Application Report
SLVA730–May 2016

Reverse Current Protection in Load Switches

Zachary Stokes and Alek Kaknevicius *Drivers and Load Switches*

ABSTRACT

Reverse current occurs when current travels from output to input (rather than from input to output), as Figure 1 shows. This application note outlines where reverse current comes from, why it can be harmful to a system, and how to modify a design to provide protection from reverse current in a system.

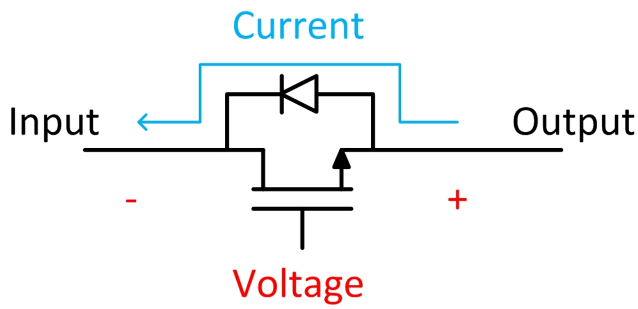

Figure 1. Reverse Current

Contents

USB Type-C is a trademark of USB Implementers Forum, Inc..
All other trademarks are the property of their respective owners.

Copyright © 2016, Texas Instruments Incorporated

1 Sources of Reverse Current

Reverse current is when there is a higher voltage at the output of a system than at the input, causing current to flow backwards through the system. There are two common sources of reverse voltage: (1) when power is disconnected from a system and (2) when the body diode of a FET becomes forward-biased. One source is when system input power is disconnected, a higher voltage can be left at the output, which temporarily produces reverse current.

Reverse voltage should not be confused with negative voltage (also known as reverse polarity). Negative voltage occurs in situations where the positive and negative terminals of a power supply are switched. In this case, what should be connected to ground actually has a voltage from the positive input to the system. This causes a different current phenomenon through the part than reverse voltage.

2 Why Avoid Reverse Current?

Reverse current can damage internal circuitry and power supplies. Depending on the path from output to input, reverse current spikes can also damage cables and connectors. If a FET is present in a design, reverse current can travel backwards through its body diode if it becomes forward-biased due to the FET output voltage being greater than the input voltage (as shown in Figure 1). This causes a linear rise in power dissipation across the body diode expressed by P = IV:

$$P_D = I_{REV} V_{DROP}$$

where

- Where P_D is power dissipated across the body diode
- I_{REV} is reverse current through the device
- V_{DROP} is the voltage drop across the body diode (1)

If the heat generated by this power dissipation through the device exceeds the thermal rating of the device, then combustion can occur, as seen in Figure 2. Therefore, device protection necessitates that reverse current flow, or reverse voltage, must be limited.

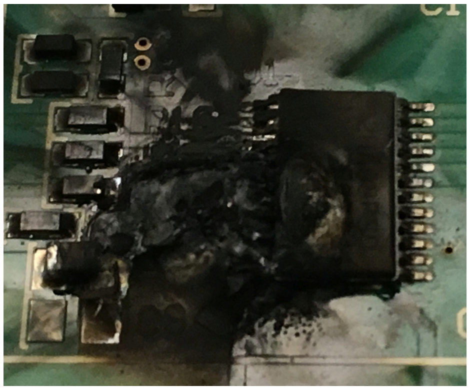

Figure 2. Thermal Damage Caused by an Overcurrent Event

There are three common ways to protect from reverse current: diodes, FETs, and load switches.

3 Methods for Reducing Reverse Current

3.1 Diodes

Diodes are great for high-voltage, low-current applications. However, diodes cause a forward-voltage drop which increases total power dissipation in the system and limits V_{CC} by 0.6 V to 0.8 V. This can cause decreased efficiency in the system and a shortened battery life. A popular alternative is the use of a Schottky diode; they have lower forward-voltage drops, but they are more expensive and have higher reverse current leakage which could cause problems for the system.

Figure 3 illustrates reverse current blocking with a diode.

