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OVERALL SELECTION OF TRANSIENT VOLTAGE SUPPRESSOR PART NUMBERS FOR RTCA/DO-160

Previous Microsemi MicroNotes 104, 125 and 127 have described how to calculate and select Transient Voltage Suppressor (TVS) devices when knowing the waveform, the source impedance (Z_S), and the open-circuit voltage (V_{OC}) of the transient. This also involved considerations of different Peak Pulse Power (P_{PP}) capabilities for various pulse widths beyond those specifically rated in TVS data sheets (such as 10/1000 µs). Further methods will now be demonstrated to calculate and summarize in two convenient tables all Microsemi TVS part numbers compliant to the RTCA/DO-160E (or D) specification for "Environmental Conditions and Test Procedures for Airborne Equipment."

One of the fundamental relations in selecting the TVS is identifying the resulting surge or pulse current (I_P) with the above features. This has previously been shown as:

$$\mathbf{I_P = (V_{OC} - V_C)/ Z_S}$$

With this example, we can also determine the resulting P_{PP} by multiplying the I_P value by the V_C. For this worst-case calculation, the V_C is considered the maximum value shown on the TVS data sheets and I_P becomes the Peak Pulse Current (I_{PP}) at the pulse width and waveform of interest. We then have:

$$\mathbf{(V_C)(I_{PP}) = P_{PP} = V_C(V_{OC} - V_C)/ Z_S} \qquad \textbf{EQ 1}$$

Placing emphasis on the power instead of current simplifies matters when gaining insight to various TVS products with specific P_{PP} ratings. It also gives opportunity to examine a large number of products and what specifications may be met that have also provided information on V_{OC} and Z_S for defining the transient pulse. In this analysis, the P_{PP} is the value determined for the TVS at the desired waveform and pulse duration after a conversion is made from the original data sheet ratings (such as 10/1000 µs). These methods for conversion are also described in MicroNotes 104, 120, and 127. When using the appropriate P_{PP} values, we can then solve for V_C and what values comply with the needed P_{PP} after these conversions are made.

When rearranging terms in EQ 1, we have:

$$\mathbf{Z_S P_{PP} = V_C V_{OC} - V_C^2}$$

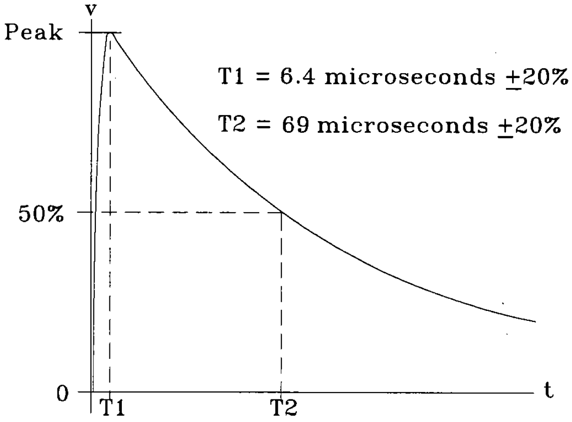
or,

$$\mathbf{V_C^2 - V_{OC}V_C + Z_S P_{PP} = 0}$$

This is in a format for easily solving V_C using the Quadratic Equation. When using that method, we have:

$$\mathbf{V_C = 0.5(V_{OC}) \pm 0.5(V_{OC}^2 - 4Z_S P_{PP})^{1/2}} \qquad \textbf{EQ 2}$$

This calculation for V_C provides a relatively easy method to recognize what Clamping Voltages are required for each of the popular TVS ratings to comply with various industry specifications such as the RTCA/DO-160E for aircraft lightning. For example, we can use the RTCA/DO-160E, Section 22, and Table 22-2 therein concerning "Test Levels for Pin Injection" and its described Z_S and V_{OC} values to determine what Vc values will comply using EQ 2 for various power ratings of TVSs after converting the P_{PP} to the desired Waveform. For Waveform 4 (6.4/69 µs as shown in Figure 1), MicroNote 127 describes a P_{PP} conversion factor of 3.33 from the longer duration 10/1000 µs rating used in the industry. This conversion factor includes an added 20% worst-case condition in duration (6.4/83 µs) as also required in the RTCA/DO-160E specification for "Environmental Conditions and Test Procedures for Airborne Equipment."



