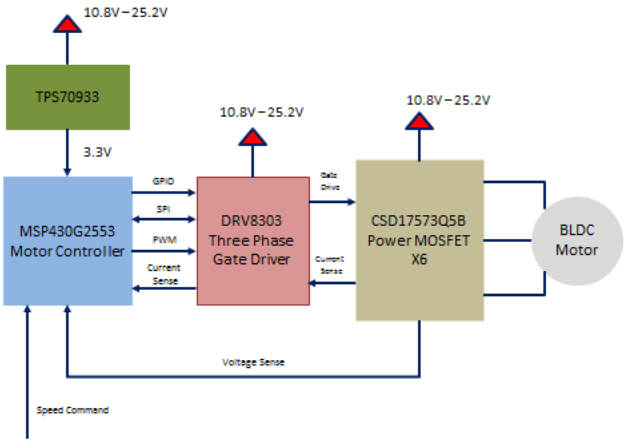
TIDA-00735 Brushless DC Propeller Controller Reference Design

Design Overview

The TIDA-00735 reference design is a 10.8V to 25.2V brushless DC motor controller for high power propeller, fan, and pump applications. It uses the DRV8303 brushless DC motor gate driver, CSD17573Q5B 30V NexFET™ power MOSFETs, MSP430 16-bit low power MCU, and TPS70933 30V ultra-low IQ LDO. It controls motor with trapezoidal sensor-less control algorithm and commands the motor speed through an external reference signal from a central controller. This design is focused on demonstrating a highly efficient and high power BLDC motor system.

Design Resources

TIDA-00735	Design Folder
DRV8303	Product Folder
MSP430G2553	Product Folder
TPS709	Product Folder
CSD17573Q5B	Product Folder

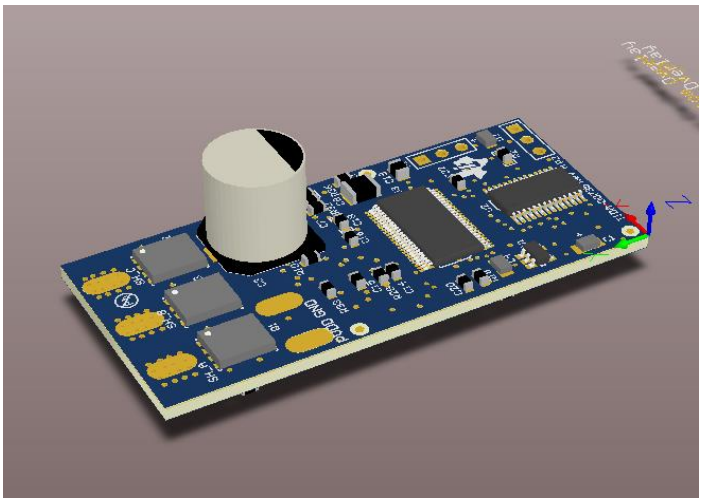


Design Features

- 10.8 V to 25.2 V input voltage range
- 15 A RMS, 23 A peak output current capability
- Small form factor (L x W): 2.2” x 1.0”
- Speed control with single reference signal
- Sensor-less trapezoidal control
- Wide array of system protection features including MOSFET VDS overcurrent and supply under-voltage protection

Featured Applications

- Drone Propeller Electronic Speed Controller
- Unmanned Air Vehicles
- Remote Control Applications with Speed Control Motor Drive
- High Power Fans and Pumps



1. Introduction

TIDA-00735 is a compact motor controller designed for high power, brushless DC (BLDC) propellers. It mimics the function of an off the shelf electronic speed controller (ESC) often used in RC and hobby applications. The

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motor controller decodes a speed reference from a central controller and processes this into the appropriate drive signals for the BLDC motor. This allows the central controller to off load the processor functions related to BLDC motor control and focus on functions central to the system. This type of motor controller can also be used for high power fan or pump applications.

The motor controller is composed of two main components. The first component is the MCU, which decodes the speed reference signal from the central controller, measures the motor's back-EMF and current signals, and sends the appropriate control signals for the power stage. The second component is the power stage which consists of the gate driver and power MOSFETs. The power stage amplifies the control signals from the MCU to the motor.

The motor controller uses the trapezoidal sensor-less control algorithm for brushless DC motors. The algorithm uses the signals of back-EMF from the motor to interpolate where the motor rotor is located and send the correct drive patterns. Power is supplied to the motor controller from the main power input through a LDO.

