TECHNICAL INFORMATION

A MULTILAYER APPROACH TO TRANSIENT VOLTAGE SUPRESSORS

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Abstract

Improvements in integrated circuits have resulted in increased speed and increased ESD sensitivity. New systems require external protection more than ever before but advances in surface mount technology and product miniaturization place severe size constraints on protection components.

Advances in ceramics now allow transient voltage suppressors to be built with multilayer structures resulting in improved electrical performance and in smaller sizes than comparable disc configurations. Clamping voltage and peak current performances approaching zener diode transient suppressors are achieved in the common 1206 (3.2 x 1.6mm) chip size, one third the size of SMT disc varistors or SMT zener diode supressors.

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Electrical overstress, especially due to ESD (electrostatic discharge), has become a mounting concern to designers due to increased system densities and speed. These performance gains are due to the giant strides made in integrated circuit complexity and the resulting smaller device sizes. Internal protection devices built into integrated circuits have been reduced in size to minimize their impact on speed and circuit area. Unfortunately the price paid is increased ESD sensitivity. External protection is now required at system inputs and outputs to eliminate overstress damage and surface mount technology (SMT) is now placing severe size constraints on components in addition to providing protection.

Overstress protection falls into three categories: filters (R-C, R-L-C, etc.), crowbars such as gas discharge tubes or thyristors, and low voltage clamps like zener diodes or varistors. All semiconductor transient voltage protraction devices such as thyristors, zener diodes, or varistors need large active areas to handle the high peak currents associated with transients. Silicon transient supressors like thyristors and zener diodes can only be fabricated in a single plane with increased size to accommodate peak current requirements. When packaging is included the resulting size can become unmanageable for SMT assemblies.

Varistors are semiconducting ceramics and are not limited to single plane processing even though discs or pressed pills have dominated in the past. Continuing advances in ceramic technology make high performance, low voltage surface mountable varistors possible by using a multilayer structure instead of single plane devices. These gains are similar to those when the shift was made from disc capacitors to multilayers many years ago. There are also significant improvements in the electrical performance in addition to size and usability in SMT assemblies when multilayer varistor or Transguard transient voltage suppressors are used.

Modern varistors are ceramics composed of conductive zinc oxide grains doped with bismuth, cobalt, manganese, and other metal oxides[1]. The nonlinear current/ voltage characteristic is due to the conduction of Schottky barriers at each grain interface with maximum current density limited by bulk grain resistivity. Typical zinc oxide (ZnO) varistor materials have a macroscopic breakdown voltage per intergranular barrier of approximately 3.6V. From this fixed breakdown voltage per grain, Vn, the varistor voltage and dielectric (ceramic) thickness are found.

The varistor breakdown voltage is then

$$Vb(DC)=(3.6V)(n)$$

with n = average number of grain boundaries between electrodes

The dielectric or ceramic thickness, D, is

$$D= (n+1)(d) \approx (Vb)(d)/(3.6V)$$

with d = average grain size

(a)

(b)

