TI Designs: TIDM-1003

Low-Voltage, 50-A Sensorless FOC for Brushless DC or Permanent-Magnet Synchronous Motors Reference Design

Description

The TIDM-1003 design is a 30- to 54-V brushless DC motor (BLDC) or permanent-magnet synchronous motors (PMSM) controller for low-voltage, high-current, high-power e-bike, power tool, fan, and pump applications. This TI Design uses the Texas Instruments' UCC27211D MOSFET drivers, CSD19506KCS 80-V NexFET™ power MOSFETs, TMS320F28027F MCU with InstaSPIN™ technology, TPS54360 buck converter, and LDOs. The design uses InstaSPIN-FOC™ technology to identify and tune PMSM or BLDC motor parameters, as well as control motor speed through an external throttle. Overall, the design focuses on demonstrating highly efficient control of high-power, low-voltage BLDC motors or PMSMs.

Resources

TIDM-1003	Design Folder
TMS320F28027F	Product Folder
UCC27211	Product Folder
TPS54360	Product Folder
CSD19506KCS	Product Folder
OPA4374	Product Folder
InstaSPIN-FOC	Tools Folder
MotorWare™	Tools Folder

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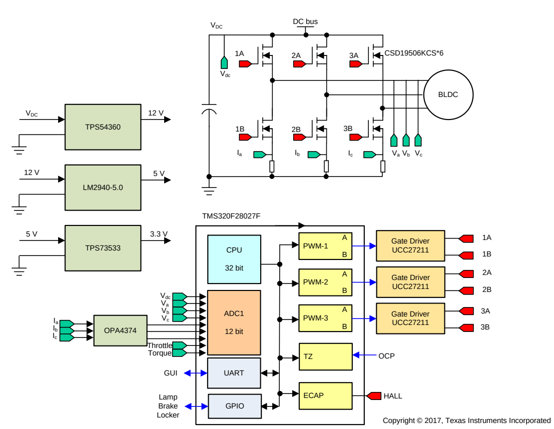
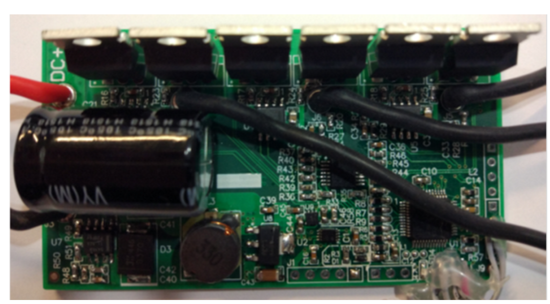
Features

- Up to 500-W Power Stage With Sensorless FOC Based InstaSPIN for BLDC Motors and PMSMs, Efficiency > 90% Over Full Input Range
- 30-V to 54-V Input Voltage Range, 50-A Peak Output Current Capability
- Small Form Factor (L × W): 80 mm × 45 mm, Wide Environment Temperature Test: –40ºC to 55ºC
- Protects Against Overcurrent, Over and Undervoltage, Over- and Underload, Lost Phase, Phase Unbalance, Stall, Motor Overtemperature, Power Module Overtemperature, Lost Communication
- High-Performance Speed Control Includes High Trajectory Changes and Speed Reversal Capability Using InstaSPIN-FOC
- Automatic Motor Parameter Identification, Flying Start Capability to Synchronize to Already Moving Motor

Applications

- E-Bikes and E-Scooters
- Power Tools
- Low-Voltage, High-Power Fans, and Pumps





1 System Description

The TIDM-1003 reference design is an InstaSPIN-FOC solution implemented on a high-power stage for brushless motor control intended for power tools, e-bikes, e-scooters, and similar applications. Compared to conventional brushed motors, permanent magnet brushless motors exhibit advantages such as high efficiency, high torque-to-weight ratio, low maintenance, high reliability, and low rotor inertia. A brushless permanent-magnet synchronous motor (PMSM) has a wound stator and a permanent magnet rotor assembly. These motors generally use internal or external devices to sense the rotor position. The sensing devices provide position information for electronically switching the stator windings in the proper sequence to maintain rotation of the magnet assembly. The sensor-based solution requires accurate mechanical assembly of sensors. The rotor position can also be estimated using sensorless algorithms implemented in microcontroller units (MCUs).

An electronic drive is required to control the stator currents in a brushless permanent magnet motor. The electronic drive has the following parts:

- Power stage with a three-phase inverter
- Gate driver for driving the three-phase inverter
- MCU to implement the motor control algorithm
- Position sensor for accurate motor rotor angle to implement current commutation
- Power supply to power the MCU

Permanent magnet motors can be classified based on Back-EMF (BEMF) profiles: brushless direct current (BLDC) motor and permanent magnet synchronous motor (PMSM). Both BLDC motors and PMSMs have permanent magnets on the rotor but differ in the flux distributions and BEMF profiles. In a BLDC motor, the BEMF induced in the stator is trapezoidal, and in a PMSM, the BEMF induced in the stator is sinusoidal. Implementing an appropriate control strategy is required to obtain the maximum performance from each type of motor.

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS
DC input voltage	48-V nominal (30-V minimum, 54-V maximum)
Maximum input DC current	10 A
Maximum peak output current	50 A
Rated power capacity	500 W
Inverter switching frequency	20 kHz
Inverter efficiency	≥ 95% (theoretical) at rated load
Power supply for MCU	3.3 V ± 5%
Protection	Overcurrent, overtemperature, overvoltage, undervoltage
PCB size (L × W)	80 mm × 45 mm

2 System Overview

2.1 Traditional FOC for PMSM

The PMSM has a sinusoidal BEMF. The sinusoidal BEMF motor offers its best performances when driven by sinusoidal currents and constant torque will be produced. In sinusoidal current control, three phases of the motor are ON at the same time.

Field oriented control (FOC) is used to control the permanent magnet motor. FOC achieves better dynamic performance. The goal of FOC (also called vector control) on the synchronous or asynchronous machine is to separately control the torque producing flux and magnetizing flux components. Several mathematical transforms are required to decouple the torque and magnetizing flux components of the stator current as Figure 1. The processing capability provided by the MCUs enables these mathematical transformations to be carried out very quickly. These transformations in turn imply that the entire algorithm controlling the motor can be executed at a fast rate, enabling a higher dynamic performance.

The FOC algorithm enables real-time control of torque and rotation speed. As this control is accurate in every mode of operation (steady state and transient), no oversize of the power transistors is necessary. The transient currents are constantly controlled in amplitude. Moreover, no torque ripple appears when driving this sinusoidal BEMF motor with sinusoidal currents.

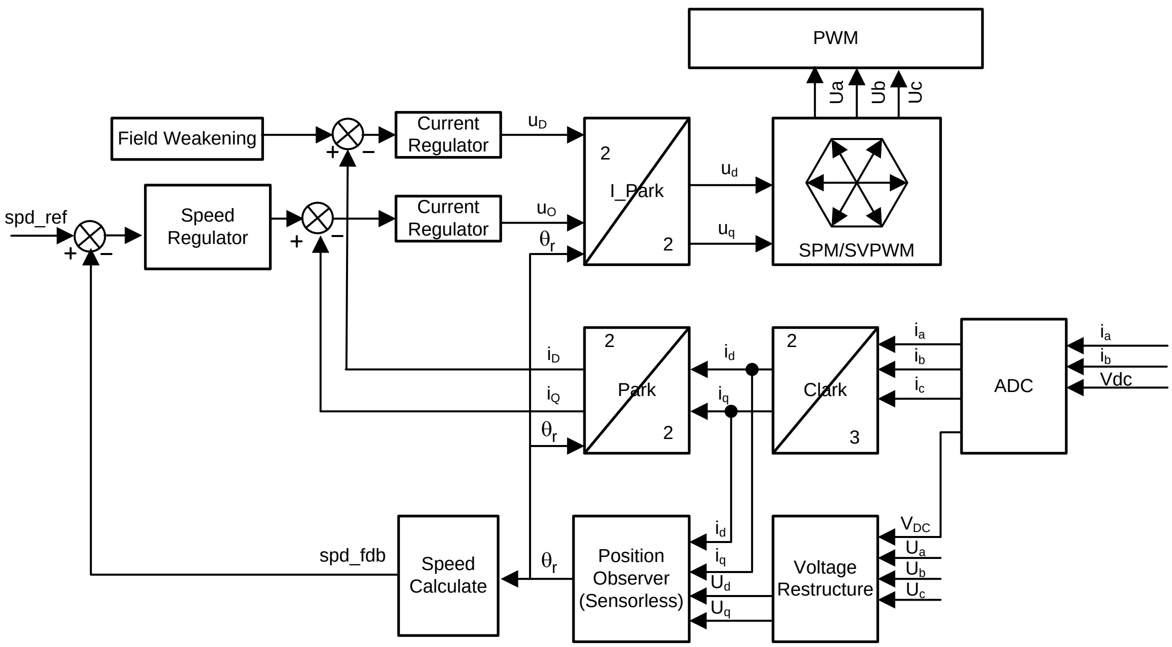


Figure 1. Block Diagram of FOC

2.2 InstaSPIN-FOC for PMSM

TI's InstaSPIN-FOC technology enables designers to identify, tune, and fully control any type of three-phase, variable speed, sensorless synchronous, or asynchronous motor control system. This new technology removes the need for a mechanical motor rotor sensor to reduce system costs and improve operation using TI's new software encoder (sensorless observer) software algorithm, FAST™ (flux, angle, speed, and torque), embedded in the read-only memory (ROM) of Piccolo™ devices. This ROM enables premium solutions that improve motor efficiency, performance, and reliability in all variable-speed and variable-torque applications. Figure 2 shows the block diagram of the InstaSPIN-FOC.

