

# Application Note: Transient Voltage Suppressors (TVS Diode) Applications Overview

## Transient Threats - What are Transients?

Voltage Transients are defined as short duration surges of electrical energy and are the result of the sudden release of energy previously stored or induced by other means, such as heavy inductive loads or lightning. In electrical or electronic circuits, this energy can be released in a predictable manner via controlled switching actions, or randomly induced into a circuit from external sources.

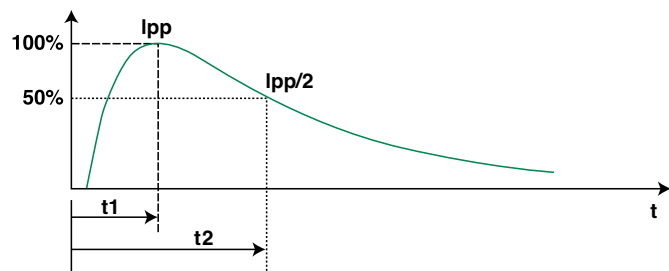
Repeatable transients are frequently caused by the operation of motors, generators, or the switching of reactive circuit components. Random transients, on the other hand, are often caused by Lightning and Electrostatic Discharge (ESD). Lightning and ESD generally occur unpredictably, and may require elaborate monitoring to be accurately measured, especially if induced at the circuit board level. Numerous electronics standards groups have analyzed transient voltage occurrences using accepted monitoring or testing methods. The key characteristics of several transients are shown in the table below.

|           | VOLTAGE | CURRENT | RISE-TIME  | DURATION |
|-----------|---------|---------|------------|----------|
| Lightning | 25kV    | 20kA    | 10 $\mu$ s | 1ms      |
| Switching | 600V    | 500A    | 50 $\mu$ s | 500ms    |
| EMP       | 1kV     | 10A     | 20ns       | 1ms      |
| ESD       | 15kV    | 30A     | <1ns       | 100ns    |

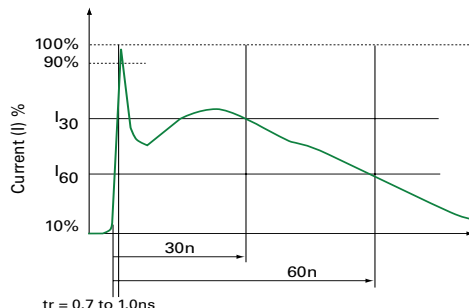
**Table 1: Examples of transient sources and magnitude**

## Characteristics of Transient Voltage Spikes

Transient voltage spikes generally exhibit a “double exponential” wave, as shown below for lightning and ESD.



**Figure 1: Lightning Transient Waveform**



**Figure 2: ESD Test Waveform**

The exponential rise time of lightning is in the range 1.2 $\mu$ sec to 10 $\mu$ sec (essentially 10% to 90%) and the duration is in the range of 50 $\mu$ sec to 1000 $\mu$ sec (50% of peak values). ESD on the other hand, is a much shorter duration event. The rise time has been characterized at less than 1.0ns. The overall duration is approximately 100ns.

## Why are Transients of Increasing Concern?

Component miniaturization has resulted in increased sensitivity to electrical stresses. Microprocessors for example, have structures and conductive paths which are unable to handle high currents from ESD transients. Such components operate at very low voltages, so voltage disturbances must be controlled to prevent device interruption and latent or catastrophic failures.

Sensitive microprocessors are prevalent today in a wide range of devices. Everything from home appliances, such as dishwashers, to industrial controls and even toys use microprocessors to improve functionality and efficiency.

Most vehicles now also employ multiple electronic systems to control the engine, climate, braking and, in some cases, steering, traction and safety systems.

Many of the sub- or supporting components (such as electric motors or accessories) within appliances and automobiles present transient threats to the entire system.

Careful circuit design should not only factor environmental scenarios but also the potential effects of these related components. Table 2 below shows the vulnerability of various component technologies.

| Device Type         | Vulnerability (volts) |
|---------------------|-----------------------|
| VMOS                | 30-1800               |
| MOSFET              | 100-200               |
| GaAsFET             | 100-300               |
| EPROM               | 100                   |
| JFET                | 140-7000              |
| CMOS                | 250-3000              |
| Schottky Diodes     | 300-2500              |
| Bipolar Transistors | 380-7000              |
| SCR                 | 680-1000              |

## TVS Diode Transient Voltage Scenarios

### Electrostatic Discharge (ESD)

Electrostatic discharge is characterized by very fast rise times and very high peak voltages and currents. This energy is the result of an imbalance of positive and negative charges between objects.

