TI Designs
Laptop/Notebook Computer Fan Controller

TI Designs

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Design Resources

TIDA-00578	Design Folder
DRV10963	Product Folder

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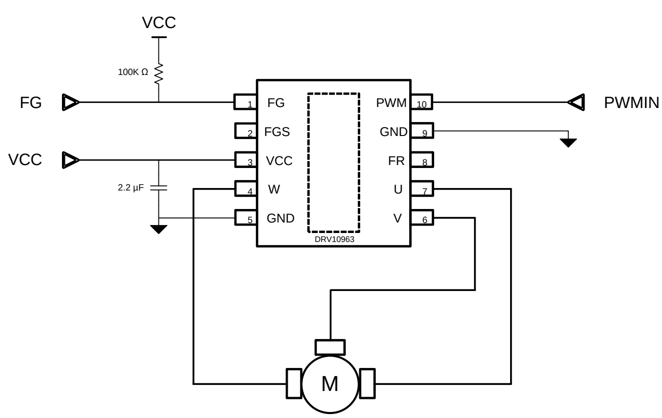
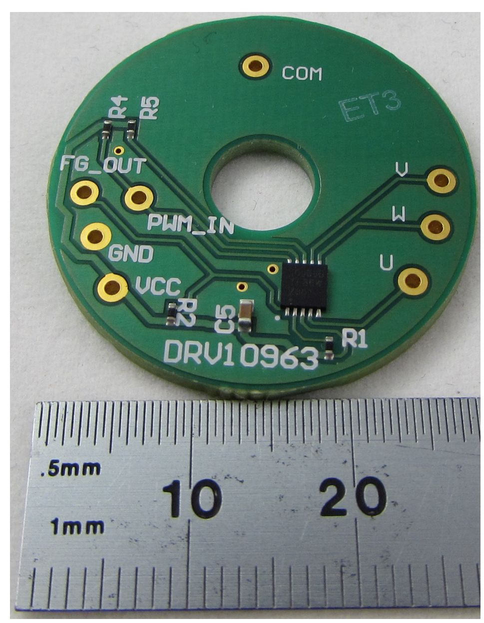
Design Features

- Low Acoustics Noise Controller Ideal for Personal Handhelds and Medical Equipment
- Low Quiescent Current Ideal for DC Battery Operation
- Sensorless 180° Sinusoidal Motor Control
- User Configurable Spin-up Profile to Operate Different Motors Easily
- 3-cm Diameter PCB Design Mates With Small Footprint Fan Enclosure
- No Firmware or Software Needed

Featured Applications

- 5-V Laptop/Notebook Cooling Fan
- 5-V PC Cooling Fans
- USB Fan Applications
- Game Station CPU Fan
- Medical Equipment Requiring Low Acoustics





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

1 Key System Specifications

The DRV10963 is a three-phase sensorless motor driver with internal integrated power MOSFETs. The embedded proprietary sensorless 180-degree sinusoidal commutation scheme demonstrates significant acoustic noise reduction. Compared to alternative solutions, a reduction of 2 dB in the overall sound pressure level (acoustic noise) is revealed with a three-phase 5-V laptop/notebook cooling fan motor with a sinusoidal back-emf (BEMF) profile (with 8-cm diameter blades).

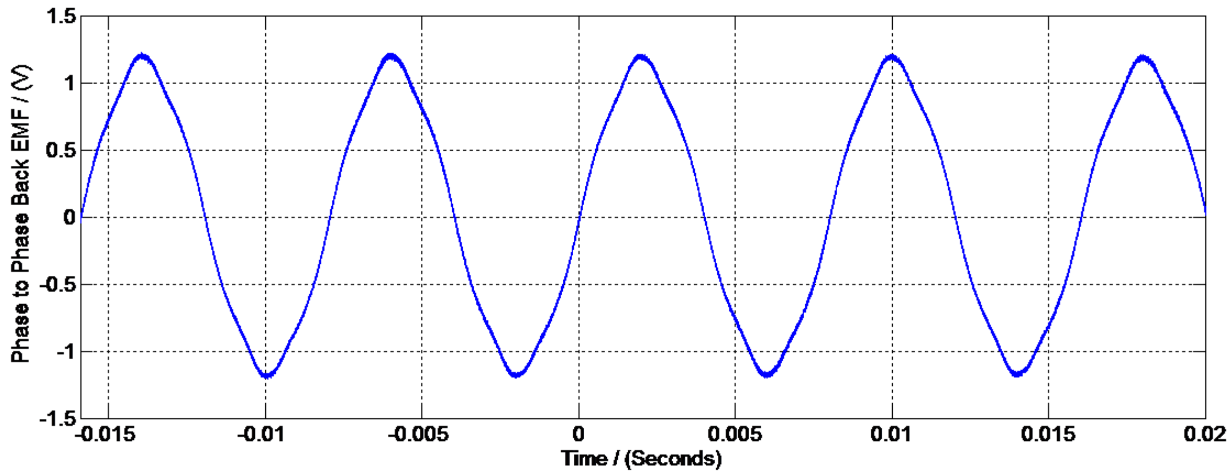


Figure 1. Phase-to-Phase BEMF of the Motor

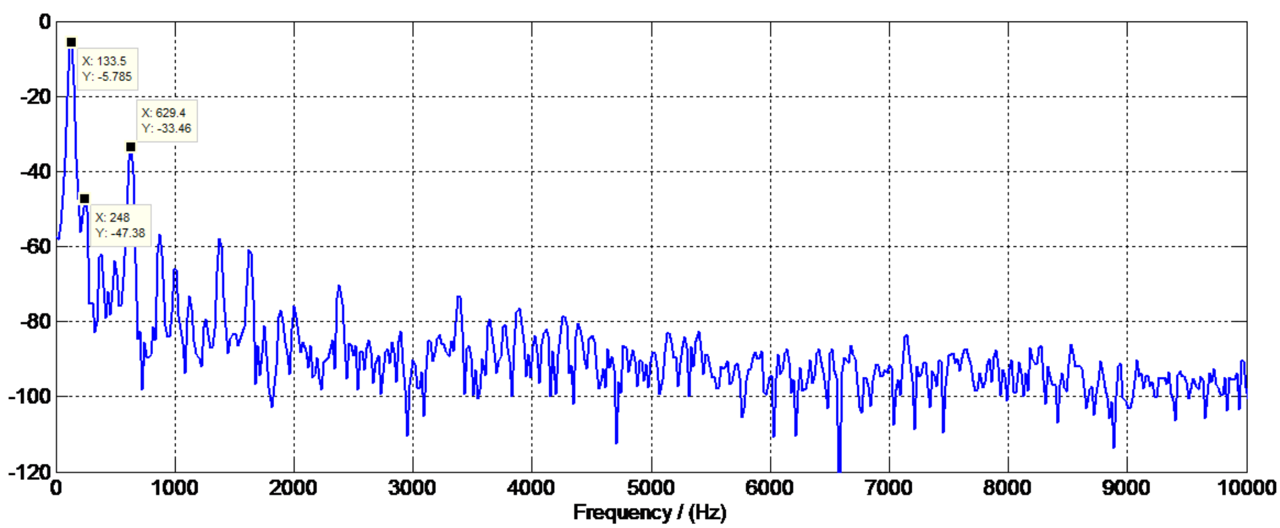


Figure 2. Frequency Content in the Phase-to-Phase BEMF

Figure 2 illustrates the frequency content of the BEMF waveform shown in Figure 1. Both the third and the fifth harmonics are at least 20 dB below the fundamental component. Therefore, the motor BEMF is closer to a sinusoidal profile.

Table 1. Overall Sound Pressure Level Comparison

FREQUENCY	SINUSOIDAL BEMF MOTOR		NON-SINUSOIDAL BEMF MOTOR	
	DRV10963	COMPETITOR	DRV10963	COMPETITOR
50 Hz (1500 RPM)	–15.9 dB	–13.3 dB	–7 dB	–5.9 dB
100 Hz (3000 RPM)	–10.5 dB	–8.4 dB	0.7 dB	1.1 dB

2 System Description

This BLDC motor system implements the DRV10963 and a generic 5-V laptop cooling fan motor. The sinusoidal control scheme is suitable for 5-V fan applications where low noise is desired. The motor voltage support is 2.1 to 5.5 V, and the max current is 500 mA. Motor speed is controlled by the PWM input typically offered by microcontroller. Low quiescent current standby mode is available. The motor drive stage has integrated protection, including short-circuit, shoot-through, undervoltage, over-temperature, and locked rotor detection.

