

HOW TO PROTECT YOUR HOUSE AND ITS CONTENTS FROM LIGHTNING

IEEE GUIDE FOR SURGE
PROTECTION OF EQUIPMENT
CONNECTED TO AC POWER
AND COMMUNICATION
CIRCUITS



IEEE

Published by
Standards Information Network
IEEE Press

How to Protect Your House and Its Contents from Lightning

***IEEE Guide for Surge Protection of Equipment
Connected to AC Power and Communication Circuits***



Published by
Standards Information Network
IEEE Press

Trademarks and Disclaimers

IEEE believes the information in this publication is accurate as of its publication date; such information is subject to change without notice. IEEE is not responsible for any inadvertent errors.

Library of Congress Cataloging-in-Publication Data

How to protect your house and its contents from lightning : surge protection : IEEE guide for surge protection of equipment connected to AC power and communication circuits. p. cm.

by Richard L. Cohen and others.

ISBN 0-7381-4634-X

1. Lightning-arresters. 2. Electronic apparatus and appliances--Protection. 3. Transients (Electricity). 4. Lightning protection. I. Cohen, Richard L., 1936-

TK3248.H685 2005
621.31'7--dc22

2005043304

IEEE

3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2005 by IEEE

All rights reserved. Published April 2005. Printed in the United States of America.

No part of this publication may be reproduced in any form, in an electronic retrieval system, or otherwise, without the prior written permission of the publisher.

The National Electrical Code and NEC are registered trademarks of the National Fire Protection Association (<http://www.nfpa.org/>).

NEMA is a registered trademark of the National Electrical Manufacturers Association (<http://www.nema.org/>).

UL is a registered trademark of Underwriters Laboratories, Inc. (<http://www.ul.com/>).

TiVo is a registered trademark of TiVo Inc. (<http://www.tivo.com/>).

Yvette Ho Sang, Manager, Standards Publishing
Jennifer Longman, Managing Editor

IEEE Press/Standards Information Network publications are not consensus documents. Information contained in this and other works has been obtained from sources believed to be reliable, and reviewed by credible members of IEEE Technical Societies, Standards Committees, and/or Working Groups, and/or relevant technical organizations. Neither the IEEE nor its authors guarantee the accuracy or completeness of any information published herein, and neither the IEEE nor its authors shall be responsible for any errors, omissions, or damages arising out of the use of this information.

Likewise, while the author and publisher believe that the information and guidance given in this work serve as an enhancement to users, all parties must rely upon their own skill and judgement when making use of it. Neither the author nor the publisher assumes any liability to anyone for any loss or damage caused by any error or omission in the work, whether such error or omission is the result of negligence or any other cause. Any and all such liability is disclaimed.

This work is published with the understanding that the IEEE and its authors are supplying information through this publication, not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought. The IEEE is not responsible for the statements and opinions advanced in the publication.

Review Policy

The information contained in IEEE Press/Standards Information Network publications is reviewed and evaluated by peer reviewers of relevant IEEE Technical Societies, Standards Committees and/or Working Groups, and/or relevant technical organizations. The authors addressed all of the reviewers' comments to the satisfaction of both the IEEE Standards Information Network and those who served as peer reviewers for this document.

The quality of the presentation of information contained in this publication reflects not only the obvious efforts of the authors, but also the work of these peer reviewers. The IEEE Press acknowledges with appreciation their dedication and contribution of time and effort on behalf of the IEEE.

To order IEEE Press Publications, call 1-800-678-IEEE.

Print: ISBN 0-7381-4634-X SP1137

*See other IEEE standards and standards-related product listings at:
<http://standards.ieee.org/>*

Background and Acknowledgments

The IEEE Surge Protection Devices Committee (SPDC) has been writing Standards for lightning and surge protection for more than 30 years. The current versions of the IEEE C62 Family of Standards represent the state of the art in these areas.

This application guide was written to make the information developed by the SPDC more accessible to electricians, architects, technicians, and electrical engineers who were not protection specialists.

Many people aided in this process. François Martzloff and Don Worden provided much of the initial inspiration. Chrys Chrysanthou, Ernie Gallo, Phil Jones, Chuck Richardson, François Martzloff, and Steven Whisenant lent their expertise and guidance at the beginning of this project. Duke Energy and Steven Whisenant provided the resources for drawing the figures, and George Melchior of Panamax created the cover art. Many other people within the IEEE SPDC actively supported the project. We thank Yvette Ho Sang and Jennifer Longman, of the IEEE Standards Information Network, for their creativity in finding a niche for this work and managing it through the editorial process.

Richard L. Cohen
Doug Dorr
James Funke
Chuck Jensen
S. Frank Waterer

About the Authors

Richard L. Cohen (*Editor, Author*) is a Consultant for lightning and surge protection. He was Vice President of Engineering at Panamax, Incorporated. Prior to joining Panamax, he was the manager for lightning protector development at Bell Laboratories. He started and was Chair of the IEEE Surge Protection Device Working Group 3.6.10, for multi-port surge protector standards, and is a member of the UL Standards Technical Panels for low-voltage AC protectors and lightning protection systems. Dr. Cohen is a Senior

Member of the IEEE, and a Fellow of the American Physical Society and of the American Association for the Advancement of Science. He holds a B.S., M.S., and Ph.D. in Physics, and has seven patents, with four more applications pending. He has authored over 200 research papers and reviews.



Doug Dorr (*Author*) is Director of Technology Development at EPRI Solutions, Inc. He has been involved in power quality research and surge protective device testing for the past 14 years. He is the Vice Chair of the IEEE Surge Protective Devices Main Committee and also Chair of the Low-Voltage AC Surge Protective Device Working Group. Mr. Dorr has been involved in development of more than a dozen standards and currently chairs the 2005 revision to the IEEE Emerald Book, an “IEEE Recommended Practice on Power and Grounding Electronic Equipment”. He is a Senior Member of the IEEE, and received a Bachelor of Science degree in Engineering, with electrical concentration, from the Indiana Institute of Technology in Fort Wayne, Indiana.



James Funke (*Associate Editor, Author*) is Chief Engineer of Eaton's Cutler-Hammer business unit. He was previously Chief Engineer for Tycor International. He has specialized in surge protection research throughout his career. He is Chair of the IEC SC37A Technical Advisory Group reporting to the Standards Council of Canada. He is also the Chair of the CSA committee writing safety standards for SPDs, and actively participates on Surge Protection committees with NEMA and UL. Mr. Funke is contributing to several IEEE SPD Committee working groups on surge protection, and has received two Working Group awards for contributions to surge protection standards. He holds seven surge protection patents, with three more applications pending. He is an IEEE Senior Member and has a Bachelor of Science degree in Electrical Engineering (1988) and a Masters of Business Administration (2004).



Chuck Jensen (*Author*) is Senior Engineer with Duke Power Company. He serves as a Power Quality Specialist, providing consulting engineering services to customers of the utility, and specifies and designs surge protection systems. He is a Member of the IEEE, serving on several IEEE SPD Committee working groups. Mr. Jensen also serves on the UL Standards Technical Panel for Surge Protective Devices, STP 1449, and is a Registered Professional Engineer in the states of North Carolina and South Carolina. He has a Bachelor of Science degree in Electrical Engineering (1984).



S. Frank Waterer (*Author*) is a Staff Engineer at Schneider Electric. He provides consulting engineering services to commercial and industrial customers about power distribution systems, power equipment applications, grounding systems, protective relaying, ground fault protection, and surge protection. He is a Member of IEEE and is the Secretary of IEEE/SPDC. Mr. Waterer is a member of numerous IEEE, UL, NEMA, and ANSI working groups and technical committees relating to grounding and surge protection. He has a Bachelor of Science degree in Electrical Engineering (1980).



Contents

1. Introduction	1
1.1 The Environment	2
1.1.1 Lightning	2
1.1.1.1 Damage from Lightning	4
1.1.1.2 Basic Protection Against Lightning	5
1.1.1.3 Enhanced Protection against Lightning	8
1.1.2 AC Power Fluctuations	10
2. Building Service Entrance Surge Protectors (SPDs)	12
2.1 The Surge Environment	13
2.1.1 Normal Conditions	14
2.1.2 Abnormal Conditions	15
2.1.2.1 Temporary Overvoltage (TOV)	15
2.2 Surge Protective Device Ratings	15
2.2.1 Typical Modes of Protection	16
2.2.2 Surge Current Ratings	18
2.2.3 Surge Limiting Voltage (Let-Through Voltage)	19
2.2.4 Coordination with Downstream SPDs	21
2.3 Installations	21
2.3.1 Grounding	22
2.3.2 Lead Length	22
2.3.3 Overcurrent Protection	24
2.4 Combined AC Panel Protection and Signal Protection	24
2.5 Other Factors	25
2.5.1 Joule Rating	25
2.5.2 Limitations of Panel SPDs	26
3. Primary Signal Protection	27
4. Ground Potential Rise	30
4.1 Ground Potential Rise within a Building	31
4.2 Ground Potential Rise for Equipment Outside a Building	34

5. Multi-port Point-of-Use (Plug-In) Protectors	35
5.1 AC Protection Circuits	36
5.2 Signal Protectors	40
5.3 Inter-System Bonding	42
5.4 Special-Purpose Protectors	44
 6. Specific Protection Examples	 45
6.1 Home Theater with Satellite Receiver or CATV Feed	45
6.2 PC with Cable Modem and Wireless Link	48
 7. Further Information	 50
7.1 General Information about Lightning and Protection Standards	50
7.2 Lightning Protection and Protection Equipment.	51
7.3 Codes and Standards	51

1. INTRODUCTION

This guide is intended to provide useful information about the proper specification and application of surge protectors, to protect houses and their contents from lightning and other electrical surges. The guide is written for electricians, electronics technicians and engineers, electrical inspectors, building designers, and others with some technical background, and the need to understand lightning protection.

Surge protection has become a much more complex and important issue in recent years. The value of electronic equipment in a typical house has increased enormously. That equipment is also more vulnerable to surges produced by lightning, because it is networked with other equipment throughout, and even outside, the house. AC protection alone, the traditional approach, is totally inadequate to protect most of the equipment in a typical residence. This guide is intended to make more widely known the approaches required to protect modern electrical and electronic equipment in houses.

While these surge protection recommendations are broadly applicable, the emphasis will be on single-family residential buildings, supplied by split-phase 240/120 V AC power systems, in which the AC neutral is bonded to the building ground at the service entrance. The discussion also assumes that the building electrical system and the lightning protection system, if any, comply with the appropriate codes: the National Electrical Code[®] (NEC[®])¹ for the United States, or the Canadian Electrical Code (CEC) for Canada, and the Lightning Protection Code, NFPA 780, for a lightning protection system, if installed. (See Section 7 for more complete listings.)

It has been difficult for homeowners and installers to get a good overview of protection options and issues, because several different codes and standards [the NEC/CEC, NFPA 780, and eight Underwriters Laboratories, Inc.[®] (UL[®])

¹ The NEC is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA (<http://www.nfpa.org/>). Copies are also available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

standards] control the equipment and installation requirements for various parts of the protection system. Electricians, lightning protection system installers, and cable, telephone, satellite, and security system technicians install the electrical and electronic equipment in the house. These installers may or may not provide surge or lightning protection equipment. In general, there is little understanding of how the different parts of the protection system need to work together. Since the different electronic systems are often interconnected by signal and control wiring, a defect in the lightning protection for one system can allow surges from lightning to propagate to other systems, producing massive damage.

This *Guide* is intended to help provide a systematic understanding of what the various parts of a protection system do. It describes the roles of the different elements of protection systems—air terminals (lightning rods), the grounding system, bonding, and building service entrance and point-of-use surge protectors, and the way these elements work together to protect equipment inside a residential building.

1.1 The Environment

1.1.1 Lightning

Lightning is a natural phenomenon caused by separation of electrical positive and negative charges by atmospheric processes. When the separated charge gets very large, the air between the positive and negative regions breaks down in a giant spark (an intra-cloud stroke), or a charged region breaks down to ground (a cloud-ground stroke). The resulting current flow ionizes and heats the air along the path to ~30,000 K (54,000° F). The ionized air glows brightly (the lightning), and the sudden increase in temperature expands the channel and nearby air, creating a pressure wave that makes the thunder. Most (~80%) lightning strokes are within a cloud; most of the remainder are cloud-ground strokes. Strokes between clouds are relatively rare. Most cloud-ground strokes transfer negative charge from the cloud to ground.

Most lightning properties are beyond normal human experience. The cloud-to-ground voltages leading to the discharge are tens of millions volts or more. The peak discharge currents in each stroke vary from several thousand amperes to 200,000 A or more. The current rises to these values in only a few millionths of a

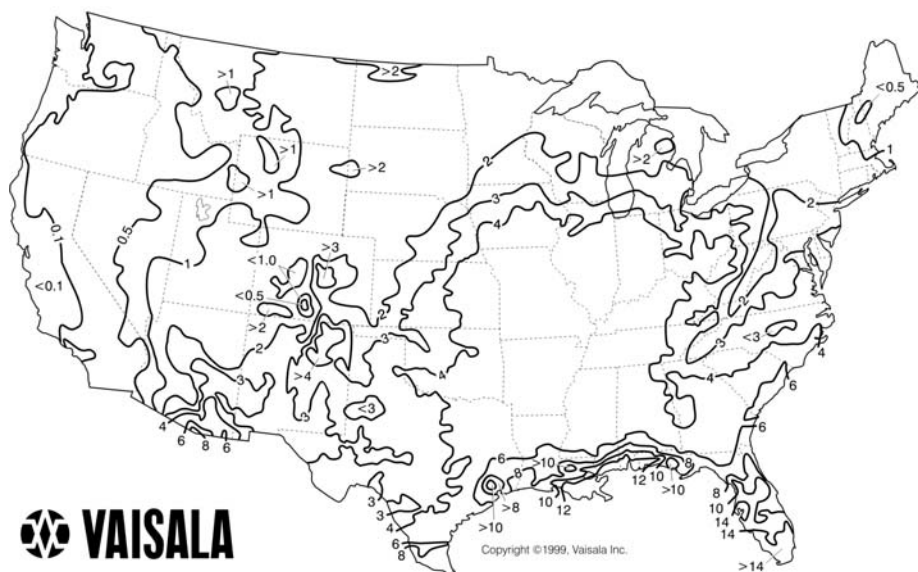


Figure 1: 1989-1998 Average US lightning flash density, in flashes/km² per year. The highest level corresponds to 37 flashes/mi² per year. The frequency varies widely from year to year and with local terrain variations. Lightning map reprinted with permission by Vaisala.

second (microsecond), and the major part of each stroke usually lasts much less than a thousandth of a second. Each visible event, referred to as a flash, typically consists of 1–6 (or more) individual strokes, separated by <0.1 second. Further details are cited in the references in Section 7.1.

