

AD-A137 701

PROTECTION REQUIREMENTS AND CONCEPTS FOR DATA AND
CONTROL LINES REVISION(U) LIGHTNING ELIMINATION
ASSOCIATES SANTA FE SPRINGS CA JAN 82 LEA-80-8-REV-1

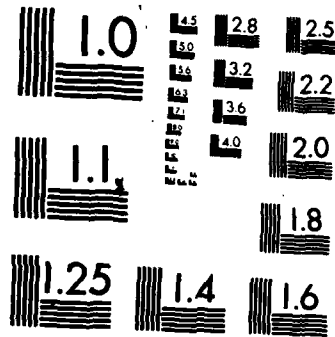
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PROTECTION REQUIREMENTS
AND CONCEPTS
FOR
DATA AND CONTROL LINES

NOVEMBER 1980
REVISED JANUARY 1982

Report No. LEA-80-8, Rev.1

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INTRODUCTION

Data and Control Systems have a high susceptibility to anomalous voltages of many forms, usually created by outside influences, but sometimes created within the system itself. These anomalies may be classified as destructive - requires maintenance to restore operation; or disruptive - requires a rerun of at least part of the program.

Destructive anomalies will destroy or damage the sensitive components at the system interfaces, which include:

- (1) The power line, a subject covered in another paper (1).
- (2) The data or control lines - These wires or coaxial cables carry either data, sensory information or commands between a CPU and its peripherals, or between the CPU and the control elements. Either end of these interconnections can be susceptible to relatively low energy transients.

There is now a requirement for intrinsically safe circuits (ISC) which has complicated the problem because the ISC involves the data and control circuits at the same point as the subject anomalies. The ISC must be designed such that in an explosive environment the energy available at the terminations would not initiate an explosion. These requirements may seem unrelated, however, both involve energy control, both involve similar technology, and both require implementation at the system interfaces.

This paper is to deal with the protection of phone lines, data and control lines, single wire, coaxial lines and multipaired cables against these anomalies. The paper defines the requirement parameters, the various forms of contemporary protectors, the rationale for the design of the LEA Transient Eliminator family of products and the performance objectives for these LEA TE units.

THE HAZARDS

Natural Causes

The natural causes of electrical disturbances are all related to atmospheric activity. Included in this category are such phenomenon as lightning, static, corona and even tornados. Each of these phenomena is responsible for some form of electrical disturbance or destructive force.

Natural hazards are also related to geographical areas. The higher the storm activity in an area, the higher the probability of

- (1) Surge/Overvoltage Protection Concepts and Considerations for Electrical and Electronic Equipment, No. LEA-80-10

encountering naturally created disturbances. Figure 1 presents a map of the U.S.A. and Canada whereon the probability of a natural electrical disturbance has been plotted by area using iso-format. That is, the number reflects the potential number of lightning days for a naturally induced hazard to be created for any given day. Of course, it does not take into account the impact of seasons, which vary the probability significantly, i.e., from summer to winter.

Natural hazards include the following parameters:

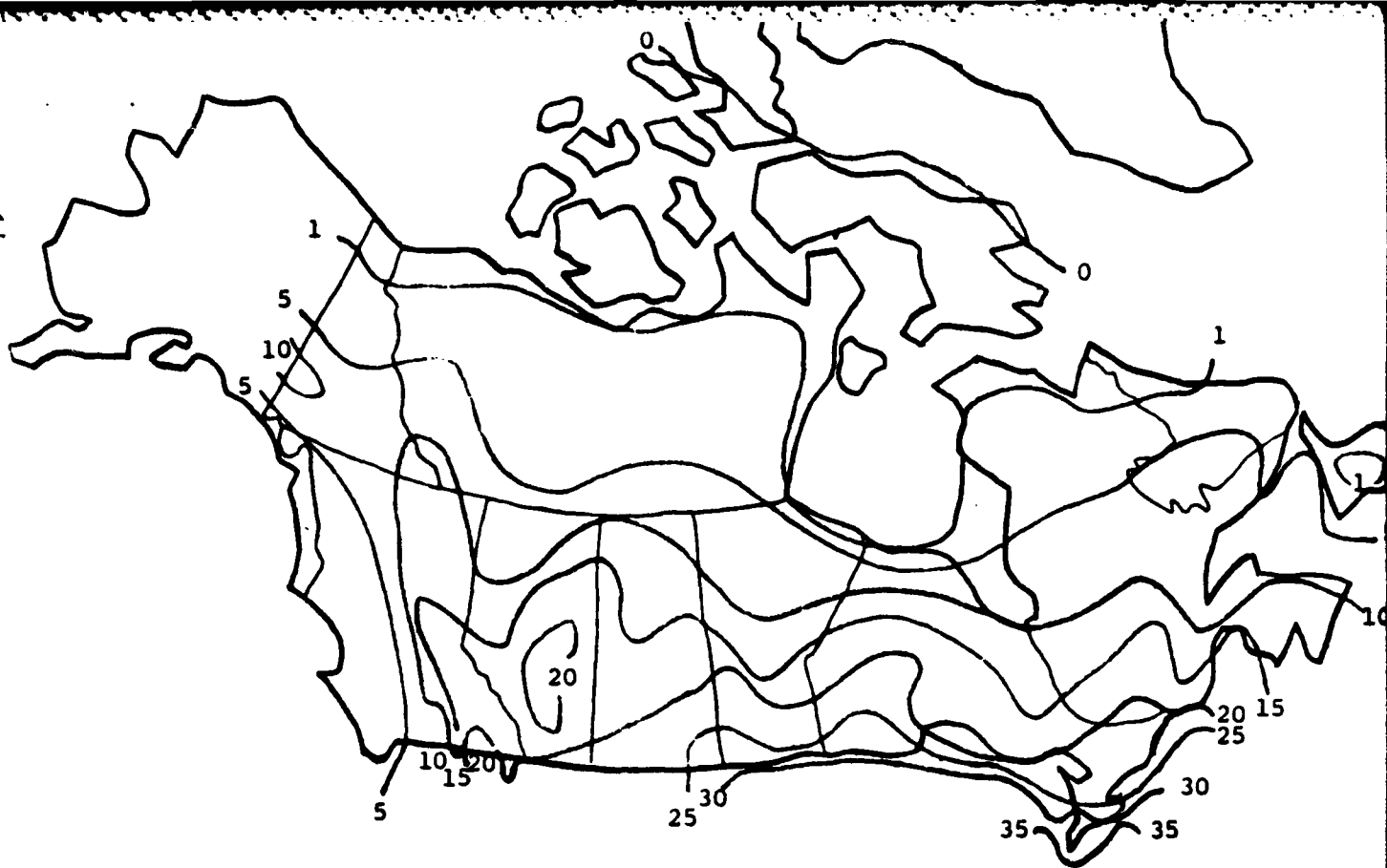
Direct lightning strikes to data or control lines are unlikely, but are possible, and do happen. If a protective system is to include at least some form of protection against this phenomenon it must satisfy the following specifications (to protect against 99 out of 100 possible events):

Peak Voltage	45,000 Volts
Peak Current Surge	160,000 Amperes
Minimum Rise Time	300 Nanoseconds
Maximum Energy	5,000 Joules
Duration	Less than 100 Microseconds

Lightning strikes in general are manifest in the two phenomena shown by Figures 2 and 3, where the term "I" refers to current flow. Note that there is a rapid flow of current between several different locations where the change in current flow with time is in thousands of amperes per microsecond. There is also an invisible, but highly potent, electrostatic field induced between the clouds and earth, not illustrated.

Atmospherically induced transients are created by sudden variations in that electrostatic potential of the atmosphere. Where the clear air field may be 150 volts per meter elevation above earth, during an electrical storm this field can achieve levels of up to 30,000 volts per meter of elevation. Nearby cloud-to-cloud and cloud-to-earth discharges can cause significant field variations continuously throughout the storm period, on a random basis, in both the time and magnitude domains.

As illustrated by Figure 4, a charged cloud in the area of concern charges everything on the surface of the earth beneath it to an equal but opposite potential by induction. The resulting field between the cloud and earth can achieve levels in excess of thirty thousand volts per meter of elevation above earth. A wire elevated above the earth by ten meters in this field would be charged to a potential equal to its surroundings, which could equal up to 300,000 volts with respect to earth. A sudden lightning discharge to earth or another cloud will cause this field to collapse leaving the



The probability of lightning for each day is: $\frac{\text{Iso number}}{365}$

The maximum for the USA is 0.27 or a probability of approximately one chance in three.

