Stepper Motor Driving With Peripheral Drivers (Driver ICs)

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ABSTRACT

This application report describes in detail how to interface stepper motors with TI peripheral drivers. Primarily, this report discusses how to connect and drive stepper motors, including the stepper motor driving patterns. Advantages and disadvantages to each stepping pattern are discussed; and logic tables, timing diagrams, and pictorial representations of each driving pattern are provided.

Contents

1 Peripheral Driver (Driver IC) Overview

A peripheral driver is a type of integrated circuit (IC) that can be used to drive relays, solenoids, stepper motors, LEDs, and other peripherals. These peripheral driver ICs are typically described as high-voltage, high-current Darlington transistor arrays, multi-channel relay and inductive load sink drivers, or quadruple Half-H drivers.

Peripheral Drivers are useful for driving both low and high voltage peripherals within appliance, HVAC, automotive, telecom, and other applications.

The BOOSTXL-ULN2003 BoosterPack can be paired with an MSP430 Launchpad (ti.com/launchpad) to drive stepper motors and help understand stepper motor driving patterns. See http://www.ti.com/tool/boostxl-uln2003 for additional information including hardware evaluation and software examples.

2 Stepper Motors

There are two types of stepper motors: the unipolar stepper motor and the bipolar stepper motor. A unipolar stepper motor has current flowing through each of the coils in a single direction, and the bipolar stepper motor has current flowing in both directions of the coil.

2.1 Unipolar Stepper Motors

Unipolar stepper motors only require current to flow in a single direction, which makes hardware design simpler because only a low side switch/driver is required (a switch to conduct current to ground from the component - see Figure 1). The high-side of the motor phase is connected directly to the supply voltage without a switch. Unipolar stepper motors can be driven by a stepper motor sequence using a peripheral driver - ULN2003A and TPL7407L are examples of devices that can drive these stepper motors. See Section 3.1 for additional information regarding how to connect a stepper motor to a peripheral driver.
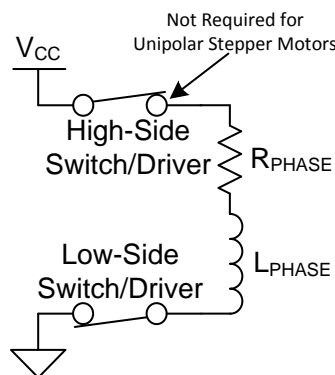

Figure 1. Low-Side and High-Side Switches/Drivers

Unipolar stepper motors come in three primary wiring configurations, 5-wire, 6-wire, and 8-wire, where 5-wire and 6-wire stepper motors are the most common. In a 5-wire stepper motor the center tap connections are shorted together internally as shown in Figure 2. In a 6-wire stepper motor the center tap connections are separate connections as shown in Figure 3. A 6-wire stepper motor can effectively act as a 5-wire stepper motor by connecting the two center tap wires.
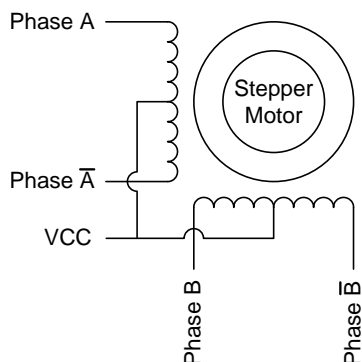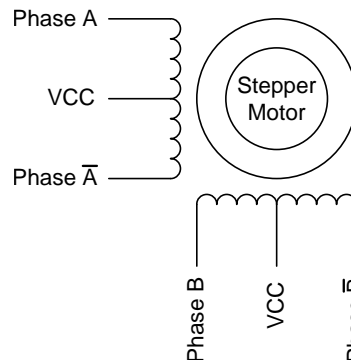

Figure 2. 5-Wire Unipolar Stepper Motor

Figure 3. 6-Wire Unipolar Stepper Motor

2.2   *Bipolar Stepper Motors*

Bipolar stepper motors require both a low-side driver and a high-side driver (see Figure 4). This allows the coils to be biased in both directions, requiring two Half-H drivers (one Full-H bridge). The L293D is an example of a device that can drive these types of stepper motors, see Section 3.1 for additional information.
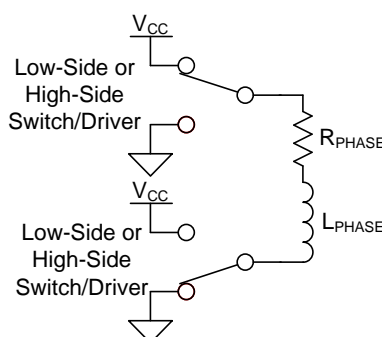

