Benefits of P-Channel PowerMOSFETs in Automotive Applications

In the automotive field, many power electronic applications are realised with N-channel trench PowerMOSFET. There are, however, some applications where using a P-channel trench PowerMOSFET has substantial advantages. This article discusses the benefits of a P-channel PowerMOSFET in standard automotive applications like reverse polarity protection and H-bridge DC motor drives. **Peter Hogenkamp, Assistant Manager, Power Semiconductors Product Unit, NEC Electronics (Europe), Düsseldorf, Germany**

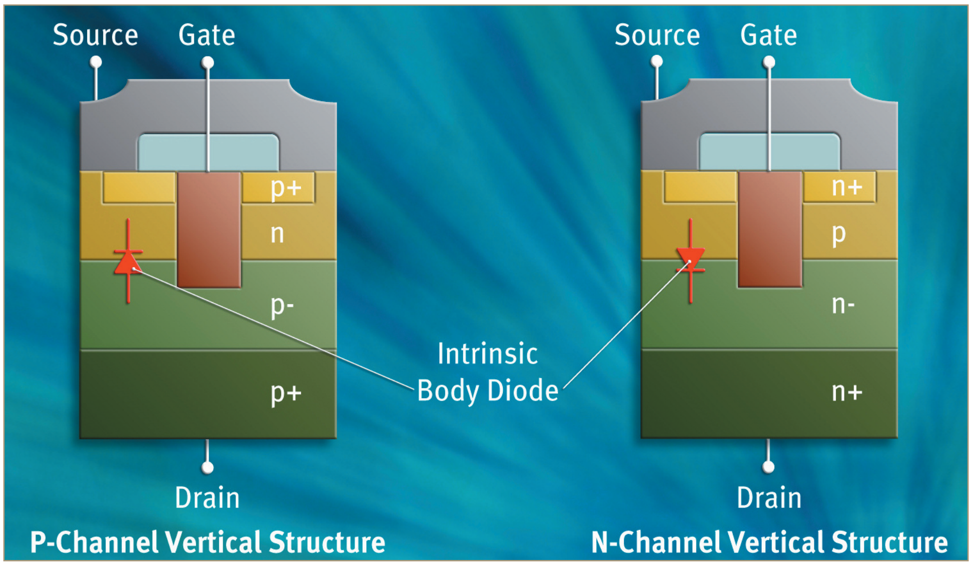


Figure 1: Cross-sectional view of a P-channel and N-channel PowerMOSFET

At lower switching frequencies, almost all the power dissipation of a PowerMOSFET in a switched-mode power application occurs when the device is in on-state. The instantaneous power dissipation in on-state of the PowerMOSFET is given by $P = I^2 \times R_{DS(on)}$. One way to reduce the $R_{DS(on)}$ of a PowerMOSFET is to enhance the cell integrity of the chip by using advanced design rules and trench techniques. The UMOS4 trench process technology with a design rule of 0.25µm enables NEC Electronics to realise a 40V P-channel PowerMOSFET with a specific on-state resistance of 93.75mΩ/mm².

Using a P-channel PowerMOSFET gives the designer a further opportunity to simplify the circuit design. Basically, a P-channel PowerMOSFET can do anything that an N-channel PowerMOSFET can do. An N-channel PowerMOSFET as a high-side switch requires an additional driving circuit for the gate, whereas the P-channel PowerMOSFET does not. This naturally affects the complexity of a circuit. In the past, the main advantage of a P-channel PowerMOSFET was the circuit simplification in low and medium power applications. Now very low $R_{DS(on)}$ P-channel PowerMOSFETs suitable for high-power applications are available.

