Application Note

Three-Phase vs Three-Single Half-Bridge Gate Drivers

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ABSTRACT

Brushless DC motors are three-phase motors that are driven through electrical commutation. Voltage applied to the stator coils generate magnetic field which interacts with the rotor magnetic field. Interaction between these two fields causes the rotor to spin. The inputs for the commutation come from the controller and are scaled through a power stage to send power to the motor phases. The power stage for driving the motor consists of turning on or off the MOSFET half-bridges per phase. A motor driver is a power converter that switches the MOSFET based on several PWM modulation techniques. Modulated PWM voltage is applied to the BLDC motor to control speed, torque and position of the motor

The leading implementation of motor drivers in the market, can be split into two categories based on architecture for the purposes of this technical report.

1. Three-Phase BLDC Drivers
2. Half-Bridge Drivers

This application note includes the key differences and pros and cons for each architecture. Three-phase architecture offers advantages with more half bridge integration making final implementation more straight forward with one package but faces challenges in signal integrity. Whereas using three half bridges require more local passives but offer flexibility in MOSFET placement, thereby, improving signal integrity and reducing effects of trace inductance.

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1 Introduction

A three-phase BLDC driver can commutate three half-bridges (six MOSFETs) and a single Half-Bridge driver as the name implies drives one half-bridge (two MOSFETs).

There are unique advantages to both systems which makes them desirable for their intended applications. Knowing the system level benefits can make the decision easier for which method can be beneficial for your application.

Note

Either implementation can have integrated MOSFETs or have them external. This document focuses on external MOSFET drivers also referred to as gate drivers.

TI's current Brushless DC (BLDC) motor drivers' portfolio contains predominantly three-phase BLDC drivers serving as a one unit package to spin a brushless motor. However, with the addition of drivers such as DRV8161 and DRV8162 we are expanding our portfolio to include single half-bridge drivers (Figure 1-1). These single half-bridge drivers offer key advantages in reducing driver to power stage distance. This results in greatly improving efficiency and decreasing the effects of parasitic.

