TI Designs Electric Toothbrush Controller Reference Design



TI Designs

This TI Design uses Texas Instruments' low-voltage H-Bridge motor driver with an integrated LDO voltage regulator and an ultra-low-power microcontroller (MCU) to demonstrate a full implementation of a battery powered electric toothbrush.

Design Resources

TIDA-00602	Design Folder
DRV8850	Product Folder
MSP430G2210	Product Folder
SN74LVC1G14	Product Folder
SN74LVC1G80	Product Folder
DRV8850EVM	Tools Folder



Block Diagram



Design Features

- Battery voltage ranging from 2 to 5.5 V
- Delivers 5 A continuous and 8 A peak-drive current
- Small PCB form factor of 43.2 x 14.6 mm
- Low component count to reduce cost
- Less than 50 nA Battery Leakage Current
 When Off

Featured Applications

- Electric Toothbrush
- Electric Shaver
- Battery Powered DC Motor Driver
- Personal Care Devices

Board Image



1 Key System Specifications

PARAMETER	DESCRIPTION	SPECIFICATION	
Input voltage	Can operate from most 2 to 5.5 V battery supplies	2.0 to 5.5 V	
Off-state leakage current	Typical system leakage current when switched off	30 nA	
Maximum continuous current		5 A	
Maximum peak output current		8 A	
Maximum observed PCB	Using a magnetic vibration motor	38 °C	
temperature	Using a brushed DC motor	29.8 °C	
Vibration motor	Motor coil inductance and resistance	560 μH	0.4 Ω
DC motor	Motor coil inductance and resistance	1.78 mH	4.5 Ω

2 System Description

The TIDA-00602 functions as a control circuit and amplifier to an electric toothbrush motor. The design features an ultra-low-power microcontroller unit (MCU) for generating the appropriate waveforms to the H-Bridge motor driver. The motor driver amplifies the signal that is coming from the MCU and drives either a brushed DC motor or a magnetic vibration motor.

The following sub-sections describe the various blocks within the TI Design system and what characteristics are most critical to best implement the corresponding function.

2.1 DRV8850 H-Bridge Motor Driver

The DRV8850 is used for its ability to drive high current loads while operating at a low voltage. The low minimum input voltage of 2V makes the DRV8850 perfect for battery powered applications. The integrated LDO reduces the board footprint, allowing for a more compact and economical solution. In this design, it is used to supply power to the MCU and on-board status LED.

2.2 MSP430G2210 MCU

The DRV8850 motor driver allows for independent control of each high-side and low-side of the H-Bridge. This was implemented by utilizing four General Purpose Input/output (GPIO) pins from the MCU to control both high-side and low-side FETS of the DRV8850. To minimize power consumption, the MCU stays in a low power sleep mode and only wakes up to change the output drive direction of the DRV8850. In addition, the MCU is operating at the minimum clock frequency of 1MHz to conserve power.



3 Block Diagram



Figure 1: Typical System Block Diagram

3.1 Highlighted Products

The Electric Toothbrush Reference Design features the following devices:

- <u>DRV8850</u>: Low-Voltage, High Current, H-Bridge Motor Driver with LDO Voltage Regulator
- <u>MSP430G2210</u>: 8-pin, 16-MHz Ultra-Low-Power Microcontroller
- <u>SN74LVC1G14</u>: Single Schmitt-Trigger Inverter
- <u>SN74LVC1G80</u>: Single Positive-Edge-Triggered D-Type Flip-Flop

For more information on each of these devices, see their respective product folders at <u>www.ti.com</u>.

3.1.1 DRV8850 H-Bridge Motor Driver

The DRV8850 device provides a motor driver plus LDO voltage regulator solution for consumer products, toys, and other low-voltage or battery-powered motion-control applications. The device has one H-bridge driver to drive a DC motor, a voice-coil actuator, one winding of a stepper motor, a solenoid, or other devices. The output driver block consists of N-channel power MOSFETs configured as an H-bridge to drive the load. An internal charge pump generates the needed gate-drive voltages. The DRV8850 device supplies up to 5 A of continuous output current (with proper PCB heat sinking) and up to 8-A peak current. It operates on a supply voltage from 2.0 to 5.5 V.

