Application Note

How to Solve Voltage Overshoot While Hot Plugging

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ABSTRACT

Hot-plugging refers to attaching a powered up voltage source to the input power or battery connector of an electronic device. Voltage transient spikes from hot-plugging can damage the integrated circuits inside the device. This application note explains the root cause for these voltage transients and provides potential designs to prevent these transients from damaging the integrated circuits (ICs) in the electronics.

Table of Contents

1 Introduction.....2
2 Root Cause.....2
3 RC Snubber.....4
4 TVS Diodes and Zener Diodes.....5
5 Summary.....6
6 References.....7

List of Figures

Figure 2-1. Simplified Equivalent Circuit During Adapter Insertion.....2
Figure 2-2. Effect of Capacitance on V_{Ci}.....3
Figure 2-3. Effect of Inductance on V_{Ci}.....3
Figure 2-4. Effect of Resistance on V_{Ci}.....3
Figure 3-1. Recommended Input Filter Design.....4
Figure 4-1. TVS Diode Characteristics.....5

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1 Introduction

When hot-plugging a higher than 5 V USB adapter or multi-cell battery into an electronic device, it is not usual to see some voltage spikes and or ringing. If the IC pin that is connected to the input power or battery connector does not have enough voltage rating, the IC can be permanently damaged. This application note explains and identifies the root case of the voltage spikes and or ringing. In addition, this application explains how a properly sized resistor and series capacitor (RC) and or a diode can be used to prevent the device from being damaged.

2 Root Cause

Long power adapter or battery cables have resistance and inductance. The resistance and inductance is modeled by Ri and Li in Figure 2-1. The Rc and Ci represent the input capacitance and series resistance to ground that precedes an IC's power or battery pin.

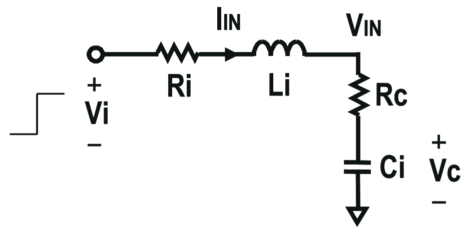

Figure 2-1. Simplified Equivalent Circuit During Adapter Insertion

The voltage on the charger input side V_{IN} is given by the following mathematical model.

$$V_{IN}(t) = I_{IN}(t) \times R_C + V_{Ci}(t) = V_i e^{\frac{R_i}{2L_i}t} \left[\frac{R_i - R_C}{\omega L_i} \sin \omega t + \cos \omega t \right] \quad (1)$$

in which, the total impedance, Rt, is

$$R_t = R_i + R_C \quad \omega = \sqrt{\frac{1}{L_i C_i} - \left(\frac{R_t}{2L_i} \right)^2} \quad I_{IN}(t) = \frac{V_i}{\omega L_i} e^{\frac{R_i}{2L_i}t} \sin \omega t \quad (2)$$

This equation gives the voltage across capacitor Ci as

$$V_{Ci}(t) = V_i - V_i e^{\frac{R_t}{2L_i}t} \left(\frac{R_t}{2\omega L_i} \sin \omega t + \cos \omega t \right) \quad (3)$$

The following figures below plot V_{Ci} over time with different values for the capacitance, inductance, and resistor. Almost all power IC high current pins have some external capacitance, Ci. Figure 2-2 demonstrates that a higher Ci helps dampen the voltage spike but not eliminate the voltage spike. Figure 2-3 demonstrates the effect of the input stray inductance Li upon the input voltage spike and confirms that longer leads with higher inductance cause higher voltage spikes and long ringing. As shown in Figure 2-4, the only way to suppress the voltage ringing is to add series resistor Ri to Ci (*bq24753A Host-Controlled Li-Ion and Li-Polymer Battery Charger With Low Iq and System Power Selector*).