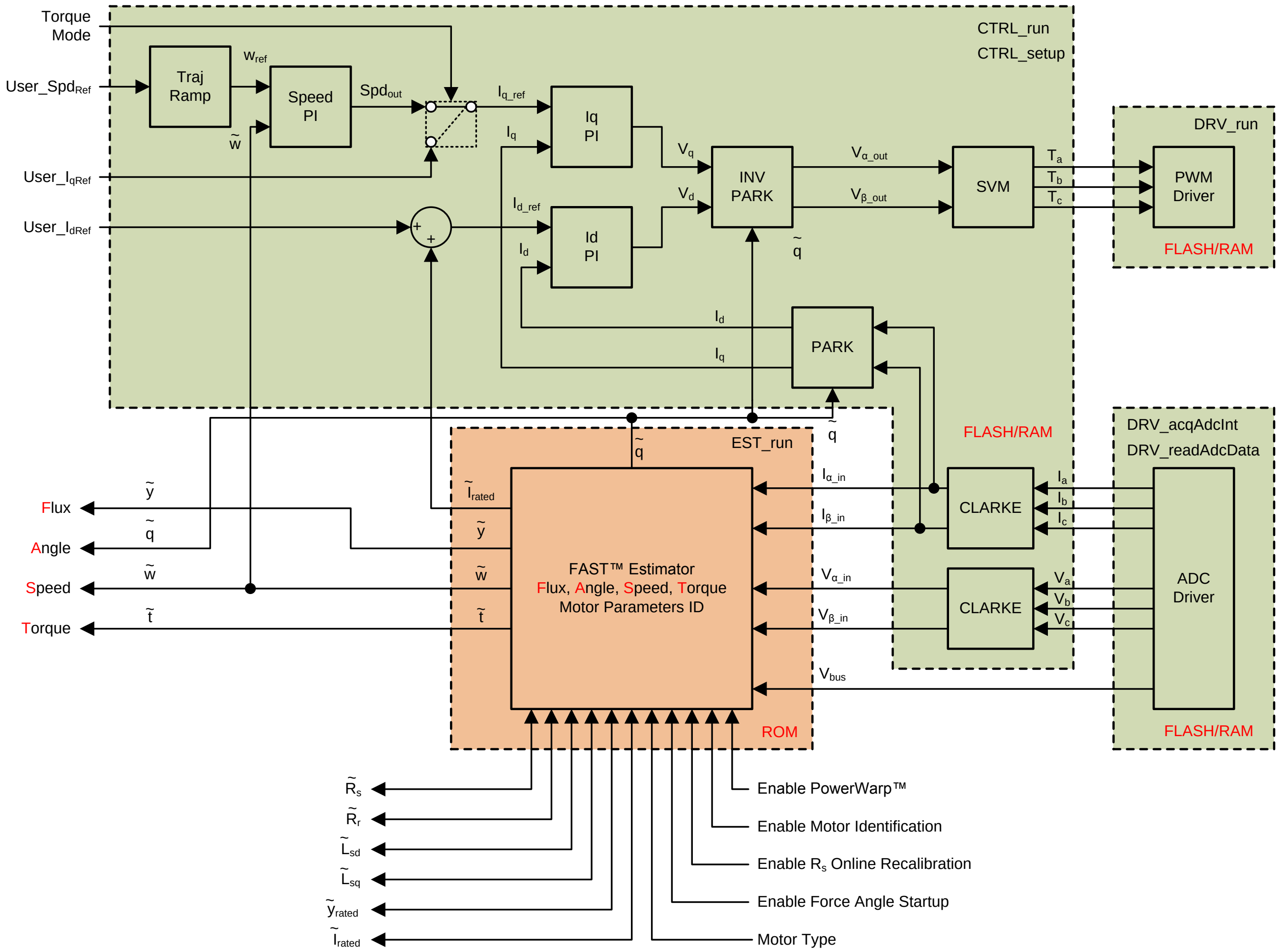


Figure 2. Block Diagram of InstaSPIN-FOC

InstaSPIN-FOC benefits include the following:

- FAST estimator to measure rotor flux magnitude, rotor flux angle, motor shaft speed, and torque in a sensorless FOC system
- Automatic torque (current) loop tuning with option for user adjustments
- Automatic configuration of speed loop gains (Kp and Ki) provides stable operation for most applications and user adjustments required for optimum transient response
- Automatic or manual field weakening and field boosting
- Bus voltage compensation
- Automatic offset calibration ensures quality samples of feedback signals

2.3 Drive Controller Block Diagram

Figure 3 shows the block diagram of the motor drive controller. The main parts of the power stage consists of the InstaSPIN-FOC controller TMS320F28027F, the three-phase MOSFET bridge, the gate driver UCC27211, a 3.3-V step-down DC-DC converter, ESD protection, overtemperature protection, and the current and voltage sense feedback circuits.

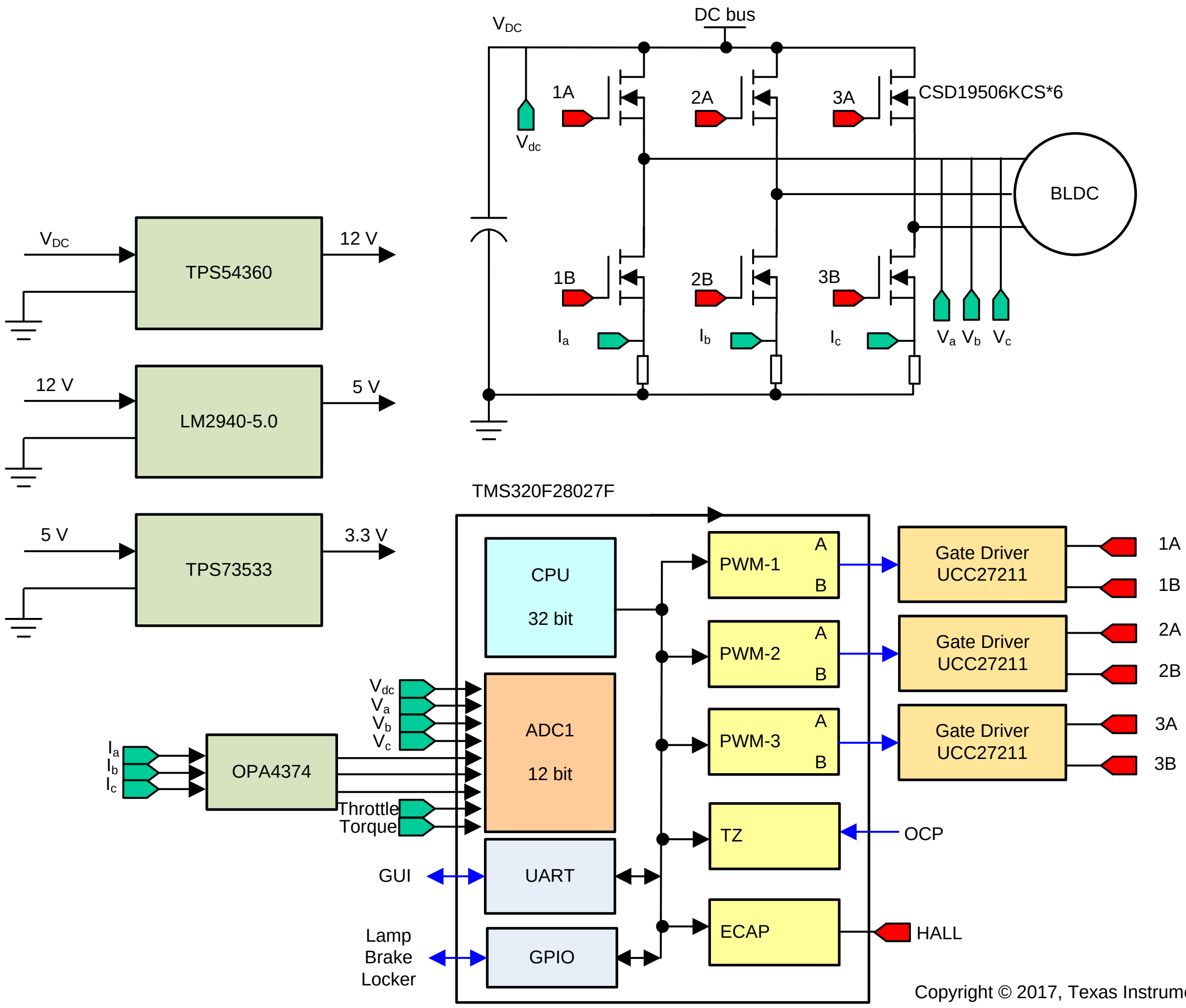


Figure 3. Drive Controller Block Diagram

2.4 Highlighted Products

2.4.1 TMS320F28027F

The TMS320F28027F microcontroller is the C28x core coupled with highly integrated control peripherals in low pin-count devices, as shown in Figure 4. An internal voltage regulator allows for single-rail operation. Analog comparators with internal 10-bit references have been added and can be routed directly to control the PWM outputs. The ADC converts from 0- to 3.3-V fixed full-scale range and supports ratio-metric VREFHI/VREFLO references. The ADC interface has been optimized for low overhead and latency. The device also supports advanced emulation features such as analysis and breakpoint functions and real-time debug through hardware.

The TMS320F28027F includes the FAST estimator and additional motor control functions needed for cascaded speed and torque loops for efficient three-phase FOC. TMS320F28027F peripheral drivers in user code enable a sensorless InstaSPIN-FOC solution that can identify, tune the torque controller, and efficiently control a motor in minutes without the use of any mechanical rotor sensors. This entire package is called InstaSPIN-FOC. The FAST estimator is called from protected ROM, while the rest of the functions required for InstaSPIN-FOC reside in user memory (flash and RAM). InstaSPIN-FOC was designed for flexibility to accommodate a range of system software architectures and customizations.

The InstaSPIN sensorless, three-phase motor solutions makes designing motor control applications easier whether it is a simple application or a complex design.

