# TI Designs IoT Wi-Fi<sup>®</sup> Microstepping Stepper Motor Control



# **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**

TIDM- TM4C123IOTSTEPPER MOTOR	TI Design Files
TM4C123GH6PM	Product Folder
DRV8833	Product Folder
<u>CC3100</u>	Product Folder
EK-TM4C123GXL	Tool Folder
DRV8833 EVM	Tool Folder
CC3100 BoosterPack	Tool Folder



ool Folder

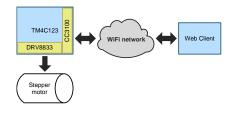
ASK Our E2E Experts

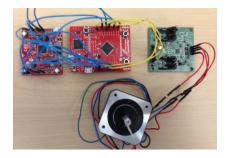
### **Design Features**

- The TM4C123 Microcontroller Uses Four PWM Channels to Control DRV8833 to Rotate the Bipolar Stepper Motor in Full Step and Microstep Modes.
- The CC3100 BoosterPack<sup>™</sup> Hosts a Webserver Interface to Control the TM4C123 LaunchPad<sup>™</sup> and Stepper Motor Remotely From a Wi-Fi-Enabled Device Such as a PC or Mobile Device.
- The Software is Designed to Work With an EK-TM4C123GXL LaunchPad, CC3100 BoosterPack, and DRV8833 EVM.
- The HTML/MCU Code Also Lets the User Remotely Control the Operation of EK-TM4C123GXL LaunchPad, Including LED Toggling, Internal Temperature Reading, and Button Press Recording Through a Web Browser.
- This TI Design Supports Control of the Stepper Motor Using a UART Interface or a Webserver Over Wi-Fi<sup>®</sup>.

#### **Featured Applications**

- Industrial Application and Automation
- Speed Control Applications
- Precision Motion Control
- Textile Equipment and Medical Analyzers
- Consumer Applications Such as Metering Pumps, Printers, Antenna Positioning, and Security Cameras







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

BoosterPack, LaunchPad, Internet-on-a-chip, SimpleLink, TivaWare, Code Composer Studio are trademarks of Texas Instruments. Stellaris is a registered trademark of Texas Instruments. ARM, Cortex are registered trademarks of ARM Limited. Wi-Fi is a registered trademark of WiFi Alliance. All other trademarks are the property of their respective owners.



### 1 System Description

This system shows how to control a bipolar stepper motor in full step and microstep modes with the TM4C123 high-performance microcontroller and DRV8833 motor driver. The CC3100 BoosterPack is integrated with TM4C123 LaunchPad to implement a Wi-Fi webserver interface to control the TM4C123 and stepper motor through a web browser. The functionalities for this project can be extended in real applications requiring the high-performance features of the TM4C device and connection to a wireless domain. The software accompanying this design is developed and tested on an EK-TM4C123GXL LaunchPad, DRV8833 EVM, and CC3100 BoosterPack.

# 1.1 TM4C123GH6PM

The TM4C123GH6PM microcontroller is targeted for industrial applications including the following:

- Remote monitoring
- Electronic point-of-sale machines
- Test equipment
- Measurement equipment
- Network appliances
- Switches
- Factory automation
- HVAC
- Building control
- Gaming equipment
- Motion control
- Transportation
- Security

The TM4C123GH6PM is an 80-MHz high-performance microcontroller with up to 256KB of on-chip flash and 32KB of on-chip SRAM. There are up to 43 GPIOs with programmable control for GPIO interrupts, pad configuration, and pin muxing. The MCU is integrated with the following:

- Six 32-bit general-purpose timers (up to twelve 16-bit)
- Eight UARTs
- · Four synchronous serial interface (SSI) modules
- · Four inter-integrated circuit (I2C) modules
- Two 12-bit analog-to-digital converters (ADCs) with 12 analog input channels and a sample rate of one million samples per second
- Eight pulse width modulation (PWM) generator blocks
- Two quadrature encoder interface (QEI) modules

The on-chip universal serial bus (USB) controller supports the USB OTG mode, host mode, and device mode. The ARM® PrimeCell 32-channel configurable µDMA controller is also integrated to provide a method to offload data transfer tasks from the ARM Cortex®-M4 processor and to efficiently use the processor and the bus bandwidth. See Figure 1 for more information.



