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TVS Diode Selection and Theoretical Calculation in Automotive Electronics

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Abstract. In the automotive electronic function module protection, in addition to electrostatic protection (ISO10605), the most important to calculate the road vehicle electrical transient interference protection, that is, we usually mentioned the automotive electronic test standard ISO 7637-2 and enhanced version of ISO 16750-2 standard. Among them, the load test is to simulate the battery power loss, by the generator to supply power to the load, verify whether the load at this time can't meet the requirements of the situation [1]. For the load throwing test, TVS is usually used to release the energy injected by the power line to achieve the purpose of protecting the later circuit.

Keywords. Automotive electronics, TVS diode, clamp voltage, breakdown voltage.

1. Introduction

Voltage transient refers to the short-term surge of electric energy, which is the consequence of the sudden release of formerly stored energy or energy generated by other means (such as heavy induction load or lightning). Repeatability is usually caused by the operation of motor or generator or the switching of reactive circuit components. Random transients are usually caused by lightning and electrostatic discharge. And lightning and electrostatic discharge are usually unpredictable, and may need accurate monitoring to correctly measure, especially in the state of circuit board potential induction. Many electronic standards organizations use recognized monitoring or testing methods to analyze the occurrence of transient voltage. For example, electrostatic discharge with a duration of 100ns and a voltage of 15kv can be quantified as 30A current.

2. Why do People Pay More and More Attention to Transients?

Miniaturization of components leads to higher requirements for electrical stress sensitivity. For example, the structure and conductive path of microprocessor are not suitable for dealing with the large current generated by ESD transient. These components work at a very low voltage, so voltage interference must be controlled to

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prevent equipment interruption or potential or catastrophic failure. Nowadays, sensitive microprocessors have been widely used in various devices.

3. Working Principle and Main Parameters

As shown in figure 1, when subjected to the reverse transient high energy impact, TVS tube is broken down and becomes a low impedance path. Energy is released to GND through TVS every 10-12 power seconds. And clamp the voltage at a predetermined value; So as to effectively protect the components of the later circuit. The voltage applied at both ends of TVS rises instantaneously from the reverse turn-off voltage VRWM to VBR and is broken down [2]. With the appearance of the breakdown current, the current flowing through TVS reaches the peak IPP and the voltage is clamped below the predetermined maximum clamped voltage value VC. After that, the pulse current decays exponentially, and the inter-electrode voltage of TVS also drops continuously and finally returns to its initial state.

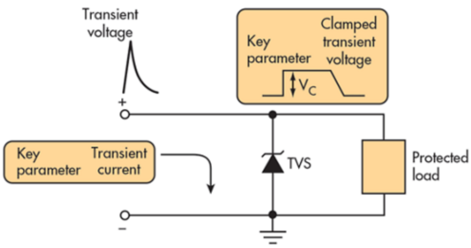

Figure 1. Working principle diagram of TVS diode.

3.1. Isolation voltage (VR):

The VR of the device should be greater than or equal to the peak operating level of the circuit (or part of the circuit) to be protected. This ensures that the TVS diode will not reduce the driving voltage of the circuit. For unidirectional TVS diodes, the reverse isolation voltage refers to the maximum peak voltage applied in the "blocking direction" to ensure that there is no obvious current. In the case of bidirectional transient, the reverse isolation voltage is applicable in either direction. It is the same as the definition of highest off-state voltage and maximum working voltage.

3.2. Peak current (IPP):

Peak current is the maximum current that TVS diode can bear without damage. The required IPP can only be determined by dividing the peak transient voltage by the source impedance. Note that the failure mechanism of TVS diode is short circuit. Even if TVS diode fails due to transient effect, the circuit will still be protected. The maximum pulse current can be repeatedly applied. Usually, a double exponential waveform of 10/1000µs is used. If specified, 8/20µs can also be used.

3.3. Maximum clamping voltage (VC):

The peak voltage will appear when TVS diode is subjected to peak pulse current (IPP). This peak voltage is based on 10/1000μs exponential waveform. TVS "Clamped" level that will be seen at the protection signal line. The lower clamping voltage is better to protect IC chip.