2.1 DRV10963 Internal Functional Blocks

TI"s DRV10963 is desired in applications that demand low-acoustic noise performance and the ability to change direction (forward or reverse) on the fly through the external pin FR. Furthermore, the device gives the user the flexibility to startup at different duty cycle and to control the speed by controlling the duty cycle of the PWM signal through the external pin PWM. The output of the FG signal monitors the electrical cycles of the motor speed.

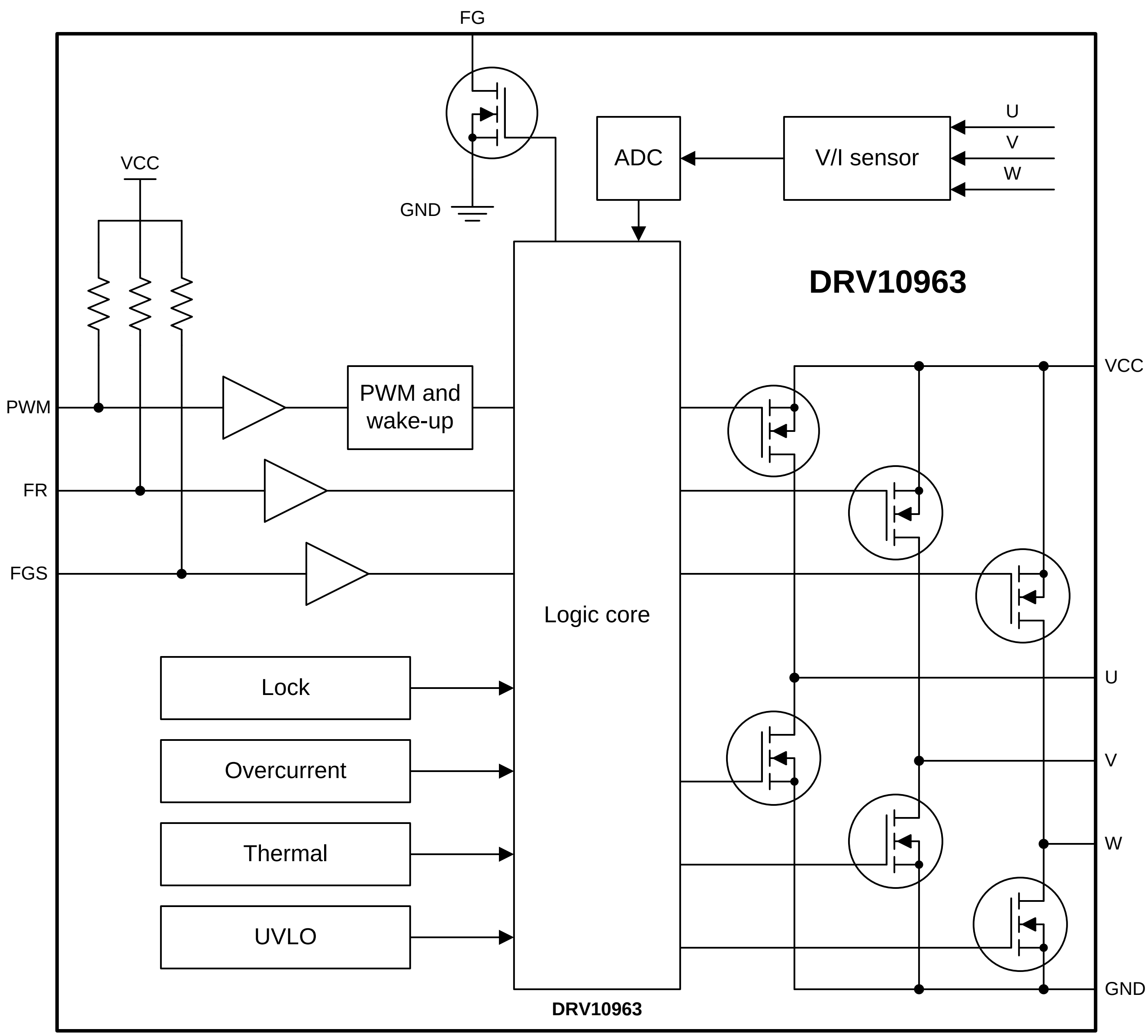


Figure 3. DRV10963 Internal Functional Blocks

3 Application Block Diagram

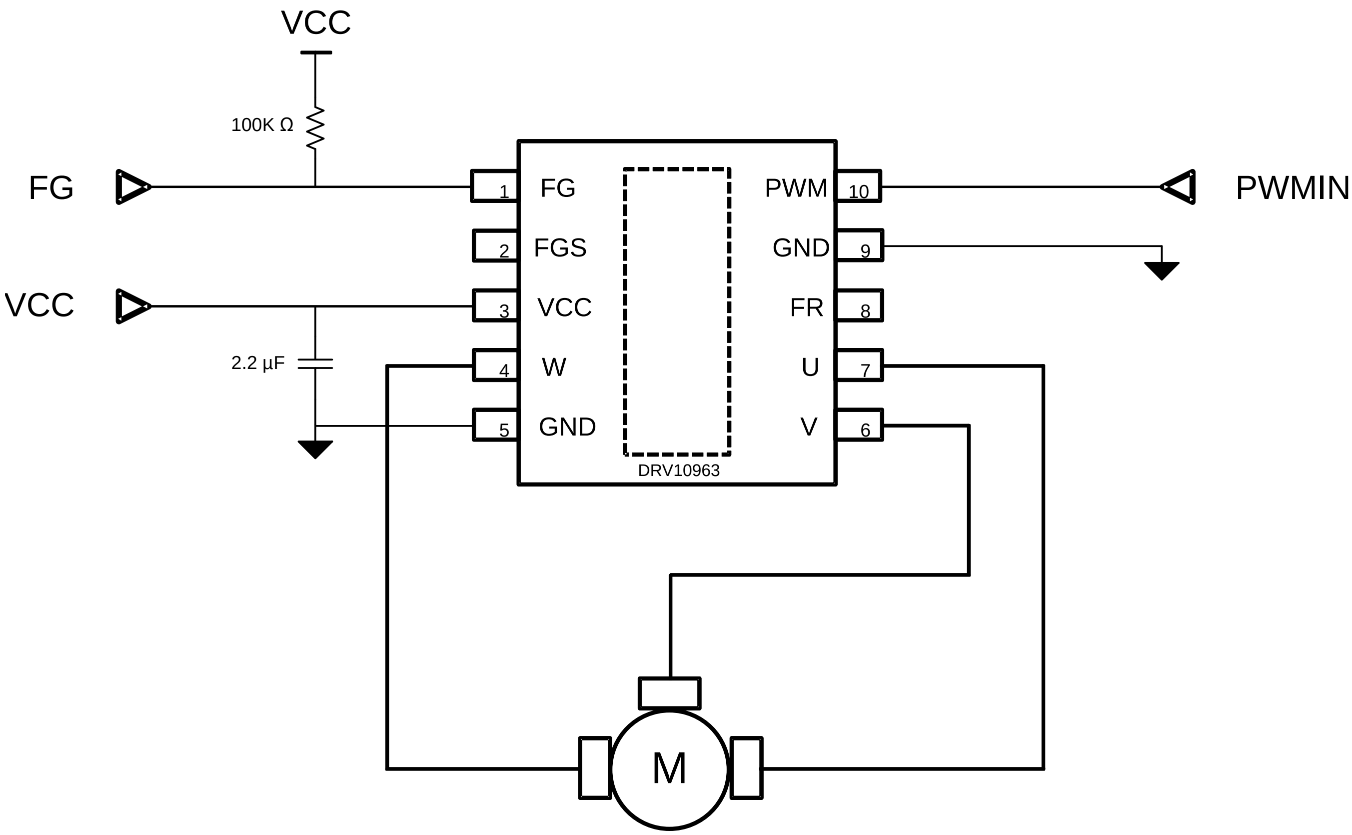


Figure 4. Application Block Diagram With External Components

4 System Design Theory

The core logic of the DRV10963 embedded into the hardware will spin a 3-PH motor (5-V laptop/notebook cooling fan) in the direction indicated by the FR input pin. In the reference design, the FR pin is pulled high. The speed is determined by the duty cycle of the PWM pin (15 to 100 KHz). Internally, the output of the phases will toggle around 25 KHz; this is outside of the human audible hearing range.

