TI Designs
Sensored BLDC Sinusoidal Drive Controller for Refrigerator Fans

Design Overview

The DRV10970 is an integrated, three-phase BLDC motor driver for home appliances, fans, and other general-purpose motor control applications. The embedded intelligence, small form factor, and simple pin-out structure reduce the design complexity, board space, and overall system cost. The integrated protections improve the system robustness and reliability. The design is targeted for fans in refrigerators.

Design Resources

TIDA-00919	Tool Folder Containing Design Files
DRV10970	Product Folder
DRV5013	Product Folder

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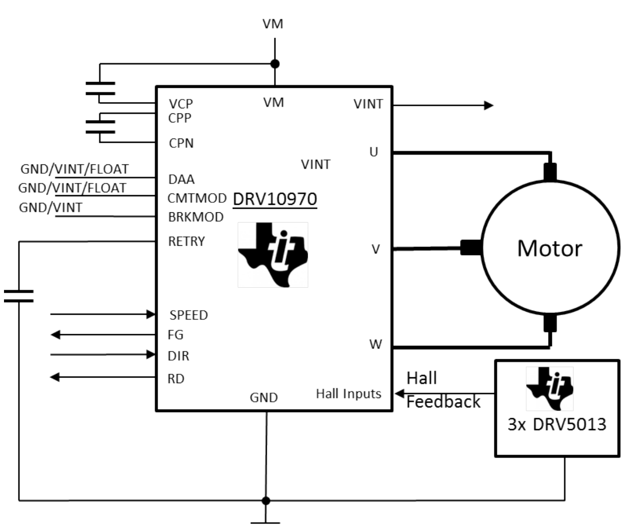
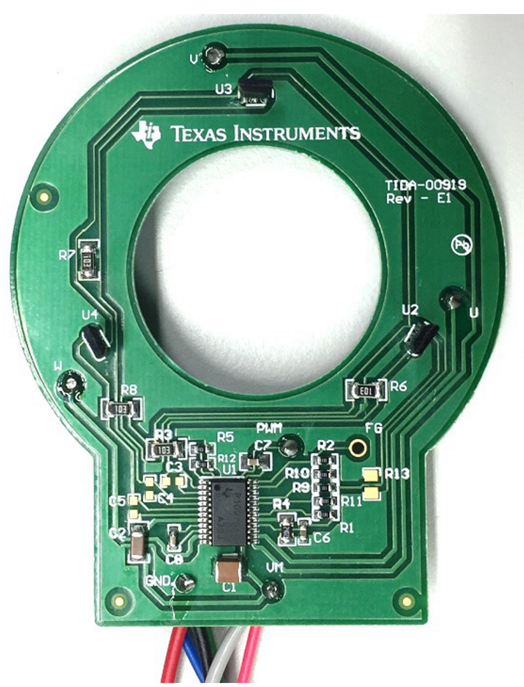
Design Features

- Output Stage of DRV10970 Consists of Three Half Bridges With Rds_{on} of 450 mΩ (With Each Half Bridge Capable of Delivering 1-A RMS and 1.5-A Peak Current)
- Cost-Effective Single-Side Board Design
  - Small Form Factor Board With Hall Sensors
  - Speed Control Through External PWM Control
- 180° Sine Wave Commutation Algorithm Helps for High Efficiency, Superior Acoustic Performance, and Low Torque Ripple
- Automatic Drive Angle Adjustment Enables Optimized Efficiency
- Supports Single Hall- and Three Hall-Based Applications
- Features Such as PWM Speed Input, Direction Reversal, FG Output, and Motor Lock Indicator

Featured Applications

- Cooling Fans
- Small Appliances
- General-Purpose BLDC Motor Drivers





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1 Key System Specifications

A refrigerator is a very common household appliance which consists of a main compressor motor and a motor for a circulation fan. The circulation fan serves as a blower that rotates cold airflow throughout the unit to keep it cold. The fan for a refrigerator is typically a sensored brushless DC (BLDC) motor, which requires an electronic controller. The TIDA-00919 reference design is a ready platform for driving such a fan motor.

This reference design is a cost-effective, small-form-factor, three-phase sinusoidal motor drive for sensored BLDC fan motors specified up to a maximum current of 1 A RMS at 18 V maximum. Unlike most sensored drivers, the DRV10970 drives a motor with a 180° sinusoidal commutation, which results in low torque ripple, better acoustics, and a high drive efficiency. The speed input command can be utilized in the form of a pulse width modulation (PWM) input and a direction control by controlling a pin high or low.