A LDO voltage regulator is integrated within the motor driver to supply power to a microcontroller or other circuits. It can be active in device sleep mode, so that the driver may be shut down without removing power to any devices powered by it.

Internal shutdown functions provide overcurrent, short-circuit, undervoltage, overvoltage, and overtemperature protection. In addition, the device also has built-in current sensing for accurate current measurement.





Figure 2: DRV8850 Functional Block Diagram

Features:

- H-Bridge Motor Driver
 - \circ $\;$ Drives a DC Motor, One Winding of a Stepper Motor, or Other Loads
 - \circ $\;$ Low MOSFET On-Resistance: 45 m Ω per FET
- 5-A Continuous 8-A Peak-Drive Current
- Internal Current Sensing With Current Sense Output
- 2 to 5.5-V Operating Supply Voltage Range
- Overvoltage and Undervoltage Lockout
- Low-Power Sleep Mode
- 100-mA Isolated Low-Dropout (LDO) Voltage Regulator
- 24-Pin QFN Package
- 24-Pin HTSSOP Package

3.1.2 MSP430G2210 MCU

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 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 μ s.

The MSP430G22x0 series is an ultra-low-power mixed signal microcontroller with a built-in 16-bit timer and four I/O pins. In addition, the MSP430G2230 has a built-in communication capability using synchronous protocols (SPI or I2C) and a 10-bit A/D converter. The MSP430G2210 has a versatile analog comparator.



Figure 3: MSP430G22x0 Functional Block Diagram

Features:

- Low Supply Voltage Range: 1.8 V to 3.6 V
 - Ultra-Low Power Consumption
 - \circ ~ Active Mode: 220 μA at 1 MHz, 2.2 V ~
 - \circ Standby Mode: 0.5 μ A
 - \circ Off Mode (RAM Retention): 0.1 μA
- Five Power-Saving Modes
- Ultra-Fast Wake-Up From Standby Mode in Less Than 1 μs
- 16-Bit RISC Architecture, 62.5-ns Instruction Cycle Time
- Basic Clock Module Configurations
 - \circ Internal Frequencies up to 16 MHz With Four Calibrated Frequencies to ±1%
 - Internal Very-Low-Power Low-Frequency Oscillator
- 16-Bit Timer_A With Two Capture/Compare Registers
- On-Chip Comparator for Analog Signal Compare Function or Slope Analog-to-Digital (A/D) Conversion (MSP430G2210 Only)
- 10-Bit 200-ksps Analog-to-Digital (A/D) Converter With Internal Reference, Sample-and-Hold, and Autoscan (MSP430G2230 Only)
- Universal Serial Interface (USI) Supports SPI and I2C (MSP430G2230 Only)
- Brownout Detector
- Serial Onboard Programming, No External Programming Voltage Needed, Programmable Code Protection by Security Fuse
- On-Chip Emulation Logic With Spy-Bi-Wire Interface
- Family Members:



- MSP430G22x0: 2KB + 256B Flash Memory, 128B RAM
- Available in 8-Pin Plastic Packages (D)
- For Complete Module Descriptions, See the MSP430x2xx Family User's Guide (SLAU144)

3.1.3 SN74LVC1G14 Inverter

This single Schmitt-trigger inverter is designed for 1.65-V to 5.5-V V_{CC} operation.

The SN74LVC1G14 device contains one inverter and performs the Boolean function Y = A. The device functions as an independent inverter, but because of Schmitt action, it may have different input threshold levels for positive-going (V_{T+}) and negative-going (V_{T-}) signals.

NanoFree[™] package technology is a major breakthrough in IC packaging concepts, using the die as the package.

This device is fully specified for partial-power-down applications using I_{off}. The I_{off} circuitry disables the outputs, preventing damaging current backflow through the device when it is powered down.

Features:

- Available in the Texas Instruments' NanoFree Package
- Supports 5-V VCC Operation
- Inputs Accept Voltages to 5.5 V
- Max t_{pd} of 4.6 ns at 3.3 V
- Low Power Consumption, 10-µA Max ICC
- ±24-mA Output Drive at 3.3 V
- I_{off} Supports Partial-Power-Down Mode Operation
- Latch-Up Performance Exceeds 100 mA Per JESD 78, Class II
- ESD Protection Exceeds JESD 22
 - o 2000-V Human-Body Model (A114-A)
 - 200-V Machine Model (A115-A)
 - 1000-V Charged-Device Model (C101)

3.1.4 SN74LVC1G80 D-Type Flip-Flop

This single 2-input exclusive-OR gate is designed for 1.65-V to 5.5-V V_{cc} operation.

