

Low-Side MOSFET Gate Drivers in Power Applications

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PURPOSE

The purpose of this application note is to support the circuit designer in choosing the right low-side MOSFET Gate driver for their power design. **This is directly applicable for the whole portfolio of Microchip's low-side MOSFET Gate Drivers.**

This document will briefly describe:

- What is a low-side MOSFET driver
- Why it is needed in power applications
- What applications require this type of driver
- What to consider in choosing the right driver for your design
- Layout guidelines.

Figure 1 illustrates the Low-Side MOSFET Configuration:

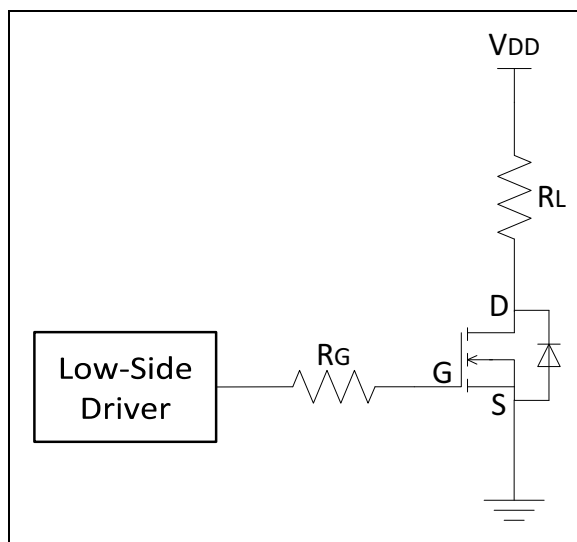


FIGURE 1: Low-Side MOSFET Configuration.

GENERAL INFORMATION

MOSFET Gate Drivers are electronic devices used to enhance the operation of a MOSFET as a switch by charging and discharging the gate capacitor at high currents and speed. MOSFET Gate Drivers are used in fast switching and high-power applications in which case a gate control signal capable of sinking and sourcing high peak currents is required.

Another important feature of the MOSFET gate drivers is that the voltage level present at the output of the driver is enhanced from typically 5V input voltage level to higher voltage levels, typically up to the maximum supply voltage level of the driver. There are many drivers in Microchip's portfolio, but one must be aware of the many existing trade-offs.

One of the most relevant trade-offs is between low switching losses and low EMI, because the latter implies slow rise and fall time for the control signal.

For a better understanding of the low-side gate drivers, a deep study of the MOSFET and its parasitic elements are required, because these elements highly influence MOSFET's operation. These elements are listed below and illustrated in Figure 2:

- Parasitic capacitors: C_{GS} , C_{GD} , C_{DS}
- Body diode: D_{SD}
- On state resistance: $R_{DS(ON)}$
- Parasitic inductances: L_G , L_D , L_S

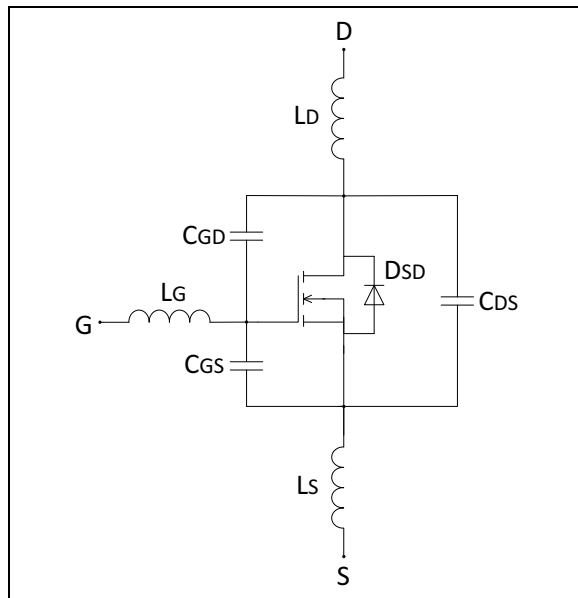


FIGURE 2: MOSFET and its Parasitic Elements.

During the process of turning ON the MOSFET, a large constant parasitic capacitor C_{GS} connected between the gate and the source charges up until the voltage between these terminals reaches the gate-source threshold voltage ($V_{GS(th)}$) of the MOSFET.

While this voltage is present, a small non-linear capacitor C_{GD} also known as “Miller” capacitor charges up. At this time, the gate to source voltage remains at the $V_{GS(th)}$ level and the MOSFET runs in the linear region.

Once this period ends, the gate to source voltage increases and reaches MOSFET driver peak drive voltage and the MOSFET becomes fully enhanced allowing current to flow from drain to source.

The current flowing through the drain and source will have a resistance, which is typically known as the ON resistance, noted as $R_{DS(ON)}$. This resistance has an inversely proportional relationship with respect to the voltage applied across the Gate to Source (V_{GS}), of MOSFET. Meaning the higher the V_{GS} , the lower the $R_{DS(ON)}$. Generally, the goal is to have the lowest $R_{DS(ON)}$ while the MOSFET is conducting current to minimize the power loss while switched on.

During the on state the stray drain to source capacitor C_{DS} is charged. To turn OFF the MOSFET, charge must be removed from the gate capacitance. This can be achieved by applying 0 volts or ground to the gate. It should be noted, removing voltage only does not ensure the MOSFET will turn OFF, there must be a path to ground from the gate.

Another element that is inherently present in MOSFETs is the body diode, which can conduct if voltage is reversed bias across drain to source. Reverse conduction can occur typically with inductive loads. The gate, drain and source terminals each have stray

inductances L_G , L_D and L_S . The stray inductance L_G contributes to the ringing of the gate signal especially when the MOSFET switches rapidly. The way to limit this effect is to place a resistor of a few ohms in series with the MOSFET gate. One must be aware of the trade-off, as a big resistor will greatly slow the charging of the gate capacitance and therefore the MOSFET will turn ON and OFF slower. However, in some cases a resistor of a few ohms is not enough to limit the ringing on the gate signal.

