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

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TI Designs provide the foundation that you need including methodology, testing and design files to quickly evaluate and customize the system. TI Designs help *you* accelerate your time to market. This TI design focuses on discrete rotary quadrature decoder (RQD) implementation, which enables the software overhead on the MCU to free up considerably.

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
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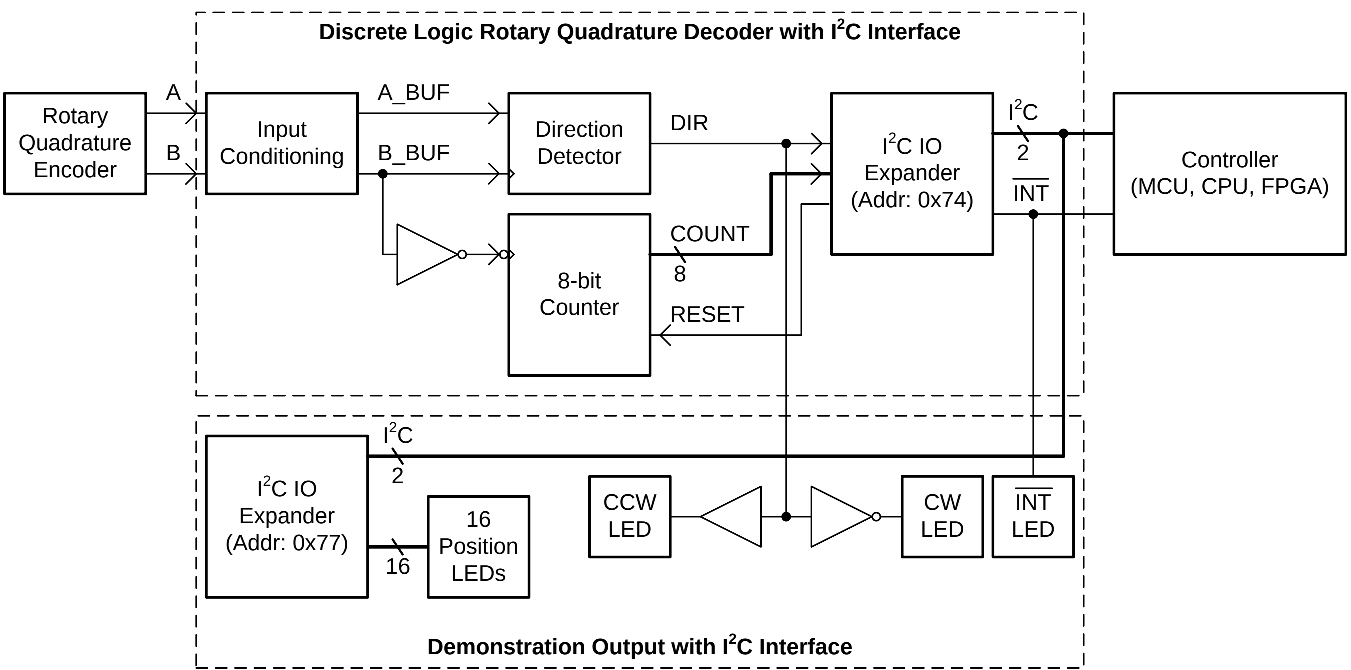
Design Features

- 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



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1 System Description

A rotary quadrature encoder (RQE) is a simple, infinitely-turning knob that outputs two 90º 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 I^2C 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* is 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 I^2C and SMBus Low-Power I/O Expander With Interrupt Output, Reset, and Configuration Registers

The I^2C 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
- I^2C 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

