# An Introduction to International Rectifier P-Channel HEXFETs®

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With the introduction of International Rectifier's line of P-Channel power HEXFETs, a new option is available to the designer that can simplify circuitry while optimizing performance and parts count. This application note discusses the basic characteristics of P-Channel HEX-FETs and gives a conceptual overview of typical circuit applications.

## Basic Characteristics of P-Channel HEXFETs

Like their N-Channel counterparts, International Rectifier P-Channel HEXFETs are all presently enhancement mode devices; that is, application of voltage between the gate and the source terminals enhances the conductivity and allows current to flow, while no drain current flows when the gate is shorted to the source. For drain current to flow, the gate voltage has to be increased (in absolute value) towards the drain voltage. In a P-Channel device, the conventional flow of drain current is in the "negative" direction — that is, current flows out of the drain, with a negative gate-to-source voltage applied (Figure 1).

While the basic physical principles of operation for P- and N-Channel HEXFETs are similar, the different resistivity of the base silicon material has a distinct bearing on their specific characteristics, as well as upon cost. Since the resistivity of P-type silicon is much higher than that of N-type silicon, the P-Channel device requires a larger active area to achieve the same on-resistance and current rating.

This difference in resistivity of the basic silicon material is an obstacle to the construction of a P-Channel device that is truly electrically complementary in all respects to an N-Channel counterpart. Since for a given drain-source voltage capability, the on-resistance is the most basic parameter, the P-Channel HEXFET device will have the larger active area needed to achieve the same on-resistance as its complementary N-Channel counterpart. Gate threshold voltage, transconductance and self-capacitances are equalized as nearly as possible by accurate device design. Table 1 shows the parameters of two typical complementary P- and N-Channel HEXFETs (the IRF9130 and the IRF120) and shows to what extent their major parameters match one another. Voltage ratings, on-resistance, threshold voltage and, of course, package configuration, are exactly the same. Input capacitance and transconductance are also fairly closely matched. However, those parameters that are closely related to the die area, specifically thermal resistance, pulsed current rating, safe operating area and, to some extent, continuous current rating, are different, as would be expected. While these last parameters do not affect circuit operation directly, they have a bearing on circuit design and, whenever matched operation is required, the P-Channel device will operate with a larger safety margin with respect to its current ratings and thermal limits.

A close analysis of the data sheet would also show that the temperature variations of the threshold voltage, on-resistance and transconductance for a P- and an N-Channel are slightly different. This difference can, however, be considered a second or-
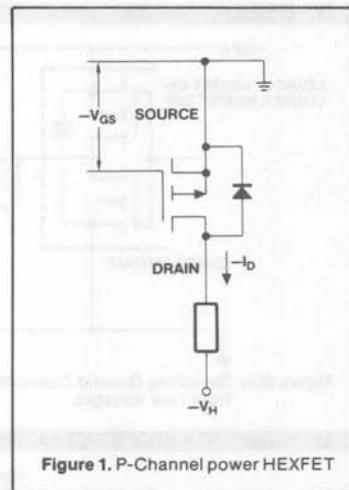


**Figure 1.** P-Channel power HEXFET

der effect in most practical applications.

As shown in Figure 1, the P-Channel HEXFET, like its N-Channel counterpart, has an integral reverse rectifier, whose anode is connected to the drain. This diode is specified as a real circuit element with a current handling capability as high as that of the transistor itself. It is a very valuable circuit component in some applications.

