

Introduction

The proper marriage of a MOSFET driver to a power MOSFET is essential for optimized switch performance. Designing for adequate gate drive, resulting in fast rise and fall times of the MOSFET, reduces MOSFET switching losses. However, using the wrong MOSFET specifications can result in inaccurate switching speed calculations and poor performance.

MOSFETs have subtle characteristics that affect switching speed which may be overlooked. A solid understanding of the internal operation of the MOSFET makes selecting the appropriate driver much easier. Using the input capacitance specification (C_{ISS}) may not provide the accuracy needed to estimate MOSFET gate drive requirements; calculations based on gate charge (Q_G) are better at predicting actual behavior. This note will help clarify what is important when considering a specific MOSFET and will aid in choosing a Micrel low-side driver to optimize the application.

Understanding the MOSFET

Depending on the application, a number of variables must be considered when choosing a MOSFET. The maximum drain-to-source voltage (V_{DS}), on-resistance ($R_{DS(on)}$), drain current (I_D) and input capacitance are typical parameters used by designers when incorporating MOSFETs into their systems. Another very important specification is gate charge. This is the amount of charge (energy) necessary at the gate to switch a MOSFET. The total gate charge is due to parasitic effects internal to the device. The construction of the device creates input capacitance from the gate to source and Miller effect capacitance from drain to gate. Miller effect is capacitive feedback internal to an electrical device. In the case of the power MOSFET, parasitic capacitance from the drain to the gate is the Miller effect path. This feedback path is what makes the input capacitance specification misleading. To switch the MOSFET, all capacitances must be taken into consideration in the design process and the gate charge specification paints a cleaner picture.

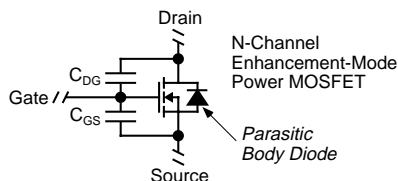


Figure 1. N-Channel Power MOSFET Showing Internal Capacitance and Body Diode

When a voltage is applied to the gate, it charges the gate-to-source capacitance. When the voltage at the gate crosses the threshold voltage of the MOSFET, the drain-to-source voltage begins to fall (the MOSFET begins to become en-

hanced). Subsequently, the gate-to-drain capacitance requires more current due to the changing drain voltage, which steals from the available gate-drive current of the MOSFET drive circuit. This causes the gate voltage to remain constant until the drain-to-source voltage falls to its minimum and the device is fully on ($V_{DS} = R_{DS(on)} \times I_D$). Once fully charged, the voltage on the gate begins to rise. As the voltage on the gate rises, the drain-to-source resistance of the MOSFET falls to its optimally low level.

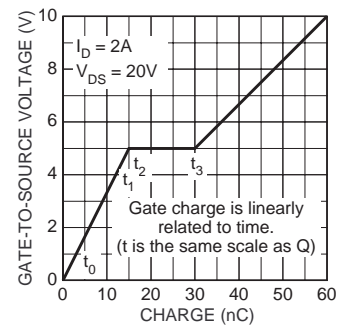


Figure 2. Gate Charge vs. Gate-to-Source Voltage

This behavior is best visualized in the gate-to-source voltage vs. gate charge curve (Figure 2) commonly found in power MOSFET data sheets. The initial rise on the graph, from t_0 to t_1 shows the voltage at the gate rising while charging the gate-to-source capacitance. This time corresponds to the delay time of the MOSFET. Then at a voltage V_{TH} (t_1), the threshold voltage of the MOSFET is crossed and the device begins to switch. Next, the drain voltage starts to fall and the Miller effect capacitance steals current from the available gate-drive current and causes the plateau region from t_2 to t_3 . At time t_3 , the device is saturated and the voltage at the drain stops changing, allowing the gate voltage to rise. At this level, drain-to-source resistance should be optimally low and the gate fully enhanced. Good design practice requires the designer to assure that adequate drive is provided to fully enhance the MOSFET. This helps lower on-resistance and reduce switching losses.

Designing with Micrel MOSFET Drivers

Micrel's family of low-side MOSFET drivers covers a broad range of drive capability. The different peak output current specifications of the drivers allow the designer freedom in incorporating a Micrel part into the design. The MIC44xx series of low-side drivers is one of the broadest lines in the industry, ranging in peak output current from 1.2A (MIC4416/4417) to 12A (MIC4451/4452) capability. With single, dual, and quad drivers, there is a full range of products which can be implemented into any low-side switching application.