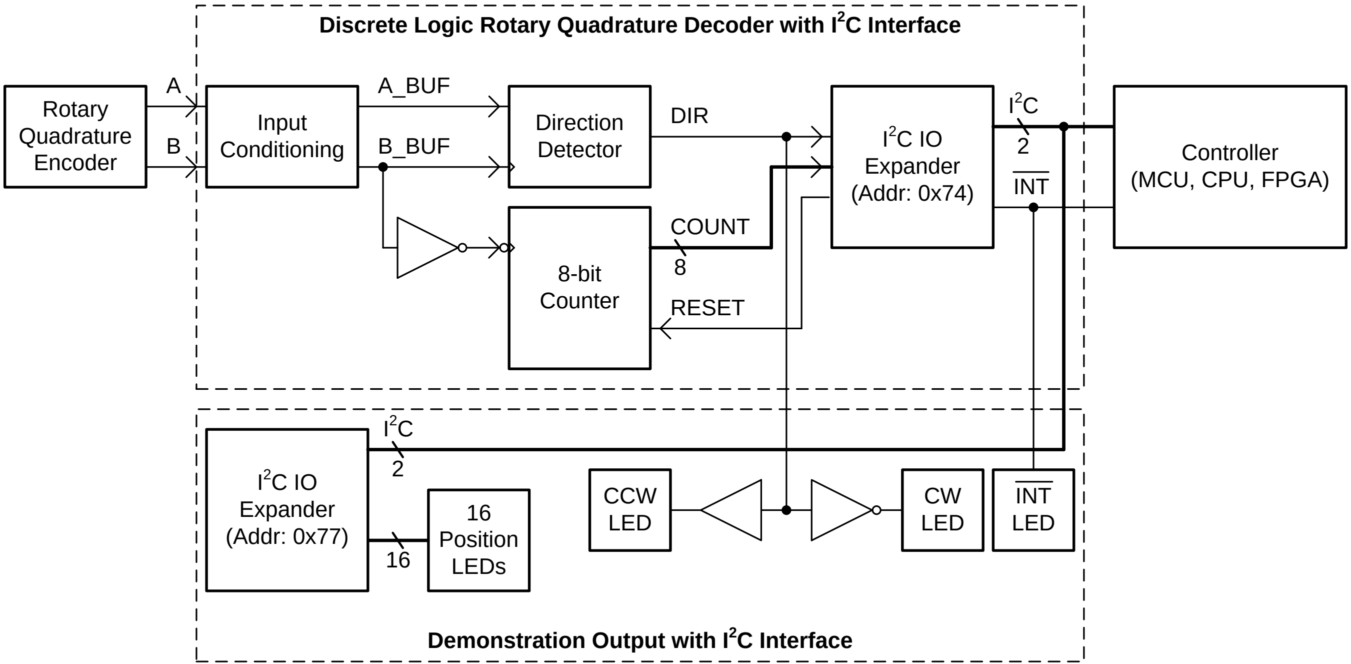

Figure 1. Rotary Quadrature Decoder TIDA-00580 Block Diagram

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.

4.1 *SN74LVC2G17-Q1 Features*

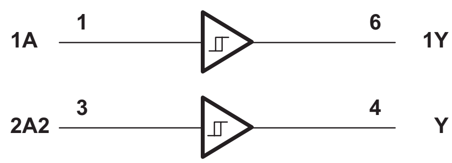

Figure 2. Device 1 Block Diagram

- 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

4.2 *SN74LVC1G04-Q1 Features*

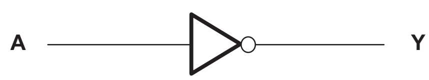

Figure 3. Device 2 Block Diagram

- 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-mm^2 package (DPW) with a 0.5-mm pitch

