basic bonding and grounding objectives are presented in appendix A. The following limitations are presented but not completely covered in this standard.

1.2.1 Electrical/Electronic Equipment. - For individual units of electrical/electronic equipment, either facility equipment or ground support equipment (GSE), bonding and grounding requirements are specified primarily to ensure proper interfacing between the unit and the facility within which it is installed. Bonding and grounding specified herein should be supplemented by additional requirements applying specifically to GSE.

1.2.2 Electrical Power Systems. - Bonding and grounding practices for alternating current (ac) and direct current (dc) power systems are specified only to the extent that such practices may affect the safety of personnel or equipment or may be a factor in electromagnetic compatibility (EMC) control requirements. Bonding and grounding practices that may be required solely for the functional operation or economical consideration of power systems are not covered.

1.2.3 Electromagnetic Compatibility Control Design. - Unit level equipment EMC design and requirements are specifically excluded from this standard. Such requirements must be identified and specified by system designers. This standard deals with EMC only insofar as bonding and grounding of facilities and bonding and grounding of equipment to facilities are concerned.

1.2.4 Protection Zones. - For purposes of this standard, zones to facilitate identification and specification requirements classify areas having different bonding and grounding requirements. These zones (Zone 1, Zone 2, and Zone 3) are defined in 6.2.19, 6.2.20, and 6.2.21, respectively.

1.3 Lightning Protection and Transient Voltage Surge Suppression (TVSS) Systems. - The requirements outlined herein shall be observed when designing and constructing systems for lightning protection and for the application of TVSS systems for use at KSC and at CCAFS. An appraisal shall be given each new facility to determine its intended use, criticality, personnel contained, etc., before designing a lightning protection or TVSS system. Any facility that contains a launch-critical system that could be destroyed or damaged by lightning or voltage transients, or cause a delay or scrub if struck, shall be given maximum protection. Modifications to existing facilities shall not deteriorate the existing protection systems. Paragraphs 3.3 and 3.4 of this standard cover the protection of KSC and CCAFS facilities from direct lightning strokes and transient voltage surge suppression of various types of facilities and systems. This standard does not treat lightning-related matters, such as design practices for equipment used at the facility for protection from indirect (induced) effects. Refer to KSC document TM-667, for design for protection of equipment from lightning-induced effects, and to GP-1098 for personnel lightning protection procedures.

2. APPLICABLE DOCUMENTS

The following documents form a part of this document to the extent specified herein. When this document is used for procurement, including solicitations, or is added to an existing contract, the specified revision levels, amendments, and approval dates of said documents shall be specified in an attachment to the Solicitation/Statement of Work/Contract. KSC organizations in performing internal operations shall use the latest available issue or revision of each document. In the event of difference between this standard and the referenced document, this standard shall govern to the extent of such difference.

2.1 Governmental.

2.1.1 Specifications.

John F. Kennedy Space Center (KSC), NASA

KSC-SPEC-Z-0005	Brazing Steel, Copper, Aluminum, Nickel, and Magnesium Alloys, Specification for

Federal

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

2.1.2 Standards.

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

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

Department of Defense

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

2.1.3 Drawings.

76K04892	Fastener Assembly Pipe Flange - LOX Mechanical System
76K04932	Fastener Assembly Pipe Flange LC39 B and LH_2

2.1.4 Other Documents.

John F. Kennedy Space Center (KSC), NASA

TM-667	Handbook of Design Requirements and Practices for Protection from Lightning-Induced Effects
GP-1098	KSC Space Transportation System Safety Plan
KSC-DL-124	Lightning Susceptibility Analysis of RF Communications System Installation at the Kennedy Space Center

Department of the Air Force

AFR 127-100	Explosive Safety Standards

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

National Bureau of Standards

FIPS PUB 94	Guideline on Electrical Power for ADP Installations

National Space Transportation System (NSTS)

NSTS 07636	Space Shuttle Lightning Protection, Test and Analysis Requirements
NSTS 20007	Space Shuttle Lightning Protection Design and Test Specification

(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.)

2.2 Non-Governmental.

Industry Publications

National Fire Protection Association (NFPA)

NFPA 70	National Electrical Code
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

(Applications for copies should be directed to the National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101.)

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 81	IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System

(Applications for copies should be directed to the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331

Underwriters Laboratories (UL) Inc.

UL 497A	Secondary Protectors for Communications Circuits
UL 497B	Protectors for Data Communication and Fire Alarm Circuits
UL 1449	Transient Voltage Surge Suppressors

(Applications for copies should be directed to the Underwriters Laboratories, 333 Pfingsten Rd., Northbrook, IL 60062-2096.)

3. REQUIREMENTS

3.1 Requirements Applicable to All Zones. - All buildings and structures at KSC and CCAFS shall be designed to provide adequate grounding, lightning, and transient surge protection systems as required by the applicable standards and additional requirements of this document. Bonding and grounding requirements, as a minimum, shall be those specified by NFPA 70. Lightning protection requirements, as a minimum, shall be those specified by NFPA 780.

3.2 Bonding and Grounding Requirements.

3.2.1 Power Systems. - Where the voltage transformer is located within the building or facility, ac power distribution systems shall be grounded to the counterpoise at one point only. In the event that the voltage transformation point is external to the building or facility, a ground connection shall be made to the power ground on the secondary side of the supply transformers, and a grounding electrode conductor connection shall be made on the supply side of the service entrance equipment. The external supply transformer, or unit substation, shall have its own No. 4/0 bare copper counterpoise system that is connected to the building or facility ground network with a No. 4/0 bare copper ground conductor.

3.2.2 Wiring System Enclosures and Electrical Equipment Grounding. - Any type of metallic electrical enclosure component that may come in contact with a conductor shall be grounded or shall be bonded to other component parts that are grounded.

3.2.2.1 Electronic Equipment Enclosures. - The grounding of electronic equipment, whether single point, multipoint, or a combination, depends on the expected noise frequencies, cable lengths, and network connections involved, as discussed in appendix A, A.2.6. Refer to MIL-STD-188-124, FIPS PUB 94, and NFPA 75 for guidance in the grounding and protection of automatic data processing/electronic computer systems.

3.2.2.2 Instrumentation and Communication Terminal Distributors. - Grounding conductors shall be No. 6 American wire gage (AWG) copper or larger.

3.2.2.3 Bonding of Cable Trays. - 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 facility ground network with a minimum No. 1/0 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 0.5 meter (m) [2 feet (ft)] of each end and at intervals not exceeding 15 meters (50 feet) 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.

3.2.2.4 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 be considered to serve as the sole equipment grounding connector. A separate equipment grounding conductor shall be installed in each raceway for grounding connections.

3.2.2.5 Mobile and 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 in mobile 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. Mobile equipment shall be grounded as follows:

a. Cranes

(1) Grounding

(a) Feed Rail and Collector Type Electrification. - A separate grounding rail shall ground the crane to the facility ground through an equipment grounding conductor.

(b) Festoon Cable or Cable Reel Type Electrification. - A separate equipment grounding conductor shall ground the crane to the facility ground.

(c) 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.

(2) Bonding. - Bonding of crane rail sections shall be provided by the rail clips and rail connecting plates.

b. GSE Enclosures. - A No. 4/0 ground lug in an accessible location for equipment ground shall be provided.

3.2.3 Electrical Manholes. - In all electrical power and communications cable system manholes, at a convenient point close to a wall, a 6-meter (m) (20-foot) ground rod shall be driven (before the manhole is poured) so that the top of the rod is approximately 100 millimeters (mm) [4 inches (in)] above the manhole floor. When precast concrete manholes are used, the top of the rod can be below the floor and a No. 4/0 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. Where possible, exothermic welds shall be used for bond connections to manhole hardware. 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.

3.2.4 Exterior Structures. - Exterior 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 3.3. Fences used as personnel barriers and around power substations shall be grounded as specified in 3.2.14 and 3.2.15 to provide protection from high-voltage hazards. Grounding shall be provided whether or not the exterior structure is exposed to lightning strokes.

3.2.5 Metal Pipe (General). - Metal pipe shall be bonded to ground at the end terminations and at intervals of not more than 90 meters (300 feet).

3.2.6 Ground Rods. - Ground rods shall be 19-millimeter (3/4-inch) diameter, 3-meter-length (10-foot length) copper-clad steel rods conforming to A-A-55804, Type II, Class B rods. The 3-meter (10-foot) 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. Ground rods shall be driven to a depth of at least 6 meters (20 feet). Testing shall be in accordance with 4.3.5.

3.2.7 Earth Grounding Counterpoise Design. - An earth-grounded counterpoise shall be installed at lightning-protected facilities. The counterpoise design will vary in the number of ground rods, number of interconnections, etc., depending on the size of the facility and function of the counterpoise. 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 copper paths between any two points in the counterpoise.

b. Ground rods shall be installed so any point on the counterpoise is within 15 meters (50 feet) of a ground rod. Spacing between ground rods shall be as uniform as practicable throughout the counterpoise.

c. Wires used for interconnecting ground rods shall be bare-stranded copper conductors not less than No. 4/0 AWG in size.

d. Ground rods shall be driven not less than 300 millimeters (12 inches) from structure foundations as practical and to a depth such that the tops of the rods are not less than 300 millimeters (12 inches) below grade level. Interconnecting wires shall be buried not less than 460 millimeters (18 inches) below grade level. The interconnecting wire for a building counterpoise shall consist of a complete loop around the building, shall be installed in the excavation for curtain wall and column footings, and shall be not less than 300 millimeters (12 inches) below grade level, and shall not exceed 1800 millimeters (72 inches) from the building foundation.

e. 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 50 millimeters (2 inches).

f. The design of large counterpoise systems shall consider the use of test well or test point locations that would allow for the ease of periodic testing of the network ground resistance.

g. New counterpoise systems shall be bonded to existing adjacent counterpoise systems.

3.2.8 Instrumentation and Electronic Equipment Grounding. - Specification of the detailed requirements for ground networks is dependent upon the characteristics of the systems with which the ground networks are to be used. Individual ground planes may consist of flat conductive surface, tubular conductors, solid or stranded wire, or combinations thereof. The design of ground networks shall be in accordance with the general guidelines stated below and in appendix A, A.2.6. Three grounding schemes for use are:

a. Structural Steel as a System Ground Point. - This grounding scheme utilizes the structural steel in the structure as a low-impedance extension of the earth ground. Individual instrumentation and communication system reference planes are single-point grounded to the building steel using a minimum of No. 2/0 insulated copper ground wire. 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.

b. Separate Ground Risers. - This scheme requires that each individual instrumentation/electronic equipment system reference plane be connected to the building ground system at one common point. Insulated grounding conductors, of a minimum of No. 2/0 copper, shall be run from each equipment system to a common point where the building steel is connected to the earth ground. The maximum resistance of each insulated conductor shall not exceed 50 milliohm.

c. Use of Structural Steel for Multiple Grounds.

(1) Multiple Grounds (for High Frequencies). - The multiple ground configuration is used for high-frequency electronic equipment and computer ground networks. In this method, many conductive paths from the instrumentation or 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.

(2) Raised Floors. - Metallic components of raised floors can 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 well bonded together and also connected to the earth electrode system. The designer may use single-point or multipoint grounding for the equipotential plane as required by the noise frequencies and the network size. Raise 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 1. See 3.2.17 for test resistance values.

3.2.9 Critical Instrumentation and Control Cable Overall Shields. - All critical electrical cable and wires for interior use shall have an overall shield for lightning protection, unless protection is provided by other means. The following requirements shall apply.

