Application Note AP5179, Rev B

Transient Suppression for MIL-STD-1275 Applications Application Note

INTRODUCTION

Sensitron's SCP-5282 Series of devices are high pulse power Transorbs, the only COTS devices which meet and exceed the MIL-STD-1275 voltage surges and transients on the market today.

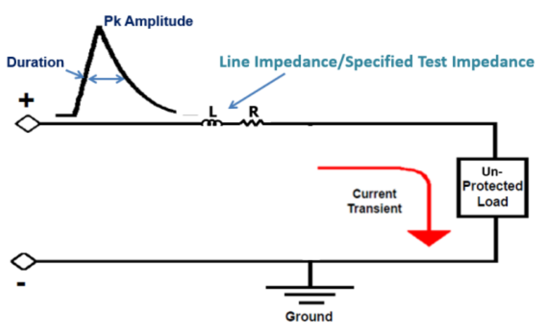
This application note covers transient voltage suppression and the capability of the SCP-5282 Series in meeting stringent MIL-STD-1275 requirements.

The purpose of this presentation is to provide a primer on MIL-STD-1275 transient surges, protection requirements and protection solutions for 28V (and 24V) power systems.

Although the primary focus is on military vehicle power systems and their long duration voltage surges, the same surges and solutions can apply to 28V systems on aircraft and ships.

Contact Sensitron for protection on bus voltages other than 24V/28V, or transients other than those discussed here.

Basics of Transients and Protection



By specification; Transients are described as

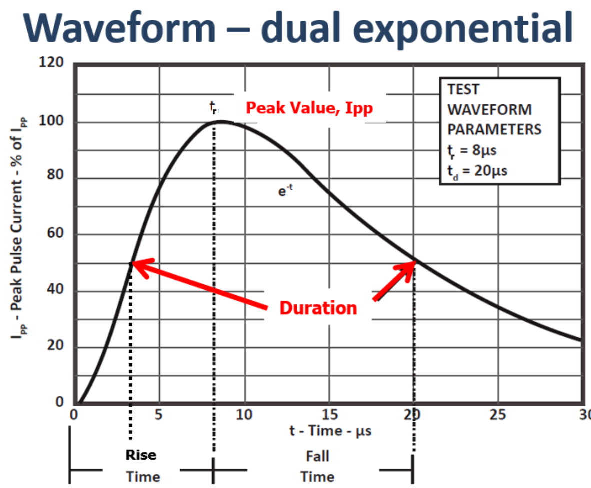
1. A voltage waveform fed thru a source and/or line impedance, or

2. A current waveform supplied by a current source to a short circuit.

Standard Transient Waveform Parameters

To address a vehicle requirement, we need the following info about the waveform:

1. **Duration** = time between 50% points
2. **Ipp** = Peak current value
3. **Polarity** = uni-directional or bi-directional



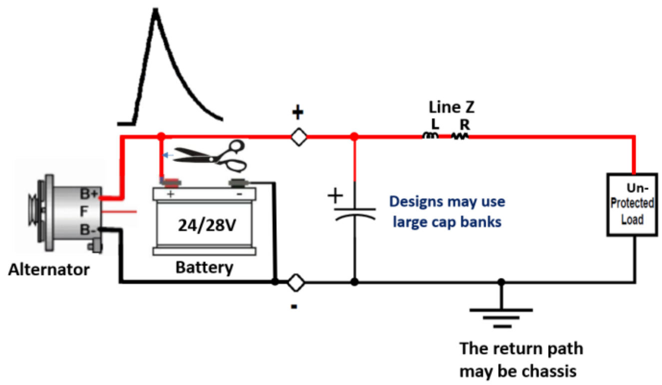
Depending on **Specifications and Applications**, the times of concern can be defined differently.

Causes of Transients

Vehicle power system transients come from a variety of sources. One major factor is that vehicle alternators have winding inductances that store energy that needs to be released when a load current is suddenly removed.

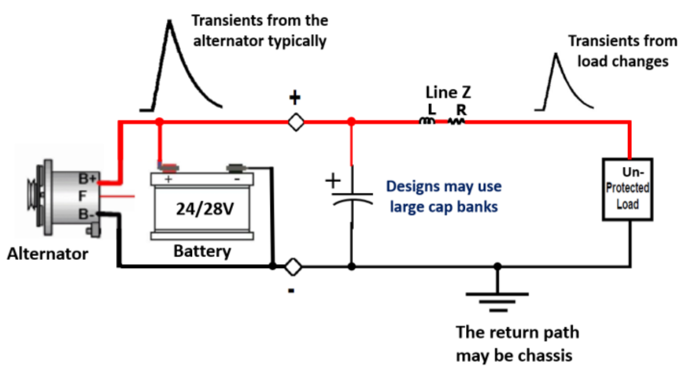
Load Dump – a sudden drop in load current which causes inductive transients in wiring and the alternator. This commonly occurs when high power loads, like motors, are switched off. e.g. in MILI-STD-1275 environments- blowing horns, operate pumps, rotating turrets, starting/stopping the engine.

An extreme case of "load dumping" is while charging a drained battery- a drained battery being charged and the battery cable opens or becomes intermittent (at high current levels). This is a "worst case" inductive kick as the battery does not help absorb the transient – which must be handled by the load.



Another example of "load dumping" include alternators being less than perfect – prolonged over voltages are seen especially with newer, higher power alternators.

Jump starts and other connections to vehicles with low quality power systems. e.g., Nato Slave connections, also are prime examples.



Transient Voltage Suppression Devices
A Transient Voltage Suppression device, a TVS, protects a system from damage when exposed to a short interval of higher energy.

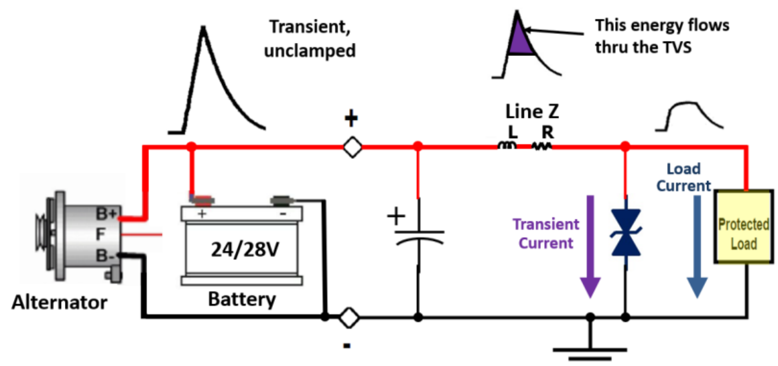
There are different forms of TVS technologies. We will be focusing on the TVS Diode approach where the dangerous transient energy is absorbed in the diodes.

