# Lightning Protection for Aircraft Electrical Power and Data Communication Systems

**By Mel Clark and Kent Walters**

A jetliner is struck by lightning at least once every 1,000 flying hours while safely transporting passengers and crew to their destination. Within its thin metal and composite shell, tens of thousands of sensitive semiconductor chips are performing critical functions, from navigation to jet engine controls. Each of these components must be protected to maintain a safe, reliable performance. Every new jet aircraft design undergoes more than 1,000 simulated lightning zaps to determine the protection levels and suppressor placement required for its myriad of power and signal lines.

Lightning-caused transient voltages are defined in the aircraft standard RTCA/DO-160G. Both voltage and current threat levels, along with their waveform types, are defined in Section 22, Tables 22-2 and 22-3 with peak pulse currents ranging from 4 A to 5,000 A. Waveform durations range from a few microseconds up to 500 microseconds, illustrating the broad range of lightning threats to avionics equipment.

Transient voltage protection from lightning must be totally effective in order to prevent equipment failure from potentially damaging surges. The silicon transient voltage suppressor (TVS) has been designers' first choice for optimum performance. TVS devices populate circuit boards extensively throughout aircraft systems. TVS devices across ac and dc power distribution lines must also be compatible with short-term, high-line voltage excursions produced by electrical generating systems.

This Microsemi application note provides a thorough guide for the design engineer in determining the most effective TVS protection across power and signal line interfaces. It explains how to convert the power and current levels of the traditional 10/1000 $\mu$s waveform as specified for most TVS devices, or any other waveform, to those for aircraft protection requirements. Many examples will illustrate and assist TVS device selection for almost all aircraft lightning protection applications.

## Lightning Threats

Power distribution lines in recent aircraft designs are a growing risk to lightning, due to reduced shielding afforded by weight-saving composite materials. More rugged TVS devices are needed in this increasingly severe lightning environment to withstand a greater magnitude of threat. Meeting these stringent surge requirements in a single package has been accomplished with Microsemi's RT130KP TVS series, which is available for protection across 120 V ac and 28 V dc power distribution lines. The RT130KP295 (normal clamp) and RT130KP295KPCV (low clamp) devices are specifically available for 120 V ac and RT65KP48A for 28 V dc aircraft power distribution lines. Datasheets for these and other newer applicable TVS types, such as the high power PLAD products (rated up to 36 kW for 10/1000 $\mu$s), can be accessed on Microsemi's web site at www.microsemi.com.

Data interface transfer signals (DITS), as defined in ARINC 429, normally operate from 5 V to 15 V levels to control and monitor a vast number of functions, including jet engine controls, navigation and exterior control surfaces, and a host of others. Many of these functions are redundant for added reliability. Compared to power, signal line impedances are inherently high (75 $\Omega$ for transmitter outputs and 12,000 $\Omega$ for receiver inputs) and have impedance matching resistors that significantly attenuate induced lightning currents. Shielded, twisted pairs for interconnections further reduce lightning threats. Typically, 600 W to 1.5 kW, for 10/1000 $\mu$s rated devices, provide adequate protection. Specific TVS selection for signal and power lines is addressed below.

Pin injection tests, featured in RTCA/DO-160G as shown in Table 1 (see page 2), represent worst-case lightning threats to power and data interfaces. These are expressed in a matrix of pin injection levels for open circuit voltage (Voc), short circuit current (Isc), and pulse waveforms. Threats to a given pin depend upon the level of exposure defined by location, length of interconnecting conductors, proximity to aircraft skin, and the degree of inherent shielding. Lightning exposure is listed in five ascending degrees of magnitude defined in levels 1 through 5, with three different waveforms for a combination of fifteen individual threat types. The Voc and Isc provide the necessary information for calculating the transient voltage source impedance, Zs.
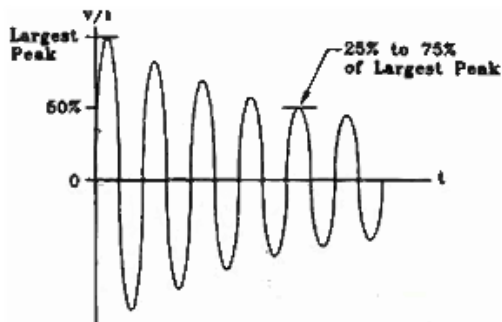
**Table 1: Test Levels for Pin Injection**

