# Transient Voltage Suppressors (TVS) for Automotive Electronic Protection

*By Soo Man (Sweetman) Kim,*
*Senior Application Manager*

Vishay's Diodes Division offers leading automotive electronic TVS protection products under the renowned Vishay General Semiconductor brand.

## I) IMPORTANT PARAMETERS OF TVS

Important TVS parameters include the power rating, the stand-off voltage, the breakdown voltage, and the maximum breakdown voltage

**Power rating**

The power rating of a TVS is its surge-absorbing capability under specific test or application conditions. Vishay's TVS products use the industrial-standard test condition of 10 µs/1000 µs pulse form (Bellcore 1089 spec.), as shown in Figure 1. This test condition differs from the TVS ESD test condition of 8 µs/20 µs pulse form, as shown in Figure 2.

The breakdown voltage, maximum breakdown voltage, and stand-off voltage are specified in the datasheet, as shown in Table 1.

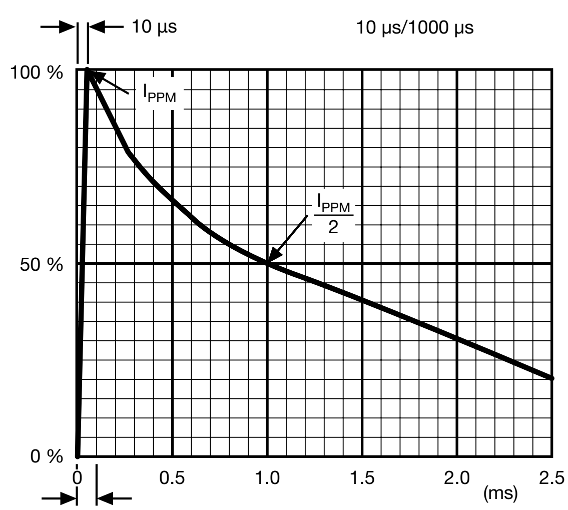


Figure 1. Test Waveform of TVS

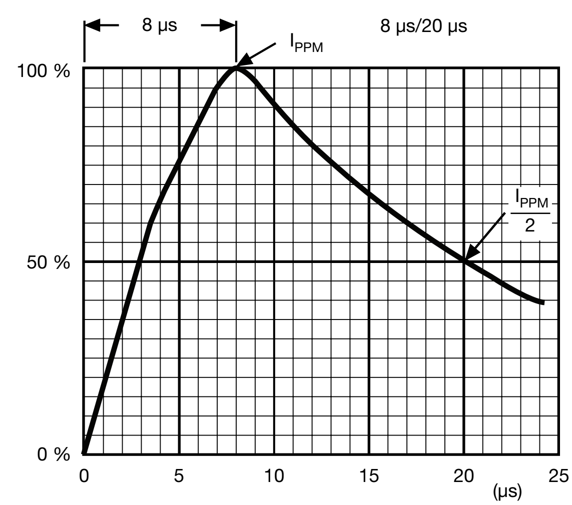


Figure 2. Test Waveform of TVS ESD

# Transient Voltage Suppressors (TVS) for Automotive Electronic Protection

**TABLE 1 - ELECTRICAL CHARACTERISTICS OF VISHAY'S SM6T SERIES**
(Ratings at 25 °C ambient temperature unless otherwise specified)