4.1 Lock Detection Block

The hardwired algorithm will detect a stall automatically when the motor is running or in a stationary position. When the stall is detected, the DRV10963 will stop driving the motor for five seconds as per specification parameter T_{OFF_LOCK}. After this time, the DRV10963 will automatically issue a restart. Lock detection works across the entire range of VCC in the specification.

5 Getting Started Hardware

The reference design hardware does not require any external software or firmware to operate. The reference design does require the following:

- Obtain a 5-V fan; Practice safe operation for fan and blades.
- Obtain a 2- to 6-V power supply (PS) with 1-A current clamp (max).

1. First, connect the GND of the EVM to GND of the power supply (or battery).
2. Connect the U/V/W terminal of the motor to the U/V/W of the EVM.
3. Adjust the power supply to 5 V and the current clamp to 500 mA
4. Connect VCC to the power supply.

Upon completing these steps, the motor starts to spin.

On the EVM, the PWM input is pulled high. Therefore, the motor is going to speed up to ~ 95% duty cycle. If an input duty cycle is needed, the PWM pin needs to be connected to a pulse generator (AWG) with an ability to continuously drive at 40 KHz from 0 to 5 V.

The FG pin (hooked) to a scope will output the speed in electrical cycles of the motor.

6 Test Setup and Acoustics Equipment

- DRV10963 reference EVM
- Four pole, three-phase with sine-BEMF motor
- LeCroy scope
- Acoustic chamber model: FAV 03
- Acoustic sensor: RION NH-17A
- Sound system display unit: UV-12A
- Sound level meter: UN-04A
- Sampling frequency: 200 kHz
- Motor poles: 4

Figure 5. Lecroy Scope Model

7 Test Data

7.1 Motor Performance and Acoustic Characteristics

The DRV10963 is tested with a sine BEMF motor and a non-sine BEMF motor. The acoustics data is compared with the retail available 5-V laptop/notebook fan with a blade diameter of 8 cm and revolves at 50 Hz and 100 Hz.

The device's spin parameters, align time (ms), acceleration (Hz/s), and threshold (Hz), were optimized per the device datasheet to obtain the startup profile. Refer to the *DRV01963 Evaluation Module User's Guide* (SLAU643) and measure the motor parameters to optimize the spin the parameters. The guide takes the user step by step through alignment, start-up operation, close-loop operation, lock detection, and current control for the desired motor to work in conjunction with the reference PCB.

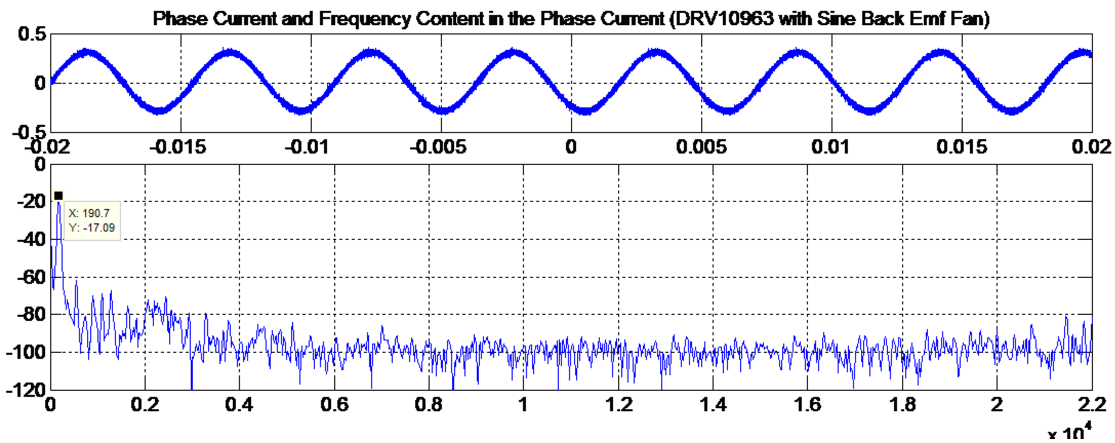


Figure 6. Drive Currents of TI-DRV10963 With Sinusoidal BEMF Motor (190-Hz Electrical Frequency = 5700 RPM)

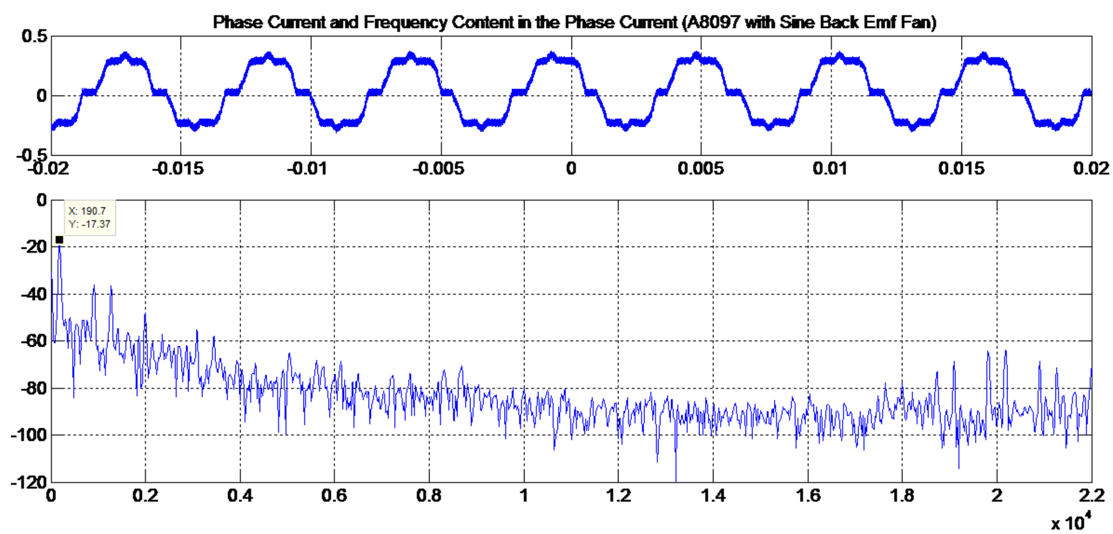


Figure 7. Drive Currents of Competitor Device With Sinusoidal BEMF Motor (190-Hz Electrical Frequency = 5700 RPM)

The human audible hearing range is 20 Hz to 20 KHz. Cooling fans inside of laptops, notebooks, and ultra-thin notebooks during operation can emit acoustic noise threshold levels that can cause discomfort to the user. This section details the data that differentiates the DRV10963 from the competition to provide significant reduction in the acoustic noise level when driving notebook cooling fan motors. The acoustic noise is a critical system level care-about for the OEMs.

The acoustic profiles in the following figures present the acoustic frequency verses noise (dB) content of a 5-V notebook cooling fan when driven by the DRV10963 and a competitor's part. A significant improvement in the acoustic profile is noticeable with the DRV10963 across the overall spectrum. In addition to the overall sound pressure reduction, the DRV10963 demonstrates a reduction as much as 15 dB at certain frequencies. At high motor speeds, the overall air flow noise dominates increasing the low frequency signal magnitudes.

