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1.3 LIGHTNING PROTECTION FOR STRUCTURES.

1.3.1 Principles of Protection.

A structure, for lightning protection purposes, is defined as a building mast, tower, or similar self-supporting object other than power lines, power stations, and substations. To provide minimum protection for structures against direct lightning strikes, four requirements must be fulfilled:

a. an air terminal must be provided to intentionally attract the leader stroke,

b. a path must be established that connects this terminal to earth with such a low impedance that the discharge follows it in preference to any other,

c. a low resistance connection must be made with the earth electrode subsystem, and

d. a low impedance interface must be established between the earth electrode subsystem and earth.

These conditions are met when a lightning discharge is permitted to enter or leave the earth while passing through only conducting parts of a structure. The conditions can be satisfied by one of two methods, each having specific applications. These methods are:

a. the installation of an integral protection system consisting of air terminals interconnected with roof and down conductors to form the shortest practicable distance to ground, or

b. the installation of a separately mounted protection system of one of two types:

(1) a mast type consisting of a metal pole which acts as both air terminal and down conductor (a nonconductive pole may be used if provided with metal air terminals and down conductors connected to an earth ground), or

(2) two or more poles supporting overhead guard wires connected to an earth electrode subsystem with down leads.

1.3.2 Integral Protection System. When designing and installing an integral system of protection, perform the following steps:

a. Erect air terminals on the points of highest elevation and on other exposed areas to intercept the stroke before it has an opportunity to damage the structure or equipments or components mounted thereon. The terminal points must be placed high enough above the structure to eliminate the danger of fire from the arc.

b. Install roof and down conductors so that they offer the least possible impedance to the passage of stroke currents between the air terminals and the earth. The most direct path is the best. The radius of conductor bends shall not be less than 8 inches nor shall the angle of such bends be less than 90 degrees. Additional information may be found in para 3-12.5 of NFPA 78.

c. Distribute ground connections symmetrically about the circumference of the structure rather than grouping to one side.

d. Interconnect all metal objects close to the discharge path to prevent side flashes. (Representative interconnections are shown in Figure 1-15.)

e. Make certain that the mechanical construction of the air terminal system is strong and that the materials used offer high resistance to corrosion.

1.3.2.1 Air Terminals. Air terminals (lightning rods) must intercept, or divert to themselves, any lightning stroke that might otherwise strike the building or structure being protected. Antennas and their associated transmission lines/supporting structures shall be protected by air terminals meeting the requirements of 1.3.2.1.l.a rather than be dependent upon transient protection/suppression devices described in 1.3.3.5.22.

1.3.2.1.1 Size and Materials. To keep from exploding, igniting, or otherwise being destroyed, air terminals should be made of copper, aluminum, brass, or bronze. The minimum sizes are 1.27 cm (1/2 inch) in diameter for solid copper, brass, or bronze rods and 1.6 cm (5/8 inch) in diameter for solid aluminum rods.

a. Air terminals must extend at least 25.4 cm (10 inches) directly above the object being protected and be of sufficient height so as to provide a 1:1 zone of protection for adjacent objects (antennas and associated support/control towers, etc). Rather than choosing the shortest terminal which will provide this minimum height, all parts of the structure must be checked graphically or analytically in the manner described in the next section to determine if the zone of protection provided by the terminal is adequate. Where taller terminals are required to provide complete protection, adequate support and bracing as specified by ANSI-C5.1 (2.1.15) must be provided.

b. Where air terminals are mounted on or very near (less than 1.5 meters (5 feet)) to vents or stacks which emit potentially explosive or ignitable dusts, vapors, or gases, provide additional clearance.

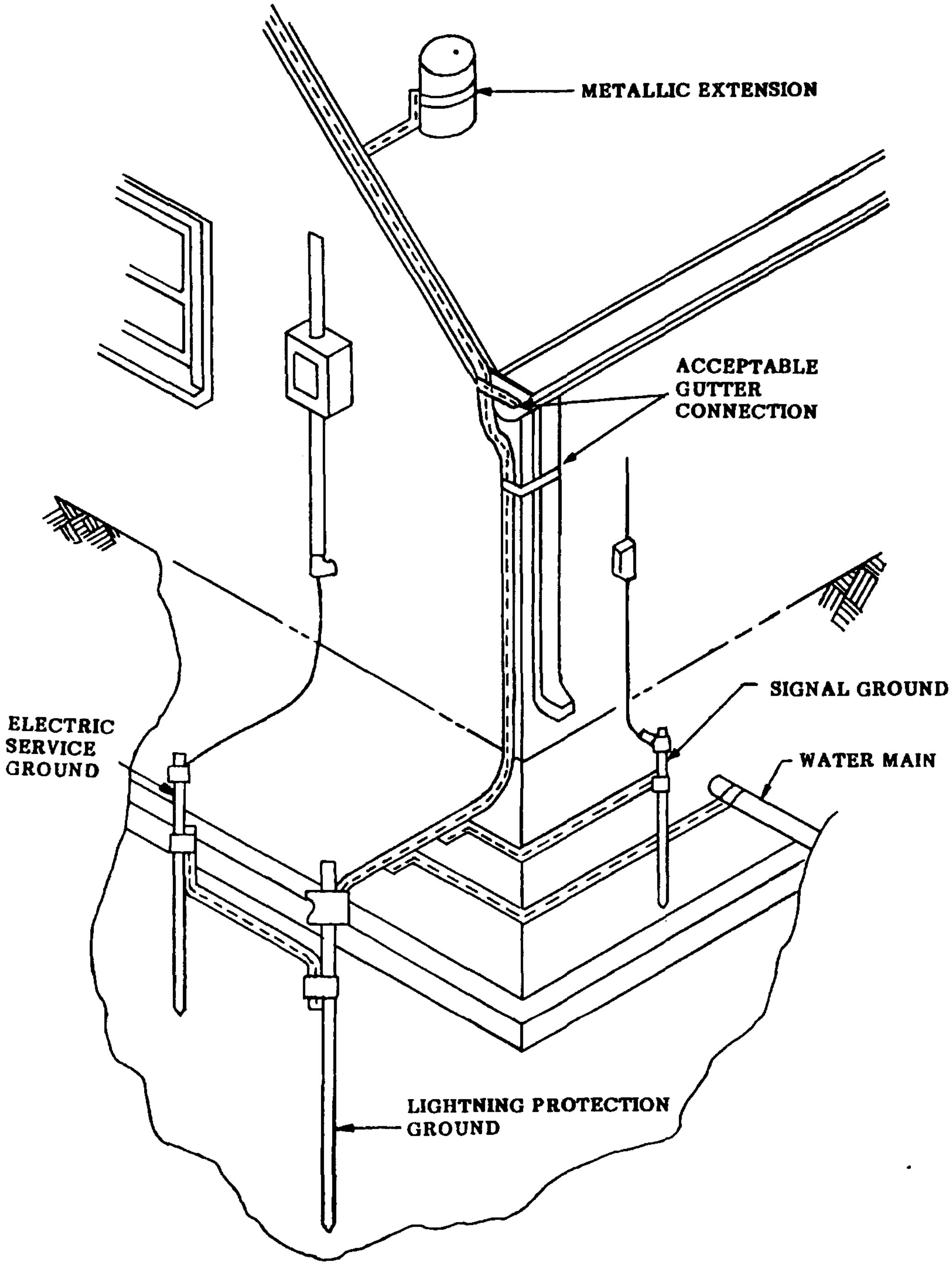
(1) Over hooded vents emitting explosive substances under natural draft, the air terminals should extend at least 1.5 meters (5 feet) above the opening.

(2) Above open stacks emitting explosive substances under forced drafts, air terminals should extend at least 4.5 meters (15 feet) above the opening.

1.3.2.1.2 Location.

a. Locate air terminals along the ridges of gable, gambrel, and hip roofs in the manner illustrated in Figure 1-16.

b. Place them on the corners and along the edges of gently sloping roofs as shown in Figure 1-17. Gently sloping roofs are defined as (1) having a span of 40 feet or less with a rise-to-run ratio, i.e., pitch, of one-eighth or less or (2) having a span greater than 40 feet and a rise-to-run ratio of one-quarter or less.



NOTE: CONNECTION TO WATER PIPE AS SHOWN

Figure 1-15. Grounding Practices for Lightning Protection

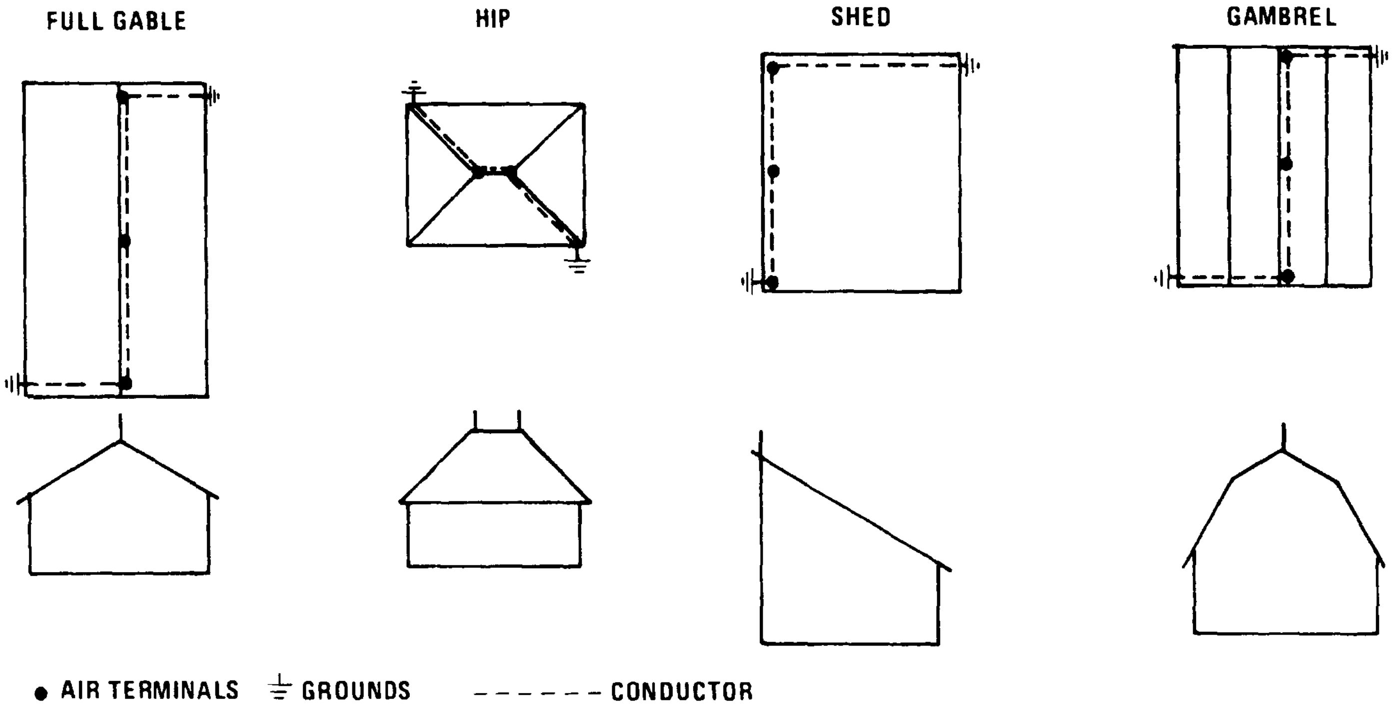


Figure 1-16. Location of Air Terminals for Common Roof Types

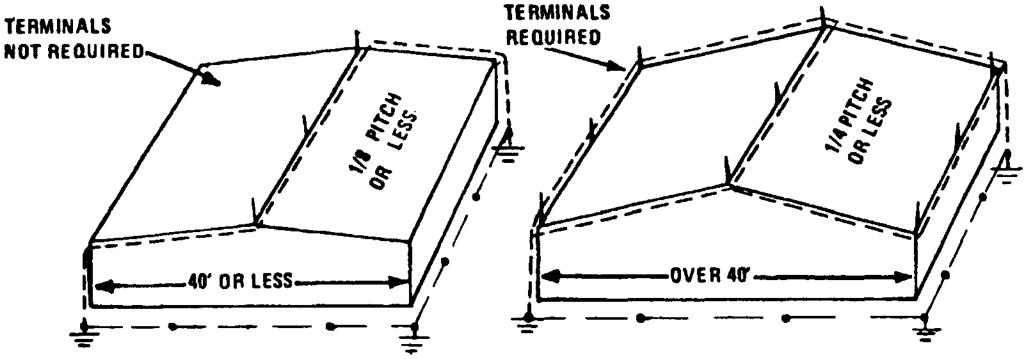


Figure 1-17. Location of Air Terminals on Gently Sloping Roofs

c. On flat roofs position the air terminals around the perimeter in the manner shown in Figure 1-18. Provide additional air terminals placed at 50-foot intervals over the interior of flat and gently sloping roofs which exceed 50 feet in width.

d. Terminals are to be provided within 2 feet of corners, the end of ridges, or edges of main roofs.

e. Terminals less than 24 inches in height are to be spaced 20 feet or less. Terminals 24 inches or taller may be placed at intervals not exceeding 25 feet.

f. Ensure that no part of the structure extends outside the cone of protection established by the air terminals. Determine the cone of protection by preparing a simple scaled profile drawing of the structure and then superimposing a 45-degree (a 1:1 cone of protection) triangle on the profile. The apex of the triangle should coincide with the tip of the air terminal whose protected zone is being verified, as illustrated in Figure 1-19. Alternatively for existing structures, the field expedient method illustrated in Figure 1-20 showing a 2:1 cone of protection can be used to determine the coverage of prominent projections. This method is particularly useful for small structures.

To determine if all parts of a flat roofed structure such as vents, pipes, cabling, or raised extensions are protected, use the method illustrated in Figure 1-21 to calculate the zone protected by two vertical terminals. This method can also be used to determine the coverage provided by vertical masts or horizontal wires. In Figure 1-21 point P represents the point of discrimination. That is, the point of departure of the final stepped leader of the downward traveling stroke (see Volume I, Section 3.2). To determine if the air terminals are actually the nearest objects to point P, use P as a center and swing an arc of radius X through the tips of the terminals. Let the value of this radius X be 100 feet, since 100 feet represents the shortest length usually associated with a stepped leader (see Volume I, Section 3.2). Because of the large differences between the height of typical terminals and the striking distance X, graphical determination of the protected zone will usually be awkward. For greater accuracy, calculate the critical distances through the use of the following equation:

$$G = H - X + \sqrt{X^2 - \left(\frac{S}{2}\right)^2} \tag{1-2}$$

which is valid for $S \leq 2X$. In this equation, G is the minimum height between the terminals that is completely protected; H is the height of the terminals, S is the spacing between terminals, and X is the radius of the arc.

Sample calculation. To illustrate the application of this method, suppose it is necessary to determine the minimum spacing between 3-foot air terminals that will guarantee that all parts of a flat roof remain in the protected zone. In other words, what value of S corresponds to $G = 0$ in Equation 1-2? To perform the calculation, first set $G = 0$:

$$0 = H - X + \sqrt{X^2 - \left(\frac{S}{2}\right)^2}$$

Rearranging to be

$$X - H = \sqrt{X^2 - \left(\frac{S}{2}\right)^2}$$

and squaring both sides produces

$$X^2 - 2HX + H^2 = X^2 - \left(\frac{S}{2}\right)^2$$

Eliminating X^2 and changing signs on both sides of the equation yields

$$\left(\frac{S}{2}\right)^2 = 2HX - H^2$$

or

$$\frac{S^2}{4} = H(2X - H)$$

$$S = 2\sqrt{H(2X - H)}$$

Substituting $H = 3$ feet and $X = 100$ feet in this last equation shows that S must equal 48.6 feet or less to guarantee that all parts of the roof remain within the protected zone.

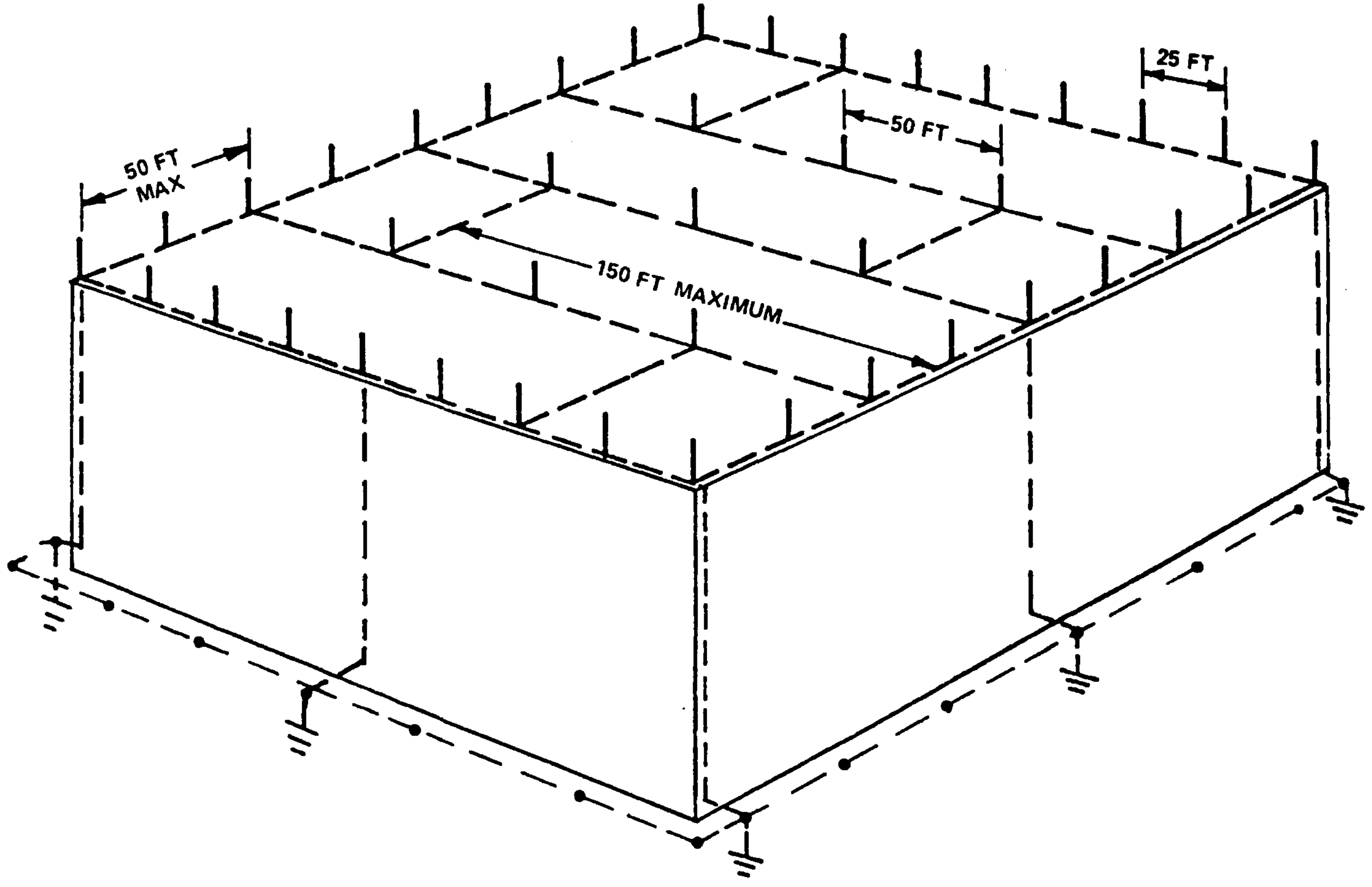


Figure 1-18. Air Terminal Placement on Flat-Roofed Structures

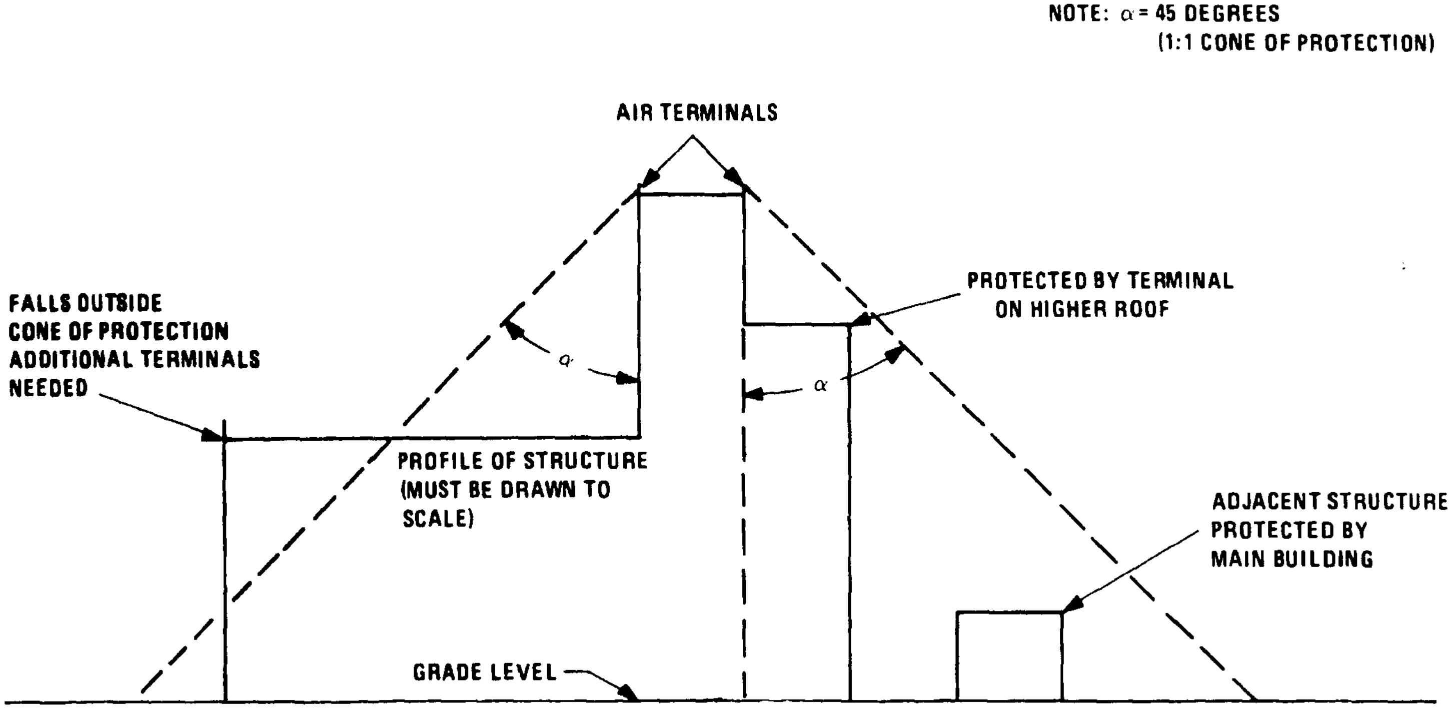


Figure 1-19. Graphical Method for Determining Need for Additional Air Terminals

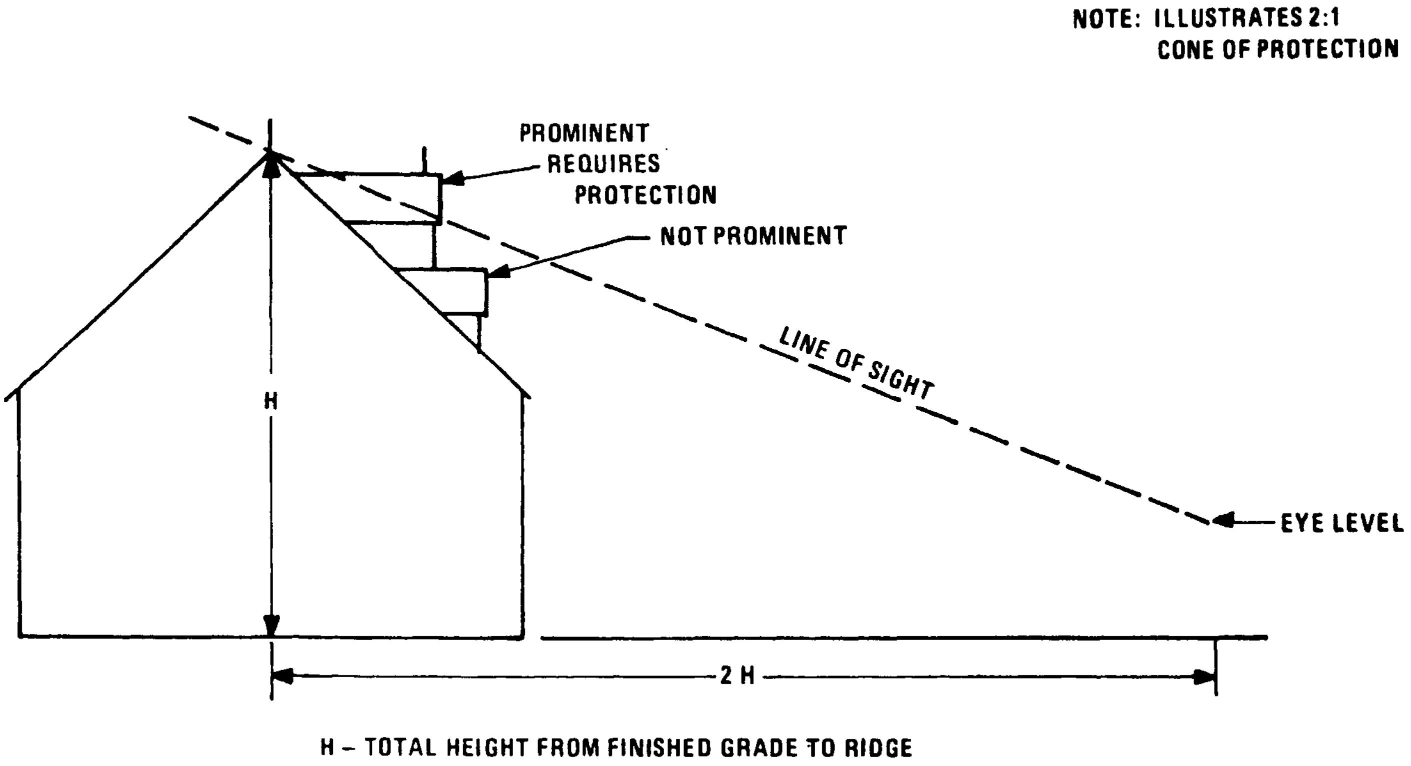


Figure 1-20. Field Expedient Technique for Determining the Protection of Prominent Dormers