4.3 SN74LVC1G374-Q1 Features

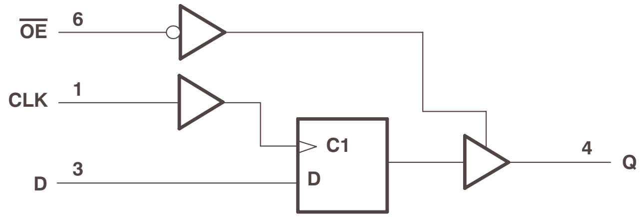

Figure 4. Device 3 Block Diagram

- 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

4.4 SN74LV393A-Q1 Features

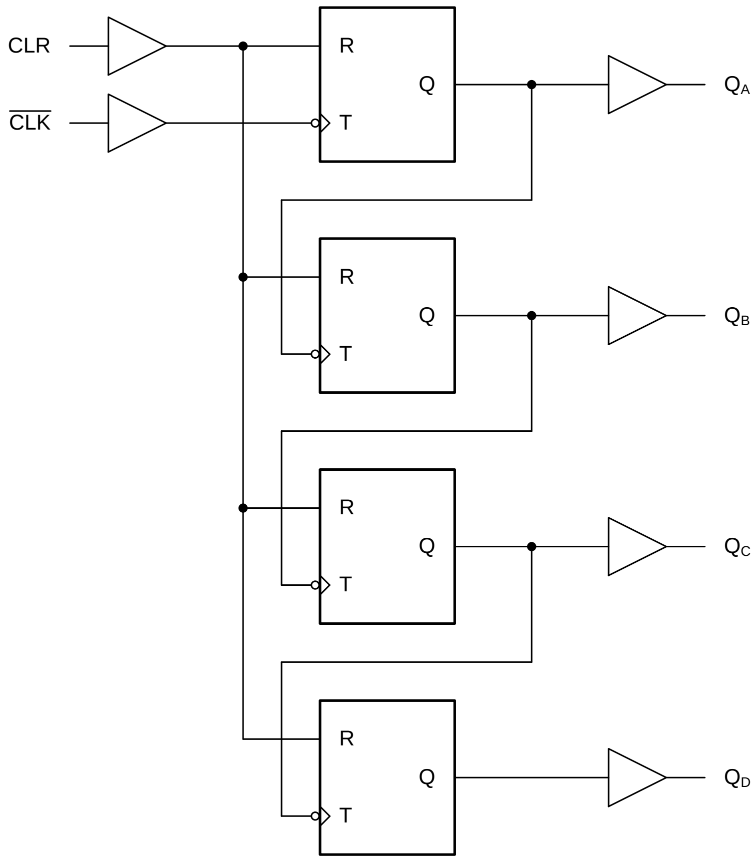

Figure 5. Device 4 Block Diagram

- 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

4.5 TCA9539-Q1 Features

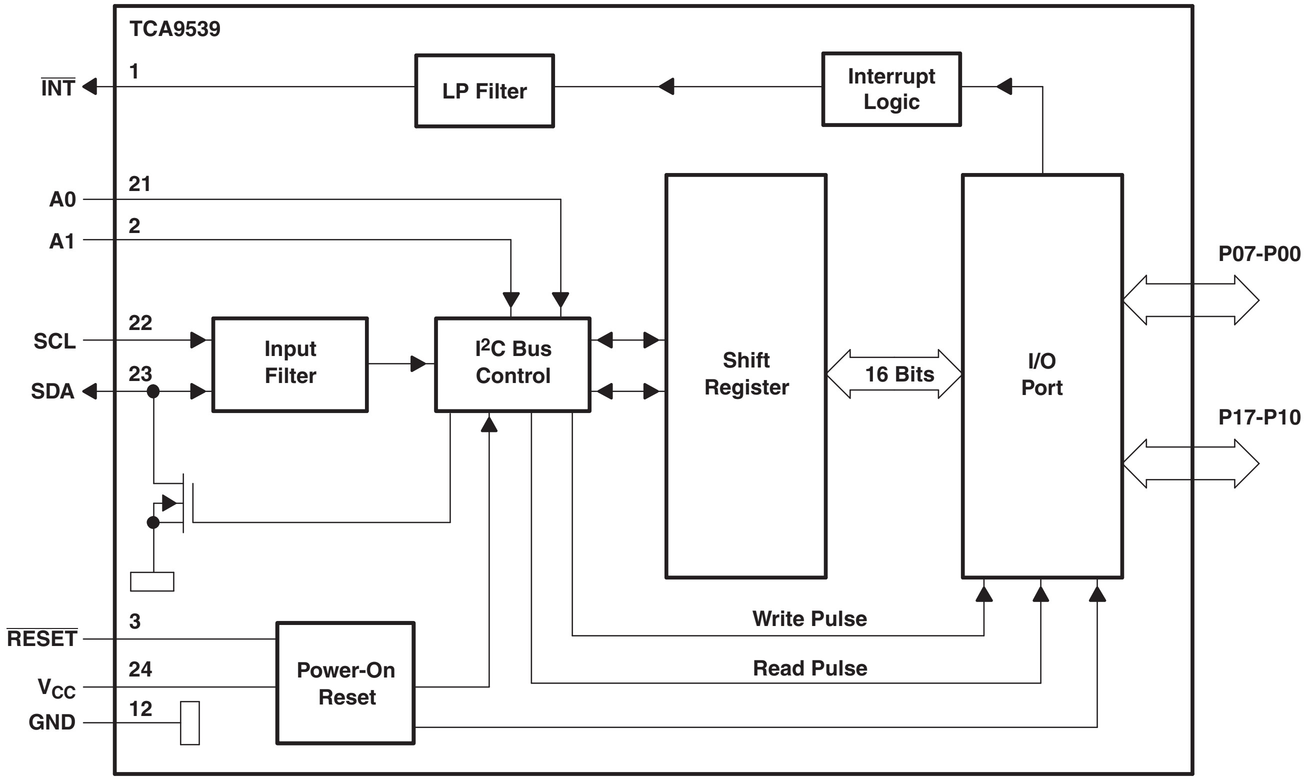

Figure 6. Device 5 Block Diagram

- 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.

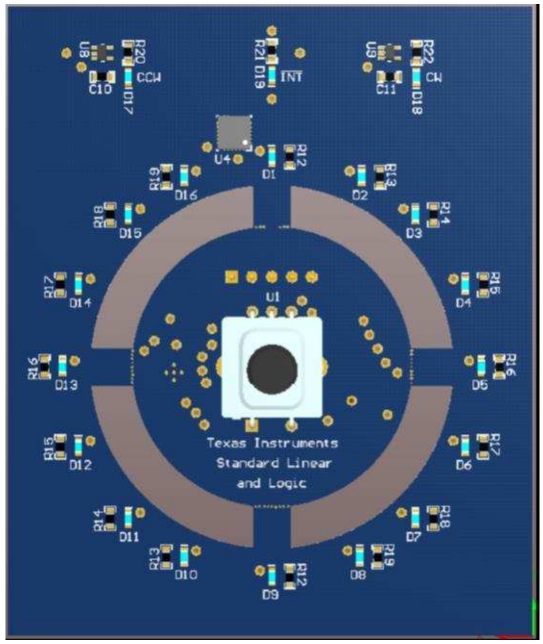

Figure 7. Prototype Hardware With Rotary Quadrature Decoder and Output Circuitry

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.

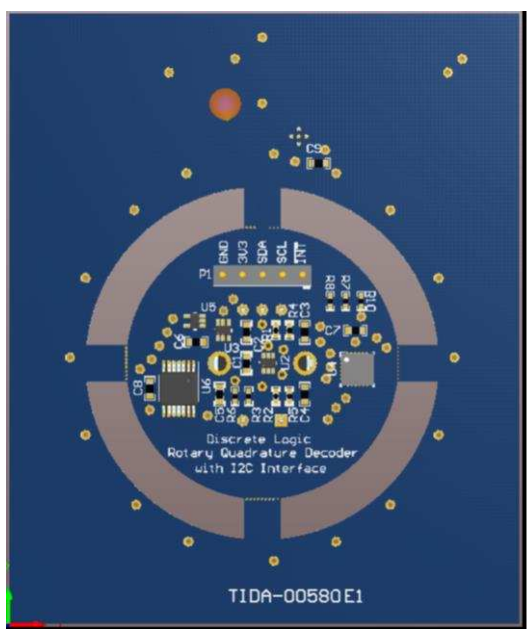

Figure 8. Rotary Quadrature Decoder Bottom View

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

PIN			
NUMBER	NAME		DESCRIPTION
1	GND	-	Ground
2	3V3	-	Supply input from 2 V to 5 V
3	SDA	I/O	Bidirectional data line for I²C (1)
4	SCL	I	Clock line for I²C (1)
5	$\overline{\text{INT}}$	O	Active low activity indicator

(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

HEX	BINARY	COMMENTS
0x74	0111 0100	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.
0x77	0111 0111	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.

