Developing a Consumer-Oriented Guide on Surge Protection

Thomas Key, EPRI-PEAC, 942 Corridor Park Blvd, Knoxville TN 37932 TKey@epri-peac.com
François Martzloff, National Institute of Standards and Technology, Gaithersburg MD 20899 f.martzloff@ieee.org
Roger Witt, State Farm Insurance Co., 1 State Farm Plaza, Bloomington IL 61710
Jim May and **Stacey Black**, Illinois Power Company, 500 South 27th Street, Decatur IL 62525

Reprinted from Proceedings, PQA'97 Conference, 1997

Significance:
Part 2 Development of Standards – Reality checks

Caught among contradictory stories on the need for surge protection as well as unsupported anecdotes of surge-related failures, the typical consumer is in a quandary on how to best allocate personal resources to protect the expensive electronic equipment found in a modem household.

To help provide some answers to this quandary, a team of experts developed and engineering guide on the basics of surge protection. One of the recommendations addresses the issue of ineffective configuration of utility connections that are responsible for surge-induced failures. This paper served as a progress report, documenting the status of the project at the end of 1996. An update on this project was reported under Key et al. 1999, which is included in Part 6 of this Anthology

Reprinted from
Proceedings, PQA '97

Developing a Consumer-Oriented Guide on Surge Protection

Thomas Key
EPRI-PEAC
10521 Research Dr.
Knoxville, TN 37932

François Martzloff
National Institute of
Standards and Technology*
Gaithersburg MD 20899

Roger Witt
State Farm Insurance Co.
1 State Farm Plaza
Bloomington, IL 61710

Jim May and Stacey Black
Illinois Power Company
500 South 27th Street
Decatur, IL 62525

ABSTRACT

Caught among contradictory stories on the need for surge protection as well as unsupported anecdotes of surge-related failures, the typical consumer is in a quandary on how to best allocate personal resources to protect the expensive electronic equipment found his in a modern household. To help provide some answers to this quandary, a team of experts is currently developing a practical application guide on the basics of surge protection, providing a tutorial suitable for the "average consumer." This paper shows how the guide intends to take the reader through the thicket of surge protective devices and applications.

The guide covers a range of application issues from basic information on the occurrence of lightning and switching surges to the selection of cost-effective and technically sound mitigation methods. It explains how protection applications must be suitable for the geographic area (lightning flash density), power distribution type (urban or suburban), and grounding practices (recent NEC or grandfather). The ultimate goal is that the guide will become the basis for better mitigation practices, will decrease losses and the number of loss claims, and will reduce the fear and frustration levels among end-users relative to surge-related upset or damage to their appliances and electronics.

INTRODUCTION

Each year lightning is estimated to be responsible for 250 to 500 million dollars in property damage in the United States. This estimate is based on an analysis of insurance claims compared to cloud-to-ground lightning flash data by operators of the National Lightning Detection Network, described by Byerley et al [1]. Since about 1989 this system has provided a very accurate count and location of lightning flashes to ground and of the resultant ground flash density in the United States. For some insurance companies the data have been used to confirm or deny lightning damage claims.

An analysis of 5500 detailed claims found more than half of the loss was related to telephone and electronic appliances. Considering that many of these losses are preventable, the insurance companies that pay millions of dollars per year replacing lightning- or other surge-damaged appliances are highly motivated to help prevent such damage. As a first step toward minimizing surge damage, State Farm Insurance Companies, Illinois Power, and EPRI have joined forces to devise a recommended practice for residential surge protection, wiring, and grounding. To achieve

* Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce. Contributions from the National Institute of Standards and Technology are not subject to United States copyright.