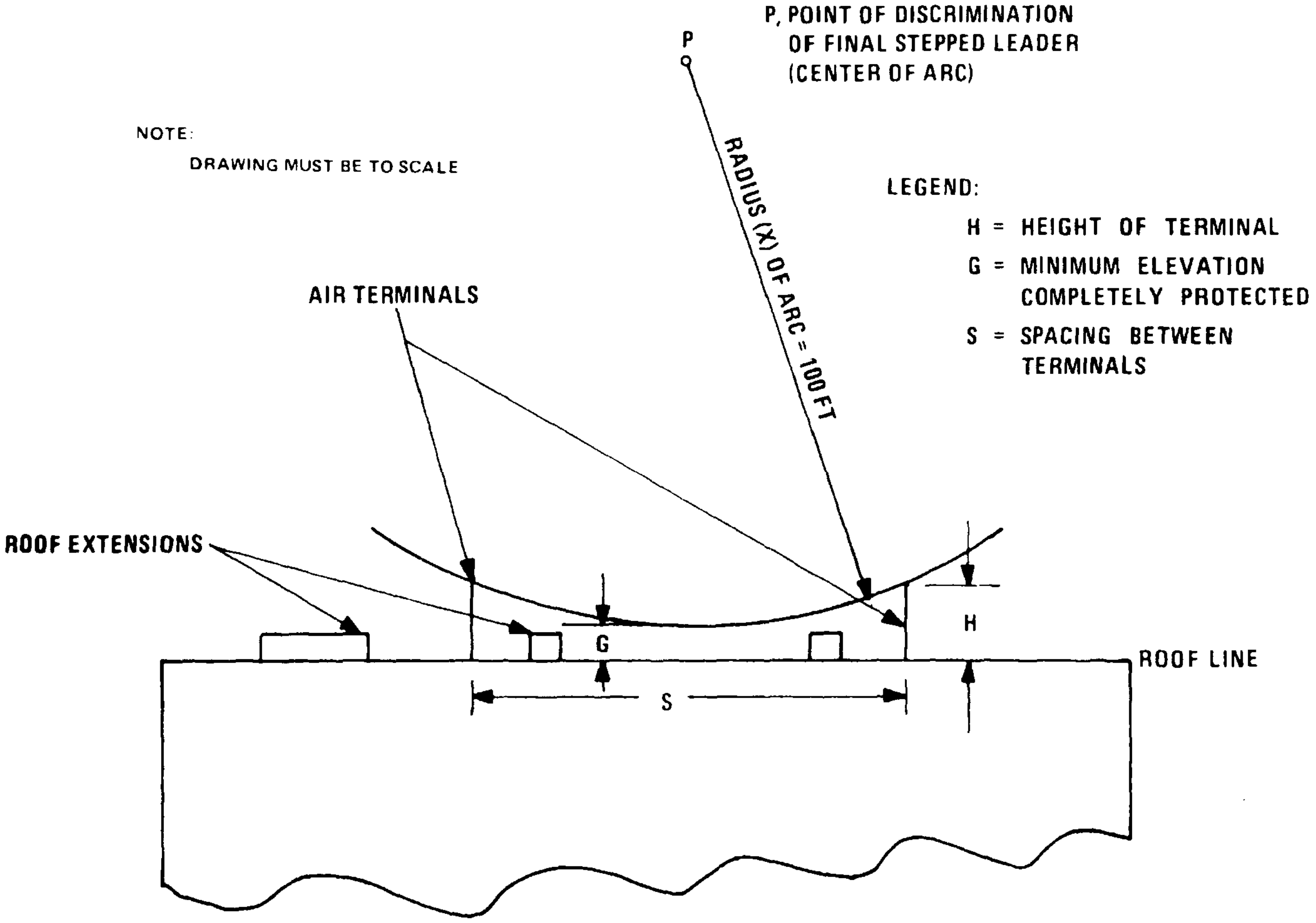


Figure 1-21. Illustration of Method for Determining the Protection of Flat Surfaces as Provided by Air Terminals (1-4)

1.3.2.2 Grounding Conductors. Provide each air terminal with a two-way path to earth through the installation of roof and down conductors conforming to Table 1-2 for structures not greater than 75 feet in height and conforming to Table 1-3 for structures greater than 75 feet in height. An exception is that air terminals located on prominent dormers extending less than 16 feet from the main structure need have only one connecting path from the terminal to the main down conductor as shown in Figure 1-22. Additional information on copper wires is contained in Table 1-4.

1.3.2.2.1 Roof Conductors.

a. Roof conductors should be routed along ridges of gable, gambrel, and hip roofs, and around the perimeter of flat and gently sloping roofs.

b. Roof grounding conductors routed throughout decks, flat surfaces, and flat roofs should be interconnected to form closed loops to insure that all air terminals have at least two paths to earth.

c. Ridge conductors may drop from a higher to a lower roof level without installing an extra down lead at the point of intersection of the two roof levels if there are not more than two air terminals on the lower roof level.

d. On roofs that exceed 50 feet in width, additional conductors are to be provided to interconnect the air terminals required to protect large flat areas (see Figure 1-18). One additional conductor for each 50 feet in width is necessary. For example, on roofs 50 to 100 feet wide, add one additional run; on roofs 100 to 150 feet wide, add two additional runs; etc. These additional runs must be interconnected together and to the perimeter conductor at 150-foot intervals with cross conductors as illustrated in Figure 1-18.

Table 1-2

Minimum Requirements for Roof and Down Conductors on Structures Not Greater than 75 Feet (23 Meters) in Height (1-3)

Type of Conductor		Material	
		Copper	Aluminum
Cable	Strand Size	14 AWG	12 AWG
	Weight per 1000 feet*	187-1/2 pounds	95 pounds
	Area*	59,500 Cir roils	98,500 Cir roils
	DC Resistance	0.176 ohms/1000 ft	0.176 ohms/1000 ft
Solid Strip	Thickness	14 AWG	12 AWG
	Width	1 inch**	1 inch**
	DC Resistance	0.176 ohms/1000 ft	0.176 ohms/1000 ft
Solid Rod	Weight Per 1000 feet	186-1/2 pounds	95 pounds
	DC Resistance	0.176 ohms/1000 ft	0.176 ohms/1000 ft
Tubular Rod	Weight per 1000 feet	187-1/2 pounds	95 pounds
	Wall Thickness	0.032 inch	0.064 inch
	DC Resistance	0.176 ohms/1000 ft	0.176 ohms/1000 ft

* Acceptable substitutes are No. 2 AWG copper cables and 1/0 AWG aluminum cables.

**This is the minimum width for a strip void of perforations. If perforated, the width shall be increased equal to the diameter of the perforations.

Table 1-3

Minimum Requirements for Roof and Down Conductors on Structures Greater than 75 Feet (23 Meters) in Height (1-3)

Material	Minimum Wire Strand Size*	Weight Per Foot	Weight Per 1000 Feet	DC Resistance Per 1000 Feet
	AWG	Ounces	Pounds	Ohms
Copper	14	6	375	0.088
Aluminum	12	3	190	0.088

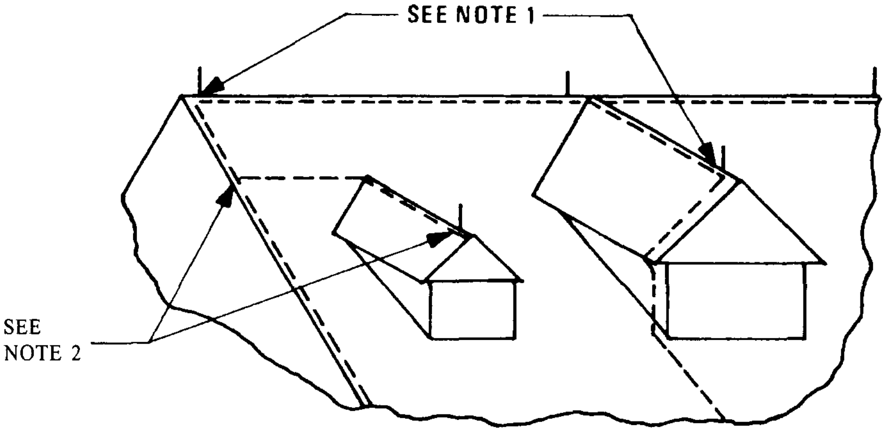
*Equivalent standard AWG cable: Copper - 2/0, Aluminum - 4/0

Table 1-4. Solid Copper Wire — Weight, Breaking Strength, DC Resistance
(Based on ASTM Specifications B1-56, B2-52, and B3-63)

		Area		Weight		Hard		Medium		Soft	
Size, AWG	Diameter, in.	Cir mils	Sq in.	Lb per 1,000 ft	Lb per mile	Breaking strength, minimum lb	DC resistance at 20° C (68° F) maximum, ohms per 1,000 ft	Breaking strength, minimum lb	DC resistance at 20° C (68° F) maximum, ohms per 1,000 ft	Breaking strength, maximum lb	DC resistance at 20° C (68° F) maximum, ohms per 1,000 ft
4/0	0.4600	211,600	0.1662	640.5	3382	8143	0.05045	6980	0.05019	5983	0.04901
3/0	0.4096	167,800	0.1318	507.8	2681	6720	0.06362	5666	0.06330	4744	0.06182
2/0	0.3648	133,100	0.1045	402.8	2127	5519	0.08021	4599	0.07980	3763	0.07793
1/0	0.3249	105,600	0.08291	319.5	1687	4518	0.1022	3731	0.1016	2985	0.09825
1	0.2893	83,690	0.06573	253.3	1338	3688	0.1289	3024	0.1282	2432	0.1239
2	0.2576	66,360	0.05212	200.9	1061	3002	0.1625	2450	0.1617	1928	0.1563
3	0.2294	52,620	0.04133	159.3	841.1	2439	0.2050	1984	0.2039	1529	0.1971
4	0.2043	41,740	0.03278	126.3	667.1	1970	0.2584	1584	0.2571	1213	0.2485
5	0.1819	33,090	0.02599	100.2	528.8	1590	0.3260	1265	0.3243	961.5	0.3135
6	0.1620	26,240	0.02061	79.44	419.4	1280	0.4110	1010	0.4088	762.6	0.3952
7	0.1443	20,820	0.01635	63.03	332.8	1030	0.5180	806.7	0.5153	605.1	0.4981
8	0.1285	16,510	0.01297	49.98	263.9	826.1	0.6532	644.0	0.6498	479.8	0.6281
9	0.1144	13,090	0.01028	39.61	209.2	660.9	0.8241	513.9	0.8199	380.3	0.7925
10	0.1019	10,380	0.008155	31.43	166.0	529.3	1.039	410.5	1.033	314.0	0.9988
11	0.0907	8,230	0.00646	24.9	131	423	1.31	327	1.30	249	1.26

Table 1-4. Solid Copper Wire — Weight, Breaking Strength, DC Resistance
(Based on ASTM Specifications B1-56, B2-52, and B3-63) (Continued)

		Area		Weight		Hard		Medium		Soft	
Size, AWG	Diameter, in.	Cir mils	Sq in.	Lb per 1,000 ft	Lb per mile	Breaking strength, minimum lb	DC resistance at 20° C (68° F) maximum, ohms per 1,000 ft	Breaking strength, minimum lb	DC resistance at 20° C (68° F) maximum, ohms per 1,000 ft	Breaking strength, maximum lb	DC resistance at 20° C (68° F) maximum, ohms per 1,000 ft
12	0.0808	6,530	0.00513	19.8	104	337	1.65	262	1.64	197	1.59
13	0.0720	5,180	0.00407	15.7	82.9	268	2.08	209	2.07	157	2.00
14	0.0641	4,110	0.00323	12.4	65.7	214	2.63	167	2.61	124	2.52
15	0.0571	3,260	0.00256	9.87	52.1	170	3.31	133	3.29	98.6	3.18
16	0.0508	2,580	0.00203	7.81	41.2	135	4.18	106	4.16	78.0	4.02
17	0.0453	2,050	0.00161	6.21	32.8	108	5.26	84.9	5.23	62.1	5.05
18	0.0403	1,620	0.00128	4.92	26.0	85.5	6.64	67.6	6.61	49.1	6.39
19	0.0359	1,290	0.00101	3.90	20.6	68.0	8.37	54.0	8.33	39.0	8.05
20	0.0320	1,020	0.000804	3.10	16.4	54.2	10.5	43.2	10.5	31.0	10.1
21	0.0285	812	0.000638	2.46	13.0	43.2	13.3	34.4	13.2	24.6	12.8
22	0.0253	640	0.000503	1.94	10.2	34.1	16.9	27.3	16.8	19.4	16.2
23	0.0226	511	0.000401	1.55	8.16	27.3	21.1	21.9	21.0	15.4	20.3
24	0.0201	404	0.000317	1.22	6.46	21.7	26.7	17.5	26.6	12.7	25.7
25	0.0179	320	0.000252	0.970	5.12	17.3	33.7	13.9	33.5	10.1	32.4
26	0.0159	253	0.000199	0.765	4.04	13.7	42.7	11.1	42.4	7.94	41.0



NOTES:
1 - DEAD ENDS ARE NOT ACCEPTABLE ON MAIN RIDGES OR ON RIDGES OF DORMERS OR SIDE WINGS AS HIGH OR HIGHER THAN THE MAIN RIDGE,
2- TOTAL CONDUCTOR LENGTH NOT TO EXCEED 16 FEET.

Figure 1-22. Criteria for Dead End Coverage

e. Maintain a horizontal or downward course with roof conductors. Provide "U" or "V" (up and down) pockets with a down conductor from the base of the pocket (see Figure 1-23(a)) to ground or to a convenient lead of the main down conductor.

f. Route conductors through or around obstructions which lie in a horizontal plane with the conductor (Figure 1-23(b) and (c)). Bends in the conductor should not include an angle of less than 90 degrees and should maintain a radius of 8 inches or greeter (Figure 1-23(d)). In particular, re-entrant loops should be avoided (1-5). When routing around obstructions, wide gradual bends are preferred. Other recommended practices are illustrated in Figures 1-23(e) thru (h).

g. Securely attach the conductors directly to the ridge roll or roof with UL-approved fasteners every 3 feet.

h. Conductors may be coursed through air up to 0.9 meters (3 feet) without support. With an acceptable support such as a 1.9 cm (3/4-inch) copper-clad ground rod or its equivalent, securely fastened at each end, a conductor may be coursed up to 1.8 meters (6 feet) through air.

1.3.2.2.2 Down Conductors.

a. Course down conductors over the extreme outer portions of the structure and separate them as far apart as possible. Preferred locations are at diagonally opposite corners on square or rectangular structures and symmetrically distributed around cylindrical structures.

b. Locate down conductors as close as practical to air terminals and to the most convenient places for attaching the conductors to the earth electrode subsystem of the structure. The down conductors should be equally and symmetrically spaced about the perimeter of the structure.

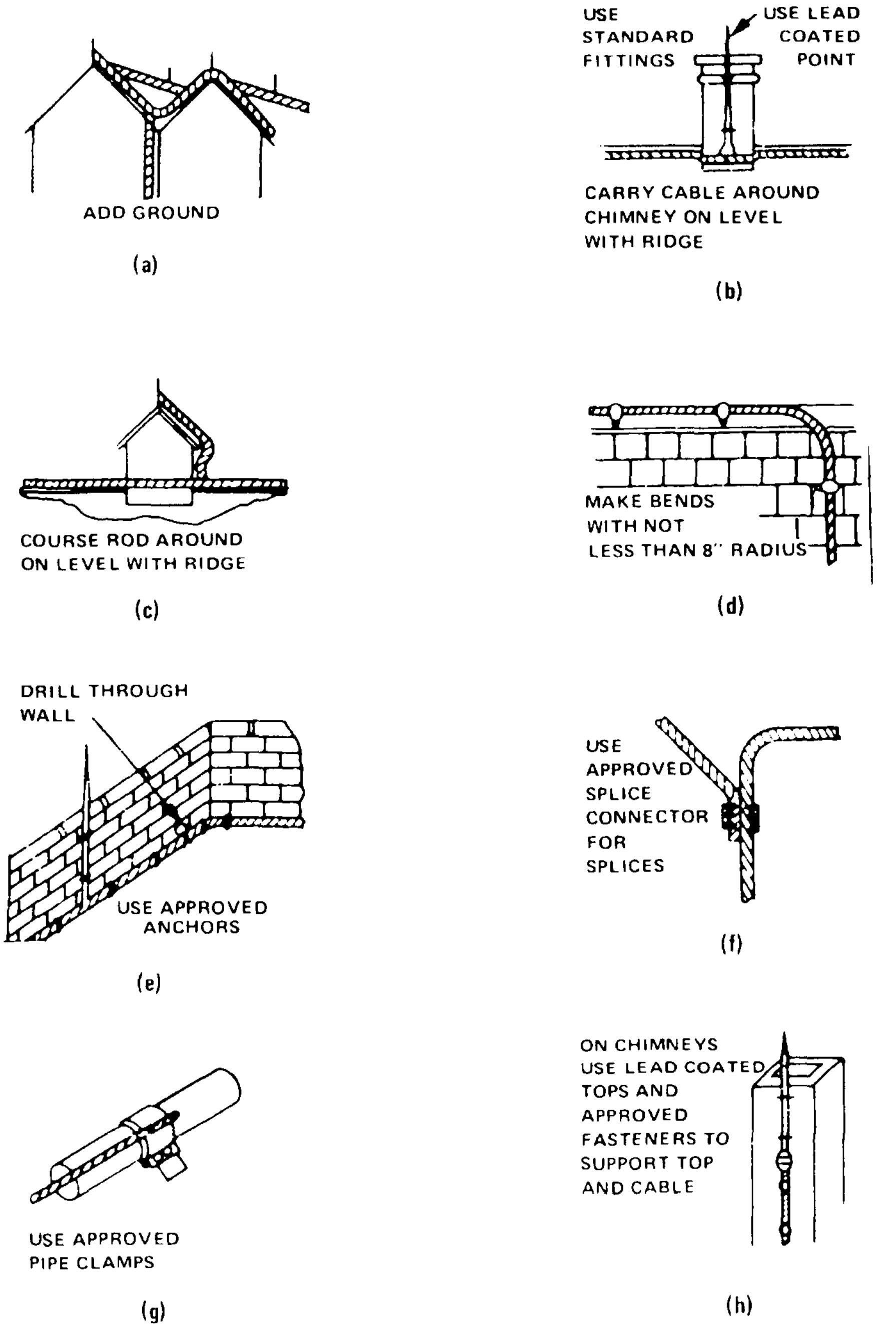


Figure 1-23. Recommended Construction Practices for Integral Lightning Protection Systems

c. At least two down conductors are required on all structures except on slender objects like flag poles, antenna masts (not substantial towers), light poles, and the like.

d. Provide one additional down conductor for each additional 30 meters (100 feet) or fraction thereof on structures having a perimeter exceeding 75 meters (250 feet). On structures having flat or gently sloping roofs and on irregular-shaped structures, the number of down conductors should be such that the length of the average roof conductor joining them does not exceed 30 meters (100 feet). On structures higher than 18 meters (60 feet) where down conductors are required, install at least one additional down conductor for each 18 meters (60 feet) of height or fraction thereof; however, the spacing between down conductors need not be less than 15 meters (50 feet).

e. Down conductors are to be provided or located appropriately to avoid dead ends in excess of 4.8 meters (16 feet) in length. See Figure 1-22, Note 1.

f. Maintain down conductors in a downward course with routing around or through any obstruction which may lie in the path. Sharp bends or turns are to be avoided with necessary turns limited to not less than 90 degrees and not less than 20 cm (8 inches) in radius.

g. Where large re-entrant loops (i.e., those with greater than 90-degree turns) cannot be avoided, e.g., around cornices or over parapets, the conductor should be routed to ensure that the open side of the loop is greater than one-eighth the length of the remaining sides of the loop. It is advised, however, to course the conductor through holes or troughs through the obstacles and avoid the loop completely (as shown in Figure 1-23(e)) whenever possible.

h. On structures with overhangs such as antenna towers with extended platforms or buildings utilizing cantilevered construction, run the down conductors vertically through the interior of the structure (1-5). Internally routed conductors must be enclosed in nonmetallic, noncombustible ducts.

i. Substantial metal structural elements of buildings may be substituted for regular lightning conductors where, inherently or by suitable electrical bonding, they are electrically continuous from the air terminal to the earth electrode connection. The structural elements must have a conducting cross-sectional area, including that in joints, at least twice that of the lightning conductor that would otherwise be used. There need be no difference whether such conductors are on the interior or exterior of the structure when used for down conductors. Steel frame buildings encased in bricks or other masonry products must have external air terminals and roof conductors installed and bonded directly to the structural members to keep the lightning discharge from having to penetrate the masonry shell to reach the frame members.

1.3.2.3 Fasteners.

a. Securely attach air terminals and roof and down conductors to the building or other object upon which they are placed.

b. Fasteners (including nails, screws, or other means by which they are attached) should be substantial in construction, not subject to breakage, and should be of the same material as the conductor or of a material that will preclude serious tendency towards electrolytic corrosion in the presence of moisture because of contact between the different metals. (For further information on corrosion, see Volume I, Section 7.8.)

c. Keep all hardware, component parts, and joints that are not welded or brazed and that require inspection for maintenance and repair readily accessible.

d. Any special fixtures required for access should be permanently attached to prevent loss. However, appropriate locks or other devices essential to safety, security, and physical protection of the hardware or of the area in which it is located may be used.

1.3.3 Separately Mounted Protection Systems.

1.3.3.1 Mast Type.

a. No part of the structure being protected should extend outside the protected zone as calculated by the procedure illustrated by Figure 1-19 (a conservative estimate for two masts can be made with the aid of Figure 1-24).

b. Where it is impractical to provide a common mast to provide protection for an entire structure, additional masts should be provided.

c. If the pole is made of a nonconducting material, provide an air terminal extending not less than 0.6 meters (2 feet) nor more than 0.9 meters (3 feet) above the top of the pole.

d. Connect the base of the mast (if metal) or the down conductors to the earth electrode subsystem of the protected structure with at least a No. 6 AWG copper conductor or equivalent.

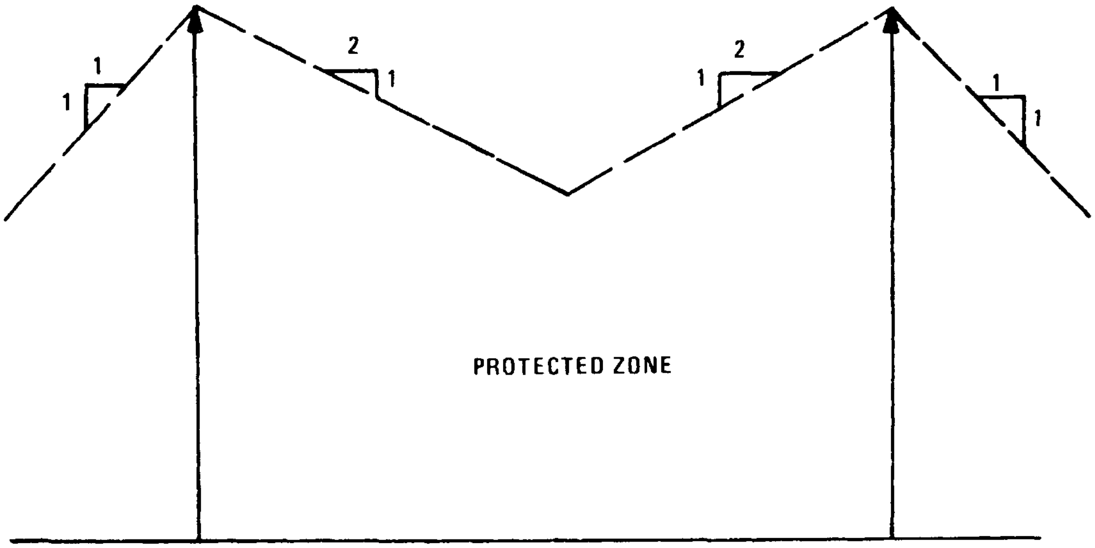


Figure 1-24. The Protected Zone Provided by Two Vertical Masts

1.3.3.2 Overhead Ground Wire Type.

a. If the poles are of a nonconducting material, an air terminal shall be securely mounted on the top of each pole, extending not less than 0.45 meters (1.5 feet) above the top of the pole. Down conductors are run down the side of the pole or the guy wire may be employed as the conductor as shown in Figure 1-25. If the guy wire is used, it shall meet the requirements of paragraph 1.3.2.2 and both this wire and the overhead ground wire are dead-ended at the pole. The overhead ground wire and the guy wire shall be interconnected with a separate cable. Down conductors and guy wires used as down conductors are to be connected to the earth electrode subsystem of the structure being protected. Guy wires not located near existing earth electrode subsystems shall be grounded either to their respective ground anchor (by use of an interconnecting cable) or to a separate ground rod.

b. The height of the poles should be sufficient to provide a clearance of not less than 1.8 meters (6 feet) between the overhead ground wire and the highest projection on the building. When the overhead ground wire system is used to protect stacks or vents which emit explosive dusts, vapors, or gases under forced draft, the cable is installed so that it has a clearance of at least 4.5 meters (15 feet) above the object receiving protection.

c. With either the mast type or the overhead ground wire type of system, the pole is placed at a distance from the structure that is at least one-third the height of the structure, but in no instance less than 1.8 meters (6 feet). Figure 1-25 refers.