2. Block Diagram

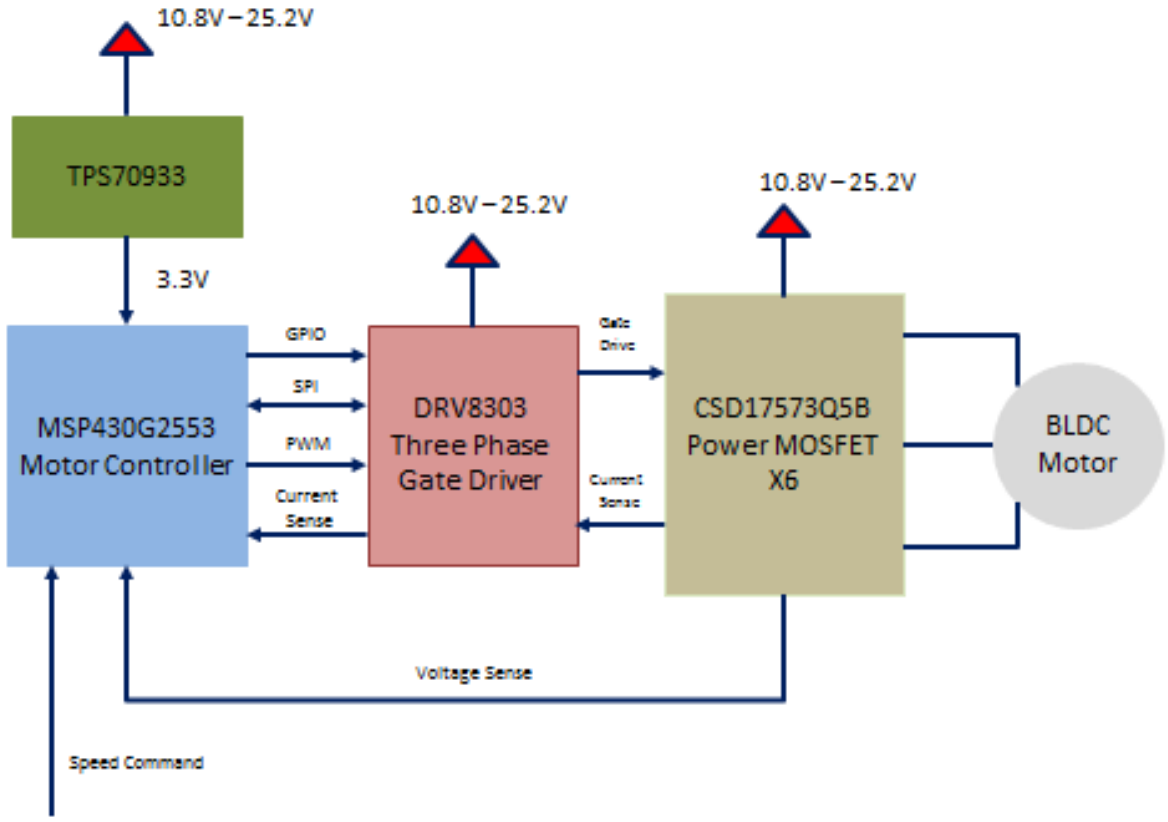

Figure 1. TIDA-00735 Block Diagram

2.1 Highlighted Products

The critical devices to this design are outlined below.

- DRV8303: Three phase motor gate driver with current shunt amplifiers

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- CSD17573Q5B: NexFET ™ N-Channel Power MOSFET
- MSP430G2553: 16-bit low power MCU

2.1.1 DRV8303

The DRV8303 is a gate driver IC for three phase motor drive applications. It provides three half bridge drivers with slew rate control, each capable of driving a high-side and low-side N-channel power MOSFET with large driving capability up to 2.3A. A charge pump driver supports 100% duty cycle and low voltage operation.

The gate driver could prevent current shoot through with programmable dead time. And over-current could be detected by the accurate VDS sensing to the external high-side and low-side MOSFETs. As well, the gate driver could also provide over-voltage, under-voltage and over-temperature protections.

The DRV8303 includes 2 bidirectional current shunt amplifiers with adjustable gain levels and blanking times for accurate low-side current measurements. The SPI interface and device registers provide detailed fault reporting and flexible parameter settings such as the current shunt amplifier configurations, gate driver slew rate control, and numerous protection features.

