

TI Designs

Drive a Single Phase Brushless DC (BLDC) with a Brushed Motor Driver Reference Design



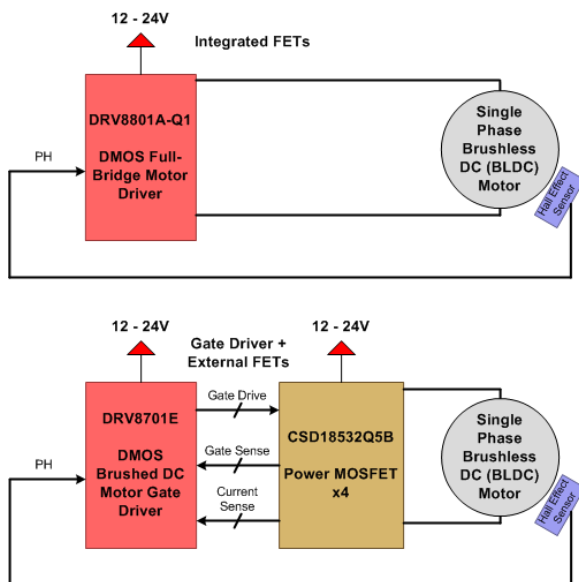
Design Overview

The TIDA-00875 reference design demonstrates how to configure a brushed motor driver as a single phase brushless motor driver. It uses the Texas Instrument's DRV8801A-Q1 and DRV8701E to demonstrate this capability. The DRV8801EVM and the DRV8701EVMs are modified to demonstrate operation of both a brushed motor driver with integrated FETS (DRV8801A-Q1) and a brushed gate driver (DRV8701E with CSD18532Q5B 60V, N-Channel NexFET Power MOSFETs). This design is focused on demonstrating the configuration of the motor driver section. Additional circuitry, such as reverse voltage protection and EMI/EMC filters, can be added to complete the system.

Design Resources

TIDA-00875	Design Folder
DRV8801A-Q1	Product Folder
DRV8701E	Product Folder
CSD18532Q5B	Product Folder
DRV5013ADQ	Product Folder

Block Diagram



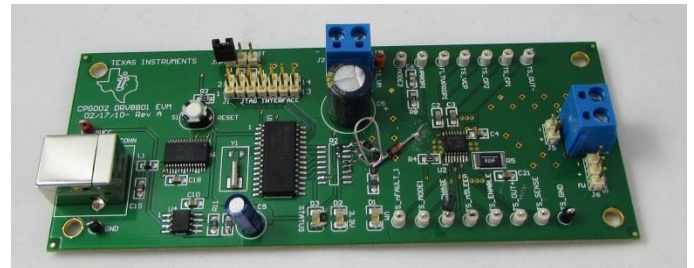
Design Features

- 12 to 24 V input voltage range
- 2.8 A peak output capability (DRV8801A-Q1 based system)
- 20 A peak (DRV8701E based system)
- Wide array of system protection features including overcurrent and supply undervoltage protection

Featured Applications

- Fans
- Industrial Pumps
- Robotics
- Vacuum Cleaners
- Power Tools

Board Images



1 System Description

TIDA-00875 configures the DRV8801EVM and the DRV8701EVM to demonstrate single phase brushless dc (BLDC) operation with a brushed motor driver. The concepts for both the DRV8801EVM and the DRV8701EVM are similar. The procedure to modify the EVMs is provided to allow quick evaluation without requiring the fabrication of a PCB.

The motor controller is composed of two main components. The first component is the motor driver, either the DRV8801A-Q1 with integrated FETS or the DRV8701E plus external CSD18532Q5B power MOSFETs. Both devices have a phase/enable (PH/EN) interface that allows the hall effect sensor to control current direction. The second component, the DRV5013ADQ Hall effect sensor, controls the direction of the current using the PH input pin.

Two schematics are provided. The DRV8801A-Q1 schematic demonstrates a basic operation. When the device is powered, the motor is operated at 100% duty cycle. The DRV8701E schematic demonstrates use of a PWM input to control the EN pin, allowing the motor speed to be adjusted using the duty cycle of the PWM signal.

Both schematics show the components required to control a BLDC motor using the brushed motor driver. Additional circuitry, such as reverse voltage protection and EMI/EMC filters, can be added as desired.

1.1 DRV8801A-Q1 Brushed Motor Driver / DRV8701E Brushed Motor Gate Driver

The DRV8801A-Q1 motor driver, or DRV8701E brushed motor gate driver in conjunction with 4 CSD18532Q5B Power MOSFETs, controls the current through the motor. The DRV8801A-Q1 is a single device rated to 2.8A peak and operating voltages to 36V. The combination of the DRV8701E and external power FETs allow the current to be increased to the desired level.

Both the DRV8801A-Q1 and DRV8701E provide system protection such as overcurrent, thermal shutdown, undervoltage, and short circuit protection.

1.2 CSD18532Q5B NexFET™ N-Channel Power MOSFET

The DRV8701E motor controller uses four CSD18532Q5B to complete the H-bridge. This power MOSFET is an ultra-low $R_{DS(on)}$ device designed to minimize losses in power conversion and switching applications. It comes in a compact, 8 pin SON 5 x 6 mm package with an $R_{DS(on)}$ of 2.5 m Ω at a V_{GS} of 10 V to minimize board space required and limit thermal dissipation.

Product Summary

$T_A = 25^\circ\text{C}$		TYPICAL VALUE		UNIT
V_{DS}	Drain-to-Source Voltage	60		V
Q_g	Gate Charge Total (10 V)	44		nC
Q_{gd}	Gate Charge Gate-to-Drain	6.9		nC
$R_{DS(on)}$	Drain-to-Source On Resistance	$V_{GS} = 4.5\text{ V}$	3.3	m Ω
		$V_{GS} = 10\text{ V}$	2.5	m Ω
$V_{GS(th)}$	Threshold Voltage	1.8		V

Figure 1 CSD18532Q5B Summary

1.3 DRV5013ADQ Digital-Latch Hall Effect Sensor

The DRV5013 device is a chopper-stabilized Hall Effect Sensor that offers a magnetic sensing solution with superior sensitivity stability over temperature and integrated protection features.

The magnetic field is indicated via a digital bipolar latch output. The IC has an open drain output stage with 30-mA current sink capability. A wide operating voltage range from 2.5 to 38 V with reverse polarity protection up to -22 V makes the device suitable for a wide range of industrial applications.

2 Block Diagram

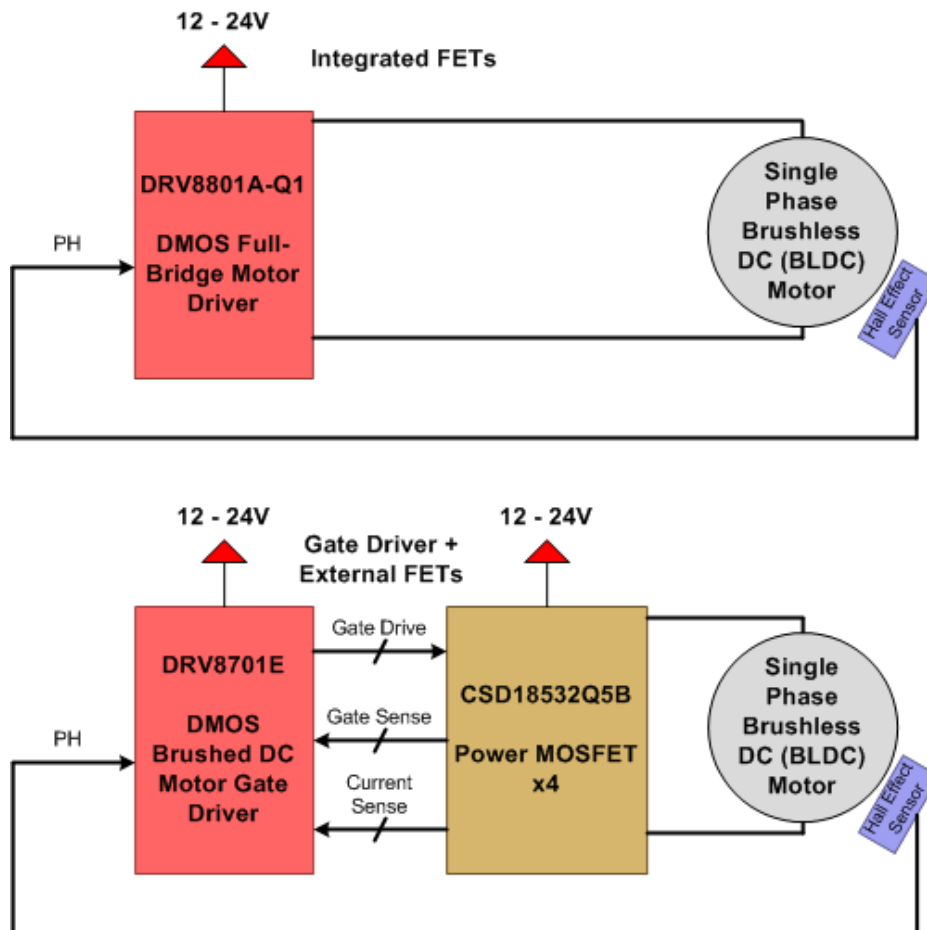


Figure 2 TIDA-00875 Block Diagram

2.1 Highlighted Products

The critical devices to this design are outlined below.

- DRV8801A-Q1: DMOS Full-Bridge Motor Drivers
- DRV8701E: Brushed DC Motor Full-Bridge Gate Drivers
- CSD18532Q5B: 60-V N-Channel NexFET™ Power MOSFETs
- DRV5013ADQ: Digital-Latch Hall Effect Sensor

2.1.1 DRV8801A-Q1

The DRV8801A-Q1 device provides a versatile motor-driver solution with a full H-bridge driver. The device can drive a brushed DC motor or one winding of a stepper motor, as well as other devices like solenoids. A simple PHASE and ENABLE interface allows easy interfacing to controller circuits.

The output stages use N-channel power MOSFETs configured as an H-bridge. The DRV8801A-Q1 device is capable of peak output currents up to ± 2.8 A and operating voltages up to 36 V. An internal charge pump generates required gate drive voltages.

A low-power sleep mode is provided which shuts down internal circuitry to achieve very low quiescent current draw. This sleep mode can be set using a dedicated nSLEEP pin.

Internal protection functions are provided undervoltage lockout, overcurrent protection, short-to-supply protection, short-to-ground protection, overtemperature warning, and overtemperature shutdown. Overcurrent (including short-to-ground and short-to-supply) and overtemperature fault conditions are indicated via a nFAULT pin.

A block diagram for the DRV8801A-Q1 is shown below.