RTCA/DO-160 Voltage Waveform 4

FIGURE 1

If we initially use an example TVS in the industry rated at 500 W at 10/1000 µs, this equates to a P_{PP} level of 3.33 x 500 = 1665 W for the described Waveform 4. When also using the V_{OC} and Z_S values for Waveform 4 from Table 22-2 of RTCA/DO-160D, we can solve EQ 2 for V_C. For all five Levels of Waveform 4, the generator source impedance is 5 Ohms (V_{OC}/I_{SC}). Starting with Level 1 or Level 2 conditions with their low V_{OC} values and substituting into EQ 2, we find that the roots of the equation are both imaginary numbers since there is a square root of a negative value. This indicates the V_{OC} for Level 1 and 2 are comparatively low (50 V and 125 V respectively) relative to the product of source impedance Z_S and Peak Pulse Power P_{PP} in the square root portion of EQ 2. However this is not the case for Level 3 or higher where the calculation gets more interesting. Level 3 specifies a V_{OC} of 300 V. Substituting the V_{OC} value of 300 V from Table 22-2 with the Z_S of 5 Ohms as well as the earlier determined P_{PP} value of 1665 W as the equivalent capability for the shorter Waveform 4 into EQ 2, we have the following:

$$\mathbf{V_C = 0.5(300) \pm 0.5[300^2 - 4(5)(1665)]^{1/2}}$$

$$\mathbf{V_C = 150 \pm 0.5(90{,}000 - 33{,}300)^{1/2} = 150 \pm 119}$$

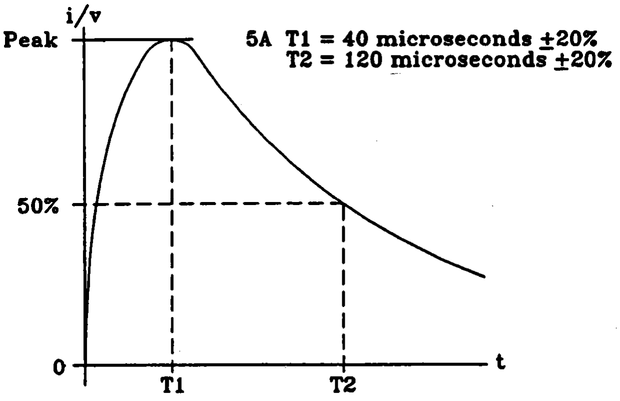
Therefore: $\mathbf{V_C = 31.0\ V \text{ and } V_C = 269\ V}$

When further comparing these V_C values with EQ 1, the P_{PP} will be less than or equal to 1665 W at 6.4/83 µs (500 W at 10/1000 µs) when $V_C \leq 31.0$ V or $V_C \geq 269$ V. As a result, the TVS device will also meet the requirements of the DO-160D specification for Pin Injection tests of Waveform 4 at Level 3 conditions at 25ºC when the V_C is in these lower or higher specified ranges. If the 500 W series of TVSs does not have the higher voltage devices included in that series where $V_C \geq 269$ V, only the lower voltage device part numbers will comply where $V_C \leq 31.0$. For example in the 500 W rated TVSs of the SMAJ5.0A thru SMAJ170A (or CA) series, only the SMAJ5.0A thru SMAJ18A (or CA) may be used for Waveform 4, Level 3 after comparing the maximum Clamping Voltage V_C values specified in the data sheet for each device in this particular series.

A similar analysis for the more severe Level 4 with a higher V_{OC} of 750 V would reveal the clamping voltages must be $V_C \leq 11.3$ V or $V_C \geq 738.7$ V. This only allows the lowest TVS part numbers in the 500 W SMAJxxx series to be used such as the SMAJ5.0A, SMAJ6.0A, and SMAJ6.5A (or CA). The very high clamping voltage devices above 738.7 V have virtually no practical application and do not exist in this TVS series.

A further similar analysis for the next higher Level 5 of Waveform 4 would reveal that no devices in the standard 500 W rated TVS products at 10/1000 µs would comply with that test level threat. As a result, higher P_{PP} ratings for TVSs must be used.

The same calculations can be made for other popular TVS devices from Microsemi with P_{PP} ratings up to 200,000 W. These are all summarized in the Tables shown herein for the important Waveforms and threat Levels in the RTCA/DO-160E specification including Waveform 5A (40/120 µs as shown in Figure 2) that is much more severe with its longer duration and lower source impedance.