Why it is not possible to achieve the same on-state resistance performance for a P-channel PowerMOSFET as for an N-channel PowerMOSFET when using the same process technology? The drift zone in the vertical structure (Figure 1 shows the vertical structure of N-channel and P-channel PowerMOSFETs) largely determines the on-state resistance. In the drift zone of an N-channel PowerMOSFET (N-type epitaxial layer), the electrons are accelerated by the electric field toward the drain; in a P-channel PowerMOSFET (P-type epitaxial layer) holes are accelerated. Because of physical effects, the mobility of holes is lower than the mobility of electrons and, as a result, the on-state resistance of a P-channel device is always higher.

Two standard automotive applications demonstrate the benefits of a P-channel PowerMOSFET. The first example describes reverse polarity protection, one of the most important considerations in nearly all electronic

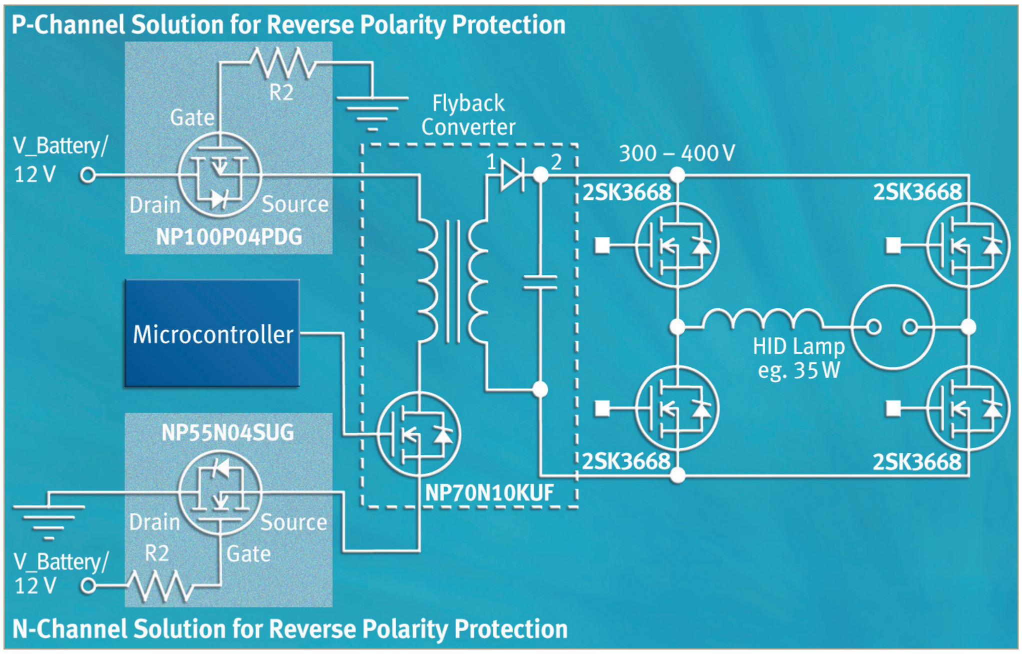


Figure 2: **Circuit with reverse polarity protection**

control units. The second example is a DC motor application with a complementary H-bridge PowerMOSFET configuration.

