Application Report
SLVA767A–September 2016–Revised December 2016

Stepper Motor Driving With Peripheral Drivers (Driver ICs)

Michael Schultis *HVAL – Standard Linear and Logic*

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 2
2 Stepper Motors 2
2.1 Unipolar Stepper Motors 2
2.2 Bipolar Stepper Motors 3
3 Stepper Motor Driving Overview 4
3.1 Unipolar Stepper Motor Driving Block Diagram 4
3.2 Detailed Design Considerations 4
3.3 Bipolar Stepper Motor Driving Block Diagram 5
3.4 Detailed Design Considerations 5
4 Stepper Motor Driving Patterns 6
4.1 Wave Drive Operation 6
4.2 Full-Step Operation 7
4.3 Half-Step Operation 8

Trademarks

Copyright © 2016, Texas Instruments Incorporated

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.

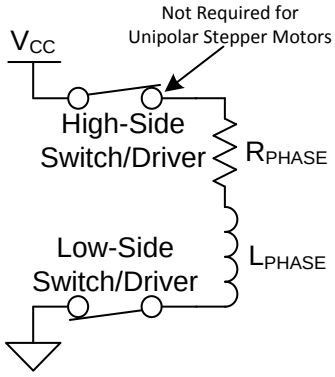

Figure 1. Low-Side and High-Side Switches/Drivers

Copyright © 2016, Texas Instruments Incorporated

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.

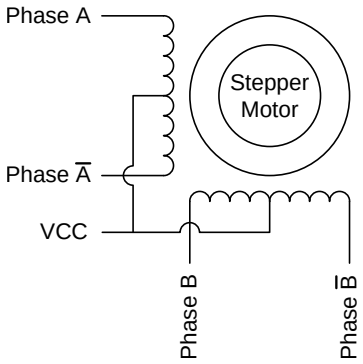

Figure 2. 5-Wire Unipolar Stepper Motor

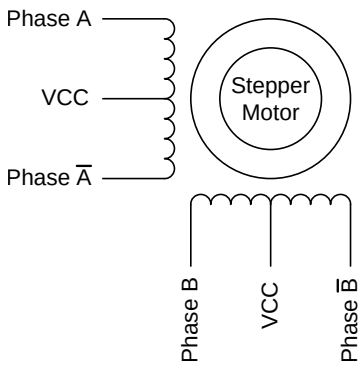

Figure 3. 6-Wire Unipolar Stepper Motor

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.

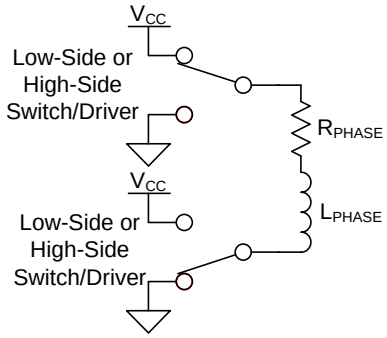

Figure 4. Variable Low-Side and High-Side Switches/Drivers

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.

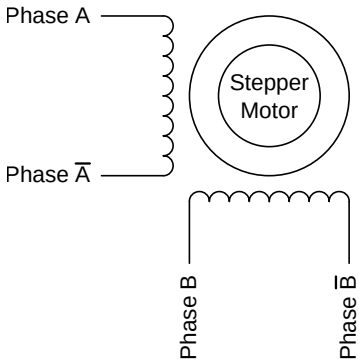

Figure 5. 4-Wire Bipolar Stepper Motor

Copyright © 2016, Texas Instruments Incorporated

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.

