**TI Designs**

**Discrete Automotive Rotary Quadrature Decoder Reference Design With I^2C Interface**

**Design Features**
- Operating Voltage Supply Range of 2 V to 5.5 V
- Low Standby Power Consumption of 5 µA (Measured)
- I^2C interface With Four Selectable Addresses
- Automotive and Industrial Application Ready

**Featured Applications**
- Industrial Control Systems
- Home Lighting Solutions
- Home User Appliances
- Automotive Infotainment
- Audio Receivers
- Electronic toys

**Design Resources**
- TIDA-00580 Tool Folder Containing Design Files
- SN74LVC2G17-Q1 Product Folder
- SN74LVC1G04-Q1 Product Folder
- SN74LVC1G374-Q1 Product Folder
- SN74LV393A-Q1 Product Folder
- TCA9539-Q1 Product Folder
- SN74LV1T34 Product Folder
- SN74LV1T04 Product Folder

**ASK Our E2E Experts**
- WEBENCH® Calculator Tools

**NanoFree, NanoStar are trademarks of Texas Instruments.**
All other trademarks are the property of their respective owners.

TIDUA8–September 2015
Submit Documentation Feedback
Copyright © 2015, Texas Instruments Incorporated
1 System Description

A rotary quadrature encoder (RQE) is a simple, infinitely-turning knob that outputs two 90° out-of-phase square waves as it is turned and is often used in electronics as a method of human interface. The accuracy of these encoders varies widely. The encoder used in this design has 16 pulses per revolution, but almost any existing RQE can be used with this design. The normal method to monitor the direction and amount of rotation is to use a microcontroller (MCU) to constantly monitor both outputs (either through polling or interrupts) and determine which signal, if any, has changed. The requirement for constant monitoring can cause two problems. The first issue this process poses is monopolizing the processor's time, especially when more important processes can be utilized by the processor. The other problem is that some pulses can pass by unnoticed if the processor does not utilize a large portion of its time to monitor the knob. The end effect in either case is a reduction in system performance for the end user.

Processor time is at a premium in many systems. By offloading this process onto hardware, the MCU can simply monitor a single interrupt line and utilize the I²C bus to access the direction and amount of rotation.

1.1 SN74LVC2G17-Q1 Automotive Qualified Dual Schmitt-Trigger Buffer

The Schmitt-trigger input buffers between the RQE and the other circuitry are necessary because of the slow edge rate outputs of the RQE. These buffers are also overvoltage tolerant on the inputs, which allows the logic level of the input from the RQE to be any value from 1.72 V to 6.5 V.

1.2 SN74LVC1G374-Q1 Automotive Qualified Single D-Type Flip-Flop With Three-State Output

A D-type flip-flop is used to determine the direction of rotation of the RQE. The A input to the data input and B is input to the clock input of the flip-flop. When A is leading B, the flip-flop outputs HIGH. If B is leading A, the flip-flop outputs LOW. This process directly translates into clockwise and counter-clockwise turning, but the direction depends on the particular RQE used.

1.3 SN74LV393A-Q1 Automotive Qualified Dual 4-Bit Binary Counter

An 8-bit counter is desired for a maximum of 15 triggers in one cycle, so a dual 4-bit counter device is selected and the counters are cascaded to produce a single 8-bit counter. This counter can be replaced with a smaller or larger bit count device depending on the system requirements.

1.4 TCA9539 Low Voltage, 16-Bit I²C and SMBus Low-Power I/O Expander With Interrupt Output, Reset, and Configuration Registers

The I²C I/O expander is used in this system to reduce the number of required communication lines from 11 to 3. This part does not currently have an automotive qualified version, but one is in development at the time of this writing.

1.5 Additional Parts

The test board contains several additional TI parts that are not part of the TI design, but are used for testing purposes. The SN74LV1T34 non-Inverting buffer is used as a light-emitting diode (LED) driver for the direction indicator and the SN74LV1T04 inverting buffer is used as an LED driver to indicate the opposite direction.
2 Design Features

- Operating voltage supply range of 2 V to 5.5 V
- Low standby power consumption of < 5 µA
- I²C interface with four selectable addresses
- Automotive and industrial application ready
- Small layout fits directly behind most RQE
- Schmitt trigger allows for slow and noisy inputs

3 Block Diagram

![Discrete Logic Rotary Quadrature Decoder with I²C Interface](image_url)

**Figure 1. Rotary Quadrature Decoder TIDA-00580 Block Diagram**
4  **Highlighted Products**

The RQD reference design features the following devices:

- SN74LVC2G17-Q1
- SN74LVC1G374-Q1
- SN74LVC1G04-Q1
- SN74LV393A-Q1
- TCA9539-Q1

For more information on each of these devices, see the respective product folders at [www.Ti.com](http://www.Ti.com).