Sensitron TVS diodes are avalanche diodes or assemblies of avalanche diodes called "Transorbs". (Our SuperClamp parts are enhanced with active clamp circuitry.)

Avalanche diodes, like zener diodes, will "breakdown" at a certain voltage set by how they are made. The diodes will try to maintain that voltage no matter how much current flows thru it. This action allows the diodes to protect other devices from transients, as long there is not too much energy to absorb.

Basic Mililary Vehicle System – Added TVS

- Load Current Does NOT Flow Thru the TVS
- With TVS diodes, the load is not interrupted by the transient event.



TVS Protection Approach
The optimal protection approach depends on:

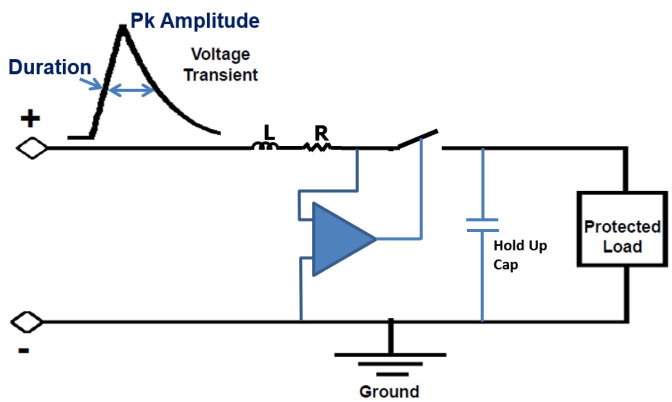
- How much transient current and energy must be dealt with
- What the nominal operating voltage is
- How low the clamping voltage needs to be in order to save the equipment or to meet specifications
- Repetition rate of transients
- How much capacitance can be tolerated on the protected line is not usually a concern for a 28V vehicle bus application
- System requirements. e.g., how important is it to avoid resetting a system due to a disturbance? In some instances it could take minutes to reboot.

Other Transient Suppression Methods

Series Protection with a switch:
Open switch when input overvoltage detected, close switch when voltage returns to safe level

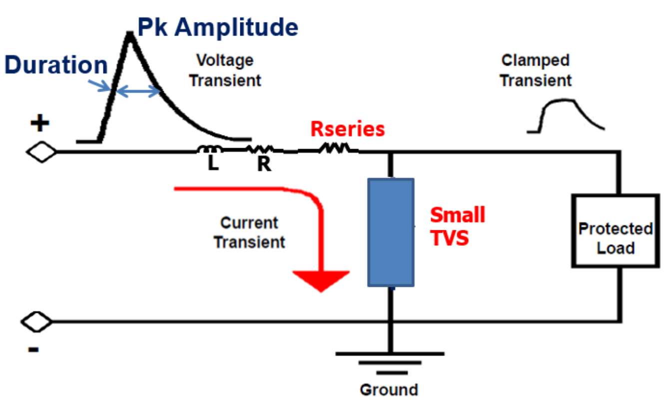
Hold up cap must store enough energy to power circuit thru the open-switch duration.

- Switch resistance causes power loss during on-time, **not good for high current systems**.
- Requires quick response for fast spikes but eliminate nuisance tripping on noise.
- Customer has to engineer his own "glitch free" circuit and locate it on the power bus.
- Typically not suited for High Power



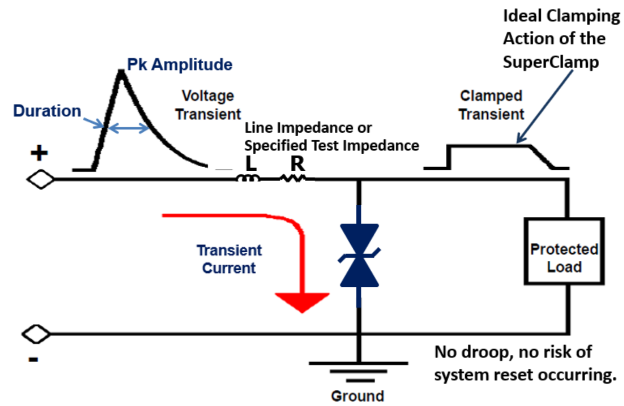
Shunt Protection for Low Power Circuits

- For lower power circuits, a series resistor can be placed in the power path without causing too much loss, which is not good for high current systems.
- Because power is limited - smaller, lower cost devices like MOVs, small TVS diodes, etc., can be used for the Shunt TVS Device.



Shunt Protection By TVS Diode

- A large TVS diode assembly can protect the whole power system, rather than having protection on each circuit.
- The TVS must be sized for the expected transients.
- The transients expected in Military Ground vehicles is typically defined by Mil-STD-1275



Sizing the TVS

Many semiconductors have an absolute voltage or current rating. In a similar vein, a TVS device will often have a peak pulse power or peak pulse current. To a certain extent so do TVS devices. The "peak power" rating is often part of a data sheet. But the peak power or duration of a transient event doesn't determine how much stress a TVS will see. MIL-STD-1275 defines transients as Spike or Surges.

For sustained transients, or surges, as specified via MIL-STD-1275, the main concern is the combination of power (V-A) and duration (t). This is typically in Joules and the accumulation of heat, and its dissipation are used to determine the size and ratings required of a TVS.

- Spikes are defined as transients lasting less than 1mS
- Surges are defined as lasting more than 1mS.

Energy is a good measure of the effect of a system transient and should be used for evaluating the capability of a TVS. Spikes can have much higher instantaneous peak power, but surges contain much more energy.

Spikes

The limit for a spike is analogous to the instantaneous power or peak power. It represents the peak power (V-A) handling capability of the die and its attachment so there is no cracking, wire bond failures, or no hot spots. An individual spike generally has an interval lasting less than 50 microseconds (μs) but may take up to one millisecond (ms) to decay to the steady-state level. Spikes can have much higher instantaneous peak power, but surges contain much more energy.

