Application Report
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Power Multiplexing Using Load Switches and eFuses

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ABSTRACT

Backup power supplies are necessary for systems whose critical operation and data transmission must be maintained. If the main power supply were to fail, the system must have the capability to quickly switch to the backup supply in order to preserve continuous operations. A power multiplexing (MUXing) circuit should be considered to either select or transition automatically between main and backup power rails.

Texas Instruments' load switch and eFuse portfolio provides the user with a flexible Power MUXing solution for a variety of systems that require a controlled transition between supplies. The solution is further enhanced with capabilities such as adjustable rise time and power good. This application note explores concerns related to power MUXing and demonstrates multiple multiplexing solutions for a wide range of input requirements. Table 1 provides a guide of the recommended load switch or eFuse, based on system requirements.

Table 1. Device Selection Guide

Voltage	Max Current	Switchover Method	Recommended Device
1.4 V – 5.5 V	2 A	Manual	TPS2291xx, 61-mΩ On-Resistance Load Switch With Controlled Turn-on (SLVSB49)
0.7 V – 5.7 V	5 A	Automatic	TPS2295x, 14-mΩ On-Resistance Load Switch With Voltage Monitoring (SLVSCT5)
2.7 V – 18 V	5 A	Automatic	TPS25942x/44x, 42-mΩ On-Resistance eFuse With Integrated Reverse Current Protection, IMON and PG (SLVSCE9)
4.2 V – 55 V	2 A	Automatic	TPS2660x, 150-mΩ On-Resistance eFuse With Integrated Input Reverse Polarity Protection (SLVSDG2)

Contents

1 What is Power MUXing

In some applications, a system may need to switch between two separate voltage rails for proper functionality. Often, a power MUX has two inputs and one output as shown in Figure 1:

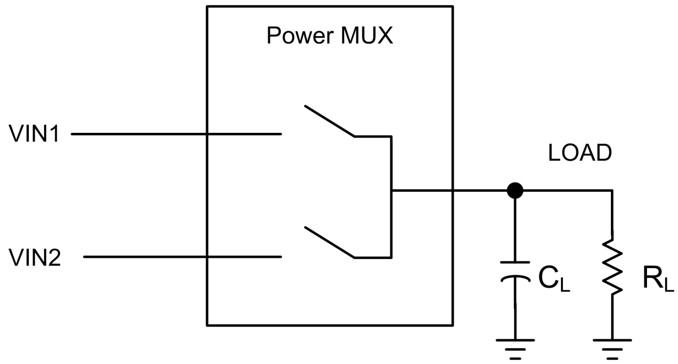


Figure 1. Power MUXing Block Diagram

Systems such as servers often require a backup power supply in the case of supply failure or disconnection. An efficient power MUXing circuit transitions seamlessly to auxiliary power to prevent undesired operation such as a system reset or loss of critical data. Additionally, systems can be operated by two different voltage rails. SD cards, for example, can operate at either 3.3-V or 1.8-V. By utilizing a power MUXing solution, the system can select between the 3.3-V or 1.8-V power rails for proper functionality. In order to implement a successful power MUXing solution, power MUX tradeoffs must be considered. Note that these precautions affect each system differently.

1.1 Concerns of Power MUXing

The common concerns for power MUXing are as follows, but may not apply to every system:

- Output Voltage Drop
- Inrush Current
- Reverse Current
- Switchover Time

Each concern has an inherent impact over another. However, the two main concerns of this application note are output voltage drop and inrush current. An output voltage drop occurs during switchover when break-before-make logic is used. This occurs when the first device completely turns off before the second device is turned on, presented in Figure 2. The output voltage will also depend on the RC time constant of the load while both switches are OFF in transition.

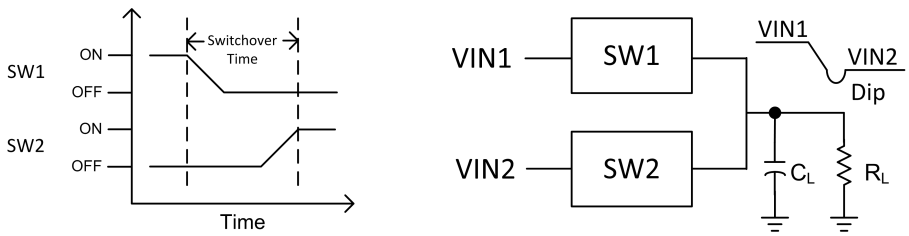


Figure 2. Voltage Drop During Power Supply Transition

To minimize this loss of output voltage, a large capacitor can be connected to the load to better hold the output up during supply transition. Reducing switchover time from one power source to the other will assist in decreasing the amount of time that the output capacitor discharges by the load. Alternatively, the switchover time can be reduced to minimize the time the output capacitance has to sustain the load. However, the tradeoff for faster output voltage ramp rate results in inrush current. An example of the inrush current caused by a faster switchover time is shown in Figure 3.

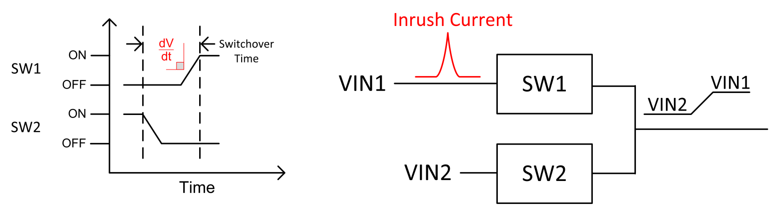


Figure 3. Fast Switchover Time Increases Inrush Current

If inrush current is not acceptable in a system, a slower voltage ramp or switchover time should be considered. Further consideration on reducing output capacitance must be applied to mitigate inrush current problems.

2 Manual Switchover MUX using GPIO

To reduce the inrush current caused by a load capacitance in the system, the voltage rise time of the load must be controlled. This rise time reduces the amount of inrush current since it limits the rate at which the capacitive load charges. The TPS22912C load switch is capable of managing the slew rate for startup conditions when it is used as the main load switch. Furthermore, the TPS22910A and the TPS22912C load switches have reverse current blocking, a useful feature for power MUXing.