Lightning behaves very capriciously. Cloud-ground strokes have been recorded reaching as far as 18.6 miles (30 km) horizontally from the base of the cloud.

The frequency of lightning flashes varies widely with location and season. Figure 1 is a cloud-ground flash density contour map showing the wide variation in lightning frequency, from <0.1 flash/km² (<.26 flash/mi²) per year in the Pacific Northwest to ~14 flash/km² (~37 flash/mi²) per year in Florida, more than 100x higher. In addition to this broad range, there are wide local variations

due to local topography. Hilltops and ridges are generally struck much more frequently than valleys. Also, year-to-year weather changes create major variations; there are years when locations in the midwest actually have flash densities as high as those in Florida.

1.1.1.1 Damage from Lightning

People generally think of lightning damage as what happens at the point where a cloud-ground stroke terminates on a tree, structure, or elevated wiring. This is generally called a lightning strike. Unless the struck items are protected from lightning, the results of the strike are often visible and lasting. But the lightning current pulse continues into conductive parts of the structure, cables, and even underground wiring and pipes. Because the initial lightning impulse is so strong, equipment connected to cables a mile (1.6 km) or more from the site of the strike can be damaged.

Figure 2 shows four ways in which a lightning strike can damage residential equipment, in order of decreasing frequency of occurrence. The most common damage mode shown in Figure 2 (labeled 1) arises from a lightning strike to the network of power, phone and cable television (CATV) wiring. This network, especially if it is elevated, is an effective collector of the lightning surges. The wiring then conducts the surges directly into the residence, and then to the connected equipment. While not shown in Figure 2, lightning can also travel through the ground (soil), reaching underground cables or pipes. This is another route for lightning to come into a building, and can also damage the cables.

The second most common mode (2) shown in Figure 2 results from strikes to, or near, the external wiring network common to most suburban and rural houses. Air conditioners, satellite dishes, exterior lights, gate control systems, pool support equipment, patios and cabanas, phone extensions, electronic dog fences, and security systems can all be struck by lightning, and the lightning surges will then be carried inside the house by the wiring.

As shown in Figure 2, lightning may strike nearby objects (trees, flagpoles, signs) that are close to, but not directly connected to the house (mode 3). In this situation, the lightning strike radiates a strong electromagnetic field, which can be picked up by wiring in the house, producing large voltages that can damage equipment.

Finally, Figure 2 shows (mode 4) a direct lightning strike to the structure. This type of strike is very rare, even in high-lightning areas. It can severely damage a structure without a lightning protection system (LPS), and will generally damage most electronic equipment in the house. The structure damage can normally be prevented by a properly installed LPS of Faraday rods and down conductors, but the LPS alone provides little protection for the electronic equipment in the house.

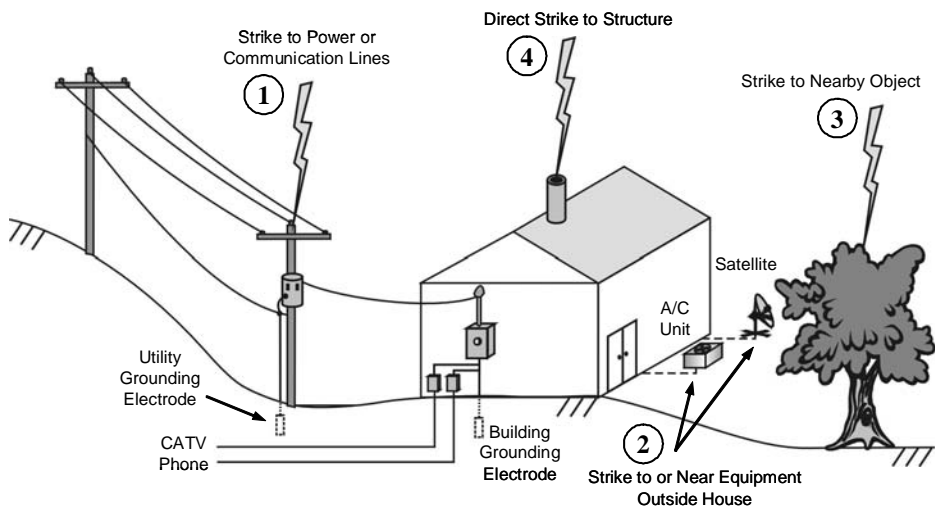


Figure 2: How Lightning Creates Damaging Voltages Inside the Home. The most common source of damage is from strikes to power and communications lines, which then conduct the surges directly into the equipment. Direct strikes to the building, while rare, can damage the structure as well as the contents.

1.1.1.2 Basic Protection Against Lightning

The National Electrical Code (NEC) and CEC require certain grounding, bonding and protection features which are intended to protect against lightning. Figure 3 shows certain basic grounding and protection requirements of the NEC and CEC. Figure 3 is not intended to be comprehensive of the NEC and CEC requirements. These safeguards greatly reduce the risk of shock or electrocution to a person in the house, and the risk of fires caused by lightning. However, they are totally inadequate to prevent damage to electrical and electronic equipment.

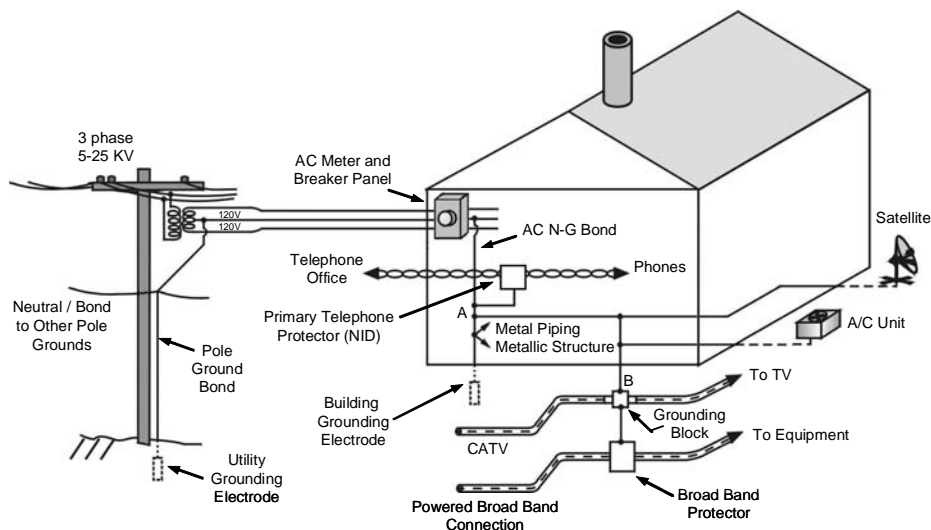


Figure 3: Basic Grounding and Protection Required by 2002 NEC. The CEC and NEC require grounding of the electrical service to an appropriate ground electrode, protectors for telephone lines and powered broadband connections, and grounding of the sheaths of all coaxial cables. Metallic piping and structure parts must be connected to the building ground.

The main features² shown in Figure 3 are as follows:

- 1) The main building ground (grounding electrode system, in NEC/CEC terminology) is used as the central ground point to which all lightning currents will be conveyed. Independent, unbonded ground rods are not accepted. This is discussed further in Section 4 of this *Guide*.
- 2) The NEC/CEC requirements are intended to remove most lightning surge currents from all signal wires entering the building from utilities. For coaxial cables, only the sheath must be grounded; for telephone wiring (twisted pair) a special building entrance protector (the “NID,” see Section 3 of this *Guide*) limits the impulse voltage between both

² Consult actual NEC requirements in Articles 250, 800, 810, and 830, or the corresponding CEC Articles, for full details.

wires and ground to less than ~1000 V. Sheaths of coaxial cables from satellite antennas must also be bonded to the building ground (NEC Art. 810, and CEC).

- 3) The NEC/CEC requirements for connecting all metal piping and large metal parts of the structure to the building ground serve two purposes: If there is metallic buried water piping, bonding it to the building ground improves the quality of that ground. Also, in the rare event of a direct strike to the piping, or to a metallic part of the structure, the ground bond conducts the lightning currents safely into the building ground. This greatly reduces the voltage differences between the parts of the structure, and therefore decreases possible injury to the residents, and reduces the possibility of a fire within the structure due to surge currents and voltage flashovers.

These requirements greatly reduce the likelihood of injury to the residents, and damage to the structure itself, from lightning. However, there are many loopholes in the basic NEC/CEC requirements. Most obviously, there is little mitigation if there is a direct strike to the building, especially if the upper sections of the building have no wiring or conductive material to terminate the strike. (Because of the extremely high lightning voltages and surge currents, building distribution wiring built to NEC/CEC standards is inadequate to terminate direct strikes safely.)

More importantly, most buildings now have many additional outside connections—exterior lighting, remote gate controls and security monitors, electronic dog fences, auxiliary buildings, etc., which are often not dealt with in the codes. Any of these connections can bring damaging lightning currents into the building.

Finally, and most significant for many people, modern houses have from \$5,000 to, in rare cases, \$500,000 of electrical/electronic equipment, such as in utility systems, home entertainment systems, computers, security systems, and building automation systems. All of these are extremely vulnerable to lightning surges brought in on power or signal cables, and the basic NEC/CEC requirements do little to protect them.

This *Guide* is also intended to provide both general guidelines and specific examples of the use of surge protectors to mitigate this problem.

1.1.1.3 Enhanced Protection against Lightning

The NEC/CEC allow for increased protection in high-lightning areas by the optional installation of the following:

- 1) A lightning protection system (LPS);
- 2) Surge protectors on the AC power wiring;
- 3) Additional surge protectors on signal wiring;
- 4) “Supplementary protection” (also called “Point-of-Use” protection) at the equipment to be protected.

Figure 4 shows schematically how the first three above are installed.

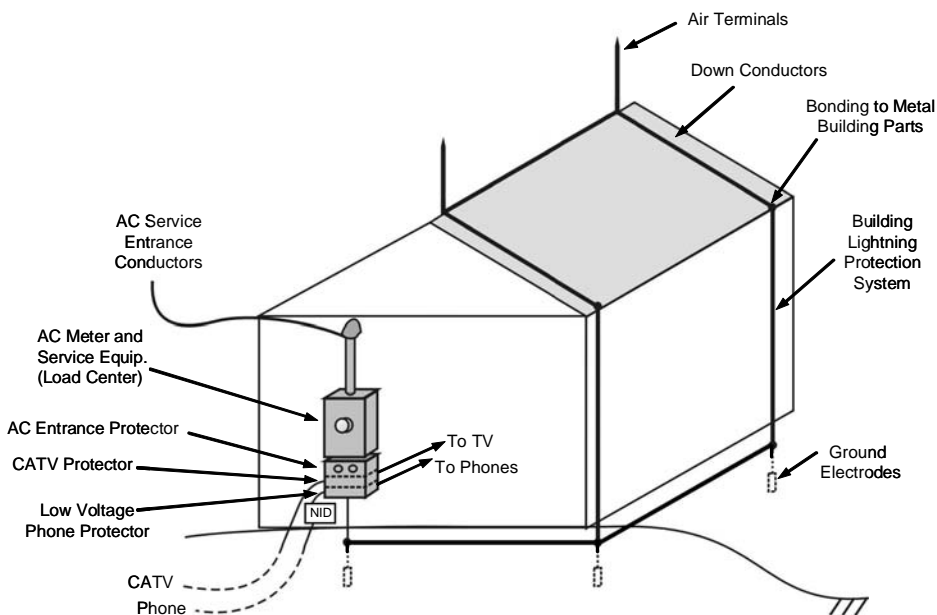


Figure 4: Additional Protection Described by NEC. The NEC allows the addition of air terminals (“lightning rods”), bonded to the building ground, and additional AC protectors, coaxial protectors, and telecom protectors. The three ground electrodes and the bonds between them form the building ground electrode system.

Although the lightning protection system is the most visible improvement, it is only useful in the extremely rare direct strike scenario, such as in mode 4 of Figure 2. The basic elements are shown in Figure 4. The lightning strike attaches to the tip of the air terminal, and the lightning current flows via the down conductors into the lightning ground system, which is bonded to the building ground. Properly installed systems should be undamaged by even the largest recorded strikes. They should, however, be inspected periodically to assure that mechanical damage has not occurred.

The design and installation of the lightning protection system is not described by the NEC, but by a related document, NFPA 780-2004. Fortunately there has just been a major recent revision to this code, with strong improvements, especially in requirements to install surge protectors to protect the electrical and electronic equipment inside the house. The new code recognizes only passive strike-terminating devices such as metal rods and heavy wires.

The later sections of this *Guide* provide more detailed information on the selection and installation of surge protectors than is provided in the NEC/CEC and NFPA 780.