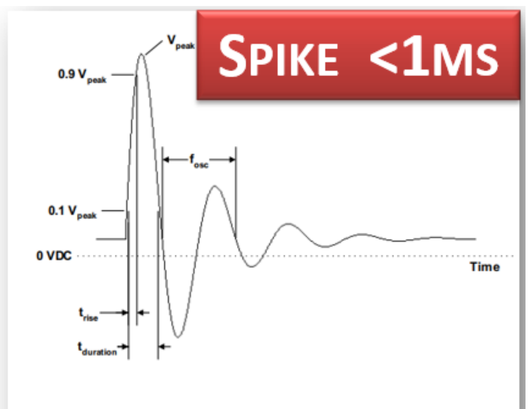


Figure 3. Voltage spike.

Surges

Surges typically have significantly higher energy level; (V-A-t). In this sustained overload for a longer period of time, it is not merely the "mass" of the die abut also concerns about Power Dissipation over time, especially for repetitive energy pulses being shunted from the load and absorbed by the TVS.

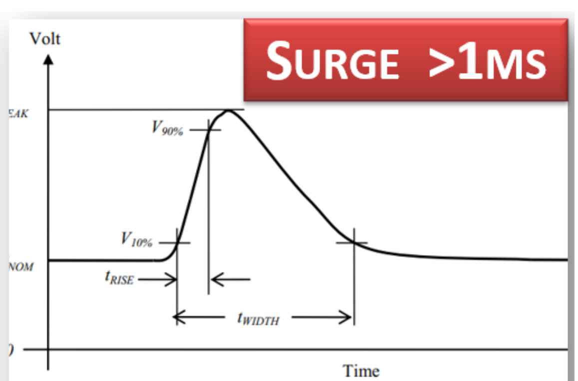


Figure 4. Sample alternator load dump waveform.

The accumulation of energy (HEAT) determines the transorb size. Devices protecting from Surges are necessarily larger than those providing protection from spikes. The limit for a surge is the thermal mass of the die/dice, the thermal impedance to the immediate nearby packaging, and package thermal capacity. As a general rule of thumb for discrete power devices:

- 1 millisec for heat to get out of the die
- 1 sec for heat to get out of the package

MIL-STD-1275 Considerations

Spikes

- MIL-STD-1275 requires systems to withstand the application of spikes having an amplitude of 250V in both positive and negative polarities, and with a specified maximum energy and repetition rate. As depicted in the following figure.

MIL-STD-1275E

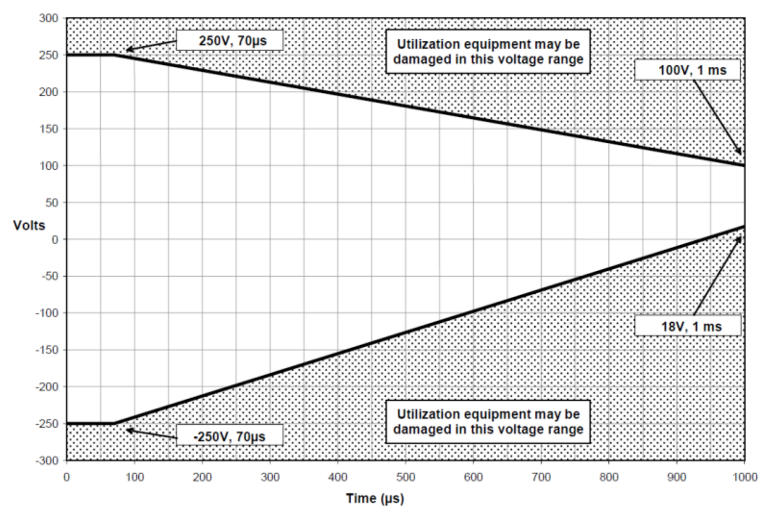


Figure 7. Envelope of spikes for 28VDC systems.

- A voltage spike is an energy-limited transient waveform having a duration less than or equal to 1 ms. These typically result from the interaction of the power delivery system wiring and switching of reactive loads or a mismatch in impedance between the wiring harness and equipment.

- The MIL-STD-1275 spikes are to be applied in both positive and negative voltage spikes shall be applied to the EUT. A minimum of fifty (50) 250V spikes of each polarity shall be applied at one (1) second intervals. Each test spike shall have a peak amplitude of 250V, a risetime not exceeding 50 ns, a frequency of oscillation greater than 100 kHz and less than 500 kHz, and a maximum energy content of 2 Joules (refer to the representative waveform above).

NOTE:

- The limited energy (shorter duration) allows transorb devices sized for surges to easily absorb these spikes and protect the system taking two things into consideration:
- A low inductance connection between the TVS device and the device being protected.
- Wiring inductance can isolate the fast edges of the spikes from the TVS.

(See section Details of Application, "Location and Wiring Recommendations" for more information.)

SURGE

A surge is a transient waveform having a duration greater than 1 ms and a specific wave shape, typically a rising/falling edge and a slow exponential decay for the falling edge. Surges result from the switching of reactive loads containing a significant level of stored energy or sudden disconnection of a constant load. Surges may also occur due to the application of high-demand loads.

MIL-STD-1275 surges are to be applied to the EUT. A 100V surges shall be applied five (5) times. Each surge shall have a peak amplitude of 100V, a risetime of 1-10 mS, a duration or 50mS and a maximum energy content of 60 Joules. The current shall be defined by a source impedance of 500mΩ (see the representative waveform above).