| TYPE | DEVICE MARKING CODE | | BREAKDOWN VOLTAGE $V_{BR}$ AT $I_T$ $I_T$ (V) | | TEST CURRENT (mA) | STAND-OFF VOLTAGE $V_{RM}$ (V) | LEAKAGE CURRENT $I_{RM}$ AT $V_{RM}$ (µA) | CLAMPING VOLTAGE $V_C$ AT $I_{PP}$ 10 µs/1000 µs | | CLAMPING VOLTAGE $V_C$ AT $I_{PP}$ 8 µs/20 µs | | $T_{MAX.}$ $0^{-4}$/°C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Uni | Bi | Min. | Max. | | | | (V) | (A) | (V) | (A) | |
| SM6T6V8A | KE7 | KE7 | 6.45 | 7.14 | 10 | 5.80 | 1000 | 10.5 | 57.0 | 13.4 | 298 | 5.7 |
| SM6T7V5A | KK7 | AK7 | 7.13 | 7.88 | 10 | 6.40 | 500 | 11.3 | 53.0 | 14.5 | 276 | 6.1 |
| SM6T10A | KT7 | AT7 | 9.50 | 10.5 | 1.0 | 8.55 | 10.0 | 14.5 | 41.0 | 18.6 | 215 | 7.3 |
| SM6T12A | KX7 | AX7 | 11.4 | 12.6 | 1.0 | 10.2 | 5.0 | 16.7 | 36.0 | 21.7 | 184 | 7.8 |
| SM6T15A | LG7 | LG7 | 14.3 | 15.8 | 1.0 | 12.8 | 1.0 | 21.2 | 28.0 | 27.2 | 147 | 8.4 |

**Breakdown Voltage ($V_{BR}$)**

The breakdown voltage is the voltage at which the device goes into avalanche breakdown, and is measured at a specified current on the datasheet. In Table 1, the SM6T6V8A has a 6.8 V breakdown characteristic with a 5 % tolerance at a 10 mA reverse current condition, and the SM6T10A has a 10 V breakdown characteristic at a 1 mA reverse current.

**Maximum Breakdown Voltage ($V_C$: Clamping Voltage)**

The clamping voltage appears across the TVS at the specified peak pulse current rating. The breakdown voltage of a TVS is measured at a very low current, such as 1 mA or 10 mA, which is different from the actual avalanche voltage in application conditions. Thus, semiconductor manufactures specify the typical or maximum breakdown voltage in large current. Table 1 shows the maximum clamping voltages in the 10 µs/1000 µs and 8 µs/20 µs waveforms.

**Stand-off voltage ($V_{WM}$): Working Stand-off reverse voltage**

The stand-off voltage indicates the maximum voltage of the TVS when not in breakdown, and is an important parameter of protection devices in circuits that do not operate under normal conditions.

In automotive applications, some regulation of the automotive electronics is provided by "jump-start protection". This condition supplies 24 $V_{DC}$ in 10 min to 12 V type electronics, and 36 $V_{DC}$ in 10 min to 24 V type electronics without damage or malfunction of the circuit. Thus, the stand-off voltage is one of key parameters in TVS for automotive electronics.

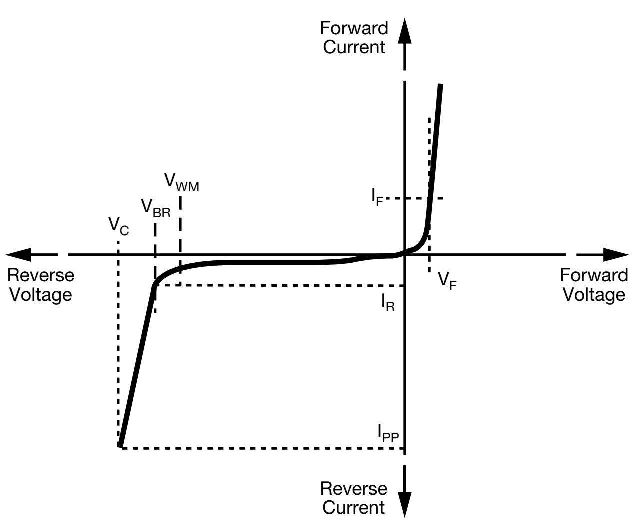


Figure 3. Parameters of voltage and current

# Transient Voltage Suppressors (TVS) for Automotive Electronic Protection

## II) PRIMARY PROTECTION OF THE AUTOMOTIVE POWER LINE (LOAD DUMP)

Automotive electronics, such as electronic control units, sensors, and entertainment systems, are connected to one power line. The power sources for these electronics are the battery and alternator, both of which have unstable output voltages that are subject to temperature, operating status, and other conditions.