| 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 |

Cable bundle testing per DO-160G is a system function test in which all interconnecting cables between multiple interfacing system components are simultaneously surged via current coupling into each cable bundle. Multiple bundles may be tested simultaneously. Under such conditions, the current is divided among the conductors as determined by the impedance of each line within the bundle. Low impedance shields and power lines conduct the majority of induced current. Induced voltage waveforms will re-conform to the rate of change of the magnetic field in adjacent conductors. Equipment meeting pin injection tests will also meet the cable bundle induced current test requirements.
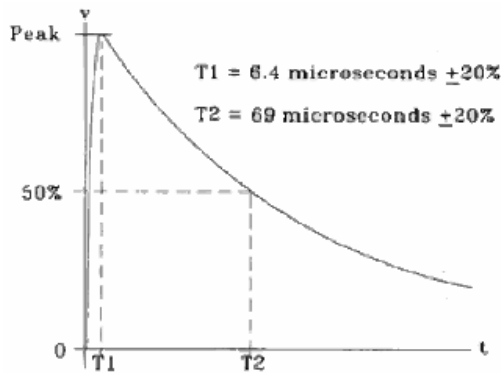
Product datasheets specify 6.4/69 μs surge waveforms for Microsemi's RT65KPxxCA and RT130KPxxxCA series. However, 10/1000 μs waveforms are traditional for most silicon TVS series from 400 W and higher. For aircraft applications, datasheet parameters must be converted into the DO-160G waveform equivalents shown in Figure 1 (see page 2) through Figure 3 (see page 3). These equivalents are derived using the peak pulse power (Ppp) versus pulse time (tp) curve shown in Figure 4 (see page 3). The pin injection test levels are the most severe as they define specific values of open circuit voltage and short circuit current threats applied directly to fragile semiconductor components.
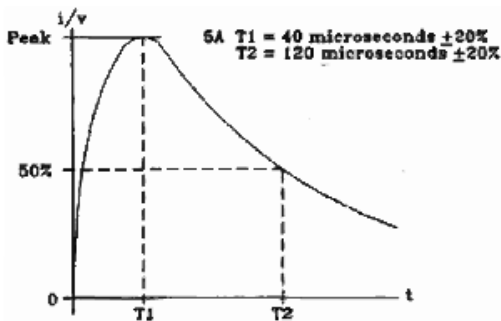
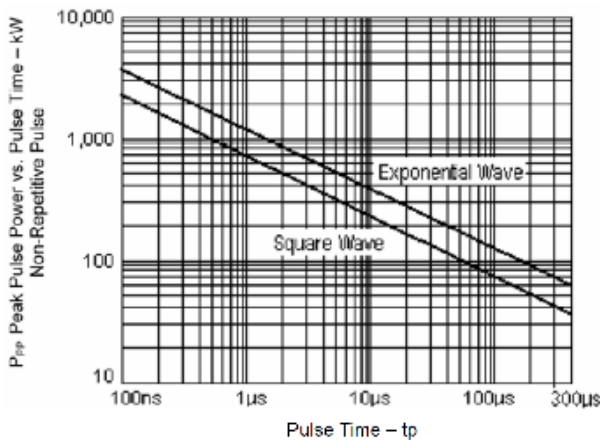**Figure 1: Waveform 3**



Note: Frequency is 1 MHz

**Figure 2: Waveform 4**



T1 = 6.4 microseconds ±20%

T2 = 69 microseconds ±20%

**Figure 3: Waveform 5A**



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

**Figure 4: Peak Pulse Power vs Pulse Time**



The peak pulse power versus pulse time (Ppp vs tp) graph shown in Figure 4 (see page 3) applies only to the RT130KP series, but the slope of the power curve, ΔPpp vs Δ tp, is virtually the same for all silicon TVS devices. Amplitudes vary with rating.

Always use the associated power versus time curve for a given device family (e.g., SMB, SML, 5KP, etc.) when interpolating for power (current) that is different from the value for which it is specified. For the RT130KP types, the pulse rises to peak in 6.4 $\mu s$ and decays to ½ peak value in 69 $\mu s$ , beginning from pulse start time. Note that in Figure 4 (see page 3), the power is 130 kW for a 69 $\mu s$ pulse width.

# Surge Current Ratings

Peak pulse current (Ipp) ratings for all silicon TVS devices follow a linear Log-Log peak power vs time duration relationship as illustrated in Figure 4 (see page 3). The numbers will vary according to the TVS rating but the slope of the graph is constant for TVSs over a broad range of power ratings. Based on the Wunch-Bell curve (developed at BDM under government contract in the late 1960s) two decades of decrease in time duration will yield an increase in power capability of one decade. The converse also applies. Most of the Ppp vs tp curves found in data sheets are conservative for pulse widths shorter than 50 $\mu s$ . Also see MicroNote 120.

Converting levels of peak pulse current as specified in a given datasheet to values over a wide range of pulse time durations is the objective of this application note. The specific goals are waveforms 3, 4 and 5A as defined in DO-160G, that are subsequently illustrated.

The oscillatory waveform 3 (DO-160G) is conservatively equivalent to an exponential pulse duration of 5 $\mu s$ . For the RT130KP295CV, rated at 69 $\mu s$, the equivalent power/current for a 5 $\mu s$ pulse has a higher peak power (500 kW) in Figure 4 (see page 3) with a subsequent peak current (Ip) rating that is calculated as follows:

Equation 1:
$Ip = (Pp/Ppp) \times Ipp$
$= (500\ kW/130\ kW) \times 282\ A$
$= 1084\ A$ for 5 $\mu s$

where:
Ip = calculated equivalent value for waveform 3 having duration of 5 $\mu s$ Ipp = 282 A,
Ipp rating of RT130KP295CV for 6.4/69 $\mu s$
Pp = peak pulse power, 500 kW, extrapolated from Figure 4 (see page 3)
Ppp = peak pulse power rating of 130 kW for RT130KP295CV for 6.4/69 $\mu s$

From the calculation above, we see that the RT130KP295CV will withstand a pulse current of 1084 A maximum for a shorter, 5 $\mu s$ time duration, 3.8 × the 69 $\mu s$ value of 282 A. The terms Ipp and Ppp define the max rating as specified in the data sheet while Ip and Pp designate a current / power waveform derived from the basic spec.