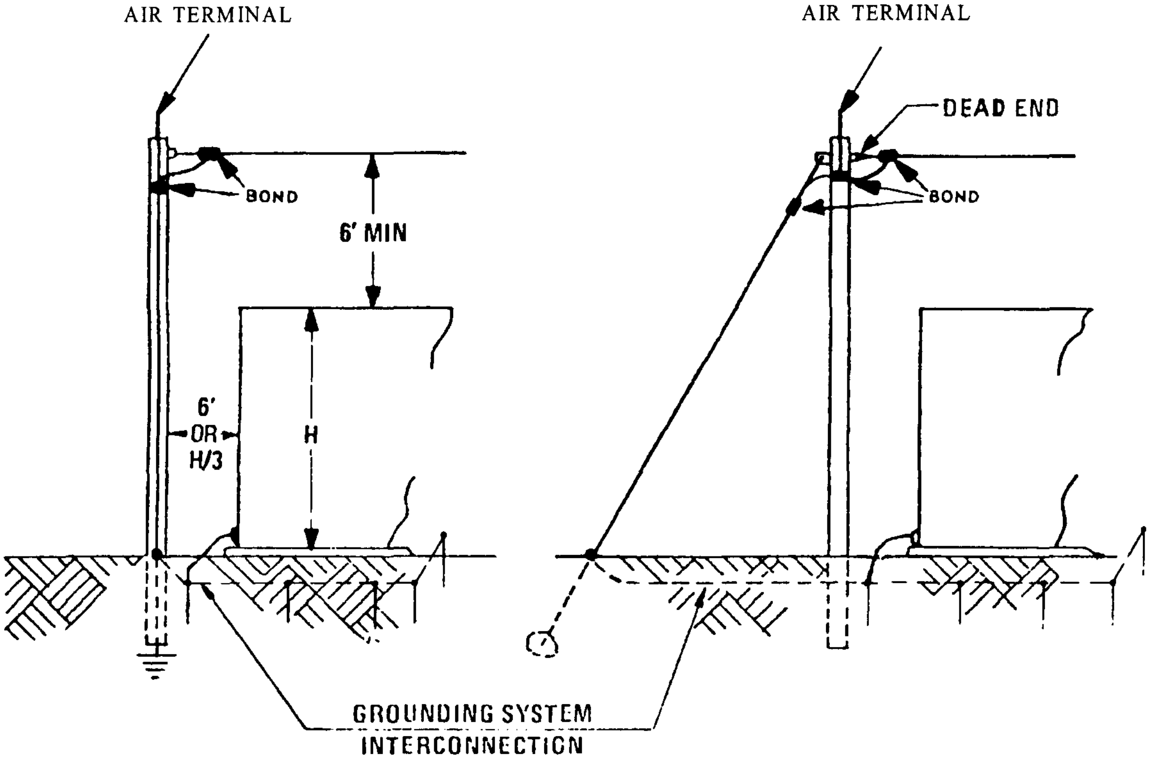


Figure 1-25. Overhead Ground Wire Lightning Protection System

1.3.3.3 Waveguide Installation and Grounding. Waveguide between the antenna and the associated transmit/receive equipment should be grounded in the following manner.

a. Each waveguide shall be bonded to the down conductor of the air terminal at the top near the antenna and also at the bottom near the vertical to horizontal transition point. The waveguide shall also be bonded to the antenna tower at the same points as well as at an intermediate point if the tower exceeds 60 meters (200 feet).

b. All waveguide support structures shall be bonded to the tower. The waveguides and supporting structure shall be bonded together at the waveguide entry plate and connected to the earth electrode subsystem.

c. All waveguides, conduit or piping entering a building shall be bonded to the waveguide entry plate, then to the earth electrode subsystem (see Figures 1-26 thru 1-31). For waveguide penetrations of a shielded enclosure or entry plate see Volume 1, Section 10.4.2.4.

d. Rigid waveguides within 1.8 meters (6 feet) of each other should be bonded together through the entry plate or by means of a crimp type lug fastened under the waveguide flange bolts and No. 6 AWG wire. The bond shall be extended to the bus at the waveguide entry point and connected to the earth electrode subsystem.

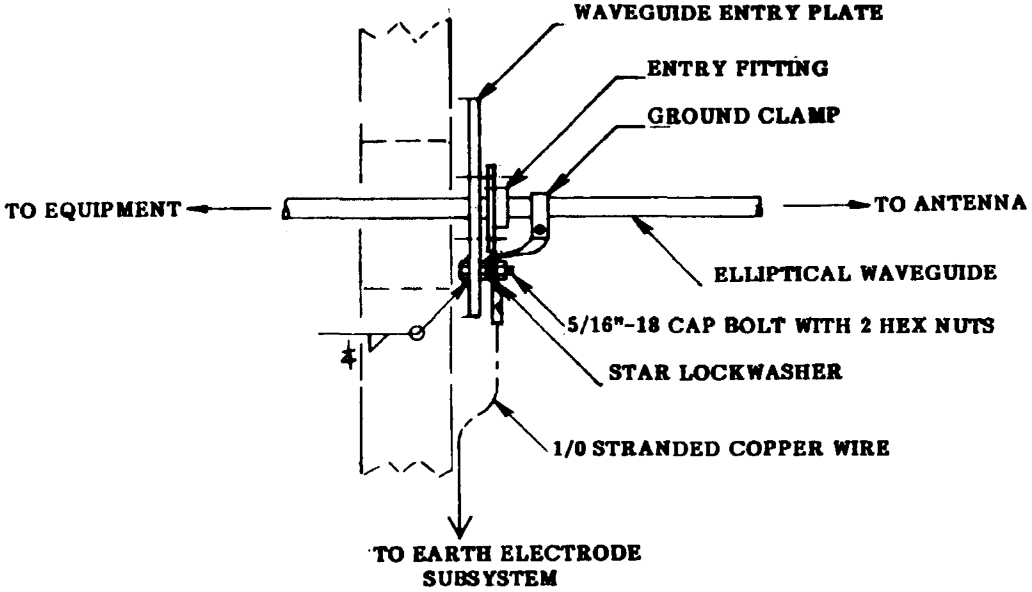
e. Determine location of ground strap position as shown in Figure 1-28A and remove waveguide jacket. The ground strap is made from a piece of waveguide as detailed in Figures 1-29 and 1-30. Clean mating surfaces (waveguide and strap) with solvent or cleaning fluid.

f. Wrap the strap with No. 14 AWG copper wire (for 8 GHz waveguide as shown Figure I-28A). For 4 GHz waveguide, use No. 10 AWG solid copper wire. Use adjustable stainless steel clamps as required to secure the strap. Tighten screw until the clamp grips firmly. Excessive tightening could damage the waveguide and impair the electrical characteristics. Weatherproof with Scotch Guard or equivalent and tape.

g. An alternate method of securing the strap to the waveguide is to use wrap-around heat shrink to cover the bond and to maintain weatherproofing. Solder one end of a solid copper wire (#10 for 4 GHz and #14 for 8 GHz waveguide) to one end of corrugated portion of the ground strap. Align the corrugated section of the ground strap with the exposed section of the waveguide (see Figure 1-28 B). Tightly wrap the wire around the ground strap and waveguide and solder the end of the wire to the ground strap for securing purposes. Apply the wrap-around heat shrink around the waveguide and heat according to the manufacturer's instructions.

h. Remove all sharp and rough edges on ground strap.

i. An alternate method for grounding waveguide is also shown on Figure 1-26.



NOTE: To satisfy HEMP requirements, peripherally bond waveguide to waveguide entry plate.

Figure 1-26. Waveguide Entry Plate Detail

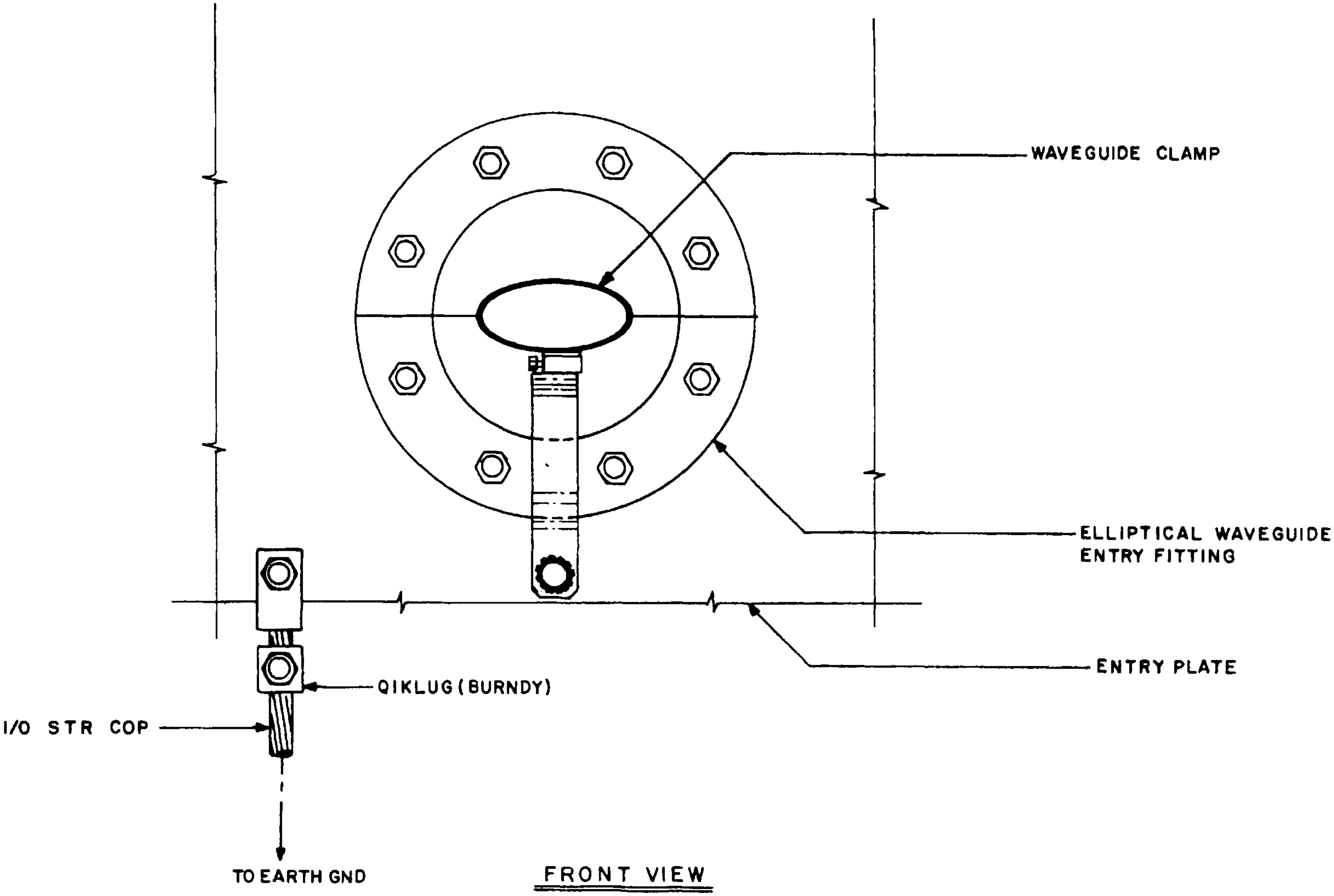


Figure 1-27. Grounding Detail for Elliptical Waveguide

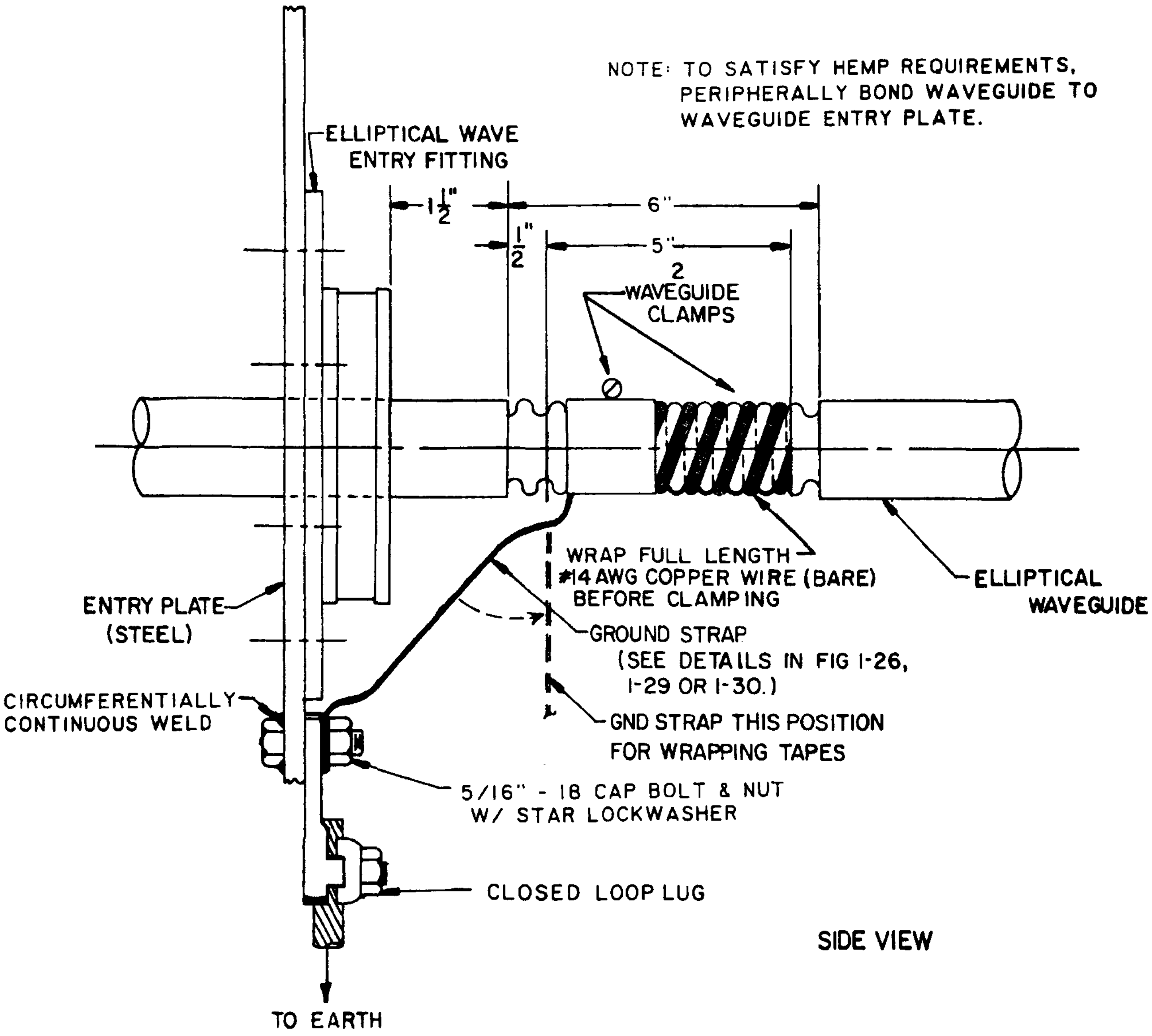


Figure 1-28A. Grounding Details for Elliptical Waveguide

Figure 1-28B. Heat Shrink Grounding

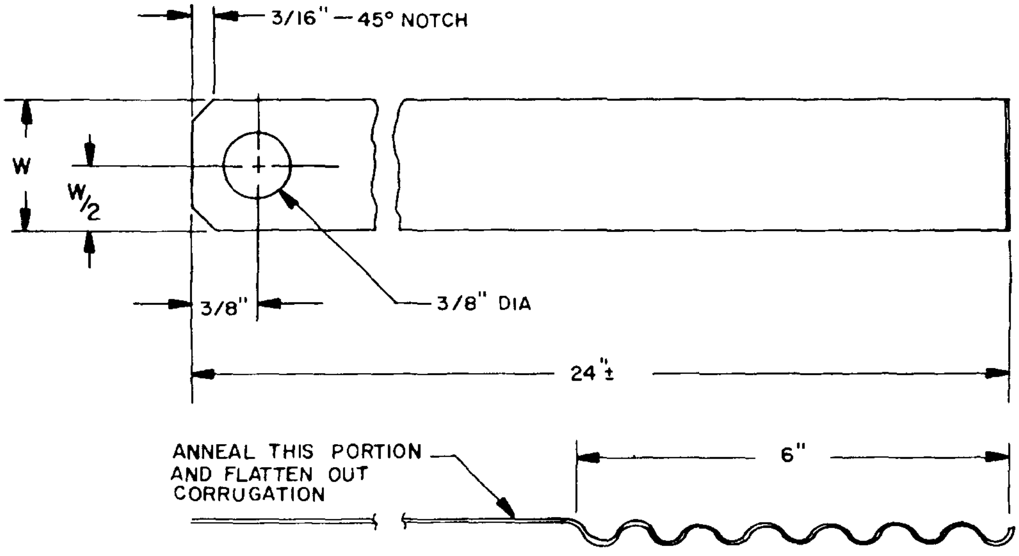


Figure 1-29. Ground Strap Detail for Elliptical Waveguide

NOTE: FOR FIGURES 1-29 AND 1-30
W = 1-1/4" FOR 4-GHz WAVEGUIDE
W = 1" FOR 8-GHz WAVEGUIDE

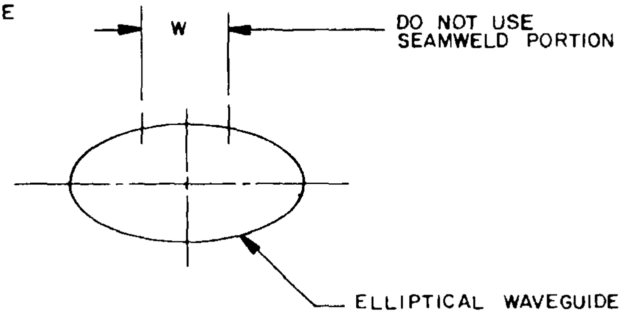


Figure 1-30. Strap Cutting Detail for Elliptical Waveguide

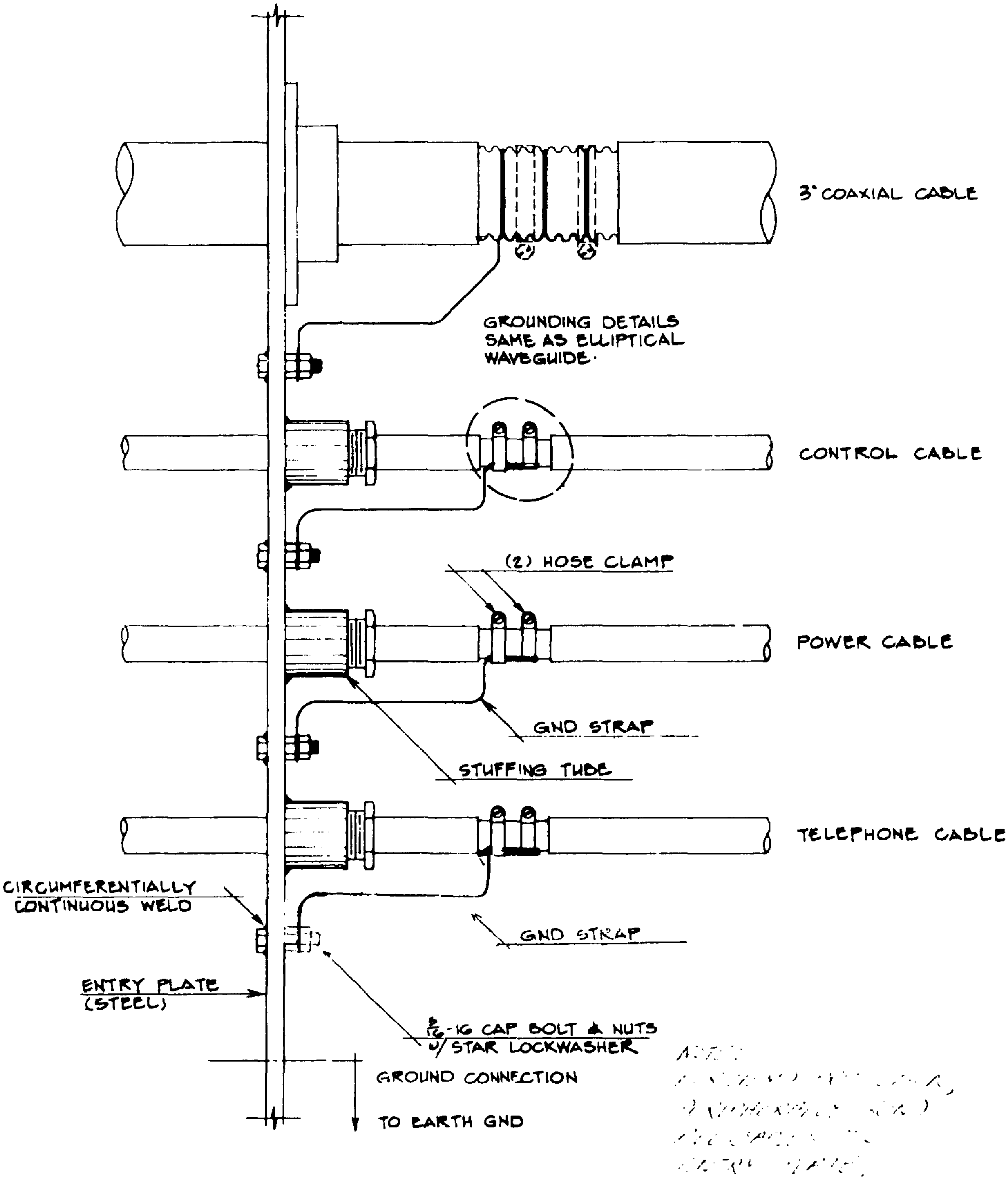


Figure 1-31. Typical Communication Cable Entry Installation

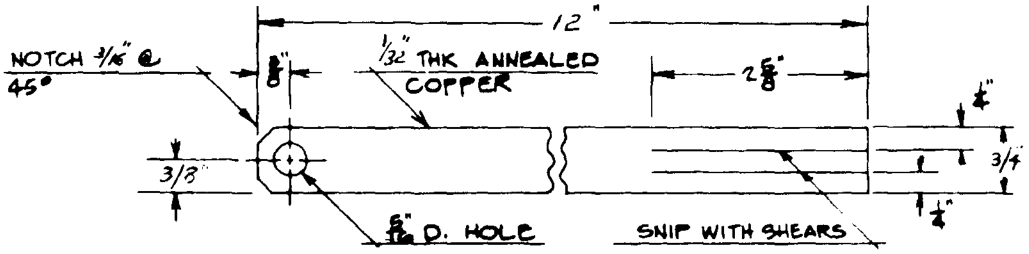


Figure 1-32. Ground Strap Detail

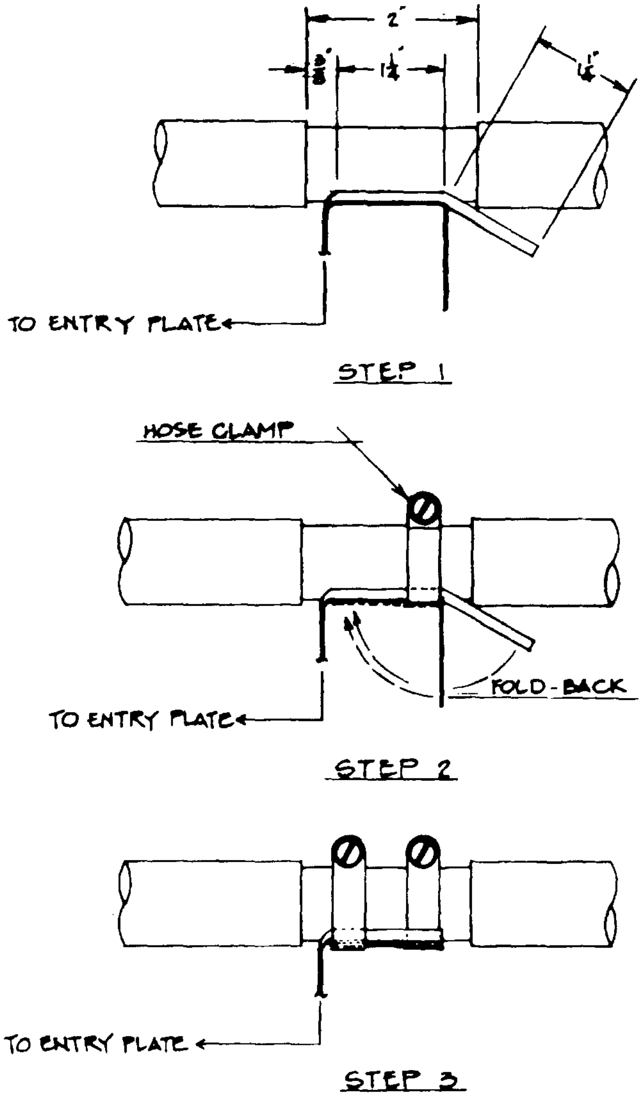


Figure 1-33. Grounding Steps for Cables

1.3.3.4 Cable Installation and Grounding. Cables which enter a facility shall be installed generally using Figure 1-31 as a guideline. The final design shall rest with the designer; however, the following steps apply in general. (Figures 1-32 and 1-33)

a. Remove outer cable jacket very carefully so as not to damage the cable shield (see Figure 1-33, step 1).

b. Preform ground strap to fit cable diameter and secure the first hose clamp as outlined in the next step (see Figure 1-33, step 2)

c. Fold back ground strap (about 3.2 cm (1-1/41") long) over hose clamp and cable for a snug fit. Secure second hose clamp around the folded strips of the ground strap described in the next step (see Figure 1-33, step 3).

d. For small diameter cable use a No. 6 AWG 7-strand copper wire with a lug connector on the other end. Secure the stranded cable using the same method as for the strap.

e. After attaching all ground straps, tape (weatherproof) the exposed area.

1.3.3.5 Lightning-Generated Transient Surge Protection. Electrical and electronic equipment at various facilities has been severely damaged by lightning-generated transients. The transients occur on externally exposed lines that directly interface equipment. Externally exposed lines are outside lines, buried, overhead, etc, that are exposed to weather elements. The lines include incoming ac service conductors, and equipment signal, status, control, grounding conductors and intrafacility ac and dc powerlines. This section identifies transient source and damage, waveforms and amplitudes of projected transients on different types of lines, frequency of transient occurrence, and effective methods to implement to preclude equipment damage and operational upset when transients occur.

1.3.3.5.1 Transient Source and Equipment Damage.

a. Electrical and electronic equipment comprising an operating system is susceptible to damage from lightning-generated transient surges via two primary sources as follows:

(1) Transient surges coupled to equipment from incoming commercial ac power conductors.

(2) Transient surges coupled to equipment by connected facility control, status, power, ground, data and signal lines that originate or terminate at equipment located externally to the building or structure housing the equipment of interest.

b. Damage resulting from lightning-generated transients occurs in many forms. Entire equipment chassis have been exploded and burned, and wall-mounted equipments have been blown off the wall by large-magnitude transient energy. However, two forms of damage are most prevalent and are listed below:

(1) Sudden catastrophic component failure at the time of transient occurrence.

(2) Shortened operating lifetime of components resulting from over-stress at time of transient occurrence.

