Standard No. S24.809
December 01, 1989
(Revised 12/22/2000)

GROUNDING STANDARD

1.0 SCOPE

1.1 Scope. This document establishes standard electrical, electronic, and mechanical requirements for ground electronic equipment.

1.2 Application. The requirements of this standard shall apply to equipment developed or fabricated to Government specifications, including commercial production (original equipment manufacture (OEM)) items. When applied to OEM items, the requirement of this document shall serve as a basis of selection among comparably performing equipment.

1.3 Contracting Officer's Technical Representative. The Contracting Officer's Technical Representative (COTR) shall provide the final interpretation of any conflict between this standard and specific contract requirements.

1.4 Waivers. Any request for waiver of specific requirements of this standard shall be submitted in writing to the COTR and to the Contracting Officer. A request for waiver must include: a) identification of the paragraphs for which the waiver is requested; b) identification of the systems, equipment, or components for which the waiver is requested; and c) a discussion of rationale for granting the waiver, including impact on reliability, maintainability, schedule, and cost if the waiver is not granted.

2.0 APPLICABLE DOCUMENTS

2.1 Government documents. The following documents, of the issue in effect on the date of invitation for bid or request for proposal, form a part of this standard to the extent specified herein:

The requirements of the following NOAA/NESDIS standards shall apply to all hardware and software, as described in this document.

Standard No. S24.801 - Preparation of Operation and Maintenance Manuals.

Standard No. S24.802 - General Requirements for Ground Electronic Equipment

Standard No. S24.803 - Cable and Wire Identification.

Standard No. S24.804 - General Requirements for Training on Electronic and Computer Equipment

Standard No. S24.805 - Spare Parts

Standard No. S24.806 - Software Development, and Maintenance and User Documentation

NOAA/NESDIS standards are available from: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, OSD3, Washington, D.C. 20233.

Military specifications and standards are available from: Commanding Officer, U.S. Naval Supply Center, 580l Tabor Avenue, Philadelphia, Pennsylvania 19120.

Federal Specifications and Standards are available from: The Superintendent of Documents, U. S. Government Printing Office, Washington, D.C. 20402.

Federal Information Processing Standards Publications are available from: The Suprintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

ANSI Standards are available from: American National Standards Institute, Inc., 1430 Broadway, New York City, New York 10018.

NASA/GSFC specifications are available from: National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt Road, Greenbelt, Maryland 20771.

NFPA Standards are available from: National Fire Protection Association, Batterymarch Park, Quincy, Massachusetts 02269.

EIA Standards are available from: Electronics Industries Association, 2001 Eye Street, N.W., Washington, D.C. 20006.

The National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service (NOAA/NESDIS), operates satellite tracking and computer processing systems which require a comprehensive grounding standard to ensure personnel and equipment safety. This grounding standard provides equipment requirements, design and installation procedures, and test methods, suitable for all communications and data processing systems. Specific requirements are defined for perimeter grounds, air terminals, down conductors, equipment rooms, antennas with integral electronic rooms, power grounds, and the interconnection of these subsystems throughout a widely spread site. The need for lightning and power fault protection, ground returns for signal and control cables, and radiation and interference suppression are addressed and integrated into a system for the entire facility. Priorities for upgrading existing facilities are identified, post installation and maintenance test procedures are detailed, and guidelines are given for tracing and correcting problems that may arise during the upgrade process.

This document was developed by MITRE Corporation under NOAA/NESDIS Contract Number 50-DGNE-5-0089. It was reviewed and approved by a panel of twenty people concerned with the grounding of electronic equipment, from both within and outside of the NOAA/NESDIS organization, which was convened by NOAA/NESDIS on November 8, 1989.

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INTRODUCTION

1.1 BACKGROUND

The National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite, Data, and Information Service (NESDIS), operates and maintains several communication and data processing facilities, through which it provides a range of weather related information to users. Some of these facilities contain many large satellite tracking antennas, with related electronics, spread over many acres of land. All facilities contain computer and communication systems spread over several rooms. Over the years since Congress directed its formation in 1961, continued improvements in technology have required that NOAA/NESDIS obtain many additions and changes to the equipment used to fulfill it's mission. This piece-by-piece acquisition of equipment has resulted in a grounding system at NOAA/NESDIS facilities that has also grown in a piece-by-piece fashion. This has resulted in varied installation practices and documentation procedures being applied to different parts of a facility and from one facility to another.

Recent lightning strikes at the Command and Data Acquisition (CDA) station at Wallops, Virginia, have highlighted the need for an overall grounding standard that would apply to all NOAA/NESDIS facilities to provide the maximum possible protection and safety for personnel and equipment.

1.2 SCOPE

This NOAA/NESDIS standard defines the requirements for the design, installation, modification, and testing of grounding systems at all NESDIS facilities. It applies to all facility construction and modification projects requiring the design or modification of, or the addition to, grounding systems within any NESDIS facility.

The grounding systems at existing facilities need not necessarily be modified for the sole purpose of complying with this standard. However, this document defines the ultimate grounding requirements to which all existing and any new NESDIS facilities must eventually comply. If problems exist at a facility which indicate a grounding system deficiency, if a normal facility upgrade includes work to the grounding system, or if new equipment is being installed, all work performed on the grounding system must comply with this standard, unless specific exemption is provided, in writing, by the Contracting Officer or his Technical Representative.

This document is based on the premise that safety is the prime requirement, for both personnel and equipment. No other requirement can be allowed to compromise it. Current technology, including fibre optics, balanced amplifiers and transmission lines, and waveguide theory as applied to ground planes, can provide solutions to interference problems that do not compromise safety.

1.3 DOCUMENT ORGANIZATION

1.3.1 Section Organization

The following sections of this document are organized in order of increasing complexity of the equipment and assemblies discussed in each section. Section 2 lists the references used in creating this document. Section 3 provides the requirements of the individual components to be used in the grounding systems and definitions of the special terms used herein. Section 4 shows how these components are to be assembled into the grounding subsystems and section 5 defines how those subsystems are to be interconnected throughout the facility. Section 6 provides guidelines for upgrading the existing facilities to comply with these requirements, section 7 defines the test procedures to be used after installation and to perform routine maintenance checks, and section 8 provides a trouble shooting guide to assist in handling problems that may arise during an upgrade process.

1.3.2 Verification Requirements

Many places in sections 3, 4 and 5 contain a number in brackets next to the word "shall". These are provided to identify the items for which some form of verification is required. Verification could take the form of inspection, analysis, demonstration, test, or sample test. Verification of individual requirements may be a part of the final acceptance tests or may be performed as a pre-test during the installation period, as identified in section 7.4. Each numbered shall is referenced in table 1, where the specific verification requirements for each are tabulated. Section 7.4 also provides more detailed descriptions of the verification requirements and defines the code letters used in table 1.

SECTION 2

REFERENCE DOCUMENTS

2.1 DOCUMENTS

The following documents provide theory, principles, and application steps and procedures in the areas of grounding, bonding, and shielding:

1. MIL-HDBK-419, Military Handbook dated 1-82: Grounding, Bonding, and Shielding for Electronic Equipment and Facilities

2. MIL-STD-188-124A, Military Standard dated 2-84: Grounding, Bonding, and Shielding for Common Long Haul/Tactical Communications Systems, including Ground Based Communications-Electronics Facilities and Equipments

3. Federal Information Processing Standards Publications (FIPS PUB) No. 94, National Bureau of Standards dated 9-21-83: Guideline on Electrical Power for ADP Installations

4. National Fire Protection Association (NFPA) No. 70, National Electrical Code

5. NFPA No. 78, Lightning Protection Code

6. MIL-F-29046(TD), Flooring, Raised, General Specification For

Item 1 above is the primary reference for this document. Users requiring additional details or theory for the procedures and practices defined herein should consult that document, unless another document is specifically cited in this text. All the requirements in this standard are in agreement with reference 1, except for the following:

> The spacing of air terminals on flat roofs, paragraph 1.3.2.1.2 of volume 2, is not self-consistent. This standard uses the equation derived for the spacing of air terminals and the coverage so provided, but not the specific spacings cited in parts "c" and "e" of the paragraph which are illustrated in figure 1-18.

2.2 SOURCES

Military Specifications, Standards, and Handbooks may be obtained from:

Naval Publications and Forms Center
Attention Code 3064
5801 Tabor Ave.
Philadelphia, PA 19120-5099

Federal Information Processing Standards Publications (FIPS PUB) may be obtained from:

National Technical Information Service
U.S. Department of Commerce
Springfield, VA 22161

Publications of the National Fire Protection Association (NFPA) may be obtained from:

National Fire Protection Association, Inc.
Batterymarch Park
Quincy, MA 02269

2.3 CONFLICT RESOLUTION

If any conflict is found between the requirements of this standard and the reference documents identified in section 2.1, the requirements of this standard take precedence. In the event of conflict between this document and any specification or other document into which it is incorporated by reference, the Contracting Officer's Technical Representative must decide the order of precedence.

SECTION 3

BASIC REQUIREMENTS

3.1 APPLICATION

A grounding system must be installed at each NESDIS facility that houses or is intended to house communications, computing, or other electronic equipment. All electrical and electronic systems must be attached to the grounding system with low impedance connections, in accordance with the requirements of the applicable paragraphs of this document. The ground system must also be connected to all metallic structures, provided they can be accessed in a reasonable manner, and without damage to their strength. This design standard is to be applied to all such facilities and systems.

3.2 DEFINITION OF COMPONENTS USED

The following paragraphs identify and define the component parts to be used in the grounding system.

3.2.1 Vertical Ground Rods

All ground rods shall[1] be copper clad steel and shall[2] be 3/4 inch or larger diameter, and with a length of 10 to 40 feet. They are to be driven vertically into undisturbed earth, or earth that has been compacted and settled. The tops of the ground rods shall[3] be between 1 and 2 feet below final grade level.

3.2.2 Horizontal Ground Conductors

Horizontal ground conductors shall[1] consist of No. 4/0 AWG bare copper cables, a minimum of 16 feet in length, and shall[2] be buried a minimum of two feet below final grade. They shall[3] be run perpendicular to an interconnecting cable, such as the perimeter ground cable, or radially from a single interconnection point. Horizontal ground conductors are permitted only when the use of vertical ground rods is not feasible due to geological conditions or other subterranean obstructions at the site.

3.2.3 Perimeter Ground Cable

The perimeter ground cable shall[1] be a No. 4/0 AWG bare copper cable, buried all the way around the perimeter of one or more structures and with its two ends fused together to completely encircle the structure(s). The actual route taken around a structure must be a compromise between the following needs:

1. To ensure that all precipitation soaks the soil around the cable, locate it 2 to 6 feet outside the drip line of the structure. This includes keeping to a minimum those parts of the cable that are

routed under roads, walkways, or other areas covered by material water can not penetrate.

2. To minimize the impedance of the cable, eliminate as many bends as possible. When necessary, bends should be of the smallest angle and the largest radius that is practical.

3. To keep the cable length as short as possible.

The contractor shall[2] submit a diagram for the approval of the Contracting Officer's Technical Representative, showing the compromises proposed.

The perimeter ground cable shall[3] be buried between 1 and 2 feet below final grade level. It shall[4] be bonded to any incidental, buried, metal structures that are within 6 feet of the perimeter ground cable through a No. 1/0 AWG bare copper cable, which must be routed in the shortest possible path from the perimeter ground cable to the metal structure.

3.2.4 Ground Terminal Plate

The ground terminal plate shall[1] be solid copper and a minimum of 1/4 inch by 2 inches by 6 inches. This size shall[2] be increased, if necessary, to allow connection of all the cables that may be required in the specific application, plus at least 25 percent extra for future expansion. Each plate shall[3] be installed in an electrical service well large enough to allow easy connection of additional cables and easy access for test purposes.

3.2.5 Interconnections

Unless otherwise specified in this document, all interconnections between the parts of the grounding system shall[1] be made by No. 4/0 AWG or larger, bare copper cable, buried between 1 and 2 feet below final grade level.

3.2.6 Bonding

Unless otherwise specified, all connections required by this standard shall[1] be made through a fusion process, such as cadwelds, brazing, or other process which causes the conductors to be melted and fused into a solid homogeneous mass. This is the only method that may be used to join dissimilar metals. Each such junction of dissimilar metals shall[2] be coated when necessary to prevent corrosion due to moisture.

When clamping is permitted, the connection shall[3] be easily accessible for inspection and test, by providing an electrical service well, if necessary, to allow access below grade level. If connection is required between a pipe carrying a flammable substance, such as oil or natural gas on which fusion can not safely be used, and the copper ground system; the pipe shall[4] be wrapped with a band of similar metal, that has been bonded previously to a copper cable, and clamped to the pipe. All clamped connections shall[5] be able to withstand a pull test of 200 lb minimum, except for clamps on waveguide. Conductive adhesive may also be used, provided the current capacity of the joint shall[6] be not less than the current capacity of the smallest of the conductors being joined.

3.2.7 Air Terminals

Air terminals shall[1] be made of solid copper or bronze, shall[2] be no less than 1/2 inch in diameter, a minimum of 2 feet in length, and extend at least 1 foot above the object being protected. Air terminals over 24 inches high shall[3] be rigidly supported at a point not less than one half their height.

3.2.8 Roof Conductors

Roof conductors shall[1] be routed around the perimeter of a flat roof or along any ridges on the roof. They shall[2] be No. 1/0 AWG copper cable, which shall[3] be insulated to prevent corrosion between dissimilar metals when installed on a metal roof. Roof conductors shall[4] be installed in a rectangular grid layout, inside the perimeter roof conductor, with a maximum spacing between any two parallel internal roof conductors, or between an internal roof conductor and a parallel portion of the perimeter roof conductor, equal to the spacing between the air terminals, along one axis of the rectangular grid, and three times the spacing between the air terminals, along the other axis of the rectangular grid. The roof conductors shall[5] be clamped or bonded at each crossover and to the perimeter roof conductor at each end and to the air terminal at that point. If necessary, due to a change in spacing between the air terminals for example, an internal roof conductor may be terminated in a bond to another internal roof conductor.

3.2.9 Down Conductors

The down conductors connect the roof conductors to the perimeter counterpoise. They shall[1] be No. 1/0 AWG copper cable, which shall[2] be insulated to prevent corrosion between dissimilar metals, if installed where contact is possible with metal siding or other metallic objects.

3.2.10 Chemical Treatment

When chemical treatment is required, magnesium sulphate, $MgSO_4$, also known as epsom salts, shall[1] be used.