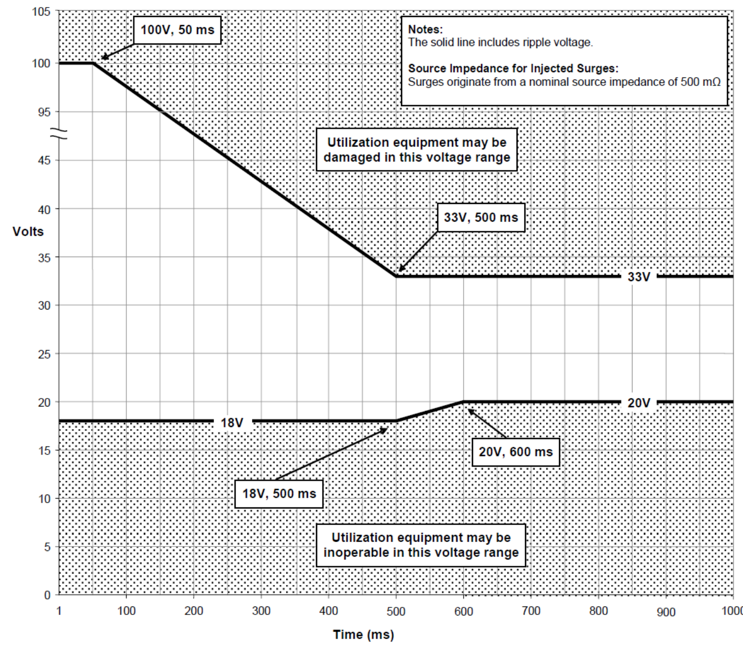


Figure 8. Envelope of surges for 28VDC systems.

- Consider that a bipolar TVS device will clamp spikes at the same voltage for either polarity. This is usually not acceptable as most systems have much less tolerance for negative transients than positive ones. The tolerance may be as small as 1V negative.
- A unidirectional device can clamp negative spikes to a forward diode drop. However, then TVS must also be protected from the application of reverse input voltage.

(See the section on 1275E spikes and the coming change in 1275 summary section.)

Selecting Transient Protection for Vehicles

- Pull together pertinent specs, functional and environmental requirements:
  - Standards for vehicle transients and transient testing
    - MIL-STD-1275
    - DEF STAN 65-1 Part 6, Issue 6, DET08.B (Load Dump)
    - ISO 16750-2 Pulse 5 (Load Dump)
  - Protecting to meet susceptibility requirements of injected surges, or to meet requirements for emitted surges? Emitted surges from regenerative braking

on motor driven equipment may require mitigation.
  - Confirm specs for bus voltage, transient voltage/current peaks, duration, line/source impedance, temperature range, polarity
  - NOTE: some applications have transient surges exceeding the MIL-STD-1275 surge envelope boundaries.
  - Further considerations:
  - Clamping voltage required at specified peak current? This will drive if a TVS or a SuperClamp are required.
  - Standoff (working voltage) required? Steady state voltage can drive the part selection, too.
  - Bidirectional or unidirectional TVS characteristic?
  - Unidirectional TVS with or without reverse polarity protection?
  - Size constraints?
  - Leakage concerns?
  - Connections: e.g., threaded studs, threaded holes
- Need an enclosure for environmental concerns, or for multiple TVS?
- If your transient requirement is below or close to a rated waveform in one of our datasheets, then you are almost done. If not, continue.
- Make a ballpark estimate of feasibility, suitability with transient energy vs. TVS device energy in rated waveforms.
- This approach is valid for durations in the MIL-1275 surge range – surges of 50ms up to a little over 100ms. The reasons behind the constraints are explained a few slides later.
- Determine estimated transient current and clamp voltage.
- Extrapolate from specified Vclamp vs. I points to estimate a Vclamp.
- Calculate Ipeak using the line impedance, and the input transient voltage minus Vclamp.
- Check if the Ipeak makes sense for Vclamp proposed of the proposed TVS and reiterate, if necessary, until a reasonable result is obtained.
- Then calculate the transient energy in Joules:
- Vclamp*Ipeak*duration =Energy. This yields energy in Joules if using volts, amps, & sec.
- Compare the transient energy to the energy rating calculated for parts' rated waveforms for initial choices. See Table 1 for the ratings for parts available today.
- Use the smallest part that meets or exceeds the requirement.
- If the transient waveform does not correlate with a data sheet waveform rating, or an energy rating in Table 1, contact Sensitron to discuss your requirements and the available options.
- If no existing options are exactly what you need, it may be possible to modify existing parts to obtain the exact part needed. Both electrical parameter changes and package dimension modifications can be discussed to determine feasibility.
- See "Notes on Paralleling" slide.

TABLE 1: Nominal Single Surge Energy Ratings

- For Sensitron MIL-STD-1275 targeted parts.
- *There are constraints on the duration time even if the resulting amount of energy is the same.* The parts are intended for the MIL-1275 type transients.
- *The active clamp parts (-4 and -9) are constrained by the peak current/peak power rating of the active devices.* Contact Sensitron if a shorter pulse with a higher peak current is required.
- The other devices being only TVS diodes, have a greater tolerance for high peak current, shorter duration waveforms. Again contact Sensitron with your requirements.
- Also contact Sensitron for comments on longer single pulse transients, and repetitive transients beyond the MIL spec.

Type	Joule Data sheet single pulse
SCP-5282-1	392
SCP-5282-1U	392
SCP-5282-2	637
SCP-5282-3	860
SCP-5282-4	565
SCP-5282-5	516
SCP-5282-5A	504
SCP-5282-6	250
SCP-5282-9	505
SCP-5282-36	470

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NOTE: Based on data sheet rated single pulse peak power and duration.

5282 SuperClamp

The new SuperClamp parts are the SCP-5282-4, -9 and SECPx-5282-x. They include added circuits providing superior performance. The added performance comes with added cost.

The TVS Clamp parts are the SCP-5282-1,-2,-3,-5,-6. They are TVS assemblies which we have been making and selling for years.

