

Load Switches: What Are They, Why Do You Need Them And How Do You Choose The Right One?

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Drivers and Load Switches

ABSTRACT

Integrated load switches are electronic relays that can be used to turn on and turn off power supply rails in systems. Load switches offer many other benefits to the system and can include protection features that are often difficult to implement with discrete components. There are many different applications where load switches can be used including, but not limited to:

- Power Distribution
- Power Sequencing and Power State Transition
- Reduced Leakage Current in Standby Mode
- Inrush Current Control
- Controlled Power down

This application note will provide the fundamental basics of what load switches are, when they should be used, and how they can be implemented in a system.

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1 What Are Load Switches?

Integrated load switches are integrated electronic relays used to turn on and turn off power rails. Most basic load switches consist of four pins for input voltage, output voltage, enable, and ground. When the device is enabled via the ON pin, the pass FET turns on, thereby allowing current to flow from the input pin to the output pin, and power is passed to the downstream circuitry.

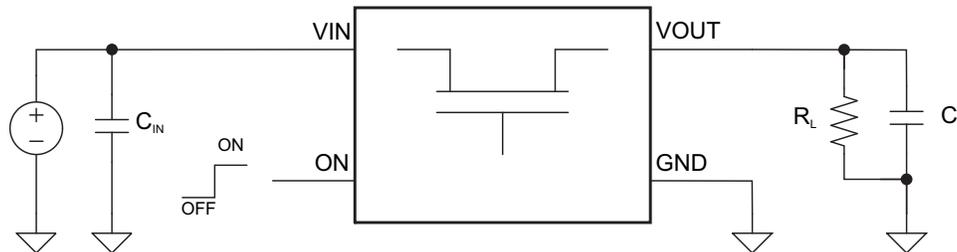
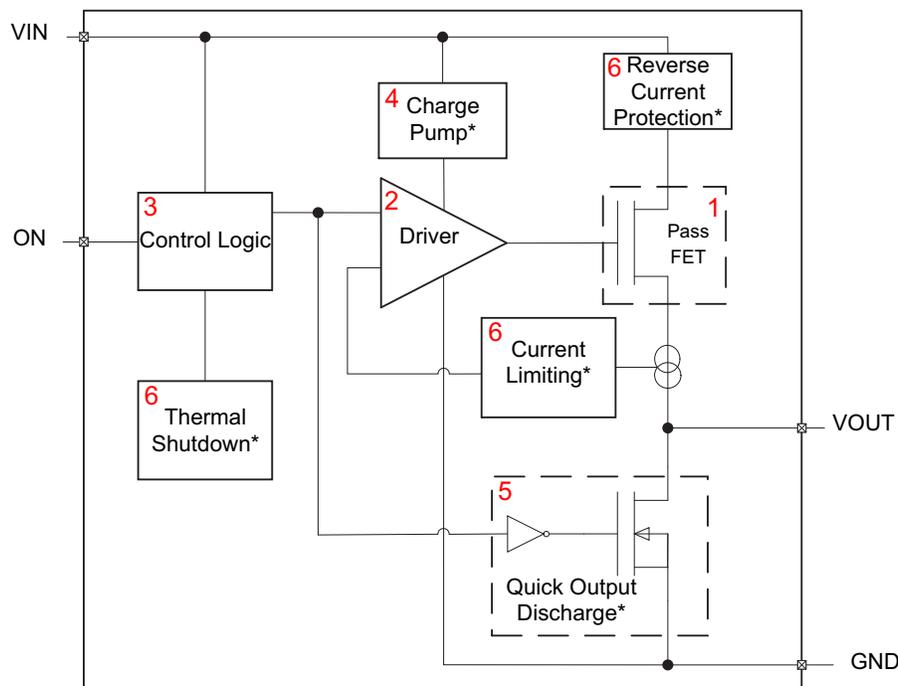


Figure 1. General Load Switch Circuit Diagram

1.1 General Load Switch Block Diagram

An understanding of what the architecture of a load switch looks like will be helpful in determining the specifications of a load switch. Shown in Figure 2 is a block diagram of a basic load switch, which is made up of five basic blocks. Additional blocks can be included to add functionality to the load switch.