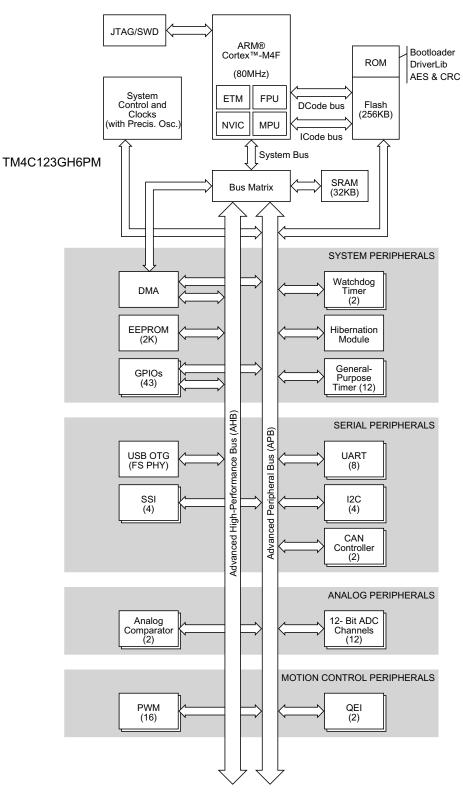


Figure 1. TM4C123GH6PM Microcontroller High-Level Block Diagram



#### 1.2 DRV8833

The DRV8833 device has two H-bridge drivers to drive a bipolar stepper motor, two DC-brush motors, or other inductive loads. Aimed at driving 3.3-V and 5-V motors, this stepper driver with integrated FETs support up to 1.5 A (rms) with a low-power sleep mode to conserve power for battery-powered applications. Internal shutdown functions with a fault output pin are provided for overcurrent protection, short-circuit protection, undervoltage lockout, and overtemperature. See Figure 2 for more information.

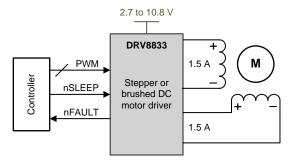


Figure 2. DRV833 Functional Block Diagram

# 1.3 CC3100

The CC3100 Wi-Fi network processor subsystem features a Wi-Fi Internet-on-a-chip<sup>™</sup> integrated circuit and contains an additional dedicated ARM MCU that completely offloads the host MCU. This subsystem includes an 802.11 b/g/n radio, baseband, and MAC with a powerful crypto engine for fast, secure internet connections with 256-bit encryption. The CC3100 device supports station, access point, and Wi-Fi-direct modes. The device also supports WPA2 personal and enterprise security and WPS 2.0. This subsystem includes embedded TCP/IP and TLS/SSL stacks, HTTP server, and multiple internet protocols. See Figure 3 for more information.

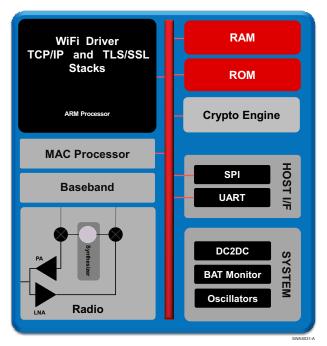


Figure 3. CC3100 Hardware Overview



# 1.4 Stepper Motor Control

A stepper motor is a brushless DC-electric motor that divides a full rotation into a number of equal steps. The position of the motor can be commanded to move and hold at one of these steps without feedback. The stepper motor is used in a wide range of applications involving precision motion control. Figure 4 shows the four PWM signals required to drive a bipolar stepper motor in full step mode with DRV8833.

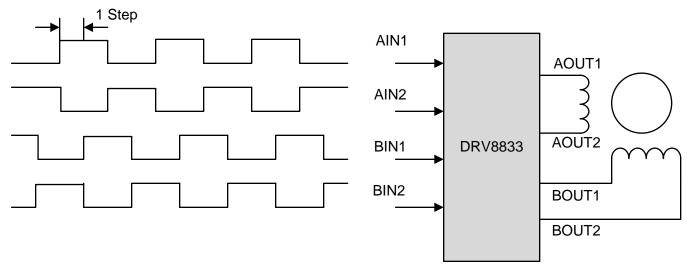


Figure 4. Driving the Stepper Motor in Full Step Mode



System Description

www.ti.com

In full step operation, the stepper motor moves through its basic step angle. For a 1.8-degree step, the motor takes 200 steps per complete revolution. In the full step mode, the current is fully on during the driving phase. This mode provides the best torque and speed performance from the motor. Figure 5 shows the PWM signals driving DRV8833 in full step mode. In Figure 5, the signals are arranged from top to bottom as AIN1, AIN2, BIN2, and BIN1.