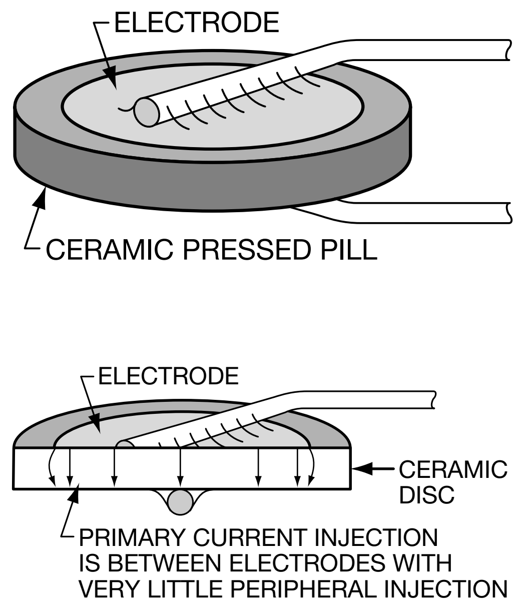


Figure 1. Radial Lead Disc Varistor Construction

It is readily apparent in Figure 1 that disc (single plane) low voltage varistors are difficult to manufacture and are fragile due to the small number of grains between electrodes required for low voltage operation. The grain size is increased to make devices thicker for mechanical reasons but processing becomes more difficult to properly control growth of these large irregular grains resulting in a profusion of breakdown voltages and part numbers. Large grain size results in a longer current path increasing the series resistance in any given electrode area reducing the varistor peak current capability. Moving away from disc or pressed pill technology to multilayer structures eliminates grain size limitations of low voltage transient voltage supressors, increases the available electrode surface area and more importantly the reduction of resistance from the ZnO grains per unit electrode area by dramatically reducing the current conduction path length. Figure 2 shows the grain structure difference between disc varistor and the Transguard transient voltage suppressor. This highly uniform grain structure was obtained by special processing and fabrication techniques which are not obtainable by the normal ceramic process.

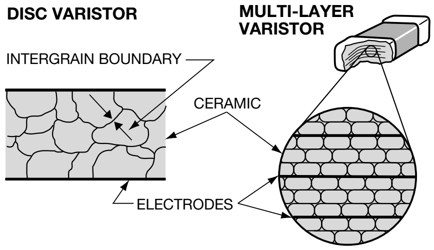


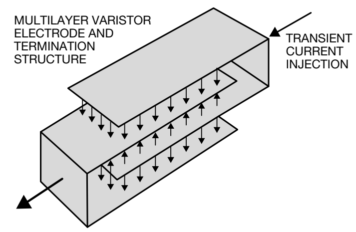
Figure 2. Grain Structure Difference Between Disc and Multilayer Varistors

Disc or pressed pill varistor construction is ideal for high voltages due to low manufacturing cost but large irregular grains in low voltage devices limits mechanical integrity and electrical performance. In low voltage applications, each disadvantage exhibited by disc varistor construction is eliminated with the multilayer construction of TransGuard suppressors.

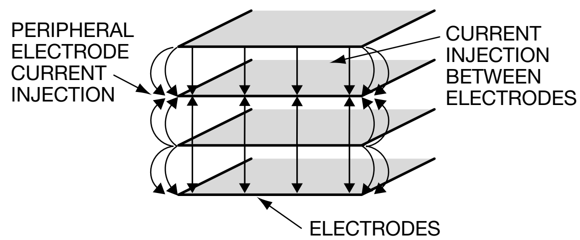
Disc Varistor	TransGuard Suppressor
Small electrode area per unit volume as only the exterior surface is available for electrodes.	Large electrode area available within the entire volume.
Device thickness changes with breakdown voltage. Low voltage devices are thin and fragile.	Breakdown voltage is dependent on dielectric thickness and not device thickness.
The ceramic firing process is different for each breakdown voltage.	A single process is used for all voltages because only the dielectric thickness changes.
Low voltage devices have huge irregular shaped grains which compounds manufacturing yields.	Small, uniform grains are used, easily yielding low voltage varistors.

Real differences become apparent when looking at minimum/maximum specifications for similar surface mount disc and multilayer (MLV) varistors. The TransGuard transient voltage supressor has a lower clamping voltage at higher peak current, higher peak current capability at elevated temperatures, and higher energy dissipation in a package one-third the size of a similar SMT disc varistor.

Increased electrode area is an improvement that multilayer construction offers resulting in increased transient energy dissipation and more efficient current distribution within the supressor. This allows smaller parts to be built. Current and energy dissipation is uniformly distributed within the ceramic volume between electrodes as shown in Figure 3. Additionally the multilayer structure has the added advantage of peripheral electrode current injection similar to high current power transistors. Not only is electrode area important for high current suppressors but electrode periphery is also important for maximum performance.