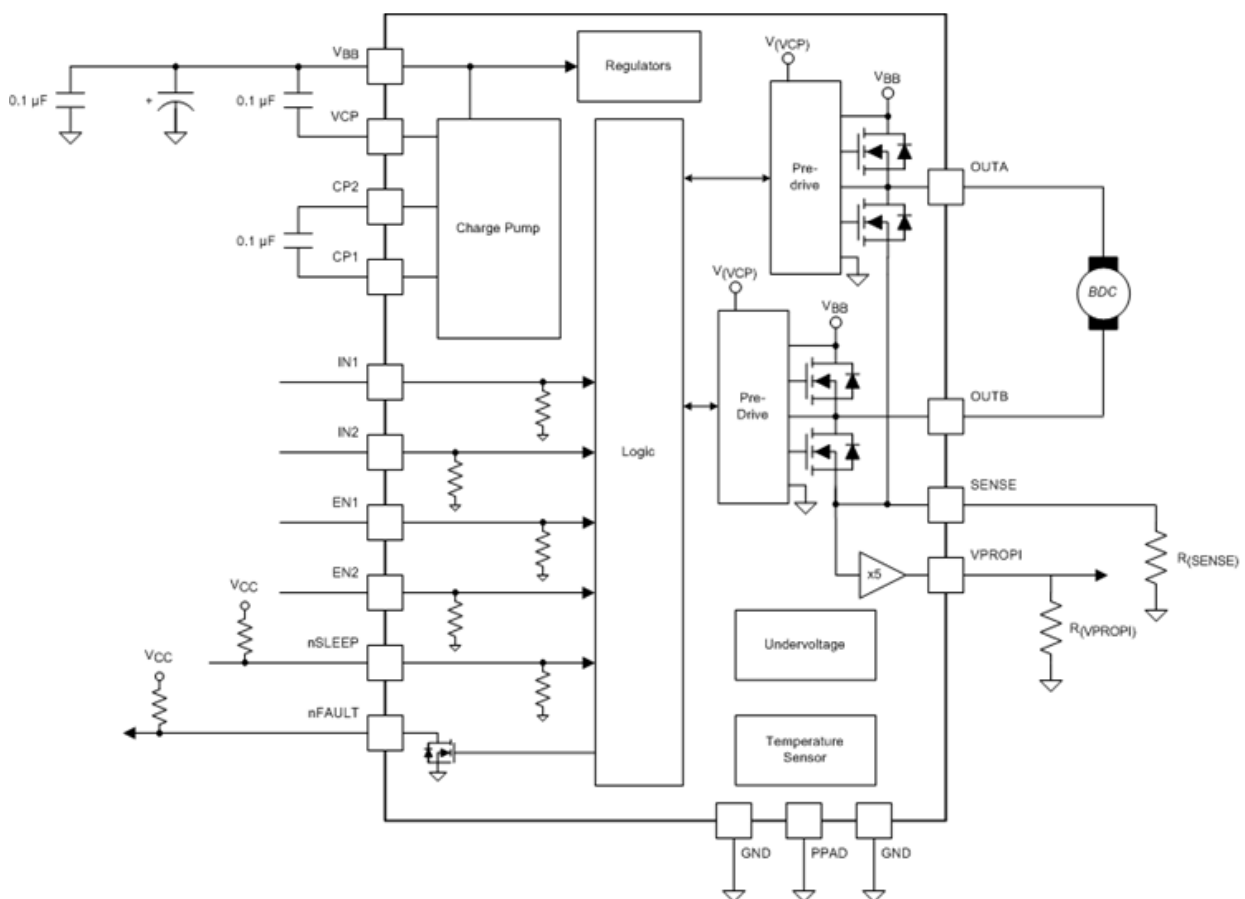


Figure 3 DRV8801A-Q1 Block Diagram

2.1.2 DRV8701E and CSD18532Q5B

The DRV8701 is a single H-bridge gate driver that uses four external N-channel MOSFETs targeted to drive a 12-V to 24-V bidirectional brushed DC motor.

A PH/EN (DRV8701E) or PWM (DRV8701P) interface allows simple interfacing to controller circuits. An internal sense amplifier allows for adjustable current control. The gate driver includes circuitry to regulate the winding current using fixed off-time PWM current chopping.

DRV8701 drives both high- and low-side FETs with 9.5-V V_{GS} gate drive. The gate drive current for all external FETs is configurable with a single external resistor on the IDRIVE pin.

A low-power sleep mode is provided which shuts down internal circuitry to achieve very-low quiescent current draw. This sleep mode can be set by taking the nSLEEP pin low.

Internal protection functions are provided: undervoltage lockout, charge pump faults, overcurrent shutdown, short-circuit protection, predriver faults, and overtemperature. Fault conditions are indicated on the nFAULT pin.

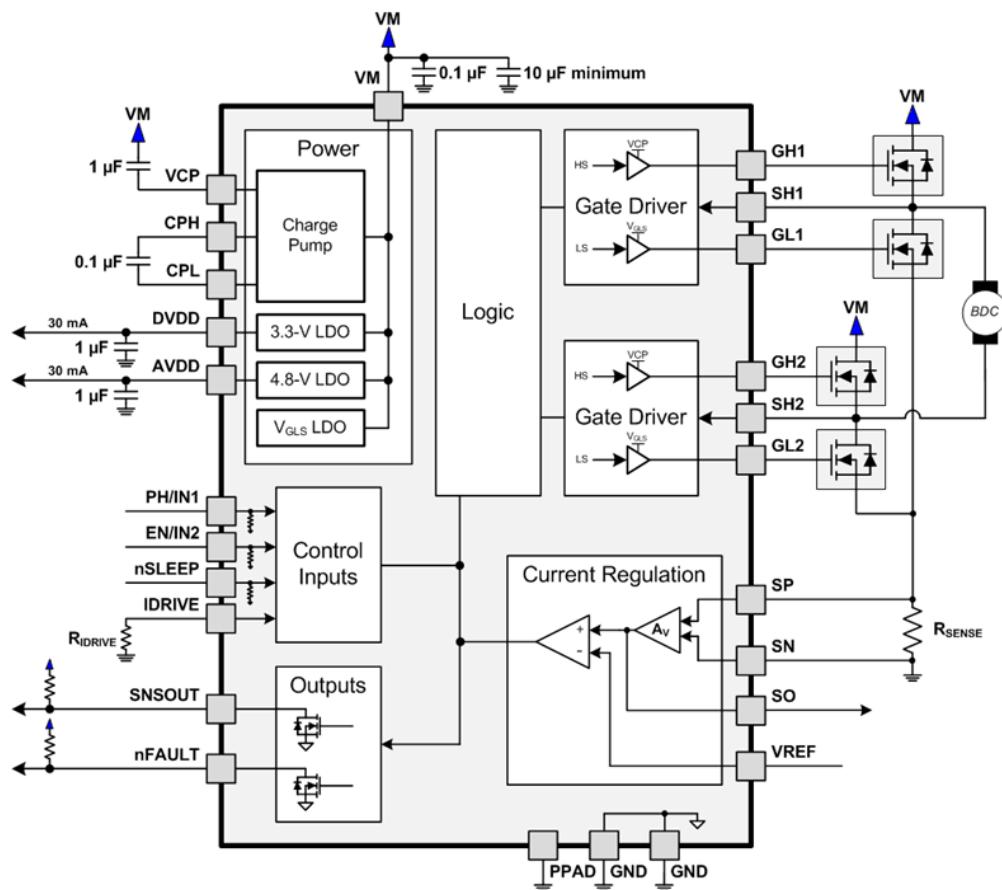


Figure 4 DRV8701E Block Diagram

The CSD18532Q5B 60-V N-Channel NexFET Power MOSFETs are used with the DRV8701E to control the current in the motor. This 2.5 m Ω , 60 V SON 5 mm \times 6 mm NexFET™ power MOSFET is designed to minimize losses in power conversion applications.

2.1.3 DRV5013ADQ

The DRV5013 device is a chopper-stabilized Hall Effect Sensor that offers a magnetic sensing solution with superior sensitivity stability over temperature and integrated protection features.

The magnetic field is indicated via a digital bipolar latch output. The IC has an open drain output stage with 30-mA current sink capability. A wide operating voltage range from 2.5 to 38 V with reverse polarity protection up to -22 V makes the device suitable for a wide range of industrial applications.

Internal protection functions are provided for reverse supply conditions, load dump, and output short circuit or over current

3 System Design Theory

A brushed motor driver can be used to drive single phase brushless DC (BLDC) motors with a few minor modifications. In brushed motors, the brushes perform the commutation, physically changing the direction of the current as the motor rotates. In a BLDC system, the current direction is changed through the use of electronics. This is typically a hall effect sensor, which changes as the magnets pass by. The motor current is electrically reversed at the commutation points. This provides an advantage in environments where carbon dust or spark caused by the brushes could be detrimental.

Another advantage of using single phase BLDC is there are no brushes to wear out, allowing the motor to last longer.

3.1 Hardware System Design Theory

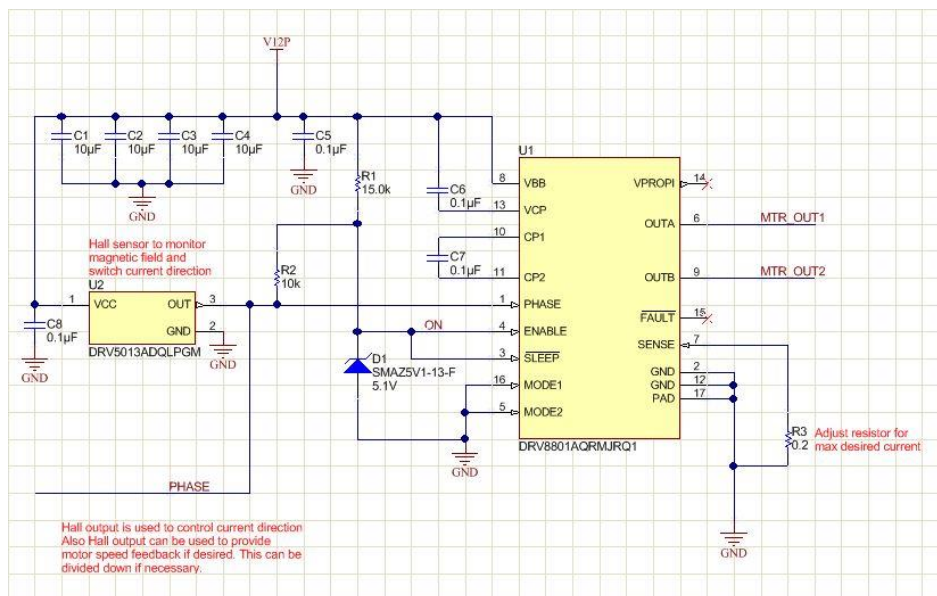


Figure 5 DRV8801A-Q1

The DRV8801A-Q1 can be connected as shown in Figure 7 above to drive a single phase BLDC motor. The DRV8801EVM has been modified to create these connections. Using the DRV8801EVM allows proof of concept.

The DRV8801EVM modifications allow for the motor to spin at 100% duty cycle upon power up. There is no adjustment for this version. If speed adjustment is desired, the connection to pin 4 (EN) can be

modified. A PWM input of approximately 20kHz with a 3.3V level can be used to control the motor. This PWM signal will alternate between drive and brake, minimizing the current ripple in the motor.

