Application Note

How to Choose a Gate Driver for DC Motor Drives

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ABSTRACT

To choose an appropriate gate driver, it is important to consider the balance of robustness, size versus cost, and compatibility with other system components (for example, the microcontroller and power switches). This application note focuses on gate driver ICs for DC motor drives like brushless DC, stepper, or linear motors. Table 6-1 and Table 6-2 summarize common design considerations and compare relevant half-bridge and low-side gate drivers.

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1 Introduction

Where there is a motor, there is a need for a driver component. Given the amount of driver options available, even from a single manufacturer, choosing the correct driver can be overwhelming. And for each one, there is a long list of parameters. Which specifications or features do you focus on to make your decision?

Driver components can come in the form of gate driver ICs (standalone gate drivers) or motor driver ICs (power switches and drivers integrated into one package). Additionally, both categories can integrate motor control. This application note focuses on design considerations for choosing half-bridge and low-side gate driver ICs to use in DC motor drive applications such as:

- Brushed and brushless DC (BLDC) motors
- Stepper motors
- DC-input servo motors (permanent magnet synchronous motors)
- Linear motor coil arrays

For more information on motor driver ICs or integrated control gate driver ICs, see *Selecting the right level of integration to meet motor design requirements.*

2 Gate Driver IC Configurations

Bridge topologies for motor drive typically consist of one or more half-bridge stages: single half-bridge, two half-bridges (H-bridge), three half-bridges (BLDC), or four half-bridges (stepper). From TI's portfolio of gate driver ICs, you can choose a single driver that integrates multiple phases or opt for standalone half-bridges. This choice often comes down to the preference of the designer, considering points like:

- H-bridge and three-phase BLDC motor drivers simplify designs by integrating multiple half-bridge stages into one package.
- Using one half-bridge driver per phase minimizes the space between the driver and the power switch, reducing switching losses and EMI challenges.
- For more complex motor control, multi-phase devices sometimes offer automatic motor tuning, sensorless control, and system-level integration.
- Half-bridge drivers are more general-purpose, so a single part number can be used across different platforms (for example, three in a BLDC motor system and four in a stepper motor system).

For driving power switches referenced to ground, low-side drivers can also be considered for motor drive applications. One of the most common motor applications for low-side drivers is a brushed DC motor. These often use a single-switch chopper topology, which only requires a single-channel low-side driver. If the system has multiple low-side switches to drive, designers can also consider dual-channel low-side drivers.

While many topics covered in this document can be applicable to multiple device categories, this application note focuses primarily on standalone half-bridge and low-side gate drivers ICs (without integrated control or power switches). To browse all of TI's drivers for motor drives, visit the Motor Drivers overview page.

3 Key Voltage and Current Specifications

The primary specifications to consider when choosing a gate driver are:

- Gate driver voltages – V_{DD}, V_{HS}, and V_{HB} [1]
  - V_{DD} refers to the voltage on the positive supply rail (pin often named VDD or VGVDD or VCC).
  - V_{HS} (half-bridge drivers only) refers to the high-side source connection to the power switch (pin often named HS or SH). This can also be called the *switch node voltage*.
  - V_{HB} (half-bridge drivers only) refers to the voltage on the high-side bootstrap supply pin (often named HB or BST). V_{HB} is given as V_{HS} + V_{DD}.
- System voltage – V_{BUS}
  - V_{BUS} refers to the voltage at the drain of the high-side of a half-bridge (also called *DC link voltage*).
- Gate driver current – Peak source and sink currents (I_{PK})
  - Sometimes referred to as peak pullup and pulldown currents, or collectively as *drive strength*.

3.1 Voltage Ratings

The supply voltage (V_{DD}) is important to consider for both half-bridge and low-side drivers. This specification is primarily tied to the power switch. In addition to general flexibility, a wide V_{DD} range (for example, UCC27531: 10 V to 32 V) is an appropriate choice for SiC MOSFETs or IGBTs as the range provides greater margin on the gate driver output for the high gate-source voltage (V_{GS}) of these switches. Some systems require a lower V_{DD} operation so that the gate driver output is compatible with power switches like Si MOSFETs or GaN (for example, UCC27517: 4.5 V to 18 V).