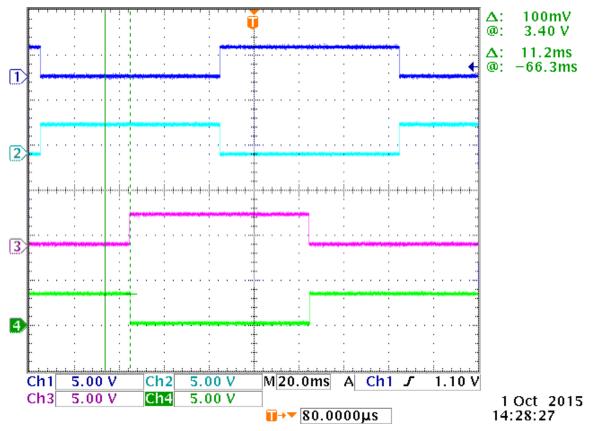


Figure 5. Driving Waveform to DRV8833: Full Step

Figure 6 shows the currents going through the motor windings in full step mode and two driving signals to DRV8833 for reference. In Figure 6, channel 1 is AIN1 and channel 2 is BIN1. There are two motor windings (A and B). Channel 3 is the current going through motor winding A and Channel 4 is the current going through motor winding B. The current flowing through the winding is FULL ON in one direction and FULL ON in the opposite direction.

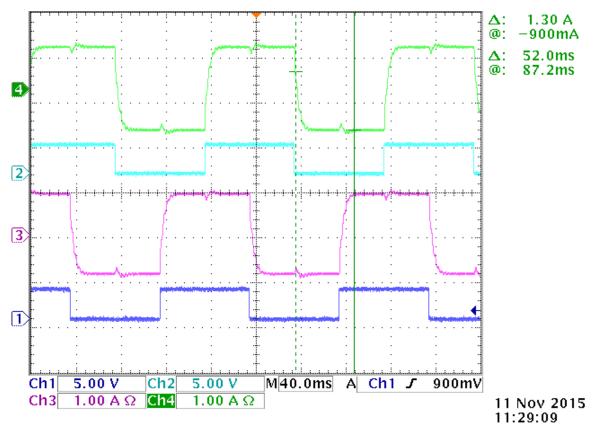


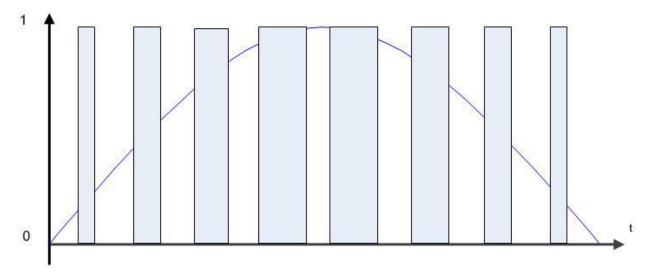
Figure 6. Motor Winding Currents: Full Step Mode

Although full step mode provides the best toque, the user might want to eliminate the mechanical vibration at low speeds. The microstepping technique eliminates the jerky and noisy character of low-speed stepping motor operation and reduces problems with resonance. Microsteps make the current flowing through the motor winding increase or decrease gradually. Microstepping allows for incremental pushing or pulling of the rotor rather than full force. In this way, the motor can move smoothly.



#### System Description

The most common driving waveform in microstepping is the sine wave. The microstepping technique approximates a sine wave by dividing a full step into multiple microsteps and regulating the current in each microstep. In this example, DRV8833 device can be only in an on or off state. To regulate current, one PWM pulse is generated for each microstep. The duty cycle of the PWM is dynamically modified to modulate the current in each microstep so that the integrated waveform is approximately a sine wave. Figure 7 shows the concept of dividing one full step into four microsteps.