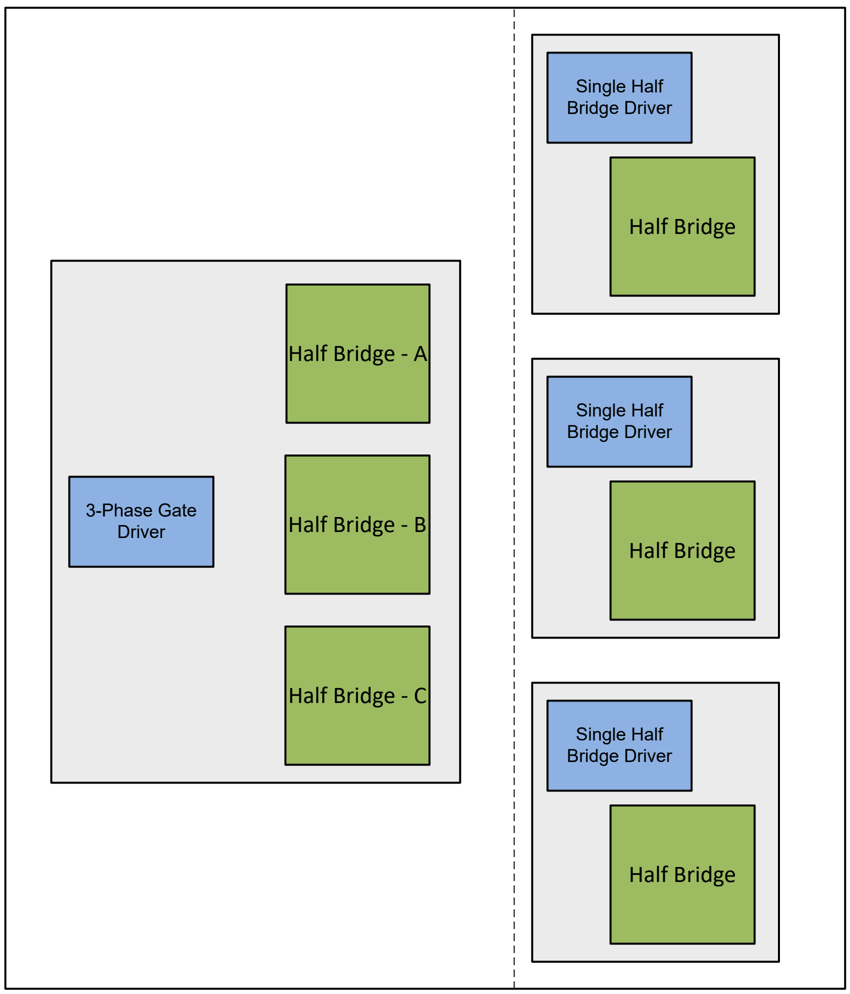

Figure 1-1. Architecture Outline: Three-Phase vs Single Half Bridge Driver

2 Three-Phase Gate Driver

2.1 Architecture

A Three-Phase gate driver can take in signals for all three half-bridges and can output up to six gate drive signals for the power stage. Figure 2-1 shows the implementation for driving a BLDC motor using a three-phase gate driver. The PWM input signals go from the microcontroller to the gate driver unit then to the MOSFET power stage.