For waveform 4, the 6.4/69 $\mu s$ equivalent Ip rating is identical to the data sheet for the RT130KP295CV since its baseline rating is for a 6.4/69 $\mu s$ pulse, 282 A.

The value of 83 $\mu s$ is used to designate the full surge length as it is at the high end of the tolerance for the 6.4/69 $\mu s$ ± 20% waveform. In all calculations in this document, the high side of waveform tolerances will be applied to include worst-case surge levels.

For waveform 5A, its surge current equivalent for the RT130KP295CV TVS is:

Equation 2:
$Ip = (110\ kW/130\ kW) \times 282\ A$
$= 239\ A$ for 40/144 $\mu s$

where:
110 kW is the Pp for a 144 $\mu s$ pulse.
239 A, a yet lower value for the longer 144 $\mu s$ pulse.

For a duration of 144 $\mu s$ , the Ip equivalent is less, because of its longer pulse. As the pulse width extends beyond that for the device for which it is rated, Ip decreases. For shorter pulses, Ip increases.

From the derivations above, we have shown that although the RT130KP295CV is rated for 282 A for 69 $\mu s$ , its equivalent peak surge current protection levels for DO-160G defined surges per waveforms 3, 4, and 5A, or any other waveform, can be calculated using the methods illustrated.

# Applications for Power

When protecting across power lines, the TVS Ipp requirements, on quick inspection, may be misleading. Source impedance and open circuit voltage can play a key role in limiting surge currents. For example, assume that a level 4 condition (750 Voc/150 Isc) must be met for a type 4 waveform (6.4/69 μs ). What is the conducted surge current of the RT130KP295CV with a clamping voltage, Vc, of 410 V? The suppressor is protecting a 400 V rated transistor in a switching power supply that will typically withstand 40 V above the transistor's rated maximum operating voltage. The RT130KP295CV protects by clamping at 410 V maximum.

First, we calculate source impedance (Zs) of the transient:

Equation 3:
$Zs = (750\ Voc/150\ Isc)$
$= 5\ \Omega$

With a maximum Vc across the TVS of 410 V the maximum peak current, Ip, through the TVS, is:

Equation 4:
$Ip = (Voc - Vc)/Zs$
$= (750\ V - 410\ V)/5\ \Omega$
$= 68\ A$ for ac power line

where:
Voc = open circuit incident voltage
Vc = max clamping voltage of RT130KP295CV TVS
Zs = source impedance

Calculations above are for 25 °C ambients with the junction temperature at 25 °C. Derating for elevated temperatures is reviewed in "Clamping Factor" (see page 11), with the derating curve shown in Figure 6 (see page 10) and Equation 12 illustrating a calculation for Ip derating for elevated temperature.

The 410 V Vc of the TVS is equivalent to a battery and subtracts from the 750 V Voc value. In this example, the Vc is more than one half of the Voc, thus reducing the Ip value to less than one-half of the Isc. However, when Vc is a small percentage of Voc, its contribution to Ip reduction becomes negligible.

Protection across lower voltage DC power distribution lines requires more peak pulse current (Ipp) capability for the same level 4 threat than for ac, because dc bus operating and clamp voltages are lower, as illustrated below.

Let's compare the pulse current requirement of the RT130KP48A with the pulse current of the RT130KP295CV for the same surge current conditions of waveform 4, level 4 (750 Voc/150Vsc).

For Zs = 5 Ω , per Equation 4 above:

Equation 5:
$Ip = (Voc - Vc)/Zs$
$= (750\ V - 77.7\ V)/5\ \Omega$
$= 135\ A$ for dc power line

where:
Vc = maximum clamping voltage of RT65KP48A

For level 4 threats, a higher pulse current of 135 A is delivered on lower voltage dc lines than on the same equivalent threat suppressing an Ip of 68 A on higher voltage ac lines as shown in Equation 4. The clamping voltage, Vc, is the contributing factor. At only 77.7 V for the 48 V line, the driving voltage increases with a proportional rise in Ip.

For low-current drain loads of small fractions of an ampere, it may be possible to insert a series resistor providing a high Zs to significantly reduce surge currents, making it possible to use a low power TVS such as a 600 W or 1.5 kW TVS across the line. Such an application is illustrated in the following hypothetical scenario:

DC power = 28 V bus
load current = 0.020 A
series resistor selection = 50 Ω

Voltage drop across the resistor per Ohm's Law is 1 V with a load current of 20 mA providing a nominal operating voltage of 27 V. A similar application is used for a booster motor in raising the overhead bins. Steady state power dissipated in the resistor is a comfortable 20 mW. The surge current through a 28 V TVS with a 45.4 V Vc per level 4, waveform 4, is:

Equation 6:
$I_p = (V_{oc} - V_c)/Z$
= (750 V - 45.4 V)/55
= 14 A for a 6.4/69 μs waveform

The SMBJ28A, rated for 13.2 A for 10/1000 μs , has an Ipp of 43.5A for 6.4/69 μs with a broad margin for safety and temperature derating in this application. Instantaneous surge power through the series current limiting resistor is 10 kW. Wire wound and carbon composition resistors normally survive the heat surge while thin film resistors are insufficiently robust and fail open. The resistor selection is left to the designer. Peak surge current conversions to DO-160G waveforms from data sheet 10/1000 μs waveforms are illustrated in the next section.

