TI Designs
24-V, 50-W BLDC Motor Sinusoidal Drive for Air Purifier Fans

TI Designs

TI Designs provide the foundation that you need including methodology, testing and design files to quickly evaluate and customize the system. TI Designs help *you* accelerate your time to market.

Design Resources

TIDA-00656	Tool Folder Containing Design Files
DRV10983	Product Folder
MSP430G2303	Product Folder

TI E2E™ Community

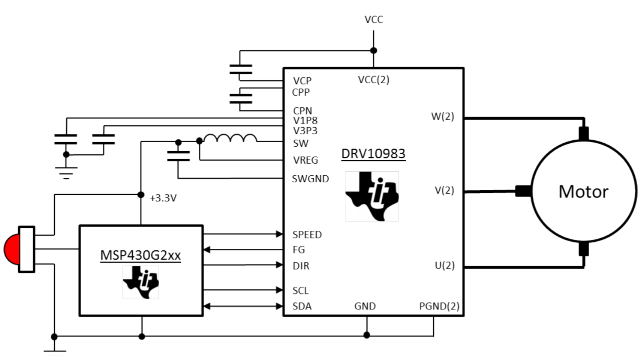
ASK Our E2E Experts
WEBENCH® Calculator Tools

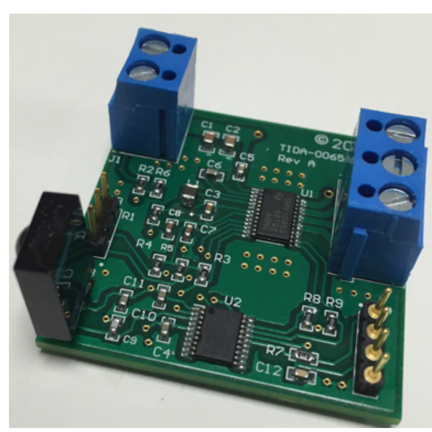
Design Features

- 50-W, 24-V Drive Capable of Driving Brushless DC (BLDC) Motors With Sinusoidal Commutation
- Uses DRV10983, a Three-Phase Sensorless Motor Driver With Integrated Power MOSFETs, Capable of Providing Continuous Drive Current up to 2 A
- DRV10983 Uses Proprietary Sensorless Control Scheme to Provide Continuous Sinusoidal Drive, Significantly Reducing Pure Tone Acoustics That Typically Occur as Result of Commutation
- Integrated Buck and Linear Regulator to Efficiently Step Down Supply Voltage to 3.3 V for Powering Both Internal and External Circuits (TI MSP430™ MCU)
- I²C Interface Allows User to Reprogram Specific Motor Parameters in Registers and Program EEPROM to Help Optimize Performance for Given Application
- MSP430G2303 Functions to Close External Speed Loop and Accept IR Input
- IR Communication Possible With Board Using IR Receiver and Implementing NEC Protocol With Software

Featured Applications

- Air Purifier Fan
- Ceiling Fans





An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

1 Introduction

The TIDA-00656 reference design is a cost-effective, small form-factor (SFF), three-phase sinusoidal motor drive for brushless DC (BLDC) motor up to a power of 50 W at 24 V. The board accepts the 24 V at the input and provides the three motor outputs to drive the BLDC motor sinusoidally. By using a microcontroller (MCU), which is the MSP430G2303 for this design, the user can close the speed loop externally.

The MCU accepts the infrared (IR) command over the remote, which supports the NEC protocol. The DRV10983 device accepts the speed commands from the MCU over the I^2C lines or as a pulse width modulation (PWM) input. The DRV10983 device sends the speed data on the FG output or through the I^2C interfaced to the MCU. The I^2C interface is also available as a header and the external graphical user interface (GUI) can also be used to program the DRV10983 device.

The integrated buck converter of the DRV10983 is configured for a 3.3-V output, which powers the onboard MCU. The optimum spin-up profile is achieved by tuning all of the applicable configuration parameters inside the EEPROM of the DRV10983 device. These parameters are accessible by the I^2C interface.

An air purifier is a common household item used to purify the air in a closed environment. Air purifiers are available in multiple sizes, various power levels, and control levels. If the system level input is line powered, the user can implement an external, AC-DC, switched-mode power supply (SMPS) converter with this TIDA-00656 design. The TIDA-00386 reference design includes a similar motor driver that uses an AC-DC SMPS without power factor correction (PFC). Many designs from Texas Instruments (TI) are available that utilize PFC power supplies, such as the PMP5112 reference design.

One of the major requirements of a purifier is to operate silently. The DRV10983 device uses a proprietary, sensorless control scheme to provide continuous sinusoidal drive, which significantly reduces the pure tone acoustics that typically occur as a result of commutation.

This reference design provides a ready platform to use a 50-W inverter drive for a BLDC motor-based air purifier.

2 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATION
DC input voltage	24 V, ± 1 V
Rated power capacity	50 W
Speed input	Infrared 38 KHz (NEC protocol)
Operating ambient temperature	–20 to +500C
Inverter efficiency	≥ 97% at rated load
Protections	Overcurrent, overtemperature, and short circuit

3 System Description

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

The DRV10983 device is an electronic drive that uses sinusoidal control to drive the BLDC motor. The MSP430G2303 MCU helps to close the speed loop that is external to the DRV10983. The MCU is also responsible for accepting the speed command using IR reception.

4 Block Diagram

Figure 1 shows the TIDA-00656 block diagram. The system is supplied with a motor voltage of 24 V and the DRV10983 device is used to drive the BLDC motor. The MCU accepts the IR commands on the IR receiver and translates these commands for the DRV10983 driver for speed control. The MCU also reads the motor speed and closes the speed loop by changing the appropriate commands to the DRV10983 driver.

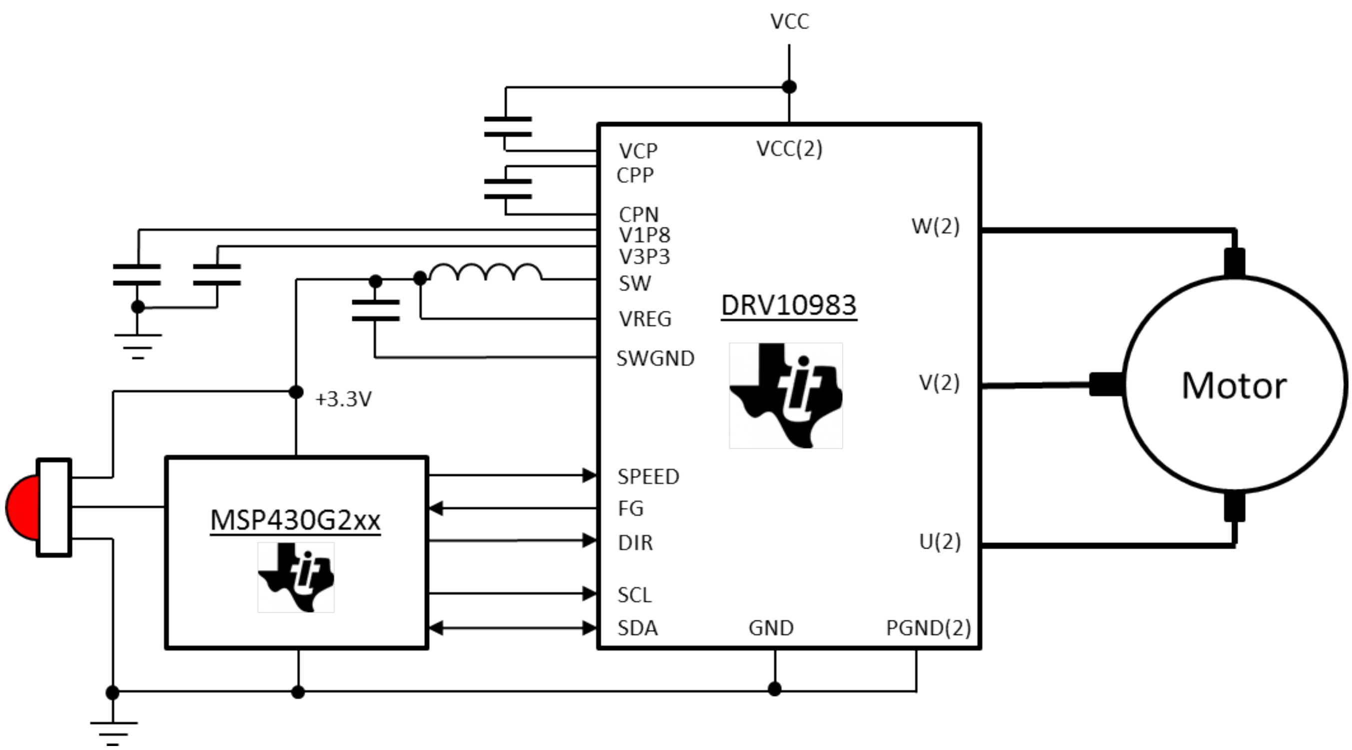


Figure 1. TIDA-00656 Block Diagram

The DRV10983 driver can also be configured through the external GUI with the header available onboard. The user can also modify the MSP430 software if additional features are required.

5 Highlighted Products

The key features of the highlighted devices are available in their respective datasheets. The following subsections detail the highlighted products used in the reference design.

5.1 DRV10983

The DRV10983 is a three-phase, sensorless motor driver with integrated power MOSFETs, which can provide continuous drive current up to 2 A. The device is specifically designed for cost-sensitive, low-noise, and low external component count applications.