Additionally, ESD, spike noise, and several kinds of transient and surge voltages are introduced into the power and signal line from automotive systems that use solenoid loads, such as fuel injection, valve, motor, electrical, and hydrolytic controllers.

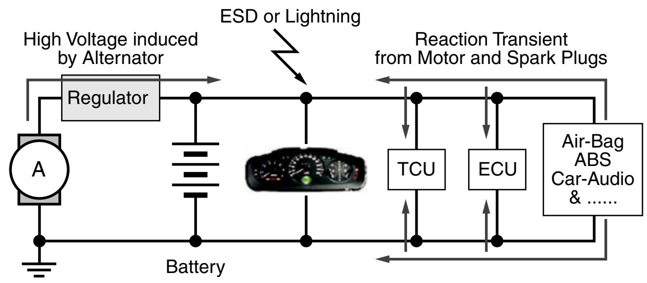


Figure 4. Typical Vehicle Power Bus

### What is Load Dump?

The worst instances of surge voltage are generated when the battery is disconnected when the engine is in operation, and the alternator is supplying current to the power line of the vehicle. This condition is known as “load dump”, and most vehicle manufactures and industry associations specify a maximum voltage, line impedance, and time duration for this load dump status, as shown in figure 5. Two well-known tests simulate this condition: the U.S.’s ISO-7637-2 Pulse 5, and Japan’s JASO A-1 for 14 V powertrains and JASO D-1 for 27 V powertrains. In this section we review the application of TVS for load dump in 14 V powertrains.

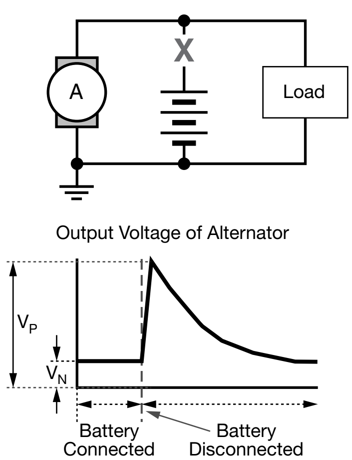


Figure 5. Output Voltage of Alternator in Load Dump Condition

As shown in Figure 6, Vishay’s high-power, silicon TRANSZORB® TVS is used to protect vulnerable electronic circuits from electrical overstress and to ensure high reliability. For primary protection, the TVS should absorb high energy under the load dump condition.

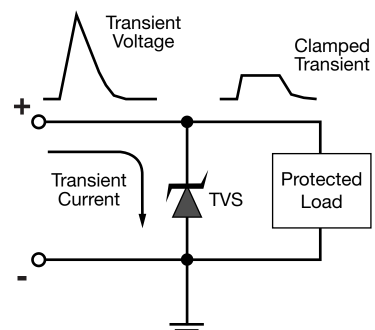


Figure 6. Typical Protection Circuit

DO-218AB




For technical questions within your region, please contact one of the following:
DiodesAmericas@vishay.com, DiodesAsia@vishay.com, DiodesEurope@vishay.com

# Transient Voltage Suppressors (TVS) for Automotive Electronic Protection

## SPECIFICATION AND RESULTS OF LOAD DUMP TESTS

The U.S.'s ISO-7637-2 Pulse 5, and Japan's JASO A-1 test for 14 V powertrains, are simulated in Table 2. The voltage waveforms of both test conditions are shown in Figure 7.

