



# THE DATASHEET OF BOOSTXL-ULN2003



# **BOOSTXL-ULN2003 Dual Stepper Motor Driver BoosterPack Hardware**

## **User's Guide**



Literature Number: SLCU002  
September 2016

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# **BOOSTXL-ULN2003 Dual Stepper Motor Driver BoosterPack Hardware**

## **1 Introduction**

### **1.1 BOOSTXL-ULN2003 Dual Stepper Motor Driver BoosterPack Overview**

The BOOSTXL-ULN2003 provides an easy-to-use development board to interface with up to two unipolar stepper motors using any Launchpad in the Launchpad Ecosystem. This user's guide details a hardware description of the BoosterPack, how to interface the BoosterPack with external hardware, various modes of operation, and additional features.

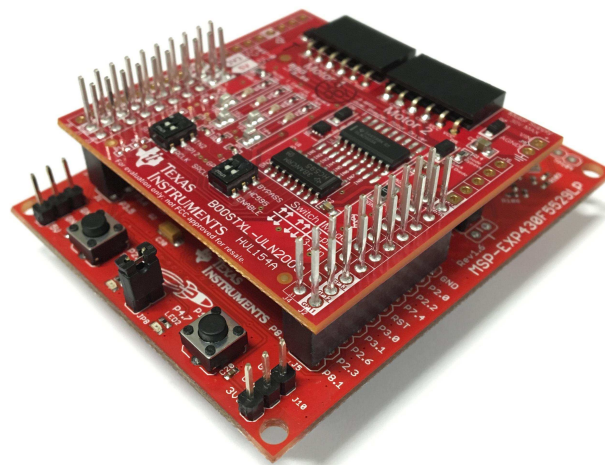
The BOOSTXL-ULN2003 allows for the control of eight high-current (up to 500 mA per channel), high voltage (up to 30 V), sink outputs. These outputs are controlled either through a serial (3-pin) or parallel (8-pin) mode. Using the BOOSTXL-ULN2003 in serial 3-pin mode allows for control of two unipolar stepper motors while only requiring 3 General-Purpose Input/Output (GPIO) pins, ultimately allowing for flexibility in design and reduction in the number of GPIO pins required.

The BOOSTXL-ULN2003 can not only be used to provide an interface to unipolar stepper motors, but also can be used in the following applications.

- Relay Driving
- Solenoid Driving
- LED Driving
- High-Voltage Logic Level Shifting

For additional information regarding these applications, see [What is a Peripheral Driver? Applications and Design Considerations](#).

The Boosterpack is not limited to one specific application at a time, but can be used for all of these applications simultaneously. For example, one BoosterPack could enable driving one stepper motor, driving one relay, driving two LEDs, and shifting a 3.3-V logic signal to a 24-V logic signal at the same time.



**Figure 1. BOOSTXL-ULN2003 Connected to MSP-EXP430F5529LP**

## 2 Hardware Description

### 2.1 Top and Bottom View

Figure 2 is a top view of the BOOSTXL-ULN2003, and Figure 3 is a bottom view of the BOOSTXL-ULN2003.

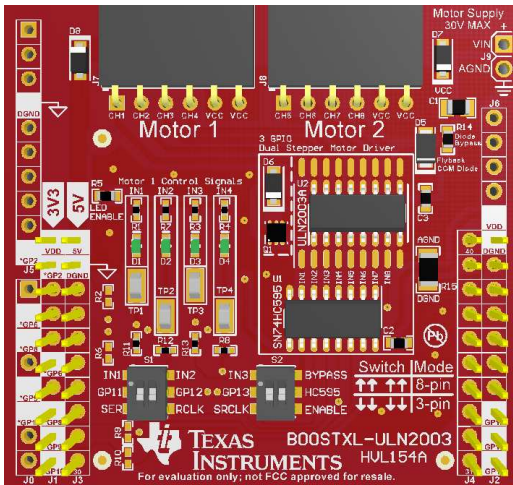


Figure 2. Top View of BOOSTXL-ULN2003

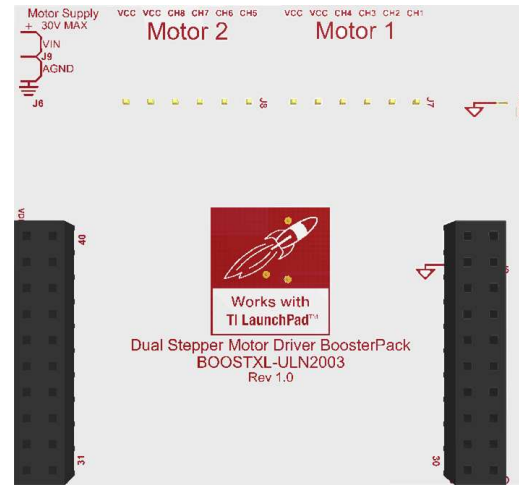


Figure 3. Bottom View of BOOSTXL-ULN2003

### 2.2 Board Overview

Figure 4 shows an overview of the BOOSTXL-ULN2003 BoosterPack. The main features such as devices, switches, connectors, and LEDs are highlighted.

See Section 2.4 for additional details regarding each section.