One of the most important parameters in choosing the gate driver for the MOSFET is the total gate charge Q_G which is the sum of the gate to source charge and the gate to drain charge. When choosing the appropriate low side MOSFET gate driver one must calculate the amount of current the driver must be able to deliver.

This is calculated over the time t_s which is the switching time by using the known total gate charge Q_G from the data sheet of the MOSFET:

$$I_G = \frac{Q_G}{t_s}$$

LOW-SIDE VS. HIGH-SIDE GATE DRIVERS

MOSFETs are used in different configurations. The most popular are high-side and low-side configurations. This document will only focus on the low-side configuration, but it will briefly mention the difference between the two types. The high-side gate drivers will drive a MOSFET which is connected between the source and load. The drain of the MOSFET is connected to the power supply and the source is connected to the load of the circuit. In the low side configuration, the MOSFET is connected between the load and the ground. The drain is connected to the load of the circuit while the source is connected to the ground. Looking at both types of configurations, below we can easily see that in the case of the high-side configuration the gate to source voltage applied by the driver of the MOSFET must be higher than the supply voltage to ensure voltage across gate to source is higher than the threshold voltage. Low-Side MOSFETs are easier to drive as the gate to source voltage applied is referenced to ground, as opposed to the high-side configuration where their source is essentially floating.

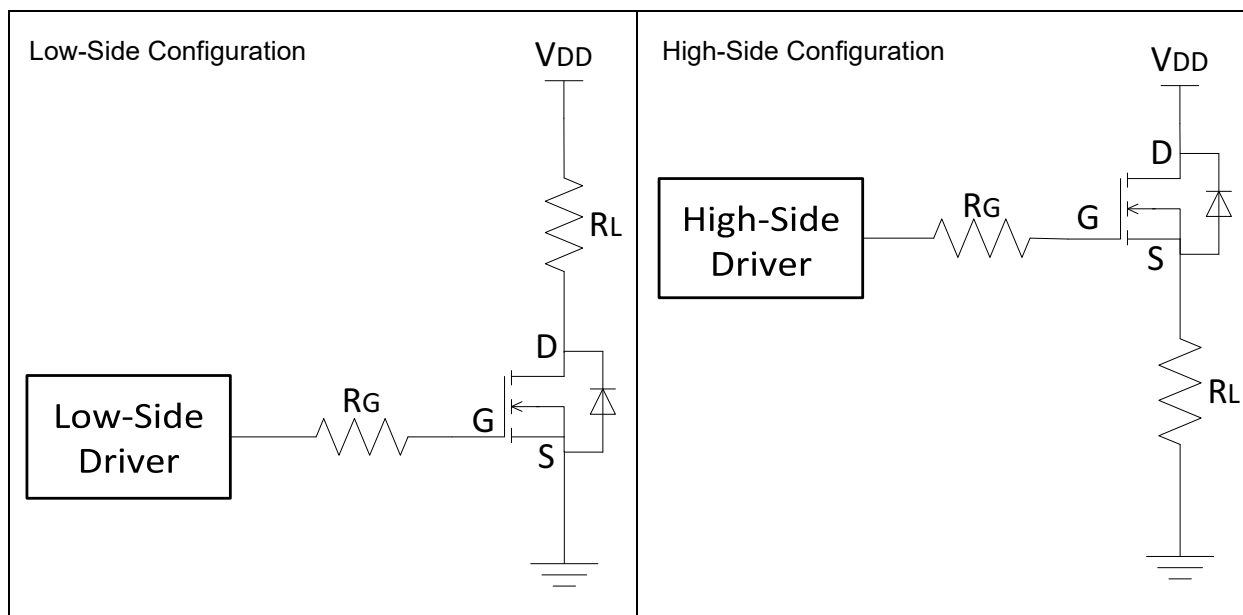


FIGURE 3: Low-Side vs. High-Side MOSFET Configurations.

LOW-SIDE MOSFET GATE DRIVERS APPLICATIONS

Low-side gate drivers are used in many applications of which the most common are Switch Mode Power Supplies, motor control circuits, power relays or load switches. Besides the supply voltage the parameters that characterize a low-side MOSFET Gate driver are the source and sink current capabilities, the rise time and fall time and the propagation delays. Not all drivers excel in every type of application without additional circuitry and higher costs and therefore one must be aware of the existing trade-offs in choosing the right parameters for their specific application.

DC-DC Isolated Converters that Require Low-Side MOSFET Gate Drivers

PUSH-PULL TOPOLOGY

This topology is used in isolated converters, both in inverters and DC-DC converters and it can be used for stepping up the input voltage or stepping it down. It has the capability of handling high voltages and switching frequencies, and it can have multiple outputs while providing different output voltages. It is often used in applications such as photovoltaic panels, fluorescent lamps, communication systems, medical instruments and many others.

A typical schematic of a DC-DC push-pull converter is shown in [Figure 4](#).

The operating principle consists of switching the input voltage connected to the center tap of the primary winding of the transformer. This is accomplished via the two MOSFETs that are configured on the low-side and are

driven so that a pulsating signal is formed on the primary side. The two MOSFETs are driven so that they are never ON at the same time by having “dead time” before each ON transition. This is a critical aspect of driving the MOSFETs as they can create an undesired short circuit, commonly known as shoot through. During the time when Q_1 is ON and Q_2 is OFF, the current comes from V_{IN} and goes through NP_1 winding entering from the dot marked terminal and exiting through the other terminal. V_{IN} is reflected to the secondary side making D_1 reversed biased and D_2 forward biased so the current flows through the inductor and the output capacitor and finally to the load. When Q_1 is turned OFF and Q_2 is turned ON, the body diode of Q_1 allows the leakage energy stored in the primary side of the transformer to forward bias D_1 through which half of the output current flows.