Table 3. Primary device I²C Configuration Commands

ADDRESS	COMMAND	DATA	COMMENTS
0x74	0x06	0xFF	Configures all of P0 on the primary TCA9539 to inputs.
0x74	0x07	0xFB	Configures all but P1.2 on the primary TCA9539 as inputs. P1.2 is an output.

The primary device must be configured with the series of commands in Table 4.

Table 4. Primary device I²C Communication Commands

ADDRESS	COMMAND	DATA	COMMENTS
To read data from the RQD, the following two commands are used.			
0x74	0x00	—	Requests read 1 byte from P0 port (COUNT0:COUNT7).
0x74	0x01	—	Requests read 1 byte from P1 Port. Only first bit is used (DIR).
To reset the counter value, the following sequence is used.			
0x74	0x03	0x04	Sets P1.2 to 'high' output, which resets the counter value to zero.
0x74	0x03	0x00	Resets P1 to 'low' to allow normal operation.

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

Table 5. Output Device I²C Commands

ADDRESS	COMMAND	DATA	COMMENTS
0x77	0x06	0x00	Configures all of P0 on the output TCA9539 to outputs.
0x77	0x07	0x00	Configures all of P1 on the output TCA9539 to outputs.
0x77	0x02	X	Sets output LEDs 1 through 8 to values indicated by X.
0x77	0x03	Y	Sets output LEDs 9 through 16 to values indicated by Y.

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.

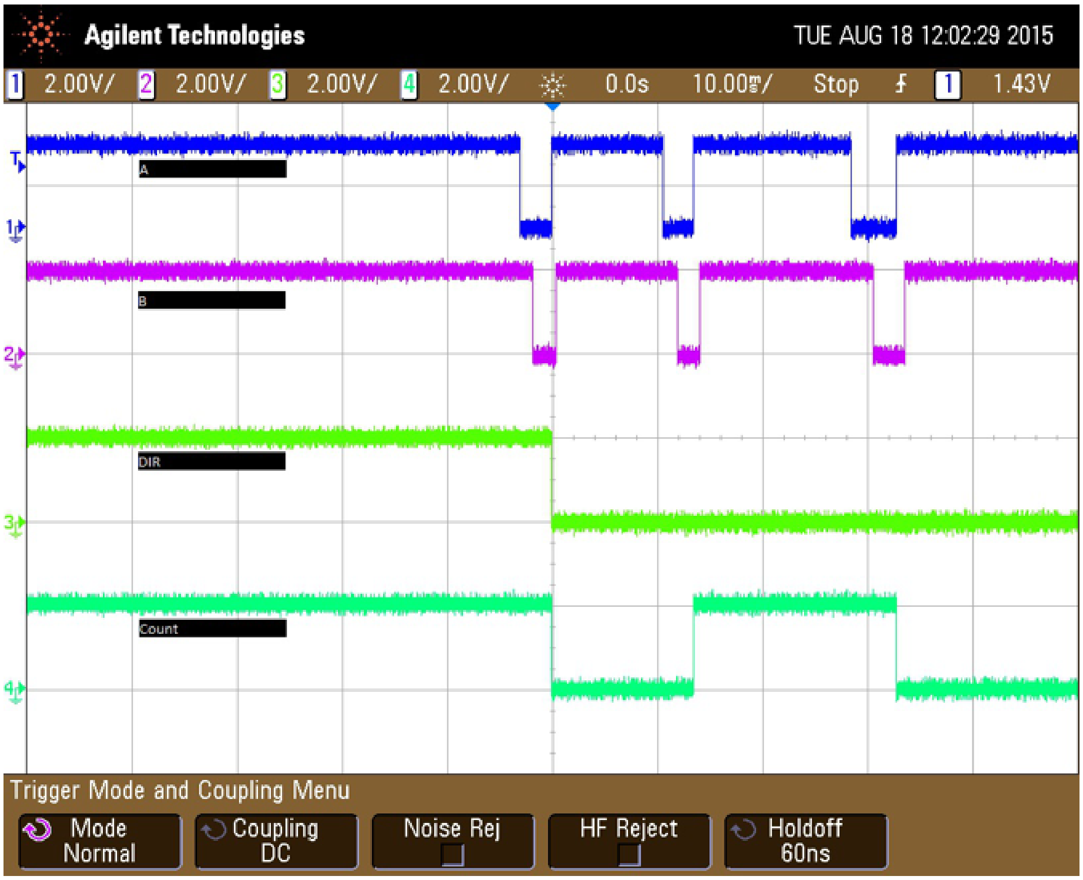

Figure 9. Counterclockwise-to-Clockwise Direction Change

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.