RTCA/DO-160 Voltage Waveform 5A

FIGURE 2

Although three Waveforms are specified in Table 22-2 of the RTCA/DO-160E specification (Waveforms 3, 4 and 5A), it has been demonstrated in MicroNote 127 that any TVS that complies with the frequently specified Waveform 4 will also easily comply with the shorter Waveform 3. The Waveform 3 calculations are therefore not shown. All the TVS part numbers relative to their V_C calculation in EQ 2 have been determined and listed for compliance at 25ºC to the worst-case conditions of Waveform 4 and Waveform 5A in Table 1 and Table 2 respectively for all five threat Levels identified in the RTCA/DO-160E specification. For higher temperature deratings, see MicroNote 132.

Table 1. WAVEFORM 4 ─ Clamping Voltage (V_C) and Microsemi TVS Part Numbers Compliant to RTCA/DO-160E @ 25°C

P_{PP} @10/1000 µs (or as specified)	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
500 W	**All** SMAJ5.0A-170A,CA P5KE5.0A-170A,CA 1N6103A-6137A 1N6461-1N6468 HSMBJSAC5.0-50 SAC5.0-50	**All** SMAJ5.0A-170A,CA P5KE5.0A-170A,CA 1N6103A-6137A 1N6461-1N6468 HSMBJSAC5.0-50 SAC5.0-50	**$V_C \leq 31.0$ V** SMAJ5.0A-18A,CA P5KE5.0A-18A,CA 1N6103A-6114A 1N6461-1N6464 HSMBJSAC5.0-15 SAC5.0-15	**$V_C \leq 11.3$ V** SMAJ5.0-6.5A,CA P5KE5.0-6.5A,CA 1N6103A 1N6461-1N6462	**None**
600 W	**All** SMBJ5.0A-170A,CA P6KE6.8A-200A,CA	**All** SMBJ5.0A-170A,CA P6KE6.8A-200A,CA	**$V_C \leq 38.2$ V** SMBJ5.0A-22A,CA P6KE6.8A-27A,CA	**$V_C \leq 13.6$ V** SMBJ5.0-8.0A,CA P6KE6.8A-9.1A,CA	**None**
1500 W	**All** SMCJ5.0A-170A,CA 1.5KE6.8A-400A,CA 1N5629A-1N5665A 1N5907, 1N5908 1N6036A-1N6072A 1N6138A-1N6173A 1N6267A-1N6303A 1N6469-1N6476 LC6.5-170A LCE6.5-170A SMCJLCE6.5-170A	**All** SMCJ5.0A-170A,CA 1.5KE6.8A-400A,CA 1N5629A-1N5665A 1N5907, 1N5908 1N6036A-1N6072A 1N6138A-1N6173A 1N6267A-1N6303A 1N6469-1N6476 LC6.5-170A LCE6.5-170A SMCJLCE6.5-170A	**All** SMCJ5.0A-170A,CA 1.5KE6.8A-400A,CA 