The DRV10983 driver uses a proprietary sensorless control scheme to provide continuous sinusoidal drive, which significantly reduces the pure tone acoustics that typically occur as a result of commutation. The interface to the device is designed to be simple and flexible. The user can control the motor directly through the PWM input, analog input, or I^2C inputs. The motor speed feedback is available through either the FG pin or I^2C interface.

The DRV10983 driver features an integrated buck and linear regulator to efficiently step down the supply voltage to either 5 V or 3.3 V for powering both internal and external circuits. The device is available in either a sleep mode or a standby mode version to conserve power when the motor is inactive. The standby mode (3-mA) version leaves the regulator running and the sleep mode (180-µA) version shuts it off. Use the standby mode version in applications where the regulator is used to power an external MCU.

An I^2C interface allows the user to reprogram specific motor parameters in registers and program the EEPROM to help optimize the performance for a given application. The DRV10983 driver is available in a thermally-efficient HTSSOP, 24-pin package with an exposed thermal pad. The operating temperature is specified from –40°C to 125°C.

5.2 MSP430G2303

The Texas Instruments MSP430™ family of ultra-low-power microcontrollers consists of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with five low-power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit reduced instruction set computing (RISC) CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 1 µs.

The MSP430G2x03 and MSP430G2x33 series are ultra-low-power, mixed-signal MCUs with built-in 16-bit timers, up to 24 I/O capacitive-touch enabled pins, and built-in communication capability using the universal serial communication interface. In addition, the MSP430G2x33 family members have a 10-bit analog-to-digital converter (ADC).

Typical applications include low-cost sensor systems that capture analog signals, convert them to digital values, and then process the data for display or for transmission to a host system.

6 System Design Theory

The block diagram in the preceding Figure 1 shows the complete system and the two major sections of the design.

- DRV10983 – Motor drive
- MSP430G2303 – IR reception and speed control

6.1 Motor Drive Section

Figure 2 shows the motor drive section.

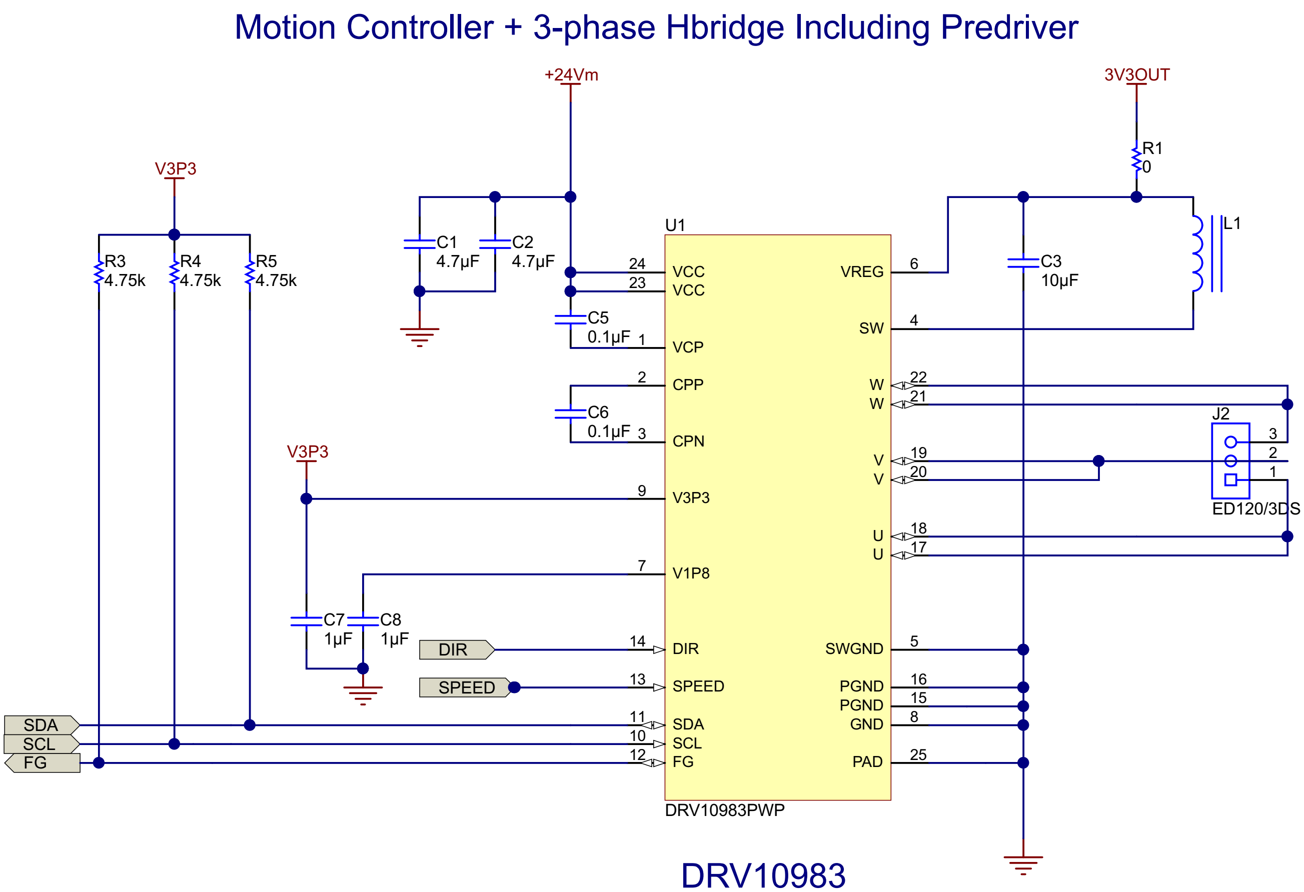


Figure 2. Main Power Input

J1 is the input connector that receives the input voltage. If speed correction is required (based on the ripple on input voltage), an onboard provision is available to measure the input DC voltage that travels through resistors R2 and R6. The user must implement the MCU with the ADC provision for this situation (MSP430G2333).

J2 is the connector where motor connections are terminated and J3 is the header where the user can connect an external device or GUI to configure the DRV10983 EEPROM.

6.2 Speed Control Section

Figure 3 shows the speed control section of the TIDA-00656 design.

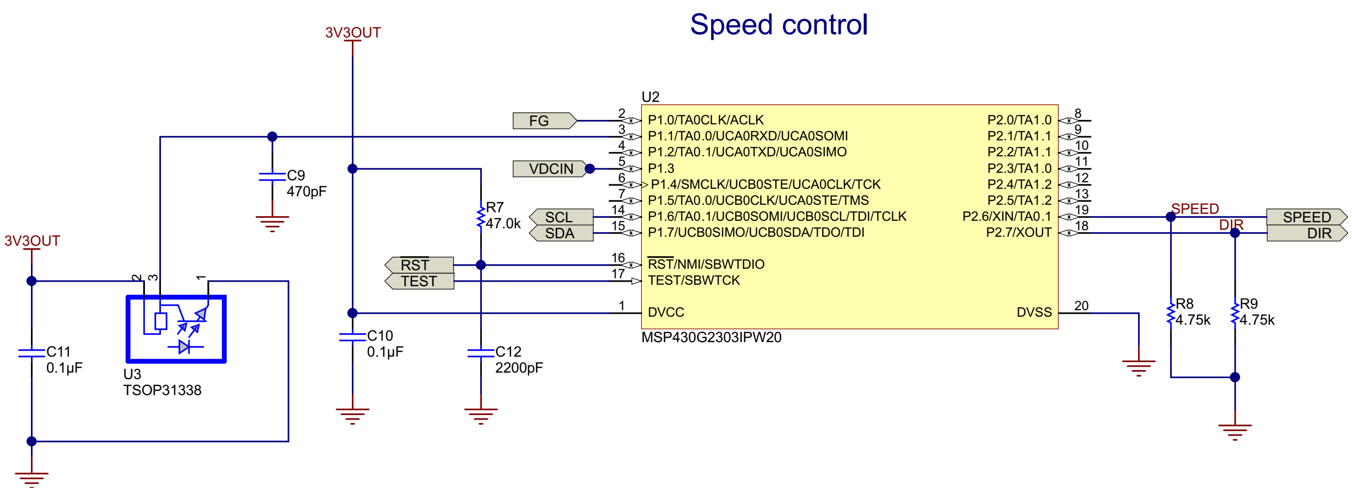


Figure 3. Speed Control Section

In the schematic, J1 is the Input connector where the input voltage is supplied. If the design requires speed correction based on the ripple on input voltage, a provision is made on the board to measure the input DC voltage through resistors R2 and R6. The MCU with ADC provision must be chosen in this case (MSP430G2333).

The MSP430 device accepts the 38-KHz infrared signals of the NEC protocol and converts them to the speed input command for the DRV10983 device. The PWM duty is modified after reading the speed of the DRV10983 device over the I^2C interface. The control loop runs at 10 Hz, which is significantly slower considering the nature of the load, which settles over a long period of time.

J4 is the programming connector for the MSP430 device. The user can program the MSP430 device by using the Spy-Bi-Wire interface.

6.3 Thermal Design

Proper thermal design is crucial for the safe and reliable operation of semiconductors. The operation of the semiconductor at higher operating temperatures leads to a reduction in the safe operating area and can result in failure or reduced life of the device.

The goal of the thermal design is to limit the junction temperature of the switches inside the DRV10983 device within the safe values. The datasheet specifies that the insulated-gate bipolar transistor (IGBT) has a maximum junction temperature rating of 150ºC. This specification indicates that the user must design a heat dissipation area to account for this limit when operating at the full load capacity.