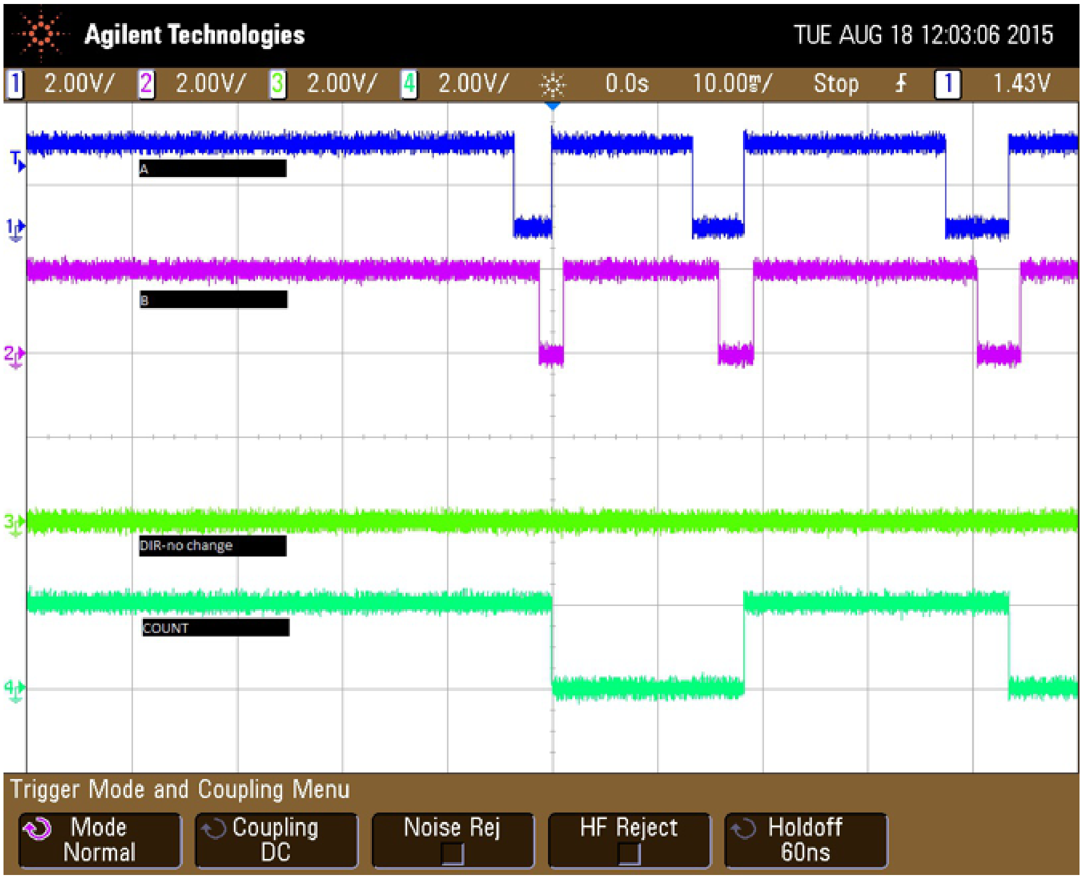

Figure 10. No Direction Change—Turning Clockwise

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.