Reverse polarity protection

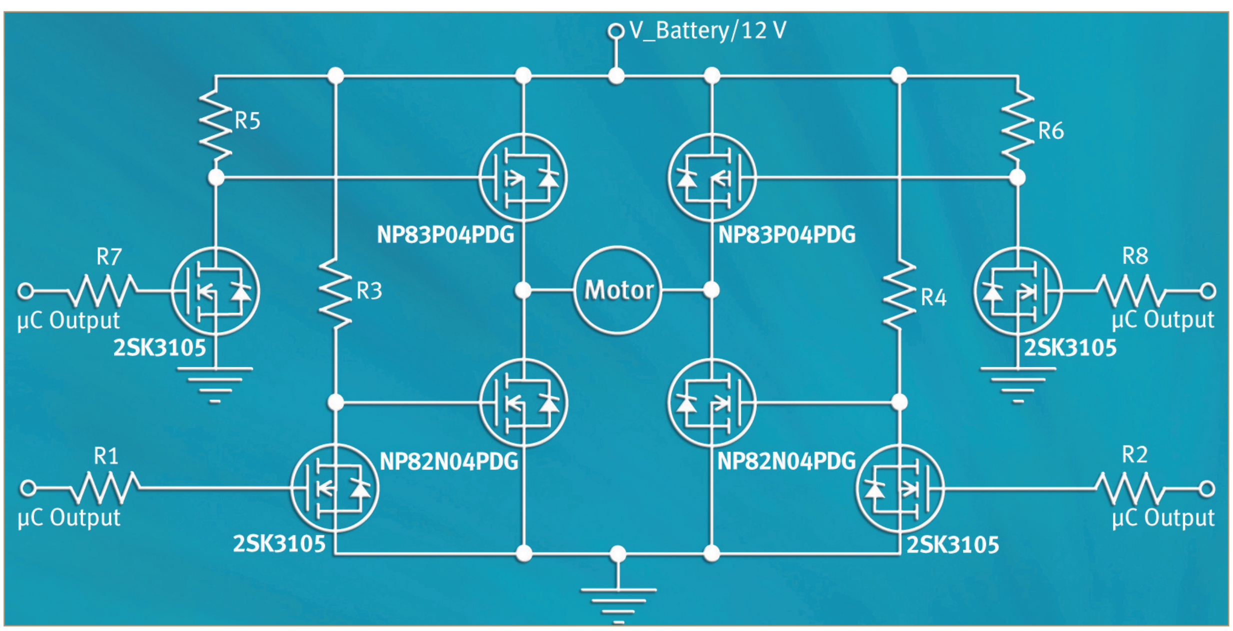
Especially in automotive applications, it is mandatory to protect circuitry from the consequences of a reversed battery. A simple and cheap approach is to use a diode in series. If the anode of the diode is connected to the plus pole of the power supply, the current can flow only in forward direction. In the event of reverse polarity, the diode simply blocks. This approach has one big disadvantage: there is always a voltage drop of a least 0.4V with high power dissipation at the diode.

A simple solution, with almost zero voltage drop, is made possible by using a relay. In case of a positive voltage at the plus pole, the relay is switched on. In case of a negative voltage, the relay cannot be switched on. The relay is a very simple and cheap solution, but the reliability and large packaging of relays argue against using them for reverse polarity protection. Because reliability and space are important issues in automotive applications, a PowerMOSFET can provide a superior solution.

In principle, there are two different ways of using a PowerMOSFET for reverse polarity protection. Figure 2 shows the basic operating principle of a Xenon lamp (HID). The lamp is supplied from a 12V battery via a flyback converter (DC/DC) and an H-bridge-connected PowerMOSFET DC/AC converter to provide the average lamp power of 35W. The diagram shows the basic configuration for reverse polarity protection with an N-channel and P-channel PowerMOSFET.

The drain of the P-channel PowerMOSFET is connected to the positive pole of the power supply and the source to the ECU (electronic control unit) side. The gate is tied to the ground with a resistor of say 10kΩ. At first glance, this solution seems incorrect because the PowerMOSFET is connected backwards. For correct operation the source should

Figure 3: **H-bridge DC motor configuration with P- and N-channel PowerMOSFETs**



V_{DSS} [V]	$R_{DS(ON)}$ max. [mΩ] @ V_{GS} =		I_D [A]	P_D [W] @ T_C = 25°C	SMD	
	10 V	4.5 V			TO-252ZK	TO-263ZK/ZP
- 40	17	23.5	-36	56		NP36P04KDG
	10	15	-50	100		NP50P04KDG
	5.3	8	-83	200		NP83P04PDG
	3.5	5.1	-100	288		NP100P04PDG
- 60	30	40	-36	56	NP36P06SLG	
	29.5	37.5		56		NP36P06KDG
	17	23	-50	100		NP50P06KDG
	8.8	12	-83	200		NP83P06PDG
	6	7.8	-100	288		NP100P06PDG

Table 1: **Overview of the new P-channel PowerMOSFETs for automotive applications**

be more positive with respect to the drain. In fact, with a positive power supply the P-channel PowerMOSFET provides outstanding forward conduction. Now consider one indispensable part of the PowerMOSFET – the intrinsic body diode. Basically, the anode of the intrinsic body diode is connected to the drain and the cathode to the source. If the P-channel PowerMOSFET is connected in backward direction, the diode is forward-biased for positive polarity at the drain, and reverse-biased for negative polarity at the drain. The P-channel PowerMOSFET can be used for protection in this way.