7 Getting Started Firmware

The firmware is written for the onboard MSP430 controller. The existing firmware serves two major functionalities:

- The firmware can configure the DRV10983 device. This firmware is usually a one-time configuration unless the user wants to modify parameters runtime of the configuration.
- The firmware can accept the IR signal's runtime from the remote and can control the speed in a closed loop.

For GUI usage and tuning, refer to the *DRV10983 and DRV10975 Tuning Guide* (SLOU395).

7.1 Connecting Programmer

The following Figure 4 shows the connections from the MSP430 LaunchPad programming board to the TIDA-00565 board. Figure 5 shows a physical image of these connections.

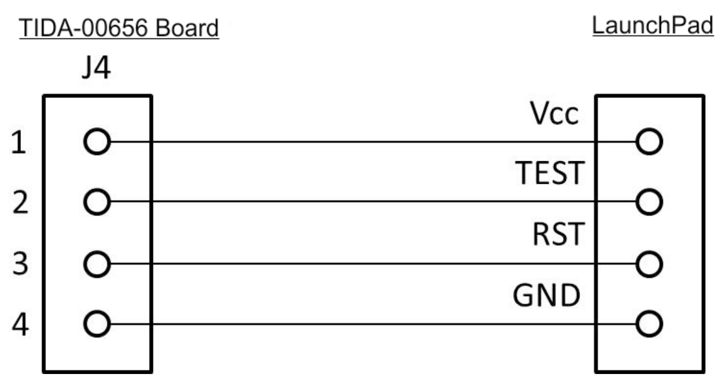


Figure 4. LaunchPad and TIDA-00656 Board Connections Diagram

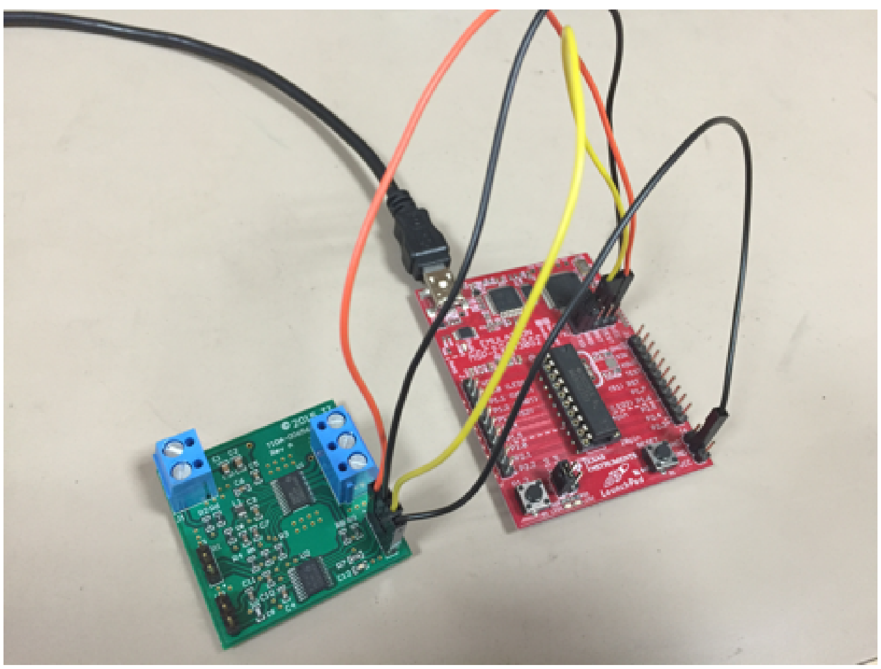


Figure 5. Connections Between LaunchPad Programmer and TIDA-00656 Board

7.2 Programming MSP430™ MCU from TI

The instructions for programming the MSP430 MCU are as follows:

- Import the “TIDA_00656_RevA” project using TI’s Code Composer Studio™ (CCS) software.
- Connect the LaunchPad programmer to the TIDA-00656 board, as the preceding Figure 5 shows.
- Build the project by clicking the *Build* button (hammer icon), which if run successfully, appears as the following Figure 6.
- Click the *Debug* button (bug icon) as the following Figure 6 shows.

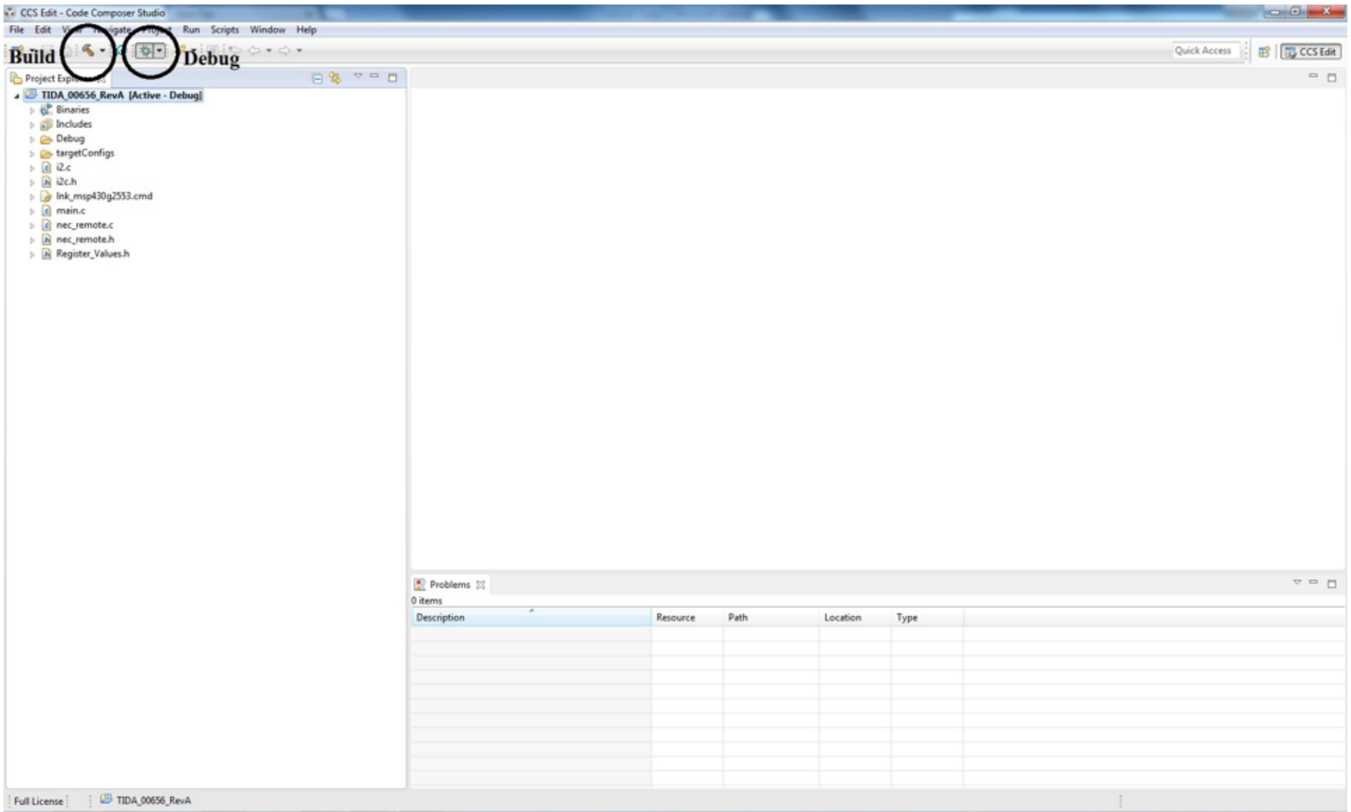


Figure 6. Build and Debug Using Code Composer Studio™ from TI

- The program downloads in the MSP430 MCU on the TIDA-00656 board.

7.3 Remote Key Code Programming

The user can program any key codes into the program. This task enables the user to use any remote for test purposes that send data over the NEC protocol. The user must carry out the following tasks for this purpose:

- After downloading the program, a break must be placed at the function *Process_Remote_Code ()* in the *ir_remote.c* file, as the following Figure 7 shows.
- Whenever a remote key is pressed in the direction of the board, a break point is hit.