In half-bridge driver circuits, it's also important to consider the V_{DD} to avoid violating key voltage specifications like V_{HB}–V_{HS}. So, before finalizing driver selection, check the recommended operating conditions table in the device's data sheet to verify the selected V_{DD} does not yield a violation in specifications.

In addition to the half-bridge driver's specifications, the other key voltage to consider is the system's bus voltage. This voltage, along with how much headroom makes sense for the system, informs the required V_{HS} and V_{HB}.

Common bus voltages for DC motor drive systems range from 12 V to 110 V (DC). Typically, systems use components rated 50–100% higher than the bus voltage. For example, for a 48-V system, a driver with 100-V or 120-V V_{HS} voltage typically provides adequate margin against transients. Systems with well-controlled noise often do not need as much headroom. In other cases, designers prefer to utilize drivers with increased margin rather than minimizing layout noise.

3.2 Peak Current

Typically, DC motor drive systems operate at lower frequencies (compared to power conversion applications) and thus do not require high current specifications. Thus, drivers optimized for motor applications often have peak currents less than 2 A. To drive multiple power switches in parallel or operate at higher frequencies, look to devices with fast switching characteristics and peak currents around 3 A or higher. For these reasons, higher-current devices can also be a good choice for driving the coil arrays of a linear motor power stage.

The minimum drive strength required by a system depends on characteristics of the system and gate driver. To estimate the minimum drive strength required, one must consider the parameters shown in Table 3-1.

[1] Note that V_{HB} and V_{HS} do not apply to low-side drivers.

Table 3-1. Summary of Parameters Used to Calculate Minimum Drive Strength for a Gate Driver

Parameter	Information source	Example value	Relationship
V_{GS} *Desired gate-source voltage*	System parameter	12 V	Higher values typically require higher current.
$Q_{G,max}$ *Maximum gate charge at desired V_{GS}*	Power switch data sheet (V_{GS} vs. Q_G curve, or maximum value in electrical characteristics table)	15 nC	Higher values typically require higher current.
$T_{ON,OFF}$ *Desired rise and fall time*	System parameter[2]	60 ns	Lower values (faster switching) typically require higher current.
N *Number of power switches driven by one driver output*	System	1 switch	Higher values (more switches in parallel) typically require higher current.

With this information, one can estimate the equivalent capacitance (C_{eq}):

$$C_{eq} = \frac{Q_{G,max} \times N}{V_{GS}} = \frac{15\,nC\ \times 1\,switch}{12\,V} = \frac{5}{4}\,nF \tag{1}$$

Which in turn, provide the minimum peak current:

$$I_{PK,min} = C_{eq} \times \frac{dV}{dt} = \frac{5}{4}\,nF \times \frac{12\,V}{60\,ns} = 0.25\,A \tag{2}$$

This example suggests choosing a driver with peak current specifications of at least 0.25 A. So, the peak drive strength capability of a driver like LM2105 (0.5 A/0.8 A) can suffice. To easily estimate this, please see the Excel tool provided in *[FAQ] LM2105: Half-Bridge Gate Driver Minimum Current Calculator*. For further explanation of key gate driver parameters mentioned previously, see *Fundamentals of MOSFET and IGBT Gate Driver Circuits*.

[2] This parameter refers to the rise and fall time of the power switch's input (for example, the gate of the MOSFET). This is also closely related to the rise and fall time of the switch node.

4 Robustness Features

When choosing a gate driver, it is important to consider how a device responds to undervoltage events, negative transients, or cross-conduction (in a half-bridge configuration). Robust specifications and integrated features allow gate drivers to have greater resilience to these events, contributing to greater reliability of the system.

4.1 Undervoltage Lockout

UVLO is a protection feature that pulls the driver output low until the supply voltage reaches a set threshold. Without a protection like this, excessive power dissipation can put the power switch at risk for damage. To read more, see *Low-Side Gate Drivers With UVLO Versus BJT Totem-Pole.* The UVLO threshold is related to the lower end of the V_{DD} specification. To pick the most appropriate driver, choose the UVLO threshold based on the power switch. Si MOSFETs typically require 4-V, 5-V, or 8-V UVLO. IGBTs typically require 8-V or 12-V UVLO. SiC MOSFETs typically require 12-V, 15-V, or 17-V UVLO.

4.2 Negative Voltage Handling

While parasitic inductance are often minimized through system design, this effect can never be eliminated. Due to this, many gate drivers are designed to handle the transients and help to avoid damage.

