Application Report
Basics of Power MUX

![Texas Instruments logo]

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ABSTRACT

A *Power Multiplexer (Power MUX)* is a set of electronic switches used to select and transition between two or more input power paths to a single output. A system targeting *flexibility* to choose between different styles of input power (barrel-jack, USB cable, wireless charging) may need a simple set of switches and logic to select the desired path to enable. In comparison, a system using a *backup* power supply may rely on critical operation and data transmission which must be maintained. These applications may require a fast or seamless switchover response to ensure the system does not reset during any power transitions.

Since most Power MUX solutions are used to manage input power paths, they are a good candidate to integrate additional protection features against overvoltage or overcurrent faults. This application note explores each of the different topologies of Power MUX solutions, different switchover behavior and what protection features are available.

Table 1-1. Power MUX Selection Guide

Integration	Voltage	Max Current	Control Method	Switchover Method	Switchover Time	Protection Features	Sugg. Device	When to use
Fully Integrated	2.8 V - 22 V	3 A	Automatic + Manual	Break-before-make	100 us	Overvoltage + Overcurrent	TPS2120	Small solution size with protection.
		4 A			5 us		TPS2121	Small solution size with fast switchover and protection.
Semi-Integrated	1.4 V - 5.5 V	2 A	Manual		20 us[1]	None	TPS22910 + TPS22912	Low voltage without protection.
	0.7 V - 5.7 V	5 A	Automatic		n/a	None	TPS22954	Low voltage with output power cycle during switchover.
	2.7 V - 18 V	5 A	Automatic	Diode-Mode	n/a	Overvoltage + Overcurrent	TPS25942	Instantaneous switchover prevents output from dropping more than 0.7 V below lowest supply.
	2.7 V - 23 V	5.5 A	Automatic		30 us		TPS25947	Low on-resistance, fast switchover with true reverse current blocking and input reverse polarity protection.
	2.5 A - 18 V	Ext. FET	Automatic		n/a		TPS24740	High power applications.
	4.2 V - 55 V	2 A	Automatic	Break-before-make	200 us[1]		TPS2660x	High voltage applications with protection.
	–80 V - –10 V	Ext. FET	Automatic	Diode-Mode	n/a		TPS23523	Negative voltage applications.

(1)   Based on test results from *Power Multiplexing Using Load Switches and eFuses*

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1 What is a Priority Power MUX?

A basic Power Multiplexer (Power MUX) selects between two or more input supplies to power a single output.
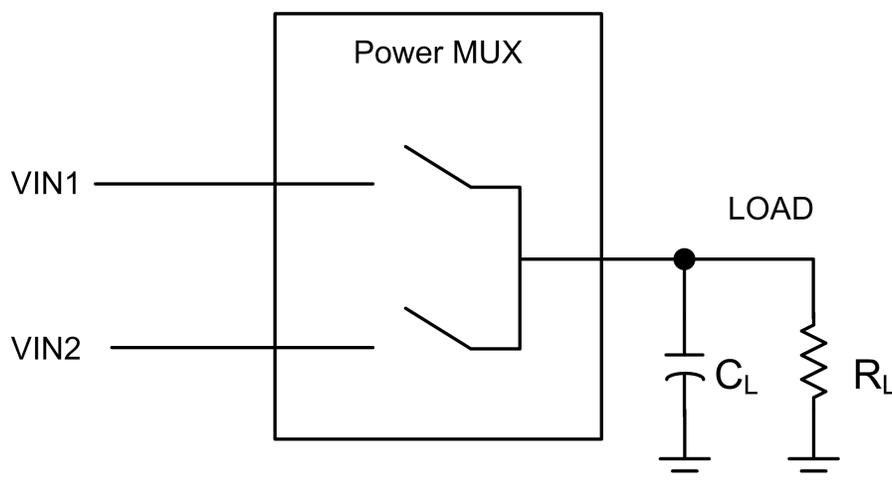