The criteria for choosing the drivers for applications with push-pull configuration:

- High Capacitive Load Drive Capability
- Short Delay Times
- Inverting and Non-Inverting Output Versions

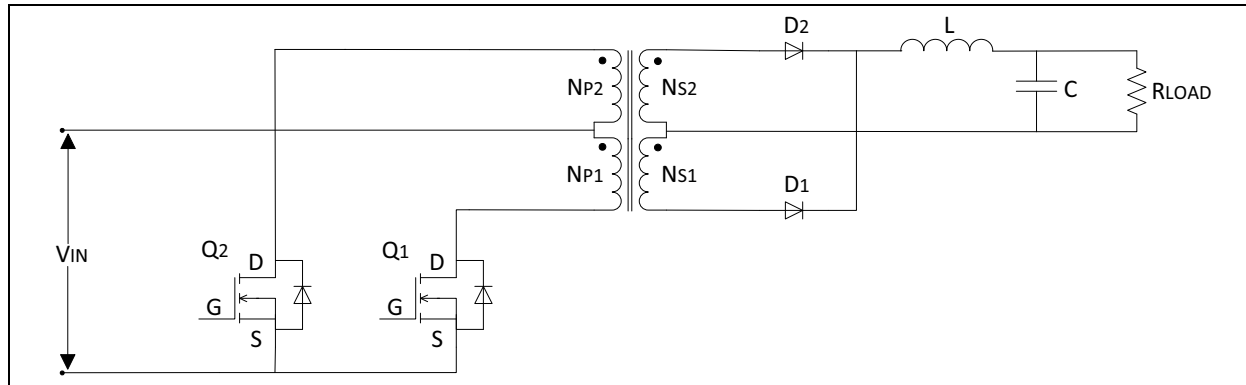


FIGURE 4: Push-Pull Topology.

FORWARD TOPOLOGY

This topology, shown below in Figure 5 is a derivative of push-pull topology described previously and so the working principle is similar. When Q_1 is ON, D_1 is reversed biased as the dot end of the N_R winding has a higher voltage than the non-dot end. The same happens in the N_P winding case as the dot end is connected to the positive terminal of the V_{IN} power supply and the non-dot end is connected to the negative terminal of V_{IN} via MOSFET Q_1 . Following the circuit path, on the secondary side the N_S winding has

the dot-end of positive polarity and the non-dot end negative polarity and so D_2 is forward biased while D_3 is reversed biased and thus making a path to the inductor and the output capacitor and load. When Q_1 is OFF the voltage is reversed and so D_1 becomes forward biased allowing the current to flow to V_{IN} . The voltage across the secondary winding N_S is also reversed and therefore D_2 becomes reversed biased while D_3 is forward biased and so allowing the current to flow in the inductor.

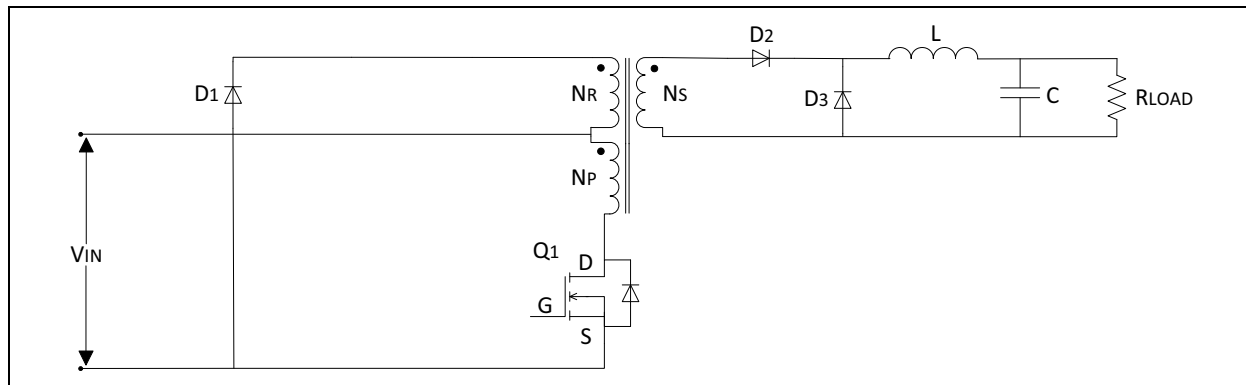


FIGURE 5: Forward Topology.

The criteria for choosing the drivers for applications with forward configuration:

- High Capacitive Load Drive Capability
- Short Delay Times
- High Peak Output Current

FLYBACK TOPOLOGY

Flyback converters are buck-boost isolated converters with low-side MOSFET configuration that can be both AC-DC and DC-DC converters. They are most commonly used in AC-DC brick chargers and in every digital gadget that you can think of. Other applications include lighting, PC power supplies, lasers, copiers, TVs and many more. They have galvanic isolation between the input and output making them safe for users.

This topology is very different from other isolated converters because the flyback transformer stores energy much like coupled inductors. In the other isolated converters, the transformer only reflects the input side to the output side and steps it up or down. A flyback converter can also have multiple outputs at different voltages and different polarities, which makes it a very versatile topology.

The operation of a flyback converter is defined by two stages. The first part is meant for energy storage in the magnetizing inductance on the primary side of the flyback transformer when Q_1 MOSFET is ON. In the second part Q_1 turns OFF which makes transformer reverse its voltage in the secondary winding, forward biasing the diode D_1 and making a path to the output capacitor and the load.

The criteria for choosing the drivers for applications with flyback configuration:

- High Capacitive Load Drive Capability
- Short Delay Times

- High Peak Output Current

A typical schematic of a flyback topology is shown in [Figure 6](#).

