GigaDevice Semiconductor Inc.

TVS Selection and Use of ESD Protection Devices

Application Note
AN051

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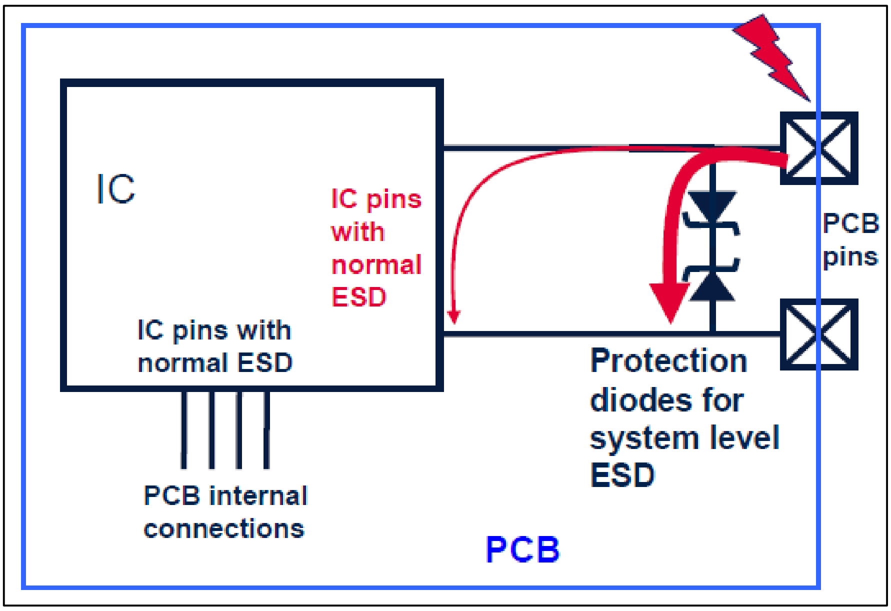
1. TVS Introduction

TVS in the narrow sense refers to avalanche breakdown diodes, a highly efficient protection device in the form of diodes. TVS diodes has large junction capacitance and large packaging (SMA/SMB). The manufacturing process is simple, and the 8-inch wafer is generally used with low cost. The main application fields are anti-surge and power line ESD. In a broad sense, TVS is a silicon-based ESD protection device that includes TVS diodes to protect multiple internal circuits, and a polymer ESD protection device, and its manufacturing process and application scenarios are very different.

2. TVS Characteristic

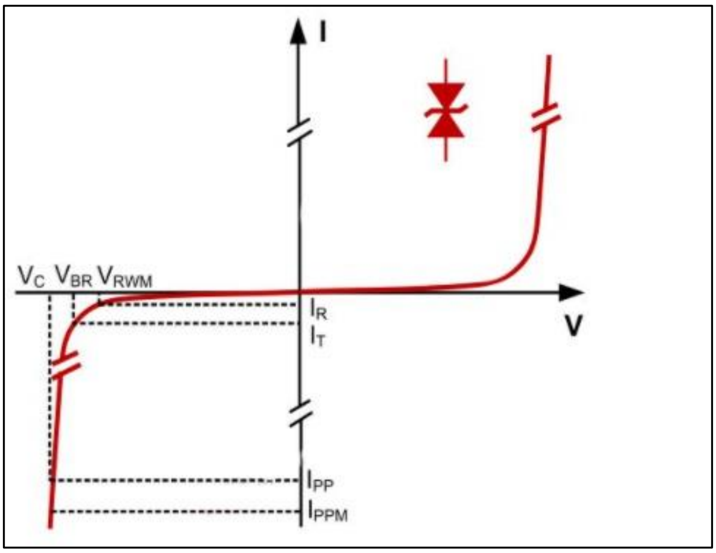
There are unidirectional and bidirectional TVS. Unidirectional TVS is generally used in DC power supply circuits, and bidirectional TVS is used in circuits with alternating voltages. The one-way TVS is applied to the DC circuit. When the circuit is working normally, the TVS is in the cut-off state (high-impedance state), which does not affect the normal operation. When the circuit has a sudden change of transient voltage and reaches the breakdown voltage (avalanche) of the TVS, the TVS will quickly change from a high-resistance state to a low-resistance state, discharging the transient overcurrent caused by abnormal overvoltage to the ground, at the same time, the abnormal voltage is clamped at a lower level, so as to protect the subsequent circuit from being damaged by abnormal overvoltage. When the abnormal overvoltage disappears, the resistance value of the TVS returns to a high-impedance state.

