MicroNote 126

Lightning Protection for Aircraft

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Threat and Environment

Lightning striking jet airliners are common. It occurs about once every 1,000 hours in flight while passengers and crew members are safely transported to their destinations. Fly-by-wire system failures at data signal interfaces are unacceptable. Surge protection at thousands of signal lines interfaces provides reliable, continuous performance from voltage spike damage using the designer's choice of silicon transient voltage suppressor (TVS) devices.

Aircraft Radio Inc. (ARINC) 429 is the signal protocol used for virtually anything that flies. It is used to transfer critical data including airspeed, temperatures, tire pressure, center of gravity, fuel weight, engine performance, external control surfaces, and a host of other information. Interconnections are twisted, shielded line pairs for reduction of noise and induced lightning transients. There are two data transmission speeds, 12 kbps–14 kbps and 100 kbps, with operating voltages ranging from ±5 V to ±17 V.

TVS types for these applications normally include bidirectional 600 W peak pulse power (P_{PP}) ratings at 10/1000 µs, such as the SMBJ5.0CA series for slow data rates and the low capacitance HSMBJSAC5.0 types for 100 kbps data rates. The 1500 W rated SMCJ5.0 and SMCJLCE low capacitance series are also required on more severe lightning threats defined in RTCA/DO160G, Table 22-2.

Silicon TVS protectors are constant power devices. When the operating voltage is doubled, the surge current rating is reduced by half. For higher signal voltages, the 1.5 kW devices may be required for protection.

Table 1: ARINC TVS Selection Matrix

I_{PP} Exposure Levels	For 12 kbps Data Rate	For 100 kbps Data Rate
Low	SMBJ5.0CA series	SMBJSAC5.0 series
High	SMCJ5.0CA series	SMCJLCE6.5 series

Aircraft Transient Waveforms

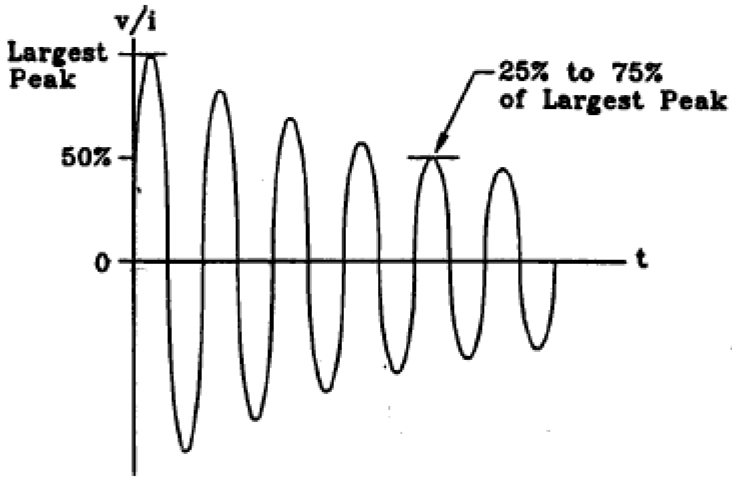
The conventional 10/1000 µs test waveform (at which most silicon TVSs are specified) was derived from a Bell Lab specication published in the late 1960s, before other standards were developed. Since that time, we have seen a host of others, including those defined by the aircraft industry. See RTCA/DO-160G. The following table lists threat levels, including open-circuit voltage and short-circuit current, plus six waveforms ranging from 5 µs to 500 µs. Pin surge levels are listed in a matrix of fifteen separate pin injection threats, as listed as follows:

Table 2: Pin Injection Levels

Level	Waveform 3 Voc/Isc	Waveform 4 Voc/Isc	Waveform 5A Voc/Isc
1	100/4	50/10	50/50
2	250/10	125/25	125/125
3	600/24	300/60	300/300
4	1500/60	750/150	750/750
5	3200/128	1600/320	1600/1600