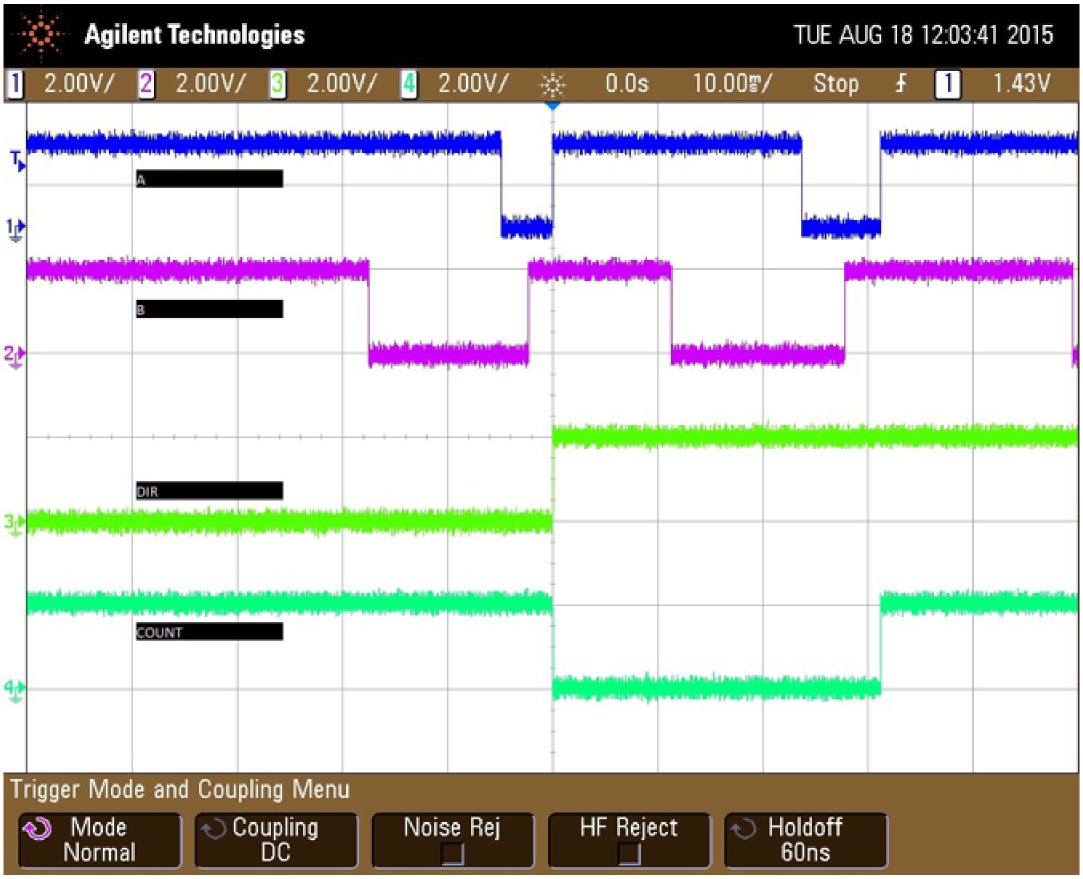

Figure 11. Clockwise to Counterclockwise Direction Change

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.