Chemical treatment of vertical ground rods is to be accomplished by digging a trench around the top of each vertical ground rod. The average dimensions for each trench shall[2] be an inner diameter of 18 inches, a depth of 12 inches and a width of 12 inches. A service well for inspection purposes shall[3] be placed around each ground rod treated with chemicals.

Chemical treatment of horizontal ground conductors is to be accomplished by digging a trench directly above each horizontal ground conductor. Each trench shall[4] average 6 inches deep, 1 foot wide, and

16 feet long. A service well shall[5] be placed at the center of the horizontal ground grid where the horizontal ground conductors are connected together to allow inspection of the conductors and the magnesium sulphate. The quantity of magnesium sulphate used shall[6] be sufficient to fill each trench at least 75 percent.

Users are cautioned that the introduction of large quantities of a chemical substance into the environment may require an impact statement. If necessary, copper sulphate, $CuSO_4$, or calcium chloride, $CaCl_2$, may be used provided their impact on the environment is less than that of the magnesium sulphate. Alternatively, a non-dispersive conductive gel may be used.

3.2.11 Signal Reference Grid

The signal reference grid is an approximation of an equipotential plane to provide a ground reference for all signal and control lines. A signal reference grid shall[1] be installed in all areas of any NESDIS facility containing more than two racks or cabinets of communications or computer equipment. The grid shall[2] consist of a No. 1/0 AWG bare copper cable routed around the perimeter of the area where the grid is required, with its two ends bonded together. At intervals of not more than 2 feet, other conductors shall[3] be routed directly between opposite sides of the perimeter cable, fused to it, and connected to each other at each intersection. Non-metallic conduit shall[4] be used to route the cables through walls or partitions.

The signal reference grid may be located under a raised (computer) floor, in or on a floor, or suspended above the equipment. Under some conditions, a raised floor may be made part of the signal reference grid.

The 2 foot conductor spacing defined above provides an adequate equipotential plane for frequencies up to approximately 50 MHz, sine wave, or 10 Mbps, digital. For areas where higher frequencies are of interest, closer spacing may be necessary, i.e., so the size of the opening is equal to or less than one eighth of a wavelength at the highest frequency of interest. However, due to the high relative difficulty in providing such closer spacing in an existing facility and the comparatively small area in which such frequencies are used, it is recommended that this not be done unless interference problems are shown to exist which involve such higher frequencies.

3.2.12 Electrical Service Well

An electrical service well is a hole in the ground to allow access to electrical connections for test and inspection as part of a long term maintenance plan. A well is required whenever a connection is made below grade level using a compression or clamping bond or as otherwise stated herein. The top of the well shall[1] be level with, or above grade, and the bottom at least 6 inches below the level of the object to be inspected. The sides may be round, square, hexagonal, or octagonal. It shall[2] be made of a non-conductive material, and shall[3] be able to support the stresses that may reasonably be expected to be placed on it, in its specific location. The well shall[4] have a removable cover of compatible strength. Cable entrance shall[5] be through holes in the wall of the well, large enough to accept a cable of at least

2 inches in diameter. Each well shall[6] have at least 8 such holes, or break-out areas, so cables may enter with minimum bending.

3.2.13 Cable Entrance Plate

The cable entrance plate is a metal plate, mounted in or on the wall of a building or antenna mounted equipment room, through which the waveguides, cables, metal pipes, and metal conduits which enter that building or equipment room must pass. When these items are run outside of equipment rooms, they will tend to pick-up voltages and currents from undesired sources. The purpose of the cable entrance plate is to keep these induced voltages or currents outside the equipment rooms, as much as is compatible with the construction style of the structure involved. If the construction style of the wall to be penetrated provides significant shielding of the internal space, the cable entrance plate shall[1] be made from a metal that is compatible with such shielding materials and be bonded to them, continuously if possible, all around the edges of the cable entrance plate. If the wall does not provide any significant shielding, the cable entrance plate is not required.

All waveguides, cables, metal pipes, and metal conduits that pass through a cable entrance plate shall[2] have their outer surfaces bonded to that plate, provided the outer surface is at a nominal ground potential. The bond shall[3] be continuous all around the perimeter of the item passing through the plate and shall[4] be made by welding, brazing, soldering, other exothermic process, by means of a feed-through connector, or as provided in section 4.3.4 of this standard. The procedure chosen for any specific case shall[5] be the one that does not damage the item passing through the plate and which will produce the longest lasting and lowest resistance bond for the particular materials to be bonded.

The cable entrance plate shall[6] be sized so that there is at least 6 inches of clearance between the edge of the plate and all of the items passing through it. The cable entrance plate may be part of a box, vault or other structure, used to facilitate installation and maintenance of cables where they enter a building.

3.3 DEFINITION OF SPECIAL TERMS

3.3.1 Zone of Protection

In this standard, the concept of a tall object protecting nearby, shorter objects from lightning discharges, is referred to as a zone of protection. Research has shown that the length (R) of the final step of the leader in a lightning strike (R) is generally 100 feet or more. It can therefore be shown that the zone of protection concept is valid only when the height of the "tall object" is equal to or less than R feet above the level of the earth's surface, or above an effective ground plane, which extends at least R feet out from the base of the tall object. Objects greater than 100 feet high will only provide a zone of protection equal to that of a 100 foot high object, if the final leader step is 100 feet. For the percentage of lightning strikes in which the final leader step is greater than 100 feet, a taller object will provide a correspondingly greater zone of protection, proportional to the actual leader step length. At this time, no data exists on the probability that a lightning strike may have a final leader length of any specified value greater than the minimum. Therefore 100 feet is used throughout this standard.

The zone of protection provided by a single object, is defined as the space enclosed by a right circular cone with its axis coincident with the tall object and its apex at the top of the object. The sloping surface of the cone is formed by an arc with a radius of 100 feet, tangent to the earth's surface at one end, and passing through the top of the object at the other end. Where two or more protecting objects are used, the same concept is applied, however, in this instance, both ends of the arc defining the protected volume must terminate at the top ends of the protecting objects, or at the 100 foot point, whichever is lower. The basic equations derived from this concept are given in appendix A and a full explanation, including the derivation of these equations is published in MITRE Technical Report No. MTR-89W00206 entitled *Calculating Lightning Protection Zones*.

3.3.2 Minimum Slope

The term minimum slope is defined as the angle between the edge of the cone defined in 3.3.1 and a vertical line at the point where the cone touches the tip of the air terminal, mast, etc. If the height of the protecting object is H, and H is less than 100 feet, this slope is given by:

$$\sin^{-1}((100 - H)/100)$$

This provides a simple, conservative estimate of the zone of protection given by a single air terminal on its own. The derivation of this equation will also be given in the above report.

3.3.3 Structure

In this standard, a structure is any object which supports or contains equipment used by NESDIS for computing or communicating.

3.3.4 Group of Structures

A group of structures is any two or more structures that are located so the straight line distance of closest approach to each other is 20 feet or less, or when one or more structures is within, or partly within, the zone of protection of another.

3.3.5 Distance Measurements

Unless otherwise stated, all distances given in this document are to be measured along the route a cable takes or is intended to take, not the straight line distance.

3.3.6 Conductor Sizes

Whenever a conductor size is specified in this document, it means that it is the minimum size acceptable for the specific application. A larger size conductor is always acceptable.

3.3.7 Parallel Connections

Many of the requirements in this standard specify the installation of cables or wires that create parallel conducting paths, from item to item, and structure to structure, at a site. Unless otherwise stated herein, combining the requirements of several paragraphs into one physical wire or cable is not permitted. The needs of each individual requirement must be met by a unique conductor. For example, the required connections for the power ground system may not "share" the connections required for the equipment room ground system, nor may the requirement to connect the power system ground at a remote structure to the power system ground at the primary structure, "share" any conductor with the requirement to interconnect the perimeter counterpoise of each structure.

SECTION 4

GROUNDING SYSTEM COMPOSITION

The grounding system at each NESDIS facility must consist of one or more of each of the following parts:

1. Perimeter counterpoise
2. Ground terminal plate
3. Lightning ground system
4. Equipment room ground system
5. Power ground system
6. Interconnections between these ground systems

4.1 PERIMETER COUNTERPOISE

The perimeter counterpoise (PCP) shall[1] consist of a perimeter ground cable and two or more vertical ground rods. The ground rods shall[2] be evenly spaced along the perimeter ground cable at intervals of between 1.5 and 2 times their length. The tops of the ground rods shall[3] be directly under the perimeter ground cable and shall[4] be bonded directly to it. The ground rods shall[5] be long enough to maintain contact with damp or moist soil year round, or else a waiver must be obtained.

4.1.1 Adjacent Structures

Structures within 20 feet of each other at their nearest points shall[1] share the same PCP, preferably routed around the combined perimeter of the structures without any internal cross-connections. However, such internal connections are not prohibited, provided the outer-most cable meets the requirements of this standard. It is therefore not necessary to remove any of an existing PCP when it is extended to include a new adjacent structure.

Structures separated by more than 20 feet, but with one inside the zone of protection of another, may be included within the same PCP. Alternatively, they may each have their own PCP, joined to each other by two interconnecting cables. If more than two structures exist with overlapping zones of protection, each PCP shall[2] be joined to all adjacent PCP's.

The requirements for interconnecting the PCP's are depicted in figure 1 and defined as follows:

1. The points of connection on the smaller of the two structures shall[3] be at the extreme ends of that section of its PCP that is closest to the larger structure. If the direct path from such an end point is obstructed, the connection may be made at an internal point where a more direct routing is possible. See note 3 of figure 1.

2. The points at which the joining cables are attached to each PCP shall[4] be separated by at least the distance equal to the spacing between ground rods, or, if the spacing between the rods is greater than the length of the side closest to the other structure, the connection points shall[5] be within 1 foot of each corner of the PCP.

3. The cable shall[6] be routed in a straight line over the shortest possible distance, unless an increase of 10 percent or less in the cable length will allow the connection to be made to a ground rod, instead of the perimeter ground cable.

4. If the PCP of one structure is rounded, or at an angle to the other structure, the minimum length connection is only possible at the single point of closest approach. In this case, the two points of attachment shall[7] be separated from each other by a minimum of 6 feet. This separation shall[8] be increased until the incremental increase in the separation is less than the incremental increase in the length of the connecting cable.

5. If structure A must be joined to structure B because of an overlapping cone of protection and Structure A must be joined to structure C because of other connecting cables, then structure B shall[9] be joined to structure C.

6. Structures separated by distances greater than defined above must be treated as separate structures or groups.

4.1.2 Resistance to True Ground

The resistance between the PCP for any structure, or group of structures, at a site, and true ground shall[1] be 5.0 ohm or less. This resistance must be measured, for each individual PCP in isolation, using the test procedures provided in paragraph 7.2.

4.1.3 Achievement Methods

The required resistance between a PCP and true ground may be achieved by the following methods, in order of preference:

1. Use rods longer than the 10 foot minimum, but not exceeding 40 feet in length.

2. Use the vertical rods at the minimum spacing.

3. Add chemical treatment to the rods.

page for figure 1

4. Add vertical rods, outside the basic PCP, at the minimum spacing.

5. Use horizontal ground conductors, as well as, or instead of, the vertical ground rods.

6. Add chemical treatment to the horizontal ground conductors.

4.1.4 Selection Criteria

The following factors should be considered when determining the method to be used to achieve the required resistance to true ground.

1. The ground rod should make contact with the water table throughout the year.

2. At least 50 percent of the ground rod should be below the frost line.

3. Underground rock formations, if present, may limit the depth to which the rods can be driven.

4. If no other alternative provides the required resistance to true ground, the ground rod spacing may be either or both wider or narrower than the standard spacing.

4.1.5 Structural Steel Columns and Other Building Metal

When the PCP dissipates the energy in a lightning strike, all the conductors connected to it are raised to some high voltage, due to the finite impedance of the grounding system. Any item connected between one of these conductors and any other conductor normally at ground potential, but not connected to the same PCP, will have this high voltage applied across it. **This will cause a hazard to both personnel and equipment.**

The procedure that provides the greatest safety is for all structural steel, and any other conducting items in the structure, such as water pipes, ducts, etc., and to conducting items buried in the vicinity of the PCP, be made a part of the ground system by connecting it to the PCP. If this preferred procedure is followed, any metallic object that is at a nominal ground potential and comes within 10 feet of any PCP or the cables which interconnect them, shall[1] be connected to that PCP or interconnect cable. In an old or shared building, it is often difficult to be sure of the routing and interconnections made by all the metallic objects in and around the structure. This could result in some objects not being connected to the PCP due to their existence being unknown, a lack of access without interrupting operations, etc. Every effort should be made to determine the safest action in any specific set of conditions. If this preferred procedure is not followed, the reasons shall[2] be documented and approved by the COTR.

When it is decided to make these interconnections, the cable used shall[3] be a No. 1/0 AWG bare copper cable, [4] bonded at each end, and [5] routed between the metal object and the PCP in the shortest possible manner.

4.2 GROUND TERMINAL PLATE

A ground terminal plate must be clamped to the PCP wherever needed to allow connections to other parts of the ground system that must be removed for test purposes.

4.2.1 Connection to the PCP

When required, this connection shall[1] be made by clamping the plate directly to a ground rod, or by clamping the plate to a short length of No. 4/0 bare copper cable, which is bonded to the ground rod. The cable shall[2] be the minimum length necessary for access to disconnect and visually inspect the parts. That rod and the ground terminal plate shall[3] be in an electrical service well large enough to allow easy inspection and test, as well as the necessary access to make the connections to the ground terminal plate.

4.2.2 Connections to Other Cables

At facilities with many structures, e.g., the CDA stations, it is necessary to interconnect the PCP's of the various structures, or groups of structures, and also to be able to isolate them from each other, so that maintenance measurements may be made. All such connections to the PCP's must be made via one or more ground terminal plates.

At these sites, all down conductors shall[1] be bonded directly to the PCP, except if a down conductor is also an interconnect to a signal reference as required by subsection 4.4.6, item 4a. All other cables that are routed to the PCP shall[2] be connected via the ground terminal plate. These cables shall[3] be routed to a common ground terminal plate, when the additional length of cable required, above the shortest, most direct route, is not more than 10 percent of its length. If this routing would increase the length of any cable by more than 10 percent, an additional ground terminal plate shall[4] be installed. The location of all ground terminal plates shall[5] be such that the total number required is minimized.