The SN74LVC1G86 device performs the Boolean function $Y = A \times B$ or Y = AB + AB in positive logic.

A common application is as a true/complement element. If the input is low, the other input is reproduced in true form at the output. If the input is high, the signal on the other input is reproduced inverted at the output.

NanoFree[™] package technology is a major breakthrough in IC packaging concepts, using the die as the package.

This device is fully specified for partial-power-down applications using I_{off}. The I_{off} circuitry disables the outputs, preventing damaging current backflow through the device when it is powered down.

Features:

- Available in the Texas Instruments NanoFree Package
- Supports 5-V VCC Operation



- Inputs Accept Voltages to 5.5 V
- Supports Down Translation to VCC
- Max t_{pd} of 4 ns at 3.3 V
- Low Power Consumption, 10-µA Max ICC
- ±24-mA Output Drive at 3.3 V
- Ioff Supports Live Insertion, Partial-Power-Down Mode, and Back-Drive Protection
- Latch-Up Performance Exceeds 100 mA Per JESD 78, Class II
- ESD Protection Exceeds JESD 22
 - 2000-V Human-Body Model (A114-A)
 - o 200-V Machine Model (A115-A)
 - \circ 1000-V Charged-Device Model (C101)

4 System Design Theory

The Electric Toothbrush Reference Design demonstrates a simple, high performance and cost effective way to design an electric toothbrush or similar portable device. With the help of a SPST switch, the SN74LVC1G80 D-Type Flip Flop and the SN74LVC1G14 Logic Inverter are used together to create the ON/OFF switch to the MCU and motor driver IC without the need to keep the button pressed down to keep the system operational. The DRV8850 H-Bridge motor driver is used to both amplify the signal from the MCU to drive the motor and to supply power to the MCU from its integrated LDO voltage regulator. The MSP430G2210 ultra-low-power MCU generates the control signals to the DRV8850.

4.1 Power Button with Latching Circuit

By using the SN74LVC1G14 inverter and the SN74LVC1G80 D Flip-Flop in the configuration shown in Figure 4, it enabled the use of a simple small tactile switch toggle between ON and OFF every time it is intermittently pressed. Without this logic circuit, the system would only stay ON if the switch was being constantly pressed down. The D Flip-Flop toggles both the LDOEN and nSLEEP pin on the DRV8850. This effectively puts the DRV8850 in a low-power standby state and disables the LDO voltage regulator which cuts all power to the MCU for reduced power consumption when the system is not in use.



Figure 4: Power ON/OFF Logic Schematic

4.2 DRV8850 – H-Bridge Motor Driver



The DRV8850 is used to drive the solenoid in both directions. The device provides two independently controlled half bridges, which together are used to drive the outputs to the motor. The device also features an integrated LDO that is used to supply power to the MSP430G2210.



Figure 5: DRV8850 H-Bridge Motor Driver Schematic

4.2.1 Low-Dropout Linear Voltage Regulator

A 100 mA isolated LDO voltage regulator is integrated into the DRV8850 motor driver. The LDO regulator is typically used to supply power for the MCU and other low power peripherals. In this design, the LDO voltage regulator is used solely to supply power to the MSP430G2210 MCU.

4.2.2 4.2.2 Current Monitoring

The DRV8800/DRV8801 adds an important feature to motion control applications wanting to determine the current level flowing through the motor winding. An analog voltage output pin, called VPROPI for voltage proportional to current, supplies a signal which analog to digital converters (ADC) and microcontroller applications can use to accurately determine how much current is flowing through the controlled motor.

Due to the simplicity of this reference design and a lack of an available ADC on the MCU, the VPROPI pin in the DRV8850 is not being monitored by the MSP430G2210 MCU. In order to utilize the VPOPI feature, a larger MSP430, or similar MCU, with an available ADC could be used in the design.