**TABLE 2 - MAJOR LOAD DUMP TEST CONDITIONS FOR 14 V POWERTRAINS**

| | V TOTAL ($V_P$) (V) | $V_S$ (V) | $V_A$ (V) | $R_I$ (Ω) | TIME (ms) | CYCLE TIME |
|---|---|---|---|---|---|---|
| JASO A-1 | 70 | | 12.0 | 0.8 | 200 | 1 |
| | 88 | | 12.0 | 1.0 | 200 | 1 |
| ISO 7637-2 Pulse 5 | 78.5 to 100.5 | 65 to 87 | 13.5 | 0.5 to 4.0 | 400 | 1 |

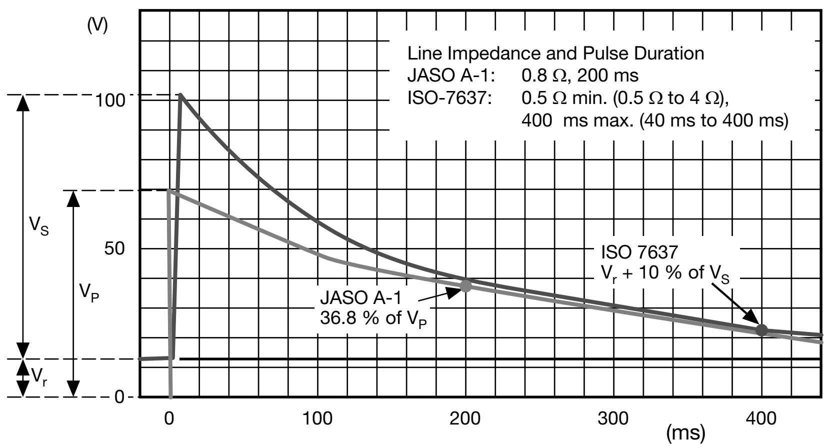


Figure 7. For ISO-7637-2 Test Conditions, the Standard Condition is a $V_S$ Range of 65 V to 87 V, and $R_i$ (Line Impedance) Range of 0.5 Ω to 4 Ω

Some vehicle manufactures apply different conditions for the load dump test based on ISO-7637-2 Pulse 5. The peak clamped current of the load dump TVS will be estimated by the following equation:

Calculation for peak clamping current

$$I_{PP} = (V_{in} - V_c)/R_i$$

*$I_{PP}$: Peak clamping current*
*$V_{in}$: Input voltage*
*$V_c$: Clamping voltage*
*$R_i$: Line impedance*

Table 3 shows the test results of Vishay's high-power silicon TVSs at different test specifications.

**TABLE 3 - CLAMPED VOLTAGES OF VISHAY'S LOAD DUMP TVSs**

| TEST CONDITION | SPECIFICATION OF $V_C$ | JASO A-1 | ISO-7637-2 PULSE 5 |
|---|---|---|---|
| | **10 µs/1000 µs WAVEFORM** | **$V_P$ = 70 V, T = 200 ms, $R_i$ = 1.5 Ω** | **$V_S$ = 87 V, T = 300 ms, $R_i$ = 0.75 Ω** |
| SM5A27 | 40.0 V at $I_{PP}$ = 55 A | 34.1 V at $I_{PP}$ = 47.4 A | 36.5 V at $I_{PP}$ = 59.4 A |
| SM5S24A | 38.9 V at $I_{PP}$ = 93 A | 33.8 V at $I_{PP}$ = 47.6 A | 36.1 V at $I_{PP}$ = 60.1 A |
| SM6A27 | 40.0 V at $I_{PP}$ = 65 A | 33.7 V at $I_{PP}$ = 48.1 A | 35.8 V at $I_{PP}$ = 60.4 A |
| SM6S24A | 38.9 V at $I_{PP}$ = 118 A | 33.5 V at $I_{PP}$ = 48.3 A | 35.8 V at $I_{PP}$ = 60.4 A |
| SM8A27 | 40.0 V at $I_{PP}$ = 75 A | 33.2 V at $I_{PP}$ = 48.4 A | 34.9 V at $I_{PP}$ = 61.1 A |
| SM8S24A | 38.9 V at $I_{PP}$ = 170 A | 32.1 V at $I_{PP}$ = 48.8 A | 34.4 V at $I_{PP}$ = 62.0 A |

The clamped voltages of Vishay's high-power silicon TVSs in these tests are lower than 37 V, meeting the required maximum input voltage range of 37 V to 40 V for voltage regulators in automotive applications.