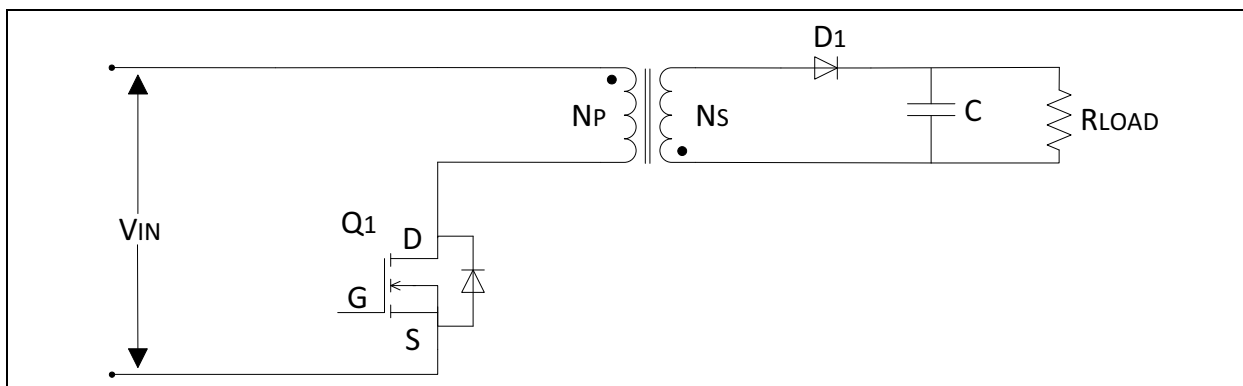


FIGURE 6: Flyback Topology.

DC-DC Non-Isolated Converters that Require Low-Side MOSFET Gate Drivers

SINGLE ENDED PRIMARY INDUCTANCE CONVERTER (SEPIC) TOPOLOGY

This topology works similarly to the flyback converter. SEPIC converter uses either two separated inductors or two coupled inductors. The two inductors must be very well matched to have the best performance in terms of output current and therefore better efficiency. Compared to the flyback converters, SEPIC is superior in terms of efficiency because the series coupling capacitor reduces the leakage from the inductor and therefore solves this issue which is the main disadvantage of the flyback topology.

When Q_1 MOSFET is OFF, D_1 is forward biased. The coupling capacitor C_1 is charged by L_1 which was charged when Q_1 was ON. It is during OFF state of the

MOSFET when the current goes to the output capacitor and load via the forward biased diode D_1 . During this time the voltage across L_2 inductor is equal to the output voltage. As Q_1 turns ON, D_1 becomes OFF and therefore the coupling capacitor C_1 and L_2 becomes a parallel configuration so that the voltage across L_2 is the reversed V_{IN} voltage.

The criteria for choosing the drivers for SEPIC converter applications:

- High Capacitive Load Drive Capability
- Short Delay Times
- High Speed Switching Capability

A typical schematic of a SEPIC topology is shown in Figure 7.

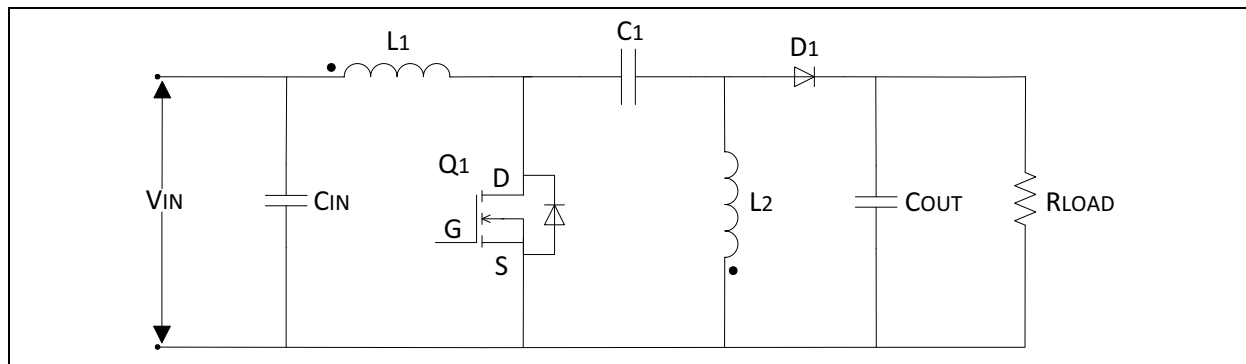


FIGURE 7: SEPIC Topology.

Synchronous Converters Topologies

Synchronous Converters are highly popular versions of the classic converters because of their high efficiency. Among the most popular synchronous converters are the buck converters which have the freewheeling diode replaced with a MOSFET. This is due to the fact that MOSFETs can have very low $R_{DS(ON)}$ which results in lower voltage drop, when compared to forward voltage of a diode, in the ON phase of switching and therefore lower losses. This type of converter is highly utilized in applications which require high currents at low output voltages such as LED drivers which can be found in the automotive industry.

SERIES RESONANT LLC TOPOLOGY

Another popular type of synchronous converter is the LLC converter. It can be found in many applications such as LED drivers, battery chargers, renewable energy generation systems and many others. They are described as having high input voltages and low output voltages at high currents. This topology consists of three parts. The input stage which is formed of two N-channel MOSFETs Q_1 and Q_2 in a half-bridge configuration where the MOSFETs are driven

alternatively. It has the role of generating a square wave signal. The next stage is the resonant tank which consist of the resonant capacitor C_R , the resonant inductor L_R and the magnetizing inductor L_M . These elements have the purpose of generating two resonating frequencies. The last stage is the synchronous rectification block which is formed by two low-side N-channel MOSFETs Q_3 and Q_4 which have the purpose of rectifying the secondary side signal which is a sinusoidal waveform. The rectified signal is low-pass filtered by the output capacitor C_{OUT} resulting in a DC output voltage.

LLC converter operates in three modes: at resonance, below resonance and above resonance. In each operation mode the stray capacitors and the body diodes of each MOSFET play a very important role in the functionality of the converter.

The operation at resonance is described by having the MOSFETs switching at the same frequency as the resonant frequency. This is achieved by properly selecting the components from the resonant tank portion of the converter. When the circuit operates below resonance the sine wave period is shorter than the switching period. Because of that the synchronous

MOSFETs in the secondary side have to be driven so that they turn OFF when the current goes to zero. Above resonance the circuit's behavior is reversed to the below resonance mode and so in this case the synchronous switches are turning ON and OFF when the MOSFETs in the primary side turn ON and OFF.

The synchronous rectification section is characterized by two low-side MOSFETs which must be carefully turned ON and OFF as this topology generally is switching at high frequencies.

When choosing the gate driver one must calculate the power dissipation of the driver at the maximum working frequency of the LLC converter.

