

Field Oriented Control (FOC) Made Easy for Brushless DC (BLDC) Motors Using TI Smart Gate Drivers

Vashist Bist, Analog Motor Drives



Introduction

Brushless DC (BLDC) motors continue to grow in popularity due to their high efficiency, high operating speed, high flux density per unit volume, compact size, low maintenance requirements and low electromagnetic interference (EMI) problems. For these reasons, the BLDC motors are replacing the brushed DC (BDC) motors in a variety of applications such as appliances, electric vehicles, medical applications, heating ventilation and air conditioning (HVAC), motion control and robotics, etc. The BLDC motor is a three-phase synchronous motor with stator composed of three-phase windings (concentrated windings for trapezoidal-BLDC motor and sinusoidally distributed windings for sine-BLDC motor) and a rotor having permanent magnets (or vice versa in exterior rotor PM motors). BLDC motors do not have mechanical brushes and commutator assembly. Therefore, issues associated with BDC motors, such as wear and tear of the brushes, sparking concerns, and EMI problems, are eliminated. This motor is also referred to as an electronically commutated motor, because an electronic commutation based on the rotor position is used rather than a mechanical commutation. The rotor position of the BLDC motor is generally sensed using the Hall-effect position sensors.

There have been numerous control algorithms developed for controlling BLDC motors. The algorithms are typically classified based on the type of BLDC motor (trapezoidal or sinusoidal), position sensor requirements (sensored or sensorless) and speed and torque (current) control requirements. With the increased capacity of today's micro-controllers, industry is expanding boundaries on the implementation of high-end control algorithms such as field oriented control (FOC). FOC implementation allows the BLDC motor to run more efficiently (high power factor and better light load efficiency), more smoothly (lower torque ripples) with quick dynamic response (better dynamic performance to load and speed changes). FOC control makes the stator and rotor magnetic field orthogonal to each other to achieve the maximum electromagnetic torque. It uses a decoupled control of flux and torque due to which it can also allow motor to run above the nominal speed using field weakening technique.

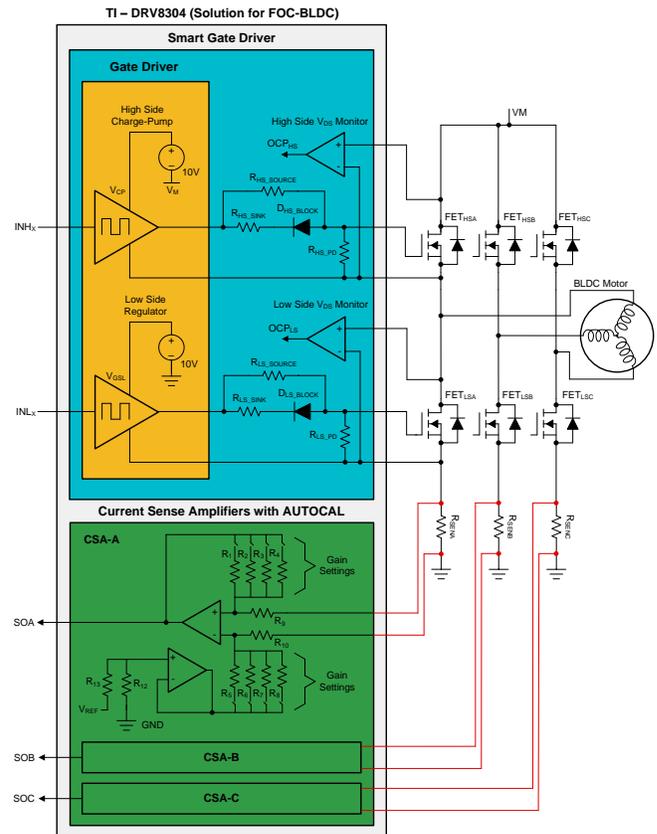


Figure 1. TI Smart Gate Driver for FOC Implementation

The 3-phase BLDC motor needs a 3-phase voltage source inverter (VSI) to feed AC current to motor. The switches of this VSI are generally field effect transistors (FETs) for low voltage applications (or Insulated Gate Bipolar Transistors - IGBTs for high power applications), which are driven by the gate driver. Most gate drivers available today require external gate components (resistors and Zener diodes) for operation and protection. However, TI's [Smart Gate Drive \(SGD\)](#) technology eliminates external gate components as shown in [Figure 1](#). With its adjustable gate drive currents (gate slew-rate control), the SGD architecture provides flexibility in reducing electromagnetic interference (EMI). The SGD architecture optimizes the dead time for a better efficiency while fully protecting the FET's to avoid any shoot-through conditions. A strong-pulldown current is also added for prevention of any spurious dv/dt gate turnon.