Copyright © 2016, Texas Instruments Incorporated

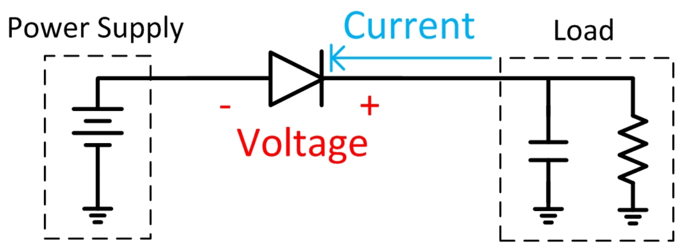

Figure 3. Reverse Current Blocking With a Diode

3.2 Dual FET / Back-to-Back

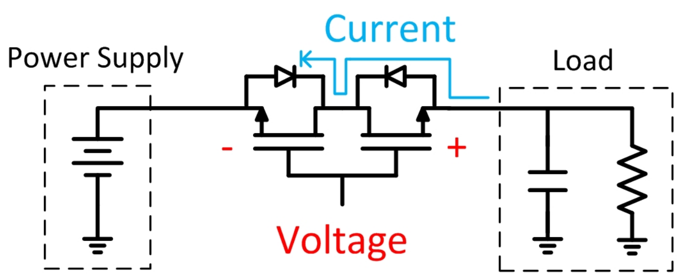

Figure 4. Reverse Current Blocking with Dual FETs

Using back-to-back FETs is a powerful option, since it offers current blocking in both directions when the FETs are turned off. In comparison to the diode solution, there is a lower voltage drop from the power supply to the load. However, this implementation takes up a larger amount of space on the board, requiring several components to build.

3.3 Load Switches

TI's load switches are integrated electronic switches which are used to turn power rails on and off. Similar to the dual-FET configuration, load switches block current in both directions when turned off, offering the added advantages of reduced footprint and BOM count. Most basic load switches consist of four pins: input voltage, output voltage, enable, and ground. They include a multitude of features, including reverse current protection, quick output discharge, inrush current control, and programmable slew rate, in a small, integrated package.

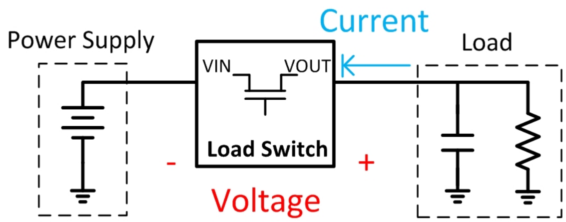

Figure 5. Reverse Current Protection With a Load Switch

4 Examples of Reverse Current in a System

In USB Type-C™ applications, the USB Type-C port can source 5 V, 12 V, and 20 V. The USB also uses the 5- and 12-V rails to power internal device components, but it is very sensitive to external voltage disturbances. If the USB port is sourcing 20 V, then protect both the 12- and 5-V internal rails from reverse current caused by the higher output voltage. This is illustrated in Figure 6.

Copyright © 2016, Texas Instruments Incorporated

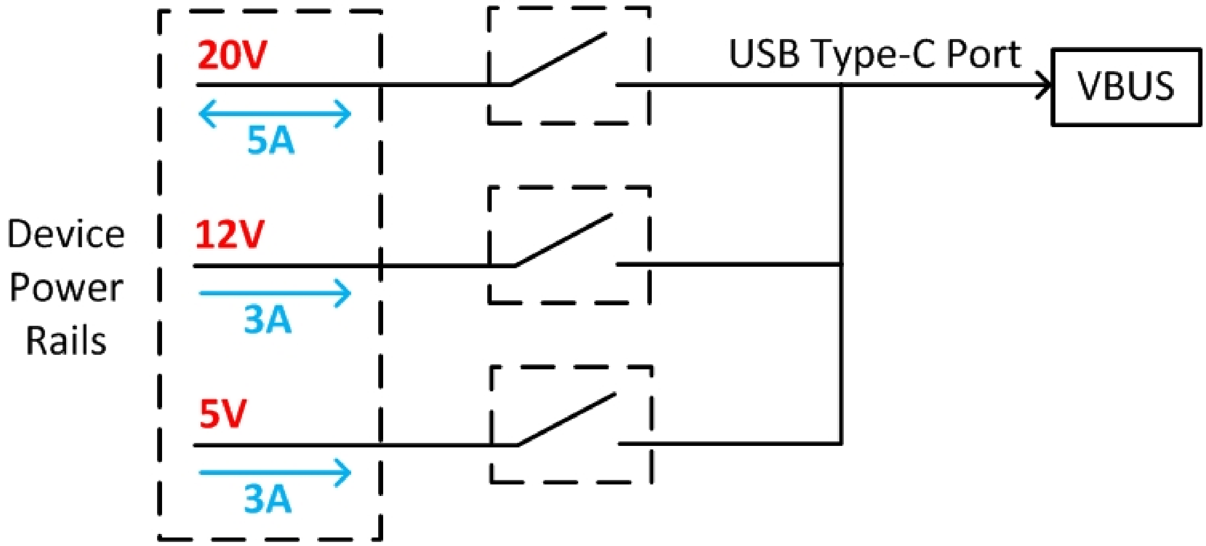

Figure 6. USB Type-C Power Muxing

Without reverse current protection, these voltage disturbances can cause damage to components further down the 5- or 12-V rails within the device.