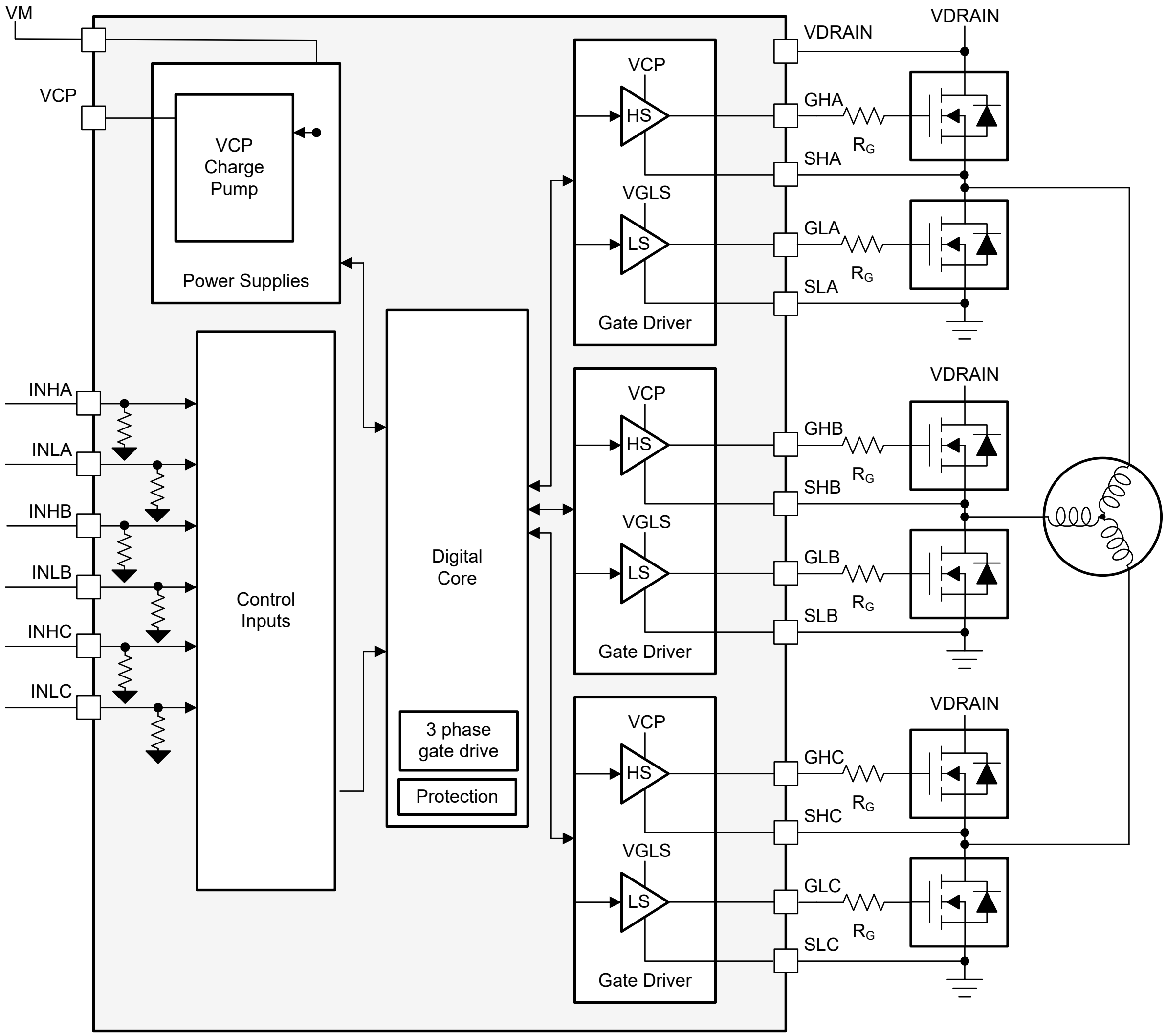

Figure 2-1. Functional Block Diagram: Three-Phase Gate Driver

2.2 Layout Considerations

2.2.1 Advantages

2.2.1.1 MCU to DRV Signal Routing

With the entirety of the three-phase pre-drivers being encapsulated into the same package there is added benefit of driver placement simplicity in board design. The MCU signals all head to the single driver IC which outputs the six gate drive signals, therefore, making the routing, for input and serial data communication signals such as SPI, easier.

2.2.1.2 Component Reduction

A three-phase gate driver uses same capacitors for major power signals for all three phases for example, PVDD, V-Drain, charge-pump, and so on. Therefore, there is a reduction in a number of components needed.

2.2.2 Challenges

2.2.2.1 MOSFET Placement

In motor driver board design, the most critical signals are the gate and source signals of MOSFET as these signals are crucial for efficient commutation. Minimizing the distance between the driver and the MOSFET for gate and source signals are needed to reduce the effects of trace inductance. Figure 2-2 shows how power stage design adds parasitic inductance in gate source signals.

Since the gate and source signals for all three phases are leaving the same driver, there is a challenge to place the half-bridges close, due to components size. This becomes more critical when the boards have space restrictions.

These routing challenges lead to

- *Signal integrity issues:*

  Another challenge in motor layout arises when the 3 half-bridges are not placed in roughly same distance or via similar trace paths from the driver. This can result in phase to phase deviation in turn on/off times of the MOSFETs or differences in measured phase current through CSA.

  Long gate traces can also result in absolute maximum violation of the driver (either overshoot or undershoot) due to the added inductance.
- *Source node transients:*

  Switch-node ringing is an LC oscillation on the switch-node due to the parasitics of the PCB and power MOSFETs. Switch-node ringing causes EMI and creates overshoot and undershoot voltages. These transients can violate the absolute maximum ratings of the MOSFET drain-to-source voltage and the gate driver pins. This also can decrease the efficiency of the power stage.

  The longer trace paths can also add a parasitic impedance between GND of gate driver device and GND of power MOSFETs. The parasitic impedance can cause a GND shift between device and source of low-side MOSFETs and can lead to similar challenges for source node transient described above.

Note

The circular PCB shown in Figure 2-2 and Figure 3-4 are common designs used in power tools and E-bike designs, where a PCB is mounted on top of the motor. This design was chosen to highlight the effects of MOSFET placement and trace inductance, but the principle applies to all board shapes and sizes.