ESD that is generated by everyday activities can far surpass the vulnerability threshold of standard semiconductor technologies. Following are a few examples:

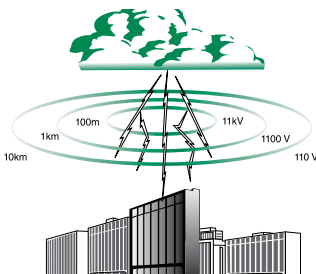
- **Walking across a carpet:**  
35kV @ RH = 20%; 1.5kV @ RH = 65%
- **Walking across a vinyl floor:**  
12kV @ RH = 20%; 250V @ RH = 65%
- **Worker at a bench:**  
6kV @ RH = 20%; 100V @ RH = 65%
- **Vinyl envelopes:**  
7kV @ RH = 20%; 600V @ RH = 65%
- **Poly bag picked up from desk:**  
20kV @ RH = 20%; 1.2kV @ RH = 65%

### Lightning Induced Transients

Even though a direct strike is clearly destructive, transients induced by lightning are not the result of a direct strike.

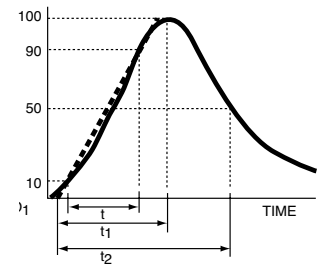
When a lightning strike occurs, the event creates a magnetic field which can induce transients of large magnitude in nearby electrical cables.

A cloud-to-cloud strike will effect not only overhead cables, but also buried cables. Even a strike 1 mile distant (1.6km) can generate 70 volts in electrical cables.



In a cloud-to-ground strike (as shown at right) the transient-generating effect is far greater.

This diagram shows a typical current waveform for induced lightning disturbances.



### Inductive Load Switching

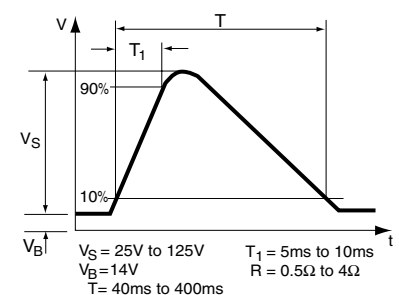
The switching of inductive loads generates high energy transients which increase in magnitude with increasingly heavy loads. When the inductive load is switched off, the collapsing magnetic field is converted into electrical energy which takes the form of a double exponential transient. Depending on the source, these transients can be as large as hundreds of volts and hundreds of Amps, with duration times of 400 milliseconds.

Typical sources of inductive transients include:

- **Generator** • **Motor**
- **Relay** • **Transformer**

These examples are common in electrical and electronic systems. Because the sizes of the loads vary according to the application, the wave shape, duration, peak current and peak voltage are all variables which exist in real world transients. Once these variables can be approximated, a suitable suppressor technology can be selected.

The diagram at right shows a transient which is the result of stored energy within the alternator of an automobile charging system.

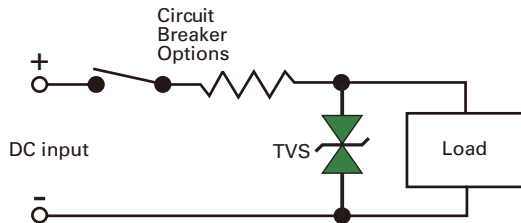


A similar transient can also be caused by other DC motors in a vehicle.

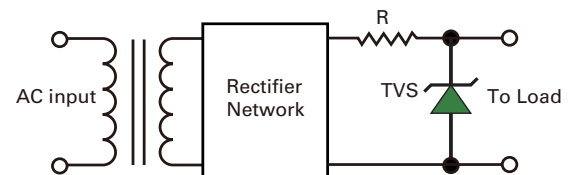
For example, DC motors power amenities such as power locks, seats and windows. These various applications of a DC motor can produce transients that are just as harmful to the sensitive electronic components as transients created in the external environment.