Figure 4. Variable Low-Side and High-Side Switches/Drivers

Bipolar stepper motors only come in a 4-wire configuration and do not have center tap connections. See Figure 5 for the wiring of the bipolar stepper motor.
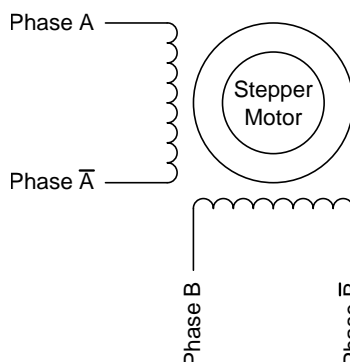

Figure 5. 4-Wire Bipolar Stepper Motor

3   Stepper Motor Driving Overview

3.1   *Unipolar Stepper Motor Driving Block Diagram*

A common application for peripheral drivers is driving unipolar stepper motors. Figure 6 shows in detail a typical block diagram for driving a unipolar stepper motor using a ULN2003A or a similar peripheral driver device such as TPL7407L.

Figure 6. Driving a Unipolar Stepper Motor

3.2   *Detailed Design Considerations*

When using a peripheral driver for stepper motor driving applications there are a few design considerations that should be highlighted.

1. Logic Inputs should be within the acceptable recommended voltage range - see device Electrical Characteristics for further information.
2. Output voltages should not exceed the maximum recommended output voltage ($V_{OUT(MAX)}$) specified for the device. Output voltage and current tolerances vary by device - see device Electrical Characteristics for further information.
3. Some devices may require a capacitor on the COM pin - see device Electrical Characteristics for further information.
4. The COM pin should be connected to the highest external supply, as this is required to suppress inductive kickback from the motor.
5. The current through each motor phase (I_{phase}) is a function of the supply voltage (V_{CC}), the low-level output voltage (V_{OL} or $V_{CE(sat)}$) and the phase resistance (R_{phase}).
   - Equation 1 provides the equation for the Relay Current
   - See device Electrical Characteristics for the maximum allowable output current ($I_{CE(MAX)}$ or $I_{DS(MAX)}$) and the low-level output voltage (V_{OL} or $V_{CE(sat)}$)

$$I_{phase} = \frac{V_{CC} - V_{CE(sat)}}{R_{phase}}$$

(1)

3.3 Bipolar Stepper Motor Driving Block Diagram

A common application for peripheral drivers is driving bipolar stepper motors. Figure 7 shows in detail a typical block diagram for driving a bipolar stepper motor using an L293D or a similar peripheral driver device such as SN754410.
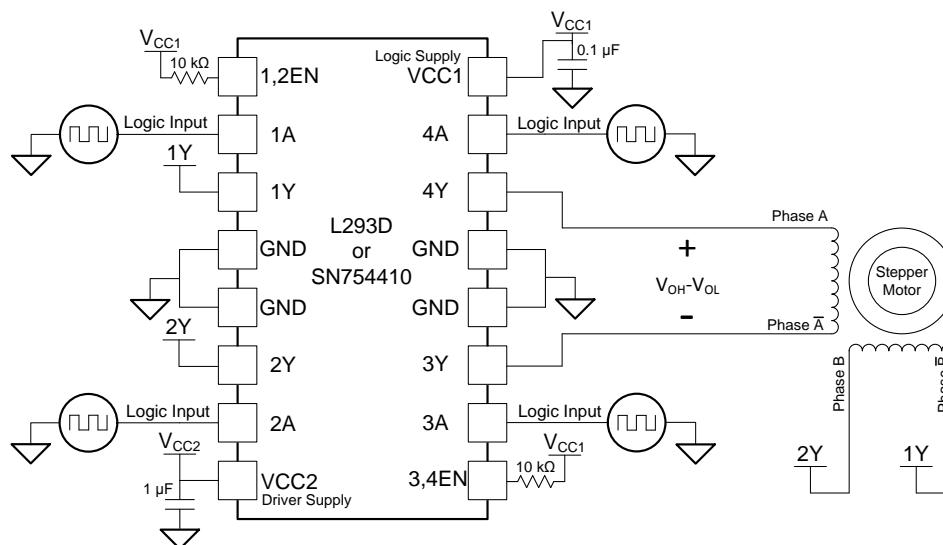
Figure 7. Driving a Bipolar Stepper Motor

3.4 Detailed Design Considerations

When using a peripheral driver for stepper motor driving applications there are a few design considerations that should be highlighted.

