

Integrated Load Switches Bring Efficient Load Management and Reliable System Protection

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In battery-powered devices, a power switch can help provide extra safety, as well as isolate parts of a circuit or sub-systems from the battery supply when not in use. This can significantly extend the lifetime of a battery cell, which is how some products today can achieve many years of operation from a single cell.

As a load switch, a conventional electromechanical relay is not very flexible. Similarly, as a safety device, a fuse is not versatile. A solid-state power switch provides a much more versatile, flexible, and useful solution. They are small enough to be integrated into any electronic product, even wearables and IoTs.

The latest smart devices include many peripherals to offer powerful features, but this also increases standby power. Load switches can reduce the standby power by lowering shutdown current. However, load switching in general provides many other potential advantages. For example, power sequencing is becoming increasingly important in embedded design. This relates to the order in which power is applied to or removed from individual ICs, to achieve stable start-up and power-down. Power switching is also useful when using power sequencing, which may be needed to manage the way peripherals powered by the same voltage bus are added.

Another feature that may be implemented separately is current limiting. This is often used to avoid the inrush current drawn by a large capacitive load from affecting the stability of the supply. While power limiting may be a feature on some integrated devices, it is not standard practice. Similarly, overcurrent/voltage protection, which can occur if a device is asked

to source more current or voltage than it is designed for, can have an impact on supply stability, but it is not a standard feature on most integrated circuits. Overcurrent and overvoltage protection needs to be considered if physical interfaces, such as USB are used. This protection avoids system-level damage in the case of unexpected events.

These features are largely implemented to protect against fault conditions and in this respect, their implementation often falls to the power supply devices. Voltage regulators, for example, will often feature overcurrent/voltage protection, as well as thermal shutdown and short-circuit protection. However, while the use of the distributed point of load power supply is increasing, it is not feasible to have a dedicated regulator for every device on a board, so the protection they offer is still limited. In addition, regulators are not typically designed to be completely shut down during steady-state operation.

Discrete load switch implementation and challenges

While all of the features mentioned above can be implemented using discrete devices, or by creating supply trees that can be gated to reduce the power used under a steady state, adding all of the safety features would require a significant number of additional components that would increase BOM cost, PCB size and design effort.

Consider a high-side power switch implemented using discrete transistors as an example. Figure 1 shows how this can be achieved, while also highlighting the potential design challenges it introduces.

First, in order to reduce the risk of reverse current when Q1 is OFF or V_{IN} is removed, the input capacitance, C_{IN} , needs to be significantly higher than the equivalent load capacitance, C_{OUT} . This could require physically large capacitors to be distributed around the PCB. The p-channel MOSFET, Q1, provides the power path switch and so needs to be chosen with the system requirements in mind, not least of the resistance it introduces and the thermal management requirements this brings. The drive MOSFET, Q2, is used as a level shift switch for active high operation and controls the turn-on speed of Q1, in conjunction with R_{SR} and C_{SR} , to limit the inrush current when the power path is in an ON-transition state.

FIGURE 1. LOAD SWITCH WITH ACTIVE HIGH OPERATION

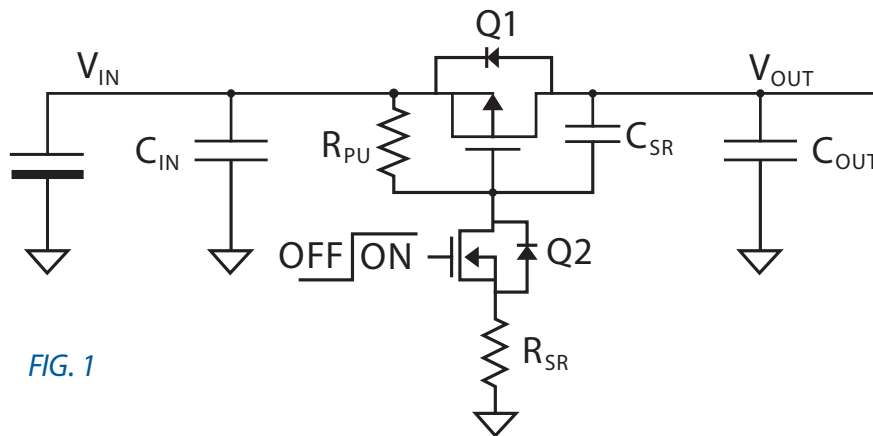


FIG. 1

There are further design considerations that emerge when implementing a load switch. Many legacy designs that have evolved may not have considered load switching when they were originally developed; even newer designs may not take load switching into account. Often, loads will have a significant equivalent capacitance, which has a slow rate which needs to be controlled in order to avoid drop in the input voltage.