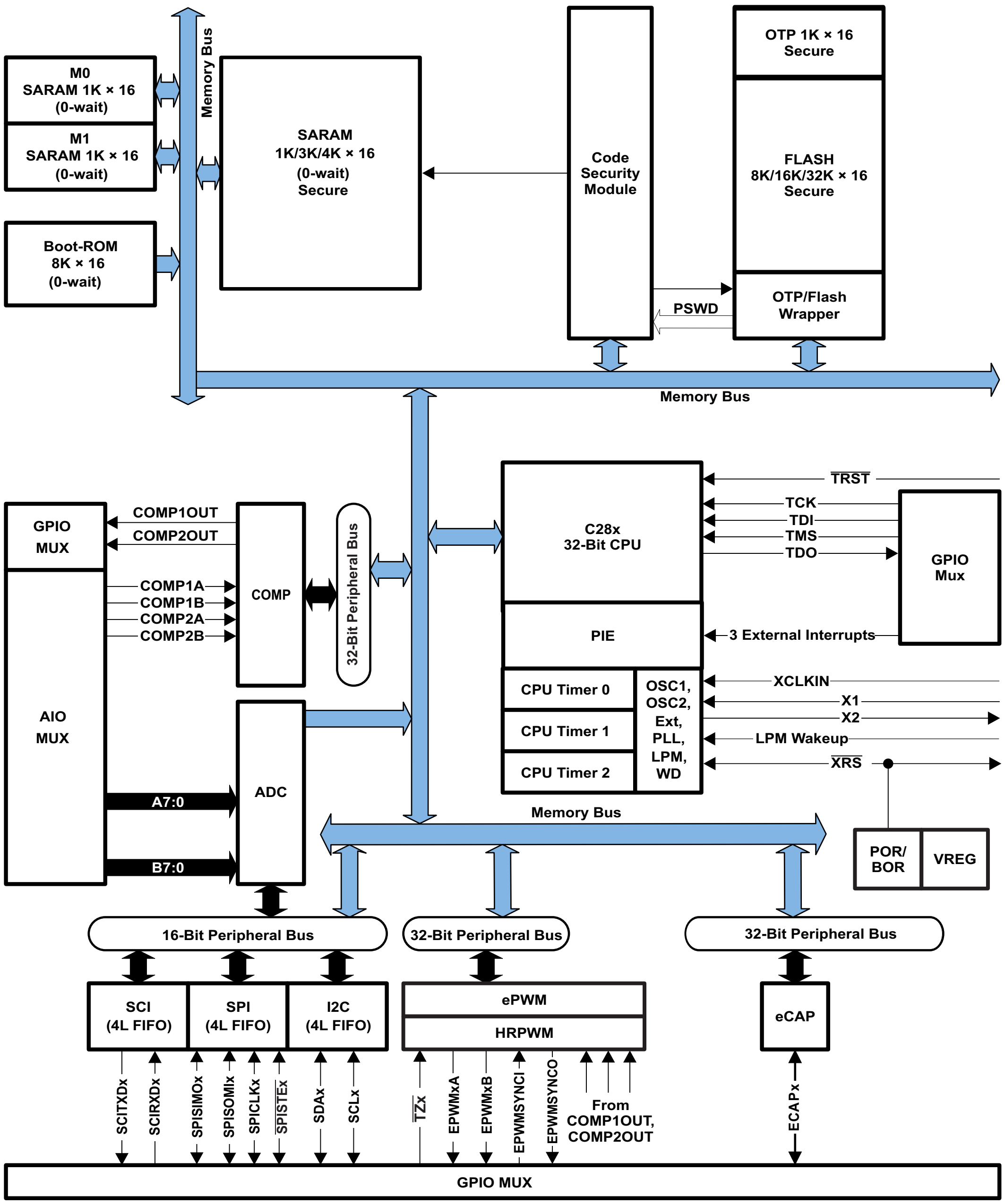


Figure 4. TMS320F28027F Functional Block Diagram

2.4.2 UCC27211D

The UCC27211D MOSFET driver (shown in Figure 5) is based on the popular UCC27200 and UCC27201 MOSFET drivers, but offers several significant performance improvements. Peak output pullup and pulldown current has been increased to 4-A source and 4-A sink, and pullup and pulldown resistance have been reduced to 0.9 Ω, thereby allowing for driving large power MOSFETs with minimized switching losses during the transition through the Miller plateau of the MOSFET. The input structure is now able to directly handle –10 V_{DC}, which increases robustness and also allows direct interface to gate-drive transformers without using rectification diodes. The inputs are also independent of supply voltage and have a maximum rating of 20 V.

The switching node (HS pin) of the UCC27211 can handle a maximum of –18 V, which allows the high-side channel to be protected from inherent negative voltages caused by parasitic inductance and stray capacitance. Supporting TTL inputs, the UCC27211 has increased hysteresis allowing for interface to analog or digital PWM controllers with enhanced noise immunity. The low-side and high-side gate drivers are independently controlled and matched to 2 ns between the turnon and turnoff of each other.

An on-chip 120-V rated bootstrap diode eliminates the external discrete diodes. Undervoltage lockout is provided for both the high-side and the low-side drivers providing symmetric turnon and turnoff behavior and forcing the outputs low if the drive voltage is below the specified threshold.

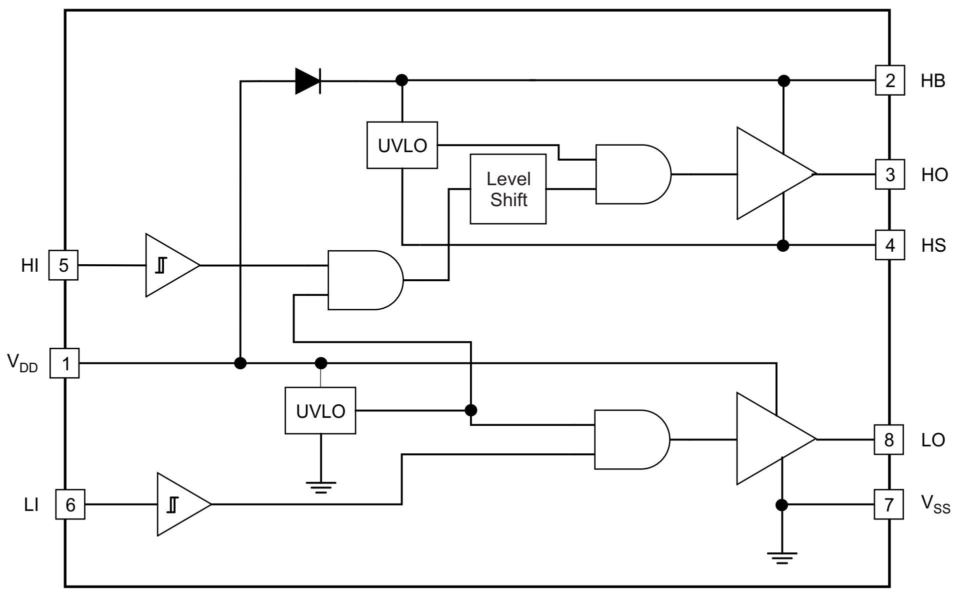


Figure 5. UCC27211D Functional Block Diagram

2.4.3 TPS54360D

The TPS54360 is a 60-V, 3.5-A, step-down regulator with an integrated high-side MOSFET as shown in Figure 6. The device survives load dump pulses up to 65-V per ISO7637 standards. Current mode control provides simple external compensation and flexible component selection. A low-ripple pulse skip mode reduces the no-load supply current to 146 µA. Shutdown supply current is reduced to 2 µA when the enable pin is pulled low.

Undervoltage lockout is internally set at 4.3 V, but can be increased using the enable pin. The output voltage start-up ramp is internally controlled to provide a controlled start-up and eliminate overshoot. A wide-switching frequency range allows either efficiency or external component size to be optimized. Frequency holdback and thermal shutdown protects internal and external components during an overload condition.

The TPS54360 is available in an 8-terminal thermally enhanced HSOIC PowerPAD™ package.

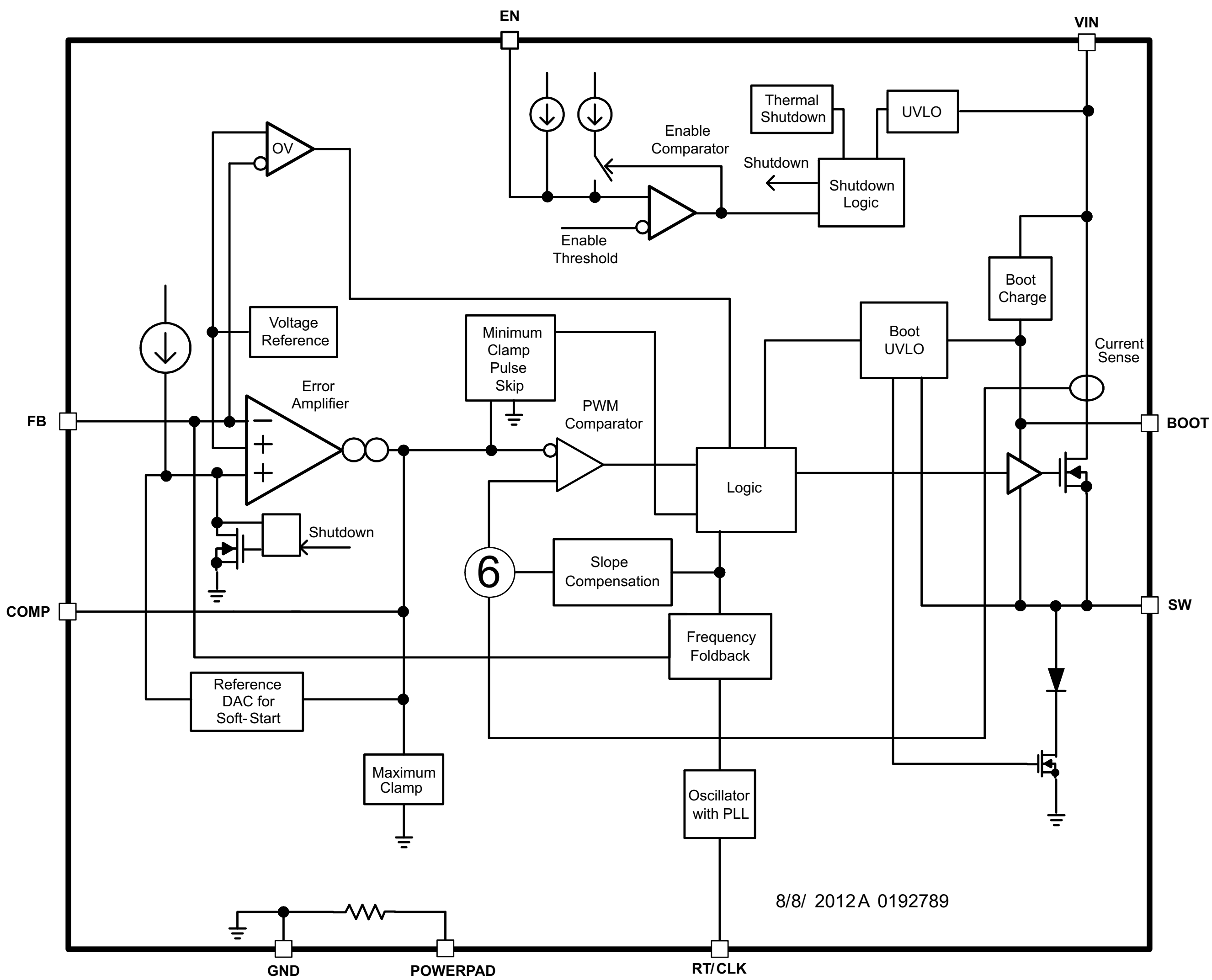


Figure 6. TPS54360 Functional Block Diagram

2.4.4 OPA4374

The OPA374 operational amplifier is low power and low cost with excellent bandwidth (6.5 MHz) and slew rate (5 V/µs). The input range extends 200 mV beyond the rails, and the output range is within 25 mV of the rails. The speed-power ratio and small size make them ideal for portable and battery-powered applications.

The OPA4374 includes a shutdown mode. Under logic control, the amplifiers can be switched from normal operation to a standby current that is less than 1 µA. The OPA4374 operational amplifier is specified for single or dual power supplies of 2.7 to 5.5 V, with operation from 2.3 to 5.5 V. All models are specified for –40°C to 125°C.

2.5 System Design Theory

The motor drive controller is composed of two main components. The first component is the TMS320F28027F MCU, which accepts the speed or torque reference from an external signal, measures the phase voltage and current signals of the motor, and generates the appropriate control signals for the power stage. The second component is the power inverter 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 drive controller uses InstaSPIN-FOC, a sensorless FOC algorithm for BLDC motors. FOC allows for optimal efficiency and noise performance from the motor being driven by the controller. InstaSPIN-FOC uses the signals from the motor BEMF and phase currents 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 switching buck converter and two LDOs.