## Circuit Applications

In the following sections, we present a brief overview of the areas where a P-Channel can be used to particular advantage.
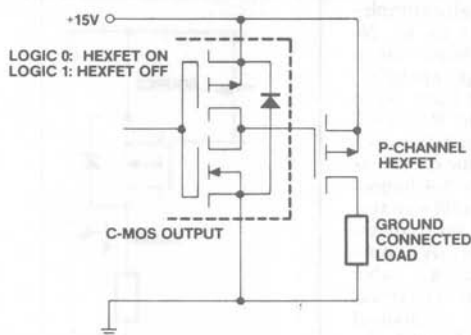
## Grounded Loads

One area where P-Channel HEX-FETs yield circuit simplification and

cost savings is where the load is connected to ground. This is mandated in many automotive and aircraft applications and, sometimes, in household appliances. In these applications, in addition to wide safe operating area and excellent switching characteristics that are common to all HEXFETs, the use of a P-Channel device allows the load to be tied to the drain so that the gate drive can be referenced to one side of the supply. If an N-Channel were used, a separate supply would be required, referenced to the source, for the gate drive voltage.

Figure 2(a) shows how such a circuit would operate when driven from a C-MOS gate. However, if the load is operated at voltages above 15V, the logic ground cannot be connected to the load ground, and a separate supply is needed for the logic circuits,

**Table 1.**

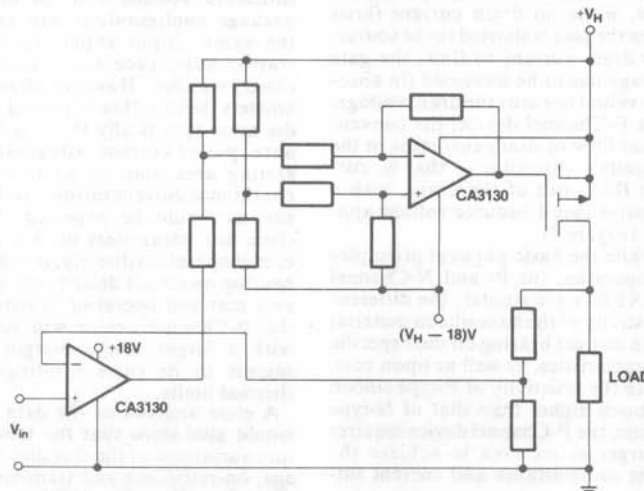|  | N-Channel | P-Channel |
|---|---|---|
| Device Type | IRF120 | IRF9130 |
| Drain-to-Source Voltage (Max.) | 100V | -100V |
| Die Size | 8.04mm² | 13.25mm² |
| On-Resistance (Maximum) | 0.3Ω | 0.3Ω |
| On-State Drain Current @ $T_C$ = 90°C | 6A | -8A |
| Pulsed Drain Current | 15A | -30A |
| Gate Threshold Voltage (Minimum-Maximum) | 2 to 4V | -2 to -4V |
| Forward Transconductance (Typical) | 2.5 S | 3.5 S |
| Input Capacitance (Typical) | 450pF | 500pF |
| Output Capacitance (Typical) | 200pF | 300pF |
| Reverse Transfer Capacitance (Typical) | 50pF | 100pF |
| Maximum Thermal Resistance | 3.12 deg. C/W | 1.67 deg. C/W |
| Package | TO-3 | TO-3 |



**Figure 2(a).** Switching Ground Connected Loads Operating from Low Voltages
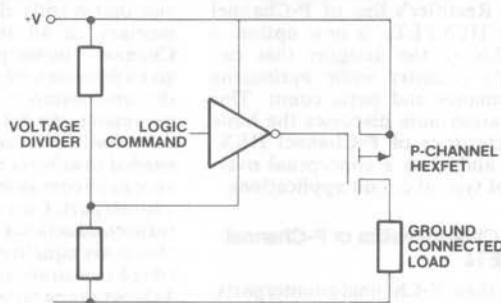


**Figure 2(b).** Switching Ground Connected Load at Higher Voltages
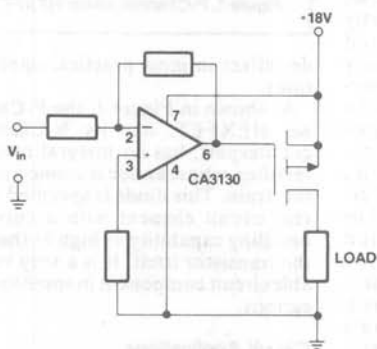


**Figure 3(a).** Driving Grounded Load in Linear Mode (Low Voltage)



**Figure 3(b).** Driving Grounded Load in Linear Mode (High Voltage)

as shown in Figure 2(b). An alternative approach is to drive the P-Channel HEXFET through a level shifter, as shown in Figure 5. Notice that to achieve the same result with an N-Channel HEXFET, a separate supply referenced to the source would be required.