This can have a negative effect on many of the benefits that come from using load switching, such as power sequencing. For this reason, the process of active load discharging has become necessary in order to remove the stored charge in the load as quickly and efficiently as possible. Modern integrated load switching will provide this feature.

Another relatively new but related condition that must also be managed is reverse current blocking. If the voltage at the output of a pMOS transistor is higher than the voltage at the input, it will allow a reverse current to flow via the body diode; using two p-channel MOSFETs back-to-back can avoid this. However, using them in this way increases the total power dissipation and doubles the component count. Using an integrated load switch allows reverse current blocking to be implemented using just one MOSFET without ON resistance or increased size. This has big benefits in terms of power dissipation and small form factors.

Other power management techniques such as overcurrent/voltage protection are common in dedicated devices. The benefits of this level of protection extend beyond the power rail, particularly in applications where peripherals are frequently added or removed, such as with a USB port. Adding protection is possible using a discreet approach but

could quickly become too complex and costly to implement in many products.

For example, a resettable fuse can be a simple way of adding overcurrent protection, but it cannot offer features such as controlled on and off times or reverse current blocking. The response time of a passive resettable fuse is slow, by active semiconductor device standards. Furthermore, the current limit is not adjustable with a resettable fuse, beyond fitting a device with a (fixed) parameter. Another consideration is determining the cause of the fault; a resettable fuse isn't able to log incidents.

Using a load switch, if only to provide port protection for over/under current/voltage conditions, is a much more flexible and scalable solution. The integrated load switch has been designed to provide the features mentioned above. It replaces the majority of the discrete devices that would be needed to implement a range of safety features and brings the additional benefit of a convenient way to add power switching.

How integrated load switches reduce the design challenges

As a switching device based on solid-state technology, the load switch will transition between states over a definable period of time. As with any transistor-based level change, this switching time is described as the slew rate. In purely mechanical switches and electromagnetic relays, the transition between on and off can cause arcing and current surges but in many load switches, the slew rate is designed to be adjustable, providing a way to control the subsequent surge. This can be particularly useful when the load has a large equivalent capacitance.

Slew rate control is one of the key features to consider when selecting an integrated load switch. Other parameters include a programmable current limit and some control over what happens when an overcurrent condition occurs. This functionality would typically include several modes, such as latching, which requires a power cycle to reset; auto-restart mode, which isolates the load for a defined time before reconnecting, with

the ability to repeat until the fault clears; and current limiting mode, which reduces the supply current until the fault is cleared. Similarly, the addition of undervoltage lockout, which activates the load switch if the input voltage drops below a predefined limit, is an effective way of maintaining control over a system when the supply voltage drops unexpectedly. The ability to respond to a fault in a way that a host processor can recognize is another feature that system engineers will appreciate. Often this is a simple open-drain output that pulls the pin low when a fault mode has been entered.

An undervoltage lockout (UVLO) feature makes sure the device operates within a known area, which gives robust system performance, since the control and power blocks have different minimum operating voltage levels. If the supply voltage is too low, the MOSFET will not be fully ON or OFF, which can cause logic circuits to generate the wrong control signals based on a wrong bandgap reference voltage.

How integrated load switches reduce the design challenges (Cont)

This is also why it is recommended to select the appropriate V_{IN} range, which is provided in the datasheet, to guarantee the correct performance of the device.

Active output discharge or quick output discharge (QOD) is a feature that discharges an output capacitor actively when the device is disabled. It can be useful to manage timing or sequence control, in designs with big output capacitors. It can also clear any unknown state at an output node. This feature should not be used if the output is connected to a power source such as a battery, as it could cause high leakage current.

