Lightning Protection for Aircraft per RTCA/DO-160D and ARINC 429 Protocol

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Threat and Environment

Lightning strikes to jet airliners are common, about once every 1,000 flying hours, while passengers and crew are safely transported to their destinations. Any failures of *fly-by-wire* systems at data signal interfaces are totally unacceptable. Surge protection at thousands of signal line interfaces provides reliable, continued performance from damaging voltage spikes using the designer's choice of **silicon Transient Voltage Suppressor** (TVS) devices.

ARINC (Aircraft Radio Inc.) 429 is the signal protocol used for virtually everything that flies, transferring critical data including airspeed, temperatures, tire pressure, center of gravity, fuel weight, engine performance, external control surfaces and a host of others. Interconnections are twisted, shielded line pairs for reduction of noise and induced lightning transients. There are two data transmission speeds, 12 - 14 kbs and 100 kbs with operating voltages typically ranging from +/- 5 V up through +/- 17V.

TVS types for these applications normally include bi-directional 600 W Peak Pulse Power (Ppp) ratings @ 10/1000 μs such as the SMBJ5.0CA series for slow data rates and the low capacitance HSMBJSAC5.0 types for 100 kbs data rates. The 1500 W rated SMCJ5.0 and SMCJLCE low capacitance series are similarly required on more severe lightning threats defined per RTCA/DO160-D, Table 22-2.

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

The following sections guide the designer in selecting optimum suppressor devices.

ARINC TVS Selection Matrix

| Ipp Exposure levels	for 12 kbs Data Rate	for 100 kbs Data Rate
Low	**SMBJ5.0CA Series**	**HSMBJSAC5.0 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 spec 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 as described in RTCA/DO-160D. Section 22, Table 22-2 of this document accurately defines threat levels, including open circuit voltage and short circuit current plus six waveforms ranging from 5 μs up through 500μs. Pin surge levels are listed in a matrix of fifteen separate pin injections threats as shown below:

RTCA/DO-160D Table 22-2
Pin Injection Levels

| LEVEL	Waveforms		
	3	4	5A
	Voc/Isc	Voc/Isc	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 Level 4 at worst case. Waveforms are shown below:
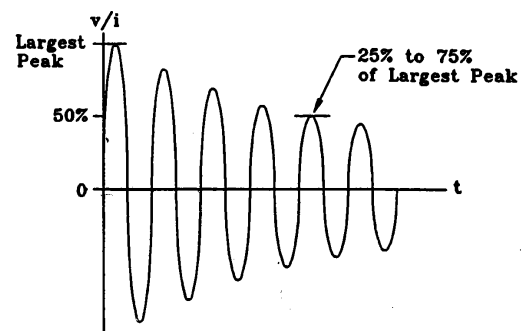
NOTE: Frequency for pin injection test is applied at 1.0 MHz (±20%). Voltage and current are not necessarily in phase.
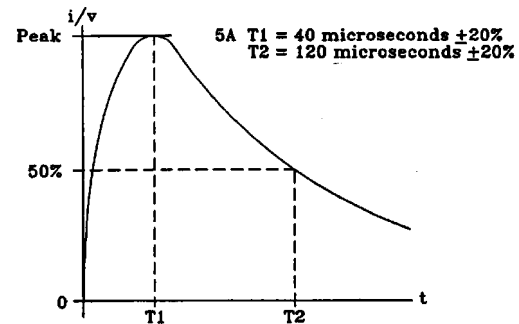
RTCA/DO-160 Figure 22-4 Voltage/Current Waveform 3

T1 = 6.4 microseconds ±20%

T2 = 69 microseconds ±20%
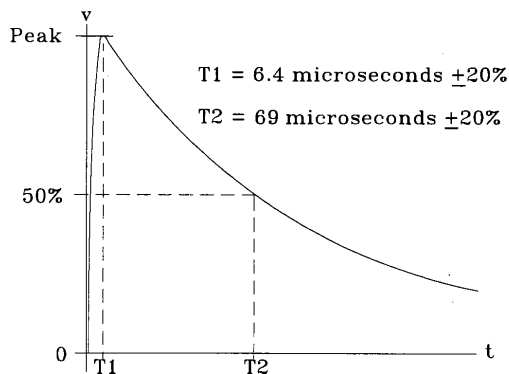
**RTCA/DO-160 Figure 22-5 Voltage
Waveform 4**