#### Figure 7. Waveform For Four Microsteps Per Full Step

As the microsteps become smaller (a full step is more divided), motor operation becomes smoother. The power of microcontroller computing and motor driver switching speed are the primary factors limiting the number of microsteps in an application. CPU needs to be interrupted at each microstep to change the duty cycle of the next PWM pulse to regulate current. At the same motor rotation speed, driving a motor with 256 microsteps requires 256 times more CPU power compared to the full step. The motor driver switching speed limits the minimum pulse width of the driving signal. In addition to the limitation of the controller processing speed and the motor driver switching speed, the mechanical friction and backlash limit the resolution. This system demonstrates how to generate the four channels of dynamically modulated PWM signals with the PWM module on TM4C123. Because the DRV8833 EVM does not support current sensing, only open-loop current regulation is used.



Figure 8 shows the PWM signals driving DRV8833 with 256 microsteps. The signals are arranged from top to bottom as AIN1, AIN2, BIN2, and BIN1.

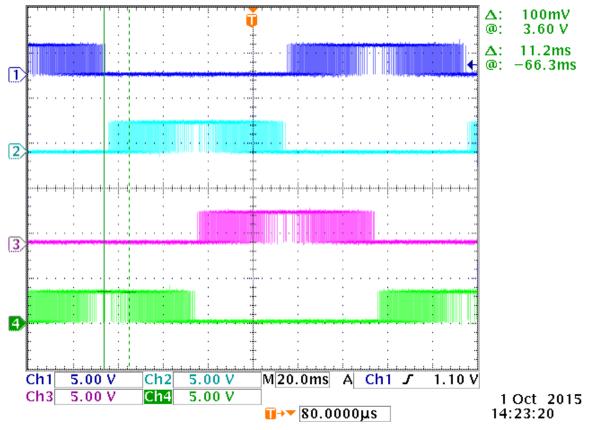


Figure 8. Driving Waveform to DRV8833: 256 Microsteps



System Description

www.ti.com

Figure 9 shows the currents going through the motor windings with 256 microsteps and the two driving signals to DRV8833. In Figure 9, channel 1 is AIN1 and channel 2 is BIN1. There are two motor windings (A and B). Channel 3 is the current going through motor winding A and Channel 4 is the current going through motor winding B.

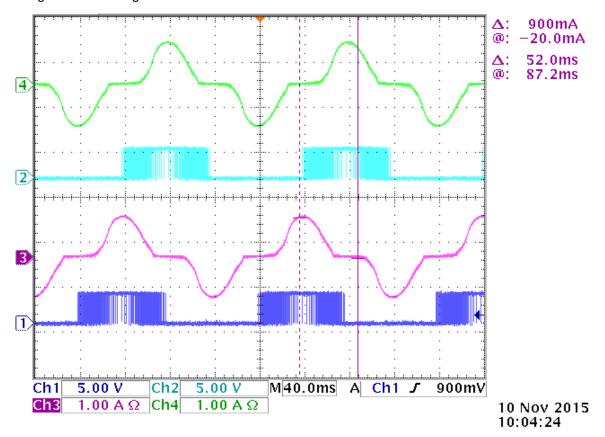


Figure 9. Motor Winding Currents: 256 Microsteps



### 2 Getting Started–Hardware

Figure 10 shows the connection signals of TM4C123, DRV8833, and CC3100. TM4C123 generates four channels of PWM signals to drive the stepper motor through the DRV8833 device. The period and duty cycle of the PWM signals are changed dynamically to drive the motor with the required mode (that is, full step and microstep) and speed.

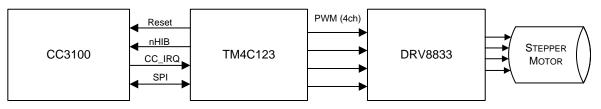


Figure 10. TM4C123, DRV8833, and CC3100 Integration

Two motor control user interfaces are provided in this system:

- The Wi-Fi function of CC3100
- A TM4C123 UART port

In addition to the standard SPI interface, there are three control and handshaking signals between TM4C123 and CC3100. The TM4C123 device uses the reset signal to reset CC3100. The TM4C123 uses the nHIB signal to enable and disable CC3100. The CC3100 uses the CC\_IRQ signal to notify TM4C123 when it requires service. The SPI interface is used for the data communication between TM4C123 and CC3100. The TI SimpleLink<sup>™</sup> library driver processes the message and controls the communication. The application running on TM4C123 can process the requests from CC3100 using http callback events without knowing the SPI messaging format.