# Transient Voltage Suppressors (TVS) for Automotive Electronic Protection

Figure 8a shows the current and voltage waveforms of the SM5A27 in the JASO A/1 test.

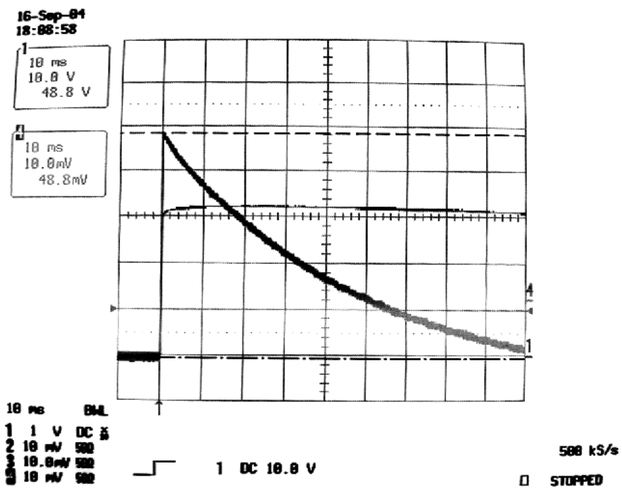


Figure 8a. Clamped Voltage and Current of SM5A27 in JASO A-1 Test

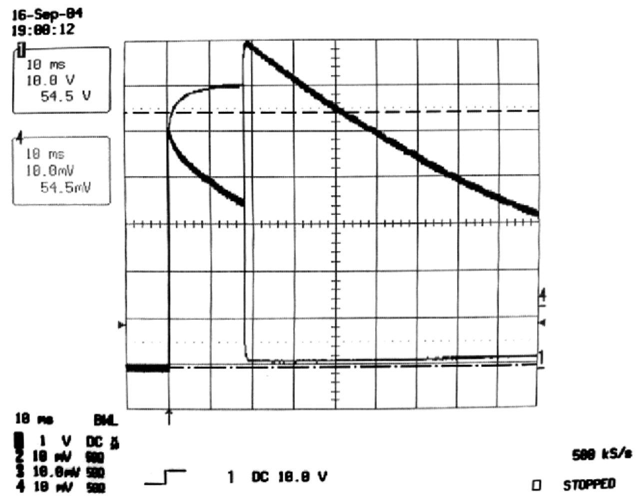


Figure 8b. Clamped Voltage and Current of Load Dump TVS Failures in ISO7637-2 Test

Figure 8b shows the clamped voltage and current of load dump TVS failures in the ISO-7637-2 test. The clamping voltage drops to near zero, and the current passed through the device is increased to the maximum allowed by the line impedance.

Table 4 shows the failed rate in various load dump test conditions of Vishay's load dump TVSs. The SM8S24A is the strongest device under the maximum ratings of ISO-7637-2 Pulse 5.