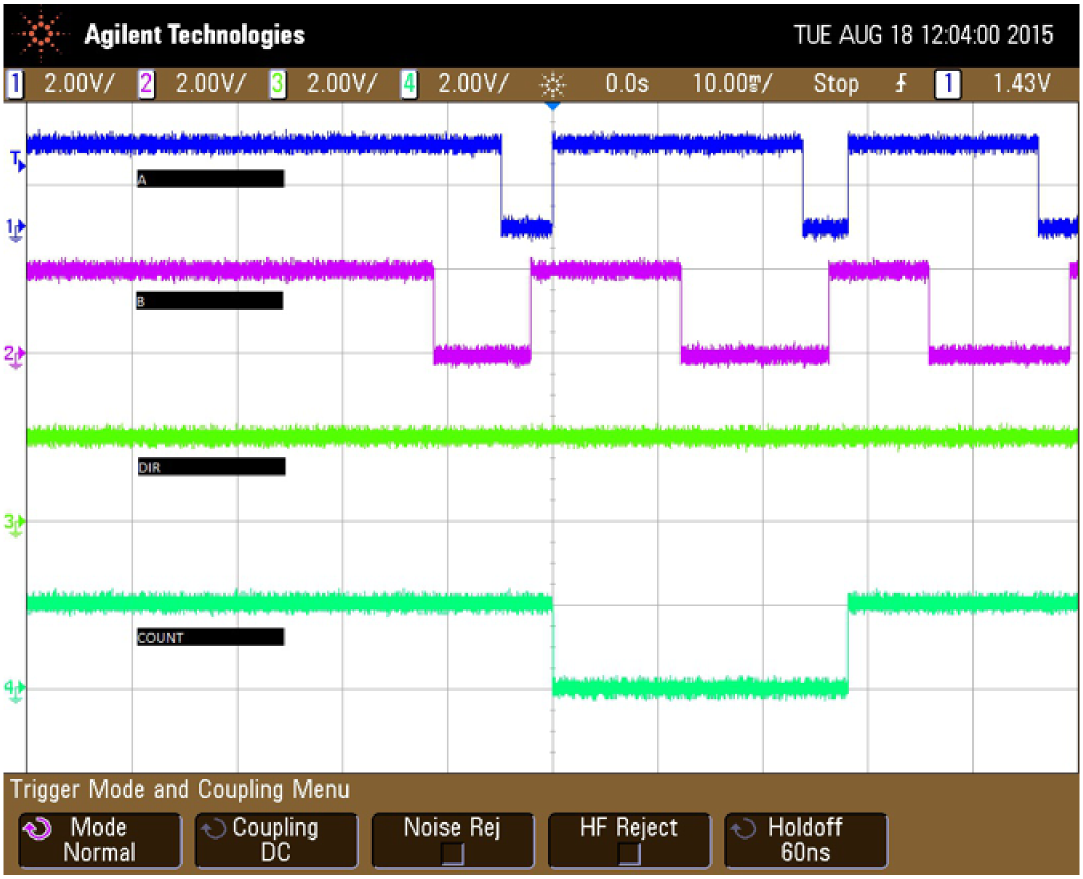

Figure 12. No Direction Change—Turning Counterclockwise

7 Design Files

7.1 Schematics

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

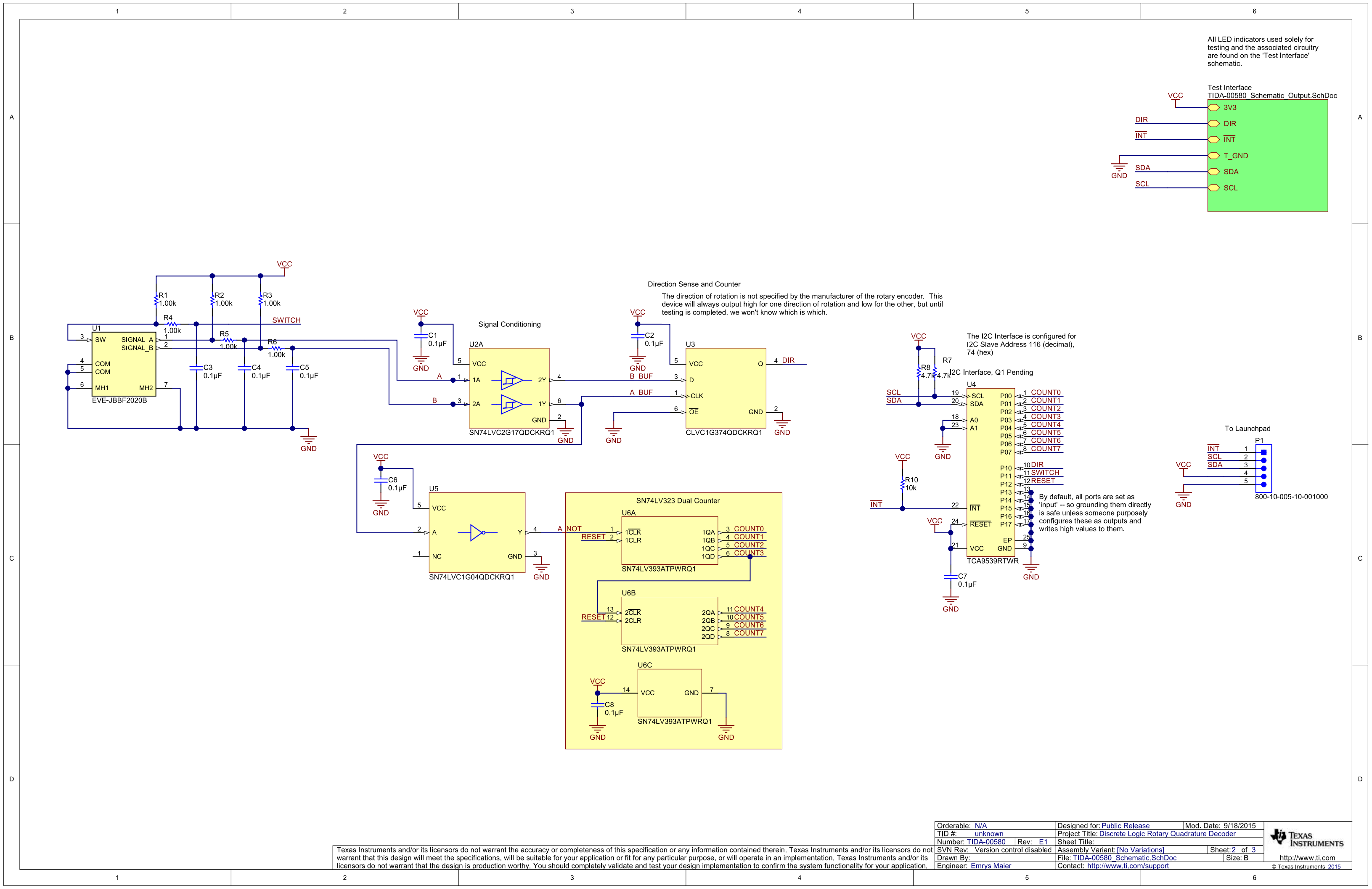

Figure 13. Schematics Page 1—Rotary Quadrature Decoder Circuitry

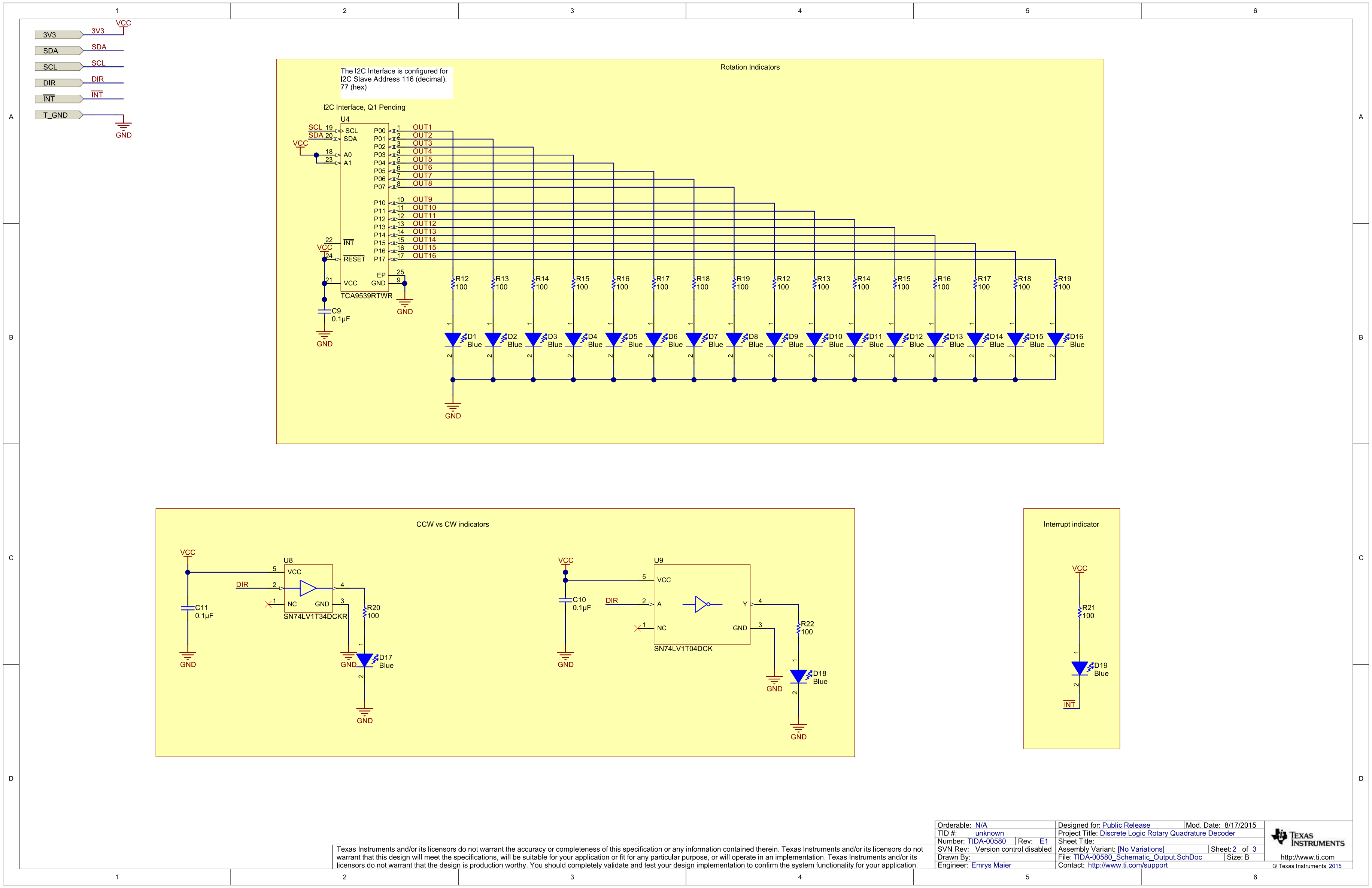

Figure 14. Schematics Page 2—Output Circuitry

7.2 Bill of Materials

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

Table 6. BOM

FOOTPRINT	COMMENT	LIBREF	DESIGNATOR	DESCRIPTION	QUANTITY
0603	0603YC104JAT2A	0603YC104JAT2A	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11	CAP, CERM, 0.1 µF, 16 V, +/- 5%, X7R, 0603	11
LB Q39G_BLUE	LB Q39G-L2N2-35-1	LB Q39G-L2N2-35-1	D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14, D15, D16, D17, D18, D19	LED, Blue, SMD	19
Mill-Max_800-10-005-10-001000	800-10-005-10-001000	800-10-005-10-001000	P1	Header, 100mil, 5x1, TH	1
0402	CRCW04021K00FKED	CRCW04021K00FKED	R1, R2, R3, R4, R5, R6	RES, 1.00 k, 1%, 0.063 W, 0402	6
0402	CRCW04024K70JNED	CRCW04024K70JNED	R7, R8	RES, 4.7 k, 5%, 0.063 W, 0402	2
0402	CRCW040210K0JNED	CRCW040210K0JNED	R10	RES, 10 k, 5%, 0.063 W, 0402	1
0603	CRCW0603100RJNEA	CRCW0603100RJNEA	R12, R12, R13, R13, R14, R14, R15, R15, R16, R16, R17, R17, R18, R18, R19, R19, R20, R21, R22	RES, 100, 5%, 0.1 W, 0603	19