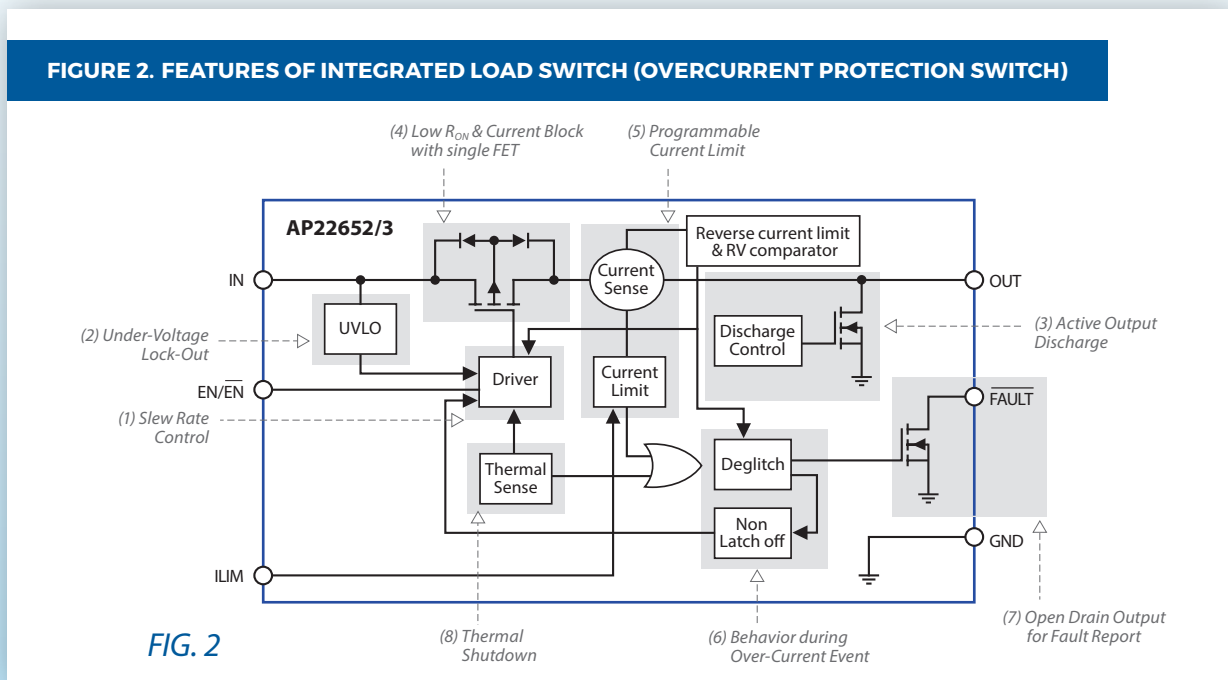
Reverse current block (RCB) can be implemented using a single low voltage pMOS with body control without ON-resistance sacrifice. A current limit feature uses current mirror circuits without a sense resistor in series with a pMOS transistor. A sense current, proportional to I_{OUT} , is formed using an external resistor to develop a voltage drop.

This is used as feedback to regulate the output current during an overcurrent (OC) event. When an OC happens, a faster OC response time is preferred, and a response time in the tens of micro-seconds is usual.

Blanking time and deglitching circuits are also used, along with fault flags, to avoid any unnecessary system interrupts caused by noise spikes. Non-latchoff or constant current mode represents one of the possible overcurrent limit modes used, which limits the output current until the cause of the overcurrent event is removed, or thermal shutdown is activated. A fault FLAG output is helpful here, as it allows the system to recognize that some abnormal issue has occurred, and the load switch has reacted to it. It is usually implemented using an open-drain output with some external bias and a pull-up resistor. The FLAG is asserted if an OC, RCB or thermal shutdown event happens.

Thermal shutdown protects the device from damage caused by over-heating, resulting from high power dissipation when in a current-limit mode. It is also recommended that devices operate within their defined working temperature range. It is necessary to estimate junction temperature under normal conditions, as well as maximum system operating temperatures, to make sure thermal shutdown is not falsely triggered.

An example of typical features incorporated in an integrated power switch, AP22652/3, is shown in figure 2.