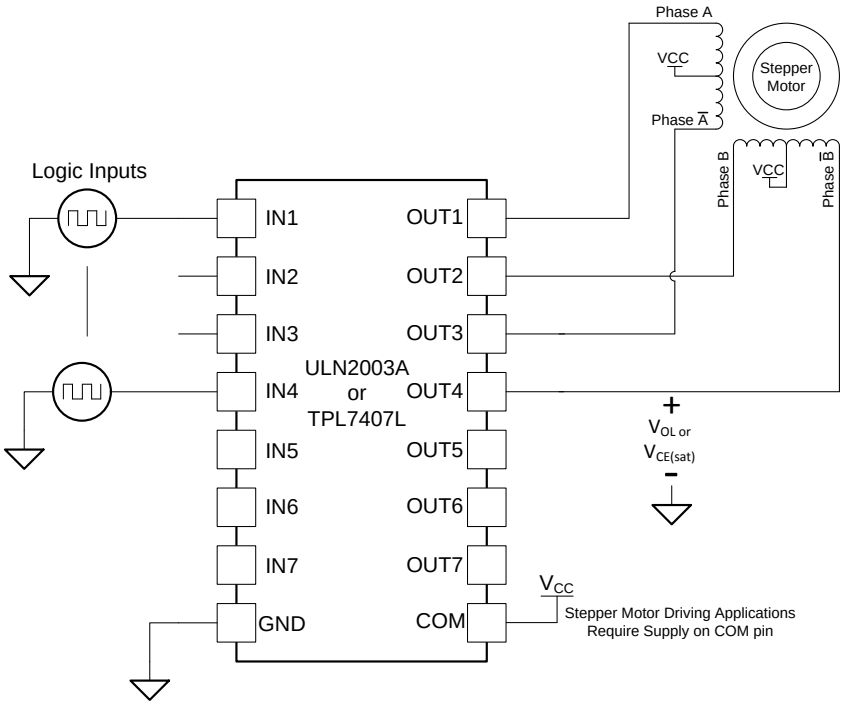

Figure 6. Driving a Unipolar Stepper Motor

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 $V_{CE(sat)}$)

$$I_{phase} = \frac{V_{CC} - V_{CE(sat)}}{R_{phase}} \quad (1)$$

Copyright © 2016, Texas Instruments Incorporated

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.

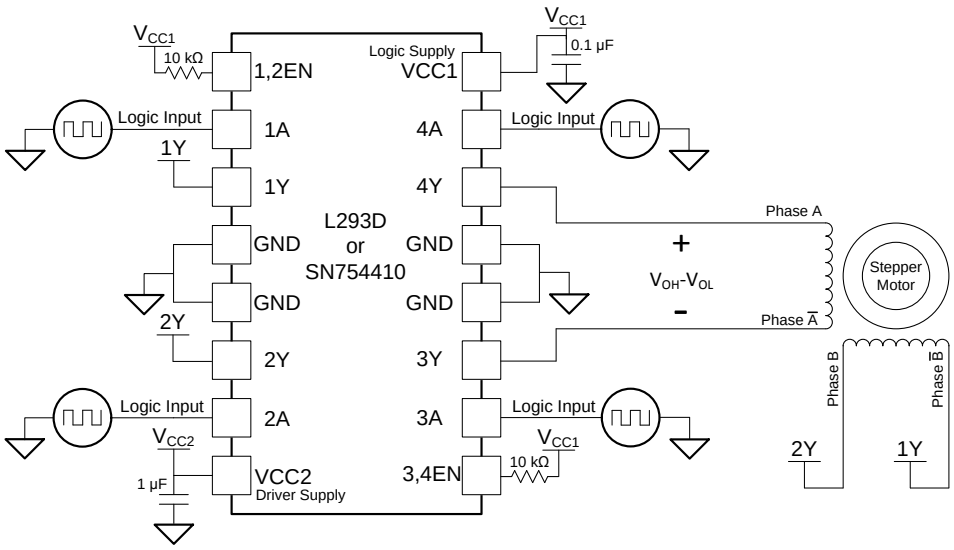

Figure 7. Driving a Bipolar Stepper Motor

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})

$$I_{phase} = \frac{V_{OH} - V_{OL}}{R_{phase}} \quad (2)$$

Copyright © 2016, Texas Instruments Incorporated

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.