At facilities with only one structure, or group of structures, e.g., Federal Building 4 at Suitland MD, no such disconnect is required and all connections may be made by bonding directly to the PCP.

4.3 LIGHTNING GROUND SYSTEM

A lightning ground system must be installed on each structure that is not entirely within the zone of protection of another structure. Structures that are partly within such a zone of protection may still require some parts of the lightning ground system, as designated herein. The lightning ground system must provide as direct as possible a path to ground for all lightning induced currents.

The lightning ground system consists of air terminals, roof conductors, and down conductors. The requirements that define how these components are incorporated into the system are given in the following paragraphs and illustrated with various examples in figures 1, 2 and 3.

4.3.1 Air Terminal Mounting

When not within the zone of protection of another structure, air terminals shall[1] be permanently and rigidly attached to the roof or upper walls of a building, or at the highest point(s) of a tower or antenna, so that the tips of the air terminals are at the desired height, or more, above the structure, or any other objects mounted on the top of such structure.

Mounting to structural metal is permitted, provided all structural metal and all conductive items within 6 feet of any structural metal are bonded together to form part of the lightning protection system and, for antennas, that any bearings are bridged by suitable jumpers, as defined in subsection 4.3.3.3. Air terminals shall[2] be mounted so they do not interfere with the operation of antennas or lighting fixtures, but protrude above all objects by the designed amount. Examples of acceptable mounts for buildings are shown in figure 3.10-1 of NFPA 78, Lightning Protection Code.

If meeting all the requirements of section 4.3 would cause interference to, or degradation of, the normal operation of any equipment at a facility, an additional structure shall[3] be built to provide the required lightning protection without the undesired effects.

4.3.1.1 Roof Mounting

The preferred method of attachment to buildings is to use lag bolts into masonry or concrete. Through bolts are also permitted. Either method must have at least 6 feet of clearance between all the conductive parts of the attachment device and any other conductive material that is not part of the lightning protection system.

For sloping roofs, air terminals shall[1] be placed as close as possible to, and in any case within 2 feet of, each end, or each corner, of the peak of the roof. This is the minimum requirement. The air terminal spacing along the peak of the roof shall[2] be such that the maximum distance between them is no greater than 28 feet if the air terminals project 1 foot above the level of the roof peak, 40 feet for a 2 foot projection, or 48 feet for a 3 foot projection. This will provide sufficient protection, provided the slope, from the tip of the air terminals to the building edge, including any protrusions (e.g., dormer windows, chimney, vent pipe), is less than the minimum slope. If it is greater than the minimum slope, the more accurate calculation given below must be made, and the locations modified to comply with the results.

On flat roofed structures, air terminals shall[3] be mounted at each corner, along each edge of the roof, and in a square pattern over the rest of the roof. Air terminals at the edge and corners of the roof shall[4] be mounted as close as possible to the outermost edge or corner, and in any case, within 2 feet of that edge or corner. The maximum length of the side of any such square pattern shall[5] be 20 feet if the air terminals project 1 foot above the level of the roof, 28 feet for a 2 foot projection, or 34 feet for a 3 foot projection. The minimum requirement shall[6] be two air terminals at diagonally opposite corners, projecting 1 foot above the roof line or anything mounted on the roof. This is adequate provided no wall of the structure is greater than 14 feet long. Figures 2 and 3 show some general examples of these requirements.

page for figure 2

page for figure 3

The above requirements are specific instances of the following general equation, which shall[7] be used whenever necessary to determine the protection range of any air terminal, provided only that H does not exceed 100 feet.

$$S = (200H - H^2)^{1/2}$$

Where:

S = The protection range, i.e. the horizontal distance from an air terminal to the point where protection is desired. This is normally the upper surface, such as the roof of a building, or the highest point of an antenna or support pole where protection is required from a direct lightning strike.

H = The height of the top of the air terminal above the roof or the highest surface on the protruding object.

If a square pattern of air terminals does not economically cover the roof area, a rectangular pattern may be used, provided the above equation is used to ensure the center of the rectangles are protected by the air terminal height and spacing to be used.

When there are other items on the roof which project above the roof surface, such as a stair well entrance, a chimney, or an air conditioner heat exchanger, the tops of these items shall[8] be the reference plane above which the air terminals must protrude, as defined above. The additional height that these air terminals are above the main roof surface may enable them to protect a larger area of the roof, adjacent to the roof mounted items. The protected area is defined by the above equation, applied to each surface in turn.

4.3.1.2 Towers and Masts

Air terminals on towers or masts shall[1] be mounted directly to the structural metal, or shall[2] be bonded to it by a No. 6 AWG bare copper cable in the shortest possible distance. Only one air terminal and one down conductor is required per tower or mast, unless otherwise recommended by the manufacturer, or unless more are needed to protect equipment mounted on the tower or mast. If the structural metal of the tower or mast is not used as the down conductor, as provided in subsection 4.3.3.2, the down conductor and the cable bonding the air terminal to the structural metal shall[3] be one continuous conductor.

4.3.1.3 Antennas

Air terminals shall[1] be mounted so that the tip of at least one air terminal is the highest object on the antenna, for any direction in which the antenna can be oriented.

4.3.1.4 Partial Protection

If one structure is partly, but not completely within the zone of protection of another structure, the need for some of the air terminals may be eliminated on the partly protected structure. An air terminal may be eliminated only if the area of protection it would have provided is totally covered by other air terminals. If any air terminals are required on a structure, the interconnecting roof and down conductor must still be provided, as specified below.

4.3.2 Roof Conductors

A continuous roof conductor shall[1] be routed around the perimeter of a flat roof and along the ridge on a ridged roof. There shall[2] be at least two current paths from each air terminal to ground. Any internal air terminals shall[3] be connected together by other roof conductors in a grid layout, with each end of the internal roof conductors bonded to the perimeter roof conductor. The maximum size of the grid shall[4] be equal to the spacing of the air terminals, in one dimension, and three times the air terminal spacing in the other dimension. The conductors shall[5] be bonded or clamped at all crossover points.

As a last resort, isolated air terminals may be connected to the grid, or a down conductor, by a dead end cable no more than 16 feet long. This should only be necessary on structures with an irregular outline, and such usage must be kept to the minimum possible.

All the conductors shall[6] be run in as straight a line as possible, on the surface of the roof. There shall[7] be no turns of more than 90^o, nor with less than an 8 inch radius at any point in any roof conductor run. If it is necessary to meet this requirement, the roof conductors shall[8] be run through walls, cornices, parapets, etc., using a non-conductive, non-flammable duct. All roof conductors shall[9] be securely fastened to the object on which they are placed, at intervals of not more then 5 feet. The fasteners may be attached by bolts, screws, nails, or adhesive and shall[10] withstand a 200 lb pull without loosening. They shall[11] be made of a material that is at least as equally resistant to corrosion as the conductor and which does not form an electrolytic couple with the conductor or any other metal with which it may be placed in contact.

When two roof conductors meet in a crossover or a "T" type intersection, they shall[12] meet at a sharp 90^o angle, i.e., no bending of either conductor is required. (See figure 4)

4.3.3 Down Conductors

Down conductors shall[1] be run in as straight a line as possible and located so as to minimize the number of bends required. There shall[2] be no turns of more than 90^o, nor with less than an 8 inch radius at any point in any down conductor run. Where possible, the down conductors should be run on the surface of the structure, but may be run through walls, cornices, platforms, balconies, etc., to avoid sharp bends. When this is necessary, the conductor shall[3] be run in a non-conductive, non-flammable duct.

The down conductors shall[4] be securely fastened to the object on which they are placed, at intervals of not more then 3 feet. The fasteners may be attached by bolts, screws, nails, or adhesive and shall[5] withstand a 200 lb pull without loosening. They shall[6] be made of a material that is at least as equally resistant to corrosion as the conductor and which does not form an electrolytic couple with the conductor or any other metal with which it is to be placed in contact.

4.3.3.1 Down Conductors for Buildings

There shall[1] be a minimum of two down conductors on all buildings, unless the structural metal is used as the down conductors. Down conductors shall[2] be located:

1. At the diagonally opposite corners of square or rectangular structures, and symmetrically distributed around cylindrical structures

2. On irregularly shaped buildings, e.g., L, T, or E shapes, at the two corners separated by the greatest distance

3. So that the down conductors may be conveniently attached to roof conductors and to the PCP

4. So that the down conductors are always routed downward, with a minimum of horizontal run

The spacing between down conductors shall[3] be a maximum of 100 feet, measured along the perimeter roof cable. The down conductors shall[4] be equally and symmetrically spaced along the perimeter of the structure, except small variations are permitted to accommodate doors, windows, or conducting objects that should not be grounded. Buildings higher than 60 feet shall[5] have one additional down conductor for each additional 60 feet, or fraction thereof, in height. Figures 2 and 4 also illustrate these down conductor requirements.

If the structural metal is used as the down conductors, each riser shall[6] be bonded to the PCP, in the shortest, most direct manner, using No. 4/0 AWG bare copper cable.

4.3.3.2 Down Conductors for Towers and Masts

The structural metal of towers or masts may be used as the down conductors, provided each joint in each leg and major cross member can maintain electrical continuity under all conditions of use. If not, the joints may be bridged by minimum length No. 1/0 AWG or larger copper cable, bonded to the structure on each side of each joint that requires bridging. Alternatively, a No. 1/0 AWG insulated copper cable shall[1] be run from top to bottom of the structure and extended to connect to the PCP for the structure. The down conductor shall[2] be bonded to the top and bottom of the structure.

If the tower or mast has a single support point, an additional No.1/0 AWG copper cable shall[3] be bonded to the structure, opposite the point where the down conductor is bonded to the structure, and connected to the PCP in the shortest, most direct manner. If the tower has multiple legs, each shall[4] be connected to the PCP in the same way. Circular towers shall[5] be connected to the PCP by a four No. 1/0 AWG bare copper cables, spaced at 90 degrees around the circumference.

4.3.3.3 Down Conductors for Antennas

On antenna structures, the air terminals shall[1] be connected together by the shortest possible run of No 1/0 AWG insulated copper cable which does not interfere with the performance of page for figure 4, page 1 of 2.

NOTES:

1. Ground rod spacing is shown at 20 feet, equal to twice a 10 foot rod depth, as required for the PCP per subsection 4.1.

2. Air terminals set in a square grid pattern with the sides 34 feet long. This assumes an air terminal protrusion of 3 feet above the surface of the roof or items mounted on the roof.

3. The spacing of the roof conductors is shown at maximum, i.e., three times the spacing of the air terminals in one dimension and equal to the air terminal spacing in the other dimension.

4. Maximum down conductor spacing of 100 feet is shown. This is measured along the roof perimeter cable.

5. Transition between air terminal spacing of 34 feet and 20 feet. Coverage of the roof in this area should be checked by careful graphical layouts, or by applying the equations given in subsection 4.3.1.1. Note that "T" connections for roof conductors are permitted if necessary.

6. If a mast were to be erected beside this building, in the inside corner of the "L", so as to provide a zone of protection from lightning strikes, as shown by the dotted line, the air terminals shown with (6) beside them, would not be needed. Other air terminals, which are also located within the dotted circle, are still required because part of the area of the roof they protect falls outside of the dotted circle.

7. If the air terminals (6) are not required, then those portions of the roof conductors shown with (7) beside them are also not required. All the other sections are needed to provide at least two paths to ground from all air terminals, or else they are part of the roof perimeter cable, which must be retained in full.

Figure 4. Example Lightning Protection Layout for Large Buildings (Concluded)

the antenna, so that all air terminals have at least two paths to the PCP. Two down conductors shall[2] be bonded to these interconnecting cables, routed down the antenna structure, as far from each other as possible, and connected to the PCP. Under no circumstances is any down conductor to enter the feed box, vertex box, or other shelter housing electronic or electrical equipment that may be present on the antenna structure.

Alternatively, all, or any part, of these cables may be replaced by the structural metal of the antenna. This is acceptable, provided the cross section of the metal that may carry the lightning induced currents shall[3] be at least twice that of the copper that would otherwise be used. All bearings shall[4] be bridged by a minimum practical length No 4/0 AWG cable bonded to the structural metal on either side of each bearing.

There shall[5] be 4 No. 1/0 AWG cables bonded to the PCP and to the outer most structural metal of the base (fixed) portion of the antenna structure and equally spaced around the antenna base. If down conductors are used, two of these shall[6] be a continuation of the down conductor. Antenna structures that have a central "maypole" type cable entrance, shall[7] have these four cables run radially from the maypole to the PCP, at 90^o spacing.

4.3.4 Waveguide, Coaxial and Shielded Cable Grounding

Each waveguide, coaxial and shielded cable shall[1] be bonded to the PCP of any structure that it enters, and [2] as close as possible to the highest and lowest points that it reaches on any tower or antenna structure to which it is attached. The bonds shall[3] be made before the bend that directs the waveguide or cable away from the tower. If the run on a tower exceeds 200 feet, the waveguide or cable shall[4] be bonded to the tower at additional points so that the distance between any two bond points does not exceed 200 feet. Each waveguide or cable entering a large antenna structure shall[5] also be bonded to the structure at the point at which it enters the feed box, vertex box, or other equipment shelter mounted within the antenna structure. Paragraph 4.4.7 also applies.

Connection to the waveguide or cable shall[6] use ground kits supplied by its manufacturer, if available. Otherwise connection to rigid waveguide shall[7] be made using a No. 6 AWG bare copper cable bonded to a lug mounted under a flange bolt, or by wrapping a copper ground strap around the waveguide and clamping them firmly together, but without distorting the waveguide shape. A minimum length pigtail shall[8] be left to the tower metal, entrance plate, or interconnecting cable. Connection to elliptical waveguide, or coaxial or shielded cable, shall[9] be made by tightly wrapping a minimum of three turns of bare copper braid, at least one inch wide, around the waveguide or cable, at a point where the outer sheath has been removed, exposing the outer conducting surface. This joint shall[10] then be clamped, taped, and sealed, leaving a minimum length pigtail of flattened braid to be bonded to the tower metal, entrance plate, or interconnecting cable. Other acceptable grounding methods are given in MIL-HDBK-419, paragraphs 1.3.3.3. and 1.3.3.4.

Individual connections shall[11] use a No. 6 AWG copper wire, if its length does not exceed 12 inches.

If a longer length is needed, a No. 1/0 AWG copper cable shall[12] be used. Multiple waveguide or cables may be jumpered to the one No. 1/0 cable using No. 6 or larger wire. Waveguide or cables entering an enclosure shall[13] pass through an entrance plate and be grounded to it. The plate shall[14] be grounded to the PCP for the structure by the shortest route, using a No. 1/0 AWG cable.