(a) Current Distribution



(b) High Current Injection

Figure 3. TransGuard Current Injection

Besides structural improvements, TransGuard transient voltage suppressors have smaller ceramic grains. This is important for three main reasons: first, the transient current path is greatly reduced, typically a ten to one improvement over disc structures. Second small ceramic grains are more uniform in size and shape allowing more uniform contact of Schottky barriers between grains which is needed for high current conduction. Third, there is much more electrode area available in any given volume increasing peak current capability.

Table 1. Comparison of Surface Mount Varistors

Suppressor Type		**5.5V DC** TransGuard	**5.5V DC** Disc	**14VDC** TransGuard	**14VDC** Disc
Dimensions	L x W	.126" x .063"	.180" x .120"	.126" x .063"	.180" x .120"
Maximum Breakdown Voltage @ 1mA	V_B	8.4V	11V	20V	21.6V
Clamping Voltage 8 x 20μS, 2 Amp peak	V_C		30V		44V
Clamping Voltage 10 Amp peak	V_C	15.5V		30V	
Peak Current @ 85°C 8 x 20μS Pulse	I_{PEAK}	150A	25A	150A	50A
Transient Energy 10 x 1000μS Pulse	E_{TRAN}	.45J	.1J	.8J	.2J

Multilayer construction and improved grain structure results in excellent transient clamping characteristics in excess of 150 amps peak current while maintaining very low leakage currents under DC operating conditions. Figure 4 shows the voltage/current characteristics for both the 5.6V and 14V DC parts with currents ranging from parts of a micro amp to tens of amps.

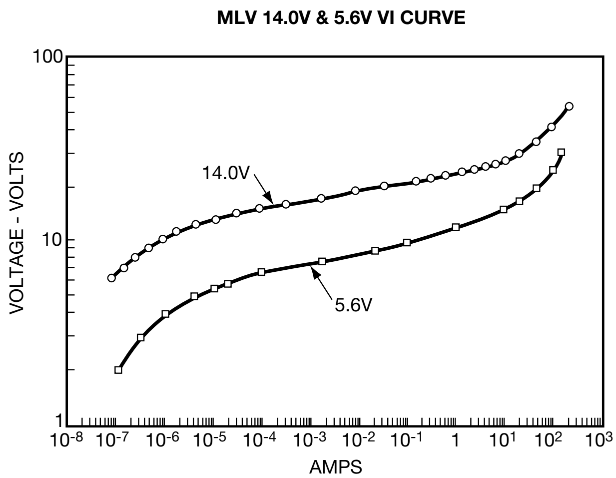
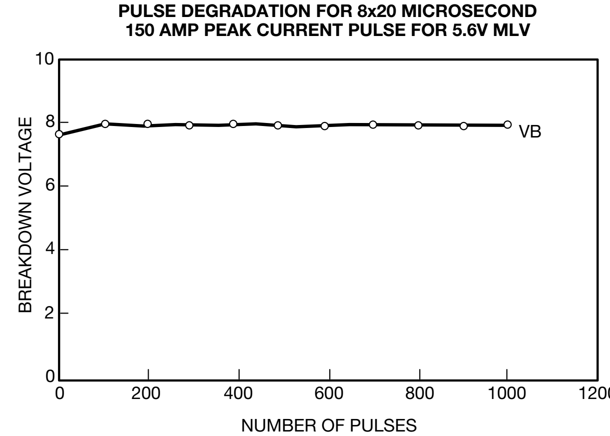
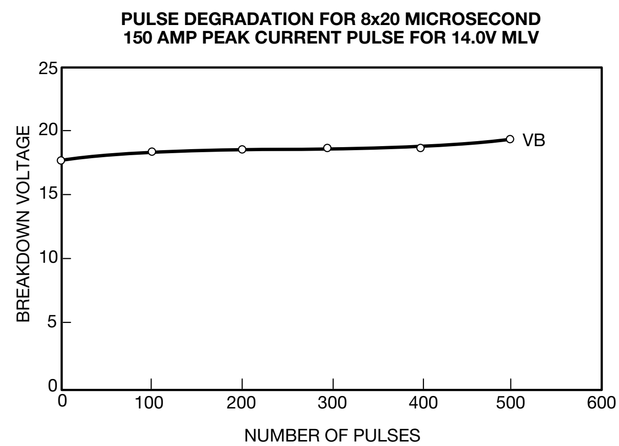