## Converting 10/1000 μs Pulse Equivalents to DO-160G Waveforms
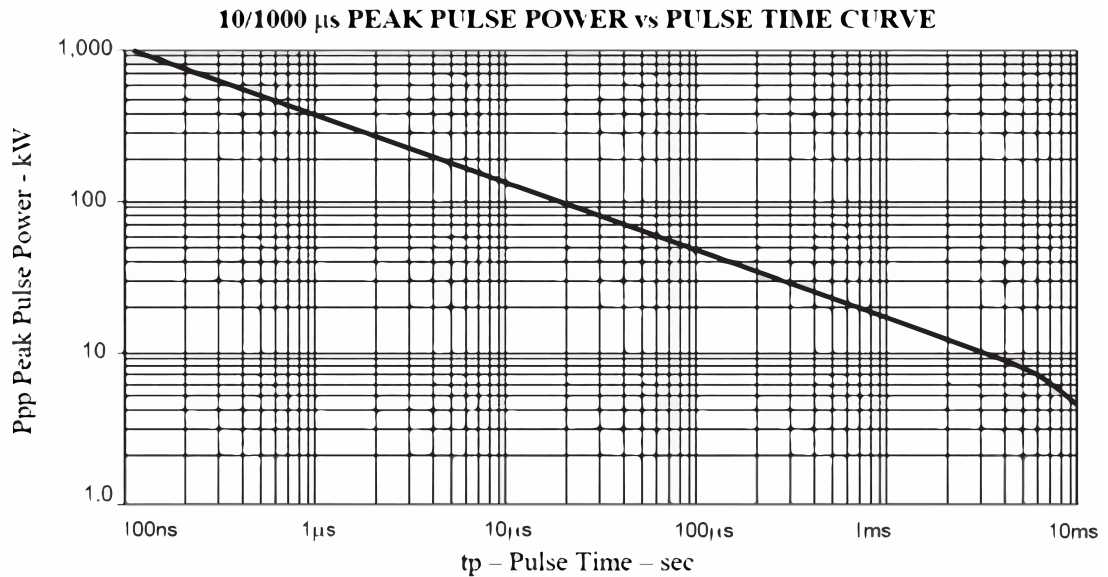
Silicon TVS devices are rated for peak pulse current, Ipp, with a 10/1000 μs waveform, a carryover from an early Bell Telephone Laboratories specification still in effect when silicon TVS technology was in its embryonic stages. Since early TVS components, test equipment and customer needs were developed to the Bell Lab standard, it has been universally accepted by the industry for all devices from 400 W Ppp rating and higher. MicroNotes 104 and 120 illustrate converting the power and current rating of the listed 10/1000 μs wave into the equivalent Pp and Ip of other pulse widths.

Waveform conversions from 10/1000 μs to DO-160G types are subsequently illustrated including the oscillatory waveform 3, the exponential 6.4/69 μs waveform 4 and the 40/120 μs waveform 5A. These conversions provide the equivalent pulse current rating of the 10/1000 μs waveforms found in most TVS datasheets, easing the task of the design engineer in selecting a TVS for a given DO-160G threat level and waveform.

The peak pulse power (Ppp) vs pulse time (tp) curve immediately below was developed for the 15 kW power TVS series and covers five decades of time, from 100 ns to 10 ms, and four decades of power from 1 kW up through 1000 kW. For a four decade decrease in pulse width, power is increased by two decades.

The slope of this curve is the same for all device power levels so it can be used for conversion of all TVS power/current levels, from 400 W up through 30 kW ratings at 10/1000 μs .

**Figure 5: 10/1000 µs Peak Pulse Power vs. Pulse Time Curve for 15KPxxx series**



The oscillatory DO-160G waveform 3 (Figure 1 (see page 2)) is conservatively equivalent to a 5 µs duration pulse. To calculate the equivalent 10/1000 µs Ipp rating for a 15KP48A silicon TVS for 5 µs, use the following method:

Interpolate the Ppp versus tp curve and select the Pp value equivalent to 5 µs, which is 170 kW, and insert it into the equation below. Insert the Ipp for the closest estimated device fit for your application. In this example, we are considering the 15KP48A for a 28 V bus, the 48 V required for abnormal high-line conditions.

Equation 7:
Ip for 5 µs = (Pp at 5 µs/Ppp at 10/1000 µs) × Ipp of 15KP48A
= (170 kW/15 kW) × 193 A
= 11.3 **×** 193 A
= 2,190 A for 5 µs
For a 5 µs pulse, the increase in Ip capability is 11.3 × the Ipp at 10/1000 µs for DO-160G waveform 3. Values may vary ±10% depending on small variations in the graph used for interpolation. Ipp represents the data sheet specified value while Ip is the derived value per Equation 7.