*Not present on all load switches

Figure 2. Block Diagram of General Load Switch

1. The pass FET is the main component of the load switch, which determines the maximum input voltage and maximum load current the load switch can handle. The on-resistance of the load switch is a characteristic of the pass FET and will be used in calculating the power dissipated by the load switch. The pass FET can be either an N-channel or P-channel FET, which will determine the architecture of the load switch.
2. The gate driver charges and discharges the gate of the FET in a controlled manner, thereby controlling the rise time of the device.
3. The control logic is driven by an external logic signal. It controls the turn-on and turn-off of the pass FET and other blocks, such as quick output discharge, the charge pump, and blocks with protection features.
4. The charge pump is not included in all load switches. This is used in load switches with an N-channel FET, since a positive differential voltage between the gate and the source (V_{OUT}) is needed in order to turn on the FET properly.
5. Quick output discharge is an on-chip resistor from V_{OUT} to GND that is turned on when the device is disabled via the ON pin. This will discharge the output node, preventing the output from floating. For the devices with quick output discharge, this feature is only present when V_{IN} and V_{BIAS} are within the operating range.
6. Additional features are included in different load switches. These include, but are not limited to, thermal shutdown, current limiting, and reverse current protection.

1.2 Datasheet Parameters

Below is a list of common datasheet parameters and definitions for load switches.

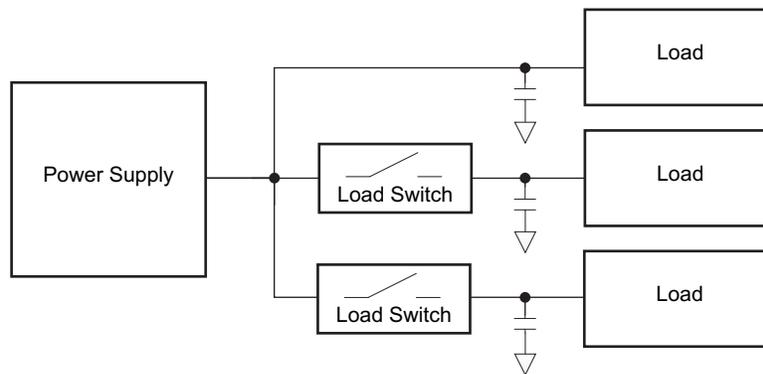
- Input voltage range (V_{IN}) – This is the range of input voltages that the load switch can support.
- Bias voltage range (V_{BIAS}) – This is the range of bias voltages that the load switch can support. This may be required to power the internal blocks of the load switch, depending on the architecture of the load switch.
- Maximum continuous current (I_{MAX}) – This is the maximum continuous DC current the load switch can support.
- ON-state resistance (R_{ON}) – This is the resistance measured from the V_{IN} pin to the V_{OUT} pin, which takes into consideration the resistance of the packaging and the internal pass FET.
- Quiescent Current (I_Q) – This is the required amount of current to power the internal blocks of the device, which is measured as the current flowing into the V_{IN} pin without any load on V_{OUT}.
- Shutdown Current (I_{SD}) – This is the amount of current flowing into V_{IN} when the device is disabled.
- ON pin input leakage current (I_{ON}) – This is the amount of current that is flowing into the ON pin when the ON pin has a high voltage applied to it.
- Pull-down resistance (R_{PD}) – This is the value of the pull-down resistor from V_{OUT} to GND when the device is disabled.

2 Why Do You Need Load Switches

This section will provide a general overview of some applications where using a load switch is beneficial.