Figure 1-1. Power MUX Block Diagram

If there is no preference for which input supply to use, or if the preference is to always use the highest input voltage supply available, then the minimum requirement for a power MUX solution would be reverse current blocking for each input path. This can be accomplished using any combination of diodes or ICs which behave like a diode (such as *Ideal Diode Controllers*).
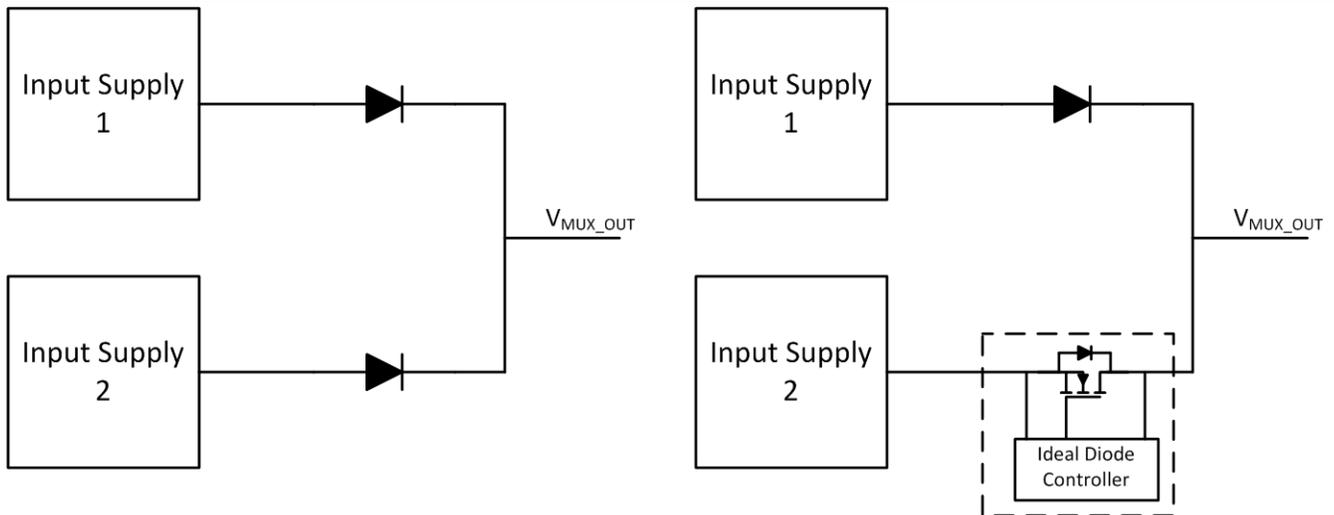
Figure 1-2. Minimum Functionality for Power MUX Without Priority

A schottky or silicon diode will result in a voltage drop around 0.4 V or 0.7 V, respectively. Using an ideal diode controller will result in a much lower voltage drop (on the order of 10 mV to 100 mV and there will be a parasitic body diode which must be positioned to block reverse current when the switch detects reverse current or is disabled.

If there is a priority, then additional switches must be added to have full control over which path to enable. Reverse current blocking (through a diode or a FET) must remain present and now a MOSFET must be added to turn on/off each power path to the load.
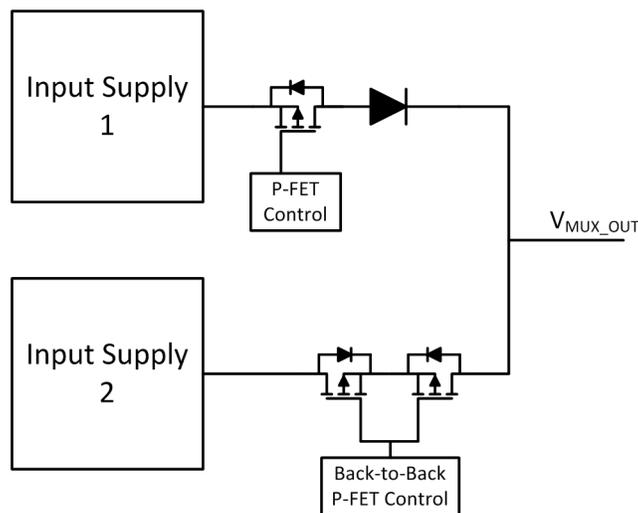

Figure 1-3. Example Priority Power MUX

The focus of this application note will be on *priority* power MUX solutions and how they can be implemented.

2 Control Method

Power MUX solutions need a way to determine which input supply should provide power to the output. There are generally three options available on the market: Manual, Automatic, or Both.

2.1 Manual

A manual power MUX is one in which each path is individually controlled by an external signal (logic or microcontroller). The example of two load switches used in Figure 2-1 is a manual power MUX. There could be one or two EN pins which need to be controlled. This method is generally used when there is already a microcontroller present in the system which can decide under what conditions to enable each input.
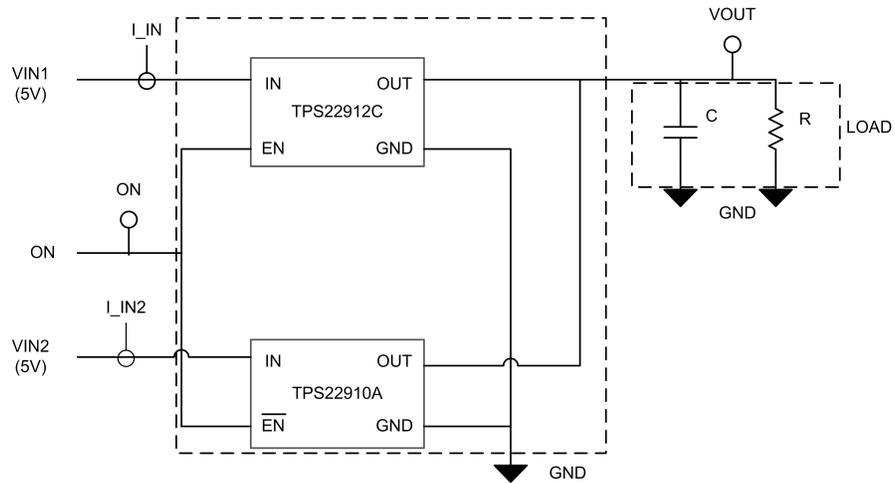
Figure 2-1. Manual Power MUX using TPS22910 and TPS22912 Load Switches