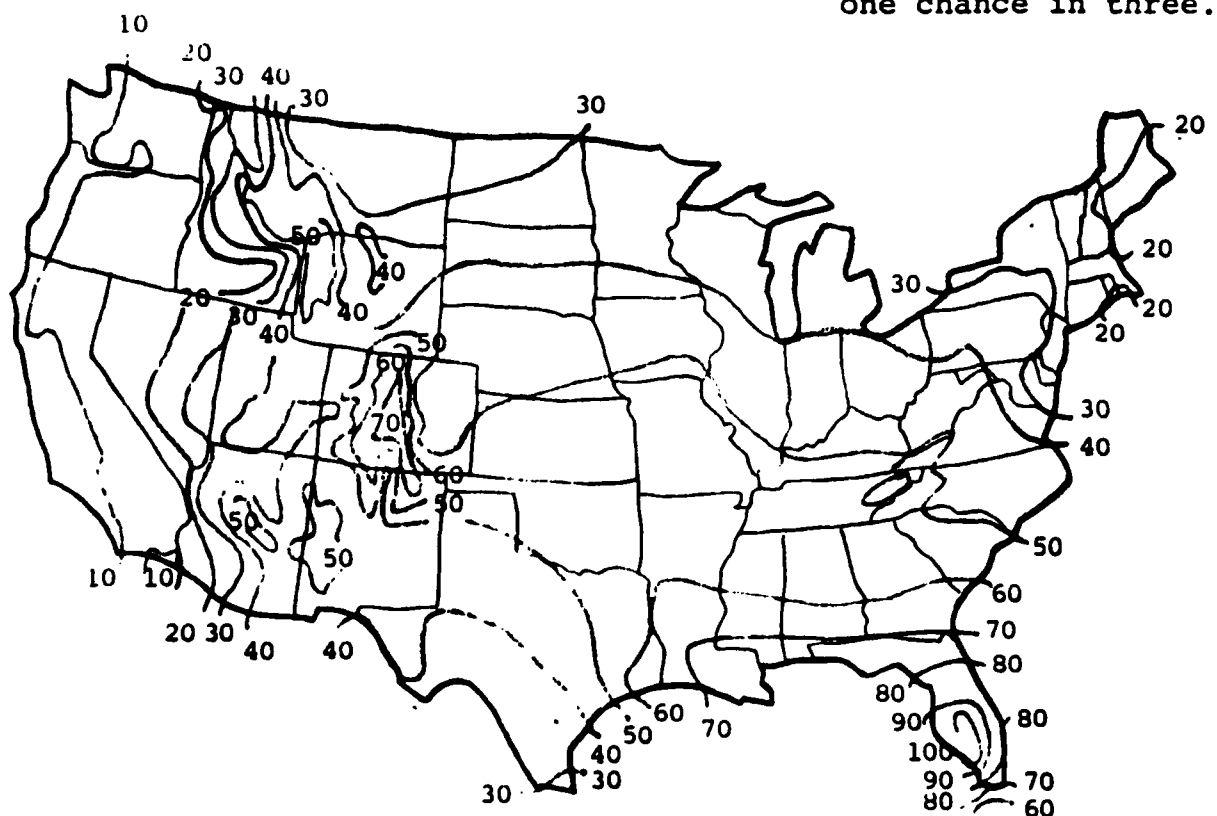


Figure 1, Number of Lightning Days per Year for U.S.A. and Canada

Figure 2, Vertical Lightning, Cloud-to-Ground

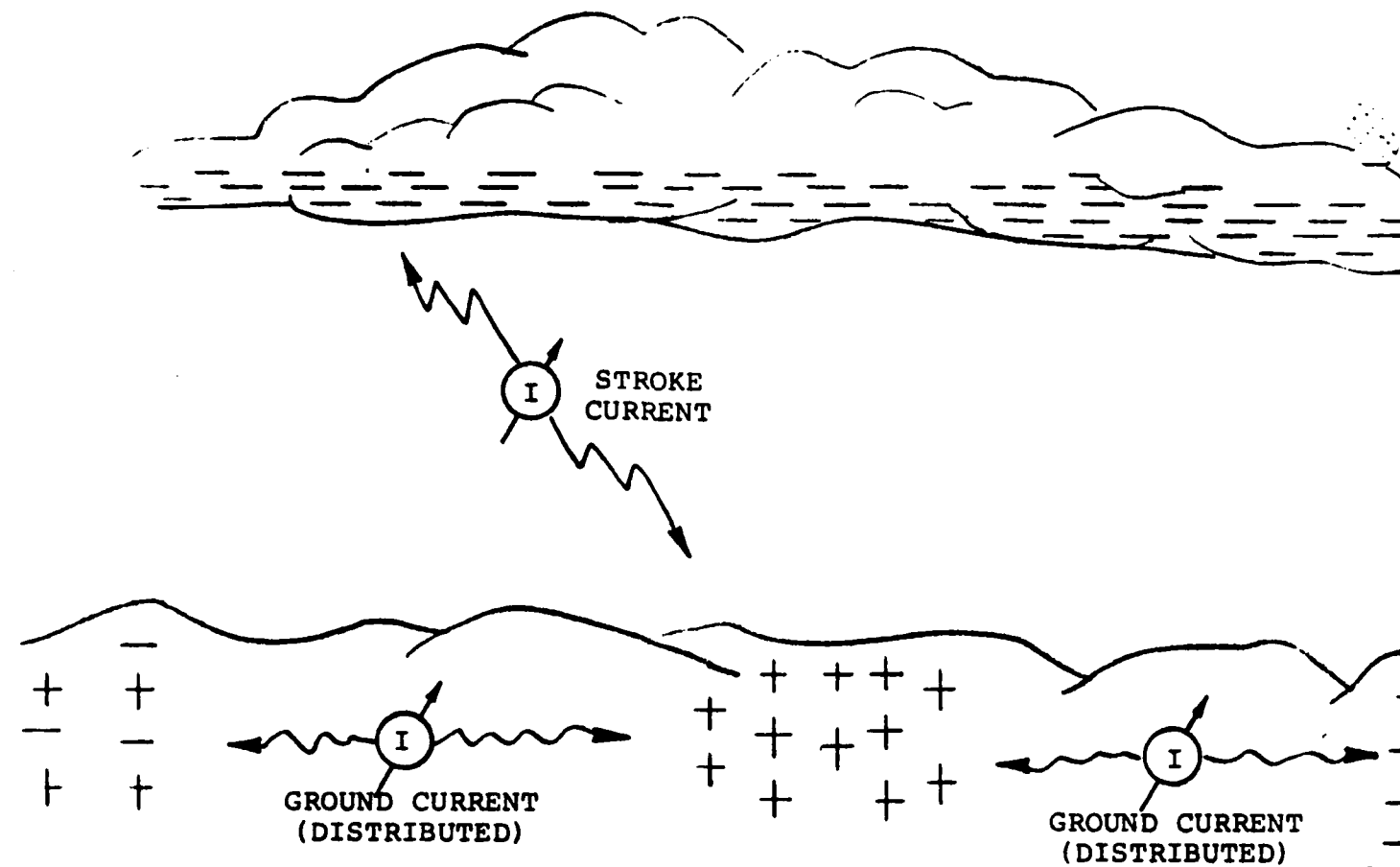
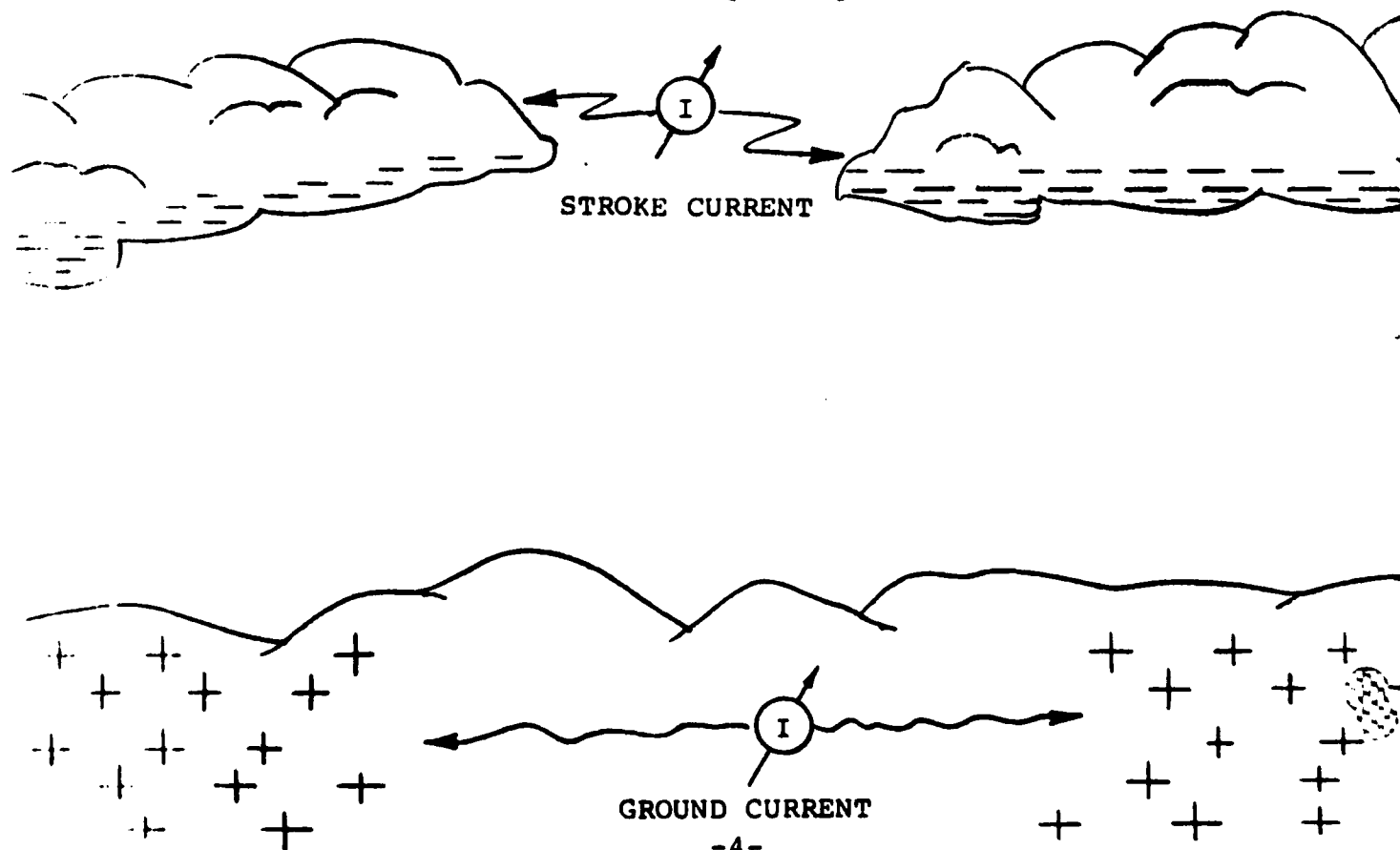


Figure 3, Horizontal Lightning, Cloud-to-Cloud



elevated wire with a "bound charge". It seeks ground through any available path, even jumping large insulators in the way, thereby creating a voltage pulse that could easily exceed 100,000 volts. Transients resulting from electrostatic field changes can be propagated over long distances, depending on the circuit parameters.

A nearby cloud-to-cloud discharge or a strike one mile away will induce as much as 70 volts per meter of exposed wire into a thus connected data processor and/or its peripherals.

Earth current induced transients are created by lightning strikes to earth, to or near the facility of concern. With the termination of a stroke to earth all the charge induced into the earth by that cloud must move from the point where it was induced to the point of impact of the stroke (see Figure 5), and thereby neutralize the charge. As a result of this motion of the induced charge, earth currents are set up within the earth's crust on or near the surface. Any good conductors buried in the earth within the charged area will provide a preferred path for these earth currents and thus be the recipient of these severe earth currents. The results are transients within the conductor, either directly or indirectly related to the earth current character. Current along the sheath of wires will induce transients into the inner conductors through mutual induction, or these currents are superimposed on the conductors without sheaths. Figure 6 illustrates two other forms of earth current transient effects.

Electromagnetic field induced transients are also created by lightning discharges. For this phenomenon the lightning flash channel acts as a vertical radiator or antenna. The large flow of current in a short time down the ionized lightning flash channel sets up a rapidly changing electromagnetic field propagating out from the stroke channel in much the same fashion as a broadcasting station using a single tower/antenna. These waves propagate for many miles and are the cause of static in a radio receiver, reflected waves in the transmitters and transients in nearby conductors as illustrated by Figure 7. Generally, cloud-to-cloud strokes produce predominantly horizontally polarized waves while the cloud-to-earth strokes produce vertically polarized waves. The di/dt 's can exceed 100,000 amperes per microsecond.