1.3.3.5.2 Minimizing Damage.

a. Damage can be minimized, and in most instances eliminated, by properly using the generally field-proven protection methods detailed in this section. In order to be cost effective and to provide effective protection, allocation of protection must be divided into three general categories which are:

(1) Transient suppression (metal conduit and guard wires) for outside lines that interface equipment to be protected.

(2) Installation of transient suppression devices on both ends of exterior lines immediately after equipment building penetration or at exterior equipment termination, and on incoming ac service entrance lines at the facility main service disconnect means. On shielded facilities, transient suppression devices (TSD's) should be installed in an entry vault or inside the main service disconnect box.

(3) Including transient suppression as an integral part of protected equipment at the exterior line-equipment interfaces.

b. If realistic transient protection is to be designed, frequency of transient occurrence, amplitudes and waveforms of transients, and the withstand level of protected equipment must be defined. The withstand level is the short-duration voltage and current surge levels that equipment can withstand without overstressing or immediate destruction of components occurring, and without equipment operational upset occurring. The information required for effective protection is provided in this section. The most susceptible components are identified together with typical withstand levels. Frequency of transient occurrence is also provided. Because of the large physical size of incoming ac service conductors, less impedance (resistance and inductance) is presented to transient surge current flow. As a result, amplitude and waveforms of transients appearing at ac inputs are quite different from those appearing at control, status, data, signal, and in-system powerline inputs. Therefore, protection for incoming ac power service conductors is discussed separately from that for other externally exposed lines.

1.3.3.5.3 Susceptible Components. Integrated circuits, discrete transistors and diodes, capacitors, and miniature relays, transformers, and switches used in the design of solid-state equipment are very susceptible to damage from lightning-generated transient surges. Other components are not immune to damage but are susceptible to a much lesser degree. Standards do not exist for specifying the withstand level against lightning-transients for most equipment and components. Therefore, accurate information must be obtained from manufacturers, laboratory testing performed or conservative engineering estimates made. Typical withstand level limits for some common types of equipment and components are:

a. Integrated circuits: 1.5 times normal rated junction and Vcc voltage.

b. Discrete transistors: 2 times normal rated junction voltage.

c. Diodes: 1.5 times peak inverse voltage.

d. Miniature relays, transformers, and switches: 3 times rated voltage.

e. Capacitors: 1.5 times dc working voltage unless transient dielectric punch-through voltage known.

f. DC power supplies with step-down transformer and diode bridge: 1.5 times diode peak inverse voltage (PIV) rating times the transformer secondary to primary voltage ratio.

g. Small motors, small transformers and light machinery: 10 times normal operating voltage.

h. Large motors, large transformers and heavy machinery: 20 times normal operating voltage.

1.3.3.5.4 Frequency of Transient Occurrence. Precise calculation of the number of lightning-generated transients that will occur at a specific location n a specified time interval is not possible. However, enough observations have been made to permit statistical evaluation of the number of lightning flashes that are likely to occur in an area with a known average number of thunderstorm days per year. Some flashes may not produce any transients while others will produce several transients. The available data, after considerable averaging and rounding, is provided in Table 1-5. The table lists a typical number of transients that might be expected to occur from lightning strikes at facilities located in high-and low-incident lightning areas. When used in conjunction with Figure 1-34, the table will permit calculation of the number of lightning surges that will occur anywhere in the United States in a 10-year period. Decrease 1750 by 10% for each 10 decrease in the number of thunderstorm days per year.

Table 1-5. Frequency of Transient Occurrences

Number of Lightning Surges In 10 Years at One Facility	
High Incident Area (100 Thunderstorm Days Per Year)	Low Incident Area (10 Thunderstorm Days Per Year)
1750	175

1.3.3.5.5 Transient Definition, AC Service Conductors. Prediction of the exact amplitude, waveforms, and number of transients that will occur at a particular facility over a specific time interval is not possible. However, current amplitudes generated by many direct lightning strikes have been measured, and the waveforms for the current have been measured and recorded. Also, sufficient data has been recorded to permit statistical calculation of waveforms and amplitudes that are likely to occur. This data is provided in subsequent paragraphs. Frequency of occurrence is provided in paragraph 1.3.3.5.4.

a. Transient amplitudes from direct strikes. Measured current amplitudes resulting from direct lightning strikes have varied from 1,000 amperes to 250,000 amperes. Results of several thousand measurements have been reduced and are provided in Table 1-6. As shown in Table 1-6, typical peak current is 10 to 20 kiloamperes. Table 1-7 tabulates the peak current amplitudes measured for 2721 flashes. The median peak value for the peak currents was approximately 15 kiloamperes. This is in agreement with the typical values provided in Table 1-6, and there is agreement among authoritative sources that the peak current for a large percentage of strikes is in the 10 to 30 kiloampere range. Note that in Table 1-7, 1818 of the 2721 current amplitudes or 66.8% were in the range of 1 to 20 kiloamperes. Also note that only 14% were greater than 40,000 amperes, and it follows directly that 86% of the peak amplitudes were 40 kiloamperes or less. Only 45 of the 2721 measured amplitudes, or 1.65%, were above the 100-kiloampere level. Also, it is emphasized that the peak current amplitudes noted in the foregoing resulted from direct strikes to metal towers for primary transmission lines.

b. Induced transient amplitude. After installation of appropriate transient suppression, induced transients will still occur as a result of close proximity, high-intensity strikes, and some transient energy will be coupled through the service transformer onto the incoming ac service lines. The amplitude of those coupled and induced transients will be reduced a minimum of 50% of direct strike amplitudes due to earth resistance, attenuation of electromagnetic fields due to propagation through air, and coupling losses imposed by the service transformer winding. Therefore, 86% of the transient current surges appearing at a facility main service disconnect means will be 20 kiloamperes or less, and the greatest percentage, 68%, of the surges will be in the 500 ampere to 10,000 ampere range. Only 1% of the surges will be above 50 kiloamperes, and only 0.25% will be above 75 kiloamperes. Table 1-8 provides a tabulation of transient amplitudes and the percentage of transients on incoming ac lines that will as a maximum be of the amplitude listed.

c. Transient waveforms, ac lines. Waveshapes for transients will vary depending on the proximity of the strike, intensity of the strike, and length and inductance of the incoming ac service lines. Table 1-6 lists the typical time to peak current as 1.5 to 2 microseconds and 40 to 50 microseconds as the typical time from the start of the pulse until the current decays to 50% of peak value. Thus, a typical waveform for current surges generated by a direct strike is 2-by-40 microseconds. Transients measured at main service disconnects (amplitudes in excess of 3,000 volts) have had rise times of 1 to 2 microseconds and decay times of 20 to 40 microseconds. However, the inductance of some incoming ac service lines will slow down the rise time slightly. Most manufacturers of secondary ac surge arresters use either 8-by-20 or 10-by-20 microsecond current waveforms for testing and specification purposes, primarily because the waveform is relatively easy to generate while a 2-by-40 microsecond waveform is quite difficult to generate. The 8-by-20 or 10-by-20 microsecond waveforms are considered suitable for testing. However, the user of the arrester should be aware of the following:

(1) Transients with rise times faster than 8 microseconds may appear across the arrester terminals resulting in a higher sparkover or turn-on voltage for the arrester than specified.

(2) Transients with decay times up to 40 microseconds may appear across the arrester terminals which will require the arrester to dissipate considerably more transient energy than would be required for a 20 microsecond decay time.

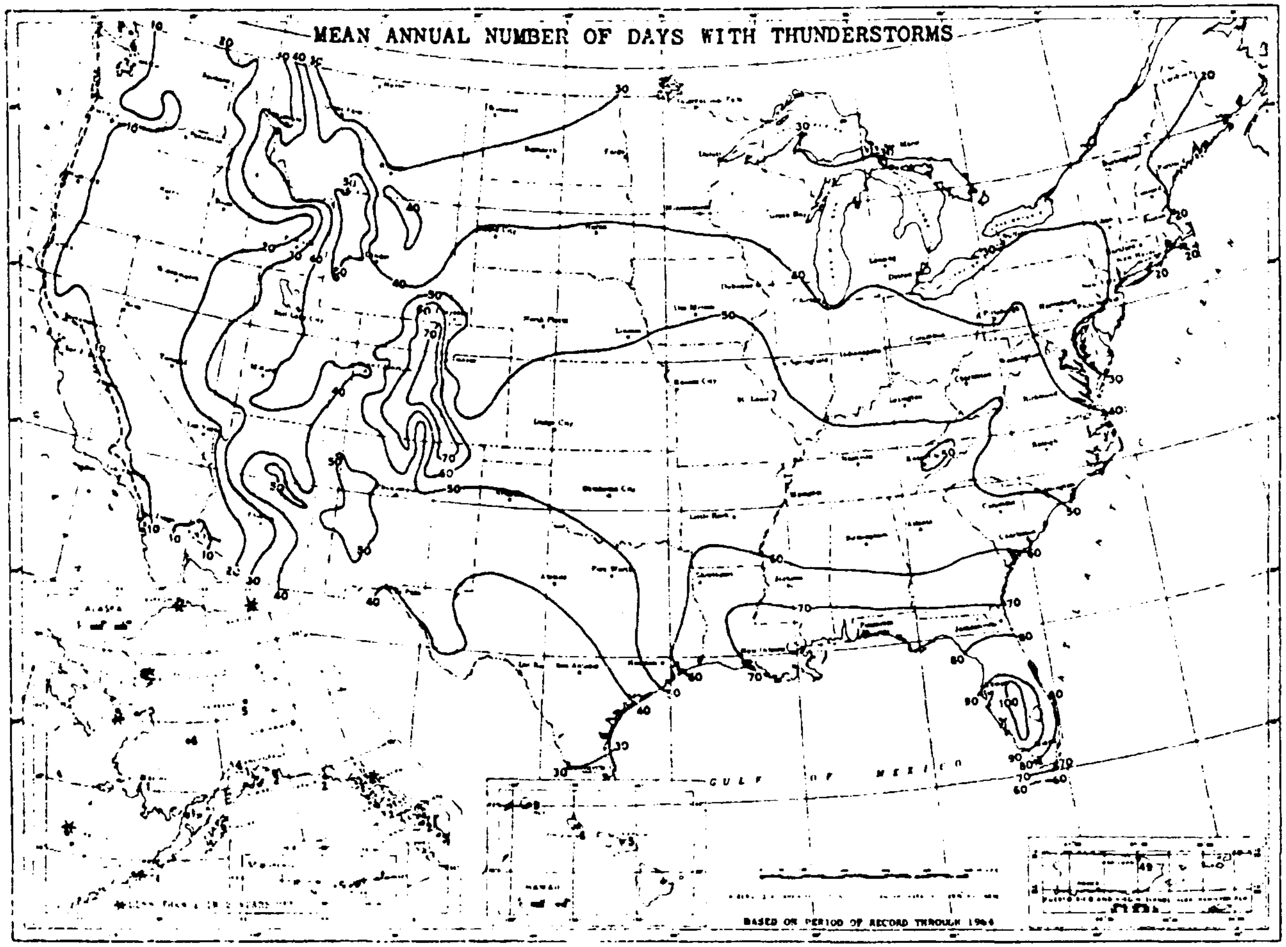


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Figure 1-34. Mean Number of Thunderstorm Days per Year for the United States

Table 1-6

Parameter for Direct Lightning Strike Current

Parameter	Minimum	Typical	Maximum
Number of return strokes per flash	1	2 to 4	26
Time between strokes (ms)	3	40 to 60	100
Peak current per return stroke (kA)	1	10 to 20	250
Time to peak current (ps)	< 0.5	1.5 to 2	30
Rate of rise (kA/μs)	< 1	20	210
Time to half-value (μs)	10	40 to 50	250
Duration of continuing current (ins)	50	150	500
Peak continuing current (amperes)	30	150	1600

Table 1-7. Peak Currents from Direct Lightning Strikes

Range of current, (amperes)	No. of Flashes with Peak Current in Range	No. at or above Level	Percentage at or above Level
1,000 - 5,000	567	2,721	100
5,001 - 10,000	611	2,154	79.2
10,001 - 20,000	640	1,543	56.7
20,001 - 30,000	296	903	33.2
30,001 - 40,000	227	607	22.3
40,001 - 50,000	140	380	14.0
50,001 - 60,000	80	240	8.82
60,001 - 70,000	61	160	5.88
70,001 - 80,000	22	99	3.64
80,001 - 90,000	21	77	2.83
90,001 - 100,000	11	56	2.06
100,001 - 110,000	11	45	1.65
110,001 - 120,000	9	34	1.25
120,001 - 130,000	9	25	0.918
130,001 - 140,000	7	16	0.588
140,001 - 150,000	2	9	0.331
150,001 - 160,000	3	7	0.257
160,001 - 170,000	0	4	0.137
170,001 - 180,000	1	4	0.147
180,001 - 190,000	0	3	0.110
190,001 - 200,000	1	3	0.110
200,001 - 210,000	0	2	0.073
212,000	1	2	0.073
218,000	1	1	0.037
	2,721		

Table 1-8. Transient Surge Amplitudes

Transient Surge Amplitude (Amperes)	Percentage of Transients at Listed Amplitude
500 to 2,500	21%
2,501 to 5,000	23%
5,001 to 10,000	24%
10,001 to 20,000	19%
20,001 to 30,000	8%
30,001 to 40,000	3%
40,001 to 50,000	1%
50,001 to 75,000	0.9%
75,001 to 100,000	0.1%

1.3.3.5.6 Methods for Transient Protection on AC Service Conductors. Proper use of the following provides effective protection against lightning generated transients on incoming ac powerlines.

a. Completely enclosing buried lines in ferrous metal, electrically continuous, watertight conduit.

b. Use of overhead guard wires to protect overhead lines.

c. Installation of a secondary ac surge arrester at the facility main service disconnect means.

d. Including surge suppressors as in integral part of equipment at ac power inputs and rectifier outputs of low-level (5 to 48 volt) power supplies, when a power supply operates from commercial ac power and supplies operating power for solid-state equipment.

e. Installation of suitable surge arresters on the primary and secondary of the service transformer.

f. Installation of powerline filters shall be in accordance with NACSIM 5203.

1.3.3.5.7 Use of Ferrous Metal Conduit. Since transients are induced on buried lines by electromagnetic waves created by lightning current flow, all buried incoming ac service lines should be completely enclosed in ferrous metal, watertight conduit. To be effective, the conduit must be electrically continuous and effectively bonded to the building entry plate and grounded to earth ground at each end. No. 2 AWG bare copper stranded cable is suitable for the earth ground connection, and exotherrnic welds provide effective bonding in earth. Approved pressure connectors are suitable for use above ground. The conduit should extend from the service transformer secondary to the facility main service disconnect means. This use of metal conduit will eliminate low-level induced transients, and will attenuate otherwise high-amplitude induced transients by 90% minimum. Although the conduit provides effective protection against induced transients, it does not provide protection against transients that enter the service conductors directly from the secondary of the service transformer.

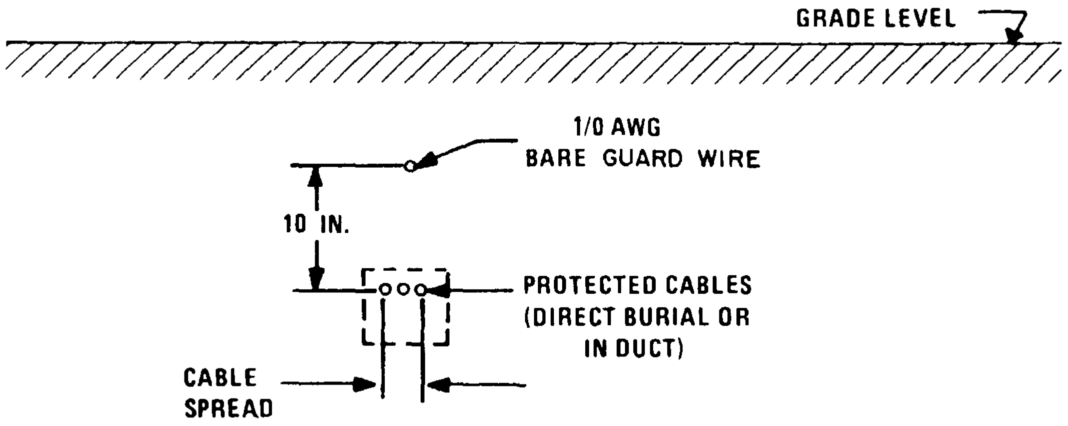
1.3.3.5.8 Use of Overhead Guard Wires. Since enclosing overhead incoming ac service lines in metal conduit is not feasible, experimentation has proved that the use of an overhead guard wire provides an effective level of protection for overhead service conductors against direct lightning strikes. This guard wire also provides a low level of protection against transients induced on lines by close proximity strikes as well as nearby cloud to cloud discharges. The guard wire must be located above and parallel to the service conductors. To be effective, the height of the guard wire must be that required to form a 1:1 cone of protection for the service conductors (see Volume I, Section 3.5.2), and the guard wire must extend from the secondary of the service transformer for the facility to the facility service entrance fitting. Also, at each end the guard wire must extend to, and be bonded to, an effective earth ground or to the earth electrode subsystem of the facility. When the distance between terminating facilities exceeds 250 feet, the guard wire shall also be bonded to a ground rod meeting the requirements of MIL-STD-188-124A, paragraph 5.1.1.1.4. Also refer to MIL-STD-188-124A, paragraph 5.1.1.3.10.2 regarding the type and size requirements of the guard wire. Since the guard wire and the earth electrode subsystem are comprised of different metals, exothermic welding is recommended.

1.3.3.5.9 Protection of Underground Cables.

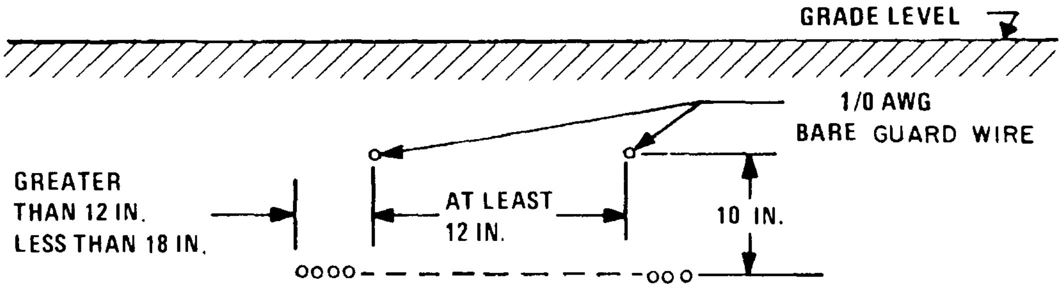
a. Protect against direct lightning strikes to buried cable by installing a guard wire above the cables or cable duct. A 1/0 AWG bare copper cable laid directly over the protected cables as shown in Figure 1-35(a) is recommended. At least 25.4 cm (10 inches) should be maintained between the protected cables and the guard wire.

b. For a relatively narrow spread of the cables, 0.9 meters (3 feet) or less, or for a duct less than 0.9 meters (3 feet) wide, only one guard wire cable is necessary. For wider cable spreads or wider ducts, at least two 1/0 AWG cables should be provided as illustrated in Figure 1-35(b). (Since the guard wire and protected cables are embedded in the earth, the applicable cone of protection is not known.)

1.3.3.5.10 Buried Guard Wire. Experimental use of a buried guard wire embedded in soil above and parallel to buried cable runs not enclosed in metal conduit has provided effective attenuation of lightning-induced transients. Use of the guard wire is recommended for protection of buried equipment lines not enclosed in metal conduit. Bare 1/0 AWG copper wire has provided the most effective protection during experimental use. To be effective, the guard wire must be embedded in the soil a minimum of 25 cm (10 inches) above and parallel to the protected cable run or duct. When the width of the cable run or duct does not exceed 0.9 meters (3 feet), one guard wire, centered over the cable run or duct, provides adequate protection. When the cable run or duct is more than 0.9 meters (3 feet) wide, two guard wires should be installed. The guard wires should be spaced at least 30 cm (12 inches) apart and be not less than 30 cm (12 inches) nor more than 45 cm (18 inches) inside the outermost wires or the edges of the duct. To be effective, the guard wires must be bonded to the earth electrode subsystem at each terminating facility. Exothermic welds provide the most effective bonding. The requirement and need for underground guard wires shall be determined by the project and civil engineer and shall be determined on a case and location basis dependent upon the priority of the circuit and the degree of lightning anticipated.



(a) CABLE SPREAD LESS THAN 3 FEET



(b) CABLE SPREAD 3 FEET OR GREATER

Figure 1-35. Lightning Protection for Underground Cables

1.3.3.5.11 Secondary AC Surge Arrester. Installation of a properly selected secondary ac surge arrester at the facility main service disconnect means provides the best method for ensuring that high energy transients are not coupled to equipment by ac distribution lines within the facility. The surge arrester installed must have certain characteristics to ensure adequate protection.

a. Characteristics.

(1) Be capable of safely dissipating transients of amplitudes and waveforms expected at the facility for a predetermined period of time. Selection of an arrester that will provide protection for a period of ten years is recommended.

(2) Have a turn-on time fast enough to ensure that transient energy will not cause damage before the surge arrester turns on and clamps.

(3) Maintain a low enough discharge (clamp) voltage while dissipating transient current to prevent damage to protected equipment.

(4) Have a reverse standoff voltage high enough to ensure nonconduction during normal operation.

(5) Be capable of complete extinguishing after firing on an energized line.

b. Additional requirements. In addition to the above, the surge arrester must be properly installed to ensure optimum operation. The input to each phase arrester contained in the surge arrester should be fused to provide protection against overload of, or damage to, the ac supply in the event an arrester should short. Also, Indicator lights and an audible alarm that go off when a fuse opens should be provided on the front of the surge arrester enclosure as a maintenance aid.

1.3.3.5.12 Surge Arrester Installation. Proper installation of the surge arrester is of vital importance for optimum operation. A surge arrester with excellent operating characteristics cannot function properly if correct installation procedures are not used. The most important installation criteria are provided below and applies to surge arrester phase input connections and the ground connection. All surge arresters should be installed in accordance with the manufacturer's recommendations.

a. Installation criteria.

(1) If possible, install arresters inside the first service disconnect box to keep interconnecting lead lengths as short as feasible.

(2) Use interconnecting wire of sufficient size to limit resistance and inductance in the transient path to ground through the surge arrester.

(3) Interconnecting wiring should be routed as straight and direct as possible with no sharp bends, and the least number of bends possible.

(4) Do not include loops in the wiring.

(5) Must be grounded by the shortest low impedance path available.

b. Surge arrester input connections. Installation of surge arresters is shown for grounded and ungrounded service in Figures 1-36 and 1-37 respectively. For best possible protection, the line supply side of the main service disconnect means should be connected to the phase input(s) of the surge arrester. However, when necessary to facilitate removal of ac power for surge arrester maintenance, it is permissible to connect the surge arrester to the load side of the main service disconnect means. In order to prevent introducing excessive inductance and resistance in the transient path to the surge arrester, No. 4 AWG (minimum) insulated stranded copper wire of the minimum feasible length must be used to make the interconnection(s) unless otherwise recommended and guaranteed by the manufacturer. Also, the interconnecting wiring must not contain loops or sharp bends. Otherwise, the response time of the surge arrester will be delayed and a higher clamp voltage than that of the surge arrester will be impressed across the protected equipment, thus increasing the possibility of damage. In the event a very fast transient should occur, it is quite likely that the surge arrester would never turn on, and all of the transient energy would be dissipated by supposedly protected equipment.

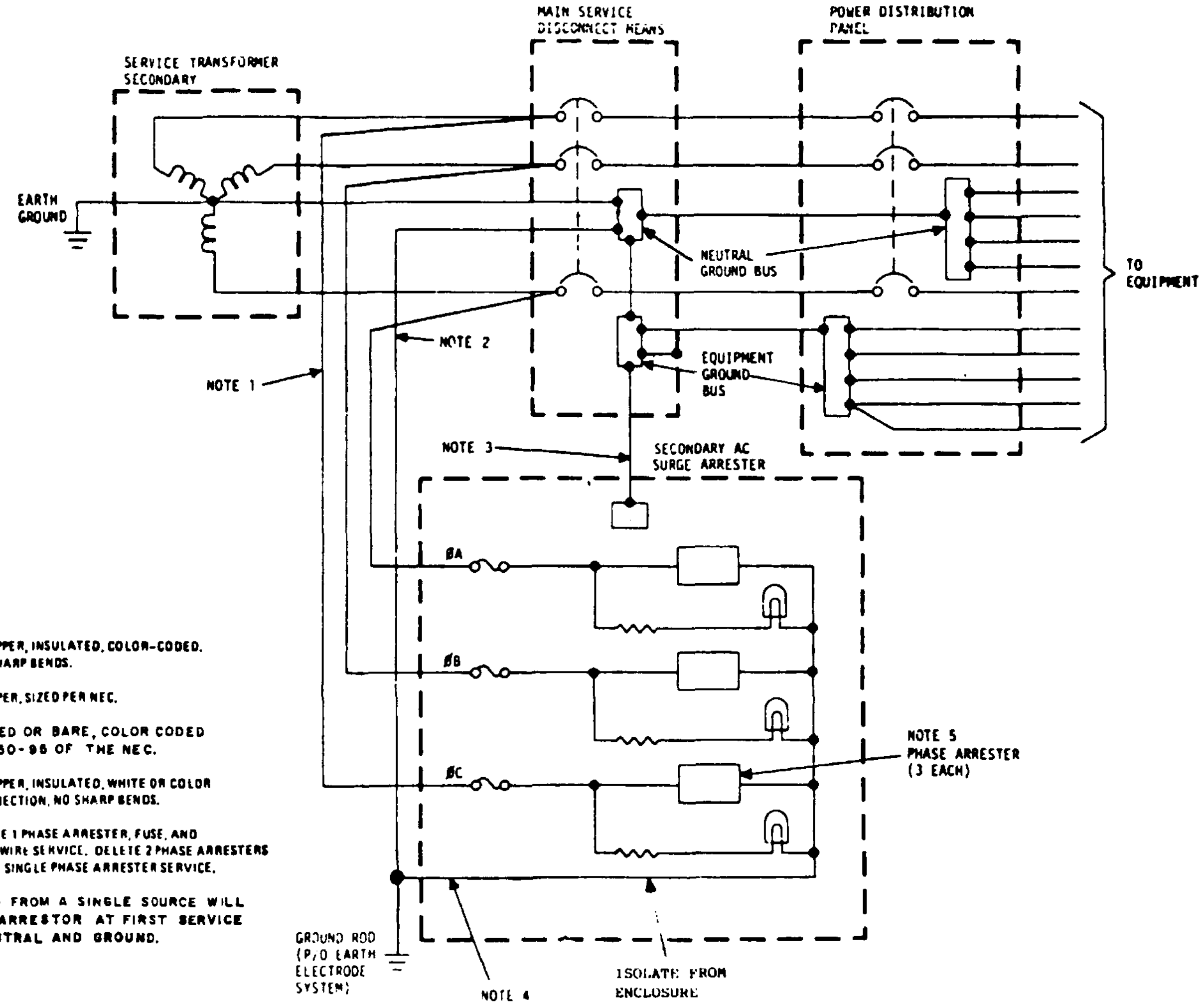
c. Surge arrester ground connection. When the surge arrester is not properly grounded, its response time will be delayed and a higher clamp voltage than that of the surge arrester will be impressed across the equipment being protected. This can also be expected if the earth ground connection for the surge arrester contains loops or sharp bends or is not properly bonded to the earth electrode subsystem. To overcome this problem, stranded copper wire specified in accordance with Article 280 of the NEC must be used to make the ground connection unless other specifications are provided by the [manufacturer of the surge arresters. Figure 1-36 shows the surge arresters installed to ensure the [nest direct route to ground thereby minimizing the lead inductance(s) and ensure the firing of the surge arresters. For best results exothermic welds should be used for bonding to the earth electrode subsystem. UL -approved pressure connectors are suitable for above-ground bonds.