AC and signal surge protectors at the building entrance (items 2 and 3 above) serve similar purposes. They collect the major part of the lightning surge currents coming in on external wiring, and direct them harmlessly into the building ground. They also limit the surge voltages that get inside the building, and greatly reduce the burden on the point-of-use protectors, at the equipment.

The effectiveness of this protection system depends on the integrity of the building wiring. A good surge protection system installation should include testing of all the receptacles to be used, for correct connection of the line, neutral, and ground. This should be done using a tester which can detect interchange of the neutral and ground connections, a common problem. Incorrectly wired receptacles can often appear to function normally, but may not allow point-of-use protectors to function properly.

Most new houses are built with power, phone, and CATV entry points close to one another. That is very desirable, and makes it easy to mount the AC protectors and signal protectors close to the main building ground point (Figure 4).

If wiring comes into a building at many different points, it is much more difficult to get proper protection against lightning surges. Even if surge protectors are installed at these alternate entry points, the long ground wires running back to the main building ground greatly reduce the effectiveness of the protectors. In high-lightning areas, where lightning protection is a major concern, it is worth routing as many AC and signal cables as possible past the building power entry point, to facilitate good grounding for protectors and cable sheaths.

The coaxial cables carrying CATV signals and small-dish (DBS) satellite signals are often the path for damaging lightning surges to enter the building. For CATV cables, the code-required bonding of the sheath to the building ground is frequently omitted. For the satellite systems, the NEC/CEC require bonding of the antenna mounting hardware, as well as the incoming cable sheath, to the building ground. This is often difficult to do. If the incoming CATV or antenna lines can be routed to a distribution closet near the AC service entry point, the required bonding can be achieved.

1.1.2 AC Power Fluctuations

In addition to lightning, there are a number of other disturbances that can come in on the AC power lines and damage equipment. Some surge protectors described in Sections 2 and 5 of this *Guide* can reduce or eliminate damage from some of these perturbations. There is considerable confusion about the overlap between damage from AC power disturbances and from lightning.

Five different anomalies in AC power can damage equipment commonly found in homes. They are as follows:

- 1) **Open neutral events**—It is not widely appreciated that “open-neutral events” are a very common cause of damage to customer equipment, at least in some areas.³ Open-neutral problems arise when the neutral wire (see Figure 3) between the center tap of the distribution transformer and the neutral at the service equipment becomes loose, broken, or disconnected, or where the neutral-ground bond inside the house is defective. At the transformer, the 240 V full-phase output is evenly divided into two 120 V phase voltages, with the neutral wire being

³ See paper by R.G. Smith, called “Did a Surge Fry Your Equipment,” available on the Panamax website at <http://www.panamax.com>.

common for both phases. If the neutral connection is disconnected or broken, the 240 V full-phase voltage at the house will no longer be divided into two equal 120 V phases. The division will be determined mainly by the relative load on the two phases,⁴ and the phase-neutral voltages can easily be as different as 200 V on one phase, and 40 V on the other. The excess voltage on one phase can easily damage 120 V equipment.

As discussed in Section 2, AC service entrance protectors alone do not provide useful equipment protection against these events. However, a combination of entrance protectors and some point-of-use (plug-in) surge protectors described in Section 5 can protect or reduce damage to equipment plugged into them.

- 2) ***Catastrophic overvoltages***—Rare “catastrophic” overvoltages can result from accidental contact between high-voltage lines and low-voltage AC distribution lines, due to icing, traffic accidents, falling trees, etc. In such situations, voltages up to thousands of volts can be brought into houses.

AC building entrance protectors described Section 2 may provide some protection against these events. Again, the combination of entrance protectors with the point-of-use (plug-in) surge protectors described in Section 5.1 can offer better protection to the equipment plugged in than either one alone.

- 3) ***Sustained AC overvoltages***—Sustained overvoltages (typically, over 135 V on 120 V service) can result from malfunction of utility regulators or damaged distribution transformers.

AC building entrance protectors do not provide useful protection against these events. Electronically controlled point-of-use (plug-in) surge protectors described in Section 5.1 disconnect for AC voltages outside a specified range, and offer useful protection to equipment plugged into them.

⁴ The resistance between the house ground rod and the utility pole ground rod is usually too large to control the voltage division.

- 4) **AC undervoltages/brownouts**—AC undervoltages (typically, below ~100 V) may result from overloaded transformers or utility or building wiring, or malfunctioning regulators. Undervoltages can lead to equipment damage because motor-driven appliances and some electronic power supplies draw higher current at low voltage and will overheat.

A few of the point-of-use (plug-in) surge protectors described in Section 5.1 are electronically controlled, and will disconnect at low voltage and should protect equipment plugged into them.

- 5) **Utility switching transients**—Utility switching transients that come into homes are generally of relatively low voltage and energy.

Switching transients large enough to damage customer equipment will normally be adequately controlled by either building entrance protectors or plug-in protectors.

In areas where the environment is very rugged and utility lines are long and subject to frequent damage, the protectors described below in Sections 2 and 5 can greatly decrease damage to residential equipment, for a modest expense. So even if there is little lightning risk, it can be worthwhile to install these protectors.

2. BUILDING SERVICE ENTRANCE SURGE PROTECTORS (SPDs)

The intent of this section is to give the user, specifier, or contractor the information needed to make an informed decision on the application of service-entrance surge protective devices. The information presented here is specific to residential and light commercial applications and does not discuss all the complexities of an industrial environment.

UL lists two different categories of SPD for use at the service entrance: an older category, Surge Arresters, and a newer category, Transient Voltage Surge Suppressors (TVSS). The TVSS are listed under UL Standard 1449.⁵

Although SPDs UL Listed/CSA Certified as Surge Arresters are allowed to be installed at the service entrance (NEC Art. 280) if listed for the purpose, the authors recommend that only products listed as TVSS be used at an accessible

⁵ The Surge Arrester products are supposed to be brought into the UL Standard 1449 in the near future.

service entrance location. TVSS devices are tested differently from Surge Arresters, and the authors consider the TVSS test to be more appropriate for SPDs to be used in accessible locations. TVSS products are only allowed to be installed downstream from the main disconnect of a building (NEC Art. 285). Upstream products need to be marked (Listed/Certified) as a Surge Arrester to meet safety codes such as the NEC or CEC.

2.1 The Surge Environment

Surge protective devices applied at the service entrance mains of residential AC power circuits will be subjected to normal and abnormal surge conditions as well as abnormal AC voltage conditions. The design of the application must consider these conditions to prevent premature degradation and failure. Figure 5 shows a typical Service Entrance and possible SPD mounting locations. This diagram does not mean to limit the places an SPD can be located but merely to give typical locations of mounting an SPD. Locations A, B, and C of Figure 5 would be

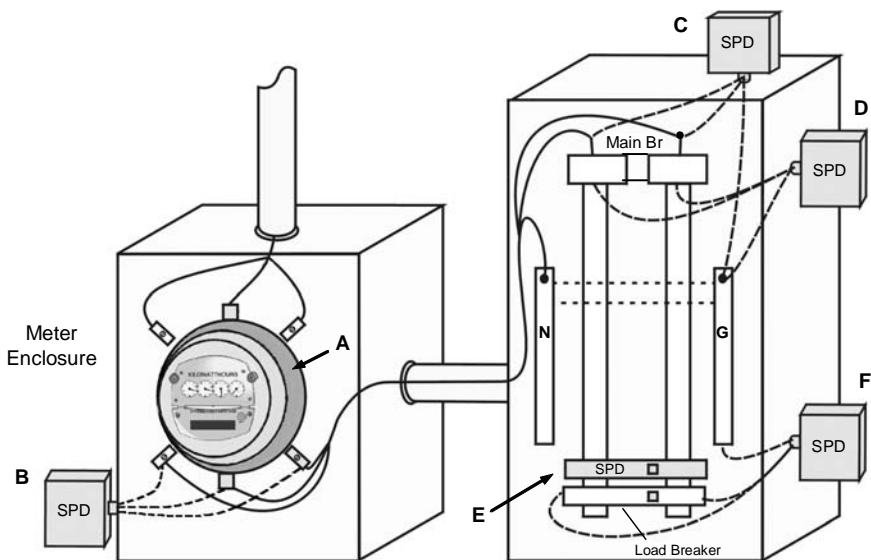


Figure 5: Possible Locations/Configurations for Hard-wired and Meter Adapter AC Protectors. Normally, A is used only by the electric utility; the others would be used by an electrical contractor. Normally only one protector would be used at the service entrance.

required to have a Surge Arrester listing while the rest could be Surge Arrester or TVSS products.

Surge voltages and surge currents in residential AC power circuits usually originate from two major sources, lightning and switching. Lightning surges are the result of a direct flash terminating on the power system, structures, or to the soil, and can also be induced on the utility system and distribution circuits by nearby lightning flashes. (See Figure 2). Switching transients result from electrical equipment switching operations, fault initiations, and interruptions in a power distribution system. The sudden change in the system current can initiate damped voltage oscillations, which can create surges and temporary overvoltages.

2.1.1 Normal Conditions

Primary factors in choosing an SPD should be to have a long life and satisfactory performance. In order to assess these needs, the normal service condition must be understood. This includes the electrical and mechanical environment. The SPD must match the existing electrical and physical environment and each rating should be checked to ensure that the product will work in the intended location. On the electrical side, a short summary of certain critical items is shown below:

- Nominal Voltage
- Frequency
- Phases and transformer type (such as wye or delta, split phase)
- Current
- SPD Ratings (see Section 2.2)
- Monitoring Desired

For the mechanical side, there are a similar number of issues that need to be determined:

- Indoor or Outdoor
- Altitude
- Temperature Range
- Mounting Type and Location
- Container Protection (NEMA or IP rating)

These requirements will determine some of the primary features and performance required of the SPD.

2.1.2 Abnormal Conditions

Abnormal conditions are simply those areas that exceed the normal conditions. Voltage is one of the most important and potentially damaging conditions and is covered separately in section 2.1.2.1. If any condition is exceeded, the unit might operate incorrectly or become inoperable. Incorrect operation may be permissible. An example could be a monitor on an outdoor unit does not display correctly at -10°C , but when the temperature increases to 0°C , the monitor begins to work correctly and no permanent damage is sustained. In a northern climate, this might be unacceptable, while a southern location would see this as acceptable on those rare occasions.

2.1.2.1 Temporary Overvoltage (TOV)

Temporary and long-term overvoltage conditions (TOV) can lead to rapid degradation and even failure of SPD components. If the applied voltage exceeds the maximum continuous operating voltage rating (normally called MCOV) of the SPD, the SPD will attempt to suppress the overvoltage and will begin to conduct current. The result can be thermal runaway of the SPD components, creating significant heating and eventual destruction of the SPD. TOVs are typically the result of loose or open neutral conductors, voltage regulator problems, or the inadvertent contact of higher voltage systems to the residential system.

2.2 Surge Protective Device Ratings

There are three requirements of the service entrance SPD. They are as follows:

- 1) To suppress the larger surges from the outside environment to levels that would not be damaging to equipment at the service entrance, or to equipment (air conditioning, wired-in appliances) directly connected to the branch circuits.
- 2) To reduce the surge current to the downstream SPDs (including multiport SPDs).

- 3) To stop the large lightning currents from passing into the house wiring system and damaging the wiring or inducing large voltages that would damage electronic equipment.

There are a number of specifications and design details that must be addressed to determine if an SPD is acceptable for use in a given situation.


2.2.1 Typical Modes of Protection

The modes of protection required at the service entrance depend on the configuration of the electric distribution system. Surges can be transmitted in the “normal mode,” line-to-neutral (L–N) or line-to-line (L–L), or in the “common mode,” line-to-ground (L–G) or neutral-to-ground (N–G). For the main entrance, or immediately after a transformer, L–G or L–N might be the only protection modes that are required, but further into the building, L–N, L–G, and N–G modes should all be protected.

Figure 6 shows the how the components⁶ are connected in simplified SPD circuits. The entrance protector shown (6A) uses two varistor groups to protect the L–G modes. The L–L modes are protected by the two varistor groups in series, as discussed below. The point-of-use protectors (6B, 6C) use three varistors to protect all three modes, L–N, L–G, and N–G, as recommended above.

Since the N and G are directly bonded at the service entrance, SPDs used there normally have no need to protect the N–G mode. However, protectors downstream from the service entrance or at the load should protect the N–G mode, since N–G surges might arise from events downstream in the building.

Many multiphase products use L–N connected components to protect L–L modes. This approach effectively uses two varistors in series, each rated for the L–N supply voltage, to provide the L–L voltage limiting. Although the surge voltage limiting obtained this way may not be as low as that from separate L–L components, this configuration is usually satisfactory.

⁶ In Figure 6 and Figure 10, the symbol  stands for a generalized surge protection component (SPC), which is a voltage limiting device. For SPDs discussed here, varistors, gas tubes, silicon crowbar devices, and silicon avalanche diodes are used, depending on the application. All of these SPCs conduct negligible current until a specific limiting voltage across the terminals is reached. Above that voltage, the device starts to conduct, thereby limiting the voltage across the terminals. This is discussed more in Section 3 and Section 5 of this *Guide*.

