TEXAS INSTRUMENTS

Application Report
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Basics of Power Switches

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ABSTRACT

A *Power Switch* provides an electrical connection from a voltage source or ground to a load. A power switch saves power across multiple voltage rails and protects subsystems from damage. It also provides enhanced component protection, inrush current protection, and minimizes printed-circuit board (PCB) size.

There are several power switch topologies with different features that address different applications. *Load Switches* establish the power switch foundation by providing safe and reliable distribution of power. Applications typically using load switches include power distribution, power sequencing, inrush current control, and reduced current leakage. Integrated *Power MUX* devices are similar to load switches and can seamlessly switch between different input power sources while providing protection features.

eFuses and *Hot Swap* controllers offer additional power path protection features such as current sense monitoring, current limiting, undervoltage and overvoltage protection, and thermal shutdown. This makes these devices ideal for hot-plug and transient events that would otherwise damage system components. These benefits help reduce system maintenance costs and maximize equipment uptime.

Ideal diode, ORing controllers provide protection against reverse-polarity conditions by monitoring an external FET, significantly reducing power loss, and blocking reverse current. Whenever a transient event occurs, the controller monitors and adjusts the external FET to prevent damage to upstream components.

Smart high-side switches provide additional diagnostic telemetry that monitors the output load current and detects short-circuit and open-load events. *Smart high-side switches* provide high current limits, allowing integration into applications that have large inrush current startup profiles.

Low-side switches connect the load to ground, instead of providing a connection between a power supply and the load. By including an integrated flyback diode, *low-side switches* help to eliminate inductive load transients by dissipating current in a circular loop. This allows them to drive inductive loads such as solenoids, relays, and motors.

This application note highlights the different topologies within the power switch portfolio, and provides suggestions in choosing the correct solution for a faster design time.

Table 1. Power Switch Topology Table

Features	Load Switch	Power MUX	eFuse	Hot Swap	Ideal Diode Controller	Smart High-Side Switch	Low-Side Switch
Voltage Range	0 V to 18 V	2.8 V to 5.5 V	1.62 V to 55 V	±80 V	±75 V	3 V to 65 V	0 V to 100 V
Max Operating Current	15 A	1 A	12 A	N/A	N/A	4 A	1 A
Inrush Current Control	✓		✓	✓		✓	
Adjustable Current Limit	✓	✓	✓	✓		✓	
Reverse Current Blocking	✓	✓	✓	✓	✓		
Analog Current Monitoring			✓	✓		✓	
Digital Current Monitoring				✓			
Short-Circuit Protection		✓	✓	✓		✓	
Overvoltage Protection			✓	✓		✓	
Reverse Polarity Protection			✓	✓		✓	
Power Good Signal	✓		✓	✓		✓	
Inductive Load Compatibility						✓	✓
Load-Dump Compatibility			✓	✓	✓	✓	✓
Thermal Shutdown	✓	✓	✓	✓		✓	

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1 Load Switches

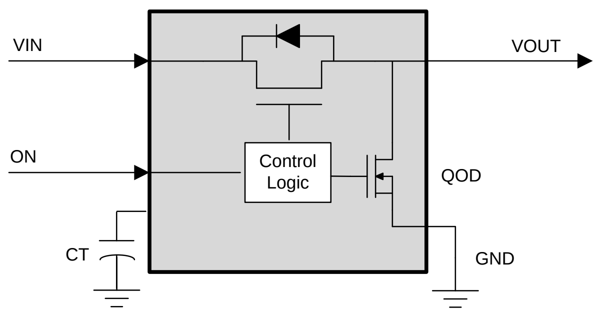

Figure 1. Load Switch Block Diagram

Integrated load switches are electronic switches that turn power rails on and off. When the internal FET turns on, current flows from the input to output and passes power to the downstream circuitry. When the device is enabled, the rise time of the output voltage (V_{OUT}) can be controlled by adjusting the capacitance on an external pin (CT pin). When the device is disabled, the fall time of V_{OUT} is controlled through the quick output discharge (QOD). QOD pulls the output to ground whenever the device is turned off, preventing the output from *floating* or entering an undetermined state.