## TVS Diode Device Typical Applications

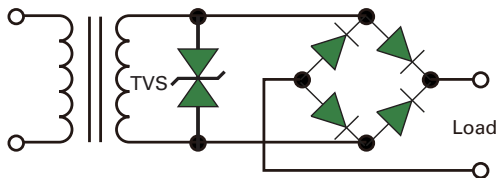
### DC Supply Protection



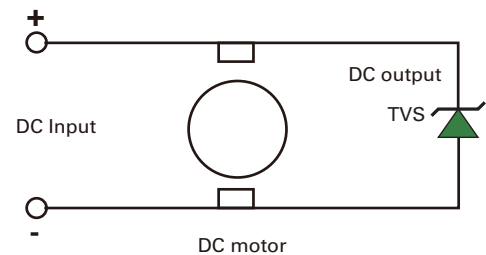
### DC Load Protection



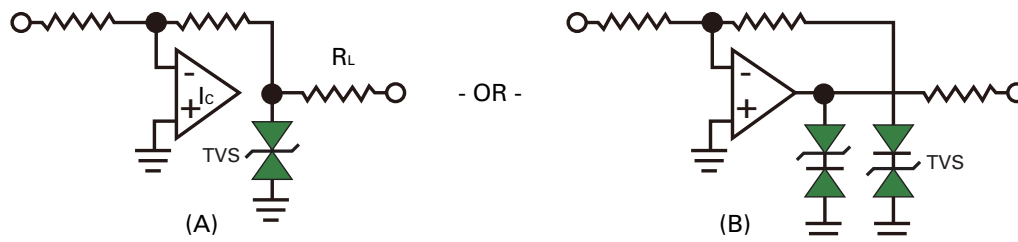
### AC Supply Protection



### Electro-Magnetic Interference Limiting

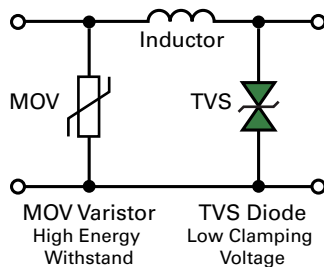


### Operational Amplifier Protection

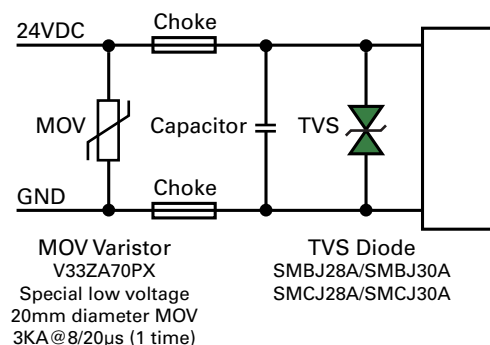


### Combined MOV Varistor and TVS Diode Protection Scenarios

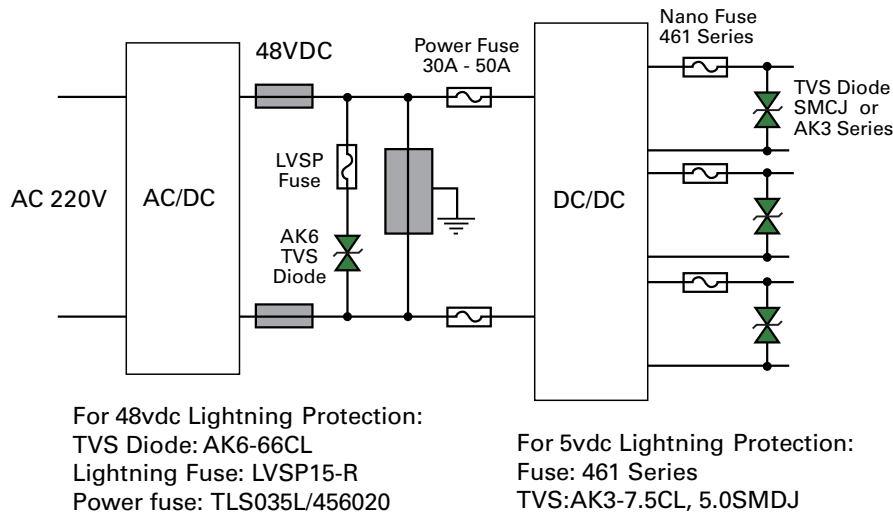
#### MOV + TVS Combination:



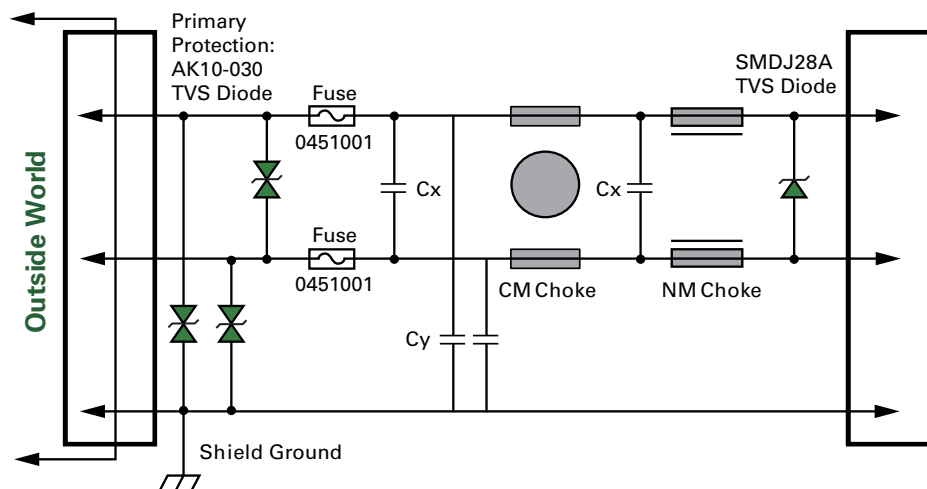
#### MOV + Choke + TVS Combination:



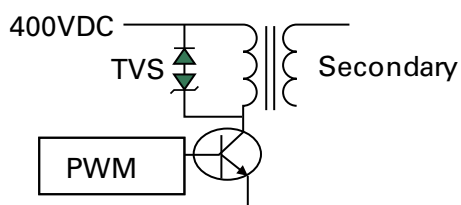
### Telecom DC/DC Protection



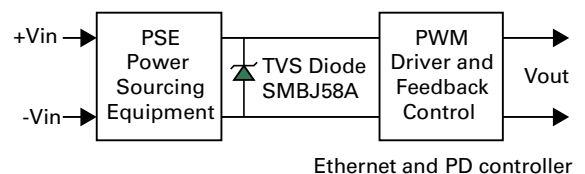
### Circuit Protection of 24VDC with High Surge Capability



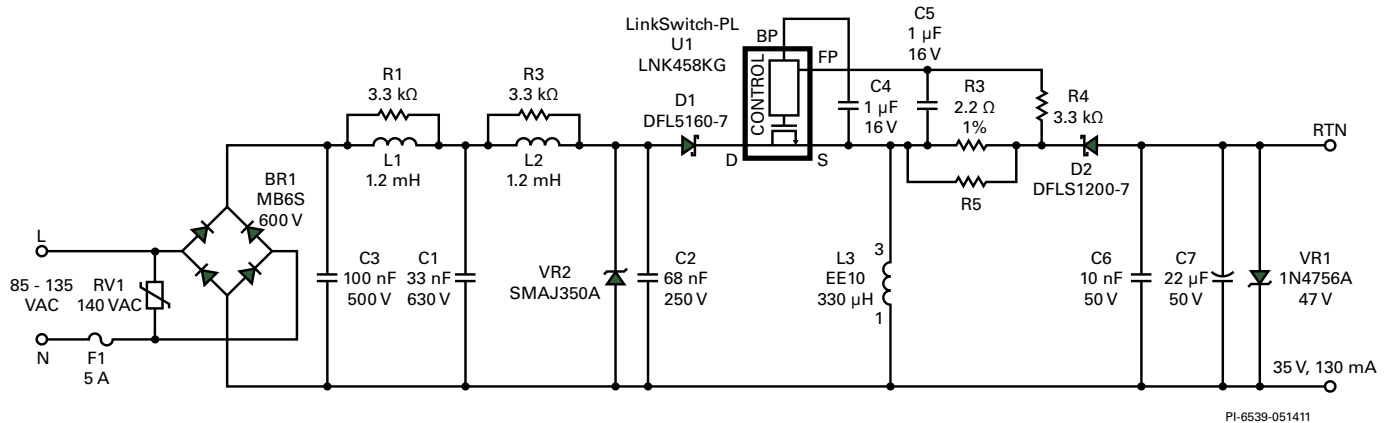
### Pulse Width Modulated (PWM) Driver Protection