The [DRV8304](#) device is a three-phase gate driver based on the TI's Smart Gate Drive (SGD) architecture. The operating maximum voltage of 38-V of this device is fully optimized for the 12-V and 24-V BLDC motor FOC application. DRV8304 support external N-channel high-side and low-side power MOSFETs and can drive up to 150- mA source, 300- mA sink peak currents with a 15- mA average output current. DRV8304 is a highly integrated device which includes gate driver supplies (high side charge-pump and low side linear regulator), three current sense amplifiers (CSA) and a 3.3-V, 30- mA regulator which can be used for powering up the external controller.

The integrated current-sense amplifiers (CSA) in DRV8304 are used for sensing three phase currents of BLDC motors for optimum FOC and current-control system implementation. An adjustable gain settings of 5, 10, 20 and 40 V/V provides a flexibility to user for choosing the optimum sense resistor suiting the end-application. The CSA can also be configured to sense the unidirectional current which can be used in implementing the current limit control for trapezoidal BLDC motor. The CSA in DRV8304 includes an AUTOCAL feature which automatically calibrates the CSA offset error at power-up for accurate current sensing.

Various PWM modes are available in DRV8304 which make it an easy-to-interface driver. User has the flexibility to choose 6x or 3x mode for the FOC (or sinusoidal current control), 1x mode for trapezoidal current control with on-chip block-commutation feature and independent mode for driving the solenoids relays. A high level of protection feature-set makes this device invulnerable in any operating scenarios. These features include power-supply undervoltage lockout (UVLO), charge-pump undervoltage lockout (CPUV), VDS overcurrent monitoring (OCP), gate-driver short-circuit detection (GDF), and overtempertaure shutdown (OTSD) and fault events are indicated by the nFAULT pin. A summary set of features which makes DRV8304 an ideal for BLDC motor FOC application is as follows.

- Optimized driver absolute maximum voltage (40-V) for 12-V and 24-V BLDC motors
- Triple CSA for three phase BLDC motor current sensing with 4 settings of gain selection
- AUTOCAL feature for reduced CSA input offset error which provides better motor rotation jitter

- performance
- High operating switching frequency for achieving better noise performance
- Adjustable slew rates for optimized EMI performance
- Very low dead time for higher switching efficiency
- Very low propagation delay for better pulse-control accuracy and better dynamic response
- Highly integrated driver and small package size for reduced board area
- Advance on-chip protection features and diagnostics

Alternate Device Recommendation

Depending on the necessary system requirement, there are additional devices available that may provide the required performance and functionality. For applications requiring detailed diagnostics and limp-home mode support, [DRV8305](#) is recommended. [DRV832x](#) is preferred in the applications requiring a higher operating voltage such as 36-V battery operation.

Table 1. Alternative Device Recommendations

| Device | Optimized Parameters | Performance Trade-Off |
|-------------------------|---|---|
| DRV8305 | 45-V Abs-max Voltage Limp-Home Mode 1-A / 1.25-A (Source / Sink) Gate Drive | Higher CSA Input Offset No AUTOCAL feature |
| DRV832x | 65-V Abs-max Voltage 1-A / 2-A (Source / Sink) Gate Drive Integrated Buck Option | Higher CSA Input Offset |
| DRV835x | 100-V Abs-max Voltage 1-A / 2-A (Source / Sink) Gate Drive Integrated Buck Option | Higher CSA Input Offset |

Table 2. Adjacent Tech Notes

| SBOA174 | Current Sensing in an H-Bridge |
|-------------------------|---|
| SBOA161 | Low-Drift, Low-Side Current Measurements for Three-Phase Systems |
| SBOA171 | Bi-Directional, Low-Side Phase Current Sensing with Integrated Over-Current Detection |
| SBOA160 | Low-Drift, Precision, In-Line Motor Current Measurements With Enhanced PWM Rejection |

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ("TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products (<http://www.ti.com/sc/docs/stdterms.htm>), [evaluation modules](#), and [samples](http://www.ti.com/sc/docs/sampterm.htm) (<http://www.ti.com/sc/docs/sampterm.htm>).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2018, Texas Instruments Incorporated