1.3.3.5.13 Operating Characteristics of Surge Arresters. Operating characteristics of different types of surge arresters are discussed in the following subparagraphs. Guidelines for selection of an adequate surge arrester are also provided.

a. Transient dissipation capability. Selection of a surge arrester that will provide adequate protection against worst case transients is recoin mended. Waveforms are defined in Section 1.3.3.5.5. The worst case waveform is 2-by-40 microseconds. The number and amplitude of transients that can be expected to occur can be determined by referring to Tables 1-5 and 1-8.

(1) In a high-lightning incident area (average of 100 thunderstorm days per year), 1750 transients are expected to occur in a 10-year period. Referring to Table 1-8, it can be determined that transient amplitudes and occurrence may be as listed in Table 1-9.

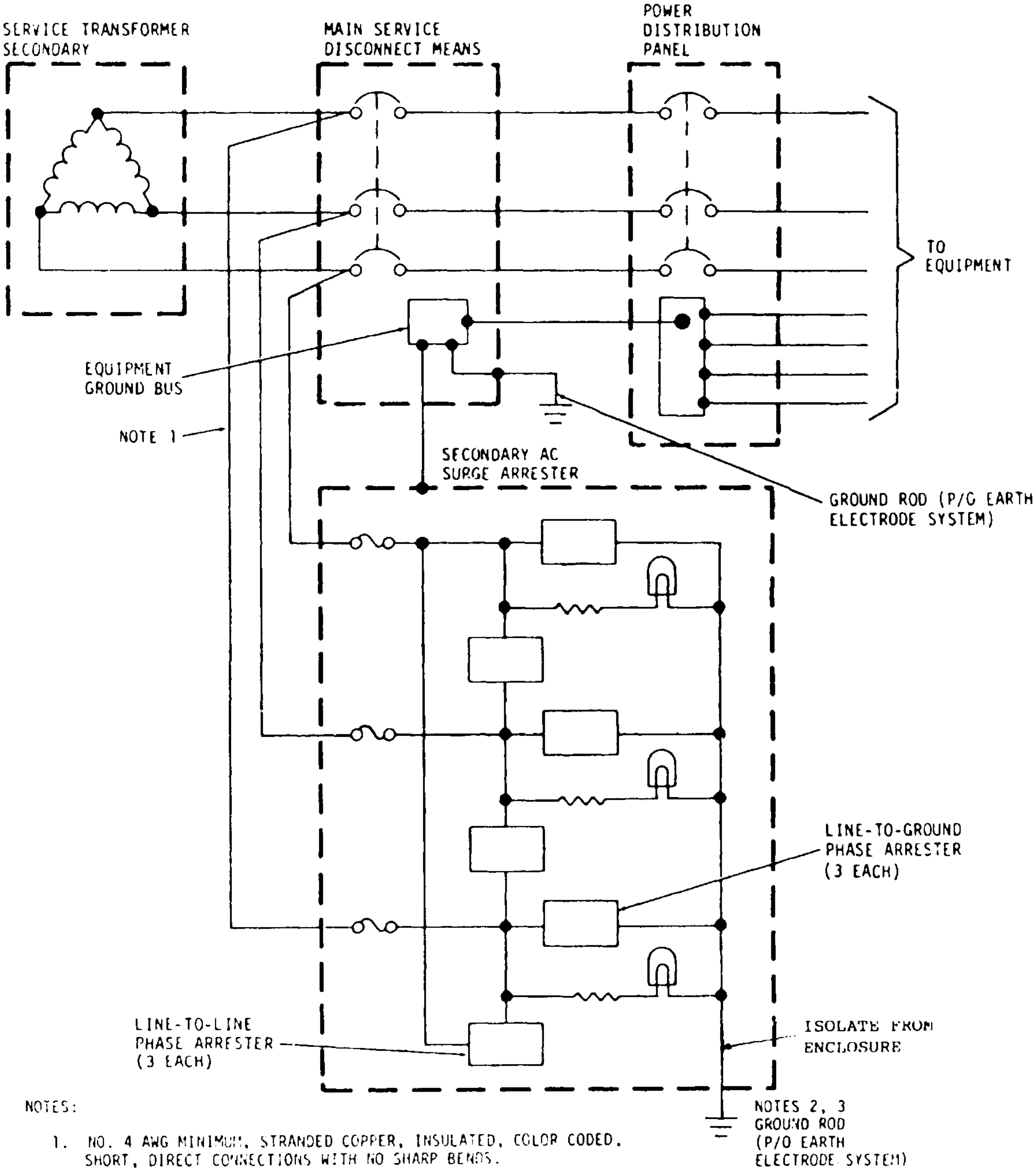
(2) In a low-lightning incident area (average of 10 thunderstorm days per year), only 175 transients are expected to occur in a 10-year period. Transient occurrence and amplitudes may be as listed in Table 1-10.



NOTES

1. NO. 4 AWG MINIMUM, STRANDED COPPER, INSULATED, COLOR-CODED. SHORT DIRECT CONNECTIONS, NO SHARP BENDS.
2. INSULATED, WHITE, STRANDED COPPER, SIZED PER NEC.
3. STRANDED COPPER, INSULATED OR BARE, COLOR CODED GREEN, SIZE IAW TABLE 250-95 OF THE NEC.
4. NO. 4 AWG MINIMUM, STRANDED COPPER, INSULATED, WHITE OR COLOR CODED WHITE. SHORT DIRECT CONNECTION, NO SHARP BENDS.
5. 3-PHASE ARRESTER SHOWN. DELETE 1 PHASE ARRESTER, FUSE, AND INDICATOR LIGHT FOR 1 PHASE, 3 WIRE SERVICE. DELETE 2 PHASE ARRESTERS FUSES, AND INDICATOR LIGHTS FOR SINGLE PHASE ARRESTER SERVICE.
6. MULTI-BUILDINGS SERVICED FROM A SINGLE SOURCE WILL REQUIRE AN ADDITIONAL ARRESTOR AT FIRST SERVICE DISCONNECT BETWEEN NEUTRAL AND GROUND.

Figure 1-36. Secondary AC Surge Arrester Installation, Grounded Service (Single Building from Single Source)



NOTES:

1. NO. 4 AWG MINIMUM, STRANDED COPPER, INSULATED, COLOR CODED. SHORT, DIRECT CONNECTIONS WITH NO SHARP BENDS.
2. NO. 2 AWG MINIMUM, STRANDED COPPER, INSULATED. SHORT, DIRECT CONNECTION WITH NO SHARP BENDS.
3. CAN BE CONNECTED TO GROUND BUS IN MAIN SERVICE DISCONNECT MEANS.

Figure 1-37. Secondary AC Surge Arrester Installation, Ungrounded Service

Table 1-9. Transient Occurrences, High-Incident Lightning Areas

Transient Amplitude (Amperes)	No. of Transients in 10-year Period
500 to 2,500	368
2,501 to 5,000	402
5,001 to 10,000	420
10,001 to 20,000	333
20,001 to 30,000	140
30,001 to 40,000	52
40,001 to 50,000	17
50,001 to 75,000	16
75,001 to 100,000	2

Table 1-10. Transient Occurrences, Low-Incident Lightning Areas

Transient Amplitude (Amperes)	No. of Transients in 10-year Period
500 to 2,500	37
2,501 to 5,000	40
5,001 to 10,000	42
10,001 to 20,000	33
20,001 to 30,000	14
30,001 to 40,000	5
40,001 to 50,000	1.75
50,001 to 75,000	1.5
75,001 to 100,000	0.175

(3) Transient amplitudes are less at small electronic facilities. Recorded data substantiates that large electronic facilities tend to attract higher intensity strikes than small electronic facilities. The transient amplitudes listed in Sections 1.3.3.5.13a(l) and a(2) are for large electronic facilities, and the amplitudes should be decreased by 50% for small electronic facilities. Large electronic facilities are defined as requiring more than 100 amperes per phase for norm al operation. The transient amplitudes of Tables 1-9 and 1-10 should be decreased by 50% when relating to a small facility.

b. Turn-on time. Turn-on time (response time) is the time required for an arrester to turn on and clamp a transient after turn-on voltage is impressed across device terminals. All basic suppressor devices used in manufacture of surge arresters are voltage dependent for ionization, breakdown, and other phenomena associated with breakdown. Therefore, a low turn-on voltage enhances a faster turn-on time. Turn-on time requirements for a surge arrester must be directly related to the withstand level for equipment and components being protected. For instance, if only heavy duty electrical equipment, such as motors, contractors, and switches are being protected, relatively slow turn-on of 1 to 5 microseconds can be tolerated. However, if solid-state electronic equipment, or a combination of electrical and electronic solid-state equipment is being protected, turn-on time becomes much more critical. In general, the most rapid response time available is desirable. However, cost and current dissipation capability normally place constraints on such selection criteria. Four types of arresters are currently manufactured as noted below. Additional data for each type is provided in 1.3.3.5.15.

(1) Gas-filled spark gap with series-connected nonlinear resistance.

(2) Zinc oxide nonlinear resistor (ZNR) or metal oxide varistor (MOV).

(3) Solid-state.

(4) Hybrid of above components (development stage).

c. Important turn-on time characteristics. Generalized characteristics for the three basic types of surge arresters are listed in Table 1-11. Turn-on time of 50 nanoseconds is sufficiently fast to protect all except very critical components that would directly receive transient energy prior to turn-on and clamp of the surge arrester. Solid-state units may be used for protection of very critical equipment components, and the gas-filled spark gap type will provide adequate protection for heavy duty electrical equipment such as motors, contractors and switches. However, arresters with slow turn-on time and high turn-on voltage should not be used to protect electronic equipment that has low-voltage, fast turn-on transient suppression devices or circuits included as an integral part of the equipment. Otherwise, the transient suppression in the equipment will turn on and attempt to dissipate transient energy before the surge arrester installed at the main service disconnect means turns on. In most cases, this will rapidly destroy equipment-level transient suppression. The impedance and inductance of power distribution panels and power distribution wiring within the facility will tend to slow down transient rise time and also dissipate some transient energy both before and after the surge arrester turns on. The resistance and inductance works in conjunction with the surge arrester at the main service disconnect means to provide additional protection. However, the true degree of protection thus provided varies widely due to varying transient waveforms, and size and length of distribution wiring within the facility. In summary, the most important characteristics for turn-on time are:

(1) Turn-on time must be rapid enough to preclude damage to equipment resulting from over-voltage before the surge arrester turns on and clamps the incoming transient.

Table 1-11. Generalized Characteristics for Surge Arresters by Type

Type	Turn-on Time	Current Capacity	Firing/Clamp Voltage	cost
Gas-filled spark gap	5-250 nanoseconds for 10 kV/µs rise time	Extreme duty to 150,000 amperes lifetime: 2500 surges at 10,000 amperes	High -350 to 5500 volts (firing)	Moderate -$25 to $750
MOV or ZNR	50 nanoseconds or less, any rise time	Varies - can be equivalent to spark-gap type	Moderate -300 to 3000 volts (clamp)	Moderate -$50 to $1,000
Solid State	10 nanoseconds or less, any rise time	Varies - Generally 50 to 100 amperes except for costly units	Low -275 to 750 volts (clamp)	High -$100 to $25,000

(2) Turn-on voltage and time for the surge arrester must be compatible with the same characteristics of transient suppressors/circuits included as an integral part of protected equipment. Otherwise equipment-level transient suppressors/circuits will attempt to dissipate the transient before the surge arrester turns on. When this occurs, the equipment level transient suppression will likely be destroyed resulting in damage or operational upset of protected equipment.

d. Discharge (clamp) voltage. The clamp voltage, sometimes referred to as the discharge voltage, for a surge arrester is the voltage that appears across the arrester input terminals and the ground terminal while conducting a transient surge current to ground. The clamp voltage waveform occurring across the surge arrester installed at the main service disconnect means appears across the protected equipment after losses imposed by inductance and resistance of power distribution lines and panels.

(1) In general, a surge arrester with the lowest clamp voltage possible is desirable. An all-solid-state arrester provides the lowest clamping voltage available (Table 1-11). However, as with turn-on time, other factors such as current dissipation capability and cost normally place constraints on simply installing a surge arrester at the main service disconnect means with the lowest clamping voltage available.

(2) In new facilities calling out the latest design equipment, transient surge suppression generally is included as an integral part of the equipment ac input. Higher clamping voltages can therefore be tolerated at the main service disconnect means. When good engineering design practices are used, equipment level suppressors will have a slightly lower turn-on voltage threshold and a slightly faster turn-on time than the surge arrester at the main service disconnect means. This permits the equipment-level suppressors to maintain a lower clamping level to provide maximum equipment protection. Therefore, when a transient occurs, the equipment level suppressor(s) will turn on first.

(3) This circuit operation may generate the requirement for a properly sized (2-microhenry minimum) inductor to be installed in series with applicable ac conductors. If its need has been ascertained, it must be installed between the surge arrester and the integral equipment-level transient suppressor. It may also be designed as an integral part of the surge arrester or the equipment-level transient suppressor.

(4) The equipment-level suppressor will immediately start toward its clamp voltage as transient current is conducted. Because of resistance and inductance in the power distribution lines and panels, the surge arrester will turn on very soon (nanoseconds) after the equipment-level suppressor(s), and will dissipate most of the remaining transient energy. After the surge arrester turns on, the equipment level suppressor(s) are required to dissipate only the transient energy resulting from the clamp voltage of the surge arrester.

(5) Thus, the surge arrester dissipates most of the transient surge, and the equipment-level suppressor(s) provide equipment protection against fast rise time transients and reduce the surge arrester clamp voltage to levels that can be safely tolerated by protected equipment. In summary, the clamp voltage for the surge arrester must be low enough while dissipating a high-energy transient to provide adequate equipment protection taking into consideration:

(a) Protection provided by transient suppression that is an integral part of the facility equipment.

(b) Impedance (resistance and inductance) of power distribution lines and panels within the facility.

e. Reverse standoff voltage. Reverse standoff voltage is specified in various ways by surge arrester manufacturers such as maximum allowable voltage, voltage rating, and reverse standoff voltage. For usage herein, reverse standoff voltage is defined as the maximum voltage that can be applied across the surge arrester and still permit the surge arrester to remain in an off state (current leakage through arrester to ground 100 microampere or less). Good engineering practice dictates that the surge arrester remains off during normal operation.

(1) Design of effective lightning transient protection requires that the surge arrester turn on very rapidly at the lowest voltage possible when a transient occurs. In addition, it is desirable that a low clamp voltage be maintained across the surge arrester while conducting surge current to ground. Turn-on voltage and associated turn-on time as well as clamp voltage are proportional to reverse standoff voltage. That is, an arrester with a low reverse standoff voltage has a lower turn-on voltage (and thus a faster turn-on time) and a lower clamp voltage than an arrester with a higher reverse standoff voltage. Therefore, it is important that the surge arrester has the lowest possible reverse standoff voltage.

(2) For effective protection, the reverse standoff voltage should be between 200 to 300 percent of nominal line-to-ground voltage of the appropriate ac service lines for a spark gap type surge arrester that is to be installed line to ground. The reverse standoff voltage should also be between 200 to 300 percent of nominal line-to-line voltage of appropriate ac service lines for a spark gap type surge arrester that is to be installed line to line. The reverse standoff voltage for MOV and ZNR type arresters should be 175 ± 25 percent of the nominal line-to-ground or line-to-line voltages of the appropriate ac service lines.

1.3.3.5.14 Desirable Operating Characteristics for Transient Suppressors. The transient suppressor characteristics listed below are required for effective protection at the facility level:

a. Turn-on (response) time: 50 nanoseconds or less.

b. Standoff voltage and leakage current: To ensure that the suppressor remains off except during transient occurrence, the standoff voltage should be between 200 to 300 percent above the nominal line voltage for spark gap type suppressors and approximately 175 ± 25 percent for MOV and ZNR type suppressors. Leakage current should not exceed 100 microampere at standoff voltage.

c. Polarity: Bipolar or unipolar, depending on line voltage.

d. Turn-on voltage: 125 percent of standoff voltage maximum at one milliampere for MOV and ZNR type suppressors. Also, 125 percent of the standoff voltage for gas-filled spark gap suppressors.

e. Clamp voltage: (Also known as discharge voltage) should not exceed 200 percent of the turn-on voltage for transients 100 amperes peak or 225 percent of the turn-on voltage for transients 1000 amperes peak.

f. Operating life: Capable of dissipating number and amplitude of transients projected to occur over a 10-year period. See Section 1.3.3.5.17.

g. Self-restoring capability: Essential that suppressor automatically restores to off state when applied voltage drops below turn-on voltage.

1.3.3.5.15 Characteristics of Different Types of Surge Arresters. Various types of surge arresters are presently available for purchase as off-the-shelf items from a multitude of manufacturers. Most have desirable characteristics, and also have undesirable characteristics. Some types have the capability of dissipating tremendous amounts of current, but turn on relatively slowly (150 to 200 nanoseconds) after turn-on voltage appears across device terminals. Another type turns on more rapidly (50 nanoseconds or less) but will not dissipate as much current as the slower devices, unless many devices are connected in parallel which is not totally desirable. Solid-state arresters are available which have very fast turn-on times but most of them are limited in current dissipation capability except for expensive units that range in cost from $7,500 to $25,000. Several hybrid units are currently under development that consist of a solid-state suppressor for dissipation of low-energy transients, and a separate suppressor section for dissipation of high-energy transients. The two suppressor sections are normally separated by a choke in series with the protected phase line. The three most important characteristics of an ac surge arrester are the capability to dissipate the required levels of surge current, maintain a low discharge (clamp) voltage while dissipating the transient current, and a fast response time. The fast response time is important to prevent the appearance of high level transient energy (overshoot voltage) across protected equipment for an intolerable length of time before the arrester turns on and clamps. Various types of suppressors are discussed below together with typical operating characteristics.

a. Gas-filled spark gap with series-connected silicon carbide block. The gas-filled spark gap arrester is capable of conducting very high currents. Some units have an extreme duty discharge capacity of 150,000 amperes peak for one transient with a 10-by-20 microsecond waveform. Minimum life of such units is dissipation of 2500 surges of 10,000 amperes peak surge current with a 10-by-20 microsecond waveform. Impulse sparkover (turn-on) voltage is 1400 volts peak for a transient with a 10 kV/ µs waveform for two types of arresters. Some typical discharge (clamp) voltages are listed in Table 1-12 for 10-by-20 microsecond waveforms of the transient amplitudes listed:

Table 1-12. Typical Maximum Clamp Voltage for Spark Gap Arresters

Peak Surge Amplitude	Maximum Clamp Voltage
10,000 Amperes	2,000 volts
40,000 Amperes	3,000 volts
150,000 Amperes	5,500 volts

(1) Follow current. The typical discharge (arc) voltage across a spark gap is 20 to 30 volts while it is in full conduction. Because of the low arc voltage, the voltage and current available from the ac power supply would maintain the spark gap in an on state after a transient was dissipated until the first zero crossing of the power supply or until a supply line fuse opened, a line burned open, the spark gap burned open, or the service transformer burned open. For this reason, a silicon carbide block (nonlinear resistor) is connected in series with a spark gap to ground to ensure that the spark gap extinguishes on the first zero crossing of the connected line, and, more importantly, to limit follow current through the spark gap after a transient is dissipated until the first zero crossing of the powerline (8.3 milliseconds maximum). The silicon carbide block is a nonlinear resistance, and resistance decreases as applied voltage increases. Thus, the resistance is relatively high at powerline voltages to limit follow current, but decreases to a fraction of an ohm when high-level transient voltage is applied. However, the resistance remains high enough to generate a relatively high clamp voltage when discharging high-amplitude transient currents.

(2) Sparkover (turn-on) voltage. Sparkover time for the spark gap arrester is directly related to transient risetime since a finite amount of time is required for the spark gap to ionize and transition from the off mode through the glow region and into the arc mode of operation. Also, ionization time is to some extent related to the risetime of the transient. Transition time from off to arc mode of operation is typically 150 to 200 nanoseconds after sparkover voltage appears across arrester terminals.

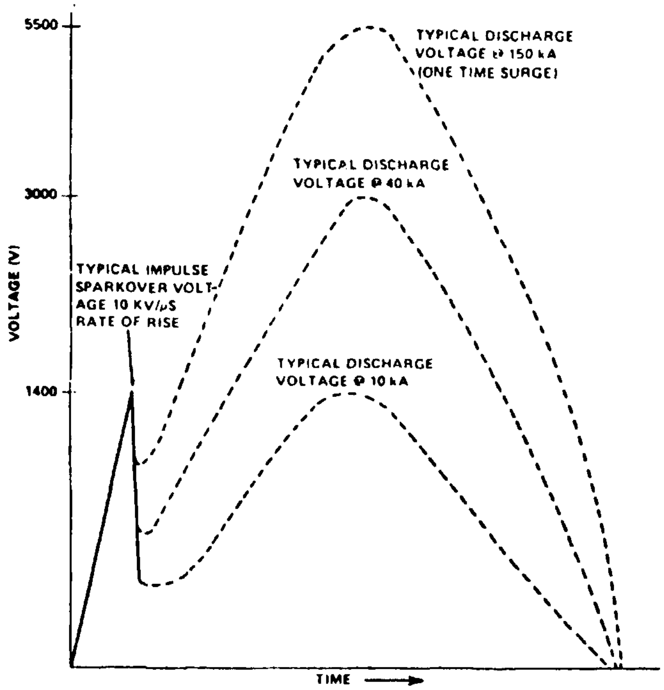


Figure 1-38. Typical Operating Curve for Two Series of Gas-Filled Spark Gap Arresters with Nonlinear Series Resistor

(3) Summary. In summary, the gas-filled spark gap is capable of discharging high-amplitude transients, but has a relatively slow response time and a relatively high discharge voltage. Follow current (10 to 80 amperes typical) occurs, but normally presents no significant problems. Figure 1-38 depicts typical operating curves for two series of gas-filled spark gap arresters with a series-connected silicon carbide resistor.

b. ZNR and MOV type arresters. The ZNR type arresters have several desirable characteristics. Other types of MOV arresters are currently under development that have voltage-current characteristics similar to the ZNR type. The ZNR type arresters have a relatively fast turn-on time (50 nanoseconds or less), low turn-on voltage, relatively low clamping voltage, and various levels of current dissipation capability since the ZNR types are available in different energy level packages. Table 1-13 lists related characteristics for ZNR available in one type of energy level package, and Table 1-14 lists related characteristics for a high-energy level package.

Table 1-13. ZNR Type Devices (Molded Case Type) Typical Characteristics

Parameter	Range of Available Devices		
	20 mm Disc	25 mm Disc	32 mm Disc
DC Breakdown Voltage at 1 Milliampere	200 to 910 volts	200 to 910 volts	200 to 910 volts
Maximum Clamping Voltage at Maximum Surge Current	525 to 2800 Volts	590 to 3200 Volts	640 to 3800 Volts
Maximum Surge Current (8 x 20 Microsecond Waveform)	2.5 to 5 kA	5 to 10 kA	10 to 20 kA
Life	Depends on Surge Current and Waveform*		

*Maximum surge current (8 x 20 microseconds) can be applied twice without incurring damage or over stressing the devices.