Calculating Ipp capability

Let's work out an example for protecting a
slow data rate line, 14kbs per ARINC 429,
initially selecting an SMBJ5.0C for this
application. What is its capability for protecting
from a surge at Level 3, Waveforms 3 and 4 in
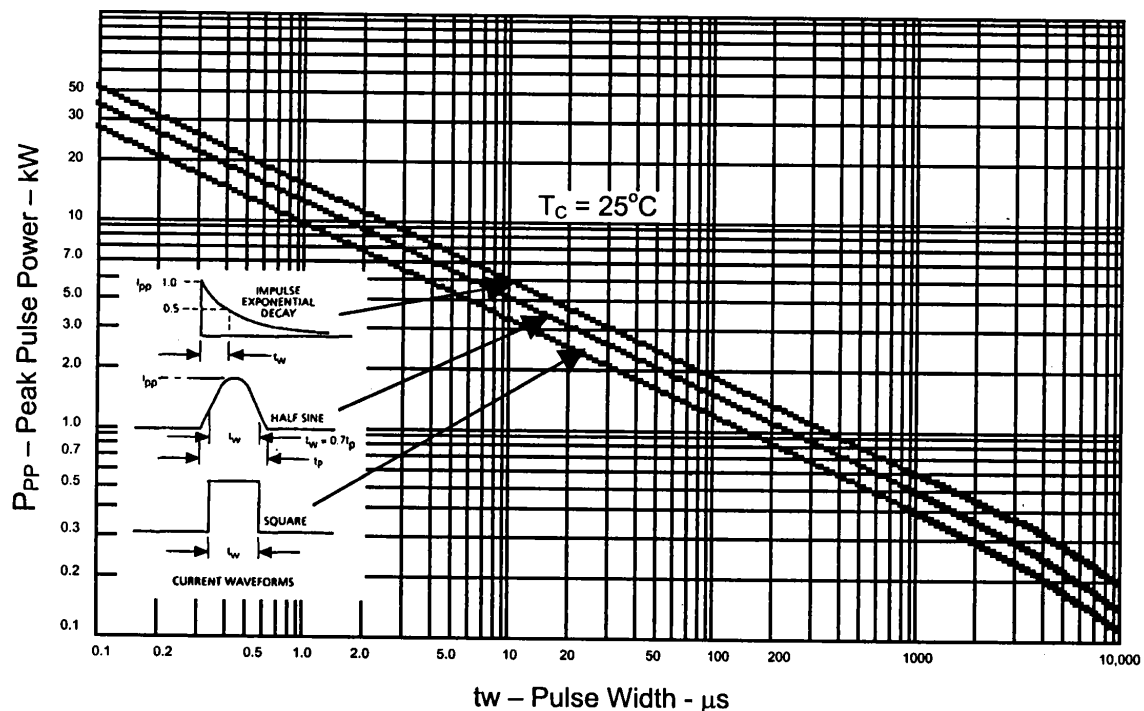**Table 22-2?** First we translate the maximum

TVS peak pulse current (Ipp) rating of the
10/1000 μs into its equivalent for waveform 3.

