Load Switch Basics

Abstract:
A high-side load switch connects or disconnects a power source to a load and the switch is controlled by an external enable signal (either analog or digital). High-side switches source current to a load, while low-side switches connect or disconnect the load to ground, thus sinking current from the load. The load switch circuits are active whenever the power is on and are thus designed to have low leakage currents. Furthermore, they must also have a low ON resistance to minimize their power dissipation when monitoring the system's current or voltage.

Introduction

High-Side Load Switches Protect Portable Electronic Systems

Although we do our best to shield our portable devices from physical harm by using protective cases, or employing rugged design techniques, there is another layer of protection that can be applied. Within portable electronic devices themselves, load switches can be used to prevent damage from electrical surges, incorrect battery insertion, and other damaging events that can enter through the power source. Many systems such as smart phones, tablet computers, laptops, digital cameras, portable medical devices, industrial equipment, and other power-sensitive products already use load switches to provide robust protection against voltage and current surges. However there are many variations and options available to designers and selecting the best match for an application can be a challenge.

Load Switch Basics

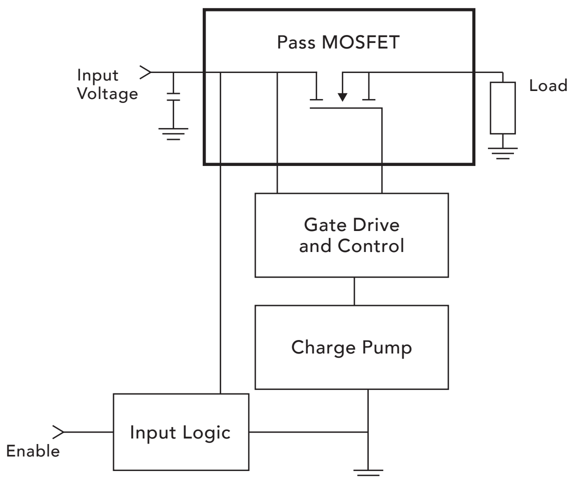
Before selecting a load switch, let's go over some basics of load switch functionality and performance. Basically, a high-side load switch connects or disconnects a power source to a load and the switch is controlled by an external enable signal (either analog or digital). High-side switches source current to a load, while low-side switches connect or disconnect the load to ground, thus sinking current from the load. The load switch circuits are active whenever the power is on and are thus designed to have low leakage currents. Furthermore, they must also have a low ON resistance to minimize their power dissipation when monitoring the system's current or voltage.

At the heart of any load switch is a MOSFET (usually an enhancement mode device) that is either integrated into a load switch integrated circuit, or for higher power handling requirements, can be a discrete device. The MOSFET passes current from the power source to the load and is turned on or off via a control signal. Providing the control signal to the MOSFET, a gate-drive circuit connects to the MOSFET's gate to switch the MOSFET on or off. Depending on the application, the gate-drive circuit can either be controlled by a wide variety of input voltages. This can receive either a low or high voltage digital signal and change the voltage to the intrinsic voltage communications level of the device. This function is also referred to as a level-shifting circuit since it has to generate a voltage high enough to fully turn on the MOSFET.

Thus, a simple load switch will typically consist of a MOSFET pass transistor and a gate-drive circuit that contains a gate drive transistor and a few passive components (Figure 1). Such a circuit can be built using discrete components or integrated in IC form. N-channel MOSFETs have lower ON resistance values than P-channel devices, however to get the lower resistance values, a charge-pump circuit is needed to increase the drive voltage applied to the MOSFET's gate.

Most of the integrated solutions include more functionality, providing multiple functions that work in tandem to protect the system. A typical load switch might contain circuit blocks to provide reverse voltage protection, reverse current protection, short circuit protection, output load discharge, overvoltage/overcurrent protection, over temperature protection, and some control logic to coordinate the various blocks (Figure 2). The switches not only protect the systems, but they also help reduce power consumption by providing simple and efficient power distribution.