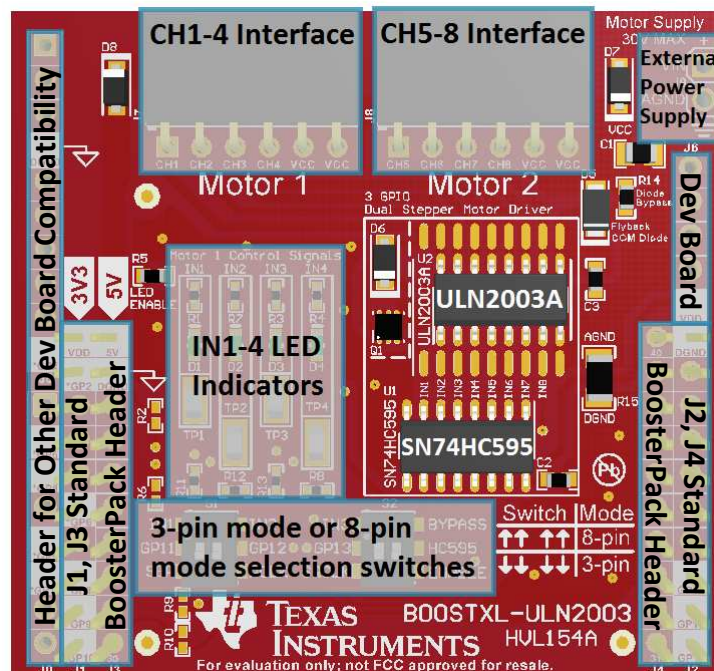
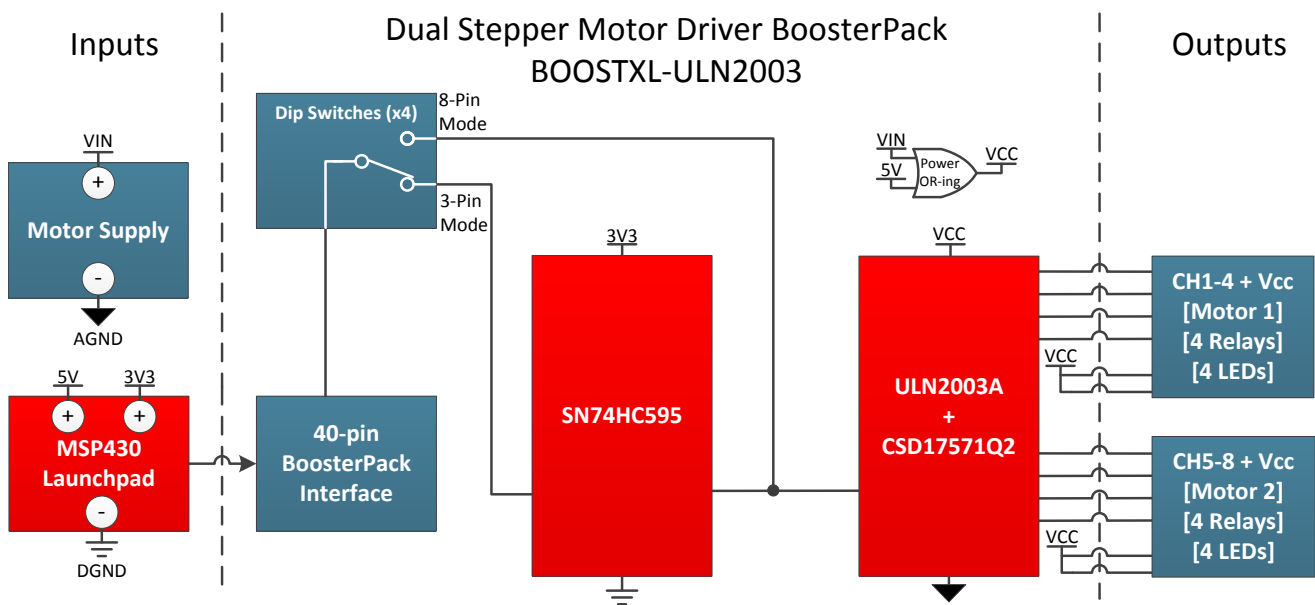


Figure 4. BOOSTXL-ULN2003 Top Side Overview

### 2.3 Block Diagram

Figure 5 details a block diagram of the BOOSTXL-ULN2003 BoosterPack. The 40-pin BoosterPack header allows the BoosterPack to be interfaced with any LaunchPad in the MSP430 LaunchPad ecosystem. See [ti.com/launchpad](http://ti.com/launchpad) for a list of all available MSP430 LaunchPads. A row of four switches allow the user to choose between a parallel, direct-drive (8-pin) mode and a serial (3-pin) mode of control of the ULN2003A.

The ULN2003A is a 7-channel Darlington pair array that is used to drive motors, solenoids, LEDs, or relays. See the [ULN2003A product folder](#) for additional overview regarding this device. The CSD17571Q2 is a TI N-Channel NexFET Power MOSFET that is paired with the ULN2003A in order to enable an eighth output channel. See the [CSD17571Q2 product folder](#) for additional overview regarding this device. The SN74HC595 shift register enables the 3-pin control mode, ultimately reducing the number of GPIOs required for driving eight output channels. See the [SN74HC595 product folder](#) for additional overview regarding this device. See Section 4 for additional information on how to select between 3-pin mode and 8-pin mode.



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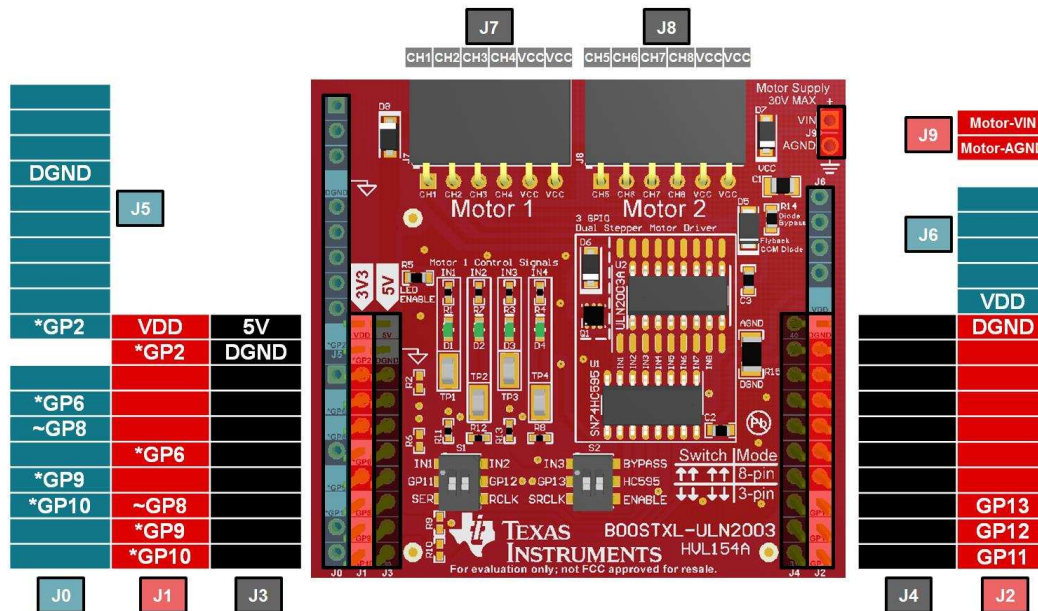
Figure 5. BOOSTXL-ULN2003 Block Diagram

## 2.4 Connector, Switch, and LED Descriptions

### 2.4.1 Connectors

The signal assignment on the BoosterPack pin connectors is shown in Figure 6. The J1-J4 descriptions on the BoosterPack follow the J1-J4 convention for the Launchpad ecosystem. See [ti.com/launchpad](http://ti.com/launchpad) for further description of the 40-pin BoosterPack standard.

Only the outer two pin columns, J1 and J2 (highlighted in red below) are required for BoosterPack operation, the inner 2 columns, J3 and J4, are provided to pass signals from any 40-pin Launchpad to other BoosterPack boards that may require these pins. The additional headers, J0, J5, and J6 are for interfacing with other development boards. See Section 3.3 for details regarding connecting to other development boards.



- (1) Pins with no name/description are not connected. Pins with the same name/description are shorted together.
- (2) \*~ These pins are not required for BoosterPack operation.
- (3) \* These pins are not connected out of the box. To enable control of this board through these pins, see Section 4.3.1.
- (4) ~ This pin is connected to IN4 out of the box. This allows for channels IN1-IN4 to be driven directly using 8-pin parallel mode. A resistor is connected to protect the line from bus contention if 3-pin mode is being used and this pin is being used for another purpose.