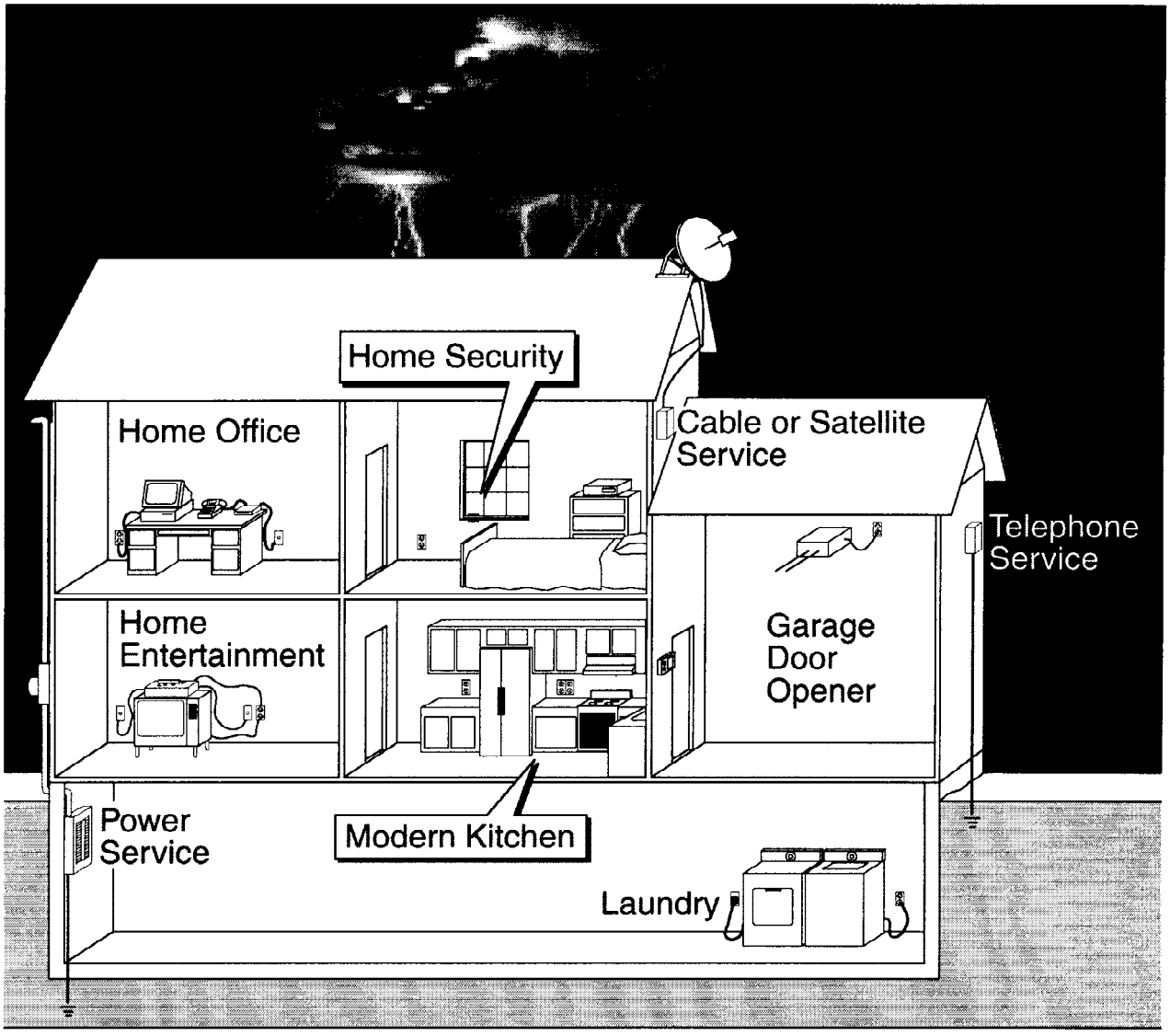


Figure 1. Typical candidate appliances and systems for surge protection in a residence

this goal, the project team is completing three specific tasks: 1) initial fact-gathering, 2) a workshop to discuss surge protection issues, and 3) completion of the manual of recommended practice.

A typical modern residence contains many electronic and multi port appliances. In order to identify specific protection practices, a typical residence was defined with electronic appliances and systems illustrated in various rooms as shown in figure 1. The main systems are home entertainment including cable TV, home office including telephone, and electronic kitchen appliances. Other common vulnerable systems are home security, intercom, satellite receiver, garage door opener, and laundry equipment. Generally, any system with micro-electronics plus exposure due to power and signal wiring can be found in lightning damage claim reports.

Technical inputs were gathered on the expected surge threat and the key elements of protection.

These including lightning, surge propagation, grounding, surge protection practice, and built-in appliance immunity. The workshop was successful in building consensus despite the fact that different experts had different backgrounds and experiences. At the end all agreed on essential principles of how to protect sensitive equipment. However, specific devices and procedures that could be applied case by case were more difficult to obtain. Also, there is currently no information about compatibility levels and points of vulnerability for many modern residential electronic appliances and systems. Consequently, specific installation methods and precise recommendations on how to protect these electronic systems from surge threats are not yet fully developed.