Table 1-14. High Energy ZNR Surge Arrester Typical Characteristics

Size:	Three 80 m m Discs in Parallel	
Powerline Voltage:	250 V AC Maximum	
DC Breakdown Voltage at 1 Milliampere:	560 Volts	
Maximum Clamping Voltage: (10 x 20 Microseconds)	Current	Clamping Voltage
	10 kA	1300 volts
	40 kA	1600 Volts
	150 kA	2450 Volts

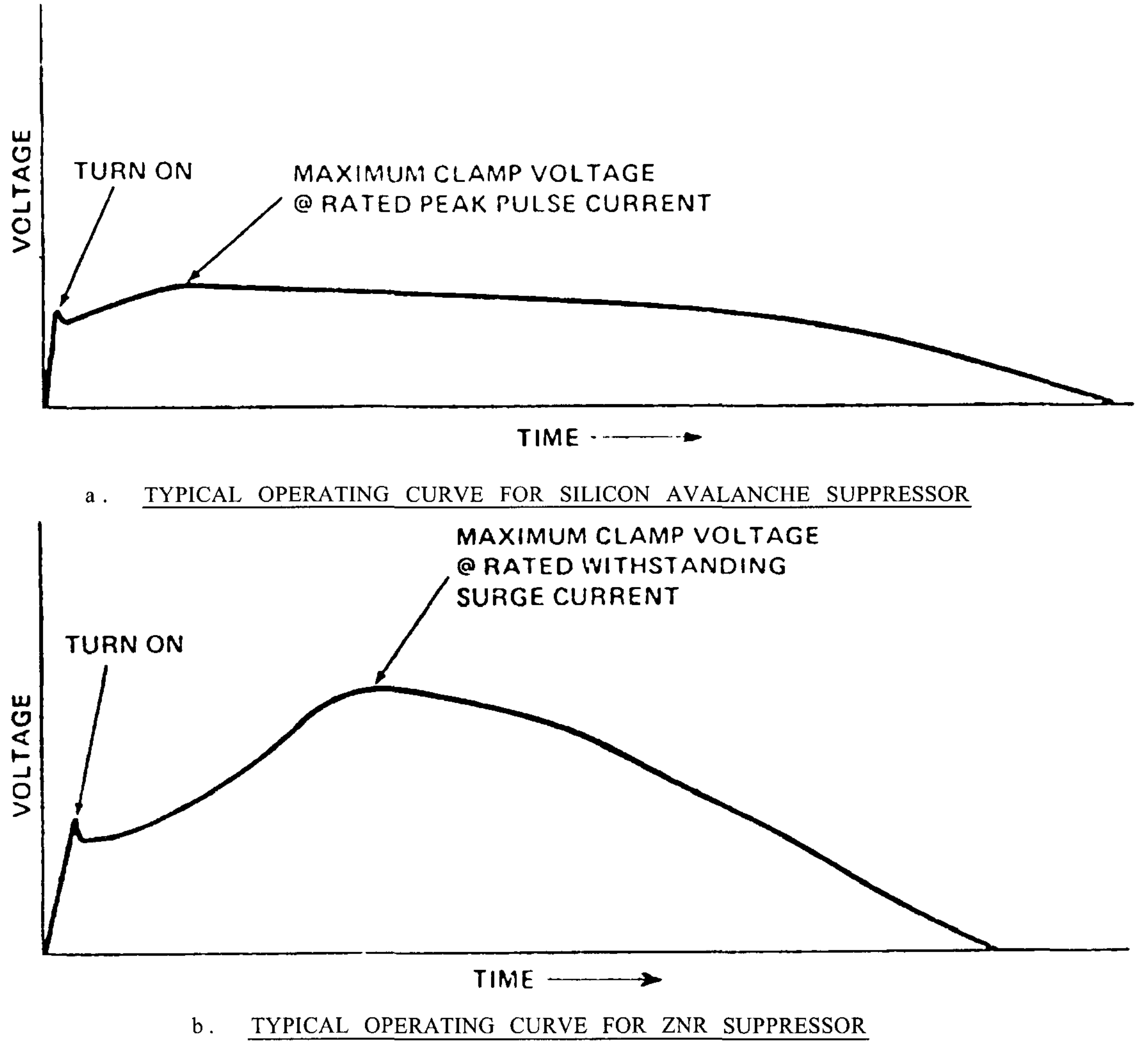
Table 1-15. Test Results for Parallel-Connected ZNR

Number of Surges Applied	Surge Amplitude	Clamp Voltage (Peak)
2000	250A @ 1000V	300V
2500	400A @ 1600V	315V
225	20,000A @ 8.75kV	500V
25	40,000A @ 16.8kV	650V
8	50,000A @ 20kV	700V

(1) Current dissipation. Testing has established that connection of the devices listed in Table 1-13 in parallel for line-to-ground or line-to-line protection is feasible. Use of the ZNR in parallel provides increased current dissipation capability and a lower maximum clamping voltage than a single, high-energy ZNR can provide. Five of the devices were connected in parallel and surged as listed in Table 1-15. The clamp voltages listed in Table 1-15 occurred. Current division was very good.

(2) Turn-on. Although the ZNR devices used in ZNR-type arresters are not solid-state junction-type devices, the arrester acts very much like junction-type devices. That is, when breakdown voltage is reached, transition from off to on occurs very rapidly as shown in Figure 1-39b which is a typical operating curve for a ZNR. Since the devices used in ZNR-type surge arresters are essentially nonlinear resistors, resistance decreases rapidly as applied voltage across the device increases above breakdown voltage. Therefore, current flow through this type of arrester increases rapidly after breakdown as shown in Figure 1-39b. Primarily because of resistance and capacitance of the ZNR, the clamp voltage slightly lags the transient current waveform. The ZNR-type arrester automatically restores to the off state when applied voltage falls below turn-on voltage. Therefore, no follow current occurs during the turn off phase.

c. Solid-state type arresters. So many different types of solid-state arresters are currently manufactured that it is difficult to generally evaluate them. In general, solid-state arresters manufactured by connecting silicon avalanche diode suppressors (SAS) in series to attain the desired current handling capability have truly fast response times of 1 to 10 nanoseconds. However, this type of arrester is generally limited to handling approximately 500 amperes surge current (waveform 8-by-20 to 8-by-40 microseconds). Figure 1-39a is a typical operating curve for a solid-state suppressor. This type of arrester also has a low clamp voltage (normally 160% of breakdown voltage, maximum) compared to other types of arresters. Other solid-state arresters are a combination of silicon avalanche diodes or rectifier diodes connected in a bridge network followed by a second stage consisting primarily of a silicon-controlled rectifier (SCR) with a varying-value current-limiting resistor in series with the SCR. This type arrester has a slow response time, sometimes approaching 1 microsecond, because of the slow turn-on time for the SCR. Also, the clamping voltage can be high depending on the value of the SCR current-limiting resistor. Because of the proliferation of solid-state arresters available, it is strongly recommended that complete laboratory demonstration testing be required prior to implementation of the solid-state arresters.



a . TYPICAL OPERATING CURVE FOR SILICON AVALANCHE SUPPRESSOR

b. TYPICAL OPERATING CURVE FOR ZNR SUPPRESSOR

Figure 1-39. Typical Arrester Operating Curves, ZNR and SAS

d. Hybrid type arresters. Hybrid type arresters are currently in development that consist of a combination of gas-filled spark gaps and ZNR or MOV, and two-stage arresters consisting of a solid-state stage for dissipation of low-energy-content transients and a separate stage for dissipation of high-energy transients consisting of gas-filled spark gaps and ZNR or MOV. The two stages are separated by a very low dc resistance choke so that the low-energy dissipation stage fires first to achieve fast response time. When sufficient voltage develops across the choke, the high energy dissipation stage turns on and dissipates the high level transient energy. Insufficient data currently exists to support analyzing the hybrid type arresters. A hybrid should emerge that effectively utilizes the best characteristics of available devices, (e. g., the fast turn-on and low clamping voltage characteristics of silicon avalanche diode suppressors and the high current dissipation capability of ZNR or MOV and gas-filled spark gaps).

1.3.3.5.16 Transient Protection for Externally Exposed Equipment Lines. In order to effectively protect equipment against damage from lightning generated transients on externally exposed (outside) equipment lines, the following must have some definition which is provided in subsequent paragraphs.

a. Frequency of Transient occurrence.

b. Amplitude and Waveform of Occurring Transients.

c. Equipment Withstand Levels.

d. Protection Methods Against Transients.

1.3.3.5.17 Frequency of Transient Occurrence. There is no existing method for precise calculation of the number of lightning generated transients that will occur at a specific location in a given period of time. However, by using the best available data listed in Section 1.3.3.5.4, projections are that 1750 transients will occur in a 10-year period at a facility located in a high-lightning incident area with an average of 100 thunderstorm days per year, and only 175 transients will occur in a 10-year period at a facility in a low-incident lightning area with an average of 10 thunderstorm days per year. Note that the number of transients is decreased by one order of magnitude for the low-lightning incident area. Therefore, by using Figure 1-34 to determine the average number of thunderstorm days per year in a specific location, and decreasing 1750 by 10% for each 10 decrease in the average number of thunderstorm days per year, the number of transients projected to occur at any location in the United States can be determined.

Table 1-16. Transients Projected to Occur on Externally Exposed Line in High-Lightning Incident Area Over 10-Year Period

No. of Transients	Percentage	Peak Voltage (Volts)	Peak Current (Amperes)
2	0.1	750 to 1,000	750 to 1,000
15	0.9	500 to 749	500 to 749
18	1	400 to 499	400 to 499
53	3	300 to 399	300 to 399
140	8	200 to 299	200 to 299
332	19	100 to 199	100 to 199
420	24	50 to 99	50 to 99
403	23	25 to 49	25 to 49
367	21	5 to 24	5 to 24

Note: The source impedance for design purposes is assumed to be 1 ohm.

1.3.3.5.18 Amplitudes and Waveforms of Occurring Transients. Transients occurring on landlines have been defined as 10-by-1000 microsecond, 1000-volt peak pulses where 10 microseconds is the time from the start of the transient to peak voltage, and 1000 microseconds is the time from the start of the transient until the amplitude exponentially decays to 50% of peak value. Source impedance cannot be precisely defined but for design purposes is assumed to be 1 ohm. Therefore, for design purposes, a typical worse case lightning-induced transient can be defined as 10-by- 1000 microseconds, 1000 volts peak with a peak surge current of 1,000 amperes. Using Table 1-8, the 1750 transient pulses defined in Section 1.3.3.5.17 and the worst case transient pulse defined above, the number of transients of varying amplitude would be as listed in Table 1-16 over a 10-year period for an externally exposed line in a high-incident lightning area (average of 100 thunderstorm days per year).

1.3.3.5.19 Equipment Withstand Levels. Equipment withstand levels were generally defined in Section 1.3.3.5.3. Nothing of substance can be added. However, manufacturers generally do not specify equipment or component withstand levels against lightning generated transient surges. It is imperative that the withstand level be analyzed and determined for each item of equipment to be protected. The withstand level should be 10% below both the damage threshold level and operational upset level for the equipment. The damage threshold level is defined as the level where immediate component destruction occurs or the repeated application energy level that decreases useful operating lifetime of equipment components, whichever is lower. The operational upset level is defined as the transient voltage that causes an intolerable change in equipment operation. It is imperative that an accurate withstand level be established. Otherwise, designed transient suppression may not be effective, or conversely, costly transient protection may be designed when not required.

1.3.3.5.20 Protection Methods Against Transients. Methods listed below are effective, when properly implemented, in providing equipment protection against lightning generated transients appearing on externally-exposed equipment signal, status, control and ac and dc intrafacility lines. Subsequent paragraphs delineate proper implementation techniques for the listed methods.

a. Completely enclosing buried lines end-to-end in ferrous metal, watertight conduit.

b. Installation of buried guard wire above buried cable runs not in metal conduit.

c. Connecting transient suppressors line-to-ground on both ends of externally exposed equipment lines as soon as feasible after building penetration or at point of termination at exterior equipment.

d. Including transient suppressors or transient suppression circuits as an integral part of protected equipment at all external line-equipment interfaces.

e. Peripherally bonding the shields of rf coaxial lines to building entry plates by use of bulkhead connector plates.

1.3.3.5.21 Enclosing Cable Runs in Ferrous Metal Conduit. Transients are induced on external lines by electromagnetic waves created by lightning current flow, and by cloud-to-cloud lightning discharges. Therefore, completely enclosing buried external cable runs in ferrous metal, watertight, electrically continuous conduit provides an effective protection level against lightning-generated transients.

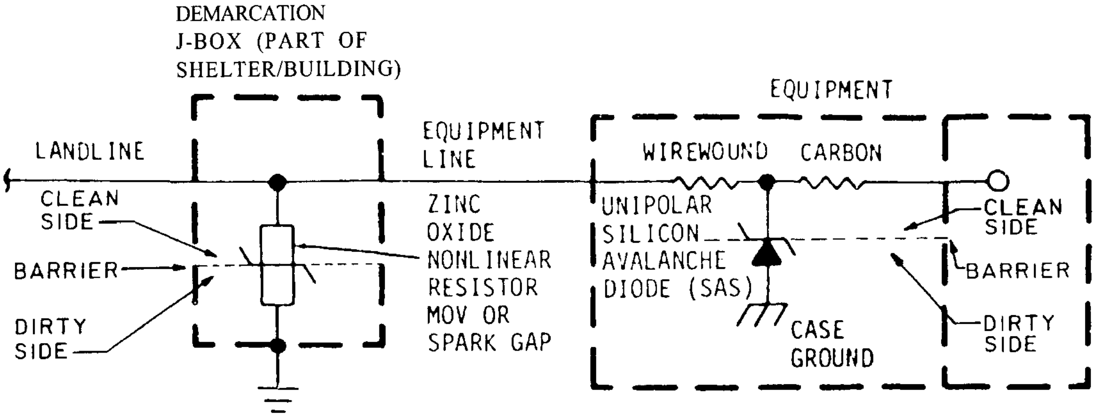
a. Cost considerations. When a buried cable run is 90 meters (300 feet) or less in length, it is economically feasible to enclose the cable run end-to-end in metal conduit. When the cable run exceeds 90 meters (300 feet), it is normally more economically feasible to provide transient suppression at building penetration and equipment level than to install the conduit. However, use of metal conduit provides effective protection against induced transients, regardless of the length of the cable run. The conduit must extend from building penetration to building penetration, or building penetration to exterior equipment termination.

b. Grounding of conduit. To be effective, the conduit must be electrically continuous and effectively bonded to earth ground at each end. If building entry plates are available the conduit should be peripherally welded. NO. 2 AWG bare copper stranded cable is suitable for the earth ground connection, and exothermic welds provide effective bonding underground. Approved pressure connectors are suitable for use above ground. For runs over 90 meters (300 feet), the conduit should be connected to earth ground at each end and every 30 meters (100 feet). The structural steel of antenna towers may be used to effectively ground the conduit provided the total bond resistance from the conduit to the earth electrode System is 5 milliohms or less.

c. Transient suppression for lines in metal conduit. Only one level of transient suppression is required for exterior line/equipment interfaces to provide effective protection against induced transients conducted by lines in metal conduit. The one level of suppression may be located at building penetration or designed as an integral part of the applicable equipment. The one level of suppression may consist of a single suppressor connected line to ground, or two resistors connected in series with the external line input and a silicon avalanche diode connected between the junction of the two resistors and earth ground or equipment case ground, depending on location of the transient suppression.

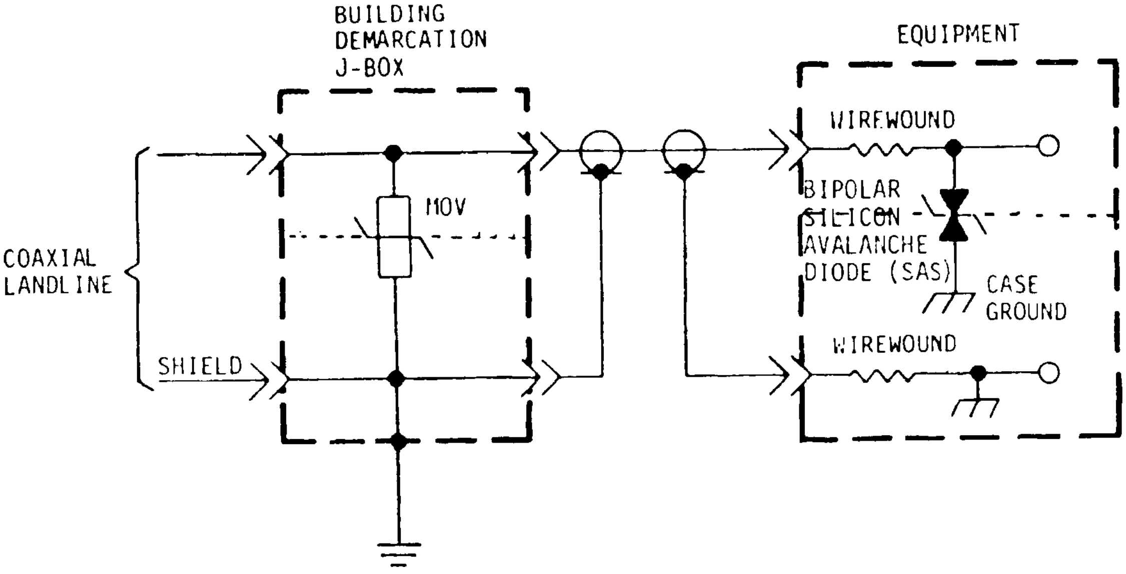
d. Amplitude of transients on external lines enclosed in metal conduit. The number of lightning generated transients occurring on external cables will not change as a result of enclosing cable runs in metal conduit. However, the voltage and current amplitudes will decrease a minimum of 90%. Therefore, Table 1-16 can be used to determine the number and amplitude (voltage and current) of transients that are projected to occur on externally exposed lines, enclosed in metal conduit, in high-lightning incident areas.

1.3.3.5.22 Transient Suppression. In order to provide effective equipment protection against lightning generated transients, externally exposed lines must have transient suppression installed on each end where the line directly interfaces electrical/electronic equipment. This requirement applies in all cases when the withstand level of the interfaced equipment is below the transient levels projected to occur at the line/equipment interface. As previously noted, transient amplitudes projected to occur on lines enclosed end-to-end in electrically continuous, ferrous metal conduit are only 10% of the transient amplitudes projected to occur on lines not enclosed in metal conduit (Table 1-16). Primarily because of insertion losses and impedance mismatch, transient suppression is not currently available that is satisfactory for installation on externally exposed rf coaxial lines at building penetration when the lines carry signals above 3 MHz in frequency. Therefore, all protection for these line/equipment interfaces must be designed as an integral part of the equipment. The most effective design for equipment protection is provided by installing a high energy level transient suppressor at building penetration (on all lines that carry signals 3 MHz or less in frequency) connected line to earth ground, and including low-energy suppression as a part of integral equipment design. Figure 1-40 depicts typical transient suppression at the facility and equipment level for both coaxial cables and single wires or pairs. Suppressors installed at building penetration should be located in the junction box that first terminates the externally exposed lines after building penetration.



NOTE: SAS MAY BE UNIPOLAR OR BIPOLAR DEPENDING ON LINE VOLTAGE

a. TYPICAL TRANSIENT PROTECTION CONFIGURATION



NOTE: TRANSIENT PROTECTION FOR SHIELD REQUIRED ONLY WHEN SHIELD IS NOT GROUNDED AT EQUIPMENT

b. TRANSIENT PROTECTION FOR EXTERNALLY-EXPOSED COAXIAL CABLES

Figure 1-40. Typical Transient Suppressor Installation, Facility and Equipment Level

a. Grounding for transient suppression. In order for the transient suppression to operate properly and provide optimum equipment protection, the ground side of the transient suppressor must be connected as directly as possible to ground. The ground for the high-energy level suppressor must be connected directly to the nearest J-Box wall.

b. Suppressor installation. Suppressors can be installed between applicable terminal boards and the ground with short direct connections. Maintaining short lead lengths is important to prevent inductance of long lead lengths from delaying turn-on and response of the transient suppressors.

1.3.3.5.23 Types of Available Transient Suppressors. Three different types of suppressors are available to provide transient protection as listed below. Operating characteristics for each type are provided in subsequent paragraphs, followed by desirable operating characteristics.

a. Zinc oxide nonlinear resistor (ZNR) or metal oxide varistor (MOV).

b. Silicon avalanche diode suppressor (SAS).

c. Gas-filled spark gap.

1.3.3.5.24 Operating Characteristics of Transient Suppressors.

a. Characteristics of ZNR-type suppressors.

(1) Response time: 50 nanoseconds or less, any risetime.

(2) Clamping voltage: 225% of breakdown voltage maximum for surge currents projected.

(3) Breakdown voltage: 22 V dc to 1800 V dc at 1 milliampere.

(4) Standoff voltage: 14 V dc to 1599 V dc.

(5) Surge current dissipation: 500 to 2000 amperes, 8-by-20 microsecond waveform.

(6) Lifetime: Variable, depends on amplitude of surge current, satisfactory for 10-year protection, projected.

b. Characteristics of SAS-type suppressors.

(1) Response time: 1 nanosecond or less, any risetime.

(2) Clamping voltage: 165% of breakdown voltage maximum at rated peak pulse current.

(3) Breakdown voltage: 6.8 V dc to 200 V dc at 1 milliampere.

(4) Standoff voltage: 5.5 V dc to 200 V dc.

(5) Surge current dissipation: Peak pulse current ratings from 139 amperes for 6.8 V dc suppressor to 5.5 amperes for 200 V suppressor for 10-by-1000 microsecond waveforms.

(6) Lifetime: Not presently defined. Requires current-limiting resistor in series with protected line to provide required surge current dissipation at facility level.

c. Characteristics of gas-filled spark gap suppressors.

(1) Response time: 3 to 5 microseconds for 10-by-1000 microsecond waveforms.

(2) Clamping voltage: Arc voltage is 20 volts typical.

(3) Breakdown voltage: 300 to 500 volts typical.

(4) Standoff voltage: 75 V dc to 1000 V dc.

(5) Surge current dissipation: 5,000 amperes for 10-by-50 microsecond waveform.

(6) Lifetime: Varies depending on surge current amplitude, 50 surges of 500 amperes peak current with 10-by-1000 microsecond waveform typical.

1.3.3.5.25 Transient Suppressor Packaging Design. Packaging of transient suppressors for standard wires and twisted shielded pairs is not critical. Leads should be as short as feasible to enable short, direct connections without bends. Transient suppressors for coaxial and twinaxial lines should be contained in a metal and epoxy package with appropriate connectors on each end, one male, and one female, to permit inline installation at the connector panel in the demarcation junction box. Two suppressors must be included in all twinaxial protector packages.

1.3.3.5.26 Coaxial Cable Shield Connection Through an Entrance Plate. Effective transient protection can be provided by peripherally bonding each rf coaxial cable to a metal bulkhead connector which in turn is peripherally bonded to the building entry plate and grounded to the earth electrode subsystem. This scheme will route transient currents from cable shields to earth ground instead of through terminating equipment to ground.

Also, transient surge currents will be shunted to ground before transient energy is cross-coupled to other equipment lines in the facility. The entry plate should be a minimum of 0.64 cm (1/4-inch) thick, and constructed of steel. The entry plate must contain the required number of appropriate coaxial feedthrough connectors to terminate all applicable incoming lines. The connectors must also provide a path to ground for connected cable shields. If external and internal coaxial cables are of a different physical size, the changeover in connector size should be accomplished by the feedthrough connectors of the entry plate. The entry plate should be connected to the earth electrode subsystem with a 1/0 AWG (minimum) insulated copper cable. The cable should be bonded to the entry plate and the earth electrode subsystem with exothermic welds.

1.3.3.5.27 Grounding of Unused Wires. All unused wires/pairs of Communication cable runs should be connected to ground at each end. This action will reduce transients on the unused lines which otherwise could be coupled to in-service lines of the cable.

1.3.3.5.28 Transient Suppression for RF Coaxial Lines. At the present time, effective transient suppressors for connection from line-to-ground at building penetration for externally exposed rf coaxial lines carrying signals above the 3 MHz range are still in the development stage, primarily because of insertion losses. The best method for protecting the lines at present is end-to-end enclosure in ferrous metal conduit, and providing transient suppression as an integral part of using equipment.

1.3.3.5.29 Equipment-level Transient Suppression. Equipment-level transient protection is discussed in paragraph 1.3.3.7 of this chapter. In general, effective protection is provided by low-value resistors in series with external line inputs, and silicon avalanche diode suppressors connected line-to-ground. Suppressors are currently available as special order items that are suitable for connection line-to-ground on rf lines carrying signals up to 500 MHz. The suppressors consist of a spark gap, a silicon avalanche diode suppressor in parallel with an rf choke, or a combination ZNR and rf choke.

1.3.3.6 Lightning Generated Transient Protection Evaluation. This portion of the procedure is performed to determine whether effective and adequate transient suppression is provided for protection against damage from lightning-generated transients. The procedure consists of a detailed review of facility drawings and a detailed visual inspection.

a. Facility drawings. Review facility drawings required to determine the following. Sketch items of interest to aid in subsequent visual examination.

(1) Are lightning protectors installed on the primary and secondary of commercial ac service transformer(s)?

(2) Are buried, incoming ac power service lines enclosed in watertight, ferrous metal conduit connected to earth ground at the service transformer and to the earth electrode subsystem at the facility end? Is No. 2 AWG (minimum) bare, stranded copper wire used for earth ground connections?

(3) Are overhead incoming ac power service lines protected by an overhead guard wire from the service transformer to the facility service entrance? Is the guard wire connected to earth ground at each end? Does the guard wire provide a 1:1 cone of protection for the incoming service lines?

(4) Is an ac surge arrester installed at the facility main service disconnect means (each main disconnect if more than one)? Note manufacturer and part number on sketch.

(5) Are the external landlines and lines which terminate at exterior equipment (including rf coaxial lines that connect to facility equipment) enclosed in watertight, ferrous metal conduit if the cable runs are 90 meters (300 feet) or less in length? Is the conduit connected to the applicable earth electrode subsystem at each end?

(6) Do buried landlines (more than 90 meters (300 feet) in length and not enclosed in ferrous conduit) have a guard wire installed end-to-end in the cable trench? Is the guard wire connected to the earth electrode subsystem at each end?

(7) Are all rf coaxial cables grounded to the metal bulkhead connector plate at building penetration?

(8) Are transient suppressors or transient suppression circuits installed line-to-ground on each end of all exterior lines not enclosed in ferrous metal conduit (except rf lines carrying signals above 3 MHz) at first termination after building penetration?

b. Inspection. A survey form in Section 2.2.2.4, Part II, is provided for guidance in accomplishing a thorough visual inspection. Detailed written notes fully describing all noted deficiencies should be made.

c. Corrective action. Specific corrective action to accomplish in response to each noted deficiency is difficult to detail. For instance, cable runs less than 90 meters (300 feet) in length are not normally enclosed end-to-end in electrically continuous, watertight, ferrous metal conduit. Intensity and incidence of lightning in the immediate area, together with economic feasibility and operational requirements, are normally the overriding factors in determining whether the installation of metal conduit is justified and feasible. In most cases, for the example cited, installation of transient suppression circuits on each end of externally exposed equipment lines is the most feasible solution. However, installation of transient suppression directly at the line-equipment interface may also be warranted, depending on equipment susceptibility and lightning incidence. Consider each deficiency individually. Refer to Sections 1.3.3.5 and 1.3.3.7 as required, and correct deficiencies in the most feasible manner. Some typical and required corrective actions are listed below:

(1) If a secondary ac surge arrester is not installed at the facility, and there is any history of lightning incidence in the area, install a surge arrester on the line or load side of the main service disconnect means. Refer to Section 1.3.3.5 to determine that the surge arrester selected will be adequate and effective.

(2) If the surge arrester and transient suppressor does not have a low-impedance, effective path to earth ground, take whatever action is necessary to provide effective grounding. Neither the arrester nor suppressor will provide effective transient protection if an effective ground is not available.

(3) If no transient suppressors are installed on externally exposed equipment lines not enclosed end-to-end in metal conduit, and the lines interface susceptible equipment, as a minimum install transient suppressors on each end of each line that interfaces susceptible equipment. Refer to Sections 1.3.3.5 and 1.3.3.7 as required.