**Figure 6. BOOSTXL-ULN2003 2x20 Header Description**

**Table 1. J1 and J2 Connector Pinout Description**

| Direction | Pin Name | Pin Number | Pin Number | Pin Name | Direction |
|-----------|----------|------------|------------|----------|-----------|
| POWER     | VDD      | J1.1       | J2.20      | DGND     | POWER     |
| INPUT     | GP2*     | J1.2       | J2.19      |          |           |
|           |          | J1.3       | J2.18      |          |           |
|           |          | J1.4       | J2.17      |          |           |
|           |          | J1.5       | J2.16      |          |           |
| INPUT     | GP6*     | J1.6       | J2.15      |          |           |
|           |          | J1.7       | J2.14      |          |           |
| INPUT     | GP8~     | J1.8       | J2.13      | GP13     | INPUT     |
| INPUT     | GP9*     | J1.9       | J2.12      | GP12     | INPUT     |
| INPUT     | GP10*    | J1.10      | J2.11      | GP11     | INPUT     |

### 2.4.2 Switches

The four on-board dip switches are used to select between 3-pin mode and 8-pin mode operation of the BoosterPack. Descriptions for each of the switches are provided in [Table 2](#).

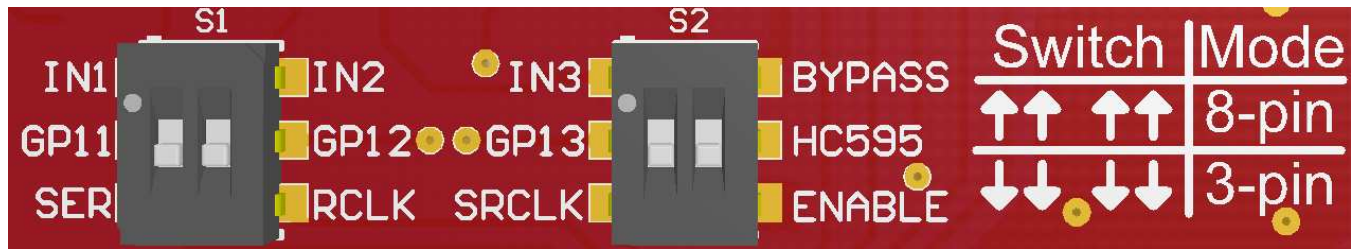


Figure 7. Board Image of Switches

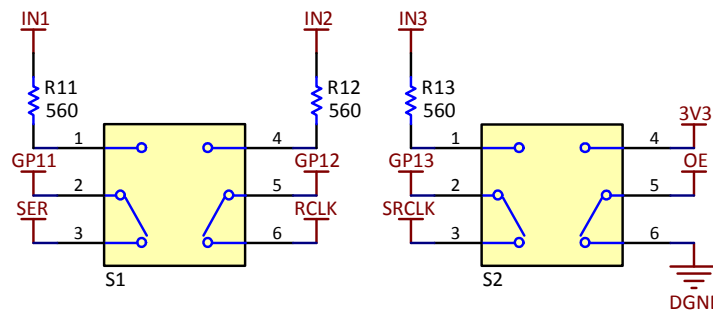


Figure 8. Schematic View of Switches

Table 2. Dip Switch Description

| Reference  | Description  |
|------------|--|
| S1 - GP11  | This SPDT switch directs the signal from BoosterPack header input GP11. If the switch is down, it connects GP11 to the SER input of the SN74HC595. If the switch is up, it connects GP11 directly to IN1 – ultimately connected to the gate of the CSD17571Q2 FET.<br>Switch Down = 3-pin Serial Mode<br>Switch Up = 8-pin Parallel Mode   |
| S1 - GP12  | This SPDT switch directs the signal from BoosterPack header input GP12. If the switch is down, it connects GP12 to the RCLK input of the SN74HC595. If the switch is up, it connects GP12 directly to IN2 – ultimately connected to 1B of the ULN2003A device.<br>Switch Down = 3-pin Serial Mode<br>Switch Up = 8-pin Parallel Mode   |
| S2 - GP13  | This SPDT switch directs the signal from BoosterPack header input GP13. If the switch is down, it connects GP13 to the SRCLK input of the SN74HC595. If the switch is up, it connects GP13 directly to IN3 – ultimately connected to the 2B of the ULN2003A device.<br>Switch Down = 3-pin Serial Mode<br>Switch Up = 8-pin Parallel Mode  |
| S2 - HC595 | This SPDT switch connects the $\overline{OE}$ pin either to 3V3 or DGND. This determines whether or not the SN74HC595 outputs are enabled or are in high-impedance (Hi-Z) mode. If the switch is down, it enables the SN74HC595 outputs. If the switch is up, it disables the SN74HC595 outputs. Disabling these outputs is required for 8-pin Parallel Mode to avoid bus contention at the inputs of the ULN2003A and the CSD17571Q2 FET.<br>Switch Down = 3-pin Serial Mode<br>Switch Up = 8-pin Parallel Mode |

### 2.4.3 LEDs

The four on-board LEDs provide visual feedback for the IN1 through IN4 signals. When operating in 3-pin mode these LEDs are driven by the SN74HC595, and when operating in 8-pin mode these LEDs are being driven directly by the MSP430 GPIO pins.

If the user wants to disable the onboard LEDs, resistor R5 can be removed. Additional details are found in [Section 2.6.2](#).

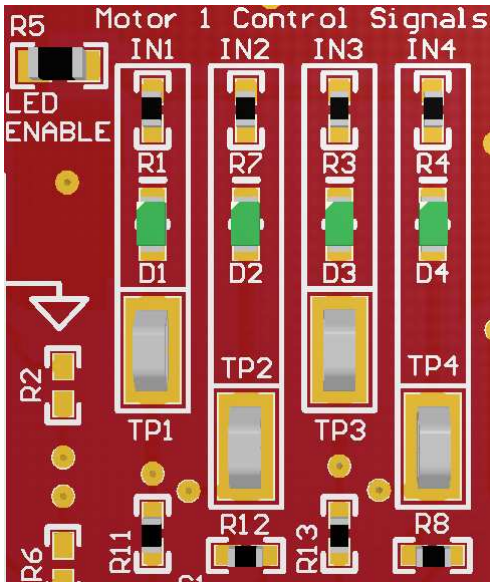


Figure 9. Board Image of LEDs

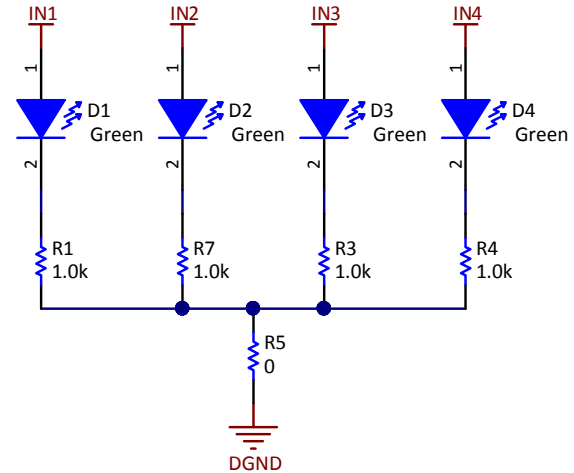


Figure 10. Schematic View of LEDs

Table 3. LED Description

| Reference | Description   |
|-----------|---|
| D1        | D1 is connected to the signal IN1. D1 is on when IN1 is high, and is off when IN1 is low. When IN1 is high, M1_CH1 is activated – ultimately being pulled to AGND as the CSD17571Q2 inverts the logic signal. |
| D2        | D2 is connected to the signal IN2. D2 is on when IN2 is high, and is off when IN2 is low. When IN2 is high, M1_CH2 is activated – ultimately being pulled to AGND as the ULN2003A inverts the logic signal.   |
| D3        | D3 is connected to the signal IN3. D3 is on when IN3 is high, and is off when IN3 is low. When IN3 is high, M1_CH3 is activated – ultimately being pulled to AGND as the ULN2003A inverts the logic signal.   |
| D4        | D4 is connected to the signal IN4. D4 is on when IN4 is high, and is off when IN4 is low. When IN4 is high, M1_CH4 is activated – ultimately being pulled to AGND as the ULN2003A inverts the logic signal.   |

