

Transient Lightning Protection for Electronic Measurement Devices

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INTRODUCTION

We have all heard of or seen the devastating effects of a direct lightning burst. Communication equipment destroyed. Transmitters and EFM devices vaporized into slag metal. Complete process and measurement systems down with extended recovery times. These effects are the most dramatic and the easiest to trace. However, these kinds of events are rare. The more prominent events are those that occur on a day-to-day basis without we, the user, even knowing.

With the advent of the transistor and today when surface mount electronics is the norm and not the exception, transient suppression has become a science of necessity. Tight tolerances of voltage requirements and limited current carrying capabilities makes the new compact integrated circuits much more susceptible to many types of transients.

What is a transient?

Webster's defines a transient as a ' temporary oscillation that occurs in a system because of a sudden change of voltage or load ' ¹

This definition does not describe the magnitude or duration of the change, but only that a change has occurred. For this paper we will add to Webster's definition with the following terms.

1. Transients have a short duration in comparison with normal signal times.
2. The magnitude of the transient is beyond the capability of the standard device to accept or reject without damage or unacceptable behavior.

Taken in this context, the ability to protect a system, any system, from all sources of transients would be beyond the scope of this paper. What will be covered, in some fundamental fashion, is the ability to protect a system from the everyday sort of low energy and medium energy, fast response transients.

To protect a system from transients we must first isolate and define the transients we wish to eliminate. Starting at the lowest and most common form of transient and then upgrading the system until we cover the sources in question. It would be expensive and not practical to apply level 3 protections on a system that only requires a level 1 or at most level 2 protection.

TRANSIENT SOURCES

Low Energy Transients (ESD Electrostatic Discharge)

Static electricity is the imbalance of electrons on objects ("object" also including the human body). Static electricity can be caused by friction and subsequent separation between the objects (triboelectrical charging), but also by other means, such as induction, ion/electron bombardment etc. The level of "tribocharging" depends on the type of materials, the nature of contact, the speed of motion and the relative humidity of the environment.

¹ Webster's Ninth New Collegiate Dictionary

Electrostatic discharge (ESD) is the transfer of electrical charge between the two objects, re-establishing the electrical balance. ESD happens in many cases in a very short time, often in the form of a visible spark (an electric arc). The best-known ESD-events from everyday life are the "doorknob shock", the prickling effect of a woolen garment being removed, and even lightning.

What is the impact of ESD:

This ESD phenomenon might be damaging or even dangerous in certain circumstances. Many "objects" are much more sensitive to ESD than the human body. While it takes about 3000 volts for a discharge to cause human discomfort, 100 volts can destroy magnetic information on a data carrier. A spark of only 50 volts may ignite explosive gases and 30 volts can damage electronic components.

In many cases, ESD causes so-called "latent defects" that will be manifested later in certain circumstances, causing operating failures or other disturbances. ESD is also a source of EMI (Electromagnetic Interference). An ESD event may create a type of radio signal that might influence electronic/electromagnetic equipment.

Low to Medium Energy Transients

Behavioral problems, caused by transients, are the most frustrating of the definition. These problems may or may not be first attributed to transients, but may be initially explained as isolated occurrences of 'glitches' or 'hiccups' in the system. The time and occurrence interval may not be consistent or repeatable enough for the user to see a pattern. The transients that fall into this class will include radios (both base and mobile), television transmission units, microwave transmission units and electrical lines not directly connected to the measurement device.

At first glance these sorts of transients do not appear to be as damaging as the ESD class and in some cases they are not. However, take as an example a metering station that controls the input gas or water to a manufacturing facility or an entire town. If one of these transients were to effect the measurement, the system could see this as a major upset and take the utility off line.

At the upper end of the medium energy transients are those caused by power switching equipment in close proximity. These are most certainly damage causing transients and account for a good portion of failures in the field. We could include in this group electrical motors, electrical valves or any electrical service that might have a faulty load in the circuit.

The measurement system itself could have a faulty load that could cause an electrical transient that can cause a failure in multiple devices attached to the system.