Some common applications of load switches include power savings, power sequencing, and inrush current control. Power savings is important in applications looking to minimize current dissipation and maximize power efficiency. By disconnecting the supply from a load or subsystem, the switch minimizes power drawn from inactive loads. Power sequencing is important in applications where individual voltage rails need to be turned on and off in a specific order. By configuring the CT and QOD pins, the ramp-up and power-down timing can be adjusted. Inrush current control protects systems that contain large bulk capacitors near the load. When power is initially applied to the system, charging these capacitors can result in a large inrush current that exceeds the nominal load current. If left unaddressed, this can cause voltage rails to fall out of regulation due to the drop, resulting in the system entering an undesired state. Load switches can mitigate the inrush current by using the CT pin to manage the rise time of the power rail. This leads to a linear output slew rate with no voltage dips or external regulators required.

Table 2. Load Switch Examples(1)

Description	Devices	Voltage Range	Max Current	Typical R_{on}	Package
Adjustable rise time, adjustable QOD	TPS22918	1 V to 5.5 V	2 A	52 mΩ	SOT
	TPS22810	2.7 V to 18 V	2 A	79 mΩ	SOT
Space-constrained applications	TPS22915	1.05 V to 5.5 V	2 A	37 mΩ	CSP
	TPS22916	1 V to 5.5 V	2 A	60 mΩ	CSP
Lowest ON-resistance, Power Good indication	TPS22990	1 V to 5.5 V	10 A	3.9 mΩ	SON
Fast turn-on time (≤ 65 µs), Power Good indication, QOD, Thermal shutdown	TPS22971	0.65 V to 3.6 V	3 A	6.7 mΩ	DSBGA

(1) For more information about load switches, visit *http://www.ti.com/loadswitches*.

2 Power Multiplexing

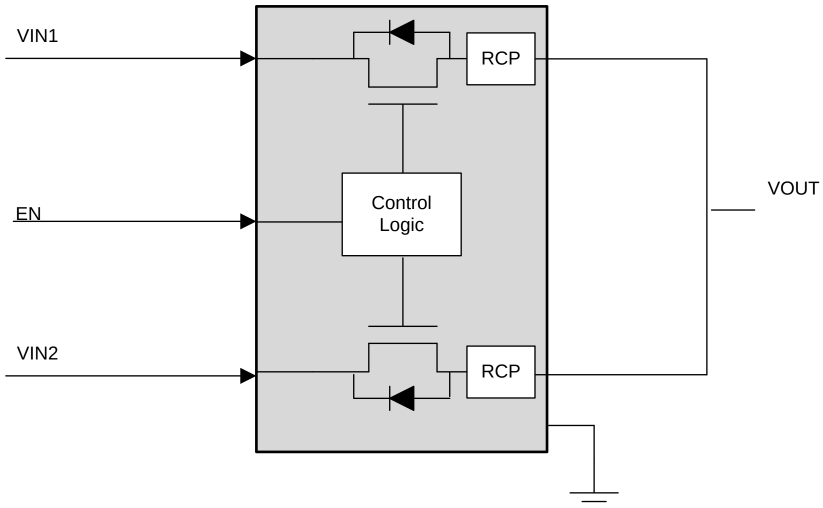

Figure 2. Power MUX Block Diagram

Integrated *Power MUX* devices allow a system to transition between different power sources seamlessly. If the main power supply fails, power multiplexing allows the system to switch to a backup power supply, such as a battery, to preserve operating conditions. Power multiplexing can also provide switching between two different voltage levels for subsystems that operate at two different voltages. In this scenario, to prevent reverse current flow from V_{OUT} into one of the V_{IN} channels, reverse current protection (RCP) blocks current from flowing back through the body diode. Power multiplexing also contains adjustable current limits. If the current exceeds the threshold set by the switch, the switch will clamp the channel and prevent current from exceeding the limit. Furthermore, if the current limit forces the device to reach higher temperatures, thermal shutdown will turn off the switch until it can operate at safe conditions again. Similar to load switches, power MUX switches also contain inrush current control to prevent large transient current events.

Power MUX devices can switch between different power rails manually or automatically. Manual switchovers occur with an external GPIO. Whenever the user wants to switch between power rails, the enable pin is toggled and the output is powered by the other power rail. Automatic switchover occurs whenever the primary power supply fails or is disconnected. When the device detects the voltage drop, it will automatically switch to the backup power rail.