Figure 2-1. TVS Protection Principle



3. TVS Parameter

Figure 3-1. I-V characteristic parameters of TVS



3.1. V_{RWM} Reverse standoff voltage/Reverse working voltage

Reverse standoff voltage / reverse working voltage, the highest working voltage of circuit, TVS can continuously apply the highest working peak voltage or DC peak voltage that does not cause TVS deterioration or damage. For AC voltage, expressed by the effective value of highest working voltage, under V_{RWM}, the TVS is considered to be non-working, that is, non-conducting. When designing the circuit, the highest working voltage must be less than V_{RWM}, otherwise it will cause the TVS to work and cause the circuit to be abnormal.

3.2. I_R Reverse Leakage Current

The reverse leakage current is generally the standby current of TVS. The maximum current flowing through the TVS at the specified temperature and maximum operating voltage. The leakage current of TVS is generally measured under the reverse working voltage. For a certain type of TVS, the I_R should be within the specified value range. For the voltage value applied across the TVS is V_{RWM}, the current read from the ammeter is the leakage current I_R of the TVS. For TVS of the same power and voltage, when V_{RWM} is less than or equal to 10V, the leakage current of bidirectional TVS is twice the leakage current of unidirectional TVS. The general leakage current is less than 100 nA. For some analog ports, the leakage current will affect the sampling value of ADC, so the smaller the leakage current of TVS, the better.

3.3. V_{BR} Breakdown Voltage

The breakdown voltage, when the ESD protection starts to work, is generally the voltage when the TVS passes 1 mA. Generally, the current applied time does not exceed 400 ms to avoid damage to the device. V_{BR} min and max are deviation of the TVS breakdown voltages. Generally TVS is plus or minus 5% deviation. When V_{BR} falls between min and max during measurement, it is regarded as a qualified product.

3.4. I_{PP} Peak Pulse Current

Peak current, the peak value of a given pulse current waveform. TVS generally uses a current waveform of 10/1000 us or 8/20 us.

3.5. V_C Clamp Voltage

The clamp voltage is the peak voltage across the TVS when the peak pulse current I_{PP} of the specified waveform is applied. I_{PP} and V_C are parameters that measure the ability of TVS to resist surge pulse current and limit voltage in circuit protection. These two parameters are related to each other. For the same type of TVS, the larger the I_{PP}, the stronger the resistance to current impact, and the smaller the V_C under the same I_{PP}, the better the clamping characteristics of the TVS.

3.6. C_j Junction Capacitance

Junction capacitance is the parasitic capacitance in TVS, which needs to be paid attention to in the protection of high-speed IO port. Excessive junction capacitance may affect the quality of the signal.

3.7. TVS Power

TVS power is when considering anti-surge, TVS will not be damaged by surge current pulse.

4. TVS Selection

There are three points to pay attention to when choosing TVS:

- Appropriate clamping voltage can protect the subsequent circuit.
- The junction capacitance of the TVS introduced cannot affect the circuit response.
- The TVS power has sufficient power margin, meets the test standards, and cannot fail before the fuse.

4.1. Select the highest working voltage of TVS, namely reverse standoff voltage V_{RWM}

Under normal working conditions, the TVS should not work, that is, in the cut-off state, so the cut-off voltage of the TVS should be greater than the maximum working voltage of the protected circuit. In this way, it can be ensured that the TVS will not affect the circuit operation under the normal operation of the circuit. However, the working voltage of TVS also determines the level of TVS clamping voltage. When the cut-off voltage is greater than the normal working voltage, the TVS working voltage cannot be selected too high, and the clamping voltage will be higher if it is too high. Therefore, when choosing V_{RWM} When the working voltage of the protected circuit and the bearing capacity of the subsequent circuit should be comprehensively considered, V_{RWM} is required to be greater than or equal to the working voltage, otherwise the working voltage greater than V_{RWM} will lead to an increase in the leakage current in the TVS direction, which will affect the normal operation when it is close to conduction.

$V_{RWM} = (1.1\sim1.2)^* V_{CC}$

(Where V_{CC} is the highest working voltage of the circuit)

4.2. Select the appropriate clamping voltage V_C

The TVS clamping voltage should be less than the maximum transient safety voltage that the protected circuit of the latter stage can withstand. V_C is proportional to the TVS breakdown voltage and I_{PP}. For a TVS of the same power level, the higher the breakdown voltage, the higher the V_C. Therefore, the maximum clamping voltage V_C of the TVS should not be greater than the maximum voltage that the protected circuit can withstand. Otherwise it will cause damage to the circuit when the TVS is clamped at V_C.