A typical schematic of a LLC topology is shown in [Figure 8](#).

The criteria for choosing the drivers for LLC converter applications:

- High Capacitive Load Drive Capability
- High Peak Output Current
- Short Delay Times

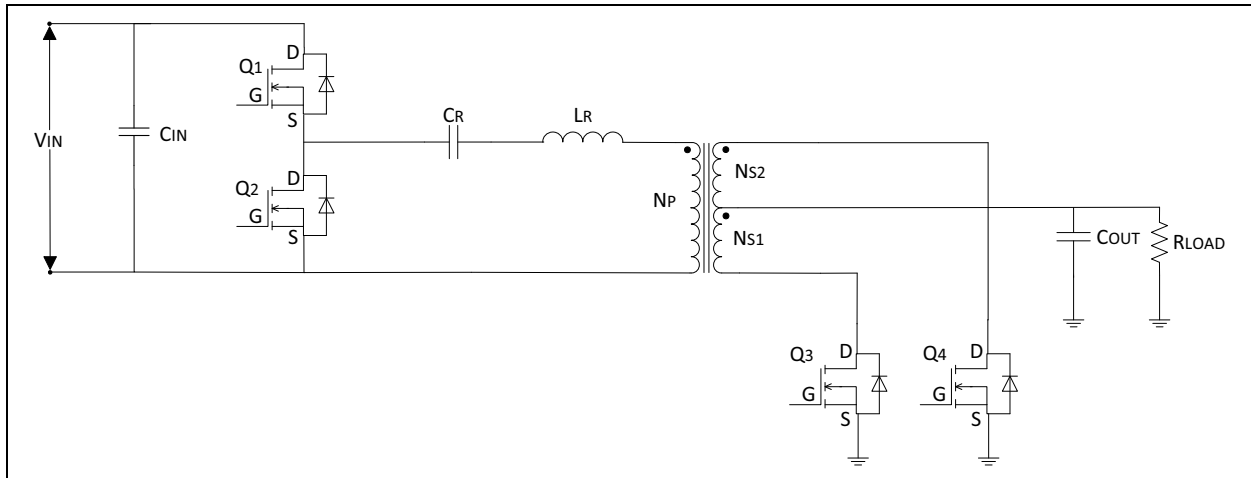


FIGURE 8: LLC Topology.

Discharge Circuit

Every power supply has output capacitors, sometimes these capacitors have very high capacitances and so the discharge process takes a lot of time and in doing so it becomes a danger for users. In order to avoid electrical hazards, especially in high-voltage and high-power applications such as chargers for electrical vehicles, discharge circuits are absolutely essential. Such circuit is usually based on a low-side MOSFET and the adequate driver. In this type of applications usually the discharge circuit is separate from the controlling circuitry by having them on different PCBs, therefore a low-pass filter capacitor has to be designed at the input of the driver in order to filter the ripple that comes with the long trace. The ripple can potentially create false triggers on the discharge circuit.

A typical schematic of a Discharge Circuit is shown in [Figure 9](#).

The criteria for choosing the driver for Discharge Circuits applications:

- High Speed Switching Capability
- Short Delay Times
- High Capacitive Load Drive Capability

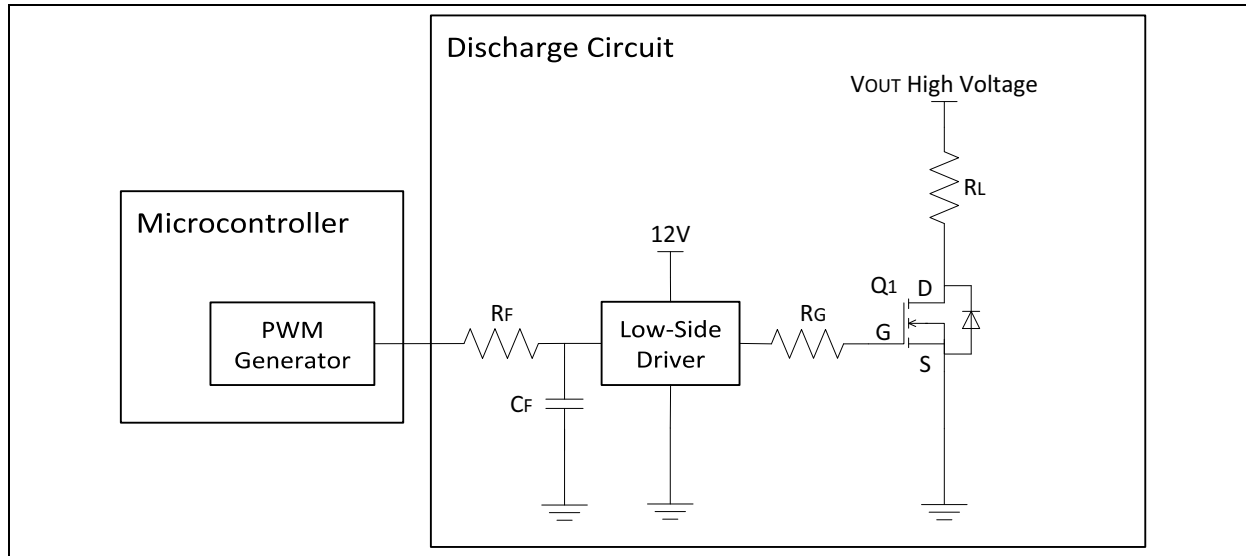


FIGURE 9: Discharge Circuit.

Low-Side MOSFET Gate Drivers in Brushed DC Motor Applications

BDC Motors are found in many household applications such as washing machines, kitchen robots, vacuum cleaners, and in many other markets. A low-side gate driver is used to enable the user to control the current in the motor and by doing so controlling its speed.

Low-side gate drivers find their place in brushed DC motor applications with configurations such as single MOSFET low-side and H-bridge. Ideally, the driving signal in motor control applications should have a slow ON transition and a fast OFF transition as this is the requirement of most BDC motor applications.