Figure 4. Voltage /Current Characteristics of Multilayer Varistors

Traditionally varistors have suffered degradation of electrical performance with repeated high current pulse resulting in decreased breakdown voltage and increased leakage current. It has been suggested that irregular intergranular boundaries and bulk material result in restricted current paths and other non-Schottky barrier parallel conduction paths in the ceramic. Repeated pulsing of both 5.6 and 14V DC TransGuard transient voltage suppressors with 150Amp peak 8 x 20µS wave forms shows negligible degradation in breakdown voltage and minimal increases in leakage current. This does not mean that TransGuard suppressors do not suffer degradation but it occurs at much higher currents. The plots of typical breakdown voltage vs number of 150A pulses shown in Figure 5 is for devices that are only one-eighth of an inch long and a sixteenth of an inch wide.



(a) 5.6V DC TransGuard



(b) 14V DC TransGuard

Figure 5. Breakdown Voltage Shift vs Number of 150A 8 x 20µS Pulses

Low voltage transient suppressor applications have been dominated by specially designed zener diodes because of better clamping characteristics and smaller size. On the other hand varistors have better high surge current capability than do zener diodes. This is because energy is dissipated in the entire volume of ceramic between electrodes. When a failure occurs, only a few grain boundaries are destroyed in a varistor leaving most intact to offer protection. Zener diodes have only a single diode junction to fail resulting in a dead short in an electrical overstress situation. This is due to the planar construction of zener diodes that have the cathode or anode diffused into the silicon body. Zener diodes, or more appropriately avalanche diodes, are operated in the reverse bias mode which supports the clamping voltage under transient conditions in the diodes' depletion region. There is some bulk silicone heating in the contact and bulk resistance of the device but most energy is dissipated in the thin depletion region near the zener diode surface. Figure 6 shows a diffused cathode zener with a greatly exaggerated depletion region that supports most of the voltage and energy dissipation during transient conditions. The depletion region is only a 100nM thick forcing most energy dissipation into a very thin region at the surface of the diode.

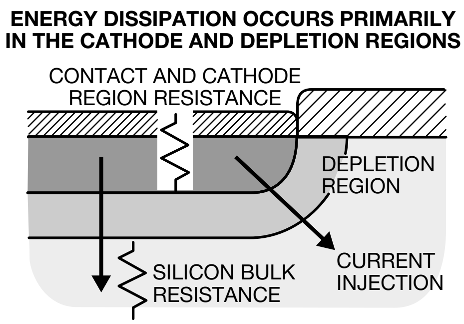


Figure 6. Diffused Cathode Zener Diode Depletion Region

Varistors or semiconducting ceramics are in reality series/parallel combinations of Schottky diodes that also support most energy dissipation in thin depletion regions at each Schottky barrier. Zener diodes have only a single thin depletion region at the surface while varistors have many in series/parallel combination distributed throughout the whole ceramic volume as seen in Figure 7. This results in superior energy dissipation per unit volume without having to resort to internal package heat sinks found in high peak current zener diode suppressors.

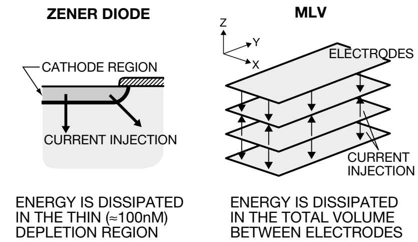


Figure 7. Energy Dissipation for Zener Diodes and Multilayer Varistors

Comparisons between surface mount TransGuard suppressors and zener transient suppressors shows little difference in peak transient current or energy dissipation but the clamping voltage is better for the zener diodes.