4.3 MSP430G2210 MCU

The MSP430G2210 is the controller for the DRV8850 motor driver. Its only function in this system is to provide the appropriate control signals that the DRV8850 needs to properly drive the motor. Since the MCU has been configured to operate from a 1 MHz clock, it can operate with a minimum supply voltage of 1.8 V.





Figure 6: MSP430G2210 MCU Schematic



5 Getting Started Hardware

The TIDA-00602 requires a battery, preferably 2.5 to 4.5 V, and a motor. Either a vibration motor or brushed DC motor may be used.

5.1 Required Equipment

- 1. 2.5 V to 4.5 V battery or power supply
- 2. DC brushed motor or a magnetic vibration toothbrush motor

5.2 Procedure

- 1. Connect the motor terminals to the OUT1 and OUT2 pads on the board.
- 2. Connect the power source to the VM and GND pads on the board.
 - a. If using a power supply for testing, set the output voltage from 2 V to 4.5 V and maximum current to 8 A. Be cautious of using voltages that are higher than 4.5 V to account for voltage spikes across the motor outputs.
- 3. Intermittently press down on the power switch (SW1) to wake up the DRV8850 and enable power to the rest of the system.
- 4. Press down on the switch once again to put the DRV8850 in a low power state and to turn off the LDO voltage regulator.



6 Getting Started Firmware

The firmware used on this TI Design was developed using Code Composer Studio 6.1.0. For MSP430 firmware updates, use Code Composer Studio (v6 or newer), along with an external programmer, like the MSP-FET tool. This TI Design supports Spy-Bi-Wire (2 wire JTAG) protocol. For programming setup, supply the TI Design hardware with power. Either VM power or debugger power is suitable as a power source for programming, but if supplying power through VM and GND, the device must be switched ON.

6.1 Watchdog Timer

The watchdog timer is disabled in code because there is no reset procedure needed.

6.2 Initializing Motor Driver Control Signals Port Pins

The ports 1.2, 1.5, 1.6 and 1.7 directions must be set as outputs.

6.3 Initializing Oscillator

As per section 24.2.1 in the MSP430x2xx Family <u>User's Guide</u>, use the following settings to calibrate the DCO to 1MHz:

- Set the BCSTL1 register to 0x07h (CALBC1_1MHZ)
- Set the DCOCTL register to 0x06h (CALDCO_1MHZ)

6.4 Initializing Timer

Use the following settings to initialize the timer:

- Set the TACCR0 register to 150 sampling interval
- Set the TACCTL0 to Bit 4, or CCIE (Capture/compare interrupt enable)
- Set the TACTL register as follows:
 - TASSEL bits to 10b (SMCLK)
 - MC bits to 01b (Up mode)

7 Test Setup

7.1 Test Equipment

Oscilloscope: LeCroy HDO6054-MS Current Source Meter: Keithley 2420 SourceMeter Thermal Imager: Fluke Ti110 Battery Specifications: 3.7 V Li-Ion DC Motor Specifications: 1.78 mH 4.5 Ohm Magnetic Vibration Motor Specifications: 560 µH 0.41 Ohm



Test Data 8

8.1 Standby Power Consumption

The main battery leakage path during the system's standby state is through the VM pin in the DRV8850. The ON/OFF logic switch portion does not leak any current since it is in an open circuit condition due to the physical switch, SW1. The MCU is powered from the DRV8850's internal LDO, so it also does not provide for any leakage path.

Table 1: Standby Power Consumption			
Input Voltage	Current Drawn		
2.5 V	43 nA		
2.8 V	47 nA		
3.3 V	54 nA		
4 V	62 nA		
4.5 V	68 nA		

Table 1:	Standby	Power	Consumption
10010 11	oranasy		oonoumption

Magnetic Vibration Motor Output Waveforms 8.2

The current through the magnetic vibration motor must alternate direction at a given period in order to properly vibrate the motor. In the following test samples, the waveforms were made to vibrate the brush at 470 Hz. The frequency could be increased or decreased in order to get the best mechanical response from each unique motor. The maximum current can be limited by the amount of time that any given output, OUT1 or OUT2, stays on. If the DRV8850's overcurrent protection is tripped during startup, than a special startup waveform can be developed in firmware with either lower output on times, or a faster frequency. Once the current has settled after a couple of buffer cycles, the firmware can switch to a more optimal waveform that will enable higher operational current. This waveform is ideal from 3.3 to 4.5 V. The amount of time spent with an output turned on could be increased if operating voltages from 2 to 3.5 V to continue producing a strong mechanical vibration.