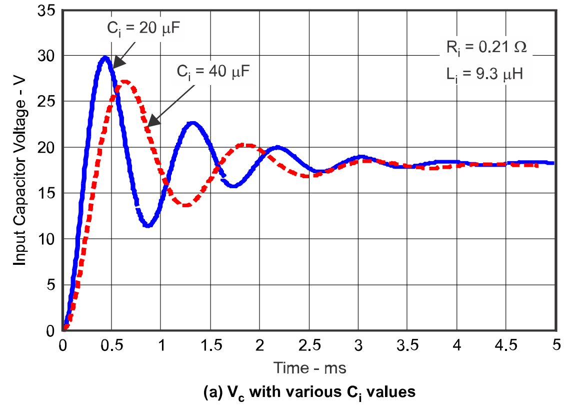

Figure 2-2. Effect of Capacitance on V_{Ci}

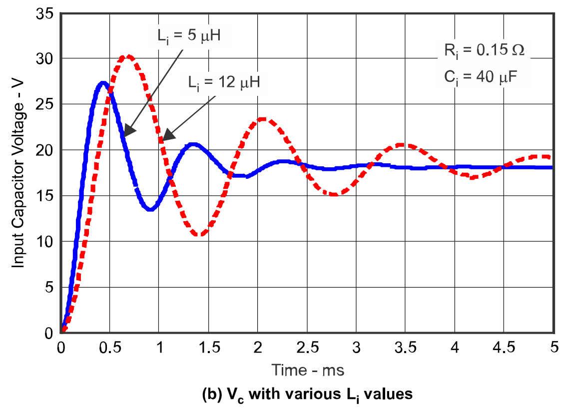

Figure 2-3. Effect of Inductance on V_{Ci}

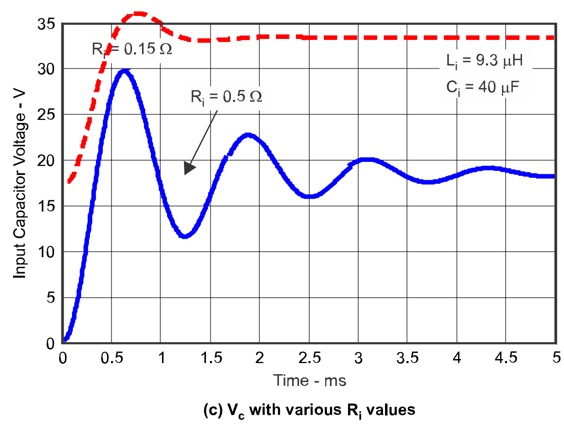

Figure 2-4. Effect of Resistance on V_{Ci}

3 RC Snubber

Figure 2-2 shows that minimizing the input stray inductance, increasing the input capacitance, and adding resistance (including using higher ESR capacitors) helps suppress the input voltage spike. However, a user often cannot control input stray inductance and adding additional large capacitance increases cost and takes up more board space.

The damping factor is

$$R_i + R_C > 2\sqrt{\frac{L_i}{C_i}} \quad (4)$$

Cable lengths for electronic devices, and therefore the series inductance Li, vary significantly. The power pin capacitance varies by IC as well and, in general, cannot have a large series resistance. Therefore, the most efficient and cost-effective approach is to not use the IC pin's capacitance but add an additional small capacitor and series resistor as a snubbing filter or, more commonly called, RC snubber.

Figure 3-1 depicts the recommended input filter design for the BQ2579x family. The filter can be placed on the PCB at the device connector or closer to the IC if long PCB traces and GND returns are used.