The power muxing setup shown in Figure 4 was constructed by connecting two 5-V supplies to the inputs of the load switches and connecting the enable pins together. The outputs of both load switches are connected to the common load. The TPS22910A is a load switch enabled by an active-low signal, and the TPS22912C is enabled by an active-high signal. These features are ideal for power MUXing as it allows control from a single GPIO signal because it ensures one is always turned on but both are never turned on at the same time.

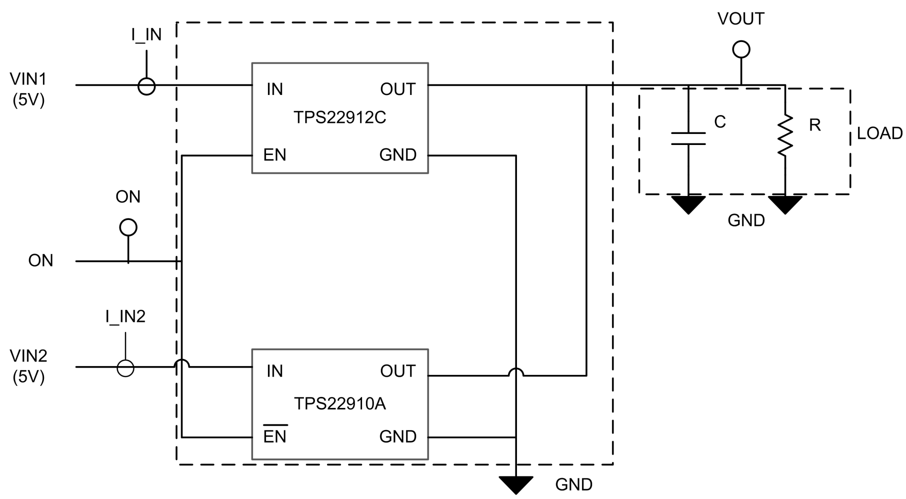
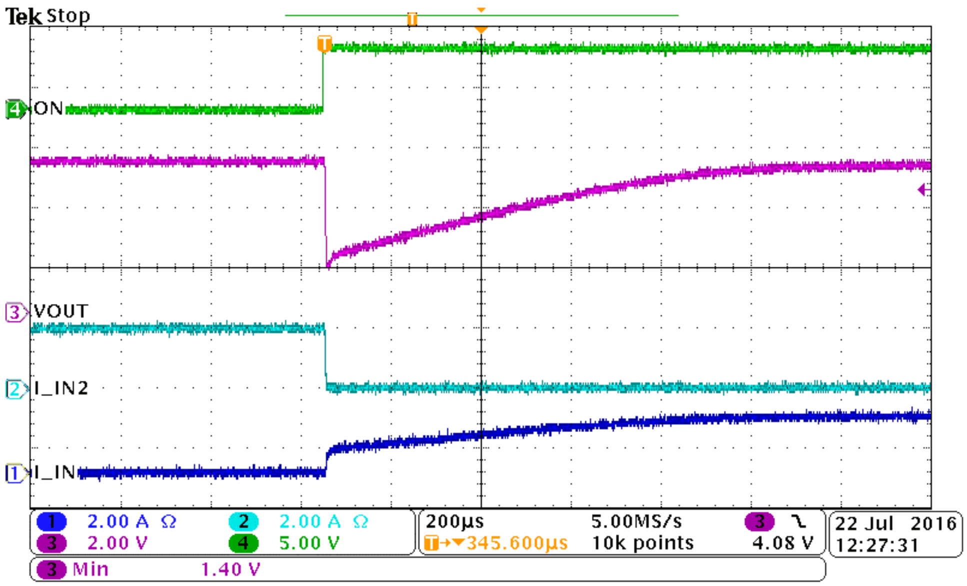


Figure 4. Power MUXing With the TPS22910A and TPS22912C

By using the TPS22912C for the main power supply, the load switch limits the inrush current. By managing inrush current, damage to the traces of the circuit and malfunctions can be avoided.

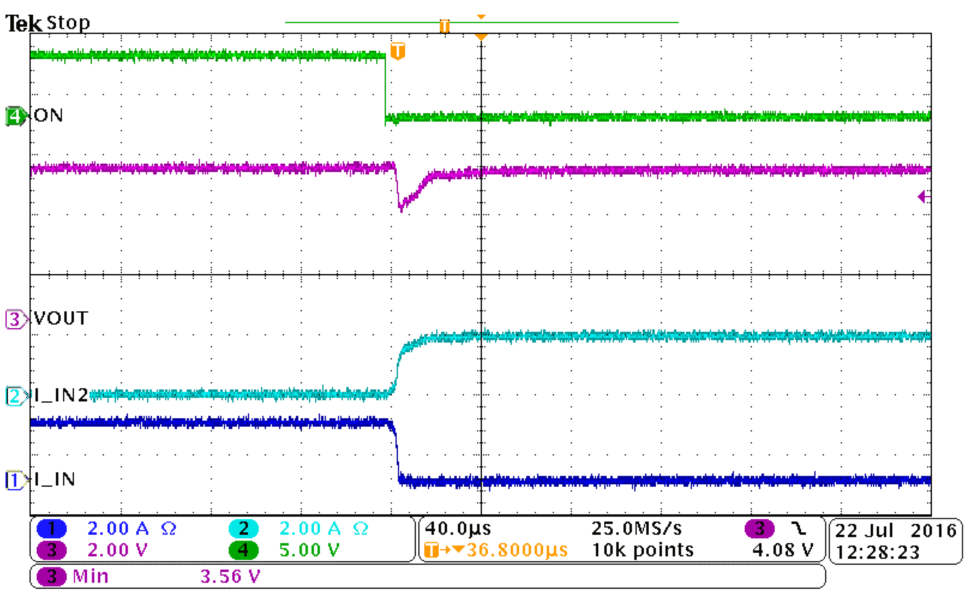
In Figure 5, the scope shot of a switchover completed from the TPS22910A to the TPS22912C is presented.