The electromagnetic pulse (EMP) resulting from a large atmospheric explosion, usually nuclear, will also create this phenomenon. The character of the EMP is usually similar to lightning, but with much faster rise times (nanoseconds) and much shorter duration (only a few microseconds). The energy content can be very high near the center of the explosion, i.e., in the hundreds of thousands of joules. It is usually not necessary to protect the equipment so that it can operate through the blast phenomenon, but, by some simple action, to prevent damage to the equipment so that it will operate after the blast.

Tornados create a cyclic phenomenon of a shape similar to a poor sawtooth generator. This is the result of charge separation

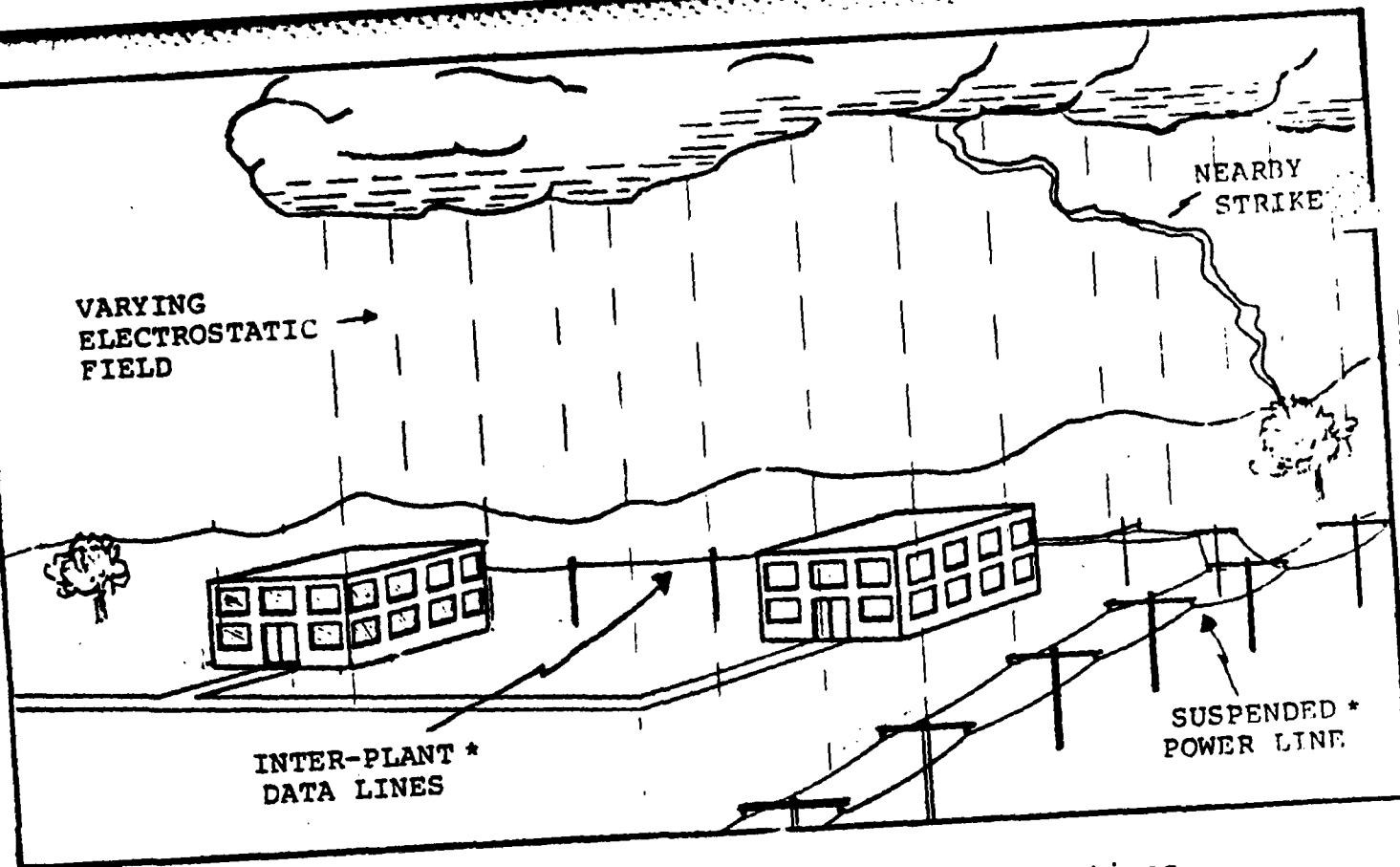


Figure 4, Atmospheric Transient Causations

*Will experience induced transients

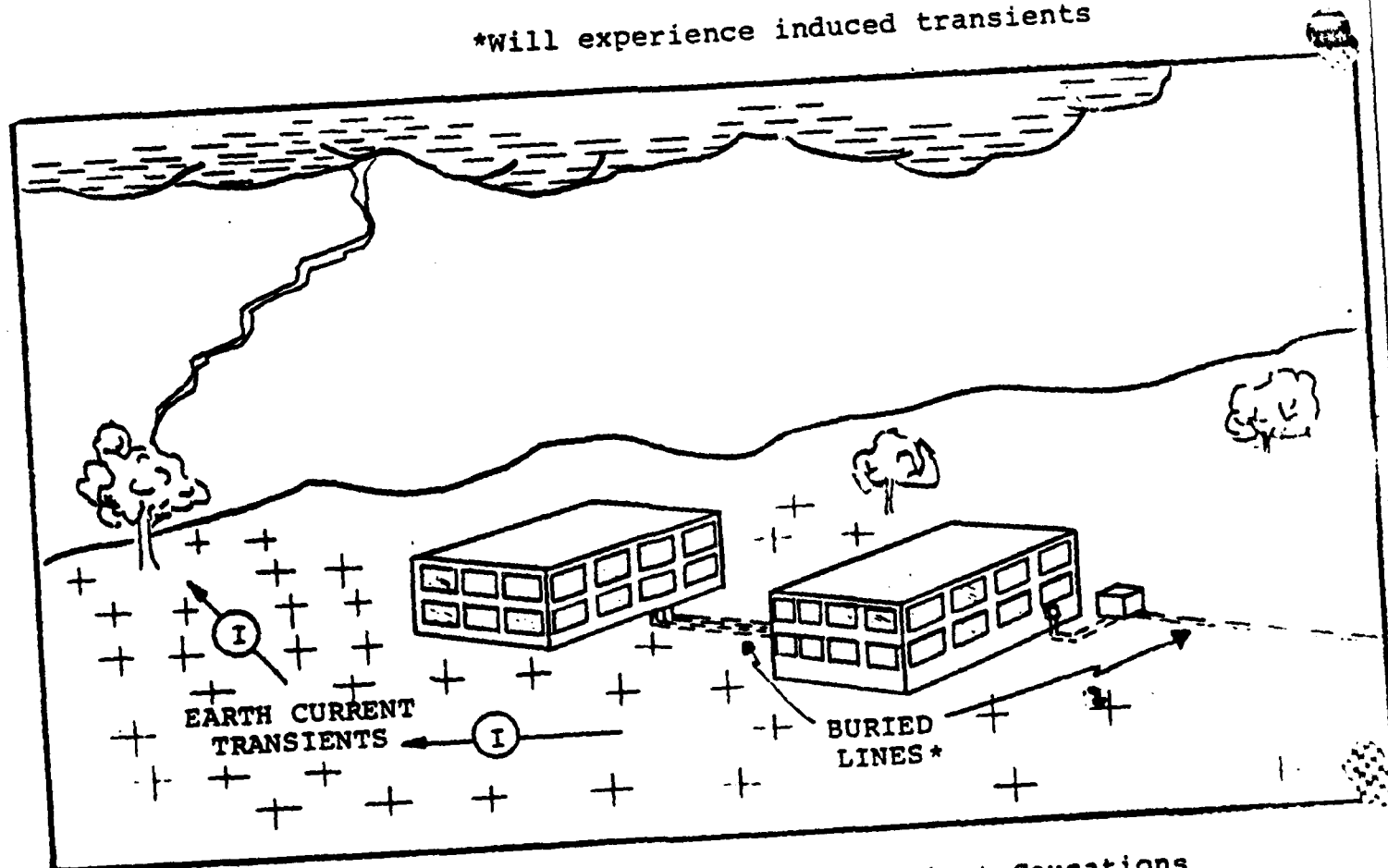


Figure 5, Earth Current Transient Causations

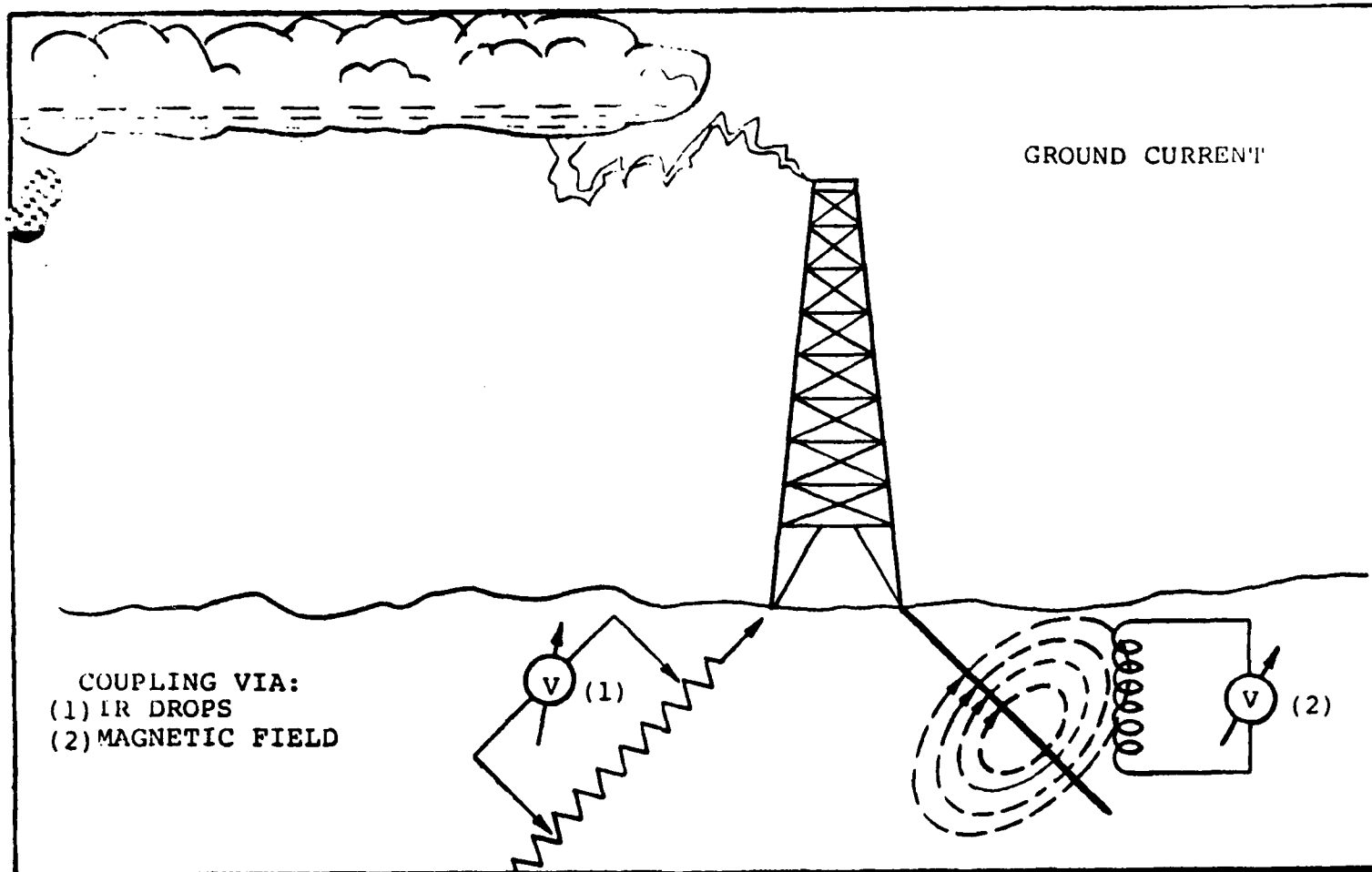


Figure 6, Other Earth Current Transient Causes

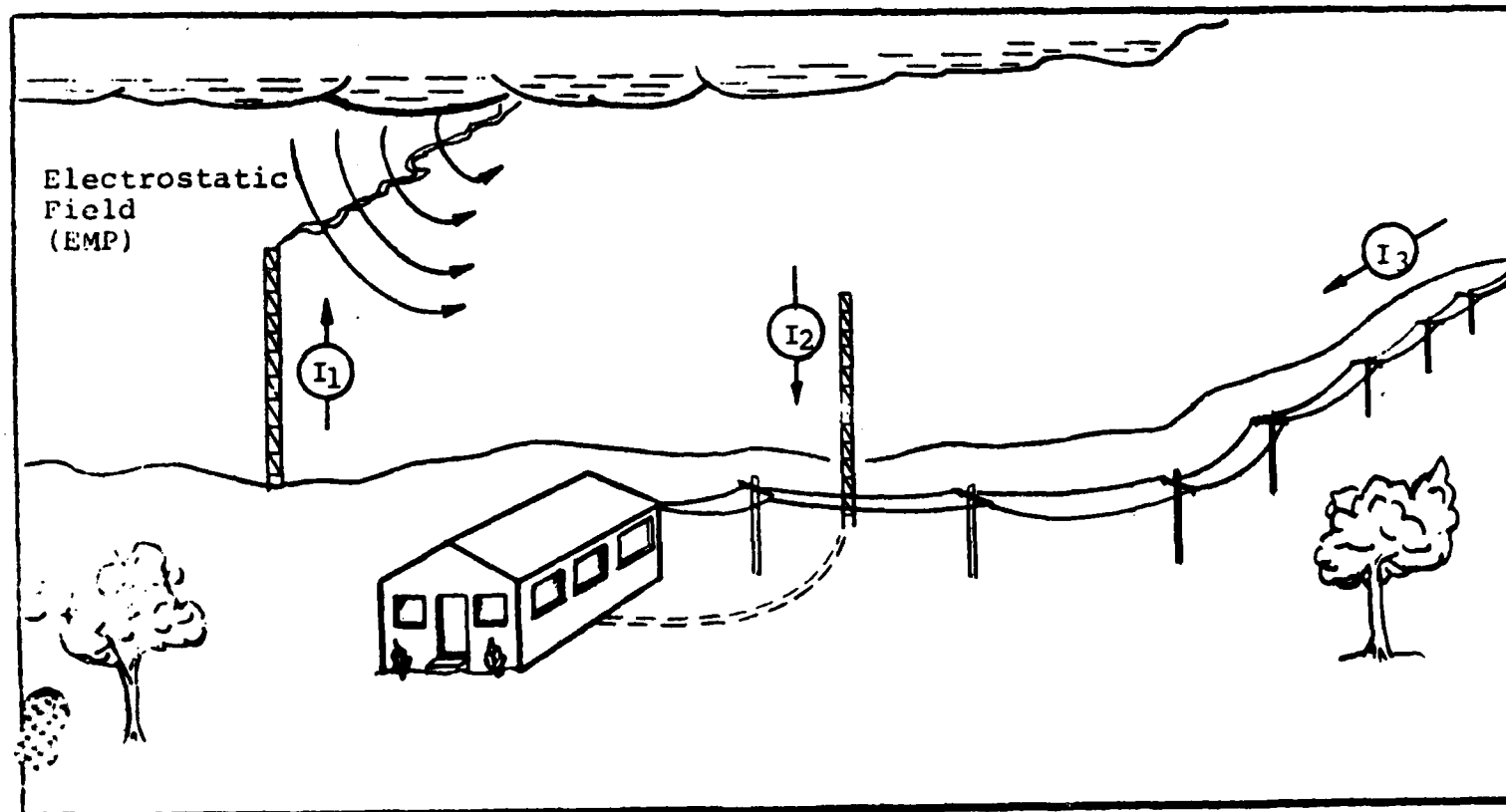


Figure 7, Electromagnetic Field Induced Transients

within the eye of the twister and its rotary motion. As the twister does its thing the induced voltage rises and falls with and at the frequency of rotation of the twister. The induced potentials can be damaging if the twister passes near an area of concern.

To protect against these induced transients, regardless of their cause, the systems must be designed to satisfy the worst case situation, i.e., at least 99 out of 100 possible events as follows:

Transient Energy	- 500 Joules
Transient Peak Current	- 20,000 Amperes
Transient Peak Voltage	- 4,500 Volts
Transient Rise Time	- 50 Nanoseconds

Man-Made Disturbances or Hazards

