TI Designs
Configurable Stepper Driver for HVAC Louver and Motor Control Reference Design

TEXAS INSTRUMENTS

Overview

This reference design provides a flexible stepper motor system designed to drive up to two stepper motors, or eight peripherals, while reducing the number of GPIOs needed from the host controller and reducing overall cost. This system is suitable for applications requiring stepper motors or coils up to 50 V and a max current of 2.5 A (with all channels enabled). This TI Design features multiple configurations for outputs allowing multiple peripherals to be driven (that is, one motor, one buzzer, one relay, and two LEDs). This design is adaptable to automated louver control in heating, ventilation, and air conditioning (HVAC) systems as well as control of relays, buzzers, and LEDs. This concept could also be more broadly expanded to drive any number of channels for other building automation designs including louver control in smart ventilation systems and automated window blind tilting as well as pan and tilt control for IP cameras.

Resources

TIDA-01329	Design Folder
BOOSTXL-ULN2003	Tool Folder
MSP430F5529	Product Folder
ULN2003A	Product Folder
SN74HC595	Product Folder
CSD17571Q2	Product Folder

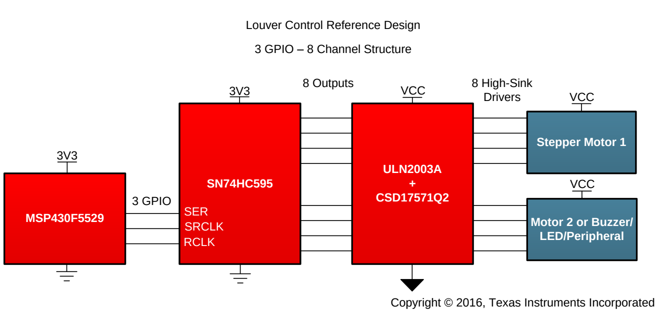
TI E2E™ Community — ASK Our E2E Experts

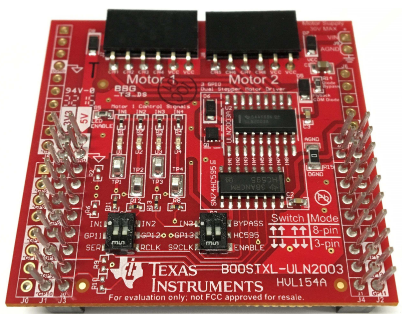
Features

- Subsystem Adaptable to a Wide Range of Building Automation Applications
- Only Three GPIO Pins Required to Drive Any Multiple of Eight Channels
- Expandable to Desired Number of Drive Channels
- Simple, Cost Effective Solution
- Adaptable Across a Wide Range of Drive Applications (Stepper Motors, Relays, LEDs)
- High-Voltage Tolerant Drive Outputs (up to 50 V)
- High-Current Sink Drive Outputs (up to 500 mA per Channel)

Applications

- Home and Building Automation
- Ductless HVAC Louver Control
- Smart Vents for HVAC
- Window Blind Tilt Control
- IP Cameras
- White Goods





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

Copyright © 2016, Texas Instruments Incorporated

1 System Overview

1.1 System Description

The TIDA-01329 reference design provides an easy-to-design, cost effective solution that implements the SN74HC595 shift register, the ULN2003A 7-channel Darlington pair array, and the CSD17571Q1 NexFET™ power MOSFET to drive eight high-voltage (50 V for ULN2003A), high-current (up to 500 mA) output sink driver channels using only three GPIOs. Often, single-room and ducted AC systems implement louvers to control air direction and rate of flow to different rooms of a building. This subsystem provides a way to control the louver in any HVAC system, cooling or heating the appropriate rooms in a building to help increase efficiency of air handling.

Additionally, this subsystem can be applied to other home and building automation applications such as window blind control. As the light from the sun changes throughout a day, window blinds can be automatically controlled to help balance natural lighting in the room while helping to decrease direct sunlight, keeping the room cooler, and allowing the AC to run more efficiently. This subsystem design is expandable and adaptable to a wide variety of home and building automation applications.

1.2 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS
Input power source	3.3 V converted from mains electricity
Number of GPIO pins required	3
Number of drive channels	8 (expandable up to 15 devices without increasing number of GPIO pins required)
Types of peripherals that can be driven	Stepper motors, uni-directional DC motors, relays, solenoids, LEDs, buzzers, and so on
Number of stepper motors to drive	2 stepper motors per 8 channels
Maximum voltage per drive channel	50 V for ULN2003A outputs, 30 V for CSD17571Q2
Maximum current per drive channel	500 mA
Operating temperature	–40°C to 85°C (up to 125°C with appropriate MCU)

