TI Designs
Automotive Multi-Switch Detection Interface Reference Design

Description

This TIDA-01237 reference design shows example implementations on how to handle a variety of high-voltage (HV) switch inputs using a multi-switch detection interface (MSDI) device. This user guide provides real-world examples of an MSDI device handling HV switch inputs for body control modules (BCMs), faceplates, and top-column module applications. In addition, the design utilizes a wide V_{IN}, low dropout (LDO) regulator for creating a fixed 3.3-V microcontroller (MCU) supply voltage.

Resources

TIDA-01237	Design Folder
TIC12400-Q1	Product Folder
TIC10024-Q1	Product Folder
TPS7B6733-Q1	Product Folder
LMT87-Q1	Product Folder
DRV5023-Q1	Product Folder

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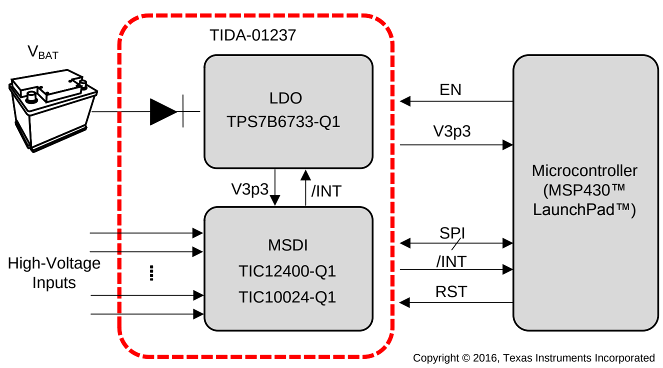
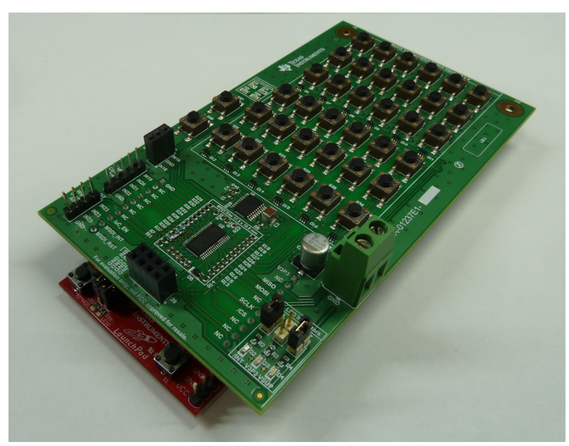
Features

- Monitors 36 High-Voltage Inputs in 6x6-Matrix Configuration Using Only 12 Input Pins
- Programable Multi-Threshold Inputs Can Handle Multi-Position Resistor-Coded Switch Inputs
- Aggregates Inputs and Communicates Status to MCU Through Five-Pin Digital Interface (Four-Pin SPI + Interrupt Pin)
- Monitors Analog Inputs through 10-Bit, 0-V to 6-V Input Range Integrated Analog-to-Digital Converter (ADC)
- Wide V_{IN} Fixed 3.3-V Low Dropout (LDO) Regulator
- Interrupt-Enabled Power Supply Control for Very-Low-Power Sleep Mode With Switch Monitoring

Applications

- Automotive Body Control Modules (BCMs)
- Automotive Face Plate Applications
- Automotive Top Column Modules





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1 System Overview

1.1 System Description

A multi-switch detection interface (MSDI) is a device that aggregates many high-voltage (HV), battery-connected switch inputs and is able to communicate switch status to a microcontroller (MCU) through a digital interface. The TIC12400-Q1 and TIC10024-Q1 are two MSDI devices from Texas Instruments (TI). The TIC12400-Q1 device is a full-featured MSDI device capable of handling matrix configuration switch inputs, resistor-coded (multiple threshold) switch inputs, and analog inputs. For applications not requiring matrix configuration switch inputs and multi-threshold inputs, the TIC10024-Q1 is a lower-cost MSDI device option without an internal analog-to-digital converter (ADC). This reference design highlights the features of both of these devices while maintaining a small solution size, low system-wide quiescent current, and a minimum amount of external discrete components.

At the time of this writing, a majority of high-voltage inputs that are handled by body control modules (BCMs), faceplate modules, and top column modules are done so discretely. This process requires a large number of discrete resistors, capacitors, and diodes that increase the overall solution size and manufacturing cost of the solution. Additionally, these solutions do not have the ability to adjust system parameters such as wetting currents over input voltage and temperature, as they require a large number of input pins on the MCU in addition to requiring the MCU to be active to monitor switch status, which increases power consumption in key-off situations. This design shows how a variety of input types can be handled for both normal operating mode and low-power sleep mode while lowering the number of required MCU pins, solution size, and overall system-wide current consumption.

1.2 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Input power source (VBATT)	Automotive 12-V battery system	Section 2.1
Operational Input voltage range (VBATT)	4.5 V to 36 V	Section 2.1
Survivable input voltage range (VBATT)	–40 V to +40 V	Section 2.1
I/O input voltage range (IN0 through IN23)	–16 V to +40 V[(1)]	Section 1.4
Regulated output voltage	3.3 V ±2.0%	Section 1.4.4
Average standby-state current consumption (monitoring six comparator inputs)	58 µA	Section 4.4.2
Form factor	Rectangular printed-circuit board (PCB)	Section 5.3.1

(1) For battery-connected switches, the survivable input voltage range on VBATT is limited to –16 V to +40 V.

1.3 Block Diagram

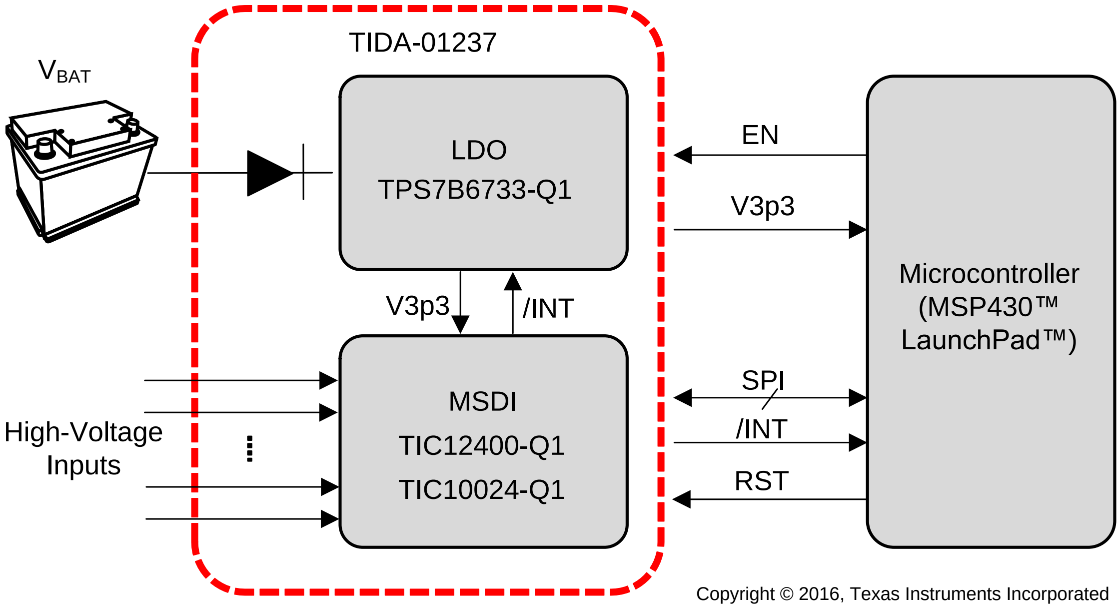

Figure 1. TIDA-01237 Block Diagram

1.4 Highlighted Products

1.4.1 Highlighted TI Products

The TIDA-01237 TI Design features the following five devices:

- TIC12400-Q1: Automotive multi-switch detection interface (MSDI) with integrated 10-bit ADC and serial peripheral interface (SPI)
- TIC10024-Q1: Automotive multi-switch detection interface (MSDI) with SPI
- TPS7B6733-Q1: Automotive 450-mA high-voltage ultra-low I_Q low-dropout (LDO) regulator
- DRV5023FA-Q1 and DRV5023FI-Q1: Automotive digital-switch hall effect sensors
- LMT87-Q1: Automotive Analog temperature sensors with class-AB output

For more information on each of these devices, see their respective product folders at www.ti.com.

1.4.2 TIC12400-Q1

The TIC12400-Q1 is an MSDI device that is designed to detect the closing and opening of switch contacts on up to 24 input pins. Ten out of the 24 inputs are configurable to monitor switch status for switches to ground or switches to battery, while the remaining 14 inputs handle only switches to ground. The device has six programmable, wetting-current settings for either sourcing or sinking current to accommodate many different application scenarios.

In addition, the TIC12400-Q1 has an internal 10-bit, 0-V to 6-V input range ADC for monitoring programmable ADC threshold inputs, multi-threshold inputs, and analog inputs. The switch status, diagnostic flags, and analog voltages are reported to the MCU through a four-pin SPI.

Figure 2 shows a block diagram of the device.

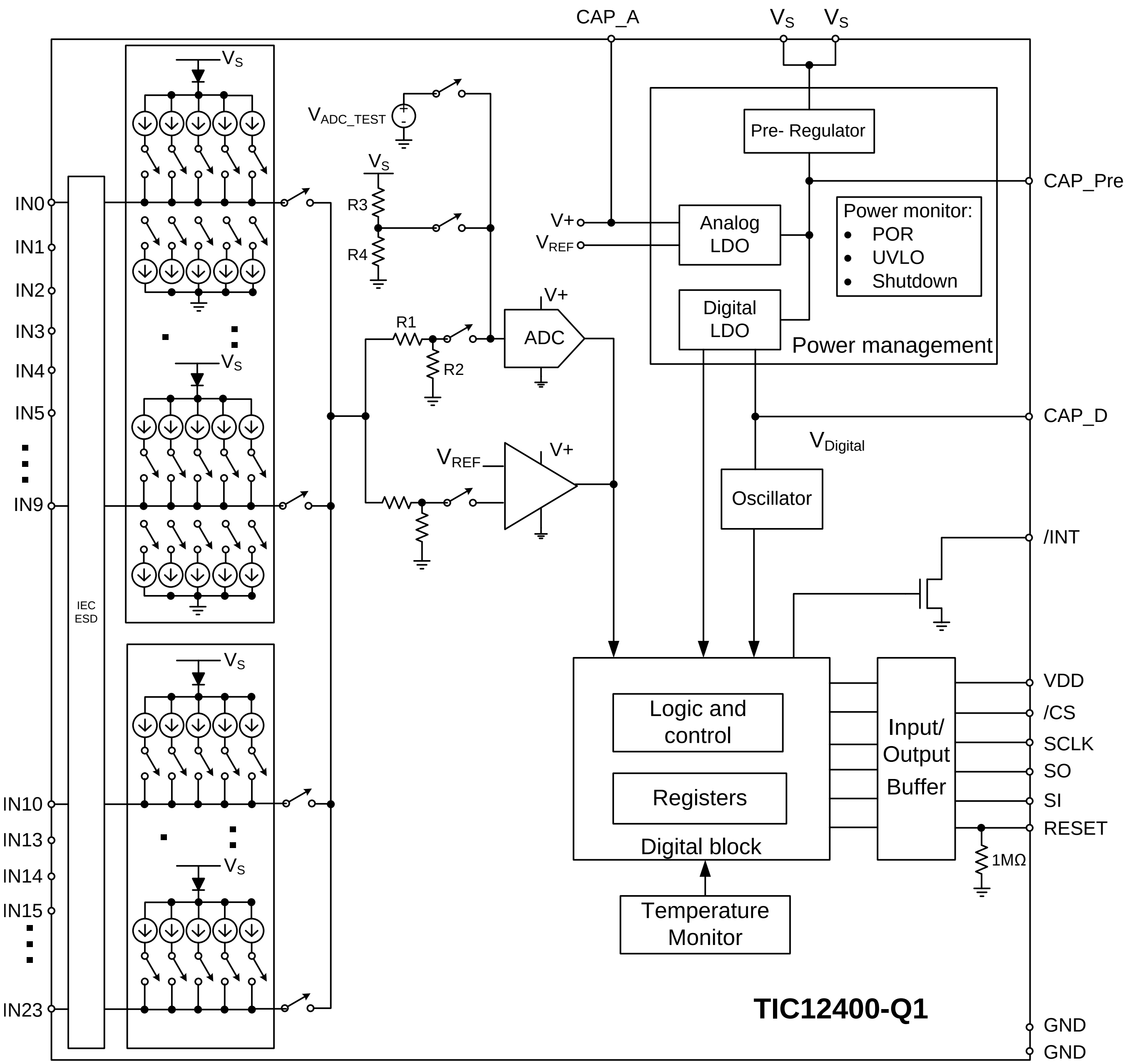

Figure 2. TIC12400-Q1 Block Diagram

- AEC-Q100-qualified for automotive applications
- Operates with supply voltage (V_S) from 4.5 V to 35 V
- Switch inputs can withstand transients up to 40 V and reverse battery conditions down to –16 V
- Monitors inputs on up to 24 HV input pins
- Six configurable sourcing or sinking wetting-current settings (0 mA, 1 mA, 2 mA, 5 mA, 10 mA, and 15 mA)
- Integrated matrix polling modes that can handle 4×4, 5×5, and 6×6 matrix configuration switch inputs
- Resistor-coded (multi-position) switch monitoring with integrated 10-bit ADC and adjustable input detection thresholds
- Ultra-low operating current in the polling mode: 65 µA typical (t_{POLL} = 64 ms, t_{POLL_ACT} = 128 µs, all 24 channels active, all switches open)
- Interfaces directly to MCU using 3.3-V- or 5.0-V SPI protocol
- Open-drain interrupt output (/INT) pin to notify microprocessor of switch state changes, system fault conditions, or both
- ISO 7637 pulse immunity on V_S and switch inputs with appropriate external components
- Integrated ±4-kV human body model (HBM) and ±8-kV ISO 10605 contact discharge electrostatic discharge (ESD) protection on HV input pins

1.4.3 TIC10024-Q1

The TIC10024-Q1 is a lower-cost MSDI device that is also designed to detect the closing and opening of switch contacts up to 24 input pins. The major difference between the TIC12400-Q1 and the TIC10024-Q1 is that the TIC10024-Q1 does not have the switch matrix polling feature and it does not have an integrated ADC, which means that it is not able to handle analog inputs or multi-threshold inputs.

Just like the TIC12400-Q1, 10 out of the 24 inputs are configurable to monitor either switches to ground or switches to battery, while the remaining 14 handle only switches to ground. Six wetting current settings can be programmed for each input to accommodate different application scenarios. The switch status, diagnostic flags, and analog voltages are reported to the microprocessor unit (MCU) through a serial peripheral interface (SPI).

Figure 3 shows the TIC10024-Q1 block diagram.