C_L = 1 µF R_L = 2.5 Ω

Figure 5. Supply Switchover from TPS22910A (5 V) to TPS22912C (5 V)

As the enable signal is asserted high, a voltage drop occurs on VOUT and I_IN slowly ramps up to the load current. There is no inrush current overshoot present for the 2-A load and the system recovers from the voltage drop in approximately 900 µs. The long recovery time corresponds to the rise time of the TPS22912C load switch that alleviates any inrush current effects.



C_L = 1 µF R_L = 2.5 Ω

Figure 6. Supply Switchover from TPS22912C (5 V) to TPS22910A (5 V)

When switching to power supply 2 (see Figure 6), a lower voltage drop occurs at the output of the system and no inrush current overshoot is present. Switching to the secondary supply has a lower voltage drop due to the fast rise time of the TPS22910A load switch allowing for a 20-µs switchover time.

Table 2 presents the results of minimum output voltage and inrush current for a 200-mA load and a 2-A load. Each load was tested with two different capacitive loads to show how well each one holds up the output voltage of the manual switchover MUX.

Table 2. Manual Switchover MUX Data Summary

	From VIN1 (5 V) to VIN2 (5 V)		From VIN2 (5 V) to VIN1 (5 V)	
Load	**Min Voltage**	**Peak Inrush Current**	**Min Voltage**	**Peak Inrush Current**
2.5 Ω, 0.1 µF	1.35 V	No Overshoot	3.08 V	No Overshoot
2.5 Ω, 1 µF	1.4 V	No Overshoot	3.56 V	No Overshoot
25 Ω, 0.1 µF	2.36 V	No Overshoot	4.44 V	No Overshoot
25 Ω, 1 µF	2.52 V	No Overshoot	4.68 V	236 mA

When switching between power rails, the larger capacitive and resistive loads presented the least amount of voltage drop in the system as these devices will have a substantial capacitance and a slow discharge.

The advantage of using the TPS22910A and the TPS22912C devices for power MUXing is having the ability to control both switches manually with a single GPIO signal. Another benefit is the considerable reduction of inrush current at startup when using the TPS22912C for the primary voltage rail.

3 Automatic Switchover MUX

In some applications, the load of a system requires an automatic switchover when the primary supply fails or is disconnected. The TPS22953 is useful for these applications because of its voltage monitoring feature and its power good signal. The TPS22953 load switches are also beneficial for systems without protection because of their reverse current blocking feature.

The power MUXing setup shown in Figure 7 is composed of two TPS22953 load switches with a break-before-make configuration which first allows the main load switch to completely turn off before enabling the second device. By adding an inverter between the power good signal of the first load switch and the enable pin of the second load switch, the enable signal is driven low whenever *Primary Power* is connected to the system. The main enable is pulled up so the secondary load switch only turns on when the main supply voltage is not present.

By leaving the CT pin open, the load switches operate at their shortest turn-on delays which minimize the output voltage drop for these devices.

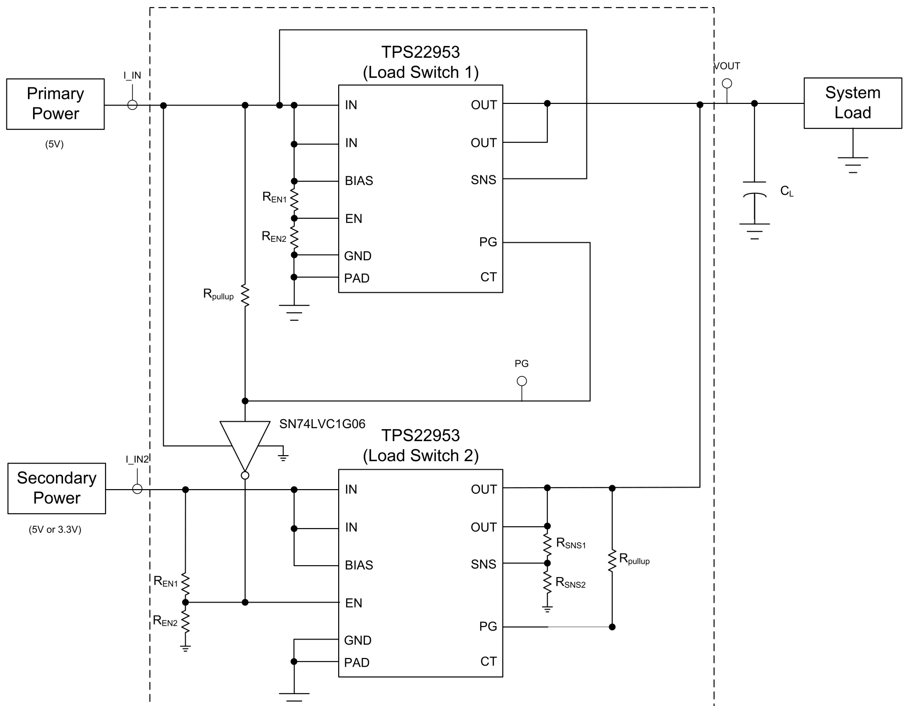
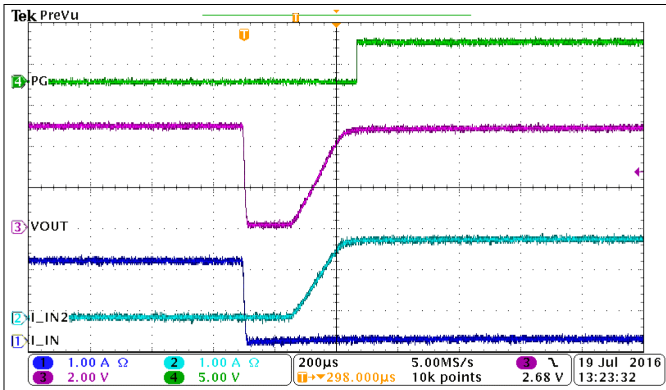


