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P-channel Power MOSFETs Approach N-Channel Performance

A new family of P-Channel MOSFETs provides performance similar to N-Channel MOSFETs, including fast switching and reverse polarity operation.

Using the latest generation of trench and polar power MOSFET technologies, both trench and polar P-channel power MOSFETs have been developed that retain all the features of comparable N-channel power MOSFETs, including very fast switching, voltage control, ease of paralleling and excellent temperature stability. Intended for applications that require the convenience of reverse polarity operation, they have an n-type body region that provides lower resistivity in the body region and good avalanche characteristics, because the parasitic PNP transistor is less prone to turn-on.[1] Compared with N-channel power MOSFETs having similar design features, P-channel power MOSFETs have better forward-bias safe operating area (FBSOA) and are practically immune to single-event burnout phenomena.[2] The most important advantage of P-channel power MOSFETs is the simplified gate driving technique in the high-side (HS) switch position.[3]

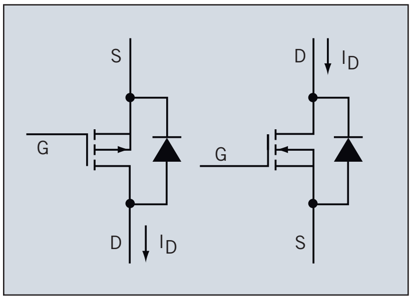

Fig. 1. Schematic symbols for P-channel (left) and N-channel (right) MOSFETs.

The source voltage of a P-channel device is stationary when the device operates as an HS switch. Conversely, the source voltage of an N-channel device used as an HS switch varies between the low side (LS) and the HS of the dc bus voltage. Thus, to drive an N-channel device, an isolated gate driver or a pulse transformer must be used. The driver requires an additional power supply, while the transformer can sometimes produce incorrect operations. However, in many cases, the LS gate driver can drive the P-channel HS switch with a very simple level shifting circuit. Doing this simplifies the circuit and often reduces the overall cost. The main disadvantage of a P-channel device is its relatively high $R_{DS(ON)}$ compared with an N-channel device. This means the cost-effective solutions with P-channel power MOSFETs require optimization of devices toward reduced $R_{DS(ON)}$.

We have developed two families of P-channel Power MOSFETs (Polar™ and TrenchP™), covering V_{DS} range of -50 V to -600 V and I_{D25} range of -10 A to -170 A. Both families offer best-in-class performance in industry-standard power packages and the proprietary ISOPLUS family packages. Fig. 1 repeats the symbols for the MOSFET types.

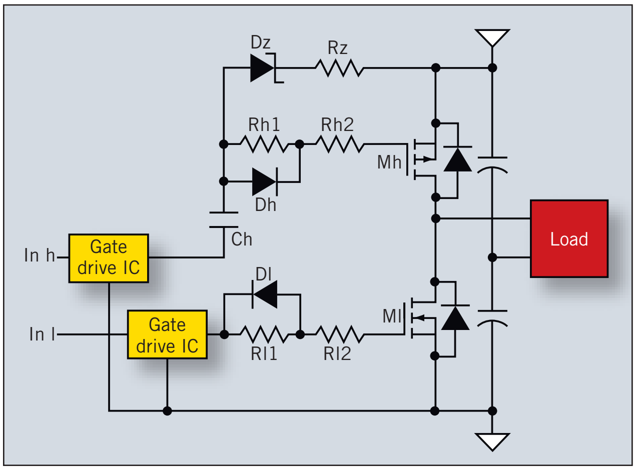

Fig. 2. P-channel gate driving example for PWM application, which is simpler and more cost-effective than the driving N-channel MOSFETs.