4.1  **SN74LVC2G17-Q1 Features**

- Qualified for automotive applications
- Schmitt-Trigger inputs provide hysteresis
- Inputs accept voltages to 5.5 V
- Low power consumption, 10-µA max $I_{CC}$
- Available in the Texas Instruments NanoFree™ package

![Device 1 Block Diagram](image)

**Figure 2. Device 1 Block Diagram**

4.2  **SN74LVC1G04-Q1 Features**

- Qualified for automotive applications
- Max $t_{pd}$ of 3.3 ns at 3.3 V
- Low power consumption, 10-µA max $I_{CC}$
- Available in ultra-small 0.64-mm² package (DPW) with a 0.5-mm pitch

![Device 2 Block Diagram](image)

**Figure 3. Device 2 Block Diagram**
4.3 **SN74LVC1G374-Q1 Features**

- Qualified for automotive applications
- Max $t_{pd}$ of 4 ns at 3.3 V
- Low power consumption, 10-µA Max $I_{CC}$
- Available in the Texas Instruments NanoStar™ and NanoFree™ packages

![Device 3 Block Diagram](image)

**Figure 4. Device 3 Block Diagram**

4.4 **SN74LV393A-Q1 Features**

- Qualified for automotive applications
- 2-V to 5.5-V $V_{CC}$ operation
- Low power consumption, 20-µA Max $I_{CC}$
- Direct clear for each 4-bit counter

![Device 4 Block Diagram](image)

**Figure 5. Device 4 Block Diagram**
4.5 TCA9539-Q1 Features

Figure 6. Device 5 Block Diagram

- Pending qualification for automotive applications
- Low standby-current consumption of 3 µA max
- Open-drain active-low interrupt output
- 400-KHz fast I2C bus
- Address by two hardware address pins for use by up to four devices
5 Getting Started

5.1 Hardware

Figure 7 shows the RQD consisting of the primary circuit and the output circuitry. The outer portion is the output circuitry, which consists of the LED indicators. The center portion of the PCB is the primary RQD circuitry, which shows the rotary quadrature encoder in the top view and the main decoder circuitry in the bottom view. The primary circuit may be broken off and used on any application when required.

![Figure 7. Prototype Hardware With Rotary Quadrature Decoder and Output Circuitry](image)

Figure 8 shows the bottom view of the PCB. This section of the PCB includes the primary RQD circuit and the essential connections required to run the circuit, as the following Section 5.1.1 explains.

![Figure 8. Rotary Quadrature Decoder Bottom View](image)
The reference platform comprises five different pieces of hardware:
1. SN74LVC2G17-Q1
2. SN74LVC1G04-Q1
3. SN74LVC1G374-Q1
4. SN74LV393A-Q1
5. TCA9539-Q1

5.1.1 Hardware Setup
To set up the reference design hardware, follow the steps listed in this section.

5.1.1.1 Step 1: Setup
The discrete logic RQD with I²C interface is designed to be simple to use. The circuit requires five connections to the MCU, which Table 1 shows.

Table 1. Pin Definitions

<table>
<thead>
<tr>
<th>PIN</th>
<th>NUMBER</th>
<th>NAME</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GND</td>
<td>-</td>
<td>Ground</td>
</tr>
<tr>
<td>2</td>
<td>3V3</td>
<td>-</td>
<td>Supply input from 2 V to 5 V</td>
</tr>
<tr>
<td>3</td>
<td>SDA</td>
<td>I/O</td>
<td>Bidirectional data line for I²C(1)</td>
</tr>
<tr>
<td>4</td>
<td>SCL</td>
<td>I</td>
<td>Clock line for I²C(1)</td>
</tr>
<tr>
<td>5</td>
<td>INT</td>
<td>O</td>
<td>Active low activity indicator</td>
</tr>
</tbody>
</table>

(1) I²C pullup resistors are included onboard (4.7 kΩ)

5.1.1.2 Step 2: Interfacing With Rotary Quadrature Decoder
The RQD uses a TCA9539 I²C I/O expander to communicate effectively with an external system. This section outlines the generic steps required to configure and operate the RQD over the I²C.

Two I/O expanders exist on the test board (see Table 2); however, only one expander is used for demonstrations to drive the 16 LEDs around the RQD.