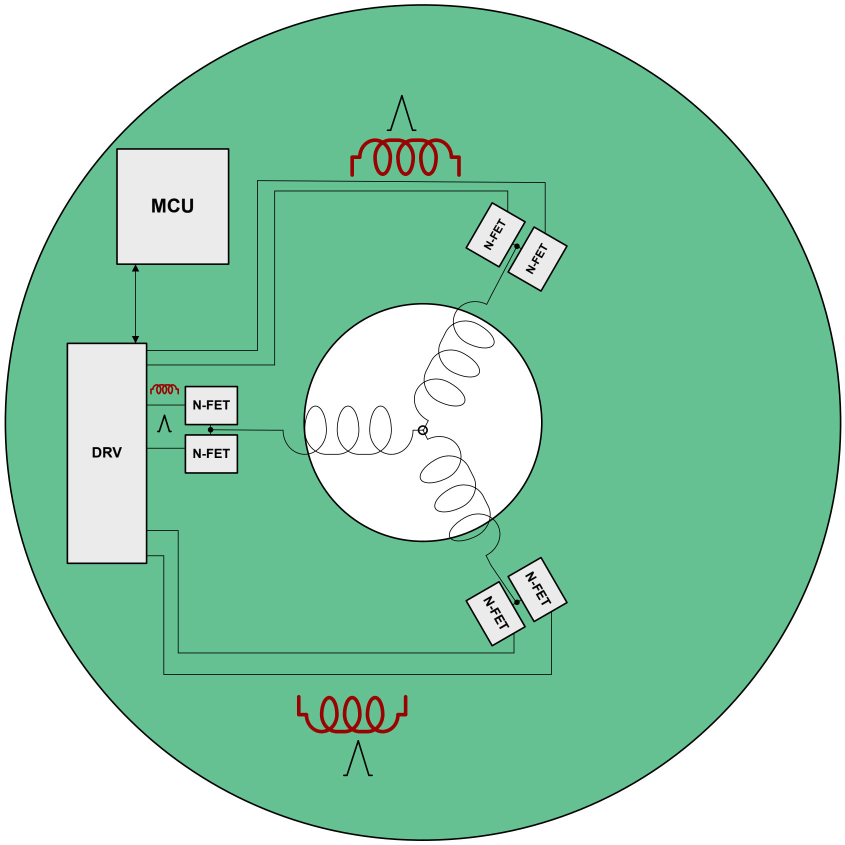

Figure 2-2. Three-Phase Gate Driver Implementation Showing Effects of Transients on Gate and Source signal due to Effects of Trace Inductance

2.3 Typical Applications

Three-phase gate drivers are becoming an industry standard for brushless motors due to several application requirements. Three-phase gate drivers are well established, robust, and have many integrated features that make them a one stop shop of commutating the three-phases.

Three-phase drivers are very well established in almost all applications involving BLDC motors. This includes power tools, drones, and medical pumps to everyday items such as toys and cameras.

3 Half-Bridge (Single Phase) Gate Driver

3.1 Architecture

A half-bridge driver only takes in two inputs signals to drive the high side and low side gate of MOSFET half-bridge. Since each DRV half bridge can only drive one phase, you need three DRV half-bridge ICs to drive a three-phase BLDC motor.

Figure 3-1 shows the implementation for driving a BLDC motor using three single half-bridge drivers.