3.4. Capacitance:

PN Junction capacitance. Capacitance value is a critical parameter for the high speed line application.The principle of TVS selection is to meet the ESD protection requirements without affecting the normal function of the circuit. For the convenience of designers in selecting TVS, please refer to the following TVS load capacitance VS data transmission rate chart. The following chart is convenient for TVS selection of high-speed signal lines and intuitive for understanding the relationship between load capacitance of TVS diode and data transmission rate, as shown in figure 2.

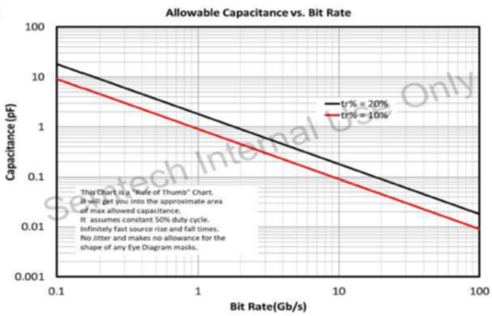

Figure 2. Allowable Capcitance vs. Bit Rate

3.5. Transmission Line Pulse - TLP

TLP is a measurement technique used to evaluate ESD protection circuits. The TLP 100ns pulse lengths and current levels closely match the pulse lengths and current levels in an ESD pulse. Main use is to obtain current-voltage (I-V) characteristic data. The slope of the TLP I-V curve is defined as the dynamic resistance (RDYN) of the device.

4. Selection Principles of TVS

When applied in the circuit, in addition to the key parameters, the following points are mainly considered:

- VRWM should be greater than or equal to the maximum operating voltage of the protected circuit [3].
- VC should be less than the damage voltage of the protected circuit, namely VC=KC×VBR (among them, KC=1.3).

- In the specified pulse duration, TVS nominal maximum peak pulse power consumption PM must be greater than the actual pulse power consumption in the application.
- After determining the maximum clamping voltage, the peak pulse current of TVS should be greater than the transient surge current of the actual application.
- TVS Breakdown Characteristics
- Type A:Avalanche or Zener
- VBR > 7V the dominant reverse breakdown is avalanche breakdown caused by impact ionization.
- At VBR<5V, the dominant mechanismis Zener breakdown caused by quantum Tunneling. If, 5V< VBR<7V, its combination of the two.
- Type B:EPD
- Enhanced punch through diode based on NPN transistor but with an additional, lightly doped, base layer. Lower leakage and cap than Zener & Avalanche diodes for Low voltage applications.
- Type C:SCR

PNP-NPN with a regenerative feedback loop. If a high current is injected such that the loop gain > 1, the regenerative loop will take over turning the device on. Anode to Cathode V will fall to very low level where the gain will fall to 1.Excellent low clamping, as shown in figure 3.

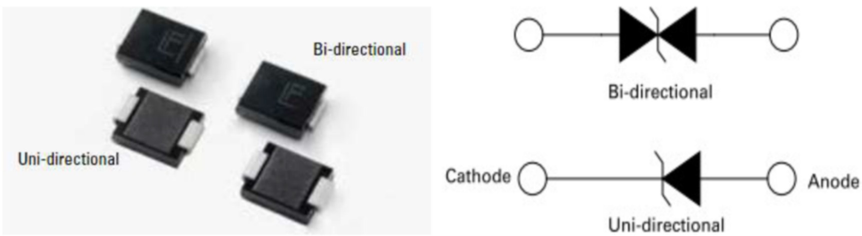

Figure 3. Physical and symbol of TVS diode.

5. TVS Failure Rate Calculation

TVS may fail in the application, and its failure rate can be calculated by referring to the following formula:

$$\lambda CL = X2(CL, 2F + 2) * 10^9 / (2 * T * SS * A) \quad (1)$$

X2:chi-square distribution function [4].
CL: confidence.
F: number of failures.
T: test time, in h.
SS: number of samples.
A: acceleration factor.

According to the service life test results: F=0, T= 504h, SS =40.