1.3 Block Diagram

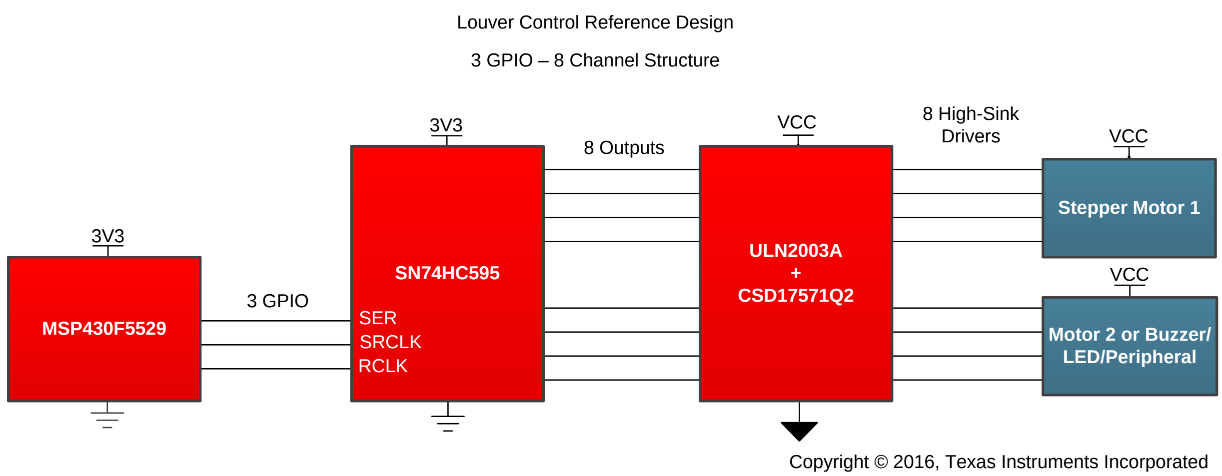


Figure 1. Block Diagram

Copyright © 2016, Texas Instruments Incorporated

1.4 Highlighted Products

1.4.1 SN74HC595

1.4.1.1 Description

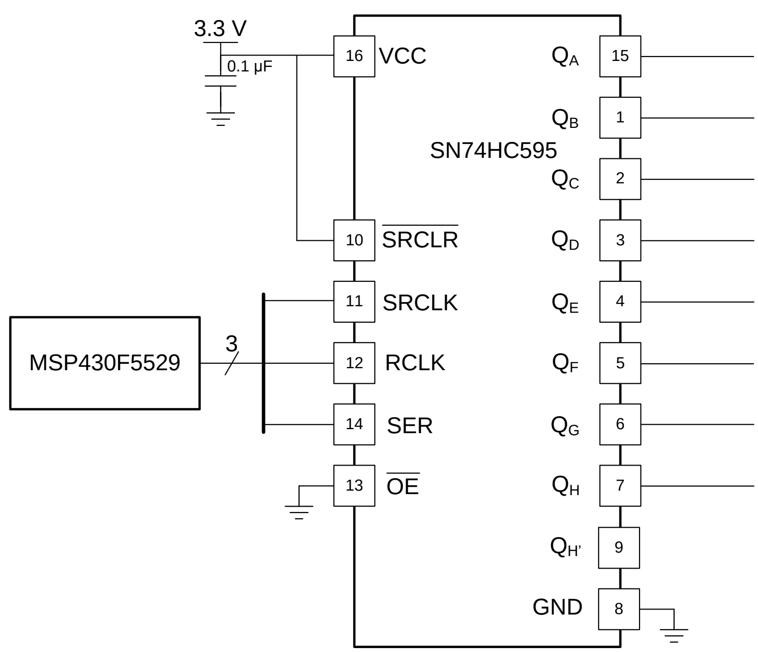
The SN74HC595 devices contain an 8-bit, serial-in, parallel-out shift register that feeds and 8-bit D-type storage register. The storage register has parallel 3-state outputs. Separate clocks are provided for both the shift and the storage register. The shift register has a direct overriding clear ($\overline{SRCLR}$) input, serial (SER) input, and serial output ($Q_{H'}$) for cascading shift registers. When the output-enable ($\overline{OE}$) input is high, the outputs are in the high-impedance state.

1.4.1.2 Features

- 8-bit serial-in, parallel-out shift
- Wider operating voltage range of 2 to 6 V
- high-current 3-state outputs can drive up to 15 LSTTL loads
- Low power consumption: 80-µA (maximum) I_{CC}
- t_{pd} = 13 ns (typical)
- Low input current: 1µA (maximum)
- Direct clear input
- Cascading output

1.4.1.3 Implementation

The SN74HC595 enables the serial-in, parallel-out functionality that is the key feature of this design. Ultimately, this device decreases the necessary GPIOs from eight or more down to three, freeing up an additional five or more GPIO pins on the microcontroller. The microcontroller sends three sets of data to the SN74HC595 and the parallel outputs drive the inputs of the ULN2003A in order to control high current outputs.



Copyright © 2016, Texas Instruments Incorporated

Figure 2. SN74HC595 Implementation

Copyright © 2016, Texas Instruments Incorporated

1.4.2 ULN2003A

1.4.2.1 Description

The UNL2003A is a high-voltage, high-current Darlington transistor array. The device consists of seven NPN Darlington pairs that feature high-voltage outputs with common-cathode clamp diodes for switching inductive loads.

The collector current rating of a single Darlington pair is 500 mA. The Darlington pairs can be paralleled for higher current capability. Applications include relay drivers, solenoid drivers, LED drivers, logic buffers, and stepper motor drivers.

1.4.2.2 Features

- 500-mA rated current outputs (per channel)
- High-voltage outputs: up to 50 V
- Output clamp diodes for switching inductive loads
- Inputs compatible with various types of logic
- Seven outputs

1.4.2.3 Implementation

The ULN2003A is a parallel-in, parallel-out Darlington pair array. The Darlington pair configuration allows for the outputs to sink high-currents (up to 500 mA per channel) to ground. Additionally, each channel of the ULN2003A has a common collector diode that enables driving of inductive loads. In this scenario, the inductive load is the stepper motor and the ULN2003A can be driven in a particular pattern to control the angle of the louver in the system.