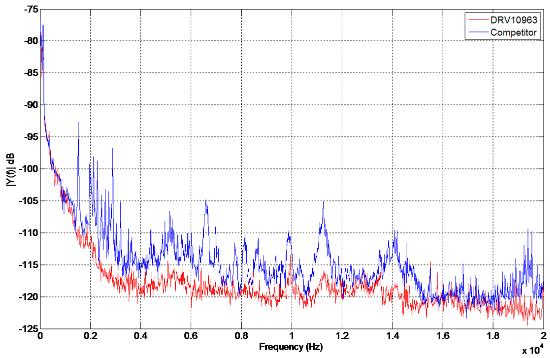


Figure 8. Acoustic Comparison With Sinusoidal BEMF Motor at 50 Hz (1500 RPM)

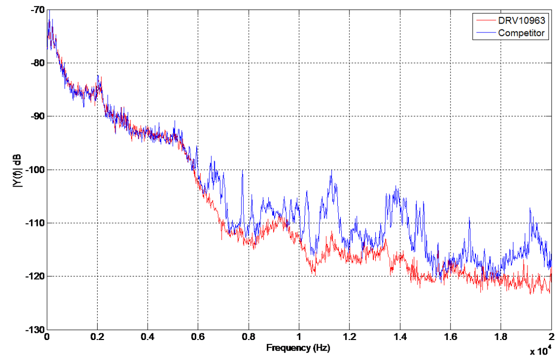


Figure 9. Acoustic Comparison With Sinusoidal BEMF Motor at 100 Hz (3000 RPM)

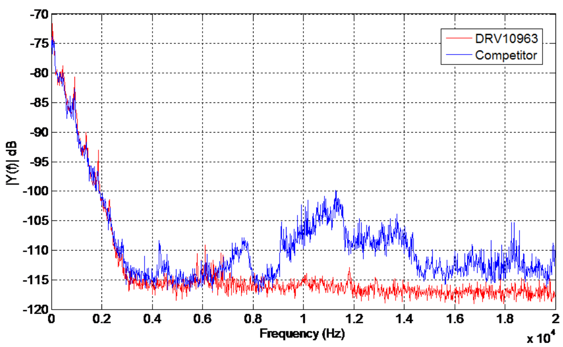


Figure 10. Acoustic Comparison With Non-Sinusoidal BEMF Motor at 50 Hz (1500 RPM)

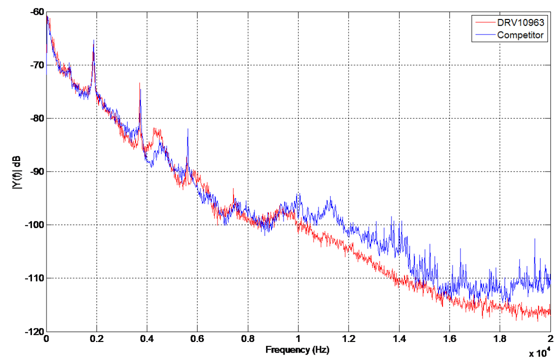


Figure 11. Acoustic Comparison With Non-Sinusoidal BEMF Motor at 100 Hz (3000 RPM)

Operational Description

After startup, the DRV01963 will spin motor in the direction commanded by the FR input signal. In the reference design, FR is pulled high, thus the motor's phase sequence will follow the sequence of Phase U → Phase V → Phase W.

The motor speed is controlled by adjusting the duty cycle of the PWMIN pin. The duty cycle is selected to be greater than 10% to avoid the device from entering the standby mode. In standby mode the device stops driving. If the PWMIN pin is not driven external, the pin would be pulled high and thus commanding the speed control at 98% duty cycle.

The FG (FGOUT) pin is used an indicator of the speed of the motor, as in frequency of the motor commutation.

The 180-degree sensorless control scheme continuously measures the motor phase current and voltage for BEMF estimation to minimize torque ripple and thus ultra-quiet commutation of the motor.

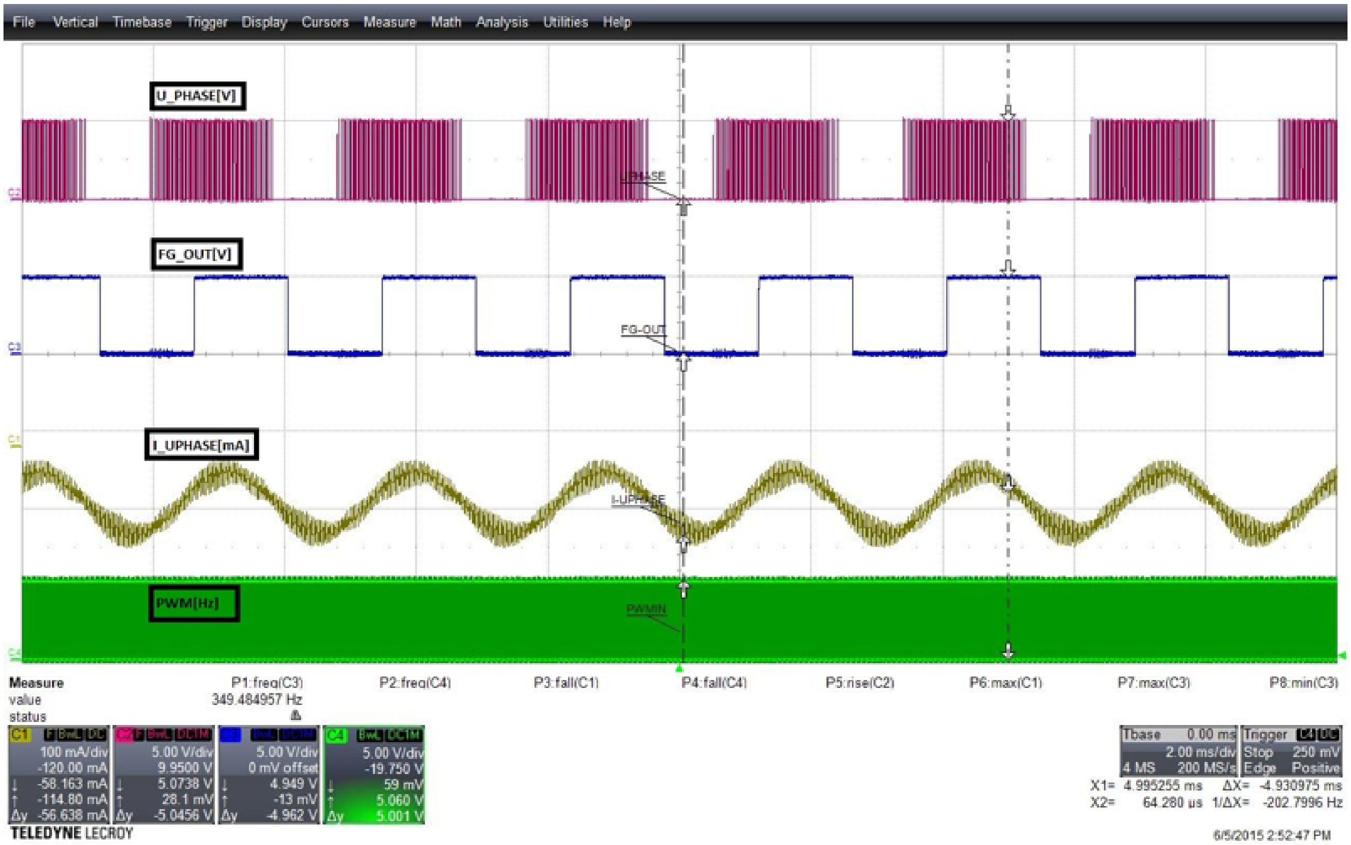


Figure 12. Reference PCB Sinusoidal Current Profile

Referring to Figure 12, FG_OUT indicates the electrical speed of the motor. For the 4-pole, 3-PH motor, the mechanical speed translates to [349.48 × 60] / 2] = 10.5K RPM.