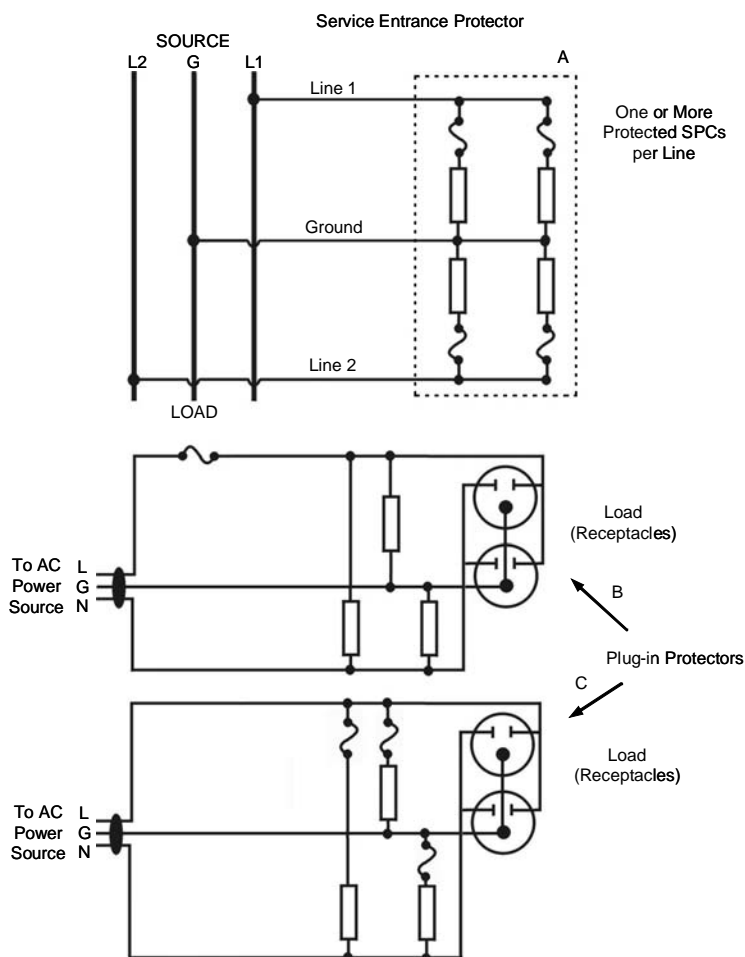


Figure 6: Hard-wired Protector vs. Plug-in (point-of-use) protectors. The load current doesn't flow through the entrance protector, so that if the fuses open, the power continues to the load. For plug-in protectors (B, C), the load current flows through the protector. "Disconnecting" protectors (B) disconnect the load if a severe surge or overvoltage occurs. However, some plug-in protectors (C) disconnect only the surge protection components, allowing the surge to flow into the load. In all figures, the symbol \square represents a surge limiting component (gas tube, MOV, transorb, sidactor) that becomes conductive when the voltage across it exceeds a certain level.

2.2.2 Surge Current Ratings

The surge current rating is normally the largest single surge that a device can withstand without damage. This should exceed the largest surge that the SPD would experience in service. Some documents (IEEE Std C62.41.2⁷) suggest 10 kA (8/20 μ s) as the largest surge that can reasonably be expected at a service entrance, and this value has been used as the basis for some standards. UL 1449, for example, requires only resistance to multiple 3000 Amp (8/20 μ s) surges for panel protectors, which could be used at the service entrance. Most manufacturers meet a much higher surge withstand level. The NEMA[®] LS-1 Standard allows the SPD manufacturer to test and certify survival of an SPD at any level using the 8/20 μ s impulse. Unfortunately, except for the low UL test levels, none of these manufacturers' ratings are required to be verified by independent test laboratories.

Typically, manufacturers rate a service entrance SPD by the surge current per phase. The surge current per phase can be calculated by adding the surge current from the individual modes of protection L–N and L–G. The surge current is usually measured using an 8/20 μ s waveform, but this is not universal. Products now offered for the residential market show a range of surge current ratings from about 10 kA to 70 kA per phase. Industrial products are available with ratings generally in the range of 40 kA to in excess of 300 kA.

Test waveforms other than 8/20 μ s are also acceptable, although relatively rare in North America. In the industrial world, 4/10 μ s, 10/350 μ s and 10/1000 μ s are sometimes used. Ratings of different products can only be compared if they have been obtained using the same test waveforms.

For residential or light commercial locations, a surge current rating of 20 kA to 70 kA (8/20 μ s) per phase should be sufficient. Installations in high-lightning areas should use SPDs with higher surge current ratings, in the range of 40 kA to 120 kA, in order to provide a longer service life and higher reliability. The recently revised NFPA 780-2004 Lightning Protection Standard requires a 40kA withstand level for SPDs used at the service entrance.

⁷ IEEE Standards are trademarks of the Institute of Electrical and Electronics Engineers. IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

The authors recommend a minimum surge current rating of 20 kA to 70 kA (8/20 μ s) per phase for SPDs to be used in residential or light commercial service in low or moderate lightning areas. For houses in lightning-prone areas, or with severe exposure, higher surge current ratings in the range of 40 kA to 120 kA should be specified.

2.2.3 Surge Limiting Voltage (Let-Through Voltage)

The voltage peak to which an SPD limits an incoming surge has been given many different names, including “protection level”, “Suppressed Voltage Rating” (SVR), “surge response voltage”, “let through voltage”, “clamping voltage”, “surge residual”, and “surge remnant”. Technically, the proper term is “surge residual”, that is, the voltage remaining after a surge protector has acted to limit a surge. However, few products in the residential market are so labeled. In most instances, these terms are used interchangeably. The surge response voltage is usually used to describe the limiting voltage of the SPD alone without any additional leads, while the surge remnant is used to describe the effective limiting voltage in an installed condition, i.e., at the service equipment bus bars. The difference between the protector's limiting voltage, and the let-through voltage of the installation is critically dependent on the quality of the installation. An example is shown below.

There are several different ways that limiting voltage specifications are generated. Most SPDs will be listed to UL Standard 1449 and will have an SVR, determined by the UL test, marked directly on the device. The term SVR is specific to UL Standard 1449 testing, and is the result of applying a 6 kV 500 A (8/20 μ s) impulse to the protector and measuring the limiting voltage obtained with a lead length of 6 inches (15 cm). UL assigns an SVR from a table, a list that includes the following values: 330 V, 400 V, 500 V, etc. A product with a 331 V to 400 V measured limiting voltage will be assigned a 400 V SVR rating. This assigned voltage offers a means of comparing the level of protection offered among various SPDs at that 500 A test level.

The test is slightly different for UL Recognized surge protection components and the lead length could be zero. The user is cautioned about comparing a UL SVR on a listed SPD product to a UL SVR on a recognized component.

Due to the different ways that the limiting voltage can be measured, the use of the UL SVR rating, and the different terms that are used, it is important to compare published ratings based on similar tests. Some products list voltage ratings based on 1 mA tests (sometimes called “onset of clamping” voltage) while others cite tests using 3,000 A or 10,000 A pulses. Generally, larger surge currents produce higher limiting voltages, but that is not universally true. Different technologies used in SPDs (e.g., Metal Oxide Varistor (MOV), gas tube, and silicon avalanche diode) have the best performance at different current levels, so no single current test value is uniquely correct. There are also different ways to measure the value such as the peak of the sine wave to the peak of the surge voltage rather than from zero to the peak of the surge voltage. There is also no requirement for SPD manufacturers to measure their products in a standardized way. Most panel protectors are measured during surge testing at 6 inches (15 cm) from the container’s edge as in the UL SVR test, however this is not universally applied, and may not be possible. Great care must be taken to determine what tests the manufacturers have actually carried out before making product comparisons based on claimed specifications.

One of the main functions of the service entrance SPD is to reduce the surge current reaching any downstream protectors (see requirement 2 under Section “2.2 Surge Protective Device Ratings” on page 15 of this *Guide*). For this use, the surge limiting voltage is not critical. But for requirement 1 (in Section 2.2), protection of hard-wired equipment, a low let-through voltage might be important. Selection of a service entrance protector may require a compromise between emphasizing a lower limiting voltage rating (best protection for the hard-wired appliances) versus choosing a higher voltage rating SPD that may be less vulnerable to temporary AC overvoltages.

Two-stage protection, where an upstream SPD takes the major surge current and a downstream SPD protects the equipment, is the best protection for equipment. Unless the downstream SPD is very close to the upstream SPD, the surge limiting voltage of the upstream device will have little impact on the final voltage seen by the load after the second SPD has limited the surge remaining from the first SPD.

2.2.4 Coordination with Downstream SPDs

As stated above, the service entrance SPD has the primary job of intercepting large incoming surges and disposing of them into the building ground. However, some of the surge will be conducted downstream to the appliances in the building, and to other SPDs, either hard-wired or plug-in protectors. “Coordination” is the term used to describe the way in which an incoming surge is apportioned between the first SPD and the downstream SPDs. The coordination is a complex issue determined by the voltage limiting behavior of the first and second SPDs, the impedance of the wiring between them, and the size and waveform of the incoming surge.

For the SPDs we are discussing here, the current division is mainly controlled by the relative limiting voltages of the two protectors, and the impedance of the wiring between them. The lower the limiting voltage of the first SPD, and the longer the connecting wiring between the two SPDs, the less surge current will pass to the downstream protector.

2.3 Installations

Only a qualified electrician should install SPDs on an electrical system. The SPD can be mounted either external to the load center or can be internally mounted by the manufacturer of the load center. SPD lead length (a potential performance limitation) can be minimized and wiring errors can be reduced with the internally mounted SPDs. Externally mounted devices are much easier to install in pre-existing facilities. Some SPDs can even be installed inside of or mounted on the utility meter base. Figure 5 shows SPDs mounted externally in positions B, C, D, and F, while an internally installed SPD is shown in position E. Finally, the utility meter base SPD is shown in position A.

Effectiveness of an SPD is strongly affected by the installation. The installation is fully under the control of the SPD purchaser and should not be treated lightly. The primary issues that need to be addressed are grounding, lead length, and over-current protection. They are addressed below.

Most manufacturers have a local number or a toll free number where assistance with installation can be obtained. The proper operation of the SPD will depend on the proper installation, so if there is any doubt, manufacturer’s assistance should be requested to assure proper installation.

2.3.1 Grounding

An effective, low-impedance ground path is critical for the successful operation of an SPD. High surge currents impinging on a power distribution system having a relatively high grounding resistance can create enormous ground potential rises (see Section 4 beginning on page 30), resulting in damage. Therefore, an evaluation of the service entrance grounding system at the time of the SPD installation is very important. At the very least, the grounding system should be inspected to see that it meets the National Electric Code (NEC Article 250) requirements in the United States or the Canadian Electric Code requirements in Canada. Some of the basic NEC requirements are shown in Figure 3.

2.3.2 Lead Length

To achieve optimum overvoltage protection, the connecting leads between the SPDs and the panel or protected equipment should be as short as possible and without sharp 90-degree bends. Figure 6 shows a schematic installation of a service panel SPD. The leads “Line 1” and “Ground,” and the loop the leads make, have significant inductance. For fast-rising lightning pulses, the inductance of these leads produces large voltage drops.⁸ These large inductive voltage drops are added to the inherent limiting voltage of the SPD, raising the effective limiting voltage at the service equipment terminals. The inductance of the wire is the determining factor rather than the resistance of the wire. The inductance is a function of the length and the loop area of the circuit including the SPD. Self inductance is a property of the length and diameter of the wire, while mutual inductance is a function of the loop area. Both types of inductance are present in every wire.

The extra voltage on top of the SPD's inherent surge response voltage is also dependent on the wire gauge and the way that the wire is positioned. Twisting of the wires to the SPD reduces the loop inductance and can result in an improved performance. High surge currents generate more voltage per unit wire length than

⁸ The inductive voltage drop is $L \times dI/dt$, so it is proportional to the current rate of rise (kA/ μ s). Since lightning currents rise very fast (typically less than 3 μ s), the current rate of rise is very large for surges from lightning. The 8x20 μ s impulse used in the tests below actually underestimates the inductive voltage produced by typical lightning waveforms.

low currents, so lead length is a critical issue in a service entrance SPD installation, where the surge currents can be extremely large.

The following table indicates the relationship between lead length, surge current, and measured limiting voltage across the service equipment bus bars. This experiment used a 150 VAC-rated Metal Oxide Varistor (MOV) connected with 14 gauge wire twisted together and laid flat. This is a simplified version of the protector shown in Figure 6A; the measured voltages are between the L1 and G conductors at the service equipment. Larger wire would have reduced the extra voltage, but poor wiring practices would have increased this voltage. Table 1 is meant to show the order of magnitude of the effect of additional lead length.

Table 1: Voltage at the connecting lead ends for a model protector using a 150 V MOV connected with #14 AWG wire

<div>Lead Length Surge Current</div>	Zero	6 inches (15 cm)	20 inches (50 cm)	39 inches (1 m)
500 A	401 V	460 V	582 V	726 V
3 kA	466 V	536 V	686 V	862 V
10 kA	592 V	810 V	1160 V	1680 V

For 20 inch (50 cm) leads, the extra voltage from the inductance of the leads is almost 600 V for the 10 kA impulse, almost doubling the limiting voltage of the protector itself. The voltage drop in the leads increases with current, and could be about 1700 V for a 30 kA pulse of the same waveform. The self-inductance decreases only very slowly with wire diameter. Doubling the wire diameter, e.g., going from a #14 to a #8 AWG size, only decreases the inductance by ~15%. To minimize the inductive drop, make the leads as short as possible, and twist the leads to the protector to minimize the loop area.

2.3.3 Overcurrent Protection

To reduce the severity of the SPD damage in overload situations, and to protect the integrity of the power distribution system, the service entrance SPD should be installed with overcurrent protection if it does not have internal fusing. Some models come with integral fusing; others offer it as an option. Some manufacturers allow direct installation to the bus bars, but in most cases the use of fusing or circuit breakers for the SPD is recommended.

The manufacturer's installation instructions should be clear in the mounting and installation of the SPD. The required fuses or circuit breakers should be specified in the installation manual or on the SPD itself and these specifications must be followed precisely to provide the maximum reliability. In many cases the UL "conditions of use" for an SPD require specific protection. If these requirements are violated, the installation is not in compliance with the NEC. If the circuit breaker opens or the fuse blows, the facility is left without surge protection!