GATE DRIVING

Driving a P-channel MOSFET is much simpler and more cost-effective than driving an N-channel MOSFET as HS switch.[5] Fig. 2 shows one example of a gate driving circuit for an HS P-channel power MOSFET. This is much simpler and more cost-effective than the driving N-channel MOSFETs. In this circuit, Dz, Rz and Ch were added to the typical gate driving

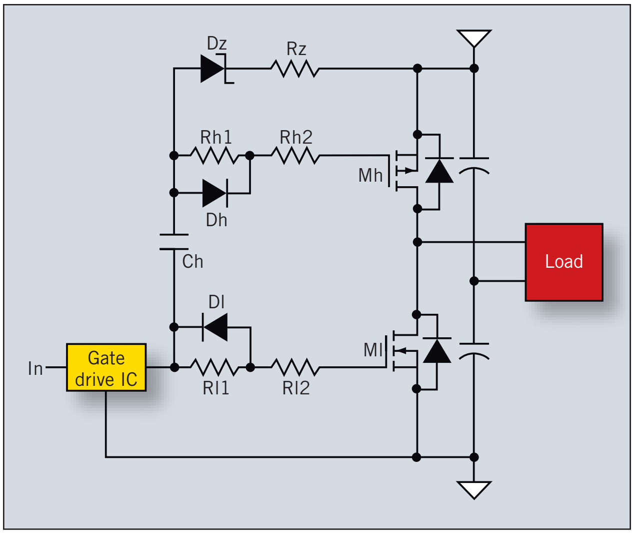

Fig. 3. Single gate drive IC drives both P-channel and N-channel MOSFETs is the most cost-effective and simple gate driving method for a half-bridge.

circuit for an N-channel power MOSFET. Capacitor ìChî holds dc voltage between the higher and lower gate drive circuits, so it must be much larger than the input capacitance of the P-channel MOSFET. Dz keeps the gate to source voltage in the range of ñZener voltage to 0.

The product of Ch and Rz determines the speed of the dc voltage adjustment across Ch. If itís too small, there will be a large current, which can damage the gate drive IC or Dz. If itís too big, the P-channel MOSFET will switch on too slowly. This is due to the slower rise time of the gate pulse amplitude and can damage the MOSFET. Rh2 and Rl2 are resistors for controlling MOSFET turn-off speed. (Rh1 + Rh2) and (Rl1 + Rl2) are resistors for controlling MOSFET turn-on speed. In most cases, it is better to have slower turn-on speed than turn-off speed.[4]

In many cases, both P-channel and N-channel MOSFETs can be driven by a single gate drive IC, as shown in Fig. 3. This is the most cost-effective and simple gate driving method of half-bridge. To avoid cross conduction, dead time is to be provided by the difference of turn-on and turn-off speed. If dead time is too short, there is a chance of too much heat generation and risk of MOSFET failure. If dead time is too long, then the output voltage of the bridge circuit may be reduced. Fig. 4 shows the dead times in a single gate drive IC case. With this circuit, at the beginning of the turn-on period of each MOSFET, the gate source voltage is not enough to fully turn on the MOSFET, and it will result in some additional power loss. Therefore, this circuit may not be suitable for hard switching applications. However, for some zero-voltage switching (ZVS) applications, in which MOSFETs are turned on while the opposite MOSFET operates in diode mode, this circuit can be cost-effective.[4]

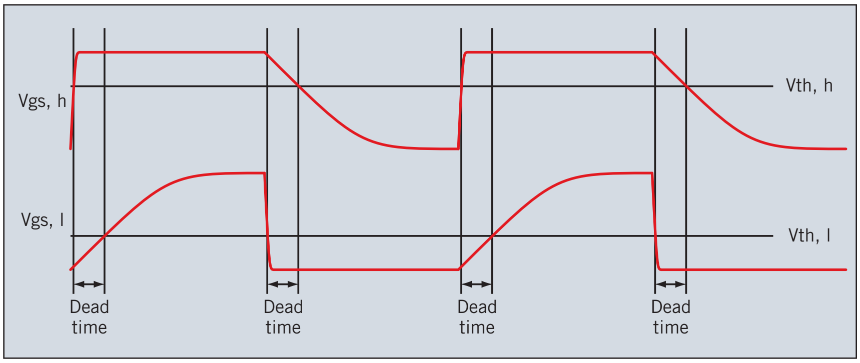

Fig. 4. Dead times in single gate drive IC case depend on the gate-source voltage, V_{GS}.