1. V_{CC1} and V_{CC2} should be within the acceptable recommended voltage range - see device Electrical Characteristics for further information.

2. Logic Inputs should be within the acceptable recommended voltage range - see device Electrical Characteristics for further information.

3. The current through each motor phase (I_{phase}) is a function of the high-level output voltage (V_{OH}), the low-level output voltage (V_{OL}) and the phase resistance (R_{phase})

   - Equation 2 provides the equation for the Relay Current
   - See device Electrical Characteristics for the maximum allowable continuous output current per channel (I_O), high-level output voltage (V_{OH}), and low-level output voltage (V_{OL})

$$I_{phase} = \frac{V_{OH} - V_{OL}}{R_{phase}}$$

(2)

4 Stepper Motor Driving Patterns

There are multiple methods to driving stepper motors, each with their own advantages and disadvantages. The sections below describe each method as well as their advantages and disadvantages.

4.1 Wave Drive Operation

The Wave Drive mode of operation is typically considered to be the most simple way of driving a stepper motor, but is also the least common mode of stepper motor driving, due to its shortfalls relative to Full-Step (torque) and Half-step (precision) patterns. The wave drive mode would likely be used in applications where reduced power consumption is important and high torque is unnecessary. Because of its simplicity, it is easiest to help discuss the functional operation of stepper motors.

For this mode of operation, each phase of the motor is activated in succession with only a single phase being activated at any point in time. Figure 8 and Figure 9 describe the step pattern required for the wave drive method, while Figure 10 provides a pictorial representation of the motor steps. Depending on the motor, each step in the sequence will rotate a defined angular distance. Figure 10 represents a motor with 4 steps per revolution, but many common stepper motors will have 32 or 64 steps per revolution; furthermore, others can have even higher precision. Each step for the motor in Figure 10 spins the motor 90°. As each phase is activated in succession, the permanent magnet on the rotor is attracted to the activated coil in the stator.

Motor Phase	Step Sequence			
	1	2	3	4
A	1	0	0	0
B	0	1	0	0
$\overline{A}$	0	0	1	0
$\overline{B}$	0	0	0	1

Figure 8. Wave Drive Logic Table
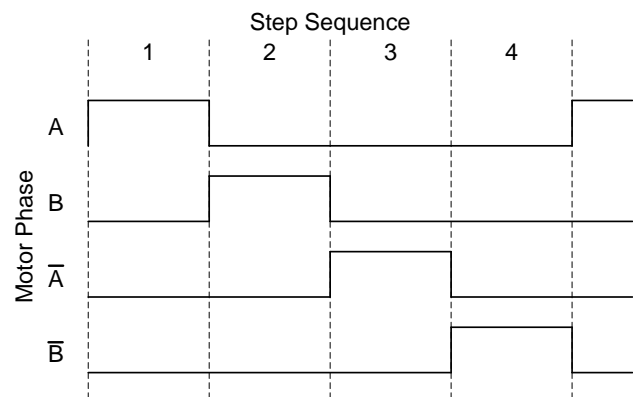
Figure 9. Wave Drive Timing Diagram
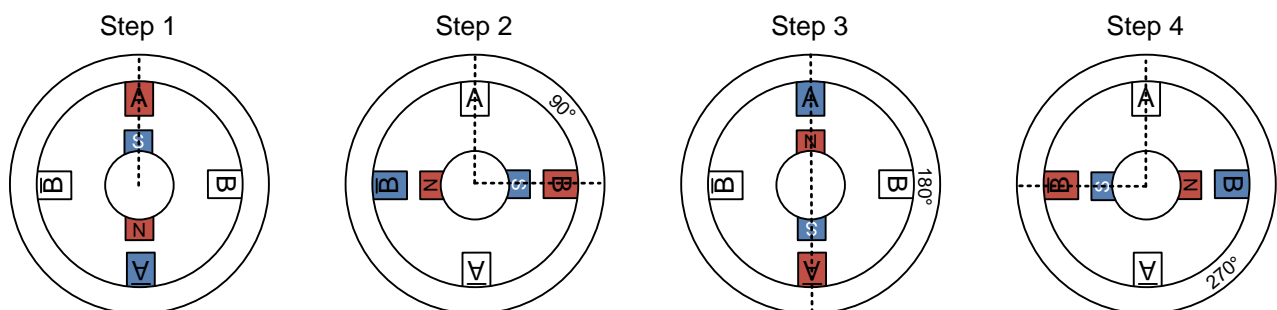
Figure 10. Wave Drive Motor Coil Sequence

4.2 *Full-Step Operation*

The full-step mode of operation is the most commonly used way to drive a stepper motor, as it has improved torque over the wave drive method and constant torque relative to the half-step method. The wave drive mode would likely be used in applications where increased torque is required.