Table 1 lists the key system specifications for the design.

Table 1. Key System Specifications

PARAMETER	SPECIFICATION
DC input voltage	12 V
Rated power capacity	15 W
Speed input	PWM
Operating ambient temperature	–20°C to 50°C
Inverter efficiency	≥ 97% at rated load
Protections	Overcurrent, overtemperature, and short circuit

The drive board has been designed for a small form factor in consideration of the small factors of the appliance fans. Because the motor driver has sensors, the printed-circuit board (PCB) is typically housed inside the motor, which explains the requirement for placing Hall sensors on the board. The low-cost requirement also confines the design to a single-side board.

2 System Description

The use of permanent-magnet brushless DC motors continue to gain prominence in the field because of their high efficiency, low maintenance, high reliability, low rotor inertia, and low noise as compared to the brushed motor counterpart. A brushless permanent-magnet motor has a wound stator, which is a permanent magnet rotor assembly. These types of motors generally use internal or external devices to sense rotor position. The sensing devices provide logic signals for electronically switching the stator windings in the proper sequence to maintain rotation of the magnet assembly.

The DRV10970 is an electronic drive which is used to sinusoidally control the drive of a sensored BLDC motor. The system operates at 12-V power and provides the motor terminal outputs. The design implements Hall sensors because the electronic components are placed inside the motor for most sensored BLDC motors. The system also accepts user inputs such as direction and speed also in addition to providing some feedback, such as lock detection and speed feedback.

3 System Design Theory

The DRV10970 device controls three-phase BLDC motors using a speed command (PWM), direction (FR) interface, and Hall signals from the motor. The device is capable of driving up to 1-A RMS and 1.5-A peak current.

When the DRV10970 device powers up, it starts to drive the motor in trapezoidal communication mode based on Hall sensor information. If all three Hall sensors have been connected, the commutation logic relies on all three Hall sensors. If a U-phase Hall sensor is the only sensor connected (V_{HP} is floating), then the DRV10970 device starts to drive the motor in a single Hall sensor mode.

After six electrical cycles, the device switches to sinusoidal drive mode if the CMTMOD pin is not floating. If the motor has a 0° placement for the Hall sensor (set on the CMTMOD pin accordingly), the DRV10970 device automatically adjusts the driving angle based on the feedback from the motor. The DRV10970 device optimizes the efficiency regardless of the motor parameters and the load conditions.

This automatic function that drives the angle adjustment can be disabled by the DAA pin. A fixed driving angle is available for the user to optimize the motor drive efficiency if this automatic function has been disabled.

The PWM input duty cycle commands the steady-state motor speed, which converts to an average output voltage of VM multiplied by the duty cycle. A floating PWM pin functions as the full-speed command. The FR input can be used to control the direction of motor rotations. The user can adjust the rotational direction while the motor is spinning. The device has a time delay (T_{LOCK_EX}) before reversing direction.

The FG output is aligned with a U-phase Hall sensor signal, which indicates the motor speed. If the motor has been locked by an external force for T_{LOCK_EN}, then the RD output is asserted to indicate the motor lock condition and DRV10970 retries after the T_{LOCK_EX} period, which is determined by the capacitor on the RETRY pin.

When the motor is not spinning (either in lock condition or PWM = 0), the state of the phases are selected by the BRKMOD pin. The phases can be maintained floating (coasting condition) or pulled down to GND (braking condition).

The DRV10970 device enters sleep mode when the PWM has been driven low for T_{SLEEP} time and internal circuits including regulators are turned off and the power consumption is less than 35 µA.

Overcurrent, current limit, thermal shutdown, and undervoltage protection circuits prevent system components from being damaged during extreme conditions.

3.1 Single-Side Design

The design targets the use of a single-side board because of the extremely cost-sensitive application.

With the constraint of a single-side board, the GND connection is routed to multiple places throughout the board. To avoid the noise associated with ground loop on current sense and VINT, a provision has been established to connect an optional resistor R13 of 0 Ω, which acts as a jumper if required.

3.2 Hall Sensor Connections

Hall sensors and their connections are very important parameters to consider while driving a sensored BLDC motor. The DRV10970 device has been designed to work with Hall sensor elements as well as the latched output types of Hall sensors. Apart from working with these sensor types, the DRV10970 also works with different Hall sensor placements and with single hall mode and three-hall mode as well.