The general direction of the waveguide and cable grounding components on the outside of an enclosure, shall[15] always guide lightning induced currents towards the PCP, i.e., the placement of all connections and the routing of all cables must not attempt to route the current back on itself.

Waveguide and cables shall[16] also be grounded to the signal reference grid, using these procedures and the requirements of paragraph 4.4.4. In some instances, this may require attaching two ground kits to a cable within a few inches of each other. However, both are necessary and must be separately installed and connected, one outside the wall and the other inside the equipment room.

If any cable has more than one shield, or if a shielded cable in run inside a metal pipe or metal conduit, these requirements apply only to the outermost item providing the shielding. The other shields may, but need not, be connected as well, depending on the source and strength of the interference against which they are intended to protect the conductors inside each shield.

4.4 EQUIPMENT ROOM GROUND SYSTEM

4.4.1 Signal Reference Grid

A signal reference grid shall[1] be formed by routing, on the sub-floor, a No. 1/0 AWG bare copper cable around the perimeter of the entire equipment area. The cable shall[2] be continuous with both ends fused together, forming a complete loop. At intervals of not more than 2 feet, No. 4 AWG conductors shall[3] be routed across the area, fused to the 1/0 perimeter cable at each end and fused or clamped at each intersection. If the conductors pass through any walls or partitions they shall[4] be bonded to any metallic items that are in the wall and within 6 feet, or the reference grid cable shall[5] be enclosed in non-metallic conduit. If routed under a raised floor the support pedestals shall[6] be grounded to the grid at intervals of 10 feet or less, by bonding the grid cable to the pedestal column.

4.4.2 Raised Floor as Reference Grid

If desired, the raised floor supporting structure may be used in place of the above No. 4 AWG copper grid, provided the following conditions are met.

1. The pedestals and stringers are bolted together using spring washers or equivalent, and are made of aluminum, or tin or zinc plated steel, so that low resistance, long life, pressure connections can be made. The electrical resistance between an individual stringer and pedestal

shall[1] be less than 0.1 milliohm. Clip nuts and sheet metal screws must not be used. (Reference MIL-F-29046(TD)).

2. The joint areas shall[2] be clean and free from oxidation. A light coating of a joint protective compound shall[3] be used to protect the joints against oxidation after installation.

3. The No. 1/0 AWG perimeter cable shall[4] be bonded to the outer row of support pedestals on all sides of the grid area. If any side is greater than 20 feet, intermediate cables of No. 4 AWG shall[5] be routed across the sub-floor and bonded to the perimeter cable, at intervals of no more than 20 feet. The routing shall[6] be along the line of a row of support pedestals, each of which shall[7] be bonded directly to the No. 4 AWG cable.

4. The ground connection from each piece of equipment in the room to the grid, and from the grid to the perimeter cable, shall[8] be made without joining dissimilar metals, except by a fusion process.

5. The raised flooring materials shall[9] conform to the requirements of MIL-F-29046, revision 2.

4.4.3 Other Reference Grids

If an existing equipment area does not have a raised floor, the signal reference grid may be implemented in either of the following ways:

1. A grid shall[1] be formed using 1 inch wide by 1/16 inch copper strap with a center to center spacing of not more than 2 feet, bonded at all intersections, laid on the existing floor and covered with carpet or tile. Access shall[2] be provided through the covering to allow ground straps to be connected to the equipment.

2. A grid shall[3] be formed using No. 4 AWG copper wire with a center to center spacing of not more than 2 feet, bonded at all intersections, and suspended from the ceiling.

The perimeter wire around the grid area shall[4] be No. 1/0 AWG. If the spacing of the conductors is less than 2 feet, their size may be reduced proportionally, to a minimum of No. 14 AWG wire, or 1/8 inch by 1/16 inch strap.

4.4.4 Spacing Variations

If the existing cabinets, racks, ducts, pipes, etc, in the equipment area, do not allow this spacing of the conductors, the following modifications are allowed:

1. Each bay or group of cabinets or racks shall[1] have the conductor run in front, behind and at each end of the bay and as close as possible to it. If possible, intermediate conductors shall[2] be run between the conductors at the front and rear of the racks of cabinets. If it can fit in the available space, the conductor shall[3] be the same size as the conductors in the grid. If not, any conductor of No. 14 AWG or larger may be used.

2. Each cabinet or rack that stands alone, shall[4] have the conductor run in front, behind and at each side.

3. The desired 2 foot maximum grid spacing may be increased to fit around obstructions, but to the minimum extent possible.

4.4.5 Entrance to Signal Reference Grid Area

All items at a nominal ground potential, except the neutral and ground wires of the power system, shall[1] be grounded to the signal reference grid at the point where they enter the area of the signal reference grid. This applies to all waveguides, coaxial cables, shielded cables, pipes, conduits, ducts, and cable trays, except items that are run inside of other grounded conductors. For example, a coaxial cable with two shields, must have the outer shield grounded to the signal reference grid, but need not have its inner shield grounded at the same point, as long as the outer shield is not terminated there and the inner is then exposed to contact with other objects. Multiple shielded pairs in a cable with an overall shield, and shielded or coaxial cables within a metal pipe or a metal conduit, could be treated in the same manner.

If the entrance point is closer to the perimeter cable than it is to other items that must be connected to the perimeter cable, the connection shall[2] be made directly from the item to the perimeter cable using No. 6 AWG copper wire, if further away, the connection may be made via the closer item. If the item is one of a group, all the items in the group may be bonded to each other with a No. 6 AWG copper wire, each end of which shall[3] be bonded to the perimeter cable. Alternatively, each item may be bonded, by a No. 6 AWG copper wire, to a No. 1/0 AWG jumper wire, which is in turn bonded to the perimeter cable. The total length of wire between any one item and the perimeter cable shall[4] be no more than 20 percent longer than the straight line distance from the item to the perimeter cable.

If power distribution equipment, which provides power to the equipment in the reference grid area, is mounted in, or immediately adjacent to, a signal reference grid, any distribution boxes, conduits, pipes, and any ground bus therein, shall[5] be connected to the grid by the shortest possible No. 6 AWG wire.

Items crossing from one signal reference grid area to another, shall[6] be bonded to each at the respective entrance points.

4.4.6 Interconnection of Signal Reference Grids

If a building has more than one signal reference grid, they must be interconnected as follows:

1. Signal reference grids with less than 6 feet spacing between their adjacent sides shall[1] be combined into one grid with a single perimeter cable. Grids with larger spacing may also be combined, if desired.

2. Signal reference grids on different floors of the same building, if they overlap in the vertical plane, shall[2] be connected at the corners of the overlapping area, with a No. 1/0 AWG copper cable, by the shortest possible route. Additional connections shall[3] be made, if necessary, so that the distance between the connecting points on either grid perimeter cable is not greater than 20 feet, provided such additional cables can be routed at least 6 feet away from, and are no more than 20% longer than, the cables connected to the corners.

3. Signal reference grids on different floors of the same building, that do not overlap in the vertical plane, or on the same floor but separated by more than 6 feet, shall[4] be connected by at least two No. 1/0 AWG copper cables, routed between the corners of each grid that are closest to the other grid, by the shortest possible route. Additional connections shall[5] be made, if necessary, so that the distance between the connecting points on either grid perimeter cable is not greater than 20 feet, provided such additional cables can be routed at least 6 feet away from, and are no more than 20% longer than, the cables connected to the corners.

4. The perimeter cable of each signal reference grid shall[6] be connected to the building PCP, by the shortest, most direct route, with No. 1/0 AWG copper cables using the following guidelines:

    a. Connections to the PCP shall[7] be made from each corner of the grid perimeter cable. Additional connections shall[8] be made, if needed, so that the distance between the connecting points on the grid perimeter cable is 20 feet maximum.

    b. If there is a large difference in the distances to the building perimeter cable when measured from the different corners of the grid perimeter cable, the connections need be made only from the two sides of the grid perimeter cable that are closest to the building perimeter cable.

    c. If the grid perimeter cable is connected to another signal reference grid, which is between it and the building perimeter cable, and to which connection is made as required above, additional cables are not required in that direction to connect to the building perimeter cable.

    d. If any of these cables would come within 6 feet of a down conductor of the lightning protection system, the cable from the grid perimeter cable shall[9] be routed directly to the down conductor and be bonded to it. If desired, the cables may be located so as to maximize these junctions with the down conductors, provided the other requirements of this paragraph are met.

5. If any reference grids are separated by too great a distance, or if the available routes for cable interconnections are too few or too complex, so the above requirements seem unreasonable, they may be reduced to a single No. 1/0 AWG cable, provided a written waiver is obtained from the Contracting Officer's Technical Representative.

If any of these interconnecting cables are located so that contact is possible with any other bare interconnecting cable, or any other metallic items, that connection shall[10] be bonded or clamped to make a permanent connection.

4.4.7 Equipment Connections

Each equipment rack or cabinet shall[1] contain a ground bus clamped or bonded to it and to the signal reference grid at the closest point by a No. 6 AWG copper wire. All equipment chassis within the rack shall[2] be connected to the ground bus through a copper wire or braid of cross section equal to No. 12 AWG copper cable. The chassis jumper shall[3] be just long enough to allow the access necessary for maintenance, and shall[4] be clamped to the outside of the chassis, whenever possible.

Any individual item of equipment in an equipment room shall[5] have its chassis directly connected to the signal reference grid by a No. 12 AWG copper wire, or an equivalent strap or braid. This connection shall[6] be as short as possible.

Interconnections between individual equipments in an equipment room, using waveguide, coaxial, or shielded cables, will normally have their outer conducting surfaces grounded through their connections to the equipments to which they are attached. No additional grounding is required, provided the waveguide or cables do not leave the equipment room. The practice of leaving one end of the shield of a cable ungrounded, to prevent ground loops, etc., is permitted as a last resort, and **only for shielded cables that do not leave the area of the reference grid**.

The requirements of this subsection are in addition to the requirements in subsection 4.5.3.

4.4.8 Electronic Equipment Mounted in a Feed Box or Vertex Box

All mounting hardware, grounding lugs, etc., shall[1] be surface mounted on the inside or outside of the feed box, or vertex box. Penetration of the wall of the box is not permitted.

All waveguide, coax, and shielded cables shall[2] be grounded to the outside of the feed box, or vertex box, immediately prior to entry.

All non-coaxial wires and cables which enter the feed or vertex box shall[3] have an external shield, or be run in conduit or pipe. This shield, conduit, or pipe, and the outer conductor of coax cables and waveguides, shall[3] be bonded to the outer surface of the box so that the entire perimeter of the shield or outer conductor and the outer surface of the box form a continuous conducting surface. Feed through connectors may be used, if they can provide such bonds. If possible, these shields should be continued inside the box to the equipment chassis they are intended to serve and then be terminated on, or bonded to, the outside wall of the chassis. If possible, this should be done through the body of a suitable connector, mounted on the equipment chassis, in which electrical contact is made between the connector shell and the outside of the chassis.

All ground surfaces in the inside of the feed or vertex box shall[4] be made into an equipotential plane, by mounting equipment on common solid plates, multiple connections between the plates, bonding equipment grounds together using wide straps, etc. If a rack style is necessary to mount some equipment, it must comply with the following requirements:

1. The rack shall[5] be located as close as possible to an inside wall of the feed or vertex box.

2. It shall[6] be bonded to the inside surfaces of the feed or vertex box at a minimum of 6 places. Each area of contact between the rack and the feed or vertex box, shall[7] have a perimeter of at least one inch, including any intermediate item in the current path between the rack and the surface of the box. If smaller items must be used, a bridging strap shall[8] be added with a perimeter of at least one inch.

3. A ground bus shall[9] be run at one side of the rear of the rack and bonded to it at top and bottom. The bus shall[10] be copper or brass with a minimum cross section of 1 inch by 1/8 inch. It shall[11] be directly connected to the inside surface of the feed or vertex box by a No. 1/0 AWG copper cable, or an additional 1 inch by 1/8 inch copper strap, routed in the shortest, most direct manner possible.

4. All equipment mounted in the rack shall[12] be connected to the ground bus by a copper wire or strap equivalent to a No. 6 AWG or larger, of the minimum length necessary to allow access to the equipment for testing and maintenance.

All AC power cables shall[13] have the ground lead attached to the chassis of the equipment item using the power, preferably the outside of the chassis. The neutral conductors shall[14] be isolated from ground at all points except at the service disconnect point, reference subsections 4.5.2 and 4.5.3. Contact between the neutral and ground wires in any item of equipment is prohibited.

Since the AC power for blowers, heaters, and lights is required to be run on a separate distribution system from the AC power for the technical equipment, reference subsection 4.5.1, each distribution system shall[15] have a separate ground conductor. These ground conductors may be interconnected at any convenient points, e.g., power outlets or distribution boxes which are close to each other.

4.4.9 Electronic Equipment Mounted Elsewhere on an Antenna Structure

Equipment mounted in shelters which are located within the structure of a large antenna must meet all the grounding requirements for equipment rooms and for cable entrance to a building, with the following exceptions:

1. The cable shields and outer conductors, waveguides, pipes, etc., shall[1] be connected to the structural metal of the antenna, immediately prior to entering the shelter.

2. A signal reference grid need not be installed in existing shelters if it can be shown that the existing ground system complies with the requirements of this document in all other respects.

4.5 POWER GROUND SYSTEM

This system provides personnel and equipment with protection against power fault currents and static charge buildup. It is part of the power distribution system, with the power distribution conductors and the power ground system conductors run close and parallel to each other. Since the power ground conductors are only to be connected to the neutral conductor at a single point, reference subsection 4.5.2, the power ground conductors will only carry current under fault, or lightning strike, conditions.

4.5.1 Power Distribution Systems

There shall[1] be separate power distribution systems for technical and utility power which must meet the following requirements:

1. Utility power shall[2] be used for all lights, heaters, air conditioners, blowers, antenna positioning motors, and any other high current consumption parts of the antenna positioning system that are located at or near the antenna. It is desired that as much of the antenna positioning system as possible draw power from the utility bus, except for the remote control equipment in the primary equipment building.

2. Technical power shall[3] be used for all signal processing equipment, such as receivers, down/up converters, transmitters, computers, disk and tape drives, displays, printers, etc, and the parts of antenna positioning systems that are located in the primary equipment building.