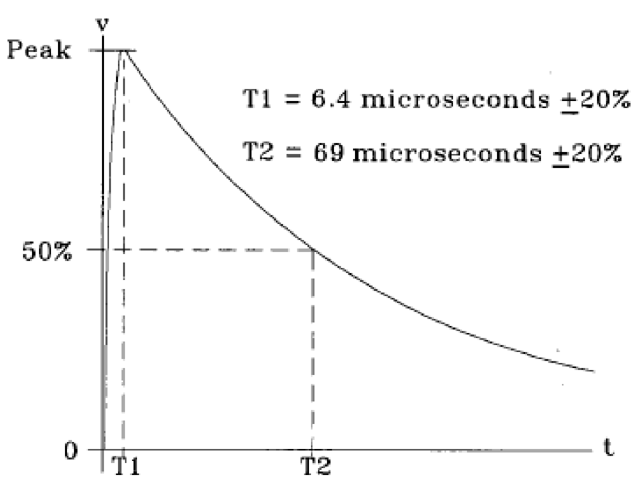
The most common specified injection threat levels for data lines include waveforms 3 and 4, and normally, at level 3 or 4 as the worst case. Waveforms are shown as follows.

Figure 1: Voltage/Current Waveform 3



Note: Frequency for pin injection test is applied at 1.0 MHz (20%). Voltage and current are not necessarily in phase.

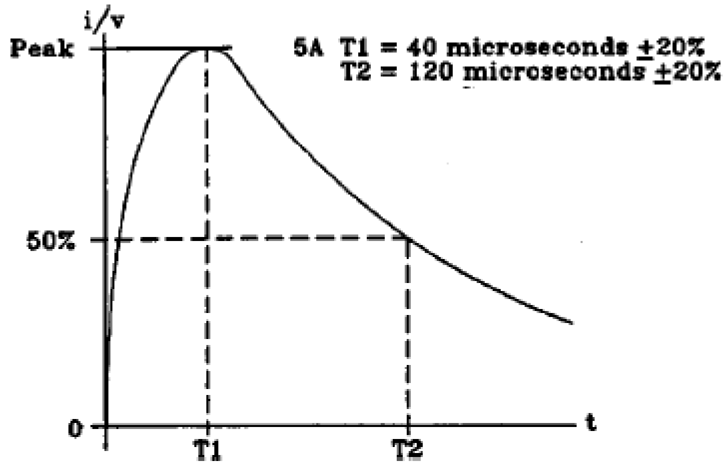
Figure 2: Voltage Waveform 4



Calculating Ipp Capability

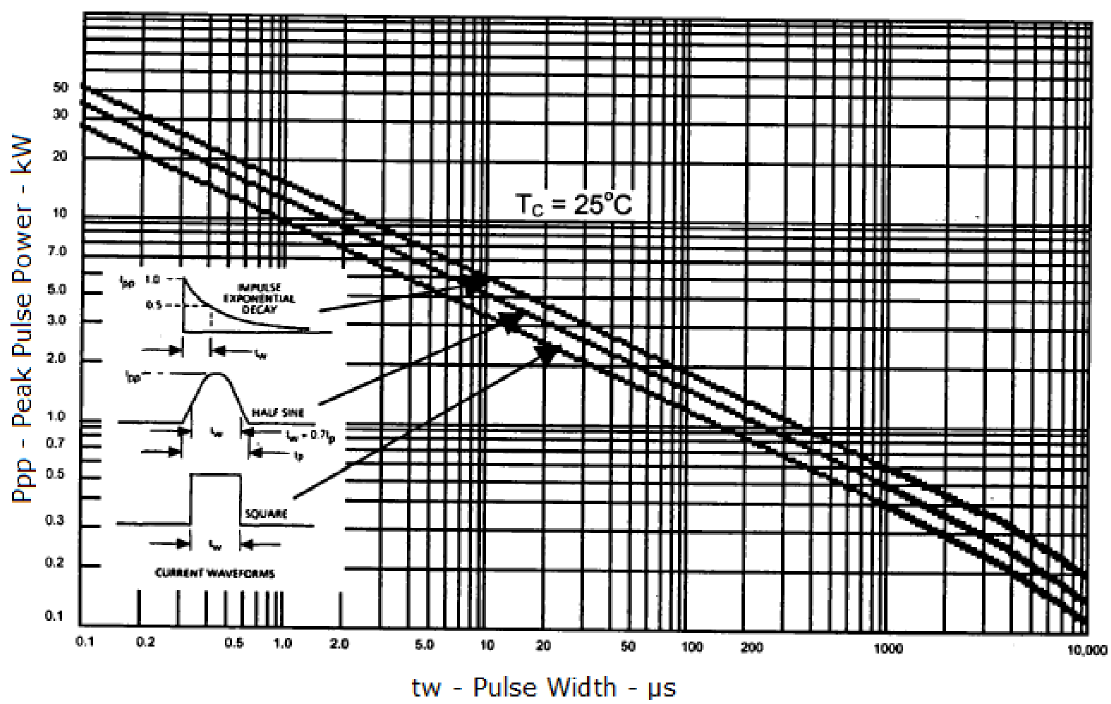
Let's work out an example for protecting a slow data rate line, at 14 kbps per ARINC 429, using 600-W rated SMBJ5.0CA for this application. To find out its ability to protect from a surge at level 3, waveforms 3 and 4, we translate the maximum TVS peak pulse current (I_{PP}) rating of the 10/1000 µs into its equivalent for waveform 3.

