Protect USB Type C Power Switch at Hot Plug/unplug and Shutdown Events

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Introduction

USB Type C protection power switches such as the AOZ132xDI and AOZ1398xDI product family (AOZ1327/1376, AOZ13984/13987/13929) are powerful and effective protection ICs, which protect downstream devices from any abnormal power situation such as over/under voltage, over/surge/reverse currents, overpower, and over-temperature conditions, to name a few.

However, the type C power switch needs protection when the voltage spike goes over its limit, i.e., Plug/unplug events, as shown in Figure 1. It is violent affairs that can interact with board and cable inductances and input capacitances to produce voltages beyond the maximums allowed by the internal control circuit. Another case is the part shutdown at faults with high peak current. In this case, the fast shutdown can make the input cable inductance resonant with input caps, causing the high input ringing voltage. For this case, enough input caps can slow down the ringing frequency and lower the ringing voltage. In both cases, the overvoltages can be controlled or eliminated by using enough input capacitors, proper component placement, and transient voltage suppressors (TVS).

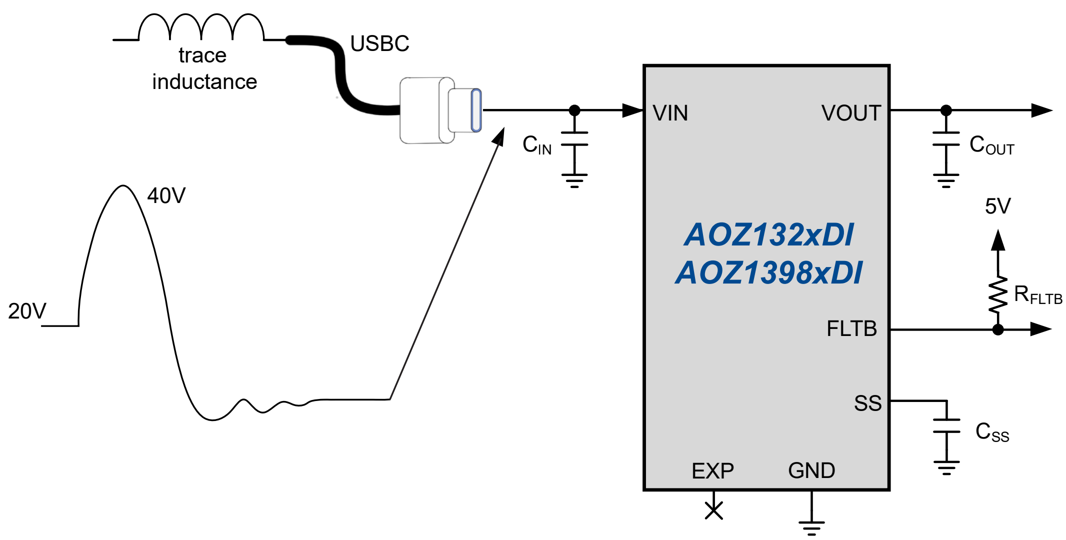


Figure 1. Transients Due to USBC Plug/Unplug or Shutdown Event

As shown in Figure 2, the TVS handles overvoltage events by clamping the ringing input voltage to be less than the rated MAX voltage of the type C power switch. When the voltage increases beyond the breakdown voltage of the TVS, the TVS becomes low impedance. It absorbs the energy of the over voltage event until it decreases below the TVS breakdown voltage. Once the voltage is less than break down voltage, the TVS becomes high impedance and stops conducting large current.

In AOZ132xDI/9xDI controller, the V_{IN} pin has an internal ESD diode used for electrostatic protection in compliance with IEC 61000-4-2 spec. This ESD diode is not designed for surge current protection specified in IEC 61000-4-5 spec, and it should not carry a large surge current. The external TVS diode is critical to carry the surge current and ensure no large current flowing into this internal ESD diode, both at shutdown and hotplug events.