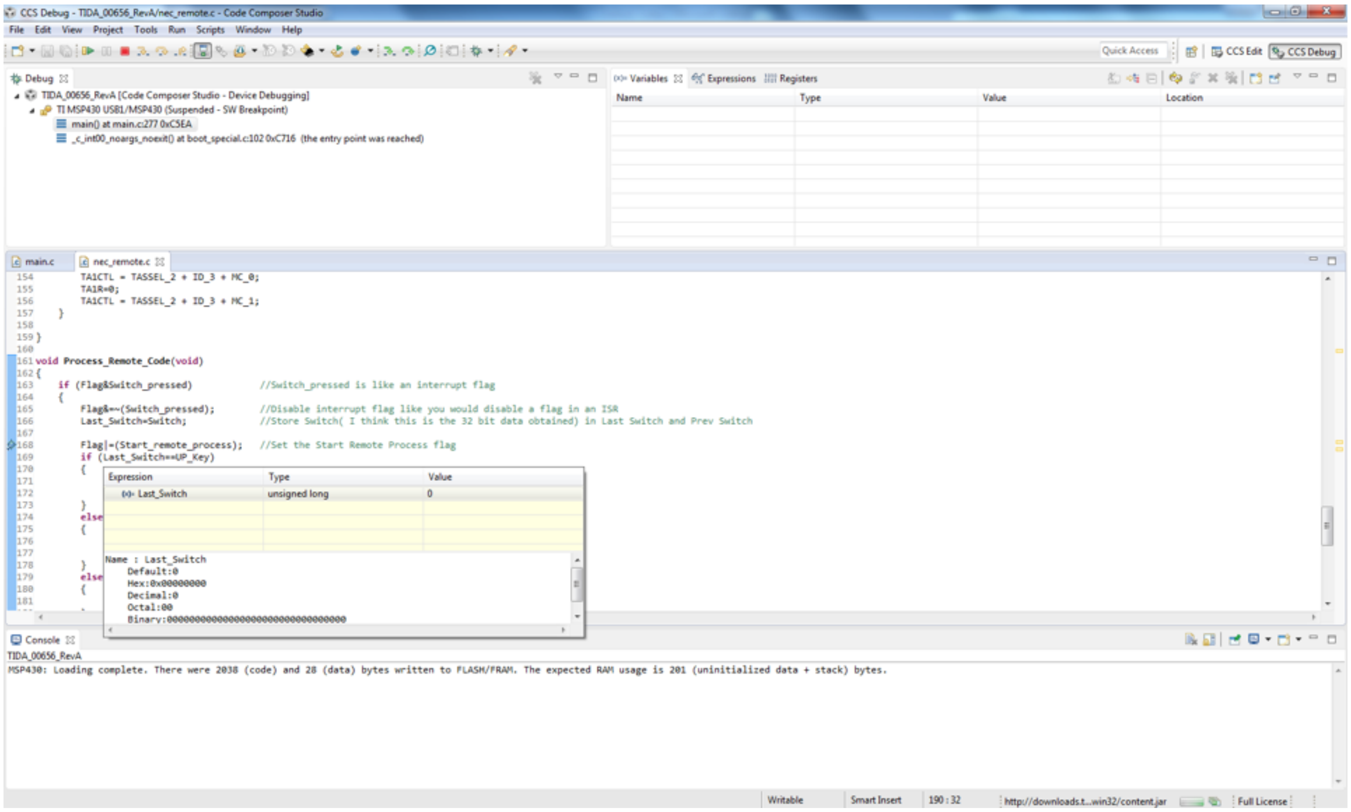


Figure 7. Placing Breakpoint for IR Key Code Programming

- Read the value of the *Last_Switch* variable. The values can be hard coded in the program (*ir_remote.c*), as the following Figure 8 shows.
- The three keys (up, down, and direction change) can be programmed.

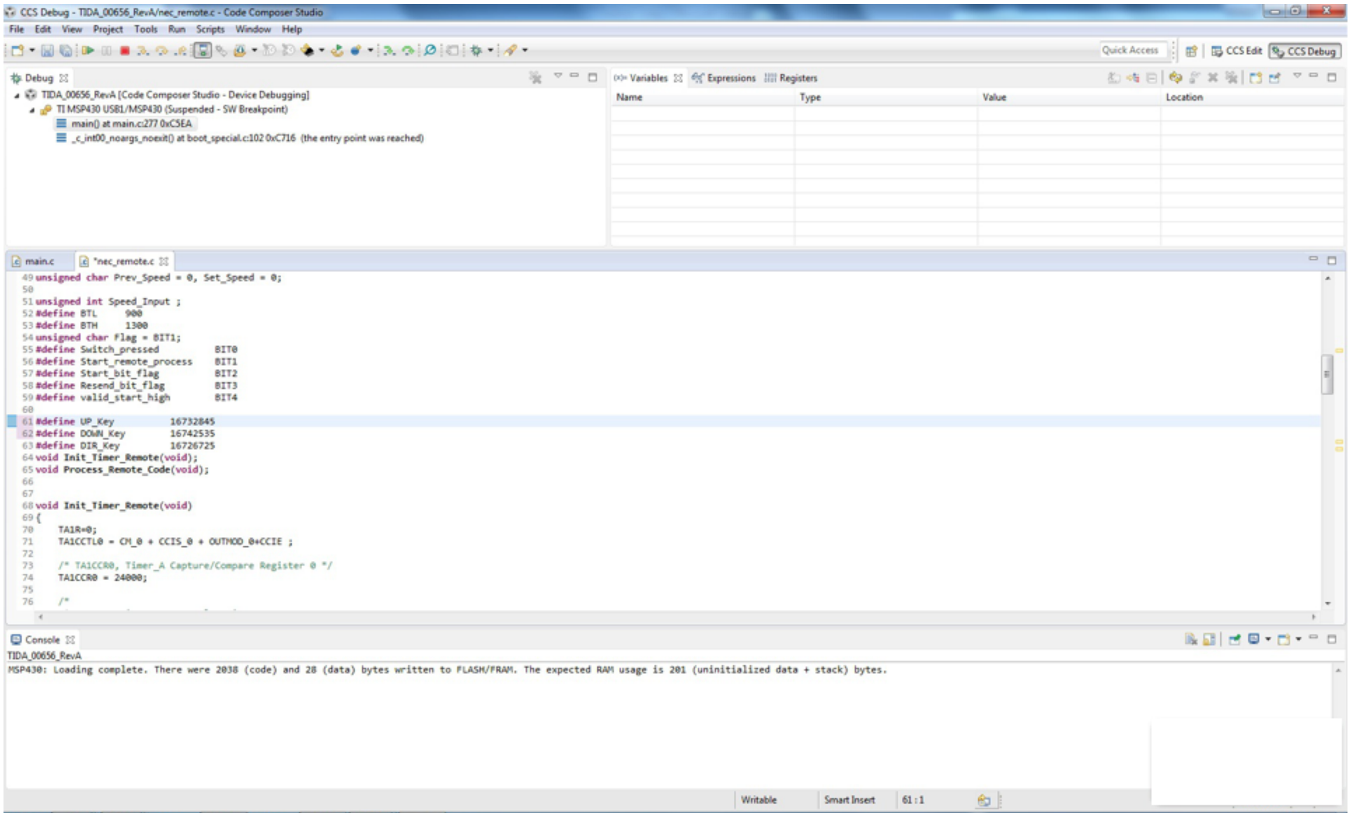


Figure 8. Placing Key Codes Corresponding to Functions

7.4 Code Implementation

As the following Figure 9 shows, if the highlighted portion of code is commented, the MSP430 MCU is utilized strictly for speed control purposes.

The code within the black box in Figure 9 can remain unchanged if the user wishes to download the configuration parameters on each power-on cycle.

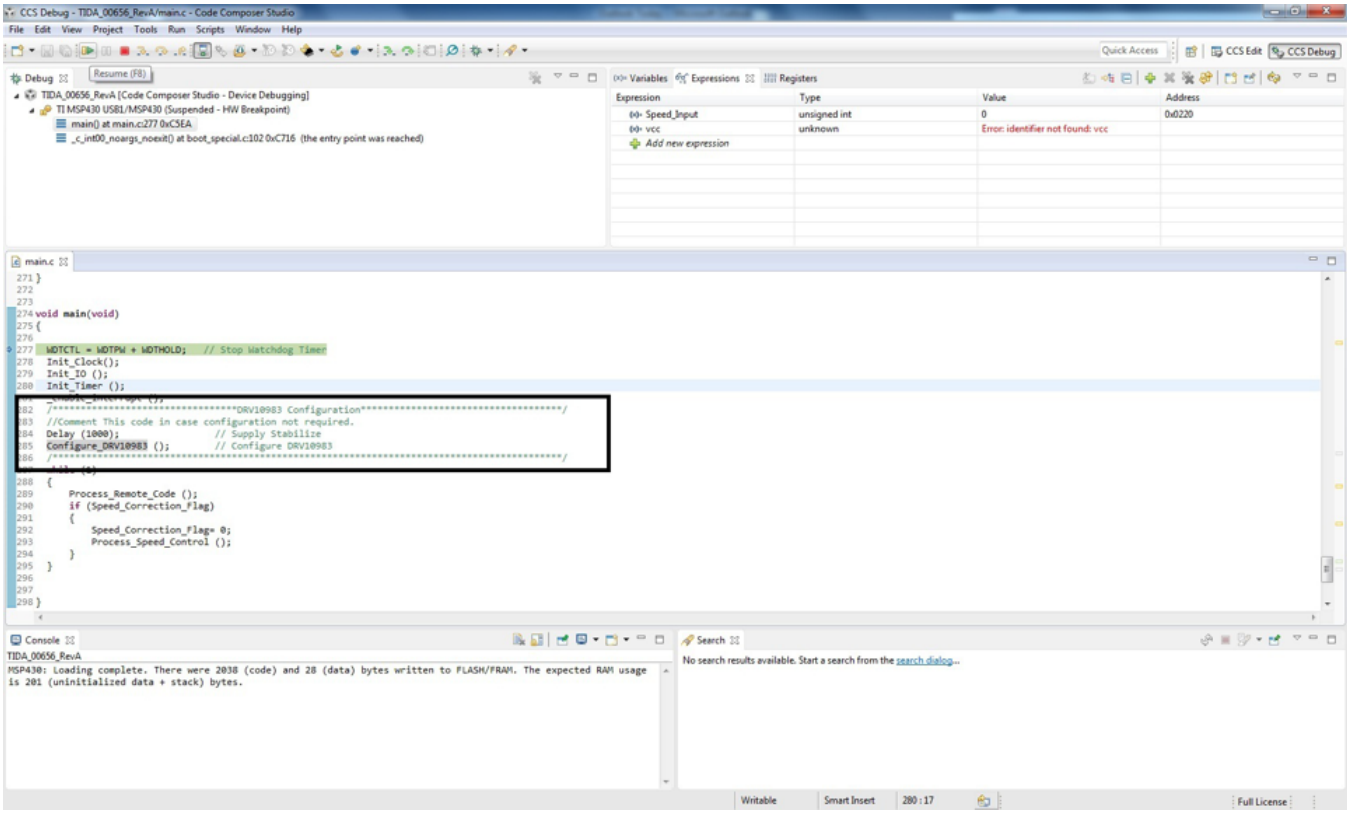


Figure 9. Using Code for Configuration

To program the register values, the *Register_Values.h* must be modified as shown in the following Figure 10.