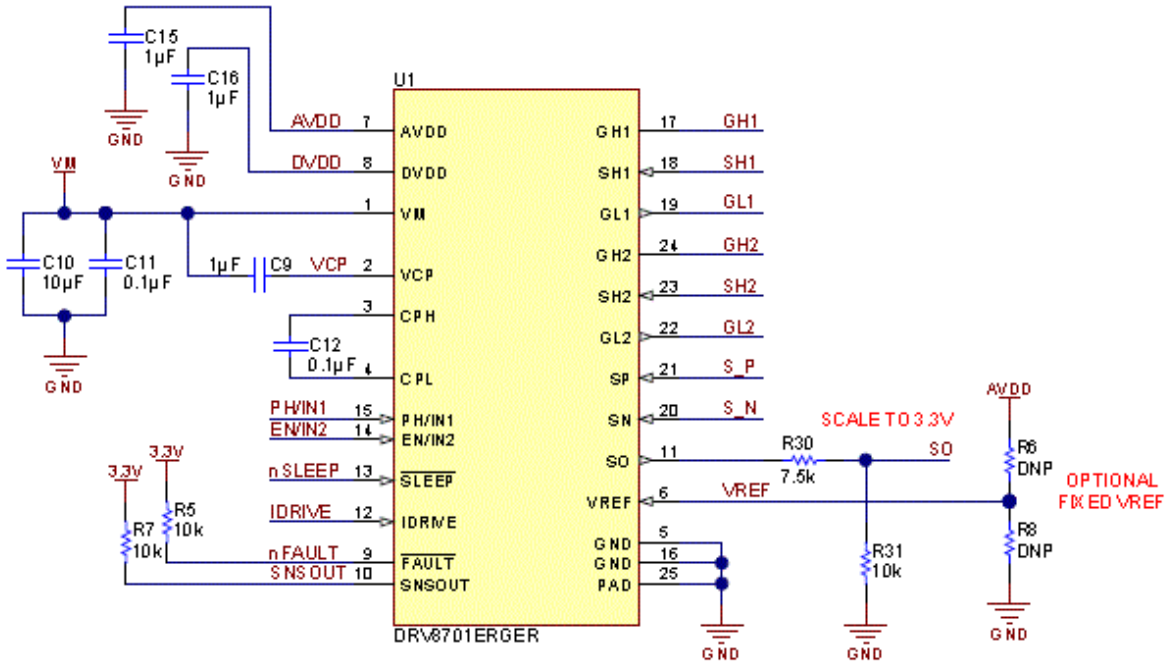


Figure 6 DRV8701 Device connections

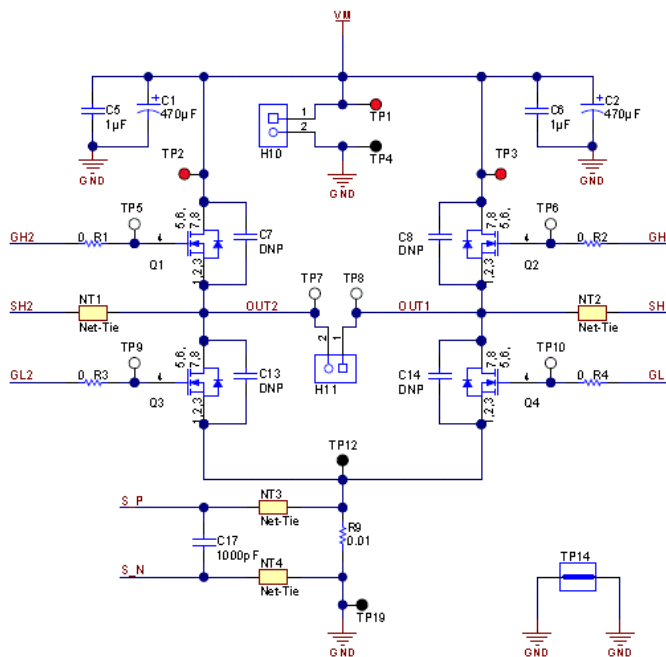


Figure 7 DRV8701 Power Stage

Four CSD18532Q5B N-channel power MOSFETs are used to control the current in the single phase brushless DC motor. The DRV8701 PH input controls the direction of the current

To improve the efficiency the design, the MOSFET are driven with the DRV8701 gate drivers. This allows for minimal conduction and switching losses. To understand more about motor gate drivers and MOSFETs see this [app note](#).

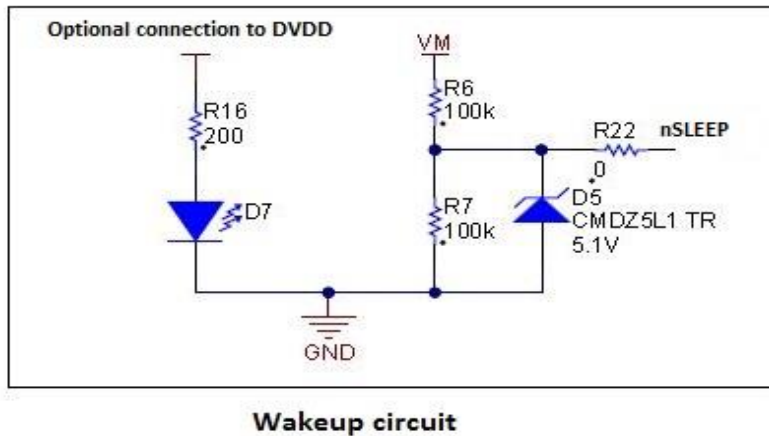


Figure 8 Wake Up Circuit

The wake up circuit is used to wake the motor driver when power is applied. As VM rises above the nSLEEP VIH voltage, the device will automatically awaken. The voltage is held to a safe voltage by clamping it with a Zener diode. It is recommended to use a Zener that will activate only when the VM voltage rises above the expected range

4 Getting Started Hardware

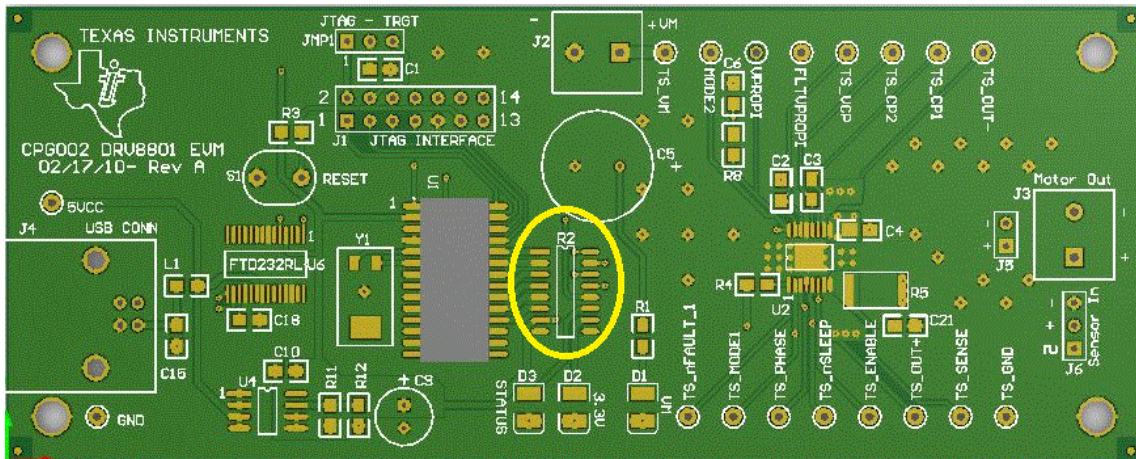
4.1 Connections

The TIDA-00875 reference design uses the DRV8801EVM and DRV8701EVM to control a single phase brushed dc (BLDC) motor. Instructions to modify the EVMs are provided below.

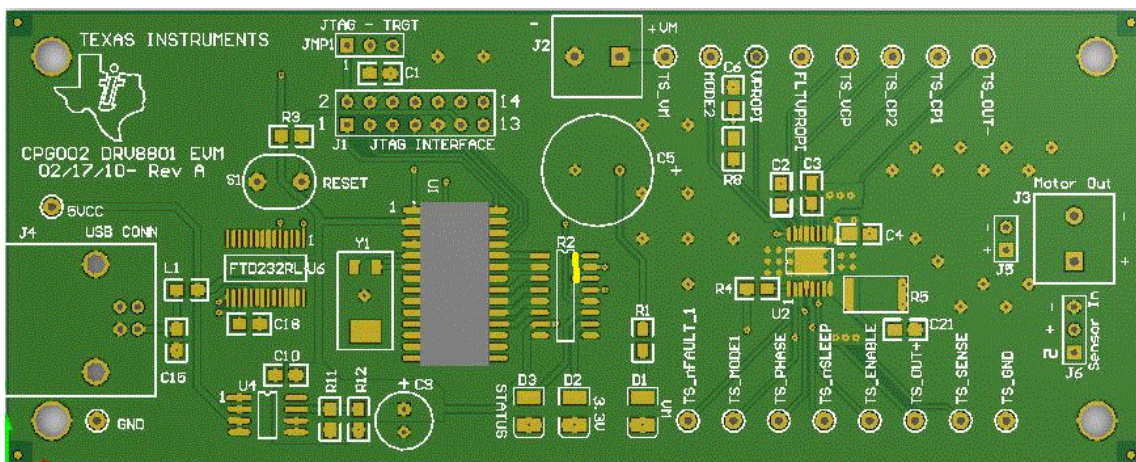
4.1.1 DRV8801EVM Connections

The procedure to modify the DRV8801EVM is described below:

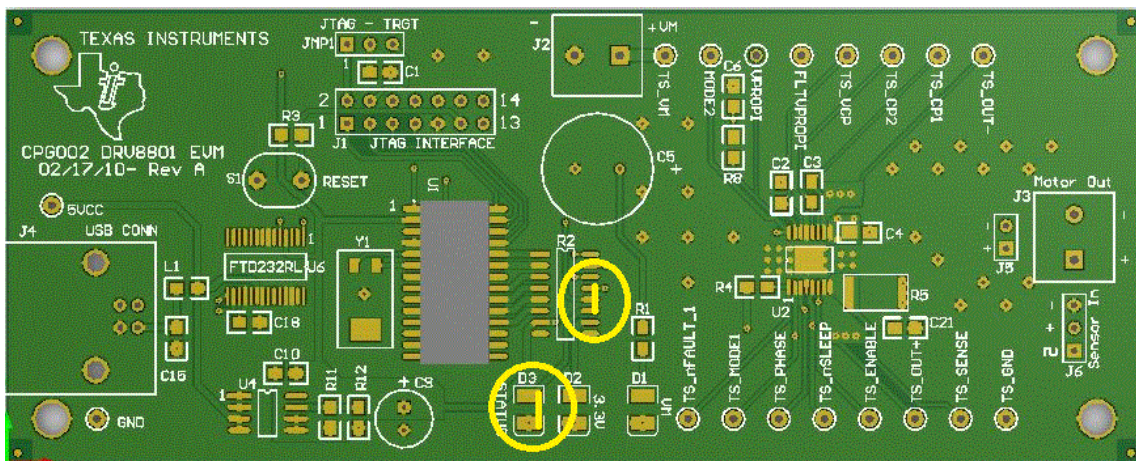
- 1) Remove resistor pack R2 to isolate signals from mcu



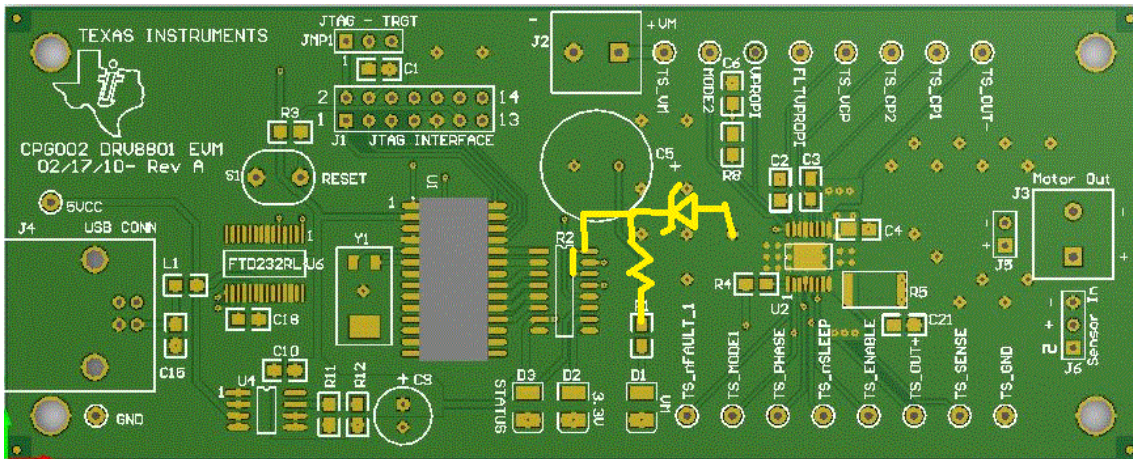
- 2) Short pins 14 and 16 of resistor pack R2. This connects nSLEEP and ENABLE in preparation for Step 4



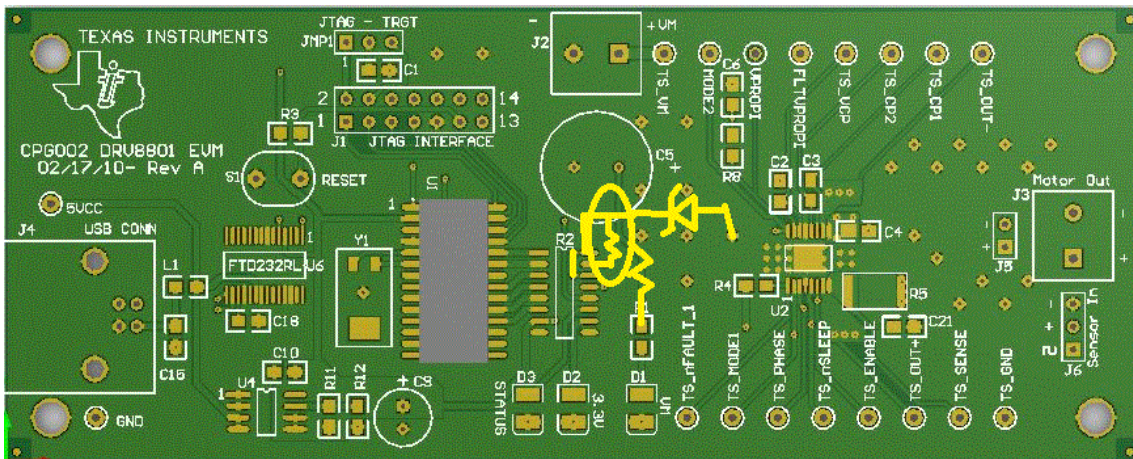
- 3) Short pins 11,12, and 13 of resistor pack R2. Short Diode D3. This connects MODE1 and MODE2 to GND



- 4) Connect a 15kOhm resistor from R1 to pin 16 of resistor pack R2 as shown. Connect a 5.1V Zener diode to GND to prevent excessive voltage.