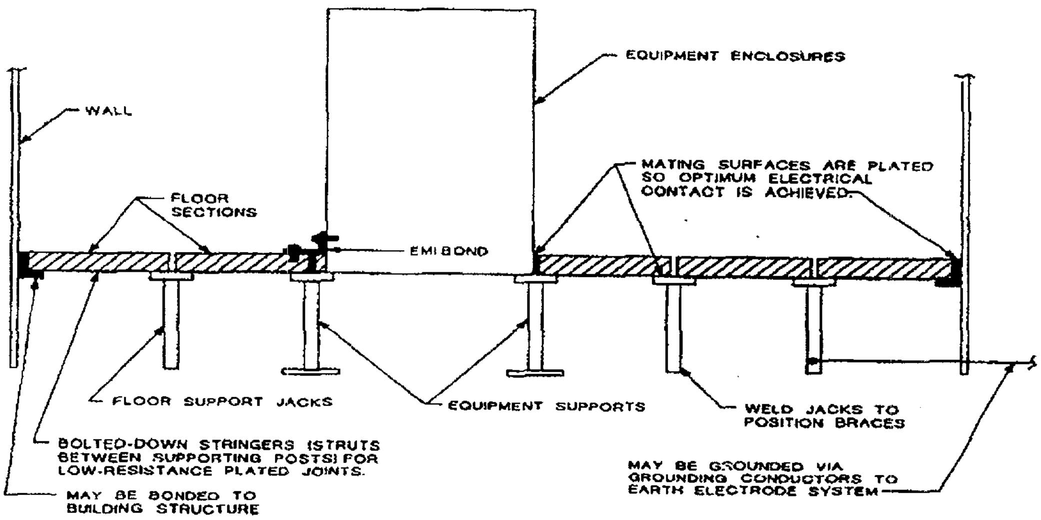

Figure 1. Grounded Raised Floor

a. Shields shall have a minimum optical coverage of 85 percent.

b. Overall cable shields shall be grounded at both ends of the cable. If this is not possible due to interference from other sources, then a cable having two shields shall be specified. The outer shield shall be grounded at both ends, and the inner shield shall be grounded at the source end only and then only to a signal ground bus.

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.

3.2.10 Types of Bonds. - Unless otherwise specified herein, bonding of metal surfaces shall be accomplished by (1) brazing, (2) welding, (3) clamping, or (4) structural joining methods or a combination thereof.

3.2.10.1 Brazing. - Brazing solder shall conform to specifications in KSC-SPEC-Z-0005.

3.2.10.2 Welding. - In accordance with the manufacturer's recommendations, welding shall be by the exothermic process in which the conductors are joined by molten superheated copper produced by reduction of copper oxide by aluminum. The welding procedure shall include the proper mold and powder charge and shall conform to the manufacturer's recommendations.

3.2.10.3 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 so constructed that positive contact pressure is maintained at all times. 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.

3.2.11 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 blasted 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 6.4-millimeter (1/4-inch) or larger fillet weld with a 50-millimeter (2-inch) 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.

3.2.11.1 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 joint 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.

3.2.11.2 Dissimilar Metals. - All mating surfaces that comprise a bond shall be of the same material where possible. When necessary, dissimilar metallic joints shall not form galvanic couples with a value greater than 1 as taken from table 1.

3.2.11.3 Corrosion Inhibitor. - All bonds made using compression or bolted connectors shall be prepared as described in 3.2.11.1. A conductive corrosion inhibitor shall be applied to the connector mating surfaces before the connection is made.

3.2.11.4 Protection of Finished Bonds. - Finished bonds shall be protected by painting to match the original finish after the bond is made.

3.2.11.5 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.

Table 1. Potential Tendency for Galvanic Corrosion

Anode-Corroded End (Less Noble) — rows Magnesium through Hastalloy A (Active); Cathode-Protected End (Noble) — rows Brasses through Platinum

	CATEGORY	1	1	2	3	3	3	4	5	5	6	7	8	8	9	10	10	11	11	11	12	13	14	15	15	15	16	17	18	18	19	20	20
CATEGORY	METAL OR ALLOY	Magnesium	Magnesium Alloy	Zinc	Clad 70 Al	Clad 7075 Al	Clad 6061 Al	Clad 2024 Al	3003 Al	6061-T6 Al	Cadmium	2024-T4 Al	Steel or Iron	Cast Iron	Chromium Iron (Active)	304 S/S (Active)	316 S/S (Active)	Lead-Tin solders	Lead	Tin	Nickel (Active)	Hastalloy C (Active)	Hastalloy A (Active)	Brasses	Copper	Bronzes	Silver Solder	Nickel (Passive)	304 S/S (Passive)	316 S/S (Passive)	Silver	Graphite	Platinum
1	Magnesium	0	0	1	2	2	2	3	4	4	5	6	7	7	8	9	9	10	10	10	11	12	13	14	14	14	15	16	17	17	18	19	19
1	Magnesium Alloy		0	1	2	2	2	3	4	4	5	6	7	7	8	9	9	10	10	10	11	12	13	14	14	14	15	16	17	17	18	19	19
2	Zinc			0	1	1	1	2	3	3	4	5	6	6	7	8	8	9	9	9	10	11	12	13	13	13	14	15	16	16	17	18	18
3	Clad 70 Al				0	0	0	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	11	12	12	12	13	14	15	15	16	17	17
3	Clad 7075 Al					0	0	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	11	12	12	12	13	14	15	15	16	17	17
3	Clad 6061 Al						0	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	11	12	12	12	13	14	15	15	16	17	17
4	Clad 2024 Al							0	1	1	2	3	4	4	5	6	6	7	7	7	8	9	10	11	11	11	12	13	14	14	15	16	16
5	3003 Al								0	0	1	2	3	3	4	5	5	6	6	6	7	8	9	10	10	10	11	12	13	13	14	15	15
5	6061-T6									0	1	2	3	3	4	5	5	6	6	6	7	8	9	10	10	10	11	12	13	13	14	15	15
6	Cadmium										0	1	2	2	3	4	4	5	5	5	6	7	8	9	9	9	10	11	12	12	13	14	14
7	2024-T4 Al											0	1	1	2	3	3	4	4	4	5	6	7	8	8	8	9	10	11	11	12	13	13
8	Steel or Iron												0	0	1	2	2	3	3	3	4	5	6	7	7	7	8	9	10	10	11	12	12
8	Cast Iron													0	1	2	2	3	3	3	4	5	6	7	7	7	8	9	10	10	11	12	12
9	Chromium Iron (Active)														0	1	1	2	2	2	3	4	5	6	6	6	7	8	9	9	10	11	11
10	304 S/S (Active)															0	0	1	1	1	2	3	4	5	5	5	6	7	8	8	9	10	10
10	316 S/S (Active)																0	1	1	1	2	3	4	5	5	5	6	7	8	8	9	10	10
11	Lead-Tin solders																	0	0	0	1	2	3	4	4	4	5	6	7	7	8	9	9
11	Lead																		0	0	1	2	3	4	4	4	5	6	7	7	8	9	9
11	Tin																			0	1	2	3	4	4	4	5	6	7	7	8	9	9
12	Nickel (Active)																				0	1	2	3	3	3	4	5	6	6	7	8	8
13	Hastalloy C (Active)																					0	1	2	2	2	3	4	5	5	6	7	7
14	Hastalloy A (Active)																						0	1	1	1	2	3	4	4	5	5	6
15	Brasses																							0	0	0	1	2	3	3	4	5	5
15	Copper																								0	0	1	2	3	3	4	5	5
15	Bronzes																									0	1	2	3	3	4	5	5
16	Silver Solder																										0	1	2	2	3	4	4
17	Nickel (Passive)																											0	1	1	2	3	3
18	304 S/S (Passive)																												0	0	1	2	2
18	316 S/S (Passive)																													0	1	2	2
19	Silver																														0	1	1
20	Graphite																															0	0
20	Platinum																																0

Note: Numbers are qualitative only; the larger the number, the greater the tendency for galvanic corrosion.

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.

3.2.12 Ground Connections (General). - All ground connections shall be bonded connections, made in accordance with the applicable requirements of 3.2.10. If not otherwise specified, grounding conductors shall be solid or Class B stranded copper of a size sufficient to meet the grounding resistance requirements specified herein. Welding or brazing is the preferred method of attaching grounding conductors, and these methods shall be employed wherever possible. When welding or brazing is unsafe, bolted or clamped connections may be used. When connectors are required on ground wires or straps, the connectors shall be attached by welding, brazing, or compression methods. A conductive corrosion inhibitor shall be applied to mating surfaces before the connections are made.

3.2.13 Ground Plate and Ground Point Identification. - Where required in the design, equipment grounding plates and grounding points shall be made easily identifiable. A typical ground point for horizontal or vertical use shall be identified as shown in figure 2. The dimension may be adjusted to fit available space. A typical grounding plate shall be identified as shown in figure 3. The border may be adjusted to fit the available space. An Operational Check sticker (KSC FORM 22-420) 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 the operations and maintenance (O&M) agency.

3.2.14 Metallic Fences Used as Personnel Barriers. - All gates, gate posts, corner posts, and fences shall be grounded at intervals not to exceed 300 meters (1,000 feet). In addition, fences shall be grounded at a distance of 45 meters (150 feet) on either side of a point where power lines and/or communication lines cross the fence. Fences within 3 meters (10 feet) of a lightning-protected structure shall be grounded to the structure counterpoise.

3.2.15 Metallic Fences for Electrical Substations. - Substation fences shall be bonded to the station counterpoise at intervals not exceeding 30 meters (100 feet). 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 and 5).