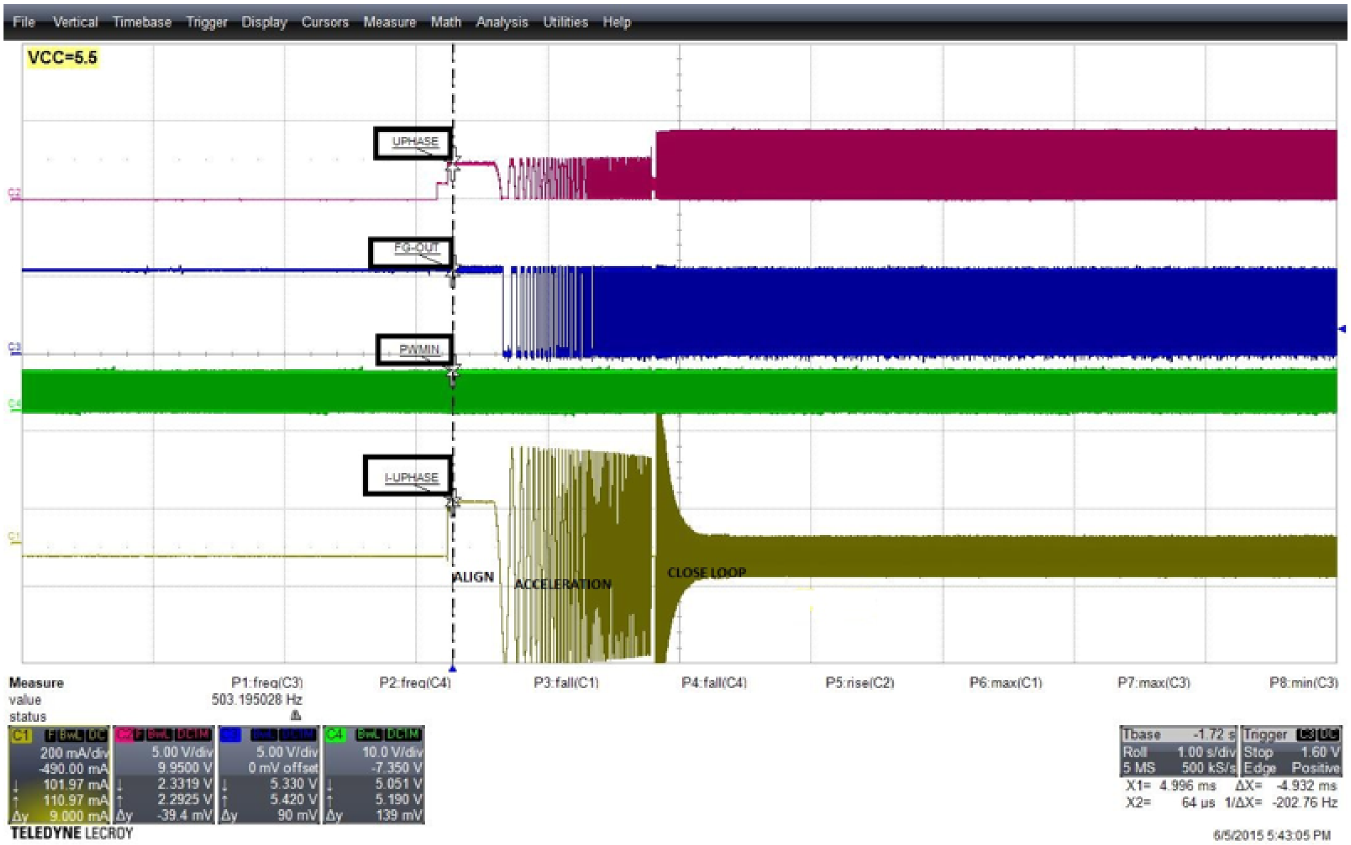


Figure 13. Reference PCB Start-up (Align Acceleration) Profile

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NOTE: FG_OUT signal being held HIGH during locked rotor condition (stall).

The motor start profiles are inclusive of open loop to close loop transition threshold, align time, acceleration rate, and can be tweaked using the *DRV01963 Evaluation Module User's Guide* (SLAU643).

7.2 Motor Operations in Open and Close Loop

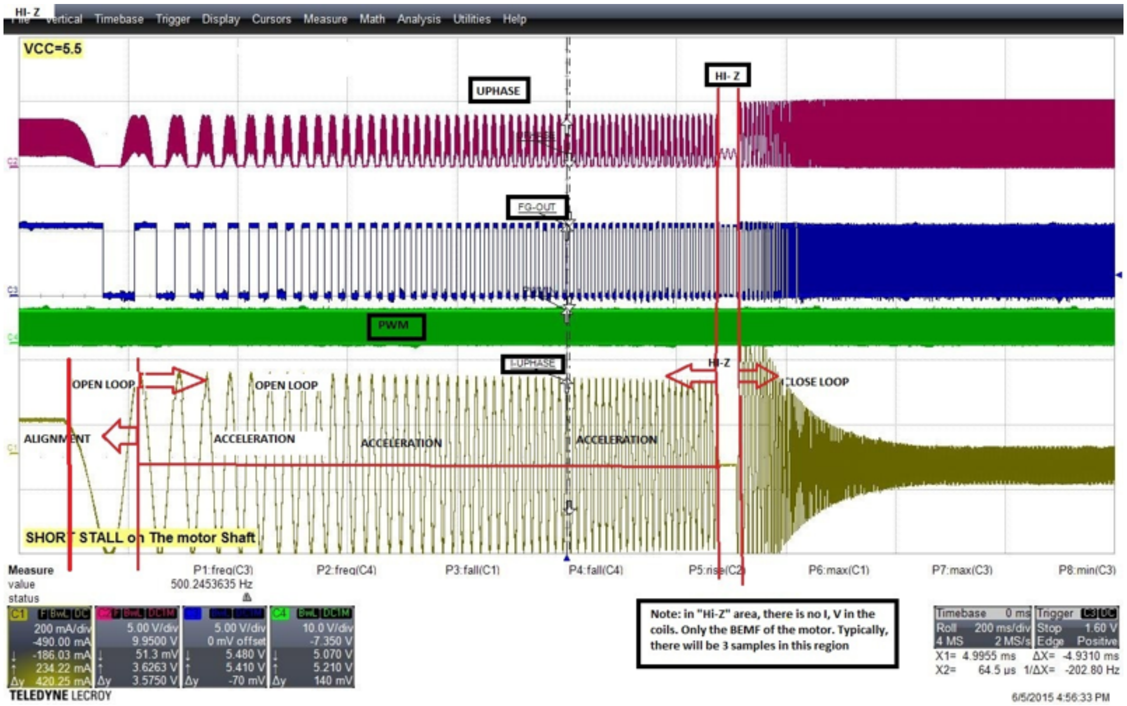


Figure 14. Reference PCB Open Loop and Close Loop

In Hi-Z (region) the motor is coasting with its inertia. In the Hi-Z area, there is no current or voltage in the coils. The BEMF is measured through the ADC. Typically, there are three to four cycle of commutation in this region.