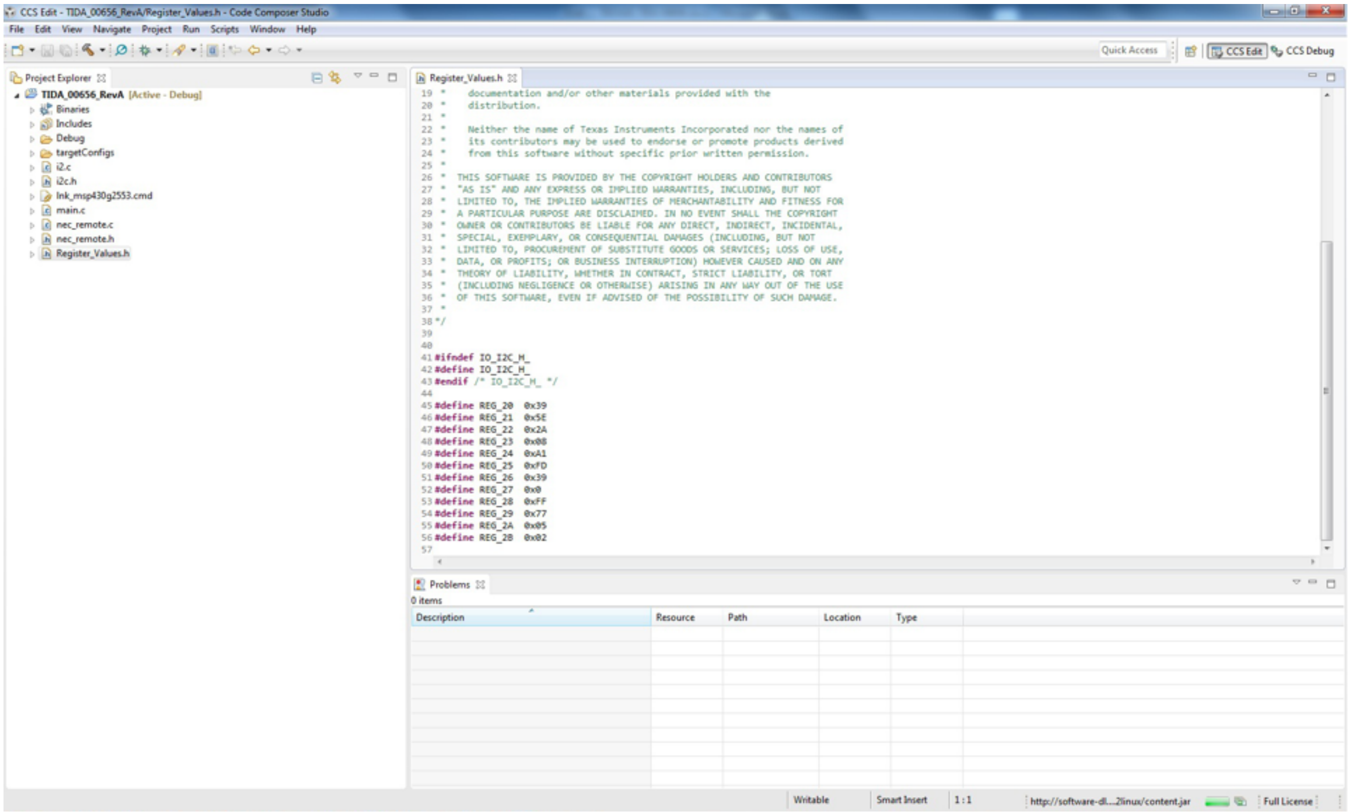


Figure 10. Register Values Programming

8 Test Results

Figure 11 shows the top view of the TIDA-00656 Rev A board. Figure 12 shows the test setup image as well as the connector positions for testing the board.

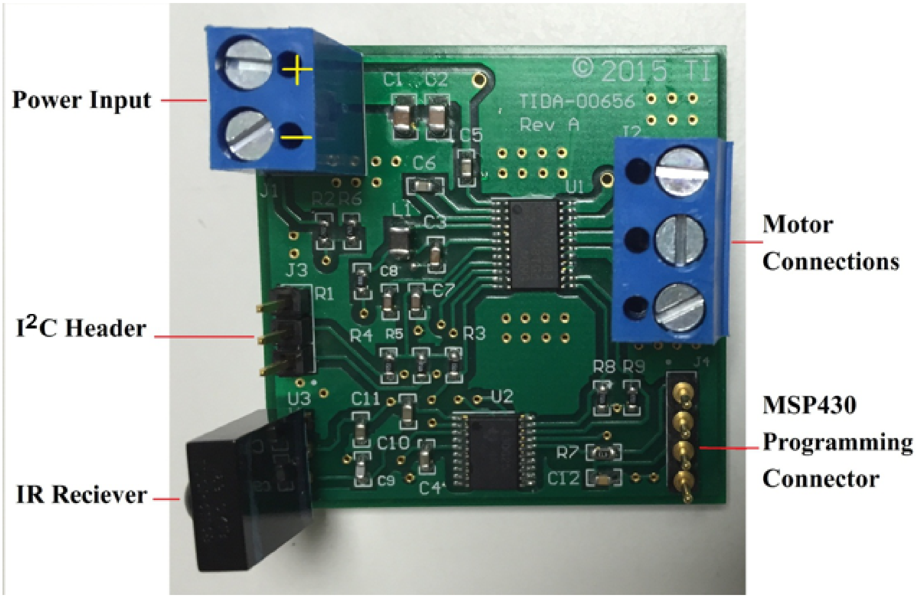


Figure 11. Assembled TIDA-00656 Rev A Board

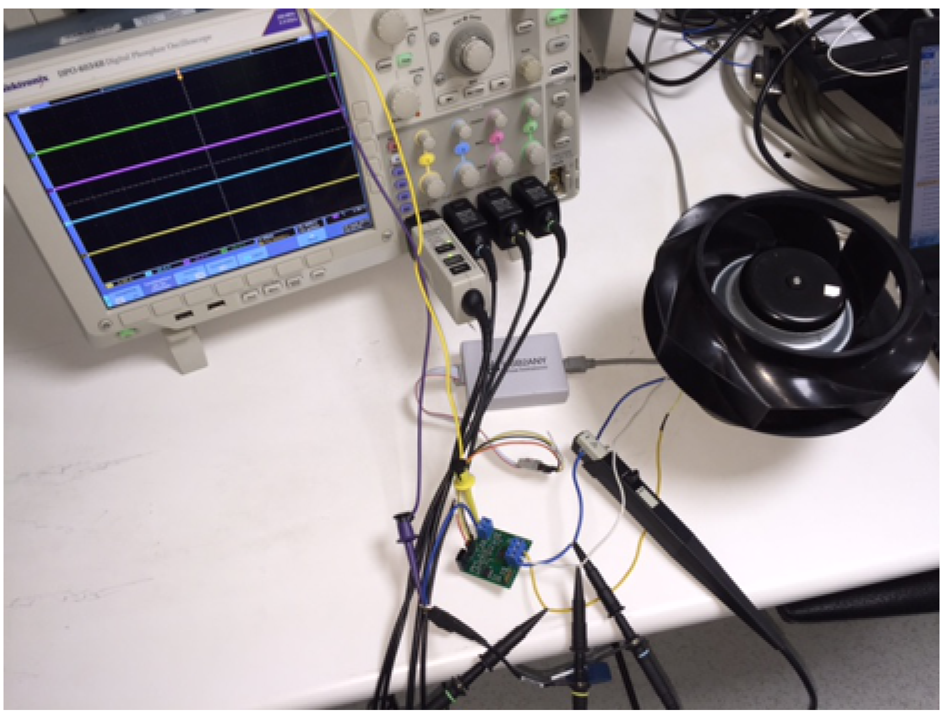


Figure 12. Test Setup

8.1 Functional Test—Spinning Purifier Fan

For this test, the board was supplied with a 24-V power supply with the current limit at the source set at 3 A. When the conjuration is finalized with the GUI, the parameters are modified into the MSP430 configuration program, as well. The code has a provision for the same task and the user has the choice to load the configuration through the MSP430 or the GUI.

A GUI was used during functional testing of the board to configure the parameters of the DRV10983 device to spin the specific motor, which was used in testing procedures. The speed was modulated using the GUI parameter.

The following paragraphs specify the configuration of parameters for the tested motor.

Start-up with align:

As Figure 13 shows, during the align time, the supply draws a very small current. After the motor align time, the open loop acceleration occurs. When the motor reaches the threshold, the speed threshold enters a closed loop where it accelerates further.