Table 3. Integrated Power MUX Examples[1]

Description	Device	Recommended Voltage Range	MAX Current	Typical R_{on}	Package
Auto-switching, controlled voltage transition time, adjustable current limit	TPS2113A	2.8 V to 5.5 V	1.25 A, each channel	84 mΩ	SOP and SON
Manual switching, low standby and operating current, adjustable current limit	TPS2115A	2.8 V to 5.5 V	1.25 A, each channel	84 mΩ	SON

(1) For more information about power multiplexing, visit *http://www.ti.com/power-management/multiplexer-mux/products.html*.

3 eFuses

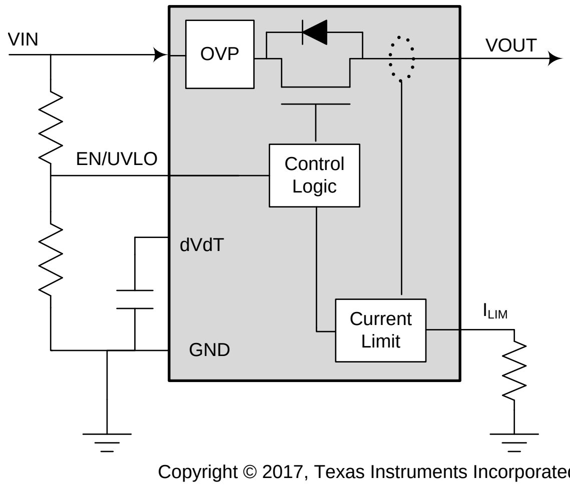

Figure 3. eFuse Block Diagram

eFuses are integrated power protection switches that provide voltage and current protection during fault events. These include short-circuit, overcurrent, overvoltage, undervoltage, and temperature events that might otherwise damage downstream loads. During a short-circuit transient event, the current through the *eFuse* increases very rapidly. The *eFuse* enables a fast-trip current threshold that terminates this rapid increase in less than 200 ns, protecting the supply. If an overvoltage event occurs on the input (VIN), the *eFuse* monitors the voltage across the internal FET and clamps the output voltage until the input falls below the overvoltage threshold. *eFuses* also come with built-in overtemperature protection that shuts down the FET if the junction temperature exceeds 150°C (typical). The *eFuse* will either remain off (latch-off version) or attempt to restart (auto retry version) the device after the junction temperature decreases. *eFuses* offer many additional features similar to load switches including adjustable inrush current control and reverse current protection.

Managing current flow from an active power bus to a subsidiary system can be a challenging task. As a device is inserted or removed from a live supply, it is possible to see a very large spike in current during the initial capacitor charging. An *eFuse* or Section 4 controller ensures the safe insertion and operation of these systems. Unlike hot swap controllers, *eFuses* contain an integrated FET which minimizes total solution size. This allows *eFuses* to be used in applications such as power multiplexing. By using two *eFuses*, each *eFuse* can control a power rail while providing reverse current protection for its respective supply. *eFuses* are also UL 2367 certified, cutting down on system testing time.

Table 4. eFuse Examples[(1)]

Description	Device	Recommended Voltage Range	Max Current	Typical R_{on}	Package
Overvoltage or undervoltage clamp, QOD using FLT pin, adjustable current limit	TPS2595	2.7 V to 18 V	4 A	34 mΩ	SON
Lowest R_{on}, circuit-breaker device, high I_{LIM} accuracy	TPS24751	2.5 V to 18 V	12 A	3 mΩ	QFN
Back to back FETs, status monitoring, thermal shutdown, internal reverse current blocking	TPS25942A	2.7 V to 18 V	5 A	42 mΩ	QFN
Reverse polarity protection, current sense output, adjustable current limit	TPS2660	4.2 V to 55 V	2 A	150 mΩ	SOP and QFN

(1) For more information about eFuses, visit *www.ti.com/efuses*.