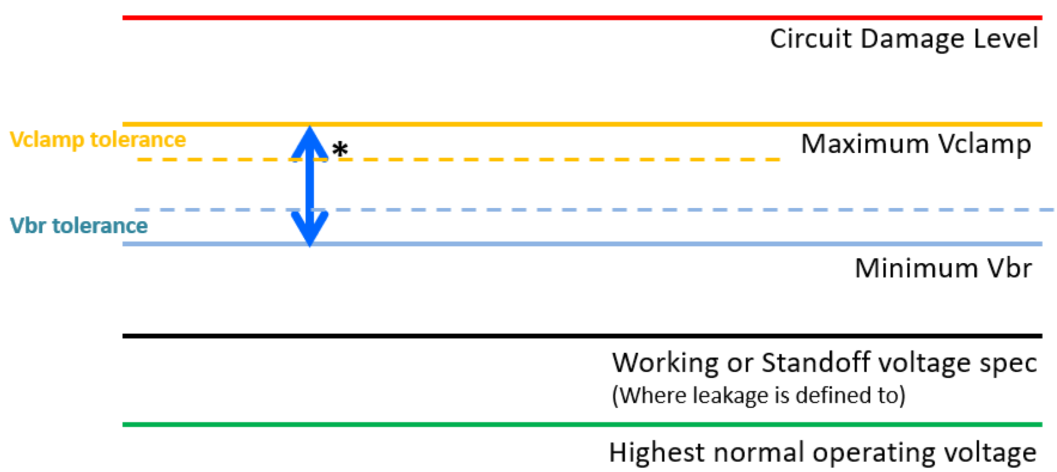
TVS Clamp
SCP-5282 – 1, 1U, 2, 3, 5, 5A, 6

- Clamping below 49V (for all but the -6) at currents up 135A
- The smaller -6 clamps below 77V at 54A
- Rugged and widely used

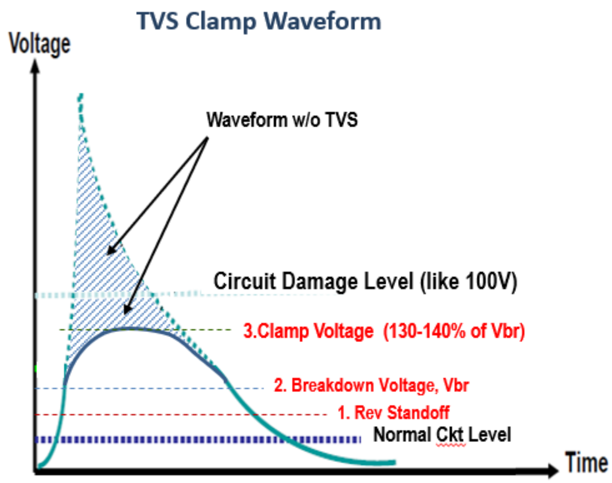
SuperClamp
SCP-582-4, SCP-5282-9

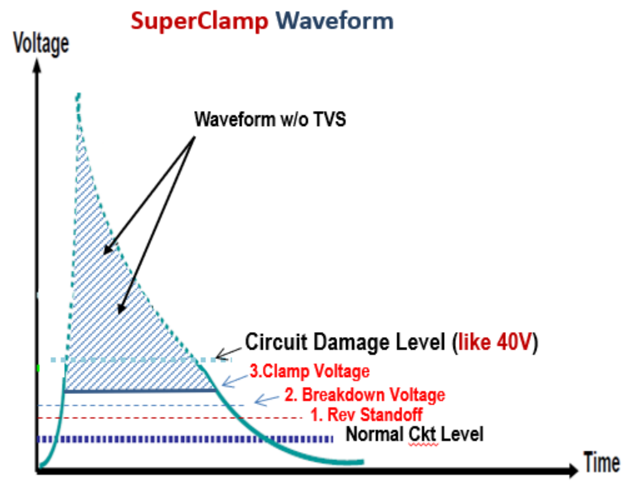
- Temperature Independent Clamping
- Precision Clamping Level
- Clamping under 35V or 38V at 120A
- Safe Paralleling up to 6 units for higher power, lower clamping

SuperClamp vs. TVS Clamp

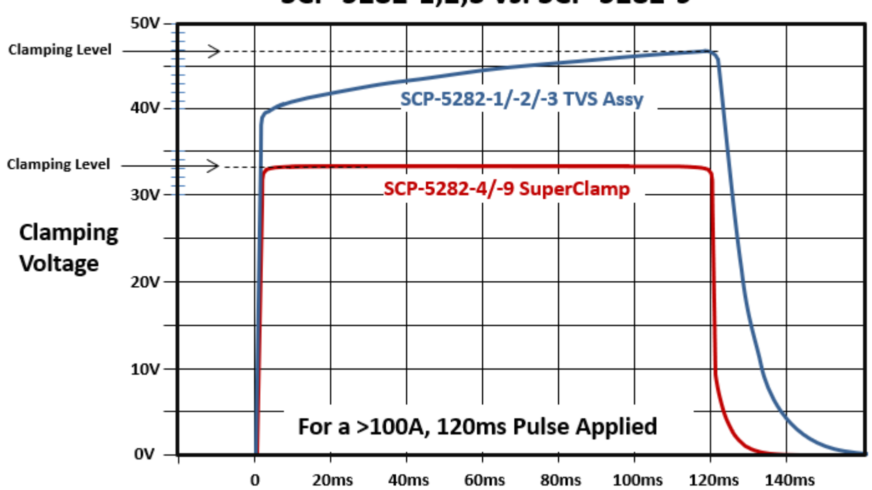


***The physics of the avalanche diodes dictate that Vclamp will be ≥130% of Vbr for a DIODE ONLY solution.**





Typical Clamping Voltage Performance for:
SCP-5282-1,2,3 vs. SCP-5282-9



Note the differences:

- Flatter clamping – temperature independent
- Lower clamping level – don't need big margins between breakdown and clamping levels

Performance is not dependent on the inherent avalanche diode characteristics. Some side by side examples.