For this mode of operation, two phases of the motor are activated simultaneously to provide an additional attractive force relative to the wave drive method, while still maintaining the resolution of the wave drive method. Figure 11 and Figure 12 describe the step pattern required for the full-step method, while Figure 13 provides a pictorial representation of the motor steps. Depending on the motor, each step in the sequence will rotate a defined angular distance. Figure 13 represents a motor with 4 steps per revolution, but many common stepper motors will have 32 or 64 steps per revolution; furthermore, others can have even higher precision. Each step for the motor in Figure 13 spins the motor 90°. Note that the full-step method has the stator attracted to a space between each of the phases that are activated, as opposed to the wave drive method where the stator is attracted directly to the activated phase. Because the stator is attracted to a space between two phases, there is a point where the two phases are pulling in opposite directions. As a consequence the full-step method does not provide torque twice that of the wave-drive method (despite twice the power consumption), but rather more equivalent to 1.4x the wave drive method.

	Step Sequence			
	1	2	3	4
A	1	0	0	1
B	1	1	0	0
$\overline{A}$	0	1	1	0
$\overline{B}$	0	0	1	1

Figure 11. Full-Step Logic Table
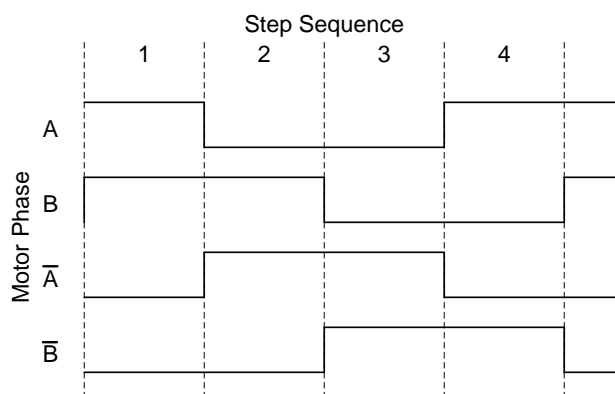
Figure 12. Full-Step Timing Diagram
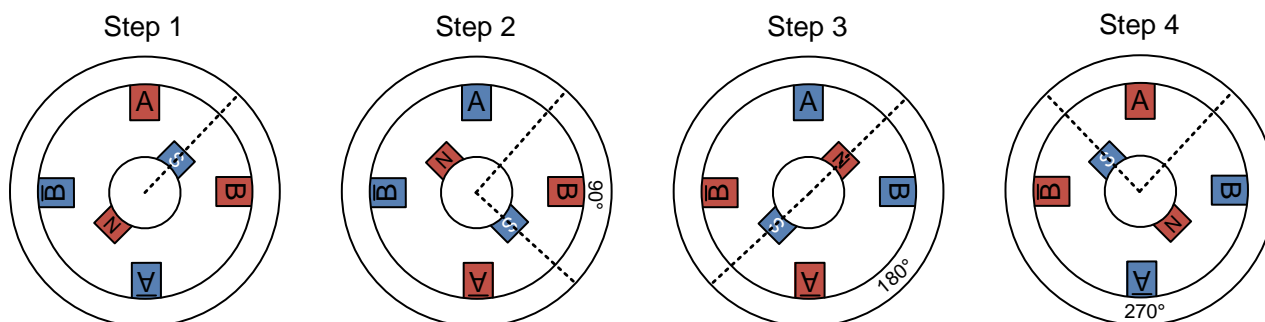
Figure 13. Full-Step Motor Coil Sequence

4.3 Half-Step Operation

The half-step mode of operation is less commonly used compared to the full-step method, but is typically more common than the wave drive method, as it enables better stepper resolution with the same motor. One disadvantage to the half-step method is that the torque swings between that of the wave drive method and that of the full-step method. Some devices, however, have internal circuitry to limit current and reduce torque ripple when half-stepping. The half-step mode would likely be used in applications where increased resolution is required.