2.2 Automatic

An automatic power MUX does not require an external signal to switch between loads. There is often a default priority (such as IN1) and the device will determine under what conditions to switch to IN2. The first condition will be when IN1 drops below a certain threshold (such as if IN1 is removed and the voltage decays). There could be other conditions such as during an overvoltage event on IN1, where the supply may switch to IN2 to power the load. This control method is commonly used when there is no microcontroller available or to simplify the design architecture and eliminate the need to rely on the microcontroller's resources. Note that most automatic power MUX solutions can be used in automatic mode or manual mode but not both.
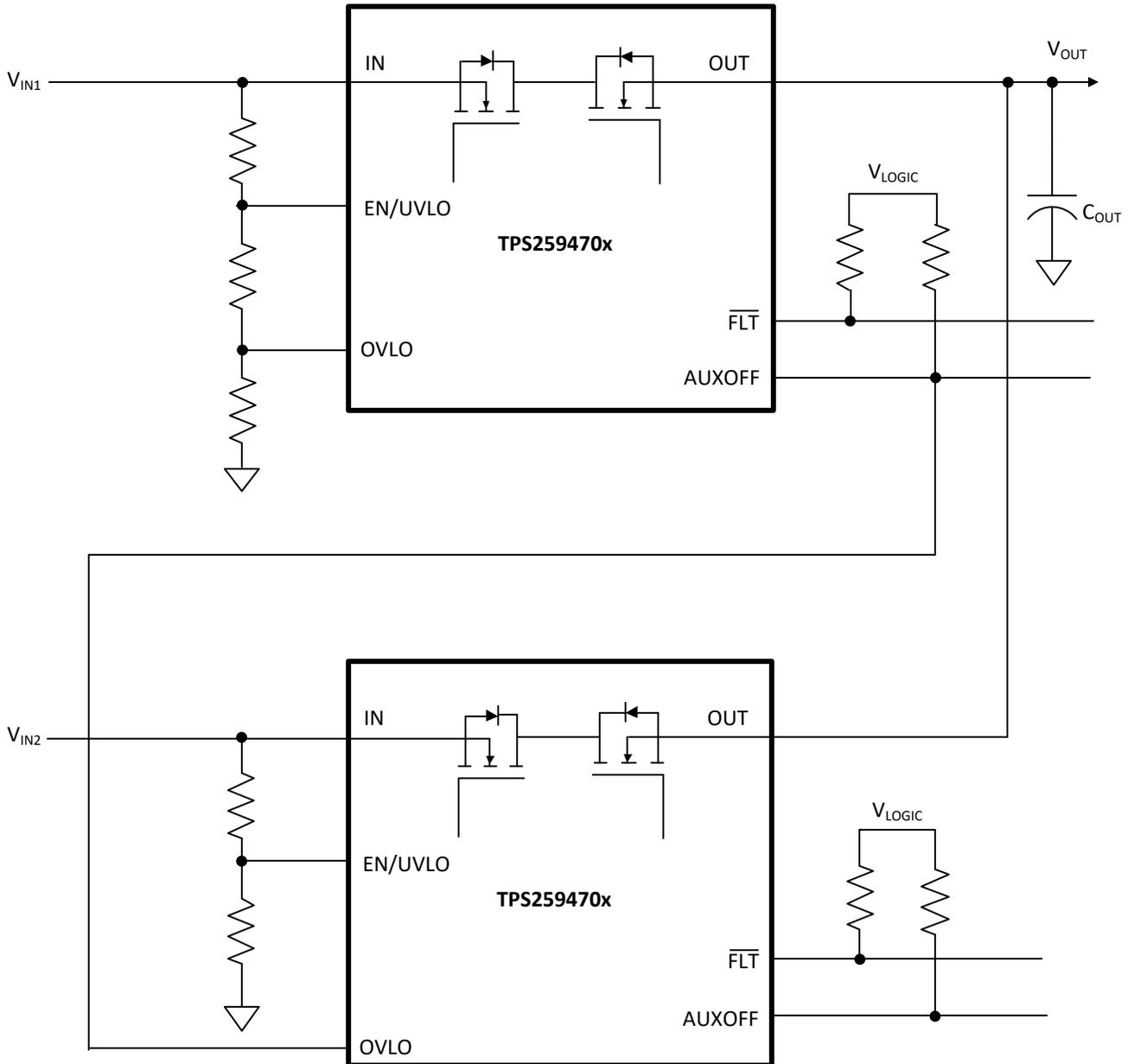