High Energy Transients

High-energy transients include several sources that are beyond the scope of this paper but the most dramatic and certainly the most devastating is lightning. With mean current pulses of 20,000 amps and measured peak values of 150,000 amps, the ability to shunt this energy after it has entered most measurement equipment is simply not feasible. That being the case then we must disperse the energy outside the device. We must make all attempts possible to ensure that high-energy transients do not have a mechanism to enter the system in question.

IMPORTANT ITEM TO REMEMBER

If the reader takes away nothing else remember this one equation $V_e = R_e * I_e$. Simply stated this equation says current will flow from the point of highest potential to the point of lowest potential and if the resistance between 2 points equals zero then a voltage level cannot exist. If a voltage level does not exist then damage to a device is not possible and the reader can find better things to do with his or her time.

Of course removing all resistance between 2 points is not totally possible so a discussion on alternatives along with this basic theory will be theme for the rest of this paper.

HOW TRANSIENTS GET INTO THE SYSTEM

In order for transients to cause damage to a measurement device they must find a way into the system. If the probability of direct lightning strikes is low, then we must look at what mechanism is available for transient energy into the measurement system.

The coupling of transients from the source to the measurement device can be direct, inductive or capacitive in nature. Each approach carries with it different energy levels and Voltage/Current waveforms.⁵

Direct Coupling

Transients are coupled directly from the source of interference to the susceptible equipment as a result of common impedance (connection cables).

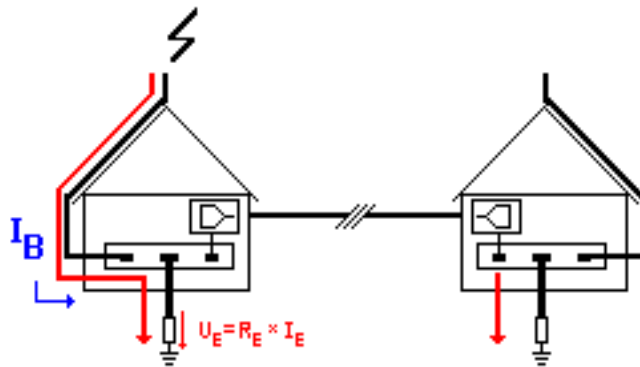


FIG 1. Directly Coupled

As the stroke energy is dissipated to the ground connection, a difference in potential will be seen from point "A" to point "B". This difference of potential may be in excess of several hundred volts caused by the impedance difference between the 2 points. Along with this voltage rise, the equipment on both ends now must withstand the relational current surge. Without interrupters of some sort the probability of equipment loss on both ends of the connection is very high.

Electronic measurement equipment and devices connected to AC power are especially susceptible to direct coupling effects. Even the military equipment with its extremely high survivability standards has problems with direct coupling. As stated in an U.S. Navy publication⁹: 'The most predominate power supply failures are caused by peak instantaneous transients and subtle factors within and external to the power supply... '.

Inductive Coupling

When a current flows in a conductor it establishes lines of flux (magnetic fields) around that conductor. The field strengths of the flux lines are in direct proportion to the amount of current that flows through the conductor. The generated magnetic field induces voltage in nearby signal loops.

In AC circuits this law of propagation is used to transformer couple primary windings to secondary windings. Radio transmission is another example of low-level controlled energy being passed form one point to another via radiated energy fields.

As measurement locations are automated, the main contributors to this type of transient are located in close proximity to low-level measurements. Electric motors, switch contactors and high power communication devices are major sources of broad-spectrum transient fields. Without suitable installation practices these devices will cause intermittent behavior and premature failures within the measurement system.

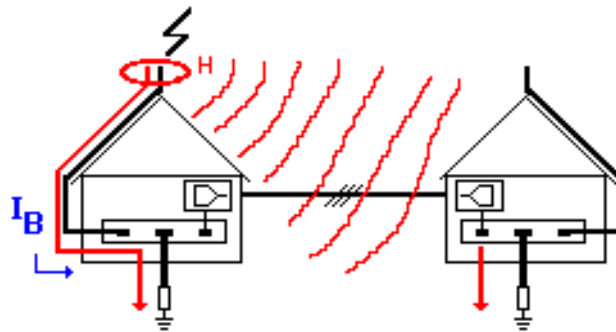


FIG 2. Inductively Coupled

Induced currents will travel in both directions through the cable. In situations where the cable has a shield wrap the initial current will be induced along the shield, the energy will then be capacitively coupled through all of the conductors within the cable. Shields are a good, low cost way of protecting some devices from damage, but they must be installed correctly or they become just as good an entry point.

