# MicroNote 122

## Transient Voltage Protection Across High Data Rate and RF Lines

**By Mel Clark and Kent Walters**

Early systems using RS-232 ambling along at 19.6 kbps were compatible with the capacitance of silicon transient voltage suppressor (TVS) devices of that era. No significant signal attenuation was observed because of the relative low data transmission rates. However, with today's signal rates pushing into the Gbps range, TVS capacitance becomes a significant issue. It often becomes a challenge for the designer to find protective devices compatible with high data rates, such as those used on universal serial bus lines at 10 Mbps, IEEE -1394 (FireWire) at >100 Mbps, and recent CATV innovations at rates up to 1 GHz. Microsemi now offers a broad spectrum of LoCAP™ low-capacitance silicon TVS devices specifically for protection across data lines to prevent signal attenuation at these high transmission rates.

Electrostatic discharge (ESD) is the most significant threat with induced lightning and load switching also contributing to upset or failure of I/O port components. Don't overlook the possibility of latch-up or latent failures that can occur weeks or months after the electrical overstress event.

## Designing LoCap TVS Devices

For high data rates, low capacitance is achieved by inserting a high-voltage rectifier chip, which inherently has a low capacitance value in series with and in opposite polarity to the TVS chip. Proper selection of the diode chip will provide the required capacitance and sufficient cross sectional area to withstand rated surge current. Higher powered LoCap TVSs are inherently higher in capacitance from the larger chip sizes required to withstand the associated higher surge currents. The rules for diode capacitance reduction are basically those governing capacitors in series and parallel as shown in Figure 1 (see page 2).

TVSs are attributed to the high doping level of the starting silicon material to produce lower breakdown voltage devices. Figure 1a (see page 2) illustrates typical capacitance values for a 500 W, 10 V TVS with an appropriate rectifier chip for fabricating a 10 V low-capacitance silicon TVS, while Figure 1b (see page 2) illustrates their polarity relationship. With more than an order of magnitude between the value of the series capacitance of the two chips, the total value is calculated to be slightly less than the smallest value, which is 14.6 pf for this example.

Figure 1c (see page 2) illustrates the V/I curve of the combined low-capacitance rectifier chip with the TVS. Note that clamping protection is provided only in one direction, the third quadrant, with the first quadrant containing the reverse breakdown of the rectifier. Hence, it becomes necessary to place two of the rectifier/TVS strings in antiparallel, forming a functionally bidirectional LoCap, low-capacitance element as shown in Figure 2a (see page 4). Figure 2b (see page 4) illustrates the resultant electrical characteristics of the symmetrical V/I curve with clamping protection for both positive and negative transient voltage excursions.

The bidirectional LoCap TVS is bilaterally symmetrical, having the same electrical characteristics in both the first and third quadrants as depicted in Figure 2b (see page 4). This feature accommodates signals having both positive and negative excursions. For most LoCap devices, the "legs" are connected externally to the package.

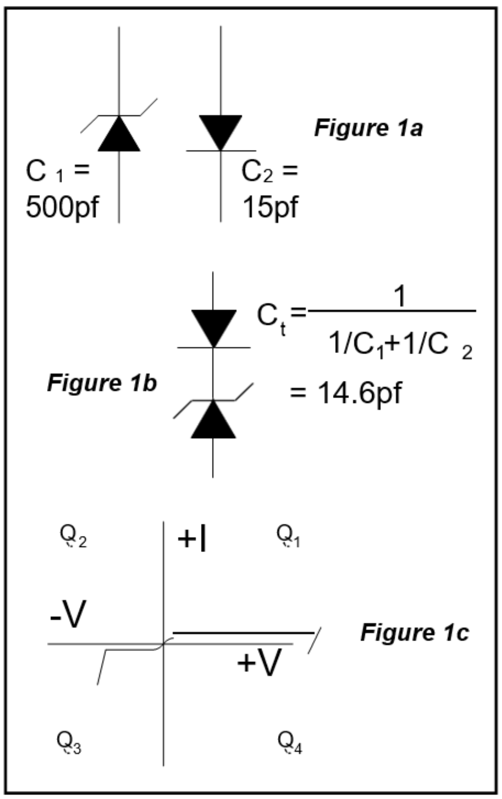
Microsemi provides the broadest offerings of LoCap silicon TVS devices in the industry. This includes the fllowing types listed below in Table 1 (see page 2).

Many of Microsemi's devices have very conservative values listed for capacitance. For example, the SAC5 and the SMBJSAC types typically measure 13 pF–17 pF, and the USB series typically ranges from 1.8 pF–2.0 pF. The USB0805C (5 V operating voltage) has been configured as shown in Figure 3 (see page 4) to reduce the capacitance to 1.5 pF maximum for use across RF amplifiers up to 750 MHz with no noticeable attenuation.

### Table 1: LowCap TVS Examples

| Device Series | Surge Power | Waveform (μs) | Capacitance | Package | Voltage Range |
|---|---|---|---|---|---|
| LC6.5 | 1.5 kW | 10/1000 | 100 pf | DO-13 | 6.5 V–170 V |
| LCE6.5 | 1.5 kW | 10/1000 | 100 pf | Axial lead | 6.5 V–170 V |
| SAC5 | 500 W | 10/1000 | 30 pf | Axial lead | 5.0 V–50 V |
| SMCJLCE5.0 | 1.5 kW | 10/1000 | 100 pf | SMT/DO-214AB | 5.0 V–50 V |
| SMBJSAC5.0 | 500 W | 10/1000 | 30 pf | SMT/DO-214AA | 5.0 V–50 V |
| SM8LC03 | 500 W | 8/20 | 25 pf | SO-8 | 3.0 V–24 V |
| SM16LC03 | 500 W | 8/20 | 25 pf | SO-16 | 3.0 V–24 V |
| USB50403C | 500 W | 8/20 | 3 pf | SO-4 | 3.0 V–24 V |
| USB50803C | 500 W | 8/20 | 3 pf | SO-8 | 3.0 V–24 V |

### Figure 1: Capacitance of TVS and Low-Capacitance Rectifier Chips




The 5 V, USB0805C elements have been wired in series to reduce the capacitance by one-half, which is normally about 1 pF. Figure 4 (see page 5) depicts the capacitance values for a USB0805C as configured in Figure 3b (see page 4), from 0 V through –4 V bias. In this same graph, an equivalent competitive device is compared with Microsemi's LoCap TVS.

Note the significant difference with Microsemi's part having the lowest value of these two devices, both of which have the same datasheet specifications. The competitive device is 2 pF over its limit of 5 pF per line. However, the Microsemi LoCap TVS has a capacitance well within its upper specified limit: about 3 pF below its maximum limit of 5 pF per protected line.

## Applications

Most RF and data I/O signal inputs are sensitive to electrical overstress. During operation "Desert Watch," the inputs on solid state receivers reportedly failed at an alarming rate. This was attributed to static electricity generated when wind-blown desert sand blasted external antennas.

For data rates >50 kbps, low-capacitance TVSs are often necessary to minimize signal attenuation while still providing overvoltage protection. The earlier standards calling out maximum bit rates no longer apply as maximum operating limits. For example, RS-232 originally specified a max bit rate of 19.6 kbps, but some users are demanding (and getting) up to 300 kbps operating capability.

Typical data transmission/reception specifications are listed below:

| Signal Type | Data Rate |
|---|---|
| EIA - 232 | 19.6 kbps |
| EIA - 422 | 10 Mbps |
| EIA - 423 | 100 kbps |
| EIA - 485 | 10 Mbps |
| USB 2.0 | 12.5 Mbps |
| USB 3.0 | 3.0 Gbps |
| Telecom modem | 60 kbps/1.5 Mbps |
| IEEE 1394a (firewire) | 400 Mbps |
| IEEE 1394b | 800 Mbps |
| CATV | up to 1 Gbps |

The maximum rates listed above are with 10 m or less of interconnecting cable representing minimum load capacitance. Speeds are significantly reduced with increasing lengths of interconnecting cable. IEEE-485 is subject to a number of boundary conditions governing its maximum data rate. USB runs at either 1.5 or 10 Mbps depending on the signal type transmitted. Cable lengths are normally less than 3 m. Computer modems normally transmit at rates of 60 kbps or 1.5 Mbps depending on the modem and its capability.

Illustrating the advantage of the higher speed, if a program requires 10 minutes to download at 60 kbps, this time would be reduced to less than half a minute at 1.5 Mbps.

Applications for one of the developing transmission protocols, "FireWire," is still over the horizon as this technology has not matured sufficiently to determine the specifics for protection requirements. Internet access is being offered on a few selected CATV locations at about 100 Mbps, almost two orders of magnitude greater than the fast telecom modems. Some new generation computers, now in the development stages, reportedly operate at data rates well into the Gbps region. Their sensitive interfacing I/O ports will require external protection for their sub-micron on-chip components.

**Figure 2: Configuration of Microsemi's Bidirectional LoCap TVS**

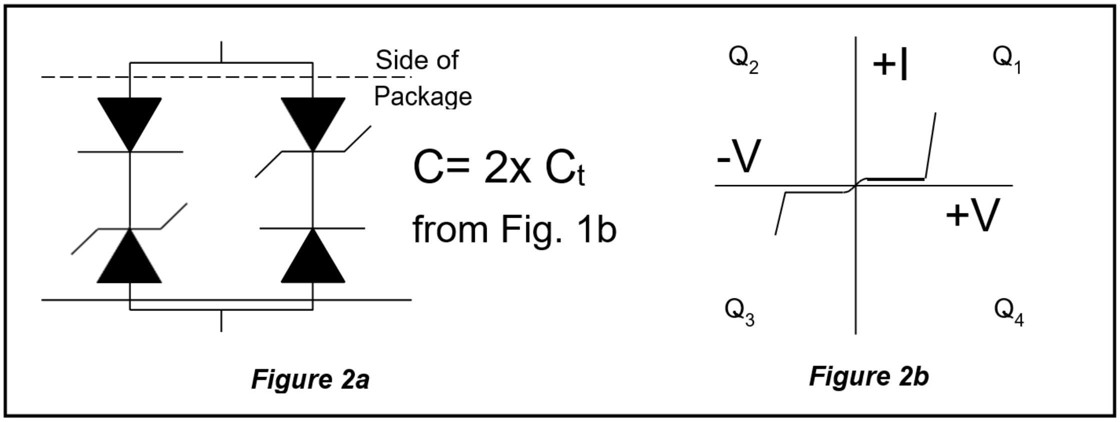



**Figure 3: USB Capacitance (3 pF max/line) & Reduced Capacitance Config.**

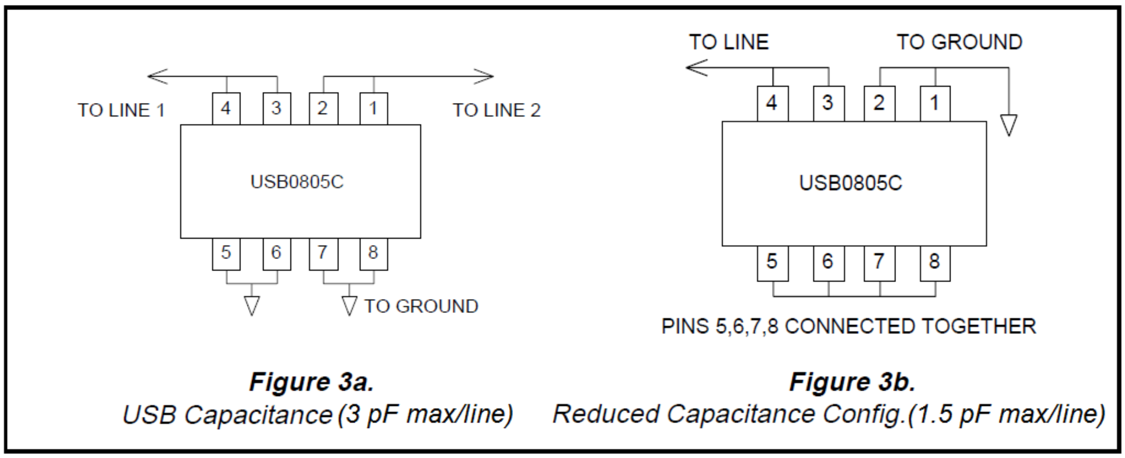
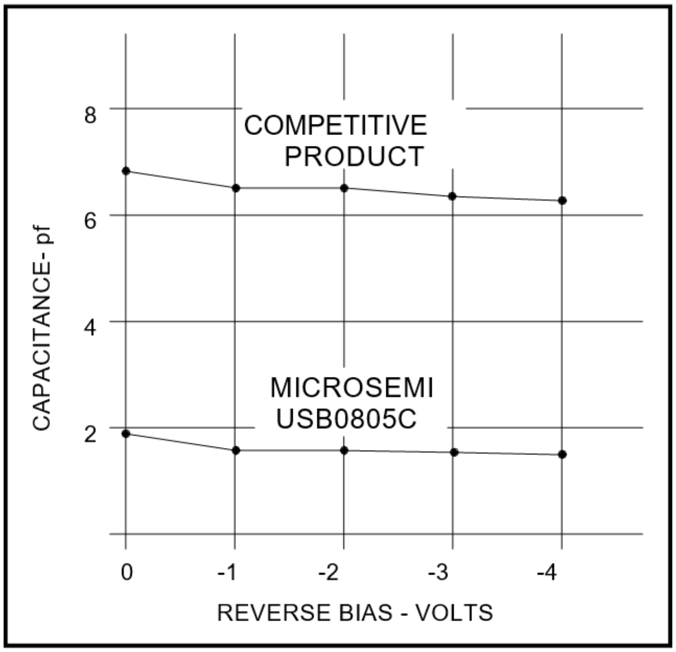


**Figure 4: Capacitance Values of LoCap TVS Under Reverse Bias**




## Protection Guidelines

The following Microsemi TVS devices are recommended for protection in the applications listed in the following table.

The information in this table may not be applicable for some circuits depending on the amount of signal distortion the system will tolerate.

**Table 2: Recommended TVS Series**

| Upper Limits | Primary Threats | | | Recommended TVS | Surge Power |
|---|---|---|---|---|---|
| **bit/s** | **ESD** | **Load Switch** | **Lightning** | **Family** | **@ 10/1000 µs** |