**TABLE 4 - FAILED RATE IN VARIOUS LOAD DUMP TEST CONDITIONS**

| | JASO TEST | | | ISO-7637-2 PULSE 5 | | | |
|---|---|---|---|---|---|---|---|
| | T = 200 ms, $R_i$ = 0.8 Ω | | | T = 300 ms, $R_i$ = 0.5 Ω | | | |
| **SUPPLY VOLTAGE** | **70 V** | **77 V** | **84 V** | **87 V** | **100 V** | **110 V/25 °C** | **110 V/85 °C** |
| SM5A27 | 20/0 | 20/0 | 20/0 | 20/0 | 20/0 | 20/20 | - |
| SM5S22A | 20/0 | 20/0 | 20/0 | 20/0 | 20/0 | 20/20 | - |
| SM5A24A | 20/0 | 20/0 | 20/0 | 20/0 | 20/0 | 20/20 | - |
| SM6A27 | 20/0 | 20/0 | 20/0 | 20/0 | 20/0 | 20/20 | - |
| SM6S24A | 20/0 | 20/0 | 20/0 | 20/0 | 20/0 | 20/20 | - |
| SM8A27 | 20/0 | 20/0 | 20/0 | 20/0 | 20/0 | 20/3 | 20/9 |
| SM8S24A | 20/0 | 20/0 | 20/0 | 20/0 | 20/0 | 20/0 | 20/0 |

The peak current in the maximum test conditions of ISO-76372 can calculated by the equation:

$$I_{PP} = (V_{in} - V_c)/R_i = (110 - 35)/0,5 = 150\ A$$

# Transient Voltage Suppressors (TVS) for Automotive Electronic Protection

## TWO GROUPS OF VISHAY LOAD DUMP TVS

Vishay has two kinds of load dump TVS for the primary protection of automotive electronics: EPI PAR TVS and Non-EPI PAR TVS. The product groups for the PAR TVSs are listed in Table 5.

**TABLE 5 - PAR LOAD DUMP TVS PRODUCT GROUPS**

| PACKAGE TYPE | EPI PAR TVS | NON-EPI PAR TVS |
|---|---|---|
| Axial | 6KA24 | |
| Surface mount package | SM5A27 | SM5S series |
| | SM6A27 | SM6S series |
| | SM8A27 | SM8S series |

Both product groups have similar operating breakdown characteristics in reverse bias mode. The difference is that EPI-PAR TVSs have low VF characteristics in forward mode, and non-EPI PAR TVSs have relatively high $V_F$ under the same conditions, as shown in Table 6. This characteristic is important to the reverse voltage supplied to the power line.

**TABLE 6 - PARAMETER OF PAR LOAD DUMP TVS**

| | $V_F$ (TYPICAL) (0.3 ms PULSE WITH) V | | | STAND-OFF VOLTAGE AT REVERSE LEAKAGE CURRENT | BREAKDOWN VOLTAGE AT REVERSE CURRENT |
|---|---|---|---|---|---|
| | 0.1 A | 6 A | 100 A | | |
| SM5A27 | 0.70 | 0.93 | 0.95 | 22 V at 0.2 µA | 27 V at 10 mA |
| SM6A27 | 0.70 | 0.91 | 0.94 | 22 V at 0.5 µA | 27 V at 10 mA |
| SM8A27 | 0.70 | 0.89 | 0.93 | 22 V at 1.0 µA | 27 V at 10 mA |
| SM5S24A | 0.70 | 0.92 | 1.65 | 24 V at 10 µA | 28 V at 5 mA |
| SM6S24A | 0.70 | 0.88 | 1.50 | 24 V at 10 µA | 28 V at 5 mA |
| SM8S24A | 0.70 | 0.86 | 1.45 | 24 V at 10 µA | 28 V at 5 mA |

Most CMOS ICs and LSIs have very poor reverse voltage capabilities. The gates of MOSFETs are also weak in reverse voltage, at - 1 V or lower. In the reversed power input mode, the voltage of the power line is the same as the voltage of the TVS forward voltage drop ($V_F$). This reverse bias mode causes electronic circuit failure. The low forward voltage drop of EPI PAR TVSs is a good solution to this problem.

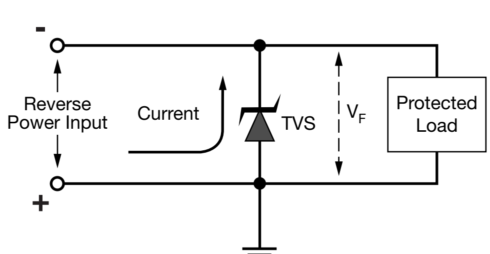


Figure 9. Reverse Bias Status

Another method to protect circuits from reversed power input is utilizing a polarity protection rectifier into the power line, as shown in Figure 9.