The 2002 NEC made significant changes to the SPD installation requirements. One of the more important changes requires the SPD to be marked with a Short Circuit Current Rating (SCCR) and to be installed so that the SPD SCCR is equal to or greater than the available fault current at that point in the circuit. The panel and the upstream circuit breakers will be marked with a fault current rating that can be compared with the SPD SCCR rating to insure that the SPD rating is adequate. For 100 A load panels in single detached homes, a typical fault current is usually less than 10,000 A. Current ratings from 10,000 A to 22,000 A are common for structures larger than a single detached home. The requirements are discussed in NEC Articles 110.10, 285.6, and especially in discussion in the 2002 NEC Handbook following those Articles.

2.4 Combined AC Panel Protection and Signal Protection

Complete Home Surge Protection (sometimes "Whole-House-Protection") has become a more popular feature in recent years. These types of products combine the main panel AC SPD with SPDs for coaxial lines and/or telephone lines, in a single housing. As with all combination products, there are advantages and disadvantages.

The most important advantage is the single-point ground provided by these products. By combining the grounds for the AC and signal SPDs in one unit, the advantages of a multiport protector are obtained. (See Section 5 beginning on page 35.)

However, if one SPD is damaged, it might be required to remove the complete device for repair, leaving all the services unprotected until a replacement is installed. There is usually less choice in the features of these types of SPDs compared to SPDs purchased individually.

2.5 Other Factors

2.5.1 Joule Rating

Some SPDs may claim a “Joule rating” in addition to surge current and clamping voltage ratings. This can lead to some confusion. Joules (J) are a unit of energy ($\text{Joules} = \text{current} \times \text{voltage} \times \text{time}$), and the Joule rating is intended to be an indication of how energetic an electrical surge the protector can withstand without damage. If two SPDs have the same clamping voltage and are tested using the same waveform, then Joule ratings can show that one device can handle more energy (larger surges) than the other device. However, there is no simple way to compare two devices using different waveforms. There are no standardized test protocols to establish Joule ratings. Also, SPDs with similar surge current ratings may claim very different Joule ratings if they are based on two different technologies. It is usually better to compare the clamping voltage and surge current ratings using the same waveform than to rely on the relative Joule ratings.

Due to the difficulty in comparing Joule ratings, many companies no longer publish this number. Most standards written recently in the surge protection industry either warn of the possible misuse of Joule ratings or, by omission, do not recommend the use of Joule ratings.⁹

⁹ For a more complete discussion, see the FAQ section of <http://www.nemasurge.com>, reference 7.2(2).

2.5.2 Limitations of Panel SPDs

SPDs discussed here, and depicted in Figure 6A, are designed to protect against very brief surges from lightning and surges from utility switching transients or other overvoltages much shorter than one second. They are very effective in this role. However, none of the standard SPDs available as panel protectors for residential applications offer useful protection against sustained overvoltages arising from open neutral conductors, high-voltage power crosses, or utility regulator failure.

If an event produces a voltage of, say, 180 V on a 120 V line, there are two possibilities: if the overvoltage is below the clamping onset level for the MOVs (see Figure 6A), it passes unaffected into the residence. If the overvoltage is above the clamping level for the MOVs, the MOVs will rapidly overheat and either burn out themselves, or open the associated fuses. Then, again, the overvoltage passes into the residence. Because there is so much current available at the service entrance, the MOVs heat and burn out almost instantly in sustained overvoltage events.

A few panel protectors have circuitry that allows them to combine a low surge limiting voltage with the capability to withstand 240 VAC phase-neutral voltage. They are thus not vulnerable to most open-neutral faults. However, they do not stop the excess voltage from passing to the connected equipment downstream.

Plug-in (point-of-use, or supplementary protectors) are the main defense against sustained AC overvoltage events. For complete protection, plug-in protectors should be used in conjunction with the panel protectors described here. These SPDs are normally located at the protected equipment and are discussed in Section 5 of this *Guide*.

3. PRIMARY SIGNAL PROTECTION¹⁰

The NEC and CEC require some form of protection to be installed at the building entrance for telephone cables (NEC Art. 800), CATV/antenna/satellite coaxial cables (NEC Arts. 810 and 820), and recently, broadband cables which carry power (NEC Art. 830). The NEC/CEC see the principal hazards as arising from accidental contact of the signal wires with power lines, but acknowledge that the protectors will also provide some protection against lightning voltages being carried in on the signal cables. Some of the code-required protectors are shown in Figure 3.

Telephone line “primary protectors” have been required for almost 100 years, and are normally spark gap protectors, based on either carbon or gas discharge tubes. “Carbon block” protectors consist of carbon electrodes and an air gap. They are generally considered obsolete, but are still found in the field. In the last 50 years, they have been mostly replaced by “gas tube” protectors, which consist of a spark gap in a small container of inert gas, like a neon lamp. The breakdown voltages are quite high, typically 600–1000 V for carbon and 400–600 V for gas tubes. They normally have a thermally-activated short circuit switch so that if a sustained high AC voltage occurs, heat generated in the arc will close the switch and carry the current harmlessly to ground. These protectors are listed under UL Standard 497. They typically have high surge current ratings, 5,000 to 10,000 A (8x20 μ s), since they may have to intercept direct lightning strikes carried in on aerial phone lines.¹¹

For coaxial connections, the NEC/CEC only require bonding of the cable sheath to the building ground where the cable enters the building. There is no requirement to limit the voltage developed between the core and the sheath. Since the aim of the code is to guard against fires and electrical shock hazard to people,

¹⁰ The general usage is that a signal “primary protector” is used at the building entrance, and is robust enough to withstand lightning or AC events it could reasonably be exposed to through signal wiring. A “secondary protector” is intended to be used with a primary protector in front of it. In AC power terminology, a “primary protector” is used in much more difficult service, exposed to direct lightning on the AC power lines. Electric utility personnel sometimes refer to the panel protectors, discussed in Section 2 of this *Guide*, as “secondary protectors”. NFPA 780 uses the term “Supplementary Protection” for point-of-use protectors.

¹¹ Lightning surge currents on communication lines tend to be much smaller than those on power lines, because the wire gauge is smaller, and the strike usually is to a multi-pair cable, so the current is shared among several conductors.

the reasoning is that it does not need to stop possible high voltage on the cable core, since the overvoltage is contained within the sheath. The only voltage limit is the breakdown of the F connectors, typically ~2–4 kV.

Under AC power cross or lightning conditions, large currents (10 A or more of AC, and hundreds to thousands of amperes of lightning surge) may flow into the telecom protectors or the grounding block, and must be carried to ground. These large currents can only be dealt with by a direct connection to the building or power panel ground. The NEC/CEC are very explicit in requiring this connection (code sections above), and it has been required for many years. The NEC/CEC specifically forbid using separate ground rods for individual lines/equipment/protectors, unless the ground rods are connected (bonded) to the building ground (NEC Art. 800.40). There is a very good reason for this, since the ground resistance produced by a single ground rod can easily be hundreds or even thousands of ohms. In residential environments, the ground resistance of a driven ground rod is rarely measured. Even in a favorable situation, if the rod ground resistance were only 25 Ω , a lightning surge of 10,000 A would produce a potential rise of 250,000 V at the ground rod!

The NEC (Art. 250.52) also disallows almost all use of water pipes as a ground for protectors or other equipment. The extensive use of plastic piping and water meters, possible corrosion, and the likelihood of later plumbing modifications make it unreliable to use pipes as ground electrodes.

Unfortunately, many providers of phone, cable, and satellite systems do not recognize the NEC/CEC requirements, and grounding of protectors and coaxial cables is often inadequate. Any attempt to provide residential surge protection should begin with an audit, and correction, if necessary, of the existing signal line protection and grounding. These should be brought up to the NEC/CEC requirements in the Articles listed above.

The configuration in Figure 4, showing the phone protector and cable entry point mounted right next to the AC protector/ground, is highly recommended. It makes the ground connection short. This limits voltage developed in the grounding connections under severe surges. Ideally, satellite antenna cables should also be routed past this point and grounded there, although that is often difficult to achieve.

The NEC/CEC require that primary (building entrance) signal-line protectors be Listed (or Certified) by a Nationally Recognized Test Laboratory, typically Underwriters Laboratories in the United States, or the Canadian Standards Association in Canada. The main Standards are UL 497 for twisted pair phone protectors, UL 452 for antenna leads, and UL 497C for coaxial cable protectors for CATV and satellite systems. Voltage limiting requirements are in the UL Standards, not in the NEC.

Telephone primary protector breakdown voltages are very high; adequate, perhaps to prevent severe shocks to users, and possibly adequate to protect older, electromechanical phone systems with no ground or AC connections. But the combination of high protector surge limiting voltage, and possible large voltage rise in the protector ground connection, means that the net surge voltage seen by the equipment may be too high to be safe for modems and fax machines with delicate electronic circuits.

Since the NEC/CEC do not require any protection (voltage limiting) between the core and sheath of the coaxial cables, there is obviously the possibility of damage to TV tuners and cable modems from the very high voltages that can be developed, especially from nearby lightning.

If the arrangement of Figure 4 can't be achieved, and the communications protectors are mounted some distance from the AC power entry point, the effectiveness of these entrance protectors is greatly reduced. Even if the grounding is carried out directly to the building ground system, in many houses a wire of 10 feet (~3 meters) or more is required to reach from the ground block or phone protector to the building ground point. With only moderate surge current, the inductance of the grounding wire produces a large voltage drop in this wire, which adds to the limiting voltage of the protector itself. For example, a 1000 A impulse, rising in 3 μ s, could be typical for an attenuated lightning surge carried in on a communications cable. This impulse would produce a voltage drop of ~1000 V¹² in a 10 foot grounding wire, which would add to the limiting voltage of the protector. So a protector with a nominal 400V limiting voltage would actually be limiting to (400 V + 1,000 V) = 1,400 V! Using heavy grounding wire

¹² Calculated from the inductance of the wire, approximately 3 microhenries, using $V = L \times dI/dt$, where dI/dt is the rate of change of the current, 3.3×10^8 A/s.

(e.g., #8 or larger) does not improve things significantly, since the inductance does not decrease much with wire diameter (see Section 2.3.2 above).

The answer to both these problems, as discussed below, is the use of multi-port (combined AC and signal) surge protectors at the equipment to be protected. The protectors themselves can have much lower limiting voltage than those used at the building entrance, and with the AC and signal protectors in the same housing, the ground voltage difference between the protectors can be almost eliminated. This will be discussed in Section 5.

4. GROUND POTENTIAL RISE

People familiar with electricity frequently accept the idea that “Ground is ground,” i.e., that in a house, especially with a grounding system that complies with the NEC or CEC, all points of the grounding system are at the same voltage. The NEC/CEC support this impression by requiring that no AC current pass through the ground wiring, except under narrowly defined exceptions: fault conditions (a line-ground short or leakage), or the action of surge protectors, sending the surge currents into the grounding system.

Without lightning, in a properly wired house, this impression is correct. For the most common source of lightning damage shown in Figure 2 (as mode 1), with a good surge protector installed at the building entrance (Figure 4), indeed, major lightning currents are stopped at the service entrance. However, with nearby lightning, or lightning which may attach to wires that come into the house via other paths (modes 2, 3, 4 of Figure 2), lightning can generate large currents in the house ground system.

Section 2 (and Table 1) discussed the voltages developed by large, fast-rising lightning currents in the relatively short wires connecting the AC protector to the service panel. For the longer grounding wires in many real installations (Figure 7 and Figure 8), the voltage drop in the wire can be much larger. For the examples shown in Figures 7 and 8, with a 3,000 A surge (10% of a moderately strong lightning pulse), with a 3 μ s rise time, and a 30 foot (~9 meter) long ground connection between A and B or C, the voltage developed in wire A–B is ~10,000 V! This voltage difference between different points in the grounding system is called ground potential rise, abbreviated as GPR. It is inevitable

whenever large lightning surge currents flow through the grounding system of the house.

4.1 Ground Potential Rise within a Building

Figures 7 and 8 show simplified circuits for TV sets connected to a CATV utility. The only protection required by the NEC/CEC is a grounding block that connects the cable sheath to ground, where the CATV cable enters the building. A similar diagram would be valid for small-dish satellite receivers. If the grounding block were replaced by a telephone (primary) entrance protector (NID), the circuit would be valid for a fax machine, or a PC with modem.

In all these cases, the equipment (TV, satellite receiver, or fax machine) is referenced on the AC side to point B (via the branch circuit neutral and ground), but on the signal side, to point A (via the coax sheath). As stated above, during even a modest lightning strike to the signal cables, the voltage difference (GPR) between A and B can easily reach 10,000 V. This is enough voltage difference to flash over most ordinary insulating barriers in the equipment. If this happens, the equipment will probably be severely damaged.¹³

If the CATV, satellite, or phone cables do not enter the building near the service entrance, the only effective way of protecting the equipment is to use a multiport protector, as shown in Figure 7. Multiport protectors eliminate damage due to ground potential differences by using voltage limiting devices or a direct bond to reference together the signal wires and the AC wires when the voltage differences exceed safe levels, typically a few hundred volts. These protectors are discussed in detail in Section 5.

It is important to realize that the multiport protectors usually do not significantly reduce the GPR between point A and point B. In most cases, the impedance of the signal wire to the equipment, plus the impedance of the AC wiring, is much greater than the bond impedance between A and B. So the vast majority of the incoming lightning surge current flows through the A–B ground bond, and exits the house via the grounding electrode, as the NEC/CEC writers intended.

¹³ If the NEC-required grounding is NOT present (i.e., if the entrance grounding block is connected only to an unbonded ground rod, water pipe, etc.), the situation is considerably worse, and may lead to fire or other damage in the house itself.