A block diagram for the gate driver is shown below:

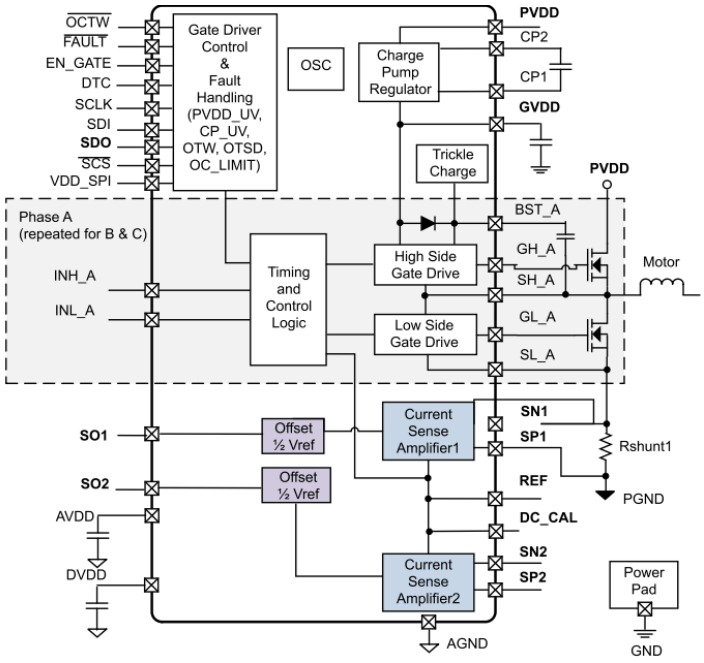

Figure 3. DRV8303 Block Diagram

2.1.2 CSD17573Q5B

The motor controller uses six CSD17573Q5B to form the inverter for the brushless DC motor. This power MOSFET is an ultra-low R_{DS}(on) device designed to minimize losses in power conversion, switching applications.

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It comes in a compact, 8 pin SON 5 x 6 mm package with an R_{DS}(on) of 0.84 mΩ at a V GS of 10 V to minimize board space required and limit thermal dissipation.

Product Summary

T_A = 25°C		TYPICAL VALUE		UNIT
V_{DS}	Drain-to-Source Voltage	30		V
Q_g	Gate Charge Total (4.5 V)	49		nC
Q_{gd}	Gate Charge Gate-to-Drain	11.9		nC
$R_{DS(on)}$	Drain-to-Source On-Resistance	V_{GS} = 4.5 V	1.19	mΩ
		V_{GS} = 10 V	0.84	mΩ
$V_{GS(th)}$	Threshold Voltage	1.4		V

Figure 4: CSD17573Q5B Summary

2.1.3 MSP430G2553

The MSP430G2553 is the brain of the motor controller. Its uses the feedback signals from the motor and the speed reference signals to determine the proper signal pattern for the brushless DC motor.

The MCU supports sensor-less trapezoidal control algorithm for BLDC ESC applications. Sensor-less algorithms remove the need for a mechanical motor rotor sensor in order to reduce system costs and size. The algorithm uses Back EMF zero-crossing point to obtain commutation position.

Through the MCU ADCs the system obtains the motor back-EMF and phase currents. The PWM modules provide the PWM modulation signals to the power stage, and the CAPTURE module receives the speed reference signal from the central controller.

3. System Design Theory

The 10.8V to 25.2 V, 15 A Brushless DC Propeller Controller Reference Design demonstrates a high performance three phase BLDC motor controller using the DRV8303 motor gate driver and MSP430G2553 microcontroller.

The motor controller receives speed commands from an external reference signal that is fed to the MCU CAPTURE module. Using the speed reference and feedback signals from the motor, the MCU determines the correct signals to send to the power stage composed of the DRV8303 and CSD17573Q5B.

Section 3.1 will describe the hardware design theory and section 3.2 will describe the software theory of the reference design.

3.1 Hardware Design Theory

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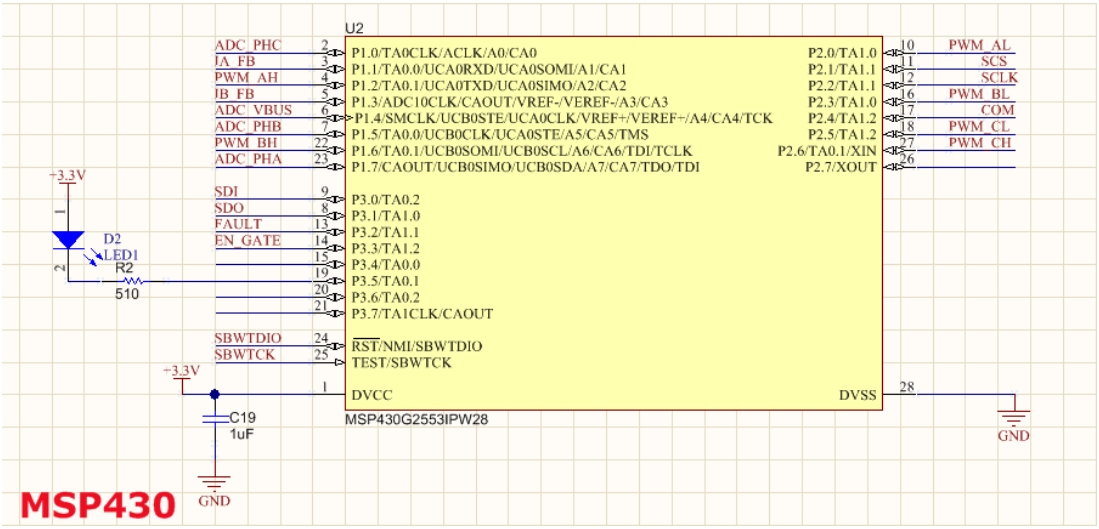