Ground Point Marking

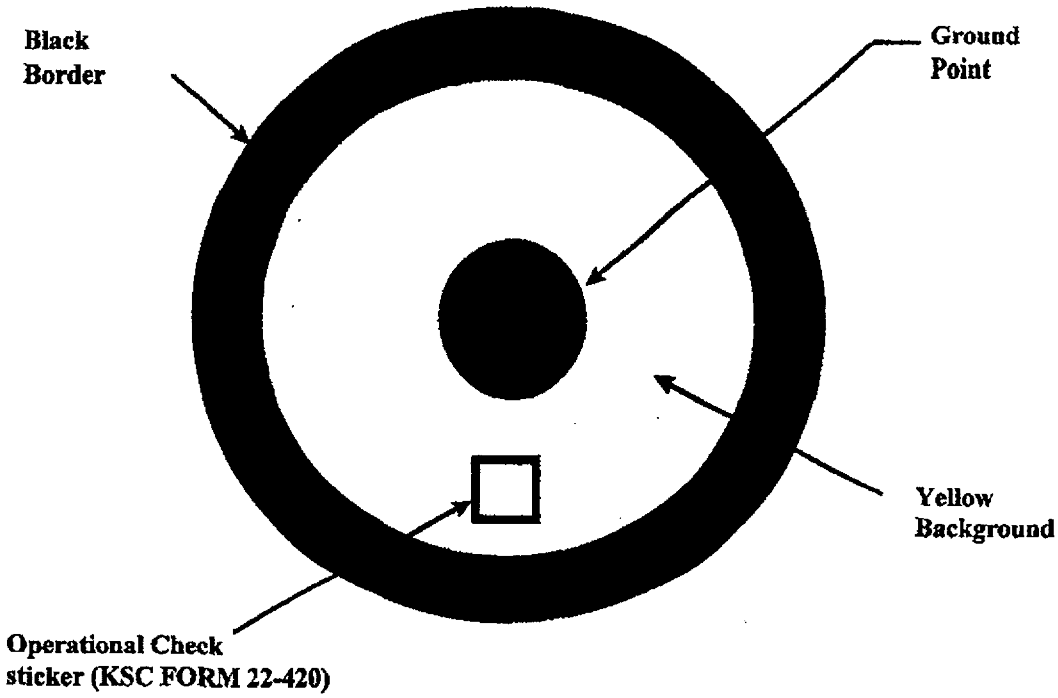

Figure 2. Ground Point Marking

Ground Plate Marking

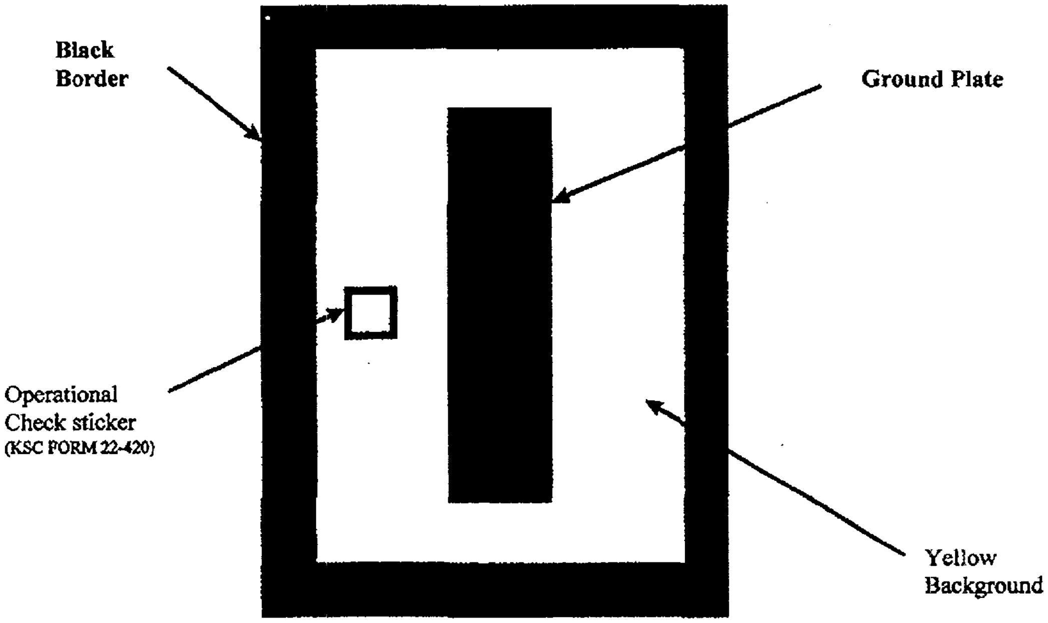

Figure 3. Ground Plate Marking

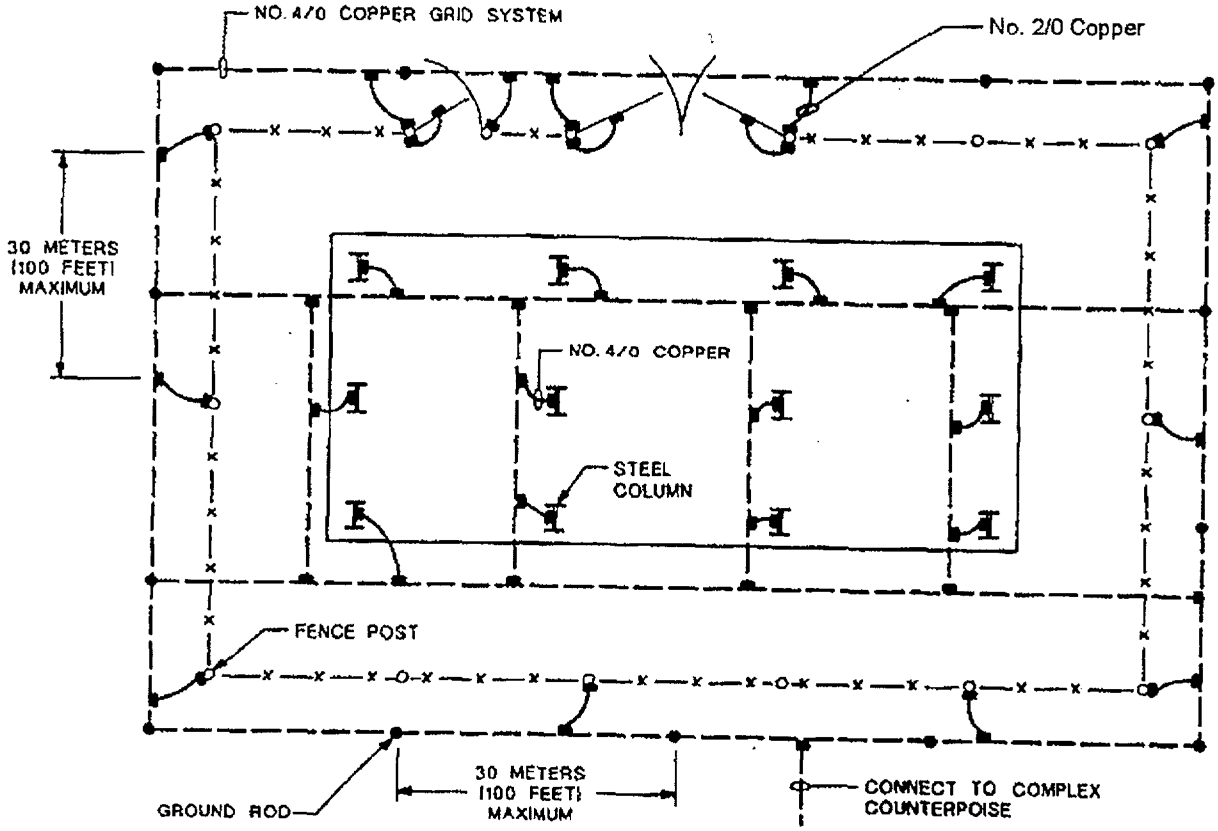

Figure 4. Connection of Substation Fence and Structural Steel

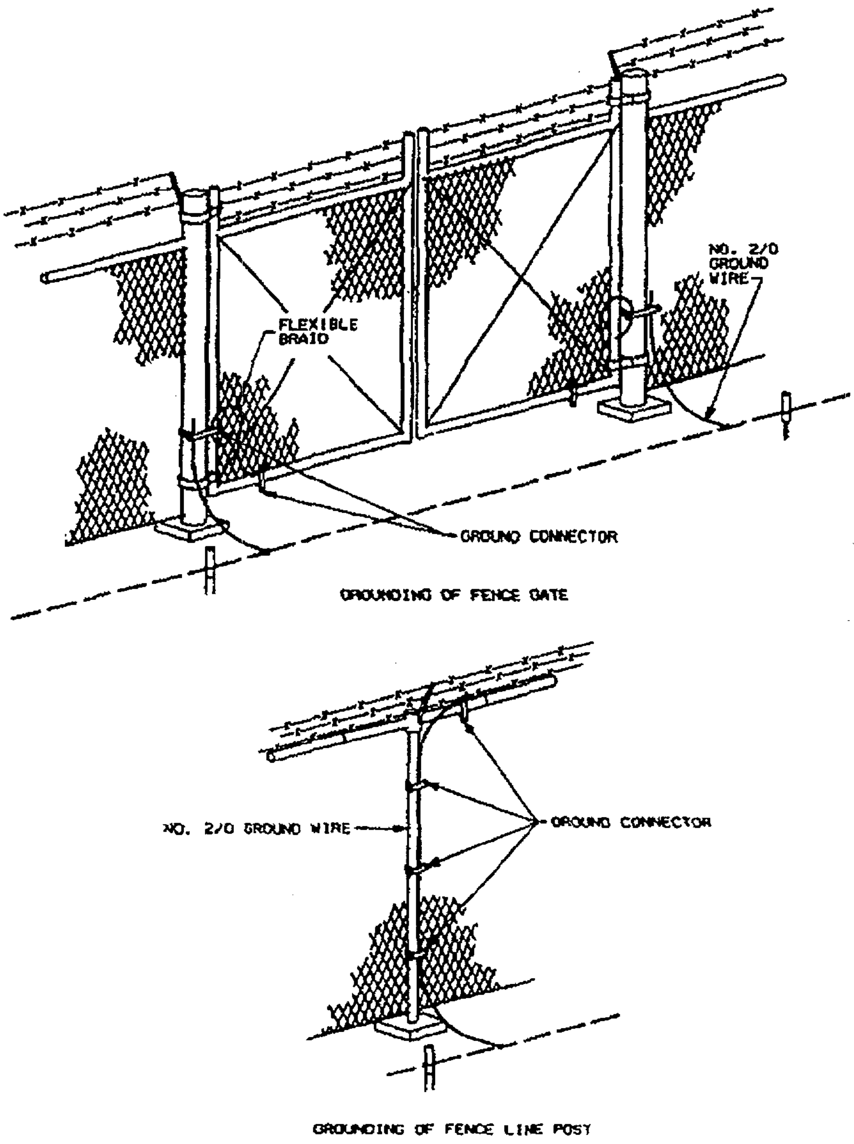

Figure 5. Substation Fence Detail

3.2.16 Additional Requirements for Zones 1 and 2. - In addition to the general Zone 3 requirements specified above, areas as classified as Zones 1 and 2 shall comply with the requirements of 3.2.16.1 and 3.2.16 as indicated. Refer to 6.2 for definitions of Zones 1, 2, and 3. Some locations, such as certain areas of the Mobile Launchers, will have more than one zone classification. In such cases, the bonding and grounding requirements specified for all applicable zones shall apply.

3.2.16.1 Zone 1.

a. Metal Objects. - All exposed metal objects exceeding 1200 millimeters (48 inches) in any dimension shall be bonded to ground. Unexposed metals (such as reinforcing steel completely encased in concrete, in objects that are completely buried, or in objects completely contained in hazardproofed locations) do not require bonding or grounding as a Zone 1 requirement. Fuel and oxidizer handling equipment shall be bonded to ground.

b. Heating, Ventilating, and Air-Conditioning Systems. - 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.

c. Metal Pipe (General). - Metal pipe shall be bonded to ground at the end terminations and at intervals of not more than 30 meters (100 feet). For internal locations, bonding can be by clamping methods if continuous pressure followup 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 the 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.

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

3.2.16.2 Zone 2.

a. Structural Metals. - In structures housing Zone 2 areas, 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 600 millimeters (24 inches) in their largest dimensions are exempted.

b. 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 15 meters (50 feet). Welded wire fabric shall be brazed or welded together at the edges on 1200-millimeter (4-foot) centers and connected to reinforcing steel on 1200-millimeter (4-foot) centers.

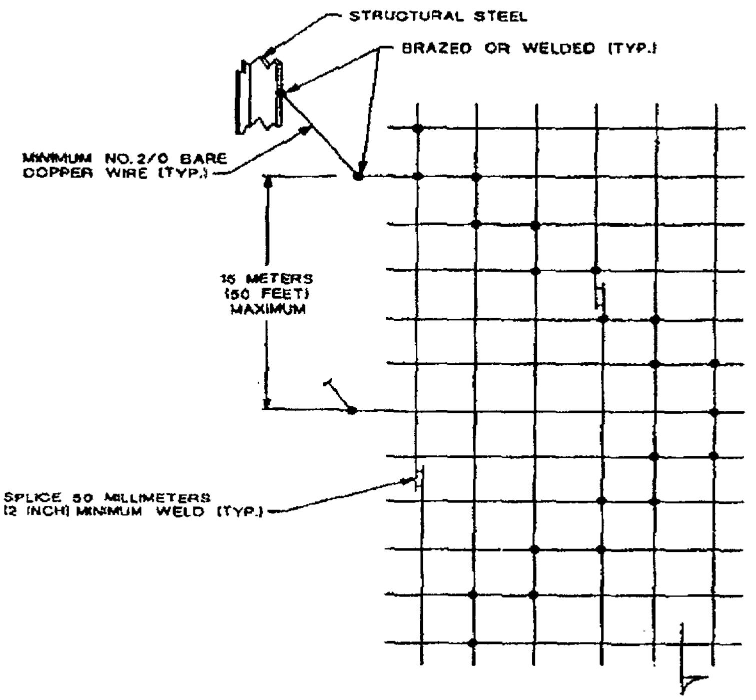

Figure 6. Bonding and Grounding of Reinforced Concrete

c. 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.