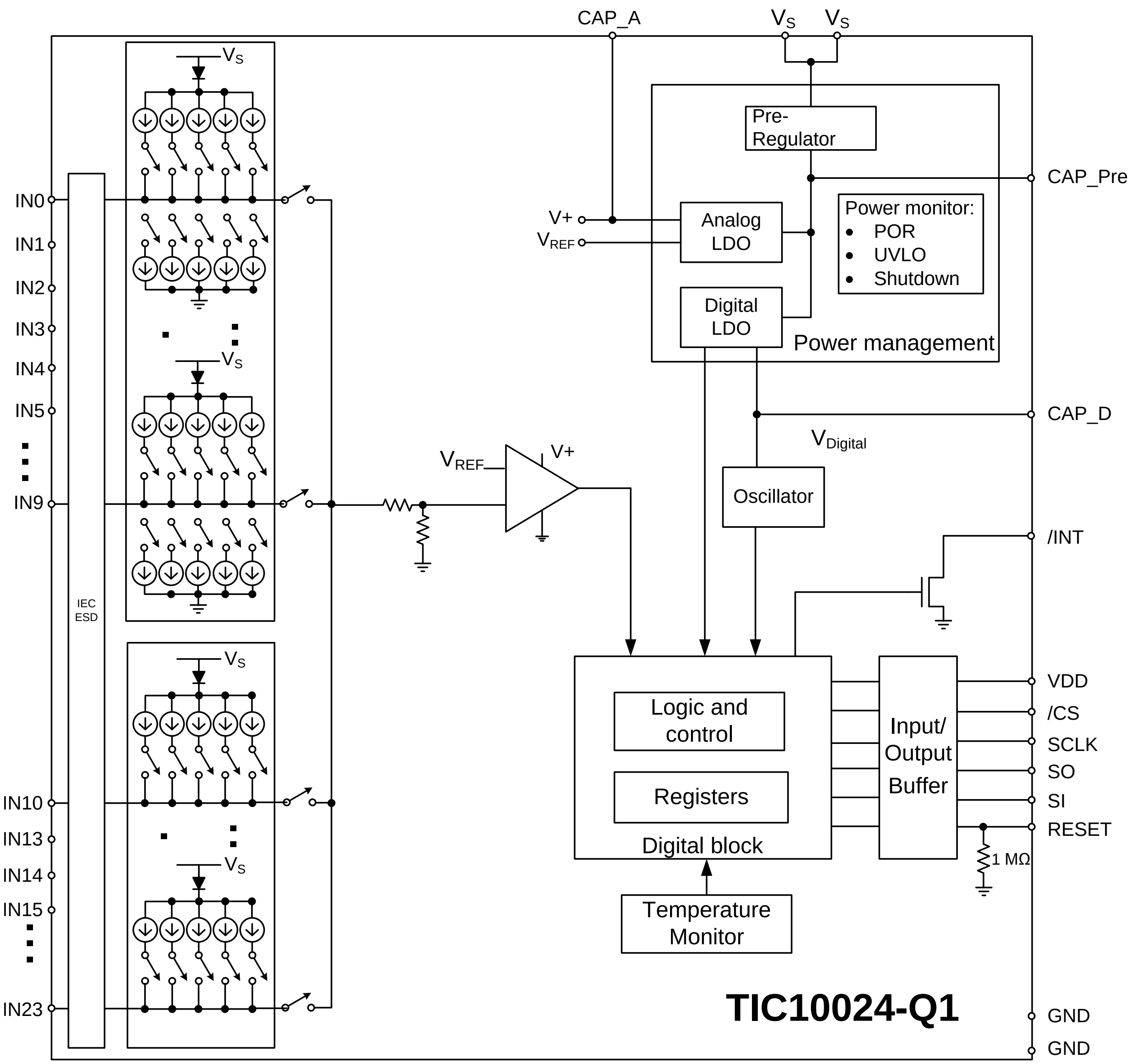

Figure 3. TIC10024-Q1 Block Diagram

- AEC-Q100 qualified for automotive applications
- Operates with supply voltage (V_S) from 4.5 V to 35 V
- Switch inputs can withstand transients up to 40 V and reverse battery conditions down to -16 V
- Monitors inputs on up to 24 HV input pins
- 6 configurable wetting current settings (0 mA, 1 mA, 2 mA, 5 mA, 10 mA, and 15 mA)
- Ultra-low operating current in the polling mode: 65 μA typical (t_{POLL} = 64 ms, t_{POLL_ACT} = 128 μs, all 24 channels active, all switches open)
- Interfaces directly to MCU using 3.3 V- or 5.0-V SPI protocol
- Open-drain interrupt output (/INT) pin to notify microprocessor of switch state changes, ,system fault conditions, or both
- ISO 7637 pulse immunity on V_S and switch inputs with appropriate external components
- Integrated ±4 kV human body model (HBM) and ±8-kV ISO 10605 contact discharge ESD protection on HV input pins

1.4.4 TPS7B6733-Q1

The TPS7B67xx-Q1 devices are a family of low-dropout (LDO) linear regulators designed for wide V_{IN} applications handling up to 40 V on the input voltage rail. With only 15-μA (typical) quiescent current at light load, these devices are suitable for standby MCU-based systems, especially in automotive applications.

Figure 4 shows the TPS7B6733-Q1 block diagram.

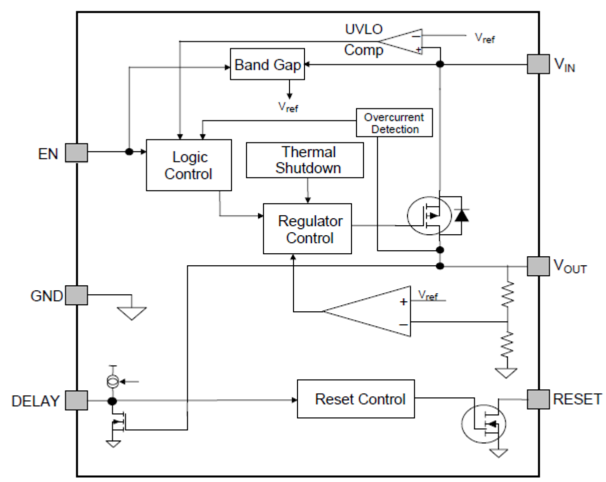

Figure 4. TPS7B6733-Q1 Block Diagram

- AEC-Q100 qualified for automotive applications
- 4-V to 40-V wide input voltage range for the fixed 3.3-V version with up to 45-V transient input voltage range
- 450-mA maximum output current
- Low quiescent current (I_Q): 15 μA typical at light loads and 25 μA maximum over full temperature range
- 240-mV typical dropout voltage at 400-mA load current
- Stable with low equivalent-series-resistance (ESR) ceramic output capacitor (10 μF to 500 μF)
- Fixed 3.3-V and 5-V output versions and an adjustable 1.5-V to 18-V output version
- Integrated power-on reset, open-drain output with programmable reset pulse delay
- Integrated fault protection: thermal shutdown and short-circuit protection

1.4.5 DRV5023-Q1

The DRV5023-Q1 family of devices are chopper-stabilized Hall effect sensors that offer a magnetic-sensing solution with superior sensitivity stability over temperature and integrated protection features. When the applied magnetic flux density exceeds the operating point threshold, the DRV5023FA-Q1 open-drain output drives low. The output stays low until the field decreases to less than the release point threshold, at which point the output returns to the high impedance state. The DRV5023FI-Q1 device has the opposite behavior; the output is low until the flux density exceeds the operating point threshold and then goes high impedance. When the field decreases to less than the release point threshold, the output is once again driven low. By using both the FA and FI devices together, a complimentary dual-output scheme can be set up, which is how these devices were evaluated for this design.

The current output drive of both the FA and FI versions are able to sink up to 30 mA and they both have a wide operating voltage range from 2.7 V to 38 V with reverse polarity protection up to –22 V. These devices are both AEC Q100 Grade 0 and Grade 1 qualified, which makes them suitable for a wide range of automotive applications.

Figure 5 shows the DRV5023-Q1 block diagram.

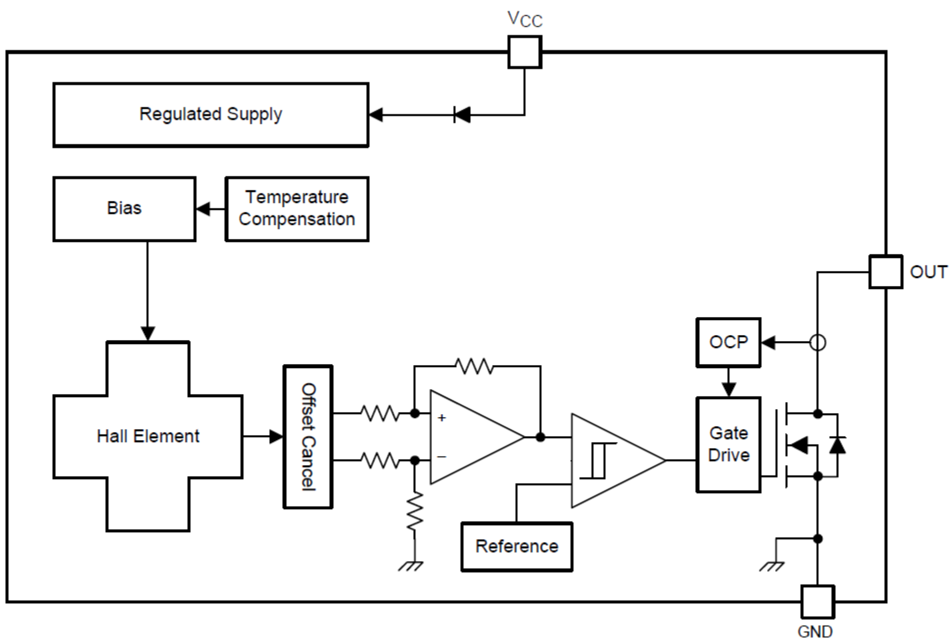

Figure 5. DRV5023-Q1 Block Diagram

- AEC-Q100 Grade 0 and Grade 1 qualified for automotive applications
- Digital unipolar-switch Hall sensor
- Standard output (FA) and inverse output (FI) options
- Superior temperature stability (10% over temperature)
- Multiple sensitivity options
- Supports wide input voltage range without the need for a regulator (2.7 V to 30 V)
- Open drain output (30-mA sink)
- Fast 35-µs power-on time
- Surface mount and through-hole packaging options (SOT-23 and TO-92)

1.4.6 LMT87-Q1

The LMT87-Q1 is a precision CMOS integrated-circuit temperature sensor with an analog output voltage that is linearly and inversely proportional to temperature. The following features make it suitable for many general temperature sensing applications. The device can operate down to a 2.7-V supply with 5.4-µA power consumption. Package options include through-hole TO-92 and a surface mount SOT23 3-pin package, which allows the LMT87 to be mounted onboard, offboard, to a heat sink, or on multiple unique locations in the same application.

The class-AB output structure gives the LMT87-Q1 a strong output source and sink current capability. These features indicate that the device is well-suited to drive an ADC sample-and-hold input with its transient load requirements. The LMT87-Q1 has an accuracy specified in the operating range of −50°C to 150°C. The accuracy, three-lead package options, and other features also make the LMT87-Q1 an alternative to thermistors.

Figure 6 shows the LMT87-Q1 block diagram.

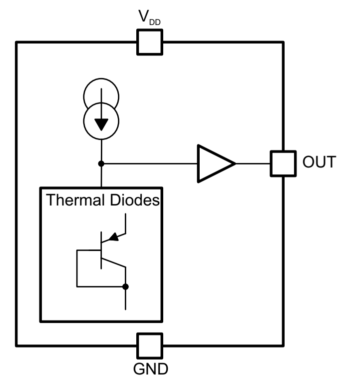

Figure 6. LMT87-Q1 Block Diagram

- AEC-Q100 Grade 0 qualified for automotive applications
- Very accurate: ±0.3°C typical
- Wide temperature range of −50°C to 150°C
- Low 5.4-µA quiescent current
- Sensor gain of –13.6 mV/°C
- Surface mount and through-hole packaging options (SOT-23 and TO-92)
- Short-circuit protected push-pull output with 50-µA source current for capacitive loads

2 Design Considerations

BCM, faceplate, and top column modules are all composed of several sub-circuits. This design covers the battery input, regulation, and switch input portions of those applications. The following subsections cover the component selection and device configuration decisions for this design.

2.1 Supply Protection and Regulation

Figure 7 shows the portion of the schematic that has the reverse battery input protection diode, input filtering capacitors, 3.3-V fixed LDO regulator, LDO enable control resistor, and the output-filtering capacitor for the supply protection and regulation of the TIDA-01237.

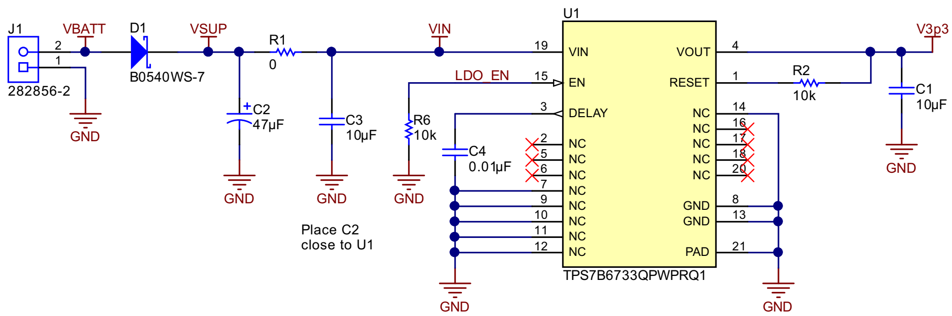

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Figure 7. Power Supply Schematic

- **Reverse battery protection:** The supply input on the TIDA-01237 design is protected with a 40-V reverse battery protection Schottky diode (D1).
- **Input and output capacitors:** Both bulk and bypass decoupling capacitors (C2 and C3) are added for input supply filtering; input capacitor C3 and output supply capacitor C1 must be placed as close to the TPS7B6733-Q1 as possible to minimize equivalent series inductance (ESL) and equivalent series resistance (ESR) .
- **TPS7B6733-Q1 enable control:** Resistor R6 from the EN pin to ground ensures that when the LDO_EN signal is not being actively driven by transistor Q1 (see Figure 10) the EN pin remains low and the TPS7B6733-Q1 remains in low-power sleep mode.
- **TPS7B6733-Q1 delay capacitor:** Delay capacitor C4 sets the RESET output delay timer to a typical delay of 1.05 ms.
- **TPS7B6733-Q1 RESET output:** The RESET output is an open-drain output that is released when the output has exceeded approximately 91.6% of its regulated output voltage and the power-on-reset delay has expired. The RESET output must be externally pulled up to V_{OUT} through an external resistor (R40).

The TP7B67xx-Q1 family of LDO regulators also comes with a fixed 5.0-V LDO version (TPS7B6750-Q1) and an adjustable output version (TPS7B6701-Q1), which are pin-to-pin equivalent to the TPS7B6733-Q1 version used in this design.

2.2 MSP430™ LaunchPad™ Connections

Female headers J2 and J3, which are installed on the bottom of the TIDA-01237 design board, are used to connect to the MSP-EXP430G2 board. Figure 8 shows the shared connections between the TIDA-01237 design board and the MSP430™ LaunchPad™ development kit. The MSP430 is the master SPI device (through the Universal Serial Communications Interface A0 module - USCIA0) and the TIC12400-Q1 or TIC10024-Q1 devices are slave SPI devices.

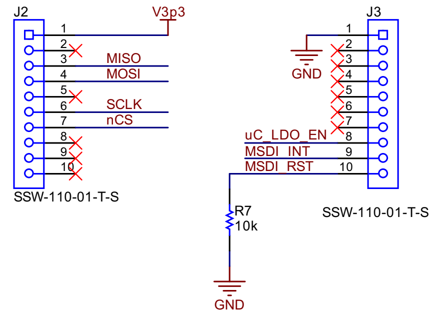

Figure 8. MSP430™ LaunchPad™ Connections

The following list provides a brief description of all of the shared nets between the TIDA-01237 board and the MSP-EXP430G2 LaunchPad board:

- **V3p3** – 3.3-V supply output of the TPS7B6733-Q1 device
- **MISO** – Master in slave out: The serial data input signal for the MSP430G2553 and serial data output signal for the TIC12400-Q1 or TIC10024-Q1 device
- **MOSI** – Master out slave in: The serial data output signal for the MSP430G2553 and serial data input signal for the TIC12400-Q1 or TIC10024-Q1 device
- **SCLK** –Slave Clock - MSP430G2553 clock output signal and clock input signal for the TIC12400-Q1 or TIC10024-Q1
- **nCS** – Active low chip select: The MSP430 output select signal and input select line for the TIC12400-Q1 or TIC10024-Q1 (driven low to begin a SPI transaction and driven high to end a SPI transaction)
- **GND** – Shared ground connection
- **uC_LDO_EN** – The MSP430G2553 LDO enable output signal (used to enable and disable the TPS7B6733-Q1 device for ultra-low-power sleep mode)
- **MSDI_INT** – TIC12400-Q1 or TIC10024-Q1 open-drain output signal used to indicate a switch state change or special event (must be externally pulled high)
- **MSDI_RST** – The MSP430G2553 output signal used to hardware reset the TIC12400-Q1 or TIC10024-Q1 device (reset is active high)

NOTE: **Pins with "x" marking:** The remaining pins that are marked with a red "x" in the preceding Figure 8 are not electrically connected on the TIDA-01237 board, but are electrically connected to the MSP430 device on the MSP-EXP430G2 board.