## 2.5 Powering the BOOSTXL-ULN2003

### 2.5.1 Powering the On-Board Devices

The BoosterPack is designed to accept power from a connected Launchpad. The 3.3 V line from the Launchpad is required to power the SN74HC595 device. The 3.3 V line from the LaunchPad cannot source enough current to power motors, relays, or LEDs, so an additional source of power is required as described in [Section 2.5.2](#).

### 2.5.2 Powering the Motor or Other Peripherals

The method of powering the external peripherals is dependent upon the LaunchPad being used in addition to the output current requirements.

For higher current or voltage applications, the external motor supply pins should be connected to an external supply as shown in [Figure 11](#). The maximum voltage supplied through these pins should not exceed 30 V, or permanent damage to components may occur. While there is some protection against reverse polarity included on the board, note the correct orientation of the motor supply pins to avoid permanent damage to the board.

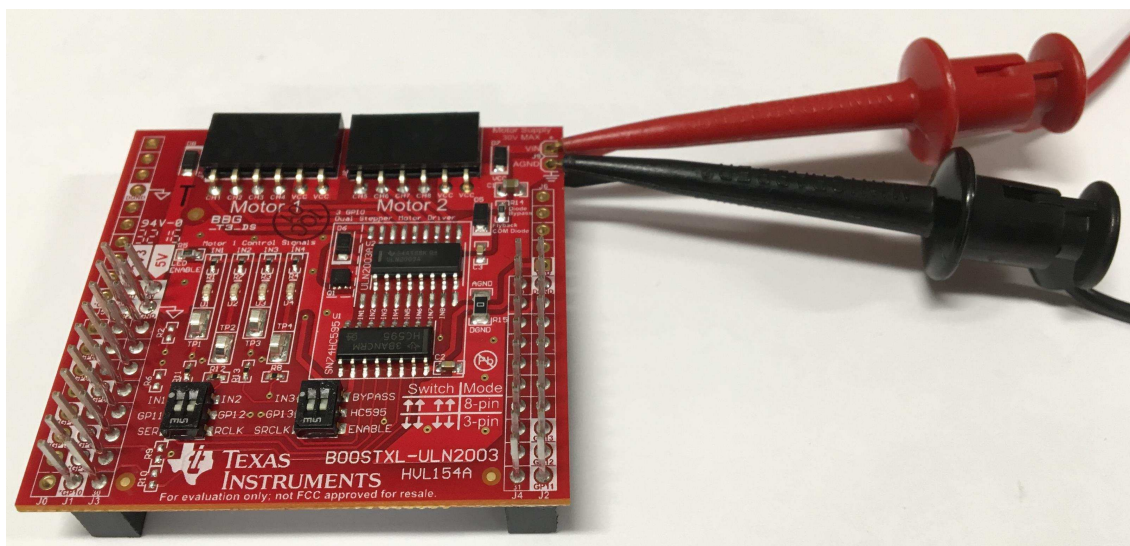


Figure 11. External Supply Connected to Motor Supply Pins

As shown in [Figure 12](#), the VCC connected to the motor peripheral to provide power is created by using power OR-ing diodes.

- If there is no 5-V line available from the LaunchPad, the motor supply is required to power the external peripherals.
- If there is a 5-V line connected, and no motor supply is connected, the VCC pins provide a voltage close to 5 V.
- If there is a 5-V line connected, and the motor supply voltage is connected and greater than 5 V, the motor supply is used to power any external peripherals.

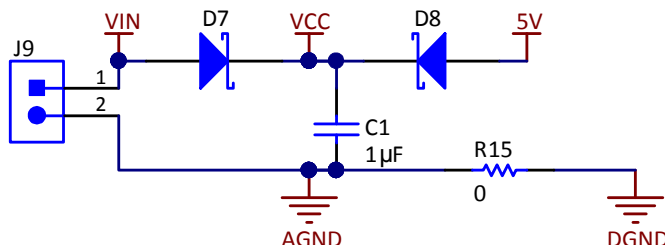
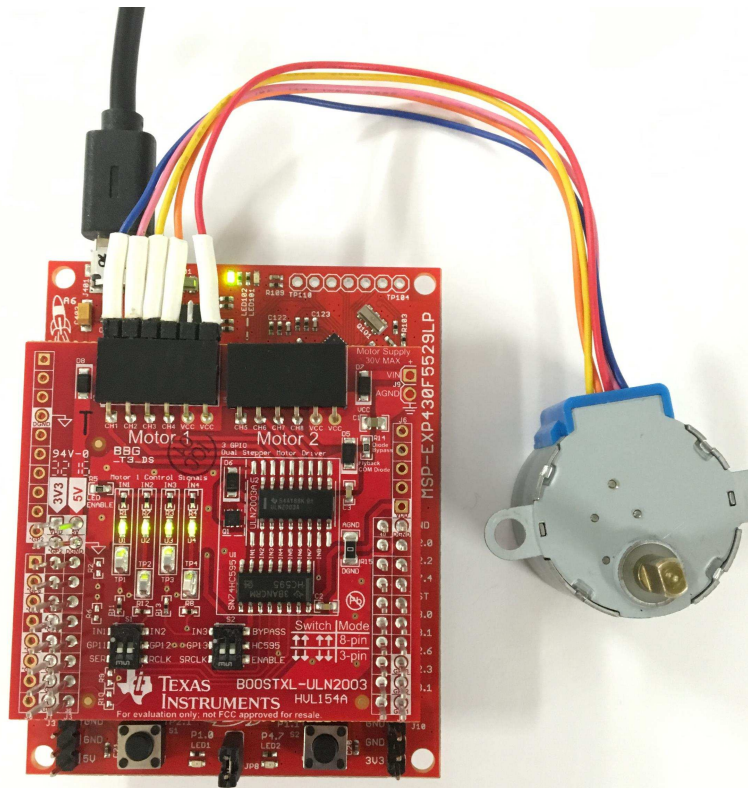


Figure 12. On-Board Power OR-ing

Some LaunchPad boards have a 5-V supply pin, which is powered directly from the USB port. This supply can be used to power peripherals, as shown in Figure 13, but there are some exceptions to when this can be used (See the following NOTE). The 5-V stepper motor used in Figure 13 below has the following Digi-Key Part Number: 1528-1366-ND. A 12-V version of this stepper motor has the following Digi-Key Part Number: 1528-1367-ND.