Another application where reverse current can be generated is when a FET is used for power switching in a circuit that relies on an output capacitor to perform critical shutdown functions after an unexpected power loss. The input voltage drops and the capacitor uses its stored charge to safely shutdown the system load. If there is no reverse current protection, the charge stored in the output capacitor can be drained backwards through the switching device instead of being used for shutdown functions. Having reverse current protection prevents this.

5 Load Switch Application Examples

5.1 *What if V_{IN} = 0 V? (V_{IN} not Powered)*

The TPS22963C is a load switch with reverse current blocking. This reverse current blocking feature is only activated when the load switch is turned off. In the following example, the TPS22963C has 5 V applied on the output and 0 V at the input to demonstrate reverse current protection while $V_{IN}$is not powered.

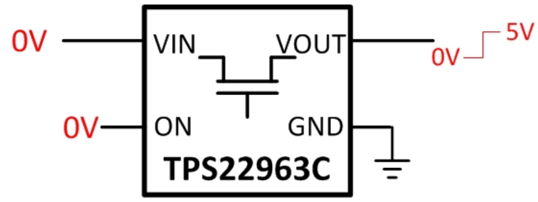

Figure 7. TPS22963C Load Switch

Using the configuration shown in Figure 7, the results shown in Figure 8 can be observed.

Copyright © 2016, Texas Instruments Incorporated

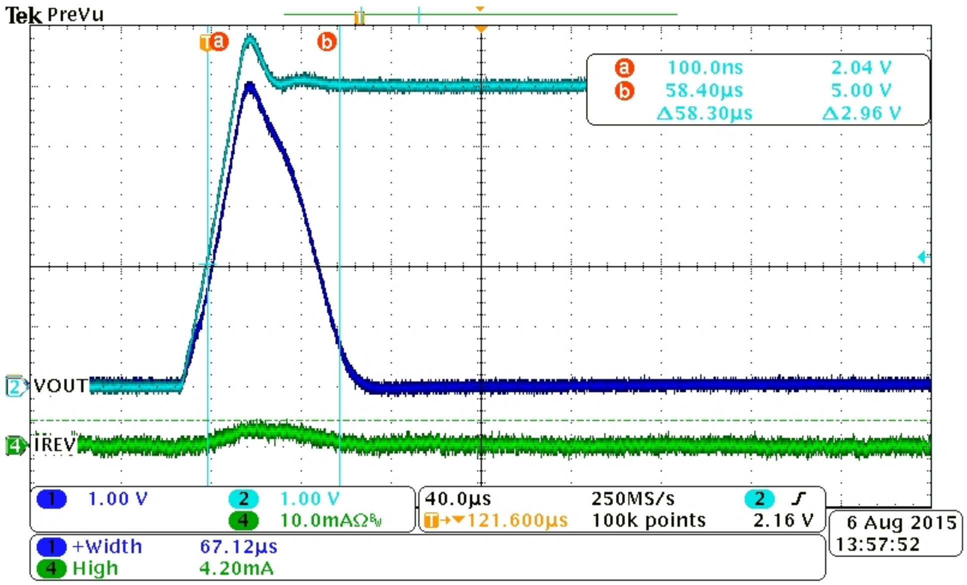

Figure 8. RCP TPS22963C V_{IN} Leveling Time

Cursors a and b are configured to measure how long it takes for the TPS22963C to level out the reverse current. In this case it takes 58 µs, as shown in the top right cursor measurement box. The oscilloscope is also configured to measure the peak reverse current which passes through the TPS22963C. This peak value is shown at the bottom of the screen shot and is 4.20 mA.

5.2 *What if Power Muxing Accidentally Causes Reverse Voltage?*

Power multiplexing, otherwise known as power muxing, is the practice of using a switching circuit to choose one of multiple power supplies for a system, with the ability to switch between them. Figure 9 shows this configuration.