Man-made disturbances come from the electrical systems environment man has created. Again, these disturbances can be the result of a directly injected phenomenon or an externally induced phenomenon. It is futile to attempt to define all the potential causes, but the following identifies and deals with some of the more significant. Man-made disturbances on data or control lines may be subdivided into those caused by electromagnetic or electrostatic fields and those caused by some form of "accident".

Man-made electromagnetic field transients usually are created by poor installation practices or inflexibility in the plant layout. This is illustrated by Figures 8 and 9. For example, the sensory lines and a power line for large motors are laid side-by-side in the same cable tray; or, data and control lines near and/or parallel power lines carrying any large loads that are switched will also create transients on those lines. Electric motors with poor commutators will radiate transients into nearby data lines, even some office equipment can be a source of transients.

Directly injected hazards are usually the result of Murphy's Law at work. The possibilities are as diverse as the industry itself; some common examples from history include:

- (1) High voltage wires dropping onto the data/control lines.
- (2) Failure of insulation or isolation devices which inject a high voltage onto the data lines. This happened three times in one year at three similar facilities separated by thousands of miles. In all three cases the related computer was destroyed.

One common problem beyond the scope of this paper is encountered by cable television operators. The overhead ground or neutral is lost or open-circuited, then the CCTV carries the return or earth currents through its sheath. However, where ground fault interrupters are used the resulting transient is similar to that mentioned herein.