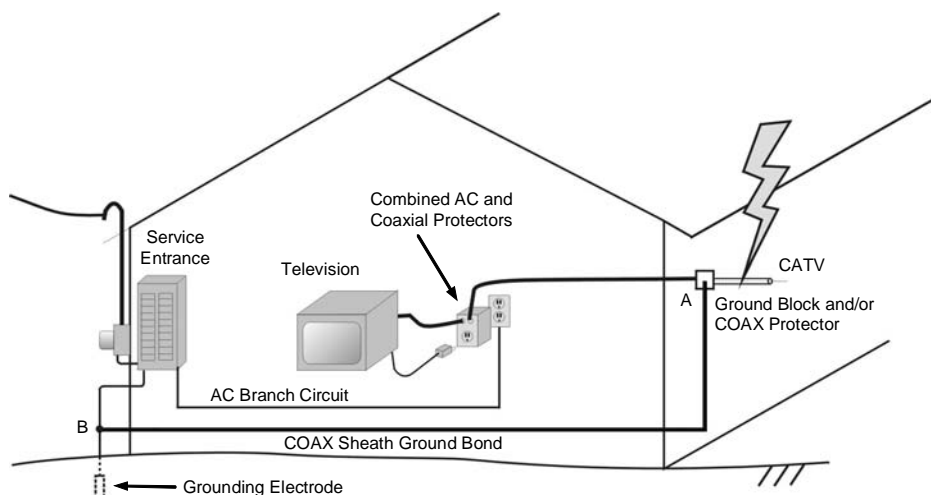


Figure 7: Even with coax cable grounding that meets code requirements, if the coaxial line enters far away from the building ground, the long grounding wire A–B can develop very large voltages which can damage the TV set. The multiport protector shown at the TV set can greatly decrease the voltage between the AC ground and the coax cable, preventing damage to the set.

If the voltage from A to B is 10 kV, and the voltage between the signal and AC connections at the equipment is only a few hundred volts, the remainder of the 10 kV must appear within the AC and signal cables, divided in proportion to their impedances. So it is perfectly possible for an AC or signal wire to have 5 kV or more between its two ends, for the short time that the lightning current lasts. Because of the short duration of the current, even small wires will usually not be damaged by these relatively small (a few hundred ampere) residual lightning currents.

The action of the multiport protector, though, generates an additional GPR disturbance. The voltage between the AC (green wire) ground at the equipment can be several kV different from the voltage at point B. If the TV set is connected to other equipment that is independently connected to B by AC wiring, that voltage difference will appear across the other equipment, and may damage it.

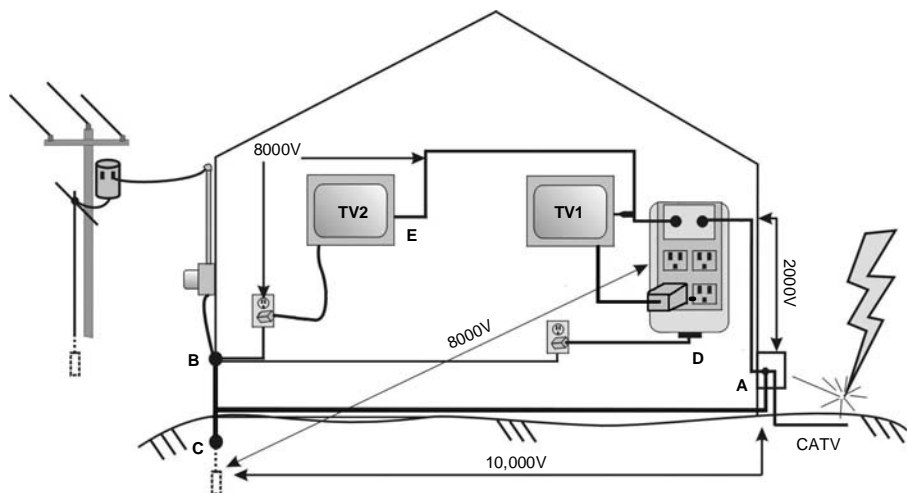


Figure 8: Ground potential differences within a building under lightning strike conditions: how down-line TV sets get damaged. With a 3,000A surge rising in $3\ \mu\text{s}$, and a 30 foot ground bond (A–C), ~10,000 V develops between A and C. Even with a multi-port protector (D) for TV1, the ground voltage at D is conveyed to TV2 by the coaxial cable, resulting in an 8,000 V potential across TV2, which will probably destroy it. A second multi-port protector as shown in Fig. 7 is required to protect TV2.

Figure 8 shows a very common improper use of multiport protectors that does not fully protect against lightning damage because of this effect. One (AC + Coax) multiport protector, D, has been used in an attempt to protect two TV sets. The installer assumed that the coaxial protector in D would remove the lightning surge, and any TV sets downstream would be safe without further protection. That assumption has limited validity for the voltage difference between core and sheath of the coax cable. But it is totally wrong in describing the ground potential differences. If the protector and TV1 are near the cable entrance at point A, most of the GPR at point A will appear at the protector D and TV1. (The 2000 V:8000 V division ratio has been arbitrarily assumed.) But with no protector on TV2, the full 8000 V potential at D is conducted to point E, the input of TV2. The 8000 V difference between point E and the voltage at B, the connection of TV2 to the service panel, will damage TV2. To protect TV2, a second multiport protector located at TV2 is required.

Full protection of equipment with multiple ports can only be accomplished by surge protection that protects all the incoming lines and interconnects (bonds) between the ports. This can be done at the main entrance if all the utilities (power, CATV, phone, etc.) are brought together and the surge protection devices are bonded to a common ground point. If this is not done, equipment can only be protected by multiport protectors, located at the equipment being protected. Surge protection alone is not sufficient to protect equipment; inter-system bonding is also required.

4.2 Ground Potential Rise for Equipment Outside a Building

Equipment mounted outside a building is vulnerable to GPR damage because it is typically referenced to two grounds. Compressors, well pumps, spa and pool heaters, and other outdoor equipment are frequently mounted on concrete pads in contact with moist soil (see Figure 9). In some cases, this pad can be a more effective ground than the building ground electrode. So the equipment ground is bonded to the pad ground, while the equipment line and neutral connections are referenced to the building ground.

During a lightning strike, even though the equipment ground is tied to the building ground (by the green equipment grounding wire) per the NEC, the wire still has the inductive impedance discussed in Section 2 of this *Guide*. For fast-rising lightning surges, the inductance of the equipment ground wire prevents the voltage at the remote pad from following the voltage at the building ground. So there can be differences of tens of thousands of volts between the building ground and the pad ground.

The voltage at the motor coils is referenced to the building ground, because initially no current flows through the line and neutral wires, so the voltage at the motor follows the voltage at the building ground. The ground potential difference between the building ground and the pad ground appears between the motor windings and the (grounded) motor frame, and will flash over the insulation. The surge protector at the service panel can not remedy this problem. Only an appropriate protector, mounted at the equipment, bonding between all line wires, neutral, and ground, can prevent damage. This protector can also protect against damage from lightning striking to or near the equipment itself, as shown in mode 2 of Figure 2.

Lack of awareness of this cause of damage, and the remedy, is responsible for many cases of damage to outside equipment. The damage could be prevented by relatively simple additional surge protection, installed at the equipment.

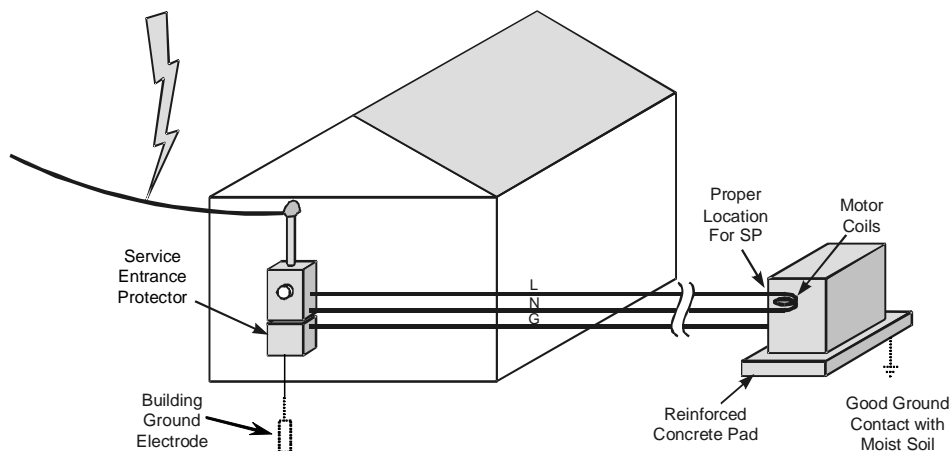


Figure 9: Equipment that has its own ground can be damaged by potential differences between two grounds. During a lightning surge into the ground electrode, the voltage rises by 750 kV for a 30 kA strike and 25 Ω ground. The insulation between the motor coil and the frame/housing sees a significant fraction of the 750 kV developed at the building ground, and may break down the insulation of the motor, controls, or wiring.

5. MULTI-PORT POINT-OF-USE (PLUG-IN) PROTECTORS

Multi-port point-of-use protectors (also called plug-in protectors) normally consist of an AC protector and one or more signal-line protectors, in a single assembly, designed to be installed near equipment that connects to both AC and signal lines.

These protectors serve three purposes:

- 1) The AC protectors normally have lower effective surge limiting voltage than the panel protectors described in Section 2, and also might protect against sustained AC overvoltage (Section 5.1).
- 2) The signal line protectors normally have lower surge limiting voltage than the primary signal protectors described in Section 3, and might also protect against voltages (such as AC voltages from accidental contact

with power lines) which are be too small to be stopped at the primary signal protector (Section 5.2).

- 3) The grounds for all the protectors are connected (bonded) so that inter-system voltages are minimized. As stated above, under lightning conditions, large voltages can be developed between, e.g., phone, CATV and AC grounds, and these voltage differences are frequently the cause of lightning damage (Section 5.3).

An additional feature of the point-of-use protectors, if they are properly used (see Section 6), is that all surge currents which come in from AC wiring and signal connections (both active wires and grounds) are disposed of via the AC (green wire) ground, back to the building ground. So downstream from the multiport point-of-use protector, there are no large circulating surge currents to damage equipment or interfere with operation.

These protectors are usually in the form of a small plastic housing with a line cord and 3-pin AC plug, 2 to 12 AC outlets, and connections for the signal lines.

Some versions are in metal housings designed to be rack-mounted, or sit on shelves, typically for “home theater” applications. Some models have a modular configuration that allows addition of signal protection modules to configure special protectors for particular systems. There are also small (cordless) wall-mount versions, designed to plug directly into an AC wall outlet, and hang from the receptacle.

The most common type of multi-port protector combines the AC protector with one line of telephone circuit protection, and is widely used to protect PCs with dial-up modems, and fax machines. The AC protectors discussed in this section are also used, without signal protectors, as the general purpose “surge strips” widely sold as consumer and commercial protection products.

5.1 AC Protection Circuits

The AC protectors are controlled by UL Standard 1449 (2nd edition, 1998, with later amendments) which includes both safety and performance requirements. The same 1449 Standard controls both hard-wired (panel) and plug-in protectors, but they must meet different requirements. The 1449 Standard also includes a

requirement that any included signal protectors must meet the requirements of the appropriate UL Standard for that type of connection (see Section 7).

For the AC protectors, Figure 6 shows a comparison between the circuits used in hard-wired protectors (6A) and those used in point-of-use protectors, (6B), a load-disconnecting design, and (6C), a design which does not disconnect the load if the protective fuses open.

Note that all the circuits in Figure 6 are simplified to show the principles of operation. Real protectors contain circuit breakers, multiple varistors and fuses, other voltage-limiting components, indicator lights, and capacitors and inductors for removing radio frequency interference (RFI).

Some high-end AC protectors also have electronic circuitry that senses the applied AC voltage and controls a relay, the contacts of which replace the fuse in 6B. In case of sustained AC overvoltage (or, possibly, undervoltage), the relay disconnects the protective elements and the load. The circuit continues to monitor the applied voltage and then reconnects the protective elements and the load after the voltage returns to safe values. No electromechanical (relay) circuit is fast enough to protect from lightning surges; the electronic protection feature works only against AC voltages outside a designed acceptance range (see below). Varistors are still used to provide protection against the fast-rising lightning surges.

The seemingly minor differences among the three circuits in Figure 6 make a substantial difference in the way the protectors deal with surges and sustained AC overvoltages. The following discussion refers to AC protectors where the voltage-limiting elements are metal-oxide varistors, usually called MOVs. The vast majority (>90%) of both hard-wired and plug-in protectors use MOVs to perform the voltage-limiting function. In most AC protectors, they are the only significant voltage limiters.

First look at the surge limiting properties of the protectors in Figure 6. Typically, the hard-wired protectors (6A) will have MOVs with higher limiting voltage than the plug-in protectors. Most hard-wired protectors use MOVs that have at least a 150 V AC RMS rating, with some running up to 275 V RMS. The corresponding surge limiting voltage would be 400 V to ~800 V peak, for the standard 500 A test pulse. (See Section 2.2.3.)

Most plug-in AC protectors use MOVs rated for 130 V AC RMS, and have a surge limiting voltage of ~330 V peak for the 500A test pulse. So, plug-in protectors tend to provide lower limiting voltages (better protection for equipment) for moderate incoming surges. The gap widens when more realistic surges, and the effects of wiring, are considered.

Section 2.3.2 pointed out how rapidly the lead length raises the effective limiting voltage of hard-wired protectors for large current impulses. For a typical installation with 20 inches (50 cm) leads, the effective limiting voltage at the panel would be ~1160 V for a 10 kA impulse (see Table 1).

In a well-constructed plug-in protector, the load is connected directly across the MOVs (Figure 6B), and there should be negligible voltage drop in the MOV leads. So for the same 10,000 A surge current, the load can actually see a ~400–500 V effective limiting voltage (with 130 V MOVs), much smaller than allowed by the hard-wired protector, and much more protective for the equipment.