2.3 Indicator LEDs

Three indicator LEDs have been added to the design for ease of evaluation. Figure 9 shows the LED indicator portion of the schematic. Each LED supply path has been equipped with a twp-pin, 100-mil header so that each LED indicator can quickly be enabled or disabled through the use of a two-pin shunt. Note that resistor R5 has been sized for a nominal battery voltage of 14 V.

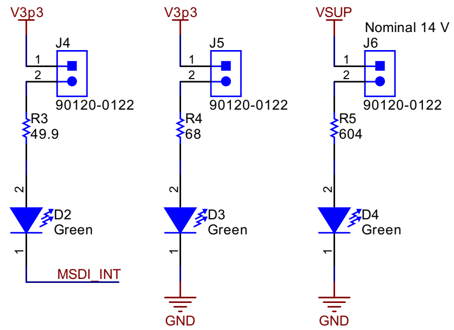

Figure 9. LED Indicators Schematic

All three LED headers (J4, J5, and J6) were open when evaluating the current consumption of this design in different modes.

NOTE: Do not install a shunt on header J6 for input supply test voltages above 20 V.

2.4 TPS7B6733-Q1 Enable Control Circuitry

Figure 10 shows the enable control circuitry that was used to drive the EN signal on the TPS7B6733-Q1 device. The purpose of the additional circuitry is to allow the system to go into an ultra-low-power current-consumption mode where only the TIC12400-Q1 or TIC10024-Q1 device remains enabled while actively monitoring switch inputs. With the LDO output disabled, and the MCU completely powered off, the quiescent current of the system is reduced to just the MSDI device and the sleep current of the LDO.

To allow the system to go into ultra-low-power current-consumption mode, the control circuitry must be able to drive the EN pin on the TPS7B6733-Q1 device high to VSUP to enable the output and allow the EN pin to be pulled to ground to disable the output and go into low-power sleep mode (using resistor R6 in Figure 7).

The control circuitry is set up so that whenever the /INT pin is driven low or the uC_LDO_EN signal is driven high by the MSP430, the EN pin on the TPS7B6733-Q1 device is pulled high through transistor Q1. The LDO output can be disabled only when both the /INT pin is in high impedance and the uC_LDO_EN pin is either in a low or high impedance state.

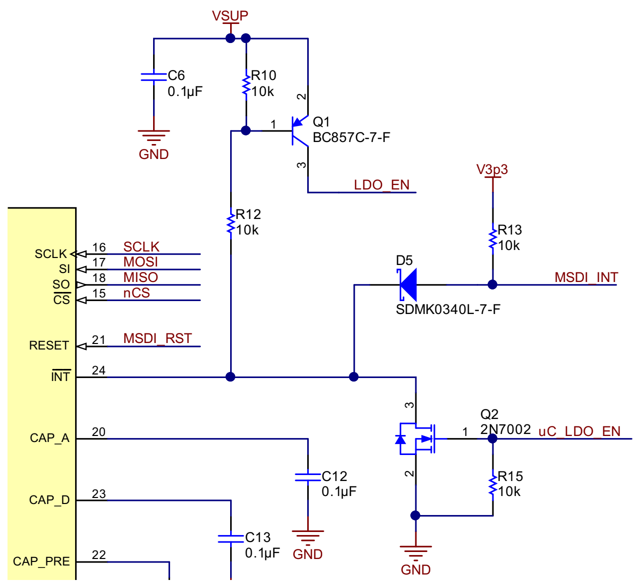

Figure 10. TPS7B6733-Q1 EN Control Circuitry

The /INT pin control circuitry works as follows. The /INT pin is an open-drain output which is driven low after setting any of the internal flags. Upon reading the INT_STAT register, the flags are cleared and the /INT output is disabled and goes high impedance. Therefore, the only two possible output states for the /INT pin are either actively driven low or high impedance. For the case where the pin is driven low, current flows from VSUP through resistors R10 and R12. This current flow causes a voltage drop across R10, which in turn forward biases the transistor Q1 and causes the LDO_EN signal to be pulled up to VSUP through transistor Q1. This process results in the LDOs output being enabled.

For the high-impedance case, no current flows from VSUP to /INT; therefore, the base (pin 1) of transistor Q1 remains at the VSUP voltage potential. This bias causes Q1 to remain off and the LDO_EN signal to be weakly pulled to the ground through resistor R6, as the preceding Figure 7 shows. With the LDO_EN signal low the output of the LDO is disabled and the TPS7B6733-Q1 device enters low-power sleep mode.

The uC_LDO_EN portion of the control circuitry works as follows. The uC_LDO_EN signal is driven by a general purpose input/output (GPIO) pin on the MSP430 device. When the MSP430 powers up and finishes initialization, the set pin functions as a push or pull output. Therefore, the uC_LDO_EN signal has two states, it can either be driven high to V3p3 or driven low to ground. An important thing to note is that when the TPS7B6733-Q1 3.3-V output is disabled the MSP430 powers off and the pin takes on a third, high-impedance state. For this reason, resistor R15 has been added from the uC_LDO_EN signal to ground to ensure that when the MSP430 is powered off and the GPIO is in a high-impedance state, transistor Q2 remains off with its gate tied to ground through R15.

For cases where the uC_LDO_EN signal is either driven low through the MSP430 or in a high-impedance state, the gate of the N-channel field-effect transistor (FET) Q2 is to be low. This bias results in the transistor Q2 being off and the source (pin 3) being pulled up to VSUP through resistors R10 and R12, which, in turn, ensures that transistor Q1 also remains off and the LDO_EN signal remains pulled low through resistor R6, resulting in the LDO output being disabled. For cases where the uC_LDO_EN signal is driven high, transistor Q2 is to be ON and the source pin (pin 3) is to be pulled to ground through the ON-state resistance of the device. This event causes current to flow from VSUP through R10 and R12 which in turn forward biases transistor Q1 and results in the LDO_EN signal being pulled high and the enables the LDO output.

Table 2 summarizes these six states.

Table 2. TPS7B6733-Q1 Enable Control Signals

/INT PIN	uC_LDO_EN PIN (MSP430 GPIO P2.5)	POWER SUPPLY LDO_EN SIGNAL
Low	Low	High
Low	High	High
Low	High impedance	High
High impedance	Low	Low
High impedance	High	High
High impedance	High impedance	Low

This design has been evaluated with two basic program flows:

1. In the first program flow, the system powers up, initializes, and then enters low-power sleep mode. During low-power sleep mode, the output of the TPS7B6733-Q1 device is disabled, the MSP430 is powered off, and the MSDI device is in low-power polling mode to monitor the switch inputs for a switch-state change (SSC) event.
2. In the second program flow the system powers up, initializes, and then enters an interrupt-enabled mode where the LDO remains enabled, the MSP430 remains powered on, and the /INT pin is monitored for a falling edge. This program flow does not use the low-power sleep mode.

Figure 11 shows the first program flow which uses the low-power sleep mode.

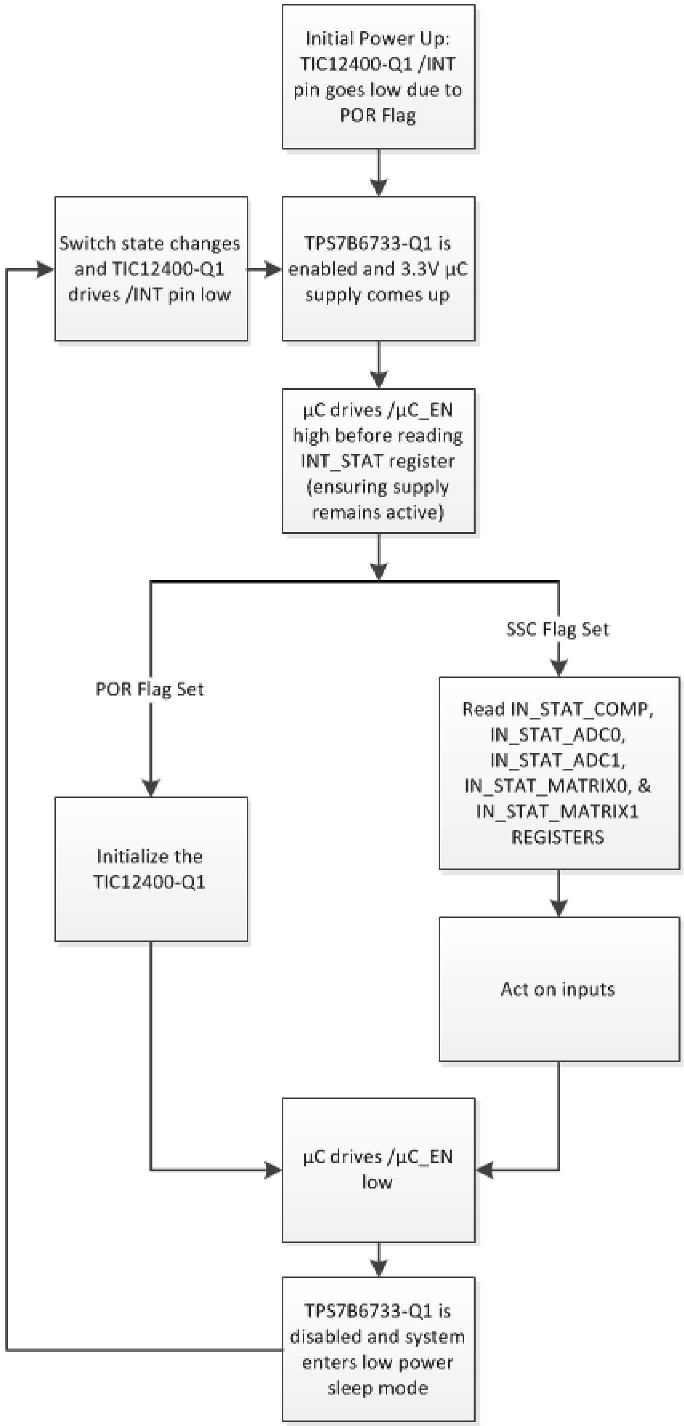

Figure 11. Program Flow With Low-Power Sleep Mode

This option is easy to implement because the TIC12400-Q1 and TIC10024-Q1 devices drive the /INT pin low on initial power up due to the power-on reset (POR) flag being set. This configuration means that the 3.3-V supply is always enabled upon initial power up. Therefore, the MCU can power up, drive the uC_LDO_EN signal high, and then read the status of the INT_STAT register through SPI. It is important that the uC_LDO_EN signal is driven high before the INT_STAT register is read so that the supply is not disabled when the flag has cleared at the completion of the SPI read transaction.

After the INT_STAT register has been read, a case structure can be used to decide what action to take depending on what internal flags are set on the MSDI device. Afer the POR flag has been set, the micro can initialize the MSDI device and when the SSC flag has been set, the micro can read the status registers to determine which input or inputs changed states and act on those events. Additionally, other routines can be added to this case structure for the SPI Error flag, Parity Fail flag, VS Threshold Crossing flag, Temperature Event flag, and Other Interrupt flag.

If low-power sleep mode with switch monitoring is not required, the designer can use the following program flow as shown in Figure 12.

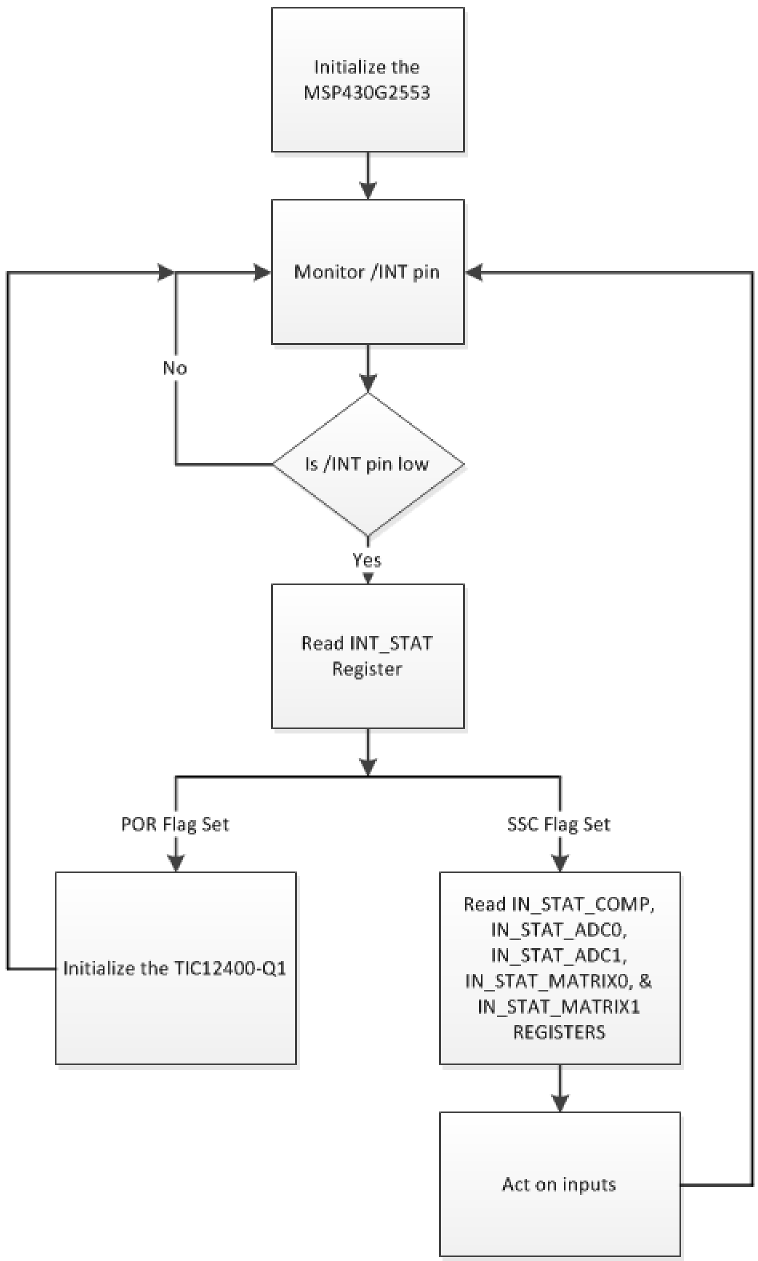

Figure 12. Program Flow Without Low-Power Sleep Mode

To use this program flow without making any hardware changes, the uC_LDO_EN signal can be driven high during MSP430 initialization and remain high during the rest of evaluation.

2.5 Input Circuitry

Each input on this design has been equipped with an ESD and transient-absorbing capacitor and a series current-limiting resistor. These values can be adjusted, removed, or both depending on the system-level performance required. See the TIC12400-Q1[1] or TIC10024-Q1[2] datasheet for more information about ESD and transient performance.

2.6 Matrix Configuration Switches Inputs

The TIDA-01237 board has a 6×6-matrix configuration switch input section; Figure 13 shows this schematic.

