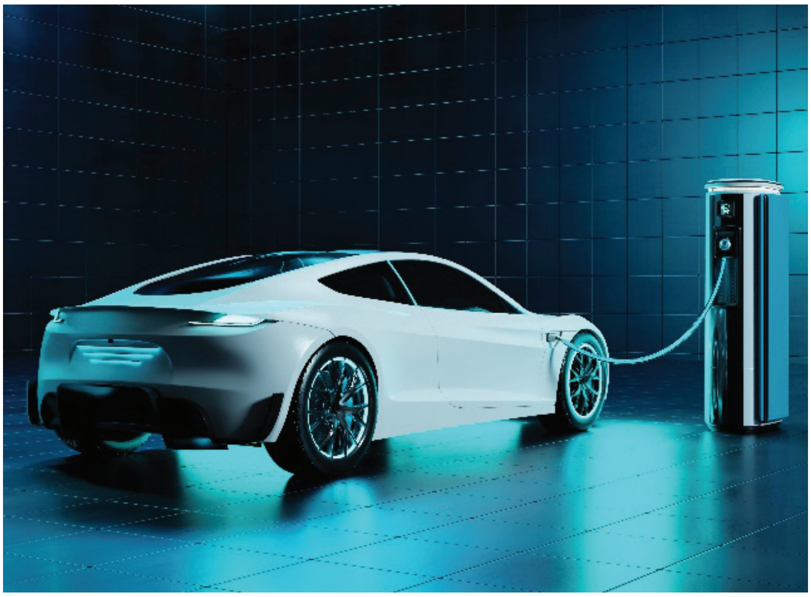
Comparing N-Channel and P-Channel MOSFETs: *Which is best for your application?*

This article compares the n-channel and p-channel power MOSFETs, introduces the complete Littelfuse p-channel power MOSFETs portfolio, and explores target applications.



Introduction

Driving a high-side (HS) p-channel MOSFET without an additional voltage source or a charge pump is uncomplicated, resulting in significantly simplified designs, space savings, reduced part count, and improved cost efficiency.

While n-channel power MOSFETs require a positive gate-source voltage to activate, p-channel MOSFETs need a negative gate-source voltage. Using a cross-sectional view, Figure 1 illustrates the differences between n-channel and p-channel MOSFETs. Their reverse doping profiles are the key distinction: p-channel MOSFETs rely on holes as the majority charge carriers, generating hole current, while n-channel devices utilize electrons, creating electron current. Due to electrons' superior mobility, approximately two to three times that of holes, moving holes in a p-channel device is more challenging than electrons in an n-channel device. This approach leads to higher area-specific on-state resistance in p-channel MOSFETs compared to n-channel MOSFETs. Consequently, achieving equivalent on-state resistance (RDS(on)) performance is impractical for p-channel MOSFETs of the same chip size as n-channel MOSFETs.

In order to achieve a similar on-state resistance $R_{DS(on)}$) as n-channel MOSFETs, p-channel MOSFETs require a two to three-times larger die size. As a result, in more high-current applications, where low conduction losses are critical, the large die p-channel MOSFETs with very low $R_{DS(on)}$) are not the optimal choice. While the p-channel device's larger chip size