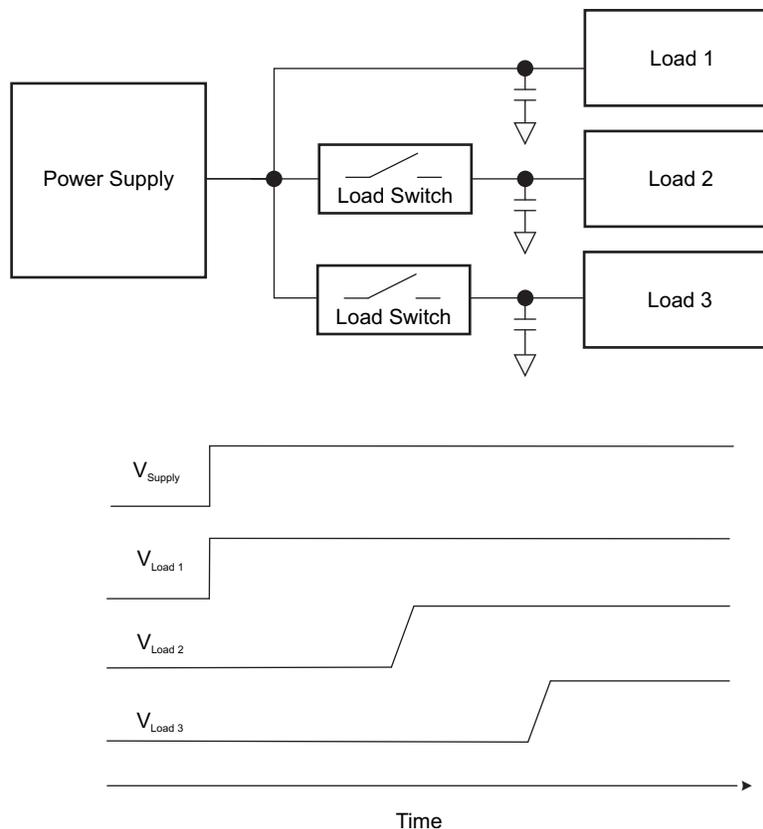
2.1 Power Distribution

Many systems have limited control of sub-systems power distribution. As illustrated in [Figure 3](#), load switches can be used to turn on and off sub-systems of the same input voltage instead of using multiple DC/DC converters or LDO's. By using a load switch, power can be distributed across different loads with control for each individual load.


Figure 3. Power Distribution Block Diagram

2.2 Power Sequencing and Power State Transition

In some systems, especially those with a processor, there is a strict power-up sequence that must be followed. By using a GPIO or I₂C interface, load switches are a simple solution to implement power sequencing to meet the power-up requirements. Load switches can provide independent control of each power path to provide simplified point-of-load control for power sequencing, as shown in Figure 4.


Figure 4. Power Sequencing with Load Switches

2.3 Reduced Leakage Current

In many designs, there are sub-systems that are only used during certain modes of operation. Load switches can be used to limit the amount of leakage current and power consumption by turning off power to these sub-systems. Figure 5 shows a comparison of the leakage current with and without a load switch. Refer to the [Input and Output Capacitance](#) section for more details.

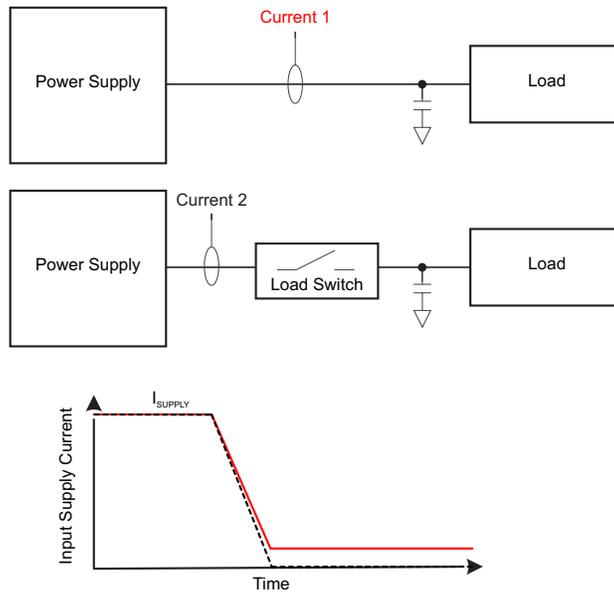


Figure 5. Comparison of Leakage Current with and without the Load Switch

In some applications, the circuitry - such as DC/DC converters, LDOs, and modules - can be disabled and put into standby mode. However, the leakage current of these modules can be relatively high, even in the shutdown state. By placing a load switch before the load, as shown above, the leakage can be reduced to significantly lower levels. Thus, power consumption can be reduced significantly with a load switch placed in the power path.