Negative voltage handling refers to a gate driver's ability to withstand negative voltages that can arise from parasitic inductance in the system. Negative voltage tolerances are typically specified for the input and output pins (and for the HS pin of a half-bridge driver). Data sheets often include negative voltage specifications for both DC voltages and repetitive pulses (typically less than 100 ns). For a robust design, take precautions to limit negative voltages through layout and choose a driver that can support the negative voltages expected in the system. Many TI gate driver data sheets include information on reducing negative voltages through layout.

4.3 Cross-Conduction Protection

For half-bridge configurations specifically, there is also the risk of cross-conduction, or shoot-through, of the two power switches. Some half-bridge drivers have a logic-based feature to prevent this called *interlock*. Interlock logic prevents the high- and low-side outputs from being on at the same time by turning off the outputs whenever both inputs are simultaneously high. This situation can occur when parasitic layout inductance cause ringing on the input signal. Gate drivers can also integrate a minimum dead time feature to avoid cross-conduction. This is often a fixed value, though some drivers have an additional pin to program the dead time duration for greater design flexibility.

5 Board Space, Thermal Performance, and Other Considerations

The primary way that gate drivers can help to reduce board space is with their packages.

For example, consider a three-phase BLDC motor drive configuration. When using a driver in a large package, evenly spacing the driver IC relative to the three power switches can be difficult, leaving one of the signals out of phase. A compact half-bridge driver helps to minimizes the space between the driver and the power switch. Minimizing the PCB traces between the driver and switch helps to reduce parasitics from layout. Figure 5-1 shows an example BLDC layout using the LM2105 in the 2 mm x 2 mm WSON package option, LM2105DSGR (U1, U2 and U3).

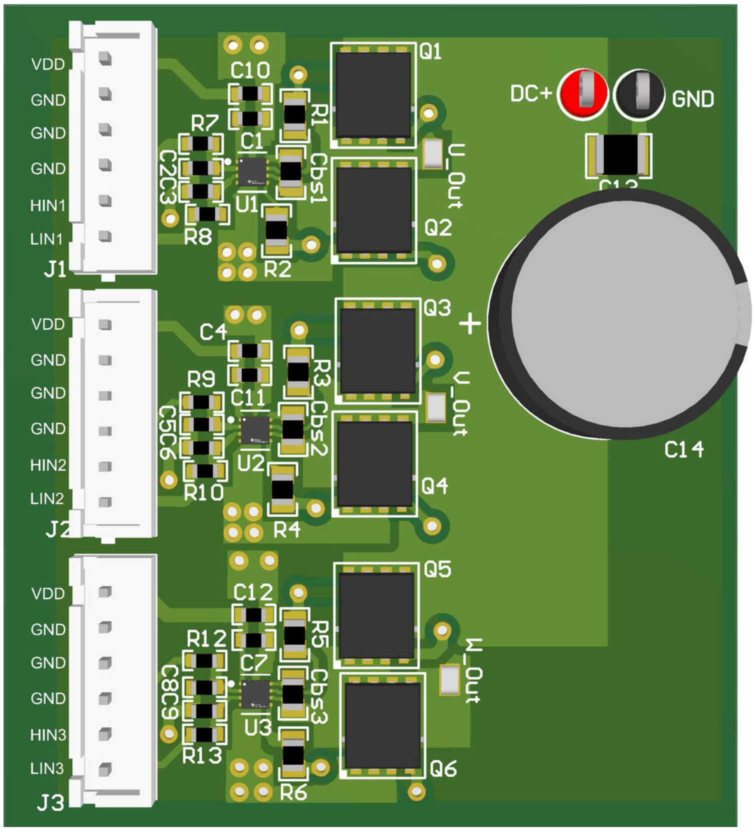

Figure 5-1. A BLDC Motor Drive PCB Layout Example Using Three LM2105DSGR Half-Bridge Drivers.

Select features of gate drivers can also eliminate the need for external circuitry, further reducing the number of components and, in turn, overall size. For example, integrated negative voltage tolerance and reverse current handling in a device like UCC27624 help to eliminate clamp diodes on the driver inputs and outputs.

Half-bridge designs often utilize a bootstrap circuit consisting of a capacitor, resistor, and diode. Another way to save on board space is to choose a half-bridge driver that integrates the bootstrap diode (and resistor) within the driver. With such a driver, the only bootstrap element required on the board is the capacitor.