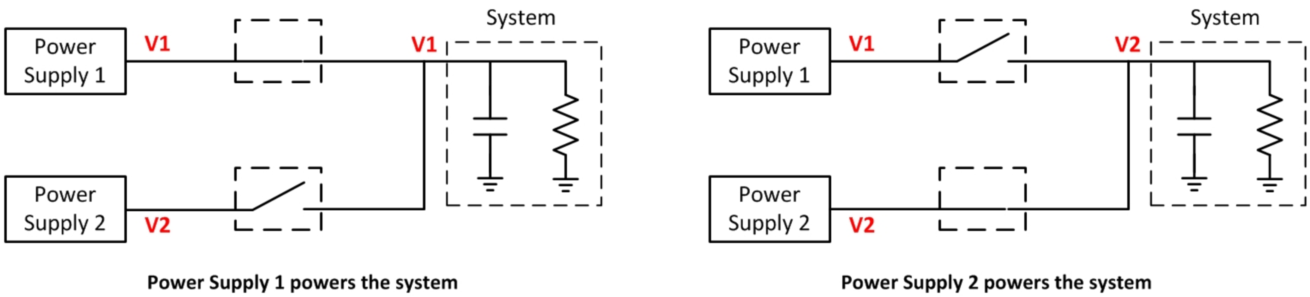

Figure 9. Power Muxing Example

If one of the power supply voltages is higher than the other, then reverse current can be generated even when the other power rail has an "open" switch. This occurs in the case where FETs are being used to switch the power supplies. The higher voltage seen at the output of the "open" FET causes reverse current to flow from the higher voltage power supply, through the FET body diode, and into the lower voltage power supply. Figure 10 shows an example where 5 V is applied to the system while the switch for the 3.3-V rail is "open."

Copyright © 2016, Texas Instruments Incorporated

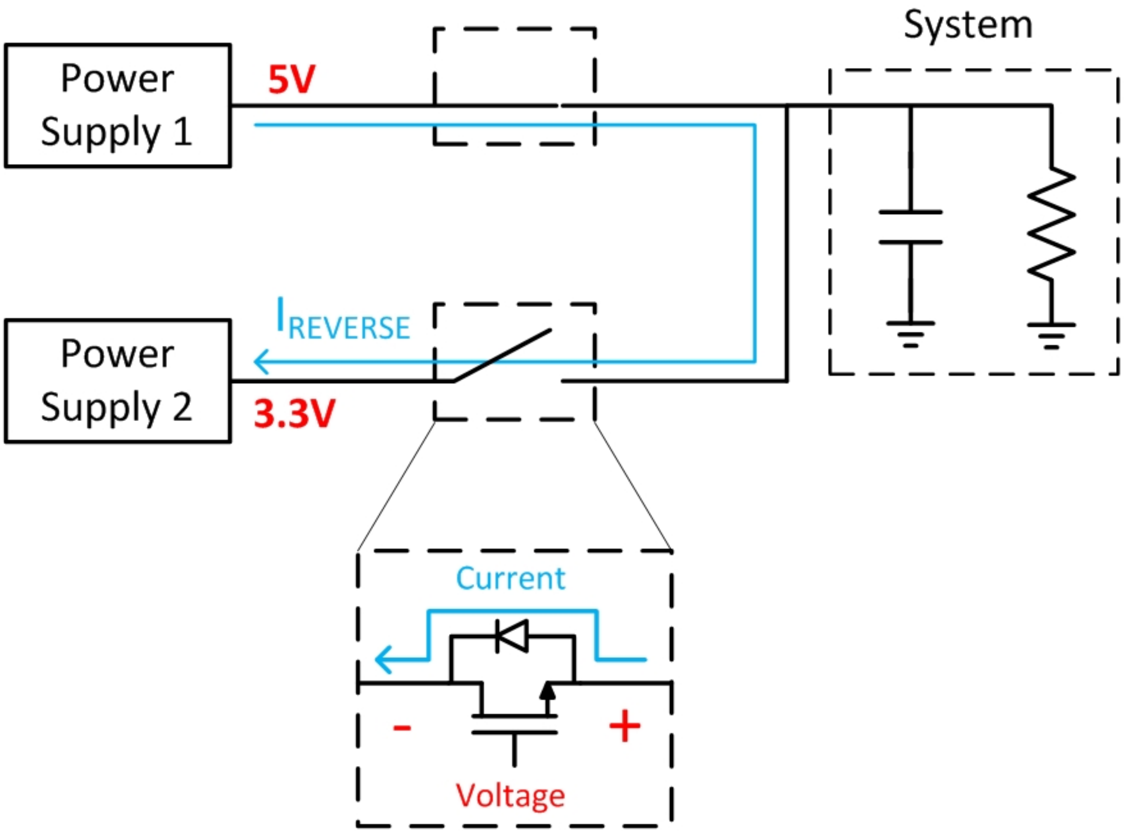

Figure 10. Reverse Current Caused by Power Muxing

As seen in Figure 10, with a simple FET solution for the switch, reverse current is able to flow through the FET body diode, even when the switch is "open."