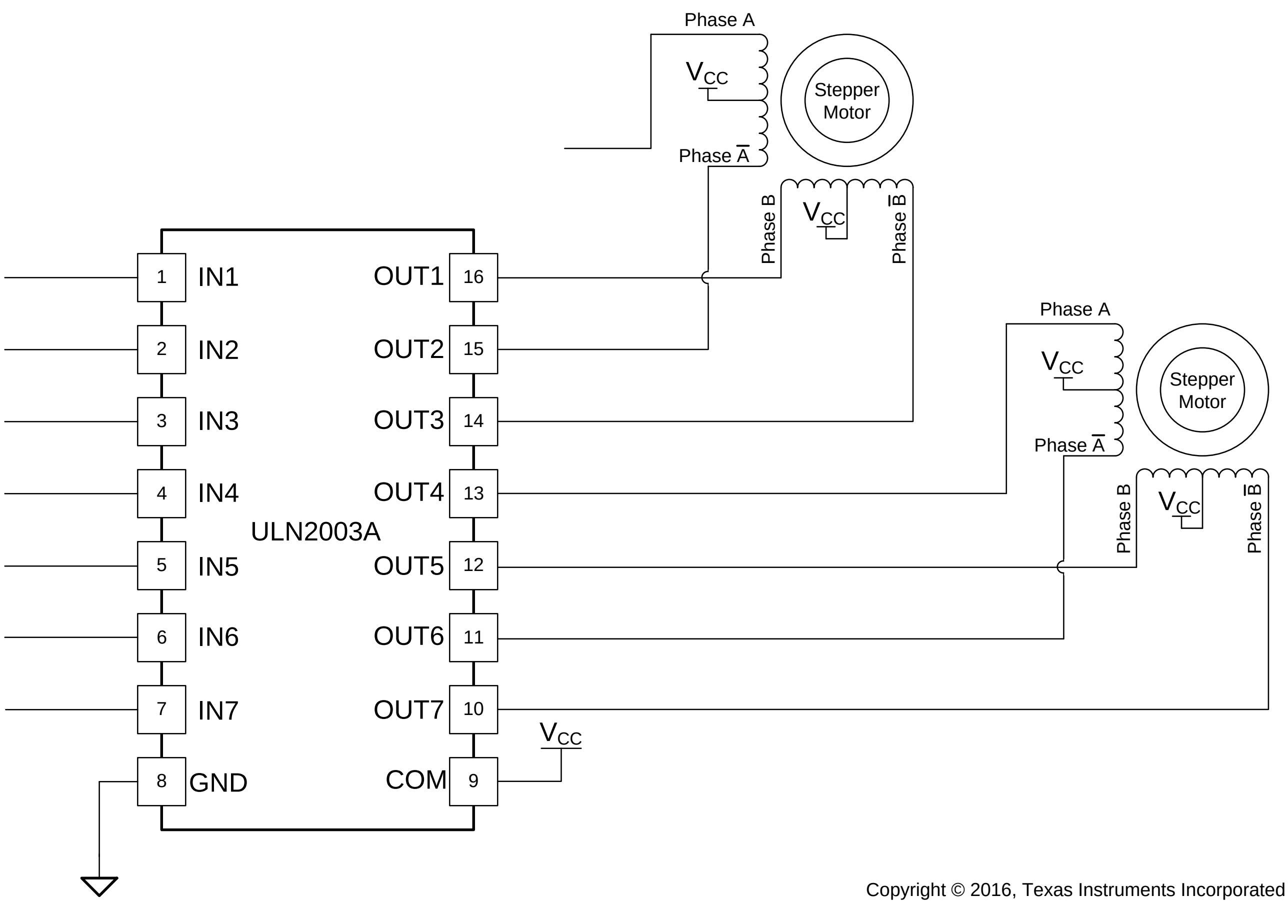


Figure 3. ULN2003A Implementation

Copyright © 2016, Texas Instruments Incorporated

1.4.3 CSD17571Q2

1.4.3.1 Description

The CSD17571Q2 is a 30 V, 20 mΩ, SON 2×2 NexFET power MOSFET designed to minimize losses in power conversion and load management applications, while offering excellent thermal performance for the size of the package.

1.4.3.2 Features

- Low Q_g and Q_{gd}
- Low thermal resistance
- Avalanche rated
- Pb-free terminal plating
- Halogen free
- SON 2-mm×2-mm plastic package

1.4.3.3 Implementation

The CSD17571Q2 enables the eight channel necessary to be able to drive two stepper motors. A unipolar stepper motor requires four channels, so adding one additional FET enables the control of two stepper motors. Other single FET or Darlington pair type devices may be suitable as well. The key specifications for this part in this application are the maximum drain-to-source voltage as well as the $R_{DS(on)}$.

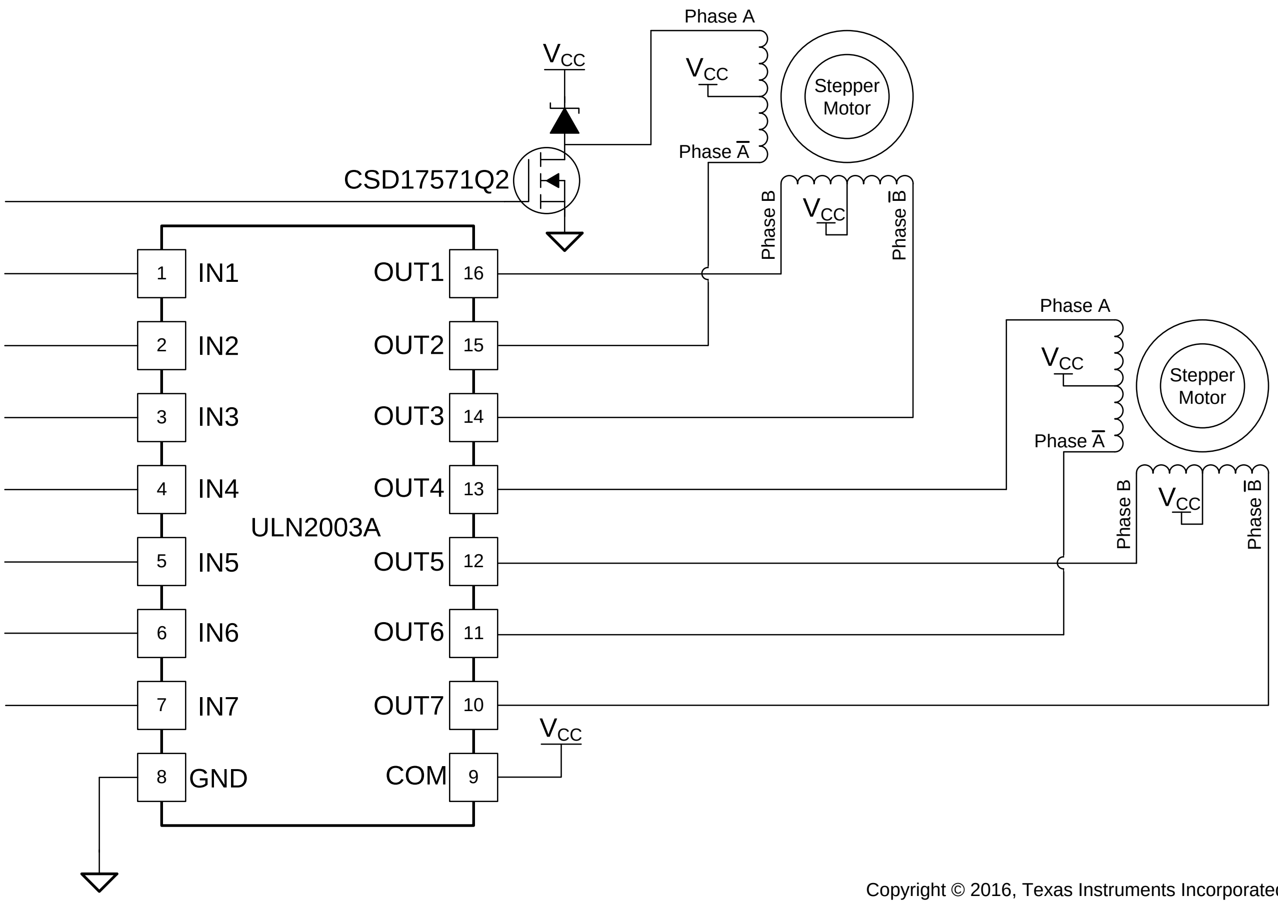


Figure 4. CSD17571Q2 Implementation

Copyright © 2016, Texas Instruments Incorporated

2 System Design Theory

2.1 System Diagram

Figure 5 describes a general overview of the connections required for this subsystem design. The MSP430F5529 drives the inputs of the SN74HC595, which converts a serial data stream to a parallel output. The parallel output data controls the inputs of the ULN2003A and the CSD17571Q2, which drive higher current peripherals such as a pair of stepper motors. The outputs of the ULN2003A can be used to drive other types of peripherals, including solenoids, relays, and LEDs. For additional information regarding peripheral driver applications and design considerations, see *What is a Peripheral Driver? Applications and Design Considerations* (SLVA822).