Application examples

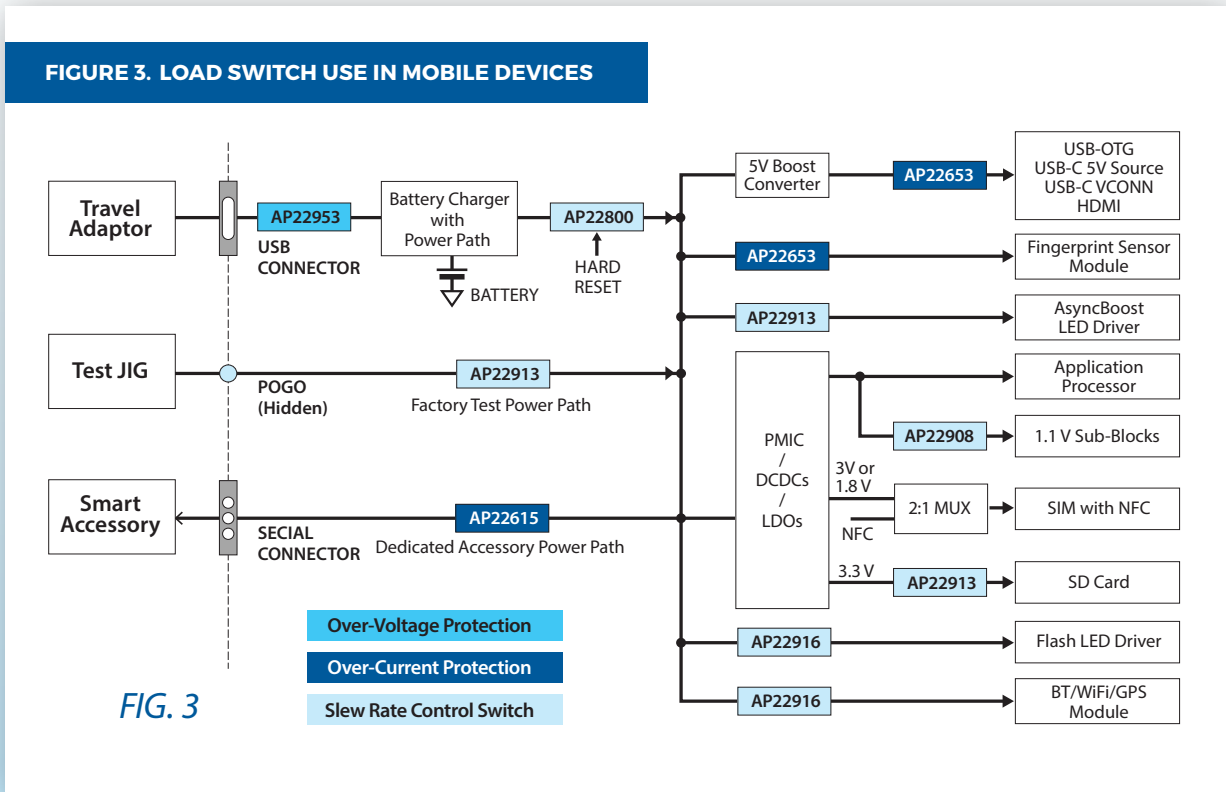
As shown in Figure 3, load switches can be applied at multiple applications, to provide a combination of the features outlined above based on the type of device selected.

For example, the AP22953 integrated power switch is a 28V rated fixed overvoltage protection switch with integrated 100V TVS in a CSP package. It is optimized to protect 5V systems from overvoltage and surge events, in a compact form factor.

In this application example, multiple AP22913 and AP22908 load switches are also used, as this device is designed to provide high-side load switching with an internally controllable slew rate to reduce inrush current or input voltage drop when the downstream system is enabled. The AP22913 and AP22908 have extremely low quiescent and shutdown currents, which is helpful for extended battery run-time. Here it is used to control the supply to larger loads, by reducing standby current to peripherals and sub-systems when the device is in standby.

The AP22653 is a precision, adjustable current-limited load switch that is used in this instance to protect systems from overcurrent or short circuit, usually at the physical interfaces such as USB and HDMI ports, and fingerprint sensor module. The AP22653 is optimized for 5V/2.1A USB power path with reverse current block. The AP22615 is an adjustable current limit power switch with 28V capability at the output, which is optimized for supplying power to dedicated accessories such as smart keyboards, while protecting against system damage caused by short circuits or an overvoltage event.

In applications such as computing, server and storage system power rails such as 3.3V or 5V where it is necessary to separate a main supply into multiple domains but with independent control, the dual-channel load switch AP22966 can be used. AP22966 implements output discharge, as described earlier, and offers independent slew rate control for both channels.



Conclusion

The latest power switches offer not only slew rate control as a fundamental operation, but also intelligent features such as UVLO, current limit, overvoltage protection, reverse current block, thermal shutdown, active output discharge and more, in a compact size.

Fully integrated power switches meet system requirements, based on wide product portfolios, and can reduce design effort and achieve fast time to market.