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. It 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 functions 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 but allow for multiple input sources. This set of electronic switches is used to select and transition between two or more input power paths to a single output while also providing input power protection.

eFuses and *Hot Swap* controllers provide additional input power path protection functions 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 are for off-board load protection. They provide additional diagnostic telemetry that monitors the output load current and detects short-circuit and open-load events. *Smart high-side switches* have adjustable current limits, allowing for more reliable integration into applications with either large inrush current startup profiles or low peak currents. Adding a smart high-side switch to a design leads to a smarter and more robust solution for driving capacitive, inductive, and LED loads.

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 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 report 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

	POWER DISTRIBUTION		POWER PATH PROTECTION				
	Load Switch	Power MUX (2 input, 1 output)	eFuse (Internal FET)	Hot Swap (External FET)	Ideal Diode ORing Controller	Smart High-Side Switch	Low-Side Switch
Voltage Range	0 V to 18 V	2.8 V to 22 V	2.7 V to 60 V	±80 V	±75 V	6 V to 40 V	0 V to 100 V
Max Operating Current	15 A	4.5 A	15 A	N/A	N/A	12 A	1 A
Functions							
Inrush Current Control	✓	✓	✓	✓		✓	
Adjustable Current Limit		✓	✓	✓		✓	
Reverse Current Blocking	✓	✓	✓	✓	✓		
Current Sense Monitoring			✓	✓		✓	
Short-Circuit Protection	✓[1]	✓	✓	✓		✓	
Overvoltage Protection		✓	✓	✓			
Reverse Polarity Protection		✓	✓	✓	✓	✓	
Power Good Signal	✓		✓	✓			
Inductive Load Compatibility						✓	✓
Load-Dump Compatibility			✓	✓	✓	✓	✓
Thermal Shutdown	✓	✓	✓	✓		✓	