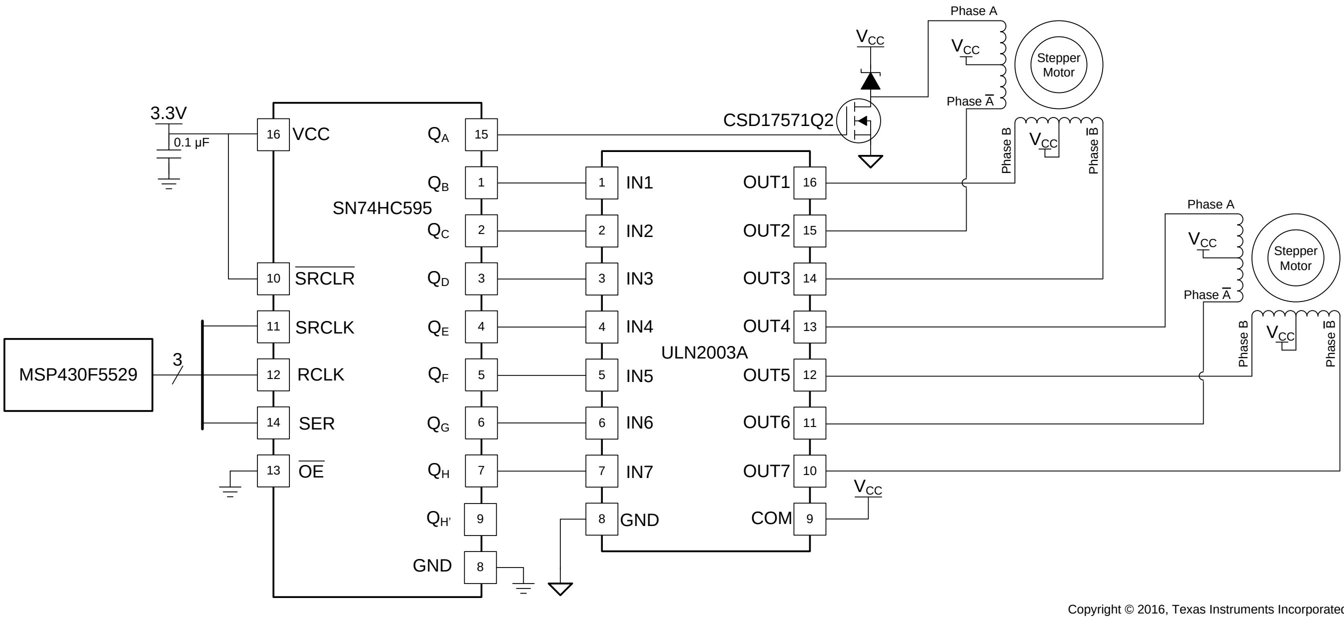


Figure 5. System Diagram

Copyright © 2016, Texas Instruments Incorporated

2.2 Detailed System Description

One advantage to this subsystem design is its ease of use. Starting with the microcontroller, only three GPIO pins are required to make this design operate. The three GPIO pins from the microcontroller control the three inputs to the SN74HC595, the data line (SER), the shift register clock (SRCLK), and the latch clock (RCLK).

The key to this design is understanding the internal operation of the SN74HC595 to be able to control the outputs effectively. Figure 6 shows the logic diagram for the SN74HC595. In this design, the OE pin is pulled low, keeping all outputs enabled. Additionally, the SRCLR input is held high so that the outputs are not cleared. This pin can be used to clear the outputs, however, that would require an additional GPIO from the microcontroller; instead, the SER input can be held low and the SRCLK and RCLK can be triggered eight times to clear all outputs.