3. Most convenience outlets are intended to power test equipment. They shall[4] be connected to the technical buss and colored brown. Other outlets are required for cleaning equipment, etc. They shall[5] be connected to the utility buss and colored white.

4.5.2 Neutral Grounding

The neutral of all three-phase and single phase power distribution systems shall[1] be connected to the ground system only at the main service disconnect for the station. This is the point where the load circuits are switched to the incoming power lines from the utility, or the back-up power source. All return currents of all power supply circuits are therefore only able to flow in the neutral conductor. The ground conductor is only used to carry fault currents. If any electrical equipment requires a ground conductor to carry currents under normal operating conditions, such as phase imbalance currents, a separate insulated conductor shall[2] be used, isolated from all other conductors, except at the single point of connection between the neutral and ground system, as defined above.

4.5.3 AC/DC Power System Grounds

Each item of equipment that uses AC power shall[1] have an insulated ground wire connected to it. If possible, this connection shall[2] be made to the outside of the chassis of the item. The wire size shall[3] conform to the requirements of the National Electric Code. This wire is in addition to the requirements of subsection 4.4.7.

DC powered items shall[4] have one side of the DC supply grounded, directly through a copper cable, if possible, or through a capacitor if necessary.

These ground wires shall[5] be routed with the active and neutral conductors back to their power distribution panels, where branch feeder cables may be commoned with other branch cables and fed by larger distribution cables. The line, neutral and ground conductors in the technical power subsystem and the line, neutral and ground conductors in the utility power subsystem must each remain separated from the other until they are brought back to the primary AC distribution panels at the main service disconnect point for the station. The ground conductors may be connected to each other whenever convenient, but this does not change the need for a separate ground conductor to be run with each group of line and neutral conductors. This applies to all power runs at the station. The presence of connections from each power distribution panel ground bus to the signal reference grid and to the ground terminal plate at each structure location, which are then interconnected throughout the site, does not compromise the above requirement.

The size of each ground wire shall[6] be calculated, in accordance with the National Electric Code, as if each power distribution run were an isolated cable, not connected in any others.

If any transformers are used in the power distribution system, the neutral conductor shall[7] always be connected to the power ground conductor on the load side of the transformer and not on the source side. This will provide a ground reference for the neutral conductor at the source of each voltage, and a suitable conductor in which fault currents may flow, without allowing any significant current flow in the ground conductor under normal operating conditions.

4.5.4 Pipes, Tubes and Conduit

All metallic pipes, tubes and conduits, with their supports shall[1] be electrically continuous and shall[2] be grounded, at a minimum of one point, to the power ground system, using a No. 6 AWG copper wire, or larger. All threaded connections shall[3] be treated with a conductive lubricant and tightened firmly. Gouging lock nuts shall[4] positively penetrate all paint or other finish. All runs greater than 10 feet shall[5] be grounded at both ends. Runs which enter an area where there is a signal reference grid shall[6] be bonded to that grid as specified in 4.4.5.

4.5.5 Cable Trays

All metallic cable trays and their supports shall[1] be electrically continuous and shall[2] be grounded at all ends. When run outside the building, they shall[3] be grounded in the same manner and at the same locations as required for the cables they carry. When in an area with a signal reference grid, the cable tray shall[4] be grounded to the grid, as specified in 4.4.4. Other internal runs shall[5] be bonded to the power ground system at each end of their run, using a No. 6 AWG copper wire.

4.5.6 Other Enclosures

All metallic enclosures, including pipe, conduit, and boxes, that are part of the power distribution system shall[1] be connected to the power system ground via the ground wires which are run inside the enclosures, and to any other object at ground potential that comes within 10 feet of the power distribution system. If the enclosures are in an area where there is a signal reference grid, they shall[2] be connected to it by a No. 6 AWG copper wire. Connections may be made by lug fasteners to the enclosure.

4.5.7 Motors, Generators, Transformers, and Switchgear

The frames of the equipment shall[1] be grounded in accordance with the National Electrical Code, except that the cable size must be No. 4/0 AWG copper cable.

SECTION 5

SITE CONFIGURATIONS

All NESDIS sites must have a ground system that consists of the necessary number of the subsystems described in the preceding sections. Compromises may be required for sites which are leased or where occupancy is shared with other organizations so that the overall safety of the facility is maintained. If so, the extent to which this standard applies must be closely examined by the Contracting Officer's Technical Representative or, if the work is undertaken as an internal NOAA/NESDIS project, by other cognizant engineering personnel designated by the project manager. The areas of concern are where the NESDIS ground system could interface with items controlled by others, e.g.:

1. Lightning protection on a shared roof.

2. Connection to structural metal, water pipes and other conducting items that extend throughout the structure.

3. Location of, and connection to, the PCP.

4. Cable routes for the down conductors.

5. Interconnection of grounds in the power supply system.

5.1 PCP INTERCONNECTIONS

The PCP of each structure, or group of structures, shall[1] be connected to a ground terminal plate of the PCP of the primary structure at the facility. This connection may be made directly, or by a daisy chain in which the PCP of a remote structure connects to the PCP of a structure that is closer to the primary structure, which connects to a still closer PCP, etc., until connection is made to the PCP of the primary structure. The total cable distance of such a daisy chain (measured along the shortest cable route through the intermediate PCPs) shall[2] be not more than 30 percent longer than a direct cable run, if less than 300 feet, or not more than 50 percent longer if 300 feet or longer. The interconnecting cable shall[3] also be connected to any other buried metallic objects that come within 10 feet, and are at a nominal ground potential.

The connection between each PCP and each interconnecting cable shall[3] be made via a ground terminal plate, so that each PCP can be isolated, when required for test measurements. The interconnecting cable may also be used as a buried guard wire, as defined in subsection 5.3.4, over all or part of it's route, provided all the requirements of this subsection and subsection 5.3.4 are met.

5.2 SPECIAL CONDITIONS FOR IRREGULAR BUILDINGS

Many structures, especially those with an irregular shape, may pose difficult problems in the routing of roof conductors, down conductors and the PCP. In resolving such problems the designer should ensure that the path provided for lightning energies connects to a ground rod in the PCP in the most direct manner possible under the following guidelines:

1. The PCP shall[1] be routed on the outside of cluttering objects, such as sheds, tanks, or generators near building walls, to avoid excessive bends.

2. The PCP shall[2] be routed across the open end of an alley, i.e., the space between two parallel wings of a building, and shall[3] be connected to a single conductor to branch into the alley along the straightest route possible.

3. If the distance from the building wall to the PCP is 10 feet or more, in either of these cases, a ground rod shall[4] be driven between 2 and 6 feet from the drip line of the structure and bonded to the down conductor, which is then routed to the PCP or the inward directed branch.

4. If a building is no more than 100 feet high, and an alley, internal courtyard, air shaft, etc. is no wider (in its smaller dimension) than twice the building height, the alley, etc., may be treated as is it were a covered part of the roof. The building PCP, the roof perimeter cable, and the internal roof conductors, may be continued across the opening, as if it were a solid part of the roof. The amount of droop allowed for all cables that pass over the opening shall[5] be approved by the COTR. If this is done, all the requirements given in paragraph 4.3.2 are to be met, except that the allowable spacing for the internal conductors shall[6] be a maximum of three times the air terminal spacing, in each dimension.

   The vertical distance between the top of the air terminals and the height of any objects in the alley, courtyard, etc., shall[7] comply with the equation given in paragraph 4.3.1.1.

5.3 UNDERGROUND CABLES

All cables that are run between structures, except the ground system interconnect cables, are to be run in corrosion-resistant metal pipes or metal conduit, in metal covered cable troughs, or must have their own shield, or buried guard wire, for protection against lightning effects and other interference.

5.3.1 Underground Pipes or Conduit

If metal pipes or metal conduit are used, they shall[1] be electrically continuous and shall[2] be bonded to the PCP of all structures they enter, or pass within 10 feet of, and any other buried metal within 10 feet, by a No.1 AWG copper cable in the shortest, most direct manner. The connection to each PCP shall[3] be made via a ground terminal plate.

The connection at the point of entry into a structure shall[4] be made through a cable entrance plate. The pipe or conduit shall[5] be bonded to the entrance plate so that the entire perimeter of the pipe or conduit and the outer surface of the entrance plate form a continuous conducting surface. The entrance plate shall[6] be bonded to the PCP for the structure by a No. 1 AWG copper cable, in the shortest, most direct manner, via a ground terminal plate.

5.3.2 External Cable Troughs

If cables are routed in metal cable troughs, the metal shall[1] be made electrically continuous and shall[2] be bonded to the PCP of all structures that the cables in them enter and any PCP that passes within 6 feet of the trough. Connection to the metal shall[3] be made to its outside surface by a No. 1/0 AWG copper cable in the shortest, most direct manner.

5.3.3 Underground Cables with Shields

All cables that run between structures and are not enclosed in metallic pipe or conduit must either have an outer shield to protect against the pick-up or radiation of interfering energy, or comply with paragraph 5.3.4 below. If a cable is shielded, the shield shall[1] be bonded to the PCP of all structures that it enters, and to any PCP that passes within 10 feet of the cable, by No. 1 AWG copper cable.

The connection to the shield, at the point of entry into a structure, shall[2] be made via a cable entrance plate. The shield shall[3] be bonded, or joined by a feedthru connector, to the entrance plate so that the outer surfaces of the shield and the entrance plate form a continuous conducting surface. The entrance plate shall[4] be bonded to the PCP for the structure by a No. 1 AWG copper cable, in the shortest, most direct manner, via a ground terminal plate.

5.3.4 Buried Guard Wire

Unshielded buried cables, not in a metallic pipe or conduit, may be protected from lightning-induced transients by a buried guard wire. This wire shall[1] be a No. 1/0 AWG bare copper cable and shall[2] be run parallel to and at least 10 inches above the cables to be protected. For cable runs or ducts less than 3 feet wide, only one guard wire is required. For wider cable runs or ducts, additional guard wires shall[3] be installed so the outermost wires are between 12 and 18 inches inside the edge of the duct or run, and the spacing between the guard wires is between 12 and 36 inches.

The guard wires shall[4] be bonded to the PCP of the structure at each end of the run and to any other PCP within 10 feet of the run. The guard wires shall[5] continue to the cable entry plate and be bonded to it. If the cable entry plate is shared with other cables, the guard wires can also be used as the wire that connects the plate to the PCP. The connection to each PCP shall[6] be made via a ground terminal plate.

This method of protection is not recommended for new construction as it does not provide shielding against pick-up or radiation of other interfering signals.

5.4 GROUNDING FOR FILTERS AND SURGE ARRESTERS

Filters and surge arresters may be required on some or all wires and cables at a facility to reduce the effects of power and lightning induced surges and interference to the signals carried on those wires and cables. Many such systems require several levels of protection, applied sequentially, and may use the cable run between each protection level as a series inductance to assist in the reduction of the transients.

The first level of protection from lightning induced transients shall[1] be located as close as possible to the point where the conductors enter the structure. The components selected shall[2] be housed in a metal box grounded to the PCP in the shortest, most direct manner possible. Any other interconnecting leads shall[3] be as short as possible and sized to minimize the added resistance and inductance in the transient path to ground through the surge arrester.

Other levels of protection and interference filters shall[4] be connected to the appropriate ground circuit, i.e. the power ground for power circuits or the signal reference grid for signal circuits. All connections shall[5] be made in the shortest, most direct manner possible.

5.5 GROUND RETURN PATHS

5.5.1 Signal and Control Return Paths

Each signal and control cable shall[1] provide all the necessary return paths for the information carried within it. These paths may be one or more conductors in a multi-conductor cable or the shields of coaxial cables, but may not be the shields of multiconductor cables. **The ground system interconnections may not be used to provide signal return paths**.

The shields of multiconductor cables and the outer conductors of coaxial cables shall[2] always be grounded at both ends, unless they remain entirely within an area having a signal reference grid and all other requirements for connection to the signal reference grid are met.

5.5.2 Power Distribution Ground Paths

The power return path is the neutral conductor, under normal conditions. The ground conductor is only intended to carry currents under fault conditions. The power ground wire shall[1] be sized in accordance with the National Electric Code, as it would apply if there were no other grounding systems at the facility.

The power supply, power return, and power ground conductors shall[2] be routed together and separated only by the necessary insulating materials. This applies to each level of the power distribution system, from the main service disconnect to the most remote using device.

5.6 FENCE GROUNDING

Any metal fence at a facility is to be grounded to protect personnel from hazardous voltages that may be carried from a distant location. All such fences are to be constructed of galvanized steel in the chain link style, with galvanized steel posts and top rail. No vinyl coating may be used.

5.6.1 Reinforcing Wire

A No. 6 AWG aluminum wire shall[1] be woven through the links of the fence along its entire length. This is called a reinforcing wire. It shall[2] be bonded or clamped to each of the support posts of the fence. Any splices that may be necessary shall[3] be made at the supporting posts.

5.6.2 Grounding

The fence shall[1] be grounded at intervals of between 100 feet for small sites to a maximum of 500 feet for large sites. The ground connection shall[2] be made by driving a ground rod adjacent to a fence post and bonding them together via a No. 6 AWG copper wire. If desired, the bond may be made to the clamp for the reinforcing wire. Grounding shall[3] also be provided on each side of every gate and [4] at points approximately 150 feet on either side of any place where high tension power lines cross the fence.

Fences shall[5] be connected to any other metallic object, at nominal ground potential, that passes within 10 feet of the fence.

5.7 PERMAFROST CONDITIONS

At facilities with permafrost, such as Fairbanks, Alaska, it becomes impossible to achieve the desired resistance to ground as specified in paragraph 4.1.2 above. Under these conditions it is much more important to ensure that the low impedance continuity of all the interconnections of the grounding systems specified in this document is maintained at all times. When a lightning strike or power fault occur, the absolute voltage of the "ground" system will be higher than if there were no permafrost, but the differential voltage between any two items within the facility will be the same as at other sites. Therefore the hazard to personnel and equipment will be totally dependant on these interconnections, without the back-up provided by conduction through low resistance soil that applies to facilities where there is no permafrost.

All clamp connections in the grounding systems and a representative sample of the bonded connections shall[1] be visually inspected during the warm season each year.