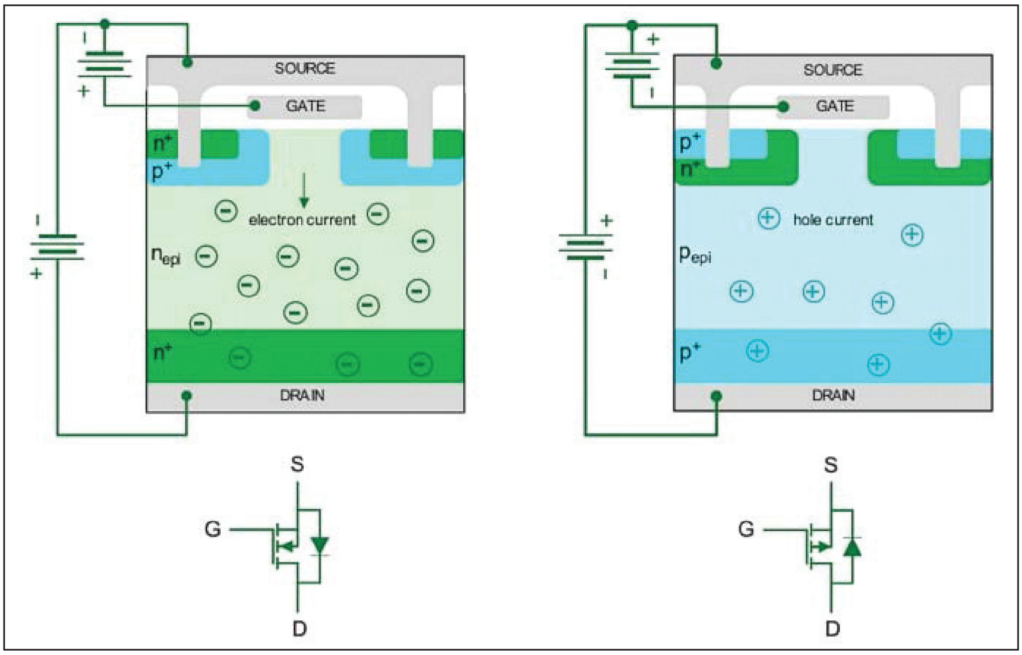
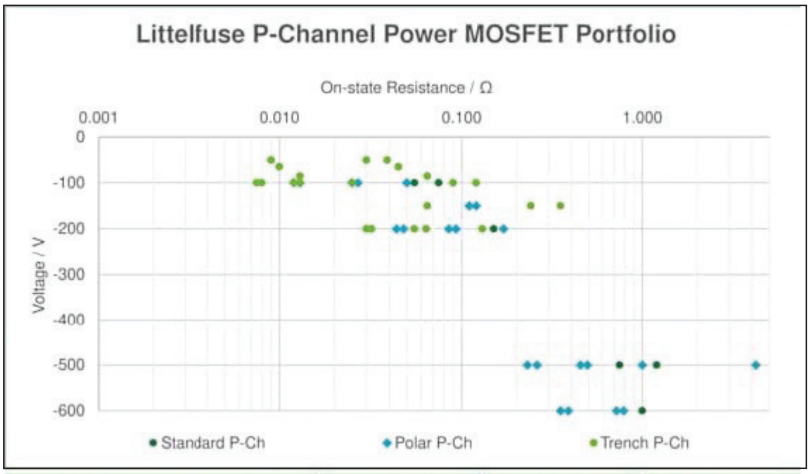


Figure 1. Cross sections comparison of n- and p-channel power MOSFETs



P-Channel Family	V_{DSS} / V	I_{D25} / A	$R_{DS(on)}$ / Ω
Standard P	-100 to -600	-8 to -50	0.055 - 1.2
Polar P	-100 to -600	-2 to -170	0.012 - 4.2
Trench P	-50 to -200	-10 to -210	0.008 - 0.35

Figure 2. P-channel power MOSFET portfolio available from Littelfuse

offers improved thermal performance, it exhibits higher switching losses and larger intrinsic capacitances. When the system operates at a high switching frequency, this disadvantage significantly impacts overall efficiency, thermal management, and system cost.

In low-frequency applications with significant conduction losses, a p-channel MOSFET should match the $R_{DS(on)}$) of an n-channel MOSFET, requiring a larger chip area. Conversely, in high-frequency applications prioritizing switching losses, a p-channel MOSFET should align with the total gate charges of an n-channel counterpart, often having a similar chip size, but a lower current rating.

Therefore, making the right p-channel MOSFET selection demands careful consideration of the device $R_{DS(on)}$) and gate charge (Q_g) specifications, as well as the thermal performance.

P-Channel Power MOSFETs from Littelfuse

The Littelfuse p-channel power MOSFETs have traditionally served in a limited range of applications. However, recent increases in demand for low-voltage (LV) applications have created a broader scope for p-channel power MOSFETs. The simplicity of Littelfuse p-channel solutions for HS applications makes them attractive for non-isolated point-of-load and LV inverters (< 120 V) solutions.

Littelfuse offers a range of industrial qualified p-channel power MOSFETs with the highest voltage class rating, lowest RDS(on) and Qg, high avalanche energy rating, excellent switching performance, and superior safe operating area (SOA) with best-in-class performance in both standard industrial and unique isolated packages. Littelfuse p-channel power MOSFETs retain the essential features of comparable n-channel power MOSFETs, such as fast switching, efficient gate-voltage control, and excellent temperature stability.