Applications like stepper motor drives often require many signals from the microcontroller. So, there is an additional focus on minimizing the number of PWM inputs required by the gate driver. In these cases, look for gate drivers that offer a single-PWM compatibility, which is often implemented in one of two ways:

- One input pin (PWM or IN, or named like a high-side input HI or INH). This is paired with a second, optional input (like EN or SD for enable or shutdown functionality). See example using half-bridge driver LM2104 in Figure 5-2.
- A high-side input pin (HI or INH) paired with an *inverted* low-side input (nLI or nINL). See example implementation using half-bridge driver LM2103 in Figure 5-2.

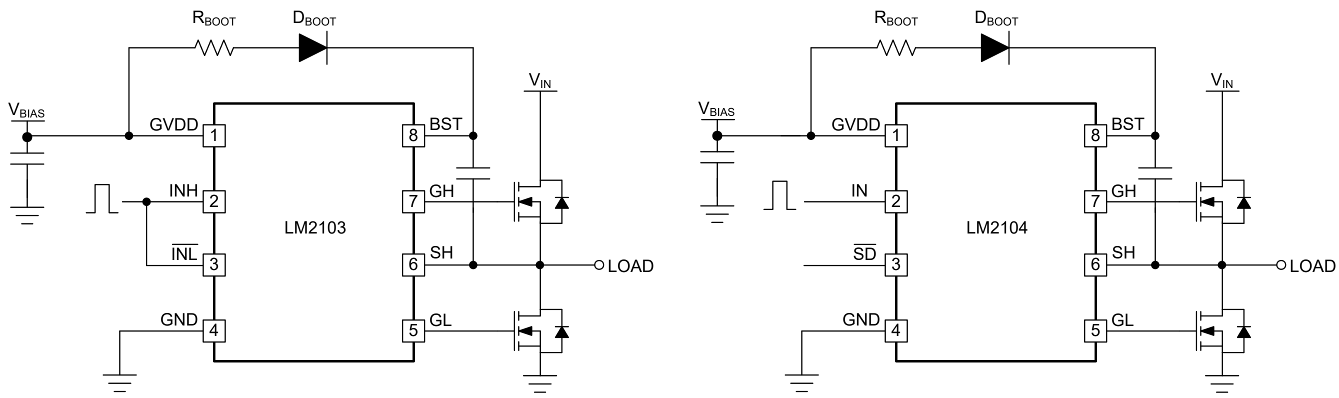

Figure 5-2. Examples of Different Input Configurations Using LM2103, LM2104

Gate drivers can especially help reduce size when multiple of these elements are combined. For example, LM2105 (105-V, 0.5-A/0.8-A half-bridge driver) has an integrated bootstrap diode and -18-V negative transient voltage capability (on V_{HS})—all within a 2-mm by 2-mm WSON package (TI package name “DSG”).

In addition to board space savings, a small package like DSG package can offer thermal benefits. For example, in a BLDC system, using three half-bridge drivers in compact packages allows each driver to dissipate power individually (as opposed to dissipating through one larger package for all three phases). The DSG package also includes a thermal pad to help dissipate additional power and further improve thermal efficiency.

To quantify this improvement in thermal performance, this example compares the SOIC (“D”) and WSON (“DSG”) packages of LM2105. The maximum power dissipation in the gate driver (P_{MAX}) can be calculated using the junction and ambient temperatures in addition to the junction-to-ambient thermal resistance ($R_{\Theta JA}$) as specified in the *Thermal Information* section of the device’s data sheet:

$$P_{MAX} = \frac{T_J - T_A}{R_{\theta JA}} \quad (3)$$

For the same junction temperature (T_J) and ambient temperature (T_A), the maximum power dissipation for each variant of LM2105 is inversely proportional to $R_{\Theta JA}$. The $R_{\Theta JA}$ for the D-package version is approximately 1.7 times larger than that of the DSG-package version (133.2 versus 78.2). So, the DSG-package version can, at maximum, dissipate 1.7 times more power than the SOIC-package version under the same temperature conditions. For more information about thermal metrics, refer to the application note *Semiconductor and IC Package Thermal Metrics*.