4 Hot Swap

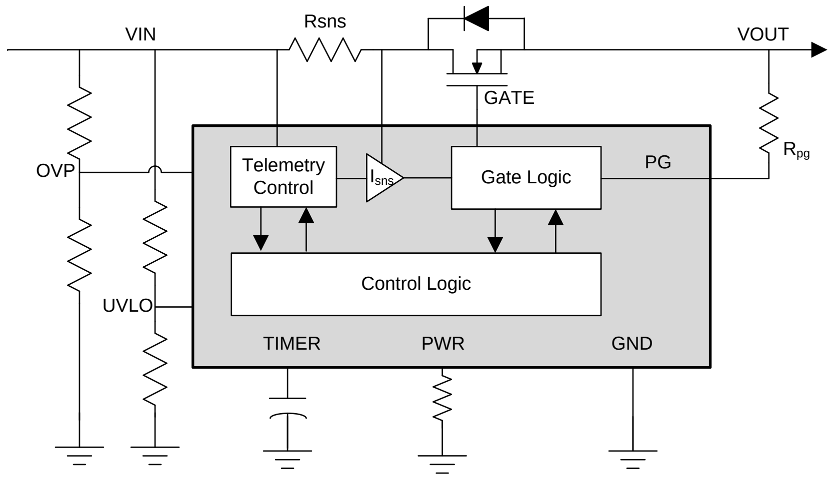

Figure 4. Hot Swap Block Diagram

Hot Swap controllers drive an external MOSFET that protects the system against hot swap events. *Hot Swap* controllers do not integrate a MOSFET as eFuses do. The external MOSFET allows *hot swap* controllers to operate at higher voltages and currents than eFuse devices. The controller monitors the gate voltage of the external FET and adjusts the voltage depending on the situation. When the device is inserted into a live power system, the controller measures the inrush current across R_{SNS}. If the value exceeds the programable current limit, the gate voltage is lowered and limits the current passing downstream. If the power dissipated across the FET exceeds the programmable power limit, then the gate voltage is reduced to lower the current flowing through R_{SNS}. The overvoltage and undervoltage pins also clamp the voltage whenever the input voltage is not within specified thresholds.

To ensure that the external MOSFET remains within safe operating area (SOA), the *hot swap* controller regulates the current limit at higher V_{DS} voltages. The device also includes an assortment of telemetry that monitors the operating conditions. The Power Good (PG) signal turns on whenever the power rail reaches regulation, and some *hot swap* controllers contain PMBus monitoring that allows real-time feedback on the device status.

Since *hot swap* controllers operate by controlling an external R_{SNS} and MOSFET, they do not contain an innate current limit. The external components allow the user to customize the solution size and power requirements to fit their application.

Table 5. Hot Swap Examples(1)

Description	Device	Recommended Voltage Range	Package
18-V analog devices, small footprint, easy-to-use	TPS247xx	2.5 V to 18 V	SOP or QFN
Meets 240-V requirements for high-end applications, similar to TPS247xx	TPS2477x	2.5 V to 18 V	QFN
PMBus and I2C communication, balance between efficiency and accuracy	LM25066A, LM25066I	2.9 V to 17 V	QFN
Higher voltage applications, PMBus and I2C communication, external FET temperature and failure sensing	LM5066	10 V to 80 V	PWP
Higher voltage applications, SOA protection, current limit	LM5069	9 V to 80 V	SOP
Negative voltage support, SOA protection, PMBus and I2C communication	LM5064	–10 V to –80 V	SOP
Negative voltage support with dual current limit, soft-start disconnect, ORing support, –200 V maximum rating	TPS2352x	–10 V to –80 V	SOP
Circuit breaker function for severe current events, programmable fault timer, PG output	LM5067	–9 V to –80 V	SOP

(1) For more information about Hot Swap controllers, visit *www.ti.com/hotswap*.

5 Ideal Diode, ORing Controllers

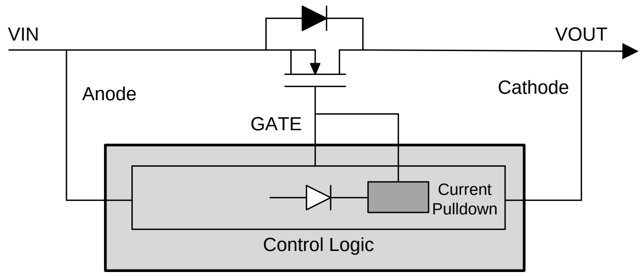

Figure 5. Ideal Diode Block Diagram

Ideal diode controllers control an external FET and, similar to a regular diode, can block reverse current whenever a reverse voltage event occurs. Whenever one of these events occur, the controller shuts off the FET and uses the body diode to prevent any transients from damaging upstream components. The controller can also prevent against ground shorts at the input (VIN) by using the same method.