The hardware in this example consist of the EK-TM4C123GXL LaunchPad, the DRV8833 motor driver EVM, and CC3100 BoosterPack. The EK-TM4C123GXL LaunchPad board connects to the DRV8833 board through the connectors on the EK-TM4C123GXL using jumper wires. Table 1 shows the signal mapping.

EK-TM4C123GXL LaunchPad	DRV8833 EVM
PB7 (M0PWM1)	AIN1
PB5 (M0PWM3)	AIN2
PE5 (M0PWM5)	BIN2
PC5 (M0PWM7)	BIN1
GND	GND

Table 1. TM4C123XL and DRV833 EVM Interface Signa	ble 1. TM4C123XL and	d DRV833	EVM Interface	Signals
---------------------------------------------------	----------------------	----------	---------------	---------

To use the PWM signals on the EK-TM4C123GXL LaunchPad connectors, the CC3100 BoosterPack cannot be plugged onto the EK-TM4C123GXL LaunchPad. Jumper wires connect the EKTM4C123GXL LaunchPad and the CC3100 BoosterPack. To more easily connect, make an interface board. For more information, see Table 2.

EK-TM4C123GXL LaunchPad	CC3100 BoosterPack
PE0	CC_SPI_CS
PA2 (SSI0_CLK)	CC_SPI_CLK
PA5 (SSI0_TX)	CC_SPI_DIN
PA4 (SSI0_RX)	CC_SPI_DOUT
PE1	CC_nHIB
PD3	CC_IRQ
RESET	MCU_RESET
3.3 V	3.3 V

EK-TM4C123GXL LaunchPad	CC3100 BoosterPack
5 V	5 V
GND	GND

The following TM4C123 peripherals are enabled in this system.

- All four PWM generators in the PWM0 modules are enabled to generate PWM signals on M0PWM1, M0PWM3, M0PWM5, and M0PWM7 pins to drive the motor. The load interrupt on the PWM generator 0 is enabled to dynamically load PWM parameters for all four PWM generators.
- SSI0 module for the communication with CC3100. PE0, PE1, and PD3 for handshaking.
- UART 0 as a separate interface for motor control
- Timer 2 interrupt to drive LED on EK-TM4C123GXL LaunchPad with GPIO pin PF1
- Timer 0 interrupt to sample button states on EK-TM4C123GXL LaunchPad from GPIO input pins PF0 and PF4, and the on-chip temperature sensor
- ADC0 for reading the on-chip temperature sensor.
- GPIO pin PC7 is configured as an output for measurement of critical processing time

# 3 Getting Started–Software

Figure 11 shows the architecture of the TM4C123 software. The TivaWare<sup>™</sup> library configures the hardware on TM4C123. The load interrupt of the PWM generator 0 is enabled to occur at the interval of the PWM period. In the interrupt service routine, the load and compare A registers are updated for all four PWM generators to configure the period and duty cycle for the next PWM cycle. The updated value is loaded to PWM module when the PWM counters reach zero so that the four PWM generators are updated synchronously. The Internet data communication is accomplished by http callback function in the TI SimpleLink<sup>™</sup> library through the http post and get events. A UART interface is also created to control the motor using the TivaWare utility library and the USB debug port on the EK-TM4C123GXL LaunchPad.

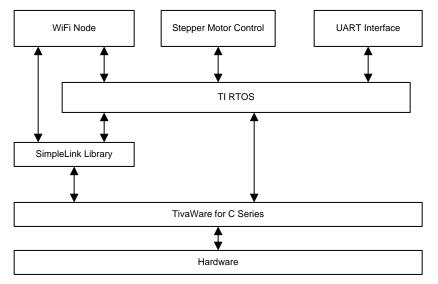


Figure 11. TM4C123 Software Architecture

TI RTOS schedules the processing. The following TI RTOS functions are statically configured in the TI RTOS configuration file.