6 Summary

To choose an appropriate gate driver, it's important to consider the balance of robustness, size/cost, and compatibility with other system components (like the microcontroller and power switches). For example:

- **Compact home appliances** can value minimizing PCB size and choose small SON packages that integrate components and offer improved thermal performance.
- **High-volume consumer markets like e-bikes** can emphasize finding general-purpose, cost-effective drivers with multisource pinouts.
- **Noisy motor systems** can prioritize robustness and carefully choose based on voltage ranges or shoot-through protection methods.
- **Stepper drive systems** can need to accommodate limited-GPIO microcontrollers and seek out drivers that support a single-PWM input.

Table 6-1 and Table 6-2 summarize some common design considerations for DC motor drive systems and gate drivers that can address them. For further detail on features and specifications, reference the device data sheet.

Table 6-1. Half-Bridge Driver Quick Reference Table

Design Consideration	LM2101	LM2103,LM2104	LM2105	LM5108	UCC27710	UCC27301A
Bootstrap supply voltage *Absolute maximum V_{HB} (for margin against motor transients).*	107 V	107 V	107 V	110 V	700 V	120 V
Negative voltage handling [3] *Abs. minimum transient V_{HS} (for margin against negative transients).*	–19.5 V	–19.5 V	–19.5 V	–7 V	–11 V[4]	–(24–V_{DD}) V
Interlock or dead time *Shoot-through protection.*	✗	✓ (fixed dead time)	✗	✓ (interlock)	✓ (interlock)	✓ (interlock)
Integrated bootstrap diode *Reduces components.*	✗	✗	✓	✓	✗	✓
Package *Approximate sizes.*	5x4mm (SOIC) 2x2mm (WSON)	5x4mm (SOIC)	5x4mm (SOIC) 2x2mm (WSON)	3x3mm (VSON)	5x4mm (SOIC)	5x4mm (SOIC) 3x3mm (VSON)
Source/sink current *Eliminates the need for external booster stages for higher current.*	0.5 A/0.8 A	0.5 A/0.8 A	0.5 A/0.8 A	1.6 A/2.6 A	0.5 A/1.0 A	3.7 A/4.5 A
UVLO *Helps protect the power switch from overheating.*	8 V	8 V	5 V	5 V	10 V	8 V
Single-input compatibility *Reduces PWM signals.*	✗	✓[5]	✗	✗	✗	✗
Recommended when…	Minimal features are needed or cost alone is most critical.	Support for a single PWM input is the top priority.	Board space and cost are most critical.	Driving multiple switches in parallel or driving at high frequency.	High-voltage application requires VHB margin > 120 V.	Driving coils (linear motors) or high-frequency DC motors.

[3] Values are verified by characterization only and are not production tested.
[4] This is the recommended minimum specification (no absolute minimum specified for this device). Logic operational for HS of –11 V to +600 V at HB–HS = 20 V. See UCC27710 data sheet for more details.
[5] LM2103 has an inverting LI pin (nLI). LM2104 has one input pin (INH) and an inverting shutdown pin (nSD).

Table 6-2. Low-Side Driver Quick Reference Table

Design Consideration	UCC27517A	UCC27531	UCC27624
Number of channels	1	1	2
Supply voltage (V_{DD}) *Absolute maximum V_{DD} (for margin against transients).*	20 V	35 V	30 V
Negative voltage handling *Rec. minimum transient V_{IN} (for margin against negative transients).*	0 V	–5 V	–10 V
Package *Approximate sizes.*	2.9x1.6mm (SOT-23)	5x4mm (SOIC) 2.9x1.6mm (SOT-23)	5x4mm (SOIC) 3x3mm (VSON)
Source/sink current *Eliminates the need for external booster stages for higher current.*	4 A/4 A	2.5 A/5 A	5 A/5 A
UVLO *Helps protect the power switch from overheating.*	5 V	8 V	5 V
Recommended when…	Driving a single MOSFET and board space and cost are most critical.	Driving a single IGBT (or MOSFET) and robustness is most critical.	Driving multiple MOSFETs and robustness is most critical.

7 References

- Texas Instruments, *Fundamentals of MOSFET and IGBT Gate Driver Circuits*, application note.
- Texas Instruments, *Low-Side Gate Drivers With UVLO Versus BJT Totem-Pole*,application note.
- Texas Instruments, *Semiconductor and IC Package Thermal Metrics*, application note.