For installations that make use of buried cables, different rules apply. The Number one difference is the built in energy distribution system. As the current flows down the shield it will produce a difference of potential between the shield and the surrounding ground. When this potential is high enough, the energy will blow a hole through the insulation of the cable causing a loss of energy at that point.

The energy reduction will be a function of the length of cable, the type of cable, the shield type, insulation resistance and the amount of available energy.

Capacitive Coupling

The capacitive coupling is formed by the strength of the voltage field around a conductor. The voltage field causes current to flow in an adjoining conductor to an area of lower field strength.

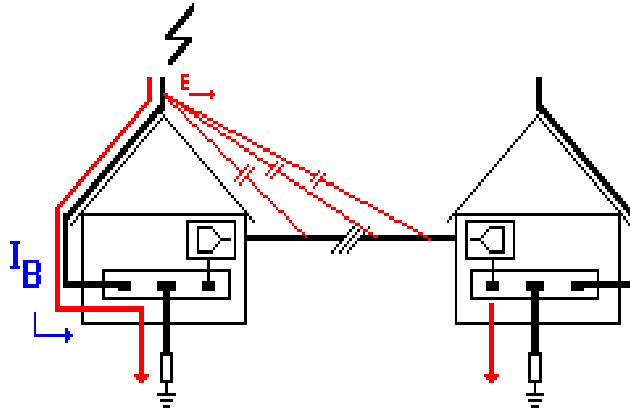


FIG. 4 Capacitive Coupled

If the inductively couple source is used as an example, then as the transient creates the voltage along the initial conductor it sets up magnetic fields that cross the other conductors within the cable or bundle. Where the fields cross a voltage is generated and now the transient has jumped from one conductor to several. This makes installation practices even more critical.

CASE STUDY – SAMPLE INSTALLATIONS

For the purpose of this paper, the sample installations will not cover direct lightning strikes. Close proximity strikes and other forms of transients will be covered instead.

The following paragraphs illustrate some basic installations and the transient entry points into each. Although the measurement device depicted in the diagrams is a completely enclosed system, the same basic principles should apply to any measurement device.

CASE 1. REMOTE INSTALLATION

In figure 5 a normal installation of an electronic measurement system is depicted. In this scenario even a close proximity lightning strike will have little damaging effect on the unit. Key points make this statement possible:

1. The only external entry point into the system will be the solar panel installation.
2. All of the ground potentials are common through the pipe.

The measurement device will ride the Voltage - Current wave just as a boat would ride through rough water. That is not to say that a direct strike will not damage the unit. A direct lightning strike could probably due major damage to this unit.

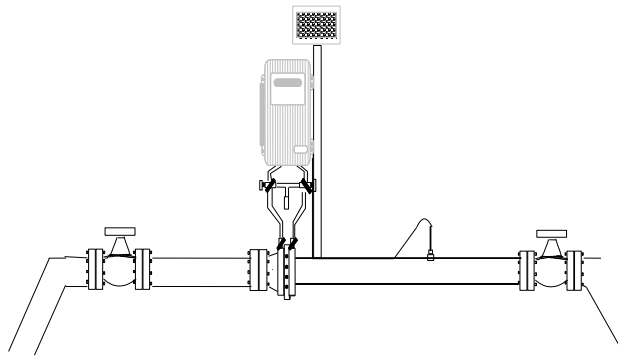


FIG. 5 Stand Alone Installation

CASE 2. REMOTE INSTALLATION WITH COMMUNICATIONS.

Figure 6 depicts an installation where the unit must be separated from its communications network because of intrinsic safety requirements. Two major entry points and one on site source for transients are shown in this configuration.