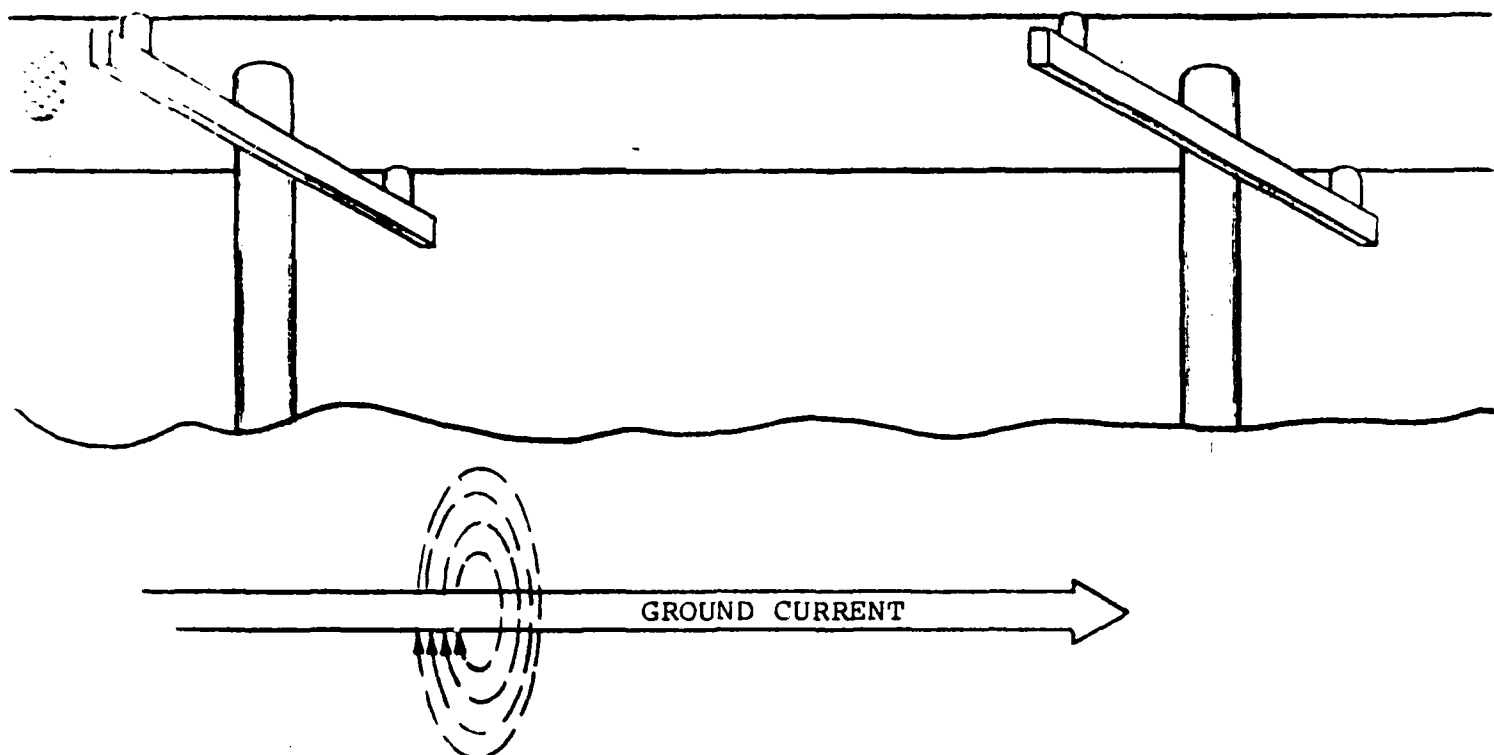


Figure 8, Earth Current, Inductively Coupled Transients

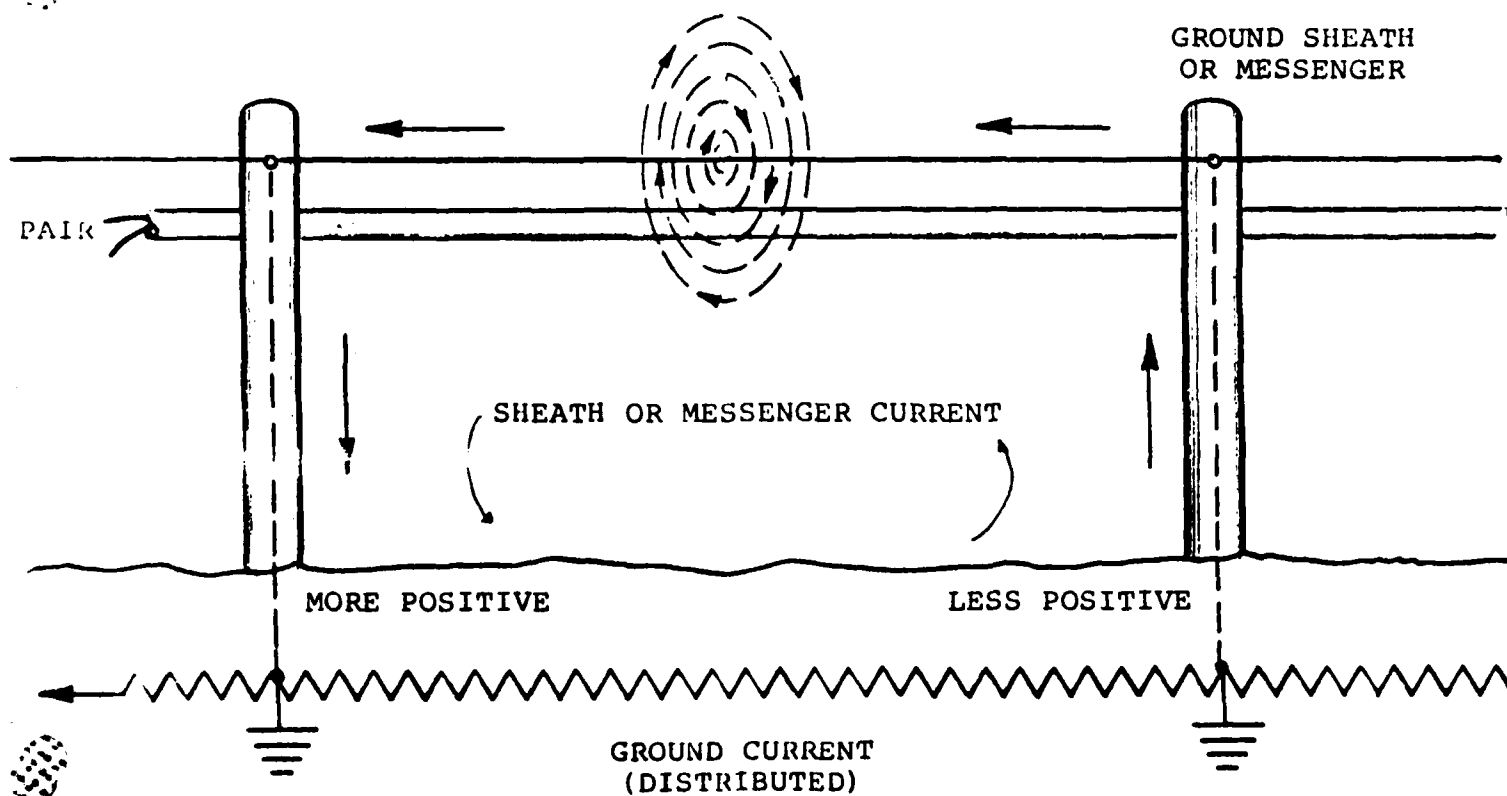


Figure 9, Earth Current, IR Coupled Transients

A Summary of Hazards for Data and Control Lines

It should be obvious from the foregoing that data and control lines can be exposed to many and widely varying hazards. An analysis of these hazards indicates that they fall into two categories: (1) Random transients of a predictable nature; and, (2) Sudden exposure to unpredictable and sometimes extreme stresses.

For the first category, design requirements may be established to assure safe and uninterrupted service. For the second category, the safest approach is to provide for safe and positive interruptions of the protected circuit until the anomaly has been corrected. Based on this philosophy, the following design criteria are recommended:

- (1) Dissipation surge currents in excess of 20,000 amperes at peak for a 1 by 20 microsecond wave form.
- (2) React within 50 nanoseconds without permitting more than ten percent overshoot above the desired clamp voltage or protection level.
- (3) Dissipate at least 500 Joules, preferably 1,000 Joules.
- (4) Recover without damage immediately after the transient.
- (5) Initiate the clamp before the destruct level of the circuit to be protected is reached.
- (6) Fail open circuit when overstressed, i.e., subjected to anomalies beyond the design level, without permitting damage to the protected circuit.
- (7) Operate independent of the grounding quality.
- (8) Introduce no appreciable load or circuit loss into the protected circuit.

Finally, removing the surge or transient must be accomplished by diverting the excess energy through some harmless path, such as ground, or dissipating it as heat within the protector. This means that the protective device must be able to sense the existing situation, influence the circuit only when there is a disturbance that has been previously defined as hazardous, and remove at least that amount of the energy that is considered hazardous to the equipment it protects.

The Intrinsic Safety Consideration

In some areas where electronic process controllers are used to monitor and control a plant operation there exists the possibility of an explosion due to the potential leakage of combustible gasses

or fluids, or the existence of explosive mixtures due to other causes (coal dust and grain for example). In these areas it is necessary to eliminate the explosion hazard by removing any possible sources of ignition. Sensory and control systems represent one possible source hazard.

In the past, explosion-proof boxes, conduit and filtering were used -- at great expense. Now, the trend is toward intrinsically safe circuits. These circuits are to limit the energy available within the hazardous area to that below the ignition point. These criteria are defined by such agencies as National Electric Code (NEC), National Fire Protection Agency (NFPA) and Instrument Society of America, and others.

Because of the common requirements for an intrinsic safety barrier and transient protectors for data and control lines, obviously one device can be designed for both functions, i.e., an Intrinsically Safe Transient Eliminator barrier.

Protective Options

In designing a protective device against possible transients or related phenomena, two factors must be considered: the available devices; and, how they may be employed.

There are too many situations already where the designer has "tried everything", often at the same time, and still without success. In summary, its not only what is used, but how it is used.

Application technology is as important as the device used. There are two basic techniques for designing transient protection into a circuit. First, it is important to recognize the need to physically separate the protected from the protector. Using the same PC boards or the same cable runs for the protected and unprotected, or the input and output circuits, will inhibit proper performance of the protector and arcing and crosscoupling will occur. Therefore, the first rule is to provide a separate module for the protector circuits; high density circuit cards are impractical as protectors. Secondly, and of equal importance, it is essential to separate the exposed wires from the protected wires by as much space as possible. It is preferable to run them at right angles to each other when possible.

A third factor in the implementation concept is the circuit concept itself. There are two possible protective circuit concepts, independent of the parts used. These are illustrated by Figure 10. One concept involves the use of the protective device in parallel with the circuit to be protected as shown in Part A. Even a cursory examination of this circuit leads one to realize that the "protected" circuit will share the overstress with the "protector" to some degree. The only question is by how much.