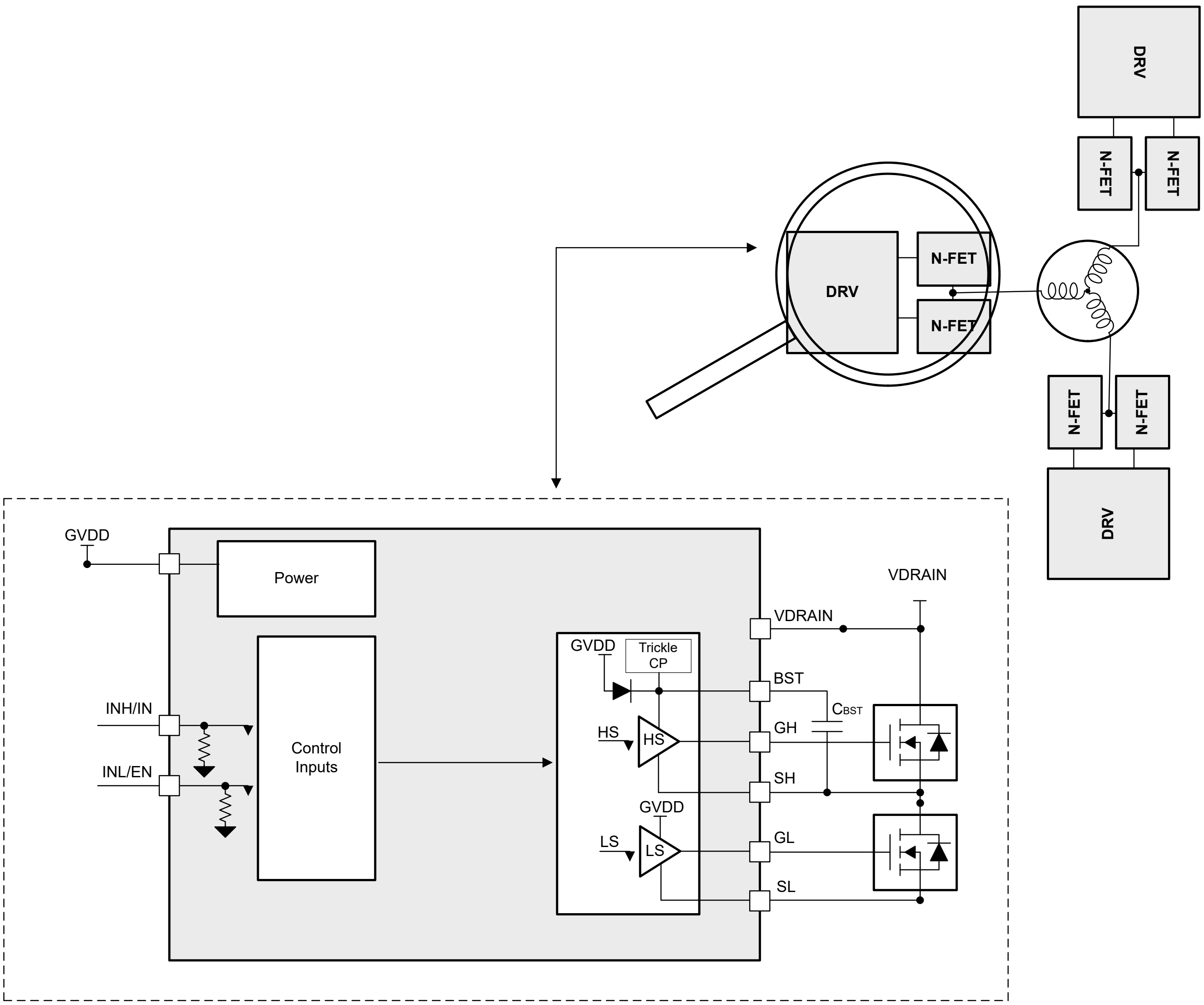

Figure 3-1. Functional Block Diagram: 3x Single Half Bridge Driver With Zoom in on one Phase

3.2 Layout Considerations

3.2.1 Advantages

3.2.1.1 MOSFET Placement

With the availability of three separate half-bridges you now have the option to place the IC close to the MOSFETs for that phase. This improves signal integrity and reduces parasitics on the gate and source nodes.

- *Source node transients or ringing:*

  Shorter gate or source paths between the driver and the MOSFET can help dampen the effects of trace inductance. This can help reduce the effects of source node ringing and improve EMI performance by effectively decreases the total loop inductance.

  With lower effects of parasitics, you can also expect to see smaller source dips or transients. Figure 3-2 shows the ringing one can see at phase voltage switching