SINGLE MOSFET LOW-SIDE CONFIGURATION

In BDC motor applications a driver is required in a low-side topology when more than a few mA of current are required to run the motor. With such a configuration the motor will only spin in one direction. The speed at which the motor spins is related to the Back Electromotive Force (BEMF) which is described as a voltage that appears in the reversed direction of the current flow. This occurs when the MOSFET turns OFF as the current is still present in the windings of the motor and begins to flow in the reverse direction. Therefore a protection diode across the motor terminals is required.

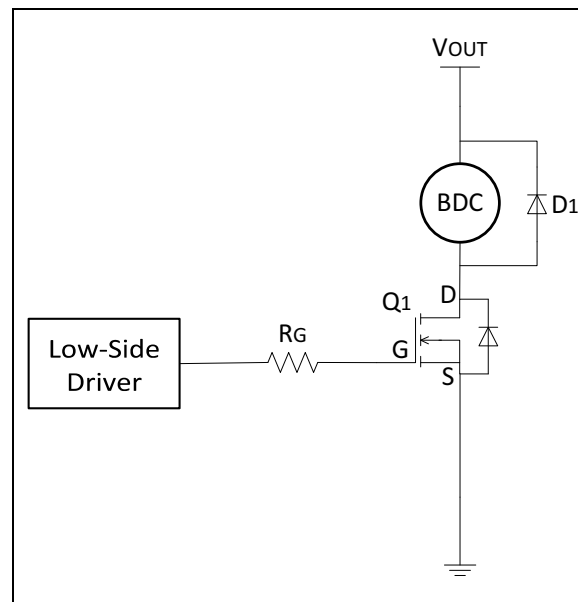


FIGURE 10: Single Low-Side MOSFET BDC Motor Circuit Configuration.

H-BRIDGE CONFIGURATION

If bidirectional spin is required in a motor application, a much more complex configuration is required. One way to do it is by using what is called an H-bridge topology. In a H-bridge configuration there are four “switches”: two low-side MOSFETs and two high-side MOSFETs. By driving these MOSFETs in different ways one can achieve four modes, one of which is mandatory as a first step before starting to run the motor. This is the idle mode which is when all the MOSFETs are turned OFF. This mode assures that the MOSFETs are in a known state preventing two scenarios that are hazardous. One unwanted scenario is to have the pair of Q_1 and Q_2 or Q_3 and Q_4 shorted which will result in a short between the ground and the power supply. The other undesired scenario is when the terminals of the motor are shorted together resulting in an equivalent infinite load. Both scenarios must be avoided to prevent damaging the power supply and the driving circuit.

H-Bridge Configuration operation modes:

- Forward - ON: Q_1, Q_4 ; OFF: Q_2, Q_3
- Reverse - ON: Q_2, Q_3 ; OFF: Q_1, Q_4
- Idle - all MOSFETs are OFF
- Break - ON: Q_2, Q_4 ; OFF: Q_1, Q_3

Typically a group of a diode and a capacitor in parallel configuration is placed in parallel with each MOSFET of the H-Bridge Configuration. It has the purpose of RF interference and BEMF protection.

A typical H-bridge topology for BDC Motor Driving Circuit is shown in [Figure 11](#).

The criteria for choosing the drivers for BDC motor applications:

- High Capacitive Load Drive Capability
- Short Delay Times
- Low Output Impedance

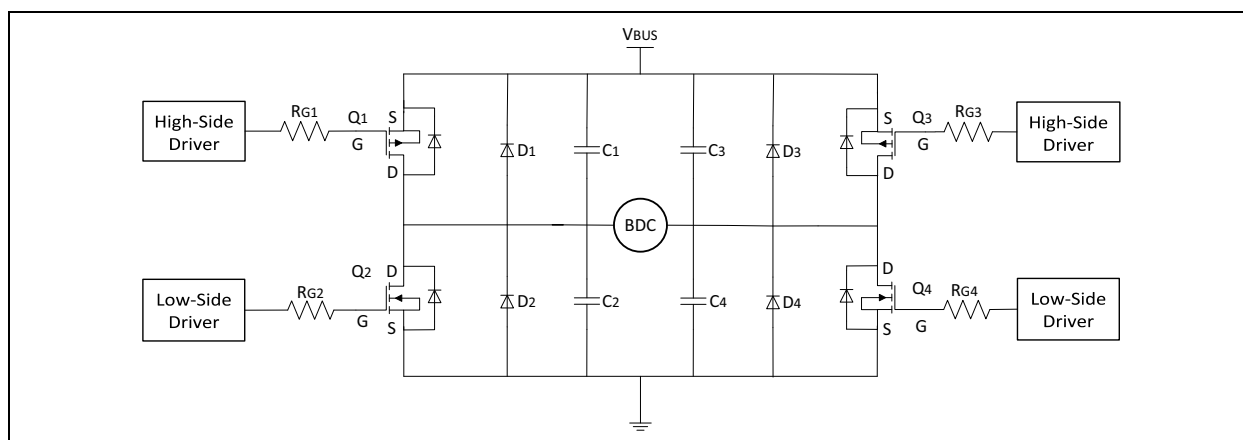


FIGURE 11: H-bridge BDC Motor Circuit Configuration.

Low-Side Gate Drivers in Relay Applications

Low-side MOSFET gate drivers also find their place in **latching** and **non-latching** relay applications. Typically a low-side MOSFET is controlled in order to turn ON and OFF the coil which is found in the primary side of a relay.

Relays have two parts: the primary side which is a coil and the secondary side which is an armature which is mechanically switched. When the coil in the primary side is energized, the electromagnetic field created controls the armature from the secondary side in either creating a conducting path for the load or switching it OFF.

Non-latching relays are typically found in low-power applications such as push buttons. The functionality is different from the latching relay. In this case when the MOSFET is conducting, the coil from the primary side of the relay first switches the armature on the secondary side ON and then immediately turns it OFF.