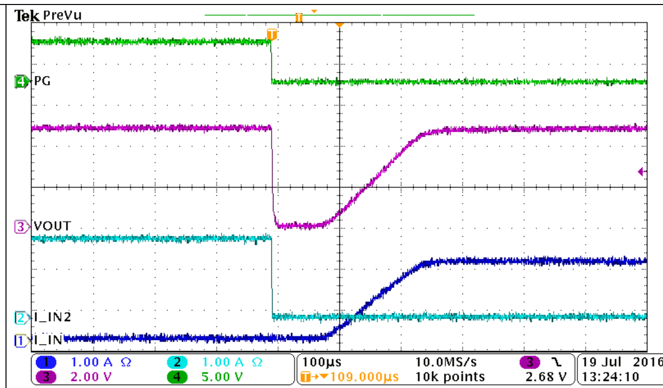
Figure 7. Break-Before-Make Power MUXing Circuit Using Two TPS22953s

[Figure 8](#) and [Figure 9](#) present the switchover behavior from the primary TPS22953 to the secondary TPS22953 and vice versa. With voltage monitoring, the power good signal is asserted after the secondary supply takes over and the output voltage recovers. The power good signal remains low as long as the primary supply remains connected and functional.



C_L = 1 µF R_L = 2.5 Ω

Figure 8. Supply Switchover from Primary (5 V) to Secondary (5 V)



C_L = 1 µF R_L = 2.5 Ω

Figure 9. Supply Switchover from Secondary (5 V) to Primary (5 V)

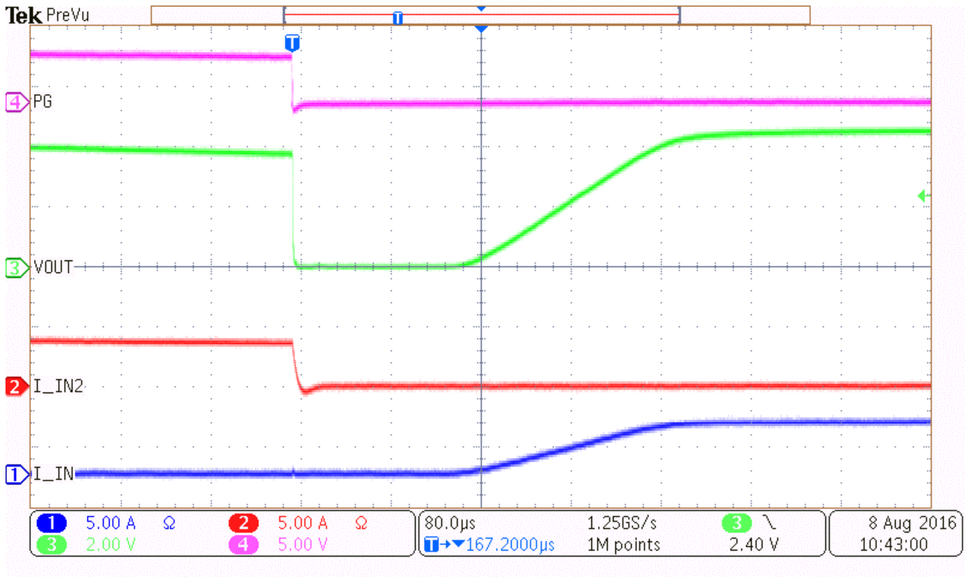
For a break-before-make configuration, taken from [Figure 8](#), a 2-A load will not cause reverse current when transitioning to the secondary power supply as the TPS22953 completely turns off before the secondary load switch fully enables. This can be seen on the output voltage as it drops completely and then it is restored in about 400 µs.

As the supplies switch back from secondary to primary in [Figure 9](#), the transition, like before, drives the circuit to completely drop the output voltage to then recover in about 300 µs.

[Table 3](#) shows the relationship between capacitive load and inrush current. As the capacitive load increases, inrush current is observed. When using a 10-µF capacitor with a smaller load, the output voltage does not drop completely due to its capability of slowing the voltage decrease until the next device is turned on.

Table 3. Automatic Switchover MUX Same Voltage Data Summary

	Primary (5 V) to Secondary (5 V)		Secondary (5 V) to Primary (5 V)	
Load	**Min Voltage**	**Peak Inrush Current**	**Min Voltage**	**Peak Inrush Current**
2.5 Ω, 0.1 µF	0 V	No Overshoot	0 V	No Overshoot
2.5 Ω, 1 µF	0 V	No Overshoot	0 V	No Overshoot
2.5 Ω, 10 µF	0 V	2.1 A	0 V	2.2 A
25 Ω, 0.1 µF	0 V	212 mA	0 V	224 mA
25 Ω, 1 µF	0 V	228 mA	0 V	232 mA
25 Ω, 10 µF	0.60 V	476 mA	0.76 V	472 mA