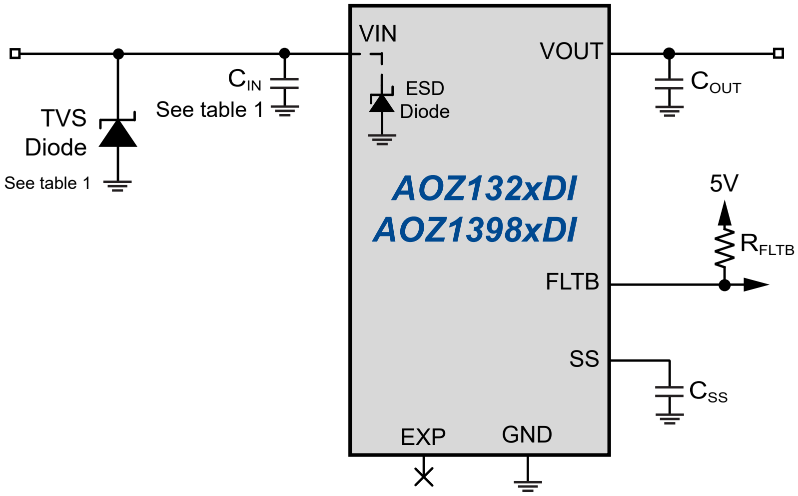
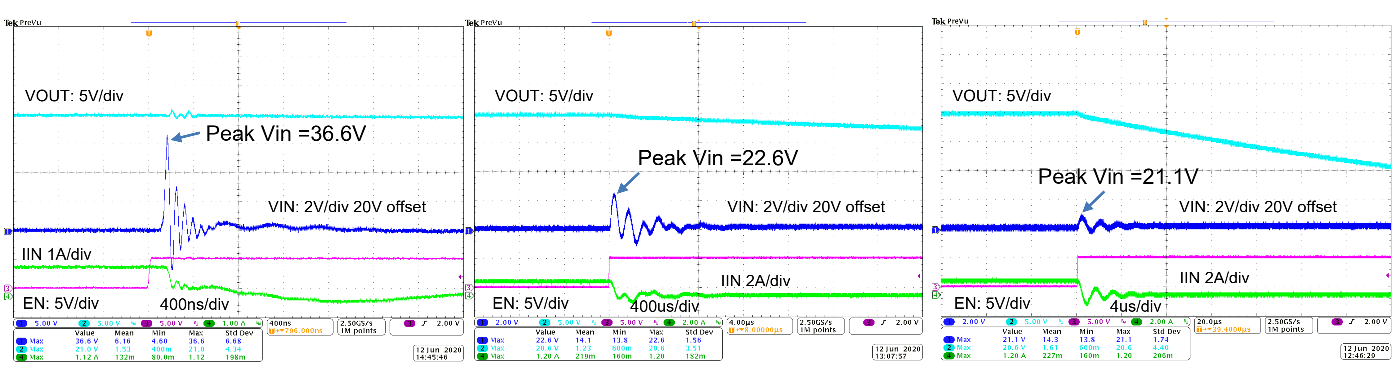


Figure 2. Schematic with TVS and Schottky on the USB Connection

In real applications, it is recommended to select the TVS diode VCL (clamping voltage) carefully at system peak surge current to ensure it less than the ESD minimum break down voltage. The typical clamping voltage is insufficient to ensure enough margins for safe operations if considering the part to part variations, temperature, and other factors. The TVS diode VCL needs to consider the maximum clamping voltage for the maximum surge current in the system. For example, AOS's high power AOZ8360DI-20 is rated for 20 V operating voltage with a maximum breakdown voltage at 25.5 V. It can handle surges of up to 135A within a DFN 2x2mm package. The maximum VCL clamp voltage is 28 V at 1 A and 29 V at 12A Ipp (8/20 µs Surge IEC61000-4-5). Therefore, if the system's maximum peak current is 12A, AOZ8360DI-20 can protect AOZ132xDI/1398xDI effectively below 30 V. With TVS protection, the high spike V_{IN} voltage is kept safely below the minimum allowed VIN ESD diode breakdown voltage.

It is also critical to choose the C_{IN} cap on the V_{IN} pin carefully. As shown in Figure 3, the V_{IN} spike voltage at shutdown event with different C_{IN} cap without TVS diode. With the input cable inductance of about 700 nH to 1 µH, the input voltage can ring up at shutdown due to the resonance between cable inductance and the input cap. The V_{IN} cap can absorb the surge current, slow down the surge voltage speed, and effectively reduce the input peak voltage. In Figure 3, with a small load current 1 A, the case with only a 22 pF input cap can generate a high input peak voltage for 36.6 V, while the peak voltage is largely reduced by using 0.1 µF and 2.2 µF input caps. With more input caps carrying the surge current at part shut down, less surge current will flow into TVS diode after reaching clamping voltage. Therefore, the smaller size TVS with less current capability can be used to ensure the safe clamp voltage.