Figure 2 presents the p-channel power MOSFETs' key highlights offered by Littelfuse, including:

- Standard P and PolarP™ planar devices have voltage ratings from -100 to -600 V and current ratings from -2 to -170 A.
- PolarP™ offers optimized cell structure with low area-specific on-state resistance and improved switching performance.
- Standard P benefits from a better SOA performance.
- Trench P utilizing a more dense trench gate cell structure offers very low RDS(on), low gate charge, fast body diode, and faster switching with device voltages ranging from -50 V to -200 V and currents from -10 A to -210 A.
- The latest addition to the portfolio, the IXTY2P50PA (-500 V, -2 A, 4.2 Ω), is the first AEC-Q101 automotive-grade p-channel power MOSFET available from Littelfuse.

Littelfuse p-channel MOSFETs drive a broad range of automotive and industrial applications like:

- battery protection,
- reverse polarity protection,
- HS load switches,
- DC-DC converters,
- onboard chargers, and
- LV inverters.

P-Channel MOSFETs in Half-Bridge Applications

Figure 3 illustrates the contrast between circuits using complementary MOSFETs and those using n-channel MOSFETs. N-channel MOSFETs are commonly found in the power stage in half-bridge (HB) applications. However, n-channel HS switches necessitate a bootstrap circuit to generate a gate voltage that is floating with reference to the source of the HS MOSFET or an isolated power supply to turn on, as depicted in Figure 3a. Hence, the advantage of using n-channel devices comes at the cost of increased complexity in gate driver design, leading to more

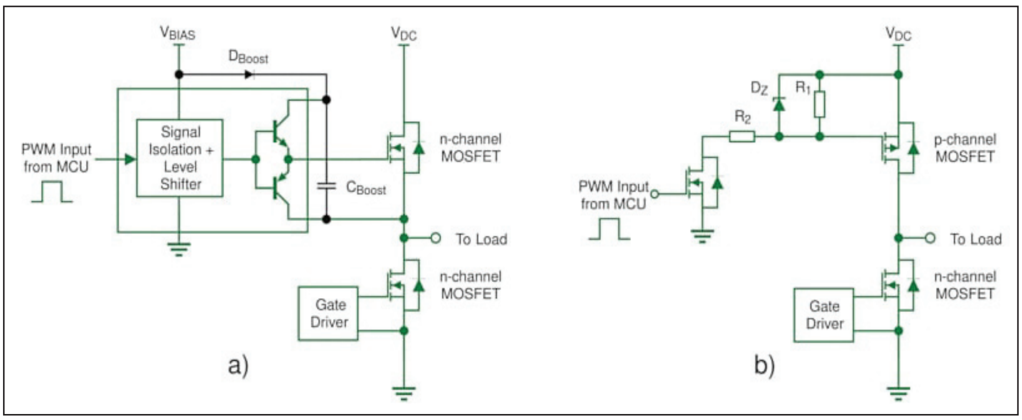


Figure 3. How to simplify the HS driver in HB application from a) N-cT to b) p-channel MOSFET as HS switch.

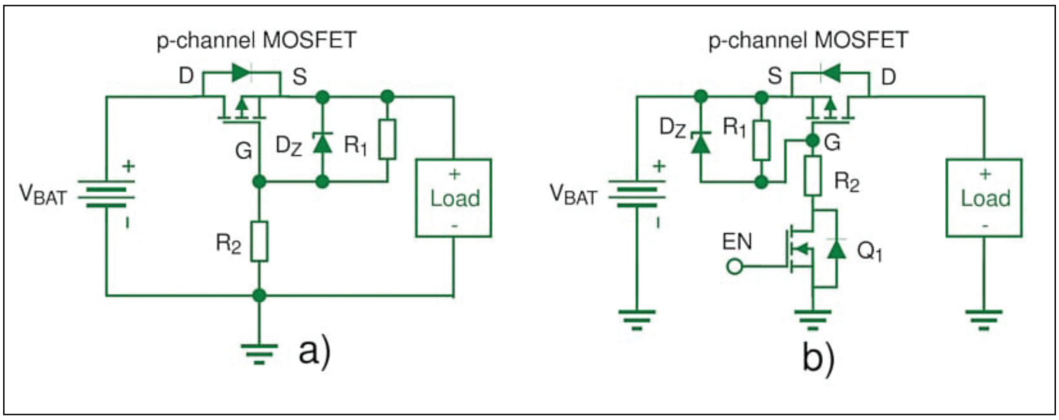


Figure 4. Using p-channel power MOSFET for a) reverse polarity protection and b) load switching.

design effort and space usage. When a p-channel MOSFET serves as the HS switch in this configuration, as shown in Figure 3b, it can significantly simplify the driver design. The designer could remove the charge pump to drive the HS switch, and the MCU can easily control the p-channel MOSFET through a simple level shifter. This approach reduces design effort and part count, resulting in a cost-efficient design that utilizes space efficiently.