Device	I _{OUT(peak)}	R _{DS(on)}
MIC4416/4417 IttyBitty™ Single	1.2A	10Ω
MIC4467/4468/4469 Quad	1.2A	15Ω
MIC4426/4427/4428 Dual	1.5A	10Ω
MIC4423/4424/4425 Dual	3A	5Ω
MIC4420/4429 Single Inverting/Noninverting	6A	2.8Ω
MIC4421/4422 Single Inverting/Noninverting	9A	1.7Ω
MIC4451/4452 Single Inverting/Noninverting	12A	1.5Ω

Figure 3. Micrel Low-Side Drivers

MOSFET Switch Circuit Design

Supply Bypassing

Proper bypass capacitors must be chosen to protect the device from voltage transients during switching transitions. Two capacitors should be used directly at the driver from power supply to ground to prevent damage or improper operation due to voltage transients during switching. One of the capacitors should be a high-performance, 0.1μF ceramic capacitor and the other a high performance, low-ESR, 1.0μF film capacitor. Directly from the supply, use a 47μF electrolytic capacitor to filter the supply line. Components in the circuit should be placed as close as possible to the driver to reduce the amount of lead inductance. This prevents ringing on the output of the driver and on the drain of the MOSFET. Most MOSFETs are very sensitive to overvoltage conditions at the gate, which can puncture the gate oxide layer and damage the device. The electrolytic capacitor does not have to be near the driver because its function does not address high-frequency transient filtering.

Board Layout

Circuit layout must be carefully considered to optimize performance. The speed of the switching gives rise to high frequency problems such as component lead inductance, ground noise, and high frequency electromagnetic interference (EMI). The amount of current being drawn for short duration could also cause voltage transients on the supply line that need to be filtered.

The board itself demands careful layout for grounding purposes. To get optimal switching, one must be certain that the circuit is free from ground bounce. This can be accomplished by using the star method of grounding, where all the leads to ground form a star pattern and return to one specified point. This point should be the power return of the bulk capacitance on the power supply, the previously mentioned 47μF capacitor, for example. Another point about grounding is when a digital control signal is used, the ground return of the logic signal should also be tied to the one central point on the board to prevent effective ground-level shifting. This should be a separate trace, not interfacing with any heavy current carrying traces.

Selecting the Driver

Choosing the driver which matches the application is critical. Some applications may not require fast switching times, therefore high current drivers may be overkill. Other applications need switching times as fast as possible to improve efficiency. The design process involved in choosing a Micrel low-side MOSFET driver for the application is simple, but requires a basic understanding of MOSFETs and some mathematical relationships to determine which driver is best for the circuit. Micrel MOSFET drivers all function as level shifters, taking a TTL/CMOS compatible input and providing high peak current at the supply voltage rails. The MIC4420 can provide 6A of peak output current until the gate of the MOSFET is charged. Its output resistance limits the current it can provide. The output resistance of the MIC4420 is approximately 3Ω, limiting output current to 6A when operating from an 18V supply (18V ÷ 3Ω). The output voltage rises essentially to the rail when the MOSFET is fully enhanced. Thermal limitations prevent low-side drivers from supplying high continuous output current.

The amount of charge necessary to switch the MOSFET can be determined from its data sheet by knowing the intended gate-to-source voltage, drain current and drain-to-source voltage. The number can be taken from the characteristic curve for gate charge or taken directly from the electrical characteristics section of the MOSFET data sheet. The gate charge number will give the total gate charge necessary to switch the device. The amount of current necessary to switch a MOSFET is directly related to the gate charge and can be determined using the following equation:

$$Q_G = I \times t$$

where:

Q_G = total gate charge number

I = gate current

t = device switching time

A simple example will demonstrate. If we have a constant-current source drive circuit that provides 1A of output current at a gate-to-source voltage of 10V, then we can determine the switching time based on our gate charge.

If the gate charge is 30nC for $V_{GS} = 10V$, then the device will switch in 30ns. With Micrel MOSFET drivers the situation is still simple. The devices are intended to provide high currents for short pulses and sustain some lower current to maintain the charge, accounting for any leakage in the MOSFET. Micrel devices will sink or source from 1.2A to 12A of peak current. We will look at a specific example of how to choose a Micrel driver correctly for the application.