Figure 5. MSP430G2553 Block

The MSP430G2553 has been configured to require minimal external components and use its internal oscillator for the 16 MHz clock. The 3.3 V power supply is supplied from the external LDO.

The PWM module is used to generate the pulse width signals for the switching power stage. Multiple ADC channels are utilized to read the motor back-EMF voltage and phase current. A 3-pin SBW connector is utilized to program the memory. Several GPIO and an SPI interface communicate with the DRV8303 to set the gate driver modes, configurations, and read back status information.

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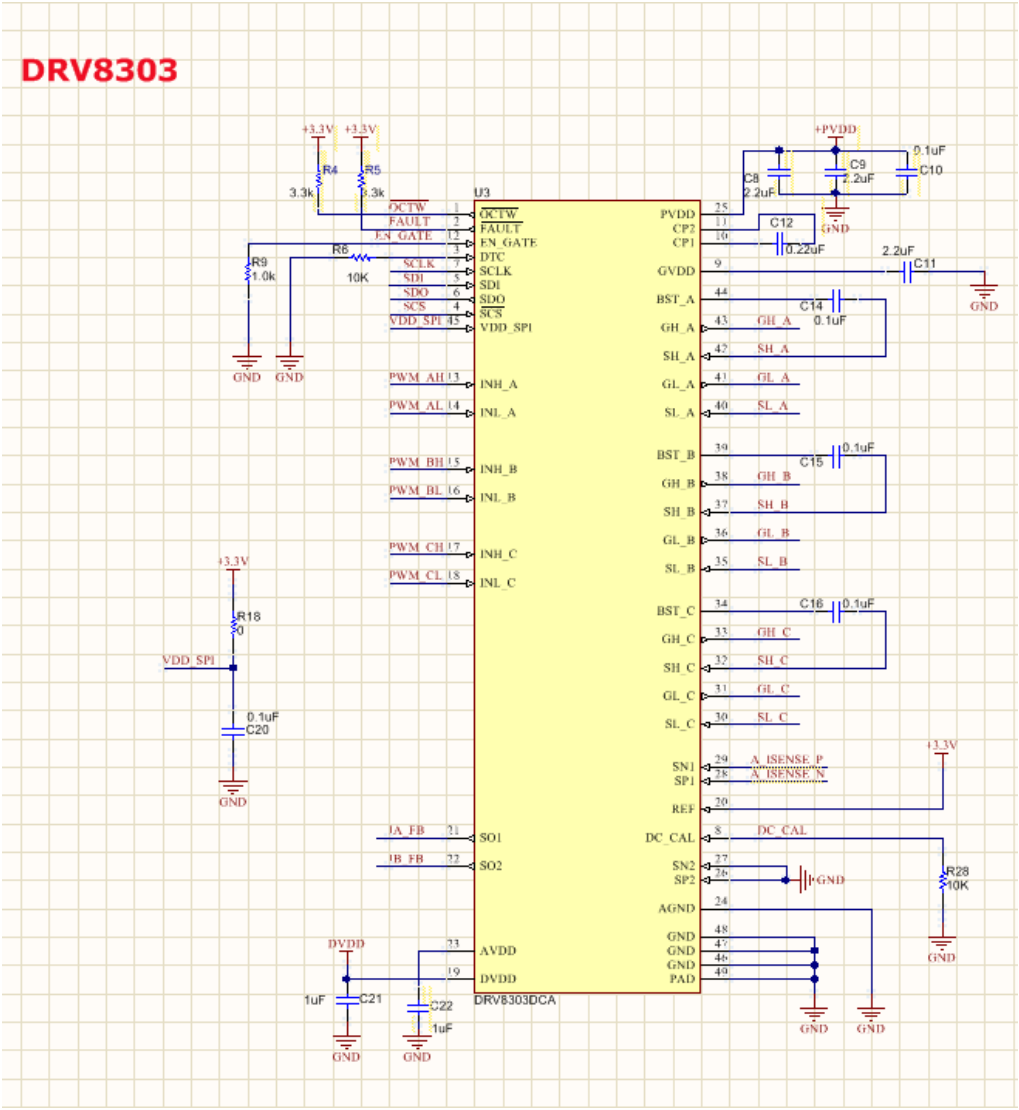