A polarity protection rectifier should have sufficient forward current ratings, and forward surge and reverse voltage capabilities.

Vishay has a wide range of standard rectifiers and Schottky rectifiers for polarity protection, with wide operating temperature ranges and superior electrical characteristics.

# Transient Voltage Suppressors (TVS) for Automotive Electronic Protection

## III) SECONDARY PROTECTION OF THE AUTOMOTIVE POWER LINE

The primary target of protection circuits in automotive systems is high surge voltages, but the clamped voltage is still high, as shown in tables 2 and 7. Secondary protection is especially important in 24 V powertrains, such as found in trucks and vans. The main reason for this is the maximum input voltages for most regulators and dc-to-dc converter ICs for automotive applications are 45 V to 60 V.

The breakdown voltages of primary protection TVSs at 24 V test conditions are shown in Table 7. These result in high voltages to the regulator and the integrated circuits of instruments clusters and other electronics.

**TABLE 7 - JASO D-1 LOAD DUMP TEST**

| P/N | JASO D-1 | | | |
|---|---|---|---|---|
| | t = 400 ms, $R_i$ = 1.5 W | | | |
| | $V_P$ = 110 V | | $V_P$ = 130 V | |
| | $V_C$ | $I_{PP}$ | $V_C$ | $I_{PP}$ |
| SM5S36A | 56 V | 39.2 A | N/A | |
| SM6S36A | 53 V | 41.1 A | 57 V | 52 A |
| SM8S36A | 52 V | 42.0 A | 55 V | 53 A |

For this kind of application, Vishay recommends using secondary protection, as shown in Figure 10.

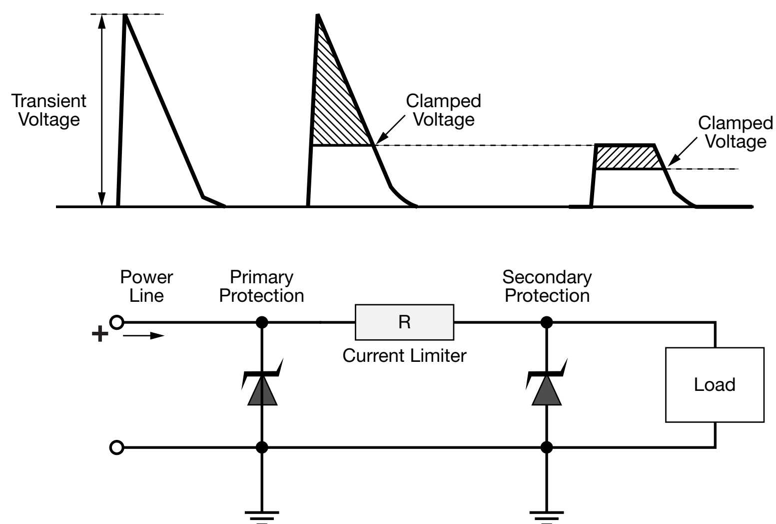


Figure 10. Secondary Protection Circuit

Adding resistor R onto the power line reduces the transient current, allowing smaller power-rating TVSs as the secondary protection. Current requirements for microprocessor and logic circuits in electronic units are 150 mA to 300 mA, and the minimum output voltage of a 12 V battery is 7.2 V at - 18 °C, or 14.4 V for a 24 V battery under the same conditions.

In a 24 V battery under the above conditions, the supply voltage at a 300 mA load is 8.4 V at R = 20 Ω, and 11.4 V at R = 10 Ω at a minimum voltage of battery of 14.4 V (24 V battery voltage in - 18 °C).

$$V_L = (V_{min}/(V_{min}/I_L)) \times ((V_{min}/I_L) - R)$$

*$V_L$: Voltage to load*
*$V_{min}$: Minimum input voltage*
*$I_L$: Load current*
*R: Resistor value*

Power rating of R = $I^2R$

This supply voltage is higher than the minimum input voltages for most voltage regulators and dc-to-dc converter ICs.