Entry Point One -- Communications Enclosure

The first obvious point of entry is through the communications network. As discussed previously the energy from a transient, lighting or nearby power surge, can be inductively coupled through the antenna mast and the data cables to the radio system. This can potentially cause two different avenues for destruction of the communications as well as the measurement equipment.

The antenna mast must be grounded properly for correct operation of radio transmission. The irony of using proper grounding techniques is illustrated by capacitively and inductively coupling transient energy from the mast into the shield of the communication cable between the radio and the antenna. This coupling could be able to induce enough energy to be destructive to the communications device.

If the antenna were not properly grounded, the current path could be through the communications enclosure and out on the communications connection to the measurement system.

Grounding the communications enclosure and associated hardware may not stop the transient from being coupled out onto the interconnection cables. If the ground potential at the measurement system is lower than the communications system, the current path could still be through the interconnection cables. Keeping the distance between the two enclosures as short as possible will help to minimize the ground differential.

Entry Point Two -- Interconnection Cable

The second entry point into the system is the interconnection cable. As shown in Fig. 2, the radiated energy from a current carrying conductor could inductively couple into the cable. This current could be in either direction causing damage to the communication network as well as the measurement device. If the cable was buried, the transient could still be coupled into the system via ground currents Fig. 3.

Transient Source -- Radio

The on sight transient source is the radio. From previous discussion it was shown that transients could be inductively coupled into a measurement system. Figure 2 depicts radiated waves originating at the strike location and intersecting some conductor along its path. This is basically radio transmission except on a broader frequency range. While the radio transmission signal is small, it is nonetheless a potential source of transients.

The installation of properly shielded cable between the communications network and measurement system will generally do an acceptable job of nulling out the effects of these low energy transients.

In installations where higher-powered radios or transmitting devices are required, filtering techniques in conjunction with energy clamping devices should probably be considered. The use of some filtering techniques, particularly capacitive filters, will be limited by intrinsic safety requirements.

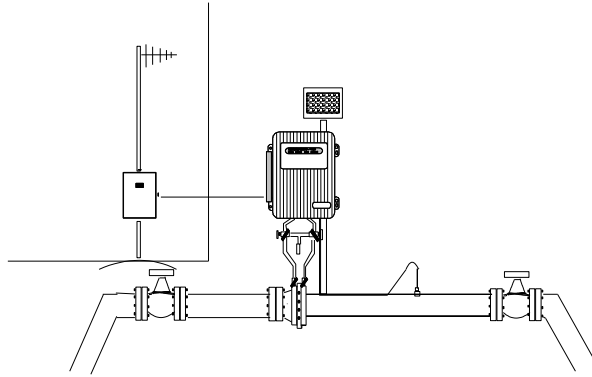


FIG. 6 Measurement Device with Communications

CASE 3. MULTIPLE UNITS -- COMMUNICATIONS NETWORK TO CONTROL

The last installation example depicts electronic measurement equipment on a communication bus tied back to a control room. Of the three presented, this one has the most probability of interference from transients. The major entry points could be the control house and associated AC lines along with the interconnection of the measurement devices.

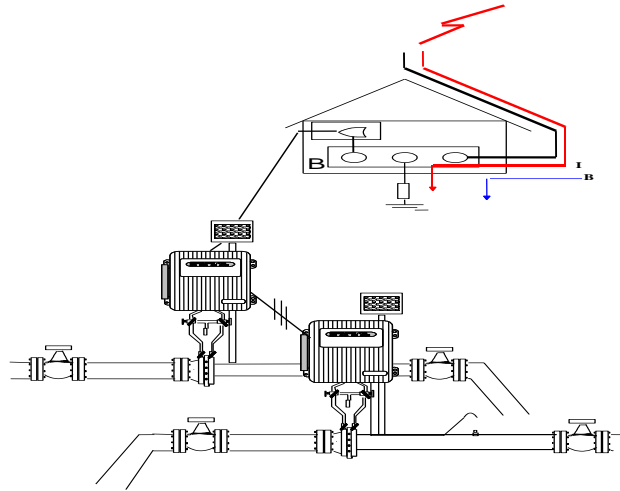


FIG. 7 Multiple Unit To Control House

Entry Point One -- Control Room

Direct and inductively coupled transients are a real threat in this application. The transient could be coupled into the system as shown from a direct lightning strike or it could be coupled into the system via the AC connections at the control house. Any relays or other power switching mechanisms located within the control house can also be a source of transients.

