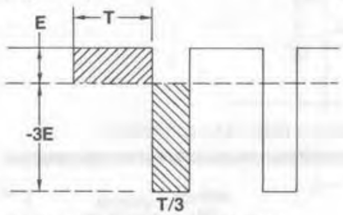
Transformer-Isolated HEXFET® Driver Provides very large duty cycle ratios

(HEXFET is the trademark for International Rectifier Power MOSFETs)

By P. WOOD

Transformer coupling of low level signals to power switches offers several advantages such as impedance matching, DC isolation and either step up or step down capability.

Unfortunately, transformers can deliver only AC signals since the core flux must be reset each half cycle. This "constant volt seconds" property of transformers results in large voltage swings if a narrow reset pulse, i.e., a large duty cycle is required (Figure 1).



NOTE: VOLT-SECONDS PRODUCT IN SHADED AREAS MUST BE EQUAL. THIS CAUSES RESET VOLTAGE TO BE 3 TIMES APPLIED VOLTAGE E.

Figure 1. Constant-Volt-Seconds Characteristics of Transformers

For this reason, transformers in semiconductor drive circuits are limited to 50% duty cycle or roughly equal pulse widths positive and negative because of drive voltage limitations of the semiconductors themselves.

For large duty cycle ratios designers must choose an alternative to the transformer, such as an optical coupler to provide the necessary drive isolation.

These devices have poor noise immunity, high impedance output and require additional floating power sources which add complexity.

When a power HEXFET is used for the power switch, the high output impedance of optical couplers is less of a problem because the HEXFET power MOSFET does not require drive current in the ON or OFF states. Switching speed, however, is seriously comprised by C_{iss} if a high impedance driver is used.

The circuit in Figure 2 provides a low impedance answer during the switching intervals, and a duty cycle ratio of 1-99%; furthermore, it can have any desired voltage ratio, and provides electrical isolation!

In Figure 2, Q2 is a power HEXFET providing the switching function for a switching power supply, motor drive or other application requiring isolation between the low level logic and high power output. Q1 is a low power HEXFET such as the IRFD1Z1, which is used to control the drive signals to Q2, and T1 is a small 1:1 driver transformer providing electrical isolation from, and coupling to, the low level circuitry.

The waveforms in Figure 3 explain the circuit operation. Waveform A is the desired logic signal to be switched by Q2. When this voltage is applied to the primary of T1 the waveform is supported by changing core flux until saturation occurs as shown in waveform B. At this time the winding voltages fall to zero and remain so until

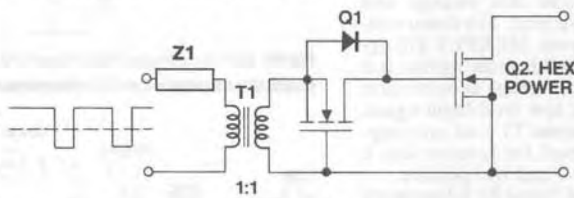


Figure 2. Wide Duty Cycle HEXFET Driver Circuit

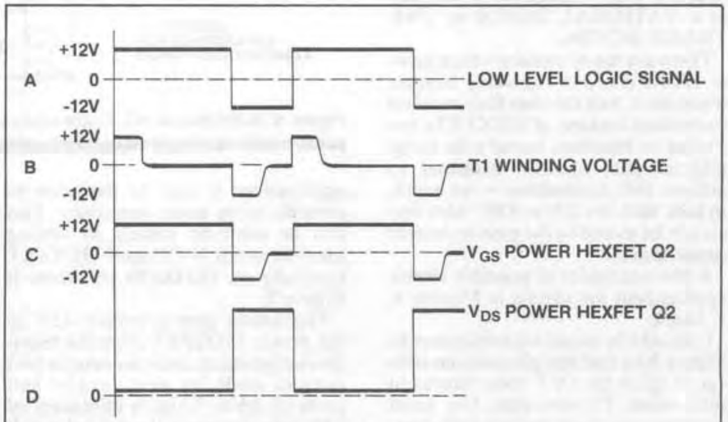


Figure 3. Waveform Characteristics of HEXFET Driver Circuit

the core flux is reversed by the negative-going portion of waveform A. Saturation will again occur if the negative-applied pulse exceeds the volt-seconds capability of the core.

During the positive portion of the secondary waveform, which, of course, has the same form as the primary, the intrinsic diode of Q1 is in forward conduction and Q2 receives a positive gate drive voltage with a source impedance of Z1 plus the intrinsic diode forward impedance. In a practical circuit this can be less than 10 Ohms total, with a consequent turn-on time of around 75nsec.

When T1 saturates, the intrinsic diode of Q1 isolates the collapse of voltage at the winding from the gate of the power HEXFET and the input capacitance C_{iss} of the power switch holds the gate bias at the fully enhanced condition for a time limited only by the gate leakage current of Q2 as indicated in Figure 3c.

When waveform A goes 12 volts negative Q1 will become fully enhanced; and the main switch Q2 will now be turned off at approximately -12V at a source impedance Z1 + $R_{DS(ON)}$ of Q2. This will again be less than 10 Ohms and will yield a turn-off time less than 100nsec.