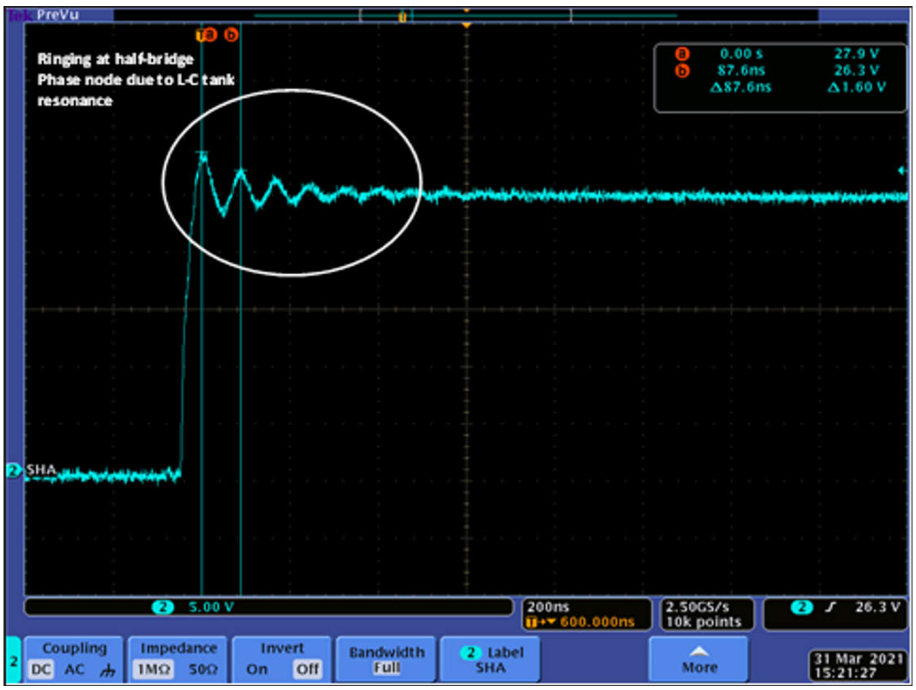

Figure 3-2. Motor Driver Phase Output Waveform Showing Ringing

- *Signal Integrity:*

  Any signal from the motor power stage that gets measured from the driver can offer benefits when the path between the origin of the signal to the measurement site gets reduced (Figure 3-3).

  Current flow being sensed by the driver across the shunt resistor can be more accurate since the CSA is physically closer to the sense resistor.

  Similarly, the VDS measurement for overcurrent protection is measured at the driver gate and source pins. So, if there is a large difference in drain to source between the driver and the FET, the VDS monitor is not accurate. Therefore, having the MOSFET and driver closer can result in smaller parasitic inductance helping reduce overshoot or ringing of gate signal.

