Protecting the TPS233x Hot-Swap Controller in a High-Transient Environment

Edward Jung

ABSTRACT

The TPS233x hot-swap controller has several pins tied to the power bus in a typical application. This exposes the TPS233x to potentially damaging transients whenever the TPS233x disconnects the load from the bus. Clamping the bus voltage with a transient voltage suppressor (TVS) protects the TPS233x in some cases, but not in all cases. Additional protection can be gained by decoupling the TPS233x from the power bus using the method described in this application report.

Introduction

Figure 1 shows a model of the power bus and hot-swap circuit. Lw and Rw model the power bus; R, D, C, Rsense, Rds(on), and S1 model the hot-swap circuit.

Interrupting the load current via S1 excites the Rw-Lw-C tank circuit and causes a voltage transient or "ringing" at node AA. If the TVS allows this transient to exceed 15 V, then the TPS233x is damaged if any of its pins are tied to node AA.

Figure 2 shows a typical TPS233x implementation where the IN pin is directly tied to node AA and the ISET and ISENSE pins are each tied to node AA through a resistor.
The TVS must not conduct at normal bus voltages, and the TVS must limit bus transients to 15 V. These boundary conditions are easily satisfied in a 5-V, hot-swap design, but they are difficult to satisfy in a 12-V, hot-swap design because accuracy considerations and non-ideal TVS characteristics leave little design margin.

Consider a system where the bus-voltage regulation is 5% and the hot-swap, short-circuit output current is limited to 40 A by circuit parasitics.

In a 5-V, hot-swap design, a SMAJ5.0A TVS clamps the bus voltage to a safe level. The SMAJ5.0A characteristics as detailed in the Diodes, Inc. data sheet are:

- Reverse standoff voltage: 5 V
- Breakdown voltage at 1 mA: 6.4 V–7.25 V
- Maximum clamp voltage at 43.5 A: 9.2 V

If S1 opens, then the short-circuit current commutates through the TVS and the TVS clamps node AA to 9.2 V, which is below the 15-V rating of the TPS233x.

In a 12-V, hot-swap design, a SMAJ12A is unable to clamp the bus voltage to a safe level. The SMAJ12A characteristics are:

- Reverse standoff voltage: 12 V
- Breakdown voltage at 1 mA: 13.3 V–14.7 V
- Maximum clamp voltage at 20.1 A: 19.9 V

If S1 opens, then the short-circuit current commutates through the TVS, the voltage at node AA rises above 15 V, and the TPS233x is damaged. A TVS with a higher power rating can be used, but the clamp voltage will still exceed 15 V.

The soft clamping characteristic is due to the series resistance of the TVS as shown in Figure 1.

**Getting Off the Bus**

The traditional hot-swap design shown in Figure 2 exposes several TPS233x pins to the bus voltage transients and relies solely on the TVS for protection. At high bus voltages like 12 V, the TVS lacks the headroom to adequately protect the TPS233x. In this case, R1, R6, and D2 can be added to decouple the TPS233x from the bus as shown in Figure 3.
Figure 3. Decoupling the TPS233x From the Power Bus

The bus voltage is low-pass filtered by R1-C1 before it powers the TPS233x. This filter has a 9.3-kHz cutoff frequency and effectively attenuates the 1-MHz transients found in a typical bus. R1 must not exceed 24.9 Ω; the voltage drop across R1 must be small in order for the TPS233x current-sense amplifier to work correctly. Place capacitor C1 close to pins 8 and 9 of the TPS233x. An X5R or X7R capacitor rated at 25 V or higher is recommended; a 25-V-rated capacitor has less capacitance dropoff at a particular bias voltage than a capacitor that is rated at a lower voltage.

D2 protects the ISET and ISENSE pins by clamping them to 200 mV above IN during a transient.

The 5-μA ISENSE bias-current causes a 1-mV drop across resistor R6 and a corresponding error in the sensed current.

Place the TVS shown in Figure 2 and Figure 3 close to the TPS233x.

The circuits shown in Figure 2 and Figure 3 can be built using a single PCB design. This makes it easy to quickly evaluate both circuits. Replace R1 and R6 with 0-Ω resistors, and remove D2 to convert the circuit in Figure 3 to the circuit in Figure 2.
Drive Safely

The TPS233x ENABLE, PWRGD, and FAULT pins can pull up to the VCC shunt-regulated output in Figure 4. These pins should not pull up to VIN because of the potentially damaging transients at VIN.

![Figure 4. TPS233x Status Outputs and Control Input Can Safely Pull Up to +VCC](image)

Summary

A TVS may not adequately protect the TPS233x from voltage transients. In these cases, additional protection can be gained by decoupling the TPS233x from the power bus. The cost is a few inexpensive components and a slight loss in current-sense accuracy. A single PCB design can be used to evaluate the decoupled and non-decoupled versions of the hot-swap circuit.
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