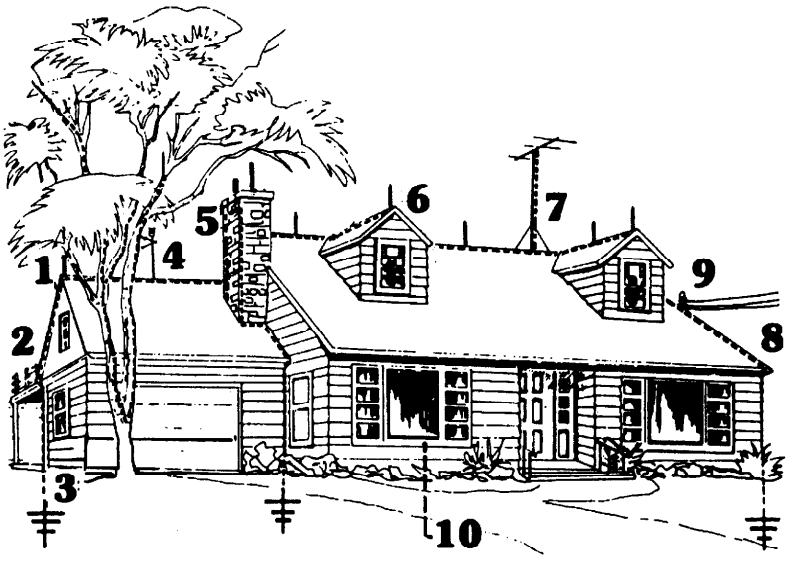
A few appliances seem to have varying susceptibility to surges. The most notable losses, according to insurance claim records, are telephones and modems, computerized equipment, TV, VCR and satellite receiver systems. These are generally multi-port appliances—that is, appliances connected to several different systems, such as an entertainment center connected to power, cable, and telephone or a security system connected to power, sensor, and control. These multiple connections, and the likelihood of potential differences between them, are believed to be major factors in surge damage susceptibility of many residential appliances and systems.

Essentials of Surge Protection

Lightning is not the only threat, but remains a dominant one.. Most of the Continental United States experience at least two cloud-to-ground (C-G) flashes per square kilometer per year. About one half of the area will see three C-G flashes per km^2, which is equivalent to about 10 discharges per square mile per year. The maximum flash densities are found along the southeastern Gulf Coast and the Florida peninsula, where the values approach $20/km^2$ or $50/mi^2$. Overall about 30 million C-G flashes strike the United States each year, and lightning is clearly among the nation's most severe weather hazards.

In high lightning areas, perhaps a threshold of three C-G flashes per square km per year, some degree of structural lightning protection is recommended. This threshold may be economically justified by the growing value, and vulnerability, of residential electronic systems. There is good information available on how to accomplish this protection. Basic lightning protection practices are well defined in the Lightning Protection Code, NFPA 780. An illustration of the basic elements of this protection is provided in figure 2. These protection techniques will not eliminate surges that enter the residence either via different wiring systems—including the grounding electrode system—or coupled into wiring from nearby flashes. In addition to the lightning threat, some basic household appliances can act as surge generators, for example a light switch or a furnace igniter.

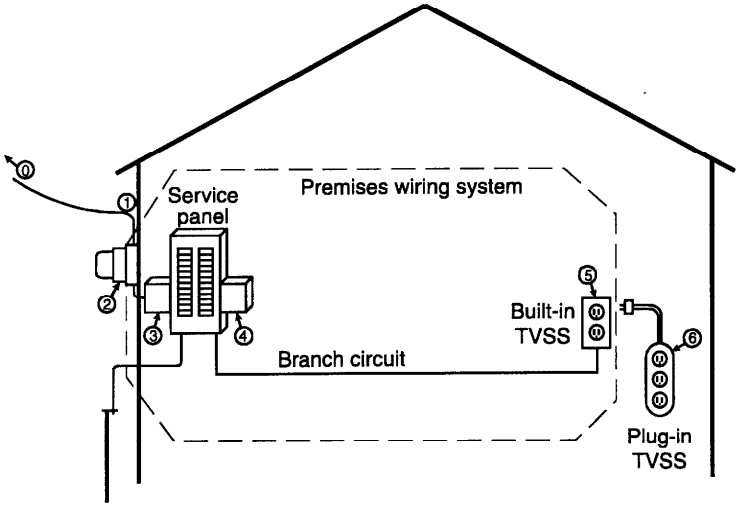
Protection against these surges can take several forms. The possibilities are: preventing the surge at its origin (impossible for lightning and difficult for surges associated with normal operation of the power system), diverting the surge to ground as it impinges on the building, before it enters the building (the most effective approach), and finally, clamping by a surge protective device (SPD) at the equipment (either by an add-on, plug-in, or built in SPD). Of these three approaches, only the service entrance and add-on SPDs are options available to the end-user. Service entrance protection may be offered by the local utility. If not, a licensed electrical contractor may offer installation service. In either case installation of service entrance protection must be done by a professional. Various locations for power line or transient-voltage surge suppressors (TVSS) are shown in figure 3.