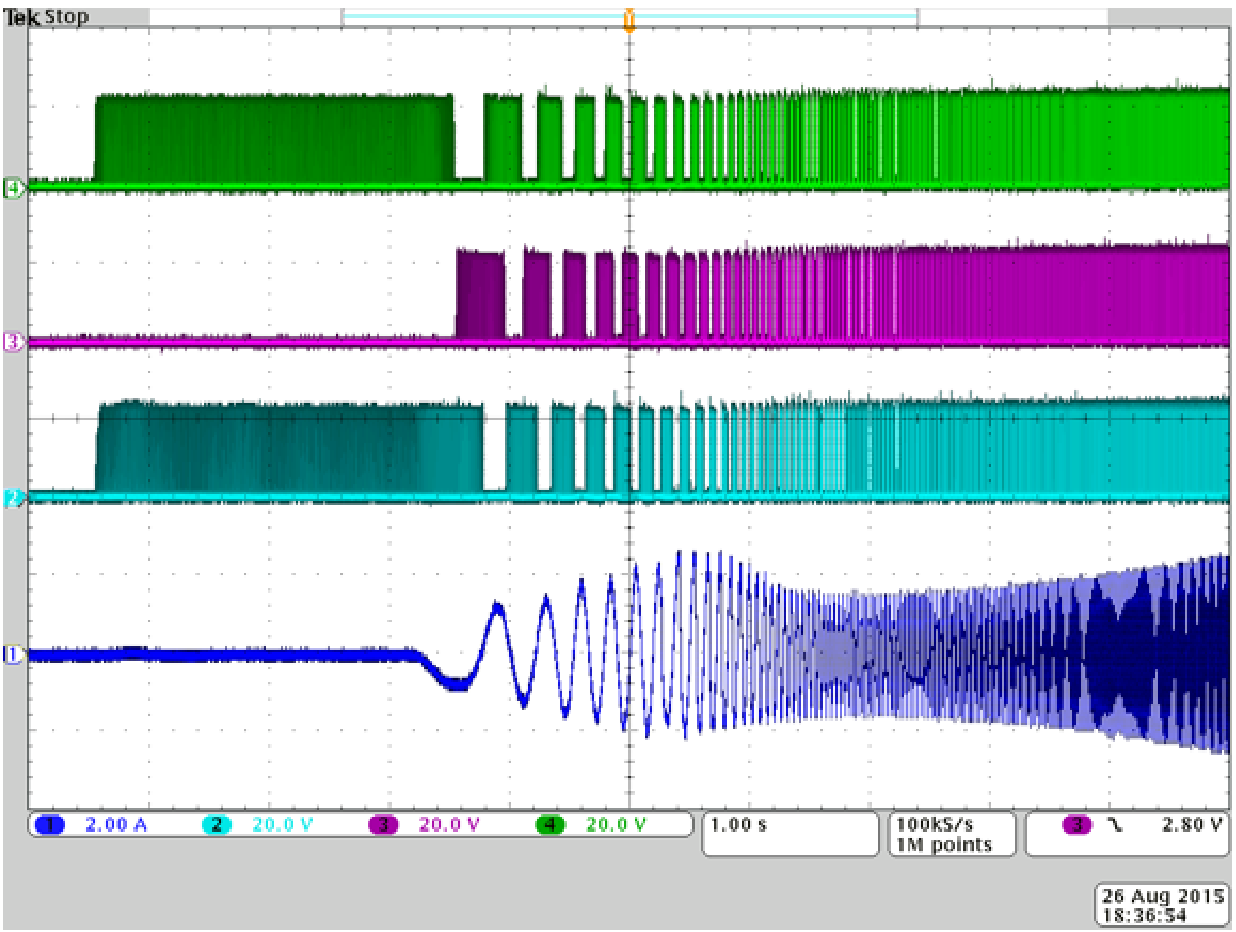


Figure 13. Startup Profile

Runtime:

Figure 14 shows the runtime specified at 24 V, 2.1 A, ≈80 Hz, and 50 W.

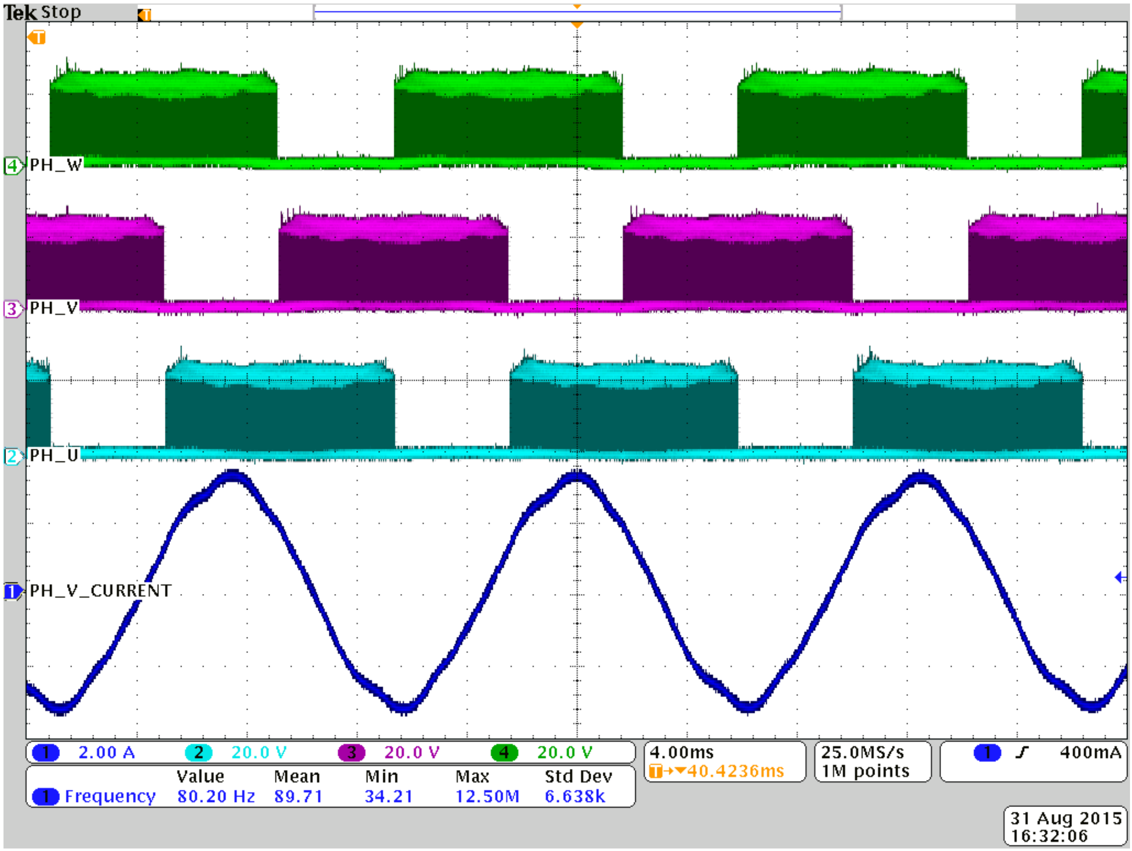


Figure 14. Runtime at 24 V, 2.1 A, ~80 Hz, and 50 W

The speed control loop was closed by an external MCU at the control loop bandwidth of 10 Hz. The fan blade has a lot of inertia and requires time to settle to the target speed, which is the reason for keeping the control bandwidth very small. Maintaining a small control bandwidth ensures the minimum oscillations of rotor speed at the target point.

Acceleration:

The following scope shot in Figure 15 shows the acceleration pattern.