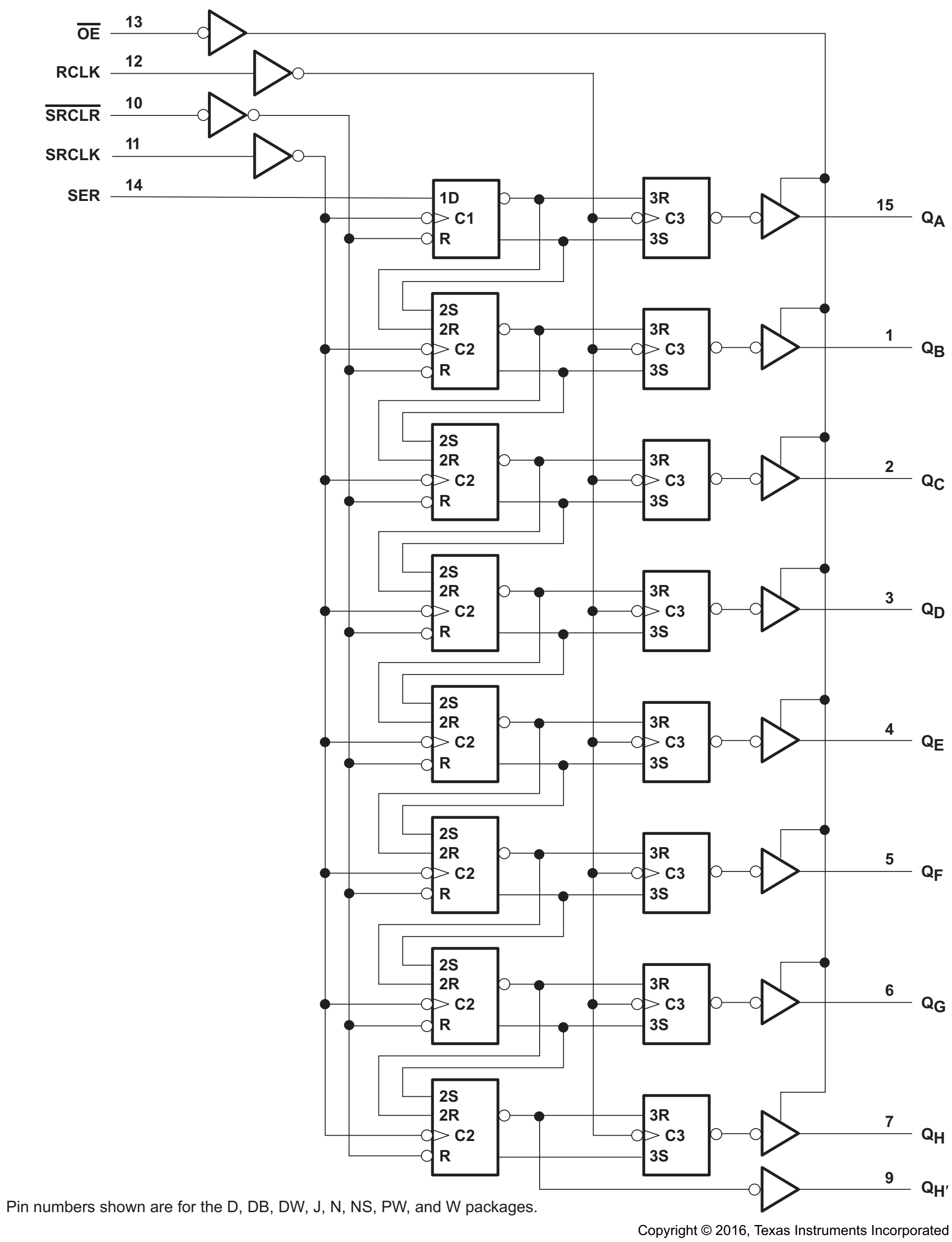


Figure 6. SN74HC595 Logic Diagram

Copyright © 2016, Texas Instruments Incorporated

In order to send the appropriate data to the outputs of the SN74HC595, a clock output is not required. The outputs of the SN74HC595 can simply be controlled by a bit-banging technique, sending low-to-high and high-to-low transitions only when they are needed and not specifically synchronized to any timer or clock. Figure 7 is a depiction of bit-banging to change the eight outputs of the SN74HC595.

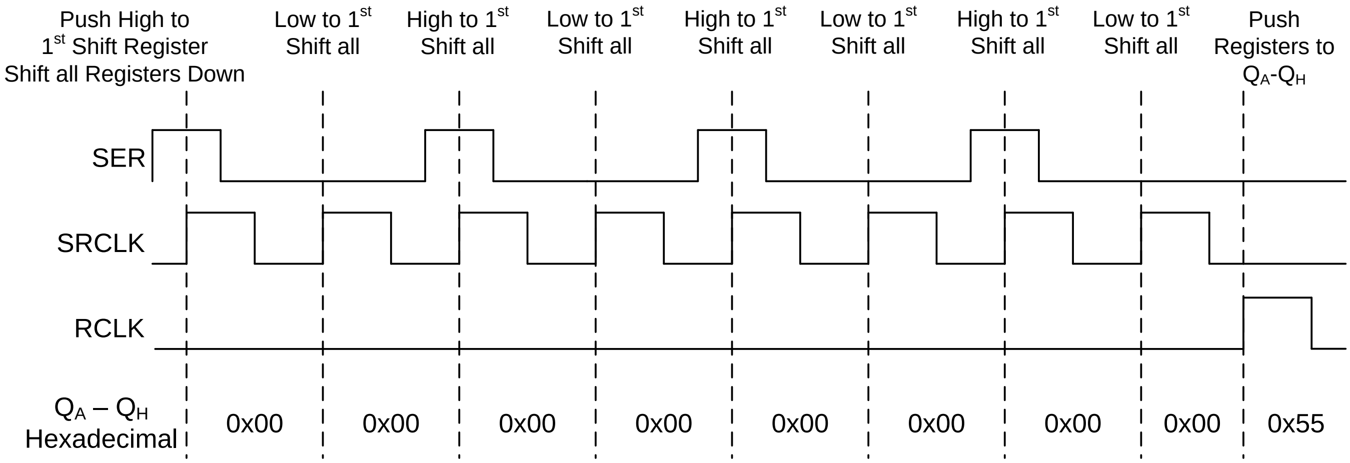


Figure 7. Bit-Banging to Set SN74HC595 Outputs

The frequency required to drive stepper motors is typically on the order of 100 Hz to 10 kHz, a speed at which any microcontroller can easily manage, so if a 1-kHz operation is assumed, the output drive channels only need to be updated every 1 ms. Shifting in and setting the output data for the motor, as shown in Figure 7, happens in a matter of microseconds, depending on the speed of the MCU. Once the SN74HC595 outputs are set, the MCU does not have to change the three GPIO pins for another millisecond, allowing it to process other actions.

Once the outputs of the SN74HC595 are set, the inputs of the ULN2003A and the CSD17571Q2 are driven high or low. Both the ULN2003A and the CSD17571Q2 act as inverters; when the input is high, the output is low. The key here is that when the output is low, it is activated, meaning the current is allowed to flow to the ground of the device. When the input is high, the output is sinking current, driving the peripheral. The resulting activation of each channel in a particular order is what allows a stepper motor to spin. For additional information regarding stepper motors and stepper motor driving patterns, see *Stepper Motor Driving with Peripheral Drivers (Driver ICs)* (SLVA767).

This method of driving a pair of unipolar stepper motors can be used to control the louver or other internals for an HVAC system. This design allows for control over as many peripherals as necessary by taking advantage of the cascade, or daisy-chain, capability of the SN74HC595. A daisy-chain configuration is shown in Figure 8. The number of channels can be expanded, and the number of GPIO pins required remains at three. Figure 8 shows an example of the easily expandable nature of this motor control subsystem. The upper highlighted section of the diagram shows the necessary implementation for a "base model" wall mounted HVAC unit, which only provides motor control, whereas the rest of the diagram shows an "additional features" implementation, which provides additional control as well as visible and audible feedback to the consumer.