A P-Channel device can also be operated in linear mode as shown in Figure 3. The device lends itself readily to voltage or current regulation which can be achieved through the use of suitable feedback. In the applications shown in Figures 3(a) and 3(b), the device drops whatever excess voltage is available from the unregulated supply. For parallel connection of devices, or where fast slew rate is important, a current boosting stage at the output of the operational amplifier may be required.

## Totem Pole Switching Circuits

One of the most common building blocks for switching applications is the "totem pole." It is used in a variety of applications, such as switching power supplies, DC-to-AC converters, AC motor speed controllers, AM transmitters and Class D switching audio amplifiers.

Figure 4 shows one such circuit, implemented with two N-Channel HEXFETs, and its associated gate drive circuit. Since the drive circuits have to be referenced to the respective sources, they are isolated from each other. The most commonly used techniques to develop an "isolated" gate drive signal are optical isolators, transformer coupling and "bootstrapping." Optical isolators, shown in Figure 4, require a separate supply and are relatively slow and susceptible to noise. Pulse transformers, on the other hand, can only transfer to the secondary an AC signal (Figure 8), and hence have a limitation on the maximum and minimum possible switching duty cycle. They also always have some unwanted amount of leakage inductance. "Bootstrapping" is a technique for deriving a local gate drive voltage via a capacitor connected in the main drain circuit. Whereas it is satisfactory in many applications, it again has limitations regarding permissible duty cycle and maximum operating frequency.

The totem pole shown in Figure 5, using one N-Channel and one P-Channel HEXFET, is a step forward in the simplification of the drive circuit, since the gate drive signals are now referenced to separate ends of the DC supply. As shown, the drive signal referenced to the other rail can be developed by means of a simple level shifter. Furthermore, if the supply voltage is less than 20V, the two gates can be connected together and driven with respect to either end of the supply (Figure 6).

When using this type of totem pole, care should be exercised to have a gate drive signal with fast rise time. If the two gates are independent, as in Figure 5, another possibility is to have a deadband between the turn-on gate command of the P-Channel and that of the N-Channel equal to the rise time of the gate drive signal. Unless this is done, a short circuit current will flow through the two devices during the transition times,
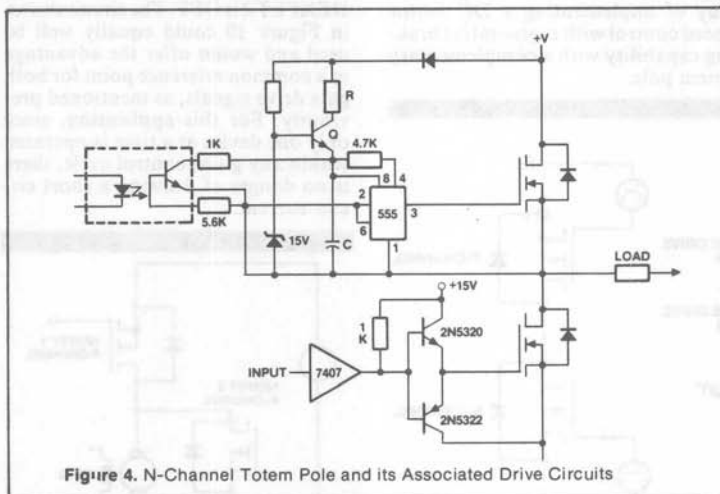