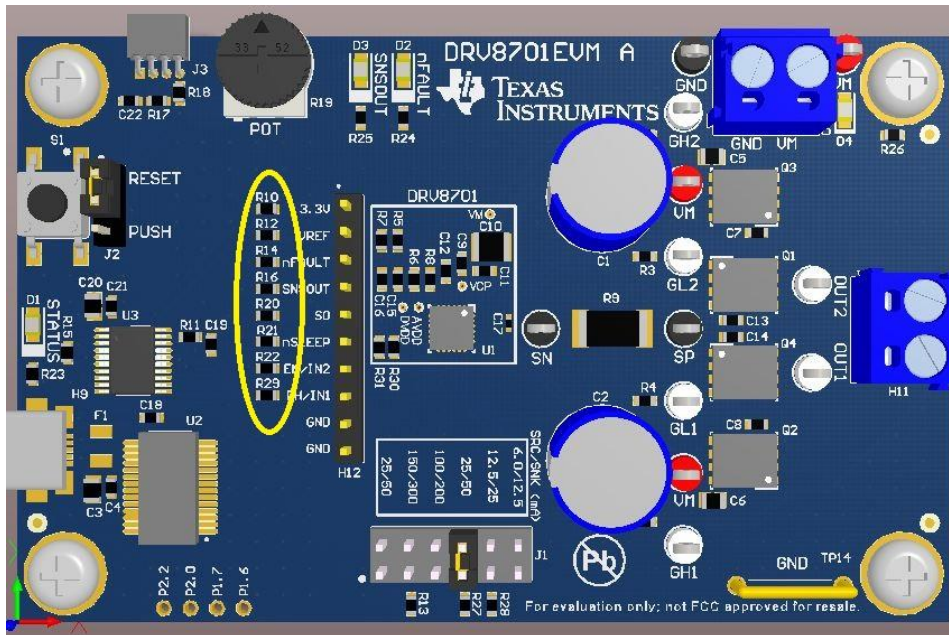
- 5) Connect a 10kOhm resistor from the cathode of the Zener diode to pin 15 of resistor pack R2. This creates a pullup resistor for the hall effect sensor.



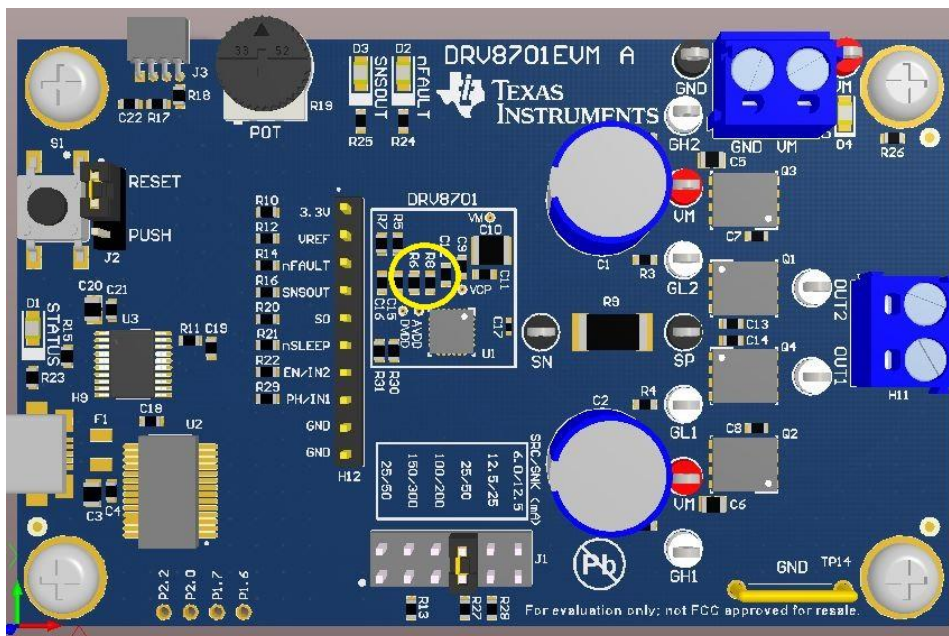
4.1.2 DRV8701EVM Connections

The procedure to modify the DRV8701EVM is described below:

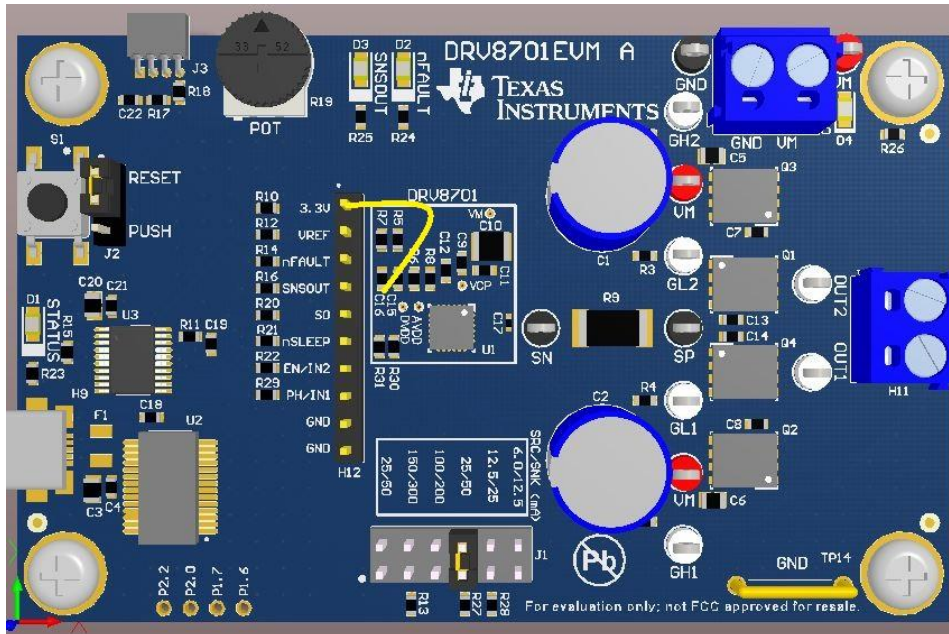
1) Remove resistors R10, R12, R14, R16, R20, R21, R22, and R29 to isolate signals from mcu



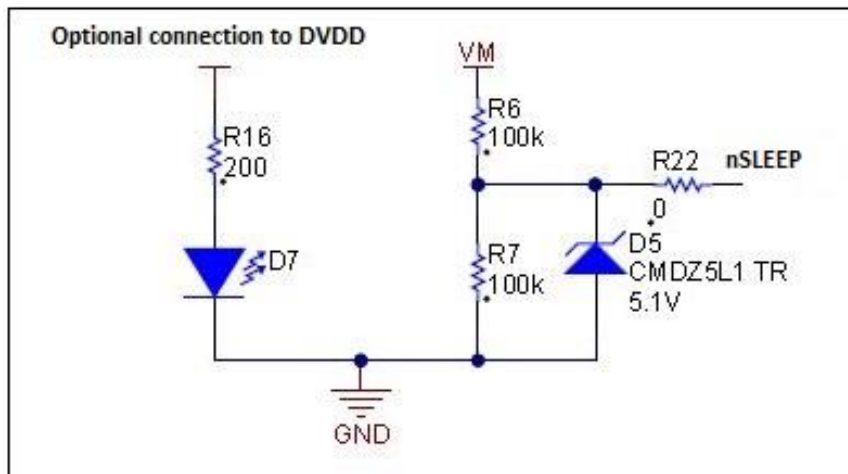
2) Set the desired VREF voltage by creating a resistor divider using R6 and R8



3) Connect H12 pin 1 (3.3V to DVCC) Recommend soldering a wire from C16 to H12 pin 1 to make the connection.

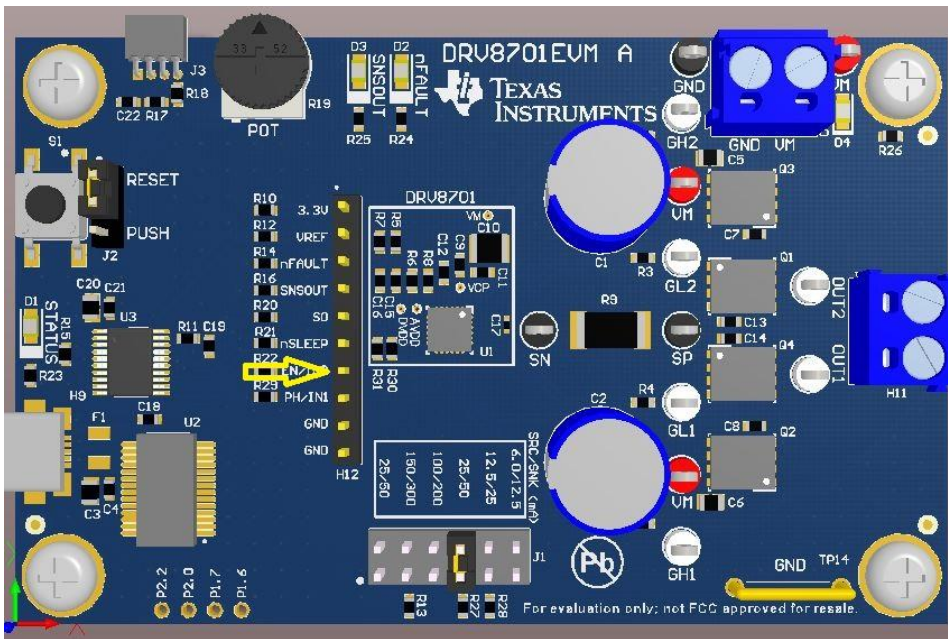


4) Create the wake circuit as shown below. The LED is optional.