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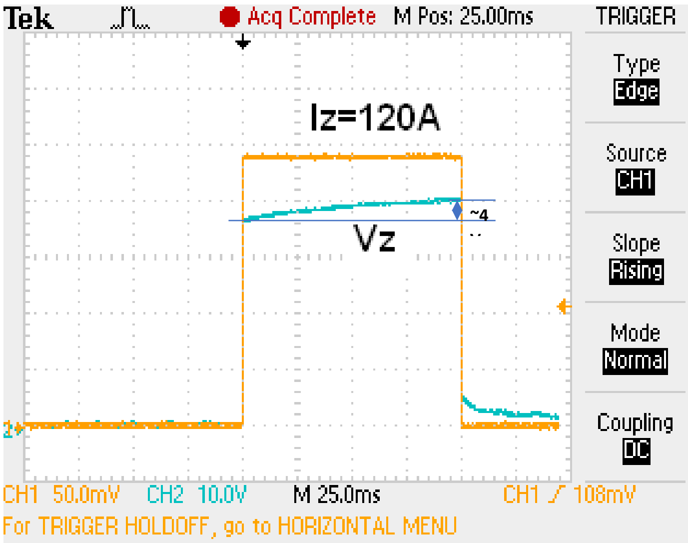
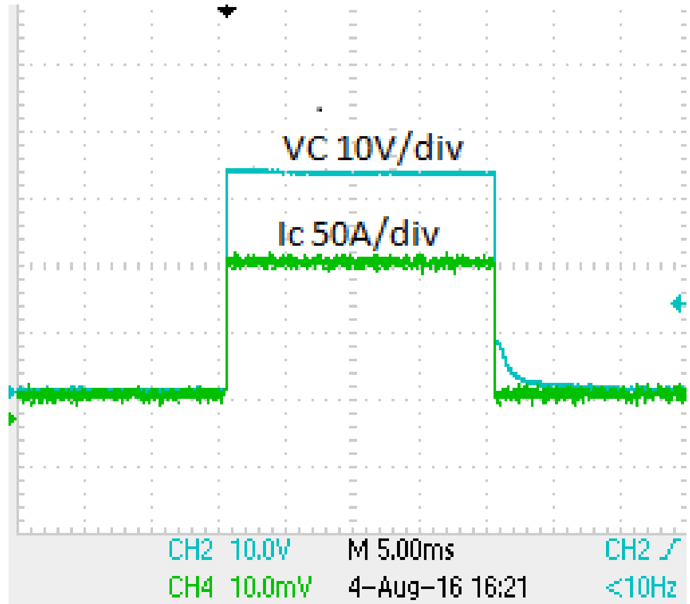


Clamping Current and Voltage Waveforms, Vz max=40.7V, for SCP-5282-5A, our best TVS Clamp
Note the slight upper trend on the clamping voltage based on diode heating.



Clamping Current & Voltage Waveforms at Ic=100A for the SCP-5282-9/ Note the independence of the clamping level to the duration and heating of the TVS.

The SuperClamp significantly reduces the Vbr to Vclamp gap – allowing protection for lower circuit damage levels.

Overview of Sensitron TVS Products

5282 TVS Clamp Family For Vehicles

Part Number	Config	Peak Pwr 1ms	Vwm, Max	Leakage Max	Diode Vbr, Min	Ippm	Vclamp @Ippm	100% Test
SAE-5282-12	Uni	4kW/ 400ms	18V	250 uA	25.1V	142A	32V	J1113-11, 142A/ 400ms
SCP-5282-1	Bi	60kW	33V	25 uA	36.7V	100A	49V	100A/80ms square
SCP-5282-1U	Uni	60kW	33V	25 uA	36.7V	100A	49V	100A/80ms square
SCP-5282-2	Bi	60kW	33V	25 uA	36.7V	100A	49V	5x 100A, 50ms sq
SCP-5282-3	Bi	100kW	33V	40 uA	36.7V	135A	49V	5x 110A, 50ms sq
SCP-5282-5	Uni	50kW	33V	250 uA	36.7V	120A	43V	120A/100ms
SCP-5282-5A	Uni	50kW	33V	250 uA	36.7V	120A	42V	50/500us
SCP-5282-6A	Bi	4kW	52V	30uA	60V	54A	77V	1275 Waveform
SCP-5282-6B	Bi	4kW	52V	30uA	60V	54A	77V	50/500us

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5282 SuperClamp TVS For Vehicles

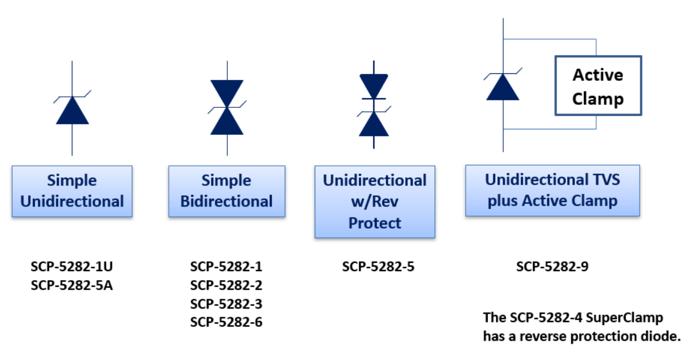
Part Number	Config	Peak Pwr 1ms	Vwm, Max	Leakage Max	Diode Vbr, Min	Ippm	Vclamp @Ippm	100% Test
SCP-5282-4	Uni	10kW	33V	20mA	33.8V	120A	37.7V	120A/100ms
SCP-5282-9	Uni	10kW	30V	20mA	30.2	120A	33.5V	120A/100ms
SCP-5282-36	Uni	10kW	34V	12mA	36.45V	100A	39.00V	100/50ms
SECP3-5282-4	IP67 Enclosure	300A	33mA	50mA		300A	37.20V	
SECP3-5282-9	IP67 Enclosure	300A	30mA	50mA		300A	33.20V	

Notes:
1. The -4 device is used where the steady state power bus has to go up to 33V (per Mil-1275)
2. The -9 device provides the lowest clamping. This device can keep the bus in spec (1275) compliance even there are severe regenerative surges dumped on the power bus.
3. Both types have been tested in customer vehicle applications and resolved the issues.

LSP Solutions for DO-160 Sect 22, Levels 4 & 5

Type	Config	Peak Pwr 50u/500us	Vrwm, Min	Leakage Max @Vrwm	Vbr, Min	Ippm	Vclamp @Ippm, max	100% Tested to DO-160 Reqt
LSP28x-750-39U	Uni	37kW	33V	30 uA	39V	750A	51V	Level 4, Waveform 5B
LSP28x-750-39	Bi	37kW	33V	30 uA	39V	750A	51V	Level 4, Waveform 5B
LSP28x-750-80	Bi	72kW	66V	60uA	78V	750A	102V	Level 4, Waveform 5B
LSP28x-1600-41	Bi	100kW	36V	30 uA	41V	1600A	60V	Level 5, Waveform 5B
LSP28x-1600-82	Bi	200kW	72V	30 uA	82V	1600A	120V	Level 5, Waveform 5B
LSP52x-1100-60	Bi	100kW	52V	30uA	60V	1100A	90V	1100A, Waveform5B
LSP52x-1600-60	Bi	137kW	52V	30 uA	60V	1600A	90V	Level 5, Waveform 5B
LSP28C-20K-37	Bi	1.3MW at 6.5us	33V	30 uA	36.7V	20kA	65V/60V	Level 5, Waveform 5B

Basic transorb configurations. The section on selection discusses options for reverse input protection.