Table 2. I²C Addresses

<table>
<thead>
<tr>
<th>HEX</th>
<th>BINARY</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x74</td>
<td>0111 0100</td>
<td>Primary TCA9539 for the rotary quadrature decoder. Used in all configurations. Used for reading counter values, direction value, and writing reset to the counter. When the center cutout is removed, only the I/O expander with address 0x74 is used.</td>
</tr>
<tr>
<td>0x77</td>
<td>0111 0111</td>
<td>Output TCA9539 for demonstration and testing of the RQD. Used only in test configuration. Used for writing output to 16 LEDs surrounding the RQD on the outside board.</td>
</tr>
</tbody>
</table>

Table 3. Primary device I²C Configuration Commands

<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>COMMAND</th>
<th>DATA</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x74</td>
<td>0x06</td>
<td>0xFF</td>
<td>Configures all of P0 on the primary TCA9539 to inputs.</td>
</tr>
<tr>
<td>0x74</td>
<td>0x07</td>
<td>0xFB</td>
<td>Configures all but P1.2 on the primary TCA9539 as inputs. P1.2 is an output.</td>
</tr>
</tbody>
</table>
The primary device must be configured with the series of commands in Table 4.

### Table 4. Primary device I2C Communication Commands

<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>COMMAND</th>
<th>DATA</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x74</td>
<td>0x00</td>
<td>—</td>
<td>Requests read 1 byte from P0 port (COUNT0:COUNT7).</td>
</tr>
<tr>
<td>0x74</td>
<td>0x01</td>
<td>—</td>
<td>Requests read 1 byte from P1 Port. Only first bit is used (DIR).</td>
</tr>
</tbody>
</table>

To read data from the RQD, the following two commands are used.

To reset the counter value, the following sequence is used.

<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>COMMAND</th>
<th>DATA</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x74</td>
<td>0x03</td>
<td>0x04</td>
<td>Sets P1.2 to ‘high’ output, which resets the counter value to zero.</td>
</tr>
<tr>
<td>0x74</td>
<td>0x03</td>
<td>0x00</td>
<td>Resets P1 to ‘low’ to allow normal operation.</td>
</tr>
</tbody>
</table>

Table 5 shows the commands to set the output LED indicators.

### Table 5. Output Device I2C Commands

<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>COMMAND</th>
<th>DATA</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x77</td>
<td>0x06</td>
<td>0x00</td>
<td>Configures all of P0 on the output TCA9539 to outputs.</td>
</tr>
<tr>
<td>0x77</td>
<td>0x07</td>
<td>0x00</td>
<td>Configures all of P1 on the output TCA9539 to outputs.</td>
</tr>
<tr>
<td>0x77</td>
<td>0x02</td>
<td>X</td>
<td>Sets output LEDs 1 through 8 to values indicated by X.</td>
</tr>
<tr>
<td>0x77</td>
<td>0x03</td>
<td>Y</td>
<td>Sets output LEDs 9 through 16 to values indicated by Y.</td>
</tr>
</tbody>
</table>
6 Test Data

6.1 Direction Change Detection—Counterclockwise-to-Clockwise

The following Figure 9 shows the counterclockwise-to-clockwise direction change. The counter indicates how many ticks have been made from the turning of the knob.

![Figure 9. Counterclockwise-to-Clockwise Direction Change](image-url)
6.2 **No Direction Change—CW to CW**

As Figure 10 shows, if the knob is turned clockwise, released, and then turned clockwise again, the direction bit is unaffected and the counter continues to count properly.

![Figure 10. No Direction Change—Turning Clockwise](image-url)
6.3  Direction Change Detection—Clockwise to Counterclockwise

The following Figure 11 shows a clockwise-to-counterclockwise direction change. The counter indicates how far the knob was turned.

Figure 11. Clockwise to Counterclockwise Direction Change
6.4 **No Direction Change—CCW to CCW**

As Figure 12 shows, when the knob is turned counterclockwise, released, and then turned counterclockwise again, the direction bit is unaffected and the clock continues to count properly.

![Figure 12. No Direction Change—Turning Counterclockwise](image-url)
7 Design Files

7.1 Schematics

To download the schematics, see the design files at TIDA-00580.

Figure 13. Schematics Page 1—Rotary Quadrature Decoder Circuitry
Figure 14. Schematics Page 2—Output Circuitry
## Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-00580](#).