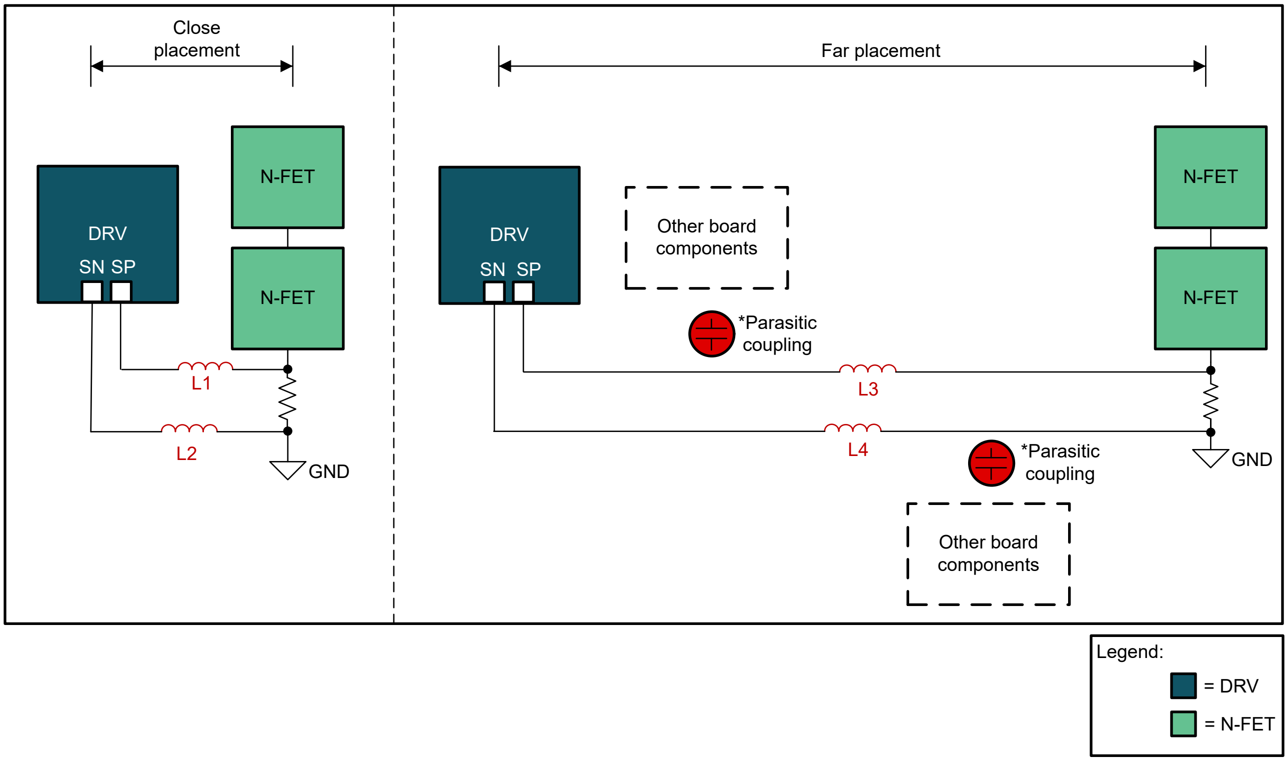

Figure 3-3. Impact of MOSFET placement on signal integrity

Note

In Figure 3-3, L1 and L2 can be much lower inductance than L3 and L4 due to smaller trace length. L3 and L4 can also be more susceptible to other signal coupling in along the long trace.

3.2.1.2 Independent Control

Since each of the half-bridge is a stand-alone unit, the user has independent control over each of them. This allows for more flexibility in the design and application as driver can receive individual commands from the MCU. Customizable gate drive current between different phases are an option with this approach. This is more of an advantage if drivers are being to drive non-three phase BLDC motor. For example, in applications where a BDC motor is used in conjunction with an actuator. Each phase can be independently driven with a three-phase gate driver but there can be space and cost disadvantages when only two phases are needed from a three-phase driver. And the settings such as Idrive, gain, and deadtime are set for all three phases and are not customizable.

3.2.1.3 Ease of Replacement

In the event of IC damage to one phase, now the customer can replace that particular phase's IC instead of replacing the total three phase driver. This reduces equipment cost and can also allow for easier repairs.

3.2.2 Challenges

3.2.2.1 Longer Routing Between Gate Driver and Micro Controller

Special attention needs to be paid to analog signals sensitive to noise in PCB. If a single-half bridge gate driver integrates a current sense amplifier (CSA), proper design practices are recommended to applied to routing from the CSA output to the micro controller. The design practices include proper routing or shielding in PCB to prevent coupling from noise source. Proper layout practices such as using kelvin connections and parallel routing, need to be observed for shunt resistor routing to get accurate measurements.

3.2.2.2 Additional Component Requirements

The single half-bridge gate driver being used to drive a three-phase BLDC motor often requires more passive components compared to a similar three-phase gate driver.

The decoupling capacitors used for charge pump, GVDD and VDRAIN can be needed for each of the half-bridge driver compared to being only being needed once for a three-phase drive.

The same logic applies for passive resistors used for device configurations set modes such as IDRIVE, VDS level, deadtime, and so on. This adds to the implementation cost of single half-bridge drivers in return for the customization offered with this architecture.

Table 3-1 shows the extra passive components that can be required in a 3x half-bridge system as opposed to three-phase system. Note that the passive resistors are not needed on devices with SPI.

Table 3-1. Passive Component Differences Between Three-Phase and 3x Half-Bridge Gate Driver BLDC Implementation

Passive	PIN	Three-Phase	3x Half Bridge Driver
Capacitor	GVDD	1	3
	VDRAIN	1	3
	CSAREF	1	3
Resistor	IDRIVE	1	3
	VDS level	1	3
	Deadtime	1	3
	CSA Gain	1	3
	nFault	1	3