Figure 6. DRV8303 Block

The DRV8303 is a highly integrated three phase gate driver with features specifically for motor drive. It has a single power supply (PVDD) that is bypassed with 4.7 µF ceramic capacitors. Two internal regulators (AVDD and DVDD) are externally bypassed with 1 µF ceramic capacitors. A charge pump (CP1 and CP2) and 3 bootstrap capacitors are utilized to generate the voltage supply (PVDD + 10 V) for the high-side N-channel power MOSFETs and a linear regulator (GVDD) provides the 10 V supply for the low-side MOSFETs.

The internal current shunt amplifiers are referenced to the VREF pin which is supplied from the MCU 3.3 V supply and their settings are configured over the SPI interface. The INH_X and INL_X pins control the state of the half-bridge drivers with GH_X driving the high-side MOSFET gate and GL_X driving the low-side MOSFET gate. The gate driver amplifies the logic level inputs from the MCU to the battery supply voltage (PVDD). The EN_GATE pin is used to wake the device from its low power sleep mode to work mode.

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The DRV8305 provides configurations for managing the MOSFET slew rate and switching performance along with protection features such as shoot-through, overcurrent, under-voltage, over-voltage, and over-temperature protection.

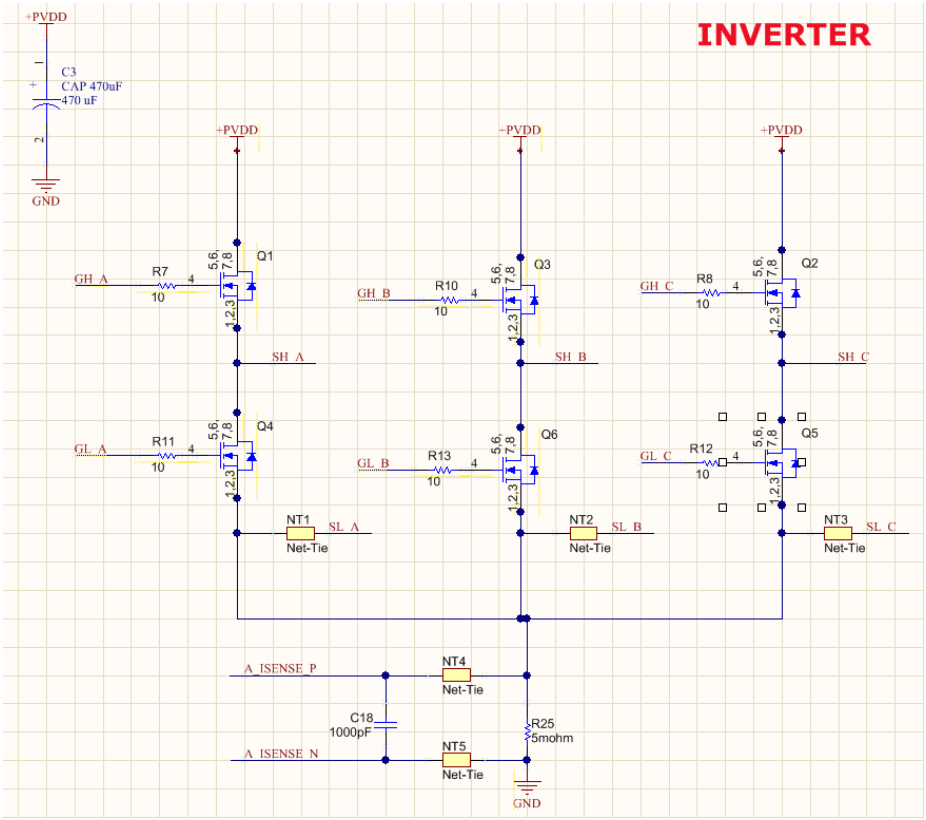

Figure 7. Inverter Block

Six CSD17573Q5B N-channel power MOSFETs form the inverter for the brushless DC motor. The inverter allows the controller to manage the voltage (and proportionally the current) across the motor windings. Applying the correct voltage/current pattern allows the motor to rotate. To improve the efficiency the design, the MOSFET are driven with the DRV8305 gate driver. This allows for minimal conduction and switching losses. To understand more about motor gate drivers and MOSFETs see this app note.