However, if TPS22963C load switches are used to switch between the two power supplies, reverse current protection is provided. This is shown in Figure 11.

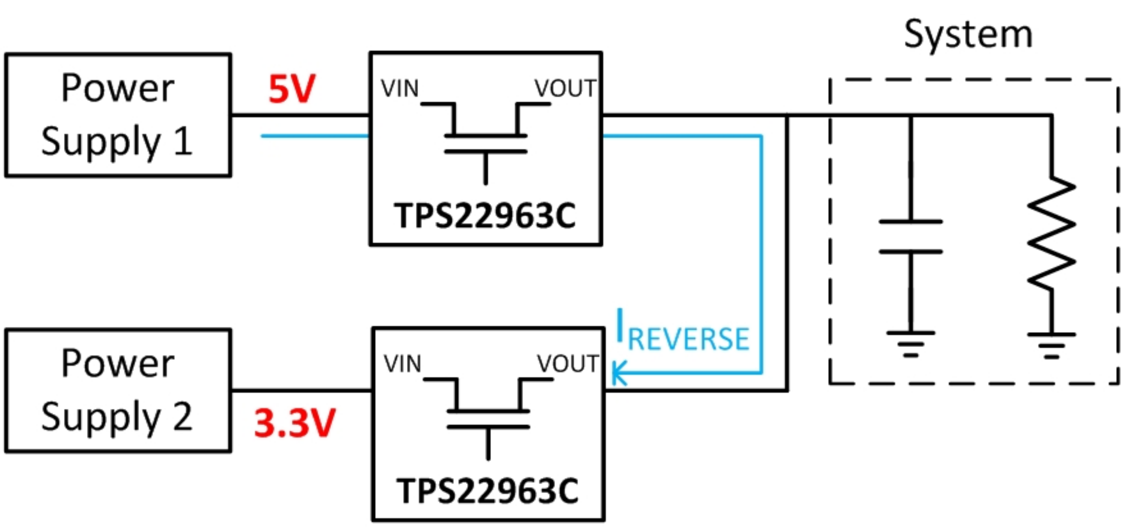

Figure 11. TPS22963C Reverse Current Blocking (5 V Closed, 3.3 V Open)

Copyright © 2016, Texas Instruments Incorporated

More information about power muxing is found at http://www.ti.com/tool/TIDA-00514.

5.2.1 TPS22963C Reverse Voltage Waveforms

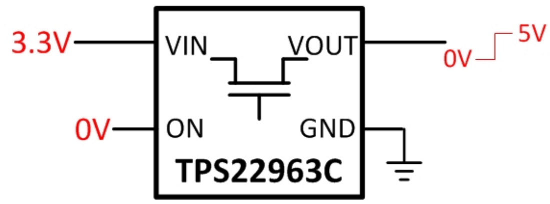

Figure 12. TPS22963C Power Muxing Conditions

Using the voltages from the power muxing example in Figure 12, V_{IN} = 3.3 V and V_{OUT} = 5 V, the TPS22963C takes 42 µs to level out the 89-mA reverse current spike induced by power muxing. This is shown in Figure 13.