2.5.1 Power Supply for MCU and Driver

The buck converter TPS54360 converts the input DC voltage to a 12-V output for MOSFET driver and the next stage, as shown in Figure 7. The LM2940 takes the 12-V input and converts it to 5 V. The TPS73533 generates the 3.3 V for the MCU power supply and other control or sampling condition circuits as Figure 8. These ICs compose the auxiliary power supply function for the system.

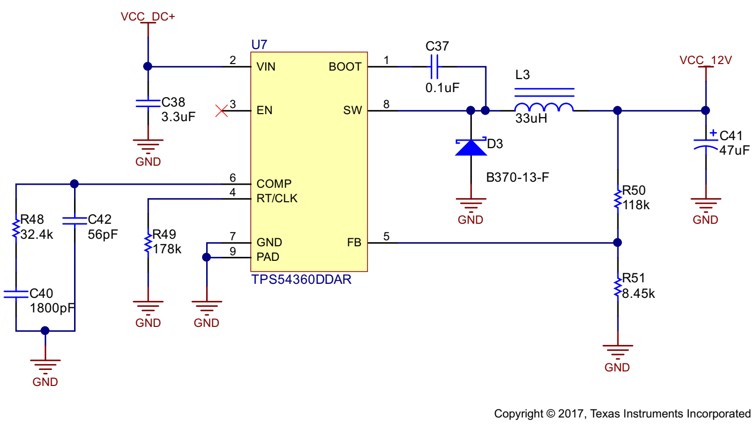


Figure 7. 12-V Power Supply Schematic

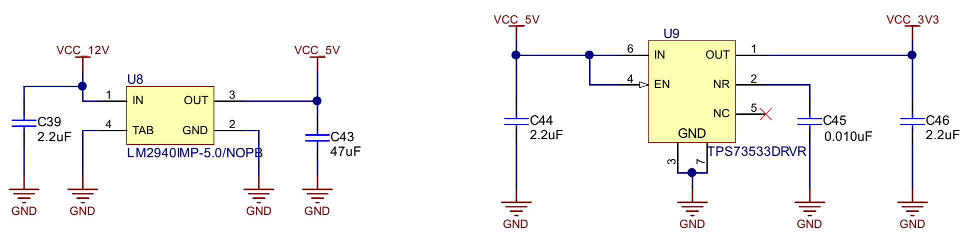


Figure 8. 5-V and 3.3-V Power Supply Schematic

2.5.2 Three-Phase Inverter and MOSFET Gate Driver

The power circuit shown in Figure 9 consists of a three-leg MOSFET bridge. The leg currents are measured using three current shunt sensors: R30, R31, and R32. The sensed currents are fed to the MCU through the current amplifiers. A gate resistance of 10 Ω is used at the input of all MOSFET gates. C22, C23, and C24 are the decoupling capacitors connected across each inverter leg.

NOTE: For better decoupling, connect these decoupling capacitors very near to the corresponding MOSFET legs.

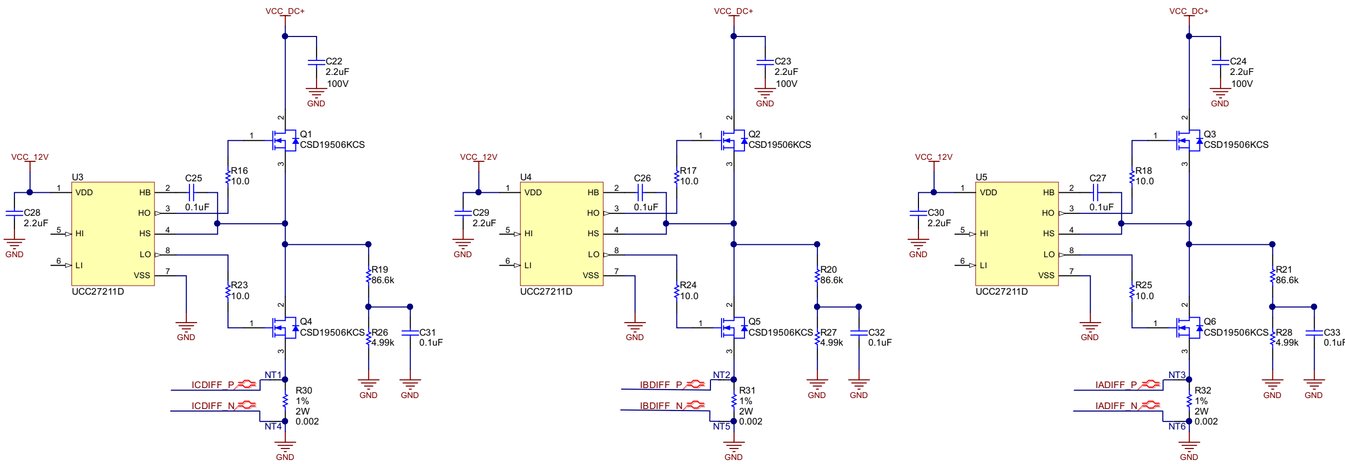


Figure 9. Three-Phase Inverter and MOSFET Gate Driver Schematic

2.5.2.1 Power MOSFET Selection

The board is designed for voltage ranging from 30 to 54 V, which means the maximum input DC voltage in the application is 54 V. Considering the safety factor and switching spikes, the MOSFET with a voltage rating of 1.5 times the maximum input voltage can be selected. A MOSFET with a voltage rating greater than or equal to 80 V is suitable for this application.

The current rating of the MOSFET depends on the peak winding current. The power stage has to provide a 15-A_{RMS} nominal current to the motor winding, so the peak value of the winding current will be $15 \times \sqrt{2} = 21.2$ A. Considering an overloading of 200% for startup with a full load, the peak winding current will be 45 A.

For better thermal performance, MOSFETs with very low $R_{DS(ON)}$ are better for high current applications. In the reference design, the MOSFET CSD19506 is selected, which is a 80V N-Channel NexFET power MOSFET with a $R_{DS(ON)}$ of 2.0 mΩ and features a very low requirement for the total gate charge. The CSD19506 has a continuous drain current capacity (package limited) of 150 A and a peak current capacity of 400 A.

2.5.2.2 Gate Driver Selection

The UCC27211D is used as the gate driver IC for the three-phase motor drive; as such, it is capable of driving two N-channel MOSFETs in high-side and low-side configuration with independent inputs, up to 4-A sink and source output currents, and a 120-V_{DC} maximum boot voltage. Figure 9 shows the schematic of the gate driver section as well.

2.5.3 Three-Phase Current and Voltage Sampling Circuit

The InstaSPIN-FOC algorithm for controlling the motor makes use of sampled measurements of the DC bus power supply voltage, the voltage of each motor phase, and the current of each motor phase, as shown in Figure 10.

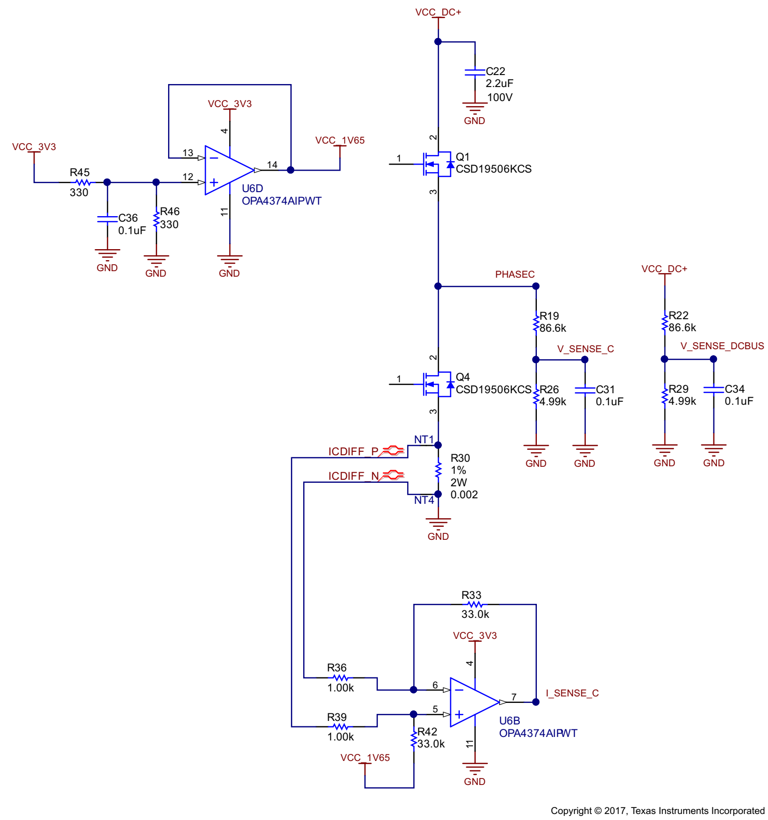


Figure 10. Phase Current and Voltage Sampling Circuit Schematic

2.5.3.1 Current Shunt Resistor Selection

Power dissipation in shunt resistors is important when selecting the shunt resistance values. The nominal RMS winding current in a motor is 15 A. By selecting a 2-mΩ resistor as the shunt resistor, the power loss in the resistor at 15 A_{RMS} is:

$$I_{RMS}^2 \times R_{SHUNT} = 15^2 \times 0.002 = 0.45\ W \tag{1}$$

Equation 1 shows that it is sufficient to select a standard 2-W, 2512-package resistor.

2.5.3.2 Motor Current Feedback Sampling Circuit

During each PWM cycle, the current through the motor is sampled by the microcontroller ADC as part of the motor control algorithm. The circuit shown in Figure 10 shows how the motor current is represented as a voltage signal, with filtering, amplification, and offset to the center of the ADC input range. This circuit is used for each of the three motor phases. The low-side current through phase A flows through shunt resistor (R30), giving a scale factor of 1 mV per amp.

The differential gain amplifier circuit (U6B and surrounding components) has a differential gain of 33, with an offset of approximately 1.65 V provided by the VCC_1V65 voltage. After the gain provided by the op amp circuit, the motor current scale factor at the input to the ADC is 20 mV/A, with a voltage of 1.65 V representing zero motor current. Thus, with a range of 0 to 3.3 V at the input of the ADC, motor currents of (1.65 ÷ 33) / 0.002 = ±25 A can be measured.

2.5.3.3 Motor Voltage Feedback Sampling Circuit

The voltage divider circuit shown in Figure 10 is used to measure the BEMF of the un-energized winding. BEMF feedback is needed for sensorless control to estimate the position of the rotor for accurate commutation. The maximum phase voltage feedback measurable by the MCU can be calculated as follows, considering the maximum voltage for the ADC input is 3.3 V:

$$V^{MAX} = V_{ADC}^{MAX} \times Gain = 3.3 \times \frac{(86.6 + 4.99)}{4.99} = 60.5\ V \qquad (2)$$

Considering a 15% headroom for this value, the maximum voltage input to the system is recommended to be 60.5 × 0.85 = 52 V.