Figure 2-2. Automatic Power MUX using 2x TPS259470x eFuses

2.3 Both - Automatic + Manual Override

There are some Power MUX solutions which offer the flexibility to be used in a automatic configuration and be controlled by a manual control signal. The *TPS212x* family of Power MUX solutions can have a default (automatic) priority, but then be overriden by an external microcontroller if needed. This method is useful in

applications which will have a default priority for most of its operation, but there will be some modes (such as diagnostics) requiring manual control to force which path is enabled.
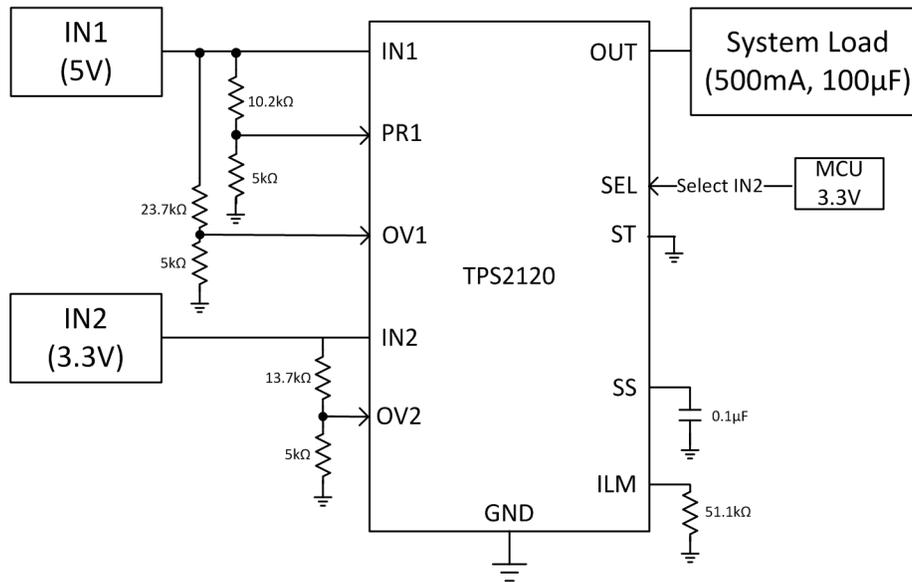

Figure 2-3. Automatic Power MUX with Manual Override using TPS2120

3 Power MUX Topologies

3.1 Discrete

A 2-input priority Power MUX solution can be implemented using 4x discrete MOSFETs (2x paths of back-back FETs) along with manual or automatic logic to determine which path to enable. PMOS based solutions are commonly used when there is no higher voltage source or charge pump available (otherwise an NMOS-based architecture would be advantageous).
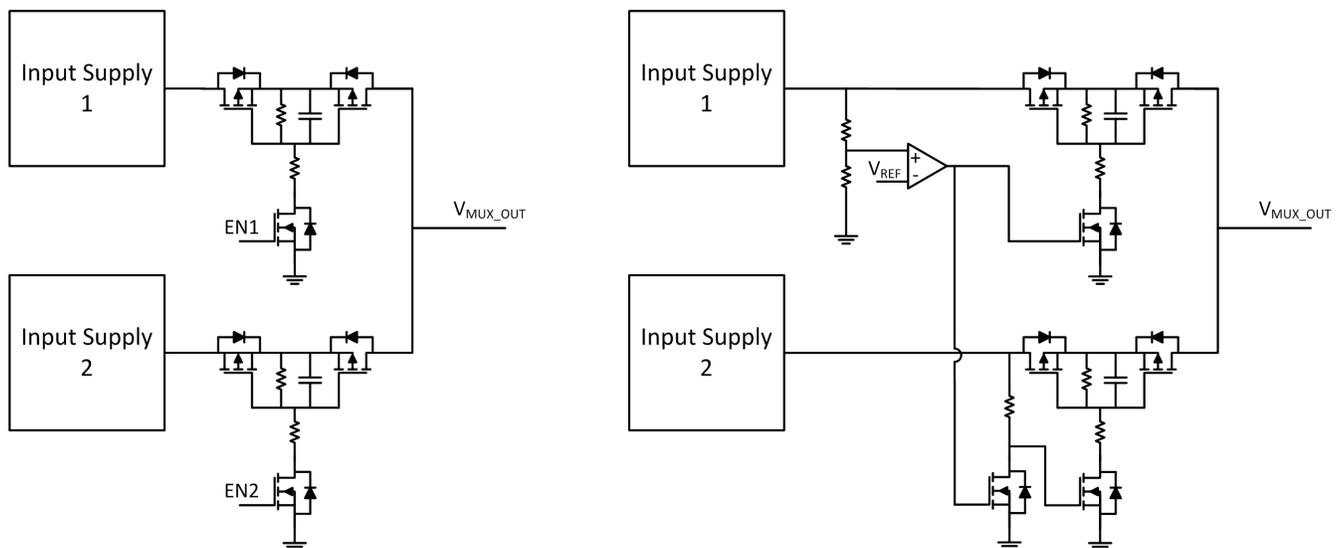

Figure 3-1. Manual and Automatic Discrete Power MUX with Priority

In this example, the manual power MUX can be controlled with two EN pins tied to a microcontroller. The microcontroller would need logic to ensure only one set of switches is on at a time, to prevent reverse current flow. The automatic MUX features a comparator followed by inverter logic to ensure only one set of switches is turned on at a time. The comparator is configured to turn on the top set of switches when input 1 is present, otherwise default to input 2 when present.