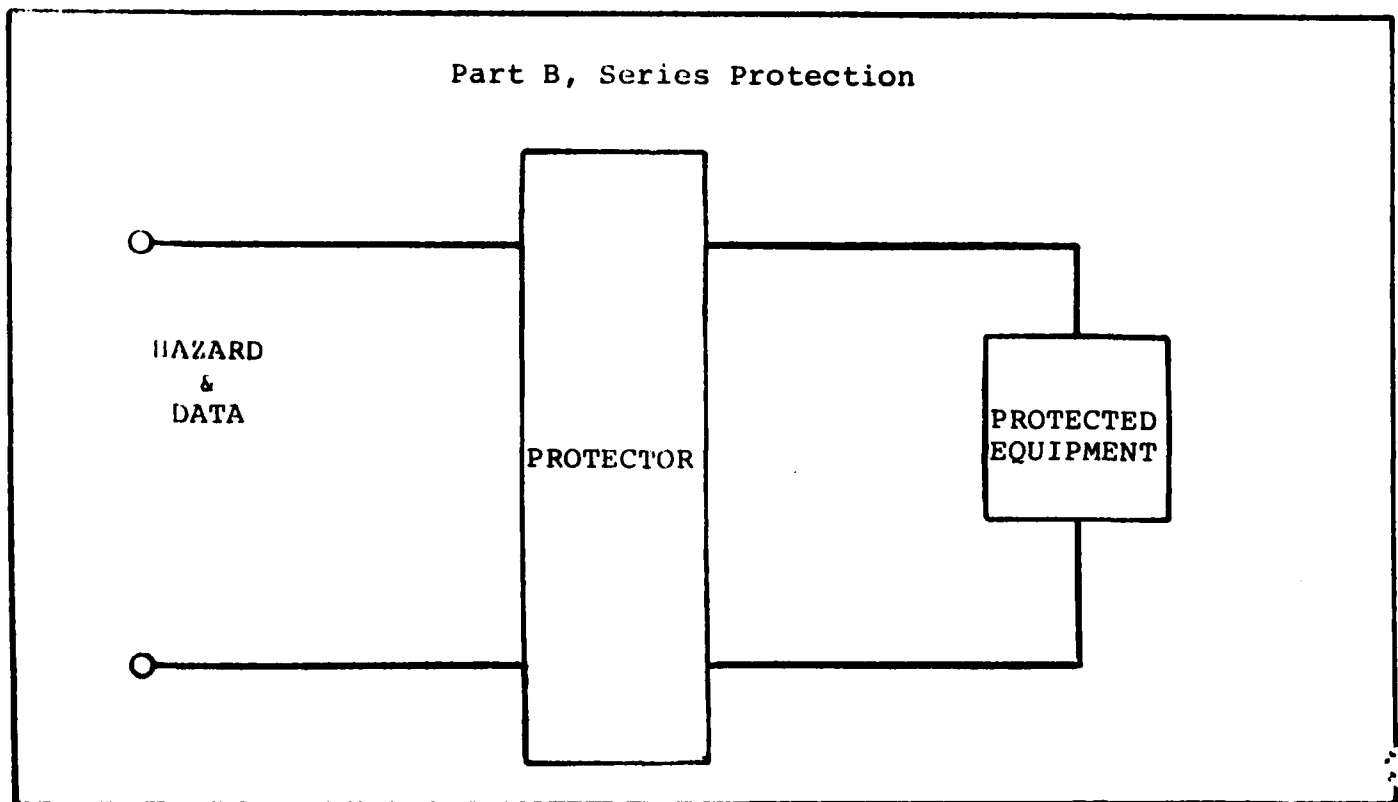
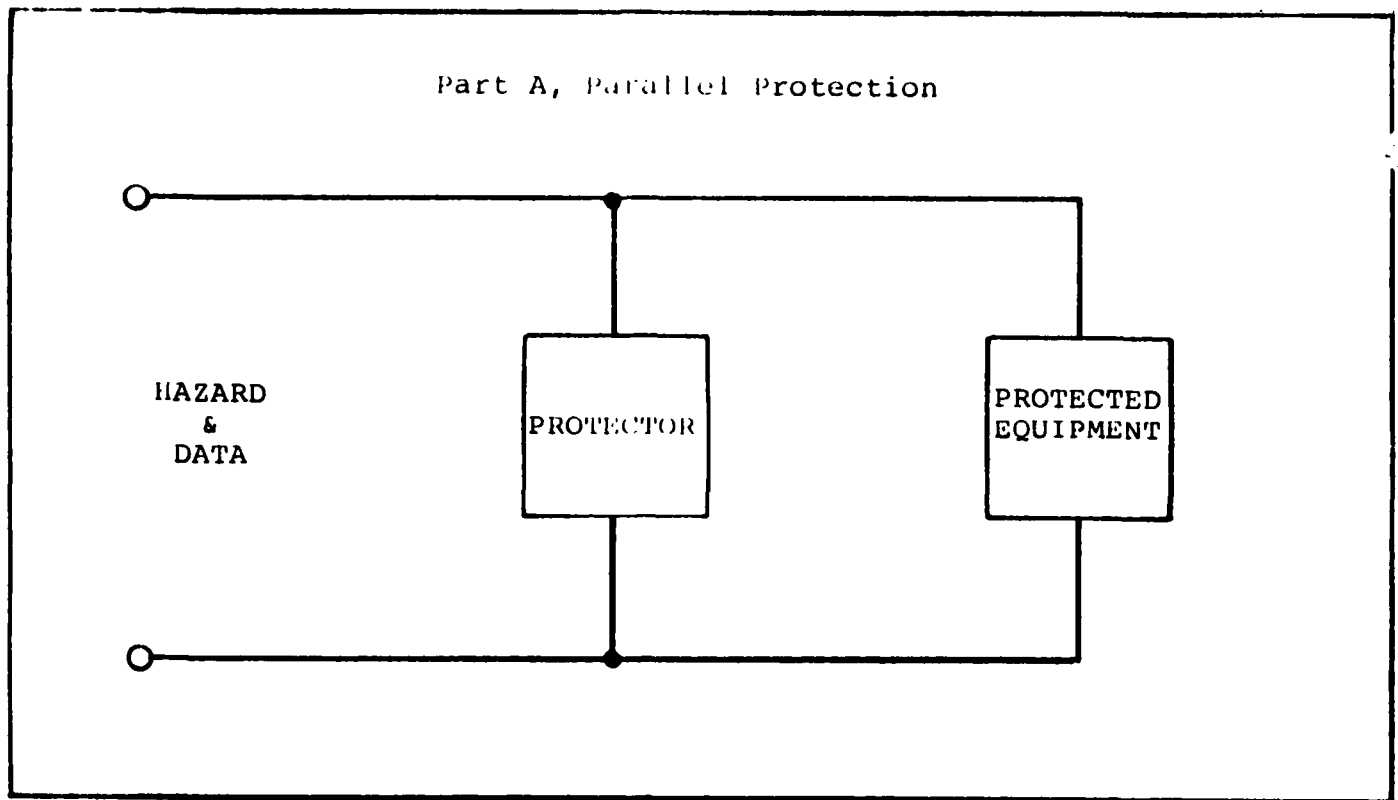


Figure 10, Protection Implementation Concepts

To determine the "how much" it is necessary to consider such factors as clamping voltage, reaction time, clamping ratio*, and the relative circuit impedances during the protecting period. In contrast, the series protector illustrated by Part B, Figure 10 is a safer concept since it intercepts, or is between, the source of the hazard and the circuit to be protected. Although the performance evaluation criteria is the same, the control over the protector performance is far greater as demonstrated in the following paragraphs.

One final consideration of significance is the grounding concept for the protector and for the protected circuit. They must both be referenced to the same grounding point or at least the same tie point (an arbitrary reference), which in turn is eventually referenced to ground. Otherwise differences in potential will develop between the various grounds and constrain the protector's ability to hold a given clamp level.

PARALLEL PROTECTORS

Conventional parallel circuit protectors are very different in character and performance. They may be considered as either a form of voltage limiting device or a crowbar device.

Gas breakdown devices, such as spark gaps and gas discharge tubes, are rugged, but require considerable energy to initiate the clamping action. They generally are limited to voltages above about 90. In the case of a fast rise surge or impulse, over 1200 volts may be required to initiate the clamp. Once in the conducting state it takes a considerable reduction in steady-state voltage and current to shut them off and prevent self-destruction, thus limiting their usefulness in DC applications. The big advantage is that these devices can handle very high transient current levels, some in excess of 40,000 amperes for short periods of time. However, the impulse overshoot renders them ineffective for computer protection.

Zeners, avalanche diodes and transzors will conduct and hold a constant voltage at a predictable overvoltage level. The clamp level is fairly independent of current flow or impedance of the transient. Both can tolerate voltage breakdown in the reverse direction without harm. Unfortunately, because of their limited physical volume, a high energy transient (1 or 2 joules) can heat and destroy the diode junction leaving the protected circuits vulnerable. Also, if the transient is very fast (nanoseconds) the energy does not have time to spread across the junction and it will fail at much lower energy levels. These components are available in a range of voltages between 7½ and 200 volts peak. They do react in nanoseconds and have a low clamp ratio*. Their high capacity to ground also limits the useable frequency range to values below about 3 Mhz.

*Clamping ratio is defined as the voltage at the peak of the surge vs the initial clamp voltage.

Selenium diodes and silicon carbide bidirectional breakdown cells are also employed as suppressors. They have considerable thermal mass and are intimately attached to metal plates for good heat transfer. The effective operating overvoltages are not as precise as those for zeners or avalanche diodes and do not provide an effective clamp for sensitive circuits. The lowest clamp voltage available is about 90 volts peak. These also have a high clamping ratio, it can be in excess of 10 to 1.

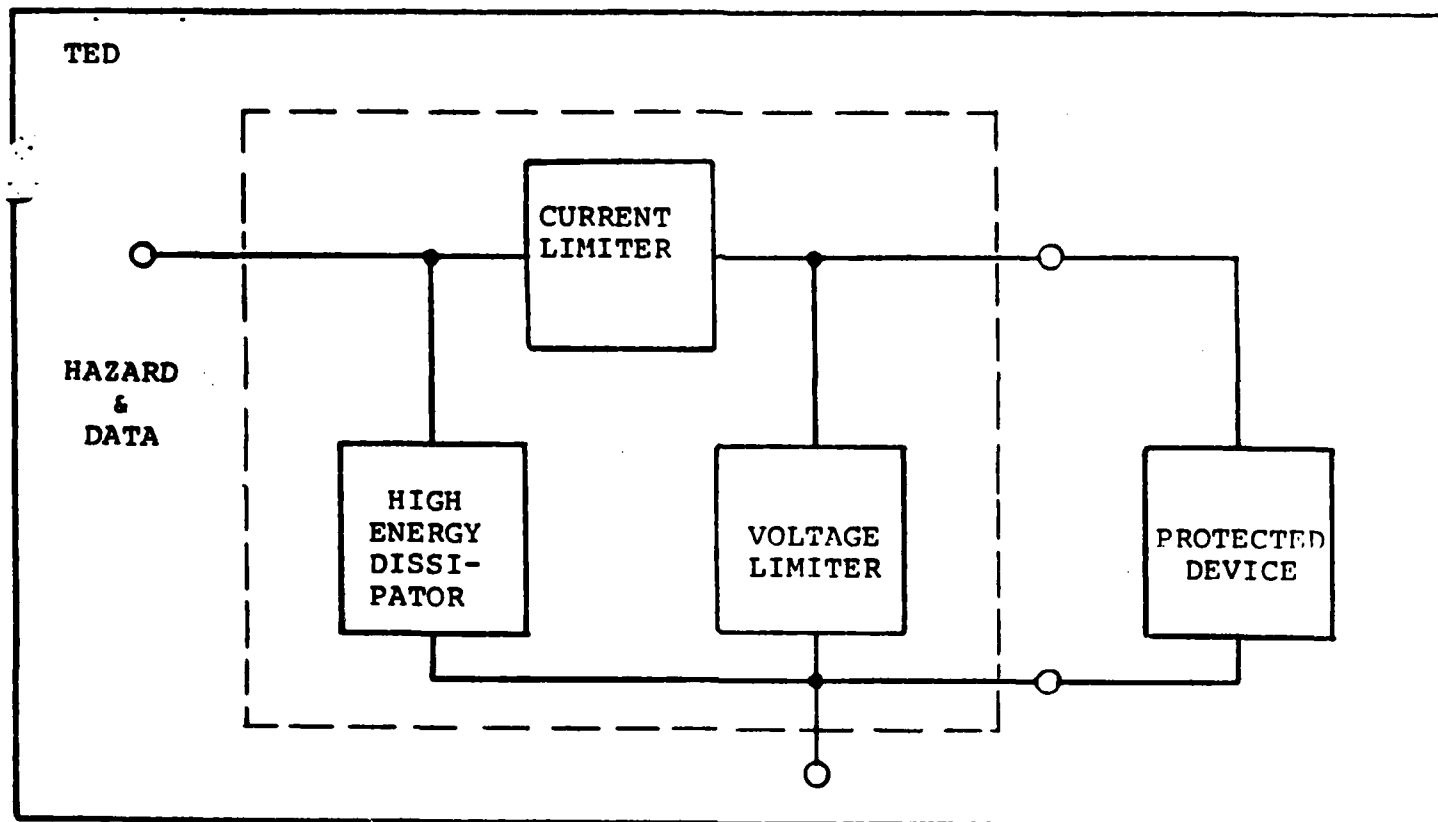
Thermistors have been used as voltage suppressors as well. Resistance of a negative temperature coefficient thermistor lowers markedly with temperature. This characteristic can be used to advantage by putting it in a circuit where the temperature rises significantly with a voltage rise. The heated thermistor will then bypass the excess current around the load. However, thermistors are both current and voltage sensitive, non-linear, unpredictable, slow and ineffective.