3 Getting Started Hardware and Software

3.1 Hardware

3.1.1 Connections for Drive Controller

The reference design can be powered from a compatible battery or DC power supply from 30 to 52 V. The supply is connected to the drive controller through the two solder pads labeled DC+ and DC–. The three motor phases can be connected to the three solder pads labeled J7, J6, and J5. The speed reference signal from the central controller is connected to the drive controller through a four-pin SCI header (JP1) or can be read as an analog voltage signal through a three-pin header (J4).

The XDS100v2 JTAG connection allows for programming and debugging of the TMS320F28027F controller. A tag-connect adapter is used to minimize the board space require for the JTAG connector.

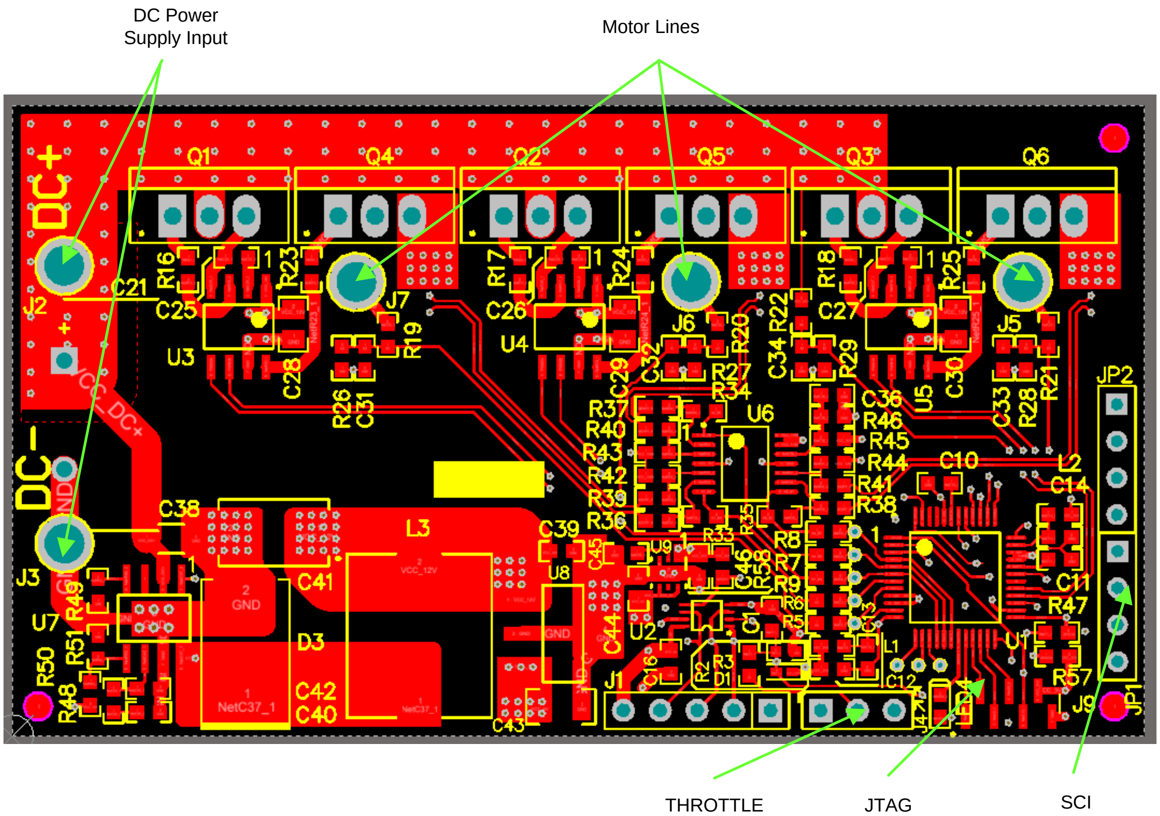


Figure 11. Drive Controller Connections

3.1.2 Test Steps

Follow these steps to get started with the reference design hardware:

1. Connect the power supply or battery to the design through the J2 and J3 solder pads.
2. Connect the motor phase wires to the design through the J5, J6, and J7 solder pads.
3. Attach the JTAG debugger, enable the power supply, and program the onboard TMS320F28027F MCU. The debugger can remain connected to interface to the design through JTAG.
4. Remove the debugger and send the appropriate control signal through the JP1 or J4 headers.

3.2 *Firmware*

3.2.1 Download and Install CCS and MotorWare

This TI Design uses MotorWare for the BLDC motor control and system controllers. To get started, go and download the latest version from www.TI.com. See the Code Composer Studio™ (CCS) web page at http://www.ti.com/tool/ccstudio for information on downloading the integrated development environment for the C2000™ code.

The MotorWare software can be downloaded from the Texas Instruments web site at http://www.ti.com/tool/MOTORWARE. Follow the installation instructions to install on a local computer.

3.2.2 Add Custom Hardware to MotorWare

After installing the MotorWare and CCS software, follow these steps to add the files necessary to use MotorWare with the TIDM-1003 board:

1. Navigate to C:/ti/motorware/motorware_1_01_00_17/sw. All changes made for this TI Design are completed in "sw" subfolders.
2. Create a new HAL directory to hold the contents of the zip folder labeled "TIDM-1003_sw_modules_hal_boards.zip," and copy the directory to "sw/modules/hal/boards." The folder should be named C:\ti\motorware\motorware_1_01_00_17\sw\modules\hal\boards\TIDM_1003.
3. Create a new project directory to hold the contents of the zip folder labeled "TIDM-1003_sw_solutions_instaspin_foc_boards.zip", and copy the directory to "sw/solutions/instaspin_foc/boards." The folder should be named C:\ti\motorware\motorware_1_01_00_17\sw\solutions\instaspin_foc\boards\TIDM_1003.
4. Add a new project source files directory to hold the project source code files, and name the directory C:\ti\motorware\motorware_1_01_00_17\sw\solutions\instaspin_foc\src.

3.2.3 Run Reference Design Software

1. Import the TIDM_1003 project from the MotorWare directory as shown in Figure 12 and the imported project files structure as shown in Figure 13.

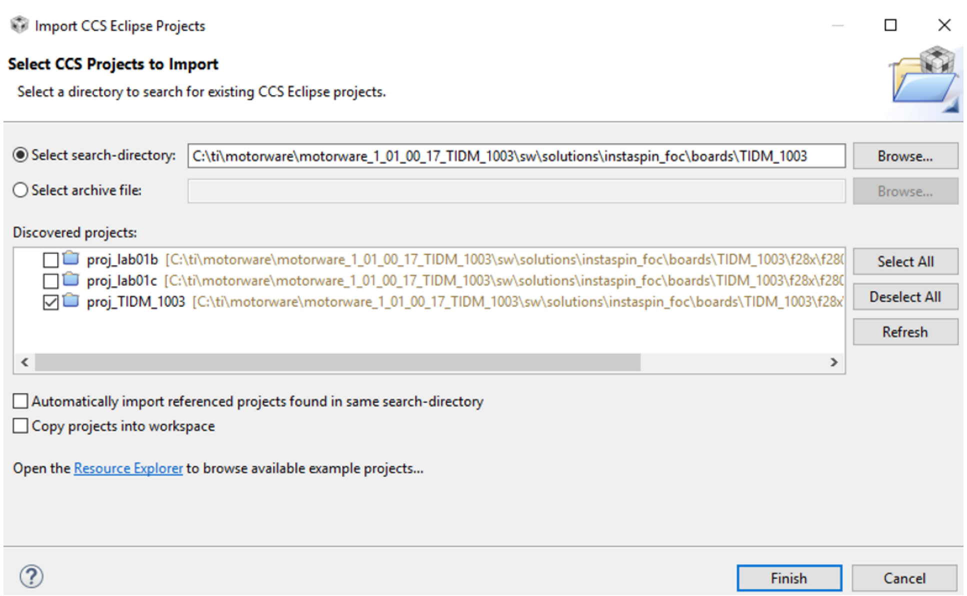


Figure 12. Import TIDM-1003 CCS Project

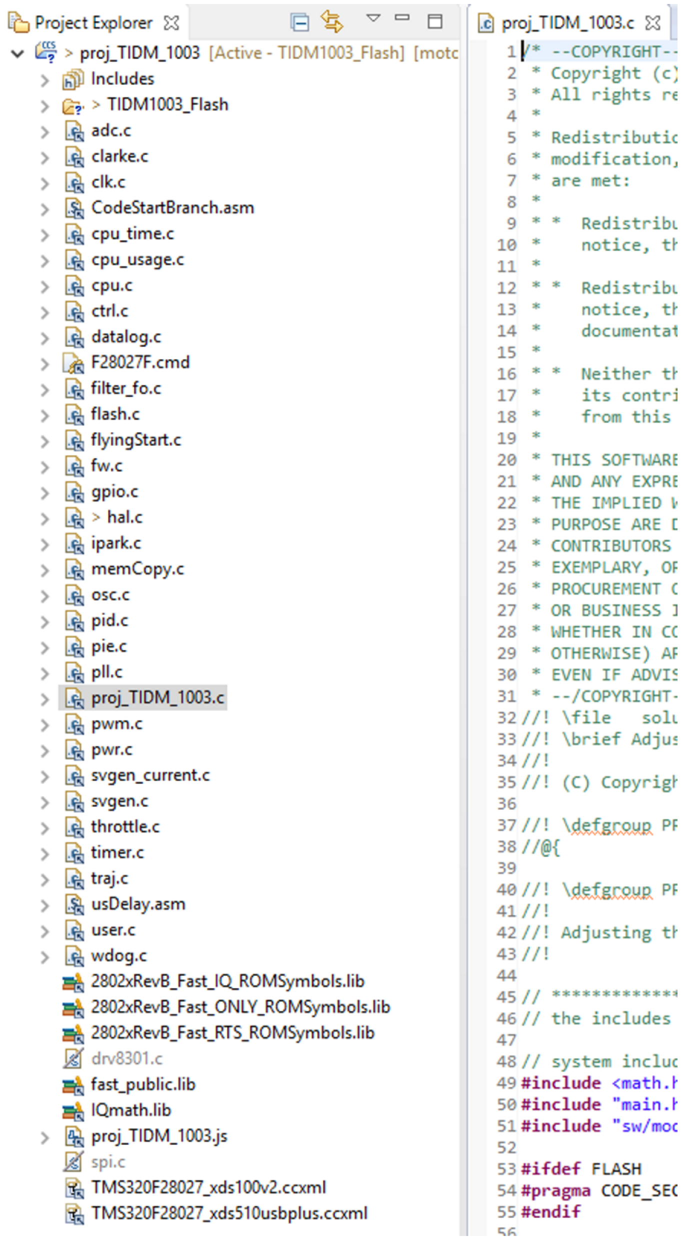


Figure 13. Imported TIDM-1003 Project and Files

2. Select the correct target configuration. The JTAG connection depends on the emulator being used. The target device on this reference board is TMS320F28027F.
3. Build and debug the project. Make sure the project is active by clicking the left key of mouse on the project name. Build the project by clicking the  icon on the CCS Edit toolbar. Start a debug session by clicking the  icon on the CCS Edit toolbar. The target code will be downloaded to the MCU of the reference board.
4. Run the project. Import proj_TIDM_1003.js into the CCS scripting console for the variable expressions necessary to debug, and enable Silicon Real-time mode by clicking the "clock" icon in the CCS Debug toolbar.
5. Run the motor. Set the flags Flag_enableSys and Flag_Run_Identify to 1, and change the value of SpeedRef_krpm to command speed.