Panasonic_EVE-JBBF2020B	EVE-JBBF2020B	EVE-JBBF2020B	U1	ENCODER ROTARY 12MM 20PPR W/SW, TH	1
DCK0006A_N	SN74LVC2G17QDCKRQ1	SN74LVC2G17QDCKRQ1	U2	Dual Schmitt Trigger Buffer, DCK0006A	1
DCK0006A_N	SN74LVC1G374DCKR	SN74LVC1G374DCKR	U3	Single D-Type Flip-Flop With 3-State Output, DCK0006A	1
RTW0024B	TCA9539RTWR	TCA9539RTWR	U4	Remote 16-Bit I2C and SMBus, Low-Power I/O Expander with Interrupt Output, Reset & Config. Register, 1.65 to 5.5 V, -40 to 85 degC, 24-pin QFN (RTW), Green (RoHS & no Sb/Br)	2
DCK0005A_N	SN74LVC1G04QDCKRQ1	SN74LVC1G04DCKR	U5	Single Inverter Gate, DCK0005A	1
PW0014A_N	SN74LV393ATPWRQ1	SN74LV393ATPWRQ1	U6	DUAL 4-BIT BINARY COUNTER, PW0014A	1
DCK0005A_N	SN74LV1T34DCKR	SN74LV1T34DCKR	U8	Single Power Supply Single Buffer GATE CMOS Logic Level Shifter, DCK0005A	1
DCK0005A_N	SN74LV1T04DCK	SN74LV1T04DCK	U9	SN74LV1T04 Single Power Supply Inverter Gate CMOS Logic Level Shifter, DCK0005A	1

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

1. Texas Instruments, *Understanding and Interpreting Standard-Logic Data Sheets*, Application Report (SZZA036)

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.

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