**Figure 13. USB Powering a Single Motor (See NOTE)**

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**NOTE:** When using the 5-V pin (USB Power) to provide power to an external peripheral, TI does not recommend to exceed 250 mA, and further caution should be taken when powering additional BoosterPacks. TI does not recommend to power more than one stepper motor from this board when using the 5-V LaunchPad power pin.

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## 2.6 Other Hardware Highlights

### 2.6.1 Additional Device Compatibility

While the board initially comes populated with a ULN2003A device, this board is compatible with many other pin-to-pin devices that perform a similar function. As shown in [Figure 14](#), the Boosterpack has the landing pattern for both the 16-pin D (SOIC) as well as the 18-pin DW (WIDE SOIC) package. [Figure 15](#) shows the Boosterpack populated with the ULN2803A device.

If the ULN2003A device is depopulated, the following list of devices can be populated in order to be evaluated.

- [ULQ2003A](#) - -40°C to +105°C Temperature Range
- [ULQ2003-Q1](#) - Automotive Qualified Variant
- [ULN2003LV](#) - FET based variant
- [ULN2003V12](#) - Wider-Voltage FET based variant
- [ULN2803](#) - 8 channel variant
- [TPL7407L](#) - FET based variant with 40V outputs and drive circuitry to decrease power dissipation

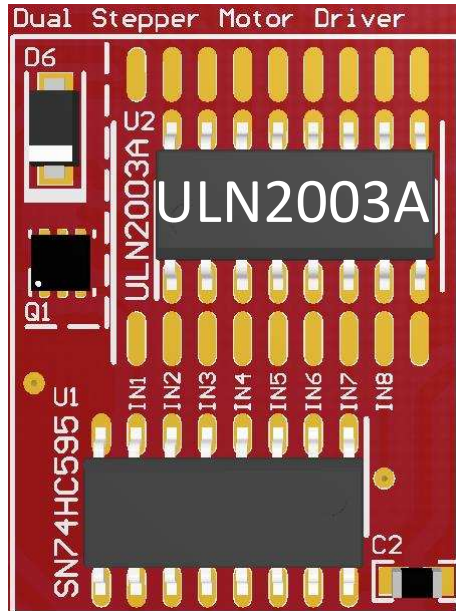


Figure 14. BoosterPack With ULN2003A



Figure 15. BoosterPack With ULN2803A

### 2.6.2 Disabling the On-Board LEDs

Figure 16 shows the section of the board with the LEDs. The R5 resistor is labeled *LED ENABLE* because when a 0-Ω resistor is populated here, it allows a path for current flow through the LEDs. The on-board LEDs can be disabled easily by depopulating this R5 resistor. Figure 17 shows the resistor depopulated, so there is no longer a path for current to flow through the LEDs, thereby disabling them.

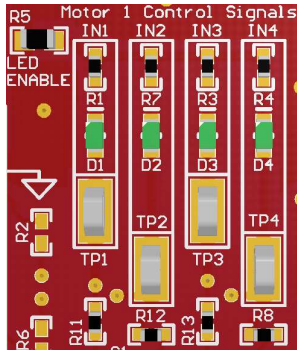


Figure 16. Board Image of LED Section

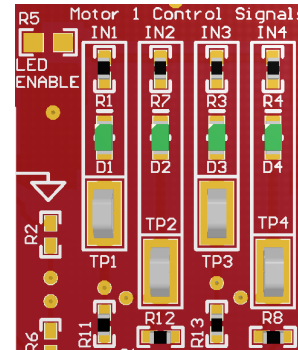


Figure 17. LED Section With R5 Depopulated

### 2.6.3 Enabling Quick Inductor Discharge

The ULN2003A has internal flyback diodes to suppress voltage spikes due to inductive kickback. Stepper Motors and relays have inductive kickback that is suppressed by these internal diodes. The rate of discharge of the inductor is also directly proportional to the voltage across the inductor when discharging.

Figure 18 shows the section of the board near the COM pin of the ULN2003A device. Diode D5, also labeled *Flyback COM diode*, is a 12-V Zener diode that is in series with the internal flyback diodes of the ULN2003A. Normally there is a 0-Ω resistor (R14) in parallel with this Zener diode, also labeled *Diode Bypass*, effectively bypassing the Zener diode. To enable the quick inductor discharge, the *Diode Bypass* resistor (R14) should be depopulated. Figure 19 shows the board with this resistor depopulated, ultimately enabling quick inductor discharge.

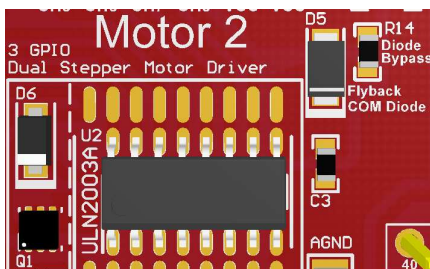


Figure 18. Board Image of COM Diode Section

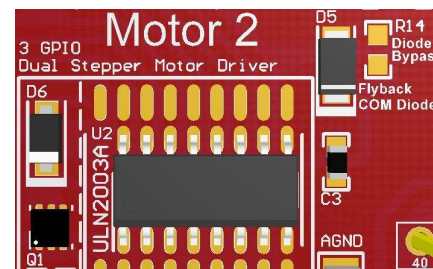


Figure 19. COM Diode Section With R14 Depopulated

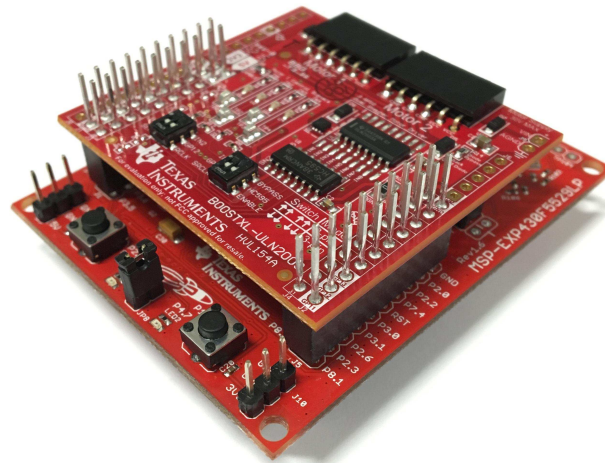
### 3 Interfacing With External Hardware

#### 3.1 Connecting to a LaunchPad

The BoosterPack is ready to connect to any LaunchPad out of the box. [Figure 20](#) shows the correct orientation of the BoosterPack on the LaunchPad.

**CAUTION**

The connectors should be aligned carefully as misalignment could cause permanent damage to the BoosterPack.