4 Testing and Results

4.1 Test Setup

Table 2. Test Equipment

EQUIPMENT	NAME
DC power supply	Agilent, N5769A
Oscilloscope	Agilent, DSO-X 3024A
Multimeter	Fluke, 189
Motor	Anaheim, BLY341S-48V-3200
Dynamometer	Magtrol, HD-705-6N
Dynamometer controller	Magtrol, DSP6001

4.2 Test Results

The following tests are performed to characterize each individual functional block as well as the entire board:

- Functional tests include power supply output and gate drive
- Motor parameter identification
- Motor running with load

4.2.1 Power Supply and Gate Drive Tests

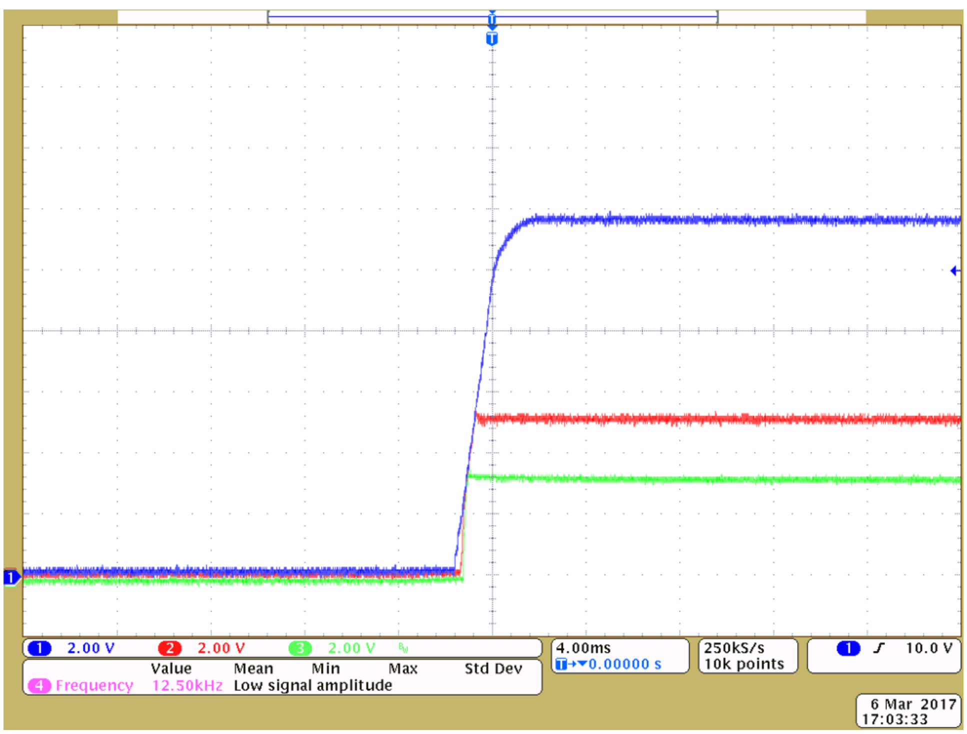


Figure 14. 12-, 5- and 3.3-V Power Supply Output at 36-V Power Input

- CH1 (blue): 12-V power supply for gate driver
- CH2 (red): 5-V power supply for interface
- CH3 (green): 3.3-V power supply for MCU

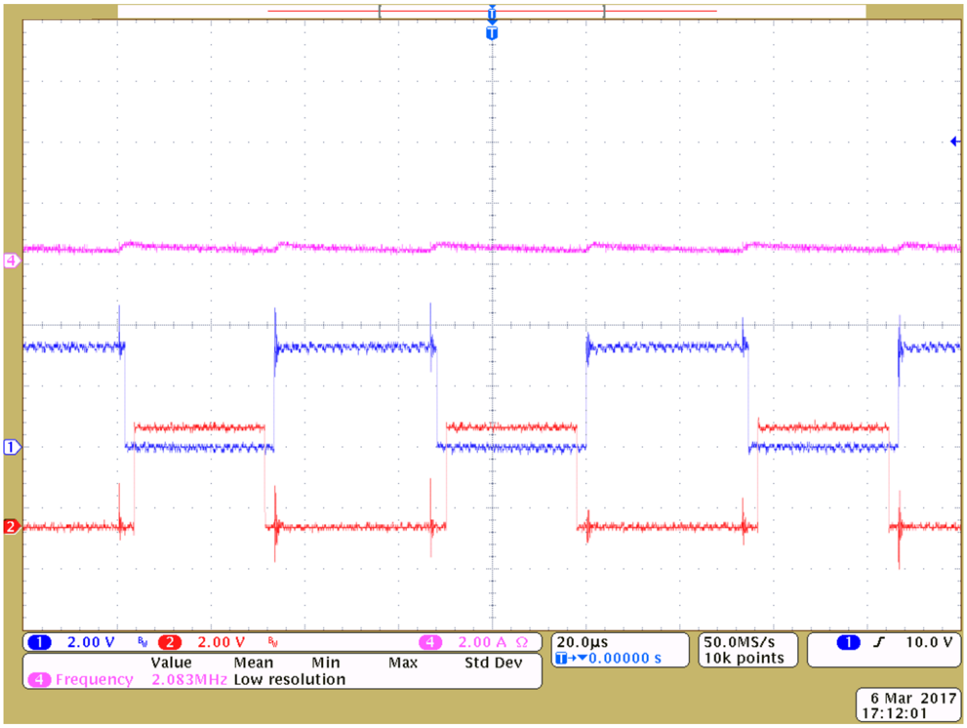


Figure 15. High-Side and Low-Side Gate With Dead Band From MCU

4.2.2 Motor Parameters Identification Without Load

Open user.h from the directory of the project. The user.h file has definitions of motor parameters. A few values can already be put into the user.h motor parameters, which need to be set for the actual motor parameters:

- USER_MOTOR_TYPE: The motor type, ACI, or PMSM
- USER_MOTOR_NUM_POLE_PAIRS: The number of pole pairs of the motor
- USER_MOTOR_MAX_CURRENT: The maximum nameplate current of the motor
- USER_MOTOR_RES_EST_CURRENT: The motor will have to initially be started in open loop during identification. This value sets the peak of the current used during initial startup of the motor. If the motor has high-cogging torque or some kind of load, increase this current value until the motor will start spinning. After motor identification, this value is never used.
- USER_MOTOR_IND_EST_CURRENT: For PMSMs, this value can be set to the negative of the current used for USER_MOTOR_RES_EST_CURRENT.
- USER_MOTOR_NUM_POLE_PAIRS: The number of pole pairs of the motor
- USER_MOTOR_RATED_FLUX: The motor flux linkage between the rotor and the stator