# Transient Voltage Suppressors (TVS) for Automotive Electronic Protection

The clamping voltage of small- and medium-power TVSs for secondary protection in the JASO D-1 test (110 V, t = 400 ms, $R_i$ = 1.5 Ω) for 24 V powertrains is shown in Table 8 with a current limiting resistor.

**TABLE 8 - CLAMPED VOLTAGE OF SECONDARY PROTECTION TVS UNDER JASO D-1 TEST CONDITION**

| PRIMARY PROTECTION | | SECONDARY PROTECTION | | | | |
|---|---|---|---|---|---|---|
| P/N | Clamping voltage | P/N | Clamping voltage | | | |
| | | | R = 10 Ω, 2 W | | R = 20 Ω, 2 W | |
| | | | $V_C$ | $I_{PP}$ | $V_C$ | $I_{PP}$ |
| SM8S36A | 51.3 V | TPSMC39A | 42.8 V | 0.93 A | 41.3 V | 0.56 A |
| | | TPSMB39A | 44.9 V | 0.85 A | 42.2 V | 0.50 A |
| | | TPSMA39A | 45.6 V | 0.75 A | 43.3 V | 0.45 A |
| | | TPSMC36A | 40.3 V | 1.25 A | 37.8 V | 0.70 A |
| | | TPSMB36A | 43.5 V | 1.00 A | 39.1 V | 0.65 A |
| | | TPSMA36A | 44.0 V | 0.90 A | 40.6 V | 0.60 A |

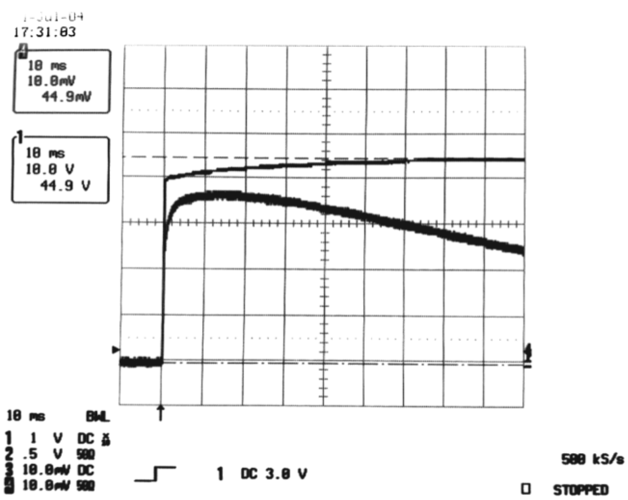


Figure 11. Clamped Voltage and Current Waveform under JASO D-1 Test

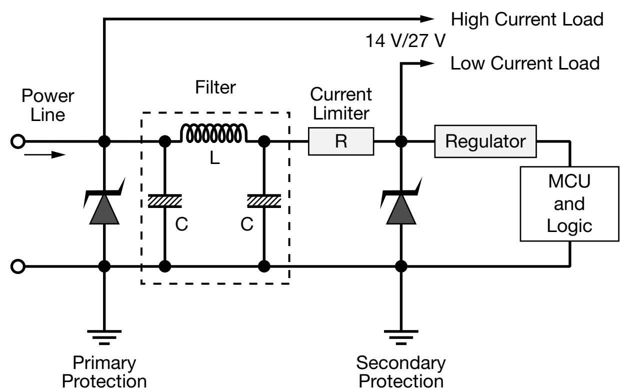


Figure 12. Secondary Protection Circuit with Noise Filter

TPSMC36A with 20 Ω resistor
- $V_C$ = 37.8 V
- $I_{PP}$ = 0.7 A

Remark: All test data is typical value and has a tolerance of ± 5 %.