3.2 Semi-Integrated

For low-voltage inputs (less than 5 V), there are load switches available with a single integrated MOSFET but have the ability to block reverse current when disabled. These switches can accomplish this by effectively removing the body diode of the integrated FET while the switch is disabled.
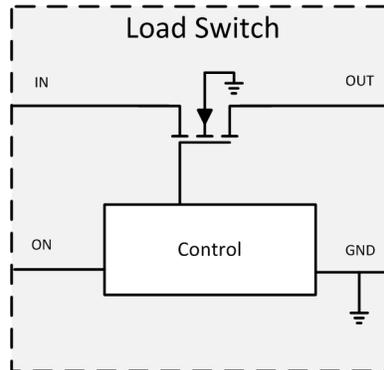

Figure 3-2. Load Switch with Parasitic Body Diode Removed

If using one of these load switches with an active high enable and another load switch with active low enable, you can select between each power path while using only 1x GPIO.
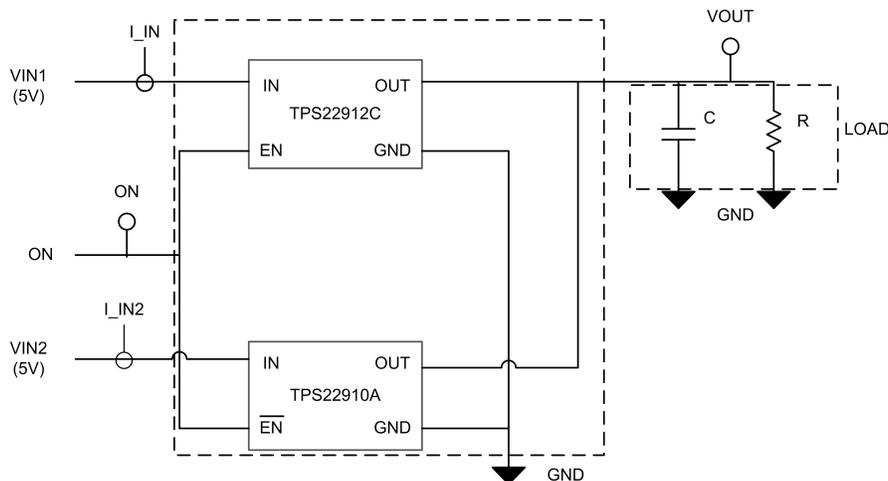

Figure 3-3. Semi-Integrated Power MUX using TPS22910 and TPS22912 Load Switches

For higher input voltages (> 5 V), there are eFuse switches available with back-back MOSFETs. They can be used in a priority mux configuration (see Figure 3-4).
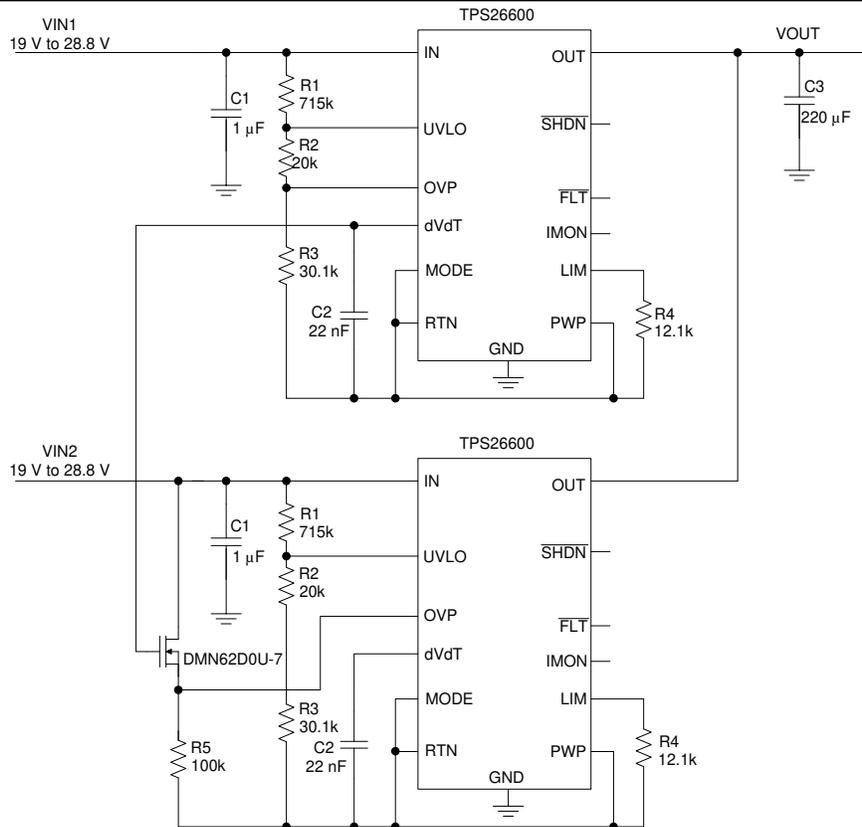
Figure 3-4. Semi-Integrated Power MUX using 2x TPS2660 eFuses

To learn more about how to use load switches or eFuses in a MUX configuration, see *Power Multiplexing Using Load Switches and eFuses*.