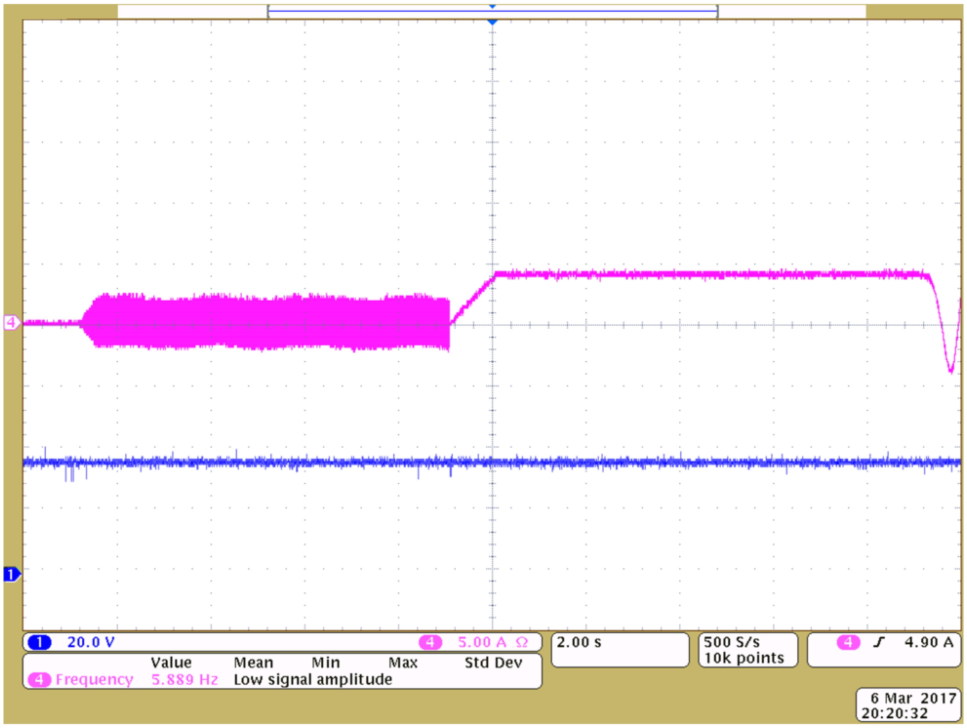


Figure 16. RoverL and Rs Identification State

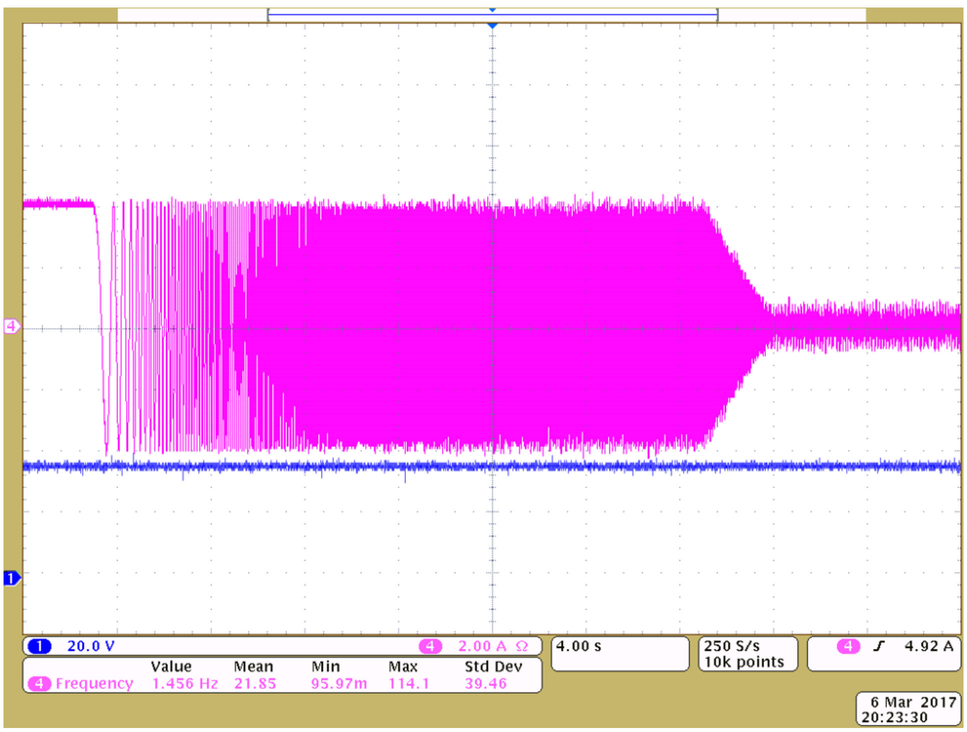


Figure 17. Rampup and Flux Identification State

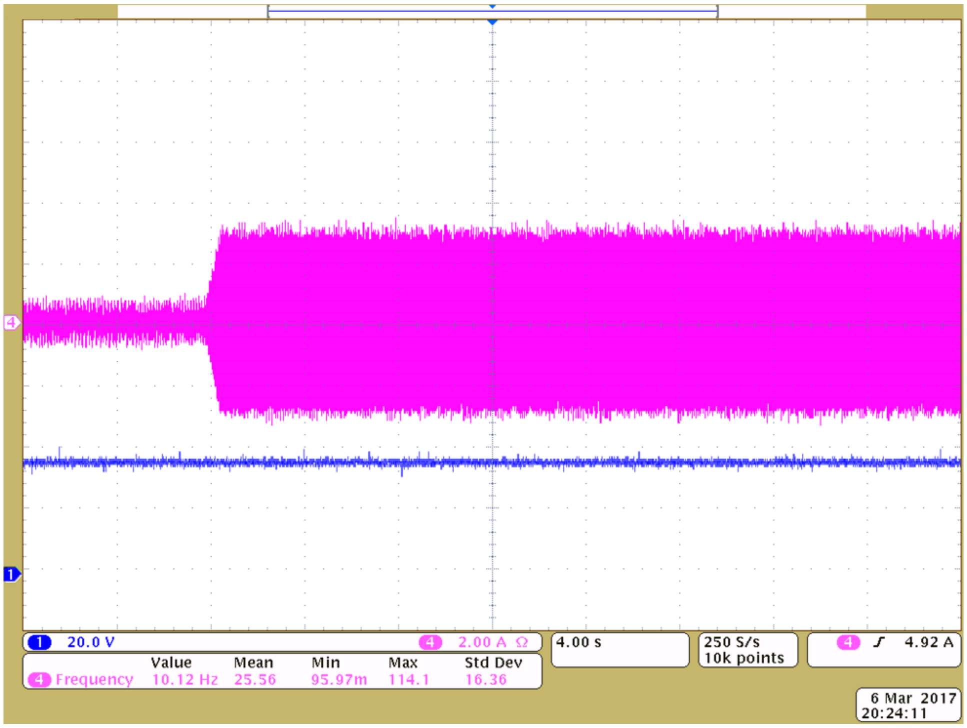


Figure 18. Ls Identification State

4.2.3 Motor Running Tests With Load

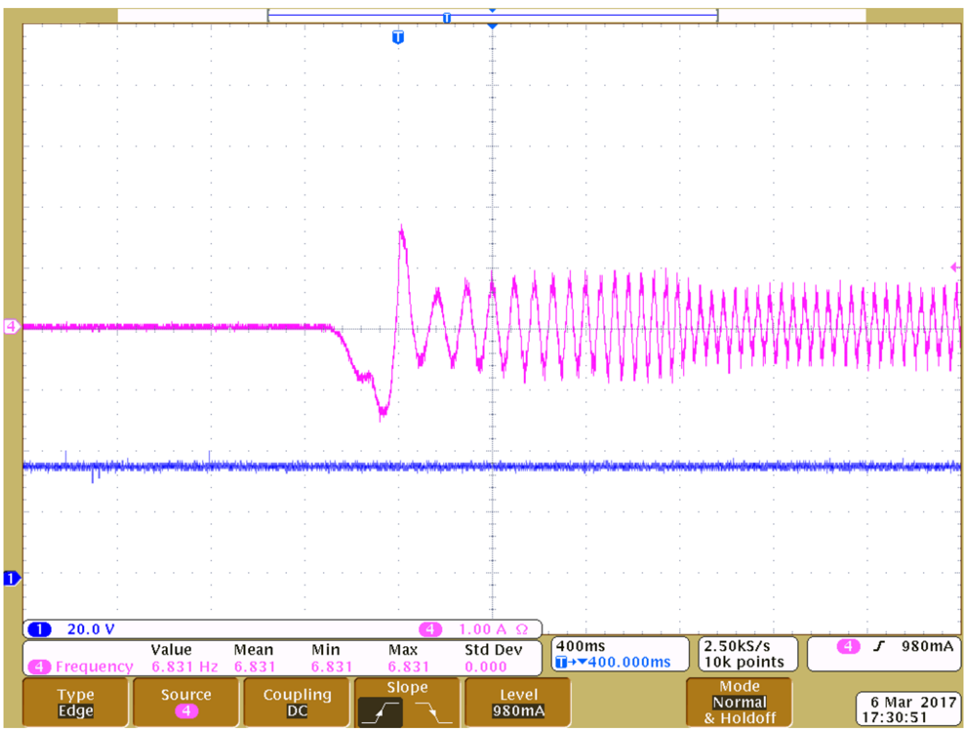


Figure 19. Motor Startup Without Load

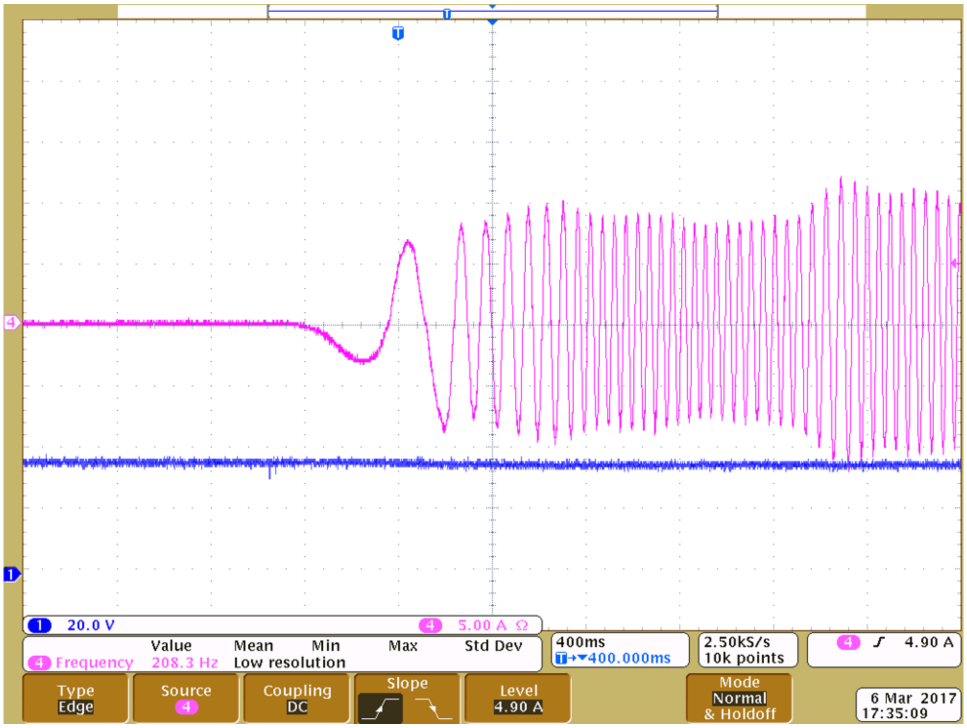


Figure 20. Motor Startup With Light Load

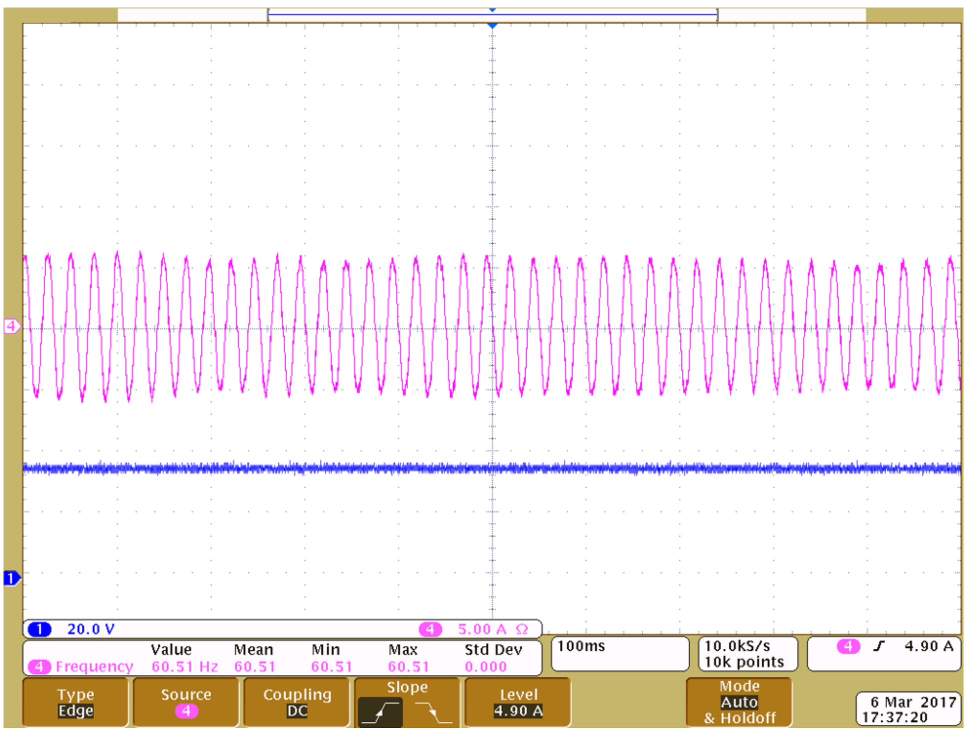


Figure 21. Motor Running at 900 rpm With Light Load

4.2.4 Test Summary

This TI Design shows how to adapt InstaSPIN-FOC to enable low-voltage, high-current motor control using TI provided software. This control is done by using the special capabilities of the C2000 processor family for advanced system debug capabilities. This can supplement the simulation effort of the engineers to avoid developing the perfect simulation tool for the system and simply use the actual hardware to debug the control algorithm issue. This hardware removes the need to build complex simulation algorithms to define specific motor or PCB parasitic effects to the system.

5 Design Files

5.1 Schematics

To download the schematics for each board, see the design files at TIDM-1003.