The TIDA-00919 design has three DRV5013 Hall sensors (U2, U3, and U4), which are of the single-ended, latch output type. The supply to the Hall sensors travels through VINT from the DRV10970 device, which is 5 V. Three Hall sensors are placed at 120° mechanical apart in the slot made for the rotor (see Figure 1). Because the device has been designed to operate as differential input Hall sensor outputs, the design requires the creation of a reference point when being supplied with single-ended Hall sensor outputs. This reference is created as VINT / 2 by a simple resistor divider formed by R3 and R5. This reference connects to all the negative terminals of the Hall sensor connections as Figure 2 shows.

Figure 1. TIDA-00919 Board Image

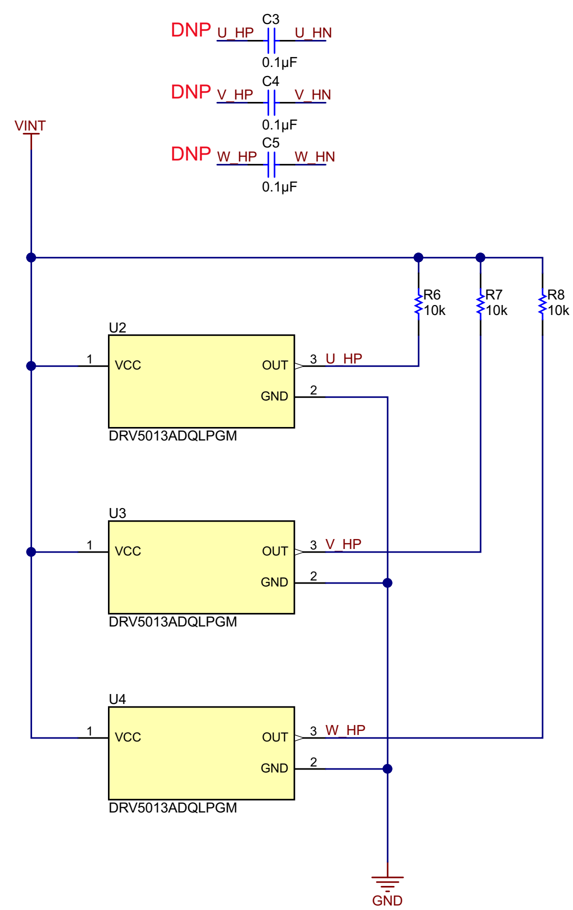

Figure 2. Hall Sensor Connections

The three capacitors C3, C4, and C5 filter the noise on the Hall sensor outputs. The Hall sensors are typically located inside the motor; for this reason, the user can connect the Hall sensor outputs across these capacitors if it is not feasible to mount the complete board inside the PCB. Take the appropriate level of care with the reference in this configuration. If using the board directly inside the motor and the Hall sensors require mounting on the component side (the design is on the top side), the user must modify the Hall sensor pinout.

3.3 Hardware Settings

The DRV10970 is capable of driving a BLDC motor in sinusoidal or trapezoidal way. The user can set other features by hardware, such as adaptive angle adjustment and brake mode adjustment. Configure the required settings by making the appropriate placements of R9 to R12, as Table 2 details and Figure 3 shows.

Table 2. Drive Settings

FUNCTION	SETTINGS	RESISTOR
Commutation mode	Place R11	Sine drive with 30° Hall placement
	Remove R11	Trapezoidal drive
Brake mode	Place R9	Coasting mode
Adaptive angle adjust	Place R12	10° drive angle adjustment
	Remove R12	Auto-drive angle adjustment
Direction control	Remove R10	Direction reversal

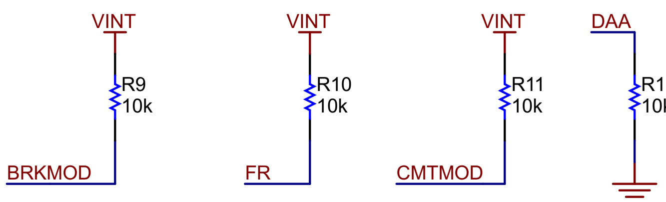

Figure 3. Hardware Settings

The current sense resistor helps to set the current limit during operation. The current sense resistor is calculated by Equation 1 (refer to the datasheet for more details).

$$I_{LIMIT} = \frac{\left(V_{ILIM\_THR} \times A_{CL}\right)}{R_{CS}}$$

where

- V_{ILIM_THR} = 1.2 V (typical)
- A_{CL} = 25000 A/A (typical) (1)