1.3.3.7 Transient Protection.

1.3.3.7.1 Protection Requirement. Individual items of electrical and electronic equipment that directly interface any externally exposed equipment lines, including commercial ac, may require transient protection that is designed as an integral part of the equipment. Whether or not protection is required is dependent on the damage susceptibility of the equipment of interest, the level of transient suppression provided on externally exposed lines at building penetration or external equipment termination and the level of transient energy that is projected to be conducted to the equipment. For use herein, externally exposed lines are defined as lines exposed to outside weather elements and environmental conditions. The lines may run overhead, run along grade surface, or be buried in earth. Included are ac power input lines and signal, control, status, and intrafacility powerlines. The lines are commonly referred to as landlines. Transient protection is not required in equipment when an interfaced landline is fiber optic in lieu of a metallic line. In order to provide effective transient protection, the damage (withstand) level for the equipment must be determined, and the amplitude and number of transients that will be conducted to the equipment must be known. This information is provided in this section. Three areas of equipment circuitry normally require transient protection, and are listed below:

a. The ac power input.

b. Where other externally exposed lines interface with the equipment.

c. Rectifier outputs of 5 to 48 V dc power supplies that operate from commercial ac power and supply operating power for solid-state equipment.

1.3.3.7.2 Transient Definition. The waveform and amplitude of transients that may appear on commercial ac input lines and other landlines connected to equipment are provided in this paragraph.

a. AC powerline transients. The number and amplitude of lightning generated transients projected to occur on ac power inputs to equipment over a 10-year period are listed in Tables 1-17 and 1-18. The waveform for the transients is 8-by-40 microseconds where 8 microseconds is the risetime from zero to peak amplitude, and 40 microseconds is the time from the start of the transient until exponential decay to 50% of peak value. The transients listed are based on the data in Section 1.3.3.5. The transients listed in the two tables represent clamp voltages that will appear across equipment by the facility secondary ac arrester installed at the main service disconnect means (see Section 1.3.3.5) when discharging transient surges. Voltages and currents actually appearing across protected equipment will necessarily be related to the amounts and type of equipment operating from power supplied by the main service disconnect means.

Table 1-17. Transient Surges, Line-to-Ground, Expected to Appear Across Equipment by Secondary AC Surge Suppressor Over a 10-Year Period

Surge Current Amplitude (8-by-40 μs)	Number of Surges
1.5 kV, 100 A	1,500
2 kV, 200 A	700
2.5 kV, 300 A	375
3 kV, 500 A	50
3.5 kV, 1 kA	5
4 kV, 1.5 kA	2
4.5 kV, 2 kA	1

Table 1-18. Transient Surges, Line-to-Line, Expected to Appear Across Equipment by Secondary AC Surge Suppressor Over a 10-Year Period (Ungrounded Service Only)

Surge Current Amplitude (8-by-40 µs)	Number of Surges
500 V, 50 A	1,000
750 V, 100 A	100
1 kV, 200 A	50
1.5 kV,300A	10

b. Landline transients. The number and amplitude of transients projected to be conducted to each landline equipment interface are listed in Table 1-19. The waveform for the transients is 10-by-1000 microseconds where 10 microseconds is the risetime from zero to peak amplitude for the transient, and 1,000 microseconds is the time from the start of the transient until exponential decay to 50'% of peak amplitude. The information presented in Table 1-19 is based on data contained in Section 1.3.3.5. Since an equipment designer will not normally know whether external lines will be enclosed in ferrous metal conduit, different transient amplitudes are not provided in Table 1-19 for external lines enclosed in metal conduit.

1.3.3.7.3 Determination of Equipment Damage (Withstand) Levels. Manufacturers do not normally specify withstand levels for components. Therefore, an analysis should be performed to determine the withstand level for each item of equipment that directly interfaces any externally exposed lines including ac input lines. Transients that are projected to be conducted to equipment are provided in Tables 1-17, 1-18, and 1-19. The analysis should be based either on results of laboratory tests or engineering analysis. Also the analysis must include all equipment circuitry that will be exposed to transients. Three factors determine the withstand level for the equipment as follows:

a. Component destruction level. The component destruction level is the transient energy level that either causes immediate component destruction or degrades component operation to a point so that useful operation cannot be achieved. This energy level is not usually specified or controlled by the manufacturer.

b. Shortened component operating life. Useful component operating life can be appreciably shortened by repeated overstressing of components. The overstressing occurs as a result of repeated application of some level of transient energy. This energy level may be difficult in some cases to determine, but is certainly meaningful when designing protection against transients.

Table 1-19. Transient Surges Projected to Occur in 10-Year Period on Externally-Exposed Landlines

Peak Amplitude Number of Surges	(Voltage and Current)
1,000	100 V, 50 A
500	500 V, 100 A
50	750 V, 375 A
5	1,000 V, 1,000 A

c. Operational upset level. The operational upset level is the transient energy level that causes a change in the equipment operating state. Since a change in the equipment operating state will normally create an intolerable change in associated system operation, transient protection must ensure that transient energy levels appearing across protected equipment do not cause operational upset.

To establish the equipment withstand level, compare the transient energy levels that cause immediate component destruction, component overstressing, or equipment operational upset. Select the lower of the three transient energy levels, and establish the withstand level at 10% below the lowest transient energy level.

1.3.3.7.4 Determination of Need for Transient Protection. Power supplies (5 to 48 V) operating from ac inputs and supplying operating power for solid-state equipment always require internal transient protection. Other equipment that directly interfaces externally exposed lines, including commercial ac inputs, may or may not require transient protection designed as an integral part of the equipment. To determine whether transient protection is required, compare the equipment withstand level with the transients of Table 1-17, 1-18, or 1-19, as applicable. If the equipment withstand level is above the transient amplitudes provided in the tables, equipment-level transient protection is not required. When the transient amplitudes are above the equipment withstand level, equipment-level transient protection is required, either at the ac input, other externally-exposed line-equipment interfaces, or both.

1.3.3.7.5 Minimizing Transient Damage. When equipment requires protection against lightning generated transient damage, transient suppression design must ensure that transients are attenuated to the equipment withstand level prior to entering any equipment component. Therefore, the transient suppression must be effective at the external line-equipment interface.

a. New equipment.

(1) AC inputs. The most feasible method for providing transient suppression is to design the suppression as an integral part of the equipment.

(2) Other external line interfaces (dc to 3 MHz). The most effective method for providing transient suppression is to design low-energy level transient suppression as an integral part of the equipment and specify that high-energy level transient suppression, of a design provided by the manufacturer, be installed on applicable lines in cable demarcation junction boxes at building penetration or exterior equipment termination. Total transient suppression may be designed as an integral part of the equipment but caution must be exercised to ensure that a separate, dedicated path to earth ground be provided for the high-energy level dissipation section of the transient suppression.

(3) External line interfaces (above 3 MHz). All transient suppression must be designed as an integral part of the applicable equipment. This is necessary because effective suppression devices/circuits are not currently available for in–line installation on rf lines above 3 MHz, primarily because of high insertion losses. If useable, effective high-energy level suppression becomes available in the future, the most effective transient protection can be realized by installing high-energy level suppression on applicable lines at a metal bulkhead connector plate at building penetration and including low-energy transient suppression as a part of the equipment.

b. Existing equipment. The most effective transient protection can be provided as described in a(l), (2), and (3) above. When room is not available in the existing equipment to add required transient suppression components, the components can be installed in a small enclosure affixed to the chassis or cabinet rack for all except rf lines that carry rf signals above 3 MHz.

1.3.3.7.6 AC Power Input. The clamp voltage, appearing across protected equipment by the secondary ac surge arrester installed at the facility main service disconnect means, when dissipating a transient surge, may be higher than the withstand level for the equipment. Therefore, effective transient suppression must be designed as an integral part of the equipment.

a. Transient suppression design. To provide effective protection, equal suppression must be installed line-to-ground on each service conductor input and the neutral input. For floating (ungrounded) line-to-line power inputs, line-to-ground suppression must be installed and line-to-line suppression is optional. Suppressors installed at the equipment power input should have a slightly lower turn-on voltage and a slightly faster response time than suppressors of the secondary ac surge arrester at the main service disconnect means. This permits the suppressors integral to the equipment to clamp short-duration overshoot voltage that occurs before the secondary ac surge arrester can turn on and clamp in response to a transient. Also, with a lower turn-on voltage, the suppressors at the equipment will nave a lower clamp voltage for a given transient surge than the secondary arrester and thus provides optimum equipment protection. However, with the specified characteristics, the surge suppressors at the equipment will tend to dissipate the occurring transient before the secondary arrester turns on. Therefore, it is imperative to have an inductor or a minimum 10 foot cable added in series with the input line. If the inductor is properly chosen, the secondary surge arrester may then turn on very rapidly after the equipment suppressor(s) turn on because of the voltage increase across the inductor. The voltage increase is caused by current drain through the equipment suppressors to ground. Figure 1-41 depicts a typical suppression circuit for use at the equipment level on ac inputs with a neutral. Figure 1-42 depicts a typical suppression circuit for use on ungrounded (line-to-line) inputs.

b. Components.

(1) Inductor L1. The inductor Ll, shown in Figures 1-41 and 1-42, is necessary to provide a voltage increase to cause the secondary ac surge arrester at the main service disconnect means to turn on very rapidly when suppressor RV1 turns on and conducts transient current to ground. The inductor must be capable of safely passing normal operating voltages and current, and current resulting from 130% overvoltage for a period of 50 milliseconds. Also, the inductor must:

(a) Have a very low dc resistance.

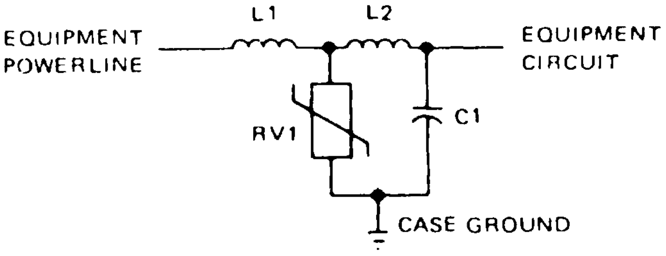
(b) Present a high impedance to transient surges.

(c) Present a very low impedance to 60 Hz line voltage.

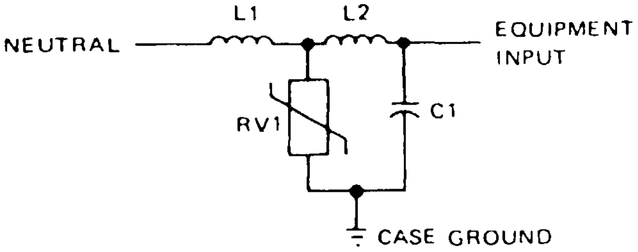
(d) Be capable of safely passing the transient current listed in Table 1-17.

(2) Suppressor RV1. Figure 1-41 shows RV1 as a metal oxide varistor (MOV) because the zinc oxide nonlinear resistor type of MOV is especially well suited for this particular application. Other types of MOV are constantly being upgraded and are now possibly suitable for use. Other devices are also suitable for use, and, in some cases will be required. Silicon avalanche diodes are effective for use in protecting very susceptible equipment. Data for different type suppressor are provided in Section 1.3.3.5. Use of a gas-filled spark gap for use at the location of RV1 is not recommended for two reasons.

(a) Available gas-filled spark gaps with the required current handling capability have a relatively high sparkover (turn-on) voltage and relatively slow turn-on times. Therefore, if spark gaps are used for transient suppression at ac inputs, additional suppression including inductors, MOV and/or silicon avalanche diode suppressors must be added to provide required protection.



a. TYPICAL TRANSIENT SUPPRESSION FOR HOT AC INPUT TO EQUIPMENT



b. TYPICAL TRANSIENT SUPPRESSION FOR NEUTRAL AC INPUT TO EQUIPMENT

Figure 1-41. Typical Configuration for Protection of Equipment from Conducted Powerline Surges and Transients (Neutral Grounded)

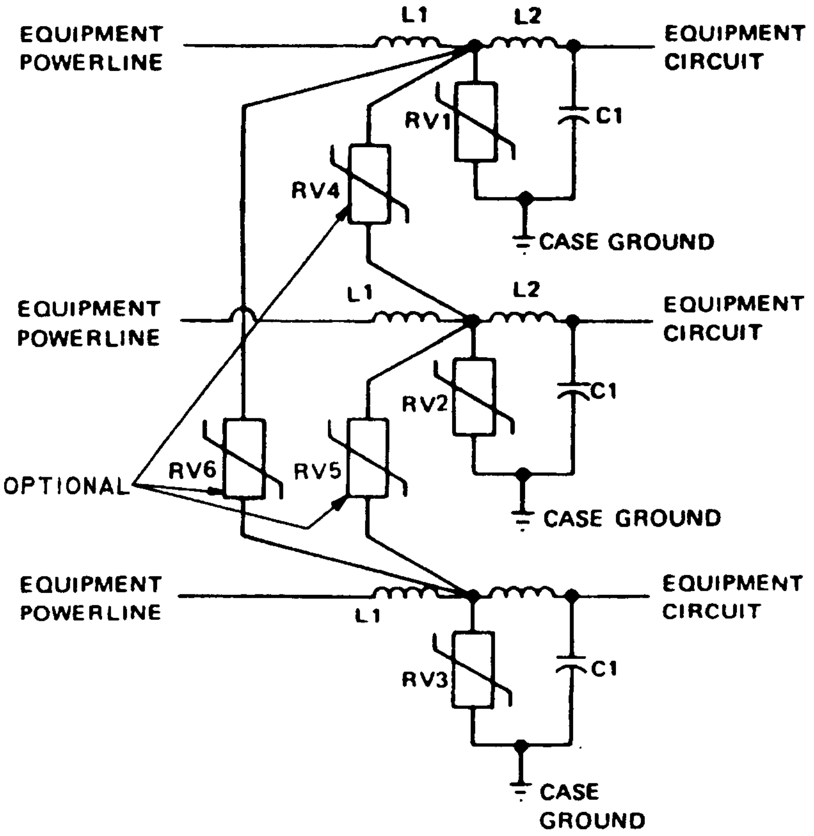


Figure 1-42. Typical Configuration for Protection of Equipment from Conducted Powerline Surges and Transients (Ungrounded)

(b) Arc voltage for spark gaps is a nominal 20 to 30 volts. Therefore, when the transient occurs causing the spark gap to turn on, normal line voltage is interrupted which will usually cause operational upset of the affected equipment. Also, since the arc voltage is only 20 volts and is across a 120-volt supply, the spark gap will likely remain in the arc mode of operation and draw current until the supply voltage waveform crosses zero or until the supply circuit breaker opens. It is likely that the spark gap will be destroyed before the supply circuit breaker opens. Either condition is very undesirable.

(3) Inductor L2 and capacitor Cl. These two components form an LC network to filter out high frequency components of transient surges and are required only for equipment susceptible to high frequency, very short duration (less than 1 nanosecond) transient pulses that might pass across RV1.

c. Transient suppression grounding. When at all feasible, transient suppressor grounds should be directly bonded to case ground. When the direct bond is not feasible, the suppressor grounds must be connected as short and direct as possible to case ground, and the case must have a low bond resistance to earth ground. Otherwise, the suppressors cannot operate properly.

d. Functional characteristics. Functional characteristics for transient suppression at the ac input-equipment interface must be as follows for effective transient suppression.

(1) Voltage characteristics. The operating (reverse standoff) voltage must be between 200 to 300 percent of the normal line voltage for gas-filled spark gap suppressors. For MOV, ZNR, and SAS type suppressors, the reverse standoff voltage should be 175 ± 25 percent of the normal line voltage. Turn-on voltage, discharge (clamp) voltage and the a amplitude and time duration of any overshoot voltage must be sufficiently low to preclude equipment damage or operational upset.

(2) Leakage current. Leakage current for each suppression component at reverse standoff voltage must not exceed 100 microamperes.

(3) Self-restoring capability. The surge suppressors must automatically restore to an off state when transient voltage falls below turn-on voltage for the suppressor.

(4) Operating lifetime. Equipment transient suppression must be capable of safely dissipating the number and amplitude of surges specified in Table 1-17 or 1-18 as applicable. Clamp voltage shall not change more than 10 percent over the operating lifetime.

(5) In-line devices. Only inductors designed to have low dc resistance shall be used as in-line devices for suppression of conducted powerline transient. In-line inductors shall safely pass equipment operation voltages and line current with 130 percent overvoltage conditions for a period of 50 milliseconds.

e. Housing. Suppression components should be housed in a separate, shielded, compartmentalized enclosure as an integral part of equipment design. Bulkhead-mounted, feedthrough capacitors should be used as necessary to prevent high-frequency transient energy from coupling to equipment circuits. Suppression components should be directly bonded to equipment case ground when at all feasible. Suppressor Connections to ground must be short, straight, and direct.

1.3.3.7.7 Power Supply Transient Suppression. Power supplies (5 to 48 V dc) that operate from commercial ac power inputs and furnish operating voltage to solid-state equipment must have a transient suppressor installed between the rectifier output and case ground. This protection (in addition to the service disconnect arrester and powerline suppression at equipment entrances) is required because of the adverse electromagnetic environmental operating conditions for much military equipment. A silicon avalanche diode suppressor will provide the best protection for this particular application. The silicon avalanche diode suppressor is recommended because of the very fast response time of the device, since the primary purpose is to clamp very fast risetime and very short duration transients. In addition, the silicon avalanche diode suppressor provides the lowest clamping voltage available. Thus, when this device is used, the clamped output of the transient suppression at the ac input-equipment interface will be clamped to a lower level by the avalanche diode at the rectifier. This, in turn, provides optimum protection for solid-state voltage regulators and other solid-state components receiving operating voltage from the power supply. Operating characteristics for the suppressor installed at the rectifier output must be as follows if the suppressor is to provide the desired function:

a. Operating (reverse standoff) voltage. Reverse standoff voltage must be 5 percent above maximum rectifier output voltage.

b. Leakage current. Leakage current to ground should not exceed 100 microamperes at standoff voltage.

c. Turn-on voltage. Turn-on voltage must be as near standoff voltage as possible using state-of-the-art suppressors, and shall not exceed 125 percent of reverse standoff voltage.

d. Discharge (clamp) voltage. Clamp voltage must be the lowest possible value that can be obtained using state-of-the-art suppressors not to exceed 160 percent of turn-on voltage.

e. Overshoot voltage. Overshoot voltage must be sufficiently low to preclude equipment damage or operational upset. Time duration of overshoot voltage shall be limited to the shortest possible time not exceeding 2 nanoseconds.

f. Self-restoring capability. Transient suppressors installed in power supplies must automatically restore to an off state when line transient falls below rated turn-on voltage for the suppressor.

g. Operating lifetime. The transient suppressors must safely dissipate 1000 surges with an amplitude of 200 volts above rectifier output voltage and a waveform of 8-by-40 microseconds. Eight microseconds defines the time from the start of the transient to peak voltage, and 40 microseconds is the time from the start of the transient until the transient exponentially decays to 50 percent of peak value.

1.3.3.7.8 Landline Transient Suppression. When the equipment withstand level is below the transient energy level projected to occur at direct landline-equipment interfaces, transient suppression must be provided by equipment design. Generally, all direct landline-equipment interfaces will require transient suppression. However, when the landlines are totally enclosed end-to-end in ferrous metal conduit, a much lesser degree of suppression is required than when the landlines are direct earth-buried or overhead cable runs. At the time of new equipment design, when provisions for transient protection must be included, the manufacturer may not know whether externally exposed landlines will be totally enclosed in ferrous metal conduit. When the manufacturer is not conclusively certain that external landlines will be enclosed in metal conduit, designed transient protection must ensure that the equipment will be adequately protected against the transient levels of Table 1-19. Subsequent paragraphs provide design guidelines for transient suppression for all types of landlines. Coaxial and twinaxial lines are treated separately. Also, externally-exposed landlines that carry signals of 3 MHz to 400 MHz are treated separately.

a. Control, status, intrafacility power, and audio landlines. Control, status, intrafacility power, and audio lines, other than coaxial or twinaxial lines, are most effectively protected by transient suppression designed as an integral part of the equipment, and specified transient suppression installed at building penetration or exterior equipment termination. Effective design is shown in Figure 1-43.

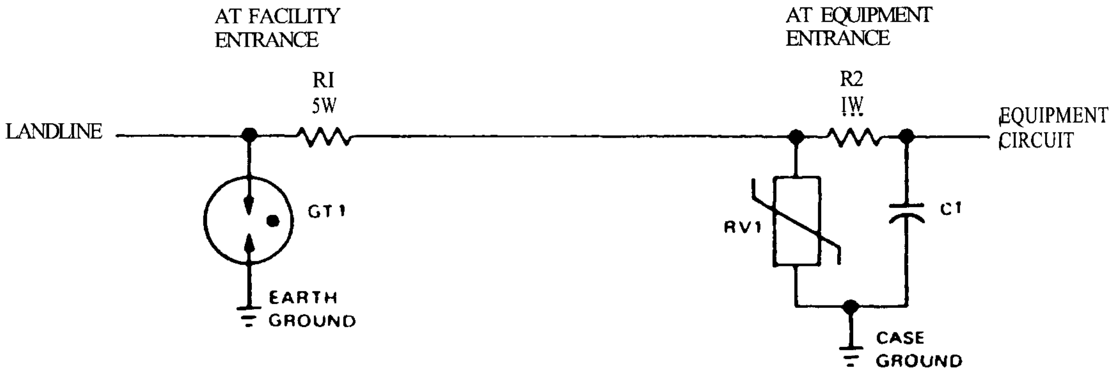
(1) Suppression design and component selection. Transient suppression will effectively protect equipment only when proper components are selected so that the components operate in conjunction to provide the desired function. This is necessary so that the clamped output of the suppression components/circuits can provide optimum equipment protection. Actual suppression components are shown in Figure 1-43 as GT1, RV1, RV2, and TS1. The suppression component at the equipment entrance should be chosen so that it has a lower turn-on and clamping voltage than the suppression component at the facility entrance. Therefore, resistor R1 must provide a voltage to turn on the suppression component at the facility entrance and limit current flow through the suppressor at equipment entrance. Otherwise, the suppression component at the facility entrance may not turn on when a transient occurs. The component will not normally turn on when a transient of less than 400 volts peak amplitude occurs and the component is a gas-filled spark gap (GT1). However, when a transient of greater amplitude occurs, the suppression component at the facility entrance must turn on. Otherwise, the suppression component at the equipment entrance will attempt to dissipate the entire transient to ground. As a result, the suppression component at the equipment entrance will attain a higher clamp voltage as it dissipates additional transient current. The higher clamp voltage is reflected across protected equipment. In addition, the suppression component is likely to fail.

(a) Gas-filled spark gap GT1. A gas-filled spark gap is suitable for use as a transient suppressor at the building/facility entrance in some cases. The device has a relatively high sparkover (turn-on) voltage and a relatively slow turn-on time when compared with a metal oxide varistor (MOV) or silicon avalanche diode suppressor (SAS). For typical lightning-induced transients on landlines, turn-on voltage is a nominal 500 volts with an associated turn-on time of 5 microseconds. These characteristics are satisfactory as long as the value of resistor R1 is 10 ohms or more, and the peak pulse current rating for the suppression component at the equipment entrance is not exceeded. When R1 is 10 ohms, a peak current of 50 amperes is required to provide a voltage of 500 volts across R1 which is the nominal turn-on voltage for GT1. Since GT1 turns on after a nominal 5 microseconds, the peak pulse current rating for most MOV and SAS devices will not be exceeded. After the spark gap turns on, arc voltage across the device is a nominal 20 volts. This may be sufficiently below the normal line voltage to create operational upset of the protected equipment, which in some cases cannot be tolerated. If normal line voltage is greater than 20 volts, difficulty may be encountered in turning off the device, depending on available current. The arc mode of operation may be sustained by current greater than 1 ampere for some devices. When the value of R1 is less than 10 ohms, an MOV or other equivalent suppressor must be used at the facility entrance because a spark gap will not turn on before the suppressor at the equipment entrance is damaged by overcurrent, particularly when the suppressor at equipment entrance is an SAS.

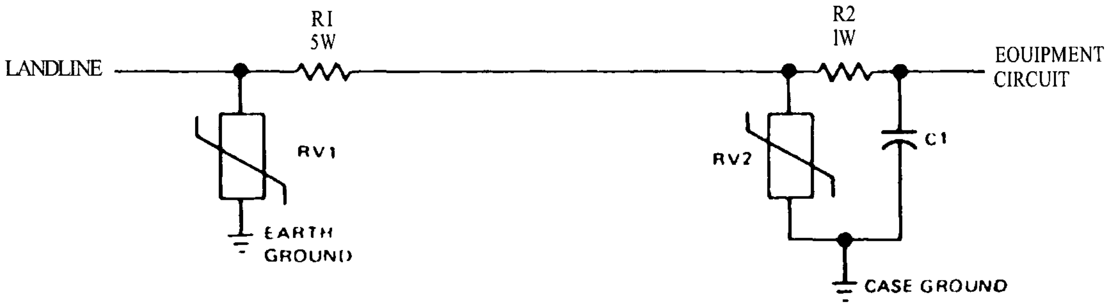
(b) Metal oxide varistor (MOV) RVl, RV2. As shown in Figure 1-43, MOVs can be used in Various configurations to provide effective transient suppression. Turn-on time for the MOV is less than 50 nanoseconds, and turn–on voltage ranges from 22 to 1800 volts. Clamp voltage is not as low as for SAS devices and turn-on time is not as fast. The turn-on time for SAS devices is typically less than 10 nanoseconds, and less than 1 nanosecond in some configurations. The configuration shown in Figure 1-43c is especially effective for protecting highly susceptible equipment. The configurations shown by Figures 1-43a and l-43b provide adequate protection when the protected equipment can safely withstand the rated clamping voltage for the MOV at the equipment entrance. An MOV with a 20 mm element diameter will normally provide required protection at the facility entrance, and a 10 m m element diameter MOV will normally provide required protection at the equipment entrance. To enable desirable functioning, the turn-on voltage of the MO V suppressor at the facility entrance should exceed that of the MOV at the equipment entrance by approximately 10%. This is desirable to permit the MOV at the equipment entrance to turn on and dissipate low-amplitude transients while reflecting a low clamp voltage to protected equipment. When a high-amplitude transient occurs, the voltage increase across Rl will cause the MOV at the facility entrance to turn on. When the MOV at the facility entrance turns on, it dissipates most of the remaining transient energy, thereby eliminating or greatly reducing the energy to the 110 V at the equipment entrance. Thus, the MOV at the equipment entrance will conduct only a small amount of current and maintain a low clamp voltage that will appear across the protected equipment. The MOV operating characteristics are similar to those for a pair of back-to-back zener diodes. Therefore, the device responds the same to a negative or positive transient voltage.