Step Sequence

Motor Phase	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

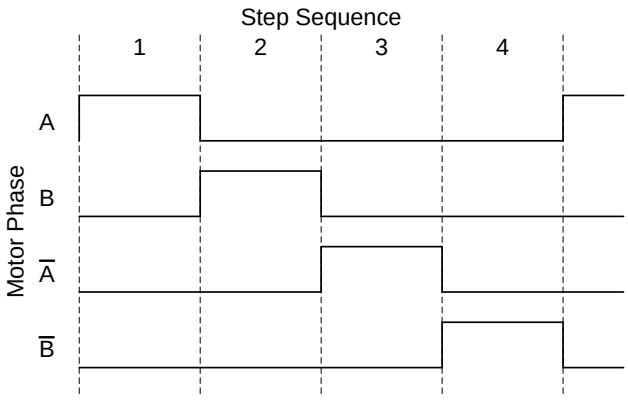

Figure 9. Wave Drive Timing Diagram

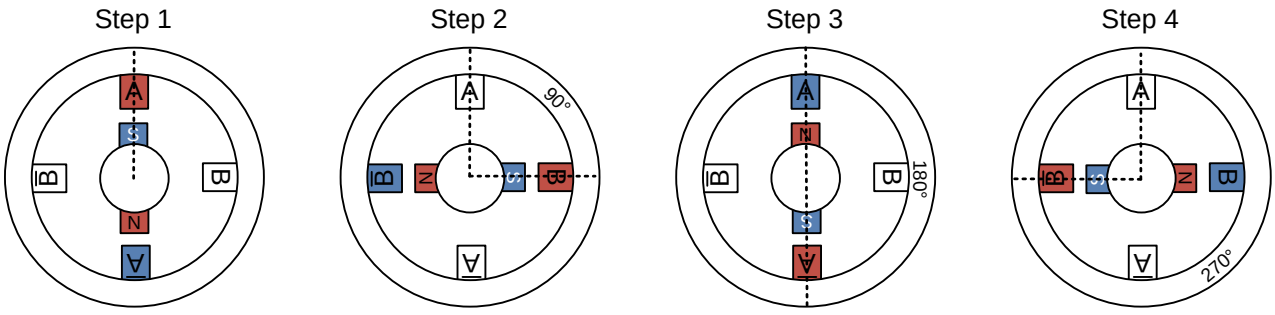

Figure 10. Wave Drive Motor Coil Sequence

Copyright © 2016, Texas Instruments Incorporated

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

Motor Phase	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

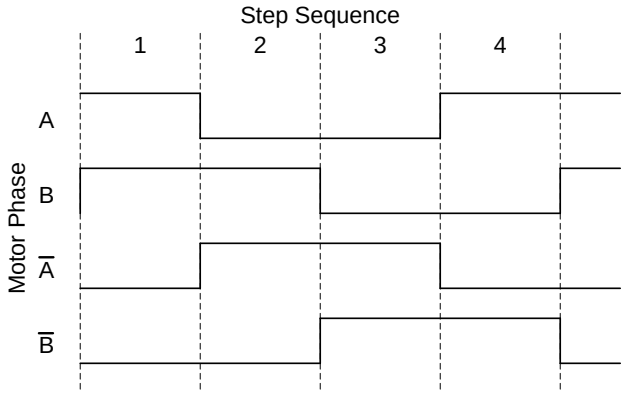

Figure 12. Full-Step Timing Diagram

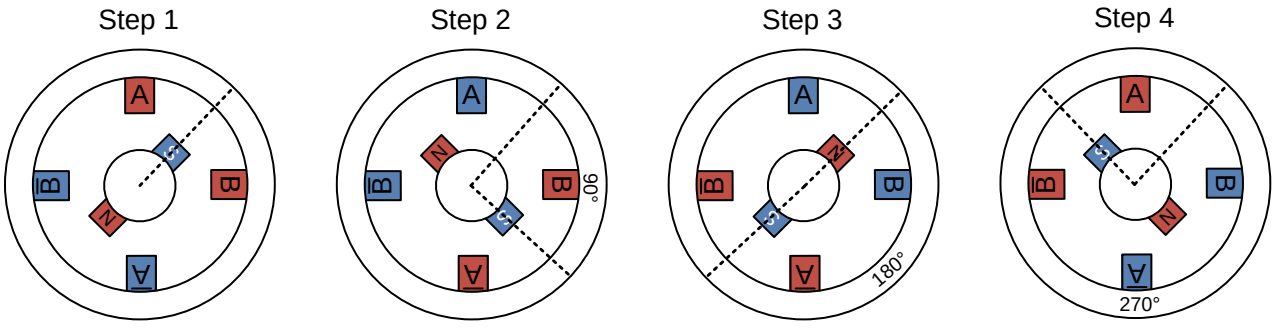

Figure 13. Full-Step Motor Coil Sequence

Copyright © 2016, Texas Instruments Incorporated

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.