Copyright © 2016, Texas Instruments Incorporated

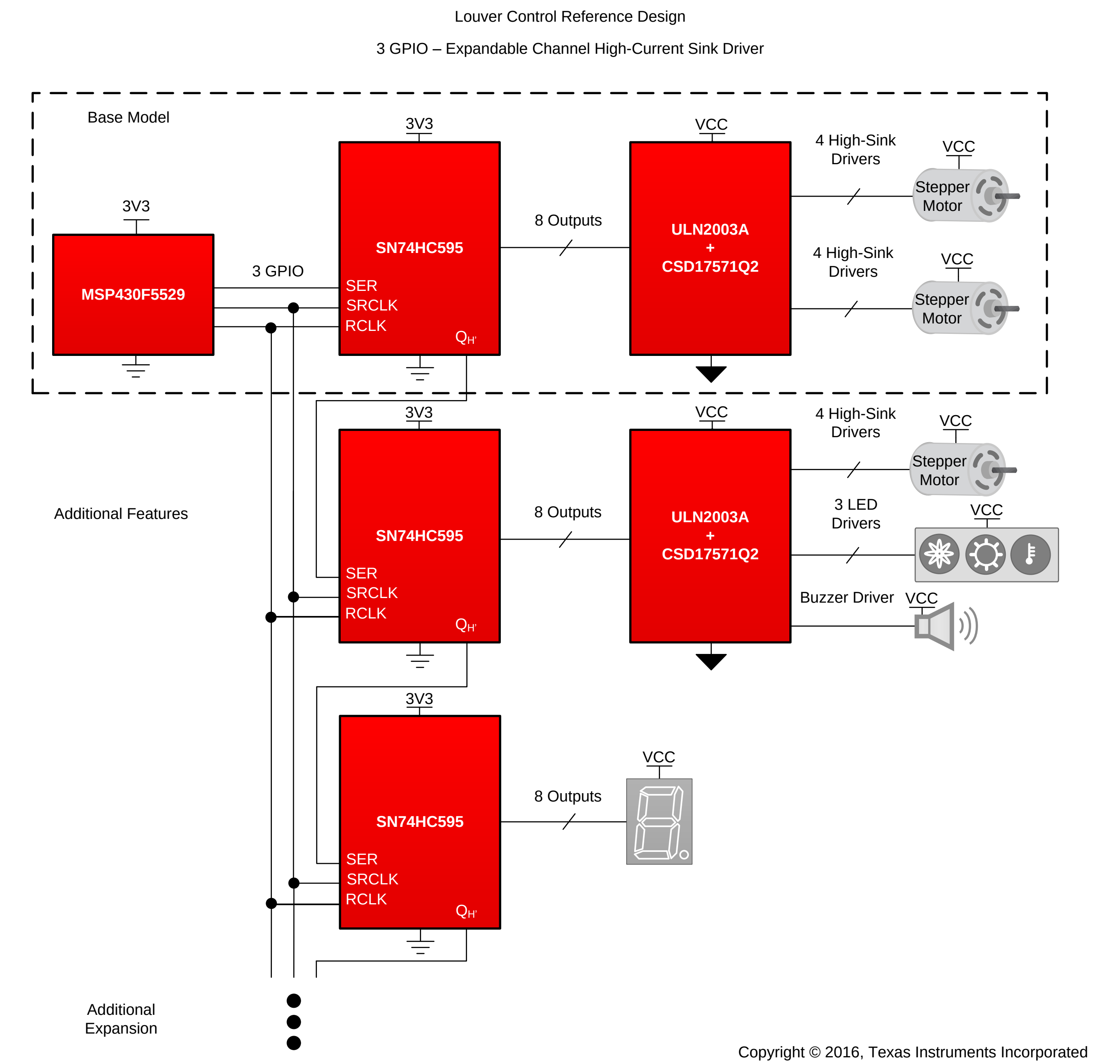


Figure 8. SN74HC595 "Daisy Chaining"

Copyright © 2016, Texas Instruments Incorporated

3 Getting Started Hardware and Software

3.1 Hardware

A BoosterPack™ module containing this reference design is available. It can be easily integrated with any LaunchPad™ in the MSP430™ LaunchPad ecosystem to drive up to eight high-current, high-voltage outputs using only three GPIO pins. For additional information regarding the BoosterPack, see the BOOSTXL-ULN2003 Tool Folder.

3.2 Software

For software examples regarding control of the SN74HC595 shift register to drive the inputs of the ULN2003A, see dev.ti.com/BOOSTXL-ULN2003.

For additional information regarding stepper motor driving patterns, including half-step, full-step, and wave drive, see *Stepper Motor Driving with Peripheral Drivers (Driver ICs)* (SLVA767).

Copyright © 2016, Texas Instruments Incorporated

4 Testing and Results

This TI Design was implemented in a BoosterPack form factor for ease of testing. Figure 9 displays how the design was tested. The BoosterPack was placed onto a MSP430F5529 Launchpad and powered through the USB connection. For more information regarding the Dual Stepper Motor Driver BoosterPack, see the BOOSTXL-ULN2003 Tool Folder.