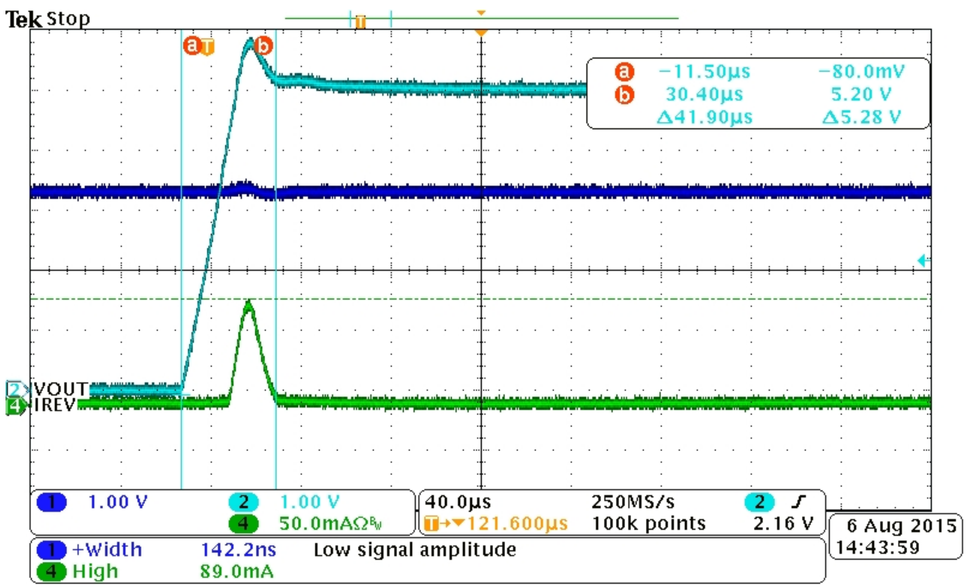

Figure 13. RCP TPS22963C Power Mux Leveling Time

In Figure 14, the cursors were moved to measure the time it takes for the reverse current protection to activate. The TPS22963C only takes 30 µs to activate the reverse current blocking feature, and at peak, the reverse current reaches 89 mA.

Copyright © 2016, Texas Instruments Incorporated

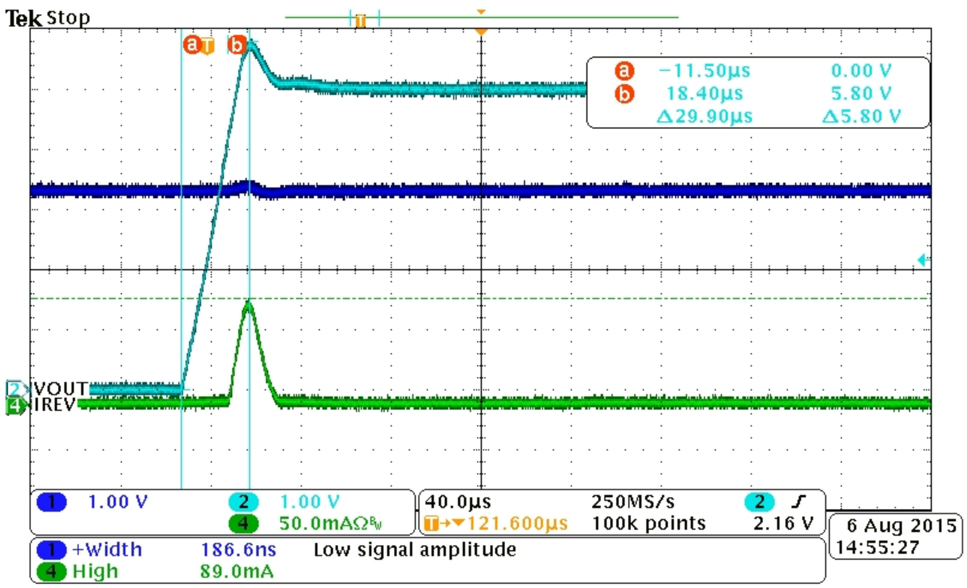

Figure 14. RCP TPS22963C Power Mux Activation Time

For the reverse current protection feature to be activated in the TPS22963C, the device must be disabled and the VOUT pin must receive a voltage greater than 1 V.

5.2.2 TPS22953 Reverse Voltage Waveforms

In comparison, the TPS22953 load switch has a VBIAS pin which biases the reverse current blocking. This can suppress the peak amount of reverse current even further than the TPS22963C. After VBIAS is powered according to the device specifications, the reverse current blocking feature is activated, meaning that there is no wait for VOUT to reach a threshold, as in the case of the TPS22963C.

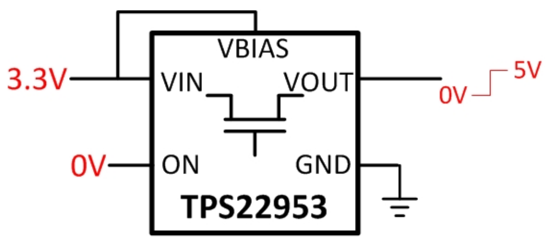

Figure 15. TPS22953 Power Muxing Conditions

Supplying 3.3 V to both VBIAS and VIN, then adding 5 V to VOUT, the TPS22953 activates its reverse current protection in 30 µs and levels out the reverse current in 46 µs. The activation time is shown in Figure 16, and the leveling time is shown in Figure 17. The reverse current peaks at 29 mA, 60 mA lower than the TPS22963C.