3.2.17 Resistance Values. - The following resistance values are the maximum desired to achieve the intended bonding and grounding objectives. The designer shall include the necessary details in the design so that these values will be met.

3.2.17.1 Facility Ground Networks. - The total resistance from any point on the facility ground network to the counterpoise shall not exceed 50 milliohms.

3.2.17.2 Power Grounds. - The total resistance from the neutral of the power source through the connection to the counterpoise ground shall not exceed 20 milliohms.

3.2.17.3 Wiring System Enclosures. - The total resistance from each wiring system enclosure to the facility ground network shall not exceed 50 milliohms.

NOTE

Paragraphs 3.2.17.1, 3.2.17.2, and 3.2.17.3 are established as a general guide. In situations where any of the legs of the fault circuit have resistances exceeding these limits, the fault circuit path shall be analyzed and modified if necessary to ensure instantaneous operation of the circuit protective devices in the event of a "bolted" fault between the circuit conductor and equipment frame or wiring system enclosure.

3.2.17.4 Lightning Protection. - The total resistance between the ground connection of any lightning arrester or air terminal and the counterpoise shall not exceed 10 milliohms.

3.2.17.5 Static Grounds. - Low resistance is not required for static grounds. Generally at KSC, resistances from 0.1 to 1 megohm are used to provide static grounds between the grounded object and facility ground. These series resistors may be installed in wriststats and legstats (refer to A.2.3 in appendix A and see TO 00-25-172 for Shuttle Landing Facility aircraft).

3.2.17.6 Ground Rods. - The resistance of individual ground rods to earth shall be measured prior to interconnection with the counterpoise. Maximum resistance values shall not exceed 25 ohms. See 4.3.5 for testing procedures.

3.2.17.7 Counterpoise. - The resistance from any point on the counterpoise to earth shall be no greater than 10 ohms. See 4.3.5 for testing procedures.

3.2.17.8 Bond Resistance. - The resistance of any bond connection shall not exceed 1.0 milliohm.

3.2.17.9 End-Device-to-Counterpoise Resistance. - The resistance between the end device and the nearest grounding point on the counterpoise shall not exceed 1 ohm (such as the floor grounding receptacle and counterpoise).

3.2.17.10 Raised-Floor Resistance. - 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 facility ground points.

3.3 Lightning Protection Requirements.

3.3.1 General. - All NASA facilities and structures at KSC and CCAFS shall be designed to include adequate lightning protection. Lightning protection shall provide a zone of protection, as defined in NFPA 780, appropriate for the facility and its intended use. A facility equipped with a lightning protection system having the proper zone or cone of protection is substantially shielded from a direct strike; however, electrical and electronic systems within or connected to the building may be damaged by lightning-induced effects if not protected by the design techniques contained in TM-667 and, where automatic data processing (ADP) systems are involved, in NFPA 75. The Space Transportation System, including the vehicle and all facilities where major tests or operations are performed, shall comply with the requirements of NSTS 07636 and NSTS 20007. For all 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 and associated appendices. Grounding systems associated with lightning protection systems shall be in accordance with the requirements of section 3.2 of this standard.

3.3.2 Level of Protection. - The protective measures described shall be applied as follows:

a. Unless otherwise directed by this document, NFPA 780 shall be used as the standard for protection of ordinary buildings, miscellaneous structures and special occupancies, heavy-duty stacks, and structures containing flammable liquids and gases.

b. For maximum protection to allow certain operations in special facilities containing explosives or flammable materials, the Faraday cage protection technique may be used.

c. Techniques used at KSC for maximum protection of antennas located on towers are detailed in KSC-DL-124.

3.3.3 Materials. - The minimum materials requirements to be used in lightning protection system design shall be those as specified in NFPA 780. It is preferred that all conductors, connectors, and air terminals be copper. Aluminum air terminals are allowed on aluminum buildings and sheds. Aluminum down conductors shall transition to copper, using approved connection hardware before entering the ground.

3.3.3.1 Overhead Ground Wire (OHGW)/Grid Wire Systems - Materials recommended for OHGW/grid wire systems are specified in 3.3.4 and in appendix B.

3.3.4 Grounded Masts and OHGW Systems.

3.3.4.1 Protected Area. - The area protected by grounded masts supporting OHGW is specified in NFPA 780. Generally, both ends of an OHGW are grounded.

NOTE

“Shield wire" and "OHGW" are used interchangeably herein.

3.3.4.2 Clearance Between Conductive Mast and Protected Structure. - For structures not over 15 meters (50 feet) in height, clearance for conductive masts or wood masts with down conductor cables shall not be less than 2 meters (6 feet) from the protected structure in order to prevent side flash from the down conductor to the structure. The clearance shall be increased by 300 millimeters (1 foot) for every 3 meters (10 feet) of structure height above 15 meters (50 feet). All masts shall be grounded and connected at ground level to the grounding system of the protected structure.

3.3.4.3 Clearance Between the OHGW and Protected Structure. - The minimum clearance between an OHGW and the highest point on the protected structure shall be 2 meters (6 feet). The clearance shall be increased by 300 millimeters (1 foot) for each 3 meters (10 feet) of cable over 18 meters (60 feet), as measured between the midpoint on the OHGW and the down conductor ground entry point. OHGW system grounds shall be bonded with the grounding system of the protected structure.

3.3.4.4 Rooftop Antenna Protection. - Rooftop antenna installations at KSC and CCAFS that require lightning protection, such as microwave dishes and helical or Yagi antennas, shall be protected from direct strikes by a bare OHGW, 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 necessary, for centerpoint-to-ground distances of less than 18 meters (60 feet) [40 meters (120 feet) between grounds], the 99 percent confidence curves for minimum spacing between shield wire and cable trays (see 3.3.10) may be used. For a shield wire with a single ground point, the spacing shall be doubled. If such antennas do not require protection from direct strikes, 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.

In addition, 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 and approved by the KSC Lightning Safety Committee.

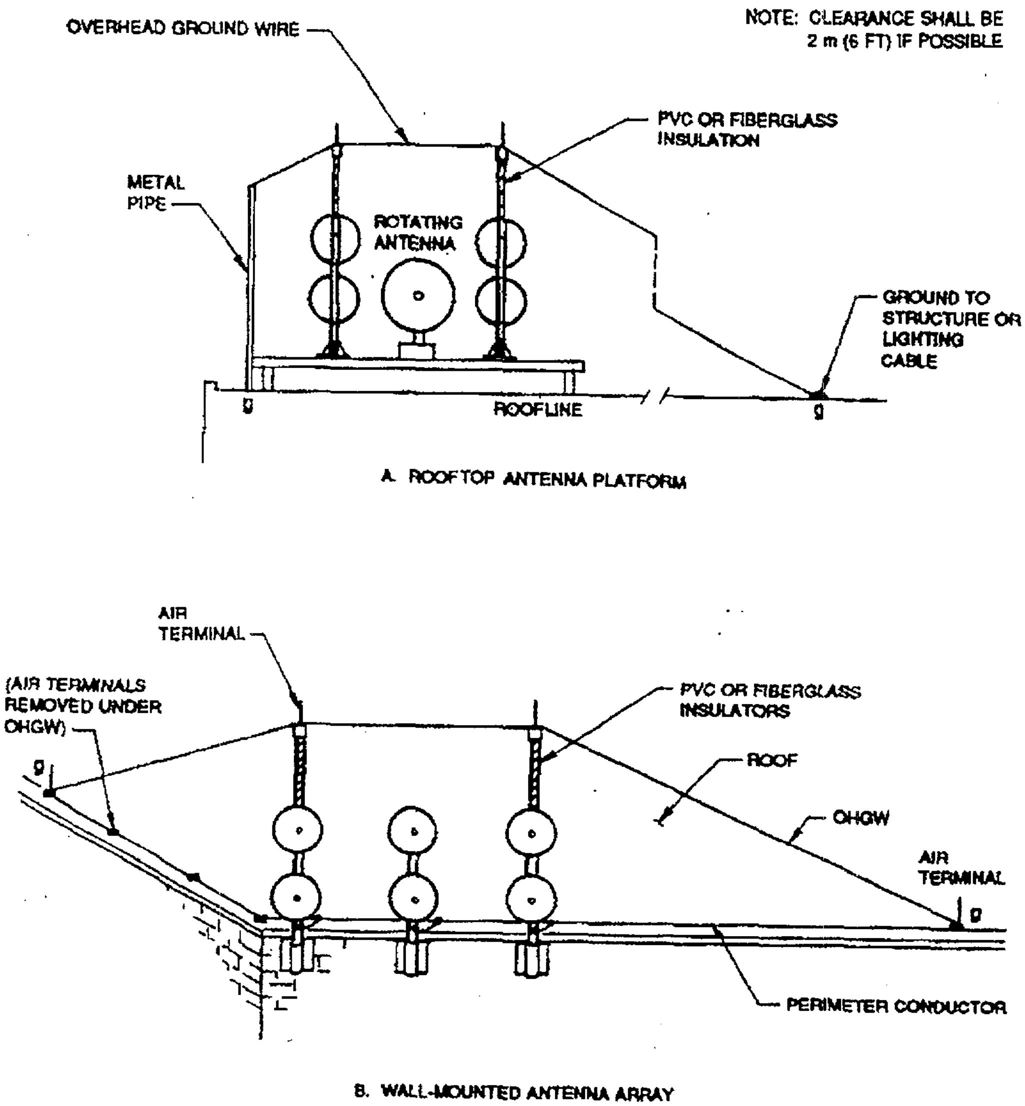

Figure 7. Rooftop Antenna Lightning Protection

3.3.4.5 Environmental Design Criteria for OHGW Installations. - IEEE C2 defines the loading requirements for extreme winds on structures exceeding 18 meters (60 feet) 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, applying a 25 percent gust factor for hurricane force winds.

3.3.5 Faraday Cage Systems. - The overhead grids for these systems differ from OHGW systems in that the suspended grid is an electrically continuous unit with multiple paths of conduction to ground, whereas an overhead cable usually has but two ground connections. All grid intersections are rigidly connected to make the grid a unistable unit that is more resistant to wind-caused sag than single-span catenary cables. The grounded conducting masts and the air terminals are arranged, insofar as possible, to result in symmetrical current flow in the grid, down conductors, and counterpoise grid. For personnel protection, a clearance of at least 2 meters (6 feet) shall be maintained between the mast down conductors and the protected area. Since potential differences may be introduced into the cage by conductors entering from outside, measures shall be taken as necessary to ensure equal potentials at the cage entry point.

3.3.6 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 must be well grounded by at least two 6-meter (20-foot) ground rods. All cables from the tower to the structure shall have an overall shield of at least 85 percent optical coverage or be enclosed in a covered metal cable tray. 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 must be well grounded by connection to the building counterpoise and to at least one 6-meter (20-foot) ground rod at the interface. Refer to MIL-STD-188-124 for further information and illustrations.

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

3.3.7 Material Corrosion-Resistance, Compatibility, and Suitability. - Cables and hardware selected for OHGW/grid wire systems shall be 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.

3.3.8 Railroads.

3.3.8.1 Railroads in Hazardous Areas and Fuel Transfer Locations. - Loading and unloading operations from ungrounded tank cars are not permitted at KSC facilities. Railroad tracks in hazardous areas and fuel transfer locations shall be grounded for lightning protection as shown in figures 8 and 9. This requirement also applies to service carts and flame-deflector tracks.