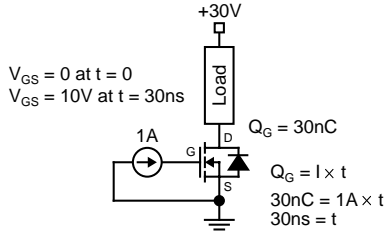


Figure 4. Simplified Gate Drive Circuit

If we have one MOSFET with a gate charge of 60nC at a V_{GS} of 10V, switching at 500kHz, then we need fast rise and fall times to achieve high efficiency. Rise and fall times of 50ns will work for the design. (Rise and fall times give the best representation of total switching time. The delay times involved with charging and discharging the gate-to-source capacitance must be considered for proper design. The drain-to-source voltage does not change until the gate-to-source capacitance is charged or discharged, so using the drain-to-source switching time will not give the total time involved in switching.) The simple equation from above gives an output current of $60nC \div 50ns = 1.2A$. The peak output current of Micrel drivers is determined by the output resistance of the device at the intended supply voltage. The output stage of the low-side drivers consists of a totem-pole MOSFET configuration. The on-resistance of the output stage is the output resistance of the device, as given by the data sheet. Ohm's law determines the maximum current the device can supply. For example, the MIC4429 has an output resistance of 3.3Ω for a supply voltage of 10V, which means it can supply $10V \div 3.3\Omega$ or 3A. (With higher supply voltages, it can sink or source up to 6A of output current.) Therefore, for a gate charge of 60nC, the MIC4429 can switch the MOSFET in 20ns. This decreases the switching time of the MOSFET by 60% over a 1.2A sink/source driver that can switch the device in 50ns, improving efficiency.

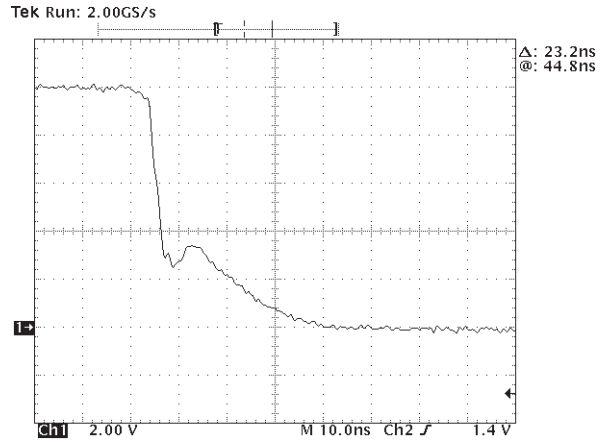
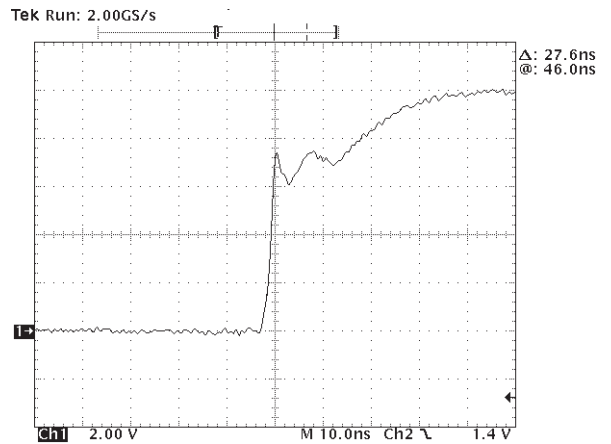


Figure 5a. Gate-to-Source Fall Time



Figures 5b. Gate-to-Source Rise Time

Figures 5a and 5b show the gate-to-source voltage of the International Rectifier IRFZ44 being driven by the MIC4429. Using the gate charge specification of 67nC from the data sheet, we can determine that the device should switch in $67nC \div 3A$, or 22ns. The actual rise time of the device is 27ns, which gives us 20% accuracy. If the measured output current (or output resistance) of the driver is determined, then the actual switching times could be predicted more accurately. Table 1 shows actual switching times of International Rectifier MOSFETs driven by the MIC4429 (see Figure 6 for circuit setup).