SECTION 6

IMPLEMENTATION GUIDELINES

6.1 PRIORITY

At all times in an up-grade process, care must be taken to ensure the changes being implemented do not create a hazard to personnel or equipment. This is most likely to occur if things which were connected together are separated, or an item is connected to a ground system component when it is not fully known what else is connected to that item. The following general order of priority should be followed:

1. If grounding related problems are known to have occurred in the past at any part of the facility, e.g., significant AC power currents flowing in ground conductors under non-fault conditions, interference that was difficult to eliminate, or installation of some equipment producing an unexpected effect on other equipment, the exact connections of all the grounding and shielding conductors in or near the effected areas should be carefully checked and compared to the requirements of this standard. All differences should be identified and the steps necessary to comply with this standard should be determined. The source of any AC power currents flowing in the ground conductors must be found and eliminated before any other step is taken. If the other steps cannot all be made continuously, the configuration of the connections at the break points should be checked for possible bad effects on other equipments or systems. If the effects of any of the steps cannot be predicted with reasonable confidence, those steps should be made so they can be reversed as easily as possible. If unexpected results occur, the procedures given in section 8 of this standard should be used to provide information for analysis and correction of the problem.

2. The lightning protection system for all existing structures should be checked as soon as possible and any discrepancy with this standard in the routing of down conductors corrected. If a structure has no lightning protection system and it is, for example, within the zone of protection of another structure if the lightning striking distance were 200 feet, it may be made a low priority item with relatively little risk.
   CAUTION: Lightning is an unpredictable phenomenon, the absence of strikes in the past is no guarantee for the future; nor is there any way to determine the chance a lightning strike will have a striking distance of twice the minimum.

3. Any structure without a PCP that complies with this standard should have one installed and tested. Down conductors and cable entrances should be connected immediately.

4. Other connections to the PCP should not be made until a safety check has been run. This should include an analysis of the possible lightning voltages and voltage differences that may be induced, possible ground loops, and AC power fault analysis. If no indication of problems

arise, start at the main equipment room and bring it to compliance with this document, then proceed to other areas in order of increasing distance from the main equipment room.

5. The equipment areas should be checked and the configuration of their ground systems determined. Even if there is no indication of a problem in this area, the designer should be aware that adding and interconnecting other parts of the ground system, as specified in this document, may cause interference problems that can be solved by implementing signal reference grids for the equipment areas.

6. Construct the other parts of the ground system, so they may be connected in the order indicated by the above analysis. Note that some of the additional items required may be put in place but will have no effect on other items until they are actually connected. Make a temporary connection from them to the rest of the ground system and check for problems before making the connections permanent. If problems do occur, re-connect to the old configuration, so normal operation can be maintained, and construct additional parts of the ground system that may alleviate the problem.

7. Connect structures that are physically close to each other before ones that are separated by large distances, unless specific problems, such as ground loops, power or signal routing, indicate otherwise. If a temporary connection produces problems, first check the expected effects of implementing other portions of this ground standard, to see if they could solve the problem. If not, other possible solutions given herein should be tried, or others may be derived from the principles given in Volume 1 of MIL-HDBK-419.

6.2 GROUND SYSTEM FILE REQUIREMENTS

Each NESDIS facility will create and maintain a file of documents showing the grounding history and current status for that facility. This file will contain the following information:

1. An overall facility diagram showing all ground system interconnects in sufficient detail to allow their easy location. This diagram will be maintained to reflect the current condition of the facility. A list of all changes to the ground system will also be maintained, giving a description of the change and the dates on which they were made.

2. Detail drawings of the parts of the ground systems. This should include the drawings, tables, and descriptions necessary to give the location of, and method of access to, all clamped joints on the facility.

3. An historical record of all tests and inspections made to, and all maintenance work performed on, the ground systems at the facility. The test data must be in sufficient detail to allow accurate

repetition of any test at any time.

4. A copy of this standard, maintained with all revisions.

6.3 CONTRACTOR DOCUMENTATION REQUIREMENTS

As part of any contract which includes this standard as a referenced document, the contractor must provide a detailed record of additions, deletions, repairs, etc., to the ground systems that were made under the contract to each facility. If the contract requires work at more than one facility, the contractor must provide a separate record for the work done at each facility. This must include descriptions, drawings, test procedures, test results, and any other information necessary to provide a complete understanding of the ground systems' status and any changes to the maintenance requirements. Three copies of all documents must be provided in paper form, plus a disk copy, in WordPerfect file format, of all items that can be handled by this word processing program. If provided by the Contracting Officer's Technical Representative, the contractor may be required to up-date existing NESDIS documents.

SECTION 7

INSPECTION AND TEST PROCEDURES

7.1 SOIL RESISTIVITY TEST

The soil resistivity measurements, required by other paragraphs of this standard, are to be made using a megger earth tester as described below and illustrated in figure 5.

Four probes, spaced at intervals of 20 to 30 feet and designated P1, P2, C1, and C2, are to be inserted into the ground to a depth of not more than 1/20th of the spacing. The test set is to be connected to the probes according to the manufacturer's instructions, and a resistance reading made. The power line frequency should not be used to make this measurement, as stray currents may affect the results. Convert the probe spacing actually used to centimeters (1 foot = 30.5 centimeters). The soil resistivity in ohm-cm is found by multiplying the measured resistance by the probe spacing in centimeters and multiplying the result by 6.28. For example, if the resistance measurement was 2 ohms with a probe spacing of 25 feet, then the resistivity is:

$$p = 2 \times 25 \times 30.5 \times 6.28 = 9577 \text{ ohm-cm.}$$

The test must be performed under normal weather conditions, i.e., close to the average for the month in which the test is made. If the test is performed during unusually dry or rainy periods, the results of the test will not be valid.

If no previous resistivity results are available, this test should be done at 100 - 200 feet intervals over the site area. The interval is to be measured between the centers of the test probe line and adjacent tests are to be done with the probe lines at approximate right angles. A diagram of the test locations must be made by the personnel performing the tests. Sufficient detail and locating dimensions must be included so that the tests may be re-run if and when desired.

7.2 GROUNDING RESISTANCE TEST

A resistance test shall be performed on each PCP at all NESDIS facilities, using the fall-of-potential method. This test shall be performed following installation, every 3 months during the next 12 months, and approximately every 9 months thereafter.

All ground terminal plates at the PCP to be tested are to be disconnected. All necessary ground terminal plates at other PCP's at the facility are to be disconnected also, so that the PCP to be tested is isolated from the other PCP's at the facility. These disconnections must be made only when actually necessary to isolate a specific PCP for testing, and must be reconnected as soon as possible thereafter, so they can protect the facility as intended.

page for figure 5

page for figure 6

The electrical center of the PCP must be determined. For PCP's with uniform spacing of ground rods and no large difference in the soil resistivity in the immediate area, the electrical center is the same as the geometric center of the PCP. If the spacing is not uniform, the PCP must be divided into convenient subsections and the theoretical resistance to true ground of each subsection calculated independently. Equations and procedures for this calculation are given in MIL-HDBK-419, volume 2, paragraph 1.2.2.3, and, if necessary for more complex arrangements, volume 1, paragraph 2.6. The distances of each subsection from the geometric center should be weighted by their relative resistance to true ground, and the weighted geometric center calculated. The choice of axes, their reference point, and orientation to the rest of the facility, for the distances used in these calculations, is purely a matter of convenience. This method will provide a reasonable approximation of the electrical center for that configuration. Note that the resistance to true ground of multiple interconnected ground rods is never a linear function of the number of rods. Therefore, there must be a relatively large difference in the ground rod spacing to make it necessary to make the weighted calculations.

A megger earth tester is to be used with the test set up as shown in figure 6. Probes C1 and P1 may be connected to any convenient point on the PCP. This point must be located such that probe C2 can be located at a distance, X, from the point where probes C1 and P1 are connected, so that the distance X +

Y is equal to at least 5 times the longest dimension, D, of the PCP under test. Y is the distance from the point where C1 and P1 are connected to the PCP and its electrical center. Probe C2 must be located on a straight line running through the electrical center of the PCP and the point where C1 and P1 are connected. If possible, probe C2 should also be located so that there is no buried metal between it and the point where P1 and C1 are connected to the PCP, nor for a distance equal to 0.5X on either side of a straight line joining C1 and C2. If the desired orientation is not possible, the best possible compromise should be used. Refer to MIL-HDBK-419, subsection 2.7.1 for further information, if required.

Probe C2 must remain fixed while at least seven resistance measurements are taken with probe P2 at distances of 0.3X, 0.4X, 0.5X, 0.6X, 0.7X, 0.8X, and 0.9X along a straight line from probe C1 to probe C2. Probe C2 should be driven about 1 foot into the ground and probe P2 should be driven approximately the same distance as C2. The data obtained is to be plotted as resistance versus distance. Additional measurements may be made at other fractions of X, if necessary to obtain a suitable plot. The true resistance of the PCP is obtained from the plot at the point where the distance from the point of connection to the PCP is equal to 0.62X - 0.38Y.

Reconnect all ground terminal plates to the PCP's as soon as possible after the test is completed.

A full record must be made of each grounding resistance test by the testing personnel, including the distances to all probes, the layout of all known buried metal within a distance equal to X from the probes, including the PCP under test, the equipment used, all the readings taken, and the resistance obtained.

If any resistance reading shows significant change from previous readings, allowing for the expected seasonal variations, the following checks shall be made to determine the cause and the necessary corrective action:

1. Check for new construction in the vicinity.

2. Inspect rods for dried out or slagged soil around them.

3. Inspect bonds between the rods and the cables.

4. Check cable continuity.

5. Check soil resistivity.

7.3 INSPECTIONS

The following inspections shall be performed on the ground systems of all NESDIS facilities at intervals of approximately 9 months.

1. Visually inspect and verify that all clamped bonds between the ground conductors are sufficiently tight, thoroughly clean, and show no signs of corrosion.

2. Inspect air terminals for corrosion or melting. Replace terminals that show any signs of these conditions.

3. Inspect all bonds between roof conductors, down conductors, and air terminals for degradation. If degradation is present, the joint must be cleaned and rebonded. If the joint is beyond repair, the materials may be replaced with the same types and sizes (or larger) of materials.

4. Ensure that any additions to the structure are protected by the lightning ground system. Record any modifications to the lightning ground system on the facility drawings.

5. With the power on and using a clamp-on ammeter, measure the stray current levels in the power ground system at several points through out the facility. The current levels should not exceed 0.1 ampere. If the current exceeds 0.1 ampere the neutral wire is likely to be connected to the green wire ground at a point other than the service disconnect.

6. Using a clamp-on ammeter, measure the stray current levels in the signal ground system at several points throughout the facility. The current levels should not exceed 0.1 ampere. If the current exceeds 0.1 ampere the neutral wire is most likely connected to the ground wire at a point other than the service disconnect.

7. If the electrical power can be temporarily turned off, ensure that the neutral wire is not grounded anywhere except at the service disconnect. This should be done by turning off the electrical power, disconnecting the neutral wire in the power supply cable from the neutral distribution bus in the local power distribution box, and checking the continuity between the neutral bus and the grounding bus. A low resistance (less than 10 ohms) indicates the neutral is probably connected to the ground some where other than at the service disconnect. This connection must be located and removed.

7.4 TEST VERIFICATION PROCEDURES

The Test Verification Table, given in table 1, lists all occurrences of shall[#] in the text of the preceding requirements, in the order of their appearance. Opposite each item is given the verification method to be used to show compliance. Only those requirements that apply to a specific contract need to be incorporated into the test procedures for that contract.

The letter "P" in the first position indicates this is part of the Pre-Acceptance Testing requirements, i.e., to be performed during the installation process and not as part of the final acceptance tests. However, an all inclusive "check-off" step in the test procedure for the final acceptance tests must be used to indicate that all the "P" requirements have been met prior to the start of the formal test procedure. Compliance with the "P" requirements may be shown by progress inspections made during the performance of the contract works, submission of design calculations, providing other documents giving proof of compliance, or methods approved by the Contracting Officer's Technical Representative. The letter "F" in the first position indicates that a formal showing of compliance for that requirement, must be included in the final acceptance tests.

The letter in the second position may be either I, A, D, T, or S, standing for Inspection, Analysis, Demonstration, Test, and Sample test, respectively. The meanings of these designations are defined below.

7.4.1 Inspection

This method requires visual examination to prove compliance and may include simple measurements of distance, such as 5/8 inch diameter rod, 20 feet maximum spacing.

7.4.2 Analysis

This method is based on proving by induction or deduction that the requirements have been met. This relies upon a technical analysis and evaluation of data that relates indirectly to the requirement, i.e. equations, graphs, diagrams, simulations, etc. All submittals based on this method must be approved by the Contracting Officer's Technical Representative.

7.4.3 Demonstration

This method requires observation of the result(s) of a action, or series of actions, without the need for special test equipment.

7.4.4 Test

This method requires the use of special test equipment to either simulate an input to, or measure the result produced by, the system under test, or to both simulate and measure.

7.4.5 Sample Test

This method is used when there is a large number of items that must meet the same requirement, the same method has been used to create and install each item, and no significant variation is expected between the items. The term "large number" is relative to the quantities of other items is the system under test. A ratio of at least 10:1 is required to be considered as large.