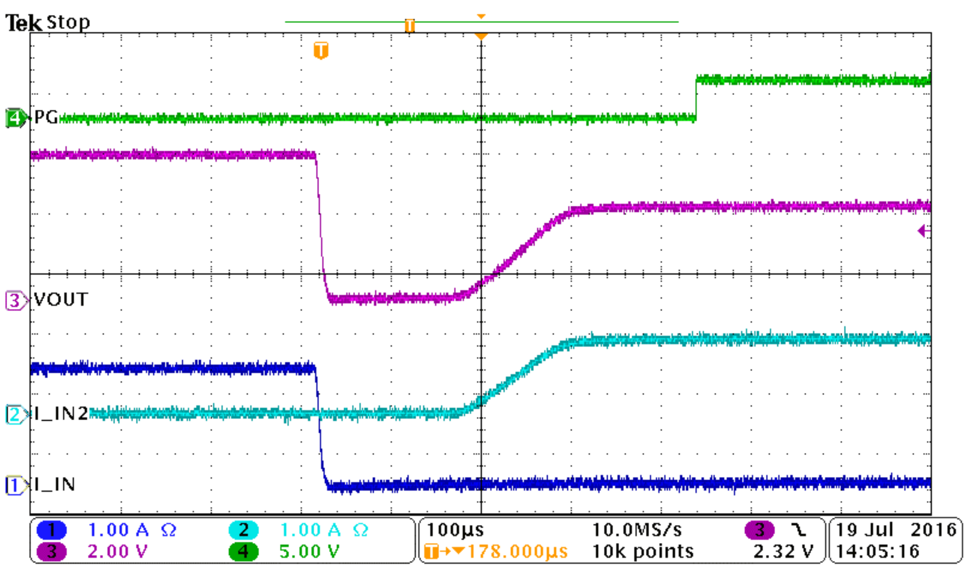


C_L = 1 µF R_L = 1 Ω

Figure 10. Supply Switchover from Primary (5 V) to Secondary (5 V) with 5 A

For a 5-A load, shown in Figure 10, the output voltage completely drops to 0 V before recovering back to 5 V in about 300 µs. This behavior is attributed to the break-before-make setup which also prevents the reverse current from the 1-µF capacitive load.

Figure 11 shows how applying different voltages to the load switches has a similar behavior to the 5-V to 5-V configuration. The break-before-make convention drives the system to disconnect the load switches before providing the new voltage level of 3.3 V. This transition is effective against reverse current which would be more noticeable for different voltage supplies as current flows from higher voltages to the lower voltages.



C_L = 1 µF R_L = 2.5 Ω

Figure 11. Supply Switchover from Primary (5 V) to Secondary (3.3 V)

Table 4 displays similar characteristics as higher inrush current originates when increasing the output capacitance. Furthermore, a transition from the secondary to the primary supply has a larger inrush current as the circuit needs to recover to 5 V instead of 3.3 V.

Table 4. Automatic Switchover MUX Different Voltage Data Summary

	Primary (5 V) to Secondary (3.3 V)		Secondary (3.3 V) to Primary (5 V)	
Load	**Min Voltage**	**Peak Inrush Current**	**Min Voltage**	**Peak Inrush Current**
2.5 Ω, 0.1 µF	0 V	No Overshoot	0 V	No Overshoot
2.5 Ω, 1 µF	0 V	No Overshoot	0 V	No Overshoot
2.5 Ω, 10 µF	0 V	1.46 A	0 V	2.14 A
25 Ω, 0.1 µF	0 V	152 mA	0 V	252 mA
25 Ω, 1 µF	0 V	164 mA	0 V	256 mA
25 Ω, 10 µF	0.56 V	412 mA	0.88 V	540 mA

The advantage of using the two TPS22953 devices for power MUXing applications is the ability of using the integrated voltage supervisor and the PG signal to automate the switchover when one supply is removed, eliminating the use of a GPIO signal.

4 MUX With Automatic and Seamless Switchover

In cases where a minimal output voltage drop must be met during an automatic switchover, a different setup is needed. The TPS25942 eFuse is a device that can develop a seamless switchover between power supplies.

Figure 12 presents a power MUXing circuit constructed with two TPS25942 eFuses connected to the system load. These devices will prioritize the primary supply chosen and if the rail were to fall below the threshold defined by the UVLO setting of the primary load switch, the secondary supply provides the voltage available.

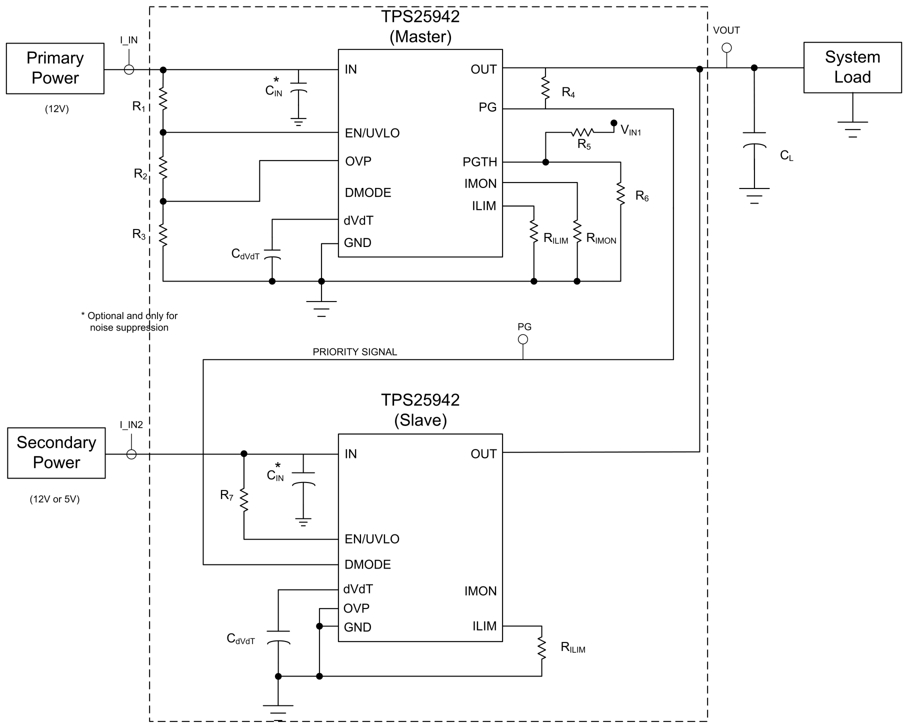
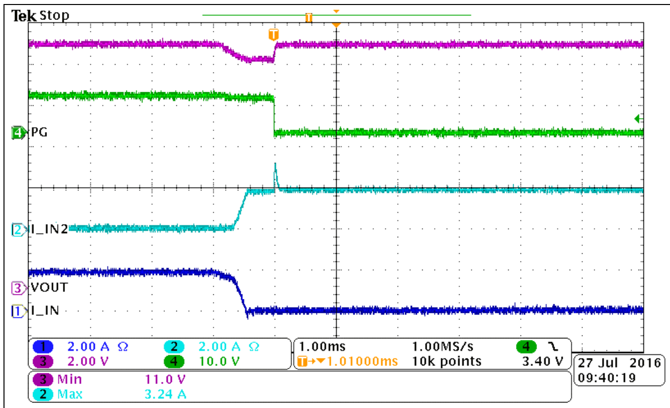