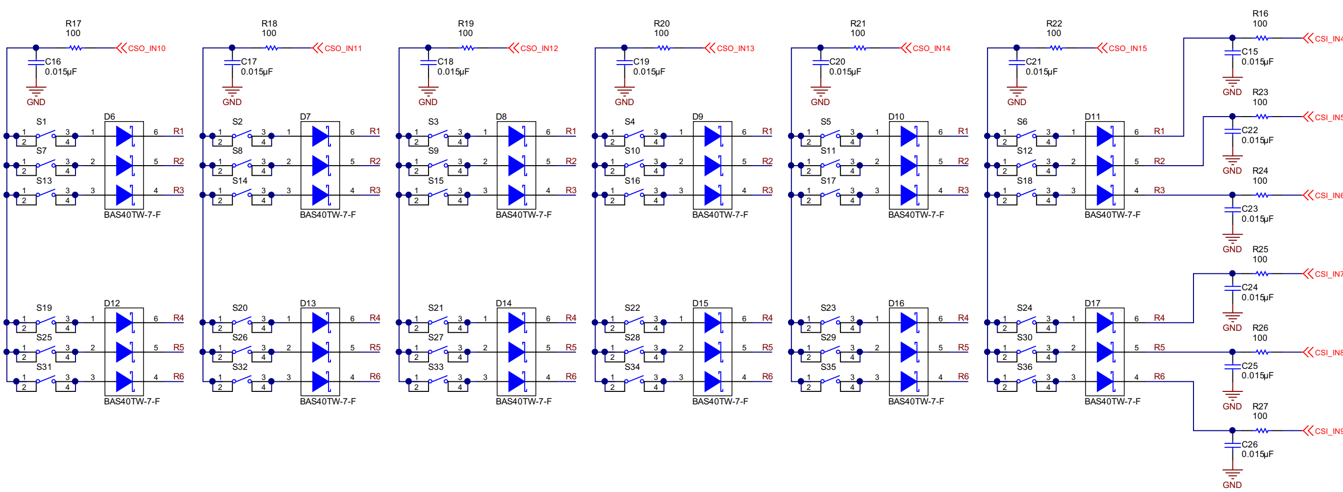

Figure 13. Matrix Configuration Switch Schematic

Setting up input switches in a matrix configuration has the benefit of reducing the number of input/output (I/O) pins required for an application. Obviously, the easiest way to handle a discrete input is through the use of a single GPIO pin configured as an input; however, as the number of switches increases, the number of required I/O pins also scales 1:1. By placing the switches into a matrix configuration, the number of I/O pins can be reduced to the total number of columns (IN10 through IN14) plus the number of rows (IN4 through IN9) in the switch matrix. For example, a 6×6 matrix of switches has 36 total switches but only requires six sourcing columns and six sinking rows, for a total of 12 I/O pins. This feature means that changing from a single push button per I/O switch configuration to the 6×6 matrix configuration has the benefit of saving 24 I/O pins.

The benefit of configuring the switches in this manner actually increases the larger the matrix gets. For instance, a 4×4 matrix requires eight I/O pins to monitor 16 switch inputs, thereby reducing the number of required I/O pins in half. Alternatively, a 6×6 matrix requires 12 I/O pins to monitor 36 switch inputs, thereby reducing the number of I/O pins required to one-third.

An additional benefit that matrix configuration switch inputs can have is saving cost by reducing the number of wires required to monitor remote switch inputs, which in turn also reduces the overall weight of the solution. Traditionally, matrix switch inputs have the caveat of requiring a much more complicated polling scheme to evaluate the state of all of the switches. Running this polling scheme is not as simple as activating the pullup supply on all of the inputs and reading in all of the states. When using matrix switches, the designer must implement a polling scheme where a single row is pulled low and then each column individually sources current. When all the columns on the first row finish sourcing current and measuring the input voltage, the next row is driven low and each column individually sources current and measures the input voltage again. This process repeats six times for the 6×6 matrix (one for each row) so that each of the 36 input states are read a single time.

One of the benefits of the TIC12400-Q1 device is that it comes with a built-in polling mode which is capable of handling 4×4-, 5×5-, and 6×6-switch matrix applications. This built-in feature means that the end user does not have to create this polling scheme to be able to use matrix configuration inputs in their application when using the TIC12400-Q1 device.

The last thing to consider when implementing a matrix of switches with the TIC12400-Q1 device is whether or not the user desires the capability to handle simultaneous button presses. If a number of buttons are pressed simultaneously, current can flow down one column, back up another, and over on a row causing an erroneous result where a button that has not been pressed "appears" to have been pressed. The simplest way to avoid erroneous results due to many switches being pressed is by placing a series blocking diode after every switch. This measure has been implemented in this design using Schottky diode array devices that contain three diodes in one small six-pin SOT23 package.

The additional series resistor on every input is for limiting any current during transient events and the capacitor-to-ground is for transient suppression. These values can be adjusted, removed, or both depending on the required system-level performance. See the TIC12400-Q1[1] or TIC10024-Q1[2] datasheet for more information about ESD and transient performance.

NOTE: Only the higher-feature TIC12400-Q1 device is able to handle matrix configuration switches.

2.7 Button and Switch LED Backlighting

Because the TIC12400-Q1 and TIC10024-Q1 devices are able to accurately source current over a wide range of input voltages, pins can also be used to source current for backlighting buttons and switches without worrying about large variations in current (and therefore LED brightness) for different battery conditions. These devices are able to accurately source 1 mA, 2 mA, 5 mA, 10 mA, and 15 mA over a large range of input supply voltages. Figure 14 shows the LED backlighting portion of the schematic that is connected to IN17.

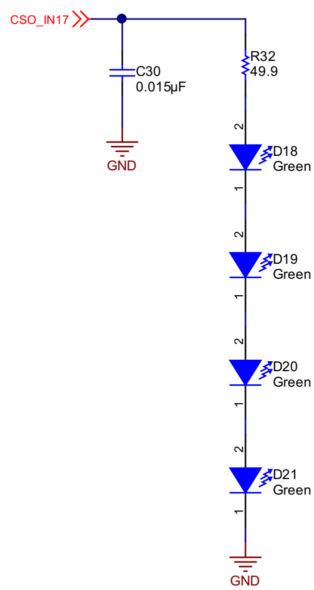

Figure 14. Button and Switch LED Backlighting Schematic

The additional series resistor is for limiting any current during transient events (if the string of LEDs is connected externally to the module the MSDI device is on), and the capacitor to ground is for transient suppression. These values can be adjusted, removed, or both depending on the required system-level performance. See the TIC12400-Q1[1] or TIC10024-Q1[2] datasheet for more information about ESD and transient performance.

The power dissipated in the TIC1xxxx-Q1 device due to the current sourced at each input pin can be estimated by taking the difference between the input supply voltage and the output voltage seen at the pin and then multiplying the result by the sourced current. In situations where many input pins are continuously sourcing current, the power dissipation inside the device can add up and must be considered during design.

NOTE: Make sure to consider self-heating of the device resulting from any wetting currents that are continually active.

2.8 Analog Inputs

The TIC12400-Q1 device has an integrated 10-bit, 0-V to 6-V ADC which is used for measuring input voltages on any input not set in comparator input mode, including any input threshold that requires special programming or any multi-threshold input. Additionally, ADC input mode can be used to directly monitor external analog signals.

Header J7 (as shown in Figure 15) has been used to evaluate the LMT87-Q1 external analog temperature sensor. The output voltage range of the LMT87-Q1 is 0 V to 3.3 V and it has been directly tied to the IN0 connection on J7. This connection is possible without any attenuation because the output voltage does not exceed the 6-V input range of the ADC. However, if the designer wishes to utilize the full range of the 0-V to 6-V input range of the ADC on the TIC12400-Q1 device, the analog signal can be fed through an amplification stage with a gain of ≈1.8 V/V.

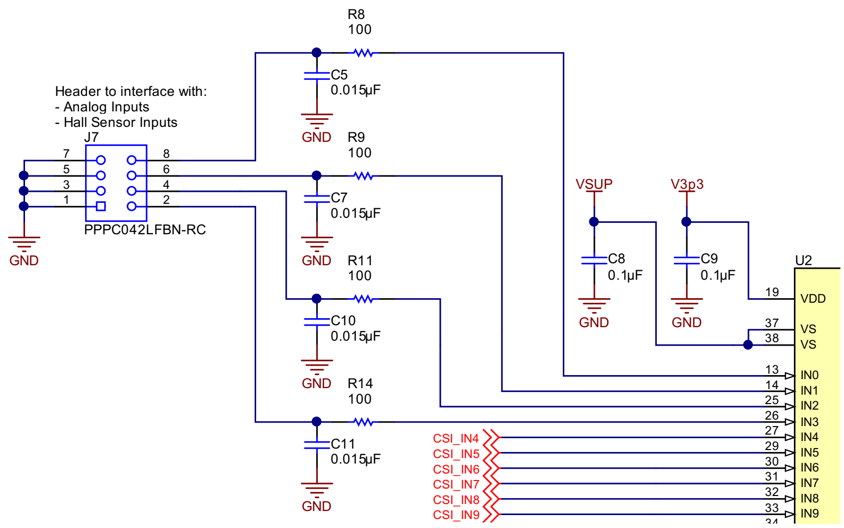

Figure 15. J7 Input Schematic for External Analog and Digital Inputs

Again, the additional series resistors are for limiting any current during transient events and the capacitors-to-ground are for transient suppression. These values can be adjusted, removed, or both depending on the required system-level performance. See the TIC12400-Q1[1] or TIC10024-Q1[2] datasheet for more information about ESD and transient performance.

NOTE: Only the higher-feature TIC12400-Q1 device is able to convert analog signals to digital for direct access over SPI.

2.9 Multi-Threshold Inputs

The last major design consideration topic to address is the ability of the TIC12400-Q1 device to handle multiple thresholds on some of its input pins. When in ADC input mode, inputs 12 through 17 have two programmable input thresholds, inputs 18 through 22 have three programmable input thresholds, and input 23 has five programmable input thresholds. An input is able to detect one more input state than it has input thresholds. For example, a single threshold input can detect two distinct states (above and below the threshold), and a two-threshold input can detect three distinct states (below the first threshold, between the first and second thresholds, and above the second threshold). The following four subsections cover the design considerations for these four example multi-threshold inputs:

1. Three-position rocker switch input
2. Dual-button input with multi-press detection
3. Light control arm input
4. Wiper control arm input

2.9.1 Three-Position Rocker Switch Input

Figure 16 shows the input circuitry from connector J10 to IN16 on the TIC12400-Q1. This pin has been set up to handle a three-position, momentary-off-momentary rocker switch like a door lock switch or a volume control switch. These switches typically have three contacts where the middle contact (pin 2) is either open, shorted to pin 1, or shorted to pin 3 for a total of three distinct states. To be able to tell the difference between pin 2 being shorted to pin 1 and pin 2 being shorted to pin 3, two external resistors (R28 and R29) with different resistance values were used.

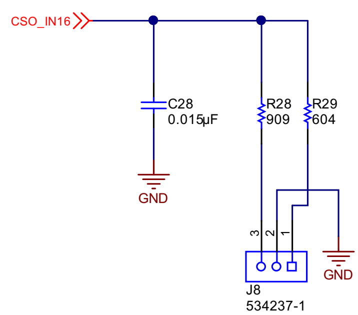

Figure 16. Rocker Switch Input Schematic

IN16 has been programmed to source 5 mA of current and therefore the following three states can be considered:

1. During the default state where the rocker switch is not pressed and pin 2 is open (not internally connected to either pin 1 or pin 3), the input voltage is pulled up to the V_S input voltage. This means that for typical battery supply input voltages the ADC is to read the max input value of 1023 (2^{10} – 1) because the input voltage is above the 6-V max input range of the ADC.
2. For the input state where the rocker switch is pressed up and pin 2 is shorted to pin 1, current flows through resistor R29, through the switch, and then to ground. The voltage seen by the ADC is to be equal to the voltage drop across resistor R29, any additional trace resistance, wire resistance, and switch resistance with 5 mA of current being sourced. If estimating an additional 5 Ω for trace, wire, and switch resistance, the typical voltage seen at the ADC would be 3.05 V.
3. For the last input state where the rocker switch is pressed down and pin 2 is shorted to pin 3, current flows through resistor R28, through the switch, and then to ground. The voltage seen by the ADC is to be equal to the voltage drop across resistor R28, any additional trace resistance, wire resistance, and switch resistance with 5 mA of current being sourced. If estimating an additional 5 Ω for trace, wire, and switch resistance, the typical voltage seen at the ADC would be 4.57 V.

Therefore, the typical voltages seen for the three states is 3.05 V, 4.57 V, and 6.0 V. By setting the input threshold voltages to THRES2A = 3.81 V and THRES2B = 5.29 V, all three states are easily distinguishable from each other with over 700 mV of margin for resistor tolerance and current source variation.

2.9.2 Dual Button Input With Multi-Press Detection

Figure 17 shows the input circuitry for IN18 on the TIC12400-Q1 device. This pin has been set up to handle two momentary push-button inputs. Real-world examples can range from digital door ajar sensors to push-button controls on the door, steering wheel, or center console. Because IN18 has three input thresholds, it can discern four distinct states:

- Both push-buttons open (not pressed)
- Only push-button S37 pressed
- Only push-button S38 pressed
- Both push-buttons S37 and S38 pressed

The ability for one input pin to detect four distinct states is accomplished by placing a series resistor of different values between IN18 and push-button S37 and between IN18 and push-button S38.

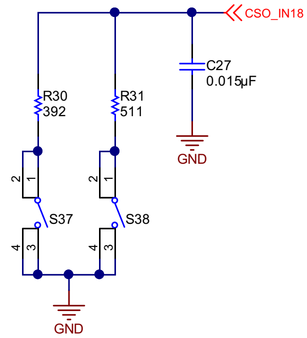

Figure 17. Dual-Button Multi-Press Detection Schematic

IN18 has been programmed to source 5 mA of current, which results in the following four scenarios:

1. During the default state, both push-button S37 and S38 are open and the input voltage is pulled up to the V_S input voltage. This means that for typical battery supply input voltages the voltage seen by the ADC results in an output reading of the max voltage of 6.0 V.
2. For the input state where only push-button S37 is pressed, current flows from IN18 through R30, through switch 37, and then to ground. The voltage seen by the ADC would be equal to the voltage drop across R30, any additional trace resistance, wire resistance, and switch resistance with 5 mA of current being sourced. Using an additional 5 Ω for trace, wire, and switch resistance, the typical voltage seen by the ADC would be 1.99 V.
3. For the input state where only push-button S38 is pressed, current flows from IN18 through R31, through switch 38, and then to ground. The voltage seen by the ADC would be equal to the voltage drop across R31, any additional trace resistance, wire resistance, and switch resistance with 5 mA of current being sourced. Using an additional 5 Ω for trace, wire, and switch resistance, the typical voltage seen by the ADC would be 2.58 V.
4. For the last input state where both push-buttons S37 and S38 are pressed, current flows through both the R30 and S37 branch and through the R31 and S38 branch. If continuing to estimate the series trace, wire, and switch resistance of each path to be 5 Ω, the parallel equivalent resistance of both paths would be 224.4 Ω (392 + 5 || 511 + 5). Therefore, the typical voltage seen by the ADC would be 1.12 V.

In conclusion, the typical ADC voltages read for the four states are 1.12 V, 1.99 V, 2.58 V, and 6.0 V. By setting the input threshold voltages to THRES3A = 1.70 V, THRES3B = 2.26 V, and THRES3C = 4.09 V, which are values picked to also work with IN21, IN22, and IN23 and are discussed in the following sections, all four states are easily distinguishable from each other with over 270 mV of margin for resistor tolerance and current source variation.

2.9.3 Light Control Arm Input

Figure 18 shows the input circuitry for IN19 through IN22 on the TIC12400-Q1 device. These pins have been used to connect to an external light control arm, which came from a top-column module. The control arm has a five-wire connection consisting of four switch-status wires and one ground return wire.