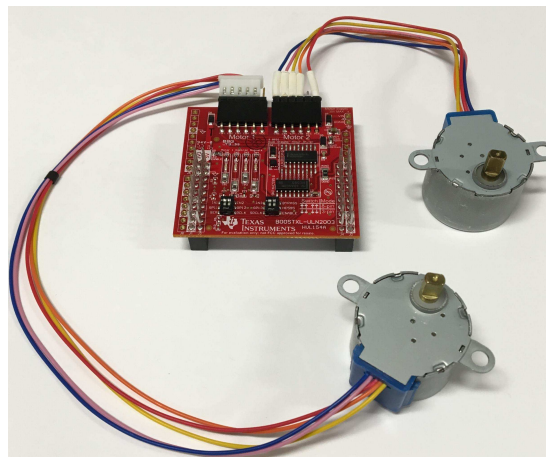


**Figure 20. BoosterPack Connected to MSP430F5529 LaunchPad**

#### 3.2 Connecting a Motor or Other Peripherals

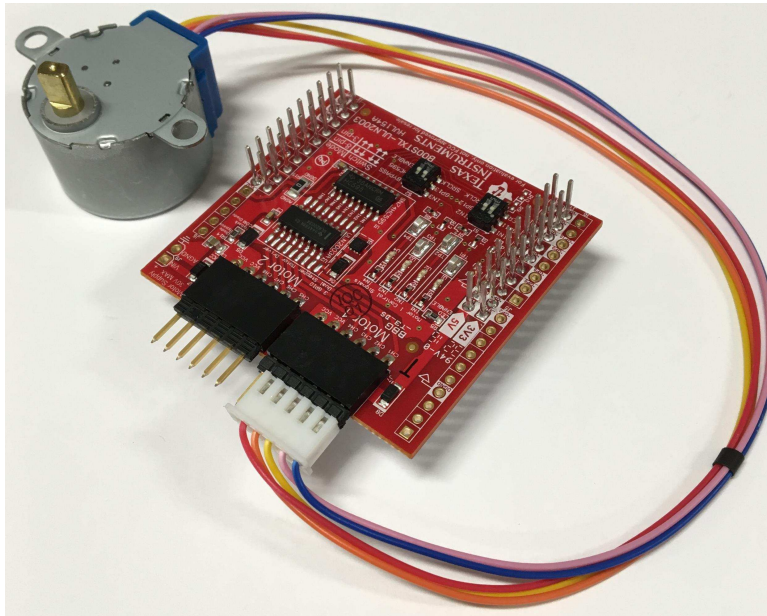
The Boosterpack provides two standard 100 mil spacing female receptacles to interface two unipolar stepper motors or other peripherals such as relays, solenoids, or LEDs.

Each receptacle provides a six-pin interface. Four pins are dedicated to the outputs of the ULN2003A and CSD17571Q2 to drive the peripheral, and two pins are connected to the motor supply that is connected to the board. These two VCC pins allow for connection to both 5-pin and 6-pin type Unipolar stepper motors. [Figure 21](#) shows two 5-pin unipolar motors connected to the BoosterPack.



**Figure 21. BoosterPack With Two Stepper Motors**

As shown in [Figure 22](#), a male to male header can also be added to the receptacle to help interface with standard 5-pin or 6-pin unipolar stepper motors with female receptacles.



**Figure 22. BoosterPack with Motor and Male Expansion Header**

### 3.3 Connecting to Other Development Boards

The BoosterPack is compatible with Arduino development boards, but some additional hardware is required beyond what is supplied in the box. The following list shows the additional required materials. These must be populated on the BoosterPack to enable a hardware interface with the development board.

- J0 Male Pin Header
- J5 Male Pin Header
- J6 Male Pin Header

Once the additional headers are populated, the BoosterPack can be connected to the development board.

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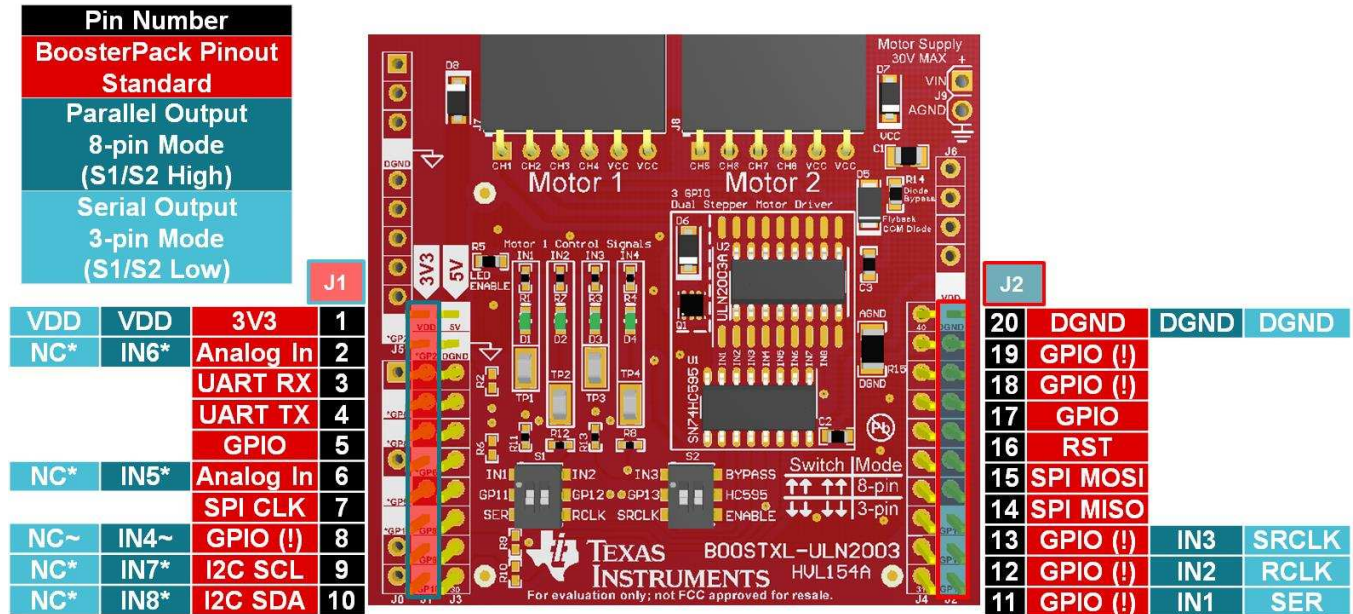
**NOTE:** The BoosterPack must be placed on the development board upside down for the pins to align properly.

---

## 4 Functional Modes

### 4.1 Modes of Operation Overview

Figure 23 provides a brief overview of how the Boosterpack pins are connected to either the SN74HC595 or the ULN2003A based on the selected mode of operation. Additional details for 3-pin mode and 8-pin mode can be found in Section 4.2 and Section 4.3 respectively.



- (1) \*There are NO resistors populated for pins GP6, GP2, GP9, and GP10, therefore there will be no direct connection to IN5, IN6, IN7, and IN8 respectively. 0 Ohm or solder bridge connections can be made to connect these pins in order to enable the full functionality of 8 pin mode. See Section 4.3.1 for additional details
- (2) ~There IS a resistor populated for pin IN4, therefore it can be used in 8-pin mode without bus contention; however, in 3-pin mode it will draw current if GP8 is set low. The resistor allows IN4 and GP8 to be different voltage levels when GP8 is being used for another purpose while the Boosterpack is in 3-pin mode. See Section 4.2.1 for additional details.