Legend

1. Air terminal spaced 6 meters (20 feet) apart along ridges and within 0.6 meter (2 feet) of ridge ends
2. Down conductors (minimum of two)
3. Grounding rods; minimum of two, at least 3 meters (10 feet) deep
4. Roof projections such as weather vanes connected to grounding system
5. Air terminals located within 0.6 meter (2 feet) of outside corners of chimney
6. Dormers protected with air terminals
7. Antenna mast bonded to roof ground conductor
8. Gutters and other metal objects bonded to grounding system
9. Surge arrester installed at service panel to protect appliances
10. Transient voltage surge suppressors installed at receptacles powering sensitive electronics

Figure 2. Typical comprehensive lightning protection of a residence (reprinted with permission from Underwriters Laboratory Inc.)



Power Line Surge Protectors

Service Entrance Arresters ⓪,①,②,③

Branch Circuit Suppressor ④

Receptacle Plug-in Suppressor ⑤

Plug Strip with Suppressor ⑥

Figure 3. Options for power-line surge protection in a residence

BASICS OF APPLICATION

A fundamental application issue in surge protection is grounding. Proper grounding is critical for the case of ground-seeking surges such as lightning currents. However, even more critical for multi-port appliances or systems is the difference in ground reference between port connections. This vulnerability issue is addressed in the National Electric Code (NFPA 70), which requires that the grounding conductors of all systems entering a facility be bonded together. As shown in figure 4 (left), a split bolt is used to bond different system grounding conductors to the power system grounding electrodes. Unfortunately this bonding is not always done and a common, but incorrect and dangerous to personnel and equipment, scenario is shown in figure 4 (right).

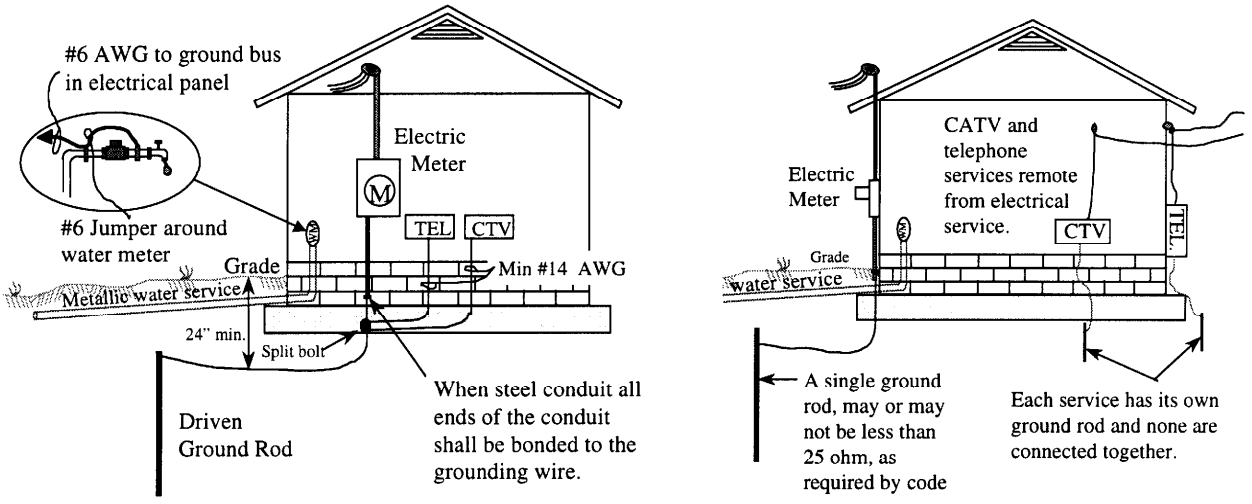


Figure 4 – Minimum code-required service grounding (left) and commonly found, but incorrect grounding of existing house (right)