Ideal diode controllers can also protect against reverse polarity conditions, commonly caused by connecting a battery incorrectly or mis-wiring a power supply. If the user accidentally switches the polarity on VIN, an additional diode from the controller to GND can be included to prevent damage to the IC or the power source. The controller also significantly lowers power dissipation normally found across diodes. By driving the external FET instead of a diode, the voltage drop typically found across diode solutions can be minimized.

Ideal diodes can also act as ORing controllers. Basic power redundancy architecture contains two or more power supplies connected to a single load. ORing solutions allow the system to switch between power sources if one were to fail, and can even connect power sources in parallel. This allows for uninterrupted power and saves on redundant power supply costs.

Table 6. Smart Diode Controller Examples (1)

Description	Device	Recommended Voltage Range	Typical Quiescent Current	Forward Voltage Threshold	Package
Internal charge pump, rapid programmable turnoff, voltage sensing	TPS241x	3 V to 16.5 V	N/A	10 mV	SOP and SOIC
Wide operating voltage range, 100-V transient capability	LM5050-1	1 V to 75 V	100 µA	22 mV	SOT
Automotive qualified, zero quiescent current	LM74610-Q1	0 V to 42 V	0 µA	30 mV	SOP
Automotive qualified, Low $R_{DS(on)}$	LM74700-Q1	3.2 V to 65 V	30 µA	20 mV	SOT
Low side ORing controller, FET diagnostics	LM5051	–6 V to –100 V	69 µA	45 mV	SOIC

(1) For more information about *Ideal diode* controllers, visit *www.ti.com/idealdiode*.

6 Smart High-Side Switches

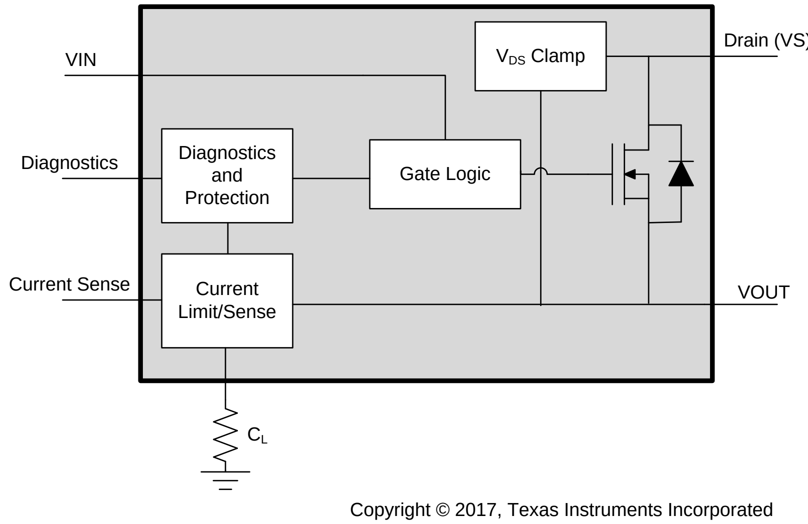

Figure 6. Smart High-Side Switch Block Diagram

Smart high-side switches offer highly-accurate current sensing to provide real-time diagnostics to the system. A current mirror sources current from VIN, reflecting this as voltage on the Current Sense (CS) pin. The CS pin does not need to be calibrated, and can serve as a diagnostics report pin. Whenever an open load or short happens, the voltage on the CS pin falls to 0 V. Whenever a current limit, thermal event, or an open load or short in the off state occurs, the voltage is pulled up to its maximum threshold.

These switches also contain highly-adjustable and selectable current limits. By connecting an external resistor to set the current-limit threshold, the switch protects the load and power supply from overstressing during short-circuit to GND events or power-up conditions. When the threshold is reached, a closed loop activates and clamps the output current to the set value. A fault is then reported on the CS pin.