Figure 1. *A simple load switch typically consists of a MOSFET pass transistor that is controlled by a gate-driver circuit that level-shifts the input control signal to a value that will fully turn on the MOSFET, reducing the device's ON resistance to its lowest possible level. (n-channel MOSFET circuit on the left, p-channel MOSFET circuit on the right).*



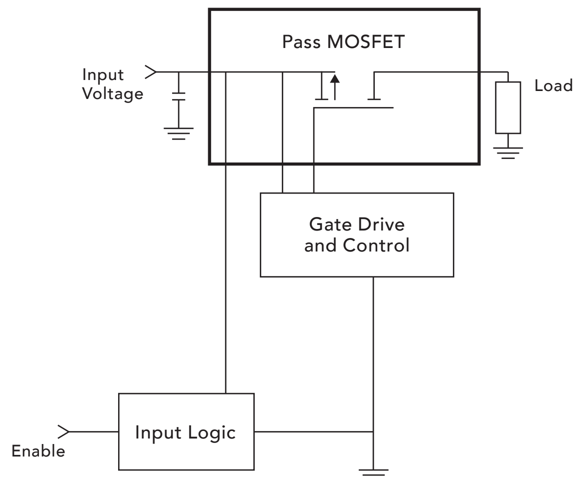
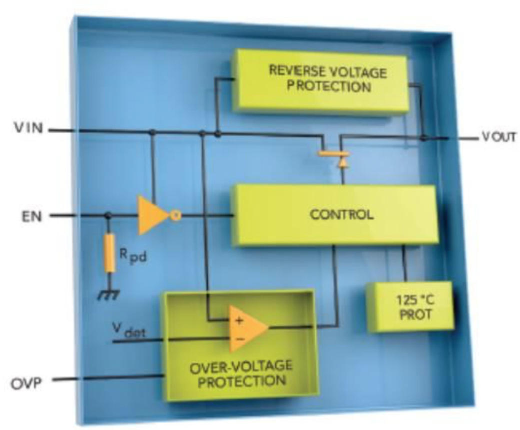


Figure 2. *A highly integrated version of the load switch will often provide multiple protection features – reverse voltage or reverse current protection, overvoltage/overcurrent protection, over-temperature protection and well as the integrated MOSFET and gate driver circuits.*

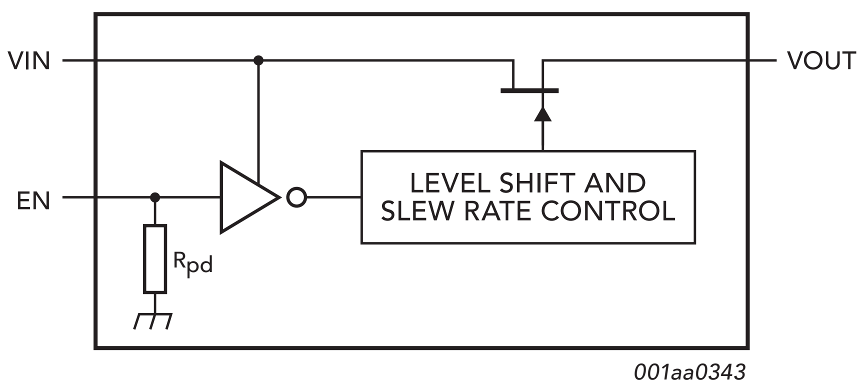


Several key parameters of a load switch are the ON resistance of the MOSFET that connects between the voltage input and voltage output pins, the current that the transistor can handle, and the voltage that the circuit can handle. The lower the ON resistance, the lower the power dissipation of the transistor and the lower the voltage drop from input to output. Today's integrated MOSFETs typically have ON resistance values in the tens of milliohms, so, for example, if the load switch has an ON resistance of 50 milliohms and controls a 200 mA load, the MOSFET dissipates just 2 mW when ON, and has an input-to-output voltage drop of 10 mV. Even a peak current of 1 A would only cause a voltage drop of 50 mV and peak power dissipation of 50 mW.

Load Switch Options

The many possible applications for load switches let the load-switch manufacturers offer multiple load-switch configurations. A basic load switch such as the NX3P190 from NXP (Figure 3) resembles the circuit in Figure 1 – it has the P-channel MOSFET controlled by a level-shifting and slew-rate control circuit.

Figure 3. *A simple high-side load switch circuit from NXP, the NX3P190, integrates a P-channel MOSFET along with the level shifting and slew-rate control circuitry.*



