AN90017

Load switches for mobile and computing applications

Rev. 1.0 — 2 September 2020 application note

Document information

Information	Content
Keywords	Load switch, MOSFET, mobile, computing
Abstract	This application note presents simple load switches in mobile and computing applications.

1. Types of load switches

There are several reasons why a circuit or subsystem is required to be disconnected from the power supply using a load switch. A very simple and very common reason is that it helps saving power. An unpowered subsystem can eliminate power consumption due to leakage or standby currents. In portable electronic devices, 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.

Before diving deeper into the key parameters, let’s look at the different types of load switches. A high-side load switch connects or disconnects a power source to a load. The switch is controlled by an external enable signal. High-side switches source current to a load. Low-side switches connect or disconnect the load to ground, thus sinking current from the load.

A load switch can be easily implemented with a MOSFET pass transistor. 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.

2. P-channel MOSFET load switch

Using a P-channel MOSFET a high-side load switch can be implemented by connecting the input voltage to the MOSFET source and the load to the MOSFET drain; see Fig. 1. Pulling the gate low will enable current to flow into the load.

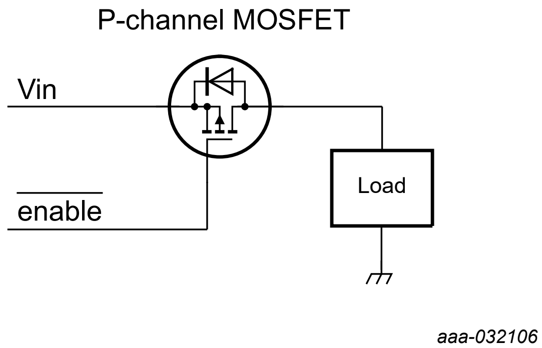

Fig. 1. P-channel MOSFET load switch

3. N-channel MOSFET load switches

N-channel MOSFETs have lower on-state resistance values than P-channel devices of the same size. However, to achieve the lower resistance values, a high voltage is needed to drive a MOSFET’s gate in the implementation of a high-side load switch using an N-channel MOSFET, see Fig. 2. A voltage higher than the input voltage V_{in} has to be provided for correct gate drive, otherwise the MOSFET would not turn on fully and will operate in linear mode with high power losses.

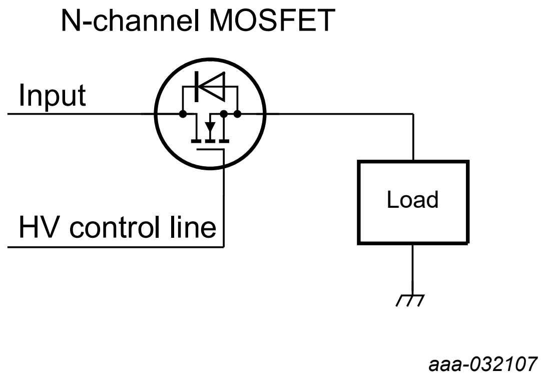

Fig. 2. N-channel MOSFET load switch with high voltage control line

If a high enough voltage to drive the gate is not available, a charge-pump circuit can be used to increase the drive voltage applied to the MOSFET's gate, see Fig. 3. While this increases the complexity of the circuit, it is rewarded with the lower ON resistance of the N-channel MOSFET. However a charge-pump circuit will disipate some power so that in very energy critical applications that may stay most of the time in stand-by mode, a P-channel topology can be more efficient.

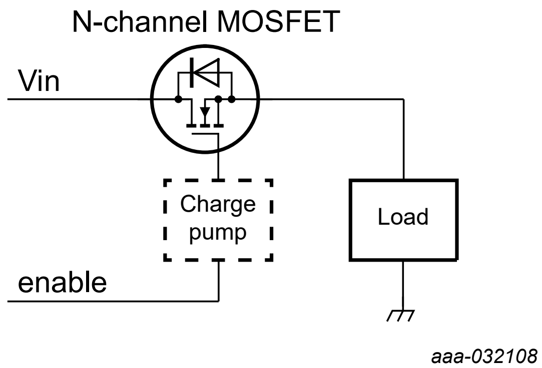

Fig. 3. N-channel MOSFET load switch with charge pump

Without high voltage or additional circuitry, the N-channel MOSFET can be used in a low-side load switch. This implementation of a low-side load switch is shown in Fig. 4. A downside of the low-side load switch is the slight lifting of the ground potential of the load. This needs to be considered especially if the load has communication lines with external components.