The incorrect grounding of the house, figure 4 right side, was identified by the study group as the primary problem in residential system surge protection. Even with independent surge protection of the power and communications ports, smart electronic appliances are left vulnerable to surges. During a surge, an elevation of only one of the port reference potentials relative to the other(s) can upset or damage appliances. The problem is depicted in figure 5, which shows the connection of a facsimile machine (FAX), to both the power system and communication system. The SPD (also called TVSS in the industry jargon) on the power port of the FAX can be built-in or installed externally by the end user. The arrester at the service entrance, shown in dotted lines, may or may not be present. According to standard practice, the telephone company has installed a network interface device (NID) at the point of entry. The NID is installed primarily to protect the telephone system and human users from hazards of faults and surges that travel from the premises toward the telephone system, rather than to protect from surges impinging from the telephone system into the premises. Nevertheless, should a surge impinge on the telephone system, the NID will divert it to ground, in this case the nearest cold water pipe.

Consider the case of a surge impinging on the entrance of the telephone system. The surge current shown as "Surge i" in figure 5 flows in the long path from the entrance of the telephone system to the grounding point in common with the power system entrance. The inductance of this path is typically tens of micro-henries, and the surge current can rise to several hundred amperes in one microsecond. The resulting voltage drop along the current path from the telephone port to ground

is L x di/dt (voltage elevation at the FAX communications port). In contrast, the FAX power port is not affected by the surge because none of the power port conductors carry any surge current. Assuming 10 μH for L and 500 A/μs for di/dt, the voltage drop that appears between the power port and telephone port of the FAX is Vdifference = 10 μH x 500 A/1 μs = 5000 V. This voltage is likely sufficient to cause a flashover on the printed circuit boards, or a semiconductor failure in the FAX. Most FAX failures can be readily explained by the elevated reference potential associated with independent surge protection of the two ports.

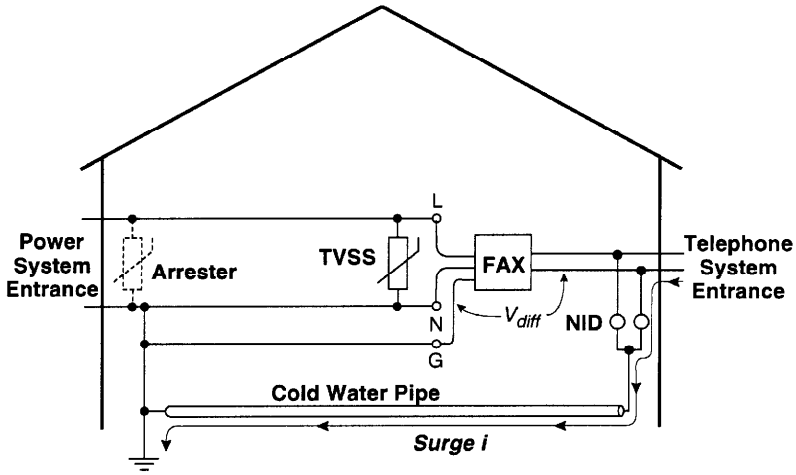


Figure 5. Surge voltage potential difference develops between two protected ports of appliance