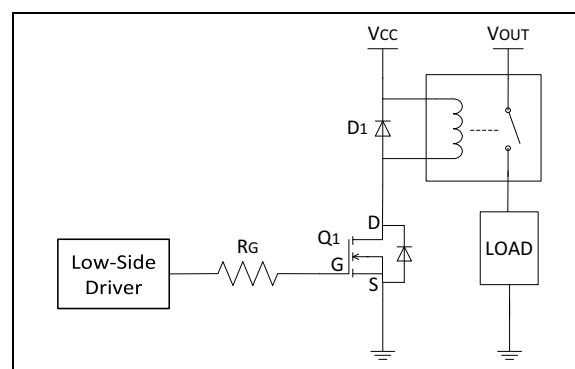


FIGURE 12: Low-Side Circuit Configuration for Relays.

Latching relays are present in high load current applications for home lighting control, security equipment and many other applications. They behave as switches as they remain in the position that was previously set and can have one or multiple coils making them very versatile. These relays can be found in many circuit

configurations and can be driven by multiple low-side MOSFETs. Depending on the requirements of the application, one or multiple low-side gate drivers can be required.

Refer to [Figure 11](#) for simple single Low-Side Configuration and to [Figure 13](#) and [Figure 14](#) for double or H-bridge driving circuits for relay applications.

The criteria for choosing the drivers for applications with relays:

- High Peak Output Current
- Latch-up protected
- Matched and Short Delay Times
- Symmetrical Rise and Fall Times
- Low Output Impedance

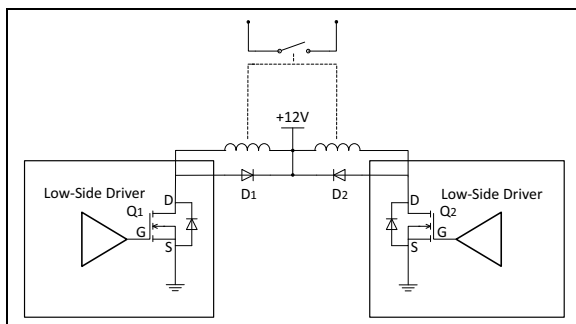


FIGURE 13: *Dual Coil Latching Relay Driving Circuit.*

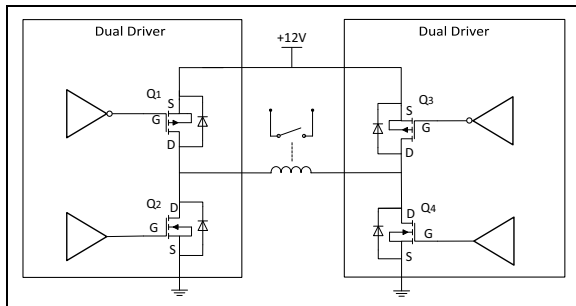


FIGURE 14: *H-bridge Latching Relay Driving Circuit.*

RECOMMENDED LOW-SIDE MOSFET GATE DRIVERS

The [Table 1](#) provides the recommended low-side MOSFET gate drivers for each type of application.

TABLE 1: RECOMMENDED LOW-SIDE MOSFET

Part Number	DC-DC Isolated Converters			DC-DC Non-Isolated Converters		Discharge Circuit	Brushed DC Motor Driver		Relay Applications		
	Push-Pull	Forward	Flyback	SEPIC	Series Resonant LLC		Single MOSFET	H-bridge	Single MOSFET	Dual Coil Latching Relay	H-bridge Latching Relay
MCP14A1201		✓	✓	✓		✓	✓				
MCP14A1202		✓	✓	✓		✓	✓				
MIC4451		✓	✓	✓		✓					
MIC4452		✓	✓	✓		✓					
MCP14A0901		✓	✓	✓		✓	✓				
MCP14A0902		✓	✓	✓		✓	✓				
MIC4421		✓	✓	✓		✓					
MIC4421A		✓	✓	✓		✓					
MIC4422		✓	✓	✓		✓					
MIC4422A		✓	✓	✓		✓					
MCP14A0601		✓	✓	✓		✓	✓				
MCP14A0602		✓	✓	✓		✓	✓				
MCP1406		✓	✓	✓		✓					
MCP1407		✓	✓	✓		✓					
MIC4120		✓		✓		✓					
MIC4129		✓		✓		✓					
MIC4420		✓	✓	✓							
MIC4429		✓	✓	✓							
MIC44F20		✓	✓	✓		✓					
MCP14A0451		✓	✓	✓		✓	✓				
MCP14A0452		✓	✓	✓		✓	✓				
MCP14A0453	✓				✓			✓		✓	
MCP14A0454								✓			
MCP14A0455								✓			
MCP1403											
MCP1404											
MCP1405	✓				✓			✓		✓	
MCP14E3											
MCP14E4											
MCP14E5	✓				✓					✓	
MIC4223											
MIC4224											
MIC4225	✓				✓			✓		✓	
MCP14E9											
MCP14E10											
MCP14E11	✓				✓			✓		✓	
MCP14A0301		✓	✓	✓		✓	✓				
MCP14A0302		✓	✓	✓		✓	✓				

TABLE 1: RECOMMENDED LOW-SIDE MOSFET (CONTINUED)

Part Number	DC-DC Isolated Converters			DC-DC Non-Isolated Converters		Discharge Circuit	Brushed DC Motor Driver		Relay Applications		
	Push-Pull	Forward	Flyback	SEPIC	Series Resonant LLC		Single MOSFET	H-bridge	Single MOSFET	Dual Coil Latching Relay	H-bridge Latching Relay
MCP14A0303								✓			
MCP14A0304								✓			
MCP14A0305	✓				✓			✓		✓	
MIC4123											
MIC4124											
MIC4125	✓				✓			✓		✓	
MIC4423											
MIC4424											
MIC4425	✓				✓			✓		✓	
MCP14E6											
MCP14E7											
MCP14E8	✓				✓					✓	
MCP14A0151		✓	✓	✓		✓					
MCP14A0152		✓	✓	✓		✓					
MCP14A0153											
MCP14A0154											
MCP14A0155	✓				✓			✓		✓	
MCP1416		✓	✓	✓		✓		✓			
MCP1416R		✓	✓	✓				✓			
MCP1415		✓	✓	✓		✓		✓			
MCP1415R		✓	✓	✓				✓			
MIC4126											
MIC4127											
MIC4128	✓				✓			✓		✓	
MIC4414		✓	✓	✓		✓					
MIC4415		✓	✓	✓		✓					
MIC4426											
MIC4427											
MIC4428	✓				✓			✓		✓	
MIC4416		✓	✓	✓							
MIC4417		✓	✓	✓							
MIC4467								✓			✓
MIC4468								✓			✓
MIC4469								✓			✓
MCP14A0051		✓	✓	✓			✓				
MCP14A0052		✓	✓	✓			✓				
MCP1401		✓	✓	✓							
MCP1402		✓	✓	✓							
MIC5020		✓	✓			✓					
TC4451		✓	✓	✓			✓		✓		
TC4452		✓	✓	✓			✓		✓		