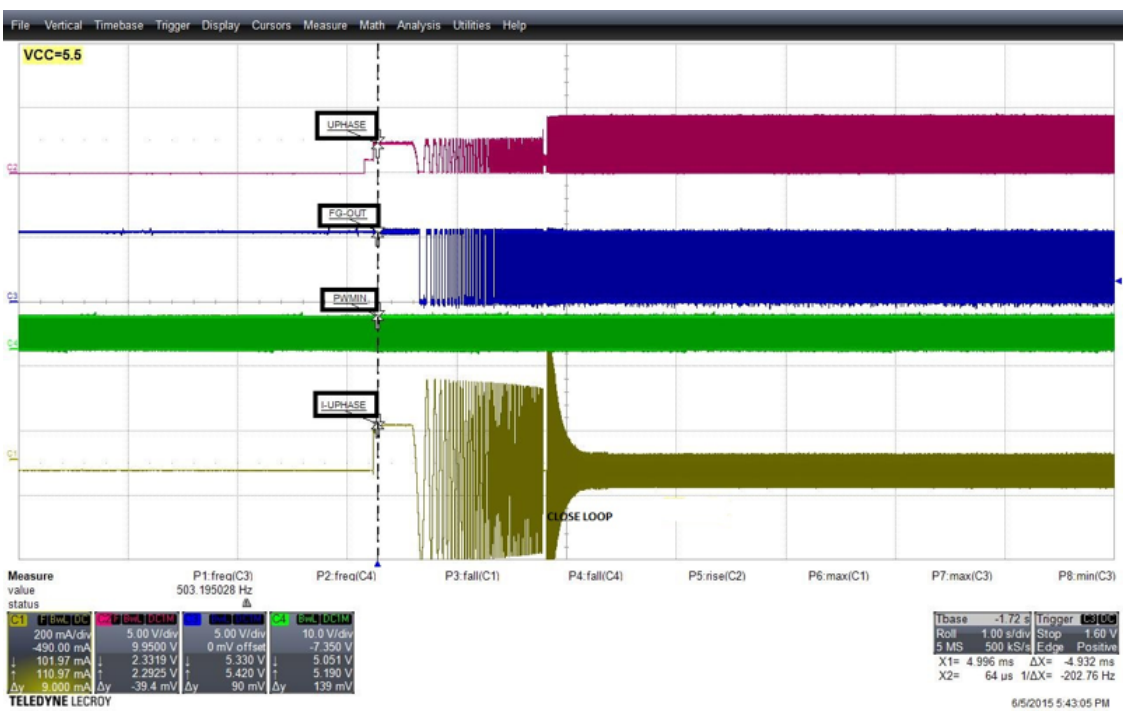


Figure 15. Reference PCB Close Loop

7.3 Lock Protection

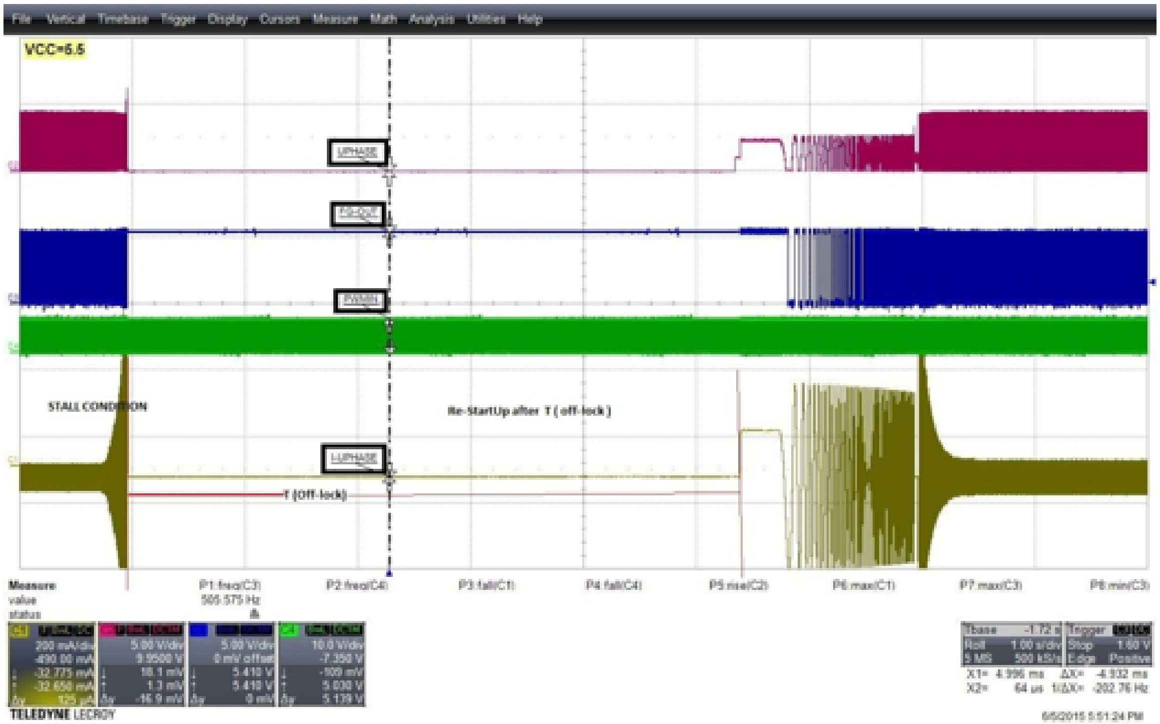


Figure 16. Automatic Restart After Stall Recovery

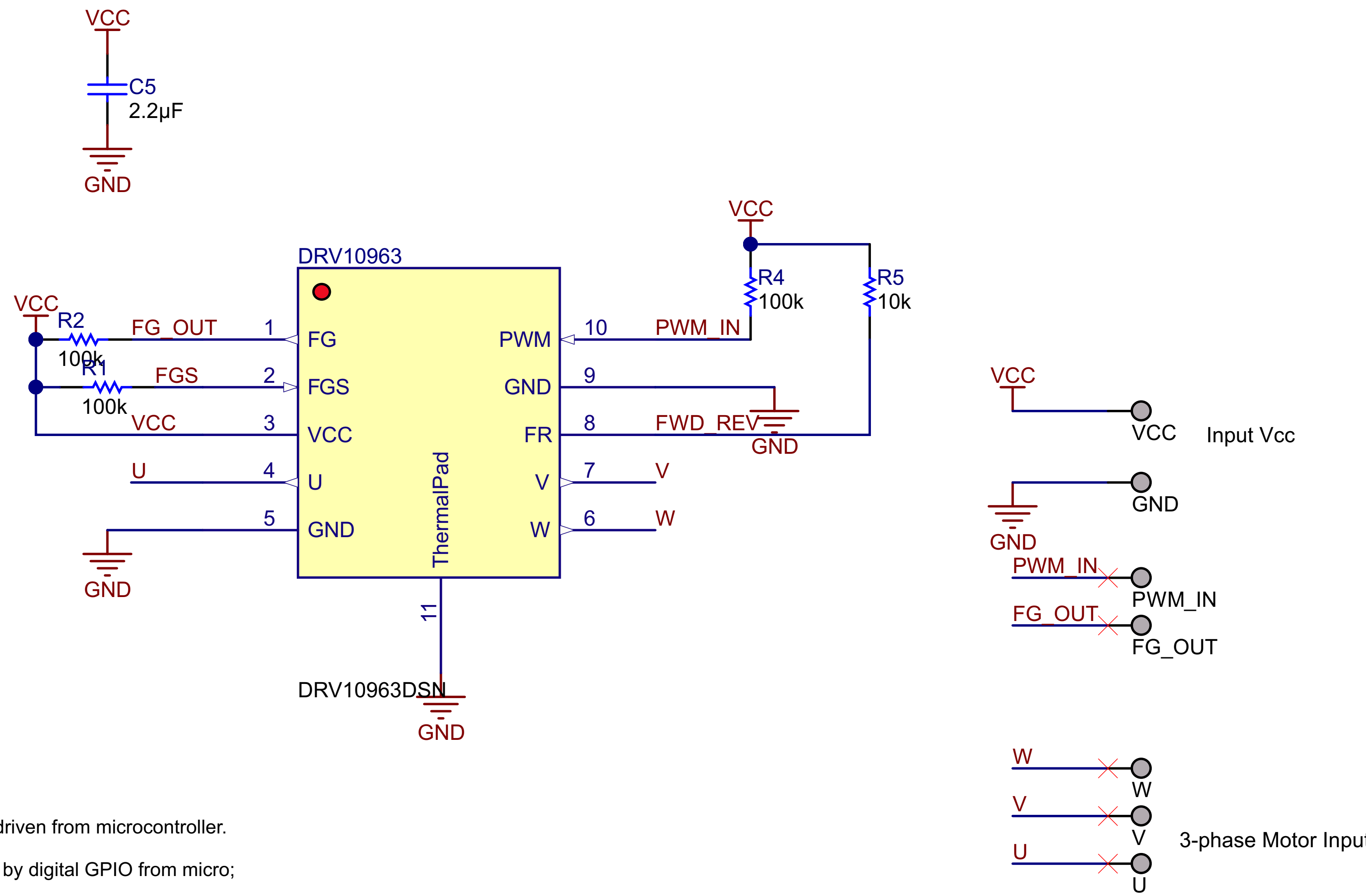
When the motor is stopped or stalled momentarily by an external force, the built-in Lock protection is automatically initiated and the DRV10963 stops driving the motor. After the $T_{OFF\text{-}LOCK}$, the device, resumes driving the motor. The device can detect the stall condition within $T_{ON\text{-}LOCK}$.

During the motor stall condition, the FG_OUT remains high.

8 Design Files

8.1 Schematics

To download the schematics, see the design files at TIDA-00578.



PWM _INsignal assumed to driven from microcontroller.

FWD_REV function to driven by digital GPIO from micro;

FGS function to driven by digital GPIO from micro.

Figure 17. Schematic for the DRV10963 5-V Laptop/Notebook Cooling Fan

8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00578.