What happens with the voltage drop over the diode in forward direction? The PowerMOSFET works like a switch with very low on-resistance. If the voltage at the gate is negative with respect to the source, and the absolute value is much higher than the threshold voltage of the PowerMOSFET, the resistance between drain and source is roughly 3.8mΩ for the NP100N04PLG P-channel PowerMOSFET. For an ECU (electronic control unit) current consumption of 10A the voltage drop across the PowerMOSFET is only 38mV. This is, of course, a great improvement on the reverse polarity protection realised with a single diode.

From a theoretical point of view, the N-channel solution works fine. From a practical point of view, there is one major advantage for using a P-channel device. In the P-channel configuration the load can be tied to the source so that the gate and the other side of the load can be connected and referenced to the minus pole of the battery. If an N-channel is used, the load cannot be referenced to ground because of the voltage drop across the PowerMOSFET channel which can result in a floating ground connection of the ECU.

H-bridge motor drive

An H-bridge motor configuration for low-voltage DC inductive motors is used in many automotive applications, eg wiper systems, power windows or EPS. Four PowerMOSFETs are connected in an H-bridge configuration with the motor and a DC source. In low-voltage DC motor drives it is common practice to use an H-bridge N-channel PowerMOSFET configuration. The trade-off for the advantage offered by N-channel devices is the increasing gate drive design complexity: a N-channel half-bridge requires a circuitry (charge pump) that produces a gate voltage above the motor voltage rails to turn on the high-side switch. Greater design complexity usually results in increased design effort and greater space consumption.

The principle of an H-bridge motor application with a complementary PowerMOSFET configuration is shown in Figure 3. In this configuration the high-side switch is realised with a P-channel PowerMOSFET; this simplifies the gate drive design enormously. No charge pump is required for the high-side switch. The PowerMOSFET can easily be driven directly by the microcontroller via a small signal MOSFET, eg 2SK4105 in a small SOT-23 package. A half-bridge with a P-channel PowerMOSFET usually has a higher on-resistance or is larger and more expensive than an N-channel version, but from a design and space point of view this is an alternative solution.

An integrated H-bridge driver configuration provides an alternative to a single discrete solution, but a driver of this type often fits only low power applications because the power dissipation cannot be handled by the package. Moreover, the designer sacrifices design flexibility.

Table 1 gives an overview of all P-channel UMOS-4 PowerMOSFETs. Key features of the new P-channel NP series are very low $R_{DS(on)}$ with 3.5mΩ in D²PAK for a V_{DSS} of 40V, high current capability up to 100ADC, maximum channel temperature of 175°C, avalanche energy rated, and RoHS compliant with pure Sn plating.

All devices are qualified for automotive applications, based on the AEC-Q101 qualification flow, and meet the quality requirements for automotive applications. Samples are available now!

Conclusion

There is a growing trend in automotive power electronic applications to use a P-channel trench PowerMOSFET as an alternative to an N-channel trench PowerMOSFET or even a simple relay. Using a P-channel PowerMOSFET gives the designer a further easy alternative to optimise and improve the circuit design. For a P-channel reverse polarity protection configuration, the ECU can be tied to the ground connection to warn the designer of a floating ground connection. Complementary H-bridge circuitry for the P-channel high-side switch requires no complex driving circuit. In combination these benefits show the designer a simple way to enhance his design effort and improve product reliability.