During a fault condition, the device stops the drive and attempts to drive the motor again after a certain time. The capacitor C_{RETRY} determines this retry time, which is controlled by the charging and discharging of the cap with V_{RETRY_H} (1.2 V) and V_{RETRY_L} (0.6 V) and source and sink current at 10 uA typical (see Equation 2 and Figure 4).

$$T_{LOCK\_EX} = 15.36 \times 10_6 \times C_{RETRY}$$

where

- T_{LOCK_EX} is in seconds (2)

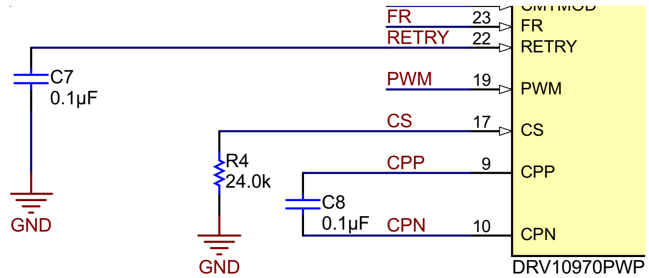

Figure 4. Current Sense and Retry Circuit

With the constraint of a single-side board, the GND connection is routed to multiple places throughout the board. To avoid the ground loop on current sense and VINT, utilize the optional resistor provision on the board. If the GND noise is too much to handle for the current sense and VINT circuit, R13 can be added on the board.

3.4 Control

The design has a provision for controlling user inputs through connections (Figure 5).

- PWM: A PWM input (frequency range of 15 kHz to 100 kHz) is used to control the speed of the motor during runtime.
- FG: The FG signal provides the electrical speed of the motor by toggling an open-drain output, which has already been pulled high to VINT on the board.

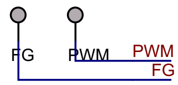

Figure 5. Control Inputs

4 Block Diagram

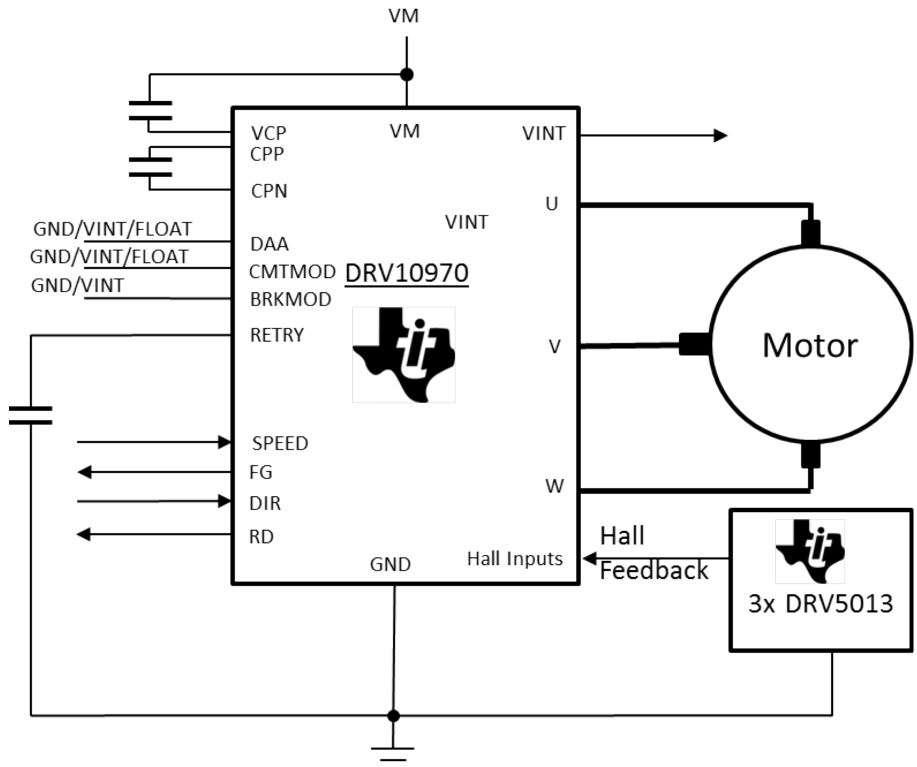

Figure 6. TIDA-00919 Block Diagram

4.1 Highlighted Products

The design contains a three-phase, sensored, sinusoidal BLDC driver (DRV10970) and three Hall sensors (DRV5013).

4.1.1 DRV10970

The DRV10970 is an integrated, three-phase BLDC motor driver for home appliances, cooling fans, and other the general-purpose motor control applications. The embedded intelligence, small form factor, and simple pinout structure reduce the design complexity, board space, and system cost. The integrated protections improve the system robustness and reliability.