Waveform 4 is 6.4/69 µs, but using the high side of +/- 20%, the worst case is 83 µs. All values should be adjusted to the high end of a specified tolerance. Continuing to use the parameters of the 15KP48A, the equivalent peak current rating at 6.4/69 µs is:

Equation 8:
Ip for 6.4/83 µs = (50 kW/15 kW) × 193 A
= 3.33 × 193 A
= 643 A at 4.6/69 µs
For waveform 4 of 83 µs (69 + 20%) the increase in capability is 3.33 times .

Waveform 5A is 40/120 µs and with a high side of +20% tolerance, it is 144 µs in duration. Continuing with the parameters of the 15KP48A, peak surge rating for this waveform is:

Equation 9:
Ip for 40/144 µs = (35 kW/15 kW) × 193 A
= 2.33 × 193
= 450 A at 40/120 µs
For waveform 5A of 144 µs (120 + 20%) the increase in capability is 2.33 times.

# DO-160G Conversions Simplified

A waveform conversion table was developed from the above information. It provides a multiplication factor to convert the Ipp of 10/1000 µs waveform silicon TVS to the desired DO-160G waveform for all pin injection test levels per Table 1 (see page 2) above. These values are for a quick estimation to determine approximate fit. Table 2 (see page 8) estimates worst-case current surge. For calculating accurate Ip values through the TVS, apply Equations 4 and 5. Ip values are valid only at 25 ° C. For elevated temperatures, derating must be applied as described later.

**Table 2: DO-160E Waveform Conversion Factors**

| Waveform Number | 3 | 4 | 5A |
|---|---|---|---|
| Pin injection waveform | Sine wave | 6.4/69 µs | 40/120 µs |
| Ip&Pp increase above 10/1000 µs | 11.3 × | 3.33 × | 2.33 × |

**Examples using the waveform conversion factors.**

From the information provided in Table 2 (see page 8), one can easily estimate the Ipp requirement of standard catalog devices rated at 10/1000 µs for DO-160G waveforms. For Waveform 4, the 10/1000 µs Ipp requirement would be one third of the equivalent for the DO-160G pulse. In selecting a device for an application, you may need to include an additional 30-40% margin of the Ipp for temperature derating as required.

For example, consider the need for protection across a 12 V line with no abnormal high limits, to meet the requirements of level 3, waveforms 3 and 4 in Table 1 (see page 2). The electrical threat is 300 Voc /60 Isc per waveform 4. From Table 2 (see page 8), the Ip must be at least 33% of the 60 A short circuit value. From the product datasheets, we find the SMBJ12A has an Ipp rating of 30.2 A, a good trial fit. Its rating for a 6.4/69 µs pulse is:

Equation 10:
Ip for (6.4/69 µs) = Ipp at 10/1000 µs × 3.33 (per Table 2 (see page 8))
= 30.2 A × 3.33
= 101 A for SMBJ12A

The Ip rating of 100 A is 40 A greater than required for 60 A protection at 25 °C . This will provide a 60% margin for derating at elevated temperatures. The SMBJ12A would be a suitable choice for this need. For a more demanding requirement, select from the next higher Ipp rated device series, the SMCJ12A.

As illustrated earlier, if the device will withstand the surge current of Waveform 4, it will easily withstand Waveform 3, having a pulse duration of 5 µs with a waveform of (600 Voc/24 Isc). The SMBJ12 equivalent surge withstand Ip for 5 µs is:

Equation 11:
Ip for (5 µs) = Ipp at 10/1000 µs × 11.3 (per Table 2 (see page 8))
= 30.2 A × 11.3
= 341 A

The Ip requirement is only 24 A for the associated waveform 3, so by inspection we can see that the Ip capability of the SMBJ12A at 5 µs, 341 A, is more than adequate for the Ip requirements.

One can see from the examples above that conversion has been reduced to simple math for making conversion of the data sheet 10/1000 µs Ipp rating and is easily translatable to the Ip requirements for the three waveforms specified for pin injected lightning threat requirements.

# Equivalent Lightning Pulse Current Ratings

As illustrated above, the 10/1000 µs waveforms have greater peak current equivalents when converting to the DO-160G standards. The following segment provides guidelines for calculated values of a broad spectrum of TVS types rated at 10/1000 µs and their equivalent Ip ratings for waveform types 3, 4 and 5A per .