Table 2. TIDA-00578 BOM

ITEM	DESIGNATOR	QTY	VALUE	PARTNUMBER	MANUFACTURER	DESCRIPTION	PACKAGE REFERENCE
1	!PCB	1		TIDA-00578	Any	Printed Circuit Board	
2	C5	1	2.2uF	C0603C225K8PACTU	Kemet	CAP, CERM, 2.2uF, 10V, +/-10%, X5R, 0603	0603
3	DRV10963	1		DRV10963DSN	Texas Instruments		OFN
4	FID1, FID2, FID3	3		N/A	N/A	Fiducial mark. There is nothing to buy or mount.	Fiducial
5	R1, R2	2	100k	CRCW0402100KJNED	Vishay-Dale	RES, 100k ohm, 5%, 0.063W, 0402	0402
6	R4	1	100k	ERJ-2GE0R00X	Panasonic	RES, 0 ohm, 5%, 0.063W, 0402	0402
7	R5	1	10k	CRCW040210K0JNED	Vishay-Dale	RES, 10k ohm, 5%, 0.063W, 0402	0402

8.3 PCB Layout Recommendations

The cut-out in the PCB is needed for motor or PCB attachment. The size of the cut depends on the motor design and attachment. The center tap (COM terminal) is not used for the motor operation. The device Thermal PowerPad and GND are connected to make a least impedance path and connected through thermal vias on the two-layer board. It is good practice to allow extra placement room for decoupling capacitors close to the bulk capacitor in situations where the VCC ripple needs to be minimized per application needs.

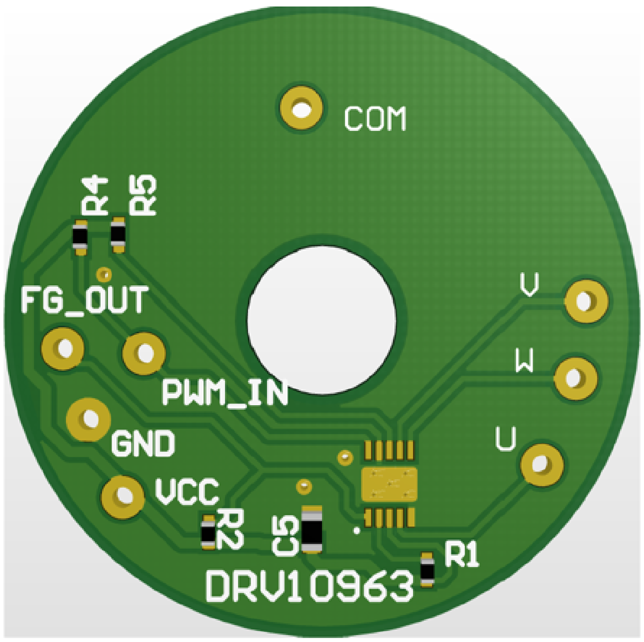


Figure 18. 3D View of Top Layer

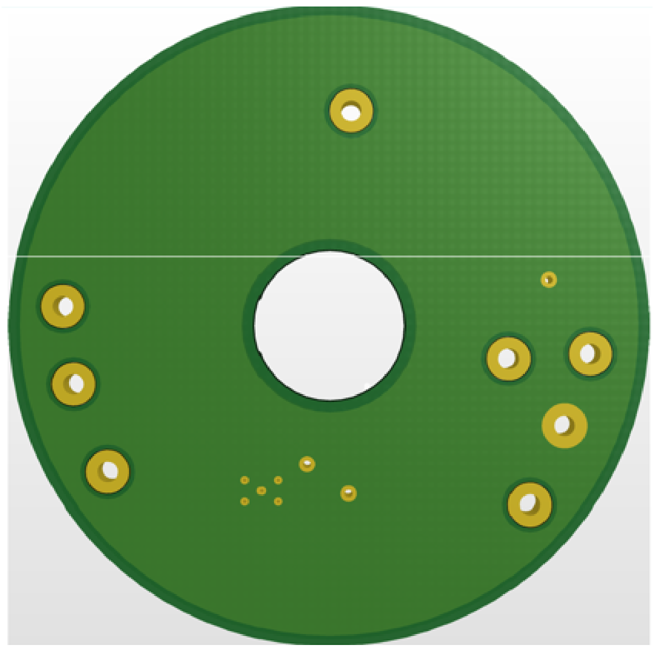


Figure 19. 3D View of Bottom Layer (Without Texas Instruments Logo)

8.3.1 Layer Plots

To download the layer plots, see the design files at TIDA-00578.

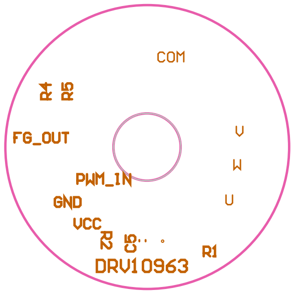


Figure 20. Top Silkscreen

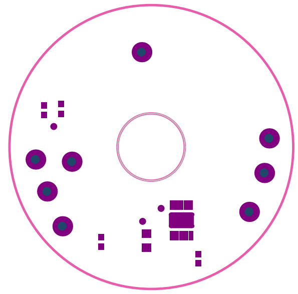


Figure 21. Top Solder Mask

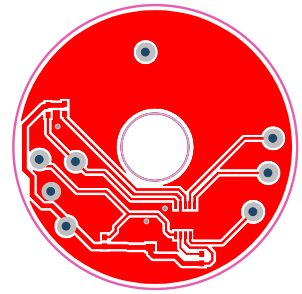


Figure 22. Top Layer

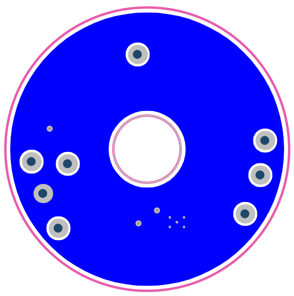


Figure 23. Bottom Layer

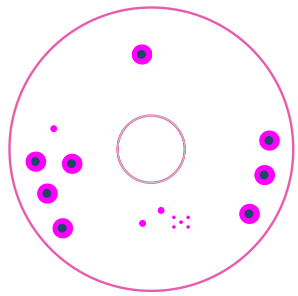


Figure 24. Bottom Solder Mask

Figure 25. Bottom Silkscreen

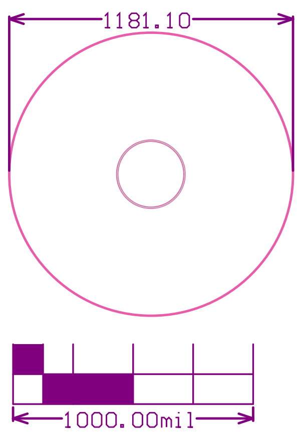


Figure 26. Board Dimensions

Symbol	Quantity	Finished Hole Size	Plated	Hole Type
○	5	5.91mil (0.150mm)	PTH	Round
▽	3	14.00mil (0.356mm)	PTH	Round
✧	7	37.99mil (0.965mm)	PTH	Round
✙	1	38.00mil (0.965mm)	PTH	Round
	16 Total			

Figure 27. Drill Drawing

8.4 Altium Project

To download the Altium project files, see the design files at TIDA-00578.

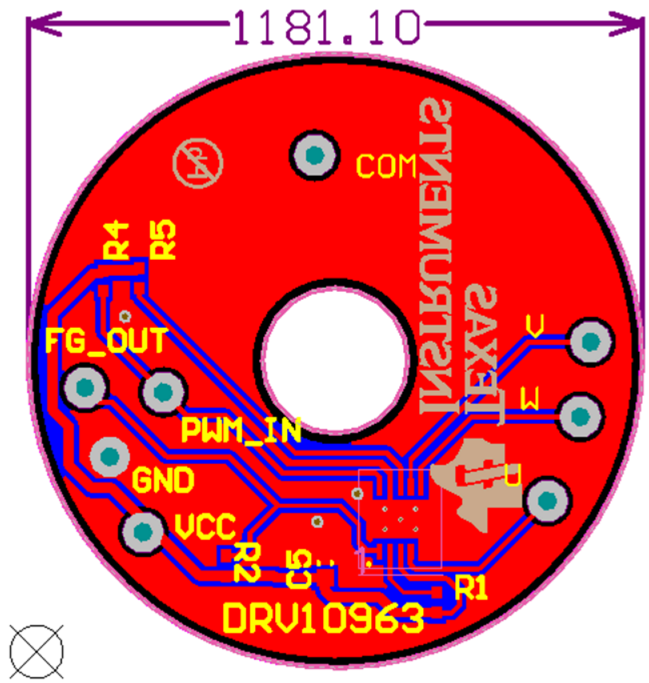


Figure 28. Top and Bottom Layer Full View

8.5 Layout Guidelines

- Consider connecting VCC, GND, U, V, and W pins with the 10 to 14-mil trace widths due to the high current passing through the traces.
- Place the 2.2-µF capacitor between VCC and GND and in proximity to the VCC/GND loop.
- Connect GND and thermal pad using a cooper pour. It is good practice for the GND to be as large as possible without any islands or gaps.