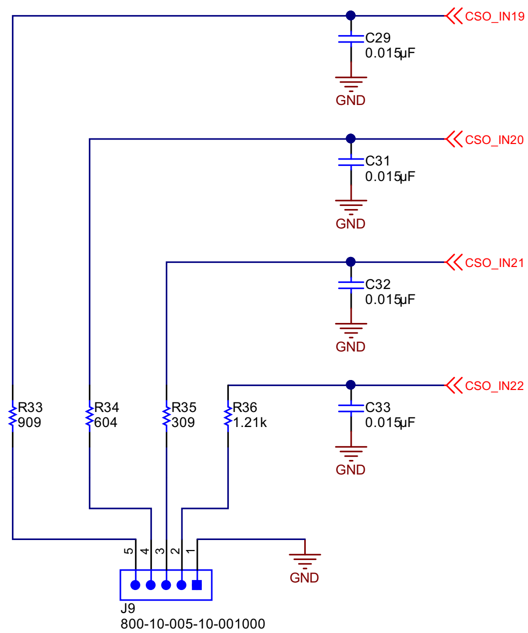

Figure 18. Light Control Arm Input Schematic

Figure 19 shows a closer view of the light control arm.

Figure 19. Light Control Arm

The light control arm has four stationary twisting knob positions, two momentary twisting positions, and one momentary button on the end of the control arm. IN19 through IN22 are able to handle all four knob positions in addition to any one of the momentary positions at the same time. The multi-threshold feature allows the following 16 input states handled by two comparator inputs and two three-threshold ADC inputs in the following list:

1. Headlights and fog lights off position
2. Headlights and fog lights off position plus momentary twist forward position
3. Headlights and fog lights off position plus momentary twist backward position
4. Headlights and fog lights off position plus momentary end button
5. Automatic headlight control position
6. Automatic headlight control position plus momentary twist forward position
7. Automatic headlight control position plus momentary twist backward position
8. Automatic headlight control position plus momentary end button
9. Headlights on and fog lights off position
10. Headlights on and fog lights off position plus momentary twist forward position
11. Headlights on and fog lights off position plus momentary twist backward position
12. Headlights on and fog lights off position plus momentary end button
13. Headlights and fog lights on position
14. Headlights and fog lights on position plus momentary twist forward position
15. Headlights and fog lights on position plus momentary twist backward position
16. Headlights and fog lights on position plus momentary end button

Table 3 shows the measured resistance between each status wire and the ground return wire for each input state.

Table 3. Resistance Measurements of Light Control Arm From Switch Status Wires to Ground Return Wire

CONTROL ARM POSITION	SWITCH-STATUS RESISTANCE TO GROUND			
	IN19	IN20	IN21	IN22
Headlights and fog lights off	0.3 Ω	Open	Open	—
Automatic headlight control	Open	Open	1.5 Ω	—
Headlights on and fog lights off	Open	0.3 Ω	Open	—
Headlights and fog lights on	Open	Open	2.67 kΩ	—
No momentary input pressed	—	—	—	5.87 kΩ
Momentary twist forward	—	—	—	0.9 Ω
Momentary twist backwards	—	—	—	818 Ω
Momentary end button	—	—	—	2.32 kΩ

As inferred from Table 3, IN19 and IN20 only have two states, either open or a short-to-ground (< 1 Ω); therefore, these two inputs have been set in comparator input mode. IN21 has a total of three resistive input states and IN22 has a total of four resistive input states, which means that both IN21 and IN22 have to be set to ADC input mode so that multiple input thresholds can be set and all of the input states can be determined.

An important thing to note is that IN19, IN20, and IN21 are used to monitor the four knob positions and are completely independent of IN22, which independently indicates whether any one of the three momentary inputs have been pressed. All four input pins (IN19-IN22) have been set to source 1 mA of wetting current.

The first step is to cover the design considerations for IN19, IN20, and IN21:

- IN19 – Two input states require consideration:
  1. When the knob on the light control arm is in the "headlights and fog lights off" position, current flows from IN19 through R33, through the wiring to the control arm, through the switch contact in

the control arm, and back through the ground return wiring from the light control arm to the TIC12400-Q1 local ground. The voltage seen by the ADC would be equal to the voltage drop across R33, any additional trace resistance, wire resistance, and switch resistance. Using an additional 5 Ω for trace, wire, and switch, the typical voltage seen by the ADC would be 0.91 V. Because this value is considerably lower than the default comparator input threshold of 2.0 V, this value does not require change.

2. When the knob is in any of the other three positions, the switch-status wire monitored by IN19 is open and the sourcing current pulls the input voltage seen by the ADC up to V_S and the ADC output reads the maximum value of 6.0 V.

- IN20 – Two input states require consideration:
  1. When the wiper control arm is in the "headlights on and fog lights off" position, current flows from IN20 through R34, through the wiring to the control arm, through the switch contact in the control arm, and back through the ground return wiring from the light control arm to the TIC12400-Q1 local ground. The voltage seen by the ADC would be equal to the voltage drop across R34, any trace resistance, wire resistance, and switch resistance. Using an additional 5 Ω for trace, wire, and switch resistance, the typical voltage seen by the ADC would be 0.61 V. Because this value is considerably lower than the default comparator input threshold of 2.0 V, this value does not require change.
  2. When the knob is in any of the other three positions, the switch-status wire monitored by IN20 is open and the sourcing current pulls the input voltage seen by the ADC up to V_S and the ADC output reads the maximum value of 6.0 V.
- IN21 – Three input states require consideration:
  1. When the wiper control arm is in the "automatic headlight control" position, current flows from IN21 through R35, through the wiring to the control arm, through the switch contact in the control arm, and back through the ground return wiring from the control arm to the TIC12400-Q1 local ground. The voltage seen by the ADC would be equal to the voltage drop across R35, any trace resistance, wire resistance, and switch resistance. Using an additional 5 Ω for trace, wire, and switch resistance, the typical voltage seen by the ADC would be 0.31 V.
  2. When the wiper control arm is in the "headlights and fog lights on" position, current flows from IN21 through R35, through the wiring to the control arm, through the switch resistance of 2.67 kΩ in the control arm, and back through the ground return wiring from the light control arm to the TIC12400-Q1 local ground. The voltage seen by the ADC would be equal to the voltage drop across R35, any trace resistance, wire resistance, and across the 2.67 kΩ on-state series resistance of the switch. Using an additional 5 Ω for traces and wires, the typical voltage seen by the ADC would be 2.98 V.
  3. When the knob is in either the "headlights and fog lights off" position or the "headlights on and fog lights off" position the switch-status wire monitored by IN21 is open and the sourcing current pulls the input voltage seen by the ADC up to V_S and the ADC reads the maximum value of 6.0 V.

  In conclusion, the typical ADC voltages read for the three states are 0.31 V, 2.98 V, and 6.0 V. By keeping the input thresholds of THRES3A = 1.70 V, THRES3B = 2.26 V, and THRES3C = 4.09 V, which are values picked to also work with IN18, IN22, and IN23, all three states are easily distinguishable from each other with over 700 mV of margin for resistor tolerance and current source variation.

The next step addresses the design considerations for IN22, which has four input states:

1. When none of the momentary inputs have been triggered, the resistance in the control arm is 5.87 kΩ. Current flows from IN22 through R36, through the wiring to the control arm, through the switch resistance of 5.87 kΩ, and back through the ground return wiring to the TIC12400-Q1 local ground. The voltage seen by the ADC would be equal to the voltage drop across R36, any trace resistance, wire resistance, and the 5.87 kΩ switch resistor in the control arm. Using an additional 5 Ω for traces and wires, the typical voltage seen by the ADC would be 7.09 V, which is greater than the 6-V maximum input range. Therefore, the ADC output will read the maximum value of 6.0 V.
2. When the control arm is in the momentary twist forward position, the resistance in the control arm is 0.9 Ω. Current flows from IN22 through R36, through the wiring to the control arm, through the switch resistance of 0.9 Ω, and back through the ground return wiring to the local TIC12400-Q1 local ground. The voltage seen by the ADC would be equal to the voltage drop across R36, any trace resistance, wire resistance, and the 0.9 Ω switch resistance. Using an additional 5 Ω for traces and wires, the typical voltage seen by the ADC would be 1.22 V.

3. When the control arm is in the momentary twist backward position, the resistance in the control arm is 818 Ω. Current flows from IN22 through R36, through the wiring to the control arm, through the switch resistance of 818 Ω, and back through the ground return wiring to the TIC12400-Q1 local ground. The voltage seen by the ADC would be equal to the voltage drop across R36, any trace resistance, wire resistance, and the 818 Ω switch resistance. Using an additional 5 Ω for traces and wires, the typical voltage seen by the ADC would be 2.03 V.
4. When the momentary push-button on the end of the control arm is pressed, the resistance in the control arm is 2.32 kΩ. Current flows from IN22 through R36, through the wiring to the control arm, through the switch resistance of 2.32 kΩ, and back through the ground return wiring to the TIC12400-Q1 local ground. The voltage seen by the ADC would be equal to the voltage drop across R36, any trace resistance, wire resistance, and the 2.32 kΩ switch resistance. Using an additional 5 Ω for trances and wires, the typical voltage seen by the ADC would be 3.54 V.

In conclusion, the typical ADC voltages read for the four states are 1.22 V, 2.03 V, 3.54 V, and 6.0 V. Using the existing thresholds that were set for IN18 and IN21 of THRES3A = 1.70 V, THRES3B = 2.26 V, and THRES3C = 4.09 V, all four states are distinguishable from each other with over 200 mV of margin for resistor tolerance and current source variation.

Another important thing to note is that for some knob positions more than one of the inputs IN19, IN20, and IN21 must be read to determine the state. For the momentary twist forward, momentary twist backwards, and the momentary button on the end of the control arm, only IN22 requires monitoring.

2.9.4 Wiper Control Arm Input

Figure 20 shows the input circuitry for IN23 on the TIC12400-Q1 device. This pin has been used to connect to an external wiper control arm, which came from a top column module. This control arm has a four-wire connection consisting of three switch-status wires and one ground return wire.

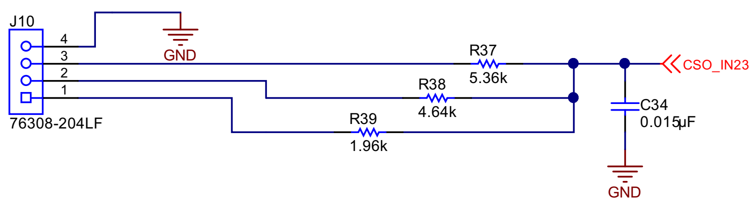

Figure 20. Wiper Control Arm Input Schematic

Figure 21 shows a closer view of the wiper control arm.

Figure 21. Wiper Control Arm

The wiper control arm has three knob positions and one momentary push-button on the end of the control arm, which results in a total of six input states handled by IN23 which has five thresholds when in ADC input mode. The following list addresses the six unique input states:

1. Wiper off position
2. Wiper off position with momentary end button pressed
3. Wiper on position
4. Wiper on position with momentary end button pressed
5. Wiper on and wash position
6. Wiper on and wash position with momentary end button pressed

Table 3 shows the measured resistance between each status wire and the ground return wire for each input state.

Table 4. Wiper Control Arm Resistance Measurements From Switch Status Wires to Ground Return Wire

CONTROL ARM POSITION	SWITCH STATUS RESISTANCE TO GROUND		
	WIRE 1	WIRE 2	WIRE 3
Wiper off	Open	Open	—
Wiper on	0.3 Ω	Open	—
Momentary wiper on and wash	Open	0.3 Ω	—
Momentary button not pressed	—	—	Open
Momentary button pressed	—	—	1.6 Ω

IN23 has been set to source 1 mA of wetting current, which results in the follow six scenarios:

1. When the wiper control arm is in the "wiper off" position and the momentary push-button is not pressed, the switch resistance seen by IN23 for all three status wires is open and the sourcing current pulls the input voltage seen by the ADC up to V_S and the ADC output reads the maximum value of 6.0 V.
2. When the wiper control arm is in the "wiper on" position and the momentary push-button is not pressed, status wire 1 presents a switch resistance of 0.3 Ω, status wire 2 is open, and status wire 3 opens. Therefore, current flows from IN23 through R39, through the wiring to the control arm, through the switch resistance, and back through the ground return wiring to the TIC12400-Q1 local ground. If the designer continues to estimate the trace, wire, and switch combined resistance to be 5 Ω, the typical voltage seen by the ADC would be 1.96 V.
3. When the wiper control arm is in the "momentary wiper on and wash" position and the momentary push-button is not pressed, status wire 1 opens, status wire 2 presents a switch resistance of 0.3 Ω, and status wire 3 opens. Therefore, current flows from IN23 through R38, through the wiring to the control arm, through the switch resistance, and back through the ground return wiring to the TIC12400-Q1 local ground. If the designer continues to estimate the trace, wire, and switch combined resistance to be 5 Ω, the typical voltage seen by the ADC would be 4.62 V.
4. When the wiper control arm is in the "wiper off" position and the push-button is pressed, status wires 1 and 2 are open and status wire 3 presents a switch resistance of 1.6 Ω. Therefore, current flows from IN23 through R37, through the wiring to the control arm, through the switch resistance, and back through the ground return wiring to the TIC12400-Q1 local ground. If the designer continues to estimate the wire and switch combined resistance to be 5 Ω, the typical voltage seen by the ADC would be 5.38 V.
5. When the wiper control arm is in the "wiper on" position and the push-button is pressed, status wire 1 presents a switch resistance of 0.3 Ω, status wire 2 presents an open, and status wire 3 presents a switch resistance of 1.6 Ω. Therefore, current flows through both the R39 branch and the R37 branch. If the designer continues to estimate the series switch and wire resistance of each path to be 5 Ω, the parallel equivalent resistance of both paths would be 1.44 kΩ (1958 + 5 || 5370 + 5). At 1 mA, the typical voltage seen by the ADC would be 1.44 V.
6. When the wiper control arm is in the "momentary wiper on and wash" position and the push-button is pressed, status wire 1 presents an open, status wire 2 presents a switch resistance of 0.3 Ω, and

status wire 3 presents a switch resistance of 1.6 Ω. Therefore, current flows through both the R38 branch and the R37 branch. If the designer continues to estimate the series switch and wire resistance of each path to be 5 Ω, the parallel equivalent resistance of both paths would be 2.48 Ω (4610 + 5 || 5370 + 5). At 1 mA, the typical voltage seen by the ADC would be 2.48 V.

In conclusion, the typical ADC voltages read for the six states are 1.44 V, 1.96 V, 2.48 V, 4.62 V, 5.38 V, and 6.0 V. Using the existing thresholds that were set for IN18, IN21, and IN22 of THRES3A = 1.70 V, THRES3B = 2.26 V, and THRES3C = 4.09 V and setting THRES8 = 5.0 V and THRES9 = 5.68 V, all six states are distinguishable from each other with at least 225 mV of margin for resistor tolerance and current source variation.

An important thing to note is that switch-status wires 1 and 2 indicate the three knob positions and are completely independent of switch-status wire 3, which independently indicates whether the momentary button on the end of the control arm has been pressed.

NOTE: Only the higher-feature TIC12400-Q1 device is able to handle multi-threshold inputs.

3 Getting Started Hardware

This section provides an overview of the TIDA-01237 board and all the external connections required to evaluate it.

3.1 Required Hardware

Three main pieces of hardware are required to evaluate the TIDA-01237 reference design:

1. The TIDA-01237 board
2. The MSP430 LaunchPad board (orderable part number MSP-EXP430G2553)
3. Additional, external analog and digital inputs that can be interfaced with the TIDA-01237 board through headers J7, J8, J9, and J10

Figure 22 shows an image of all these pieces of hardware.