5A T1 = 40 microseconds ±20%
T2 = 120 microseconds ±20%

**RTCA/DO-160 Figure 22-5 Voltage
Waveform 5A**

We need to refer to the Ipp vs time graph for the
10/1000 μs below:

Peak Pulse Power vs Time for SMBJ 600W Series

$T_C = 25^oC$

tw – Pulse Width - μs

For further reference, review MicroNote™ 104 at www.microsemi.com/micronote/104.pdf. Waveform 3 is conservatively equivalent to less than 5 μs duration with an applied frequency of 1.0 MHz (±20%). To calculate the equivalent current capability of the SMBJ5.0CA, use the following method:

Ipp @ 5 μs = (Ppp @ 5 μs / Ppp @ 1000μs) x Ipp of SMBJ5.0CA @10/1000 μs   (Eq. 1)

   = (6,400 W / 600 W) x 65.2 A – the values of 6600 W and 600 W are from the Peak Pulse
                                 Power vs time graph of 600 W SMBJ Series (on page 2)

   = **10.7** x 65.2 A
   = 698 A

For a 5 μs pulse, the multiplication factor for the 10/1000 μs pulse is **10.7x the Ipp 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.

Ipp @ 83 μs = (2,000 W / 600 W) x 65.2A (rated Ipp for SMBJ5.0)   (Eq. 2)

   = **3.33** x 65.2 A
   = 217 A

For an 83 μs pulse, the multiplication factor is **3.33x the Ipp at 10/1000 μs for Waveform 4.**

The multiplication factors of **10.7x and 3.33x** derived in these equations apply to any rated power level, e.g., 1.5 kW, 3 kW, 5 kW. The 5 μs pulse may vary +/- 10% from one chart to another, but this is a non-issue since silicon TVSs are very conservatively rated for short pulse widths. From Table 22-2, one can observe that this device will easily perform at Levels 3 and 4 for Waveforms 3 and 4 under worst-case conditions.

Calculating Requirement for the TVS

In the section above, we extrapolated the Ppp from the Ppp vs time graph and calculated the equivalent Ipp for shorter pulse widths of 5 μs and 83 μs for specific device types. In this section we will calculate the incident pulse current threat for a specified DOD-160D level factoring in the influence of the clamping voltage.

In Level 4, Waveform 4, the incident pulse threat is specified as a 750V open circuit voltage with a 150 A short circuit current. The operating voltage is +/- 12 V. Do we need an **SMBJ12CA** or a higher current **SMCJ12CA** TVS device?

First, calculate source impedance, Zs, using the values of Voc and Isc in Table 2-22.

   Z = Voc / Isc   (Eq. 3)
      = 750 V / 150 A
      = 5 ohms

The Peak Impulse Current (I_{PP}) threat when including clamping voltage (V_C) effects for Waveform 4 is:

   I_{PP} = (Voc – Vc) / Zs   (Where Vc is device max clamping voltage.)   (Eq. 4)
      = (750V – 19.9V) / 5 ohm   (19.9 V is the V_C of the SMBJ12CA or SMCJ12CA)
      = 146 A

This same method of calculation is also further described in MicroNote 125 at: http://www.microsemi.com/micnotes/125.pdf

Using the factor of **3.33x for Waveform 4** calculated in equation 2, (10/1000 μs Ipp rating) for additional examples we have:

   SMBJ12CA capability is 30.2 A (10/1000 μs) x 3.33 = 101 A (6.4/83 μs)   (Eq. 5)
   SMCJ12CA capability is 75.3 A (10/1000 μs) x 3.33 = 251 A (6.4/83 μs)   (Eq. 6)

The SMBJ12CA having an Ipp rating of 101 A, is insufficiently rated for this hypothetical application leaving the SMCJ12CA as is the only option for Level 4, Waveform 4. It is unnecessary to calculate for Waveform 3 since its threat is inherently well below the threat level of Waveform 4.

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

For an additional exercise, what would be the performance level for an HSMBJSAC5.0 under threat conditions of Level 3, Waveforms 3 and 4? Again, we only need to determine the current for waveform 4 which has Voc and Isc values of 300 A and 60 A respectively.

$$Zs = 300 \text{ V} / 60 \text{ A} = 5 \text{ ohms} \qquad\qquad \text{(Eq. 7)}$$

$$\begin{aligned} I_{PP} &= (Voc - Vc) / Zs \qquad\qquad \text{(Eq. 8)} \\ &= (300V - 10V) / 5 \text{ ohms} \\ &= 58 \text{ A for } 6.9/83 \text{ μs pulse.} \end{aligned}$$

The HSMBJSAC5.0 has an Ipp of 44 A @ 10/1000 μs. For 6.9/83 μs Ipp is:

$$Ipp = 44 \text{ A x } 3.33 = 146.5 \text{ A for a } 6.9/83 \text{ μs pulse} \qquad \text{(Eq. 9)}$$

Here we observe that the HSMBSAC5.0 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, hence further reducing the incident current and providing an increased guard band for protection of data transfer line interfaces.