In addition to the MOSFETs, a voltage divider is placed on each motor phase in order to measure the motor back-EMF. The voltage divider is fed directly into the MCU ADC. Back-EMF is voltage that the motor generates when it is spinning. It is used to help determine the rotor position. Three current shunt resistors are placed on the low-side of half-bridge in order to determine the current through each phase. The current shunt resistor voltage is fed into the DRV8303 current shunt amplifier and then to the MCU ADC. This is used to detect the overcurrent.

3.2 Software Design Theory

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The motor controller software is based on the sensor-less trapezoidal algorithm infrastructure. This algorithm integrates the Back-EMF value detected by MCU ADC module and determines the commutation points. The output duty cycle is determined by the speed command from central controller.

The speed command from the central controller is sent into the ESC MCU controller, a CAPTURE module has been configured to receive a reference signal. The reference signal sets the speed command through a servo control method. It can accept a frequency from 50 to 500 Hz with a high period of 1ms corresponding to 0 % speed and a period 2 ms corresponding to 100 % speed. The periods in between these operate with a linear speed curve.

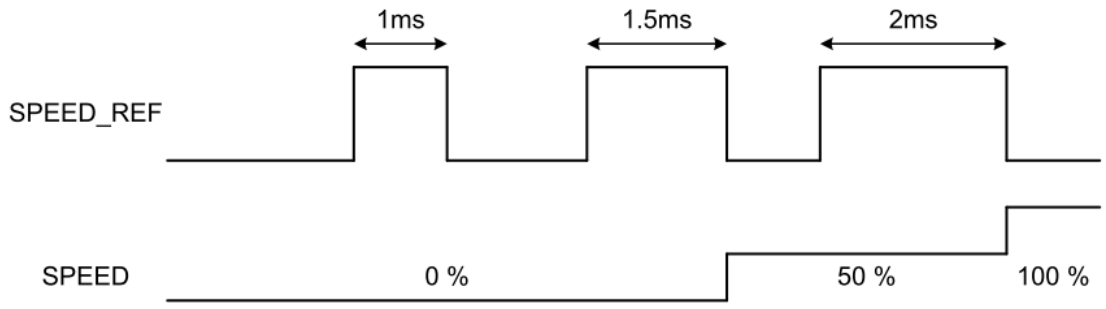

Figure 8. Speed Command Signal

4. Getting Started

4.1 Connections

The TIDA-00735 reference design can be powered from a compatible battery or power supply from 10.8V to 25.2 V. The supply is connected to the motor controller through the two solder pads labeled PVDD and GND. The motor controller can be configured for most brushless DC motors through the firmware, but is targeted at high power propeller motors that are often utilized in drone and RC applications. The three motor phases can be connected to the three solder pads labeled SH_A, SH_B, and SH_C.

The speed reference signal from the central controller is connected to the motor controller through a three pin header. The header is labeled with VDD (optional 3.3V power supply), COM (speed reference signal), and GND.

The SBW connection allows for programming and debugging of the MSP430G2553 motor controller. A three pin Connect adapter was utilized to minimize the board space require for the connector.

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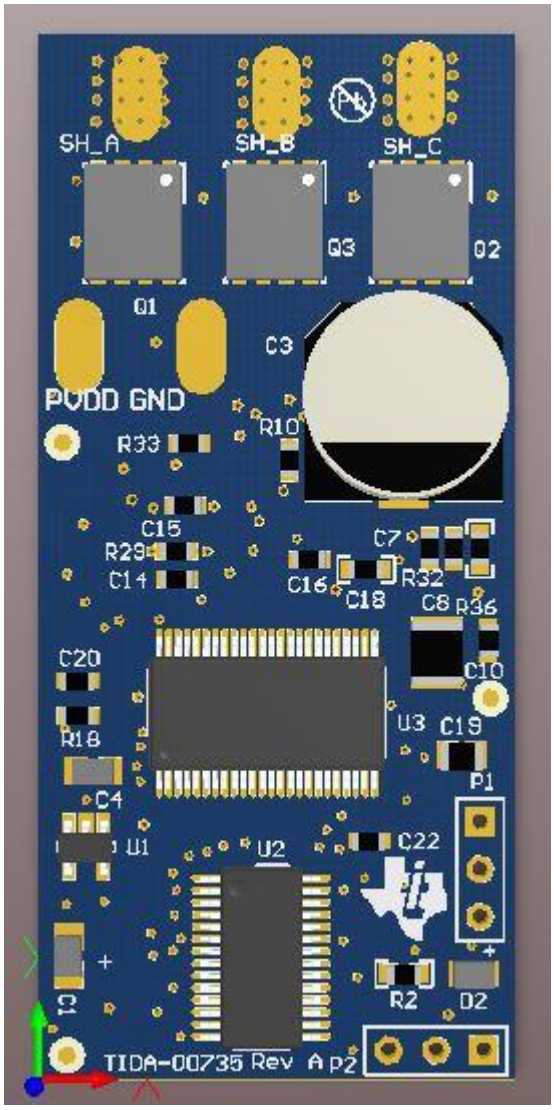