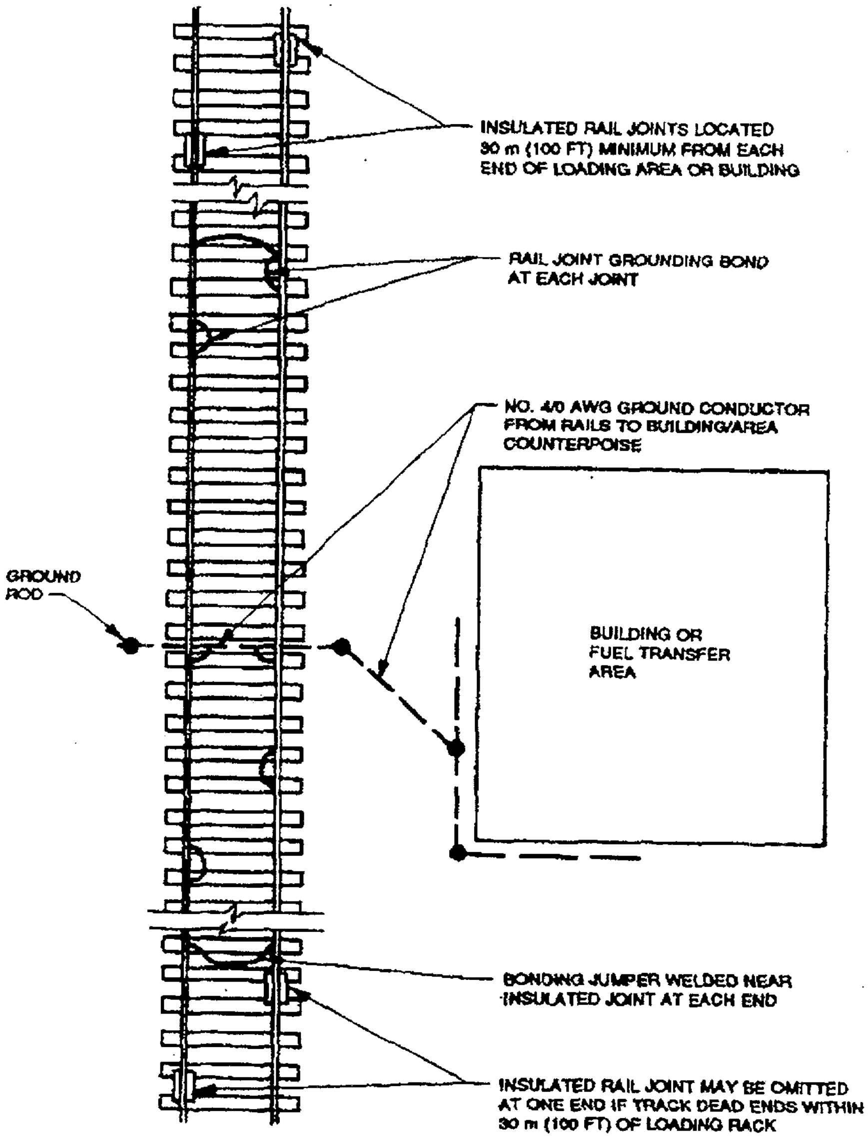

Figure 8. Lightning Protection Requirements for Railroad Tracks in Fuel Areas or Adjacent to Buildings

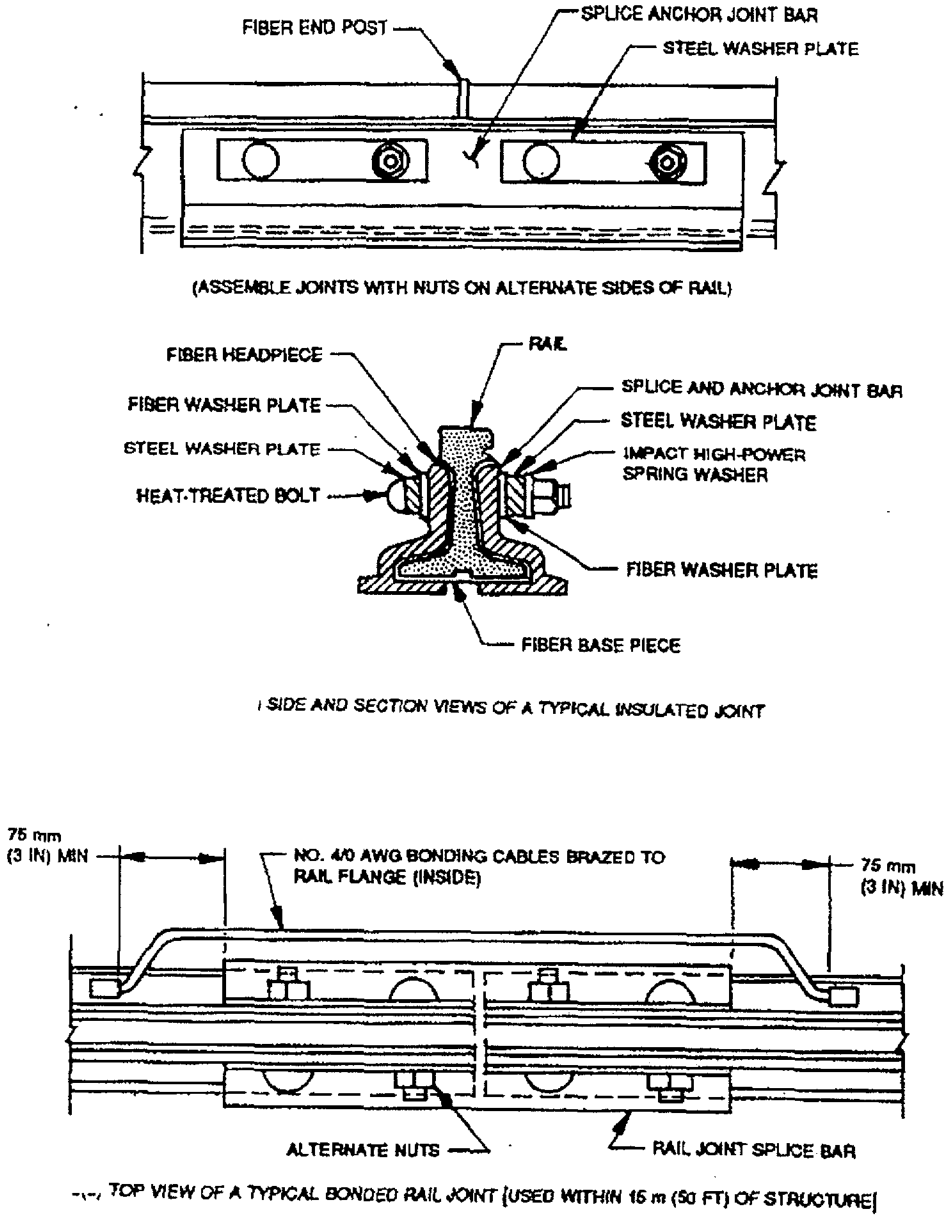

Figure 9. Railroad Track Details for Lightning Protection

3.3.8.2 Railroads Adjacent to Buildings. - Railroad tracks within 15 meters (50 feet) of a building shall be grounded and bonded as specified in 3.3.8.1.

3.3.9 Pad-Mounted Transformers, Underground Cables, and Unit Substations/Switching Stations.

3.3.9.1 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. Metal oxide varistor (MOV) arresters shall be selected in accordance with IEEE C62.22, for the proposed operating voltages.

3.3.9.2 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. Station class MOV arresters shall be selected in accordance with IEEE C62.22 for the proposed operating voltages. Cable splices shall be grounded in manholes and handholes.

3.3.9.3 Unit Substations/Switching Stations. - Substations and switching stations are generally rated from 600 volts (V) up to an including 15,000 V. These substations may be of either indoor construction or weather protected, outdoor construction (metal-clad). Housings of unit substations bonded and grounded, in accordance with the applicable requirements of section 3.2, are considered adequately protected from lightning. However, the power transformers should be protected with appropriate lightning arresters when supplied from a circuit that has any part exposed to lightning.

3.3.10 Aboveground Cable Trays. - All cross-country cable tray designs shall include an overhead No. 2/0 AWG minimum, bare copper shield wire whose spacing to the top depends on the span between grounded down leads (refer to figure 10). Vertical spacing "S" is a function of lateral spacing "X" between the grounded supports for the shield wire. The curve for 99 percent confidence shall be used in determining spacing "S." The shield wire metal support posts shall be insulated from the tray support posts by air or post insulators as shown in figure 11 and table 2. Metal posts and the cable trays shall be connected to the ground rod located near each shield wire support post. Metal posts for the shield wire shall be spaced at least 225 millimeters (9 inches) from the cable trays. The No. 2 AWG copper conductors, running down to the ground rod, shall be insulated and protected with suitable cable guards to prevent physical damage or displacement.

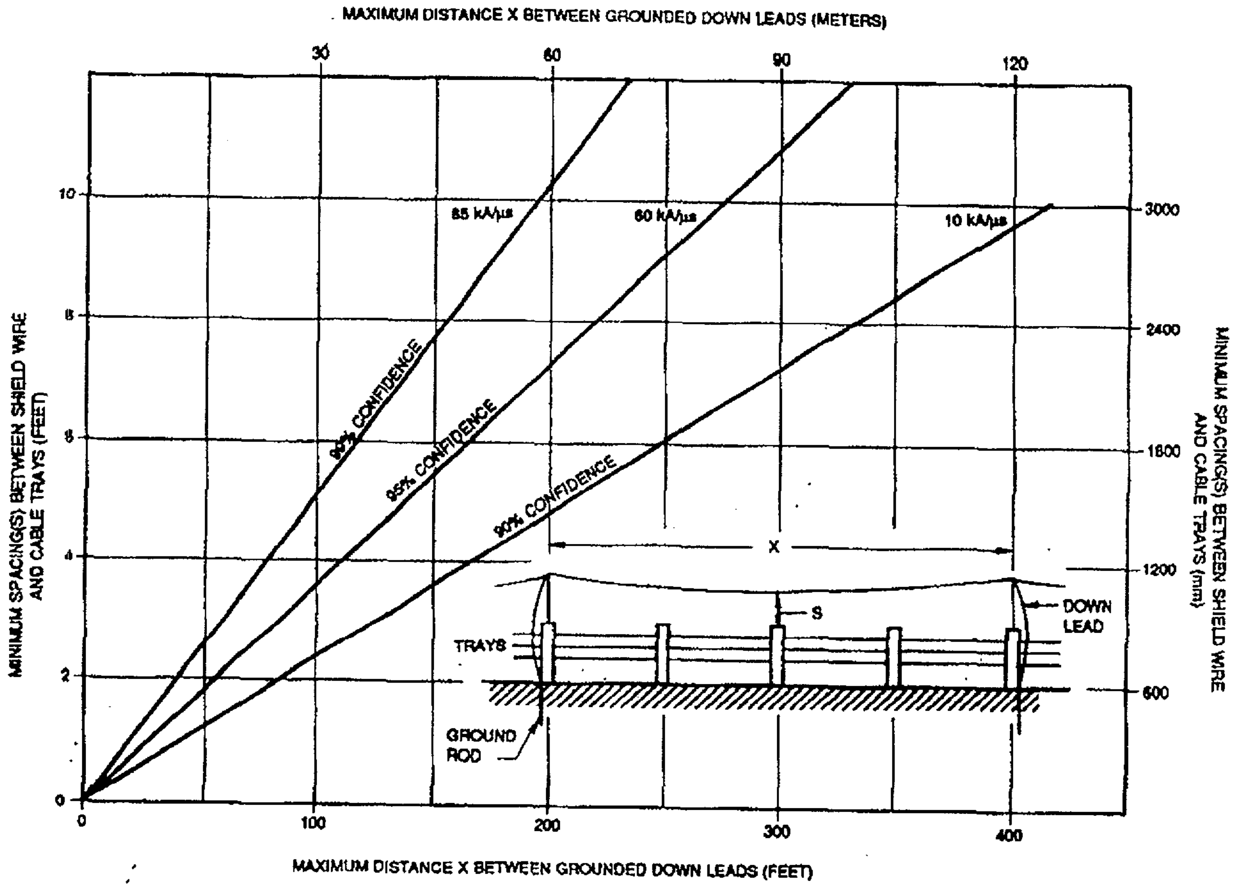

Figure 10. Shield Wire Spacing for Cross-Country Cable Trays

Table 2. Post Insulators for Shield Wires for Cross-Country Cable Trays

Location	60 Hertz (Hz) Rating Kilovolt (kV)	Twice Negative Impulse Flashover (kV)
Top of Post	15.0	400
Bottom Tray	7.5	240