(1) Self protected load switch

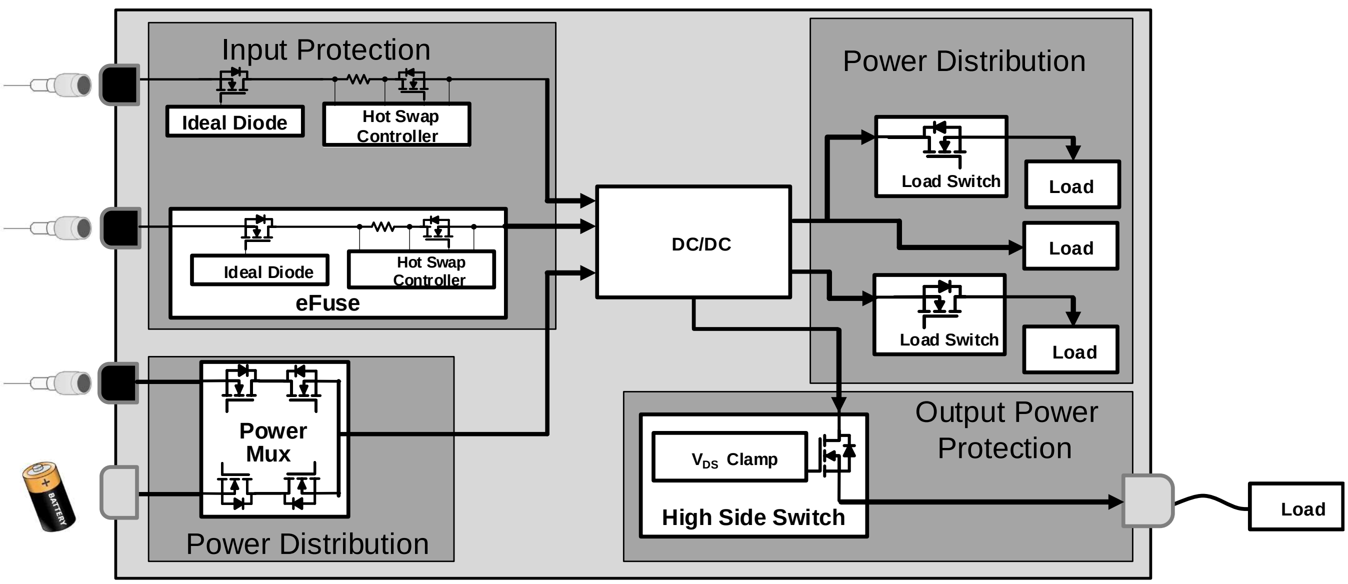

Figure 1. Typical Power Switch Use Cases

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Trademarks

1 Load Switches

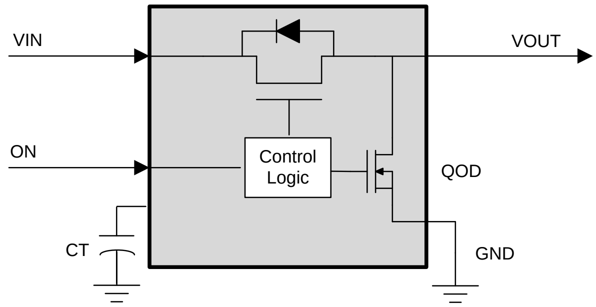

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Figure 2. Load Switch Block Diagram

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 functions 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
Self protected with controlled rise time	TPS22919	1.6 V to 5.5 V	1.5 A	90 mΩ	SOT
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) *TI.com/LoadSwitches* for more information about load switches.

2 Power Multiplexing

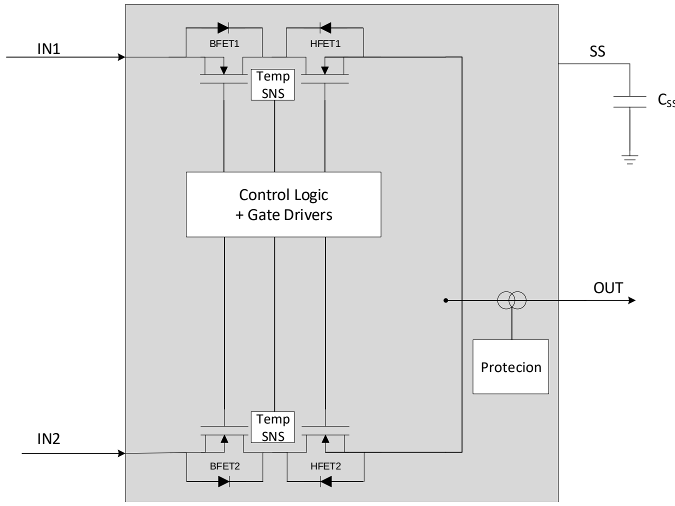

Figure 3. Power MUX Block Diagram

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 clamps the channel and prevent current from exceeding the limit. Furthermore, if the current limit forces the device to reach higher temperatures, thermal shutdown turns 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 in three general ways: manually, automatically, or both. Manual switchovers occur with an external GPIO. Whenever you want 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 automatically switches to the backup power rail. There are some Power MUX solutions which offer the flexibility to be used in an automatic configuration and to be controlled by a manual control signal. This method can have a default (automatic) priority, but can then be overridden by an external microcontroller if needed.

Table 3. Integrated Power MUX Examples (1)

DESCRIPTION	DEVICE	RECOMMENDED VOLTAGE RANGE	MAX CURRENT	TYPICAL R_{on}	PACKAGE
Automatic priority and manual override, adjustable current limit	TPS2120	2.8 V to 22 V	3 A, each channel	62 mΩ	CSP
Automatic priority and manual override, fast output switchover, adjustable current limit	TPS2121	2.8 V to 22 V	4.5 A, each channel	56 mΩ	QFN

(1) *TI.com/PowerMux* for more information about power multiplexing.