Some measurement devices are, by design, ratiometric in their output. This says that any significant power fluctuations will be represented in the returning signal. A properly shielded interconnection between the control house and the measurement system is absolutely necessary in this installation.

Depending upon the location category⁵ from which the interconnections originate it may be necessary to install protection schemes capable of handling open circuit voltages in excess of 6000V with potential current waves of 3000A. Where the control house is supplying power to the measurement devices, it may be necessary to also install Line interrupters (Circuit breaks and / or Fuses).

Entry Point 2 -- Device Interconnections

As in case 2, these interconnections may be an area for concern. The same rules apply as with case 2.

1. Keep the cable length as short as possible.
2. Use a properly shield cable where permitted.
3. If surge suppressor devices are necessary, they must be incorporated at each cable end.

TYPES OF PROTECTION DEVICES

GROUNDING AND SHIELDING

One of the most overlooked and misunderstood techniques to reduce the effects of transients is correct grounding. If a ground bed must be installed, not all applications require this, then ALL interconnected equipment must be attached to the same point. Having equipment linked together without following this simple rule can guarantee system failure from the first Medium or high-energy transient introduced into the system.

When linking equipment together for transient protection, a significant energy-transporting conductor must be installed. Do NOT rely on the communications ground path or the power ground path for transient conduction.

If a reason does not exist for grounding the system then DO NOT GROUND IT. Since transients flow from highest energy point to lowest energy point, not giving them a current path is the same as installing a free protection scheme.

For points requiring shielding, by all means install it. The shield must run the entire length of the exposed conduction path and must be attached at one end only. Shielding is intended to make the transient common mode across all conductors within the conduction path therefore giving multiple protection circuits the ability to handle part of the load and not the entire load. For Low Energy transients shielding is a valid technique that can protect circuits and system integrity. Shielding should not be relied upon to carry Medium or High Energy transients.

GENERAL WIRING PRACTICES

Antenna wiring as a good energy suppression system built in if installed correctly. By making a 90° loop in the antenna cable as close as possible to the antenna itself, a good portion of a medium or high energy transient will literally blow a hole in the cable. This action will bleed off a significant portion of the transient energy thus allowing smaller protection schemes to handle the remaining energy.

RTD cables are for the most part built with armored mesh and shield wires around 4 conductors. While the makeup may change from unit to unit, the physical properties for current carrying capability do not. Where feasible, cut the cables to fit the installation. Wrapping the excess cable around the flow pipe is a perfect example of a coil pickup for transients moving along the surface of the pipe. This wrap action could produce a gain effect of the transient and amplify the effect within the attached measurement system.

Charging source cables should follow correct installation guidelines. For solar panel charging, cutting the lines to fit the application is a good idea. Do not wrap the excess wire around the flow tube.

For AC charging sources the rules are somewhat different and much more stringent. To meet the IEEE472 as it relates to power substations and distribution trunks is well beyond the scope of this paper. Most power distribution companies have strict guidelines concerning what kind of devices or circuits can be used on main power feeds.

SNUBBERS AND FILTERS

The frequency components of a transient are several orders of magnitude above the power frequency of an AC circuit and, of course a DC circuit. Therefore, an obvious solution is to install a low-pass filter between the source of transients and the measurement system.

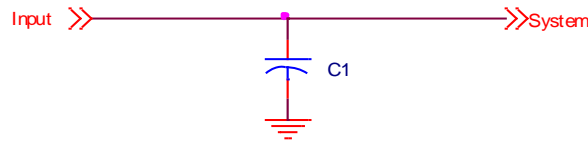


FIG 8. Capacitive Snubber Circuit

The simplest form of filter is a capacitor placed across the line. The impedance of the capacitor forms a voltage divider with the source impedance, resulting in attenuation of the transient at high frequencies. This simple approach may have some undesirable effects, such as:

- A. Unwanted resonance with inductive components located elsewhere in the circuit leading to high peak voltages.
- B. High inrush currents during switching.
- C. Excessive reactive load on the power system voltage.