Figure 9. Connections

4.1 Procedure

See the steps below to get started with the reference design hardware.

1. Connect the power supply or battery to the design through the PVDD and GND solder pads.
2. Connect the motor phase wires to the design through the SH_A, SH_B, and SH_C solder pads.
3. Attach the MSP430 debugger, enable the PVDD supply, and program the onboard MCU. The debugger can remain connected if you wish to interface to the design through debugger.
4. Remove the debugger and send the appropriate control signal through the P2 header.

5. Lab Test Data

Below figure shows the motor phase voltage and current when the system is in the normal working mode:

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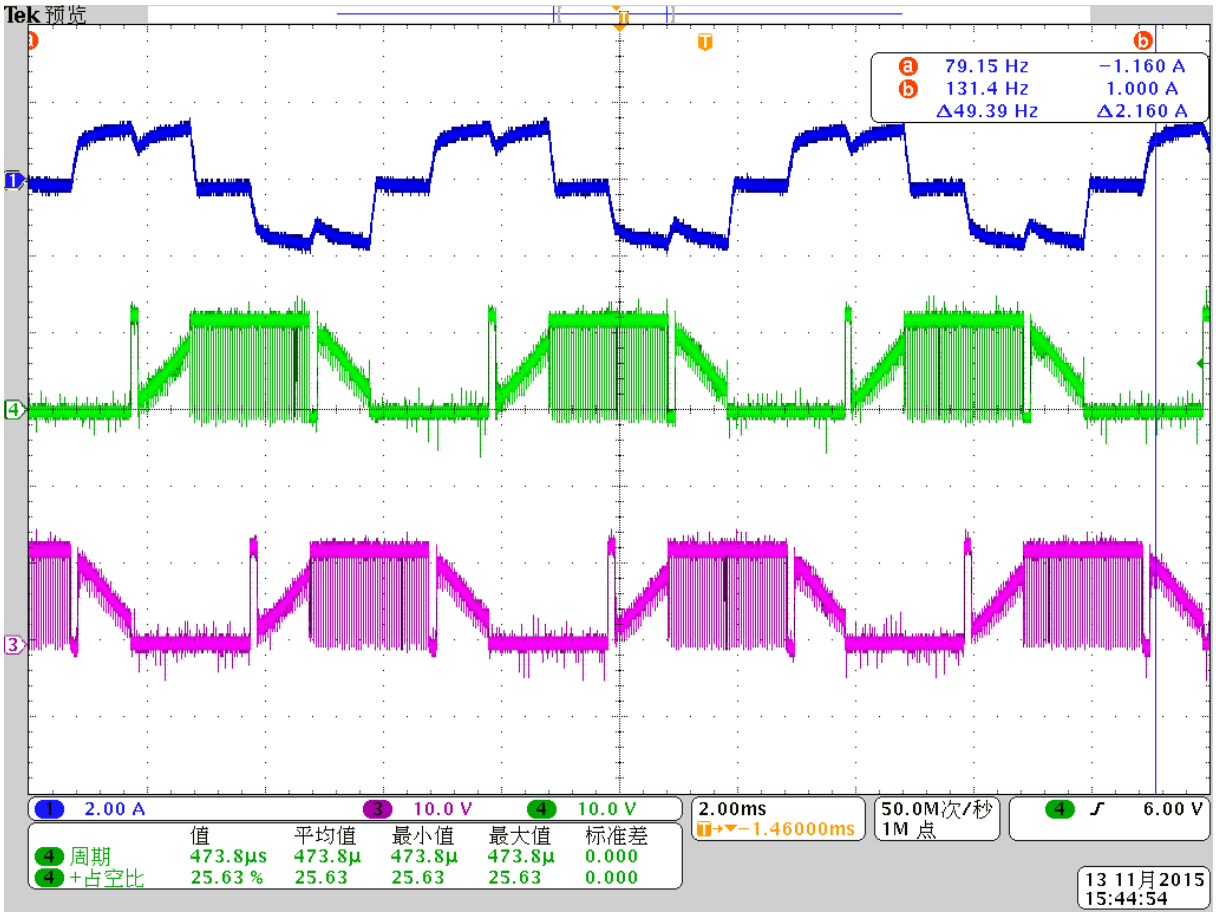