3.3 Fully Integrated

TI's portfolio of fully-integrated Power MUXes contains all 4x MOSFETs and switching logic in a single IC. These solutions provide all the functionality needed for a priority power mux in the smallest solution size possible. Additional features such as output status, slew rate control, overvoltage and overcurrent protection are included in devices such as the *TPS212x* family.
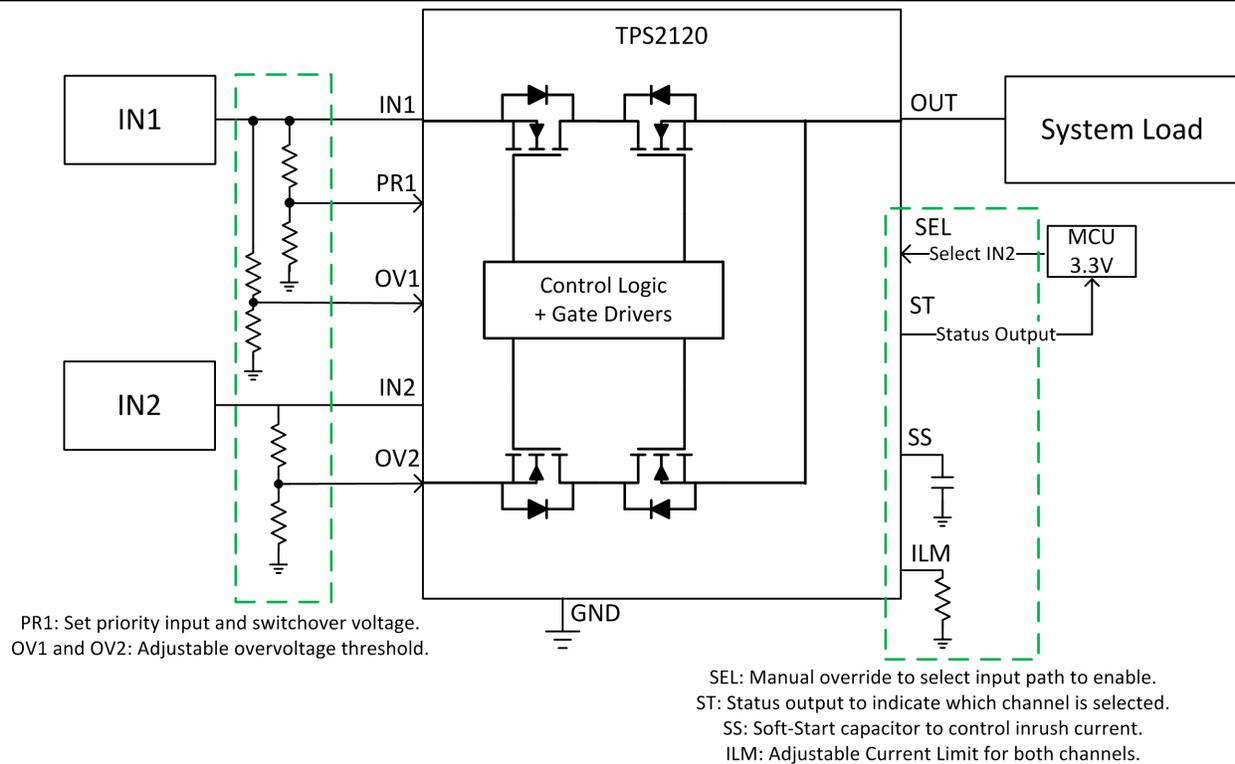
Figure 3-5. Fully-Integrated Priority Power MUX with TPS2120

4 Switchover Method

When a power MUX solution transitions powering the output from one supply to the other supply, this is referred to as the *switchover* event. The method a power MUX uses to perform the switchover will affect how much reverse current is conducted and how much the output voltage will dip.

4.1 Break-Before-Make vs. Diode Mode

There are two sets of switchover methods that power MUX solutions fall under:

1. **Break-before-make** method occurs when the switch for the first supply completely turns off before the second supply switch is turned on.
    a. This prevents reverse current flow from one supply to another.
    b. There is a period of time where no power is being delivered from the supply to the output. This is known as the *switchover time*, or t$_{SW}$.
2. **Diode mode** is a make-before-break method where the diode or switch for the first supply remains on while the second supply switch is turned on. Reverse current is then prevented by the presence of a diode or a device which detects the reverse current flow and shuts off a corresponding FET (such as our eFuse, Ideal Diode or ORing controllers).
    a. The benefit of this approach is minimal output voltage drop, as power is continuously supplied to the load.
    b. The tradeoff depends on what diode device is used:
        i. Schottky or Silicon diode will result in power dissipation and voltage drop during normal operation.
        ii. eFuse, ORing or Ideal diode controller methods will result in some level of reverse current flow, potentially significant or insignificant depending on the application.

4.2 What is Seamless Switchover?

When switching between one supply to another, there are two possible outcomes:
1. The output voltage drops below operating range, causing the loads to experience a systematic reset.
2. The output voltage remains within operating range, causing uninterrupted operation. We will classify this type of outcome as *seamless switchover*.

If using a break-before-make power MUX, then switchover time is one key factor which will determine whether a seamless switchover will or will not occur. Faster switchover time will help achieve seamless switchover, at the expense of higher inrush current. This balance should be considered and power MUX solutions are available with a range of switchover times.