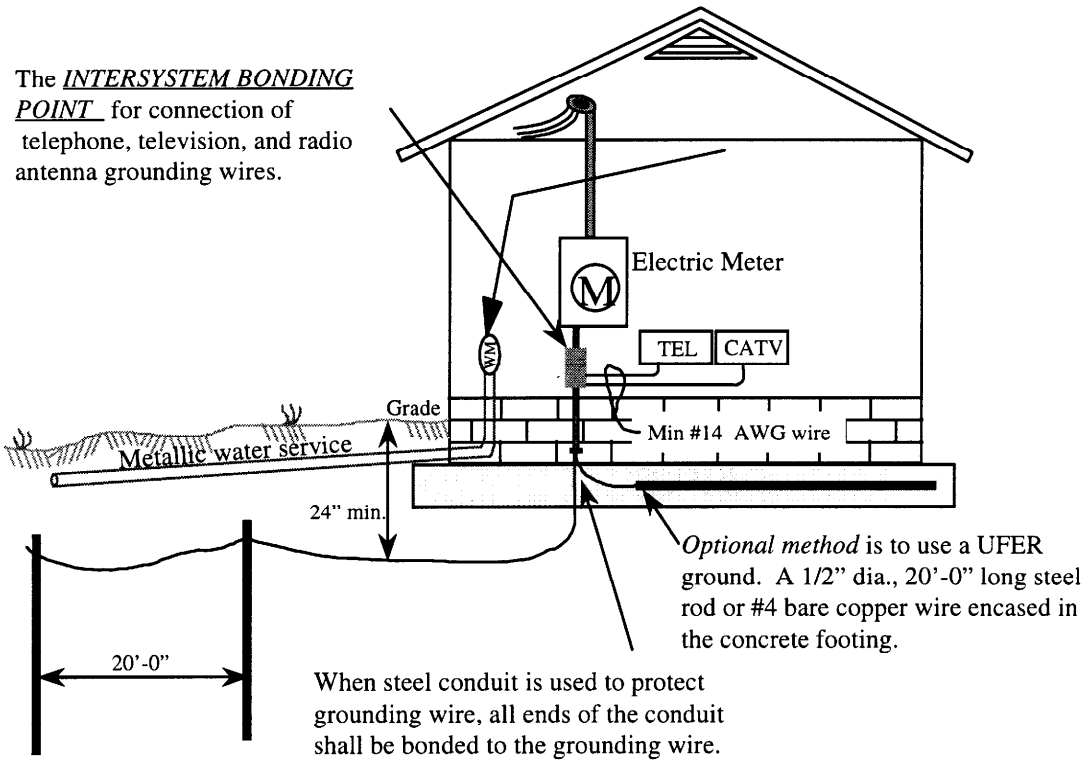


Figure 6. Recommended service grounding for enhanced surge immunity

The recommended practice to avoid the problem discussed above is an "intersystem bonding point," as shown in figures 6 and 7. This approach addresses the issue on a facility basis. The two services, power and telephone, must enter at the same point and must be bonded together at that point. The NEC requires bonding together the two service grounds, but does not require entry at the same point. As shown in figure 5 system bonding is provided by the cold water pipe, which is electrically common to both services. But the voltage potential difference still occurs because of the separated entry points. Figure 7 shows the details of how an inter-service bonding point might be constructed and installed.

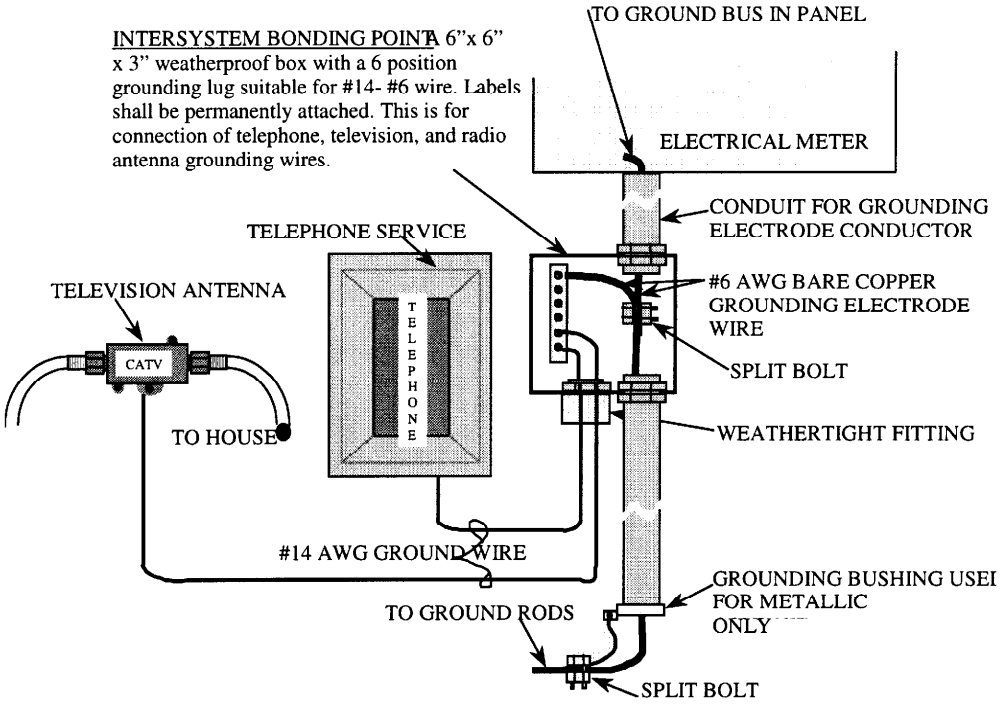


Figure 7. Details of the essential intersystem bonding point

Beyond grounding, for a surge-protective device (SPD) to be effective it must provide a protective level, or surge clamping, below a level potentially harmful to the equipment. But the level should not be so low that the device absorbs energy to the point that its life is reduced or it fails prematurely under the stresses resulting from a temporary overvoltage. This principle holds for power, signal, telephone or cable, albeit at different threshold levels. The SPD must also have a surge current handling capability commensurate with the surge currents that might occur at that location.