Figure 12. Priority MUXing Circuit with Two TPS25942s

The TPS25942 has two modes of operation: normal and diode mode. During diode mode, the TPS25942 eFuse acts as a diode blocking reverse current. By using the diode mode to block reverse current, a make-before-break control can be used to prevent output voltage drop without requiring a large load capacitance, which can result in excessive inrush current. Make-before-break configuration corresponds to where the active device turns off after the secondary device was turned on. Also, diode mode presents a minimal voltage drop similar to a common 0.7-V diode drop. However, diode mode can be turned off during the normal operation of the TPS25942. Note that if using two TPS25942 eFuses for power MUXing, then when the primary supply is disconnected, the master TPS25942 will not turn off. This means that reverse current will be able to flow through the device and bring up the input voltage of the master TPS25942.

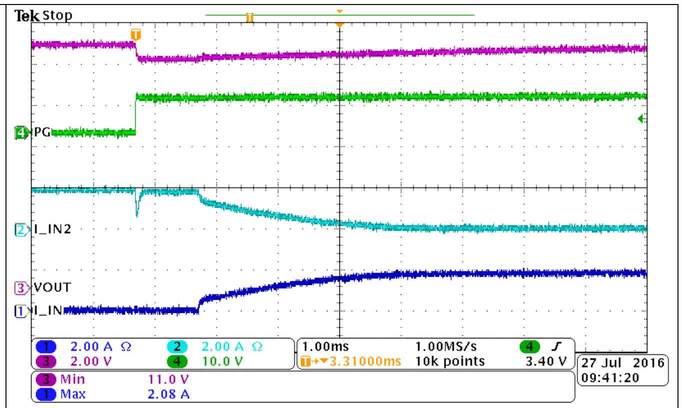
Figure 13 and Figure 14 display the behavior when a switchover is done from the primary TPS25942 to the secondary TPS25942 and vice versa.

Figure 13 shows that transition from primary to secondary supply, where the output voltage drops from 12 V to around 11 V due to diode mode operation. This transition offers minimal voltage losses that only are attributed to a common diode drop. After the primary supply has shut off, the PG signal disables the secondary switch diode mode to eliminate the diode voltage drop during steady-state operation. When diode mode is exited, there is a small spike of inrush current as the output voltage recovers back to 12 V. The transition from the secondary supply to the primary supply in Figure 14 shows the minor voltage drop occurring at the output as these power sources are switched back. The primary TPS25942 turn-on delay decreases any inrush current happening during the supply switch.



C_L = 100 µF R_L = 6 Ω

Figure 13. Supply Switchover from Primary (12 V) to Secondary (12 V)



C_L = 100 µF R_L = 6 Ω

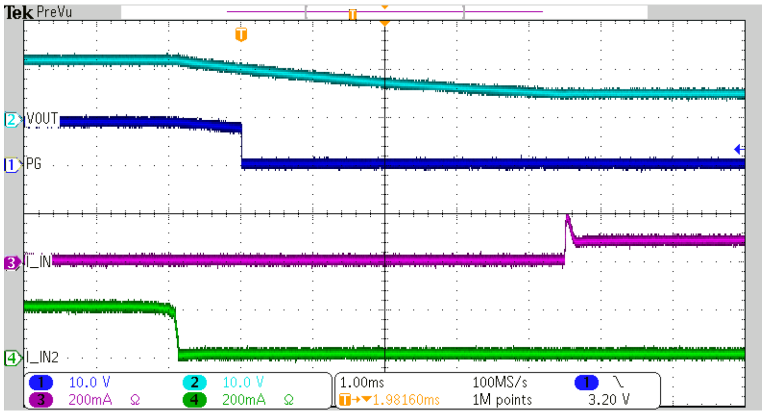
Figure 14. Supply Switchover from Secondary (12 V) to Primary (12 V)

For the 12-V rails in Table 5, the voltage drops for each case can be compared to one of a diode as the “diode mode” of the TPS25942 is utilized. In some configurations, the input current does not reflect a large inrush current as a result of the lower capacitive loads.

Table 5. MUX with Automatic and Seamless Switchover Same Voltage Data Summary

	Primary (12 V) to Secondary (12 V)		Secondary (12 V) to Primary (12 V)	
Load	**Min Voltage**	**Peak Inrush Current**	**Min Voltage**	**Peak Inrush Current**
6 Ω, 1 µF	11.0 V	No Overshoot	10.9 V	No Overshoot
6 Ω, 10 µF	10.9 V	2.36 A	10.9 V	No Overshoot
6 Ω, 100 µF	11.0 V	3.24 A	11.0 V	No Overshoot
60 Ω, 1 µF	11.2 V	470 mA	11.2 V	No Overshoot
60 Ω, 10 µF	11.2 V	610 mA	11.3 V	No Overshoot
60 Ω, 100 µF	11.2 V	856 mA	11.2 V	No Overshoot

Different power rails connected to the load switches have reduced voltage drops when switching over to the alternate supply. The transition from Figure 15 shows how 200 mA of inrush current overshoot is generated towards the 100-µF load, as the output voltage drops to 4.8 V. This response is generated due to the capacitive load quickly recovering its voltage lost during switchover.



C_L = 100 µF R_L = 60 Ω

Figure 15. Supply Switchover from Primary (12 V) to Secondary (5 V)

The different transition results shown in Table 6 demonstrate how the voltage has minimal drops when transitioning from a higher voltage rail to a lower voltage rail and vice versa.