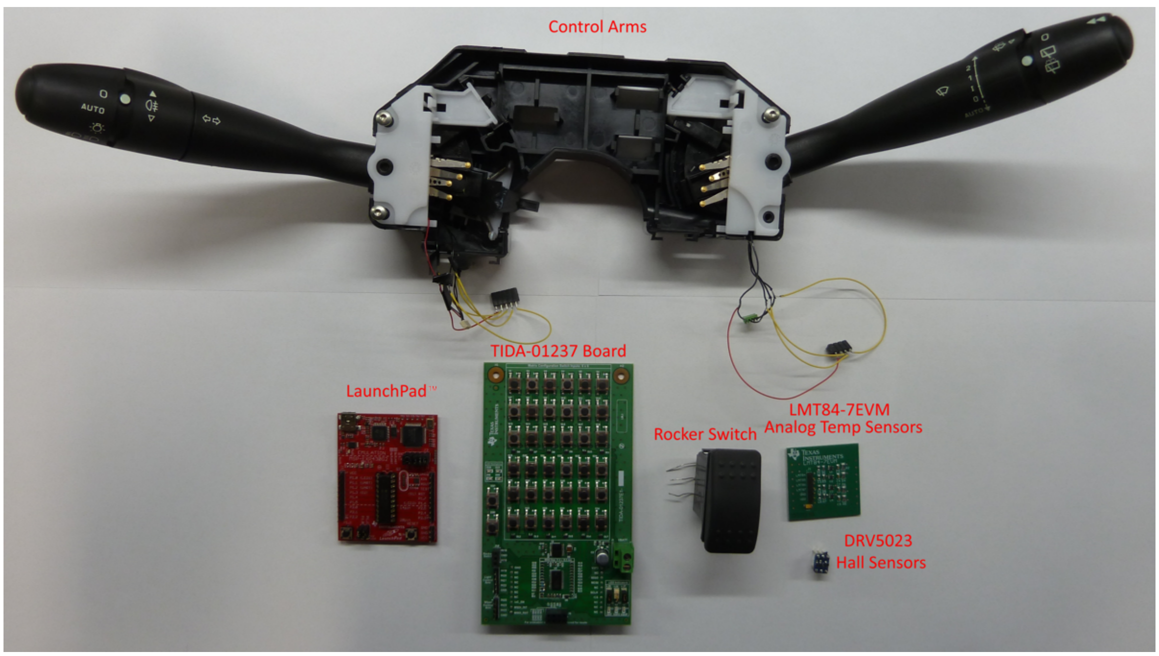

Figure 22. Hardware Test Setup

3.2 LaunchPad™ USB Connection and Jumper Selection

The TIDA-01237 board was evaluated using the MSP430 LaunchPad. The LaunchPad was plugged into a laptop through a USB cable and debug mode was used in the Code Composer Studio™ software to read the real-time register status of the MSDI device. To do this step, the V_{CC} jumper should be removed from the header block J3 before installing the TIDA-01237 board on the MSP430 LaunchPad. The TXD, RXD, TEST, and RST jumpers should be left installed so that debug communication remains intact. See Figure 23 for the USB cable connection and jumper settings on header block J3.

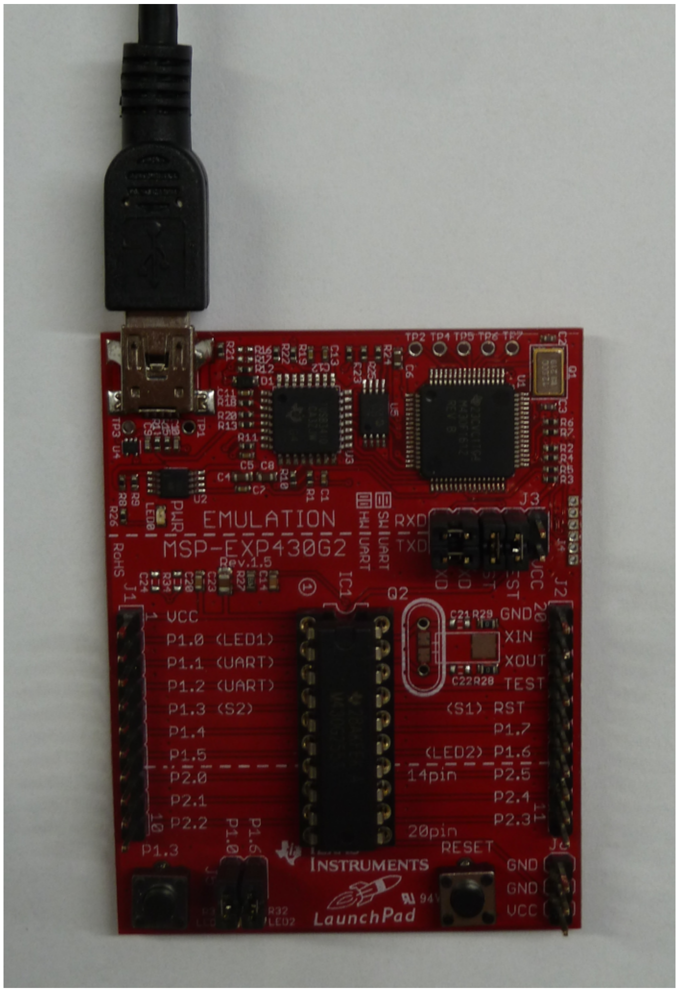

Figure 23. MSP430™ LaunchPad™ USB Connection and Jumper Settings

The user can also evaluate the TIDA-01237 in two other ways if desired:

- If the user prefers to program the MSP430 device once and does not wish to use debug mode through the USB connection to a computer, first install all the jumpers on J3 on the MSP430 LaunchPad. When programmed, all jumpers on J3 can be removed and the TIDA-01237 board supplies the MSP430 LaunchPad board with the 3.3-V supply rail through the V3p3 and GND pins of headers J1 and J2.
- If the user wants to leave the TPS7B6733-Q1 device unpowered and the logic supply of the TIDA-01237 board to be supplied by the MSP430 LaunchPad, remove resistor R1 on the TIDA-01237 board, which disconnects the input supply to the TPS7B6733-Q1 device. Additionally, the V_{CC} jumper on header block J3 on the LaunchPad must be installed. The only device running off the VBATT input is the MSDI device for this setup.

3.3 LaunchPad™ Installation

Install the TIDA-01237 board on the LaunchPad board and make sure to align all ten pins of each of the two ten-pin headers J2 and J3. The orientation is such that the bottom edge of the TIDA-01237 board aligns with the top edge of the RESET and P1.3 push-buttons on the LaunchPad (see Figure 24).

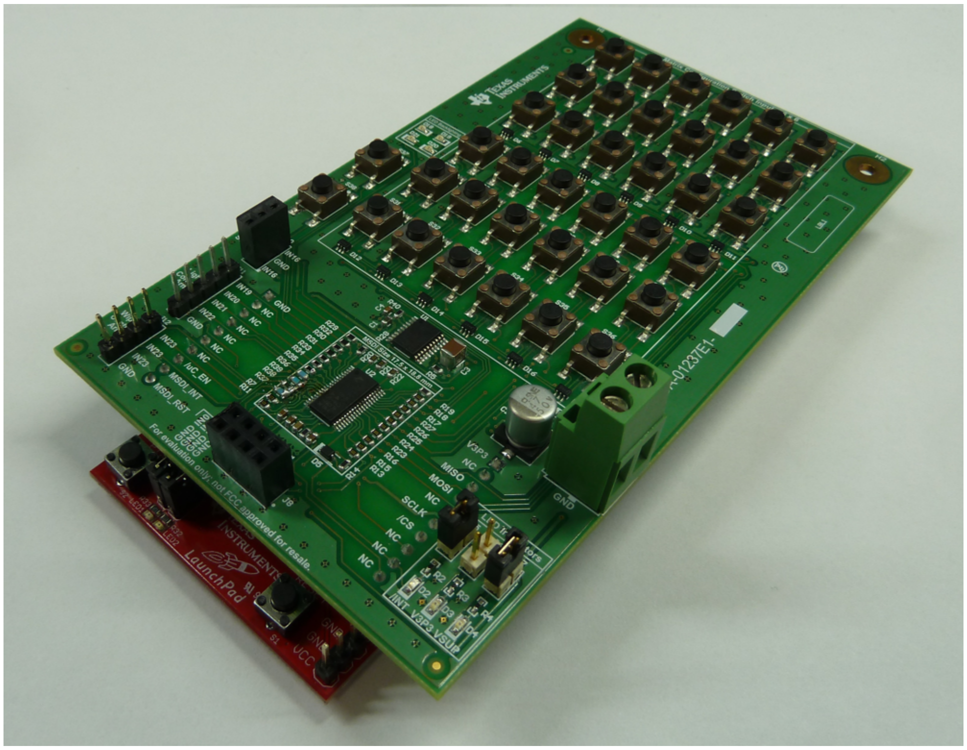

Figure 24. Orientation of TIDA-01237 Board on MSP430™ LaunchPad™

3.4 Power Supply Connection

The TIDA-01237 can be supplied through a DC power supply or an automotive lead-acid battery. A power supply capable of supplying at least 0.5 A at 12 V is sufficient to operate the design. Connect the external power supply to terminal block J1 with the 12-V line on J1-2 and the return (ground) line on J1-1, as Figure 25 shows.

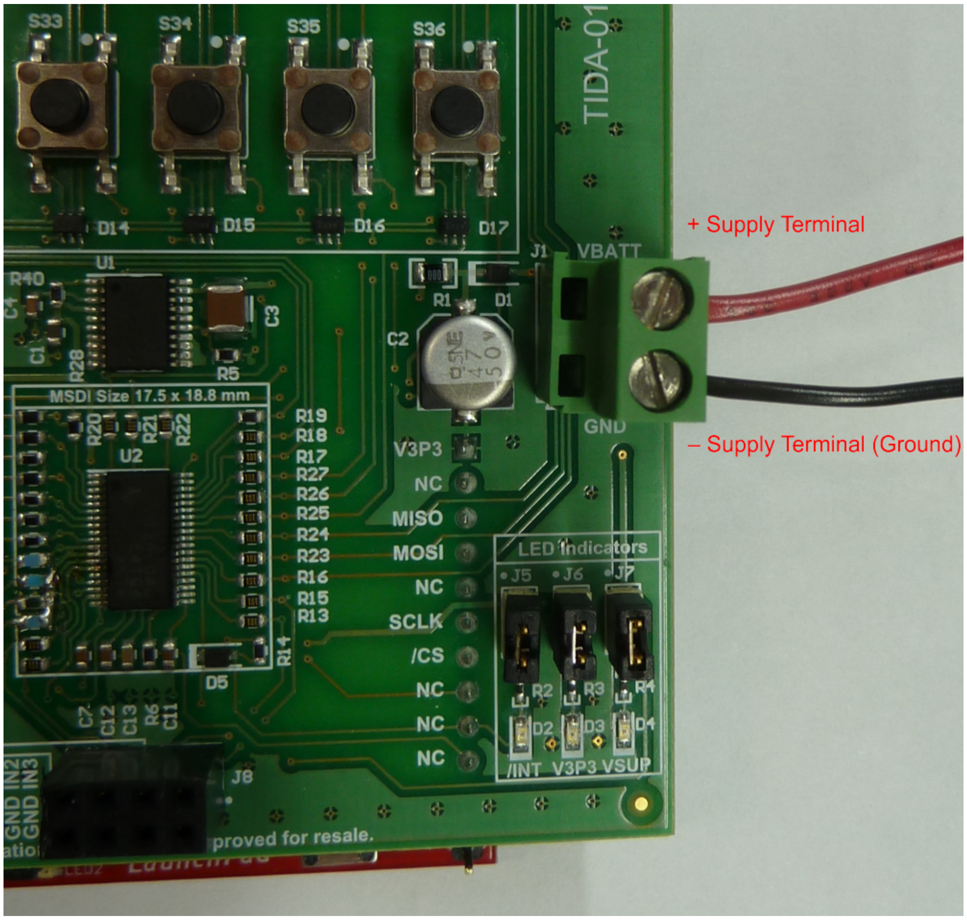

Figure 25. External Supply Connections

3.5 Indicator LEDs

The TIDA-01237 board comes with three indicator LEDs to show the status of the MSDI_INT (interrupt status), V3p3 supply voltage, and VSUP supply voltage. These indicators can be individually enabled and disabled by connecting or removing two-pin shunts on connectors J4, J5, and J6, respectively. Figure 26 shows the three indicator LEDs and the shunt control connectors.

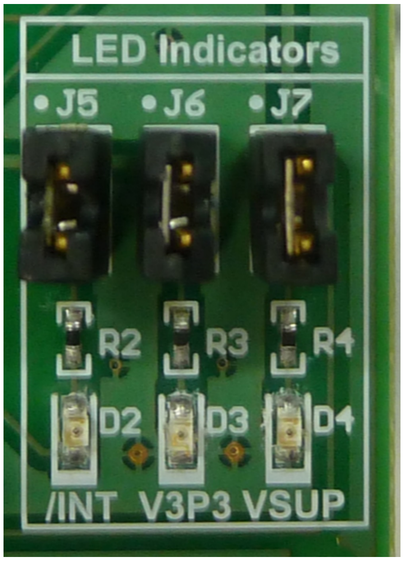

Figure 26. LED Indicators

3.6 External Analog and Discrete Inputs

Input connector J7 on TIDA-01237 allows easy access to inputs IN0 through IN3 on the MSDI device. These inputs were evaluated using an external analog temperature sensor and external complimentary Hall sensors. Figure 27 shows two external evaluation boards connected to input connector J7.

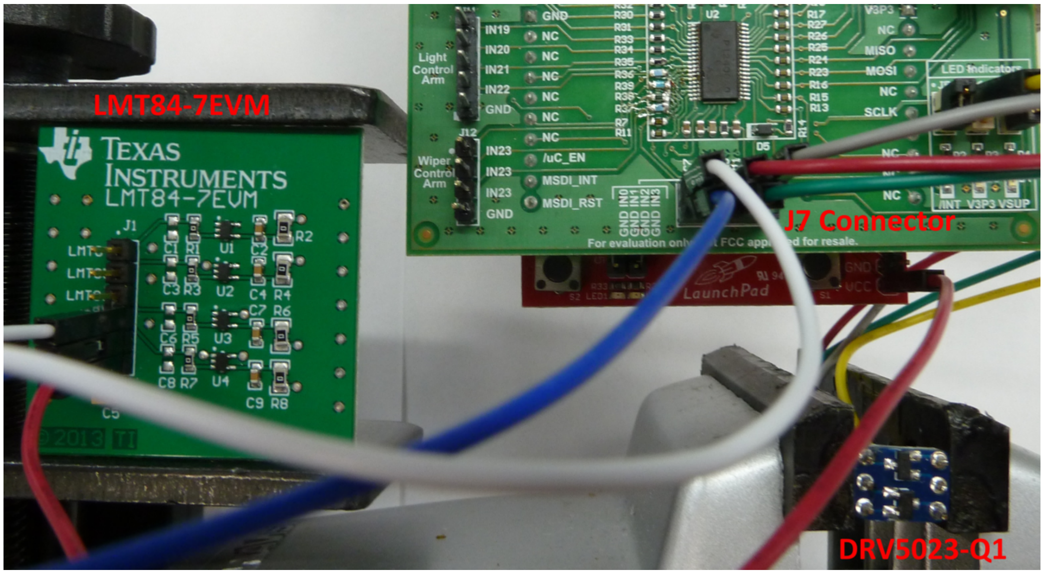

Figure 27. J7 Input Header

3.7 External Three-Position Rocker Switch Connection

Input connector J8 allows easy access to input IN16 on the TIC12400-Q1 device. This input was evaluated using an external, three-position momentary-off-momentary rocker switch. Figure 28 shows an external rocker switch connected to J8 through three wires.