2.4 Inrush Current Control

When turning on a sub-system without any slew rate control, the input rail may sag because of the inrush current that can happen from quickly charging a load capacitor. This can be problematic as this rail may be supplying power to other sub-systems (Figure 6). Load switches solve this issue by controlling the rise time of the output voltage, thereby eliminating the sag on the input voltage (Figure 7). The inrush current is proportional to the load capacitance as will be explained later in the [Section 4.2](#) section.

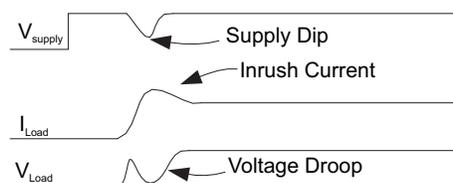


Figure 6. Inrush Current Causing Power Supply Dip



Figure 7. Slew Rate Control with Load Switch

2.5 Controlled Power Down

When a DC/DC converter or LDO without quick output discharge turns off, the load voltage is left floating and power down is dictated by the load, as shown in Figure 8. This can cause unwanted activity as modules downstream are not powered down to a defined state.

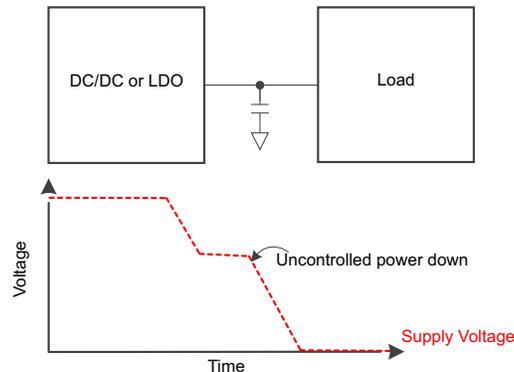


Figure 8. Uncontrolled power down without load switch

Using a load switch with quick output discharge can mitigate these problems. The load will be powered down quickly in a controlled manner and will be reset to a known good state for the next power up, as shown in Figure 9. This will eliminate any floating voltages at the load and ensure that it is in a defined power state at all times. Refer to the Quick Output Discharge (QOD) section for more details.

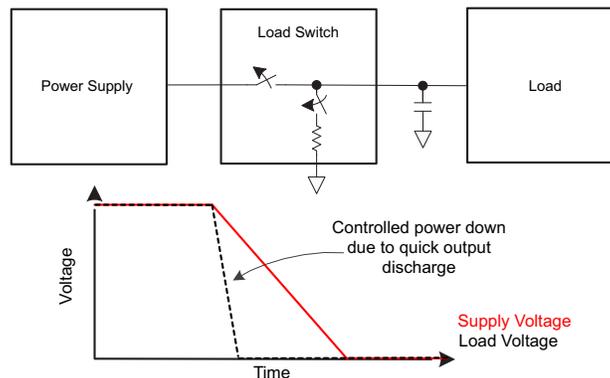


Figure 9. Controlled power down with load switch

2.6 Protection Features

Certain applications may require fault protection features to be integrated into the load switch. Some load switches include integrated features such as reverse current protection, ON pin hysteresis, current limiting, undervoltage lock-out and over temperature protection. Instead of implementing these complex circuits through discrete components, it is possible to reduce BOM count, solution size, and development time by using an integrated load switch. Below is a list that briefly explains what some of these features can be:

- Reverse current protection will stop current from flowing from the VOUT pin to the VIN pin. In the absence of this feature, current may flow from the VOUT pin to the VIN pin, if the voltage on VOUT is greater than VIN by a diode drop. Thus, reverse current blocking may be beneficial in certain applications, such as in a power mux application where current should not flow from VOUT to VIN. There are many different methods of implementing reverse current protection. In some situations, such as the TPS22912, the device will monitor the voltage levels at the VIN pin and VOUT pin. When this differential voltage exceeds a certain threshold, the switch is disabled and the body diode is disengaged to prevent any reverse current flow to VIN. Some devices, such as the TPS22963C, only have reverse current protection when the device is disabled.