Most if not all integrated circuits or power MOS transistors have internal protection devices that offer some ESD overstress protection above 50V, typically closer to 500V. Protection levels offered by TransGuard transient voltage suppressors is similar to zener diode suppressors in overstress conditions with only slightly higher clamping voltages. Unfortunately disc or pressed pill varistors do not offer adequate protection at high transient currents typical in an ESD environment which range from 10-40 Amps with a 150-250nS duration.

Transient response and package configurations are the remaining serious considerations after the required clamping and peak current characteristics are determined. Both transient response and package configurations for surface mount transient suppressors have interesting interpretations on data sheets usually not relating to the real world.

Transient response is the most obvious case of confusing "SPECSMANSHIP" faced by users. We find either no hint of transient response or a "theoretical" response given in nano or pico seconds leaving the designer in the dark. A theoretical response is the calculated transit time for charge to cross the device

Table 2. Comparison of Surface Mount Transient Suppressors

Suppressor Type		**5.6V DC**		**14V DC**	
		TransGuard	Zener	TransGuard	Zener
Dimensions	L x W	.126" x .063"	.250" x .140"	.126" x .063"	.250" x.140"
Clamping Voltage	V_c				
8 x 20µS, 10 Amp peak		15.5V		30V	
10 x 1000µS 62.5 Amp Peak			9.6V		
10 x 1000µS 23.3 Amp Peak					25.8V
Peak Current @ 85°C	I_{PEAK}				
8 x 20µS Pulse		150A	200A	150A	90A
Transient Energy	E_{TRAN}				
10 x 1000µS Pulse		.4J	.5J	.4J	.5J

depletion region but gives no indication of package inductance of package inductance of its effect. A theoretical response is better than no specification at all but much more is needed. From a practical standpoint, larger is slower because package inductance increases linearally with package length. TransGuard transient voltage suppressors respond to transients in 1nS which is the current test equipment limit. Both transient response and device inductance are specified for TransGuard suppressors.

Surface mount compatibility is another interesting problem which requires components to withstand soldering, assembly, handling, and thermal cycling. Users are now finding surface mount manufacturing far more difficult than the thru-hole counterpart due to the required process controls and material compatibility problems. Reliable SMT assemblies require far more than just slapping parts down on a board and soldering them into place; the component, substrate, and solder process all must be compatible.

Component size causes the biggest problems due to post soldering residual stress accentuated by differences in the component and substrate coefficients of thermal expansion (CTE). Components must be either small or have a compliant lead or interface to achieve reliable, long-lasting solder joints. Stress in the solder joints of a 0.126" long part ranges between 300 and 1,000 pounds per square inch or typically 10-20% of solder's tensile strength at room temperature. Circuit area requirements and solder joint stress limit the practical length of rigid parts to only 0.126" (3.2mm). Solder joint stress varies as square of length, precluding the use of longer parts for assemblies that will see 50°C or more temperature excursion. Complient leads on components minimizes solder joint stress but at greatly increased cost.

Size and increased system complexity are driving forces behind the move to SMT. Protection of numerous input/outputs cannot be assigned to a single component but to a large number of small components. The TransGuard transient voltage suppressor is one-third to one-fourth the size of comparable SMT disc varistors or zener diode transient suppressors which increases the number of protection components per unit area of a PC board. Continuing advances in surface mount assembly requirements is shrinking component sizes across the board; transistors, integrated circuits, capacitors, and resistors are all getting smaller. The 1206 (.126" x .063" or 3.2 x 1.6mm) has been the standard chip resistor and capacitor size for some time but the 0805 (.080"x .050") and 0603 (.063" x .030") sizes are rapidly gaining popularity. Only the TransGuard transient voltage suppressor will be able to keep pace with increased miniaturization brought on by surface mount technology.

Advanced ceramic technology offers a superior solution to transient voltage protection in the smallest possible package. TransGuard surface mount chips and auto insertable axial parts are effective alternatives to most low voltage transient protection requirements.

References

1. M. Matsuoka, Jpn. J. Appl. Phys., 10, 736 (1971)

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