The TVS clamping voltage should be less than the maximum transient safety voltage that the protected circuit of the latter stage can withstand. V_C is proportional to the breakdown voltage of TVS and I_{PP}. For a TVS of the same power level, the higher the breakdown voltage, the higher the V_C. Therefore, the maximum clamping voltage V_C of the TVS should not be greater than the maximum voltage that the protected circuit can withstand. Otherwise it will cause damage to the circuit when the TVS is clamped at V_C.

V_C < V_{max} (Where V_{max} is the highest voltage that the circuit can withstand)

It is currently unknown how much transient safe voltage the GD32 MCU pins can withstand.

4.3. Select the power of TVS P_{PPM}

The rated transient power of TVS products should be greater than the maximum transient surge power that may appear in the circuit. In theory, the higher the power of TVS, the better, and it can withstand more impact energy and times. However, the higher the TVS power, the larger the package and the higher the price, so the TVS power can meet the requirements. For TVS of different power levels, the V_C of TVS of the same voltage specification is the same, but the I_{PP} is different. P_{PPM} is proportional to I_{PPM}, the larger the I_{PPM}, the larger the P_{PPM}. For a certain circuit, there are corresponding test requirements. If the maximum test current in the actual circuit is Iactual, then Iactual can be estimated as

I_{actual} = U_{actual} / Ri (U_{actual} is test voltage，Ri is test voltage)

4.4. Evaluate the effect of junction capacitance C_j and leakage current I_R of TVS

If TVS is used in high-speed IO port protection, analog signal sampling, and low-power devices, it needs to consider the effect of junction capacitance and leakage current, the smaller C_j and I_R the better.

5. TVS Selection Steps

5.1. V_{RWM}

V_{RWM} is greater than or equal to the normal working voltage of the protected signal. The larger the V_{RWM} is than the working voltage of the protected signal, the smaller the leakage current; the lower the V_{RWM}, the lower the TVS clamping voltage V_C, and the better the signal protection effect.

5.2. DC or AC

Determine whether the protected signal is AC or DC. Generally, bidirectional TVS is selected for AC signal, and unidirectional TVS is selected for DC signal. The advantage of bidirectional is flexibility, IO and GND can be connected at will; the advantage of unidirectional is that the reverse clamping voltage is lower than that of bidirectional TVS.

5.3. Junction Capacitor C_j

According to the signal rate to be protected, select the appropriate junction capacitance. The common interface and the recommended ESD junction capacitance range are shown below.

Table 5-1. ESD Junction Capacitor for Common Interfaces

Interface	ESD Junction Capacitor Recommendations
GPIO	<30 pF
Button	<30 pF
Audio	<10 pF
USB 2.0	<4 pF
USB 3.0	<0.5 pF
USB 3.1	<0.3 pF
HDMI 1.4	<0.7 pF
HDMI 2.0	<0.3 pF
Ethernet port	<4 pF
Antenna	<0.2 pF

5.4. ESD Levels

The selected TVS must meet or exceed the IEC61000-4-2 Level4 standard. This standard is for ESD and corresponds to the national standard GB/T17626.2, but please note that this is only for TVS chips to pass this standard. It is guranteed that TVS will not be damaged, whether the protected circuit will be damaged or not depends on the clamping voltage.

Figure 5-1. IEC61000-4-2 Test modes and Levels

Contact discharge		Air discharge	
Level	Test voltage kV	Level	Test voltage kV
1	2	1	2
2	4	2	4
3	6	3	8
4	8	4	15
x [a]	Special	x [a]	Special

[a] "x" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification. If higher voltages than those shown are specified, special test equipment may be needed.

TVS will generally pass IEC61000-4-4 (EFT) and IEC61000-4-5 (surge) standards.

5.5. Select the appropriate clamping voltage

According to the maximum voltage that the protected signal can withstand, select the appropriate clamping voltage in the TLP curve. The following is a TVS clamp voltage data, there are four values.

Table 5-2. Common Clamps in TVS Datasheet

Characteristic	Simple	Unit	Condition	min	type	max
Clamping Voltage1	V_C	V	I_{PP} = 16 A, tp = 100 ns		14	
Dynamic resistance	Rdyn	Ω	/			
Clamping Voltage2	V_C	V	Vesd = 8 kV		14	
Clamping Voltage3	V_C	V	I_{PP} = 1 A, tp = 8/20 us		8.3	
		V	I_{PP} = 4 A, tp = 8/20 us		10	
Junction capacitance	C_j	pF	V_R = 0 V, f = 1 MHz		0.35	0.5