(a) C_{IN} = 22 pF **(b) C_{IN} = 0.1 µF** **(c) C_{IN} = 2.2 µF**

Figure 3. V_{IN} Spike at 1 A Load Shutdown with Different V_{IN} Cap (22 pF, 0.1 µF, and 2.2 µF) without TVS Clamp

Table 1 shows the recommended input cap and TVS diode combinations for different applications. The load peak current is varied on different designs and systems. And the user needs to estimate the maximum peak current on the load for C_{IN} and TVS selection and ensure to leave margins on maximum peak current estimation. As shown in Table 1, the barrel cable connection requires a much smaller input cap compared to the type C connection. Furthermore, the TVS diode has to carry most of the surge current. Thus, the TVS diode needs to ensure enough margins for clamping voltage on the V_{IN} pin. For the type C cable, more input cap can be allowed to carry the surge current, and thus a smaller size TVS diode can be used to clamp the voltage with less surge current.

Table 1. Recommendation for Barrel and Type C Cable Applications[1, 2]

Recommendations	Barrel Cable (<20A Load Peak Current)	Type C Cable (<20A Load Peak Current)	Barrel Cable (<15A Load Peak Current)
C_{IN} Cap	0.1µF/50V, X5R Cap	2.2µF/50V or 2.2µF/50V, X5R Cap	0.1µF/50V, X5R Cap

Notes:

1. TVS selection should consider the maximum VCL (clamping voltage) at load peak current to be less than 30V.
2. AOZ13929 has an integrated TVS diode in the package. For Barrel cable <15A load peak current, it only requires 0.1µF/50V cap. For Type C <20A, it is recommended to use a 2.2µF/50V cap.

Table 1, for type C cable with a smaller current (i.e., less than 7A), a TVS is needed only for the hot plug-in event. In this case, a small TVS is only needed to clamp voltage at the plug-in, to ensure the surge voltage is less than the internal ESD breakdown voltage (i.e., AOZ1327 at 30V). For some customers with small load peak current, their application has no hotplug event, and the TVS diode is optional for them.

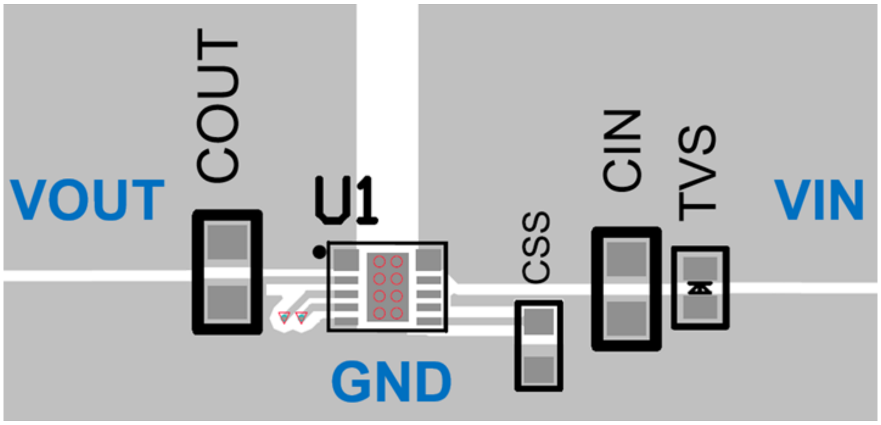


Figure 4. Input Cap and TVS Diode Placement

To ensure safe operations, the input cap C_{IN} and TVS diode placement are essential to clamp the input spike voltage. As shown in Figure 4, it is a recommended layout for guiding the placement of different components. For the best protection, place the input cap and TVS diode as close to the V_{IN} and GND pins of the IC as possible. If the ground pin is far from the V_{IN} pins, use the large plane as shown in Figure 4 to minimize the trace impedance. If the top layer is occupied and can't place large planes, use enough vias (more vias to minimize the impedance) from V_{IN} and GND pins to connect to inner layers, and then tie to the pads of C_{IN} and TVS diode. Insure wide short planes connect them to the V_{IN} pin and ground. For the exposed pad of the package, put enough vias as shown in Figure 4 to allow for good thermal dissipations and low impedance for electrical connections.

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