- CLK0: 1-ms system tick generated by timer 3
- HWI\_PWM0: PWM0 load interrupt to update the PWM duty cycle for each microstep
- HWI\_timer0a: 10-ms timer 0 interrupt for sampling buttons and internal temperature sensor
- HWI\_timer2a: Timer 2 interrupt with variable period for toggling LED



- HWI\_UART0: UART0 interrupt for sending and receiving 1 byte on UART
- TI RTOS SPI and GPIO drivers handle the communication and handshaking between TM4C123 and CC3100
- Task\_HttpServer: Process HTTP events using the SimpleLink library call back function
- Task\_UART0: Process UART command for the stepper motor control

To minimize the CPU overhead in dynamically modifying the PWM duty cycle for approximating a sine wave, TI adopted a lookup table approach. The lookup table in this system has 512 integer entries created by the formula in Equation 1 to support a maximum resolution of 256 microsteps.

Table (i) = 
$$32767 \times \sin\left(i \times \frac{\pi}{512}\right)$$
, i = 0, ... 511 (1)

At each microstep, the pointer to the lookup table is incremented. Table 3 lists that the increment size according to the resolution.

Microstepping Resolution	Lookup Table Pointer Increment Size
256	1
128	2
64	4
32	8
16	16
8	32
4	64
2	128
1	256

#### Table 3. Lookup Table Pointer Increment Size

The PWM counters are 16-bit down-counters. The period of the PWM is determined by the motor rotation speed and the microstepping resolution. For a given rotation speed and microstepping resolution, the duty cycle of the PWM is dynamically changed to approximate a sine wave for driving the motor. The duty cycle is determined by the value in the PWM compare A register and calculated as follows.

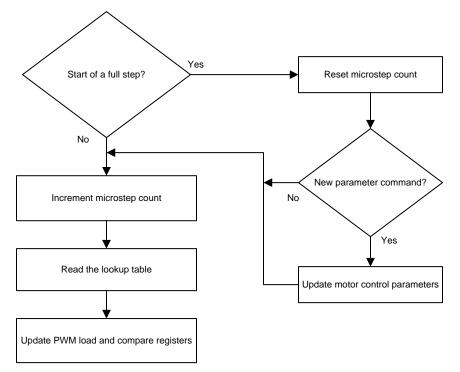
PWM Compare Register Value = (PWM period × Lookup Table Value) ÷ 32768



Getting Started–Software

www.ti.com

The PWM signal goes high when the PWM counter value matches the PWM compare register and returns to low when the PWM counter reaches zero. The PWM period and compare register are then reloaded automatically. The load interrupt for PWM generator 0 is triggered for the CPU to update the PWM period and compare register for the next PWM cycle. See Figure 12 for more details.



#### Figure 12. Processing in PWM Interrupt Service Routine

Figure 12 shows the processing in the PWM ISR. The command from the Wi-Fi and UART interface are processed at the beginning of the full step. The microstepping resolution can be changed only when the motor is stopped. The motor control interface supports the following commands.

- Configure microstepping resolution
- Configure motor rotation direction and speed
- Stop the motor
- Rotate the motor continuously
- Rotate the motor for predetermined full steps and stop
- Rotate the motor for predetermined full steps and reverse
- Display the motor control status



The command from the Wi-Fi interface is processed by the http callback function from the TI SimpleLink library. From the stepper motor control demo web page, you can send a post request to command the motor and a get request to acquire the motor control status. The text strings from those requests are processed in the http callback function and converted to a numerical value when necessary. When an http request is processed, a command flag is set to notify the motor control so that the control parameter can be updated at the beginning of the next full step. See Figure 13 from more information.

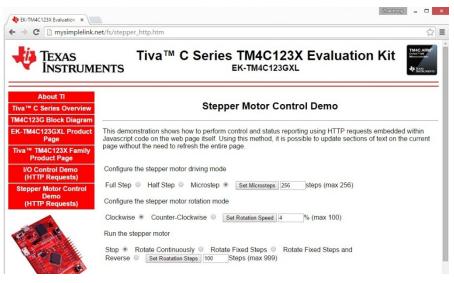


Figure 13. Stepper Motor Control Demo Web Page



Installing the Demonstration

The UART interface uses the UART0 module with the TivaWare utility library. The UART port is configured to a baud rate of 115200 with an 8-N-1 format. If the web interface and an UART interface are used in the same time, the web page must be manually refreshed to be synchronized with the UART command. Table 4 lists the command line input.