**Table 3: 5 V Through 295 V Ip Equivalents for DO-160G Waveforms 3, 4, and 5A**

| Operating Voltage | Microsemi TVS 10/1000 µs | Ipp 1 × | Equivalent DO-160G - Ip Aircraft Lightning Threat | | |
|---|---|---|---|---|---|
| | | | Waveform 3 11.3 × | Waveform 4 3.33 × | Waveform 5A 2.33 × |
| | | | 5 µs | 6.4/69 µs | 40/120 µs |
| 6.0 V 33.0 | 600 W SMBJ6.0A SMBJ33A | 58.3 A 11.3 | 658 A 127 | 194 A 38 | 136 A 26 |
| 6.0 V 33.0 | 1.5 kW SMCJ6.0A SMCJ33A | 146 28 | 1645 316 | 485 93 | 339 65 |
| 6.0 V 33.0 | 3 kW SMLJ6.0A SMLJ33A | 291 56.2 | 3288 635 | 969 187 | 678 131 |
| 33.0 47.0 | 5 kW 5KP33A 5 kW 5KP48A | 94 65 | 1062 734 | 313 216 | 219 151 |
| 48.0 240.0 | 15 kW 15KP48A 15 kW 15KP240A | 193 39 | 2181 441 | 643 130 | 450 91 |
| 48.0 250.0 | 30 kW 30KP48A 30 kW 30KP250A | 386 74 | 4362 836 | 1285 246 | 899 172 |
| **RT130KPxxxC Series** 6.4/69 µs rating | | | **From Equations 1, 2, & 3, factors are based on 6.4/69 µs as shown** | | |
| | | Ipp 1 × | 3.8 × | 1.0 × | 0.84 × |
| 48.0 295 | RT65KP48A RT130KP295CV | 836A 282 | 3177A 1072 | 836A 282 | 702A 237 |

This matrix provides guidelines for the increased level of Ip for DO-160G waveforms when selecting from the 10/1000 µs rated standard product. The lower voltages represent applications for signal lines including analog, ARINC 429 and synchro lines, the majority of which are 32 V or less. The higher power 5KPxxx, 15KPxxx, and 30KPxxx series devices are characterized for approximate values required in ac and dc power line transient applications.

Although shown as unidirectional devices, all of the above are available as either unidirectional or bidirectional. To designate bidirectional for the 10/1000 µs devices illustrated, use a CA suffix. For example, a bidirectional equivalent of the SMBJ6.0A would be SMBJ6.0CA. There are no differences in their transient suppression characteristics. The unidirectional devices clamp in the forward direction through forward diode conduction, with a low voltage drop.

The RT65KPxxx and RT130KPxxx series are rated at 6.4/69 µs , hence a reduction in Ip occurs with waveform 5A since its pulse width is greater than 69 µs .

# Abnormal Surge (High-Line Voltage)

Generator outputs on both ac and dc power lines can raise the normal line voltage by 40% or more. These anomalies are inherent in the generator regulation system and also attributed to load switching or remedial fault clearing. Duration of these voltage surges can extend to 100 ms. (Ref Section 16. RTCA /DO-160G)

It is impossible to clamp an abnormally high surge voltage produced by any large generating system such as that of a large aircraft. This over-voltage has very low source impedance, of the order of milliohms, and delivers a current level that is not practical to suppress. The only option is to select a device having a breakdown voltage above the high-line peak value. For example, an abnormal surge of up to 250 V ac peak may require a device having a Vbr of 300 V, such as for the RT130KP275CV, to include a margin for additional reliability plus high-temperature excursions.

Abnormal surge voltage is occasionally overlooked in selecting surge protection diodes, so please consider this at the initial stages of transient protection planning.

# Derating for Elevated Temperatures

Increasing the operating temperature of a silicon TVS requires a reduction in surge current. This maintains a safe working level for the device, keeping the silicon below its "intrinsic temperature," a state at which the *pn* junction becomes unstable and begins to conduct randomly instead of evenly across the surface. At this stage the full current surge funnels through a small "hot-spot," raising the temperature to the melting point of silicon, 1420 $°C$ , causing it to alloy with attachment materials and fail short. Also see MicroNote 135 on failure mechanisms for TVSs.

To prevent the junction from overheating and subsequent failure, the device is linearly derated (as shown in Figure 6 (see page )) with maximum Pp at 25 °C and subsequently decreasing to 50% at 150 °C, where it then abruptly drops to zero for plastic packaged devices. Also see MicroNote 114. Although most curves refer to Ppp, this also applies directly to Ipp since they are proportional to each other.

**Figure 6: Derating Curve**

This curve derates from maximum Ppp at 25 °C, linear to 50% at 150 °C and is applicable for all plastic encapsulated TVS devices, reducing Ipp rating at 0.4%/°C (TCV). At 80 °C a TVS is reduced to 78% of its Ipp maximum value at 25 °C as illustrated in Equation 12. Also see Micronote 114 and MicroNote 115 for further details in TVS derating, where hermetically sealed glass, metal, and ceramic packages can be extended further in temperatures out to 175 °C before abruptly dropping to zero.

For AC power distribution lines the RTCA130KP295CA, which withstands 282 A for a level 4, waveform 4 pulse (ref Equation 2), will be derated to 219 A at 80 °C as calculated:

$\Delta$ T = 80 °C – (25 °C)
= 55 °C

Equation 12:
Ip = Ipp – [Ipp × ( $\Delta$ T × (TCV)]/100
= 282 A – [282 A × (55 °C × 0.4%/ °C ) /100]
= 220 A

The derated Ip value can be interpolated with the aid of the derating curve or calculated for greater accuracy.