Table 1. Test Verification Table

REQUIREMENT SECTION #/SHALL #		TEST LEVEL/METHOD
3.2.1	Vertical Ground Rods	
[1]	Type	PI
[2]	Size	PI
[3]	Depth	
PI		
3.2.2	Horizontal Ground Conductors	
[1]	Type	PI
[2]	Depth	
PI		
[3]	Orientation	PI
3.2.3	Perimeter Ground Cable	
[1]	Size	PI
[2]	Proposed compromise	PA
[3]	Depth	
PI		
[4]	Metal connections	PI
3.2.4	Ground Terminal Plate	
[1]	Type	PI
[2]	Capacity	FI
[3]	Access	FI
3.2.5	Interconnections	
[1]	Size	PI
3.2.6	Bonding	
[1]	Fusion	PI
[2]	Coating	PI
[3]	Clamp access	FI
[4]	Flammables	FI
[5]	Pull	FT
[6]	Capacity	PA

3.2.7 Air Terminals

[1] Type	PI
[2] Size	FI
[3] Support	FI

3.2.8 Roof Conductors

[1] Route
FI

[2] Size	FI
[3] Insulation	FI
[4] Grid	FI
[5] Bonding	FI

3.2.9 Down Conductors

[1] Size	FI
[2] Insulation	FI

3.2.10 Chemical Treatment

[1] $MgSO_4$	PI
[2] Rod trench	PI
[3] Service well	FI
[4] Horizontal trench	PI
[5] Service well	FI
[6] Fill percent	PA

3.2.11 Signal Reference Grid

[1] For two or more racks	PI
[2] Perimeter cable	FI
[3] Internal conductors	FI
[4] Conduit	FI

3.2.12 Electrical Service Well

[1] Size	FI
[2] Non-conductive	PI
[3] Support stresses	PA
[4] Cover	FI
[5] Hole size for cables	PI
[6] Quantity	PA

4.1 Perimeter Counterpoise

	[1] Components	PI
	[2] Rod spacing	PI
	[3] Rod location	PI
	[4] Bonding	PI
	[5] Damp soil	PA
4.1.1	Adjacent Structures	
	[1] PCP sharing	PA
	[2] Overlapping zones	PA
	[3] Small structure connection	PA
	[4] Cable spacing	PI
	[5] Corner connections	PI
	[6] Cable routing	PI
	[7] Minimum separation	PA
	[8] Incremental separation	PA
	[9] Other connection	PA
4.1.2	Resistance to True Ground	
	[1] Five ohms or less	FT
4.1.5	Structural Steel Columns and Other Building Metal	
	[1] Within 10 feet a must	PI
	[2] Documentation	PA
	[3] Cable size	PI
	[4] Bonded	PI
	[5] Routing	PI
4.2.1	Connection to the PCP	
	[1] Clamp connection	FI
	[2] Cable length	FI
	[3] Electrical service well	FI
4.2.2	Connection to Other Cables	
	[1] Down conductors	PI
	[2] Other cables	FI
	[3] Common routing	FA
	[4] Separate routing	FA
	[5] Quantity minimized	FA
4.3.1	Air Terminal Mounting	
	[1] Location	FI

[2] Non-interference	FA
[3] Separate structure	PA
4.3.1.1 Roof Mounting	
[1] Sloping roof location	FI
[2] Sloping roof spacing	FI
[3] Flat roof location	FI
[4] Edge/corner distance	FI
[5] Square size	FI
[6] Minimum requirement	FI
[7] Coverage equation	FA
[8] Reference plane	FI
4.3.1.2 Towers and Masts	
[1] Direct mount	PI
[2] Cable bond	PI
[3] Down conductor connection	PI
4.3.1.3 Antennas	
[1] Location	PA
4.3.2 Roof Conductors	
[1] Routing	FI
[2] Two paths	FI
[3] Internal grid	FI
[4] Grid size	FI
[5] Crossovers	FI
[6] Straight line runs	FI
[7] Turns	FI
[8] Conduit	FI
[9] Fastening	FI
[10] 200 lb pull	FS
[11] Corrosion resistance	PI
[12] "T" intersection	FI
4.3.3 Down Conductors	
[1] Straight line runs	FI
[2] Turns	FI
[3] Duct	FI
[4] Fastening	FI
[5] 200 lb pull	FS

[6] Corrosion resistance	PI
4.3.3.1 Down Conductors for Buildings	
[1] Minimum	FI
[2] Location rules	FI
[3] Maximum spacing	FI
[4] Equal spacing	FI
[5] High buildings	FI
[6] Riser bonding	PI
4.3.3.2 Down Conductors for Towers or Masts	
[1] Route	FI
[2] Bonding	FI
[3] 2nd point grounding	FI
4.3.3.2 continued	
[4] Multiple leg grounding	FI
[5] Circular tower grounding	FI
4.3.3.3 Down Conductors for Antennas	
[1] Air terminal connection	FI
[2] Route	FI
[3] Structural metal size	PA
[4] Bridge bearings	FI
[5] PCP connections	PI
[6] Down conductor continuation	FI
[7] Maypole case	FI
4.3.4 Waveguide, Coaxial and Shielded Cable Grounding	
[1] PCP bonds	FI
[2] Tower/antenna bonds	FI
[3] Bond location	FI
[4] 200 feet spacing	FI
[5] Entrance bonds	FI
[6] Ground kits	PI
[7] Rigid grounding	FI
[8] Pigtail	FI
[9] Elliptical grounding	FI
[10] Covering	FI
[11] No. 6 AWG	FI
[12] No. 1/0 AWG	FI

[13]	Entrance plate	FI
[14]	Entrance plate grounding	FI
[15]	Routing	FI
[16]	Signal reference connection	FI

4.4.1 Signal Reference Grid

[1]	Perimeter	FI
[2]	Loop	FI
[3]	Internal conductors	FI
[4]	Bonding	FI
[5]	Conduit	FI
[6]	Pedestal connection	FI

4.4.2 Raised Floor as Reference Grid

[1]	Resistance	FS
[2]	Clean joints	FI
[3]	Protect joints	FI
[4]	Outer cable	FI
[5]	Intermediate cable	FI
[6]	Routing	FI
[7]	Pedestal connection	FI
[8]	Equipment to grid connection	FI
[9]	Flooring materials	PI

4.4.3 Other Reference Grids

[1]	Copper strap	FI
[2]	Access	FI
[3]	Copper wire	FI
[4]	Perimeter wire	FI

4.4.4 Spacing Variations

[1]	Rack surrounds	FI
[2]	Intermediate conductors	FI
[3]	Conductor size	FI
[4]	Single cabinet or rack	FI

4.4.5 Entrance to Signal Reference Grid Area

[1]	Connection of grounded items	FI
[2]	Bond routing	FI
[3]	Group bonding	FI
[4]	Percent increase	FA

[5]	Power distribution	FI
[6]	Multiple connections	FI

4.4.6 Interconnection of Signal Reference Grids

[1]	Combining grids	FI
[2]	Overlapping grids	FI
[3]	Connection spacing	FI
[4]	Other grids	FI
[5]	Connection spacing	FI
[6]	PCP connection route	FI
[7]	Connection from grid	FI
[8]	Connection spacing	FI
[9]	Down conductor connection	FI
[10]	Insulated cable	FI

4.4.7 Equipment Connections

[1]	Ground bus to grid	FI
[2]	Ground bus to equipment	FI
[3]	Length	FI
[4]	Clamp	FI
[5]	Single items	FI
[6]	Length	FI

4.4.8 Electronic Equipment Mounted in a Feed Box or Vertex Box

[1]	Surface mounting	FI
[2]	External grounding	FI
[3]	Shielding	FI
[4]	Equipotential plane	FI
[5]	Rack location	FI
[6]	Rack to box connection	FI
[7]	Contact perimeter	FI
[8]	Bridging strap	FI
[9]	Bus routing	FI
[10]	Bus type	FI
[11]	Bus to box connection	FI
[12]	Equipment connection	FI
[13]	AC ground	FI
[14]	AC neutral	FI
[15]	Utility and technical grounds	FI

4.4.9 Electronic Equipment Mounted Elsewhere on an Antenna Structure

	[1] Grounding connection	FI
4.5.1	Power Distribution System	
	[1] Utility and technical power	PI
	[2] Utility power use	PI
	[3] Technical power use	PI
	[4] Technical outlets	PI
	[5] Utility outlets	PI
4.5.2	Neutral Grounding	
	[1] Only at disconnect	FT
	[2] Separate conductor	FI
4.5.3	AC/DC Power System Grounds	
	[1] Ground connection	FI
	[2] Outside of chassis	FI
	[3] Conform to NEC	PA
	[4] DC ground	FI
	[5] Routing	FI
	[6] Size calculation	FA
4.5.4	Pipes, Tubes and Conduit	
	[1] Continuous	PI
	[2] Grounded	FI
	[3] Threaded connections	FI
	[4] Lock nuts	PI
	[5] Long runs	FI
	[6] Reference grid	FI
	[7] Transformer grounds	PI
4.5.5.	Cable Trays	
	[1] Continuous	FI
	[2] Grounded all ends	FI
	[3] External	FI
	[4] Reference grid	FI
	[5] Other internal	FI
4.5.6	Other Enclosures	
	[1] Power distribution enclosures	FI
	[2] Connection to reference grid	FI

4.5.7 Motors, Generators, Transformers, and Switchgear

[1] Frame grounding	FI

5.1 PCP Interconnections

[1] Connect to primary PCP	PI
[2] Daisy chain length	PA
[3] Ground terminal plate	PI

5.2 Special Conditions for Irregular Buildings

[1] Outside clutter	PI
[2] Across an alley	PI
[3] Alley branch	PI
[4] Ground rods for down conductors	PI
[5] Cable droop	FA
[6] Conductor spacing	FI
[7] Protection zone	FA

5.3.1 Underground Pipes or Conduit

[1] Continuous	PI
[2] Bond to PCP	PI
[3] Ground terminal plate	FI
[4] Cable entrance plate	FI
[5] Bonding	FI
[6] Plate to PCP	PI

5.3.2 External Cable Troughs

[1] Continuous	FI
[2] Bonding to PCP	FI
[3] Routing	FI

5.3.3 Underground Cables with Shields

[1] Bonding to PCP	FI
[2] Via cable entrance plate	FI
[3] Continuous bond	FI
[4] Plate to PCP	FI

5.3.4 Buried Guard Wire

[1] Type	PI
[2] Routing	PI
[3] Additional wires	PI

[4] Bonding to PCP	FI	
[5] Bond to cable entrance plate	FI	
[6] Via ground terminal plate	FI	

5.4 Grounding for Filters and Surge Arresters

[1] Location	FI	
[2] Housing	FI	
[3] Leads		FI
[4] Lower levels	FI	
[5] Connections	FI	

5.5.1 Signal and Control Return Paths

[1] Self contained	PA
[2] Ground connections	PI

5.5.2 Power Distribution Ground Paths

[1] Size	PA
[2] Wires routed together	PI

5.6.1 Reinforcing Wire

[1] Wire	PI
[2] Clamping	PI
[3] Splices	PI

5.6.2 Grounding

[1] Intervals	PI
[2] Connection	PI
[3] Gates	PI
[4] Power lines	PI

5.6 Permafrost Conditions

[1] Inspection	PI

SECTION 8

TROUBLE CORRECTION GUIDE

8.1 CONDUCTED OR RADIATED INTERFERENCE

If the installation of any part of this ground standard causes an unacceptable increase in conducted or radiated interference into any circuit, the following procedure should be followed.

Due to the frequencies and circuit distances used at the NOAA facilities, the most probable interference coupling mechanisms are conduction and radiation. Capacitive and inductive coupling, the other two possible mechanisms, are much less likely to occur, except if the power line is the source of the interference. In this case, the coupling mechanism will most likely be inductive.

8.1.1 Trace the Source of Interference

Starting from the place where the interference is noticed, check back up the victim signal path to find the point where the interference enters that path. Use voltage, current, magnetic, or electrostatic probes and an oscilloscope or spectrum analyzer so the waveform can be first characterized, then identified when found elsewhere. (Uncalibrated probes are adequate for this type of work and may be bought cheaply, or be of a home made type.) If it is necessary to search for a source that emits the interfering energy in a non-conducting manner, any item carrying that energy that is greater than 0.1 wavelength long can be a significant antenna. Its efficiency increases with increasing size.

8.1.2 Characterize the Interfering Waveform

If the interfering waveform is a sine wave, record its frequency and amplitude. If not, determine maximum amplitude (A) of the waveform, the time between repetitions of the waveform, the width of the pulses at the half amplitude points, and the shortest rise, or fall, time, measured between the 10 and 90 percent points. These measurements can be used to calculate the characteristic frequencies and amplitudes of the waveform.

1. The fundamental frequency = F = 1 / (waveform repetition rate)

2. The first corner frequency = $F_{C1} = 1 / \pi$ * (pulse width)

3. The second corner frequency = $F_{C2} = 1 / \pi$ * (rise, or fall time)

4. The amplitude of F = 2 * A * (pulse width) / (waveform repetition rate)

The envelope of the maximum amplitudes that could be produced by this signal is defined as equal to the amplitude of F up to F_{C1}, then decreasing at 20 dB per decade to F_{C2}, and then decreasing at 40 dB per decade until the noise floor is reached.

The source of the interfering waveform is often obvious from the waveform shape. If not, the waveform characteristics will make it easier to determine the waveshape on the source side of components that could selectively filter the interfering waveform, thereby changing its shape, e.g. increased high frequency attenuation due to propagation down a long coaxial cable.

8.1.3 Determine the Coupling Mechanism

Choose the most probable mechanism on the basis of the following guide lines.

8.1.3.1 Conductive Coupling

This requires at least two points where the source and victim circuits are physically interconnected by low impedance paths. Low impedance refers to the impedance at the interfering frequency and with reference to the actual impedance of the source circuit. Make sure all impedances are included in this evaluation. If necessary, draw a circuit diagram, showing every wire in the path and assign an impedance to each one, at the frequencies of the interfering waveform.

8.1.3.2 Radiative Coupling

If there are not two or more points of physical connection between the source and victim circuits, estimate or measure the distance between the two circuits and compare it to the wavelength(s) of the interfering signal. If the distance is greater than one wavelength for most of the length of the victim circuit, the coupling mechanism is probably radiative. If the distance is less than one wavelength, but more than $1/\pi$ wavelengths, radiation is a possible mechanism, with the probability reduced as the separation distance is reduced.

8.1.3.3 Inductive and Capacitive Coupling

If the distance between the source and victim signals is less than one wavelength, measure or calculate the impedance of the source circuit. If it is less than 377 ohms, the impedance of free space, the coupling mechanism is probably inductive, if more, it is probably capacitive. These probabilities increase in proportion to the difference between the circuit impedance and 377 ohms.

The following checks may be made to determine if the coupling mechanism is inductive or capacitive.

1. If the coupling is affected by the insertion of non-conducting, non-magnetic material between the source and victim circuits, or by movement of this type of material in the vicinity of the circuits, the coupling is capacitive, if not, it is inductive.

2. If grounding or un-grounding any shielding (conducting) material between, or close to the source or victim circuits, creates an effect, the coupling is capacitive, otherwise it is inductive.

8.1.4 Reduce the Interference

Before implementing any of the following steps, determine the amount by which the interference must be reduced, and estimate the amount of reduction that could be expected by the proposed step. If these are not at least close, re-examine the available options.

8.1.4.1 Conductive Coupling Reduction

The connections between the source and victim circuits must be reduced to one, at the frequencies of the interference. This could be done by one or more of the following:

1. Change the victim circuit to a balanced configuration.

2. Insert an optical isolator into the source or victim circuit.

3. Replace the source or the victim circuit with a fibre optic link.

4. Replace part of the connection between the source and victim circuits with two diodes in anti-parallel. This will provide effective isolation between the two circuits, provided the voltage of the interfering signal is not so large as to exceed the forward bias of the diodes. High power diodes should be used and their exact location chosen with care, to minimize the chance that the diodes could be destroyed by the high currents that may flow under lightning strike or power fault conditions.