Name	Description		
mode N	Configure the resolution to N (maximum 256) microsteps.		
dir	Change the rotation direction.		
speed N	Set the rotation speed to N (maximum 100) %.		
stop	Stop the motor.		
run	Rotate the motor continuously.		
rfs N	Rotate the motor for N full steps and stop.		
rfr N	Rotate the motor for N full steps and reverse.		
help	Display available commands.		
status	Display current motor control status.		

#### Table 4. Command Line

The released MCU software and CC3100 html code also supports the I/O control demo described in detail in the TI Design (TIDM-TM4C129XWIFI).

# 4 Installing the Demonstration

To rebuild the demonstration, you must acquire the following TI development tools and software packages.

- EK-TM4C123GXL LaunchPad
- DRV8833 EVM
- CC3100 BoosterPack
- CC3100 EMU boost board (for programming of CC3100)
- Code Composer Studio<sup>™</sup> (CCS) v6.0.1 or more
- TivaWare v2.1.0.12573 or above
- TI RTOS V2.14.0.10 or above
- CC3100 SDK 1.0.0 and above
- CCS Uniflash for CC3100/CC3200

The CC3100 html code must be programmed to CC3100 following the description in the TI Design<u>TIDM-</u><u>TM4C129XWIFI</u>.



Save the softwareanywhere in the PC from the zip file. To recompile the project correctly, configure the location of CCS, TivaWare, and CC3100 SDK to match their installation. The paths in Figure 14 are obtained with default locations for software installation. If you do not install the software to the default location, the linked paths must be modified to match the actual installation.

pe filter text	Linked Resources		▼	
<ul> <li>Resource</li> <li>Linked Resources</li> <li>Resource Filters</li> <li>CCS General</li> <li>CCS Build</li> <li>ARM Compiler</li> </ul>	Path Variables       Linked Resources         Path variables specify locations in the file system, including other path variables with the syntax "\${VAR}".         The locations of linked resources may be specified relative to these path variables.         Defined path variables for resource 'http_server_WIFI_demo_ap_stepper':         Name       Value			
<ul> <li>ARM Linker ARM Hex Utility [Disabled]</li> <li>Builders</li> <li>C/C++ Build</li> <li>C/C++ General Debug</li> <li>Project References</li> <li>Run/Debug Settings</li> </ul>	<ul> <li>CC3100_SDK_ROOT</li> <li>CCS_BASE_ROOT</li> <li>CCS_INSTALL_ROOT</li> <li>CG_TOOL_ROOT</li> <li>ECLIPSE_HOME</li> <li>EXTERNAL_BUILD_ARTI</li> <li>PARENT_LOC</li> <li>PROJECT_LOC</li> <li>TIVAWARE_ROOT</li> <li>WORKSPACE_LOC</li> </ul>	C:\ti\CC3100SDK_1.0.0\cc3100-sdk C:\ti\ccsv6\ccs_base C:\ti\ccsv6 C:\ti\ccsv6\tools\compiler\arm_5.1.5 C:\ti\ccsv6\eclipse\ C:\Users\a0322907\workspace_v6_0 C:\Users\a0322907\Desktop\tiva-c-iot-stepper-motor C:\ti\TivaWare_C_Series-2.1.0.12573 C:\Users\a0322907\workspace_v6_0	Edit Remove	
Hide advanced settings		ОК	Cancel	

Figure 14. Resource Path for the CCS Project



#### Executing the Demonstration

# 5 Executing the Demonstration

In the software, the CC3100 is configured as a Wi-Fi access point. Connect to the Wi-Fi network hosted by CC3100 as follows.

- 1. Enter *cc3100* as the name of the network without a password.
- 2. Search for mysimpleLink.net from a web browser.
- 3. Enter *admin* as the login ID and password.

NOTE: Figure 15 shows the overview page of mysimplelink.net.

> C	🗋 mysim	plelink	net			52
						~ ~ ~
TEXAS	Instrume	NTS				
SimpleLink	™ Wi-Fi® F	amily				
Welcome	Overview	About	Setup	Developer's Portal	TM4C123x Demo	
establish a se and software f support. CC3100 t is a perfect \	cure Wi-Fi and ools, reference	l Internet ( e designs on to TI's I	connectior , sample a MCUs with	n and enable battery-ope opplications, developmen	to easily create Internet applicati rated devices. TI provides various at documentation and E2E commu- ment to boost power efficiency. Th	s kits inity
Key Features	of CC3100					
<ul> <li>Integra</li> <li>Small</li> <li>Embed</li> <li>Low point</li> </ul>	ated TCP/IP sta MCU driver foo Ided crypto en ower radio with	acks and i otprint gine with n advance	ndustry sta 256-bit en ed low pov			d MAC
	ted.					
et's get star						

Figure 15. My SimpleLink Start Page



- 4. Select *TM4C123X Demo* from the top menu.
  - NOTE: Figure 16 shows the start page for the TM4X123 demonstration.