Figure 23. BOOSTXL-ULN2003 Mode Overview

## 4.2 3-pin Serial Mode

### 4.2.1 Enabling 3-pin Mode

The BoosterPack has all of the required components to run 3-pin Mode out of the box. To enable this mode of operation, the four dip switches should be in the lower position. Each switch works as defined in Table 2.

### 4.2.2 3-pin Mode of Operation

Figure 24 shows the effective schematic for the 3-pin mode of operation. Inputs GP11, GP12, and GP13 from the microcontroller are used to drive the inputs of the SN74HC595 device. This 8-bit shift register converts the serial input data to parallel output data to control the ULN2003A channels. For example software to drive the SN74HC595, see Section 5.2.

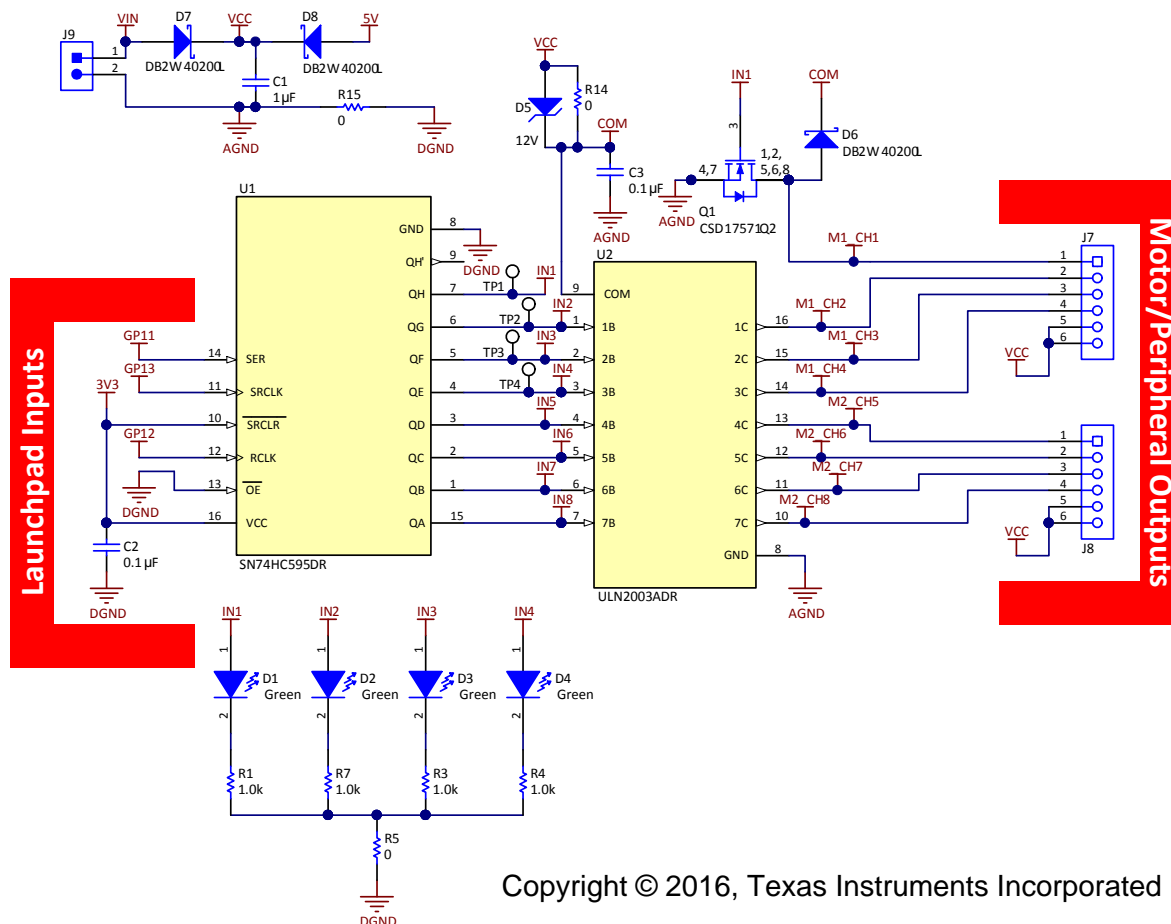


Figure 24. 3-Pin Mode Abbreviated Schematic (Zoom for Higher Resolution)

### 4.3 8-pin Parallel Mode

#### 4.3.1 Enabling 8-pin Mode

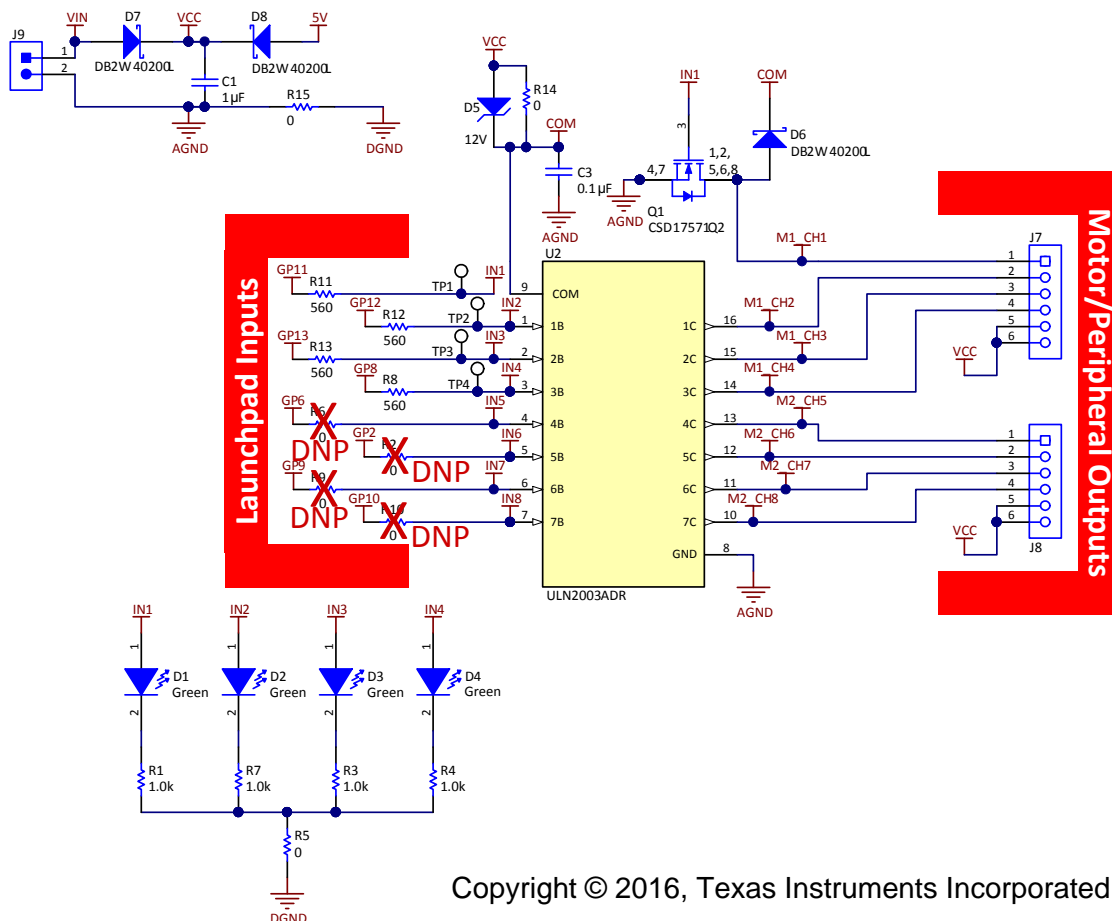
The BoosterPack has the required components to run ONLY 4 pins of the 8-pin Mode out of the box. Ultimately, this allows control of a single stepper motor in a parallel control mode, so additional components are required to enable control of all 8 outputs in parallel mode. To use 8-pin mode, the four dip switches should be in the upper position. Each switch works as defined in Table 2.