The output stage of the DRV10970 device consists of three half bridges. Each half bridge is capable of driving up to 1-A RMS and 1.5-A peak output current. When the device enters sleep mode, it consumes a typical 35-µA of current.

The advanced 180° sine-wave commutation algorithm is embedded into the device that achieves high efficiency, low torque ripple, and superior acoustic performance. The automatic driving angle adjustment function achieves the most optimized efficiency regardless of the motor parameters and load conditions.

The DRV10970 has been designed for Hall sensor-based applications. The differential Hall signal inputs are detected by the integrated comparators. The device supports single Hall-based applications and three Halls-based applications. The single Hall sensor mode reduces the system cost by eliminating two Hall sensors.

The device implements a standard control interface which includes PWM input (speed command), FG output (speed feedback), FR input (forward and reverse direction control), and RD output (motor lock indicator).

The DRV10970 supports both 30° and 0° Hall sensors (with respect to the corresponding phase back-electromotive force [BEMF]). The device implements a trapezoidal drive mode to address the higher power requirement.

The DRV10970 device determines the motor lock condition based on the absence of hall input switching. The device re-attempts to spin the motor after an adjustable auto-retry time, which can be configured by a capacitor connected to the RETRY pin.

The device incorporates multiple protection features such as overcurrent, undervoltage, overtemperature, and locked rotor conditions to improve the system robustness.

The DRV10970 is packaged in a thermally enhanced 24-pin TSSOP package (eco-friendly: RoHS and no Sb/Br).

4.1.2 DRV5013

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 through a digital bipolar latch output. The integrated circuit (IC) has an open-drain output stage with a 30-mA current sink capability. A wide operating voltage range from 2.5 V 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 have been provided for reverse supply conditions, load dump, and output short circuit or overcurrent.

Device features

- Digital bipolar-latch Hall sensor
- Superior temperature stability
  - B_{OP} ±10% overtemperature
- High sensitivity options (B_{OP} and B_{RP})
  - +2.7 / –2.7 mT (AD)
  - +6 / –6 mT (AG)
  - +12 / –12 mT (BC)
- Supports a wide voltage range
  - 2.5 to 38 V
  - No external regulator required
- Wide operating temperature range
  - T_A = –40 to 125°C (Q)
- Open-drain output (30-mA sink)
- Fast 35-µs power-on time
- Small package and footprint
  - Surface mount 3-pin SOT-23 (DBZ)
    - 2.92 mm × 2.37 mm
  - Throughhole 3-pin TO-92 (LPG)
    - 4.00 mm × 3.15 mm
- Protection features
  - Reverse supply protection (up to –22 V)
  - Supports up to 40-V load dump
  - Output short-circuit protection
  - Output current limitation

5 Getting Started

The hardware is capable of exploring all the available features of the DRV10970 device.

5.1 Hardware Settings

Before connecting the motor to the board, the user must be aware of the Hall placement if the Hall signals are being externally provided to the board. Configure the following required hardware settings before getting started with the hardware (see Table 2 as well).

- CS: Check whether the onboard resistor is correct as per the expected motor current. Change this resistor if required.
- BRKMOD: Check R9 to confirm if either must be present for the appropriate brake mode.
- CMTMOD: Check R11 for the appropriate commutation mode. A provision has been provided to either pull the pin high or keep it floating.
- DAA: The DAA settings can be changed while in three-Hall sensor mode by using R12.
- Hall sensor: Depending on the type of Hall sensors and placement in the motor, connect the Hall sensors (if they are being provided externally). Take note of the Hall sensor pinout, as this configuration depends on the way that the PCB has been used inside the motor.

5.2 Start

After having correctly implemented the hardware settings, connect the power supply to the board and motor connected to U/V/W terminals on the board.

Switch on the power supply and apply the PWM input to the PWM jumper for speed control. The FG output shows the speed as an electrical frequency.

5.3 Runtime

Change the speed command through the PWM input and observe the speed feedback on the FG pin.

6 Test Setup

The board was tested with a Hurst motor number DMB0224C10002. The board was supplied by an Agilent E3634A power supply at 12 V. The following waveforms have been captured using the Tektronix DPS4034 oscilloscope. The power supply setting was kept at 12 V with a current limit of 3 A. Figure 7 shows an image of the test setup.