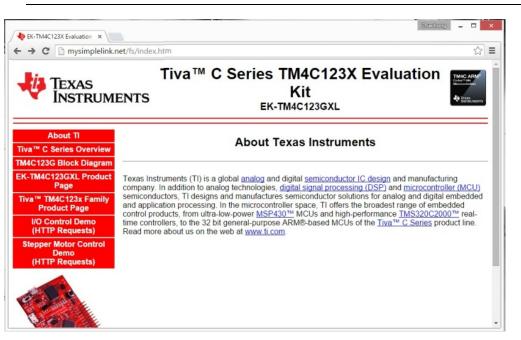


Figure 16. TM4C123 Demonstration Start Page

- 5. Click the *Stepper Motor Control* button from the menu to start the stepper motor control page as shown in Figure 16.
- 6. Click the radio buttons and input values in the text windows to control the motor.
- 7. Plug the debug USB cable into the EK-TM4C123GXL LaunchPad debug port.

**NOTE:** When the debug USB cable is plugged into the EK-TM4C123GXL LaunchPad debug port, a virtual COM port is created in the host PC.

- 8. Find the COM port number from the PC control panel.
- 9. Open the COM port with hyperterminal software.
- 10. Set the virtual COM port to 115200 baud and 8N1 data format.
- 11. Type status to display the motor control status.

TEXAS INSTRUMENTS

www.ti.com

#### Resources

### 6 Resources

To download the resource files for this reference design, see <u>TIDM-TM4C123IOTSTEPPERMOTOR</u>.

#### 7 References

- 1. TM4C123 MCU (http://www.ti.com/product/tm4c123gh6pm)
- 2. DRV8833 Stepper Motor Driver (http://www.ti.com/product/drv8833)
- 3. CC3100 Network Processor (http://www.ti.com/product/cc3100)
- 4. EK-TM4C123GXL LaunchPad (http://www.ti.com/tool/EK-TM4C123GXL)
- 5. DRV8833 EVM (http://www.ti.com/tool/drv8833evm)
- 6. SimpleLink CC3100 BoosterPack (http://www.ti.com/tool/cc3100boost)
- 7. TivaWare for C Series (http://www.ti.com/tool/SW-TM4C)
- 8. SimpleLink SDK (http://www.ti.com/tool/cc3100sdk)
- Stellaris<sup>®</sup> In-Circuit Debug Interface (ICDI) and Virtual COM Port Driver Installation Instructions (<u>SPMU287</u>)
- 10. Uniflash for CC3100 (http://www.ti.com/tool/uniflash)
- 11. High-Resolution Microstepping Driver With the DRV88xx Series Application Report (SLVA416)
- 12. Wi-Fi-Enabled IoT Node with High-Performance MCU Reference Design (TIDM-TM4C129XWIFI)

#### **IMPORTANT NOTICE FOR TI REFERENCE DESIGNS**

Texas Instruments Incorporated ("TI") reference designs are solely intended to assist designers ("Buyers") who are developing systems that incorporate TI semiconductor products (also referred to herein as "components"). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer's systems and products.

TI reference designs have been created using standard laboratory conditions and engineering practices. **TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.** TI may make corrections, enhancements, improvements and other changes to its reference designs.

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, 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 components 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 such information 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 ARE PROVIDED "AS IS". TI MAKES NO WARRANTIES OR REPRESENTATIONS WITH REGARD TO THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING ACCURACY OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO TI REFERENCE DESIGNS OR USE THEREOF. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY BUYERS AGAINST ANY THIRD PARTY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON A COMBINATION OF COMPONENTS PROVIDED IN A TI REFERENCE DESIGN. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF TI REFERENCE DESIGNS OR BUYER'S USE OF TI REFERENCE DESIGNS.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer's safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have **not** been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265 Copyright © 2015, Texas Instruments Incorporated