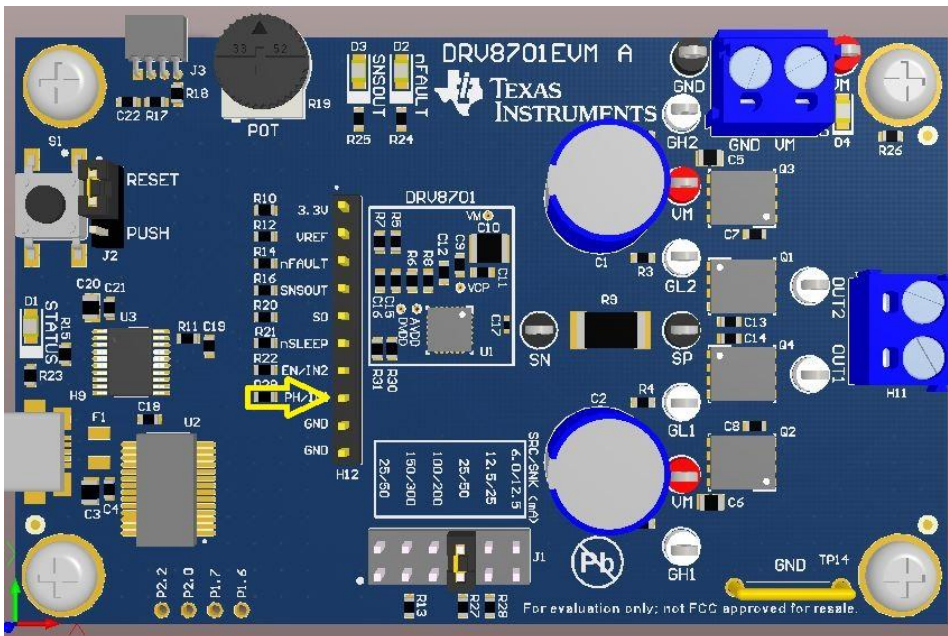


Wakeup circuit

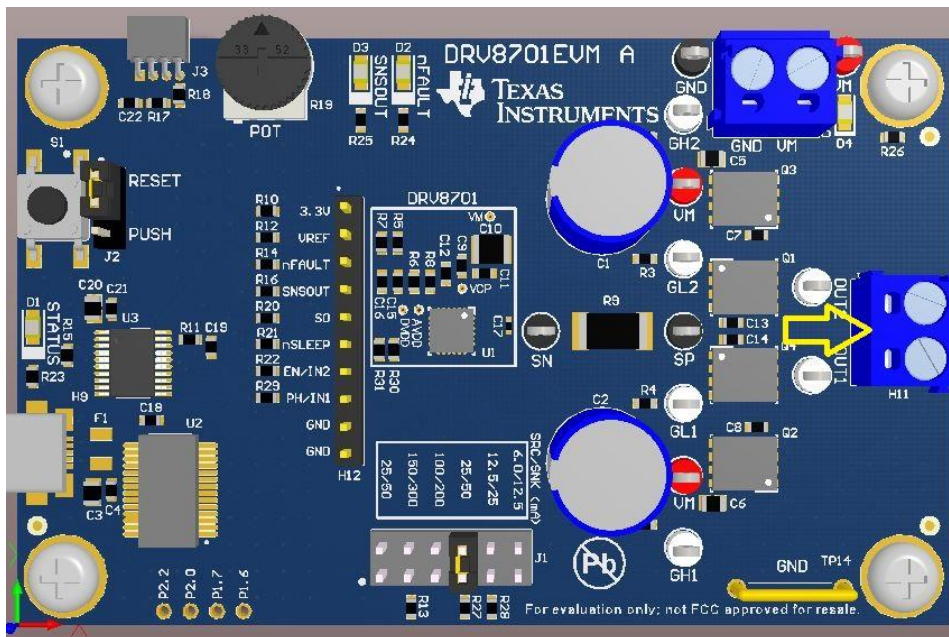
5) For the DRV8701EVM Connect the PWM input (<5V) to the IN2/EN pin (H12 pin 7).



6) Connect the hall sensor output (<5V) to the PH pin (H12 pin 8).



7) Connect the motor windings such that the hall sensor output drives the motor in the proper direction.



8) Connect the PWM input to the EN pin. PWM input is a 3.3V input at 20kHz and varying duty cycle.

For this design, a generic single phase brushless motor with the following specifications was used:

Voltage	14.4V nominal
Current	0.5A
Resistance	3.8 Ohms
Inductance	6.9 mH @ 10kHz

4.2 Procedure

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

1. Connect the power supply to the PCB
 - a. For the DRV8801EVM, connect to the J2 connector.
 - b. For the DRV8701EVM, connect to the H10 connector
2. Connect the motor to the PCB
 - a. For the DRV8801EVM, connect to the J3 connector.
 - b. For the DRV8701EVM, connect to the H11 connector
3. Connect the hall sensor
 - a. For the DRV8801EVM, connect to the PHASE pin (pin 15 of R2 or TS11)
 - b. For the DRV8701EVM, connect to the PH/IN1 pin on header H12 (pin 8)
4. Connect the EN/IN2 pin on header H12 to a PWM input to control the speed (DRV8701EVM only)

5 Test Setup

Equipment	Name
DC Power Supply	Chroma 620012P-100-50
Multimeter	Tektronix DMM 4040
Oscilloscope	Tektronix DPO 7054

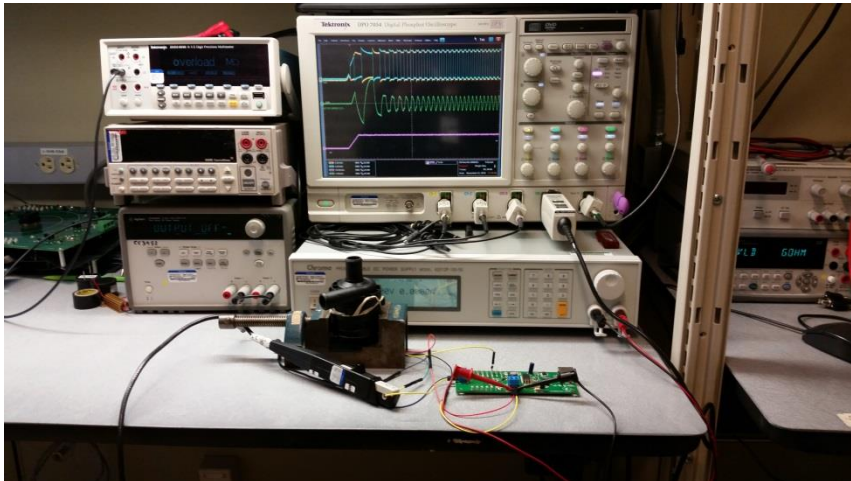


Figure 9 DRV8801 Test Setup

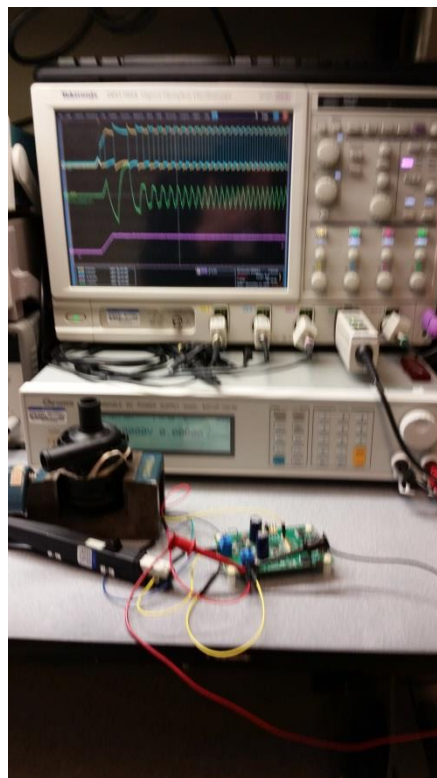


Figure 10 DRV8701E Test Setup

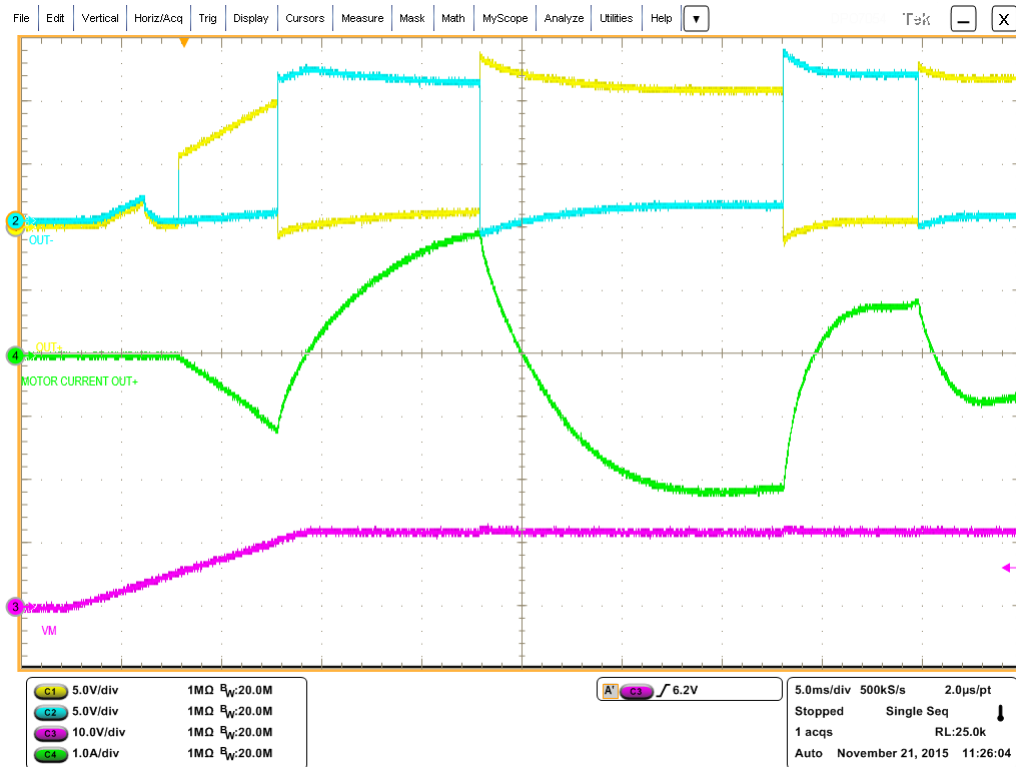
6 Test Data

6.1 Functional Tests

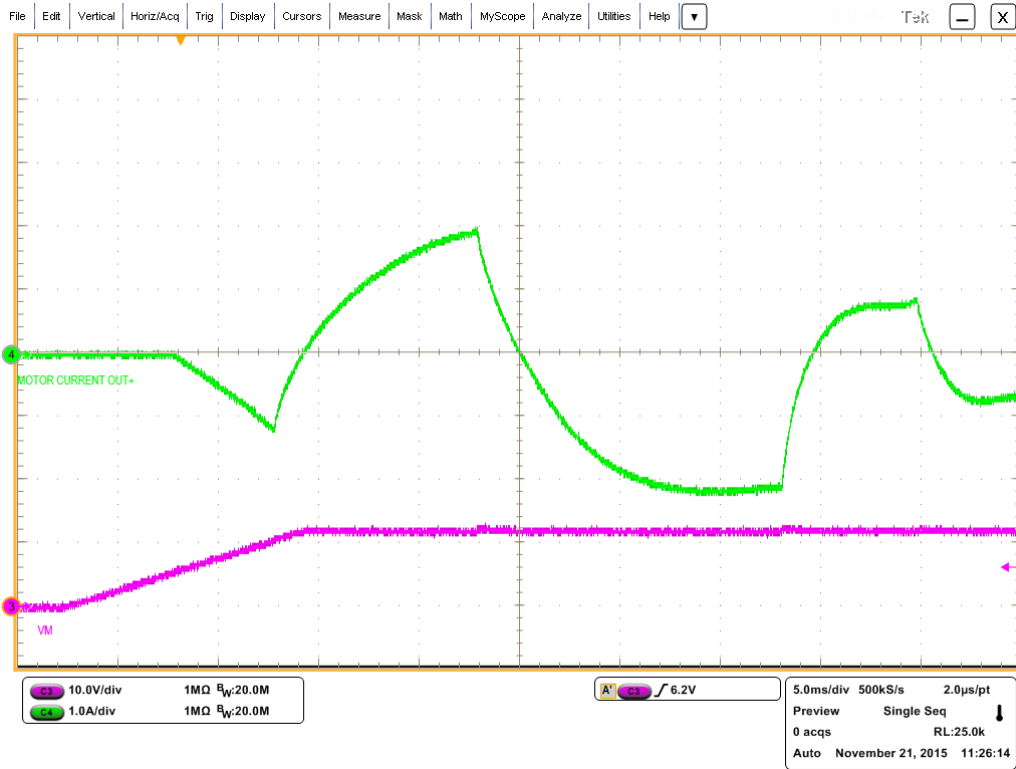
6.1.1 Startup of DRV8801

VBB was increased from 0 to 12VDC. The outputs follow the PH input, switching current direction as the hall effect sensor changes.