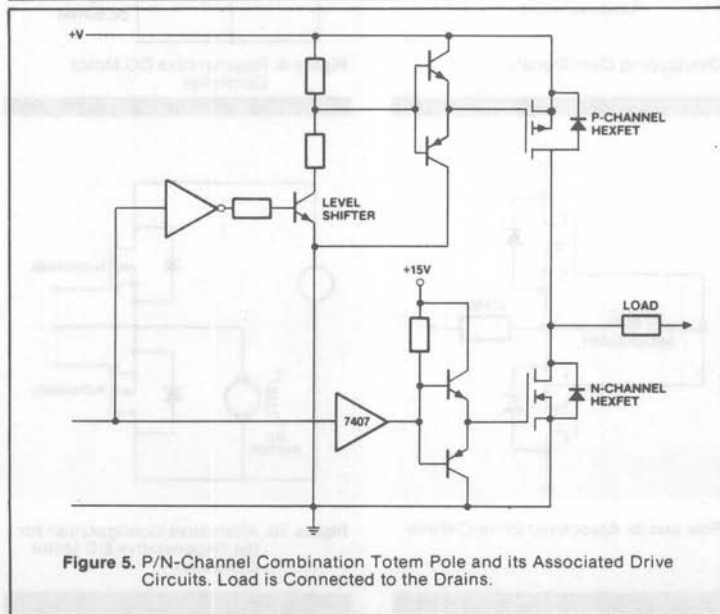**Figure 4.** N-Channel Totem Pole and its Associated Drive Circuits



**Figure 5.** P/N-Channel Combination Totem Pole and its Associated Drive Circuits. Load is Connected to the Drains.
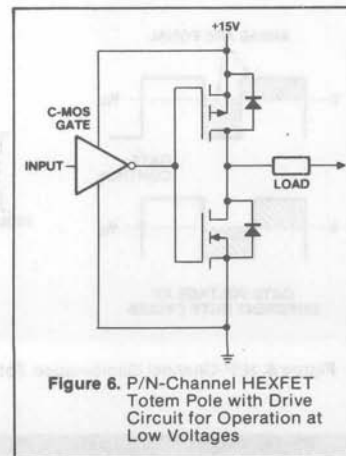


**Figure 6.** P/N-Channel HEXFET Totem Pole with Drive Circuit for Operation at Low Voltages

as shown in Figure 7. However, the current regulating characteristic of power MOSFETs tends to limit the amount of this current and, while it may significantly increase the switching losses, it would not necessarily reach catastrophic values.

Should a common reference be desired for both gate drive signals, the circuit configuration shown in Figure 8 can be used. The positions of the P- and N-Channel HEXFET devices have been interchanged so that both have the load connected to the source. The gate drive signals are now referenced to the same point; however, this point is neither of the two supply leads. This is probably the circuit configuration that affords the simplest and most noise-immune gate drive circuit. An added advantage of this circuit is that it will not draw a short circuit current (Figure 7), because it is inherently impossible

to drive both devices ON simultaneously.

## Application of the Switching Totem Pole

The switching totem pole is used in a number of different applications. Some of the most common are the following:

- DC-to-AC inverters for battery operated supplies, stand-by and uninterruptible power systems.
- Variable frequency inverter for high efficiency speed control of AC induction motors.
- Regenerative speed control of DC motors.

Taking as an example this last application, we show in Figure 9 a way of implementing a DC motor speed control with regenerative braking capability with a complementary totem pole.