# Clamping Factor

The clamping factor (CF) of a TVS is a figure of merit in rating the effectiveness of transient voltage suppressor components. It is the ratio of the maximum clamping voltage at Ipp to the breakdown voltage. At maximum Ipp, the maximum CF value for silicon devices is typically 1.33 as shown:

Equation 13:
CF = Vc/Vbr
=1.33

The 1.33 value is typical of bench measurements with conservative values of 1.35 derived from the datasheets. Clamping voltage, Vc, is the highest voltage across the protected lines at Ipp as stated on the data sheet. For some sensitive components, a lower clamping factor may be required to reduce the voltage across the protected device. For more information on this subject, review MicroNote 108.

# Inductive Load Switching

Current-carrying inductive loads store energy expressed by Faraday's laws of induction as:

Equation 14:
$E = \frac{1}{2} LI^2$
Where: E is in Joules
I is in Amperes
L is in Henrys

When current flow is abruptly interrupted, the stored energy in the inductor is induced into itself, potentially producing a broad magnitude of transient voltages and waveforms depending on its electrical and magnetic parameters. Peak voltages are determined by component values along with the time rate change of the collapsing magnetic field in the inductor expressed as:

Equation 15:
v = –L (di/dt)
Where: L is inductance in Henrys
di/dt is the time rate of change of current

Switching power supplies in aircraft and other equipment are finding increased need for high-power 30 kW silicon TVS devices to suppress high voltage spikes produced in the magnetic circuit components that would otherwise damage the power transistor. Adding low clamp silicon TVSs reduces the upper limit of required transistor voltages, thus reducing costs. Inductive loads are a source of transients when switched off as their energy is dumped into the attached power lines and can also induce current /voltage into adjacent wiring. The two most severe non-lightning threats include generator anomalies and load switching. Load switching from auxiliary to main power (dumping stored energy during this brief interval) is a major source of inductive generated spikes.

As geometries continue to spiral down in semiconductor chips, threshold failure levels also become lower adding a greater potential for failure. Load switching is part of the equation that increases potential failures and focuses more attention on transient protection.

## Applications

For the most part, the applications have been included within the text for converting the RT130KPxxxCA (6.4/69 $\mu$s ), plus examples of standard catalog (10/1000 $\mu$s ) rated data sheet peak current (Ipp) protection levels into their equivalent waveforms 3 (5 $\mu$s ), 4, (6.4/69 $\mu$s ) and 5A (40/120 $\mu$s ) for peak current (Ip) levels per RTCA/DO-160G.

The writer has provided references and equations to simplify this process to a multiplication factor for the DO-160G waveform desired:

### Table 4: For the RT65KPxxCA and RT130KPxxxCA Series

| RT130KPxxxCA | DO-160G equivalent Ip Multiplication factor | | |
|---|---|---|---|
| Waveform | 3 | 4 | 5A |
| 6.4/69 $\mu$ s | 5 $\mu$s | 6.4/69 $\mu$s | 40/120 $\mu$s |
| 1 × | 3.8× | 1× | 0.84× |

These factors allow calculating the equivalent peak power, Pp, and peak current, Ip, equivalent values for the associated DO-160G waveforms.

The most frequently employed of all product types are based on the 10/1000 $\mu$s waveform such as the 400 W series up through the 30 kW series, in seven increments of power rating. Illustrations are shown in "Table 2, DO-160G Conversions" (Page 12) which equates 10/1000 $\mu$s to each of the three aircraft waveforms. To review, multiplication factors are:

### Table 5: DO-160G Equivalents for Shared Product

| Std. Product | DO-160G equivalent Ip Multiplication Factor | | |
|---|---|---|---|
| Waveform | 3 | 4 | 5A |
| 10/1000 $\mu$s | 5 $\mu$s | 6.4/69 $\mu$s | 40/120 $\mu$s |
| 1 × | 11.3 × | 3.33 × | 2.33 × |

These equations leading to the multiplication factors exclude application of equations 4 and 5. In equation 4, repeated below, observe that the value of Vc governs the amount of Ip conducted by the TVS during the surge.

Equation 4 is repeated below for emphasis in its importance for calculating accurate values of surge current threat when dual waveform threats are defined (e.g., for a Voc of 750 V and a Vc of 410 V (for the RT130KP295CV), the Ip is reduced to less than one-half its value using full circuit parameters compared to a calculation using only the Isc value). This result significantly reduces your cost of protection for power lines. If the Vc were 41 V instead of 410 V in this example, the reduction in Ip is insignificant, about 9%.

Equation 4:
$$Ip = (Voc-Vc)/Zs$$

Where:
Ip = pulse current through the TVS
Voc = open circuit voltage
Vc = TVS clamping voltage Zs = source impedance

In this equation, as Vc approaches Voc, the Ip is reduced to zero; however, as Vc approaches zero, Ip increases to the full value of Isc.

For high-current surge protection, the RT130KPxxxCA series was developed specifically for placement across ac power distribution lines in environments with high lightning exposure. Its intended use is across 250 V peak ac lines, and with additional margin has a minimum breakdown voltage of 300 V and is also designed for a clamping factor of less than 1.33 to protect across 400 V-rated switching transistors.