- ON pin hysteresis allows for more robust GPIO enable. With a voltage difference between a logic level high and logic level low on the ON pin, the control circuitry will operate as intended when there is noise on the GPIO line. [Figure 10](#) illustrates how ON pin hysteresis can provide robustness on the GPIO enable line.
- Current limiting is a feature that will limit the amount of current the load switch will output. This will ensure that there is not an excessive amount of current being pulled by an external circuitry. If current is not limited, the external circuitry can potentially bring the main system down. In the current limited mode, load switch works as a constant current until the switch current falls below the current limit.
- Undervoltage lock-out (UVLO) is used to turn off the device if the VIN voltage drops below a threshold value, ensuring that the downstream circuitry is not damaged by being supplied by a voltage lower than intended.
- Over temperature protection disables the switch if the temperature of the device exceeds a threshold temperature. With this feature, the device can operate as a safety switch that turns off when a high temperature is detected.

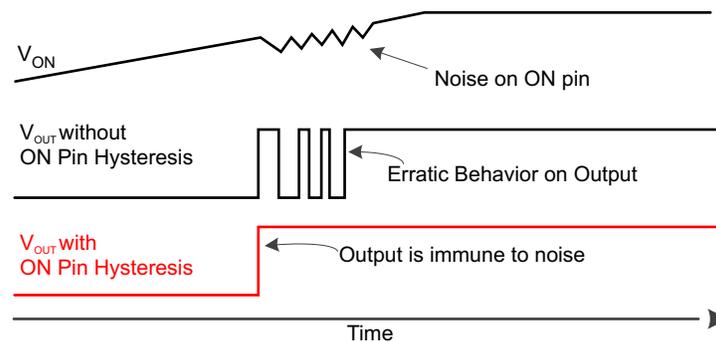


Figure 10. ON Pin Hysteresis

2.7 Lower BOM Count and PCB Area

Using an integrated load switch can lower the BOM count of a system. If there are discrete FETs that are used in conjunction with other components, a load switch could be considered to reduce the number of total components in the system. When a load switch is created discretely, there are many resistors, capacitors and transistors that will be required to implement a gate driver, control logic, output discharge and protection features. With an integrated load switch, this is all accomplished with only a single device and the BOM count is significantly reduced.

3 Part Selection and Design Considerations

This section will look at the specifications that need to be kept in mind in choosing a load switch.

3.1 NMOS vs PMOS

In an NMOS device, the pass FET is turned on by bringing the gate voltage above the source. Usually, the source voltage is at the same potential as the VIN terminal. In order to create this voltage differential between the gate and the source, a charge pump is required. Using a charge pump will increase the quiescent current of the device.

In a PMOS device, the pass FET is turned on by bringing the gate voltage below the source voltage. The architecture of a PMOS device does not require a charge pump, resulting in a lower quiescent current when compared to a NMOS device.

One major difference between a PMOS based architecture and NMOS based architecture is that PMOS based load switches do not perform well at lower voltages, while NMOS devices are good for lower VIN applications.

3.2 ON-State Resistance (R_{ON})

ON-state resistance (R_{ON}) is a particularly important specification, as this determines the voltage drop across the load switch and power dissipation of the load switch. The larger the R_{ON} , the larger the voltage drop across the load switch will be and the higher the power dissipation. Refer to [Section 4](#) for calculations on how to determine the voltage drop and power dissipation.

3.3 Voltage (V_{IN}) and Current (I_{MAX}) Rating

One of the key considerations in deciding which load switch to use is the voltage and current required for the application. The load switch must be able to support the DC voltage and current that is expected during steady state operation, as well as the transient voltages and peak currents. It is important to note that some load switches require a bias voltage to turn on the device and bias the internal circuitry. This bias voltage is independent from the input voltage.

3.4 Shutdown Current (I_{SD}) and Quiescent Current (I_Q)

Quiescent current is the current that the load switch consumes when the load switch is ON. Quiescent current, in addition to the I^2R losses, will determine the amount of power that is consumed by the load switch when it is powered on. If the load currents are large enough, the power consumed due to quiescent current is negligible.