### Table 6. BOM

<table>
<thead>
<tr>
<th>FOOTPRINT</th>
<th>COMMENT</th>
<th>LIBREF</th>
<th>DESIGNATOR</th>
<th>DESCRIPTION</th>
<th>QUANTITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>0603</td>
<td>0603VC104JAT2A</td>
<td>0603VC104JAT2A</td>
<td>C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11</td>
<td>CAP, CERM, 0.1 µF, 16 V, +/- 5%, X7R, 0603</td>
<td>11</td>
</tr>
<tr>
<td>LB Q39G_BLUE</td>
<td>LB Q39G-L2N2-35-1</td>
<td>LB Q39G-L2N2-35-1</td>
<td>D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14, D15, D16, D17, D18, D19</td>
<td>LED, Blue, SMD</td>
<td>19</td>
</tr>
<tr>
<td>Mill-Max_800-10-005-10-001000</td>
<td>800-10-005-10-001000</td>
<td>800-10-005-10-001000</td>
<td>P1</td>
<td>Header, 100mil, 5x1, TH</td>
<td>1</td>
</tr>
<tr>
<td>0402</td>
<td>CRCW04021K00FKED</td>
<td>CRCW04021K00FKED</td>
<td>R1, R2, R3, R4, R5, R6</td>
<td>RES, 1.00 k, 1%, 0.063 W, 0402</td>
<td>6</td>
</tr>
<tr>
<td>0402</td>
<td>CRCW04024K70JNED</td>
<td>CRCW04024K70JNED</td>
<td>R7, R8</td>
<td>RES, 4.7 k, 5%, 0.063 W, 0402</td>
<td>2</td>
</tr>
<tr>
<td>0402</td>
<td>CRCW040210K0JNED</td>
<td>CRCW040210K0JNED</td>
<td>R10</td>
<td>RES, 10 k, 5%, 0.063 W, 0402</td>
<td>1</td>
</tr>
<tr>
<td>0603</td>
<td>CRCW0603100RJNEA</td>
<td>CRCW0603100RJNEA</td>
<td>R12, R12, R13, R13, R14, R14, R15, R15, R16, R16, R17, R17, R18, R18, R19, R19, R20, R21, R22</td>
<td>RES, 100, 5%, 0.1 W, 0603</td>
<td>19</td>
</tr>
<tr>
<td>Panasonic_EVE-JBBF2020B</td>
<td>EVE-JBBF2020B</td>
<td>EVE-JBBF2020B</td>
<td>U1</td>
<td>ENCODER ROTARY 12MM 20PPR W/SW, TH</td>
<td>1</td>
</tr>
<tr>
<td>DCK0006A_N</td>
<td>SN74LVC2G17QDCKRQ1</td>
<td>SN74LVC2G17QDCKRQ1</td>
<td>U2</td>
<td>Dual Schmitt Trigger Buffer, DCK0006A</td>
<td>1</td>
</tr>
<tr>
<td>DCK0006A_N</td>
<td>SN74LVC1G374DCKR</td>
<td>SN74LVC1G374DCKR</td>
<td>U3</td>
<td>Single D-Type Flip-Flop With 3-State Output, DCK0006A</td>
<td>1</td>
</tr>
<tr>
<td>RTW0024B</td>
<td>TCA9539RTWR</td>
<td>TCA9539RTWR</td>
<td>U4</td>
<td>Remote 16-Bit I2C and SMBus, Low-Power I/O Expander with Interrupt Output, Reset &amp; Config, Register, 1.65 to 5.5 V, -40 to 85 degC, 24-pin QFN (RTW), Green (RoHS &amp; no Sb/Br)</td>
<td>2</td>
</tr>
<tr>
<td>DCK0005A_N</td>
<td>SN74LVC1G04QDCKRQ1</td>
<td>SN74LVC1G04DCKR</td>
<td>U5</td>
<td>Single Inverter Gate, DCK0005A</td>
<td>1</td>
</tr>
<tr>
<td>PW0014A_N</td>
<td>SN74LV393ATPWRQ1</td>
<td>SN74LV393ATPWRQ1</td>
<td>U6</td>
<td>DUAL 4-BIT BINARY COUNTER, PW0014A</td>
<td>1</td>
</tr>
<tr>
<td>DCK0005A_N</td>
<td>SN74LV1T34DCKR</td>
<td>SN74LV1T34DCKR</td>
<td>U8</td>
<td>Single Power Supply Single Buffer GATE CMOS Logic Level Shifter, DCK0005A</td>
<td>1</td>
</tr>
<tr>
<td>DCK0005A_N</td>
<td>SN74LV1T04DCK</td>
<td>SN74LV1T04DCK</td>
<td>U9</td>
<td>SN74LV1T04 Single Power Supply Inverter Gate CMOS Logic Level Shifter, DCK0005A</td>
<td>1</td>
</tr>
</tbody>
</table>
7.3 **Layer Plots**
To download the layer plots, see the design files at TIDA-00580.

7.4 **Gerber Files**
To download the Gerber files, see the design files at TIDA-00580.

7.5 **Assembly Drawings**
To download the assembly drawings, see the design files at TIDA-00580.

8 **References**

9 **About the Author**
EMRYS MAIER (Emrys@TI.com) joined TI in 2015 as part of the Applications Rotation Program (ARP). His first rotation was with the Standard Linear and Logic (SLL) group, where he supported logic, voltage translation, and switch devices. At the date of this release, he is supporting customers as part of the Centralized Applications Team. He attended the University of Texas at Arlington (UTA) and holds a Bachelor’s of Science in Electrical Engineering. While in school, he worked at the UTA Research Institute (UTARI) assisting with multiple human interface robotics projects. Prior to completing his engineering degree, he was a ground radio maintenance technician for the United States Air Force.
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.