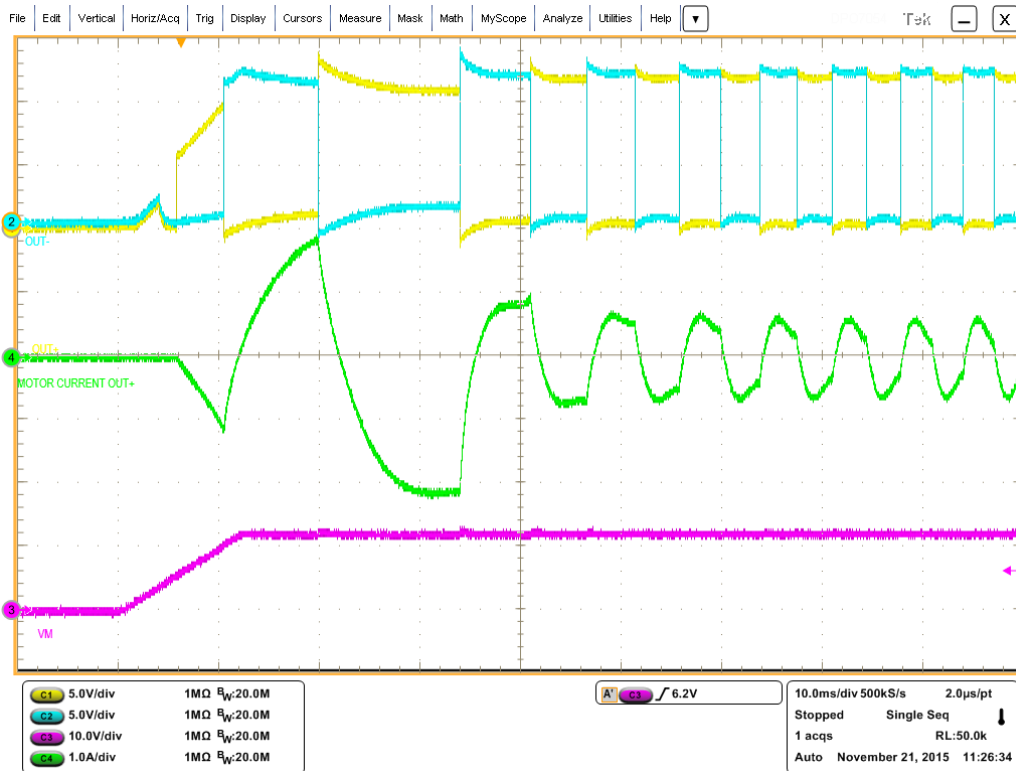
Motor startup showing VBB (labeled VM), OUT+,OUT-,and Motor Current on OUT +



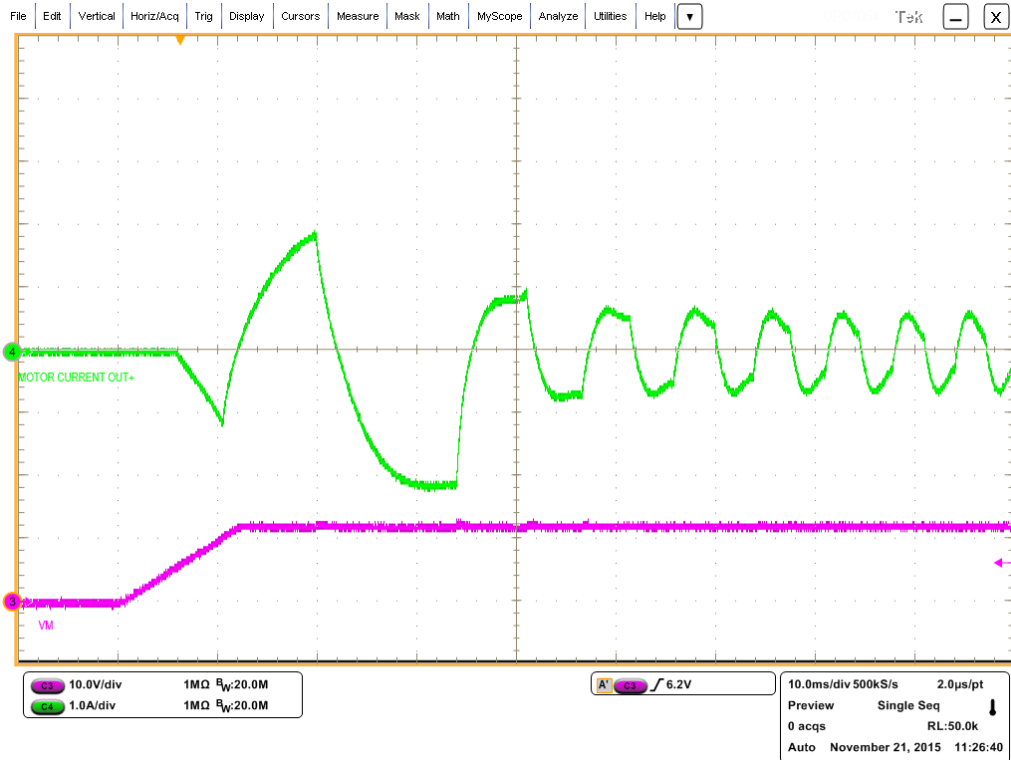
Motor startup showing VBB (labeled VM) and Motor Current on OUT +



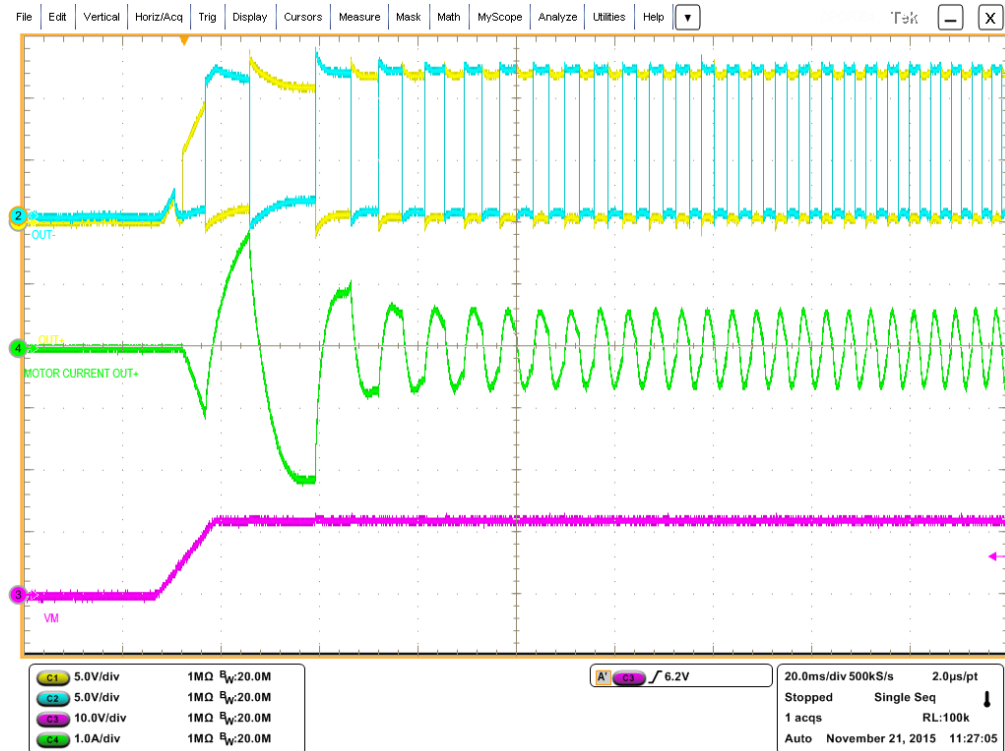
Motor startup showing VBB (labeled VM), OUT+,OUT-,and Motor Current on OUT +



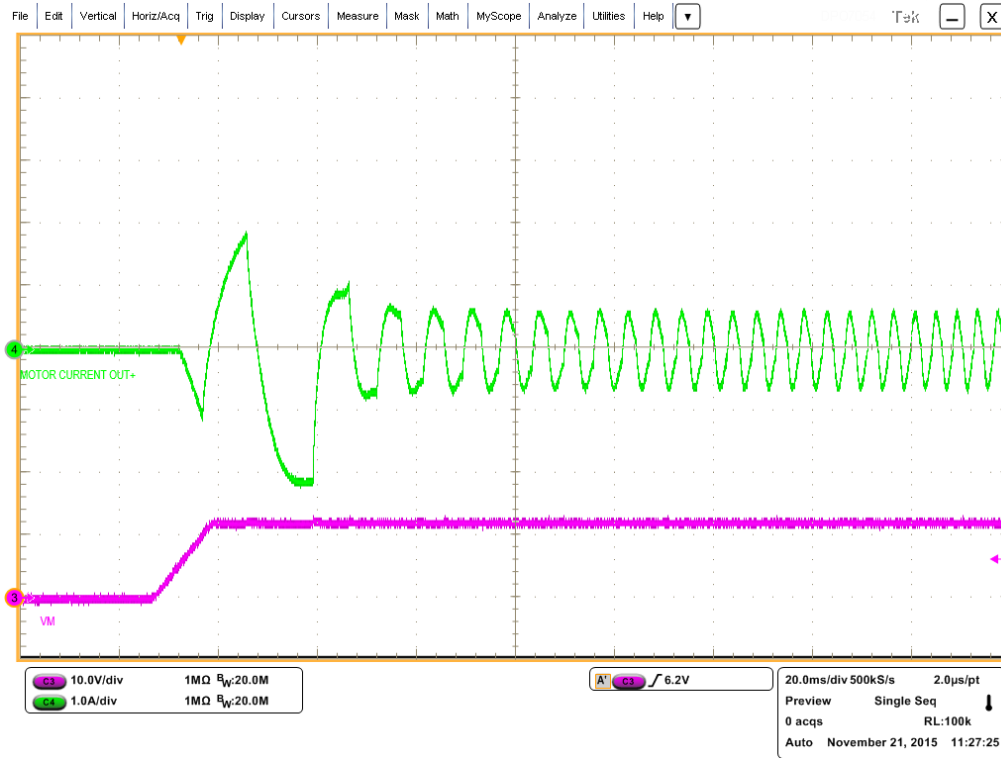
Motor startup showing VBB (labeled VM) and Motor Current on OUT +



Motor startup showing VBB (labeled VM), OUT+,OUT-,and Motor Current on OUT +



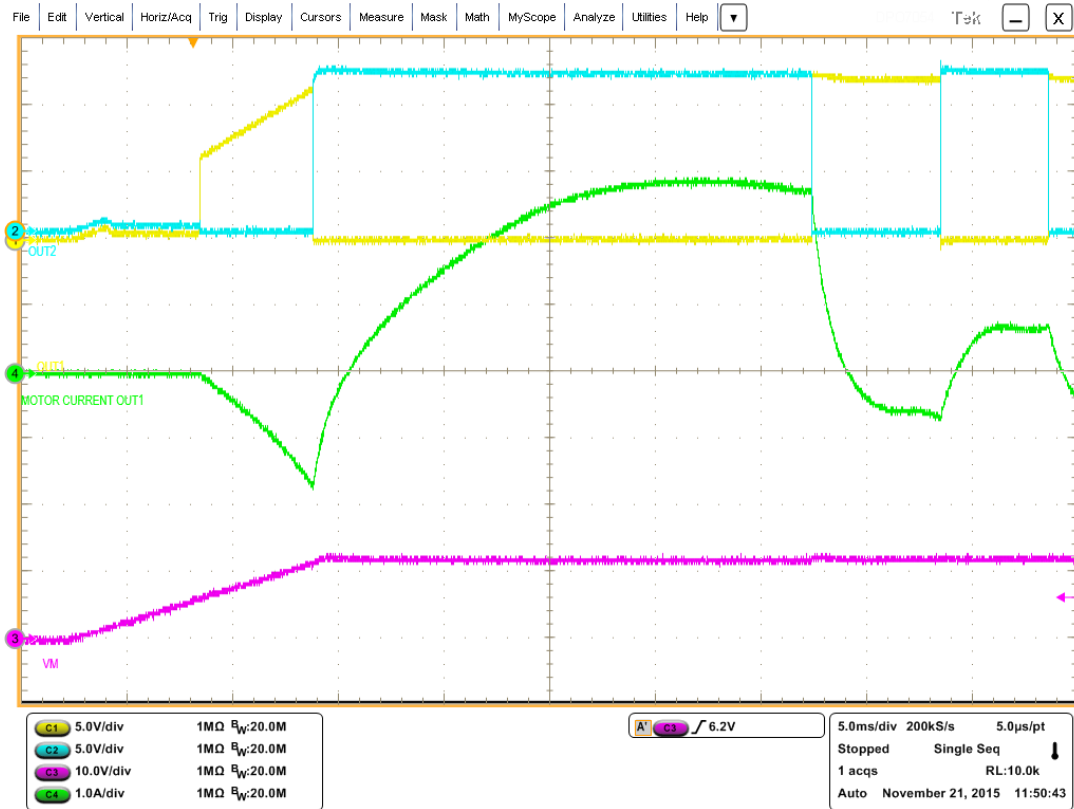
Motor startup showing VBB (labeled VM) and Motor Current on OUT +