For this mode of operation, two phases of the motor are activated simultaneously followed by a single phase. This ultimately provides additional resolution relative to both the wave drive and full-step methods. Figure 14 and Figure 15 describe the step pattern required for the half-step method, while Figure 16 provides a pictorial representation of the motor steps. Depending on the motor, each step in the sequence will rotate a defined angular distance. Figure 16 represents a motor with 4 steps per revolution, but many common stepper motors will have 32 or 64 steps per revolution; furthermore, others can have even higher precision. Each step for the motor in Figure 16 spins the motor 45°. Note that the half-step method allows for twice the resolution of the full-step method because each step is half that of the full-step method.

Motor Phase	Step Sequence							
	1	2	3	4	5	6	7	8
A	1	1	0	0	0	0	0	1
B	0	1	1	1	0	0	0	0
$\overline{A}$	0	0	0	1	1	1	0	0
$\overline{B}$	0	0	0	0	0	1	1	1

Figure 14. Half-Step Logic Table
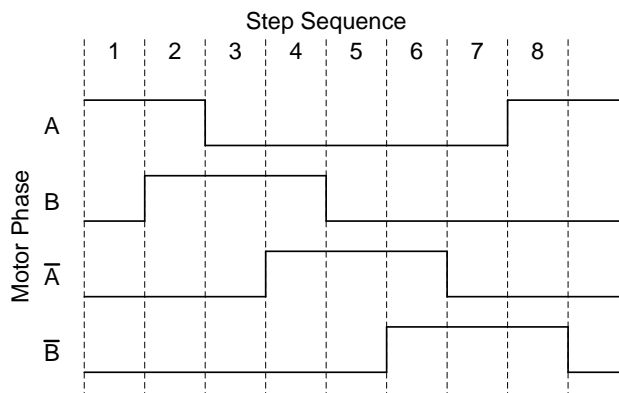
Figure 15. Half-Step Timing Diagram
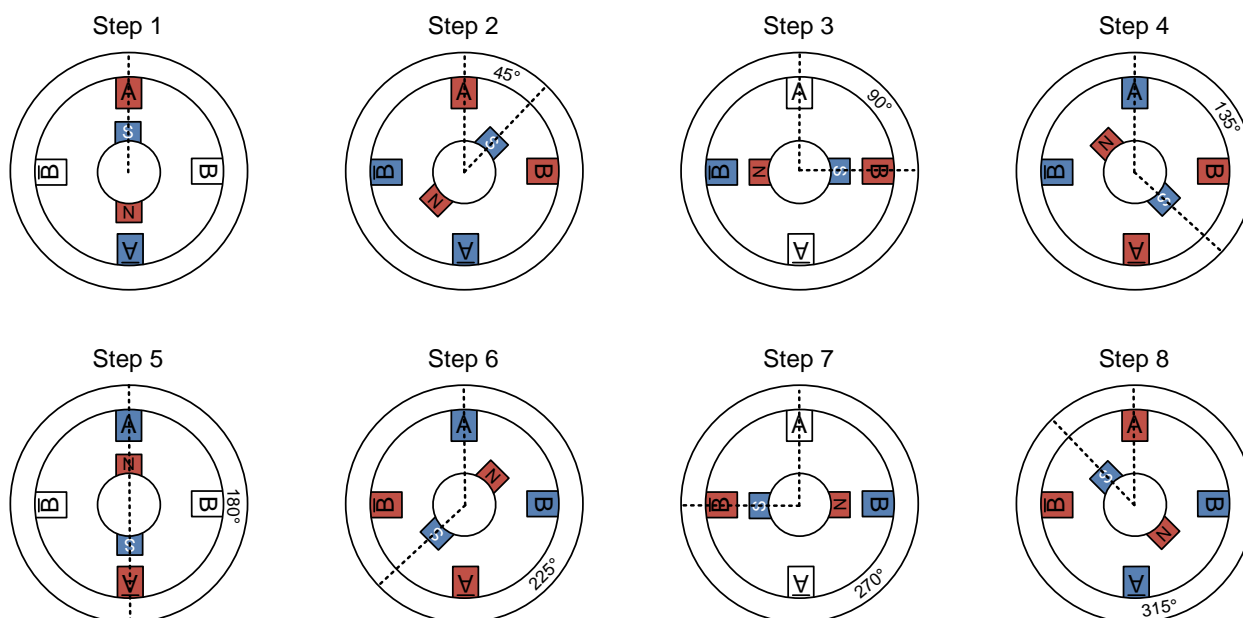
Figure 16. Half-Step Motor Coil Sequence

IMPORTANT NOTICE

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