Commonly used in automotive applications, almost all loads are connected between switches and body ground. All switches in automotive applications are located at the positive side. To drive the positive side n-channel Power MOSFET at a very low frequency, pulse transformer or bootstrap techniques cannot be used. Fig. 5 shows the circuit for providing a gate voltage higher than the dc-link voltage. When the square-wave generator output is at ground, diode, Dc charges the charge pump capacitor, Cp. When the square-wave generator output is at the positive dc-link voltage, diode Dd discharges Cp. The charge is transferred to Cd, which is the power source of the HS gate drive circuit.

As shown in Fig. 6, the P-channel MOSFET greatly simplifies the overall circuit of Fig. 5. Generally, the simpler circuit is more reliable. Although the P-channel MOSFET has higher $A*R_{DS(ON)}$ than that of the N-channel MOSFET, in many cases, this simple circuit makes the larger expensive P-channel MOSFET the most cost-effective solution.[4]

MATCHING P-CHANNEL AND N-CHANNEL MOSFETS

It is impossible to produce a P-channel Power MOSFET that has the same electrical characteristics as an N-channel Power MOSFET. Because the mobility of carriers in an N-channel Power MOSFET is about 2.5 times to 3 times higher, for the same $R_{DS(ON)}$ value, the P-channel Power MOSFET size must be about 2.5 times to 3 times that of an N-channel Power MOSFET. Because of the larger area, the P-channel device will have lower thermal resistance and higher current rating. Its dynamic performance (capacitance, gate charge, etc.) would be affected proportionally by the chip area.

In low-frequency switching applications in which conduction loss is dominant, the P-channel MOSFET should have a current rating similar to that of the N-channel MOSFET. If two MOSFETs have the same current rating, then their junction temperatures can be thought to be similar at the same case temperature and the same current. In this case, the P-channel MOSFET chip area is 1.5 ~ 1.8 times that of the N-channel MOSFET chip area.

In high-frequency switching applications in which switch-

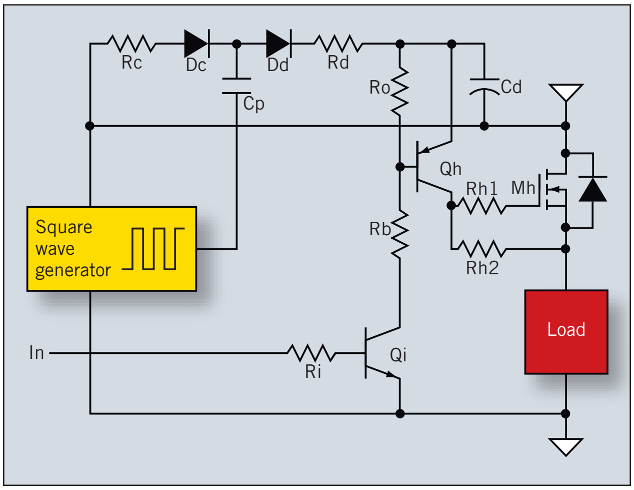

Fig. 5. Low-frequency N-channel MOSFET driving with charge pump, which provides a gate voltage higher than the dc-link voltage.

ing loss is dominant, the P-channel MOSFET should have similar total gate charge to that of the N-channel MOSFET. If two MOSFET have the same gate charge and are driven in a similar way, then their switching losses are similar. In this case, the P-channel MOSFET has similar chip area and the current rating is lower than that of N-channel MOSFET.

For operation in linear mode, we need to match P-channel and N-channel devices with similar FBSOA characteristics in the real operating area. Frequently, this means the same rated Pd, but attention needs to be paid to the ability of the device to operate in this mode.[8] In real applications, the suitable P-channel must be carefully selected in between the same current rating and the same gate charge. Applications requiring the same $R_{DS(ON)}$ are very rare.

APPLICATION EXAMPLES

Audio amplifier is perhaps the most important application of P-channel MOSFETs. Fig. 7 shows a class AB audio amplifier circuit, which has a complementary Power MOSFET output stage, a differential input stage and a biasing circuit for the output stage. It offers performance improvements over the equivalent bipolar output stage and allows a reduction in the complexity of the driver circuit.