1N5629A-1N5665A 1N5907, 1N5908 1N6036A-1N6072A 1N6138A-1N6173A 1N6267A-1N6303A 1N6469-1N6476 LC6.5-170A LCE6.5-170A SMCJLCE6.5-170A	**$V_C \leq 35.0$ V** SMCJ5.0A-20A,CA 1.5KE6.8A-24A,CA 1N5629A-1N5642A 1N5907, 1N5908 1N6036A-1N6048A 1N6138A-1N6151A 1N6267A-1N6280A 1N6469-1N6472 LC6.5-20A LCE6.5-20A SMCJLCE6.5-20A	**$V_C \leq 16.0$ V** SMCJ5.0A-8.0A,CA 1.5KE6.8A-11A,CA 1N5629A-1N5634A 1N5907, 1N5908 1N6036A-1N6040A 1N6138A-1N6143A 1N6267-1N6272A 1N6469-1N6470 LC6.5-9.0A LCE6.5-9.0A SMCJLCE6.5-9.0A
3000 W	**All** SMLJ5.0A-170A,CA	**All** SMLJ5.0A-170A,CA	**All** SMLJ5.0A-170A,CA	**$V_C \leq 74.0$ V** SMLJ5.0A-45A,CA	**$V_C \leq 32.0$ V** SMLJ5.0A-18A,CA
5000 W	**All** 5KP5.0A-110A,CA	**All** 5KP5.0A-110A,CA	**All** 5KP5.0A-110A,CA	**$V_C \leq 135.5$ V** 5KP5.0A-78A,CA	**$V_C \leq 54.0$ V** 5KP5.0A-33A,CA
15,000 W	**All** 15KP17A-280A,CA **PLAD15KP5.0-400A,CA**	**All** 15KP17A-280A,CA **PLAD15KP5.0-400A,CA**	**All** 15KP17A-280A,CA **PLAD15KP5.0-400A,CA**	**All** 15KP17A-280A,CA **PLAD15KP5.0-400A,CA**	**$V_C \leq 175.5$ V** 15KP17A-100A,CA **PLAD15KP5.0-100A,CA**
30,000 W	**All** 30KPA28A-288A,CA **PLAD30KP10-400A,CA***	**All** 30KPA28A-288A,CA **PLAD30KP10-400A,CA***	**All** 30KPA28A-288A,CA **PLAD30KP10-400A,CA***	**All** 30KPA28A-288A,CA **PLAD30KP10-400A,CA***	**$V_C \leq 426$ V** 30KP33A-260A,CA **PLAD30KP10-260A,CA***
65,000 W @ 6.4/69 µs	**All** RT65KP48-75A,CA	**All** RT65KP48-75A,CA	**All** RT65KP48-75A,CA	**All** RT65KP48-75A,CA	**All** RT65KP48-75A,CA
100,000 W @ 6.4/69 µs	**All** RT100KP40-400A,CA	**All** RT100KP40-400A,CA	**All** RT100KP40-400A,CA	**All** RT100KP40-400A,CA	**$V_C \leq 426$ V** RT100KP40-200A,CA
130,000 W @ 6.4/69 µs	**All** RT130KP275-295CA, RT130KP275-295CV**	**All** RT130KP275-295CA, RT130KP275-295CV**	**All** RT130KP275-295CA, RT130KP275-295CV**	**All** RT130KP275-295CA, RT130KP275-295CV**	**All** RT130KP275-295CA, RT130KP275-295CV**