To enable all 8 pins for this mode of operation, a 0-Ω resistor or solder bridge should be populated on the pads for resistors R6, R2, R9, and R10 to enable IN5, IN6, IN7, and IN8 respectively.

**NOTE:** The 560-Ω resistors exist on IN1, IN2, IN3, and IN4 to help protect against bus contention if the IN1, IN2, IN3, and IN4 pins are being driven by both the SN74HC595 and the microcontroller. This should only happen if the dip switches are in the wrong position. If the intent is to use the device in the 8-pin mode, and the switches are set properly, then there should be no potential for bus contention, and therefore 560-Ω resistors are not required for R6, R2, R9, and R10.

#### 4.3.2 8-pin Mode of Operation

Figure 25 shows the effective schematic for the 8-pin mode of operation. Inputs GP11, GP12, GP13, GP8, GP6, GP2, GP9, and GP10 from the microcontroller are used to drive the inputs of the ULN2003A device directly. For example software to drive unipolar stepper motors using the ULN2003A, see Section 5.2.



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Figure 25. 8-Pin Mode Abbreviated Schematic (Zoom for Higher Resolution)

## 5 Additional Information

### 5.1 Design Files

All design files including schematics, layout, Bill of Materials (BOM), Gerber files, and documentation are made available in the Texas Instruments Resource Explorer:

[dev.ti.com/tirex](http://dev.ti.com/tirex)

The schematic for the design is also attached as [Figure 26](#) to the end of the document for quick reference.

### 5.2 Software

For software examples including the out-of-box experience, 3-pin mode driving, and 8-pin mode driving, see [dev.ti.com/BOOSTXL-ULN2003](http://dev.ti.com/BOOSTXL-ULN2003).

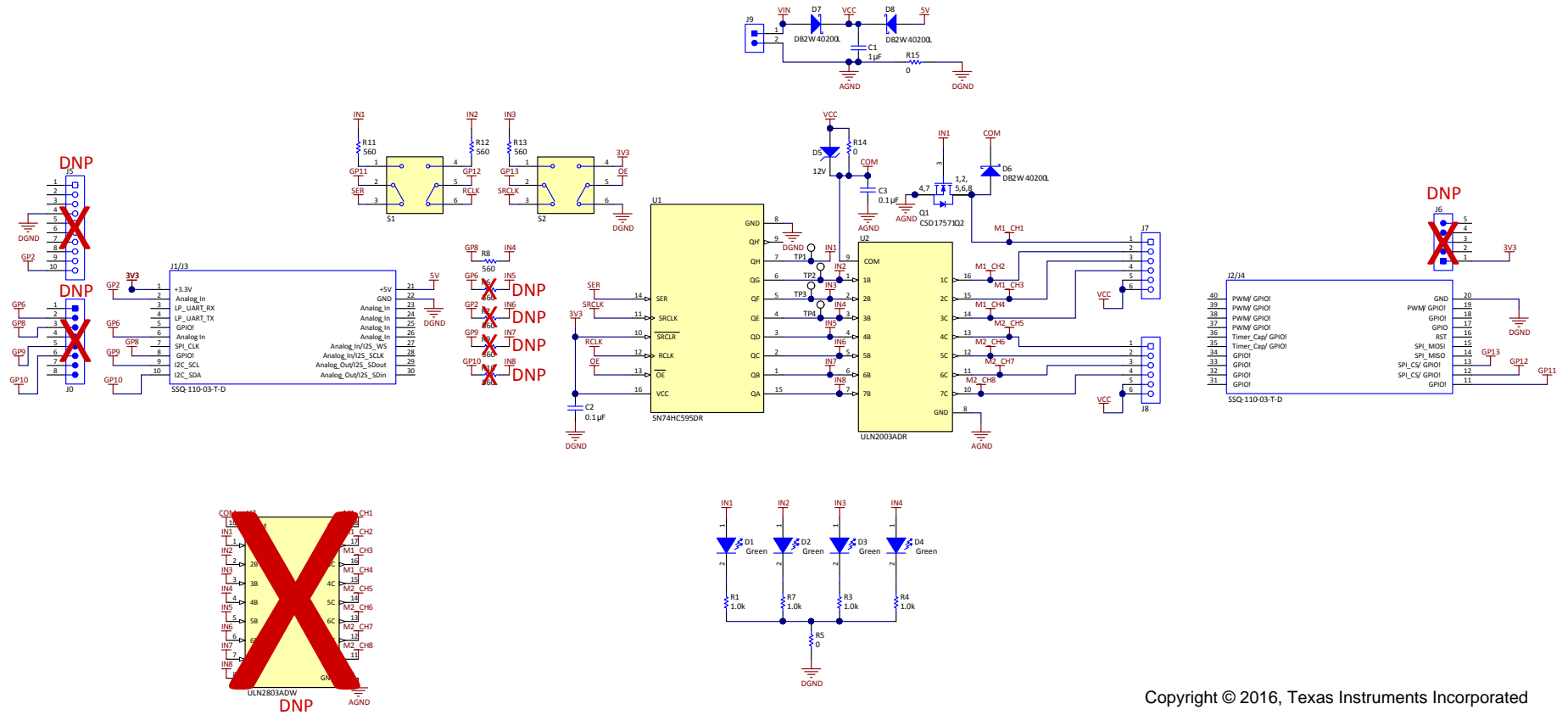
For additional information regarding stepper motor driving patterns, including half-step, full-step, and wave drive, see [Stepper Motor Driving with Peripheral Drivers \(Driver ICs\)](#)

### 5.3 Hardware Change Log

**Table 4. Description of Hardware Changes**

| PCB Revision | Description of Changes  |
|--------------|---|
| Rev 1.0      | <ul style="list-style-type: none"> <li>• Initial Release</li> </ul> |

5.4 Schematic



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Figure 26. BOOSTXL-ULN2003 Schematic (Zoom for Higher Resolution)

**NOTE:** DNP is an abbreviation for do not populate. Components highlighted as DNP in the schematic are not populated out of the box.



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