In the "motoring" mode of operation, HEXFET 1 is switched ON and OFF, at an appropriate repetition rate, and provides control of the average voltage applied to the motor. HEXFET 2 is OFF, but its integral reverse body-drain diode acts as the conventional freewheeling rectifier, and carries the freewheeling motor current during the periods when HEXFET 1 is OFF. When the motor is required to act as a generator and return energy to the DC source, HEXFET 2 is chopped ON and OFF, and controls the current fed back from the motor to the supply. In this operating mode, HEXFET 1 is OFF, but its integral reverse rectifier carries motor current back to the DC source during the intervals when HEXFET 2 is OFF. The circuit shown in Figure 10 could equally well be used and would offer the advantage of a common reference point for both gate drive signals, as mentioned previously. For this application, since only one device at a time is operated within any given control cycle, there is no danger of drawing a short circuit current.
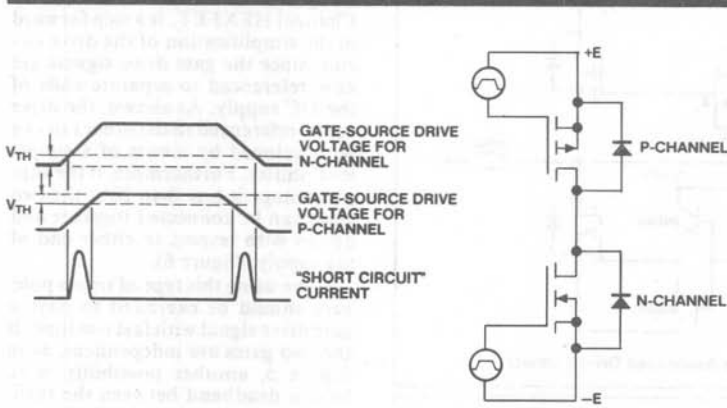


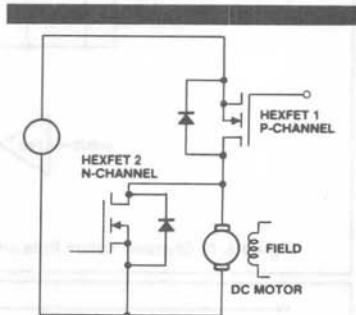**Figure 7.** Short Circuit Current Caused by Overlapping Gate Signals
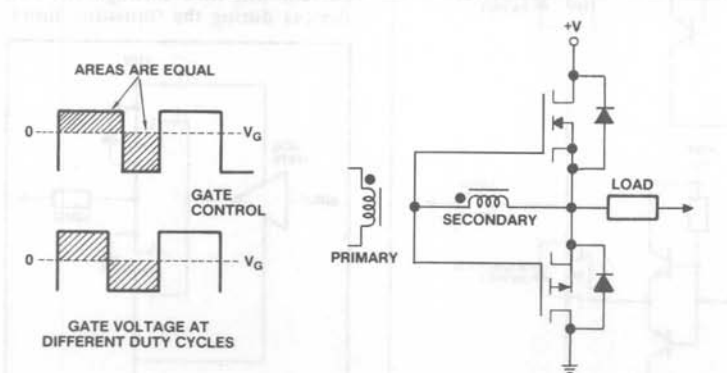


**Figure 9.** Regenerative DC Motor Controller



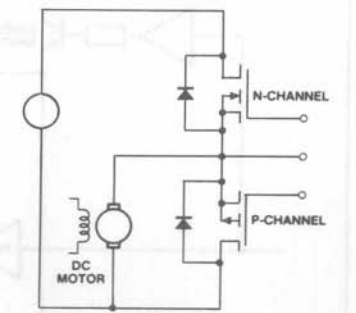**Figure 8.** N/P-Channel Combination Totem Pole and its Associated Drive Circuits



**Figure 10.** Alternative Configuration for the Regenerative DC Motor Controller

Another consideration in choosing between the circuit connections of Figure 9 or Figure 10 is the current rating of the two devices. Normally, the device that is being switched during regeneration does not need to have a current rating as high as the motoring device, since friction and windage in the motor contribute to the braking torque. Therefore, the P-Channel HEXFET, because of its lower current rating for a given die size, may be a better choice for the regenerative operation.

Apart from being the basic building block of a large variety of inverter circuits, totem poles can be profitably used to drive large transistors or a parallel combination of them whenever high performance is required (Figure 11). This circuit can be used either in linear or switching applications and provides a good low impedance gate drive source. The integral reverse rectifiers clamp possible voltage transients on the gate.