Please be certain that temperature derating is used as applicable. Silicon TVS plastic encapsulated devices linearly derate from a maximum surge capability @ 25ºC down to zero @ 150ºC whereas metal or glass encapsulated devices will derate to zero @ 175ºC. Plastic devices are reduced to 50% of their maximum rated Ipp @ 85ºC and 37% @ 100ºC. See MicroNote 114 for this and other derating methods that have also been used in the industry. TVS data sheets 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 since 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 bi-directional protection as shown in Figure 1. For a low-speed line, < 12 kbs, a single bi-directional standard capacitance device is adequate.

The incident current will be determined to an extent by the value of R3, which is specified by

Typical ARINC Line Driver
(e.g. Holt IC HI-8583)

R1   Built-in series resistor.
R2/R3   For protection and impedance matching.
        See manufacturers recommended values.
TVS   Microsemi HSMBJSAC5.0 – requires two devices
        connected in anti-parallel for each wire.
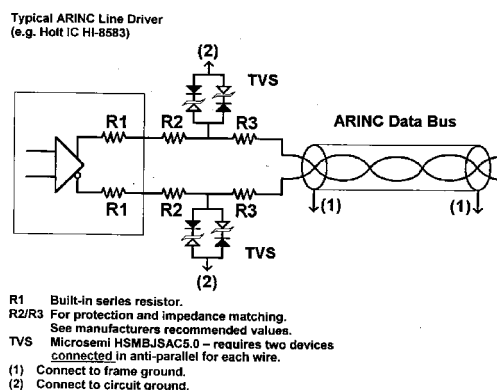(1)   Connect to frame ground.
(2)   Connect to circuit ground.

Figure 4. Protected High Speed Line Driver.

the line driver / receiver manufacturer. Use the value of R3 to recalculate the value of Zs. Assume the Zs has been increased to 8 ohms with an R3 value of 3 ohms compared to the initial value of 5 ohms in eq. 4. With equation 4, the lower value of the **Peak Impulse Current**

(**I$_{PP}$**) threat for Waveform 4, Level 4 can then be determined as follows in equation 10:

$$I_{PP} = (Voc - Vc) / Zs \qquad (eq.\ 10)$$
$$= (750\ V - 19.9\ V) / 8\ ohms$$
$$= 91\ A$$

With the added series resistance to provide a Zs of 8 ohms, the threat current is reduced to 91A from 146A . Per equation 5, the smaller, SMBJ12C will be adequate for this application and the larger, higher power SMCJ12CA device is unnecessary unless temperature derating still requires the higher power TVS.

Harsh Environments

In addition to standard product, 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 in accordance with MIL-PRF-19500, Microsemi offers equivalent JAN, JANTX, JANTXV, and JANS so 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-160D and provided the user with the means of converting surge current ratings at 10/1000 μs on TVS data sheets to voltage and current lightning waveforms specified for aviation. This should guide the designer more directly to a given TVS device for a specific requirement.

Derivation of equations for accurately calculating the surge current requirements of any aircraft surge waveform has narrowed the TVS device selection process; however, any added 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, MicroNote™ 127, has also been published for guidance in selection through conversions from the traditional 10/1000 μs wave forms to the DO-160D requirements. Several examples are provided with equations and conversion tables to aid the design engineer.

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

Please call on us to provide speedy solutions to your transient voltage protection needs.

For additional technical information, please contact Mel Clark (mclark@microsemi.com), Kent Walters (kwalters@microsemi.com), or Ken Dierberger (kdierberger@microsemi.com).

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