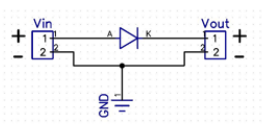
TVS devices cannot be used to protect the power bus from reverse dc input polarity.

- A bidirectional TVS will withstand the reverse bus voltage application just fine as it does normal bus voltage, remaining in high Z leakage mode.
- A simple unidirectional TVS diode will conduct forward current when reverse voltage is applied. There is very little to limit the reverse current flowing so the TVS diode will be destroyed by overcurrent.

A unidirectional TVS device can be protected from reverse input polarity by adding a rectifier in series – cathode to cathode. Shown in the figure on the previous slide.

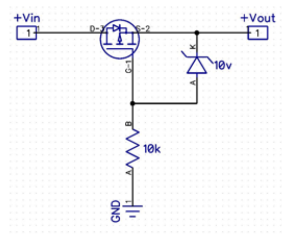
- The diode can be added in the same package with the appropriate ratings, so the user does not have to add an additional device to his circuit. Protected unidirectional TVS are available from Sensitron.
- Note: unidirectional TVS diode with reverse protection also does NOT provide any reverse protection for the power bus.
- The following slide shows some common schemes for protecting the power bus from the application reverse input voltage.

Diode Reverse Protection



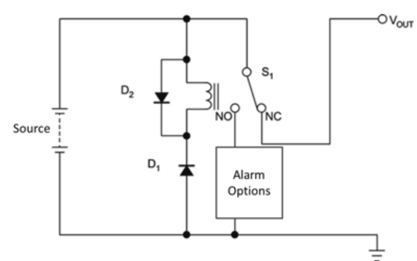
Too much loss for anything but very low power circuits

Pch FET Reverse Protection, (or Nch with driver)



Ok for moderate power, too much loss for high current apps

Relay for Reverse Protection

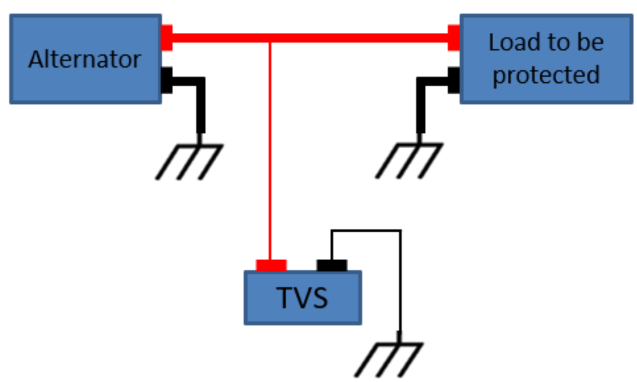


Lowest losses for high current apps like a vehicle power bus.

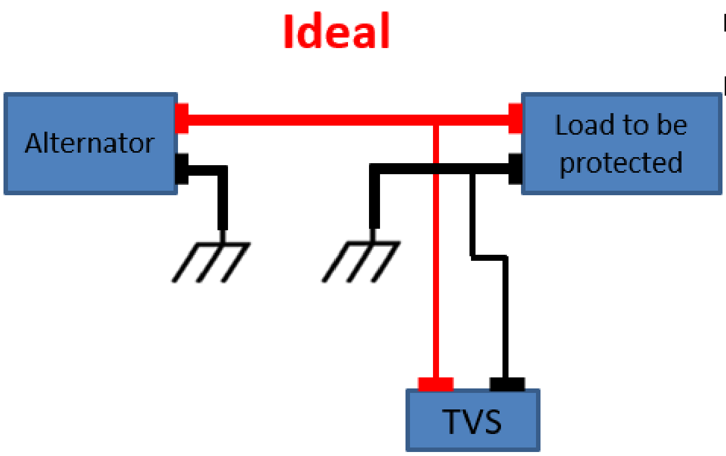
TVS Location, Mounting & Positioning Considerations

- It is better to have a low resistance and low inductance between the TVS and the loads being protected. When loads are distributed throughout the vehicle and more than one is sensitive, it may be best to use TVS in multiple locations.
- High inductance and impedance between the TVS and load will prevent the user from obtaining the full protection afforded by the TVS, especially if the TVS is not between the source and the protected load. Important for spike protection.
- See diagrams on the following slide to illustrate.
- For surge protection, normally the most concerning issue, one properly sized TVS can usually protect the whole system powered by the 24V/28V bus.

Not Ideal



- TVS not connected near the load
- TVS connected by long wire and long return path.
- OK for surge protection unless really bad



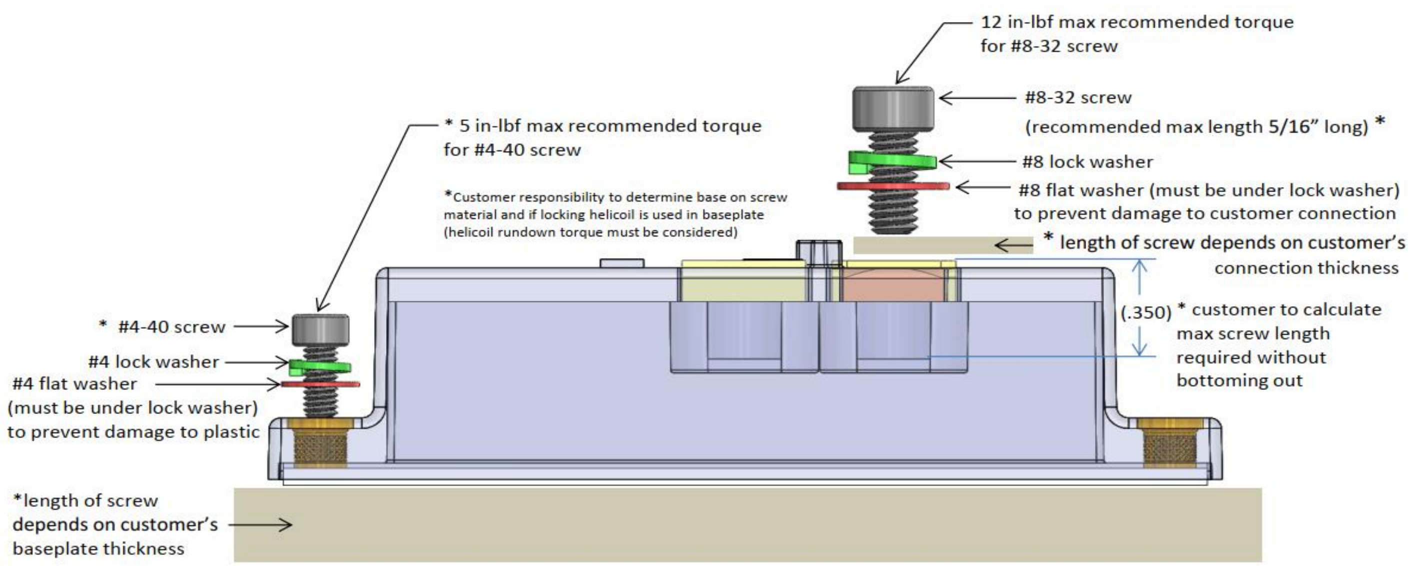
- TVS is connected near the load on bus and return
- TVS connected with lowest possible impedance.
- Best for spike and surge protection