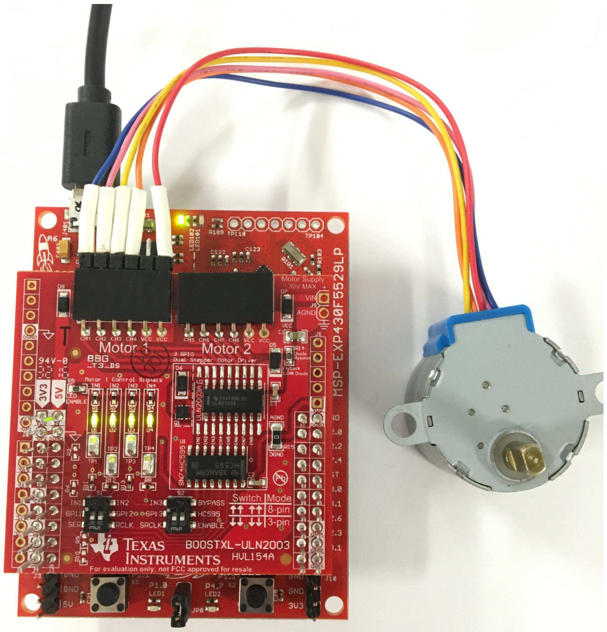


Figure 9. Test Setup

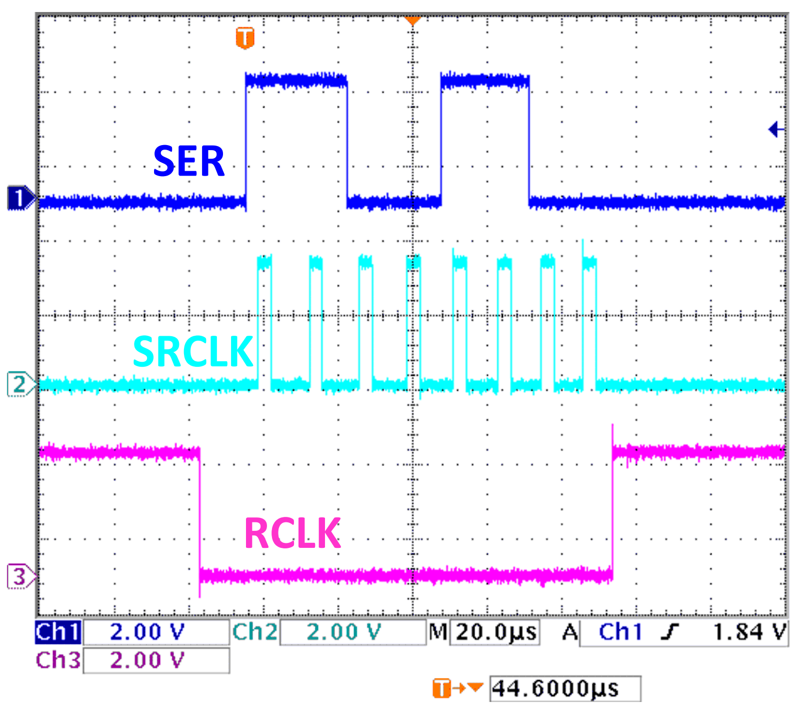


Figure 10. Oscilloscope Waveform of SER, SRCLK, and RCLK Input to SN74HC595

Copyright © 2016, Texas Instruments Incorporated

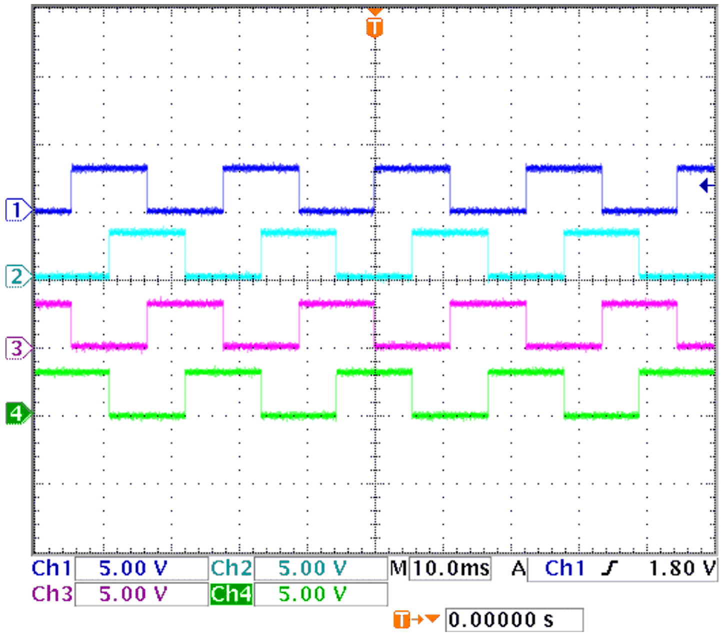


Figure 11. Output of SN74HC595 and Input to ULN2003A (Full-Step Pattern, Clockwise)

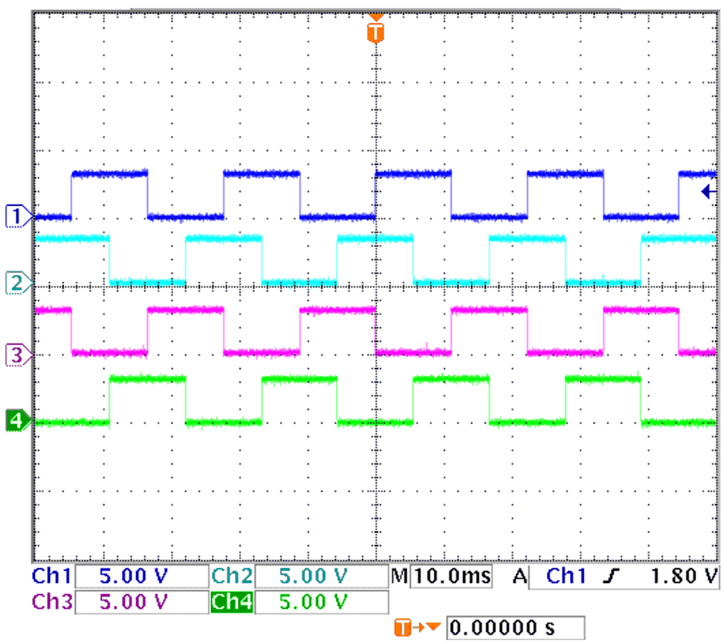


Figure 12. Output of SN74HC595/Input to ULN2003A (Full-Step Pattern, Counterclockwise)

Copyright © 2016, Texas Instruments Incorporated

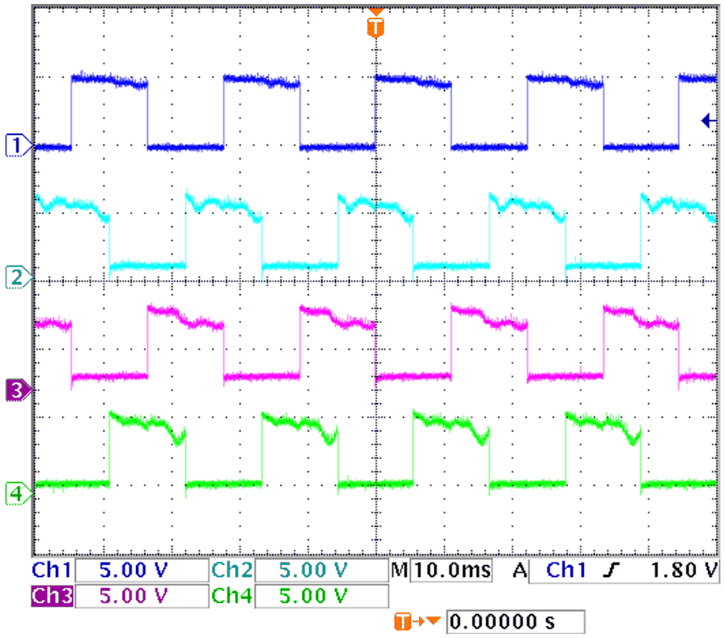


Figure 13. ULN2003A Output Motor Drive Pattern (Full-Drive Pattern, Clockwise)