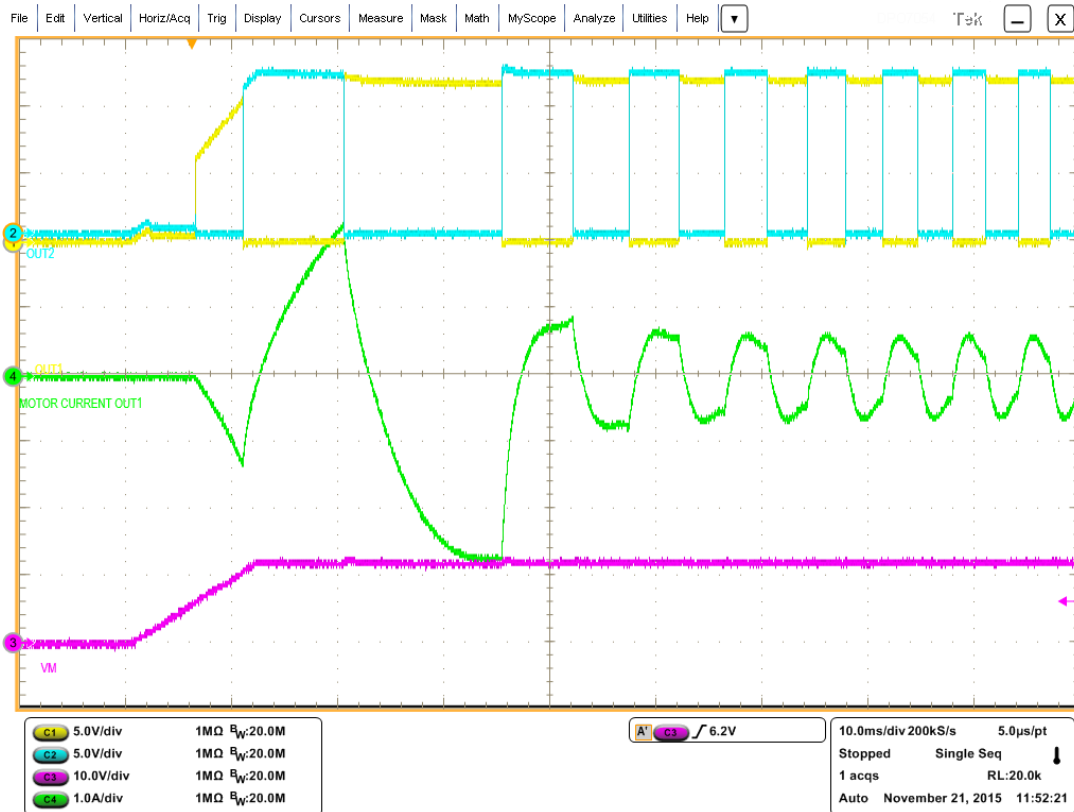
6.1.2 Startup of DRV8801

VBB was increased from 0 to 12VDC at 100% duty cycle. The outputs follow the PH input, switching current direction as the hall effect sensor changes.

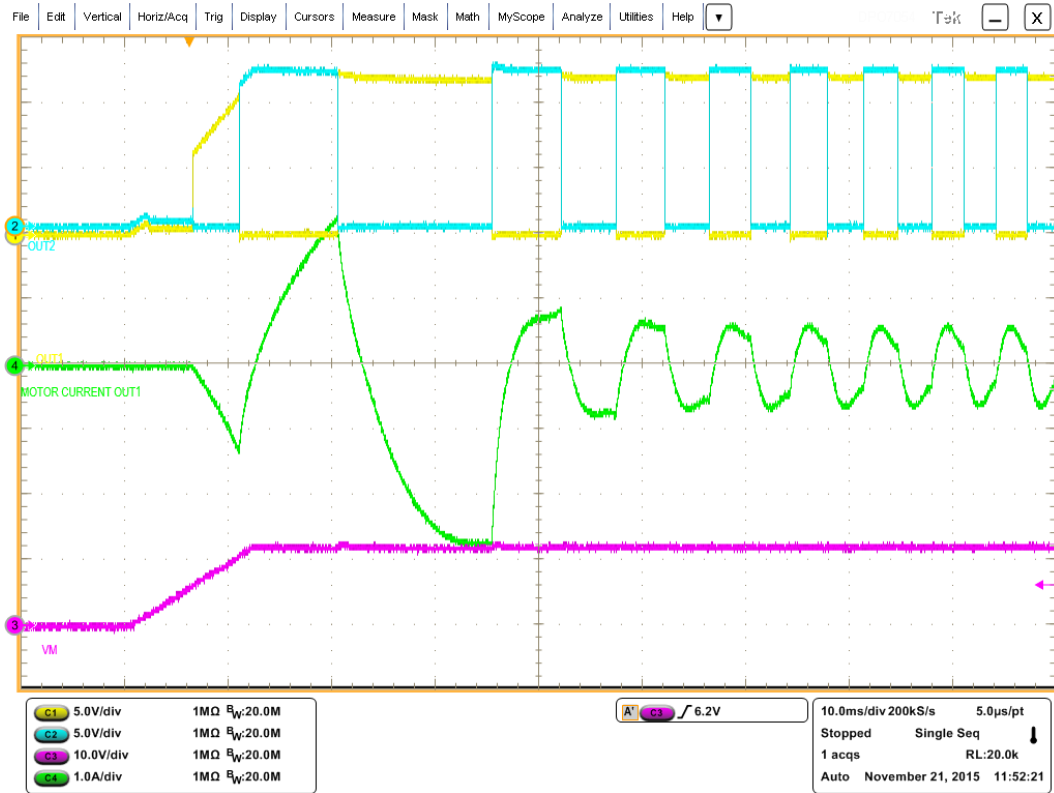
Motor startup showing VM, OUT+,OUT-,and Motor Current on OUT +



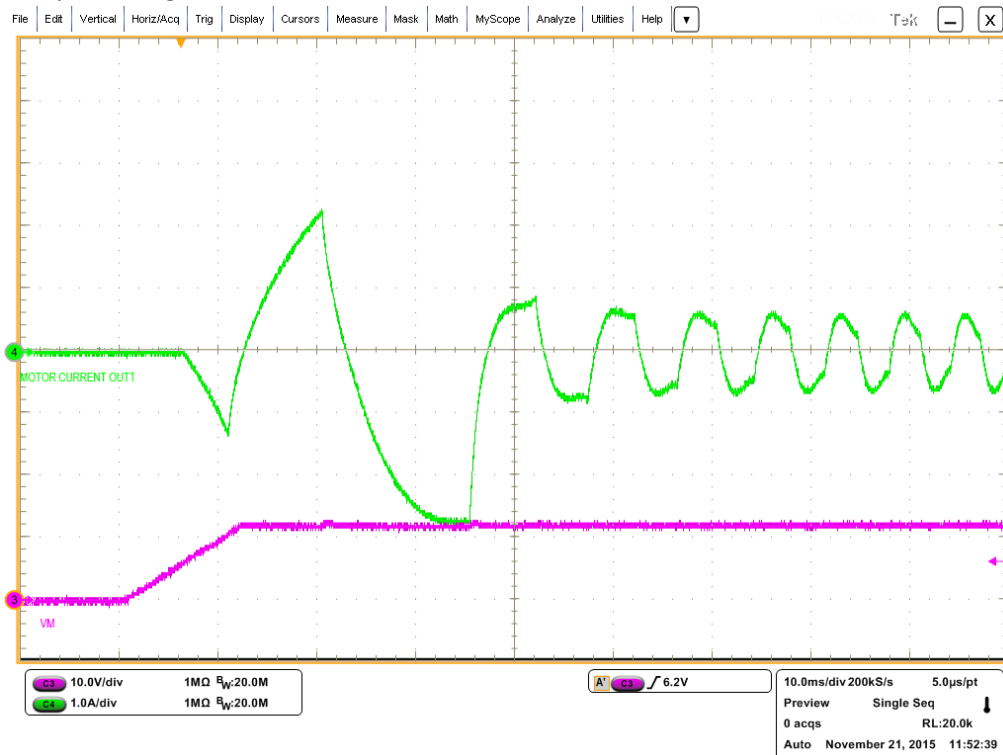
Motor startup showing VM and Motor Current on OUT +



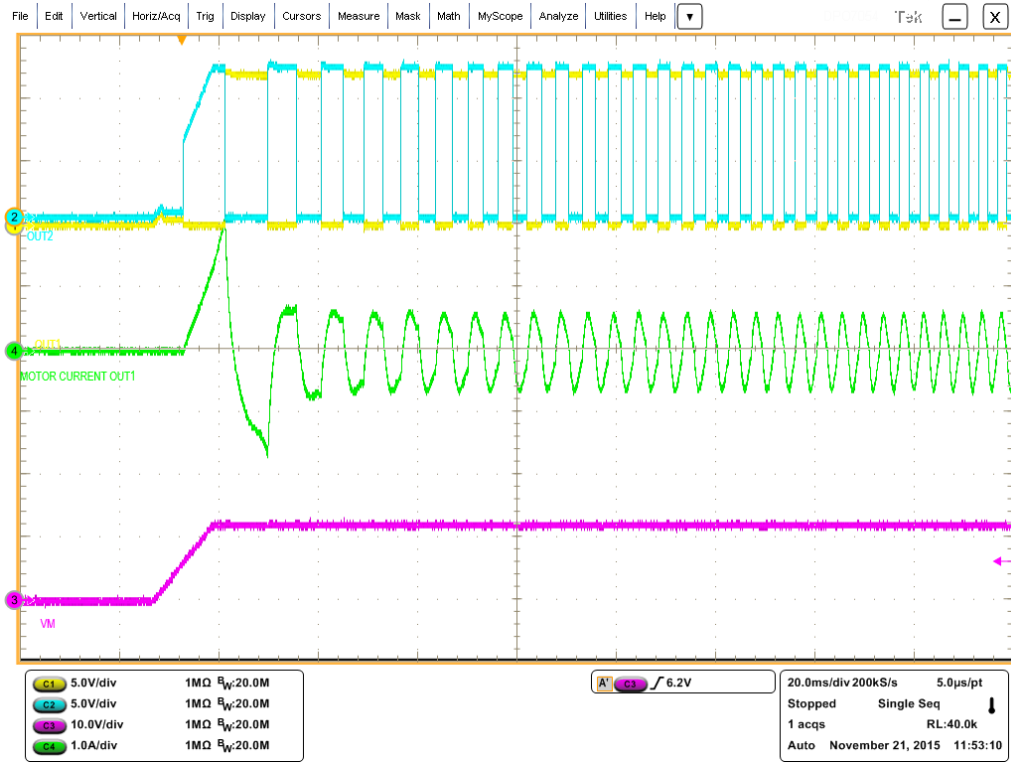
Motor startup showing VM, OUT+,OUT-,and Motor Current on OUT +