Adding a series resistor reduces these undesirable effects - hence, the very popular use of RC snubbers and suppression networks. However, the price for adding the resistance is less effective clamping.

There is a fundamental limitation to the use of filters when the source of the transient is unknown. The capacitive snubbers as well as the RC snubber are only good within a relatively tight frequency band. Outside of the band the response is at best questionable.

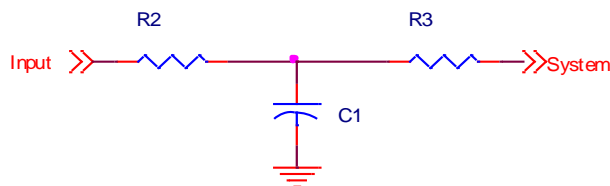


FIG. 9 Resistive Type Snubber Circuit

A second limitation for the use of RC techniques is the safety aspect of the unit in a hazardous area. Since some part of the available energy is stored in the capacitor network, this energy could be a non-safe condition for some period of time.

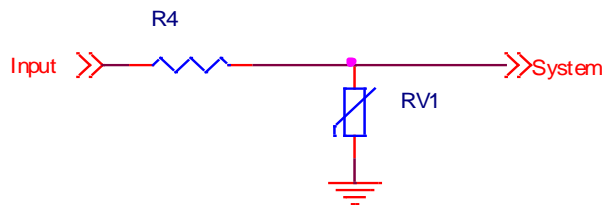


FIG. 10 Resistive MOV Snubber

One more type of circuit that falls within the snubber category is the resistive varistor combination. The circuit works by allowing the inrush currents to flow through the varistor and clamping the voltage seen by the protected circuit to a known state.

The advantages of this circuit include:

- A. Ease of use and the ability to get replacement parts at a minimal cost.
- B. Leakage currents are low.
- C. Energy capability is relatively high.
- D. Response time is fast.

The disadvantages of this circuit include:

- A. The clamping voltage may be too high to protect the circuit from damage.
- B. The capacitance as seen by the protected circuit is moderate to high.

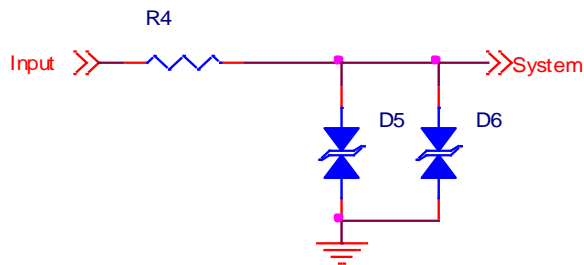


FIG. 11 Resistive TVS Circuit

The resistive TVS circuit eliminates the voltage clamp problem of the MOV Snubber. Another advantage is the lower capacitance of the device. It does however have the drawback of being a one shot device for medium to high-energy transients.

MULTI-COMPONENT PROTECTION SCHEMES

These protection devices incorporate gas filled tubes, impedance elements and silicon suppressors. This approach has been around more than half of a century, having been patented by David Bodle of Bell Telephone Laboratories in the mid '50's.

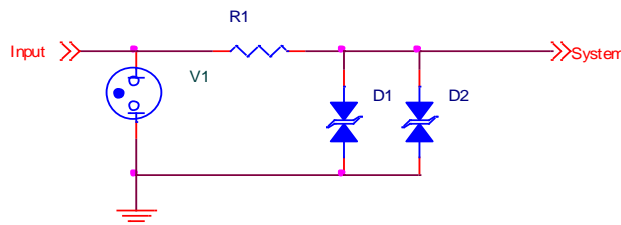


FIG. 12 Multi-Component Suppressor

The operation of this suppressor is based on the voltage clamping characteristics of the silicon suppression device as well as the current shunting capability of the gas tube. Since the gas tube requires a significant voltage before conduction can take place, the silicon suppression device along with the impedance circuit protects the downstream devices until arc mode is reached. This circuit has been found to be very effective in both laboratory tests and field use.