The input stage has a PNP differential comparator that receives input signal through R1 and C1 and the negative feedback of the output stage to the base of Q2 through the resistor R6. The comparator drives the transistor, Q4, which drives the output stage. Components R6 and R5 determine the feedback loop gain as. β = R5/R5+R6) R2 determines the bias current at the input stage and is typically 2mA. R4 and C3 create a filter that provides additional power supply ripple suppression.

VBE multiplier consisting of R7, R8, R9, C5 and Q3 provides a bias voltage, Vb, between the gates of transistor Q5 and Q6. The capacitor C5 holds the voltage. If Vbe of Q3 is ~0.6 V, R9 ~10 K and R7 ~ 100 K, then the value of the bias voltage would be about Vb ~10xVbe ~ 6 V. The purpose of this voltage is to bias the gates of Q5 and Q6, keeping them in a slightly ON state that results a quiescent current flowing through in the output stage. The quiescent current reduces the zero crossing distortion associated with the output stage. The small capacitors C2 and C4 make the entire circuit stable.[6]

The output stage comprises N- and P-channel Power MOSFETs (Q5 and Q6) connected in series between the high voltage ($+V_{DD}$) and low voltage ($-V_{DD}$) terminals. The sources of Q5 and Q6 are connected to the OUTPUT terminal, which delivers an output signal to the LOAD (speaker). The output stage is a source follower circuit with gain very close to 1 (but <1.0), which is almost an ideal voltage source. Its output voltage is practically insensitive to the output current.[6]

Both MOSFETs in a Class AB amplifier require extended FBSOA as they operate in linear mode. Power dissipation

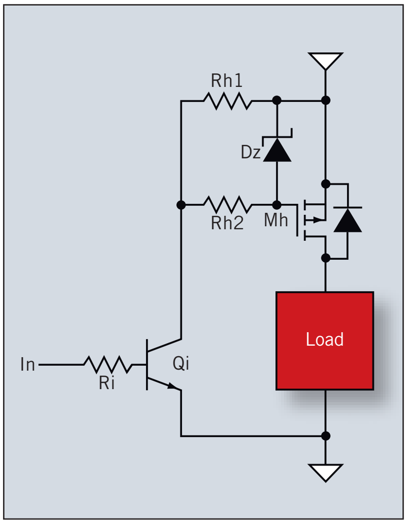

Fig. 6. Low-frequency P-channel MOSFET driving circuit simplifies the overall circuit of Fig. 5.

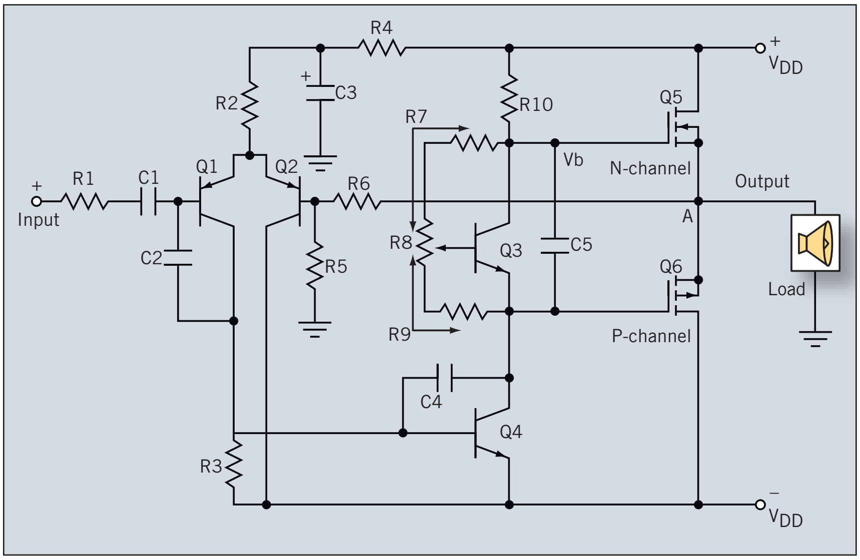

Fig. 7. Class AB Audio Amplifier circuit with a complementary Power MOSFET output stage.[6]