(c) Silicon avalanche diode suppressor (SAS) TS1. The SAS device has the fastest turn-on time of any of the three suppressor devices shown in Figure 1-43. Turn-on time is typically less than 10 nanoseconds and can be less than 1 nanosecond in some configurations depending on lead length and the path to ground for the device. Turn-on voltage ranges from 6.8 volts to 200 volts. Devices may be connected in series to obtain higher turn-on voltages and to improve power handling capability, For example, two devices connected in series can dissipate approximately 1.8 times the power dissipated by a single device. The clamping voltage for the device is also lower than for MOV devices. The maximum clamping voltage for the SAS devices is approximately 1.6 times the turn-on voltage at peak pulse current. Peak pulse current ranges from 139 amperes for a 6.8-volt device to 5.5 amperes for a 200-volt device over a period of 1 millisecond. Devices recommended for use at the equipment entrance have a peak pulse power dissipation rating of 1500 watts over a period of 1 millisecond. Devices are available in both unipolar and bipolar configurations. Operation of a unipolar device is very similar to that of a zener diode, and operation of a bipolar device is very similar to that of a pair of back-to-back zener diodes. For the most effective protection, unipolar devices should be used on lines that carry unipolar voltage provided the ac noise level on the applicable line is less than 0.5 volt. Use bipolar devices on lines that carry bipolar (at) voltage and on lines with an ac noise level greater than 0.5 volt. Select SAS devices based on the reverse standoff voltage rating. The reverse standoff voltage must be greater than maximum line operating voltage, and should exceed normal line voltage by 20% when possible.

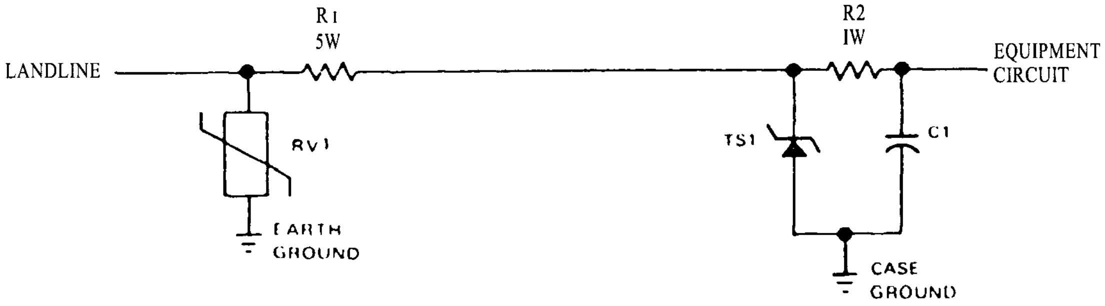
(d) Resistor Rl. The function of resistor Rl is to provide current limiting for the suppression device at the equipment entrance and to provide a turn-on voltage for the suppressor at the facility entrance. Empirical evidence has shown that the power rating for the resistor should be 5 watts. The resistance value should be as high as equipment operation will permit. Typical values are 10 to 50 ohms. Values as low as 2 ohms have been successfully used. However, when the value is less than 10 ohms, the suppressor at the facility entrance must be an MOV or equivalent type suppressor.



a. CONFIGURATION NO. 1



b. CONFIGURATION NO. 2



c. CONFIGURATION NO. 3

Figure 1-43. Typical Configuration for Protection of Equipment from Conducted Landline Transients

(e) Resistor R2 and capacitor C1. Resistor R2 attenuates current flow to protected equipment resulting from clamp voltage of the transient suppressor at the equipment entrance. The resistor also speeds up, and in some cases, generates turn-on of the transient suppressor at the equipment entrance. In addition,the resistor limits current drain from protected equipment when a transient with polarity opposite that of tile equipment power supply occurs. A power rating of 1 watt is sufficient for the resistor. The resistance value should be as high as can be tolerated by applicable equipment, taking into consideration the value of resistor R1 and the impedance of the associated landline. The purpose of capacitor C1 is to filter out some high-frequency transient components, and the value of C1 should be selected accordingly. In some cases, equipment operating characteristics and line length may preclude the use of resistor R2 and eapacitor C1.

(2) Grounding for suppresion components/circuits. The high-energy transient suppressors, shown at the facility entrance in Figure 1-43 must be grounded to earth ground by means of the shortest path. This will minimize the large voltage spikes, caused by L di/dt effects when high-amplitude transient currents flow through the high-energy transient suppressor onto the ground, which in turn may damage protected equipment or the low-energy transient suppressors at the equipment entrance.

(a) Grounding of transient suppressor at facility entrance. The high-energy transient suppressors installed at the facility entrance should be located in a junction box or the main (first) service disconnect where incoming lines are first terminated. The most effective ground for the suppressors can be provided by a ground bus bar located in the first service disconnect or the junction box. The transient protection devices (TPD's) must be bonded to the TPD box and grounded by the shortest means. It is important that the ground wire has no sharp turns or bends, and is as short as feasible. The ground bus bar should be located to permit short, direct connection of suppressors between landline terminations and earth ground.

(b) Grounding of transient suppressor at equipment entrance. The low-energy transient suppressor at the equipment entrance should be directly bonded to the equipment case when possible. The ground side of the suppressor at the equipment entrance must be connected with a short, straight, direct connection to equipment case to be effective. Connection of the suppressor to equipment case references both the suppressor and equipment circuits to the same ground potential, thus providing optimum equipment protection.

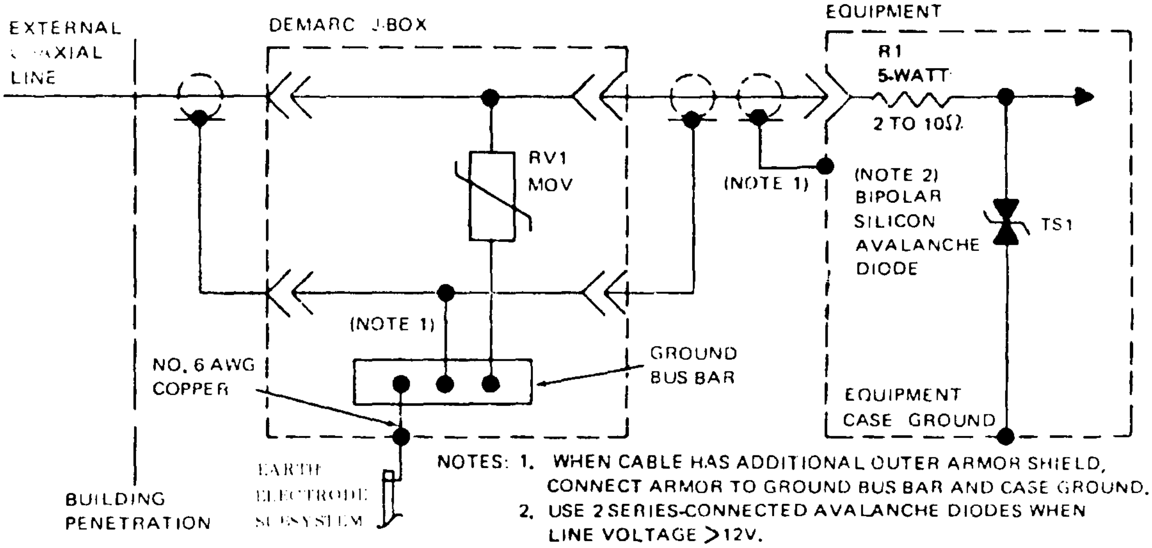
(3) Packaging design. Transient suppression components/circuits included as an integral part of equipment design should be enclosed in a shielded, compartmentalized section of the equipment. This is necessary to preclude cross-coupling of transient energy to other equipment circuits. The suppression components must be located so that transients are attenuated prior to entering any equipment component susceptible to damage, including EMI filters. Packaging design for transient suppression specified for installation at facility entrance is not critical. However, the design should provide for short, direct connection of transient suppressors between the line termination and ground.

b. Coaxial and twinaxial lines (dc to 3 MHz). The same transients are projected to occur on externally exposed coaxial and twinaxial lines as on the control and status lines discussed in paragraph 1.3.3.7.8a. In general, the same transient protection described in paragraph 1.3.3.7.8a will provide effective transient protection for equipment that directly interfaces the coaxial and twinaxial lines. That is, the most effective transient protection is provided by installing a high-energy transient suppressor and resistor at the facility entrance or exterior equipment termination, with low-energy transient suppression included as an integral part of tile equipment as shown in Figure 1-43. However, in many cases, end equipment connected to coaxial lines cannot tolerate added capacitance imposed by capacitor C_1. Also, in most cases, the added resistance of resistor R2 cannot be tolerated. Because most end equipment connected to coaxial and twinaxial lines has a relatively low withstand level, the configuration shown in Figure 1-43c, without resistor R_2 and capacitor C_1, should be used for transient suppression. The silicon avalanche diode suppressor TS_1 should always be bipolar. The configuration shown by Figure 1-43c should be used for protection of equipment that directly interfaces externally exposed twinaxial lines. In most cases, it is necessary to use a bipolar SAS since the twinaxial lines normally conduct both dc and low-level audio signals. Specific design criteria is provided in paragraphs (1) and (2) below.

(1) Facility entrance suppression. The high-energy transient suppression specified for location at facility entrance or exterior equipment termination should be designed for in-line installation on applicable lines. The lines should be terminated at a metal connector plate located in a junction box at the facility entrance or exterior equipment termination. Transient suppression components should be enclosed in a sealed, metal enclosure with appropriate connectors to facilitate in-line installation. The ground side of suppressor(s) in tile sealed package must be connected as directly as possible with No. 12 AWG copper wire (minimum) to a ground point located on the exterior of the sealed package to facilitate connection to a ground bus or tie point in the junction box. The package for a twinaxial line must include two suppression circuits, one for each of the two center conductors. Also, when a coaxial cable shield is not directly grounded at interfaced equipment, the enclosure for In-line Installation must also contain two transient suppression circuits, one for the cable center conductor and one for the cable shield. Circuit configurations for each type of line are depicted in Figures 1-44 and 1-45. Primarily because of the grounding configuration, MOV or equivalent devices should be used at facility entrance.

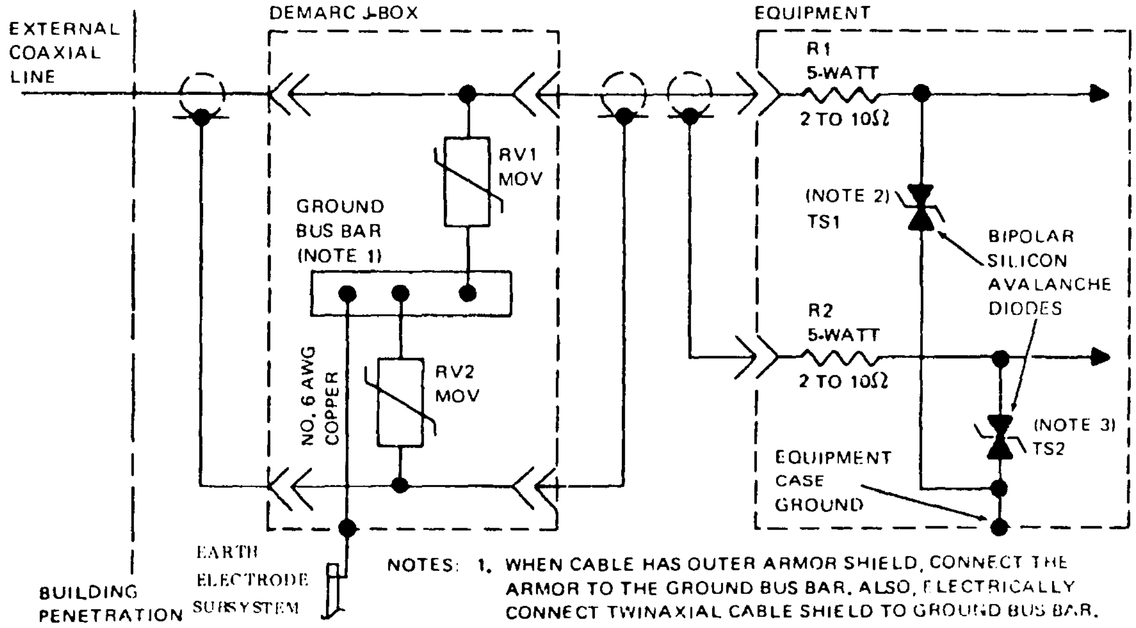
(2) Equipment entrance suppression. Equipment entrance suppression is shown in Figure 1-44 for coaxial line-equipment interfaces. The transient suppression should be enclosed in shielded, compartmentalized areas to prevent cross-coupling of transient energy to other equipment circuitry. The transient suppression must be located so that transients are attenuated prior to entering any susceptible equipment components, Including EMI filters. Because of the normally low withstand levels for end equipment, only bipolar avalanche diode suppressors should be used at equipment entrance. However, MOV suppressors may be used when the protected equipment can safely withstand tile clamp voltages that will appear across protected equipment. For the most effective protection, the ground side of transient suppressors should be bonded directly to equipment case. When direct bonding is not possible, short, direct connections to equipment case must be used.

c. Transient suppression for lines in metal conduit. When externally exposed lines are enclosed end-to-end in ferrous metal conduit, the amplitude of transients projected to be conducted to equipment will be attenuated a minimum of 90%. The number of transients that occur will not change. Therefore, the number of transients listed in Table 1-19 will still occur, but amplitudes will be only 10% of the amplitudes listed in Table 1-19. When the equipment manufacturer is absolutely certain that all externally exposed equipment lines will be enclosed in ferrous metal conduit, total transient suppression should be designed as an integral part of the equipment. The total transient suppression should consist of a 5-watt resistor in series with the landline input, and an MOV or SAS connected line-to-ground on the equipment side of the 5-watt resistor.



NOTES: 1. WHEN CABLE HAS ADDITIONAL OUTER ARMOR SHIELD, CONNECT ARMOR TO GROUND BUS BAR AND CASE GROUND.
2. USE 2 SERIES-CONNECTED AVALANCHE DIODES WHEN LINE VOLTAGE >12V.

A. TYPICAL TRANSIENT SUPPRESSION FOR COAXIAL LINE (SHIELD NOT ISOLATED FROM GROUND)



NOTES: 1. WHEN CABLE HAS OUTER ARMOR SHIELD, CONNECT THE ARMOR TO THE GROUND BUS BAR. ALSO, ELECTRICALLY CONNECT TWINAXIAL CABLE SHIELD TO GROUND BUS BAR.
2. USE 2 SERIES-CONNECTED AVALANCHE DIODES WHEN LINE VOLTAGE >12V.
3. STANDOFF VOLTAGE FOR TS2 SHOULD BE AS LOW AS POSSIBLE, BUT SHALL NOT TURN ON IN RESPONSE TO HUM VOLTAGE ON SHIELD.
4. J-BOX SHALL BE GROUNDED USING SHORTEST MEANS.

B. TYPICAL TRANSIENT SUPPRESSION FOR COAXIAL CABLES (COAXIAL SHIELD ISOLATED FROM GROUND)

Figure 1-44. Transient Suppression for Coaxial Lines (DC To 3 MHz)

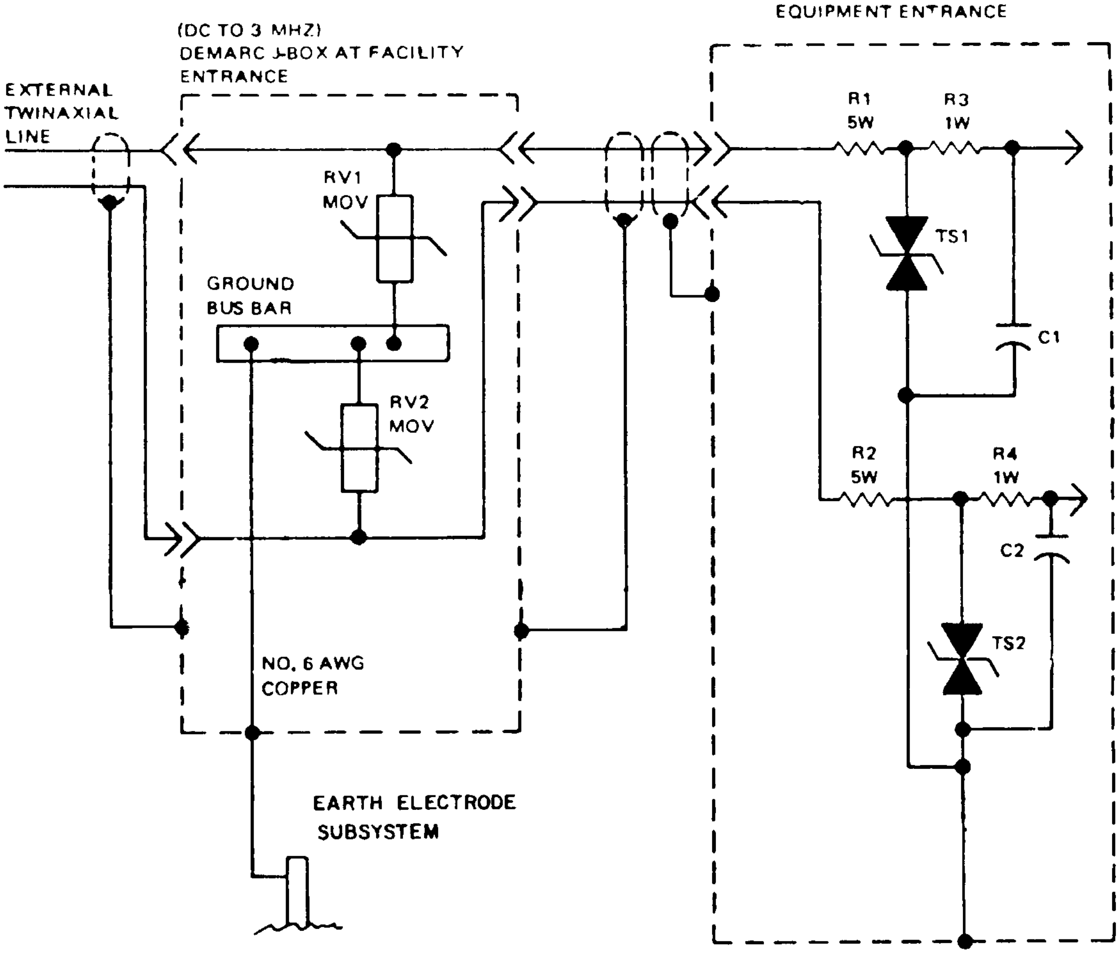


Figure 1-45. Transient Suppression for Twinaxial Lines (DC To 3 MHz)

d. Functional characteristics. For effective transient suppression, the suppression components must have certain minimum operating or functional characteristics. These characteristics are defined in paragraphs 1.3.3.7.8d(l) and (2) for high-and low-energy transient suppressors, respectively.

(1) High-energy transient suppression characteristics.

(a) Reverse standoff voltage. Reverse standoff voltage for spark gap type suppressors should be between 200 and 300 percent of the nominal operating line voltage. For MOV, ZNR, and SAS type suppressors, the reverse standoff voltage should be 175 + 25 percent of the nominal line voltage.

(b) Leakage current. Leakage current to ground should not exceed 100 microamperes at reverse standoff voltage.

(c) Turn-on voltage. Turn-on voltage should not exceed 125 percent of reverse standoff voltage.

(d) Overshoot voltage. Overshoot voltage should be the lowest voltage that can be obtained, for the shortest time possible, using the best state-of-the-art suppressors available.

(e) Clamp (discharge) voltage. Clamp voltage of the transient suppressors should be as low as possible and not more than 225 percent of turn-on voltage when discharging a transient with 1000 amperes peak amplitude.

(f) Operating life. The transient suppressor must be capable of discharging the number of transients listed in Table 1-19 with peak amplitudes that are 90% of those listed in Table 1-19. Clamp voltage must not change more than 10 percent over the operating lifetime.

(g) Self-restoring capability. The transient suppressor must automatically restore to the off state when the transient voltage level falls below turn-on voltage.

(2) Low-energy transient suppressor characteristics.

(a) Reverse standoff voltage. The reverse standoff voltage rating of the transient suppressor should be between 200 to 300 percent above the nominal line voltage for spark gap type suppressors. For MOV, ZNR, and SAS type suppressors, the reverse standoff voltage should be 175 ± 25 percent of the nominal line voltage.

(D) Turn-on voltage. Turn-on voltage of the suppression component at the equipment must be as close to reverse standoff voltage as possible using state-of-the-art devices, and shall not exceed 125 percent of reverse standoff voltage.

(c) Overshoot voltage. Overshoot voltage must be the lowest value that can be obtained, for the shortest time possible, using state-of-the-art suppressors. Overshoot voltage shall be low enough to preclude equipment damage or operational upset. The requirement will apply for transients with rise times as fast as 5,000/µs.

(d) Leakage current. Leakage current to ground should not exceed 100 microampere at reverse standoff voltage.

(e) Clamp voltage. Clamp voltage must remain below the equipment withstand level while dissipating transient currents with peak amplitude that are 10 percent of those listed in Table 1-19. The clamp voltage must not change more than 10 percent over the operating lifetime.

(f) Operating life. The transient suppressor must be capable of safely dissipating the number of transients listed in Table 1-19, with current amplitudes that are 10 percent of those listed in Table 1-19.

e. RF coaxial lines (above 3 MHz). At the present time, there is some difficulty encountered in providing effective transient suppression for lines that conduct signals above 3 MHz in frequency, and especially above 10 MHz. Most suppression devices that provide low-level clamping of transients have enough capacitance to create high insertion losses when installed line to ground on the conductor. Packaging of the devices for in-line installation without causing high insertion losses is also difficult and expensive. Gas-filled spark gaps have been successfully packaged for in-line installation on critical rf lines, but unit cost is excessive. Also, gas-filled spark gaps do not always provide satisfactory protection because of high sparkover (turn-on) voltage, slow turn-on time, and low arcing voltage. Therefore, the best alternative at present is to include transient suppression design as an integral part of new equipment.

(1) Transient suppression design. Potential sources of effective transient suppression are gas-filled spark gaps, MOV in series with rf chokes, and surge-rated, low capacitance silicon avalanche diodes paralleled with selected rf chokes. All of the suppression devices and components are for line-to-ground connection at the line-equipment interface.

(2) Transient suppression grounding. The total transient suppression is included as an integral part of the equipments, and may have to dissipate the transient currents listed in Table 1-19. However, in most cases, these lines will be enclosed in ferrous metal conduit, and the amplitude of occurring transients will therefore be only 10% of the values listed in Table 1-19. In either case, the transient suppression should be grounded directly to equipment case ground using the shortest and most direct method possible. The equipment case must, in turn, be effectively connected to the earth grounding system via the equipment rack and the equipment grounding conductor, when applicable.

(3) Packaging design. The transient suppression should be located in a shielded, compartmentalized section of the equipment and located so that conducted transients are attenuated prior to entering any susceptible circuit component.

1.3.3.8 Corrosion Control.

a. The materials of which lightning protection subsystems are made must be highly corrosion resistant. Junctions or contact between dissimilar metals must be avoided; where such unions are unavoidable, moisture must be permanently excluded from the contacting surfaces.

b. Where any part of a copper protective system is exposed to the direct action of chimney or other corrosive gases, the exposed copper elements are to be protected by a continuous hot dip coating of lead. The coating should extend at least 0.6 meters (2 feet) below the top of the chimney or past the vent or flue opening.

c. Where aluminum down conductors are used, do not permit them to come in contact with the soil.

(1) Connections between aluminum down conductors and copper ground electrode risers are not to be made lower than one foot above grade level; use UL-approved bimetallic connectors for these connections.

(2) Aluminum parts, including fasteners and anchors, should be protected from direct contact with concrete or mortar wherever such concrete or mortar is wet or damp or may become intermittently wet or damp.

(3) Aluminum parts also must be protected from contact with alkaline-based paints.

d. Aluminum parts are not to be used on copper roofing materials and must not contact other copper surfaces such as gutters, flashings, and trim. Similarly, do not use copper lightning protection materials on aluminum structures or on structures using aluminum roofing materials or aluminum siding. Avoid contact between copper conductors, terminals, and fasteners and aluminum gutters, windows, and trim.

e. In aluminum lightning-protection systems, copper, copper-covered, or copper-alloy fixtures and fittings must not be used for connectors. Where aluminum must connect to copper, only UL-approved bimetallic connectors are to be used.

1.3.3.9 Joints.

a. Welded or brazed bonds are preferred over all other types; in particular, junctions in inaccessible locations should be welded or brazed whenever practical.

b. Never use soldered connections for bonding any part of the lightning protection system.

c. Bolted or clamp-type connections should employ only UL-approved connectors.

d. Where bolted connections to flat surfaces are necessary, the surface contact area should be 3 square inches (19.5 square cm) or greater.

1.3.3.10 Physical Protection.

a. Protect all elements of the lightning protection system from damage and physical abuse by routing conductors to take advantage of any protection offered by structural features. Install appropriate guards or covers preferably made of wood or noncombustible synthetic material.

b. Where conductive conduit is used, bond the conduit to the enclosed lightning conductor at each end of each isolated section of the conduit. (Standard conduit grounding lugs are acceptable.)

c. The use of ferrous conduit to enclose lightning conductors should be avoided because it increases the impedance of the lightning conductor.

1.4 FAULT PROTECTION SUBSYSTEM.

1.4.1 Purpose. In Volume I, the equipment fault protection subsystem was described as a network which ensures that personnel are protected from shock hazard and equipment is protected from damage or destruction resulting from faults that may develop in the electrical system. To accomplish this, ground connections must be adequate for both normal and fault currents. The fault protection subsystem includes the green wire and all exposed noncurrent-carrying metal parts of fixed equipment such as raceways and other enclosures which are likely to be energized under power fault conditions. Any conductor used for grounding purposes shall not penetrate any designated rf barrier, screen room, shielded enclosure etc., but shall rather be bonded to a welded stud on the barrier. In general, the equipment fault protection subsystem will conform to the requirements established in MIL-STD-188-124A.