Reverse Polarity Protection

Reverse polarity protection is a system safety measure to prevent potential fire hazards and damage in case of a reversed power source connection. Figure 4a depicts the reverse polarity protection implemented using a p-channel power MOSFET. When the battery is correctly connected, the intrinsic body diode conducts until the MOSFET channel is activated. In the event of a reverse connection of the battery, the body diode is reverse-biased, with the gate and source at the same potential, thereby turning off the p-channel MOSFET. A Zener diode clamps the gate voltage of the p-channel MOSFET, safeguarding it in case of excessively high voltage levels.

Load Switching

Load switches connect or disconnect a voltage rail to a specific load, offering a cost-effective and straightforward way for a system to manage power efficiently. Figure 4b illustrates a circuit using a p-channel power MOSFET for a load switch. This circuit is driven by a logic enable (EN) signal to control the p-channel load switch via a small-signal n-channel MOSFET Q_1. When EN is low, Q_1 is off, and the p-channel gate is pulled up to V_{BAT}. Conversely, when EN is high, Q_1 activates, grounding the p-channel gate, and turning on the load switch. If V_{BAT} exceeds the p-channel MOSFET's threshold voltage, it can turn on when EN is high, eliminating the need for an additional voltage source to bias the gate, which is necessary for n-channel MOSFETs. The series resistor is needed to limit the current, and a Zener Diode is required in order to clamp the gate voltage to a maximum value.

DC-DC Synchronous Buck and Boost Converters

In low-power DC-DC converters like the synchronous buck converter in Figure 5a, using a p-channel device as the HS switch simplifies the circuit and saves space, eliminating the need for external gate driving circuitry. It also reduces the bill-of-materials (BOM), leading to cost efficiency.

Similarly, a P-channel device can replace a diode with low forward voltage as an output synchronous rectifier in synchronous boost converters, as seen in Figure 5b. This approach improves the converter efficiency due to the improved figure-of-merit (FoM = $R_{DS(on)}$ * Q_g) of the p-channel MOSFET.

P-Channel MOSFETs in Low-Voltage Applications

As today's low-voltage (LV) applications advance, the Littelfuse p-channel MOSFETs continue proving their versatility in meeting the evolving needs of tomorrow's power electronics. Employing p-channel MOSFETs enables designers to provide simplified, highly reliable, and optimized circuit design in advanced automotive and industrial applications. Electronics design engineers must evaluate the trade-off between $R_{DS(on)}$ and Q_g when selecting a p-channel MOSFET to achieve optimal performance for specific applications.

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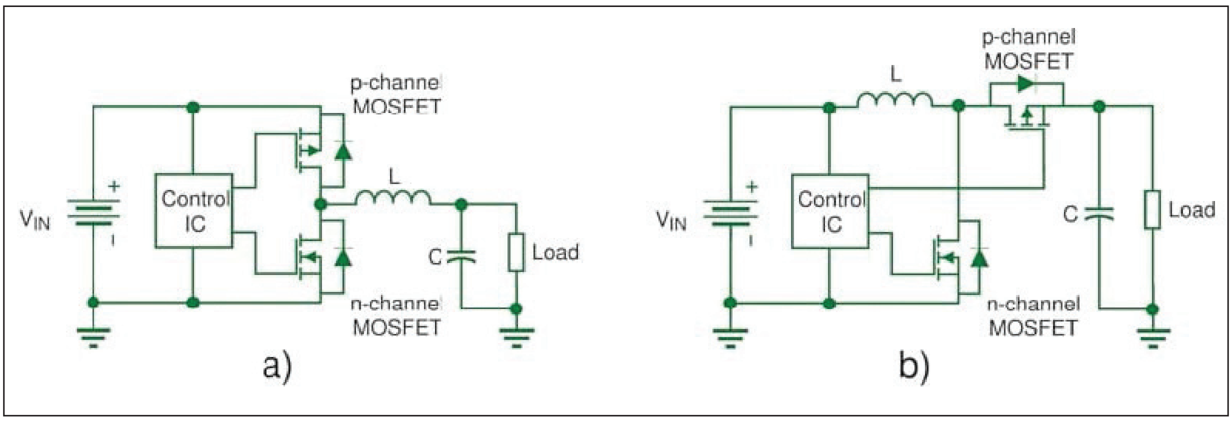

Figure 5. Using complementary MOSFETs for low power a) synchronous buck and b) synchronous boost converter.