If using a diode-mode or make-before-break power MUX, then seamless switchover is often possible since worst-case output voltage drop will be approximately 0.4 V to 0.7 V (depending on the diode used).

4.3 Output Voltage Drop

With a break-before-make power mux, there will be a period of time (t_{SW} , *switchover time*) where the input supply is not providing power to the output. This will cause the output voltage to decay based on the following equations:
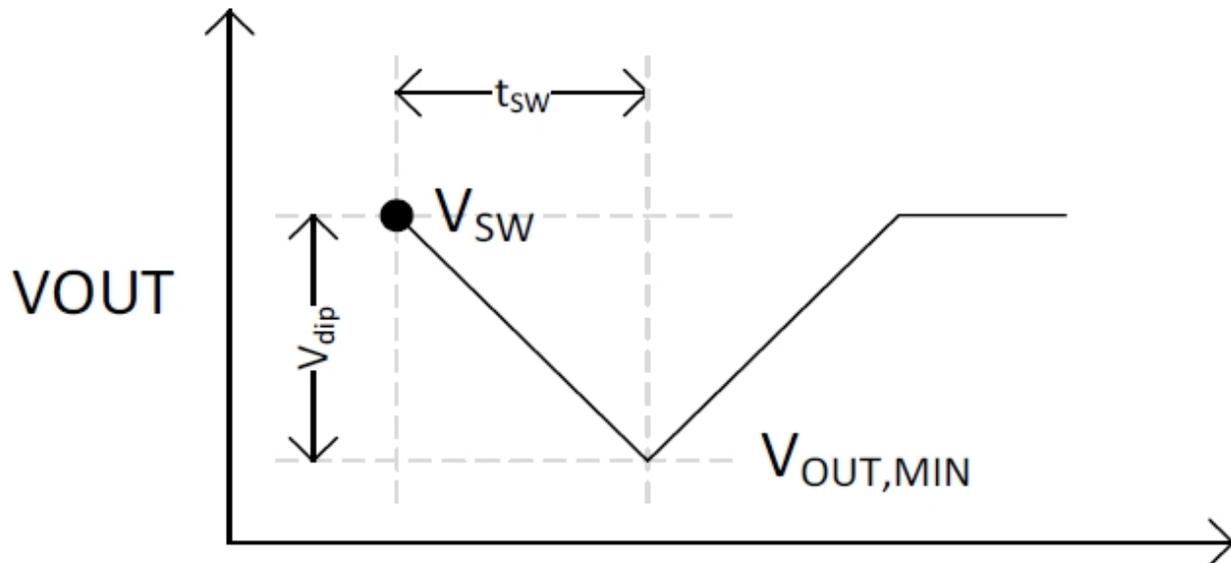

Figure 4-1. Voltage Dip on Output During Switchover Time

$$V_{OUT,MIN} = V_{SW} - V_{DIP} \qquad (1)$$

$$V_{DIP} = t_{SW} \times (I_{OUT} / C_{OUT}) \qquad (2)$$

Therefore a faster switchover time, t_{SW} will result in a smaller voltage dip on the output, V_{DIP}.

4.4 Inrush Current

A faster slew rate switch will reduce the switchover time, but will cause a faster dV_{OUT}/dt and therefore a larger spike of inrush current based on the equation:

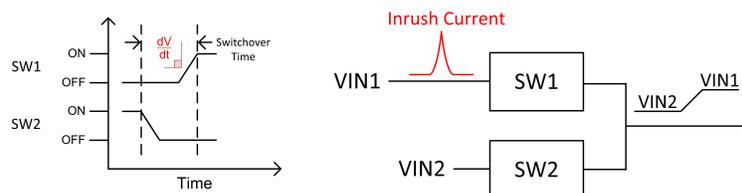$$I_{INRUSH} = C_{OUT} \times \frac{d V_{OUT}}{d t} \qquad (3)$$