5. Install one or more filters to block the interfering frequencies (This could be done by adding a balun, thinner wire, longer wire, coiled wire, increasing the size of a current loop, installing ferrite beads, or waveguide stubs, instead of lumped inductors and capacitors in a physical box called a filter.)

The added inductance which can be achieved by physically separating the desired and undesired current paths, can provide significant reduction to the interference. Since this is an inductive effect, it will be greater at higher frequencies than at lower frequencies. However, even at 60 Hz, between 10 and 20 dB change in the interference level can be achieved by this method. The relevant parameter is the total impedance around the loop it is desired the interfering current should take, as compared to the total impedance around the undesired loop.

When conductors are run close to each other and carry a current in opposite directions, their mutual inductance causes a reduction of the total inductance of the loop as compared to the sum of the inductances of the individual conductors, when considered in isolation. Equations which can be used to calculate the inductance of a single loop and of a long straight wire in isolation are included in appendix A to this standard. They will provide reasonable approximations to allow comparisons to be made of the relative impedances of the circuit loops to be expected at NESDIS facilities.

8.1.4.2 Radiative Coupling Reduction

Radiative coupling can be reduced by applying the following to the source or the victim circuit, or both.

1. Absorb the energy with lossy dielectric or magnetic materials.

2. Reflect or divert the energy with a metallic enclosure.

3. Convert the signal to light pulses and transmit it through fibre optics.

4. Reduce the size of that portion of the circuit which is acting like an antenna.

5. Reorient the source or victim circuits so the radiation is not as well coupled between them, i.e. run cables at right angles, instead of parallel to each other.

Item 2 is probably the most effective way to reduce radiative coupling at reasonable cost in the normal conditions expected at a NESDIS facility, e.g. change a coaxial cable from a type with a braided shield to a type with a solid shield.

8.1.4.3 Inductive Coupling Reduction

Inductive coupling is caused by the mutual inductance between the source and victim circuits. This requires a loop of current flow in both circuits, and is proportional to the size of the source and victim loops and inversely proportional to the distance between them. This coupling can usually be reduced by identifying exactly which conductors make up the actual source and victim current loops, and reducing their size as much as possible, or increasing the spacing between them, over all or a significant part of their routes. If necessary, either or both the source and victim loops could have their conductors twisted, so the inductive coupling would act in opposite directions at different portions of the loop.

8.1.4.4 Capacitive Coupling Reduction

Capacitive coupling can be reduced by either reducing the capacitance between the source and victim circuits, or by inserting a capacitive shield between the two circuits. The capacitance between two conducting surfaces is proportional to their opposing surface areas and inversely proportional to the distance between them. If the circuits can be re-routed to reduce their capacitance to a sufficiently low value, this is the preferred solution. If not, a shield must be inserted between the circuits. To function properly, a capacitive shield must be grounded at one point only. The location of that grounding point is critical, as it must effectively bypass all noise sources to the ground side of the load in the victim circuit. This frequently requires a shield around one or more signal wires that is only grounded at one end.

This type of connection is contrary to the basic safety requirement of this standard, as it permits possible high voltage differences to develop between two nominally grounded conductors that are near each other, under power fault or lightning strike conditions. However, this is permitted, provided the entire shield is inside an area with a ground plane or signal reference grid. In this case it is assumed that the other grounding paths throughout the area are sufficient to keep the voltage difference to a non-hazardous level.

8.1.4.5 Transient Suppression Plate

It is possible that the reinforcing mesh in a concrete floor, whether grounded or not, may be energized by stray radiation, which may then be coupled to the conductors routed over it. If this occurs, a capacitive bypass might be used to reduce the level of this interference. Such a bypass could consist of a copper plate, approximately 4 feet by 4 feet by 1/16 inch, or larger, which would be laid directly on the concrete floor, and be bonded to the power system ground and the signal reference grid. An example is given in FIPS PUB 94, September, 1983, pages 46-49.

8.2 CONTINUED LIGHTNING DAMAGE

Users of this standard should be aware that the requirements for locating air terminals specified herein is based on a theory, not known physical fact. The theory is consistent with the observational and experimental evidence currently available.

8.2.1 Interconnections

The lightning protection requirements incorporated in this standard are based on the principle that if all objects in the area of a lightning strike are connected together, the lightning can induce voltages and currents that will cause the entire group of interconnected objects to rise to a voltage far above the true ground potential. However, this will not cause any hazard to equipment or personnel, if **everything** in the vicinity is raised to the same voltage, with no significant potential differences possible between any two objects.

If lightning damage does continue to occur, the most probable cause is that some object or objects that should have been connected together, were not so connected, or at least not through a low enough impedance. The best method of correcting this type of problem is therefore to look for ways in which additional interconnections can be made, or ways in which the impedance of the existing interconnections can be reduced.

8.2.2 Desired Path Checks

Check all along the desired lightning path for any of the following:

1. Any bend more than 90^{o} or with a radius less than 8".

2. Any connection, particularly between dissimilar metals, with an impedance greater than a few milliohms.

3. If there is a path to re-route the down conductors to provide a more direct path from the point of the lightning strike to true ground. This could require less bends, or bends with smaller angles or larger radii.

8.2.3 Actual Path Checks

If the actual path taken by the lightning strike can be determined, look for any of the following:

1. The point, if any, where the strike energy left the desired path. If this exists, determine what re-routing of the desired path, or connection from it to any other possible path is necessary.

2. Any place where the desired path comes close to the actual path taken by the lightning energy without a physical connection between them. Energy may be coupled into the undesired path by the mutual inductance or capacitance between these conductors. If the close part of these conductors is 10 feet or more in length, they should be bonded together at both ends of their close parallel run. Alternatively, the conductor in the undesired path may be enclosed in a pipe which must be bonded to the desired path at each end of the close parallel run.

3. If the actual lightning strike did not occur to an air terminal, the requirements for the layout of, and connection to, air terminals, in section 4.3 of this standard must be re-examined.

8.3 MULTIPLE SHIELDS

If necessary, conductors may be protected from interference by running shields within shields. This concept includes an outer shield of pipe or conduit, or running a guard wire above already shielded cables. The benefit of such a system is enhanced if the several shields are ended at separate locations along the length of the conductor, provided the effect of the shield can be maintained.

For example, a cable of multiple shielded pairs may have an outer shield around the entire cable and be run in a metal pipe. If the source of the interference against which these shields are intended to protect is outside the structures in which the shielded pairs terminate, the pipe could be terminated at the cable entrance plate of the structures. The outer cable shield could then be terminated at its entrance point to the cabinet housing the equipment to which the pairs connect, and the shields for the individual pairs could be terminated within that equipment, or at the point of entry into its chassis.

The best protection will be achieved when the shield being terminated can be bonded to the outside of an enclosure. This will tend to make any currents flowing on the outside of the shield also flow on the outside of the enclosure, isolating them from all items within the enclosure.

APPENDIX A

REFERENCE EQUATIONS AND PROCEDURES

A.1 CALCULATIONS TO DEFINE LIGHTNING PROTECTION ZONES

The following equations are taken from MITRE Technical Report MTR89W00206 in which the derivations are given. They are included here for easy reference.

A.1.1 Protection Zone of a Single Object

The zone of protection provided by a single, isolated, grounded object, such as a single lightning rod or mast, projecting above the surface of a smooth earth, is given by:

$$S = (2.R.H - H^2)^{1/2} \quad (1)$$

Where:

S = Radius of the base of the cone

R = Radius of curvature of the cone's surface
= The minimum striking distance

H = Height of the object above surface of the earth (but not greater than the distance R)

Graphic Contains Data for Postscript Printers Only.

Figure A1. Protection Zone For a Single Rod

This relationship, between "S" and "H" can also be applied at any location within the zone of protection, provided both "S" and "H" are referenced to the point where the curve is horizontal. This is necessary because of the simple geometrical relationships used to derive this equation.

A.1.2 Rapid Approximation

If a tangent to the arc is drawn at the top of the mast, the slope of that tangent is given by:

$$SIN^{-1}((R - H)/R) \quad (2)$$

Any object within a straight sided cone with this apex angle, must be within the zone of protection created by the mast. Note that the slope is measured from the vertical, not from the horizontal.

A.1.3 Finding The Low Point Between Two Lightning Rods

The following equations may be used to calculate the height of the low point between two masts or lightning rods, or with reference to any two other points on the arc.

In figure 2:

R = Striking distance.

H_1 = Height of first mast.

H_2 = Height of second mast, $\leq H_1$.

H = $H_1 - H_2$

S_1 = Distance from first mast to where the protection curve is horizontal.

S_2 = Distance from second mast to where the protection curve is horizontal.

Graphic Contains Data for Postscript Printers Only.

Figure A2. The Low Point Between Lightning Rods

X = $S_1 + S_2$

A = The minimum height of the curve between the masts.

$$A = H_2 - R + R.\sin\{\cos^{-1}((X^2 + H^2)^{1/2}/2R) + \tan^{-1}(H/X)\} \quad (3)$$

$$S_2 = (2R(H_2 - A) - (H_2 - A)^2)^{1/2} \quad (4)$$

If the two known points are both on the same side of the low point, both the above equations apply, except:

H_2 = The height of the object to be protected.

S_2 = The distance from the low point to the nearest point on the protected object.

X = $S_1 - S_2$

For this type of calculation, the distance from the low point to the second mast and the height of the second mast are both unknowns with an infinite number of interrelated solutions. One must be chosen by other considerations, e.g., a mast of minimum height (= A) or a need for clearance past the end of the protected object.

A.1.4 Protection Zone for Two or More Masts

For the case of two protecting masts, and referring to figure A3, most of the protection zone is defined as for one mast by calculating for each mast separately. However, between the masts, the protection zone is found by the following:

Graphic Contains Data for Postscript Printers Only.

Figure A3. Protection Zone Between the Masts

1. Given H_1, H_2 and X, equation (3) gives A.

2. Given H_1 and A, and with H = H_1 - A, equation (1) gives S_1. If $H_1 = H_2$, then $S_1 = S_2$. If not:

3. Equation (4) will give S_2. S_1, S_2 and A define the lowest point on the protection curve directly between the masts.

4. To find the height, B, of some other point on the protection curve, again apply equation (1) and define H as B - A.

5. To find the height of the protection zone at some distance at right angles to the plane containing the two lightning rods, again use equation (1) with A or B in place of H.

A similar sequence may also be applied to three or more irregularly spaced rods. Determine the location of the low point between each pair of the rods. Some of the pairs can be ignored if they obviously produce a protection zone that is over-shadowed by another pair. The size of the protection zone around the outside of the group of rods is found as above. For the area inside the lines joining the rods together, the low points of all the pairs should be determined and a virtual rod inserted at each low point and of the same height as each low point. Recalculate where the low points would be if these were the protecting rods. Repeat as necessary until the low points so calculated are close enough together to be considered the same point.

A.1.5 Calculating Mast Heights

When the object to be protected is known, to find the masts heights needed, use:

$$H = R - (R^2 - S^2)^{1/2}$$

Here, H is the difference in height between the tops of the object to be protected and the mast, at a distance S that will provide that protection. The actual mast height will be the height of the object to be protected plus H.

A.2 INDUCTANCE OF COPPER WIRES

In most cases the wires and cables interconnecting the facilities at a station can be approximated as a series of straight wires and loops. If the return current flows in a conductor close to the conductor carrying the out going current, the loop equation should be used. If there is enough separation so the magnetic field of the wires do not significantly interact with each other, the inductance should be calculated by adding the results for the individual wires, each calculated separately.

The total inductance for any specific circuit may be found by breaking it into a number of subsections that can be approximated by straight isolated wires and/or loops, whose average dimensions can be determined. Each subsection should be calculated separately and the results added together for the overall circuit inductance.

The following equations are for lengths measured in centimeters, if inches are used, multiply the results by 2.54.

A.2.1 Inductance of an Isolated Straight Wire

The inductance of a single straight round copper wire, isolated from other wires is given by:

$$L = 0.002a\,\{2.303 \log (4a/d) - 1 + \delta\}$$

where:

L = Inductance in microhenrys
a = length of wire in cm
d = diameter of wire in cm
δ = skin effect correction factor from table A1
(varies between 0.25 to 0.0)

A.2.2 Inductance of a Single Loop

The inductance of a single rectangular loop of round copper wire:

$$L = 0.00921\,\{(a+b) \log (4ab/d) - a \log (a + g) - b \log (b + g)\} + 0.004\,\{\delta (a + b) + 2 (g + d/2) - 2 (a + b)\}$$

where:

L = Inductance in microhenrys
a = length of rectangle in cm
b = width of rectangle in cm
d = diameter of wire in cm
$g = (a^2 + b^2)^{1/2}$
δ = skin effect correction factor, as above

Table A1. Properties of Standard Size Annealed Copper Wires

AWG	Diameter		Skin Effect Correction Factor (δ)				DC Resistance	
Size	mils	cm	10 kHz	100 kHz	1 MHz	10 MHz	Ω/1000 ft	Ω/km
4/0	460.0	1.17	0.060	0.018	0.004	0.002	0.049	0.161
2/0	364.8	0.93	0.070	0.022	0.007	0.002	0.078	0.256
1/0	324.9	0.83	0.080	0.024	0.009	0.002	0.098	0.322
2	257.6	0.65	0.100	0.030	0.010	0.003	0.156	0.512
4	204.3	0.52	0.120	0.040	0.011	0.004	0.248	0.814
6	162.0	0.41	0.150	0.050	0.015	0.005	0.395	1.296
8	128.5	0.33	0.190	0.065	0.020	0.006	0.628	2.060
10	101.9	0.26	0.220	0.085	0.025	0.008	0.999	3.278
12	80.8	0.21	0.230	0.095	0.030	0.010	1.588	5.210
14	64.1	0.16	0.240	0.018	0.040	0.014	2.525	8.284

Notes:
1. Values derived from MIL-HDBK-419, volume 2, pages 5-2 and 5-8.
2. For 60 Hz, δ = 0.25 for all the above wire sizes.
3. For frequencies above 10 MHz, δ is essentially zero.

APPENDIX B

LIST OF ABBREVIATIONS

AC	Alternating current
ADP	Automatic data processing
AWG	American wire gauge
CDA	Command and data acquisition
DC	Direct current
FIPS	Federal information processing standards
MHz	Megahertz
NOAA	National Oceanic and Atmospheric Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NFPA	National Fire Protection Association
PCP	Perimeter counterpoise