Step Sequence

Motor Phase	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

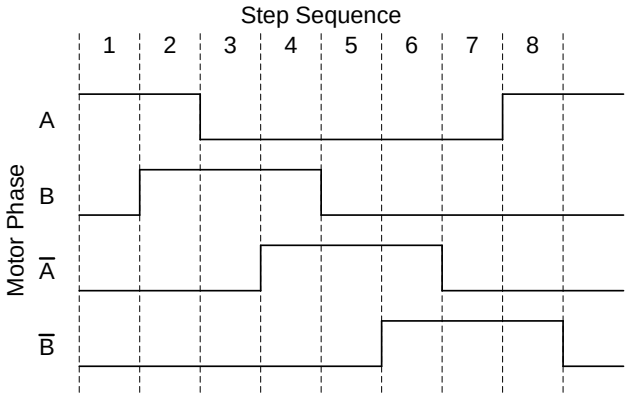

Figure 15. Half-Step Timing Diagram

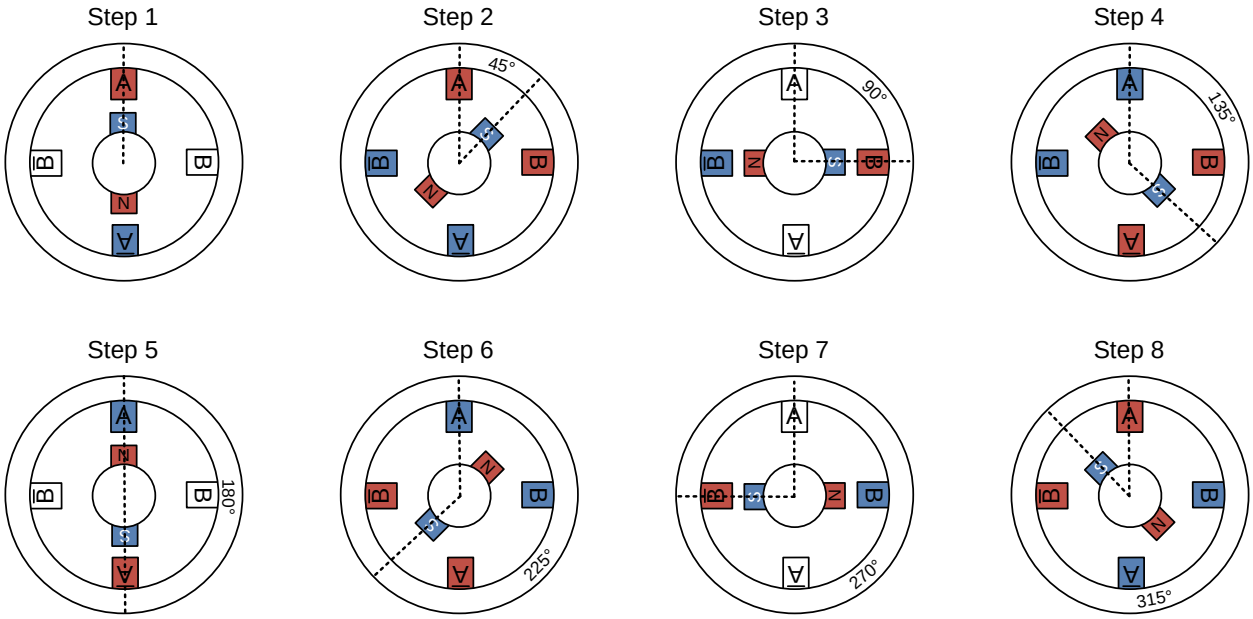

Figure 16. Half-Step Motor Coil Sequence

Copyright © 2016, Texas Instruments Incorporated

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ('TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources 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 TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have 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. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. 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 regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources 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 RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, 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 YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES 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 TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2018, Texas Instruments Incorporated