6. Reference Example-Theoretical Calculation

Example: to TPSMD24A applied in the 12V system. According to the experimental requirements, the internal resistance of power supply is Ri= 0.5Ω, dwell time TD =400ms; Engine voltage VA=14V; As shown in figure 4.

Part Number (Uni)	Part Number (Bi)	Marking		Reverse Stand off Voltage V_R (Volts)	Breakdown Voltage V_{BR} (Volts) @ I_T		Test Current I_T (mA)	Maximum Clamping Voltage V_C @ I_{PP} (V)	Maximum Peak Pulse Current I_{PP} (A)	Maximum Reverse Leakage I_R @ V_R (µA)	Agency Approval
		UNI	BI		MIN	MAX					
TPSMD24A	TPSMD24CA	PEZA	DEZA	24.0	26.70	29.50	1	38.9	77.1	2	X

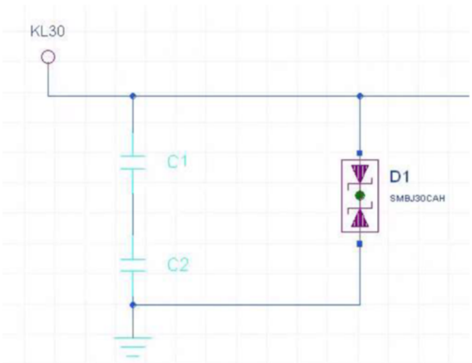

Figure 4. Device parameters and application position.

- Conduction internal resistance:
  Rd = (VC-VBR) / IPP = (38.90-26.70) / 77.10= 0.16Ω
- After TVS conduction, the current flowing through TVS:
  IPP = [(VS + VA) - VBR] / [Ri + Rd) = [(87 + 14) - 26.70] / (0.50 + 0.16) = 112.58 A
- Energy flowing through TVS:
  W = (IPP)² * Td * Rd / 2 = 112.582 * 0.40 * 0.16 / 2 = 405.58 J

Maximum Ratings and Thermal Characteristics (T_A=25°C unless otherwise noted)

Parameter	Symbol	Value	Unit
Peak Pulse Power Dissipation by 10/1000µs Waveform (Fig.2)(Note 1), (Note 2)	P_{PPM}	3000	W
Power Dissipation on Infinite Heat Sink at T_A=50°C	$P_{M(AV)}$	6.5	W
Peak Forward Surge Current, 8.3ms Single Half Sine Wave (Note 3)	I_{FSM}	300	A
Maximum Instantaneous Forward Voltage at 100A for Unidirectional Only	V_F	3.5	V
Operating Junction and Storage Temperature Range	T_J, T_{STG}	-65 to 150	°C
Typical Thermal Resistance Junction to Lead	R_{uJL}	15	°C/W
Typical Thermal Resistance Junction to Ambient	R_{uJA}	75	°C/W

Notes:
1. Non-repetitive current pulse per Fig. 4 and derated above T_A = 25°C per Fig. 3.
2. Mounted on copper pad area of 0.31x0.31" (8.0 x 8.0mm) to each terminal.
3. Measured on 8.3ms single half sine wave or equivalent square wave for unidirectional component only, duty cycle=4 per minute maximum.

Figure 5. Maximum Ratings and Thermal Characteristics.

Maximum power TVS can withstand:

According to the specification (as shown in figure 5), the maximum forward surge current is 300A in 8.3ms time, then

- The impedance during conduction is:
  $Rf = Vf / If = 3.5/100 = 0.04\Omega$
- Conduction energy is:
  $WTVS = (Ifsm)^2 * T * Rf/2 = 13.07$ J

As above, when TVS is broken down by the reverse wizard pass, W > WTVS; So, if the use of TPSMD24A in the power input end of the test, TPSMD24A will be damaged, short circuit failure.

7. Conclusion

This paper provides the calculation method of TVS diode selection for automotive electronic designers. Combined with the actual case application of TPSMD24A model, engineers can choose the appropriate TVS diode according to the manufacturer's specifications to complete the protection of automotive electronic function module and prevent the circuit from short circuit failure.

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