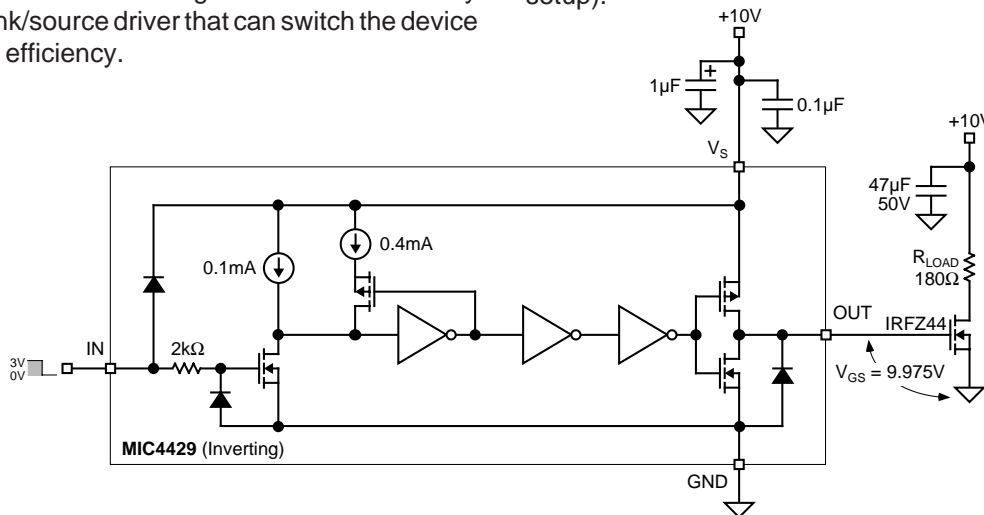


Figure 6. MIC4429 Block Diagram with External MOSFET and Load

International Rectifier		MIC4429	
MOSFET	Q _G	t _{RISE}	t _{FALL}
IRF610	8.2nC	3ns	4.2ns
IRF510	8.3nC	7.4ns	4.4ns
IRF520	16nC	11ns	9.7ns
IRFZ24N	25nC	11ns	9.4ns
IRF530	26nC	15.6ns	14ns
IRF9Z34	34nC	15.2ns	16ns
IRF730	38nC	19ns	15.6ns
IRF740LC	39nC	18.5ns	16.5ns
IRFBC40LC	39nC	17.7ns	14.9ns
IRFBC40	60nC	28.2ns	23.2ns
IRF840	63nC	30.4ns	23.2ns
IRF740	63nC	23.6ns	20.4ns
IRFZ44	67nC	27.6ns	23.2ns
IRF540	72nC	28ns	24.4ns
IRF1010N	130nC	47.2ns	37ns
IRF3710	190nC	60.8ns	47ns

Table 1. Actual MOSFET Switching Times

Figure 7 shows the switching waveforms of the MIC4416 driving an IRF7413 N-channel MOSFET, which is controlling power to a 12Ω load (Figure 8). The MIC4416 is a 1.2A low-side MOSFET driver in the IttyBitty™ SOT-143 package, the smallest low-side driver in the industry. The IRF7413 has a maximum gate charge of 60nC at V_{GS} = 10V.

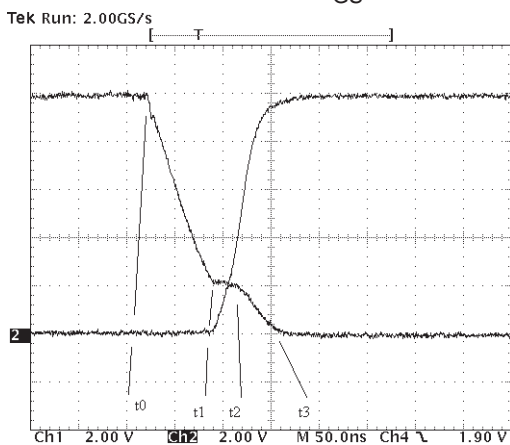


Figure 7. MOSFET Voltage Waveforms

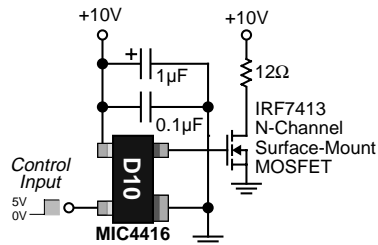


Figure 8. IttyBitty™ Low-Side Driver Application

The waveforms of Figure 7 show the gate-to-source voltage and drain-to-source voltage of the MOSFET. The waveforms show the MIC4416 sinking current to discharge the gate of the MOSFET. The drain-to-source voltage has a delay time, from t₀ to t₁, while the gate-to-source capacitance is discharging. The drain-to-source voltage starts to rise at time t₁; the MOSFET turns off and the drain-to-source resistance increases. From t₁ to t₃ the device is discharging the Miller effect capacitance and switches the device completely off. The fall time of the gate-to-source voltage accurately represents the total switching time of the device, incorporating the delay time and switching time of the MOSFET. At 10V supply, the MIC4416 can sink 0.6A of output current maximum (Figure 9), which gives us a switching time of 60nC/0.6A = 100ns. The 90% to 10% fall time of the gate-to-source voltage is 110ns, within 10% of the calculated switching time result for this particular MOSFET.

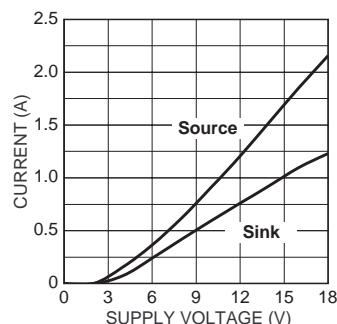


Figure 9. MIC4416/17 Peak Output vs. Supply Voltage

Conclusion

The design of a MOSFET driving circuit is relatively simple when using the proper design parameters. Gate charge allows the user to easily determine which type of driver is necessary based on the output current of the device. Micrel's low-side MOSFET driver family allows the designer to optimize the switching characteristics of the MOSFET for the application.

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