Copyright © 2016, Texas Instruments Incorporated

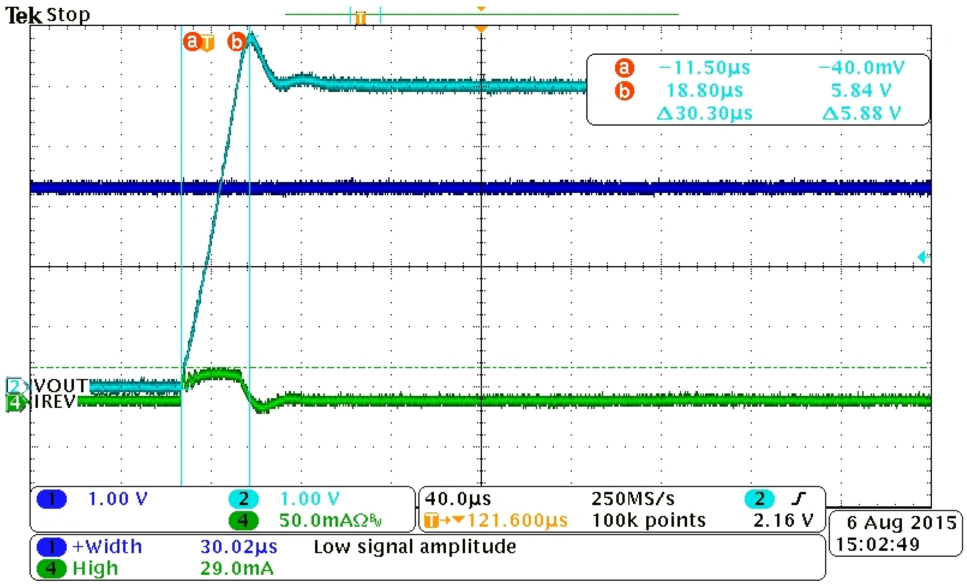

Figure 16. RCP TPS22953 Power Mux Activation Time

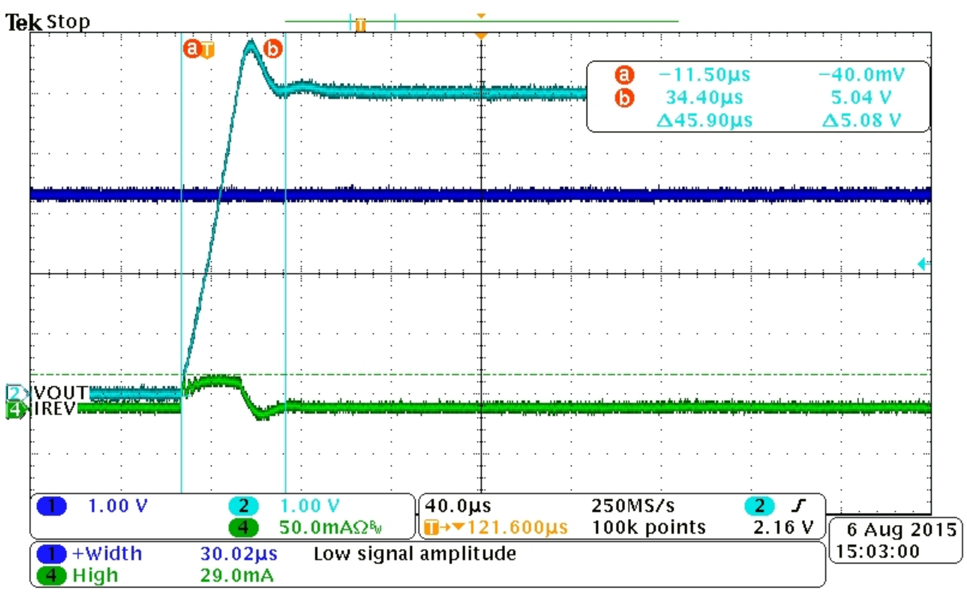

Figure 17. RCP TPS22953 Power Mux Leveling Time

5.3 Reverse Current Protection While Enabled

While all of the load switches discussed so far only offer reverse current blocking when the switch is disabled, the TPS2291xx family of load switches offers reverse current protection even when the device is enabled. This is done by using an internal comparator to compare the voltages on VOUT and VIN. If VOUT is greater than VIN by the device reverse voltage threshold, then the switch is disabled within 10 µs. Reverse current blocking then becomes active, blocking any current flowing from VOUT to VIN. Figure 18 shows the characteristic response of the TPS2291xx load switch to reverse current, where I_{RC} is the peak amount of reverse current and V_{RCP} is the reverse voltage threshold.