Figure 9. Motor Phase current & voltage

Below figure shows the system performance of high speed motor drive application:

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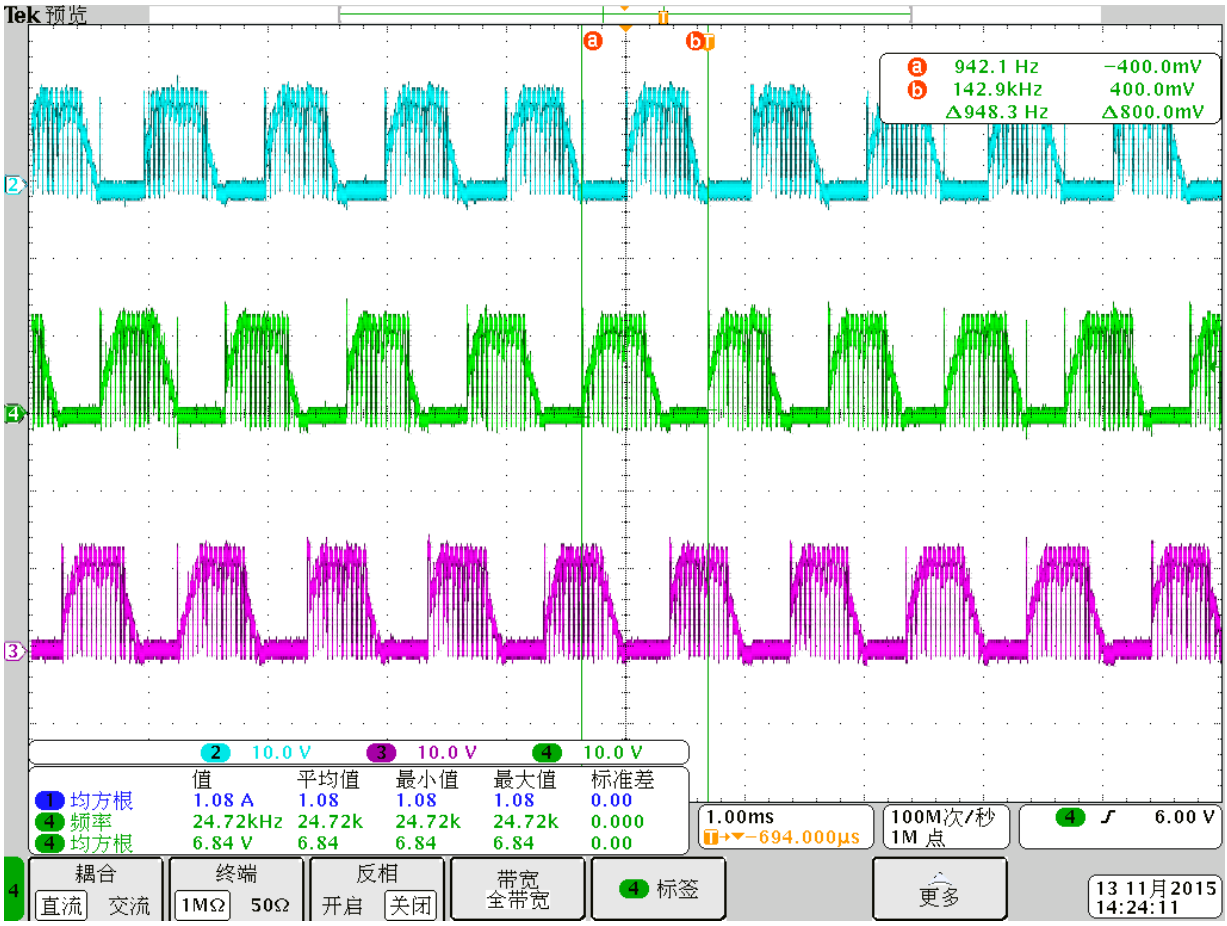

Figure 10. Motor Phase voltage in high speed application

This system could spin the motor up to 950HZ electrical frequency. For the 7-pair poles motor, the motor speed reaches 8140 RPM.

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