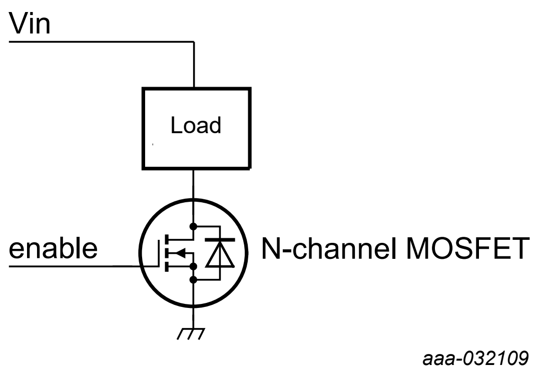

Fig. 4. N-channel MOSFET load switch low-side load switch

More advanced load switch features include reverse voltage protection, reverse current protection. These can be implemented with MOSFETs in common-drain or common-source configuration as shown in the next section.

4. Reverse current protected load switches

Load switches based on a single MOSFET topology can block current in one direction only. As MOSFETs have an inherent body diode they act like a diode in off-state if driven reverse. In some applications it is required to be able to block current flow in both directions.

Applications, that need blocking of reverse currents are e.g. battery driven applications, where discharge of the battery shall be prevented for fault conditions like a short at the charger connector side or in case of electrical failure causing leakage in connected cables and AC adapters.

A common way to block reverse currents is by applying diodes. However, this function can be realized far more efficiently with MOSFET load switches. In order to achieve blocking for both current directions, two MOSFETs have to be put in series with reverse polarity to each other. In this case one of the body diodes can block current flow if not both MOSFETs are turned on. This approach allows to create two alternative topologies of back-drive protected load switches. Either the drain contacts or the source contacts can be connected.

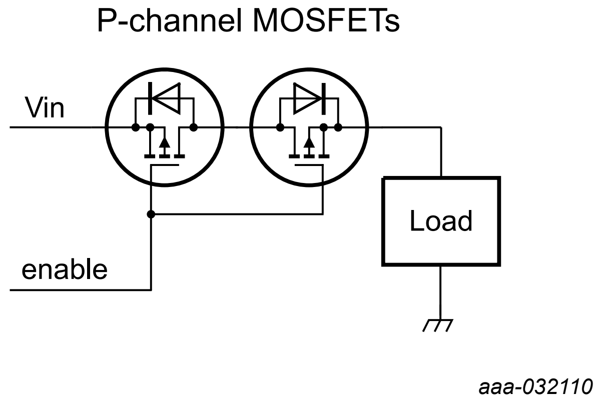

Fig. 5. Reverse current protected common drain load-switch

Control of the back-drive protected load switches can be done with separate gate drive or connected gates. The common drain topology, (see Fig. 5), has the advantage for a semiconductor component that the drain contact is located towards the substrate side. So, the common drain can be attached directly to the lead frame with a good thermal path into the PCB. For mobile applications often Chip-Scale Packages (CSP) can be found. Here the source and gate contacts are facing down to the PCB whereas a drain contact needs an additional down contact. If there is no need to make the drain accessible necessarily. In this case a CSP design becomes very space efficient because no chip area needs to be sacrificed for down connections of drain.

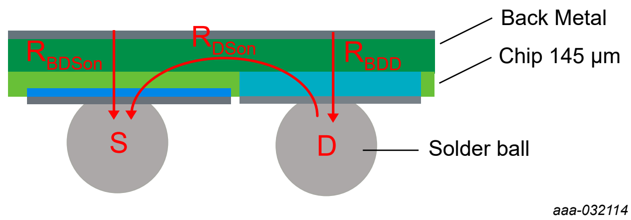

Fig. 6. Turn-on resistance (R_{DSon}) of a single Chip-scale Package MOSFET

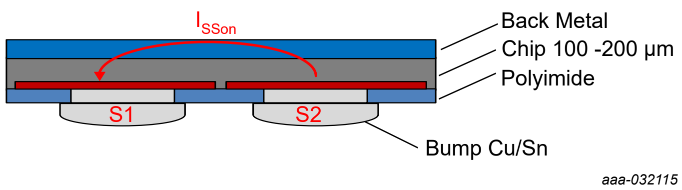

Fig. 7. Turn-on resistance (R_{SSon}) of a common-drain Chip-scale Package MOSFET

The common source topology requires an access to the source connection between the MOSFETs. The gate has to be discharged after a turn on, see Fig. 8. This does not work without access to this node as the common sources might float.