Well-designed and well-built plug-in protectors will actually withstand the 10,000 A (8x20 μ s) surge current, and that is rating required by NFPA 780-2004 for plug-in protectors. However, the UL 1449 Standard only requires plug-in protectors to withstand, without damage, ~20 500 A surges. Inexpensive protectors using the 6C type of circuit are designed to respond to overload by opening the protective fusing shown in Figure 6C, sometimes at surge currents barely over the 500 A limit. Because the UL 500 A surge withstand requirements are relatively weak, it is important to have both a hard-wired protector at the service entrance and a plug-in protector at the critical loads.

The hard-wired protectors will have a higher surge current rating and absorb most of the surge, but may not have a low enough limiting voltage to protect the equipment. Both protectors together work better than either one alone.

When a fuse opens, the user finds out the difference between the designs 6B and 6C.¹⁴ In 6B, if the fuse opens due to excessive surge current, the surge current is stopped at the fuse, which is normally calibrated to open at a surge level just

¹⁴ UL Standard 1449 has amendments that require protector manufacturers to notify users if design type 6C is used. UL plans to enforce this requirement for protectors manufactured starting in the spring of 2005, but products without the notice will be in commerce for a considerable time after that. Packaging for most protectors claims to protect equipment against overvoltages large enough to damage the protector, but may not always be accurate.

below the maximum MOV surge capacity. The MOVs continue to limit any stray excessive voltages to the load. Power to the equipment is permanently disconnected, and the user is implicitly warned that the protector has died and needs to be replaced.

In the 6C circuit, if the MOV fuses open due to surge overload, the surge limiting devices are disconnected, and the surge continues undiminished to the load, and might very well damage it. If the equipment is not damaged immediately, it continues to get power and operate, although it is now completely unprotected and vulnerable to later events.

There are two reasons for the use of the 6C type of circuit. First, it is typically easier to design, manufacture, and pass through the UL tests, and therefore less expensive than the 6B version. Second, some users may rate continuity of the power supply to the equipment as a higher priority than protecting the equipment from surge damage. The 6C circuit assures that the equipment will get power even if the protector is damaged.

Section 2.5.2 introduced the problem of sustained AC overvoltages, and the inability of hard-wired protectors to defend against them. The higher-end plug-in protectors can protect equipment against these very common events.

The best protection is obtained from the relatively expensive electronically controlled protectors mentioned above, which can disconnect when the supply voltage gets above ~145–160 V RMS. This approach not only protects the equipment, but allows the protector to survive the overvoltage event as well.

For (non-electronic) protectors with 130 V MOVs, the MOVs will begin to conduct current at ~170–180 V AC RMS, and will rapidly overheat. The UL 1449 Standard effectively requires thermal (overtemperature) fusing for the MOVs to avoid a meltdown. If the protector design follows 6B, the fuse that opens to protect the MOVs from meltdown will also disconnect, and probably protect, the load. The protector will need to be replaced. The electronically controlled 6B protectors generally provide a lower shut-off voltage level and a faster response to AC overvoltage than the non-electronic designs, and therefore should provide better protection for the equipment.

If the design 6C is exposed to sustained overvoltage, and the fuse opens, the over-voltage continues on to the equipment.

Section 2.5.1 discussed the confusion about Joule ratings for AC panel protectors. The misuse of Joule ratings is at least as severe for plug-in protectors. Typically, protector manufacturers cite a Joule rating for the protector that is the sum of the (MOV manufacturer's) Joule ratings for all the MOVs in the product, and this has become a sort of "horsepower race". However, especially in protectors of the 6C design, the fusing may be set to such a low level that the fuse opens (eliminating the surge protection) long before the stated capability of the MOVs is reached. If this happens, the claimed Joule rating is meaningless. (See section 2.5.1 for further discussion.)

Plug-in protectors typically have surge current withstand levels that are relatively low compared to the ratings for panel protectors described in Section 2. For best performance and longest service life of the plug-in protectors, panel protectors with higher surge current ratings should be installed at the service entrance, as described in Section 2 and Section 5 above.

5.2 Signal Protectors

As will be seen in Section 6, complete protection can be obtained only if every power and signal connection into a collection of equipment passes through a protector. The basic protector example in Figure 10 shows only one coaxial and one phone protector, but with the complex phone, satellite, computer, and video links being commonly used today, a wide variety of signal protectors is required. Appropriate signal protectors are available for most connections, but they must be carefully selected and matched to the application.

The most obvious requirements are as follows:

- 1) The protector must pass the signals without significant limiting, distortion, attenuation, or leakage of radio-frequency signals.
- 2) The protector must limit overvoltages to values safe for the equipment.
- 3) The protector must have adequate surge absorbing capacity.
- 4) The protector must have appropriate connections for the application.
- 5) If there is a primary signal protector (Section 3) installed at the building entry point, the point-of-use signal protector should "coordinate" properly with the primary (see below).

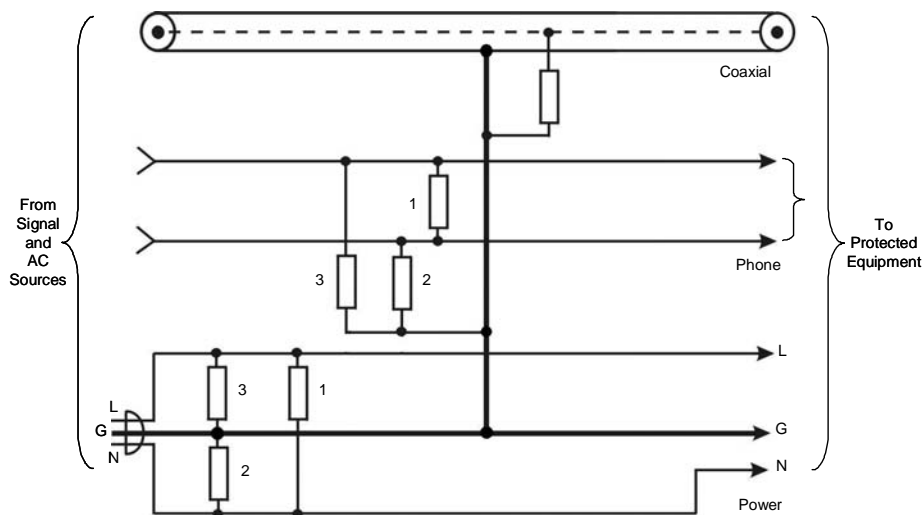


Figure 10: Basic Plug-in Multi-port Protector (Surge Reference Equalizer). There is a protector for each port (cable), and the grounds for all the protectors are connected (bonded).

Unfortunately, for most consumer electronics equipment and protectors, the information to answer these questions is not readily available. The specifier/installer must generally trust the recommendations of the protector manufacturer, and the UL tests mentioned above and in Section 7, that the protector is appropriate for the planned installation.

It is the responsibility of the specifier/installer to read the instructions that come with the protector, and make sure that it is recommended for the application. There have been many complaint/trouble calls generated by installers who tried to use a telecom protector for an Ethernet 10/100BT system, or a low-voltage CATV/Antenna protector for a satellite system, and found the system would not work. A protector with modular (RJ-11/45) jacks or F-connections might not work for every system using those connections!

There are two specific applications that require special consideration: digital small-dish satellite systems, and (high-end) phone systems where there is a central digital control unit (“KSU” systems), with extensions throughout the house.

In the first case, the high frequencies and very small “headroom” (additional signal attenuation that can be tolerated) require special low-attenuation protectors for an adequate signal to get to the receiver.

In the second case, the extensions (station sets) are driven by low-voltage (typically ~24 V) power and signals, and they are much less protected from surges than the regular analog (tip-ring) phone interfaces. Standard telecom secondary protectors (typically 260–400 V limiting) will not protect them.

In the first case, the satellite system will not work, or the performance will be marginal. In the second case, the phone system will work, but won’t be protected. The installer should consult the manufacturer of the equipment to get recommendations for protectors that meet the appropriate requirements.

“Coordination” (see also 2.2.4) is the term used by protection engineers to describe how two protectors work together. Typically, the concern is with high-current (primary) protectors at the building entrance, with high limiting voltage, connected directly to low-voltage, relatively low-current secondary protectors downstream. If the low-voltage protector is located close to the primary, it is possible for it to turn on (conduct) before the primary protector acts. In that case, the primary never gets a chance to act, and all the surge current will flow directly into the secondary protector, and possibly destroy it.

To guard against this scenario, signal protectors frequently have a series resistor (or positive-temperature-coefficient resistor) in series with the signal input line. This limits the current flowing into the secondary protector, and increases the voltage across the primary protector under surge conditions, helping it turn on, and stopping the main part of the surge current at the primary protector.

5.3 Inter-System Bonding

Figure 10 shows a multi-port protector with all the components mounted in a single unit, and a direct connection between the signal protector grounds and the AC ground. This construction provides the best equalization between signal and AC grounds, and is the least susceptible to misconnection or contact problems.

Some manufacturers supply modular systems, in which a variety of signal modules can be attached to an AC protector, with the ground bond being automatically established as part of the mechanical connection. These systems are

essentially as good as the single-unit multiport protectors, and have the advantage that they can be configured to protect even very complex systems. With the convergence of audio/video and computer systems, proper protection requires flexibly configurable protection systems.

The use of individual signal protectors, individually grounded to the AC protector or some other ground terminal, is a much less reliable way of providing the function of the multi-port protector. Even when the original installer makes the installation correctly, there are later changes and additions, and protector grounds frequently are disconnected, moved, or accidentally broken.

One unpublished analysis of (nominally protected) equipment damaged by surges showed that about half the cases resulted from inappropriate or missing signal protector grounds. Use of single-unit multiport protectors, or modular protectors with automatic ground connection to the AC unit, eliminates this concern.

In some situations, there might be significant circulating (60 Hz) ground currents in the house system, or CATV connections might bring in significant AC current on the cable sheath. If this is the case, direct connection between the cable sheath and the AC ground at the protector, as shown in Figure 10, might superimpose a 60 Hz voltage on the receiver input, resulting in “hum bars”, dark horizontal bands through the TV picture, possibly accompanied by a 60 Hz hum on the audio signal.

The best solution is to stop the source of the AC current in the ground system. If this is not possible, some protectors are available that have a low voltage (10–50 V) MOV or other voltage limiting device connecting between the coax protector ground and the AC ground. This eliminates the stray AC current that is causing the problem, but, under surge conditions, will still connect the coax and AC grounds, thereby providing the protection.

Another alternative is to use a “ground isolator.” This is a small adapter installed just before the coax connection to the protector. It breaks the cable sheath, and bridges the break with a small capacitor. The capacitor conducts the signal, but not the 60 Hz currents.

Protectors with a low-voltage isolator between signal and AC grounds are also available for RCA plug (audio) applications, where hum due to ground loops can be a problem.

5.4 Special-Purpose Protectors

There are a number of niche applications requiring specialized protectors. Three of these are electronic dog fences, power-over-Ethernet (POE) connections, and transceivers for inter-building wireless network connections.

Electronic dog fences use a low-power transmitter to drive a loop of wire at ~10 kHz; the loop surrounds the area where the dog is to be confined. The loop might be very long, and if it is outdoors, it is an excellent “lightning antenna” and will bring damaging lightning surges to the transmitter. The application requires a multi-port protector, because the transmitter has both an AC power connection and a signal (loop) connection. A number of suppliers are now selling inexpensive protectors that plug directly into a wall outlet and combine a protector for the loop with an AC protector. These multi-port protectors have greatly reduced transmitter damage from lightning.

POE is a relatively new technology that uses four wires of the standard eight-wire/RJ-45 10/100BT Ethernet connection normally. The four wires not normally used in Ethernet are used to provide power to computer network accessories such as modems, printers, hubs, etc. This approach makes it much easier to configure systems and eliminates much of the wiring tangle from small individual power supplies. The power supply voltages used, up to 48 V, are too large to pass through most protectors used for Ethernet signal lines, so special protectors are needed. An optimal design would include the POE power supply inside the protector, further simplifying the connections.

Wireless local area networks (LANs) are very popular for use within the home. They have the great advantage that they do not need lightning/surge protection for the signal side of the nodes that are linked via wireless. But when the wireless LAN is providing a high-speed digital link outside the home, as part of a local wireless service area, there is generally a small transceiver and antenna mounted on the roof. This transceiver is not only vulnerable to direct or nearby lightning, but, being connected to the home’s computer system, can bring the surge currents directly to expensive, vulnerable equipment. So far as we are aware, there are no complete protection solutions available as of this writing. Vulnerability is very much decreased if the transceiver/antenna assembly is located in a lightning-shielded area. This is well outside the scope of this document. Both NFPA 780 and UL 96A have information that can be used for this application.

6. SPECIFIC PROTECTION EXAMPLES

The previous sections have shown, in general, how to protect electronic systems in houses:

- 1) Proper grounding and bonding, especially at the service entrance.
- 2) AC panel and primary signal surge protection at or near the service entrance.
- 3) Multi-port plug-in protectors near the equipment to be protected.

For simple systems, such as a TV set without interconnections to other equipment, Figure 7 shows how simple the protection can be. For an isolated TV set, the multi-port protector consists of an AC protector with at least one AC outlet, and an RF protector with input and output F connections. The protector is plugged into the wall outlet, the TV set is plugged into the protector, and the RF signal is passed through the protector and to the TV set input.

For a fax machine or PC with a dial-up modem, the same approach is used, but the multi-port protector must have a signal protector for a phone line, instead of the RF protector. The phone protector will normally have standard modular (RJ-11/14/45) jacks, and connecting the protector simply requires telephone jumper cables to connect from the wall jack to the protector, and then from the protector to the modem.

However, most installations involve numerous pieces of interconnected equipment. Figure 11 and Figure 12 show examples of protection for two typical small systems, and we can derive some general approaches to protect similar or more complex systems.