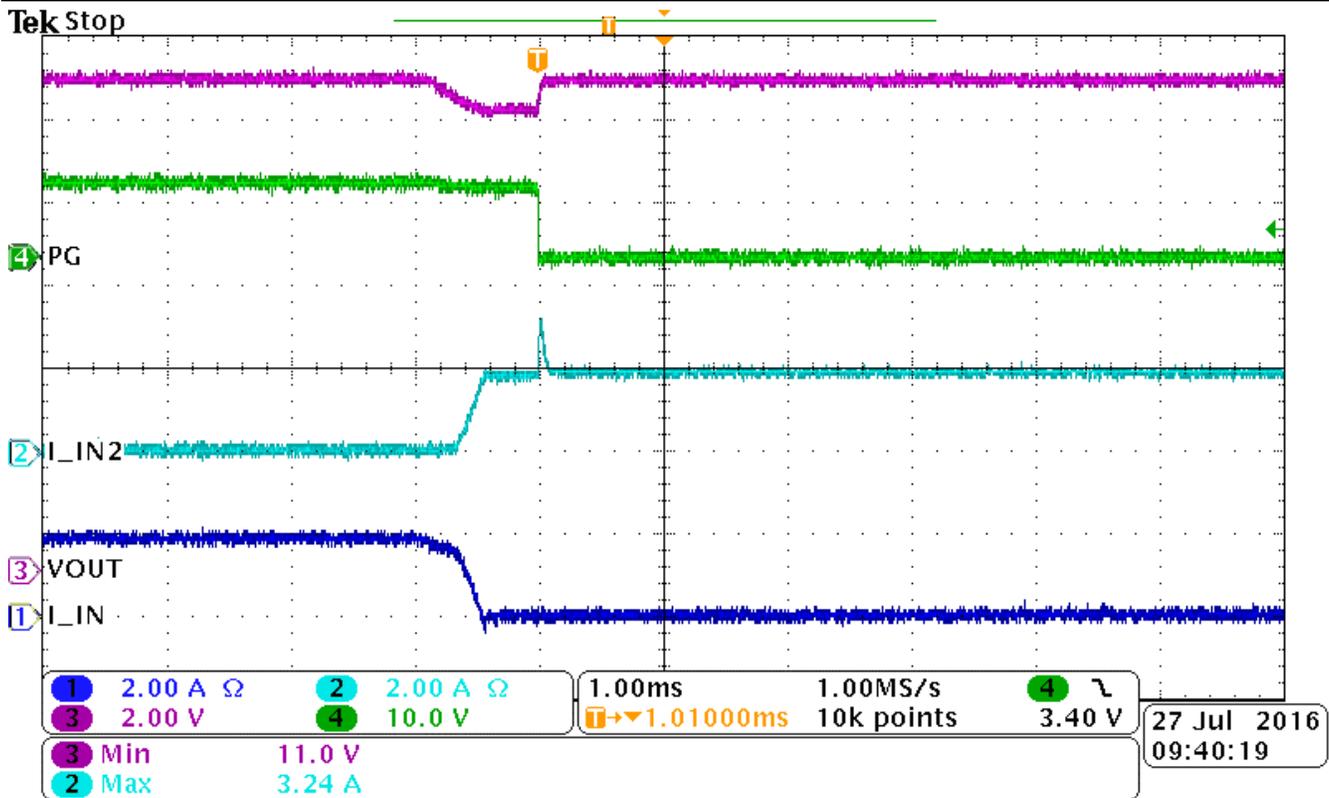**Figure 4-2. Inrush Current Spike Caused by Supply Switchover**

Figure 4-3. Inrush Current Spike on IN2 During Switchover Using 2x TPS25942

In this example, 2x *TPS25942* eFuses were used to form a semi-integrated power MUX solution. The device was initially powered by CH-1, I_IN and then transitioned to CH-2, I_IN2. During the switchover time, output voltage began to drop by a diode drop. Once the switchover passed, there was a peak inrush current spike of approximately 3.42 A in order for the output to recharge. More examples of peak inrush current test results can be found at *Power Multiplexing Using Load Switches and eFuses*.

There are two variables that can help a designer meet their target output voltage dip versus inrush current performance in a power MUX solution.

1. Output Capacitance - Following equations 1 through 4, increasing C_{OUT} will cause lower output voltage dip at the expense of higher inrush current during the transition, and vice-versa.
2. Switchover Times - Discrete power MUX solutions rely on RC delays in order to limit inrush current. This will result in relatively slow switchover times and relatively high dv/dt as the switch rise time will get exponentially larger as it turns on. In comparison, semi-integrated and fully integrated power MUX solutions often use a controlled linear rise time. This will result in relatively lower amounts of inrush current and a faster switchover time. There will be integrated power MUX solutions available at slew rate and switchover time combinations which are simply not possible with a discrete solution.

5 Additional Protection

Since power MUX solutions are often used at the input to a system, it is a good location to integrate protection features such as overvoltage or overcurrent protection.

5.1 Overvoltage Protection

Some applications need to protect against undesired high-voltage DC supplies or against transient induced voltages (such as from surge events or inductive switching). These potentially harmful voltages can be blocked from downstream components by using a power MUX with protection.

5.2 Overcurrent Protection

If a downstream circuit or fault event begins to draw excessive amounts of current, it is essential to limit that current quickly to avoid potential circuit damage or fire. This is another level of protection that can be integrated within a power mux.

TI provides power mux solutions with both overvoltage and overcurrent protection. For example, 2x *TPS2660* or 2x TPS25947 are semi-integrated power MUX solutions and *TPS212x* is a fully-integrated power MUX which each offer this level of protection.

6 Summary

There are different power MUX control methods, topologies, and switchover methods which offer a certain level of flexibility, protection and performance. System concerns such as output voltage drop or inrush current can be addressed by utilizing Texas Instruments' portfolio of semi-integrated Load Switch and eFuse solutions, or a fully-integrated Power MUX such as the *TPS212x* family which can offer the highest level of functionality in the smallest size available.

7 References

- *Seamless Switchover for Backup Power Reference Design*
- *Power Multiplexing Using Load Switches and eFuses*
- *Basics of eFuses*

8 Revision History

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

Changes from Revision * (November 2018) to Revision A (October 2020)   **Page**
- Updated the numbering format for tables, figures and cross-references throughout the document...................2

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