The application of an SPD satisfying the criteria cited above must also take into consideration the rest of the circuit where the device is to be applied. For instance, operation of the SPD must not cause adverse side effects. In the case of protection of load equipment which is connected to the power system as well as to a communication system (telephone, cable or satellite TV) particular attention must be given to this issue. It is possible that protecting the two interfaces of the equipment, each with a separate SPD, might leave the equipment in jeopardy as the result of overvoltages appearing between the two separate systems, see Key, Martzloff, [2,3].

Because effective operation of an SPD involves diverting the surge to ground, the actual grounding system and its connections in a residence must be taken into consideration. The impedance of the

grounding system to "true earth" is far less important than the integrity of the bonding of the various parts of the grounding system. As noted earlier the worst possible mistake–and a violation of the NEC–is to provide separate grounds for the power system and for the communications system. Even so, many instances are found of such multiple grounding practice in residences, either intentionally, or by accident. A typical example is services such as cable TV that used the metal pipe of an outdoor faucet as its grounding connection. This arrangement was an acceptable ground at the time of installation, but can easily be defeated when the water piping inside or outside the house is replaced with plastic. So an improper separation of grounds is camouflaged by the short link of steel pipe going through the foundation wall and sealed in the concrete.

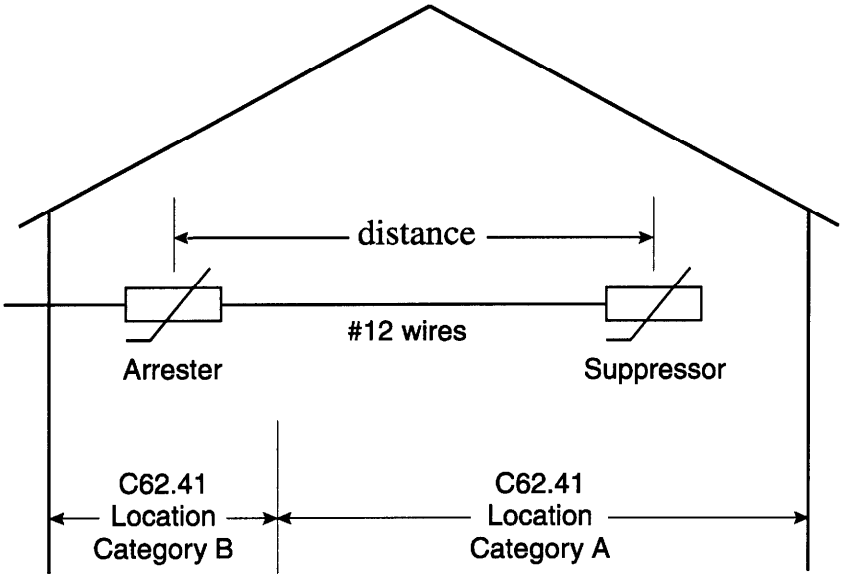


Figure 8. Cascade arrangement of upstream and downstream SPDs

OPEN AND UNRESOLVED ISSUES

Several issues remain open at this point and will be addressed in the Guide. We hope that the Guide will resolve some of these issues, but others might take more research to resolve. In some cases an iterative process will be required among end-users, utilities, and equipment manufacturers to optimize the process instead of exchanging blame.

One important problem that can be resolved by future research is the coordination of an SPD cascade, (see figure 8). If the selection of a service entrance SPD is appropriately coordinated with the installation of appropriate SPDs within the residence, then the resources will be allocated in an effective manner, both technically and economically (see Martzloff, Lai [4,5]). Clearly, this coordination can only be achieved by cooperation of the utility, SPD manufacturers, and premise occupants and full knowledge of the characteristics of the SPD's and the surge itself.