Copyright © 2016, Texas Instruments Incorporated

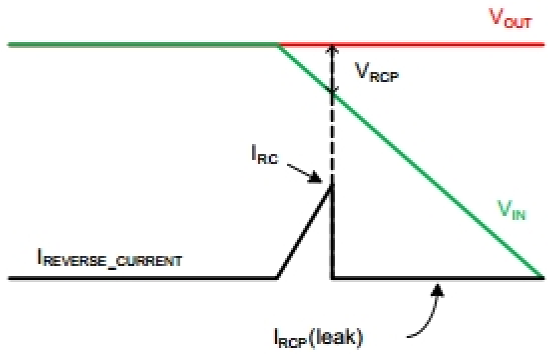

Figure 18. TPS2291xx Reverse Current Blocking Diagram

As the reverse current through the device increases, the voltage drop from VOUT to VIN also increases by a factor of the on-resistance of the device. In order to calculate the amount of reverse current it takes to activate the load switch reverse current blocking feature, use Equation 2:

$$I_{RC} = \frac{V_{RCP}}{r_{ON(VIN)}} \quad (2)$$

Depending on the device and input voltage used, I_{RC} can vary between 524 mA and 900 mA. The following scope shot from the data sheet shows the reverse current protection feature of the TPS22910A when the device is enabled.

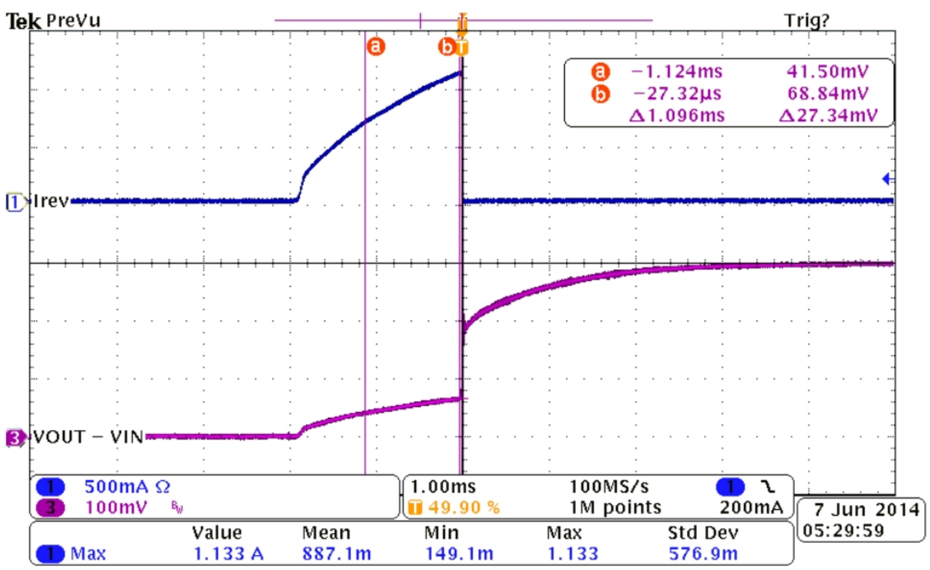

Figure 19. TPS22910A Full-Time Reverse Current Protection
(VIN = 3.0 V, VOUT Ramp up From 3.0 V to 3.3 V)

As the differential voltage between VOUT and VIN increases, the reverse current through the part also increases. Once the voltage difference reaches the fixed threshold, the reverse current protection is activated and the current drops to zero amps. Even though the ON pin is still high (device enabled), the TPS22910A is able to effectively mitigate the reverse current.

Copyright © 2016, Texas Instruments Incorporated

6 Conclusion

Applications such as power muxing or a loss of power to VIN can lead to a reverse voltage event that will induce reverse current. This can cause damage to both power supply and system. However, a TI load switch is both a size- and cost-effective solution helping to prevent damage from reverse current.

The TI load switch portfolio has a variety of devices with different specifications for reverse current protection, making them suitable for a wide variety of applications. These parts are found in the parametric search table at ti.com/loadswitches.

7 References

1. *TPS2296xC 5.5-V, 3-A, 13-mΩ On-Resistance Load Switch With Reverse Current Protection and Controlled Turn-On* (SLVSCT5)
2. *TPS2295x 5.7 V, 5 A, 14 mΩ On-Resistance Load Switch* (SLVS803)
3. *TPS2291xx Ultra-small, Low On Resistance Load Switch With Controlled Turn-on* (SLVSB49)
4. *Load Switches for Power MUXing and Reverse Current Blocking Design Guide* (TIDUA64)

Copyright © 2016, Texas Instruments Incorporated

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2016, Texas Instruments Incorporated