1. The CA suffix signifies Bidirectional TVS options where shown.
2. Part numbers with prefix SMBJ, SMCJ, or SMLJ are also available as SMBG, SMCG, or SMLG prefix respectively for Gull-wing termination options rather than the J-bend shown.
3. Compliant capabilities include a worst-case +20% tolerance for waveform durations in RTCA/DO-160E.

* PLAD15KPxxx and PLAD30KPxxx series have lower thermal resistance to minimize cumulative heating on multiple surges.
** CV suffix signifies lower clamping voltage compared to the CA suffix.

Table 2. WAVEFORM 5A ─ Clamping Voltage (V_C) and Microsemi TVS Part Numbers Compliant to RTCA/DO-160E @ 25°C

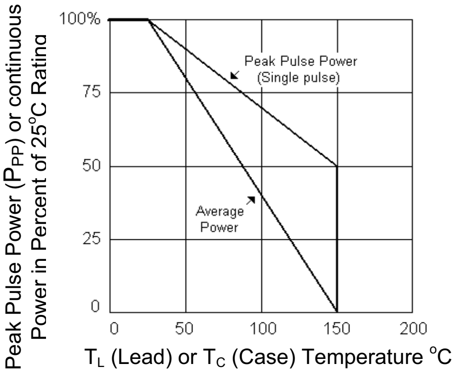
P_{PP} @10/1000 µs (or as specified)	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
500 W	All SMAJ5.0A-170A,CA P5KE5.0A-170A,CA 1N6103A-6137A 1N6461-1N6468 HSMBJSAC5.0-50 SAC5.0-50	$V_C \le 10.1$ V SMAJ5.0A,CA P5KE5.0A,CA $V_C \ge 114.9$ V ** SMAJ78A-170A,CA P5KE78A-170A,CA 1N6130A-6137A	None	None	None
600 W	All SMBJ5.0A-170A,CA P6KE6.8A-200A,CA	$V_C \le 12.4$ V SMBJ5.0A-7.0A,CA P6KE6.8A-8.2A,CA $V_C \ge 112.6$ V ** SMBJ75A-170A,CA P6KE91A-200A,CA	None	None	None
1500 W	All SMCJ5.0A-170A,CA 1.5KE6.8A-400A,CA 1N5629A-1N5665A 1N5907, 1N5908 1N6036A-1N6072A 1N6138A-1N6173A 1N6267A-1N6303A 1N6469-1N6476 LC(E)6.5-170A SMCJLCE6.5-170A	$V_C \le 42.2$ V SMCJ5.0A-26A,CA 1.5KE6.8A-30A,CA 1N5629-1N5644A 1N5907, 1N5908 1N6036A-1N6050A 1N6138A-1N6153A 1N6267A-1N6282A 1N6469-1N6473 LC(E)6.5-26A SMCJLCE6.5-26A $V_C \ge 82.8$ V ** SMCJ58A-170A,CA 1.5KE68A-400A,CA 1N5653A-1N5665A 1N6059A-1N6072A 1N6162A-1N6173A 1N6291A-1N6303A LC(E)58A-170A SMCJLCE58A-170A	$V_C \le 12.1$ V SMCJ5.0A-7.0A,CA 1.5KE6.8A-8.2A,CA 1N5629-1N5631A 1N5907, 1N5908 1N6036A-1N6037A 1N6138A-1N6140A 11N6267A-1N6269A 1N6469-1N6470 LC(E)6.5-7.0A SMCJLCE6.5-7.0A	None	None
3000 W	All SMLJ5.0A-170A,CA	All SMLJ5.0A-170A,CA	$V_C \le 25.5$ V SMLJ5.0A-15A,CA	$V_C \le 9.4$ V SMLJ5.0A,CA	None
5000 W	All 5KP5.0A-110A,CA	All 5KP5.0A-110A,CA	$V_C \le 45.8$ V 5KP5.0A-28A,CA	$V_C \le 15.9$ V 5KP5.0A-8.0A,CA	None
15,000 W	All 15KP17A-280A,CA PLAD15KP5.0-400A,CA*	All 15KP17A-280A,CA PLAD15KP5.0-400A,CA*	All 15KP17A-280A,CA PLAD15KP5.0-400A,CA*	$V_C \le 49.9$ V 15KP17A-28A,CA PLAD15KP5.0-28A,CA*	$V_C \le 22.2$ V PLAD15KP5.0-13A,CA*
30,000 W	All 30KPA28A-400A,CA PLAD30KP10-400A,CA*	All 30KPA28A-400A,CA PLAD30KP10-400A,CA*	All 30KPA28A-400A,CA PLAD30KP10-400A,CA*	$V_C \le 109.1$ V 30KPA28A-64A,CA PLAD30KP10-64A,CA*	$V_C \le 45.0$ V PLAD30KP10-26A,CA*
65,000 W **@ 6.4/69 µs**	All RT65KP48-75A,CA	All RT65KP48-75A,CA	All RT65KP48-75A,CA	None	None
100,000 W **@ 6.4/69 µs**	All RT100KP40-400A,CA	All RT100KP40-400A,CA	All RT100KP40-400A,CA	$V_C \le 109.1$ V RT100KP40-54A,CA	None
130,000 W **@ 6.4/69 µs**	All RT130KP275-295CA or RT130KP275-295CV***	All RT130KP275-295CA or RT130KP275-295CV***	All RT130KP275-295CA or RT130KP275-295CV***	None	None

1. The CA suffix signifies Bidirectional TVS options where shown.
2. Part numbers with prefix SMBJ, SMCJ, or SMLJ are also available as SMBG, SMCG, or SMLG prefix respectively for Gull-wing termination options rather than the J-bend shown.
3. Where no generic standard part is available (none indicated), consult factory for custom options.
4. Compliant capabilities include a worst-case +20% tolerance for waveform durations in RTCA/DO-160E.

* PLAD15KPxxx and PLAD30KPxxx series have lower thermal resistance to minimize cumulative heating on multiple surges.
** Part numbers are guard banded one higher value to ensure $V_C \ge$ than value shown.
*** CV suffix signifies lower clamping voltage compared to the CA suffix.