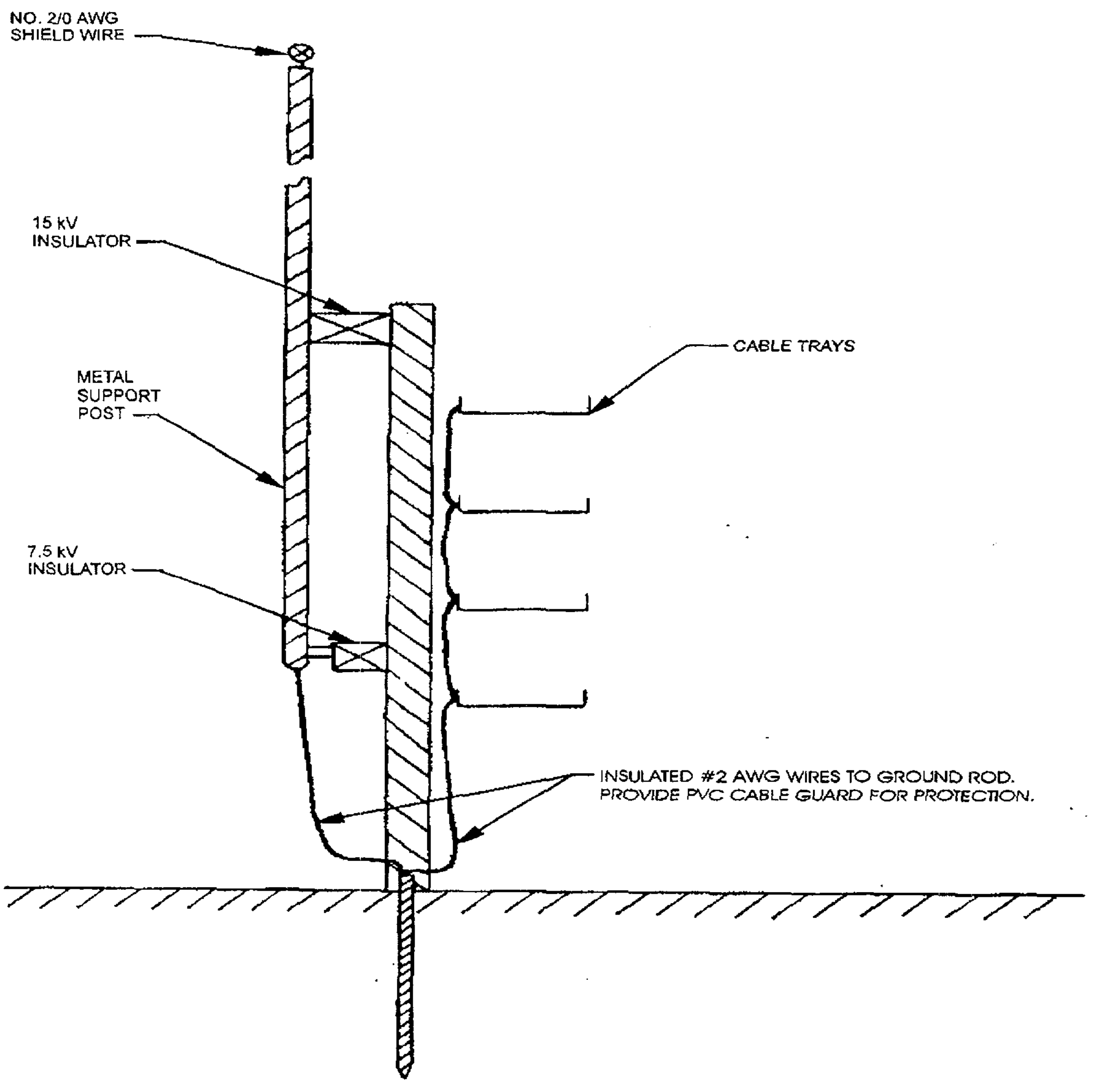

Figure 11. Lightning Protection for Cross-Country Cable Trays
(60-Hertz, 15-KV Rating)

3.3.11 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 and shall be protected against direct lightning strokes with an overhead ground wire mounted above the conductors and lightning arresters connected to protect pole-mounted equipment. The zone of protection shall be determined as per NFPA 780 requirements. (See figure 12.)

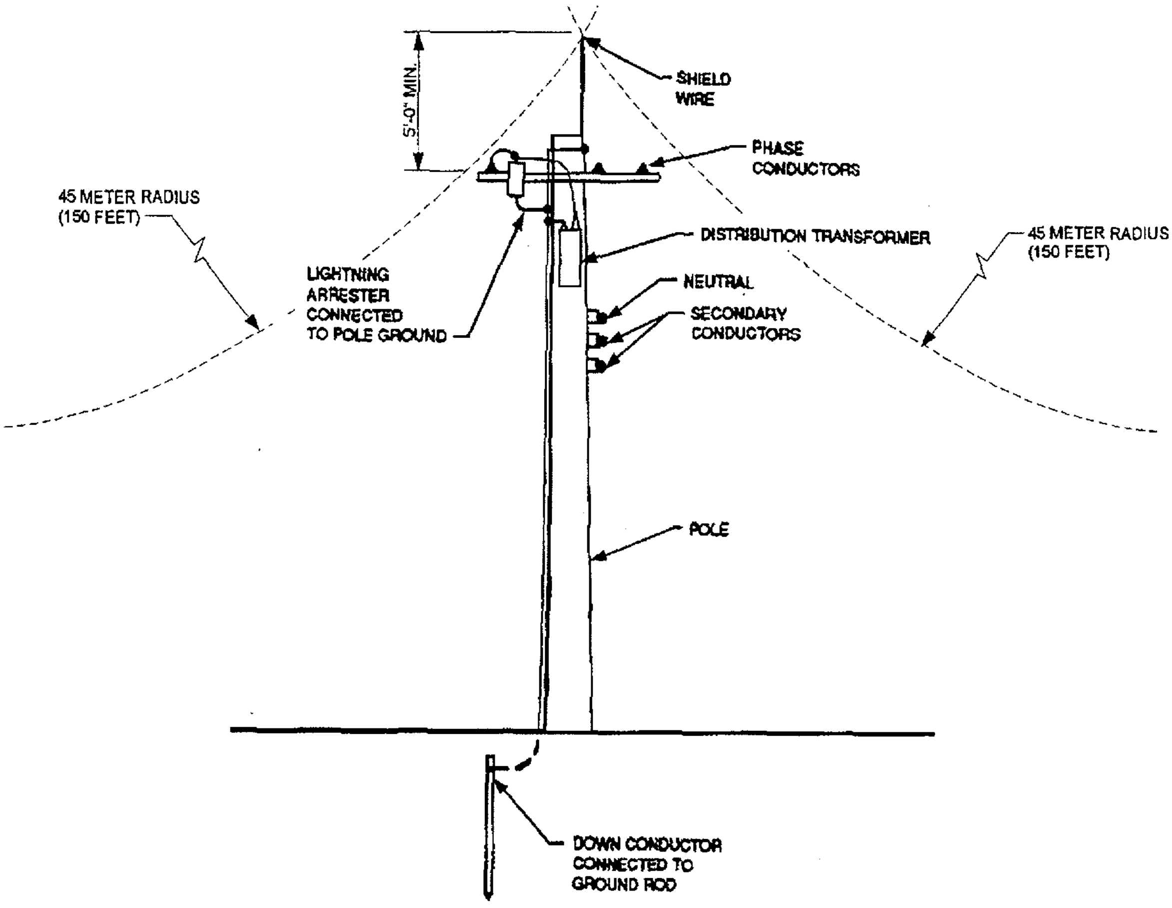

Figure 12. Shield Wire and Lightning Arrester Typical Installation

3.3.12 Exposed Communications and Instrumentation Equipment.

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

3.3.12.2 Lightning Surge Protection. - Communication and instrumentation cables, equipment, facilities, and operators 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 suppression devices, as discussed in 3.4. Where possible, fiber-optic-based cable systems, with nonconductive cable sheaths, should be considered for use.

3.3.13 Underground Duct Banks. - Designs for communication, instrumentation, and power cable duct banks shall include the following features (see figure 13):

a. A buried No. 4/0 AWG bare copper counterpoise whose spacing above the duct bank is not less than 250 millimeters (10 inches). Duct banks less than 1 meters (36 inches) wide require only one counterpoise wire. Duct banks wider than 1 meters (36 inches) require two counterpoise wires.

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 30 meters (100 feet) and at manholes.

d. New counterpoise systems shall be bonded to existing adjacent counterpoise systems using bonding methods as allowed in 3.2.10.

3.3.14 Guard Shacks. - All guard shacks shall be provided with a lightning protection system. Since methods of construction are not uniform, lightning protection requirements for guard shacks must be tailored to each installation. Some guard shacks are all metal and can be made to qualify as Faraday cages; others are made of wood, requiring roof and ground counterpoises, down conductors, and air terminals. The following design guidelines shall be considered.

a. Wood shacks shall utilize a roof and ground counterpoise system with down conductors and air terminals designed in accordance with NFPA 780.

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

c. Light poles located near guard shacks must be made part of the lightning protection system.