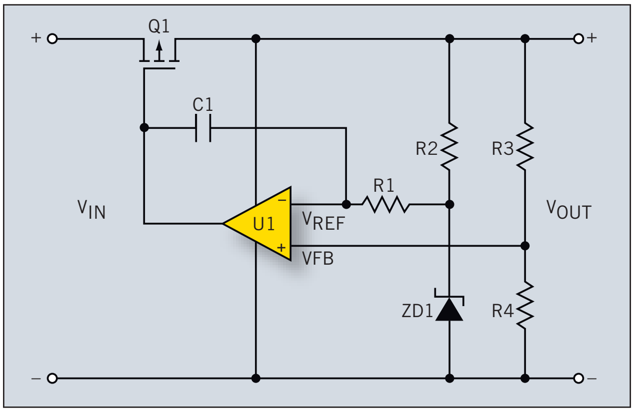

Fig. 8. A linear voltage regulator in which the voltage drop across the P-channel MOSFET can be lowered nearly zero, providing a wide input voltage range.

would be high because of linear operation.

Linear voltage regulators are widely used to supply power to electronic devices. They have a variety of configurations for many different applications. One application example is illustrated in Fig. 8. The resistive divider (R3 and R4) monitors the output voltage and provides a voltage feedback (VFB) to the positive (+) terminal of the op-amp (U1). The negative (-) terminal of the op-amp receives a reference voltage (V_{Ref}) from a Zener diode (ZD1). The op-amp provides a control voltage to the regulating transistor (Q1), a P-channel power MOSFET. Because the voltage drop across the P-channel MOSFET can be lowered nearly zero, this circuit has a wide input voltage range.

The power dissipation in the device (Q1) used in the linear voltage regulator is high because it is the function of the difference between input and output voltage and the output current. The P-channel Power MOSFET operates in the linear mode and requires an extended FBSOA characteristic, which is offered by both families of IXYSí P-channel Power MOSFETs.

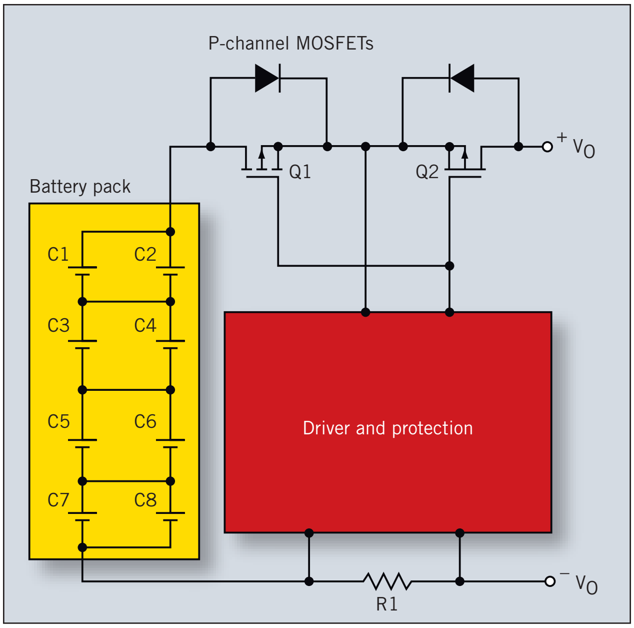

Fig. 9. A battery charging and protection circuit for an Li-ion battery uses P-channel MOSFETs.[2]

Fig. 9 shows a battery charging and discharging system for Li-ion (Li+) cells. One MOSFET enables the charging of the battery pack while the other MOSFET enables the discharging. When both MOSFETs are off, the cells are isolated from the external environment to protect the battery. At the beginning of the charging cycle, a constant current can be implemented and the MOSFET will be operated in the linear region. When the battery cell reaches a predefined voltage level, the system voltage loop will begin to reduce the charging current in order to maintain the desired voltage level, hence the constant voltage-mode operation.[5]

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