8.2.1 **Turn on Characteristics**

> Red: OUT1 Yellow: OUT2 Green: Output Current





Figure 7: 2.5-V Turn-on Characteristic, 1.8 A Peak Output Current





Figure 8: 3.3-V Turn-on Characteristic, 4 A Peak Output Current



Red: OUT1 Yellow: OUT2 Green: Output Current







Figure 10: 4.5-V Turn-on Characteristic, 7.6 A Peak Output Current



8.2.2 Typical Operational Waveforms

Figure 11: 2.5-V Typical Characteristic, 1.13 A Peak Output Current









Figure 13: 3.7-V Typical Characteristic, 1.97 A Peak Output Current



Figure 14: 4.5-V Typical Characteristic, 4.1 A Peak Output Current

8.3 Brushed DC Motor Waveforms

The DC motor waveforms should be very similar to the vibration motor waveforms from Section 8.3. The main difference is that the frequency needs to be lower in order to allow time for the motor to turn for a few degrees then return back. The following waveforms were generated from the MCU to alternate the motors' direction at 200 Hz, or every 5 ms.



Figure 15: 2.5-V Typical Characteristic, 479 mA Peak Output Current





Figure 16: 3.3-V Typical Characteristic, 637 mA Peak Output Current



Red: OUT1 Yellow: OUT2 Green: Output Current

Figure 17: 3.7-V Typical Characteristic, 723 mA Peak Output Current





Figure 18: 4.5-V Typical Characteristic, 766 mA Peak Output Current



8.4 Thermal Image Captures

All thermal image captures were taken at an ambient temperature of 22 °C. Figure 19 and Figure 20 were both captured while running the DC motor without load and then stalled. Figure 21 and Figure 22 were both captures while running the magnetic vibration motor at different voltages. The following figures illustrate the maximum thermal point on the PCB:



Figure 19: Thermal Image of DC Motor Spinning with No Load at 4.5 V



Figure 20: Thermal Image of DC Motor Stalled at 4.5 V





Figure 21: Thermal Image of Vibration Motor Operating at 4 V



Figure 22: Thermal Image of Vibration Motor Operating at 4.5 V

9 Design Files

9.1 Schematics

To download the Schematics for each board, see the design files at http://www.ti.com/tool/TIDA-00602



Figure 23: DRV8850 Motor Driver Schematic and Bypass Capacitors











9.2 Bill of Materials

To download the Bill of Materials for each board, see the design files at http://www.ti.com/tool/TIDA-00602