Another problem that can be resolved is the effective protection of equipment connected to two different systems. The concept of equalizing ground references has now been sufficiently advocated to motivate SPD manufacturers to offer SPDs with both power and telephone protection, or both power and TV protection, in the same enclosure (see figure 9). The IEEE designation of "Surge Reference Equalizer" was published in 1992, [6]. It has not yet found general use in the

industry, but for most residential applications the device can be found in electronics supply stores. Still, a possible problem in that solution is the absence of industry standards on the performance of surge reference equalizers. At this point, the user is left with some uncertainty as to how effective a particular brand may be compared to another. In this intensely competitive market, claims and counter claims need to be sifted via experiment, a role that some utilities might be willing to assume, or that consumer organizations should address.

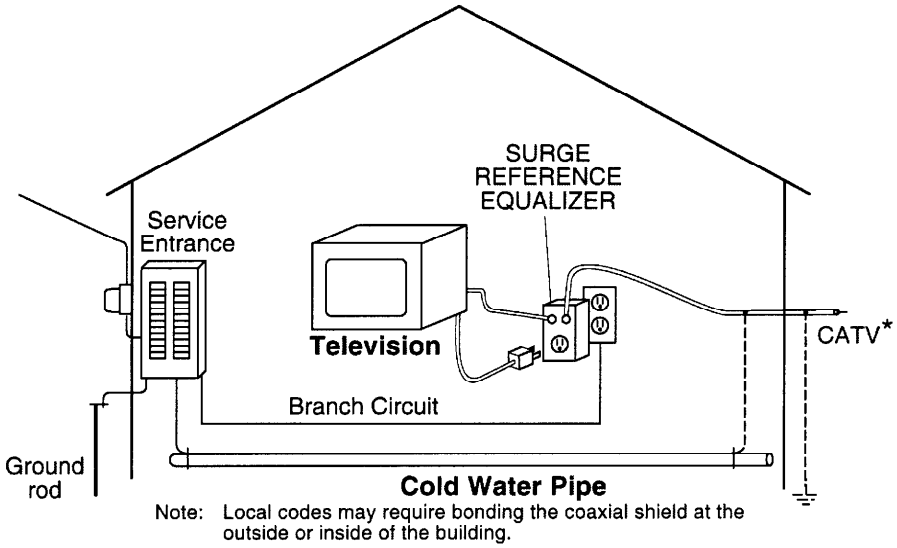


Figure 9. Surge reference equalizer to protect multi-port appliances

Last but not least, application of SPD or lightning protection must consider risk analysis. Protection of appliances against surges generated within a building, or impinging at the power service entrance, can be accomplished with relatively low cost. However additional investment may be required if multiple services (telephone, TV, and power), and multiple grounds are present. External protection against a direct lightning strike may also be needed with cost depending on the structure and location. In any case good practice should be sought in the face of an "act of God" event, where damage can be minimized by observing appropriate rules of grounding, bonding, and protection, as the Guide will propose. However, even with the best practices some degree of risk will always remain.

CONCLUSION

More attention to surge protection practices is warranted by the increased use and inherent surge vulnerability of residential electronic systems and appliances. While there is consensus on the basic principles of protection, specifics and installation procedures for cost-effective applications are not readily available. By applying data and practices for grounding, lightning and surge protections to specific appliance sets, these needed details are beginning to take form. To be successful a Consumer-Oriented Guide on surge protection will have to address complex topics of whole-house protection including such techniques as multi-port devices and cascade coordination. When complete, the Guide should provide a comprehensive document that insurance companies can use to educate their policyholders, employees, and agents about how to reduce damage resulting from surges caused by lightning.

REFERENCES

1. L.G. Byerley III, et al, Measurement and Use of Lightning Ground Flash Density," Proceedings of the International Aerospace and Ground Conference on Lightning and Static Electricity Williamsburg, VA, September 26-28, 1995.

2. Key, T.S. and Martzloff, F.D., "Surging the Upside-Down House: Looking into Upsetting Reference Voltages: Proceedings, PQA'94 Amsterdam, October 1994.

3. Martzloff, F.D., Mansoor, A., Phipps, K.O., and Grady, W.M., "Surging the Upside Down House: Measurement and Modeling Results," Proceedings, PQA'95 New York, May 1995.

4. Martzloff, F.D. and Lai, J.S., "Cascading Surge Protective Devices: Coordination versus the IEC 664 Staircase," Proceedings, PQA'91 Paris, October 1991.

5. Lai, J.S. and Martzloff, F.D., "Cascading Surge Protective Devices: Options for Effective Implementations," Proceedings, PQA'92 Atlanta, September 1992.

6. IEEE Standard 1100-1992, *The Emerald Book*, IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment.