Summing Up Circuit Protection for USB 3.0 and USB in Automotive Applications

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Version 3.0 of the Universal Serial Bus (USB) specification has been around now since 2008. The technology is now well established across a myriad of devices requiring high speed data transfer rates. One analyst firm estimated some 70 million USB 3.0 devices shipped in 2011. A further estimate claims this will balloon to more than three billion global USB 3.0 device shipments by 2018. For anyone involved in implementing USB designs, there's a lot riding on this technology. USB is critical to computing devices that are in turn also critical to everyday business or personal use. Thus proper circuit protection against electrical transients that can break such devices is a must. But, how is it best to implement proper circuit protection for USB 3.0? Also, in general, USB plays a key role in other big applications, like automotive. So, what are some of the key considerations for USB in such an application?

USB 3.0 Overview

First, a review of the USB 3.0 specification is in order. USB 3.0 offered a generational leap in performance capabilities over USB 2.0. It increased data rates by 10 times. It also expanded transmission lines to three differential pairs (compared to one in the previous 2.0 standard). USB was introduced in 1996 with version 1.0. It provided 1.5Mbit/sec in low-speed (LS) mode and 12Mbit/sec in full-speed (FS) mode. In 2000 USB 2.0 entered the market. The new high-speed (HS) mode then boosted transfer speeds up to 480Mbit/sec. It was downwards compatible to low-speed and full-speed mode.

The USB 2.0 interface is still widely used in consumer electronics. Billions of devices such as camcorders, digital cameras, digital music players, game consoles, DVD/Blue-Ray players and TVs use one or all of these USB standards. It's also widespread in portable devices such as, smartphones and in networking equipment like DSL/router units.

When the USB 3.0 specification was released it demonstrated full USB 2.0 functionality (HS, FS, LS). It also showcased the new separate ultra-high speed data link, called SuperSpeed™. The SuperSpeed link works with separate differential data lines for download (host => device, called TX direction). This is also the case for upload in RX direction (device => host). The maximum data rate in SuperSpeed mode is 5Gbit/sec. The combination of USB 2.0 functionality and the new SuperSpeed mode required new cable construction. This new construction had to serve three differential coupled signal lines (TX+/Tx-, RX+/Rx- and D+/D-). The V_{CC} and the GND line complete the cable set.

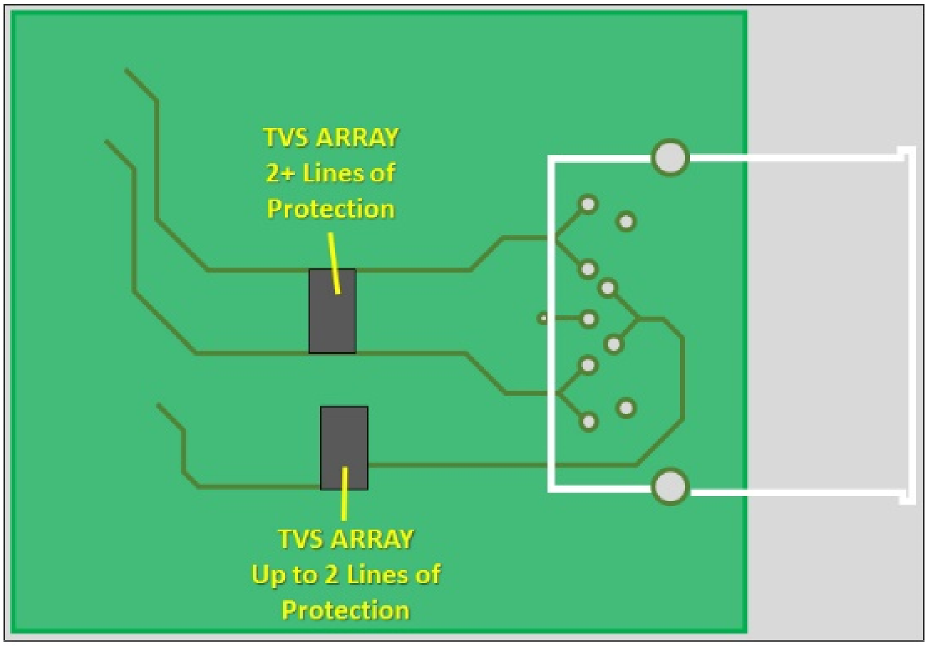
USB Engineering Design Considerations

Electronics engineers must consider a myriad of requirements when designing-in a USB 3.0 link. For example, full impedance-matched 90 Ohm differential design for all PCB lines and interconnection cables are mandatory. In addition non-differential coupled lines have to be minimized. They have significant impact to eye pattern inner eye opening. Also, trace-width and trace-separation of the 90 Ohm differential are critical.

The coupled PCB traces should not be too narrow, to avoid additional loss and being robust enough for manufacturing. A trace-width of 0.007” (0.178mm) and a separation of 0.007” (0.178mm) between the differential traces are ideal for production. Identical delay (trace length) between the positive and the negative line (including the USB 3.0 cable) of the differential coupled link (minimizing in pair skew) is needed. This is important to keep signal integrity high and to avoid common mode reflection.

Factoring in Circuit Protection

A USB 3.0 standard-A connector section can easily and cost-effectively be designed in combination with appropriate electrostatic discharge (ESD) circuit protection devices. For example, the SuperSpeed TX and RX data pairs can be protected by a transient voltage suppressor array (TVS array) that is capable of protecting many data lines, such as up to four lines. The D+ D- regular USB 2.0 pair can then be protected by a TVS array designed to protect up to a couple of data lines. It would be ideal to use a TVS array that can also protect the $V_{CCBUS.}$ Ultra-low line to ground capacitance is also necessary. This is ideal for use in any high speed application.



TVS Array layout recommendation in USB 3.0+2.0 application

Small Footprint Needs

Miniaturization requirements for ESD protection devices has introduced additional problems. This includes higher clamping and less robustness compared to larger die geometries. For example, clamping for an 8kV contact discharge, per IEC 61000-4-2, is a very low ~6 V measured at the 30nSec point.

Ultra high speed data transmission systems have a severe design obstacle. Designs must ensure a certain level of signal integrity at a receiver. High signal integrity is important to achieve a low bit error rate. For example, for USB 3.0 SuperSpeed a bit error rate of 1E-12 is typical. In a real system, the signal rise-time/fall-time is limited by the TX and the RX impedance (90 Ohm differential). And, this is in combination with all parasitic capacitance at TX side and RX side. These parasitic capacitances are inside the USB 3.0 transceiver, and/or externally on the PCB. External parasitics can be caused by unmatched PCB lines, the USB 3.0 connector, or other shunt capacitors. Values of shunt capacitors are to be kept as small as possible.