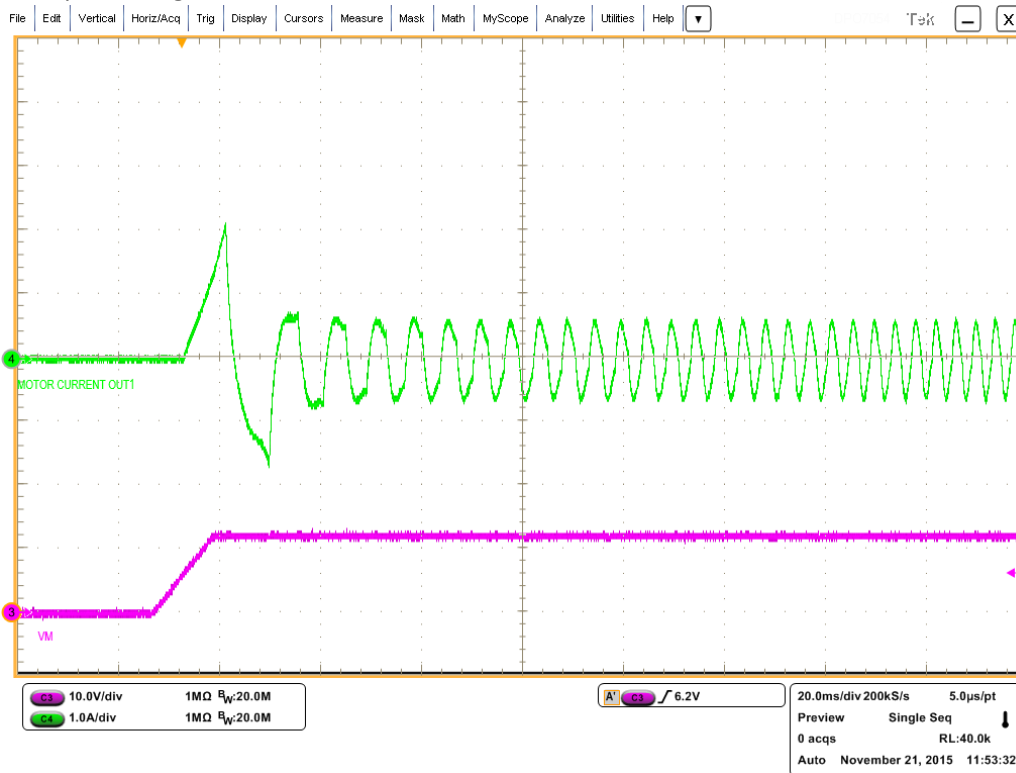
Motor startup showing VM and Motor Current on OUT +



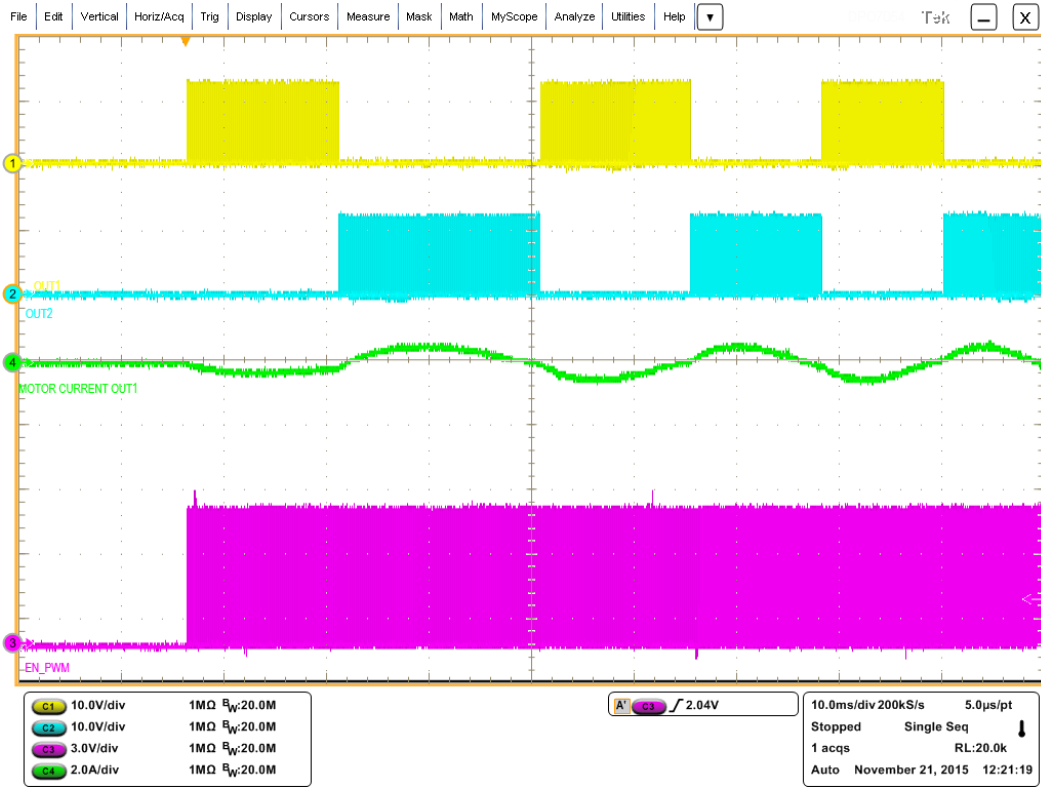
Motor startup showing VM, OUT+,OUT-,and Motor Current on OUT +



Motor startup showing VM and Motor Current on OUT +



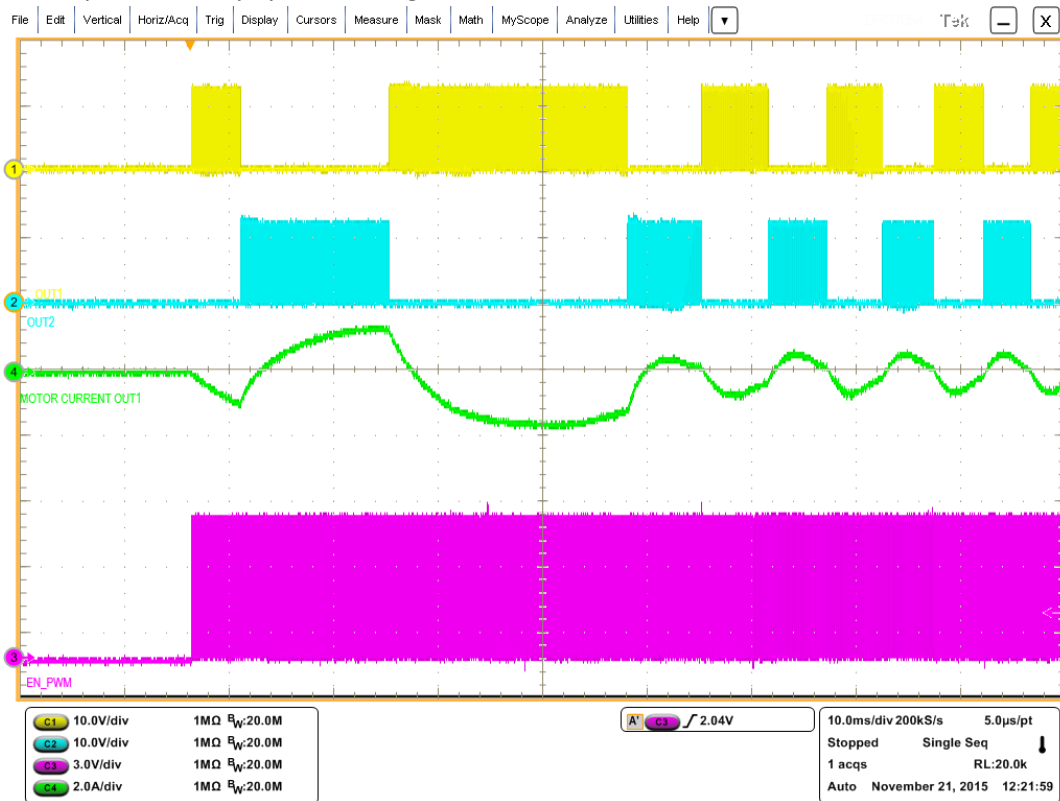
Motor startup at 20% duty cycle showing VM, OUT+,OUT-,and Motor Current on OUT +



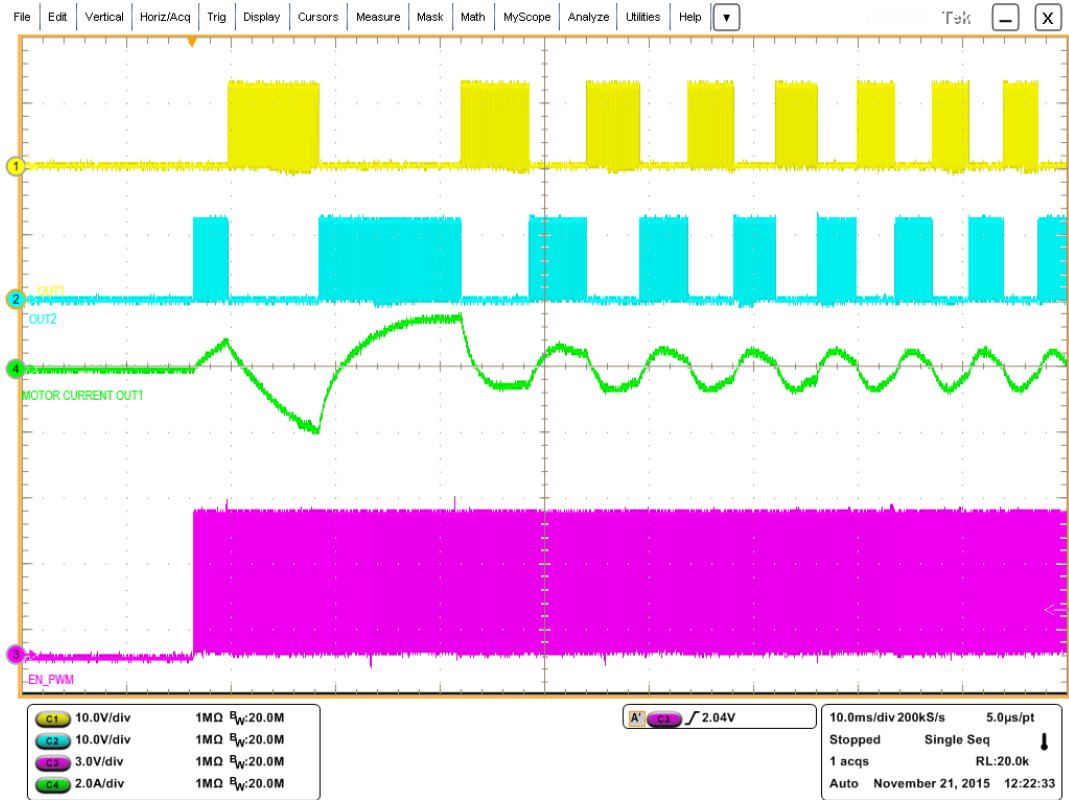
Motor startup at 40% duty cycle showing VM, OUT+,OUT-,and Motor Current on OUT +



Motor startup at 60% duty cycle showing VM, OUT+,OUT-,and Motor Current on OUT +



Motor startup at 80% duty cycle showing VM, OUT+,OUT-,and Motor Current on OUT +



7 Design Files

The complete design files can be downloaded at the reference design home page at [TIDA-00875](#).

8 References

1. <http://www.ti.com/lscs/ti/analog/motordrivers/overview.page>
2. Texas Instruments E2E Community, <http://e2e.ti.com/>
3. Texas Instruments DRV8801A-Q1 Brushed Motor Gate Driver, <http://www.ti.com/product/drv8801a-q1>
4. Texas Instruments DRV8701E Brushed Motor Gate Driver, <http://www.ti.com/product/drv8701>
5. Texas Instruments CSD18532Q5B 60V, N-Channel NexFET Power MOSFET, <http://www.ti.com/product/csd18532q5b>
6. Texas Instruments DRV5013ADQ Hall Effect Sensor, <http://www.ti.com/product/drv5013adq>
7. Texas Instruments DRV8801EVM, <http://www.ti.com/tool/drv8801evm>
8. Texas Instruments DRV8701EVM, <http://www.ti.com/tool/drv8701evm>

9 About the Author

Rick Duncan is an Applications Engineer for Texas Instrument's motor drive business, where he is responsible for supporting TI's motor drive portfolio. Rick graduated from Louisiana State University with a Bachelor's of Science in Electrical Engineering.

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