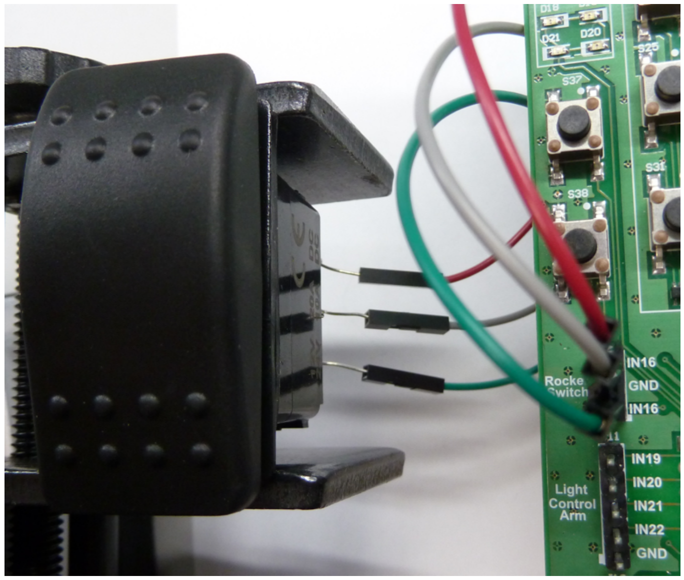

Figure 28. J8 External Rocker Switch Input Header

3.8 Dual-Button Input With Multi-Press Detection

Push-buttons S37 and S38 are connected to IN18 on the TIC12400-Q1 device. IN18 has three user programmable input thresholds (THRES3A, THRES3B, and THRES3C) and is able to detect if neither button is pressed, only push-button S37 is pressed, only push-button S38 is pressed, or if both push-buttons S37 and S38 are pressed.

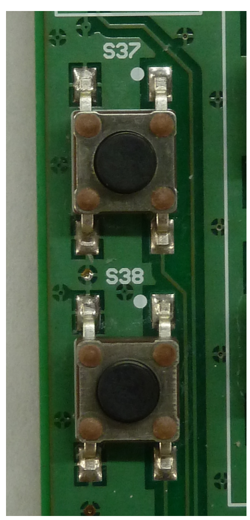

Figure 29. Pushbutton S37 and S38 on IN18

3.9 Button and Switch LED Backlighting

IN17 on the TIC1xxxx-Q1 device was used to demonstrate another way wetting currents can be used in a system for the input pins. This input was used to accurately drive four LEDs (D18, D19, D20, and D21) in series to show that button and switch LED backlighting can be accomplished with input-pin wetting currents (see Figure 30).

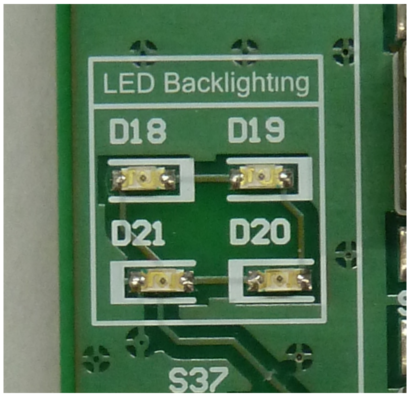

Figure 30. Button and Switch LED Backlighting

3.10 Matrix Configuration Switch Inputs

The TIDA-01237 board comes equipped with a 6×6-diode-blocked switch input matrix as Figure 31 shows. These push-buttons are used to demonstrate the ability of the TIC12400-Q1 to handle a large number of inputs in a matrix configuration using a built-in polling scheme which uses significantly less I/O pins.

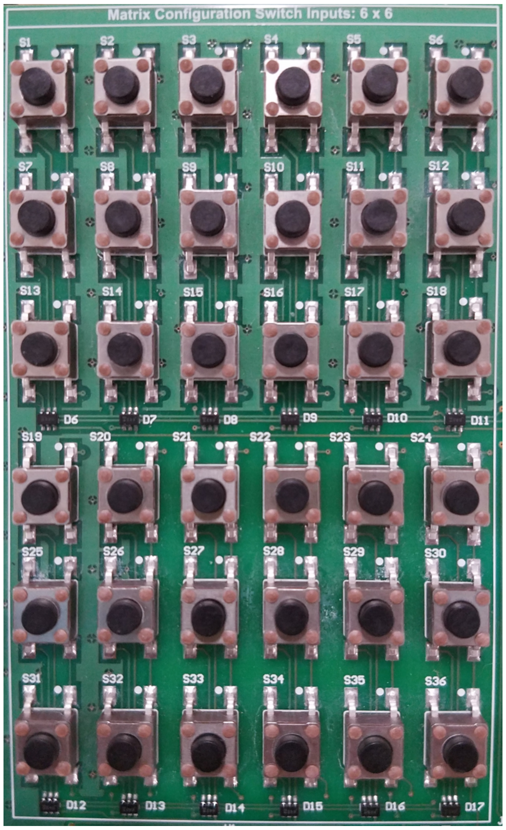

Figure 31. 6×6-Matrix Configuration Switch Inputs

These 36 input switches are connected to inputs IN4 through IN15. Refer to Section 2.6 for more details on how these inputs were handled.

3.11 External Light Control Arm Connection

Input connector J9 allows easy access to inputs IN19 through IN22 on the TIC12400-Q1 device. These inputs were evaluated using an external light control arm which was connected as shown in Figure 32.

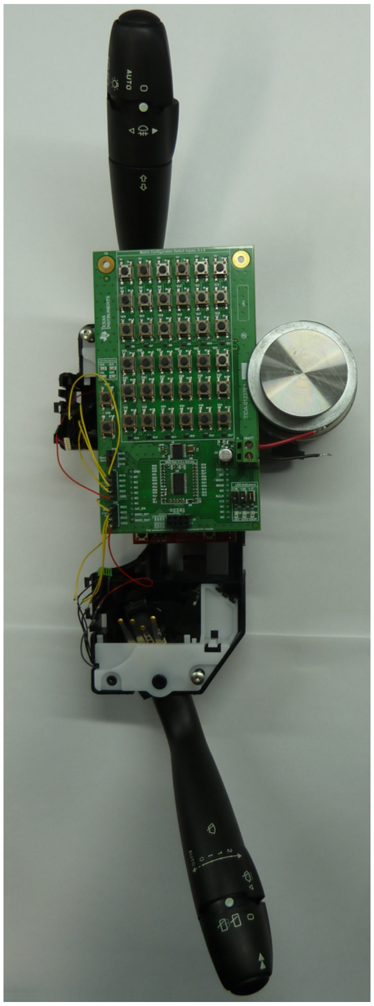

Figure 32. J9 and J10 External Control Arm Input Headers

The light control arm has one knob with four discrete positions:

1. Headlights and fog lights off
2. Automatic headlight control
3. Headlights on and fog lights off
4. Both headlights and fog lights on

Additionally, there were three other momentary inputs:

1. Momentary twist forward position
2. Momentary twist backward position
3. Momentary push-button on the end of the control arm

IN19 through IN22 are able to handle all four knob positions in addition to any one of the momentary positions, which results in a total of 16 total input states handled by two comparator inputs and two three-threshold ADC inputs. Refer to Section 2.9 for more details on how all of these input states were handled. Additionally, Figure 19 shows a closer view of the light control arm.

3.12 External Wiper Control Arm Connection

Input connector J10 allows easy access to input IN123 on the TIC12400-Q1 device. This input was evaluated using an external wiper control arm which was connected as shown in the preceding Figure 32.

The light control arm has one knob with three discrete positions:

1. Wiper off position
2. Wiper on position
3. Momentary wiper on position and wash

Additionally, there is one momentary button input on the end of the control arm. IN23 is able to handle all three knob positions in addition to the momentary button position at the same time, for a total of six input states. Refer to Section 2.9 for more details on how all of these input states were handled. Additionally, Figure 21 shows a closer view of the wiper control arm.

4 Testing and Results

Different input types were targeted for specific end equipments in automotive body applications. The three target end equipments for this reference design are body control modules, faceplate modules, and top-column modules and the following subsections list the input types that apply to each application.

4.1 Body Control Module (BCM) Applications

The following circuit blocks that were evaluated were targeted for BCM applications:

1. Supply protection and regulation - Because BCM load currents for regulated supplies are not typically very high, LDO regulators offer a low-cost low-noise solution for supply regulation. Additionally, this design has the ability to handle system-level requirements such as operation through load dump and the ability to survive reverse battery voltages.
2. Single threshold comparator inputs - Single threshold comparator inputs are the most common input type for buttons, switches, and discrete digital inputs.
3. Analog inputs - BCMs often handle many analog inputs for monitoring level, temperature, light, and analog voltage feedback from load switches or sensors.
4. Multi-threshold inputs - To reduce the number of I/O pins required to monitor discrete inputs, multi-threshold inputs offer the ability to handle multiple position inputs like rocker switches and input control knobs as well as multiple buttons, switches, or discrete digital sensors in parallel.
5. Button and switch LED backlighting - Button and switch inputs require LED backlighting for ease of use in low-light scenarios.

4.2 Faceplate Application

The following input types were targeted for faceplate modules:

1. Supply protection and regulation - Because the load currents for regulated supplies in faceplate applications are typically very low, LDOs offer a low-cost, low-noise solution for supply regulation. Additionally, this design has the ability to handle system-level requirements such as operation through load dump and the ability to survive reverse battery voltages.
2. Single threshold comparator inputs - Single threshold comparator inputs are the most common input type for button and switch inputs.
3. Matrix configuration switch inputs - Because of the high number of inputs in a small area common to faceplate applications, matrix configuration switch inputs can offer a substantial reduction in the number of I/O pins required for a solution.
4. Button and switch LED backlighting - Because of the high number of switches, there is also a requirement to drive a high number of LEDs for backlighting the switches and knobs in low-light scenarios.

4.3 Top Column Module Applications

The following input types were targeted for top-column module applications:

1. Supply protection and regulation - Top-column module applications do not require large load currents for regulated supplies and therefore LDOs offer a low-cost low-noise solution for supply regulation. Additionally, this design has the ability to handle system level requirements such as operation through load-dump and the ability to survive reverse battery voltages.
2. Single threshold comparator inputs - Single threshold comparator inputs are the most common input type for button and switch inputs.
3. Light control arm input - Input control arms on top-column modules often integrate many knob and button inputs on a single control arm with multiple switch-status wires.
4. Wiper control arm input - Input control arms on top-column modules often integrate many knob and button inputs on a single control arm with multiple switch-status wires.

4.4 Compiled Results

This subsection reviews the results for the following eight circuit blocks evaluated in this design:

- Supply protection and regulation
- Single threshold comparator inputs
- Analog inputs
- Multi-threshold inputs
- Button and switch LED backlighting
- Matrix configuration switch inputs
- Light control arm inputs
- Wiper control arm inputs

Refer to Section 2 for more detailed information on device settings and calculations for each circuit block.

4.4.1 Supply Protection and Regulation Results

Fixed 3.3-V and 5.0-V linear regulators are very common in body applications such as BCMs, faceplace modules, and top-column modules because the load current for the regulated supplies is typically not very high. Therefore, LDOs offer a low-cost, low-noise solution for supply regulation. Additionally, the supply line for this design was designed to handle system-level requirements for operating through load dump and surviving reverse battery voltages. This design is specified to operate with a recommended input supply range of 4.5 V to 35 V and can survive –40 V to +40 V on the VBATT input rail. Figure 33 shows the relation between input supply voltage and the 3.3-V regulated output supply.

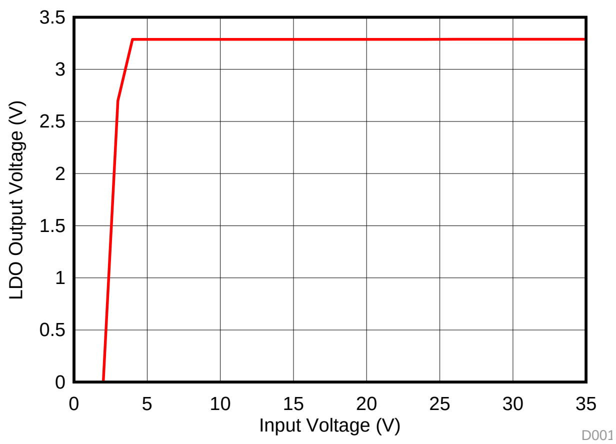

Figure 33. Input Supply Voltage Versus 3.3-V Regulated Supply Voltage

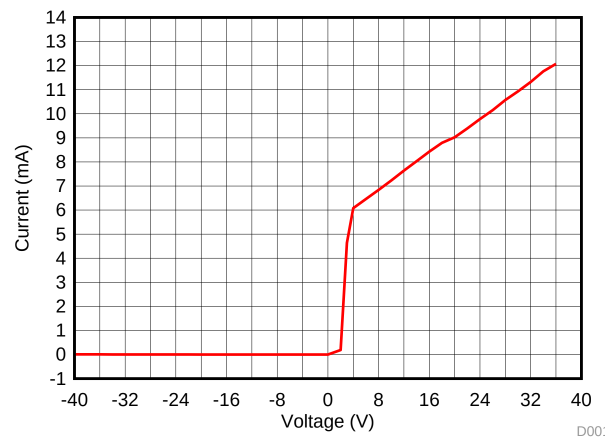

Figure 34. Input Supply Voltage Versus Input Supply Current

As Figure 33 shows, the regulator output voltage remains in regulation from 4.5 V through 35 V. The plot in the preceding Figure 34 shows that the input leakage current remains close to 0 mA (under 10 µA) for the entire negative-input voltage range from 0 V to –40 V due to the reverse battery protection diode D1.

Additionally, a delay capacitor of 0.01 µF was used to delay the release of the RESET output of the TPS7B6733-Q1 device by a typical value of 1.053 ms. Figure 35 shows the VBATT input voltage on CH1, the V3p3 output voltage on CH3, the voltage on the DELAY output pin on CH4, and the RESET output pin on CH2. The plot shows that when the V3p3 output voltage reaches 91.6% (typical) of the desired output voltage, the DELAY output pin begins charging the delay capacitor (CH4). The capacitor voltage rises and when it reaches the release threshold of 1.0 V (typical) the RESET output is released and goes high (CH2). The cursors show that the delay time, or the time that it takes to charge the delay capacitor to 1.0 V, was 1.16 ms.

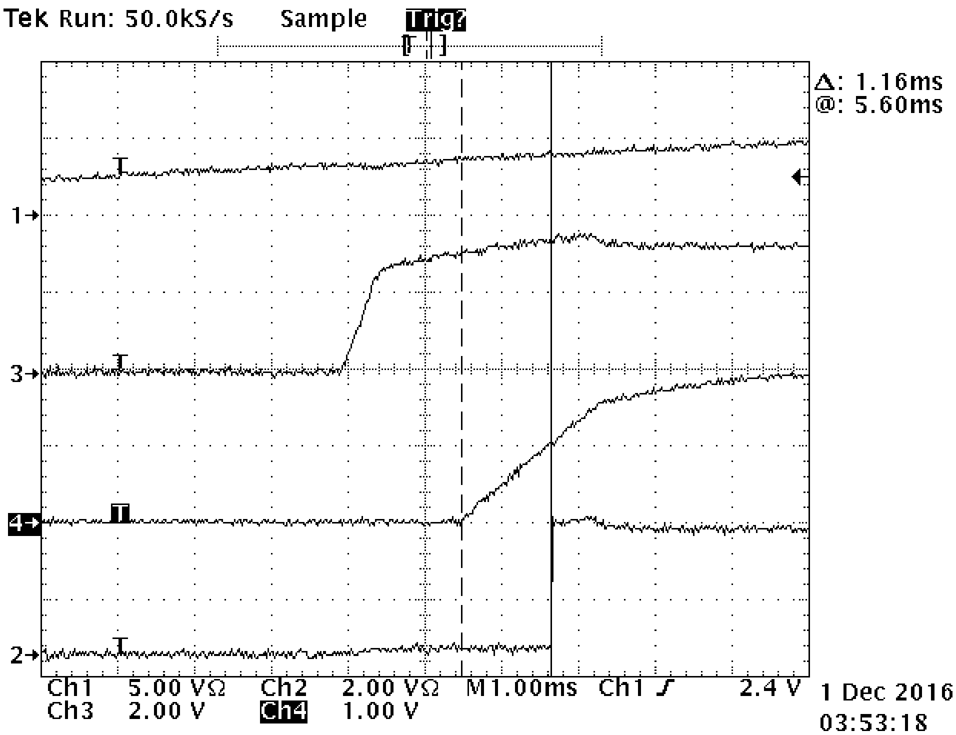

Figure 35. TPS7B6733-Q1 RESET Delay Function

Lastly, the design was evaluated for the ability of the control circuitry to enable and the disable the TPS7B6733-Q1 device through the /INT open-drain output pin and the MSP430 GPIO output pin described in Section 2.4. Figure 36 shows a full, low-power-mode program cycle as shown in the preceding Figure 11.