Shutdown current determines the amount of power the load switch consumes when it is disabled via the ON pin. By using a load switch to power down subsystems, there can be a significant decrease in the standby power of a power rail. Refer to [Section 5.2](#) for an example of how this may be an important specification.

3.5 Rise Time (t_R)

Rise time varies from device to device. The rise time may need to be shorter or longer depending on the application. In addition to this, inrush current is inversely proportional to rise time. Knowing what inrush current is acceptable for the system can be beneficial. Refer to [Section 4.2](#) for more details.

3.6 Quick Output Discharge (QOD)

Some load switches have an internal resistor that will pull the output to ground when the switch is turned off, preventing it from floating. For the quick output discharge feature to function, the voltage on the input voltage pins need within the operating range.

There are many benefits to having the quick output discharge, such as:

- The output is not left floating and is always in a determined state.
- Downstream modules are always turned off completely.

However, there are applications where quick output discharge would not be beneficial.

- If the output of the load switch was connected to a battery, quick output discharge would cause the battery to drain when the load switch is disabled via the ON pin.
- If two load switches are being used as a 2 input, 1 output multiplexer – where the outputs are tied together – the load switches cannot have quick output discharge. Otherwise, power would be constantly wasted through the quick output discharge, as current will be flowing through the internal resistor to ground whenever the load switch is disabled via the ON pin.

3.7 Package Size

Integrated load switch come in all different shapes and sizes. It is essential to ensure that the load switch is acceptable for the application. In space constrained systems, it may be necessary to choose a smaller package size. For example, it may be undesirable to use 0.4mm pitch devices, so 0.4mm pitch devices should not be considered when choosing parts. Thus, package size should be taken into consideration when deciding which device to choose.

3.8 Input and Output Capacitance

In load switch applications, input capacitors should be placed to limit the amount of voltage drop on the input supply caused by the transient inrush currents into the discharged load capacitors. A 1- μ F capacitor between VIN and GND placed near the VIN terminal (C_{IN}) is highly recommended. Higher values of capacitance will reduce the voltage drop during high-current applications. While this is highly recommended, it is not necessary for the load switch to operate.

The total output capacitance (C_L) between VOUT and GND may cause the voltage on VOUT to exceed the voltage on VIN when the supply is removed, which may result in current flow from VOUT to VIN through the body diode in the pass FET for devices without reverse current protection. It is recommended, but not required, to maintain a 10 to 1 ratio between the input capacitor and the load capacitance to prevent this.

4 Basic Calculations

This section has calculations that can be used to determine the specifications required for the load switch.

4.1 Voltage Drop

To determine an appropriate device for an application, it is necessary to understand how much voltage drop across the load switch is acceptable. The lower the acceptable drop, the lower the R_{ON} of the load switch must be. Use [Equation 1](#) to determine the VIN to VOUT voltage drop:

$$R_{ON, \max} = \frac{\Delta V_{\max}}{I_{LOAD}} \quad (1)$$

Where:

ΔV_{\max} = maximum voltage drop from VIN to VOUT

I_{LOAD} = load current

$R_{ON, \max}$ = maximum on-resistance of the device for a given V_{IN}

4.2 Inrush Current

To determine how much inrush current will be caused by the C_L capacitor, use [Equation 2](#):

$$I_{INRUSH} = C_L \times \frac{dV_{OUT}}{dt} \quad (2)$$

Where:

I_{INRUSH} = amount of inrush current caused by C_L

C_L = total capacitance on VOUT

dV_{OUT} = change in voltage of VOUT when the device is enabled

dt = the time it takes for VOUT voltage to change by dV_{OUT}

The value of the inrush current is determined by the total capacitance on VOUT and the rate of change of the VOUT voltage. Thus, it is important to ensure that the rise time of the load switch is chosen such that the device to exceed the maximum specifications – specifically I_{PLS} – upon startup as indicated in the datasheet. Some devices have a separate CT pin, which allows the rise time to be programmed via an external capacitor from the CT pin to GND.