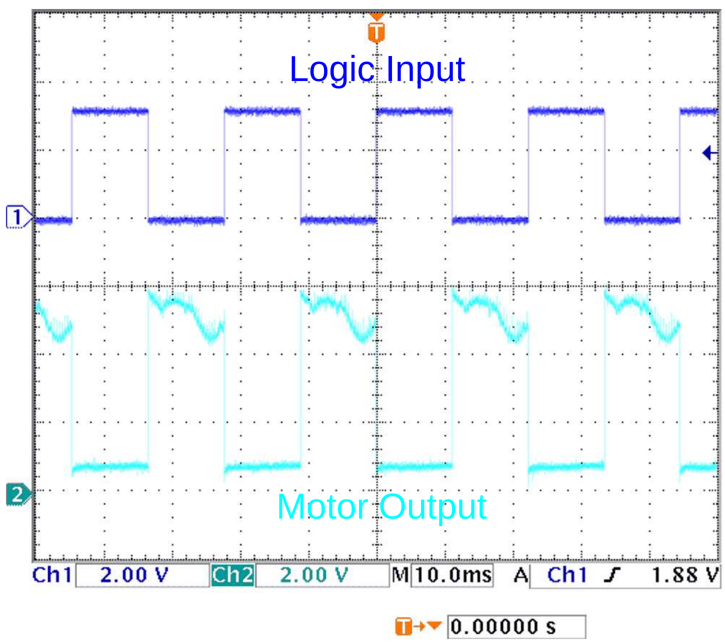


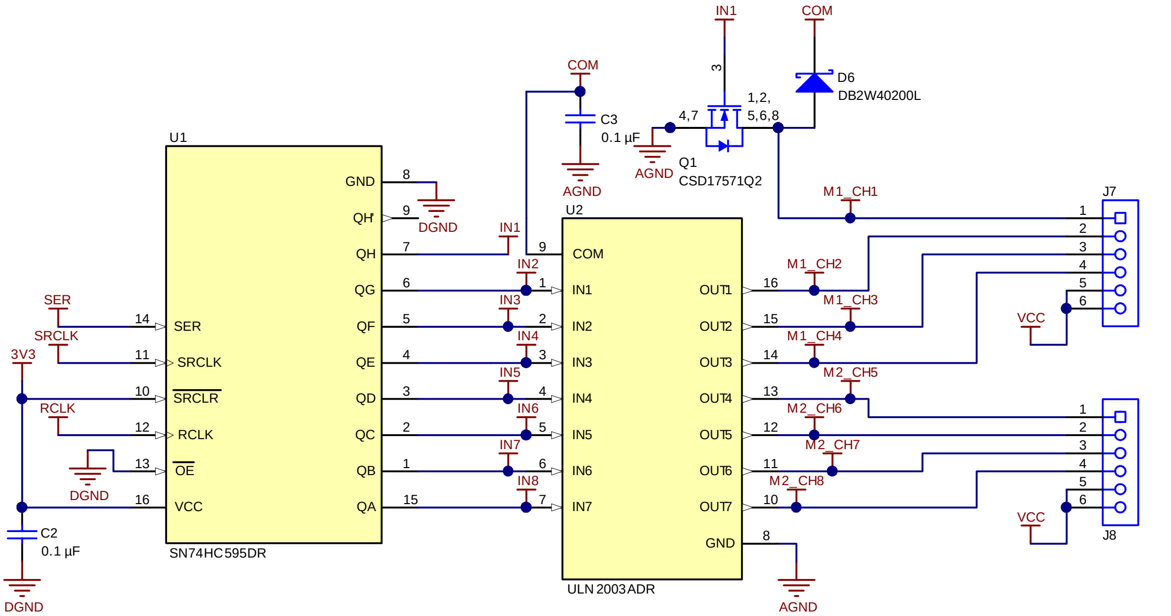
Figure 14. ULN2003A Logic Input and ULN2003A Drive Output

Copyright © 2016, Texas Instruments Incorporated

5 Design Files

5.1 Schematics

To download the schematics, see the design files at TIDA-01329.



Copyright © 2016, Texas Instruments Incorporated

Figure 15. Dual Stepper Motor Louver Control Schematic

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01329.

5.3 Layout Prints

To download the layer plots, see the design files at TIDA-01329.

5.4 Altium Project

To download the Altium project files, see the design files at TIDA-01329.

5.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01329.

5.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01329.

6 Software Files

For software examples regarding control of the SN74HC595 shift register to drive the inputs of the ULN2003A, see dev.ti.com/BOOSTXL-ULN2003.

For additional information regarding stepper motor driving patterns, including half-step, full-step, and wave drive, see *Stepper Motor Driving with Peripheral Drivers (Driver ICs)*.

Copyright © 2016, Texas Instruments Incorporated

7 References

1. Texas Instruments, *What is a Peripheral Driver? Applications and Design Considerations*, Application Report (SLVA822)
2. Texas Instruments, *Stepper Motor Driving with Peripheral Drivers (Driver ICs)*, Application Report (SLVA767)
3. Texas Instruments, *SNx4HC595 8-Bit Shift Registers With 3-State Output Registers*, SN74HC595 Datasheet (SCLS041)
4. Texas Instruments, *ULN200x, ULQ200x High-Voltage, High-Current Darlington Transistor Arrays*, ULN2003A Datasheet (SLRS027)
5. Texas Instruments, *CSD17571Q2 30V N-Channel NexFET Power MOSFETs*, CSD17571Q2 Datasheet (SLPS393)
6. Texas Instruments, *MSP430F552x, MSP430F551x Mixed-Signal Microcontrollers*, MSP430F5529 Datasheet (SLAS590)
7. Texas Instruments, *BOOSTXL-ULN2003 Dual Stepper Motor Driver BoosterPack*, BOOSTXL-ULN2003 Tool Folder (SLCU002)

8 About the Author

MICHAEL SCHULTIS is an applications engineer at Texas Instruments and is part of the Standard Linear and Logic Business Unit, where he is responsible for the linear power portfolio including developing reference designs and supporting customers regarding voltage references, linear voltage regulators, switching voltage regulators, and peripheral drivers. Michael earned his B.E. in biomedical and electrical engineering from Vanderbilt University in Nashville, TN.

Copyright © 2016, Texas Instruments Incorporated

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
Copyright © 2016, Texas Instruments Incorporated