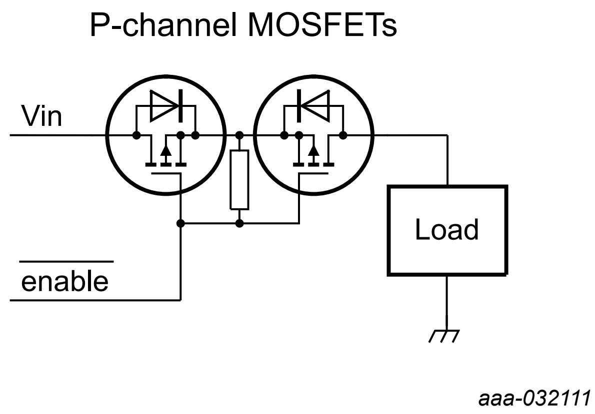

Fig. 8. Reverse current protected common source load-switch

5. Reverse polarity protection and supply OR-ing

In cases where no load switching is needed a single MOSFET can be used for reverse polarity protection only, see Fig. 9. The MOSFET can replace simple diodes e.g. in supply OR-ing applications this has the advantage of a lower voltage drop across the MOSFET compared to the voltage drop across the diode.

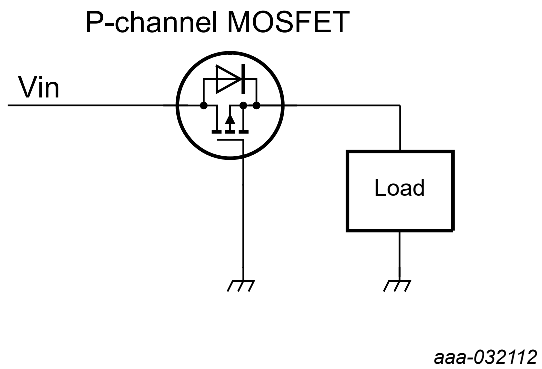

Fig. 9. Reverse current and reverse polarity protection with a P-channel MOSFET

Another important application of back-drive load-switches is power OR-ing, see Fig. 10. If a circuit is able to be powered by one of several power supplies then current flow back into a non-selected supply has to be avoided.

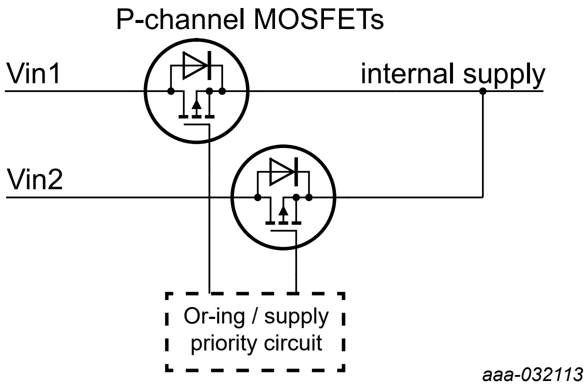

Fig. 10. Power supply OR-ing with P-channel MOSFETs

6. Important parameters

Important key parameters of a load switch are the on-state resistance (R_{DSon}) of the MOSFET that connects between the voltage input and voltage output pins, the maximum current ($I_{D(max)}$) that the MOSFET can conduct and the maximum voltage ($V_{DS(max)}$) that the circuit can withstand. The lower the on-state resistance, the lower the power dissipation of the transistor and also the lower the voltage drop from input to output.

While R_{DSon}, $I_{D(max)}$, and $V_{DS(max)}$ are parameters of the MOSFET, the maximum voltage drop and the maximum power dissipation of a load switch can be calculated for a given current I with the formulas below:

$$V_{drop} = I \times R_{DSon(max)} \tag{1}$$

$$P = I \times V_{drop} = I^2 \times R_{DSon(max)} \tag{2}$$

Today's MOSFETs typically have on-state resistance values in the tens of milliohms, so, for example, if the load switch has an ON resistance of 50 mΩ 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 a peak power dissipation of 50 mW.

As load switch circuits are active whenever the power is on they are designed to have low leakage currents, see Nexperia application note *AN90009*.

7. Revision history

Table 1. Revision history

Revision number	Date	Description
1.0	20200902	Initial version.

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