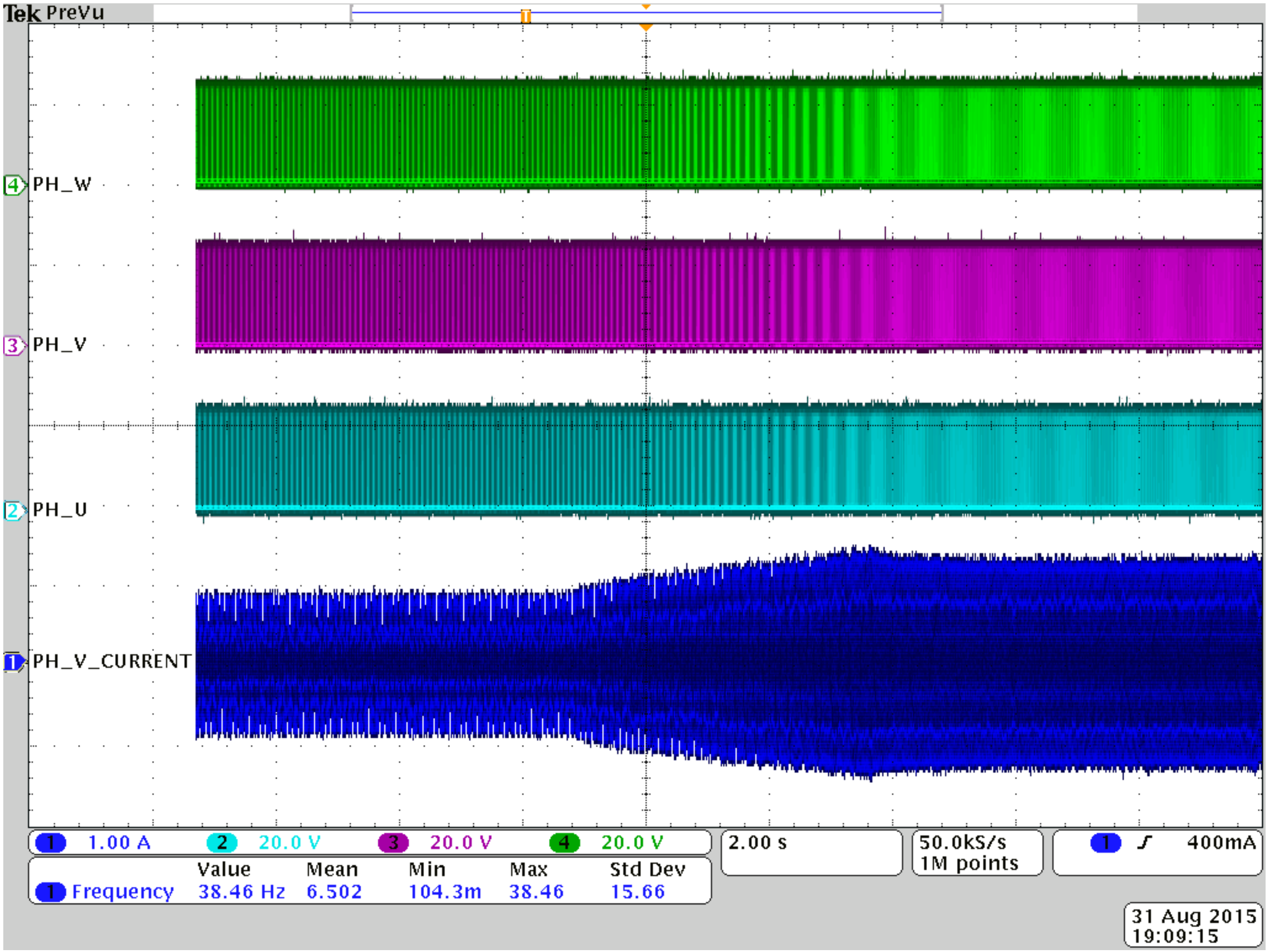


Figure 15. Acceleration

Deceleration:

The following scope shot in Figure 16 shows the deceleration pattern.

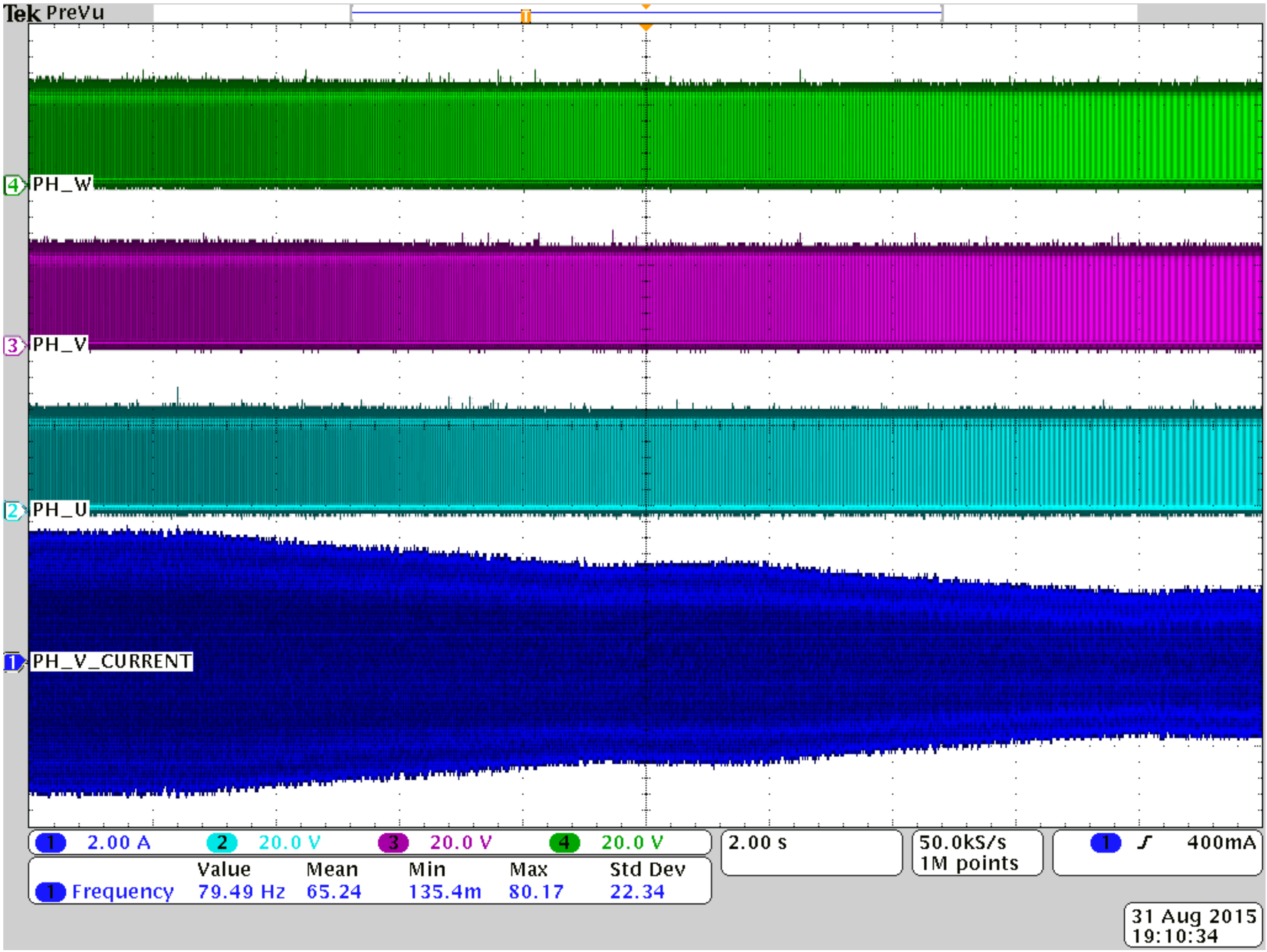


Figure 16. Deceleration

8.2 Thermal Test

Figure 17 and Figure 18 show the thermal characterization images of the TIDA-00656 board while being tested at full speed and a power of 50 W. With the power rating specified at 50 W, the system was tested for 50.4 W at 220ºC ambient and displayed a temperature of 113.50ºC. At 500ºC ambient, the temperature is around 140ºC, which is still well within the junction temperature limit of 150ºC.

The test is run at the following specifications:

- Input voltage: 24 V
- Current drawn: 2.1 A
- Speed: ≈80 Hz

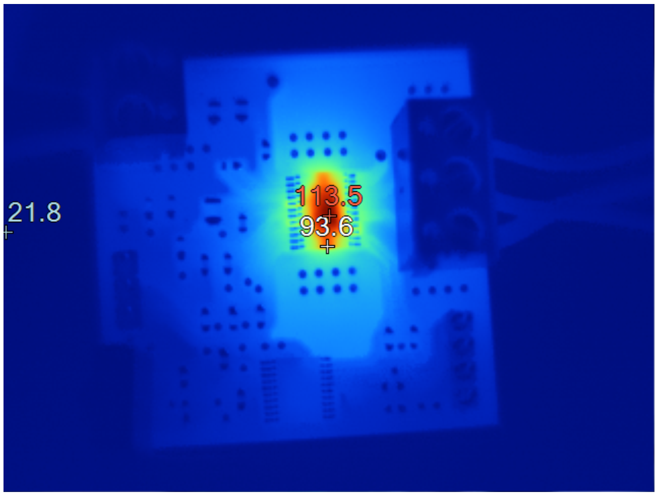


Figure 17. Top Side Thermal Image at 50.4 W, and ≈220ºC Ambient

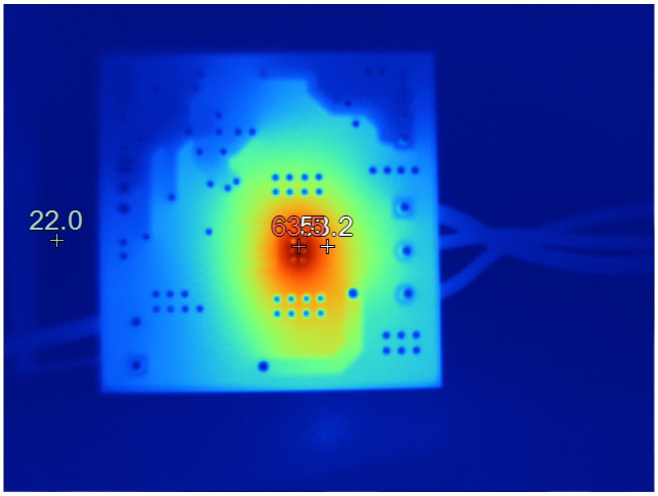


Figure 18. Bottom Side Thermal Image at 50.4 W and ≈220°C Ambient

8.3 Speed Control Test

The onboard MSP430G2303 device controls the duty cycle in such a way to maintain the motor speed at the desired setting.

The PWM duty is modified after reading the speed from the DRV10983 device over the I²C interface. To check the speed regulation, the input voltage was modulated from 18 V to 26 V in increments of 2 V while measuring the speed.

The control loop was running at 10 Hz, which is significantly slower considering the nature of the load, which takes a long time to settle.