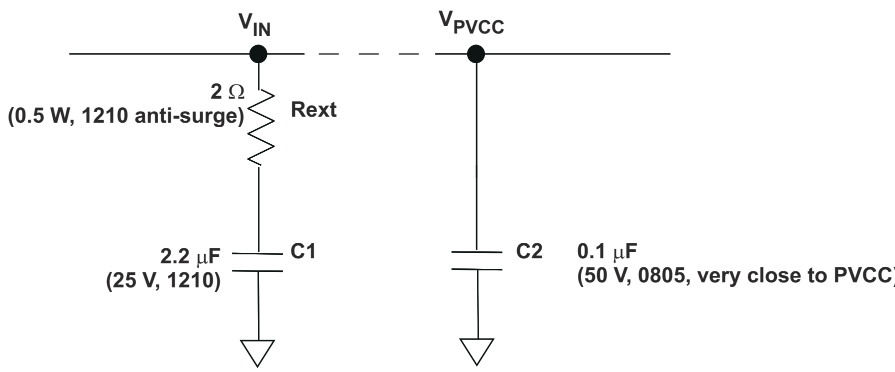

Figure 3-1. Recommended Input Filter Design

This RC combination is effective for most commonly used adapter cable lengths, but the RC combination can require adjusting for some applications (*bq24753A Host-Controlled Li-Ion and Li-Polymer Battery Charger With Low Iq and System Power Selector*.

4 TVS Diodes and Zener Diodes

RC snubbers are great for filtering transients caused by hot-plugging adapters which maintain a steady dc voltage level to power an IC. However, if the power source has large voltage swings, for instance like a battery at the output of a battery charger that frequently supplements a system transient load, the RC snubber is not the best choice. Even though more costly than an RC snubber, a TVS or zener diode can be used to suppress voltage spikes from adapter hot plug.

A transient-voltage-suppression diode, or TVS diode, is designed to protect electronic components from voltage spikes. The TVS diode begins to operate once the voltage on the diode exceeds the avalanche breakdown potential. A TVS diode resets once this voltage goes away. A TVS diode can be both unidirectional or biderectional. A graph of a TVS diode's I-V curve is shown in Figure 4-1

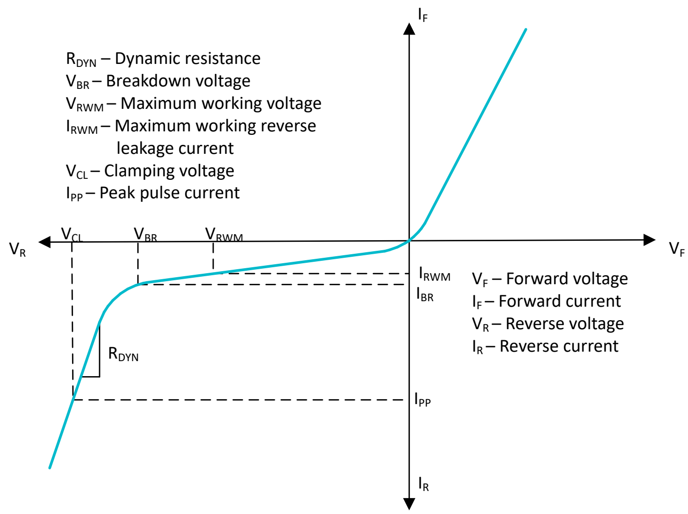

Figure 4-1. TVS Diode Characteristics

Zener diodes work the exact same way as TVS diodes do and zener diodes follow a similar curve. The only difference is that TVS diodes are designed to have a faster response time and a higher surge current conduction capability.

To select a TVS diode, first know the maximum safe working voltage of the IC pin needing protection and the minimum harmful voltage. Chose the reverse working voltage to be above the maximum safe working voltage of the circuit and the clamping voltage to be below the minimum harmful voltage.

To select a zener diode, know the maximum working voltage and minimum harmful voltage. Chose the zener voltage to be between the max working voltage and the min harmful voltage.

5 Summary

In conclusion, high voltages can cause issues when hot-plugging in circuit. High voltage spikes can cause issues immediately or over time. Fortunately, these issues are preventable using the correct engineering methods. TVS diodoes, Zener diodes, and RC snubbers are a potential workaround to solve this issue. Proper design of the circuit can save you time, resources, and potential headaches.

6 References

- Texas Instruments, *bq24753A Host-Controlled Li-Ion and Li-Polymer Battery Charger With Low Iq and System Power Selector*, data sheet.