When T1 again saturates, during the negative half cycle, its winding voltages fall to zero and Q1 turns off. As T1 voltage collapses, the gate of Q2 also follows this voltage and remains at zero bias. The drain voltage of the power HEXFET Q2 appears in Figure 3d, showing that it is indeed a mirror image of waveform A, the desired low level logic signal. Note that because T1 need only support a 12V signal, for 1μsec or less, it is very small — and inexpensive.

In a practical circuit Z1 is frequently a 0.1 μF capacitor, and the signal source is a low impedance driver such as a NATIONAL DS0026 or UNITRODE UC1706.

There are many circuits where power HEXFETs are replacing bipolar transistors, and this one illustrates an important feature of HEXFETs not shared by bipolars, namely the insignificant gate currents required to achieve full conduction — so small, in fact, that the ON or OFF bias levels can be stored in the gate-to-source capacitance!

A few examples of possible circuit applications are shown in Figures 4, 5, and 6.

It should be noted with reference to Figure 3(b) that the gate-source voltage of Q2 in the OFF state returns to zero when T1 saturates. For most applications, the noise immunity provided by the threshold voltage of Q2 is sufficient ($2V < V_{TH} < 4V$). In some

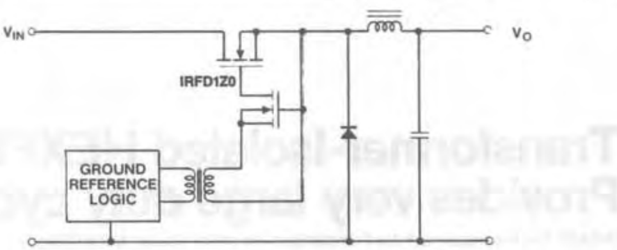


Figure 4. Single Switch Regulators

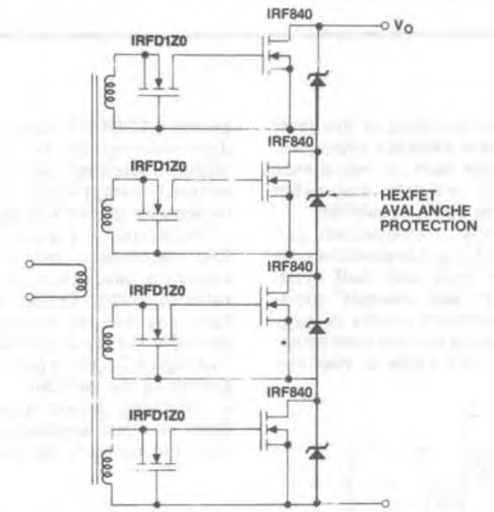


Figure 5. High Voltage, High Power HEXFET Switch (500V, 8A per Section)

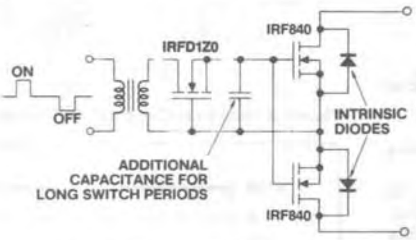


Figure 6. Bi-directional AC Switch using HEXFETs

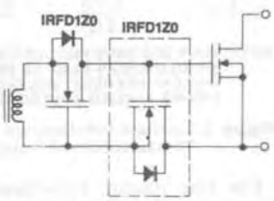


Figure 7.
HEXFET Driver Circuit with additional Noise Immunity

applications it may be desirable to provide more noise immunity. This can be achieved merely by adding another small N-Channel HEXFET (typically an IRFD1Z0) as shown in Figure 7.

The circuit now provides -12V to the power MOSFET *after the transformer saturates,* and this reverse bias remains until the next positive half cycle of drive. Thus, a minimum of 14V noise immunity is provided which should be adequate for all applications. Cost of the HEXFETs used in Figure 7 is minimal, and these are available in 4-pin HEXDIP packages, which can be stacked side by side in standard DIP sockets.

Transformer T_1 Considerations

Isolated drives using transformers have several advantages over other methods as previously mentioned.

In the circuits illustrated, the transformers were built from miniature tape wound or ferrite toroids. Typical part numbers for these cores are as follows:

(1) Tape Wound Cores
Magnetics Inc. #80558-(½D)MA
#52402-1D

(2) Ferrite Toroids
Ferroxcube #266CT125-3E2A or equivalent

Note:

Choice of a core type is not critical provided that 10 to 20 turns bifilar of suitable wire can be hand-wound onto it. The size of core should be chosen so that adequate insulation thickness can be used for the isolation voltage requirements.

Square Permalloy 80 cores are more expensive than ferrite types, but they have much narrower hysteresis loops and hence need fewer ampere turns of excitation. This can make a critical difference when the driver has limited current capability.

Bifilar windings improve the magnetic coupling of primary to secondary, and it is also important to space the turns to occupy 360° of the core circumference to minimize leakage inductance.

Unity turn ratios between primary and secondary also serve to minimize leakage inductance and hence optimize the transformer coupling coefficient.