Table 6. MUX with Automatic and Seamless Switchover Different Voltage Data Summary

	Primary (12 V) to Secondary (5 V)		Secondary (5 V) to Primary (12 V)	
Load	**Min Voltage**	**Peak Inrush Current**	**Min Voltage**	**Peak Inrush Current**
6 Ω, 1 µF	4.4 V	No Overshoot	4.9 V	No Overshoot
6 Ω, 10 µF	4.8 V	No Overshoot	4.9 V	No Overshoot
6 Ω, 100 µF	4.8 V	No Overshoot	4.9 V	2.96 A
60 Ω, 1 µF	4.8 V	No Overshoot	4.9 V	No Overshoot
60 Ω, 10 µF	4.8 V	No Overshoot	4.9 V	460 mA
60 Ω, 100 µF	4.8 V	200 mA	4.9 V	2.46 A

The benefit of using the two TPS25942 devices for power MUXing is the capability of incorporating voltages from 2.7 V to 18 V to the system chosen. Furthermore, this power MUXing circuit will minimize voltage dips when operating in diode mode while providing an automatic and seamless transition.

5 High-Voltage MUX (4.2 V – 55 V)

Many applications with back-up power operate in a higher voltage range, typically around 24 V. For MUXing applications operating between 4.2 V to 55 V, the TPS26600 eFuse can provide a seamless switchover between power supplies.

Figure 16 demonstrates a power MUXing circuit composed of two TPS26600 eFuses designed for 24-V applications, supporting an input range of 19 V to 28.8 V. Connecting these two devices together through a source follower configuration will prioritize the primary supply and switchover to the secondary supply if the primary rail falls below the set undervoltage lockout (UVLO) threshold.

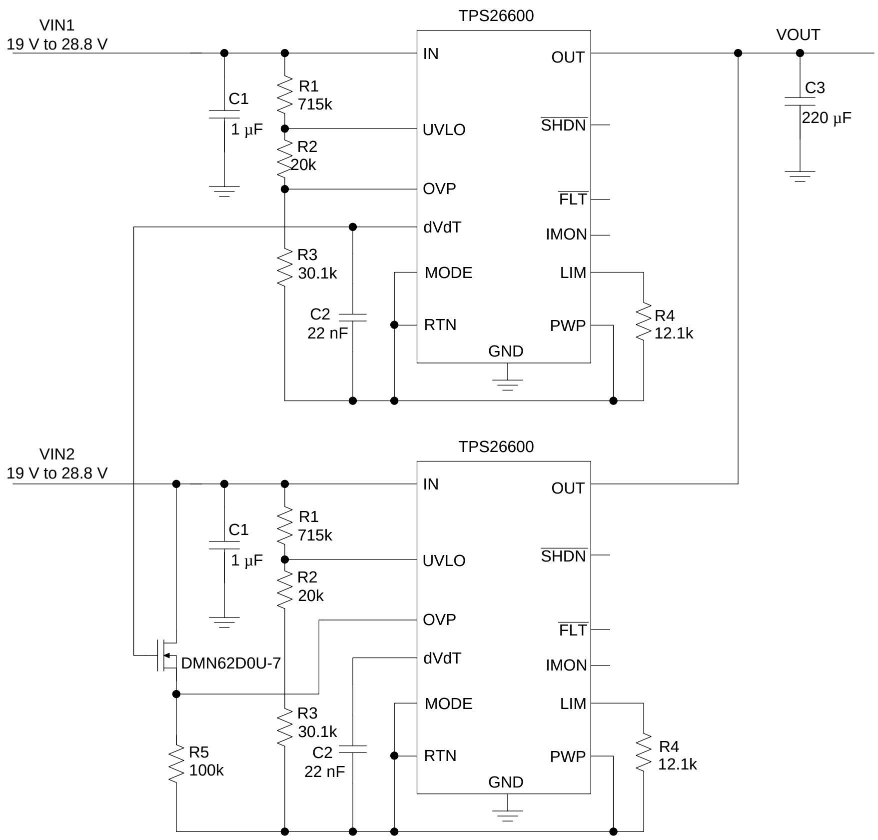


Figure 16. 24-V Source Follower MUXing Circuit Using Two TPS26600s

As shown in Figure 16, the dVdT pin of the primary eFuse is connected to the OVP pin of the secondary eFuse through a source follower circuit, using an N-Channel FET (DMN62D0U-7). Both the primary and secondary eFuses are configured as follows:

- Undervoltage lockout (UVLO) = 18.5 V
- Overvoltage cutoff (OVP) = 33 V
- Current limit ($I_{(LIM)}$) = 1 A

Under normal operation, if VIN1 is present and the voltage is within 19 V to 28.8 V, the primary eFuse turns on. When the primary eFuse is operating, the secondary eFuse is disabled due to the voltage at the OVP pin being greater than 1.2 V ($V_{dVdT(Primary\ eFuse)} - V_{TH(FET)}$ > 1.2 V, where $V_{dVdT(Primary\ eFuse)}$ is typically 4 V). This keeps the internal FET of the secondary eFuse disabled.

If VIN1 is faulty, disabled, or disconnected, the primary eFuse will fall and hit its UVLO falling threshold which is set at 17.2 V. Once the primary eFuse reaches UVLO, the dVdT voltage drops and immediately turns on the secondary eFuse, since the voltage at the secondary eFuse's OVP pin is now less than 1.2 V. During this transition, the charged output capacitor, C3, keeps VOUT steady and helps minimize output ripple. It is important to note that the secondary eFuse OVP feature is not sacrificed due to the source follower configuration from dVdT to OVP. The time it takes to switch between the primary and secondary supply is approximately 200 µs.

Figure 17 and Figure 18 present the switchover behavior from the primary TPS26600 to the secondary TPS26600 and vice versa.

Figure 17 shows the transition from the primary to secondary supply. When VIN1 is off or disconnected, the output voltage falls to 16.6 V and then ramps back up to 24 V after switching over to the secondary supply. This transition occurs once the primary eFuse hits its UVLO threshold of 17.2 V. The transition from the secondary supply to the primary supply is shown in Figure 18. When VIN1 is on or connected again, current transfers from the secondary eFuse to the primary eFuse after dVdT rises.