Mounting &Torque for SCP-5282-1, -1U, -2, -3

Mechanical Attachment

- 2 additional #8-32 nuts are required in order to secure the connection (not provided). The nuts coming on the device are part of a fixed base for the connections.
- Nuts shall be hand-tightened prior to the maximum 12 in-lb torque being applied.
- Do NOT use lock nuts – they cut and shear copper studs
- Split ring lock washers are OK.
- Non-corrosive thread-locker can be used.
- Caution: high-speed torque drivers may cause thread damage on SCP-5282-x copper screw terminals

Mounting & Torque for SCP-5282-4, -5, -5A, -9



Mounting for All Chassis Mounted Types

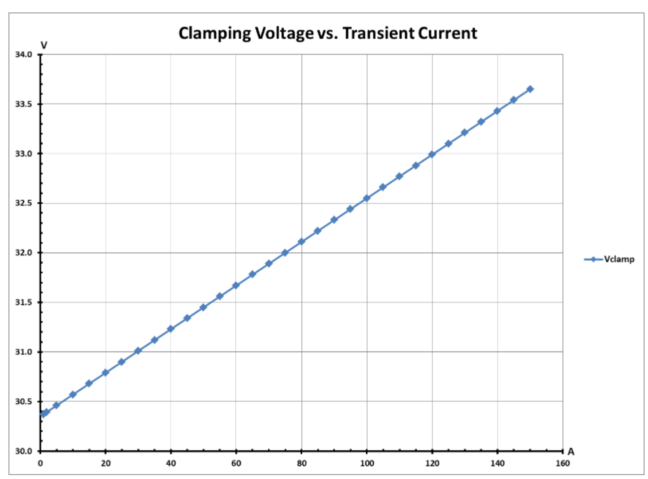
- It is critical to have the heat sink very flat in order to minimize the thermal grease thickness.
- We recommend using thermal compound part number AA-30G from Arctic Silver. This is a very stable material. http://www.arcticsilver.com/arctic_alumina.htm
- Thermal pads result in much higher thermal resistance.

Notes On Paralleling TVS Devices

Paralleling of TVS devices is NOT recommended generally.

- The small positive temperature coefficient in avalanche diode voltage is not significant compared to unbalances caused by tolerance of Vbr and Vclamp, and unbalance caused by differences in the circuit path impedances.
- One part will take too much current and fail. This leaves too much current for the other devices and then they all fail.
- Mismatches are amplified in heating of devices when very long or repetitive pulses are applied. A user discovers the problem when a unit fails.
- The Sensitron SCP-5282-x devices handle most of the MIL-STD-1275 surges using a single unit. This eliminates all the concerns and efforts needed when a user must paralled devices. These efforts include:
- Matching devices or buying matched sets of devices.
- Balancing all impedances of connections and wiring.
- Heavily derating single device capability to ensure safety. The more mismatch the more derating is needed. This means using more devices increasing required space and weight.
- The parallel solution is not guaranteed until tested in the actual configuration.
- The Sensitron SCP-5282-x devices are 100% tested to the MIL-1275 requirements providing a risk-free solution for surges within the data sheet ratings.
- For surge requirements higher than the single device ratings of the Sensitron devices, the SuperClamp can be helpful.
- The diagram on the next slide shows the positive slope of the SuperClamp's clamping voltage vs. the current flowing thru the device.
- This provides some adjustment range for compensating unbalances in wiring and location but there are limits, especially when being pushed hard.
- **We recommend that units be co-located and tied together with bus bar connections. Co-location includes being mounted on the same heat sink.**
- The SuperClamp incorporates a slight positive voltage coefficient vs. current which helps compensate for imbalances when paralleling units.

SCP-5282-9 Characteristic



	@ 120A		32.40	33.00	33.50	
Peak Pulse Current (single 100-msec square pulse)	-	I_{PP}			120	Amps
Typical Vclamp vs. Current	@ 0 to150A		30.35 +0.0221*I_{clamp}			V
Operating & Storage Temp.	-	Top& Tstg	-55		+ 150	°C

Application Note AP5179, Rev B

The SECP3 enclosure is available with up to three parallel SuperClamps for the most robust solution for demanding reqts. This provides the best matching of connections and cooling for the devices inside.

- 100A, 500msec at 5sec rep rate
- Handles 300A, 100millisec single square pulse, clamping at 33.2V max
- -55C to 150C Op & Storage
- 4.3 lb nominal weight
- 3/8"-16 threaded studs for power cable connection
- Aluminum IP-67 Enclosure with pressure equalizing vent

About Sensitron

Sensitron has over 50 years of heritage as a leading manufacturer of high reliability power electronic component solutions for the Defense, Aerospace, Space, and Medical markets. Our products provide rugged, light-weight, and cost effective solutions for switching power supplies, AC-DC rectification, primary & secondary power distribution, motion control, transient voltage spike protection, and custom applications. Sensitron is certified to MIL-PRF-38534, Class K, for Hybrid Microelectronics, MIL-PRF-19500 for JANTX, JANTXV and JANS discrete diodes, and registered to AS9100.