The addition of an interrupter (Fuse or circuit breaker) may be required in specific applications. Because the gas tube requires significantly less energy to continue to conduct than to start, it may not stop conducting after a transient has passed. The interrupter may be required to limit the amount of steady - state voltage source current that will follow the surge discharge. This is particularly true in applications where the steady state voltage of the protected circuit does not cross a zero threshold.

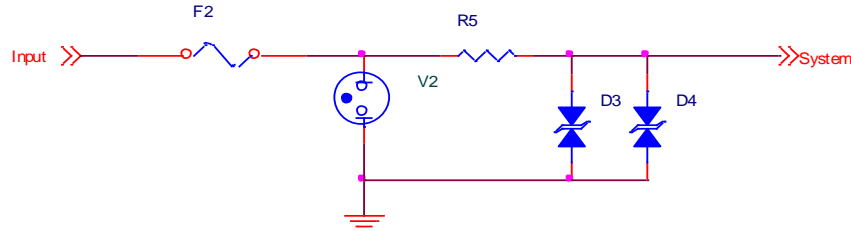


FIG. 13 Fused Surge Suppressor

In the event of a relatively small energy transient or a transient whose energy time is extremely short, the spark gap tube may not fire at all. This would leave the silicon device and the impedance element to handle the brunt of the energy. While the response time of the silicon device is fast, the energy handling capability is limited. To avoid the protection scheme from becoming a one shot and replace device, some other mechanism must be installed as a fail-safe measure. The addition of the interrupter is a small price to pay in relationship to the extra security offered.

The last circuit offered is a multi-component with no direct connection between the protection devices and the circuit being protected. This circuit would be used in mission critical applications where an indeterminate state caused by transient damage could be life threatening. It operates on the same principle as the previous example and adds the Level 3 protection on the system side. To be fully classified for Level 3 the device must be replaceable as a unit and must be testable. This device can handle multiple events with medium and high-energy transients. This unit cannot handle direct lightning strikes, but will handle close proximity events.

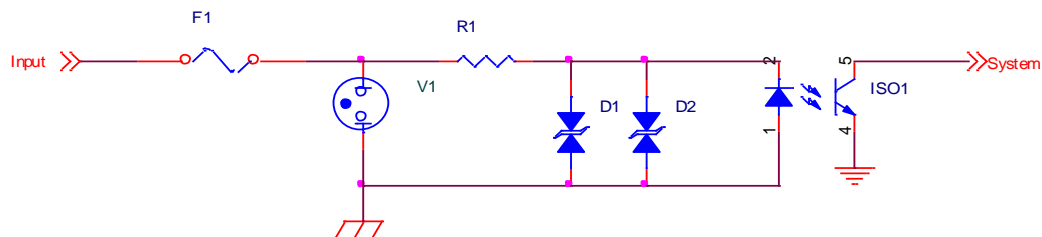


FIG. 14 Level 3 Data Line Protection

CONCLUSION

Electronic measurement devices can be reliably protected from transient voltages, but there is a cost associated with protection schemes and not all applications or installations require them. An analysis of the measurement devices, associated hardware and environmental area should be made before making the decision to incorporate protection devices.

If the decision is made to incorporate a suppression scheme then a few basic rules should also apply.

1. Transient suppressors are designed to handle high electrical loads, according to the design and application. However, too high or very frequent surge voltages may lead to degradation of performance or even failure of the protection function, in which case the device must be replaced. This basically states that the protection scheme must not be an integral part of the electronic measurement device.
2. The ability of transients to inductively or capacitively couple from protected circuits to non-protected circuits is another reason to have the protection devices separate from the measurement device. If the protection scheme is located in proximity to susceptible devices, the energy from the transient could bypass the protection scheme or be coupled from the protection scheme to the more susceptible electronics.
3. Since all suppressor schemes can fail, they must be serviceable and testable. Not all surge suppressor devices fail in a known state. Some of these devices fail open while others fail in a shorted condition. It is a must to select a protection scheme that allows the devices to be serviced and tested with little or no down time of measurement system.
4. In hazardous areas where the amount of available energy must be kept to a minimum, not all filtering techniques or devices can be incorporated.

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