Another functionality of *smart high-side* switches is load-dump compatibility, which allows these devices to connect directly to a 12-V battery without concerns about typical voltage and current transients. Some *smart high-side* switches can also support large inrush current events that would otherwise damage downstream components.

Smart high-side switches can be AEC-Q100 certified, allowing full integration into many automotive applications that require a low on-resistance and high voltage tolerances to accommodate voltage spikes and inrush current events. Some of these applications include front and rear lighting, seat heating, infotainment, cluster, powertrain, and ADAS.

Table 7. Smart High-Side Examples (1)

Description	Device	Recommended Voltage Range	Current Sense Accuracy	Continuous Load Current	Typical R_{on}	Package
Selectable current limit for design flexibility, low R_{ON}, small footprint, thermal sensing	TPS1HA08-Q1	3 V to 40 V	±5% at 1 A	0 A to 12 A	8 mΩ	SOP
Low standby current, highly accurate current sense, thermal shutdown	TPS1H100-Q1	3.5 V to 40 V	±3% at 1 A	0 A to 4 A	100 mΩ	SOP
	TPS27S100	3.5 V to 40 V	±3% at 1 A	0 A to 4 A	80 mΩ	SOP
Multi-channel support, fast hardware interrupts, low standby current, loss of GND diagnostics	TPSxH160-Q1	3.4 V to 40 V	±3% at 1 A	0 A to 1.8 A per channel	160 mΩ	SOP

(1) For more information about smart high-side switches, see *www.ti.com/smarthighsideswitch*.

7 Low-Side Switches

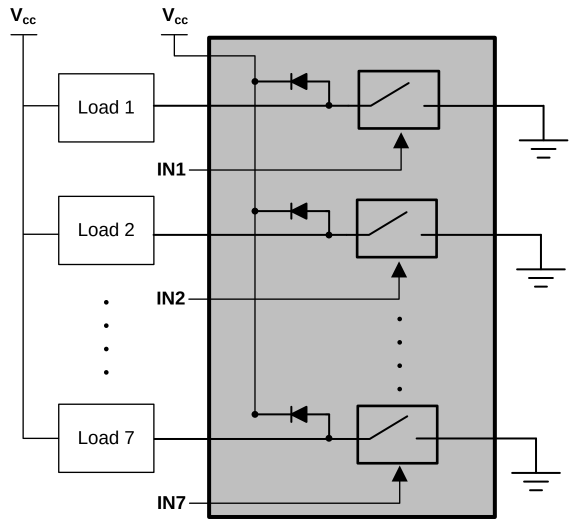

Figure 7. Low-Side Switch Block Diagram

Low-side switches are used to connect and disconnect ground from a load, unlike the rest of the power switch topologies. This configuration allows *low-side* switches to drive inductive loads; an internal flyback diode prevents inductive transients from damaging the circuit and components. Whenever the switch is opened, the inductive transients will flow through the flyback diode and dissipate throughout the load. This makes these devices ideal for motors, solenoids, and relays.

Low-side switches consists of two designs, Darlington pair arrays and low-side MOSFET solutions. Darlington pair solutions can support higher voltage applications due to the higher voltage ratings of the integrated BJTs, while the MOSFET solutions have lower on-resistances and lower leakage currents. Most of the *low-side* switches contain 7 channels, which can be tied in parallel to support higher current operation.

Table 8. Low-Side Switch Examples

Description	Device	Recommended Voltage Range	Max Current	Number of Channels	Package
Darlington pair BJTs, higher voltage support	ULN2003A	0 V to 50 V	500 mA per channel	7	SOIC, SOP, and DIP Packages
Darlington pair BJTs, 8-channel support	ULN2803A	0 V to 50 V	500 mA per channel	8	SOIC
Low-side MOSFET solutions, low on-resistance and current leakage, power efficient	TPL7407LA	0 V to 30 V	600 mA per channel	7	SOIC or SOP

8 References

1. Texas Instruments, *Basics of Load Switches Application Report*
2. Texas Instruments, *What is an eFuse? Application Report*
3. Texas Instruments, *Robust Hot Swap Design Application Report*
4. Texas Instruments, *Adjustable Current Limit of Smart High Side Switch Application Report*

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