6.1 Home Theater with Satellite Receiver or CATV Feed

Figure 11 shows the required protection elements for a TV set or small home theater system, taking signal from a satellite receiver or CATV cable. Here the multi-port protector is more complicated—it must have protectors for both the CATV connection and the satellite feed from the LNB. If there is a dual LNB, there must be two satellite signal protectors. Additionally, many satellite systems (and TiVo® as well) require connection to a phone line, so a phone protector must also be provided. This is the kind of situation for which protectors with individual

signal protection modules are very effective, especially since systems do tend to be upgraded later with additional equipment.

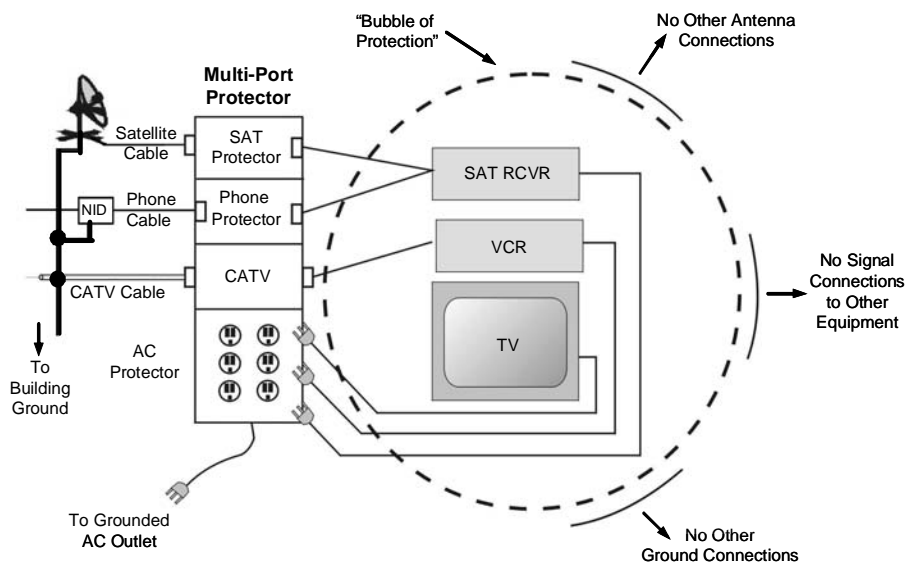


Figure 11: Application of Plug-in Multi-port Protectors (Surge Reference Equalizers). Each AC and signal connection requires a protector, and the only grounding allowed is via the ground of the protector. Equipment and coaxial cables outside the building must be bonded to the building grounding system. Signal connections within the bubble are not shown.

The basic connection of the multi-port protector in Figure 11 is very simple, but establishing complete protection requires additional checking.

- 1) Both the satellite dish itself, and the coax cable sheath, must be bonded to the building ground with at least a #10 wire (NEC Art. 810.21). If possible, the satellite RF cable should come into the building near the service entrance, so that the bond can be very short. If the cable is not bonded to the building ground, large lightning currents can be carried into the building, and will destroy equipment, and possibly cause fire or other damage. As pointed out in the NEC/CEC (Art. 810.21), a separate ground rod is not an adequate substitute for the ground bond.

- 2) The installer should examine the NID (network interface device, which contains the phone primary protector, and is normally supplied by the telephone utility), and make sure that its ground terminal is also bonded to the building ground (NEC Art. 800.40). The NID should also be inspected to make sure there is actually a protector present.
- 3) The CATV grounding block normally installed at the building entrance should be checked to make sure that it is bonded to the building ground (NEC 820.40). Again, a separate ground rod, or water-pipe ground, satisfies neither the NEC/CEC nor the need for lightning protection.

A substantial fraction of the damage to point-of-use protectors, and to equipment, occurs because these ground bonds or primary protectors are missing or inadequate. Recurrent damage to protectors or equipment in a particular location is almost always a sign of a missing or improperly grounded protector.

The most difficult part of establishing complete protection is often making sure that no unprotected wires run to the equipment. There are four common types of connections that violate the protection integrity:

- 1) Equipment plugged into an AC outlet which is not part of the multi-port protector.
- 2) Rooftop antenna or other signal input connection, bypassing the multi-port protector.
- 3) Downstream signal connections, for example to a second TV set in another room.
- 4) Any ground, intentional or unintended, to any piece of the equipment, bypassing the surge protection.

All four of these violations expose the equipment to large voltages directly from lightning surges or from ground potential rise, as discussed in Section 4 of this *Guide*. During a lightning strike, voltage differences of tens of thousands of volts can arise between different parts of the grounding network. If the connecting wires do not pass through the protector, voltage differences are carried directly into the equipment, and can cause severe damage.

Violations 1 and 2 above can also cause damage because there is no limiting of surges on the AC supply (1) or on the signal wire (2), but ground potential differences are a more common cause of damage.

Violation 3 can be cured by adding another signal protector to the multi-port protector, and “exporting” the signal through the protector. To protect the downstream equipment, another multi-port (AC + signal) protector needs to be installed at that equipment (see Figure 8).

Violation 4 is caused by attaching extra ground wires or having metal equipment racks connected to other grounds, where the ground connection does not pass through the multiport protector. This can be fixed by using only the ground from the multi-port protector. At no point should a code-required safety ground be disconnected as this may cause other hazards. In general, this situation can be dealt with by bonding the safety ground to the multi-port protector. Some multi-port protectors have ground terminals to facilitate this connection.

In the system shown in Figure 11, the satellite LNB at the antenna is not protected against direct strikes. Unless it needs to be on a roof top for line-of-sight considerations, the damage risk can be greatly reduced by mounting it on the ground near the building or on a wall, well below the top. It is possible to protect antennas from direct strikes by using shield wires well above them, or by using nearby tall poles as air terminals, but generally these are too expensive or unsightly for residential use. The lightning protection code, NFPA 780, provides some guidance for such installations.

6.2 PC with Cable Modem and Wireless Link

Figure 12 shows another example of a fully protected system, a PC supplied by a cable modem. The general rules and approach are the same as for the satellite TV system: all the AC power is derived from the multi-port protector and the only signal connection passes through an appropriate part of the same protector. The uninterruptable power supply (UPS) is plugged into the protector as well, to protect it from AC surges. The (laser) printer is plugged directly into the multi-port protector rather than to the UPS because at times laser printers draw too much current to be supplied by standard small UPSs.

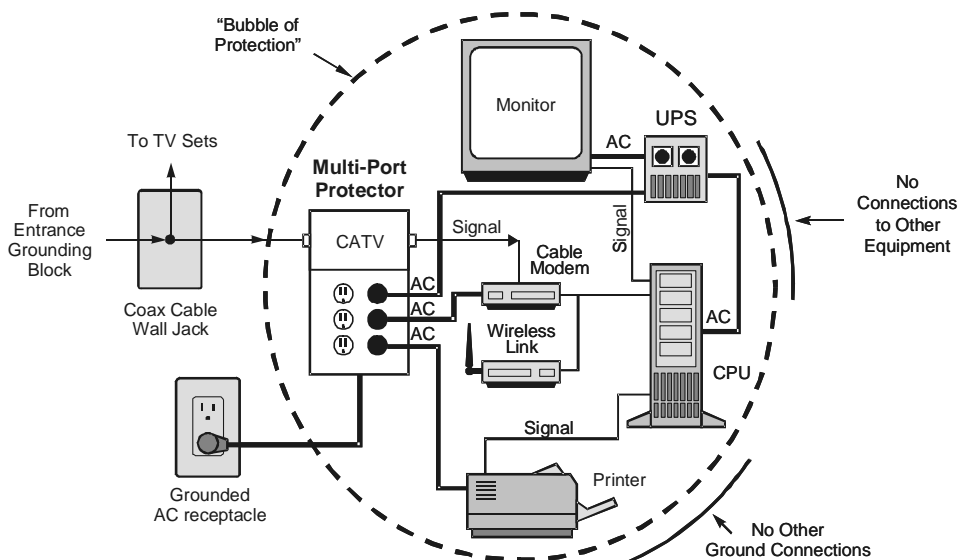


Figure 12: Connection diagram showing a multi-port (AC+CATV) protector for a computer system fed by a cable modem. A wireless link allows the cable signal and modem to be shared with other computers without interconnecting signal cables, which would need additional protectors. The UPS provides power in brownout or power failure conditions.

The system in Figure 12 uses a wireless link to carry signals/data to other computers or equipment in the building. This eliminates the complications, expense, and difficulty of installing and maintaining signal protectors over a building-wide network. The individual pieces of remote equipment should still be protected by plug-in AC protectors, however.

If the building structure will allow communication by wireless (IEEE Std 802.11™ or similar systems) links, wireless networking should be the prime candidate for data communications and electronic control systems. This is especially true in high-lightning areas. Fiber-optic systems are essentially immune to lightning damage, but are usually more expensive and less widely available than wireless links.

The diagrams in Figures 11 and 12 use an approach variously called “protected islands,” “bubble of protection,” or “circle of protection” to help the installer perfect the system design. The installer must make a diagram like that shown, containing all the equipment modules and their interconnections. This is now considered as a subsystem, and the installer should specify a multi-port protector with the required functions and connections. Each protected island may be connected to other islands (only) via signal cables that pass through the multi-port protectors. The diagrams should be retained as part of the system documentation. They will be very helpful for the inevitable changes and upgrades.

A recent innovation for permanent home-theater installations is the development of small multi-port protectors designed as wiring devices, to be mounted within the wall, like regular receptacles. These typically have a single AC receptacle, and a multi-line signal protector, and are hard-wired to the building AC distribution system. They are especially appropriate for large flat-panel TV screens, where the unsightly clutter of separate protectors and loose wires is undesirable.

The examples shown here are basic, but should give the installer ideas of how to approach the problem. The references in section 7.2 of this *Guide* provide many additional examples showing how to protect common equipment configurations. For complex systems, the installer should consult with the protector manufacturer, or with installers who specialize in surge protection for complex residential systems.

7. FURTHER INFORMATION

The additional information cited here emphasizes web sources because they are easily accessible and frequently updated. They also contain further references.

7.1 General Information about Lightning and Protection Standards

[B1] National Lightning Safety Institute: <http://www.lightningsafety.com>.

[B2] Real-time lightning map: Vaisala, at:
http://www.lightningstorm.com/tux/jsp/gpg/lex1/mapdisplay_free.jsp.

[B3] *Lightning: Physics and Effects*. V. A. Rakov and M. A. Uman, Cambridge University Press, 2003, ISBN: 0-521-58327-6. Extensive review containing more than 6000 references.

7.2 Lightning Protection and Protection Equipment

[B4] Eaton: <http://www.cutler-hammer.eaton.com/surge>. Product information and selection guide.*

[B5] National Electrical Manufacturers Association: <http://www.nemasurge.com>. Good glossary, explanations, and many links to other information.

[B6] Panamax: <http://www.panamax.com>. Many detailed application diagrams, reference papers, and product information.*

[B7] SquareD/EFI: [http://www.squared.com/us/applications/residential.nsf/unid/8F3924A6C75BF50685256A2A005CC0B4/\\$file/residentialFrameset.htm](http://www.squared.com/us/applications/residential.nsf/unid/8F3924A6C75BF50685256A2A005CC0B4/$file/residentialFrameset.htm).
<http://www.efinet.com/about.html>.*

[B8] A useful basic guide for lay people is François Martzloff's, "Surges Happen," at: <http://www.eeel.nist.gov/817/817g/-spdanthology/files/Surges%20happen!.pdf>

[B9] An extensive collection of research and tutorial papers on lightning and surge protection appears at: <http://www.eeel.nist.gov/817/817g/spd-anthology> .

[B10] Lightning protection for boats is discussed at:
<http://www.marinelightning.com> .

*Sites above marked with the * contain pdf copies of this application guide.

7.3 Codes and Standards

[B11] *Installation of Lightning Protection Systems*, NFPA 780-2004, at <http://www.nfpa.org>.

[B12] *National Electrical Code*, NFPA 70, 2002, at <http://www.nfpa.org> .

[B13] Canadian Electrical Code, C22.1, Canadian Standards Association, at: <http://www.csa-intl.org/onlinestore/GetCatalogDrillDown.asp?Parent=428>.

[B14] Underwriters Laboratories Surge Protector Standards: <https://www.comm-2000.com/SearchResults.aspx?sendingPageType=CatalogBase>.

- UL 96A: Standard for Installation Requirements for Lightning Protection Systems
- UL 452: Standard for Antenna Discharge Units
- UL 497: Primary (twisted pair) communications protectors
- UL 497A: Secondary (twisted pair) communications protectors
- UL 497B: Secondary (isolated loop) communications protectors
- UL 497C: Primary (coaxial) communications protectors
- UL 1449: AC hard-wired and plug-in protectors

No formal Standard for “Lightning Arresters.” Will be incorporated into UL Standard 1449 as “Secondary Surge Arresters.”

[B15] IEEE Standards C62.xx are available at: <http://shop.ieee.org/ieeestore/>.

The IEEE has had an active group studying surge/lightning protection information and writing standards for more than 30 years, resulting in the C62.xx series of standards. The key standards for areas covered by this guide are IEEE Std C62.43™ for data and communications circuits, and three standards: IEEE Std C62.41.1™, IEEE Std C62.41.2™, and IEEE Std C62.45™ for AC circuits. The three linked AC standards describe, respectively, (1) the sources of surges, and how the surges are affected as they move through the building wiring; (2) recommendations for standardized test waveforms and amplitudes, representative of the real environment, and (3) procedures using these waveforms to test equipment for its resistance to surges. These three standards are currently being revised, and should be available shortly. Additional standards for multi-port protectors are being developed, and should be issued as IEEE Std C62.50™ and IEEE Std C62.51™.