3 eFuses

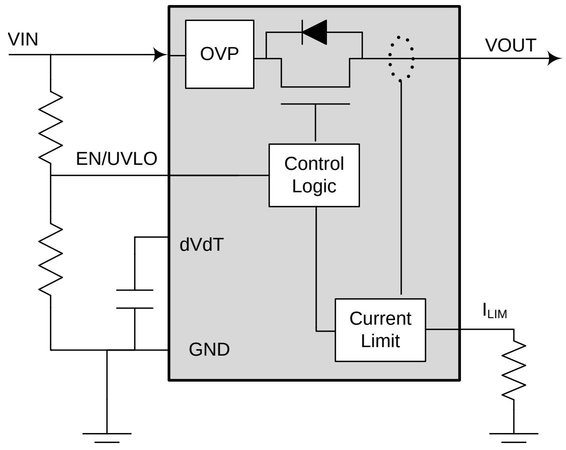

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Figure 4. eFuse Block Diagram

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* either remains off (latch-off version) or attempts 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 Ron circuit-breaker device, accurate load monitoring, adjustable transient fault management	TPS25982	2.5 V to 24 V	15 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
Power limiting, overvoltage cut-off or voltage clamping functionality	TPS1663	4.5 V to 60 V	6 A	31 mΩ	SOP and QFN
Power limiting, reverse current blocking, reverse polarity protection	TPS2663	4.5 V to 60 V	6 A	31 mΩ	SOP and QFN

(1) Visit *www.ti.com/efuses* for more information about eFuses.

4 Hot Swap

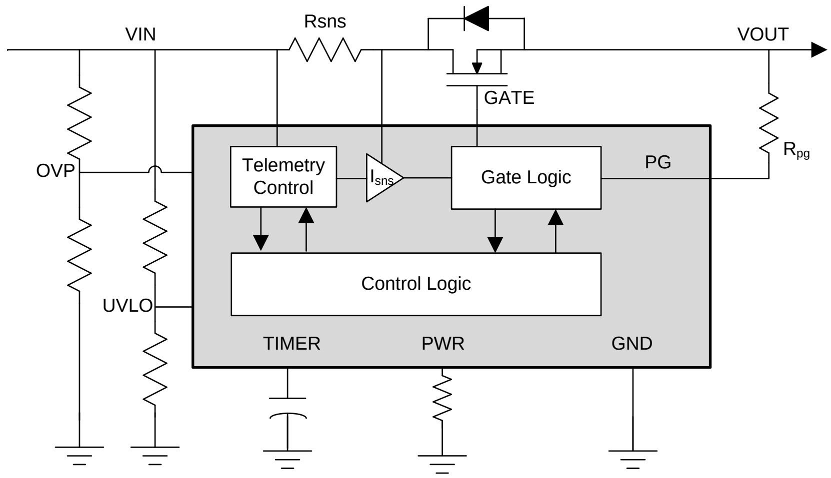

Figure 5. Hot Swap Block Diagram

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 you 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) Visit *www.ti.com/hotswap* for more information about Hot Swap controllers.

5 Ideal Diode, ORing Controllers

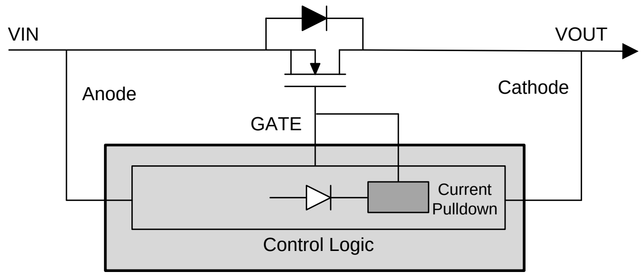

Figure 6. Ideal Diode Block Diagram

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 you accidentally switch 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. Ideal Diode Controller Examples (1)

DESCRIPTION	DEVICE	RECOMMENDED VOLTAGE RANGE	TYPICAL QUIESCENT CURRENT	FORWARD VOLTAGE THRESHOLD	PACKAGE
Fast turnoff, voltage sensing	TPS241x	3 V to 16.5 V	N/A	10 mV	SOP and SOIC
Automotive qualified, low Iq, high efficiency	LM74700-Q1	3.2 V to 65 V	80 µA	20 mV	SOT
Low side ORing controller, FET diagnostics	LM5051	–6 V to –100 V	69 µA	45 mV	SOIC
Low Iq, reverse current protection, integrated FET	LM66100	1.5 V to 5.5 V	0.2 µA	79 mV (2)	SC-70

(1) Visit *www.ti.com/idealdiode* for more information about *Ideal diode* controllers.
(2) Typical forward voltage at Iout = 1 A.