8.6 Gerber Files

To download the Gerber files, see the design files at TIDA-00578.

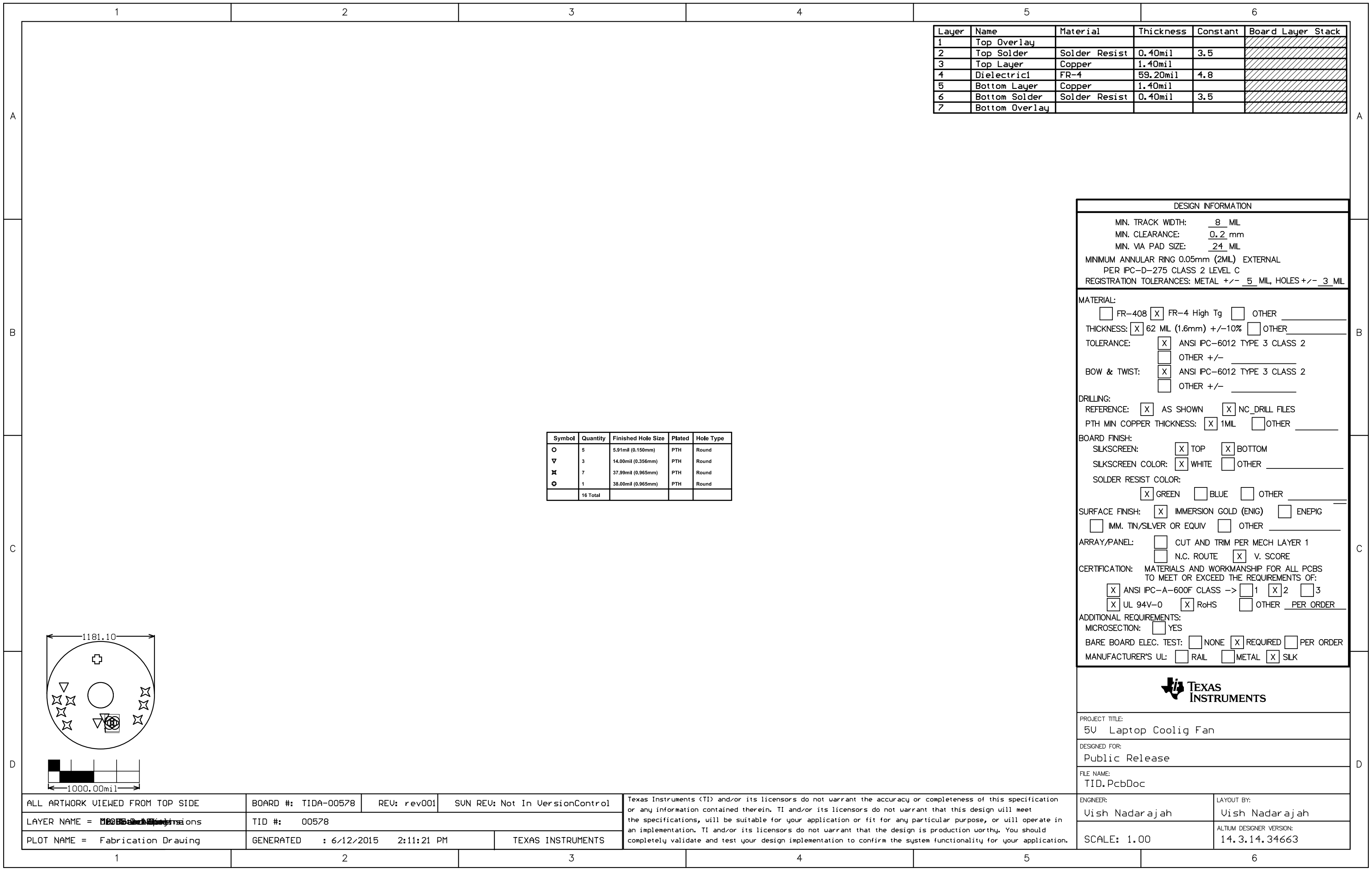


Figure 29. Fabrication Drawing

8.7 *Assembly Drawings*

To download the assembly drawings, see the design files at TIDA-00578.

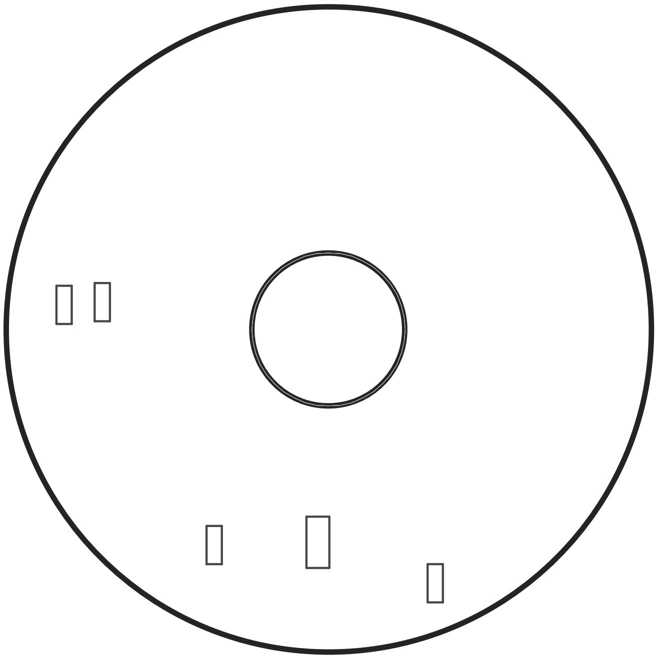


Figure 30. Top Assembly Drawing

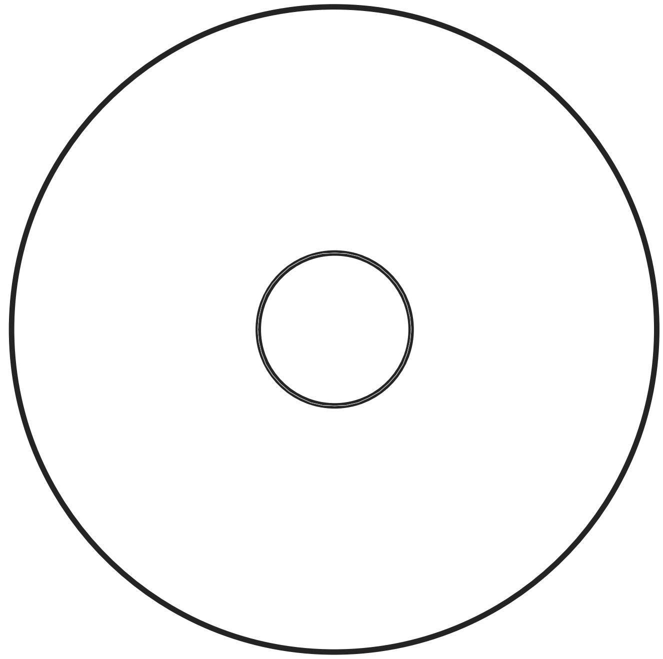


Figure 31. Bottom Assembly Drawing

9 References

1. Texas Instruments, *DRV10963 Evaluation Module User's Guide* (SLAU643)

10 About the Author

VISH NADARAJAH is an Application Engineer at Texas Instruments, Motor Driver Business unit where he is responsible for developing reference design solutions for the industrial segment. Vish brings to this role his experience in high-speed digital/analog, low-noise analog, and microwave system-level design expertise. Vish earned his master of science in electrical engineering (MSEE) from University of Texas at Arlington, TX.

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