Metal oxide varistors (MOVS) are two electrode symmetrical (reversible) semiconductors with voltage dependent non-linear resistance that is high (insulates) at normal volts and drops markedly as voltage is increased above its threshold. It normally will pass very little current and not interfere with the operation of the protected circuit until an overvoltage condition is created. It will then decrease in resistance greatly and bypass much of the current. The response varies from nanoseconds to microseconds, depending on size. MOV's are also limited in the amount of energy they can handle, usually less than 100 joules. They permit voltage rises in excess of 2.5 times the clamp initiate level. This and the high initial clamping voltage limits their application. Other characteristics to be considered include reaction time, aging and frequency limitations. The MOV reaction time seems to be inversely proportional to the size or energy handling capability; the larger the device the slower the reaction. As an example, LEA has been able to pass high voltage 10 microsecond pulses by a large MOV, even with short leads. MOV's tend to degrade with constant use and eventually fail, even when stressed well within the rated stress level. Because of the effective capacity introduced into the protected circuit the upper cut-off frequency is limited to about 3 MHz.

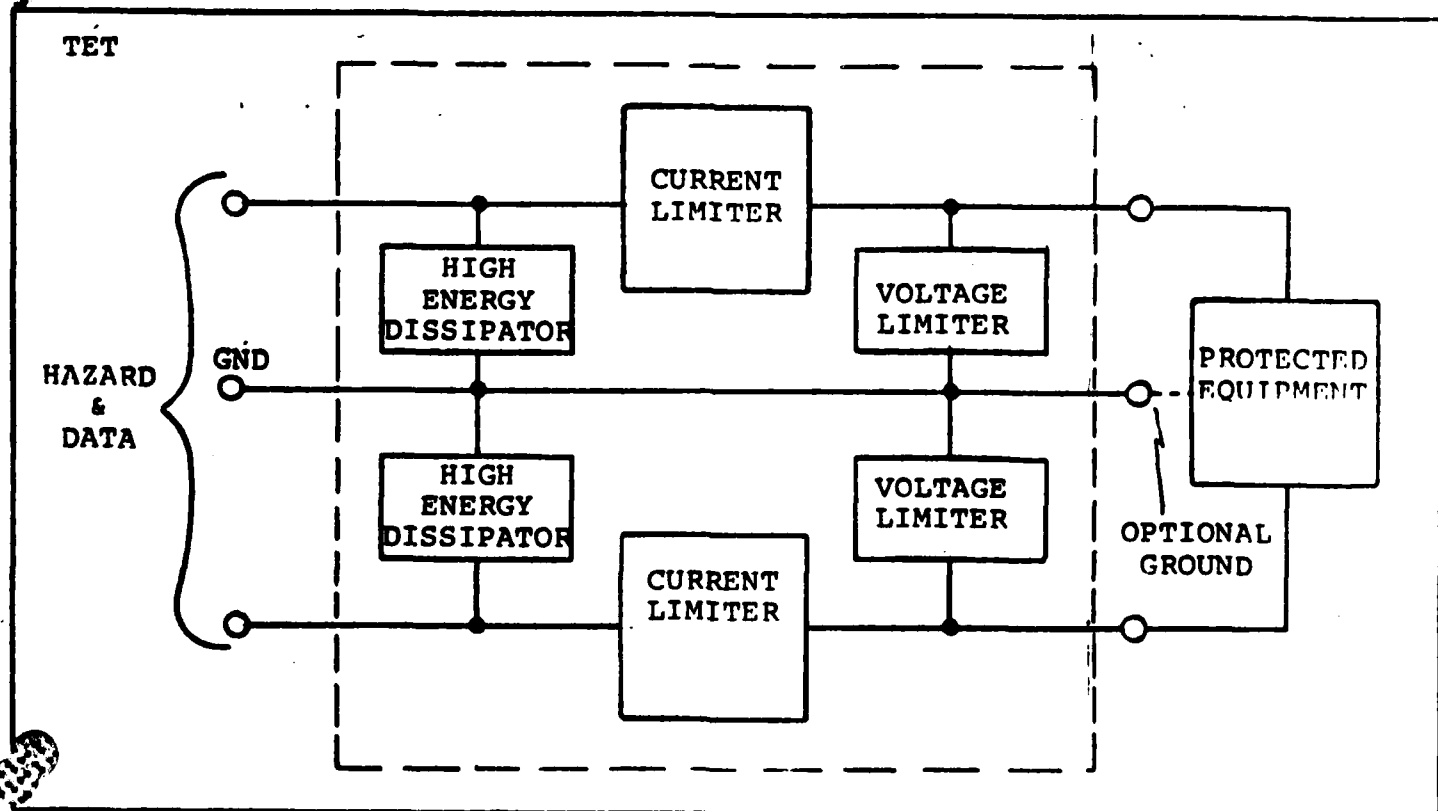
All of the foregoing devices are single low cost circuit elements of limited capability. None of them can cover the complete spectrum of transients. All of them display some weaknesses in a significant parameter that limits their usefulness. Either they respond immediately, but with very low energy handling capability, or they handle very large energies, but do not clamp the voltage at acceptable levels. Their usefulness is therefore limited to low energy applications or where the high voltage spike can be tolerated.

SERIES PROTECTORS

The series or hybrid circuit protector is a concept first marketed by LEA and assigned the trade name Transient Eliminator. The Transient Eliminator or TE family is a wide variety of protectors



For Single Lines Referenced to Ground



For Paired Circuits, with or without Ground Reference
Figure 11, Using the Series Transient Eliminator Concept

all designed around the series or interceptor principle as shown by Figure 11.

The main objectives in going to a series protector are: (1) to provide a means of isolating the voltage control function from the energy dissipator function to permit tight clamps; (2) to provide a series element that will store the excess energy and integrate over time; and (3) to provide the same and/or a separate series element to fail open circuit when excessive energy is applied to the protector. All of these functions are embodied within every LEA Transient Eliminator and they satisfy all of the requirements previously listed for data and control line protectors.

TE's all function in basically the same way. The voltage limiter controls the output voltage. If it rises above the selected limit or clamp level (which is usually set at 1.2 times the normal peak voltage) it becomes a constant voltage device holding the voltage at the selected clamp level. If the disturbance energy rises above what is termed transient level, it turns on the high energy dissipation channel, which bypasses most of the excess energy to ground. Some of the energy (up to 1,000 joules) is dissipated within the unit making the TE's relatively independent of the influence of the grounding system surge impedance. During this operation output voltage to the protected system is maintained within the operating limits of the system, neither being crowbarred to ground potential, nor allowed to rise significantly above the clamp level. As soon as the surge or transient has passed, the TE returns to its passive mode with no ill effects. If there is a severe overstress, well beyond the 99 percentile, the TE will fail open circuit. This is considered a very low probability event.

Evaluating the Options

Table 1 presents a comparison of performance factors and capabilities for the various protectors on the market. Note that although the LEA Transient Eliminator is not the only series protector on the market, it out-performs all types, series or parallel, in every significant parameter. Many of the devices vary in capabilities with such factors as clamp voltage and size of the device used. In cases where the larger size is considered, the component cost approaches or is in excess of that for the most sophisticated TE protector. The major points of contrast are energy handling, reaction time and usable frequency range. The LEA Transient Eliminator may be used in the higher RF bands (up to over 1 GHz) and at high RF powers of up to 50 Kw.

TABLE 1, PERFORMANCE ANALYSIS, COMPETITIVE CIRCUIT* PROTECTORS

Considerations	Parallel Devices					Series Devices	
	ZnO Varistor	SiC Varistor	Gas Tubes	Zeners	Transzorbs	LEA TE's	Others
Maximum Surge Energy(1) Joules	0.1 to 350 Voltage Dependent	275	100	>1 to 100	1.5 to 15	1000	<100
Maximum Surge Current(2) Amperes	40 to 6K	10	20K	200 to 10K	2.1 to 520	25K	<6K
Clamping Ratio(3) E_2/E_1	> 2	10	Crowbars Circuit	1.5	1.5	<1.1	1.1 to 1.5
Reaction Time(4) Microseconds	< 1	< 1	2 to 10	< 1	< 1	< 50 N.S.	< 1
Application Cutoff Frequency(5) Megahertz	3	3	100	3	3	> 10 GHz Higher possible	3
Voltage Range	23 to 1000	30 to 300	90 to 1000	2.4 to 200	6.8 to 311	0.6 to no limit	6.8 to 200

*Circuit in this context refers to the data and control line level circuits, low power applications.

(1) Maximum volt-ampere-seconds prior to permanent damage (many are voltage dependent).

(2) Peak current in amperes for a 8 x 20 waveform (many are voltage dependent).

(3) Ratio of voltage at peak safe current vs initial clamp voltage.

(4) Time from start of transient overvoltage to time clamping action is completed.

(5) Frequency above which significant attenuation is introduced for the completed circuit.

THE INTRINSIC SAFETY IMPACT

Since the intrinsic safety function is to limit energy at the output and all members of the LEA TE family limit both voltage and current, it would seem obvious there is a significant amount of commonality in the two circuits and their component functions. Indeed, comparison of the two schematics of Figure 12 demonstrates that this premise is true.