6 Smart High-Side Switches

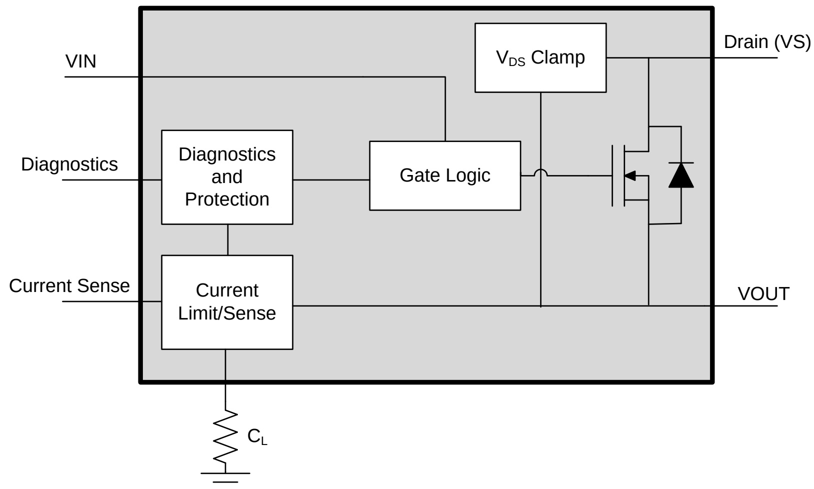

Figure 7. Smart High-side Switch Block Diagram

Smart high-side switches reliably drive off-board loads. These switches contain highly-adjustable and selectable current limits that enable a system to be optimally designed for specific loads. By connecting an external resistor to set the current-limit threshold, the switch protects the load and power supply from overstressing during short-circuits to GND events or power-up conditions. This enables more reliable designs by minimizing transient currents and supply droops. 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.

These switches also 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. High-accuracy current monitoring and adjustable current limit are ideal for industrial applications like programmable logic controllers, motor valves, servo drives, and control units.

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. Additional protection includes mitigation of 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) (2)

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) Additional devices in various typical R_{ON} values are available.
(2) Visit *ti.com/smarthighsideswitch* for more information about smart high-side switches.

Table 7. Smart High-Side Examples [1] [2] (continued)

DESCRIPTION	DEVICE	RECOMMENDED VOLTAGE RANGE	CURRENT SENSE ACCURACY	CONTINUOUS LOAD CURRENT	TYPICAL R_{on}	PACKAGE
Dual-channel, programmable current limit	TPS2HB08-Q1	3 V to 28 V	+3/-8% at 1 A	0 A to 8 A per channel	8 mΩ	SOP
Inductive load negative clamp with optimized slew rate, global fault report	TPSxH000-Q1	3.4 V to 40 V	-	0 A to 1A	1 Ω	SOP
Highly accurate current limit, supports full diagnostics with the digital status output	TPS1H200-Q1	3.4 V to 40 V	-	0 A to 2.5 A	200 mΩ	SOP

7 Low-Side Switches

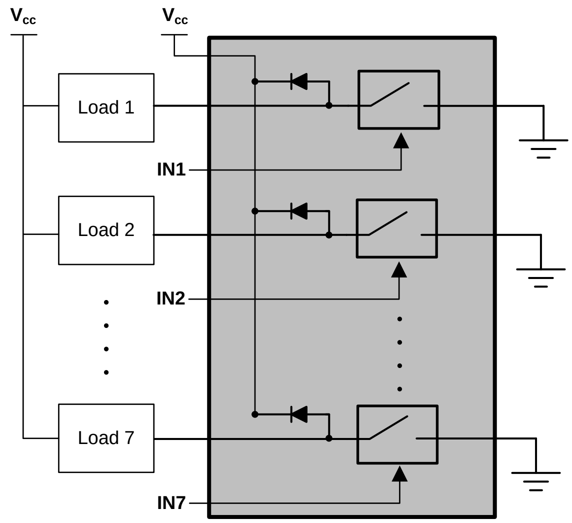

Figure 8. Low-Side Switch Block Diagram

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 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 seven 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*

Revision History

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

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