Figure 3: Voltage Waveform 5A



We need to refer to the I_{PP} vs time graph for the 10/1000 µs below.

Figure 4: Peak Pulse Power vs Time for SMBJ 600 W Series



For further reference, review MicroNote 104. Waveform 3 is equivalent to less than 5 µs duration with an applied frequency of 1.0 MHz (±20%). To calculate the equivalent current capability of the SMBJ50CA, use the following method:

Equation 1:
I_{PP} at 5 µs = (P_{PP} at 5 µs/ P_{PP} at 1000 µs) × I_{PP} of SMBJ5.0CA at 10/1000 µs
=(6,400 W/600 W) × 65.2 A, where the values of 6600 W and 600 W are from Figure 4 (see page 3)
=10.7 × 65.2 A
=698 A

For a 5-µs pulse, the multiplication factor for the 10/1000 µs pulse is 10.7 times the I_{PP} at 10/1000 µs for waveform 3. The values may vary slightly (±10%), with the curve used for extrapolation.

For a 69-µs pulse in waveform 4, the tolerance is ±20%, so we use the worst-case high side of 83 µs.

Equation 2:
I_{PP} at 83 µs = (2,000 W/600 W) × 65.2 A (rated I_{PP} for SMBJ5.0)
=3.33 × 65.2 A
=217 A

For an 83-µs pulse, the multiplication factor is 3.33 times the I_{PP} at 10/1000 µs for waveform 4.

The multiplication factors of 10.7 times and 3.33 times derived in these equations apply to any rated power level (for example, 1.5 kW, 3 kW, and 5 kW). The 5-µs pulse may vary ±10% from one chart to another, but this is a non-issue, as silicon TVSs are very conservatively rated for short pulse widths. From Table 2 (see page 2) , one can observe that this device will easily perform at levels 3 and 4 for waveforms 3 and 4 under worst-case conditions.

Calculating Requirements for the TVS

In theprevious section, we extrapolated the P_{PP} from Figure 4 (see page 3) and calculated the equivalent I_{PP} for 5-µs and 83-µs pulse widths of specific device types. In this section, we will calculate the incident pulse current threat for a specific RTCA DO-160G threat level factoring in the influencing of the clamping voltage.

In level 4, waveform 4, the incident pulse threat is specified as a 750 V open-circuit voltage with a 150 A short-circuit current. THe operating voltage is ±12 V.

First, calculate source impedance Zs using the values of V_{OC} and I_{SC} in Table 2 (see page 2) .

Equation 3:
Z = Voc/Isc
=750 V/150 A
=5 Ω

When including clamping voltage (V_C) effects for waveform 4, the peak impulse current (I_{PP}) threat is:

Equation 4:
I_{PP} = (Voc–V_C)/Zs, where V_C is the device max clamping voltage
=(750 V–19.9 V)/5 Ω, where 19.9 V is the V_C of the SMBJ12CA or SMCJ12CA
=146 A

This same method of calculation is further described in MicroNote 125.

Using the factor of 3.33 times for waveform 4 (10/1000 µs), we have additional examples:

Equation 5:
SMBJ12CA capability is 30.2 A (10/1000 µs) × 3.33 = 101 A (6.4/83 µs)

Equation 6:
SMCJ12CA capability is 75.3 A (10/1000 µs) × 3.33 = 251 A (6.4/83 µs)

The SMBJ12CA, which has an I_{PP} rating of 101 A, is insufficiently rated for this hypothetical application. This leaves the SMCJ12CA as the only option for level 4, waveform 4. It is unnecessary to calculate for waveform 3, since its threat is well below the threat level of waveform 4.