4.3 Power Dissipation

The input voltage and load current is necessary to calculate the power dissipated in the load switch. Use [Equation 3](#) to determine the power dissipation of the load switch:

$$P_D = V_{IN} \times I_Q + I_{LOAD}^2 \times R_{ON} \quad (3)$$

Where:

V_{IN} = input voltage

I_Q = quiescent current of the load switch

I_{LOAD} = load current of the load switch

R_{ON} = ON-resistance of the load switch

For large load currents, it is possible to ignore the I_Q of the device, since the product of V_{IN} and I_Q may be negligible when compared to the losses due to R_{ON} .

4.4 Thermal Considerations

The maximum IC junction temperature should be restricted to the maximum junction temperature as indicated on the absolute maximum table under normal operating conditions. To calculate the maximum allowable power dissipation, $P_{D(max)}$ for a given output current and ambient temperature, use Equation:

$$P_{D(max)} = \frac{T_{J(max)} - T_A}{\theta_{JA}} \tag{4}$$

Where:

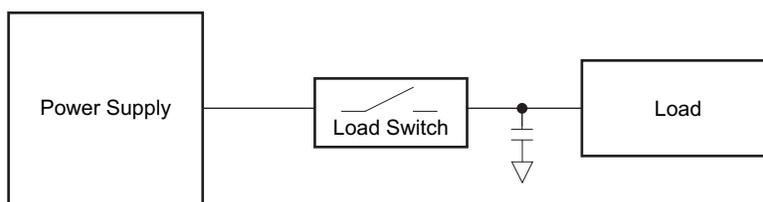
- $P_{D(max)}$ = maximum allowable power dissipation
- $T_{J(max)}$ = maximum allowable junction temperature
- T_A = ambient temperature of the device
- θ_{JA} = junction to air thermal impedance. This parameter is highly dependent upon board layout.

5 Design Examples and Application Examples

This section will discuss several examples that utilize the equations that were discussed in the previous section and present a few configurations of how a load switch can be used in a system.

5.1 R_{ON} and Inrush Current Calculations

Listed below are the system specifications for this example:



Design Parameter	Example Value
V_{IN}	5.0V
I_{LOAD}	500mA
Max I_{INRUSH}	1A
ΔV_{MAX}	0.3V
C_L	20 μ F
P_D	150mW

With this system information, the formulas listed above can be used to develop specifications for a load switch.

$$R_{ON, max} = \frac{\Delta V_{max}}{I_{LOAD}} = \frac{0.3V}{0.5A} = 600\ m\Omega \tag{5}$$

Thus, a device with an R_{ON} of 600m Ω maximum can be chosen.

Conversely, the R_{ON} constraint may be driven by a power dissipation budget. If, for example, it is determined that the maximum power dissipation of the load switch can be 150mW, the maximum $R_{ON,max}$ can be estimated by:

$$\frac{\Delta V_{max}^2}{P_D} = \frac{0.3V^2}{150mW} = 600m\Omega \tag{6}$$

Next, the minimum rise time for a given load capacitance of 20µF can be determined.

$$I_{INRUSH} = C_L \times \frac{dV_{OUT}}{dt} \tag{7}$$

$$dt = \frac{dV_{OUT} \times C_L}{I_{INRUSH}} = \frac{5V \times 20\mu F}{1A} = 100\mu s \tag{8}$$

Since C_L and I_{INRUSH} are system level constraints, it is easy to calculate the rise time of the load switch. Based on that, the rise time of the load switch can be calculated. A particular load switch can easily be narrowed down at www.ti.com/loadswitch, since the load switches can be sorted by rise time.

5.2 Standby Power Savings

For some battery operated systems, there is a power budget that must be met when operating in different modes. This section will illustrate the potential power savings with a load switch in the power path.

Some modules, such as LCD displays, power amplifiers, GPS modules, and processors, can have several mA or more of leakage current in their standby mode, but using a load switch can reduce this current to µA's. For example, there is a 5V rail with a downstream module that has 1mA of leakage current, the power dissipated by this rail with the downstream module disabled is:

$$5V \times 1mA = 5 mW$$

With a load switch in the system, the path that the leakage current is shunted to ground through the load switch and can be reduced to less than 1µA. Thus, the power dissipated by this rail now becomes:

$$5V \times 1\mu A = 5 \mu W$$

Thus, using a load switch will result in power savings by a factor of 1000. As the number of rails increase, placing additional load switches to reduce the power consumption of standby rails that have excessive leakage current can result in significant power savings.