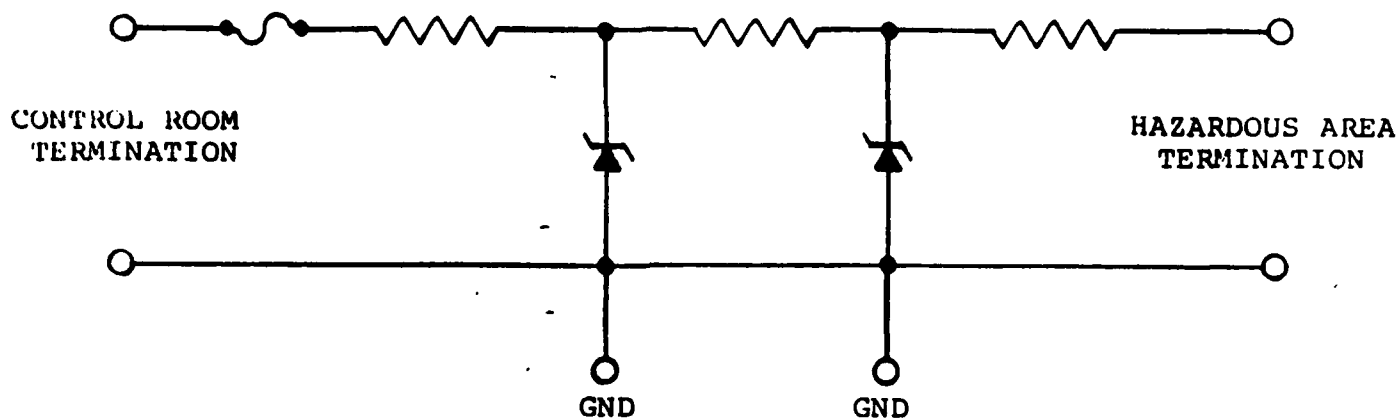
LEA has therefore made available a series of protectors under the name "Intrinsically Safe Transient Eliminators" (ISTE). The resulting integrated functional diagram is presented by Figure 13. The ISTE's are made bipolar and may be used in Zones 1, 2 or 3. Two such module concepts are illustrated by Figure 14.

THE RS232 COMPUTER/PERIPHERAL SITUATION

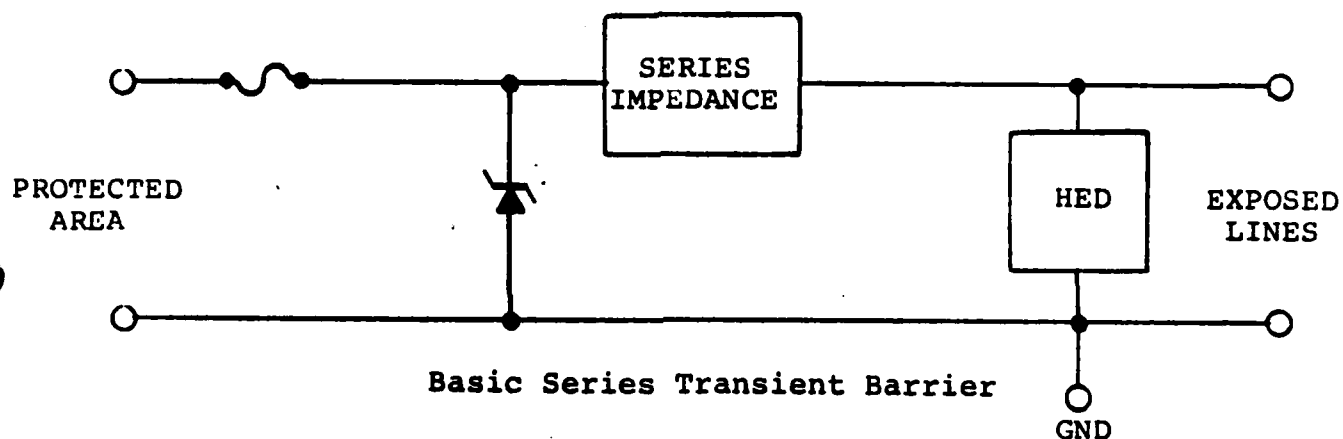
Most computer systems are designed to communicate in the same language and over the same wires, connectors and pin numbers as established by the ASCII Code, as RS232 for a standard 25-pair connector. Since computers must "talk" to each other and communicate with their peripherals, they must be interconnected. As these interconnections pass between buildings (and sometimes within the buildings) they pick up the transients previously described. To protect these lines and facilitate a non-technical retrofit, the TE's have been made available in plug-in form, designed as described, but protecting the required RS232 circuits, allowing the voltage and current levels relating to the function to pass undisturbed, but limiting peak voltages to a safe potential.

- (1) For "hard wired" units using pins 1, 2, 3 and 7, use Model TED(4)-RS232.
- (2) For modem protection using pins 1, 2, 3, 4, 5, 6, 7, 8 and 20, use Model TED(8)-RS232

Many other configurations are made to special order. Physical configuration is illustrated by Figure 15. These units may be supplied with two female connectors for exposed and protected, plus a "chassis" ground connection or any combination of 25-pin plug and connector.



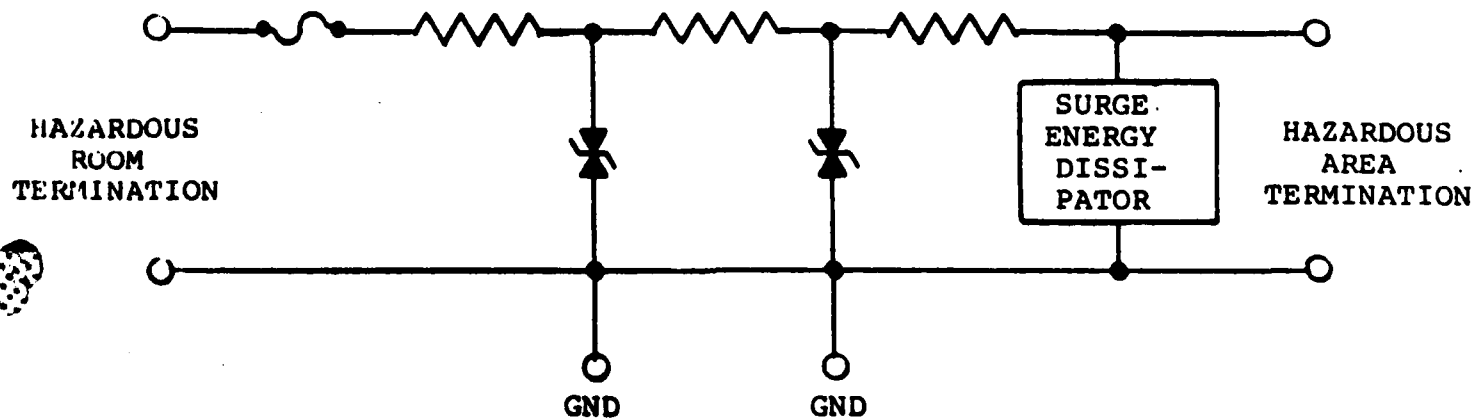
Basic Intrinsic Safety Barrier



Basic Series Transient Barrier

Figure 12, Comparison of Intrinsic Safety Barrier and Transient Barrier

Figure 13, Integrated Protection Module



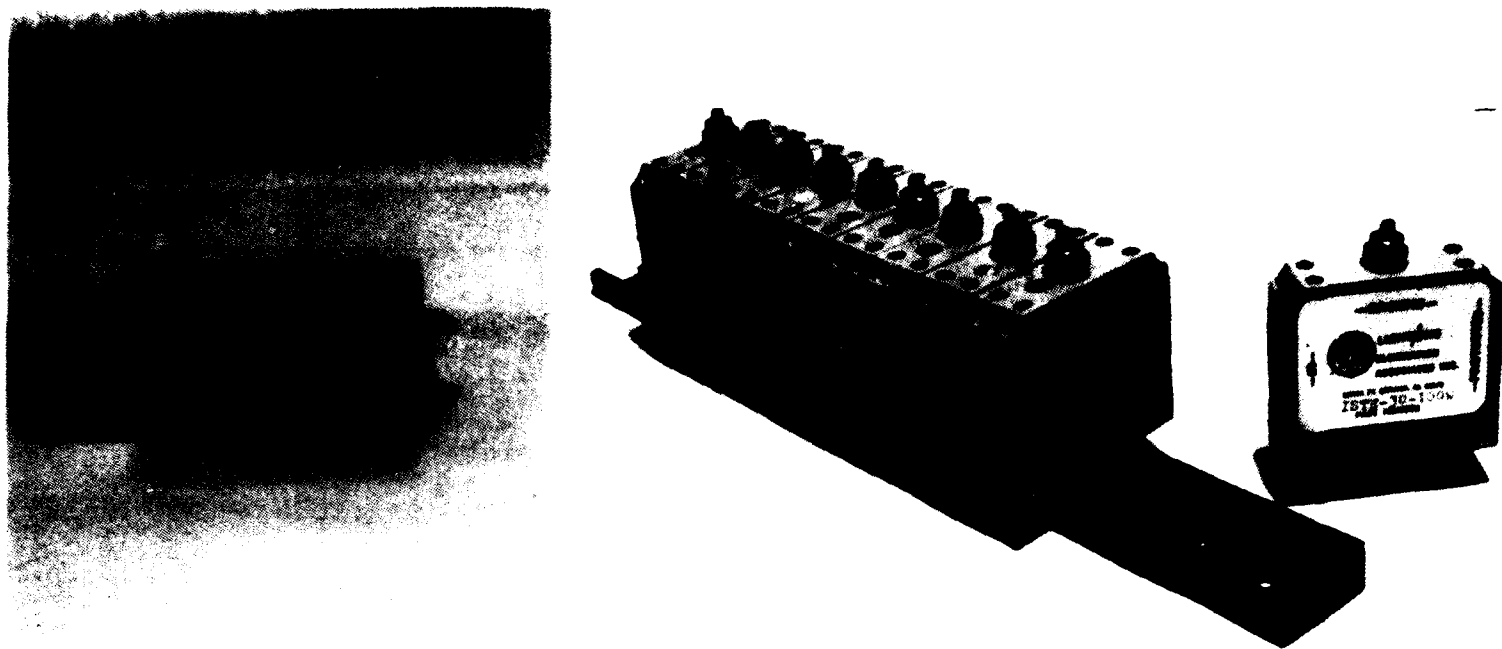


Figure 14, Two Transient Eliminator Concepts

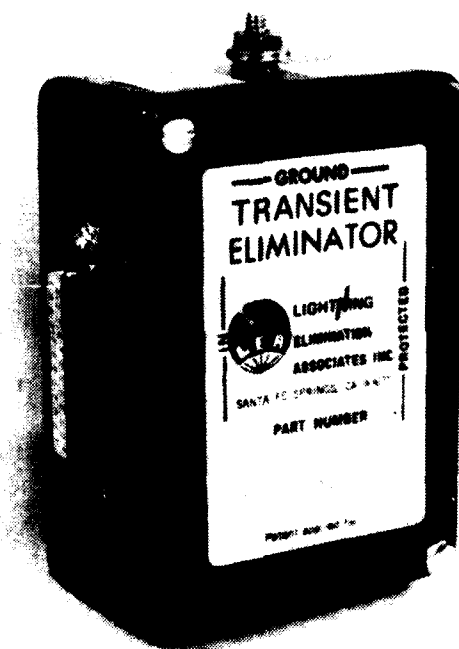


Figure 15, RS-232 Transient Eliminator Configuration

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