Install TVS devices across the input of the protected circuit with minimal inductance between terminations for both differential and common mode protection requirements. Wire terminations should be kept as short as possible to prevent self-induction of the residual lead length (ref Eq. 16), thus optimizing the effectiveness of the TVS. Voltage overshoot has been observed to produce 2 μs spikes of tens of volts with lead lengths of 2 inch lengths as tested in the lab with 1.2/50 μs pulses and surge currents of 500 A.

15KP and 30KP devices plus the RT65KPxxC and RT130KPxxxC series have been the designers' choice for protection across power lines. This is also now further complemented with surface mount TVS devices rated up to 36 kW (MPLAD36KPxxxC series). For very low power drain requirements, series resistors increase line impedance to facilitate the use of much lower surge rated TVSs.

Pin injected lightning threats are conducted directly to sensitive components, ranging from tens of volts to more than a thousand volts per Table 1 (see page 2), depending on conditions including inherent shielding, length of run, line impedance and a host of other factors. Surge current threats range from tens of amperes to thousands of amperes. Silicon TVSs have been the choice for protection because of their low clamping factor and virtually no wear-out.

For low level threats, the SMBJxxCA 600 W series has been the designers' choice for protection across low voltage, low data rate ARINC 429 and the SMBJSACxx 500 W series for 100 kbps fast data rate ARINC 429 data transmission line.

Other signal lines including analog, some ARINC 429 and synchro operate over a broad range of voltages from <1 V up through 120 V. Device types used for protection across signal lines also include SMAJP4KExxxCA, SMCJxxxCA, SMCJLCExxx, SMLJxxxCA and 5KPxxxCA series devices. These bidirectional TVSs are rated at 400 W, 1.5 kW, 3 kW, and 5 kW respectively, at 10/1000 μs and easily converted to the associated Table 1 pin injection threats.

For differential data line pairs, per AIRINC 429, the shield is normally connected to frame ground while the TVS is connected across the signal wire(s) and the circuit board common. An SMBJ12CA is typically used for 12 kbps line protection for lower voltages. Surge current rating for this part is described as follows:

The SMBJ12CA rating is 30.2 A for a 10/1000 μs pulse but for a type 4 Waveform per DO-160G, we take the increased Ipp factor, 3.33 × , from the Table 2 (see page 8), and multiply by the 10/1000 μs rating.

30.2 A (10/1000 μs rating) × 3.33 = 101 A for a 6.4/69 μs pulse width.

The SMBJ12CA with a 101 A Ip, 6.4/69 μs rating will protect at level 3 for a type 4 waveform Ip requirement of 60 A with additional margin for temperature derating.

For more detailed information addressing protection of ARINC 429 Data Information Transfer Lines, refer to MicroNote 126.

A word of caution: silicon TVS devices are designed for non-repetitive pulse suppression. Duty cycles are normally 0.01%. After a surge event, at least 10 seconds must lapse to restore the junction temperature to ambient temperature, preventing failure from a rapid follow-on surge with associated heating.

# Reliability Screening

In addition to TVS products, Microsemi also provides options for additional screening where higher reliability testing may dictate the need. For flight hardware, Microsemi offers avionics grade component screening so indicated 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 but no part exists in accordance with MIL-PRF-19500, Microsemi offers equivalent JAN, JANTX, JANTXV, and JANS so designated by adding MQ, MX, MV, or MS prefixes respectively to the standard part number. See our documentation in MicroNote 129 on this offering.

Microsemi has a wealth of experience in custom design, manufacturing and applications experience in providing service to the aerospace industry. We look forward to assisting you with your lightning protection solutions or any others applicable to use of silicon TVSs.

Call us for rapid response and solutions to your transient voltage protection needs.

# Summary

Microsemi has been the TVS technology leader for many years, meeting demands for high-current, low-clamping standard and custom transient voltage suppressor devices for lightning protection for aerospace applications. Our long-range plan to serve the aerospace industry began more than four decades ago when the space age was still on its toddling legs. Today we are recognized as the leading supplier of transient suppressors to the aerospace industry.

With increasing complexity of aircraft electronics and less inherent shielding, silicon TVS devices are rapidly evolving to maintain safe performance under this more vulnerable lightning environment. The need for higher power TVSs for ac and dc power distribution lines and increasing numbers of signal lines requiring protection will become mandatory for future reliability of aerospace hardware. Surface mount TVSs up to 18 kW and 36 kW ratings at 10/1000 μs are also now available with the MPLAD18KPxxx and MPLAD36KPxxx series.

Lower voltage clamping for protecting increasing vulnerability of semiconductor devices caused by shrinking IC geometries will continue to be a challenge. Geometries in the sub-micron range are now in use with downsizing continuing toward molecular structures. Protection needs through shielding, bonding and the use of silicon TVS devices will be in greater demand to keep pace with the rapidly growing sensitivity and complexity of aerospace electronics.

### To The Reader:

As transient suppression science continues to evolve, Microsemi recognizes the need for continued dedication to the aerospace industry. To this end, we are continuing to develop new products and supporting literature to better serve the design engineer.

# Contact

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