**Figure 11.** High Performance Drivers

### Linear Application of Complementary Pairs

Because of the wide range of linearity of $g_{fs}$, immunity from secondary breakdown, high speed and intrinsic freedom from thermal runaway, power HEXFETs are ideally suited for operation as linear amplifiers, alone or in complementary pairs. When used in linear mode, the gate has to be biased to some level, depending on the type of operation desired. Several circuit configurations will achieve this end; they are inevitably simpler than would be required for bipolar transistors, since
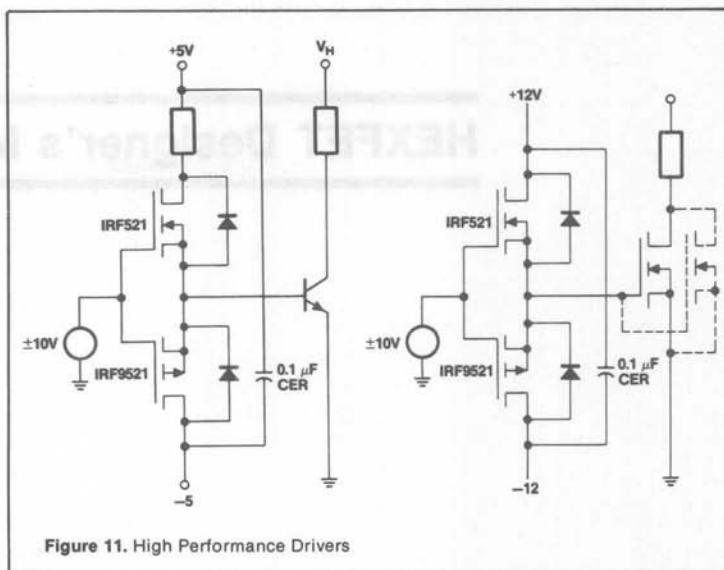
power MOSFETs require very little drive power and are not subject to thermal runaway.

Figure 12 shows the basic biasing scheme for linear operation, but much simpler versions can be developed for specific applications, as shown in Figure 13. The zener diodes should be chosen to give the desired bias current in relation to the available supply voltage. The gain bandwidth product that can be obtained with this stage driven by a simple differential amplifier is much larger than what can be obtained by a more complex bipolar configuration. The slew rate would also be much better.

### Summary

P-Channel HEXFETs are electrical complements to International Rectifier N-Channel types. The availability of these devices offers new design options to the circuit engineer, and opens up the possibility for new HEXFET applications that were not before feasible with N-Channel types alone. □
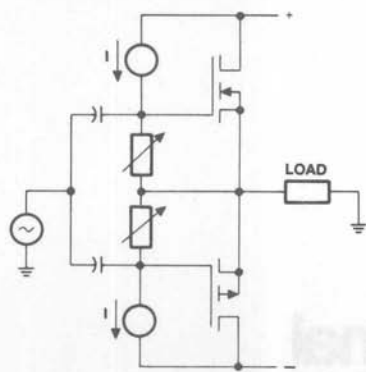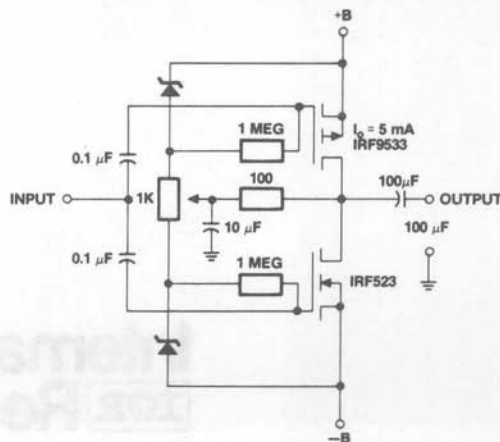
### Acknowledgements

**Figure 12.** Basic Biasing Scheme for Linear Operation



**Figure 13.** Simple Biasing Scheme for linear Operation

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