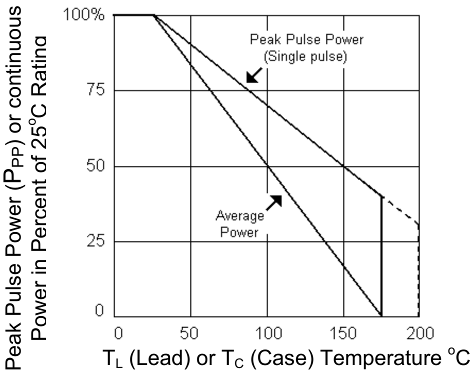
If higher ambient temperatures are used well beyond the P_{PP} ratings at 25ºC, the product selections in Tables 1 and 2 will be more limited as shown in MicroNote 132. For random recurring transient events where a TVS device recovers to ambient temperatures before the next transient, the Ppp capability at 25ºC will linearly decline to 50% at 150ºC as shown in Figure 3 below. This linear derating will stop and abruptly become zero thereafter above 150ºC if they are plastic packages. They can also further derate linearly to 175ºC (or 200ºC) if they are glass, ceramic or metal packages as determined by the applicable package material properties and overall ratings in storage and operating temperatures further shown in Figure 4 below.

Most applications are at ambient temperatures well below 150ºC. An operating temperature of 70ºC for TVS devices would derate by 18% from their maximum rating at 25ºC. This would also apply to Waveform 4 or 5A transients that are considered "Single Stroke" for Pin Injection test levels in Table 22-2 of RTCA/DO-160E. Further details of selecting devices at various elevated temperatures are shown in MicroNote 132 in "DIRECTselect" Graphs 1 thru 14. The various temperature characterizations in those graphs also show the same selection results at 25ºC in Tables 1 and 2 herein for Microsemi TVS products.



Derating Curve (Plastic Packages)

FIGURE 3



Derating Curve (Glass/Metal/Ceramic Packages)

FIGURE 4

A more severe linear slope derating to zero at 150ºC or 175ºC (or 200ºC) is applicable for longer average power considerations such as when a TVS might also be used as a Zener Voltage Regulator with continuous or dc power. In those examples, the "average power" derating method becomes applicable as further shown separately in Figures 3 and 4. As a result, there is an important distinction in "random recurring" transients for P_{PP} (duty factors of 0.01% or less) compared to average long-term power derating considerations. In some applications where "multiple stroke" or "multiple burst" surge requirements exist and higher duty factors generate cumulative heating effects, further considerations must be given to minimize those effects. This includes using TVS designs with very low thermal resistance junction to ambient with good heat sinking as may be obtained with the new PLAD15KPxxx and PLAD30KPxxx series products shown in Tables 1 and 2. This will ensure minimum case temperatures (T_C) for these type packages as shown in Figures 3 and 4 above. It will also permit greater P_{PP} performance with the described longer "multiple strokes" or "bursts" identified in the RTCA/DO-160 specification.

If the application only involves relatively low current demands for the protected load, external resistance can also be added to the source impedance Z_S thus reducing the incident surge current level on a TVS protecting that load. This is also described in the first page equations as well as in MicroNote 125 and MicroNote 127. This will effectively reduce the P_{PP} requirements of the TVS and expand the possible selection of V_C and part numbers provided in Tables 1 and 2.

In addition to these standard TVS product part numbers, Microsemi also provides options for additional screening where higher reliability testing may be required. 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 that includes additional surge tests, temperature cycling, and high temperature reverse bias (HTRB) screening. 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 screening by adding MQ, MX, MV, or MSP prefixes respectively to standard part numbers. This also includes specific options for various low capacitance TVS devices as shown in Tables 1 and 2 herein. Also see MicroNote 129 (Table II) for further details on up-screening where some differences may occur in available options between plastic versus metal or glass packaging.

In summary, this article has provided a calculation method for Transient Voltage Suppressor compliance to the five test levels of Waveform 4 and 5A for pin injection in the RTCA/DO-160F specification and many of its earlier revisions. The results of those calculations are summarized in the tables herein as an overview for providing a quick selection of TVS device part numbers. These same results are also reflected in MicroNote 132 in the “DIRECTselect” Graphs 1 thru 14 at 25°C as well as for various elevated temperatures.

For other smaller TVS components primarily intended for ESD protection including the Microsemi TVSarrays™, consult the Microsemi Scottsdale Division for further information.

For additional technical assistance and information, contact Kent Walters (kwalters@microsemi.com).

Rev E 9-13-2011