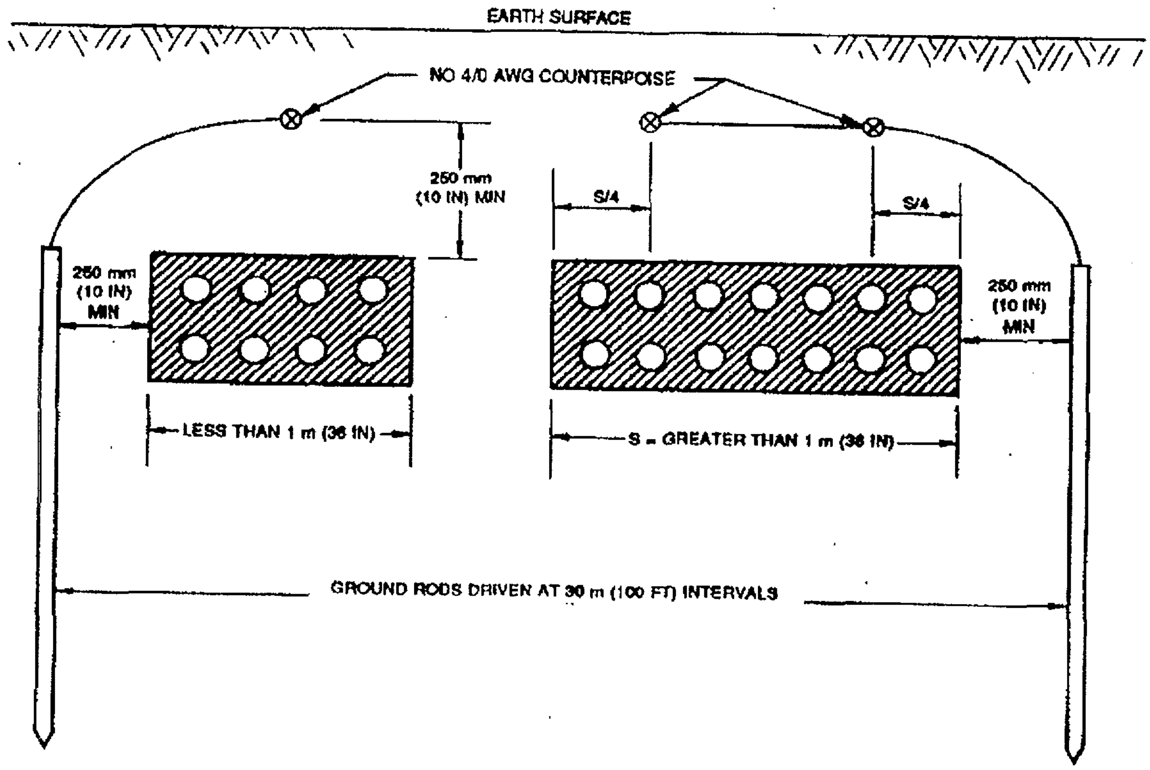

Figure 13. Lightning Protection for Underground Duct Banks

d. Since guards cannot always stay inside the shacks, it is necessary to extend the guarded counterpoise to include the personnel standing areas in order to prevent high voltage from developing between their feet (step voltages).

e. Even with good protection, the telephone and power cables feeding a shack can violate the protective system at the entrance to the shack on the outside. Protective devices, such as metal oxide varistors and transorbs, may be required when the shielding is not adequate.

3.3.15 Resistance Values. - Resistance values for all lightning protection system connections and components shall meet the requirements of 3.2.17.

3.4 Transient Voltage Surge Suppression (TVSS).

3.4.1 General. - Designs for all buildings and structures at KSC and CCAFS shall include transient voltage surge suppression (TVSS) on all main facility service entrance ac panels or switchboards and ac subpanels and on all branch circuits where critical or sensitive loads are served. TVSS devices, bonding and grounding shall be required on all electrical and electronic systems located outside the confines of a protected building. In general, all TVSS 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. The following suggested design limits shall be used as working guidelines by the design agency in selecting the various components of the system. The design agency shall make the final determination as when TVSS equipment will be required and to the component ratings required for equipment protection.

3.4.2 Purpose. - This paragraph provides recommended criteria for the selection of transient voltage surge suppressors 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 and/or capacitive load switching. (Note that the application of TVSS protection, as described in this section, is based on the requirement that TVSS 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.)

3.4.3 TVSS Protection Requirements for Main (Service Entrance) Panels. - The TVSS 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 TVSS 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. Suppressors 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. The suppressor manufacturer shall provide certified test data confirming a fail short failure mode. The suppressor should contain replaceable internal fuses that operate to isolate the TVSS protective elements under conditions of an internal short circuit. Visible indication of proper suppressor connection and operation shall be provided. Indicators shall be provided to indicate that power has been interrupted or that protection has been reduced or lost for the specified phase/phases protected. If required for the application, the TVSS shall be selected to be furnished with dry output contacts or an audible alarm for remote monitoring of the protection status. Suppressors may be mounted internal or external to the service entrance panel being protected. The mounting position of the suppressor shall permit a straight and short lead length connection between the suppressor and the point of connection to the panel board. The interconnecting leads between the suppressor and the point of connection to the bus shall be kept as short as possible [0.5m (20 in) or less] to minimize let-thru voltage and shall be twisted to minimize lead reactances. Bends should be avoided if possible.

Suppressors shall meet or exceed the following criteria.

a. Maximum single impulse current rating: 100,000 amperes per mode [8X20/microsecond (μs) current waveform].

b. Pulse life rating (IEEE C62.41, table 4, Category C3 transient): 1,000 occurrences minimum/mode, based on the highest voltage mode of the device (20kV/10kA – 8x20 μs/1.2x50 μs waveform).

c. Suppression voltage ratings (SVR's): The maximum UL 1449 Second Edition SVR for the device should not exceed those listed in table 3.

Table 3. UL 1449 SVR

Nominal Voltage	Configuration	L-N	N-G	L-G	L-L
120/240	Ground Neutral	400	400	400	700
120/208	Ground Wye	400	400	400	700
277/480	Ground Wye	800	800	800	1500
240	Delta			700	700
480	Delta			1500	1500

d. Suppressors shall be designed to withstand a maximum continuous operating voltage (MCOV) of not less than 115 percent of nominal root mean square (RMS) voltage.

e. Suppressors shall be of solid-state componentry and operate bi-directionally. "Crowbar-type" devices are not allowed.

3.4.4 <u>TVSS Protection Requirements for Distribution Subpanels</u>. - The TVSS device shall be parallel connected and shall be designed, rated, and permanently connected for distribution panel/subpanel protection, based on the distribution panel current and voltage ratings. The ac distribution subpanel TVSS shall be tested in accordance with IEEE C62.45 and rated for application in "Medium Exposure Level" (Category B3), as defined in IEEE C62.41. Suppressors 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 L-N, each L-G, and 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. Subpanel protection shall be applied on the secondary side of low-voltage transformers and subpanels serving sensitive loads. System design shall protect sensitive electronic devices against the effects of surges and transients. Effective EMI/RFI noise filtering should be provided separately at sensitive equipment locations. Suppressor manufacturer shall provide certified test data confirming a fail short failure mode. The suppressor should contain replaceable internal fuses that operate to isolate the TVSS protective elements under conditions of an internal short circuit. Visible indication of proper suppressor connection and operation shall be provided. Indicators shall be provided to indicate that power was interrupted or that protection was reduced or lost for the specified phase/phases protected. If required for the application, the TVSS device shall be furnished with dry output contacts or an audible alarm for remote monitoring of the protection status. Suppressors may be mounted internal or external to the distribution panel being protected. The mounting position of the suppressor shall permit a straight and short lead length connection between the suppressor and the point of connection to the panel board. The interconnecting leads between the suppressor and the point of connection to the bus shall be kept as short as possible [0.5m (20 in) or less] to minimize let-thru voltage and shall be twisted to minimize lead reactances. Bends should be avoided if possible.

Suppressors shall meet or exceed the following criteria.

a. Maximum single impulse current rating: 50,000 amperes per mode (8X20 μs current waveform).

b. Pulse life rating (IEEE C62.41, table 4, Category B3 transient): 1,000 occurrences minimum per mode, based on the highest voltage mode of the device (6kV/3kA – 8x10 μs/1.2x50 μs waveform).

c. Suppression voltage ratings (SVR): The maximum UL 1449 SVR for the device should not exceed the ratings listed in table 3.

Suppressors shall be designed to withstand an MCOV of not less than 115 percent of nominal RMS voltage. Suppressors shall be of solid state componentry and operate bidirectionally. "Crowbar-type" devices are not allowed.

3.4.5 TVSS Protection for Low-Voltage Signal Equipment. - This paragraph provides recommended criteria for the selection of TVSS 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 TVSS 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 suppression system designer for the proper selection of TVSS components. The system parameters to be considered in the design shall include but are not be 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 equipment low-voltage signal conductors are exempt from required protection provided all of the following conditions are met:

a. The electronic equipment within a single facility has the same ground potential as all other electronic equipment within that facility. This is accomplished by dealing with the equipment as groups or clusters not exceeding a radius of approximately 9 meters (30 feet).

b. Signal conductors extending 7.5 meters (25 feet) beyond the cluster within the facility shall be enclosed within ferrous metal conduit.

c. No wiring within the raceways containing signal conductors shall extend beyond the confines of the building. 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 suppression devices selected for the signal voltage levels and cable types involved.

d. No ac power conductors shall be installed in common conduits or raceways containing low-voltage signal conductors.

The performance of TVSS devices for the low-voltage signal conductors shall meet or exceed the following criteria.

a. Suppressors shall have a response time of less than 5 nanoseconds.

b. Suppressors selected for equipment protection shall be of a multistage design utilizing solid-state componentry and shall operate bidirectionally.

c. All secondary communications and fire alarm initiating circuit protection units shall be UL 497A listed. All data communications and fire alarm annunciator protection units shall be UL 497B listed.

d. The suppressor manufacturer shall provide certified test data confirming a fail short failure mode.

e. The suppressor shall be housed in an enclosure that is compatible with the system being protected.

f. Where required, low-voltage signal conductors with maximum operating voltages between 6 and 48 volts should be protected with TVSS devices that clamp at a voltage no greater than 150 percent of the maximum operating voltage. For signal conductors operating at a maximum voltage above 48 volts, the TVSS should provide protection to limit the voltage to a maximum of 135 percent of the maximum operating voltage. Signal conductors with maximum operating voltages of 5 volts or less should provide voltage clamping at a maximum of 8 volts.

4. QUALITY ASSURANCE PROVISIONS

4.1 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 transient voltage surge suppression systems conform to all applicable requirements of this standard.

4.2 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.

4.3 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 tests performed by the contractor and to perform these tests and any additional tests deemed appropriate.

4.3.1 Ground Rod Resistance Tests. - All newly installed ground rods shall be individually tested prior to interconnection with other ground rods, and the rod-to-earth resistance for each rod shall be recorded. Installation contractors shall furnish these data to the Contracting Officer. Refer to 3.2.17.6.

4.3.2 Continuity Tests. - Continuity tests shall be performed on all power receptacles to ensure the ground terminals are properly grounded to the facility ground network.

4.3.3 Visual and Mechanical Checks. - The contractor shall inspect all connections, conductors, arresters, and air terminals for looseness or damage. Damaged items shall be replaced by the contractor.

4.3.4 Additional Tests. - The design agency shall specify any additional tests that may be required to verify conformance with the design. The resistance values given in 3.2.17 shall be used as a guide in determining additional tests that may be required as well as the usage and general configuration of the facility.

4.3.5 Testing Procedures.

4.3.5.1 Ground-Rod-to-Earth Resistance. - The resistance between a ground rod and earth shall be determined by the fall-of-potential test method as described in IEEE Std 81.

4.3.5.2 Counterpoise-to-Earth Resistance. - The resistance between a counterpoise and earth shall be determined by the fall-of-potential method as described in IEEE Std 81.

4.3.6 Inspection Methods. - Verification of bond and ground connection acceptability 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 protection devices found to be defective

5. PREPARATION FOR DELIVERY

There are no applicable requirements.

6. NOTES

6.1 Intended Use. - This standard is intended for use by design organizations specifying bonding and grounding, lightning, and surge protection systems or devices for new installations; by operating organizations having maintenance responsibility for new and existing installations; and by installation contractors when required by the contract specifications.

6.2 Definitions. - For the purpose of this standard, the following definitions apply.

6.2.1 Crowbar Device. - A surge suppression device that, once turned on by a surge, will continue to conduct the ac power frequency current after the surge has passed, or until the power frequency current reaches the zero crossing of the sine wave. These devices use gas-tubes and thyristors in their design.

6.2.2 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 the universal ground or reference zero potential level.

6.2.3 Earth Grounding Counterpoise. - Two or more electrically interconnected driven ground rods installed for the purpose of establishing low-impedance contact with earth.

6.2.4 Facility Ground Network. - The electrically conductive network, including all structures and grounding cables bonded to the earth grounding counterpoise but excluding the instrumentation ground network and 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 materials such as masonry and in outside facility areas such as gas, propellant, or oxidizer service facilities, the facility ground network 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.