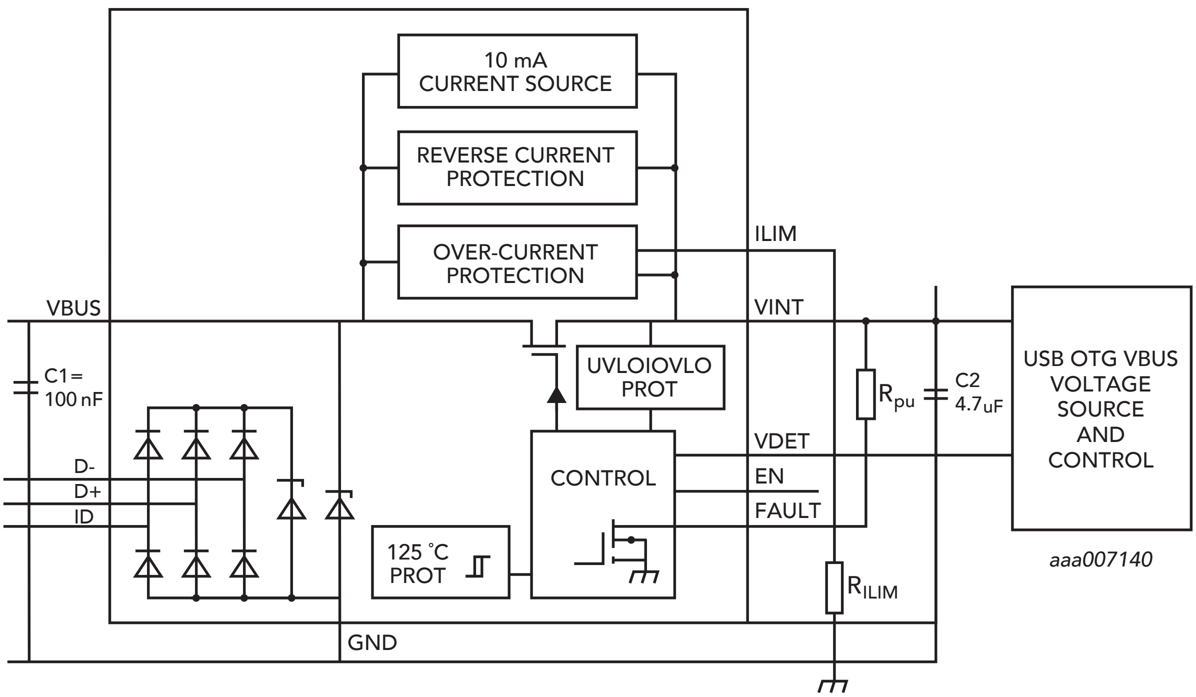
The MOSFET can support more than 500 mA of continuous current with an ON resistance of 95 milliohms at a supply voltage of 1.8 V. The voltage input, though, can handle voltages from 1.1 to 3.6 V. Logic on the Enable input includes logic-level translation so that the switch can be controlled by lower-voltage microcontrollers and other circuits operating at reduced voltages. Targeted for power-domain isolation applications, it can help reduce power dissipation and extend the system's battery life thanks to a low ground leakage current of only 2 microamps. A variation of the chip, the NX3P191 integrates an output discharge resistor that can discharge the output capacitance when the switch is turned off. This can prevent unwanted voltages from reaching the load.

Another circuit from NXP, the NX3P1107, is functionally very similar, but the company reduced the MOSFET's ON resistance by 2/3 to just 34 milliohms, thus allowing the chip to handle up to 1.5 A of continuous current. That higher current rating allows the chip to tackle heavier load applications such as battery charging, digital cameras, smartphones, and many other applications.

For applications that don't require the high current but need the output discharge capability, another version of the chip, the NX3P2902B, can handle 500 mA of continuous current and has typical ON resistance of 95 milliohms.

Taking aim at more complex system applications such as USB on-the-go (OTG) power management, the NX5P1000, an N-channel device in this case, includes under voltage protection, over voltage lockout, over-current, over-temperature, reverse bias, and in-rush current protection circuits (Figure 4). These circuits are designed to automatically isolate the VBUS OTG voltage source from a VBUS interface pin when a fault condition occurs.

Figure 4. *Designed to support the USB on-the-go interface, the NX5P1000 integrates an N-channel MOSFET and includes voltage, current and temperature protection functions as well as electrostatic protection on the USB data, ID, and VBUS lines.*



The chip can handle a continuous current of 1 A, and has an ON-resistance of 100 milliohms, maximum, at a supply voltage of 4.0 V. The power supply input pin can handle levels from 3 to 5.5 V, but the VBUS input can tolerate as much as 30 V. In a typical application, the USB OTG voltage source and control circuits connect to the chip's voltage and control inputs, and the chip delivers a clean USB power and data output. A slightly higher power version of the chip, the NX5P2090 can handle 2 A of continuous current. Depending on the load current required for your application, as well as the level of protection you need, you have a wide choice of design options to get the best fit for your application. The devices discussed in this article represent the two extremes – the simplest integrated option and one of the most complex integrated solutions. There are, of course, many solutions in-between the two offered by NXP and other vendors.