| 250 kb | * | * | * | LC6.5 | 1.5 kW |
| 250 kb | * | * | * | LCE6.5 | 1.5 kW |
| 250 kb | * | * | * | SMCJLC5.0 | 1.5 kW |
| 1.5 Mb | * | * | * | SAC5.0 | 600 W |
| 1.5 Mb | * | * | * | SMBJSAC5.0 | 600 W |
| | | | | | **@ 8/20 µs** |
| 5 Mb | * | | | SM8LC03 | 300 W |
| 5 Mb | * | | | SM16LC03C | 300 W |
| 600 Mb | * | | | USB50403C | 500 W |
| 600 Mb | * | | | USB50803C | 500 W |
| 5 Gb | * | | | US5B0403C(1) | 1000 W |

(1) Only when both elements of the TVS are in series for reduced capacitance and higher peak pulse power, as illustrated in Figure 3b (see page 4).

## Summary

High internal capacitance is inherent in low-voltage TVS devices due to the low resistivity silicon substrate required to produce low-voltage breakdown pn junctions. This high capacitance is due to the very thin region of space charge in low voltage pn junctions. Effective capacitance can be reduced by orders of magnitude by placing a rectifier chip (which inherently has low capacitance) in series, but in opposite polarity with the TVS chip.

Microsemi has a broad selection of LoCap silicon TVS devices for virtually all applications with data rates up through 5 Gbps. The tables above describe the data rates for most signal types and provide guidelines for selecting the most effective LoCap TVS for EOS protection. In harsh lightning environments, the addition of a gas discharge tube along with the TVS may be required to provide high surge withstand capability.

## Support

For additional technical information, please contact Design Support at:
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