6.2.5 Equipotential Signal Reference Plane. - An equipotential conducting plane designed to maintain a number of electrical/electronic units having a common signal reference at the same potential.

6.2.6 Fail Short Failure Mode. - A fail short failure mode takes place when the suppression elements fail as a result of a large surge current, and the surge suppressor maintains its structural integrity allowing a low impedance state to be maintained.

6.2.7 Faraday Cage Protection. - The Faraday cage protection technique encloses the area or facility to be protected in a conducting "box" comprising a grid of overhead ground wires (OHGW's), numerous grounded conducting masts surrounding the protected area and supporting the overhead grid, and a grounded counterpoise providing an underground grid similar to the overhead grid, which completes the box.

6.2.8 Ground. - If not otherwise qualified, any electrical connection to earth, either directly through a facility ground network or through some intermediary grounding system such as an instrumentation ground network.

6.2.9 Grounding. - The act of effecting optimum electrical continuity between conducting objects and earth.

6.2.10 Instrumentation Ground Network. - An electrical interconnection of low-voltage or signal-level cable shields and special electronic equipment grounding connections, utilizing techniques that minimize the possibility of EMI effects in critical systems.

6.2.11 Equipment Ground. - A connection between a unit of electrical equipment and the facility ground network..

6.2.12 Signal Ground. - A connection between a signal circuit and its zero signal reference plane.

6.2.13 Transient Voltage Surge Suppression (TVSS). - A surge protective device intended for connection electrically on the load side of the main overcurrent protection in circuits not exceeding 600 volts RMS and for the purpose of limiting lightning and switching surge transients.

6.2.14 Power Ground. - A designed connection between a power circuit conductor and a grounding counterpoise.

6.2.15 Lightning Ground. - A connection between a lightning protection system and a facility ground network or counterpoise.

6.2.16 Static Ground. - A functional term describing a connection between conductive objects and a facility ground network or counterpoise for the purpose of dissipating static electricity.

6.2.17 Bonding. - The act of effecting optimum electrical circuit continuity between adjoining conductive surfaces.

6.2.18 Wiring System Enclosures. - Normally, nonelectrified conductive enclosures containing electrical conductors that may be in electrical contact during abnormal conditions. Examples are conduit and fittings, junction boxes, outlet boxes, cable trays, electrical and electronic equipment frames and enclosures, electrical wiring cabinets, and metallic cable sheaths.

6.2.19 Zone 1. - Hazardous areas (areas in which gases, liquids, or dust may be present in quantities sufficient to produce flammable or explosive mixtures) where bonding and grounding of metallic conducting surfaces to prevent arcing are required. Bonding and grounding practices must be adequate to eliminate or negate the effects of the following phenomena:

a. Potential buildup in metal objects due to static charge accumulation

b. Induced voltages from lightning and fault currents

c. Arcing between metal components in fault current paths

6.2.20 Zone 2. - Areas with a suppressed radio frequency (RF) environment that contain EMI-susceptible equipment. Zone 2 areas are areas where: (1) radio frequency interference (RFI) from sources external to the area and sources within the area are nominally suppressed or (2) EMI-susceptible equipments are not inherently efficient receivers and are nominally shielded against RF radiation.

In physical terms, this classification includes interior areas containing sensitive electronic equipment where the enclosing structure provides effective shielding from RF radiation from external sources and in which potential sources of high-level radiated interference are nominally suppressed. Enclosed metal structures and reinforced concrete buildings with all peripheral reinforcing steel bonded and grounded to provide effective shielding against external RF radiation. Examples of Zone 2 areas are:

a. Launch Complex 39 (LC-39)

Pad Terminal Connection Room (PTCR)

Mobile Launcher Platforms (MLP's)

Launch Control Center (LCC)

Vehicle Assembly Building (VAB)

Rotation, Processing, and Surge Facility (RPSF)

b. KSC Industrial Area

Central Instrumentation Facility (CIF)

Operations and Checkout (O&C) Building

Payload Hazardous Servicing Facility (PHSF)

Vertical Processing Facility (VPF)

6.2.21 Zone 3. - Areas not normally containing hazardous materials or EMI-susceptible equipment. This classification includes all areas not classified as Zone 1 or 2. Bonding and grounding for protection from lightning hazards and electrical power system faults are required.

NOTE

Zones determinations will be made by the electrical design organization after requirements consultation with the users, operator, maintenance organization, and Safety.

6.2.22 Ordnance Facility Grounding and Bonding. - Grounding and bonding for ordnance facilities generally involve two systems: (1) external lightning protection system grounding and bonding and (2) internal system grounding and bonding for ordnance protection. The external lightning protection system is grounded as specified in this document. It is recommended that ordnance facilities with a perimeter of over 90 meters (300 feet) requiring lightning protection have either a mast or overhead wire system. The conductive parts of internal equipment should be grounded to an internal ground system, which is bonded to the lightning protection system at ground level as specified in AFR 127-100. In order to prevent shock hazard and minimize spark energy (see 3.2.17.5), personnel working on ordnance in the facility should be grounded through relatively high resistances of the order of 1 megohm. Antistatic clothing, conducting floors, conducting shoes, wriststats, legstats, and other equipment should be used to ground personnel who must handle ordnance materials. Conducting floors and other composite surfaces should have surface resistivities between 10^5 and 10^9 ohms per 10 square meters to prevent charge accumulation and enable grounding as specified in MSFC-STD-1800. Whenever possible, ordnance should be stored in metals containers. The electrical capacity of a large object in picofarads is roughly equal to its radius in centimeters. The discharge time through a high resistance is then about: TIME (sec) = radius (cm) x 10^{-11} x resistance (ohms).

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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 in order 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 eliminate electrically nonlinear junctions between conducting surfaces in order to prevent RF noise generation by nonlinear mixing and harmonic generation when the junctions are subjected to RF illumination.

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 strokes 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. Massive metal structures capable of sustaining direct lightning strokes without damage generally are not provided with additional lightning protection, and the structure itself serves as the path to the earth grounding counterpoise for lightning discharge currents. 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 decision of whether a structure is exposed to lightning and thereby requires bonding and grounding for that reason must be made by consideration of the requirements and provisions 3.2 of this specification.

A.2.2 Power System Fault Protection. - Electrical systems design practices and requirements set forth in this standard dictate that the neutral conductor of all ac power distribution systems be grounded at some point. Therefore, contact between a phase conductor and any conductive object or person will raise the potential of that object or person to phase voltage with respect to any grounded structure. The resulting hazard can be minimized by bonding all wiring system enclosures to ground to provide a fault current return path of sufficiently low impedance that potential rise in the contacted structure is limited, and extremely rapid operation of the circuit protective device is obtained. In order to avoid the flow of currents in a facility ground network that can produce EMI problems, arcing hazards, or differences in potential between metal objects, the power system within a facility or building should be grounded at one point only.

A.2.3 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 located 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.2.4 Nonlinear Junction RFI. - Uncoated junctions between metal surfaces rapidly develop oxide films over the mating surfaces, particularly in exterior locations. Such junctions have the characteristics of electrical diodes; that is, the conductivity across the junction is nonlinear and is partially unidirectional. This condition can, under certain conditions, produce radiated RFI in either or both of the following ways:

a. When illuminated by two or more RF fields, the junction acts as a diode mixer, heterodyning the induced currents across the junction to produce beat (sum and difference) frequency currents. These currents produce electromagnetic fields that are radiated along with the reradiated incident fields.

b. The nonlinear nature of the junction distorts any currents through it, producing harmonic currents with resultant radiated fields at harmonic frequencies.

Spurious RF fields generated in this manner would have a very low field strength but could theoretically constitute a source of RFI to sensitive electronic equipment, such as receiving antennas, in the immediate vicinity of the source junctions. In a case where the field strength of a desired signal to a receiving antenna is small compared to other ambient RF fields, spurious fields generated by nonlinear junctions located within the receiving pattern of the antenna could theoretically be of sufficient strength to interfere with the desired signal. The possibility of such interference could be eliminated by providing low-impedance bonds across all metallic junctions within the field patterns of receiving antennas. These bonds provide a linear shunt around the nonlinear junctions and suppress the noise-generating mechanisms but, in order to be effective, must be installed at intervals not exceeding 150 millimeters (6 inches). In order for significant noise generation by nonlinear junctions to occur, the dimensions of the metal objects comprising the junctions must be an appreciable fraction (one-tenth or greater) of the wavelength of the frequency of the RF fields incident on the junctions. Also, the reradiation efficiency of these junctions decreases with increasing frequency and is negligible above the middle ultrahigh frequency (UHF) range. This phenomenon has not been found to be a problem at KSC and, due to the high cost of guarding against it, is not considered in the requirements of this standard.

A.2.5 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.2.6 Instrumentation and Electronic Equipments Grounding. - 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

The design criteria given below should be followed in order to accomplish these design objectives:

a. At low frequencies up to 300 kilohertz, there should be no conductive loops anywhere within the grounding network. Such loops will result in induced circulating currents from inductive coupling with ambient magnetic fields and consequent noise voltages.

b. The impedance of the ground network at the highest signal frequency in the using system should be extremely small. Even though the signal circuits in the system may be single-point grounded to the ground plane, there will usually be signal currents flowing in the ground plane due to capacitive coupling between signal circuits and ground plane. Any voltage drop in the ground plane will appear as a noise signal in the system. This effect will be minimized by minimizing the impedance of the grounding network.

c. Single-point grounding minimizes low-frequency noise currents up to approximately 300 kilohertz. At higher frequencies, a multipoint ground system is preferred. An equipotential plane should be established where the equipment is located. For safety, the plane must be grounded to earth through a conductor, grounded structural steel, or copper down conductors. All digital circuits are considered high-frequency signal circuits. The final selection of grounding techniques must be made by the designer familiar with the equipment in the facility or network of facilities.

APPENDIX B

OVERHEAD GROUND WIRE CABLES

B.1 CABLES

Two types of stranded-steel cables are recommended for overhead ground wires: aluminum-clad steel (alumoweld 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 B-1; these are the minimum, average, and maximum size cables recommended for OHGW systems. The size of the cable shall be determined by the length of the span, the strength required to tension it to the desired sag and to provide the maximum windload, 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. Typically, this would be 22.8 percent of the rated breaking strength (RBS) at -1 degree Celsius (30 degrees Fahrenheit) for 10 mm (3/8 inch), 7 No. 8 AWG aluminum-clad steel cable with a 150-meter (500-foot) ruling span, and 25 percent of the RBS for a type 316 CRES cable of the same size, outside air temperature, and ruling span.

B.2 HARDWARE

Connectors, clamps, and air terminal point bases shall be galvanically compatible with the connected cable. Bimetal connectors or fused bimetal shim stock shall be used for interconnection of copper- and aluminum-clad cables.

B.3 GUY WIRES

Guy wires shall be constructed of aluminum-clad, or galvanized, stranded steel cables. However, long-term tests in salt fog atmospheres conducted by the American Society for Testing and Materials (ASTM) prove that aluminum-clad cable will outlast galvanized cable by a factor of 3 to 1. Strain insulators shall be installed in guy wires when not used as down conductors; such insulators shall have a minimum rating of 1.8 kV [2 meters (78 inches) long] and shall be located so the center of the insulator is approximately 2 meters (6 feet) from the pole.

Table B-1. 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

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

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I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER KSC-STD-E-0012	2. DOCUMENT DATE August 1, 2001

3. DOCUMENT TITLE
Facility Grounding and Lightning Protection, Standard for

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME *(Last, First, Middle Initial)*	b. ORGANIZATION	
c. ADDRESS *(Include Zip Code)*	d. TELEPHONE *(Include Area Code)*	7. DATE SUBMITTED

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