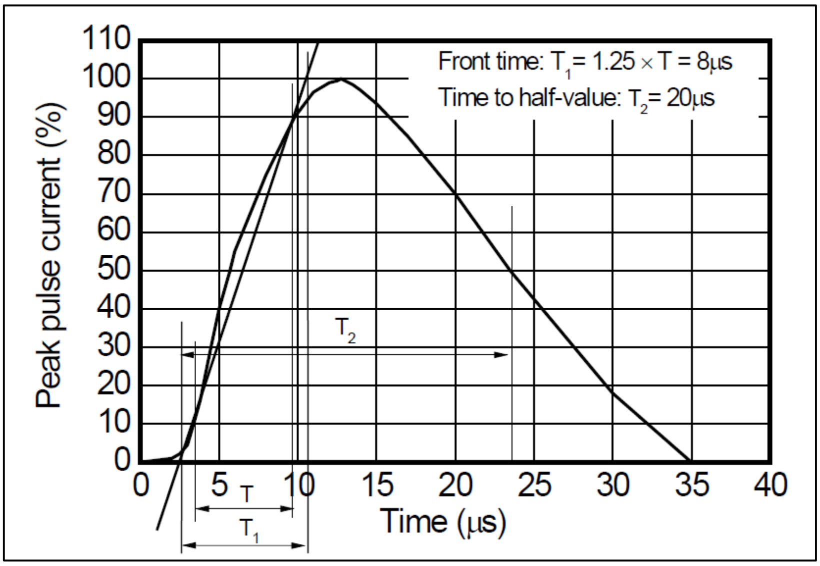
The first two clamping voltages in the Datasheet are both 14V, because TLP 16A 100ns and IEC 6100-4-2 contact discharge 8kV are one-to-one. The correspondence between IEC levels and TLPs is as follows:

Table 5-3. IEC61000-4-2 Correspondence between CD mode and TLP level

IEC61000-4-2 Contact Discharge Mode Class	TLP Pulse Level
1 kV	2 A, 100 ns TLP pulse
2 kV	4 A, 100 ns TLP pulse
4 kV	8 A, 100 ns TLP pulse
6 kV	12 A, 100 ns TLP pulse
8 kV	16 A, 100 ns TLP pulse

The test standard for the two clamping voltages is IEC61000-4-5, and the specified surge waveform is 8/20 us, which means 8 us to reach 100% I_{PP}, and 20 us to reach 50% I_{PP}. Therefore, when the reverse current peak current I_{PP} is 4A, the clamping voltage is larger than that of 1A.

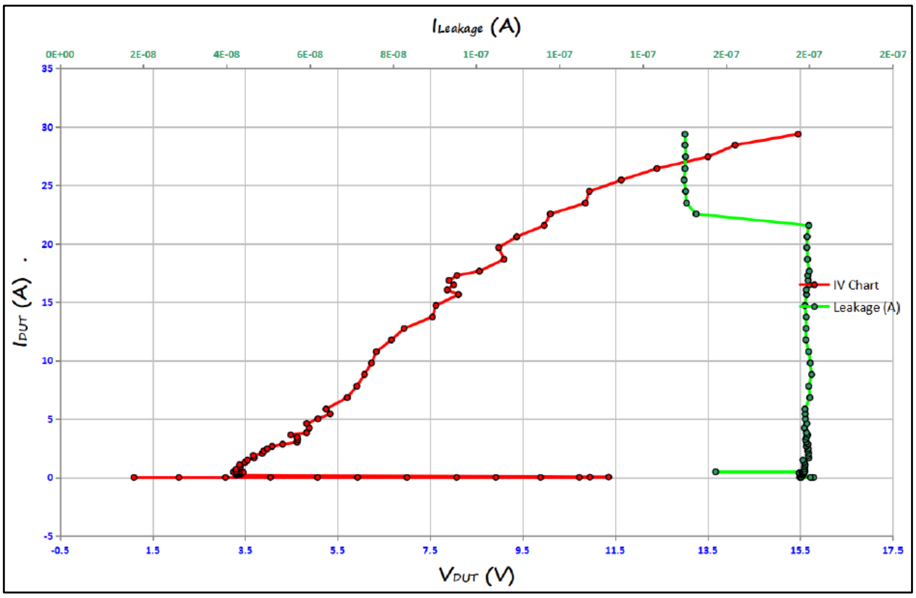
Figure 5-2. IEC61000-4-5 8/20 us Waveform



5.6. TLP

When both TVSs can pass IEC61000-4-2 8kV ESD, the lower the clamping voltage corresponding to the TLP curve, the better the performance of the TVS.

Figure 5-3. I-V Curve of TVS



It should be noted that the clamping voltage in the TLP is given by the transient 100 ns test, and it is still different from the clamping voltage that will not be damaged by continuous operation.

6. Revision history

Table 6-1. Revision history

Revision No.	Description	Date
1.0	Initial release	Apr.20 2022

Important Notice