5.2 Bill of Materials

To download the Bill of Materials for each board, see the design files at TIDM-1003.

5.3 PCB Layout Recommendations

5.3.1 Layout Prints

To download the layer plots, see the design files at TIDM-1003.

5.3.2 Power Supply Recommendations

Layout is a critical portion of a good power supply design. There are several signal paths that conduct fast changing currents or voltages that can interact with stray inductance or parasitic capacitance to generate noise or degrade performance.

1. To reduce the parasitic effects, C38 was placed near VIN as a bypass capacitor, with care taken to minimize the loop area formed by the bypass capacitor (C38) connections and the VIN.
2. The GND terminal should be tied directly to the PowerPad under the TPS54360. The PowerPAD should be connected to internal PCB ground planes using multiple vias directly under the TPS54360.
3. The SW terminal should be routed to the cathode of the catch diode (D3) and to the output inductor (L3). The output filter capacitor (C41), catch diode (D3) and output inductor (L3) should be located close to the SW terminals, and the area of the PCB conductor minimized to prevent excessive capacitive coupling.
4. The RT/CLK terminal is sensitive to noise so the RT resistor (R49) should be located as close as possible to the TPS54360 and routed with minimal lengths of trace.

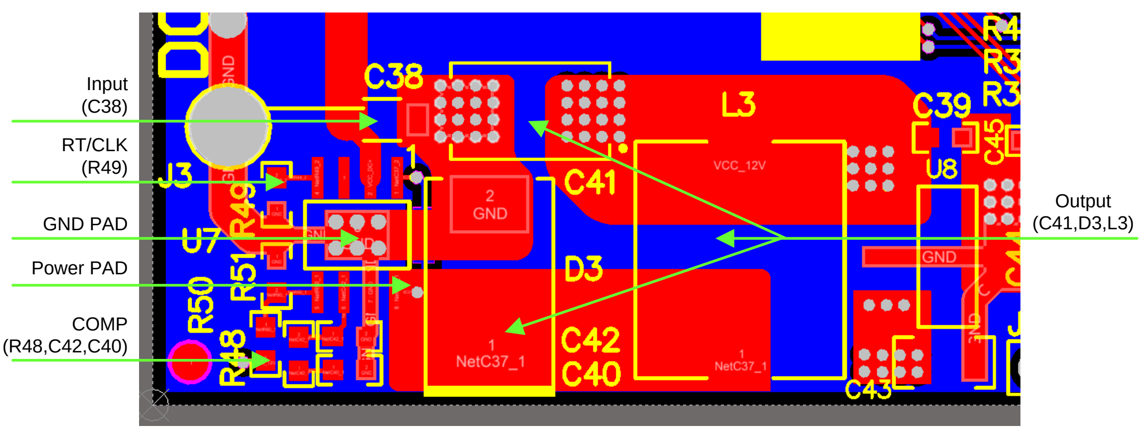


Figure 22. TPS54360 PCB Layout Recommendations

5.3.3 MOSFET Gate Drivers Recommendations

To improve the switching characteristics and efficiency of a design, follow these layout recommendations:

1. Locate the driver as close as possible to the MOSFETs.
2. Locate the bootstrap capacitor (C25) between VHB and VHS as close as possible to the UCC27211.
3. Locate the decoupling capacitor (C28) between VDD and VSS as close as possible to the UCC27211.
4. Avoid VDD traces being close to LO, HS, and HO signals.
5. Use wide traces for LO and HO closely following the associated GND or HS traces. A 60- to 100-mils width is preferable where possible.
6. Use as least two or more vias for VDD and GND were routed from one layer to another.
7. Avoid LI and HI (driver input) being too close to the HS node.

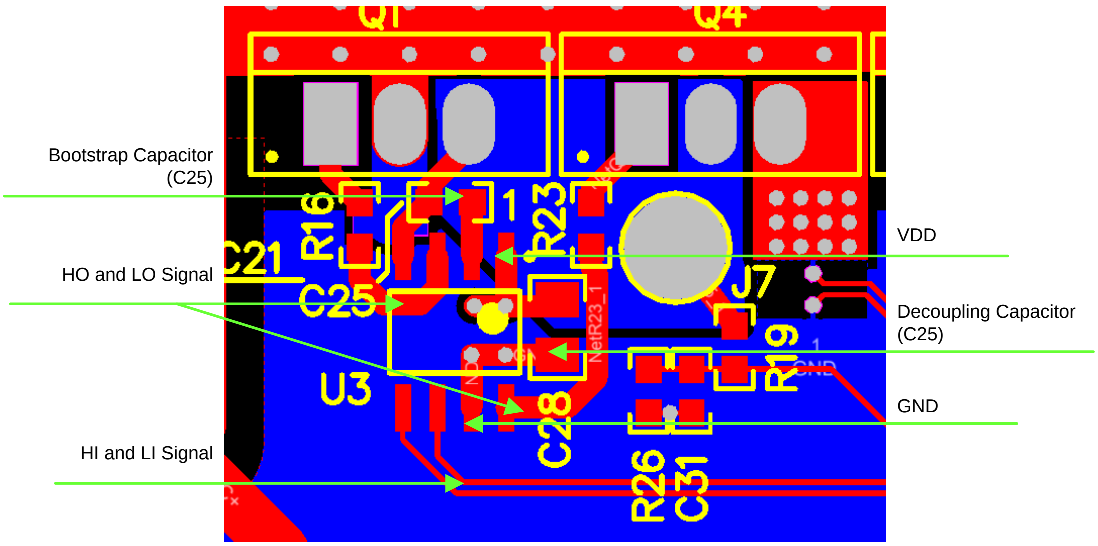


Figure 23. UCC27211 PCB Layout Recommendations

5.3.4 Motor Current and Voltage Signals Sampling Recommendations

1. Place the external components as close to the OPA4374 as possible, keeping RF (R34) and RG (R37) close to the inverting input of OPA4374 to minimize parasitic capacitance.
2. Use low-ESR, ceramic bypass capacitor (C35) and place it close to the OPA4374.
3. For differential signals for the motor current feedback across the current sense resistors, use symmetry to ensure that any noise picked up on one line is also picked up approximately equally on the other line. Keep the length of input traces as short as possible and run the input traces as far away from the supply lines as possible.
4. Separate grounding for analog and digital portions of circuitry is one of the simplest and most effective methods of noise suppression.
5. Keep the input filter resistors (R7) and capacitor (C4) of the anti-aliasing filter as close together and near to the inputs of the microcontroller ADC to minimize the loop area.

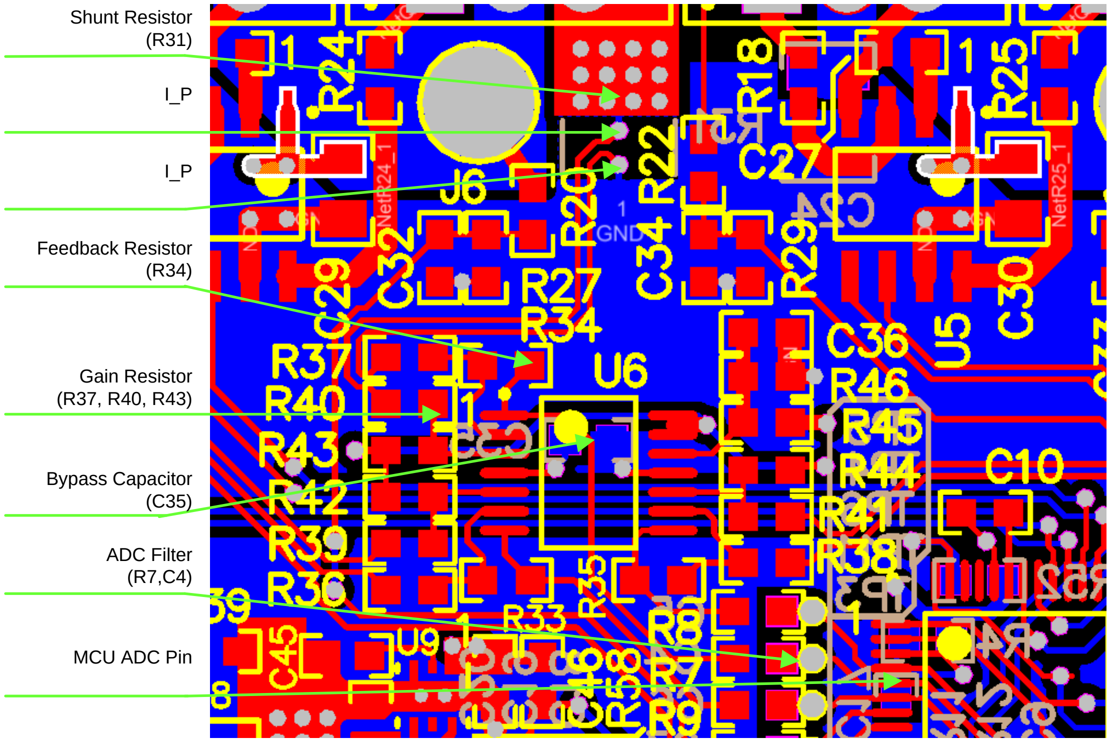


Figure 24. PCB Layout Recommendations for Motor Current and Voltage Sampling

5.4 Altium Project

To download the Altium project files for each board, see the design files at TIDM-1003.

5.5 Gerber Files

To download the Gerber files for each board, see the design files at TIDM-1003.

5.6 Assembly Drawings

To download the assembly drawings for each board, see the design files at TIDM-1003.

6 Software Files

To download the software files for this reference design, see the design files at TIDM-1003.

7 Related Documentation

1. Texas Instruments, *TI InstaSPIN™ Motor Control Solutions*
2. Texas Instruments, *Texas Instruments WEBENCH® Design Center*
3. Texas Instruments, *TMS320F2802x Piccolo™ Microcontrollers*, TMS320F28027F Datasheet (SPRS523)
4. Texas Instruments, *UCC2721x 120-V Boot, 4-A Peak, High-Frequency High-Side and Low-Side Driver*, UCC27211 Datasheet (SLUSAT7)
5. Texas Instruments, *TPS54360 60 V Input, 3.5 A, Step Down DC-DC Converter with Eco-mode™*, TPS54360 Datasheet (SLVSBB4)
6. Texas Instruments, *CSD19506KCS 80 V N-Channel NexFET™ Power MOSFET*, CSD19506KCS (SLPS481)
7. Texas Instruments, *InstaSPIN-FOC™ and InstaSPIN-MOTION™ User's Guide* (SPRUHJ1)

7.1 Trademarks

8 Terminology

FOC— Field oriented control

PMSM— Permanent magnet synchronous motor

BLDC— Brushless DC motor

MCU— Microcontroller unit

FETs, MOSFETs— Metal-oxide-semiconductor field-effect transistor

PWM— Pulse width modulation

ESD— Electrostatic discharge

TVS— Transient voltage suppressors

RPM— Rotation per minute

9 About the Authors

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