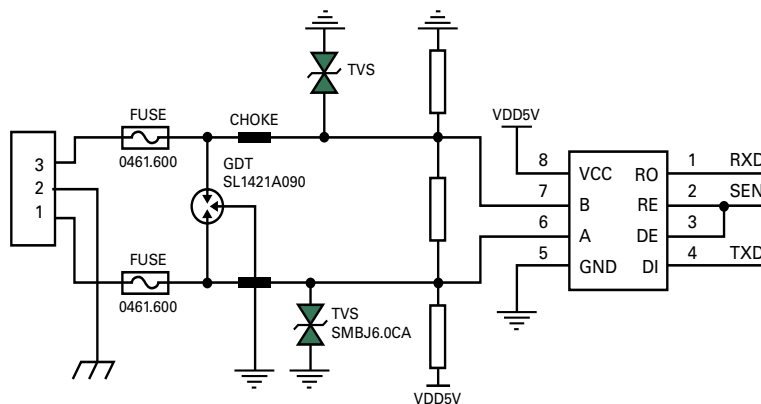
### Power Over Ethernet (PoE) Protection



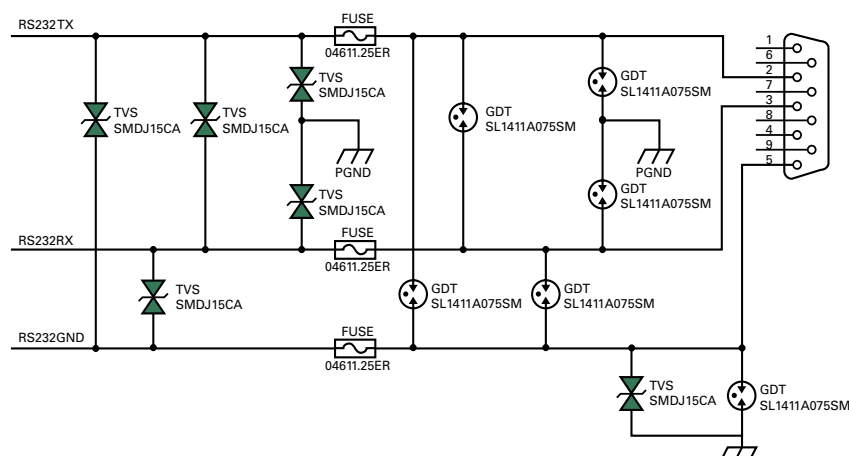
## LED Driver Protection



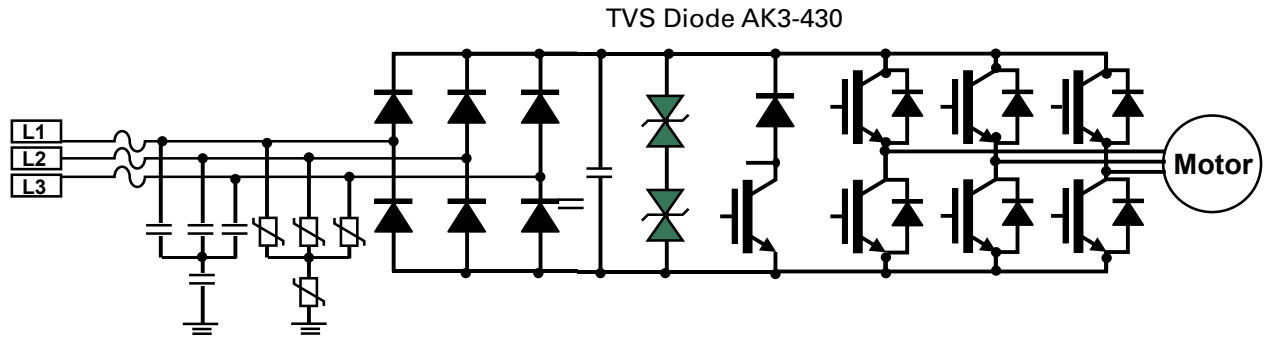
## RS485 Interface Protection



## RS232 Interface Protection with High Surge Requirement



### Inverter / VFD protection in IGBT Module Protection



### IGBT Gate Protection