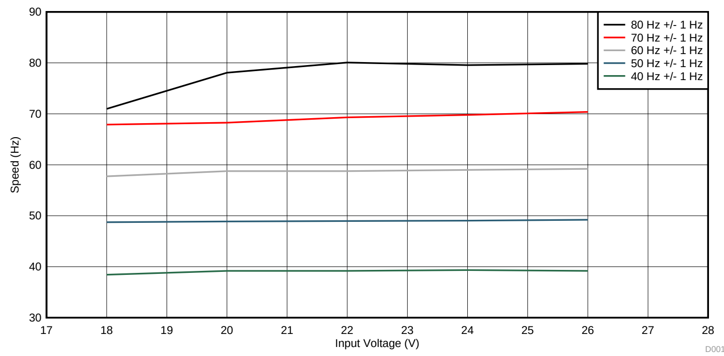


Figure 19. Speed Regulation wrt Input Voltage

8.4 Acoustic Testing

One of the critical parameters for air purifiers is the acoustic data for the system. Figure 20 shows the block diagram of the setup for acoustic measurements.

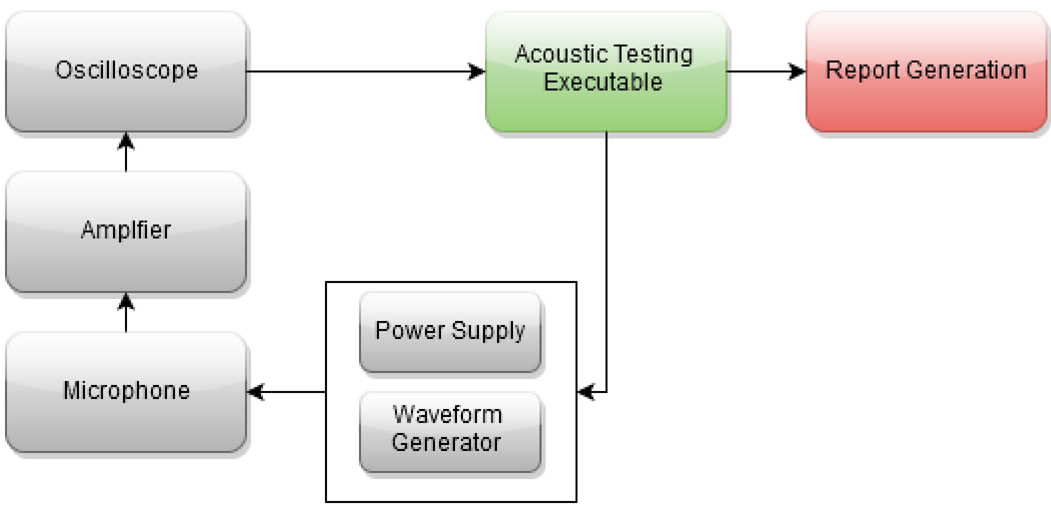


Figure 20. Test Setup Block Diagram

The acoustic data was collected for the existing electronics inside the fan and then after replacing the electronics with the DRV10983 device. Figure 21 shows the pure tone acoustic performance difference between the DRV10983 device and the competitor. Because of the sinusoidal drive and the frequency switching beyond the audible frequency range, the motor spins silently.

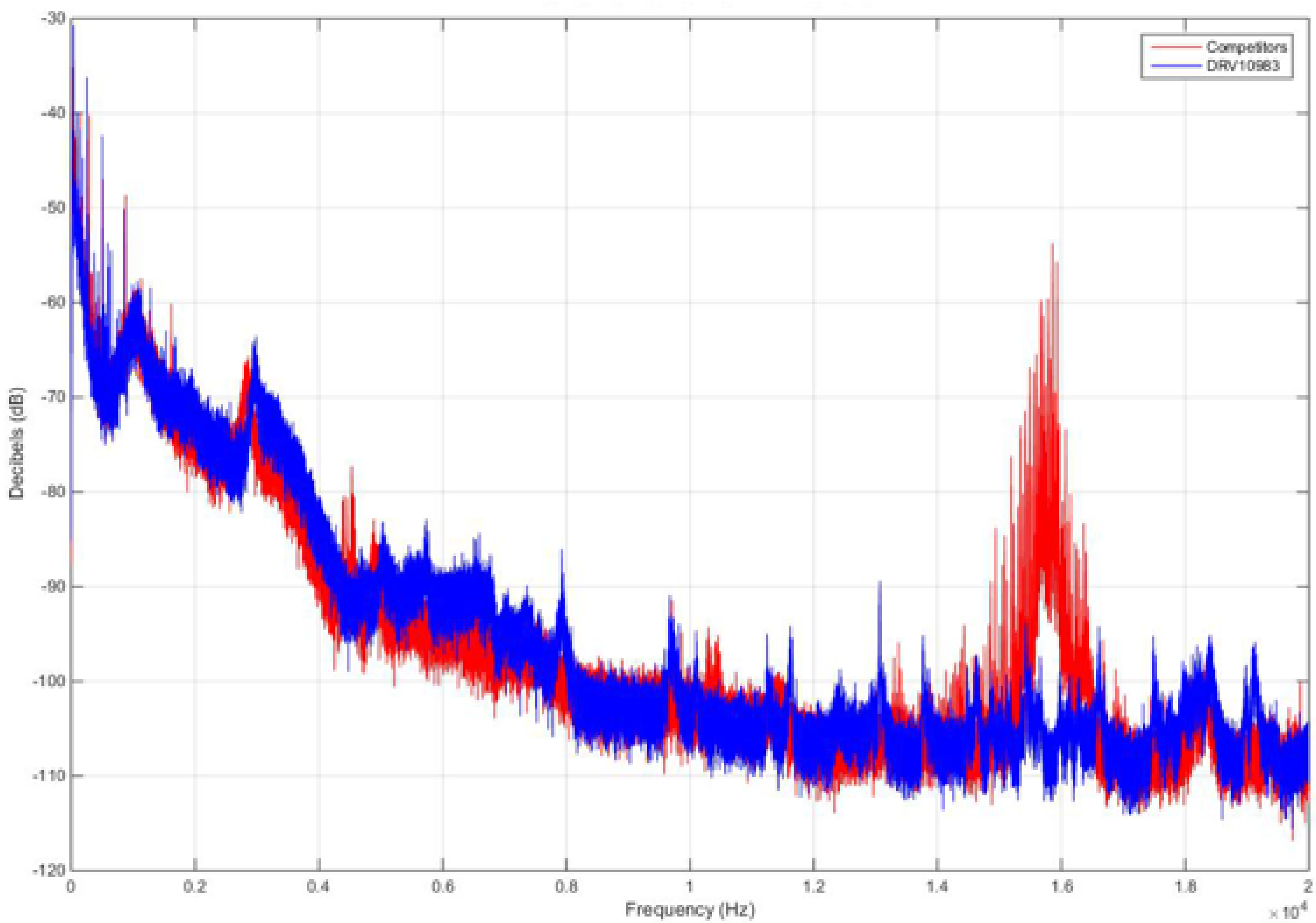


Figure 21. Acoustic Data Comparison

9 Design Files

9.1 Schematics

To download the schematics, see the design files at TIDA-00656.

9.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00656.

9.3 PCB Layout Recommendations

9.3.1 Layout Prints

To download the layout prints, see the design files at TIDA-00656.

9.4 Altium Project

To download the Altium project files, see the design files at TIDA-00656.

9.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00656.

9.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00656.

10 References

1. Texas Instruments, *DRV10983 12- to 24-V, Three-Phase, Sensorless BLDC Motor Driver*, DRV10983 Datasheet (SLVSCP6)
2. Texas Instruments, *MIXED SIGNAL MICROCONTROLLER*, MSP430G2x33 and MSP430G2x03 Datasheet (SLAS734)
3. Texas Instruments, *BLDC Ceiling Fan Controller with Sensor-less Sinusoidal Current Control*, TIDA-00386 Reference Design (TIDU699)

11 Terminology

SPI— Serial peripheral interface

PWM— Pulse width modulation

BLDC— Brushless DC motor

MCU— Microcontroller unit

RISC— Reduced instruction set computing

FET, MOSFET— Metal–oxide–semiconductor field-effect transistor

IGBT— Insulated gate bipolar transistor

ESD— Electrostatic discharge

RPM— Rotation per minute

RMS— Root mean square

12 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.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (October 2015) to A Revision	Page
• Changed listed temperatures to correct values: 1400ºC to 140ºC and 1500ºC to 150ºC	19

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated ('TI") reference designs are solely intended to assist designers ("Designer(s)") who are developing systems that incorporate TI products. TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.

TI's provision of reference designs and any other technical, applications or design advice, quality characterization, reliability data or other information or services does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such reference designs or other items.

TI reserves the right to make corrections, enhancements, improvements and other changes to its reference designs and other items.

Designer understands and agrees that Designer remains responsible for using its independent analysis, evaluation and judgment in designing Designer's systems and products, and has full and exclusive responsibility to assure the safety of its products and compliance of its products (and of all TI products used in or for such Designer's products) with all applicable regulations, laws and other applicable requirements. Designer represents that, with respect to its applications, it has all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. Designer agrees that prior to using or distributing any systems that include TI products, Designer will thoroughly test such systems and the functionality of such TI products as used in such systems. Designer may not use any TI products in life-critical medical equipment unless authorized officers of the parties have executed a special contract specifically governing such use. Life-critical medical equipment is medical equipment where failure of such equipment would cause serious bodily injury or death (e.g., life support, pacemakers, defibrillators, heart pumps, neurostimulators, and implantables). Such equipment includes, without limitation, all medical devices identified by the U.S. Food and Drug Administration as Class III devices and equivalent classifications outside the U.S.

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

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

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

TI's standard terms of sale for semiconductor products (http://www.ti.com/sc/docs/stdterms.htm) apply to the sale of packaged integrated circuit products. Additional terms may apply to the use or sale of other types of TI products and services.

Designer will fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of Designer's non-compliance with the terms and provisions of this Notice.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265