TABLE 1: RECOMMENDED LOW-SIDE MOSFET (CONTINUED)

Part Number	DC-DC Isolated Converters			DC-DC Non-Isolated Converters		Discharge Circuit	Brushed DC Motor Driver		Relay Applications		
	Push-Pull	Forward	Flyback	SEPIC	Series Resonant LLC		Single MOSFET	H-bridge	Single MOSFET	Dual Coil Latching Relay	H-bridge Latching Relay
TC4421		✓	✓	✓		✓	✓				
TC4421A		✓	✓	✓		✓	✓				
TC4422		✓	✓	✓			✓				
TC4422A		✓	✓	✓			✓				
TC429		✓	✓	✓		✓					
TC4420		✓	✓	✓		✓	✓				
TC4429		✓	✓	✓		✓	✓				
TC1413		✓	✓	✓		✓			✓		
TC1413N		✓	✓	✓		✓			✓		
TC4423											
TC4423A								✓			
TC4424											
TC4424A								✓			
TC4425	✓				✓			✓		✓	
TC4425A	✓				✓			✓		✓	
TC1412		✓	✓	✓		✓			✓		
TC1412N		✓	✓	✓		✓			✓		
TC426											
TC427											
TC428	✓				✓			✓		✓	
TC4404								✓			
TC4405								✓			
TC4426											
TC4426A											
TC4427											
TC4427A											
TC4428	✓				✓			✓		✓	
TC4428A	✓				✓			✓		✓	
TC4626											
TC4627											
TC1426											
TC1427											
TC1428	✓				✓			✓		✓	
TC4467								✓			✓
TC4468								✓			✓
TC4469								✓			✓
TC1411		✓	✓			✓			✓		
TC1411N		✓	✓			✓			✓		
TC1410		✓	✓	✓		✓			✓		
TC1410N		✓	✓	✓		✓			✓		

PCB LAYOUT CONSIDERATIONS

It is highly recommended to have short power and ground traces. A good practice is to have planes for these signals in order to minimize the inductance and therefore the transients that can lead to inconvenient behaviors such as errors in MOSFETs turning ON and OFF, slow apparent rise and fall time, ground shifting, spikes on the supply voltage that can exceed the ratings of the gate driver as well as MOSFET ratings. Another important practice is to have the decoupling capacitors placed as close as possible to the power and ground pins to filter out the possible transients going into the power supply of the driver.

The gate driving signals should have short traces as well to avoid the additional stray inductance that can produce excessive ringing, a behavior which is very inconvenient especially in the fast switching and high current applications in which cases the power losses can become greatly increased.

POWER DISSIPATION

When calculating the total power dissipation P_T in a MOSFET driver there are three different power dissipation parts that should be considered:

- Load Power Dissipation - P_L
- Quiescent Power Dissipation - P_Q
- Operating Power Dissipation - P_{CC}

$$P_T = P_L + P_Q + P_{CC}$$

Load power dissipation is different depending upon the type of load.

Resistive Load Power Dissipation

The dissipation produced by a resistive load is the product of the following elements:

- The load current I
- The output resistance of the driver when it is in the high state R_O
- The duty cycle / the portion of time when the load is conducting D

$$P_L = I^2 \times R_O \times D$$

Capacitive Load Power Dissipation

The dissipation produced by a capacitive load is described by the energy lost in the driver when the load is charged or discharged. The energy stored in a capacitor is described as follows:

$$E = \frac{1}{2} \times C \times V^2$$

Where:

- C = capacitance
- V = voltage across the capacitance

Having the energy stored in a capacitor described as above, the power dissipation in a driver caused by a capacitive load can be described as the following product:

$$P_L = f \times C \times V_S^2$$

Where:

- f = switching frequency
- V_S = supply voltage of the driver

Inductive Load Power Dissipation

During the period when the gate driver is delivering current to the inductor the power dissipation is described the same as in the resistive load case:

$$P_{LI} = I^2 \times R_O \times D$$

Where:

R_O may be the on resistance of the driver when the driver output is high or low depending upon how the inductor is connected.

When the inductor delivers power to the driver the power dissipation is described as:

$$P_{L2} = I \times V_D \times (1 - D)$$

Where:

- V_D = forward drop across the clamping diode in the driver (around 0.7V).

Adding the two parts together the power dissipation is:

$$P_L = P_{LI} + P_{L2}$$

Quiescent Power Dissipation

The quiescent power dissipation is related to the quiescent current that is drawn when the driver is not switching or does not have any load. It can be calculated as follows:

$$P_Q = (I_{QH} \times D + I_{QL} \times (1 - D)) \times V_{DD}$$

Where:

I_{QH} = quiescent currents in the high states.

I_{QL} = quiescent currents in the low states.

D = duty cycle.

V_{DD} = supply voltage for the MOSFET driver.

Operating Power Dissipation

Due to the cross-conduction current that is present when, for a short period of time, the two MOSFETs form the output stage of the driver are simultaneously on, a power dissipation occurs and it is described as the product of three elements:

- The switching frequency f
- The cross-conduction constant CC
- The supply voltage for the MOSFET gate driver V_{DD}

$$P_{CC} = f \times CC \times V_{DD}$$

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