Texas Instruments

Bill of Materials

TI DESIGNS

TIDA-00602

ltem	Qty	Reference	Part Description	Manufacturer	Manufacturer Part Number	Supplier	Supplier Part Number
1	1	C1	CAP, CERM, 2.2 μF, 10 V, +/- 20%, X5R, 0402	Wurth Elektronik	885012105013	Mouser	710-885012105013
2	2	C2, C4	CAP, CERM, 0.1 µF, 16 V, +/- 20%, X5R, 0402	Wurth Elektronik	885012105016	Mouser	710-885012105016
3	1	C3	CAP, CERM, 10 μF, 10 V, +/- 10%, X7R, 0805	Wurth Elektronik	885012207026	Mouser	710-885012207026
4	2	C5, C6	CAP, CERM, 0.1 µF, 16 V, +/- 10%, X7R, 0603_095	Wurth Elektronik	885012206046	Mouser	710-885012206046
5	1	C7	CAP, CERM, 1 µF, 16 V, +/- 20%, X5R, 0603_095	Wurth Elektronik	885012106017	Mouser	710-885012106017
6	1	D1	Diode, Ultrafast, 100 V, 0.15 A, SOD-123	Diodes Inc.	1N4148W-7-F	Digi-Key	1N4148W-FDICT-ND
7	1	D2	LED, Green, SMD	Wurth Elektronik	150060VS75000	Digi-Key	732-4980-1-ND
8	1	J1	SOCKET .050" GRID SIP 4 POS R/A, TH	Mill-Max	851-43-004-20-001000	Digi-Key	ED90474-ND
9	1	R1	RES, 127k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW0402127KFKED	Digi-Key	541-127KLCT-ND
10	1	R2	RES, 47k ohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW060347K0JNEA	Digi-Key	541-47KGCT-ND
11	1	R3	RES, 2.4k ohm, 5%, 0.063W, 0402	Vishay-Dale	CRCW04022K40JNED	Digi-Key	541-2.4KJCT-ND
12	1	R4	RES, 40.2k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040240K2FKED	Digi-Key	541-40.2KLCT-ND
13	1	R5	RES, 1.00k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021K00FKED	Digi-Key	541-1.00KLCT-ND
14	1	R6	RES, 62, 5%, 0.1 W, 0603	Vishay-Dale	CRCW060362R0JNEA	Digi-Key	541-62GCT-ND
15	2	R7, R9	RES, 20k ohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW060320K0JNEA	Digi-Key	541-20KGCT-ND
16	1	R8	RES, 0 ohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW06030000Z0EA	Digi-Key	541-0.0GCT-ND
17	1	S1	Switch, Push Button, SMD	Alps	SKRKAEE010	Mouser	688-SKRKAE
18	1	U1	Low-Voltage H-Bridge IC With LDO Regulator, RGY0024B	Texas Instruments	DRV8850RGY	Digi-Key	296-37195-1-ND
19	1	U2	MIXED SIGNAL MICROCONTROLLER, D0008A	Texas Instruments	MSP430G2210IDR	Digi-Key	296-39083-1-ND
20	1	U3	IC, Single Positive-Edge-Triggered D-Type Flip-Flop	П	SN74LVC1G80DCK	Digi-Key	296-9852-1-ND
21	1	U4	IC, Single Schmitt-Trigger Inverter	TI	SN74LVC1G14DCK	Digi-Key	296-11608-1-ND

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9.3 PCB Layout Recommendations

9.3.1 Layout Prints

To download the Layout Prints for each board, see the design files at <u>http://www.ti.com/tool/TIDA-00602</u>



Figure 27: Top Silkscreen



Figure 28: Top Solder Mask





Figure 29: Top Layer



Figure 31: Bottom Solder Mask



Figure 30: Bottom Layer



Figure 32: Bottom Silkscreen





Figure 33: Mechanical Dimensions



9.4 Altium Project

To download the Altium project files for each board, see the design files at http://www.ti.com/tool/TIDA-00602



Figure 34: PCB Layouts



9.5 Layout Guidelines

Sufficient heat sinking of the DRV8850 is critical to the design and requires thermal vias under the device and contiguous copper area. Ground plane via stitching near the device assists in transferring the heat from one layer to the other in order to effectively increase the active copper area.



Figure 35: Layout Recommendations



Figure 36: Layout Recommendations

9.6 Gerber files

To download the Gerber files for each board, see the design files at <u>http://www.ti.com/tool/TIDA-00602</u>



Figure 37: Project Gerber and Drill Files

9.7 Assembly Drawings

To download the Assembly Drawings for each board, see the design files at http://www.ti.com/tool/TIDA-00602



Figure 38: Top and Bottom Assembly Drawing

10 Software Files

To download the software files for this reference design, please see the link at http://www.ti.com/tool/TIDA-00602

11 References

1. Texas Instruments Application Report, Noise Analysis in Operational Amplifier Circuits, <u>SLVA043A</u>, 1999

12 Terminology

ESD – Electrostatic discharge FETs, MOSFETs – The metal-oxide-semiconductor field-effect transistor MCU – Microcontroller unit PWM – Pulse width modulation RMS – Root mean square SPI – Serial peripheral interface LDO – Low-dropout GPIO – General purpose input/output

13 About the Author

FABIO FERNANDES is an Applications Engineer at Texas Instruments currently in the Applications Rotational Program, who supports a broad portfolio of motor drivers. Fabio earned his Bachelors of Science in Electrical Engineering (BSEE) from University of Central Florida in Orlando, FL.

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