5.3 Power Sequencing without Processor Intervention

In the configuration shown in Figure 11, the load switches are arranged such that there is power-up sequencing without any processor intervention. In the diagram shown below, when the µC GPIO turns on the load switch, it will provide power to load 1. Once the voltage rail of load 1 has exceeded the V_{IH} level of the second load switch, the second load switch will turn on. While the diagram below only shows one additional load switch is being enabled, this can be expanded to allow for one GPIO line to sequence many load switches.

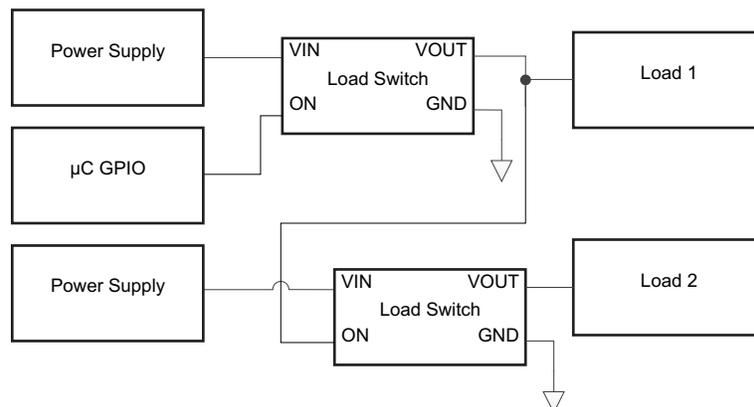


Figure 11. Power Sequencing without Processor Intervention

5.4 2-to-1 Power Mux

In the following configuration (Figure 12), two active-low load switches with reverse current protection can be configured to multiplex two supplies to one load. Active-low load switches are devices that turn on when the ON pin is pulled low. As shown in the following figure, this configuration gives priority to Power Supply 1. Whenever Power Supply 1 has a voltage applied, the load switch on the bottom gets disabled due to the resistor divider. The load switch connected to Power Supply 1 is kept on, but reverse current protection will prevent current from flowing from VOUT to VIN. Without external resistors, a microcontroller GPIO can drive the individual ON pins of the load switches.

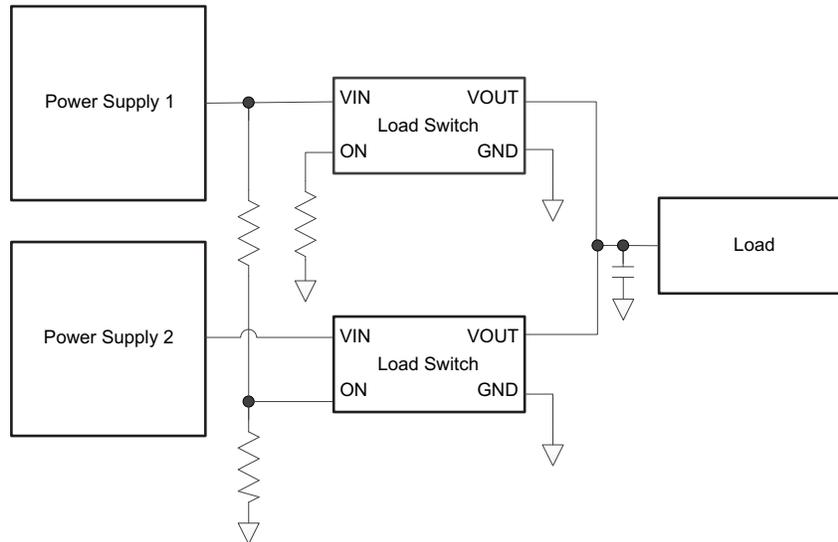


Figure 12. 2-to-1 Power Mux Configuration

6 Conclusion

Integrated load switches are an effective solution for achieving power sequencing, power distribution, controlled rise time, lower standby power, lower BOM count, and smaller PCB area. As shown in this application note, a load switch from the TPS229xx family can be easily integrated into any system with a few simple calculations to lower power consumption and simplify power supply design.

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