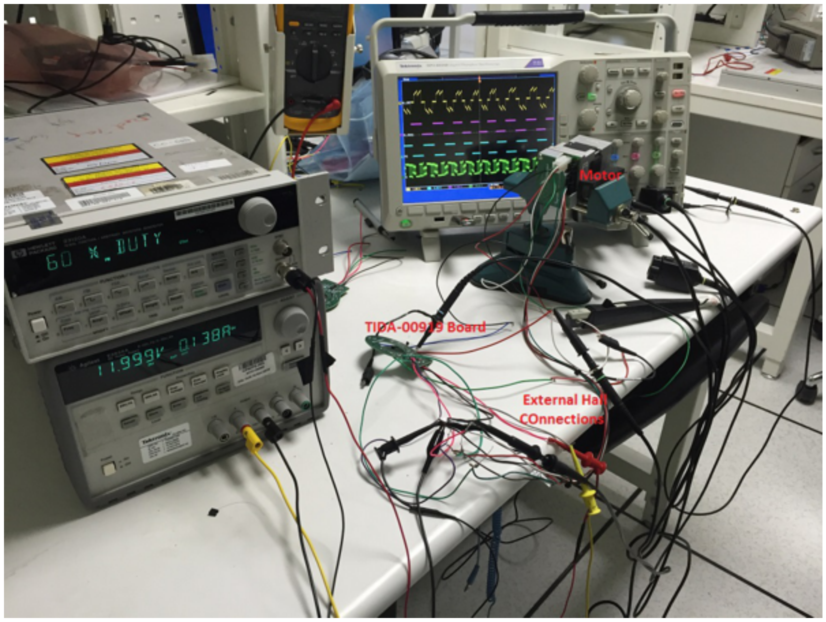

Figure 7. Test Setup

7 Test Data

7.1 DRV10970 Driving With Three-Hall Mode

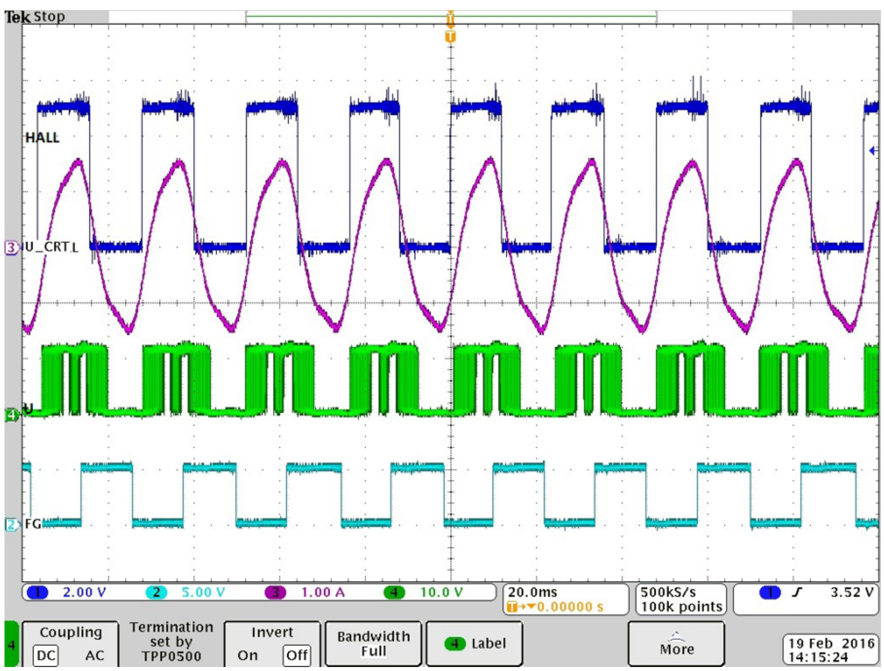

Figure 8. DRV10970 Driving Motor With Three-Hall Mode

7.2 DRV10970 Driving With Trapezoidal Mode

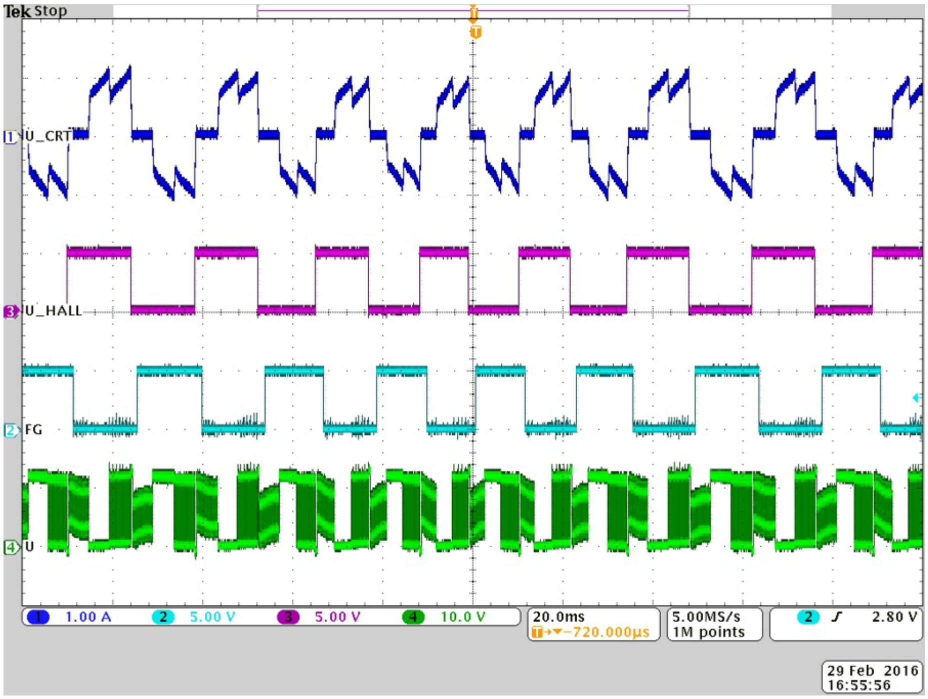

Figure 9. DRV10970 Driving With Trapezoidal Mode

7.3 DRV10970 Ph-Ph Short and Recovery

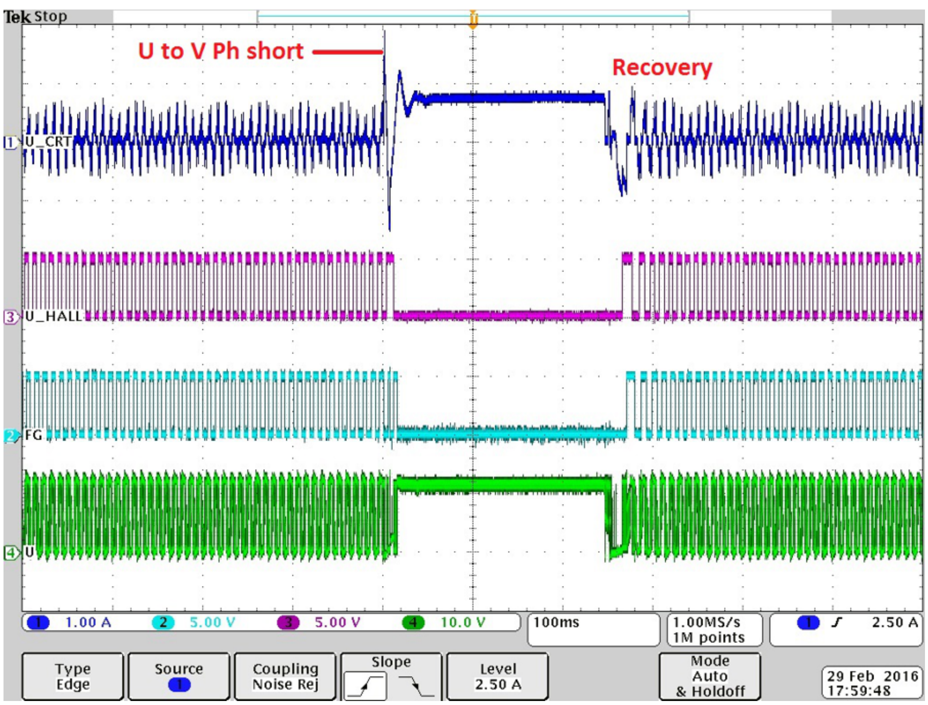

Figure 10. DRV10970 Ph-Ph Short and Recovery

7.4 Thermal Image at 18-V, 1-A Load

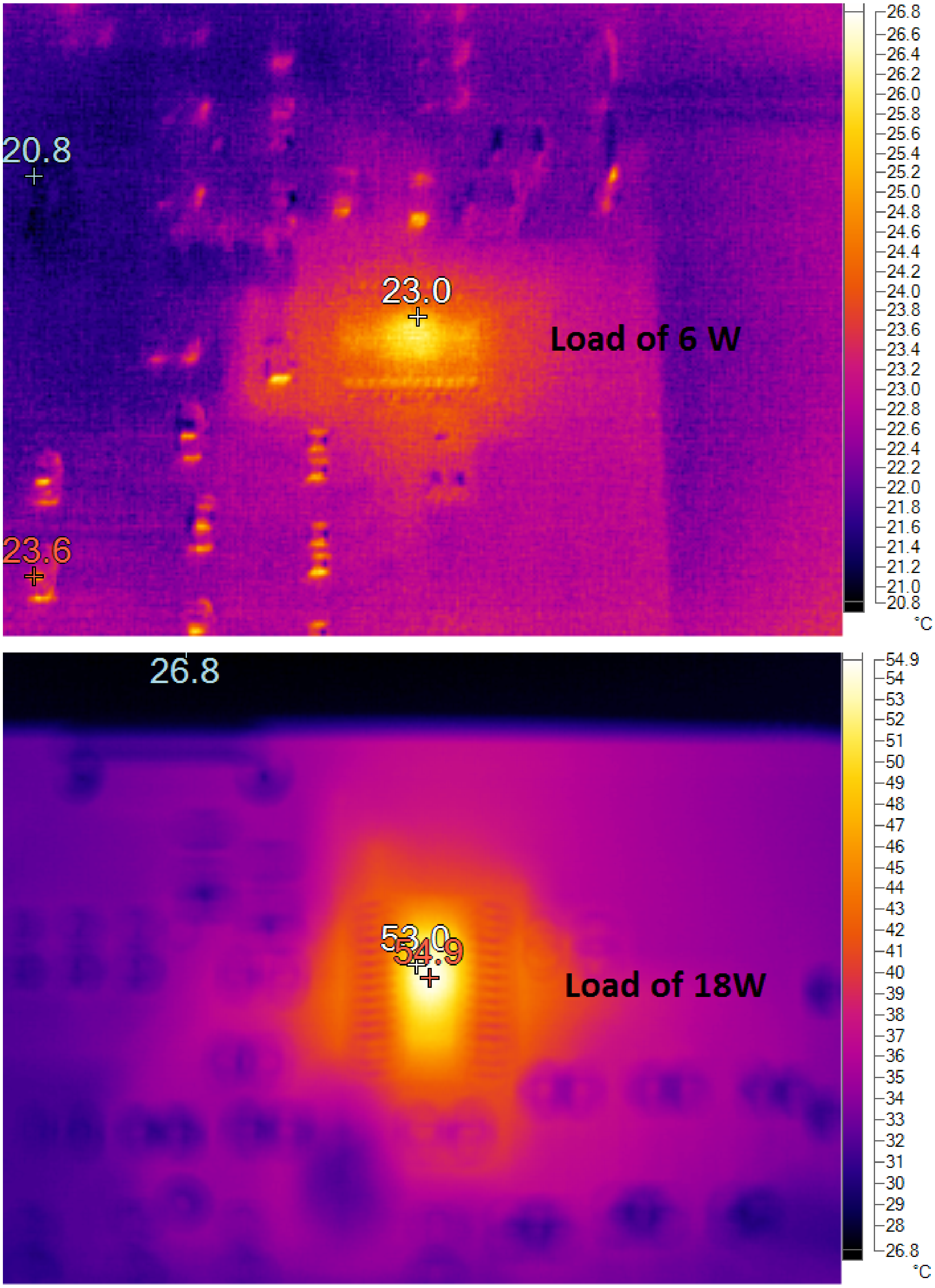

Figure 11. Thermal Image at 18-V, 1-A Load

8 Design Files

8.1 Schematics

To download the schematics, see the design files at TIDA-00919.

8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00919.

8.3 Layer Plots

To download the layer plots, see the design files at TIDA-00919.

8.4 Altium Project

To download the Altium project files, see the design files at TIDA-00919.

8.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00919.

8.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00919.

9 References

1. Texas Instruments, *DRV10970 3-Phase Brushless DC Motor Driver*, DRV10970 Datasheet (SLVSCU7)

10 Terminology

BEMF— Back-electromotive force

BLDC— Brushless DC motor

ESD— Electrostatic discharge

FET— Field-effect transistor

MOSFET— Metal-oxide-semiconductor field-effect transistor

PWM— Pulse width modulation

RMS— Root mean square

RPM— Rotations per minute

11 About the Author

JASRAJ DALVI is an applications engineer at Texas Instruments, where he is responsible for developing reference design solutions and control algorithms for motor control applications. He completed his Bachelors of Engineering degree in Electrical Engineering from University of Pune, India and his Post Graduate Diploma in Marketing Management at S.I.B.M. in Pune, India.