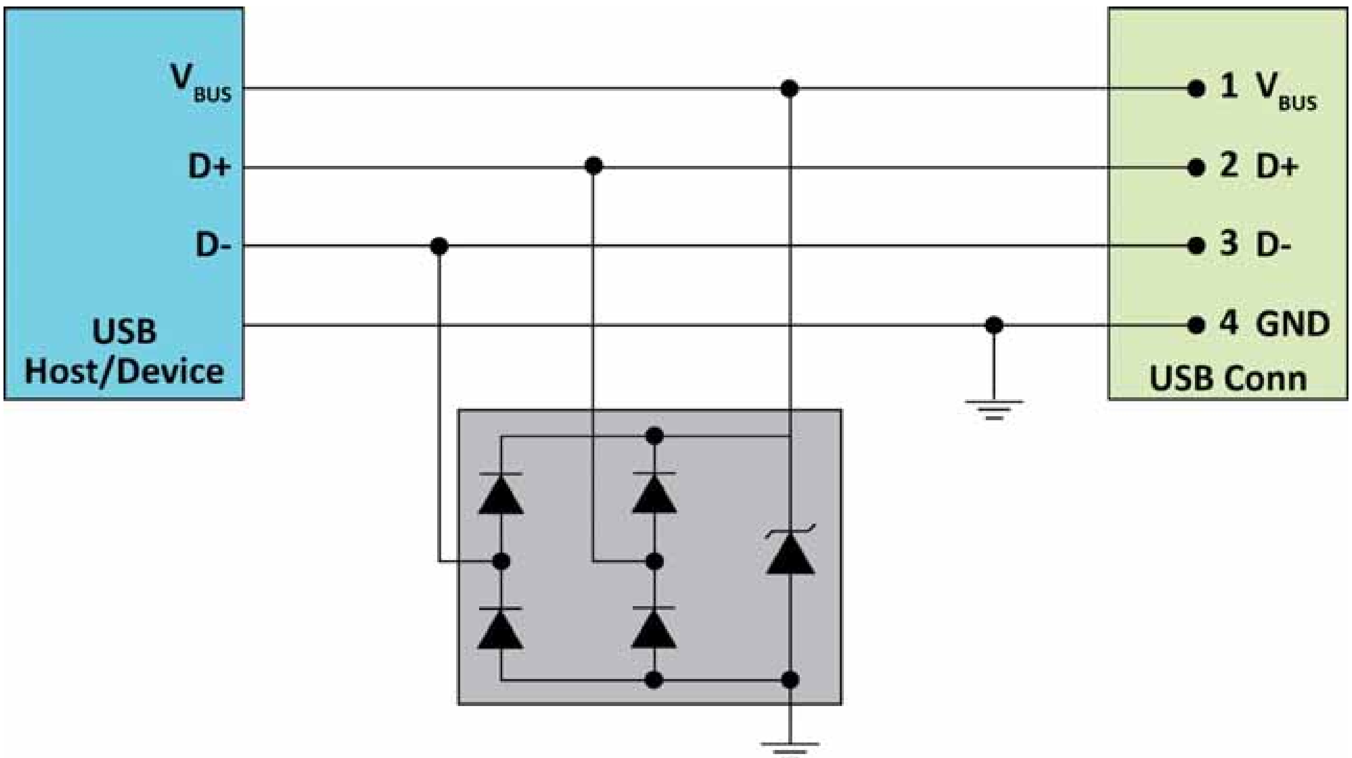
The low pass frequency response of the USB 3.0 cable has to be taken in to account as well. To compensate the attenuation of high frequency content, the signal is tuned by a dedicated equalization on TX and on RX side.

USB and Other Applications in Automotive

Today's automobiles rely on more and more electronics systems and the reliance increases with each new generation. USB has become a go-to data transfer connection in today's models. But, USB is just one of many automotive applications requiring advanced circuit protection.

The Automotive Electronics Council (AEC-Q101) provides standards for automotive circuit protection. This includes: AEC-Q101-001 (electrostatic discharge [ESD] test - human body model); AEC-Q101-002 (ESD test - machine model); AEC-Q101-003 (wire bond shear test); AEC-Q101-004 (miscellaneous test methods such as unclamped inductive switching, dielectric integrity, and destructive physical analysis); and AEC-Q101-005 (ESD test - capacitive discharge model).

These standards are applied to various automotive systems to provide proper circuit protection. In the 1970s, automobiles generally had just the engine control unit (ECU) as the sole electronics device. Today, it is estimated cars have between 30 and 100 microprocessor devices. They are used to power various systems that are either important to safety, convenience or entertainment. They include USB ports, Ethernet ports, CANBus lines, LINBus, antenna, display interfaces, power systems, fuel injection management systems, and many more.



Example USB 2.0 Interface Circuit Protection Diagram Using a Combo Steering Diode / TVS Array

Electrical transient events present a top critical risk to damaging these systems. These events also increase servicing and warranty costs for auto manufacturers. As a result, there are other automotive test standards designed to help simulate electrical transient threats. One such standard is ISO7637-2. It refers to Pulse 5 (load dump pulse) designed to simulate when a load to which a generator is delivering current is abruptly disconnected. This can be applied to disconnecting a battery while it is being charged by the alternator. Signal levels can be as high as 174 V and may take up to 400ms to decay. It is a scenario such as this one that compels a requirement for overvoltage circuit protection. TVS diodes have long been used and proven effective for a variety of automotive circuit protection situations.

Conclusions

Any USB 3.0 design today has to consider ESD protection as part of the design. When implementing circuit protection in USB applications, there are a variety of design concerns to tackle. Continued miniaturization requirements is obviously one of them. The proper selection of TVS array components is paramount. Then there are key considerations for protecting USB designs under a given application, such as automotive. The automotive industry continues to build more and more computing functions into cars. USB will continue to play a big role here, whether USB is used for data transfer or basic charging. AEC-Q101 and other such standards have helped. They are necessary standards because today proper circuit protection of USB interfaces, whether in automotive or other applications, is a requirement not a luxury.