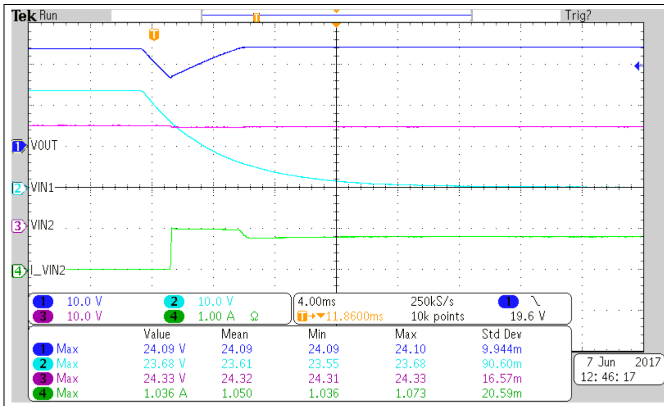


Figure 17. Supply Switchover from Primary (24 V) to Secondary (24 V)

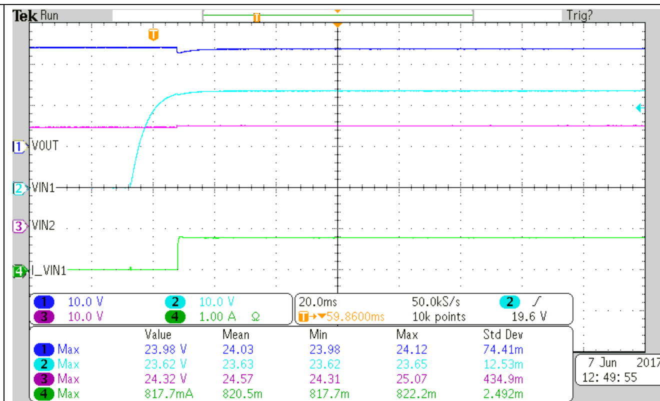


Figure 18. Supply Switchover from Secondary (24 V) to Primary (24 V)

When the primary eFuse is conducting, the status of the secondary supply has no impact on the system. The secondary supply can be on or off. Figure 19 and Figure 20 showcase the behavior of connecting and disconnecting the secondary supply while the primary eFuse is conducting.

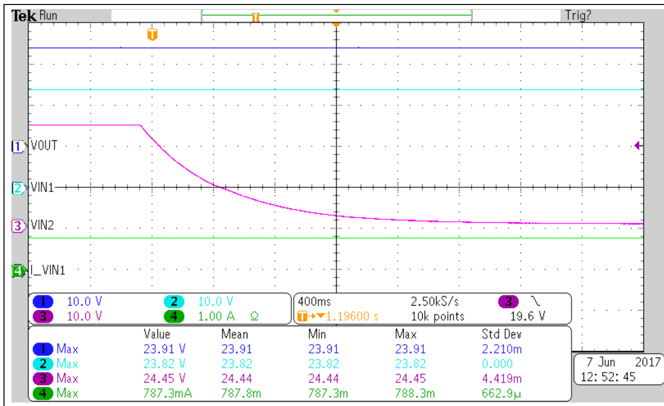


Figure 19. VOUT Impact When VIN2 is OFF

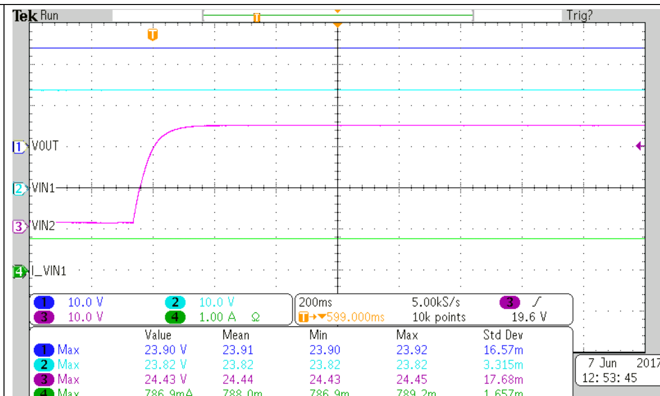


Figure 20. VOUT Impact When VIN2 is ON

Table 7 shows the relationship between capacitive load and inrush current. It can be observed that as the load capacitance increases, the output voltage increases in stability during the transition of supplies.

Table 7. High Voltage MUX Same Voltage Data Summary

	Primary (24 V) to Secondary (24 V)		Secondary (24 V) to Primary (24 V)	
Load	**Min Voltage**	**Peak Inrush Current**	**Min Voltage**	**Peak Inrush Current**
12 Ω, 22 µF	8.68 V	2.26 A	21.93 V	No Overshoot
12 Ω, 220 µF	14.55 V	2.28 A	22.11 V	No Overshoot
12 Ω, 2200 µF	21.02 V	2.26 A	22.33 V	No Overshoot
240 Ω, 22 µF	16.27 V	500 mA	23.05 V	560 mA
240 Ω, 220 µF	23.06 V	575 mA	23.74 V	450 mA
240 Ω, 2200 µF	23.98 V	600 mA	23.93 V	570 mA

Using two TPS26600 devices for priority power MUXing in high-voltage applications brings about many advantages, including automatic switchover, a small solution size, and other integrated features that provide protection in the event of a fault.

6 Conclusion

Power MUXing involves a series of tradeoffs that need to be considered carefully for each specific system. By selecting the appropriate implementation of power MUXing, specific system concerns can be mitigated for best performance. As such, voltage drop and inrush current can be addressed for proper system functionality by utilizing Texas Instruments' load switch and eFuse portfolio.

7 References

1. TPS2291xx, 5.5-V, 2-A, 61-mΩ On-Resistance Load Switch With Controlled Turn-on (SLVSB49)
2. TPS2295x, 5.7-V, 5-A, 14-mΩ On-Resistance Load Switch With Voltage Monitoring (SLVSCT5)
3. TPS25942x/44x, 18-V, 5-A, 42-mΩ On-Resistance eFuse With Integrated Reverse Current Protection, IMON and PG (SLVSCE9)
4. TPS2660x, 150-mΩ On-Resistance eFuse With Integrated Input Reverse Polarity Protection (SLVSDG2)

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (December 2016) to A Revision **Page**

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

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