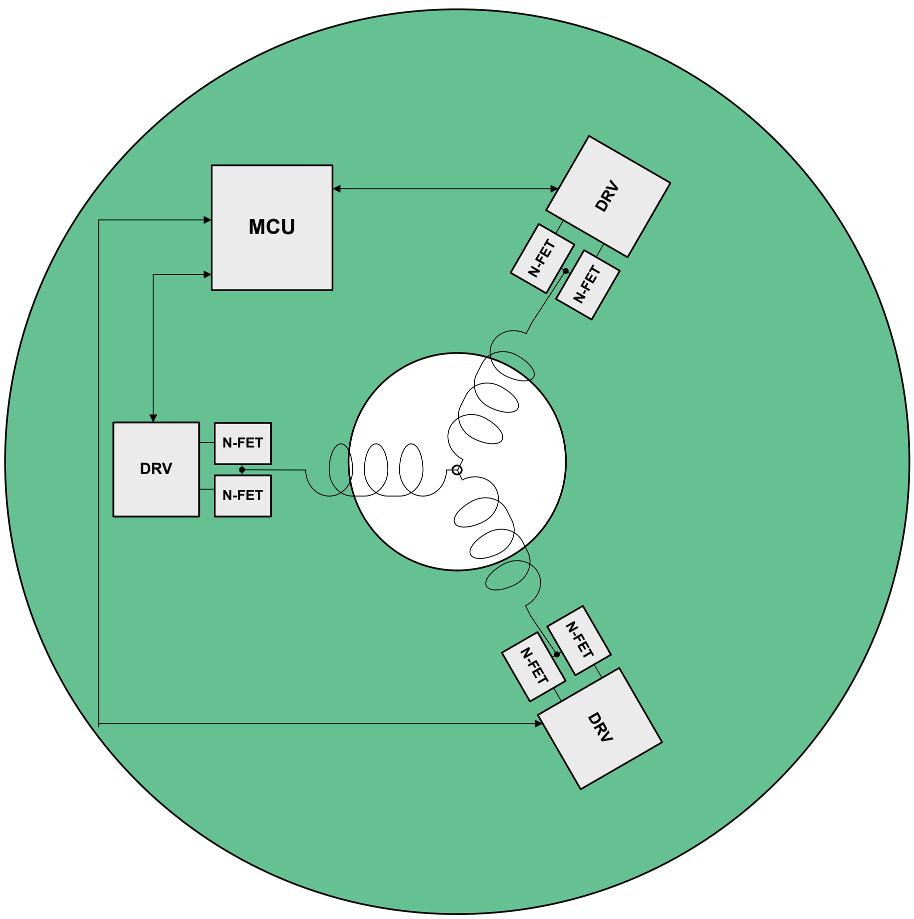

Figure 3-4. 3x Single Half Bridge Driver Showing Reduction in Gate Inductance and Layout Benefits

3.3 Typical Applications

Target applications of single-half bridge driver include the robotics and factory automation market. The current market is seeing a large shift in incorporating robots and cobots in factory automation to increase production line yields by increasing speed or efficiency. BLDC motors play a key role in offering high torque and high speed required in modern factory floors.

These applications often require the MOSFET placement advantage offered by single half-bridges. Many motor designs benefit from having the driver power stage being placed closer the motor phase magnets for signal integrity and for reducing the effects of board parasitics, as well as offering smaller system size. Therefore, the flexibility of single half-bridges in routing makes it appealing for such application than a standard 3-phase gate driver.

Another emerging market for single half-bridge drivers is in the e-mobility market with e-scooters and e-Bikes. These applications deal with system challenges of transients on source nodes due to higher load or due to accidental operation in generator mode. Having reduction in board parasitcs due to short MOSFET to driver paths makes this architecture well designed to these systems.

4 Summary

The fundamentals of driving a brushless DC motor is well established with a microcontroller sending signals to a driver. And the driver converting those signals to gate voltages of the MOSFETs to spin a motor.

The three-phase gate driver and single half-bridge driver both achieve the same goal, but fundamentally differ from a board design and system size perspective. The implementation differences result in them being better designed for different applications or market demands.

The three-phase gate driver is better designed for applications where a one stop implementation for spinning a BLDC motor is required and there is value in a larger IC but fewer external components needed. For example: Power tools, drones etc.

The three single half-bridges are designed more for applications where MOSFET placement is constrained and reduction in parastics or signal integrity is critical. For example: Robots or cobots, factory automation, and so on.

Each method offers specific advantages for their applications and is recommended to choose one that can maximize benefits while reducing design challenges for your system.

To find the right driver that best fits your system needs, please visit our BLDC portfolio on TI.com

5 References

- Texas Instruments, *DRV816x 100V Half-Bridge Smart Gate Driver with Integrated Protection and Current Sense Amplifier*, data sheet.
- Texas Instruments, *Understanding Smart Gate Drive*, application note.
- Texas Instruments, *48V, 3.5kW Small Form-Factor Three-Phase Inverter Reference Design for Integrated Motor Drives*, design guide.
- Texas Instruments, *DRV8161EVM*, evaluation module.