As stated earlier, most transient voltages have attenuation levels above the source impedance, which is added by series resistors for circuit impedance matching in the signal loop.

For additional exercise, determine the performance level for an SMBJSAC5.0 under threat conditions of level 3, waveforms 3 and 4. To do this, we only need to determine the current for waveform 4, which has Voc and Isc values of 300 A and 60 A, respectively.

Equation 7:
Zs = 300 V/60 A = 5 Ω

Equation 8:
I_{PP} = (Voc–V_C)/Zs
=(300 V–10 V)/5 Ω
=58 A for 6.9/83-µs pulse

The HSMBJSAC5.0 has an I_{PP} of 44 A at 10/1000 µs. For 6.9/83 µs, I_{PP} is:

Equation 9:
I_{PP} = 44 A × 3.33 = 146.5 A for a 6.9/83-µs pulse

Here we observe that the SMBSAC5.0 is capable of withstanding a 145-A pulse for waveform 4, and the threat current of 58 A is well within its capability.

In practice, resistors are often used in-series on each data wire for impedance matching. This further reduces the incident current and provides an increased guard band for protection of data transfer line interfaces.

Please be certain that temperature derating is used as applicable. Silicon TVS plastic encapsulted devices linearly derate from a maximum surge capability at 25 °C, down to zero at 150 °C, whereas metal or glass-encapsulated devices will derate to zero at 175 °C. Plastic devices are reduced to 50% of their maximum rated I_{PP} at 85 °C and 37% at 100 °C. See MicroNote 114 for this and other derating methods that have also been used in the industry. TVS datasheets should show the recommended derating method chosen.

Applications

Protective devices are always placed from line-to-common for common mode protection and line-to-line for differential mode protection. With many circuits, only common mode protection on each interface is required, as differential mode is provided through termination to circuit ground.

TVS devices must be placed on circuit boards at the point of entry of the signals with a direct connection to circuit ground. Shielding is connected to frame ground. For low capacitance devices, two must be used in antiparallel for bidirectional protection. For a low-speed line, less than 12 kbps, a single bidirectional standard capacitance device is adequate.

The incident current will be determined (to an extent) by the value of R3, which is specified by the line driver/receiver manufacturer. Use the value of R3 to recalculate the value of Zs. Assume the Zs has been increased to 8 Ω with an R3 value of 3 Ω, compared to the initial value of 5 Ω in equation 4. With equation 4, the lower value of the peak impulse current (I_{PP}) threat for waveform 4, level 4 can be determined as follows:

Equation 10:

$I_{PP} = (V_{OC} – V_C)/Z_S$

$=(750\ V – 19.9\ V)/8\ \Omega$

$=91\ A$

With the added series resistance providing a Zs of 8 Ω, the threat current is reduced to 91 A from 146 A. Per Equation 5, the smaller SMBJ12C will be adequate for this application. The larger, higher power SMCJ12CA device is unnecessary, unless required in temperature derating.

Harsh Environments

In addition to standard products, Microsemi also provides options for additional screening, where harsh application environments may dictate the need. For flight hardware, Microsemi offers avionics-grade component screening, available by adding an MA prefix to the standard part number. This screening is performed on 100% of the production units and includes additional surge tests, temperature cycling, and high-temperature reverse bias. For applications where a militarized device is required and no qualified part exists, Microsemi offers equivalent JAN, JANTX, JANTXV, and JANS designated by adding MQ, MX, MV, or MSP prefixes respectively to the standard part number.

Summary

The author has thoroughly reviewed the requirements of RTCA/DO-160G and provided the user with the means to convert surge current ratings at 10/1000 µs on TVS datasheets for voltage and current lightning waveforms, specified for aviation. This is to guide the designer more directly in selecting a TVS device.

Equation derivation has narrowed the TVS device selection process. However, any additional highline long-term voltages (usually tens of milliseconds) should not exceed the minimum breakdown voltage of the TVS.

A similar application note for lightning on aircraft power lines has been published, MicroNote 127. This note provides guidance in selection through traditional 10/1000 µs waveform conversions. Several equation examples and conversion tables are provided to aid the design engineer.

Microsemi has a wealth of experience in design, manufacturing, and applications experience in providing service to the aerospace industry.

Support

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