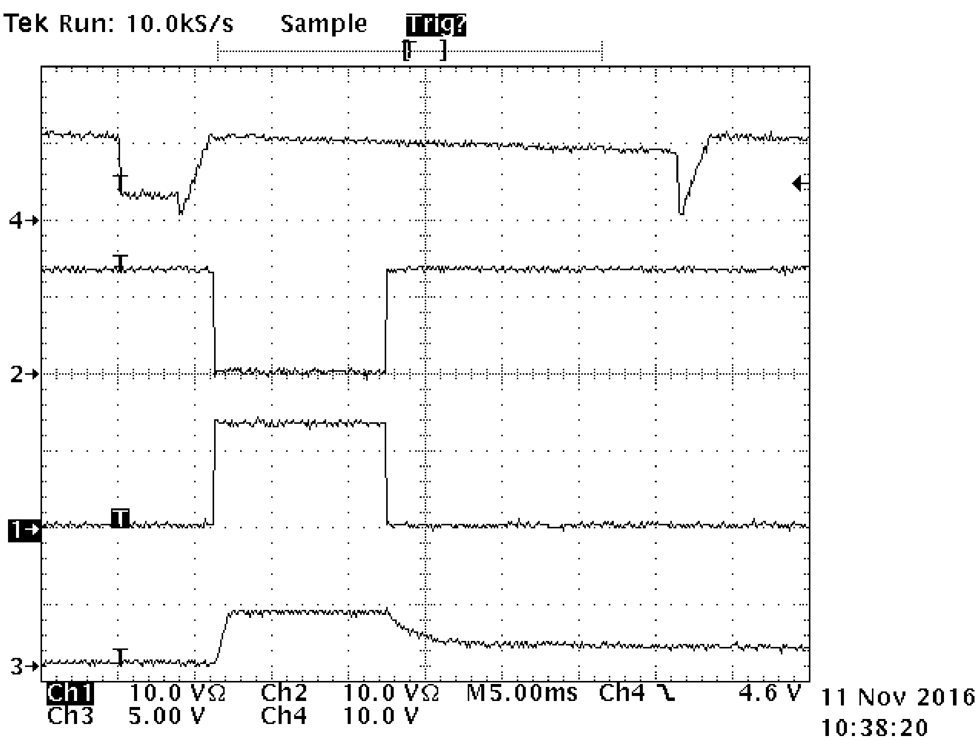

Figure 36. Power Supply Control for Ultra-Low-Power Sleep Mode

Channel 4 (top trace) is a switch input that was pressed to cause the falling edge. Channel 2 (2nd trace from the top) shows the falling edge of the /INT pin of the TIC12400-Q1 as a result of the switch state change (SSC) event. This results in the EN signal on the TPS7B6733-Q1 device to be pulled high (channel 1, 2nd trace from the bottom), and lastly the 3.3-V supply powering up (channel 3, bottom trace). When the supply powers up, the MSP430 drives the uC_LDO_EN signal high (not shown), reads the status registers, and then drives the uC_LDO_EN signal back low, which disables the LDO output and places the system back in low-power mode. By looking a the plot, it is visible that the voltage of the 3.3-V supply rail decays after the LDO_EN signal has a falling edge.

4.4.2 Single-Threshold Comparator Inputs

Single-threshold comparator inputs are used extensively in body applications. These inputs can range from passenger inputs through buttons and switches, to door, hood, and trunk sensors used to indicate open and close statuses. All 24 inputs on the TIC12400-Q1 device can be configured to handle comparator inputs with four possible input voltage thresholds of 2.0 V, 2.7 V, 3.0 V, and 4.0 V.

IN2 and IN3 were used in this design to evaluate comparator type inputs with the TI DRV5023FI-Q1 and DRV5023FA-Q1 complimentary Hall effect sensors. Section 3.6 shows the two Hall sensors connected to the IN2 and IN3 input pins of the TIC12400-Q1 device through header J7. Because the outputs are complimentary, one device actively drives the output low while the other output is high impedance and vice versa depending on the strength of the ambient magnetic field.

Evaluating single-threshold comparator inputs for these two inputs requires consideration of the following settings:

- Both IN2 and IN3 must be enabled
- The wetting-current setting must be set to source 1 mA of current
- The interrupt setting for each input must be set so that both rising and falling edges generate an interrupt
- The default comparator threshold of 2.0 V can be left unchanged
- The detection filter (debounce) is set to three consecutive samples for a valid switch-state change
- The trigger bit in the CONFIG register must be set high to begin monitoring the inputs

After accomplishing this task, the /INT pin is driven low any time either IN2 or IN3 changes state for three consecutive samples. Upon reading the status flags on any read operation, the user can verify that the interrupt was triggered due to a switch-status change (SSC), and then the IN_STAT_COMP register can be read to view the current status of all comparator inputs. Figure 37 shows a snippet of the debug window where the INT_STAT_COMP register was read to view the state of IN2 and IN3 when either no magnetic field was present near the devices or a north pole magnetic field was present. This readout shows that IN3 was high and IN2 was low.

Expression	Type	Value
(x)= spiReceive	unsigned long	00000000000000000000000000001000b (Binary)

Figure 37. Hall Sensor Inputs With No Magnetic Field

Figure 38 again shows the INT_STAT_COMP register, but this time when a south pole magnetic field was present.

Expression	Type	Value
(x)= spiReceive	unsigned long	00000000000000000000000000000100b (Binary)

Figure 38. Hall Sensor Inputs With Magnetic Field

As the readout shows, both bits 2 and 3 in the IN_STAT_COMP register changed states when the south-pole magnetic field was present and the input voltages on IN2 and IN3 crossed the 2.0-V input comparator threshold.

Additionally, the system was also evaluated for a low-power polling mode with inputs IN18 through IN23 all sourcing 1 mA of wetting current into open switches while in comparator input mode. The polling active time was set to 64 µs and the polling time was set to 64 ms. The average current consumption at room temperature was 58 µA.

4.4.3 Analog inputs

Analog inputs are also very common in body applications. These inputs can range from ambient light sensors, temperature sensors, to analog-current feedback lines. All 24 inputs on the TIC12400-Q1 device can be configured to handle analog inputs directly and the 10-bit ADC values are automatically stored after each sample in the ANA_STATx registers.

Input 0 was used to evaluate an analog input on the TIDA-01237 design. The LMT87-Q1 analog output Grade 1 automotive temperature sensor was used to directly drive the input. Section 3.6 shows the LMT84-7EVM connected to IN0 of the TIC12400-Q1 device through header J7.

To evaluate an analog input, IN0 must be enabled, the current source must be set to 0 mA of current, and the trigger bit must be set to begin monitoring the input. After completing these steps, the ANA_STAT0 register can be read at any time to receive the last sampled value of the IN0. Figure 39 shows the ANA_STAT0 register with a red box highlighting the IN0_ANA bits. This reading was taken from the LMT87-Q1 at room temperature.

Expression	Type	Value
(x)= AnaTemp	unsigned long	0000000000000000000000$\boxed{0110010100}$b (Binary)

Figure 39. LMT87-Q1 Analog Input Voltage at Room Temperature

Figure 40 shows the same ANA_STAT0 register but this time with +80°C ambient air temperature.

Expression	Type	Value
(x)= AnaTemp	unsigned long	0000000000000000000000$\boxed{0100000111}$b (Binary)

Figure 40. LMT87-Q1 Analog Input Voltage at +80°C

The binary value read at room temperature was 0110010100, which corresponds to an analog voltage of 2.370 V and the binary value read at +80°C was 0100000111, which corresponds to an analog voltage of 1.543 V. Using the look-up table in the LMT87-Q1 datasheet, this corresponds to 20°C and 80°C respectively.

Additionally, analog thresholds can be set for things like overtemperature or undertemperature warnings by setting a interrupt on a programed threshold.

4.4.4 Multi-Threshold Input Results

The two example multi-threshold inputs that were evaluated for this design were the Section 2.9.1 and Section 2.9.2 inputs. To evaluate any multi-threshold input the following settings must be considered:

- The input pin must be enabled
- The wetting current must be set to source the desired amount of current
- The interrupts must be set to trigger on the desired edges
- The input thresholds must be set
- The number of desired samples for interrupt generation must be set in the detection filter
- The trigger bit in the CONFIG register must be set to begin monitoring the inputs

After the input has been configured, the IN_STAT_ADC0 and IN_STAT_ADC1 registers can be read at any time to read the latest state of any input set to ADC input mode. If an input is in a different mode, the status bits indicate the default value of all zeros.

The first step is to review the testing results for the three-position rocker switch. Because this input was connected to IN16, bits 20 and 21 of the IN_STAT_ADC0 register indicate the status. These two status bits indicate the following three states:

1. "00" if the input voltage is below THRES2A
2. "01" if the input voltage is equal to or above THRES2A and below THRES2B
3. "10" if the input voltage is equal to or above THRES2B

Figure 41 highlights the input status bits for IN16 when they have a "10" status. This status indicates that the input voltage is equal to or above THRES2B; therefore, from the calculations performed in Section 2.9.1, the designer can conclude that the rocker switch is in the default state (not pressed up or down).

Expression	Type	Value
(x)= AnaTemp	unsigned long	00000000001000000000000000000000b (Binary)

Figure 41. Rocker Switch Not Pressed

Figure 42 highlights the input status bits for IN16 when they have a "00" status. This status indicates that the input voltage is below THES2A; therefore, from the calculations performed in Section 2.9.1, the designer can conclude that the rocker switch is pressed up.

Expression	Type	Value
(x)= AnaTemp	unsigned long	00000000000000000000000000000000b (Binary)

Figure 42. Rocker Switch Pressed Up

Lastly, Figure 43 highlights the status bits for IN16 when they have a "01" status. This status indicates that the input voltage is equal to or above THRES2A and below THRES2B; therefore, from the calculations performed in Section 2.9.1, the designer can conclude that the rocker switch is pressed down.

Expression	Type	Value
(x)= AnaTemp	unsigned long	00000000000100000000000000000000b (Binary)

Figure 43. Rocker Switch Pressed Down

The next step is to review the results from the dual-button input with multi-press detection. Because these two buttons were connected to IN18, bits 0 and 1 of the IN_STAT_ADC1 register indicate the status. These two status bits indicate the following four states:

1. "00" if the input voltage is below THRES3A
2. "01" if the input voltage is equal to or above THRES3A and below THRES3B
3. "10" if the input voltage is equal to or above THRES3B and below THRES3C
4. "11" if the input voltage is equal to or above THRES3C

Figure 44 highlights the input status bits for IN18 when they have a "11" status. This status indicates that the input voltage is equal to or above THRES3C; therefore, from the calculations performed in Section 2.9.2, the designer can conclude that neither button S37 or button S38 are pressed.

Expression	Type	Value
(x)= AnaTemp	unsigned long	00000000000000000000000000000011b (Binary)

Figure 44. Dual Button Input—Neither Button Pressed

Figure 45 highlights the input status bits for IN18 when they have a "10" status. This status indicates that the input voltage is equal to or above THRES3B and below THRES3C; therefore, from the calculations perfoirmed in Section 2.9.2, the designer can conclude that button S37 is pressed and button S38 is not pressed.

Expression	Type	Value
AnaTemp	unsigned long	00000000000000000000000000000010b (Binary)

Figure 45. Dual Button Input—Button S37 Pressed

Figure 46 highlights the input status bits for IN18 when they have a "01" status. This status indicates that the input voltage is equal to or above THRES3A and below THRES3B; therefore, from the calculations performed in Section 2.9.2, the designer can conclude that button S38 is pressed and button S37 is not pressed.

Expression	Type	Value
AnaTemp	unsigned long	00000000000000000000000000000001b (Binary)

Figure 46. Dual Button Input—Button S38 Pressed

Lastly, Figure 47 highlights the input status bits for IN18 when they have a "00" status. This status indicates that the input voltage is below THRES3A; therefore, from the calculations performed in Section 2.9.2, the designer can conclude that both buttons S37 and S38 are pressed.

Expression	Type	Value
AnaTemp	unsigned long	00000000000000000000000000000000b (Binary)

Figure 47. Dual Button Input—Both Buttons S37 and S38 Pressed

4.4.5 Button and Switch LED Backlighting Results

Most all mechanical button and switch inputs have LED backlighting for ease of use during low-light times. By setting a wetting current and enabling the input, any one of the 24 input pins on the MSDI device can be used to accurately source current for an LED. Figure 48 shows three different wetting-current settings for a series string of four green LEDs.

Figure 48. Button and Switch LED Backlighting

4.4.6 Matrix Configuration Switch-Input Results

The following parameters must be set to set up a matrix-mode polling scheme on the TIC12400-Q1 device for the 6×6 matrix:

- The polling time (POLL_TIME) and polling active time (POLL_ACT_TIME) must be set in the CONFIG register, additionally the matrix active polling time (POLL_ACT_TIME_M) can also be set in the Matrix register if the user wants a different polling active time for the matrix inputs
- Inputs IN4 through IN15 must be enabled in the IN_EN register
- The row inputs (IN4 through IN9) must be set to sink current in the CS_SELECT register
- The wetting currents must be set in the WC_CFx registers (set wetting currents of the sinking pin' higher than the wetting currents of the sourcing pin)
- Set the sourcing columns to trigger an interrupt in the INT_EN_COMPx registers
- Set the switch-state change bit in the INT_EN_CFG_0 register
- Set the 6×6 matrix bits in the MATRIX register

After setting these parameters, the INT_STAT_MATRIX0 and IN_STAT_MATRIX1 registers can be read to monitor the real-time status of all the switches in the matrix. As Figure 49 shows, when all the switches are open, the input pins are pulled high and all 36 switch states are read as logic high.

Expression	Type	Value
MatrixReg1	unsigned long	00000000111111111111111111111111b (Binary)
MatrixReg2	unsigned long	00000000000000000000111111111111b (Binary)

Figure 49. Matrix Switch Inputs—No Buttons Pressed

Figure 50 shows push-button S1 pressed, and Figure 51 shows push-button S5 pressed. As the readouts show, whenever a push-button is pressed, the corresponding bit in the INT_STAT_MATRIX register goes low.

Expression	Type	Value
MatrixReg1	unsigned long	00000000111111111111111111111110b (Binary)
MatrixReg2	unsigned long	00000000000000000000111111111111b (Binary)

Figure 50. Matrix Switch Inputs—S1 Button Pressed

Expression	Type	Value
MatrixReg1	unsigned long	00000000111111111111111111111111b (Binary)
MatrixReg2	unsigned long	00000000000000000000111111111110b (Binary)

Figure 51. Matrix Switch Inputs—S5 Button Pressed

Because the matrix inputs were designed to handle multiple button presses by placing blocking diodes in series with each switch, Figure 52 shows push buttons S1, S2, S3, and S4 simultaneously being pressed.

Expression	Type	Value
MatrixReg1	unsigned long	00000000111110111110111110111110b (Binary)
MatrixReg2	unsigned long	00000000000000000000111111111111b (Binary)

Figure 52. Matrix Switch Inputs—S1 Through S4 Simultaneously Pressed

Additionally, matrix inputs can be used in low-power polling mode. The parameters that affect the average current consumption are the sourcing wetting-current setting, the polling active time setting, and the polling time setting. Figure 53 shows a polling time of 32 ms, polling active time of 64 µs, and sourcing wetting current of 1 mA with all 36 switches being monitored. Channel 1 shows the voltage seen at one of the switches and channel 2 shows the current consumption.

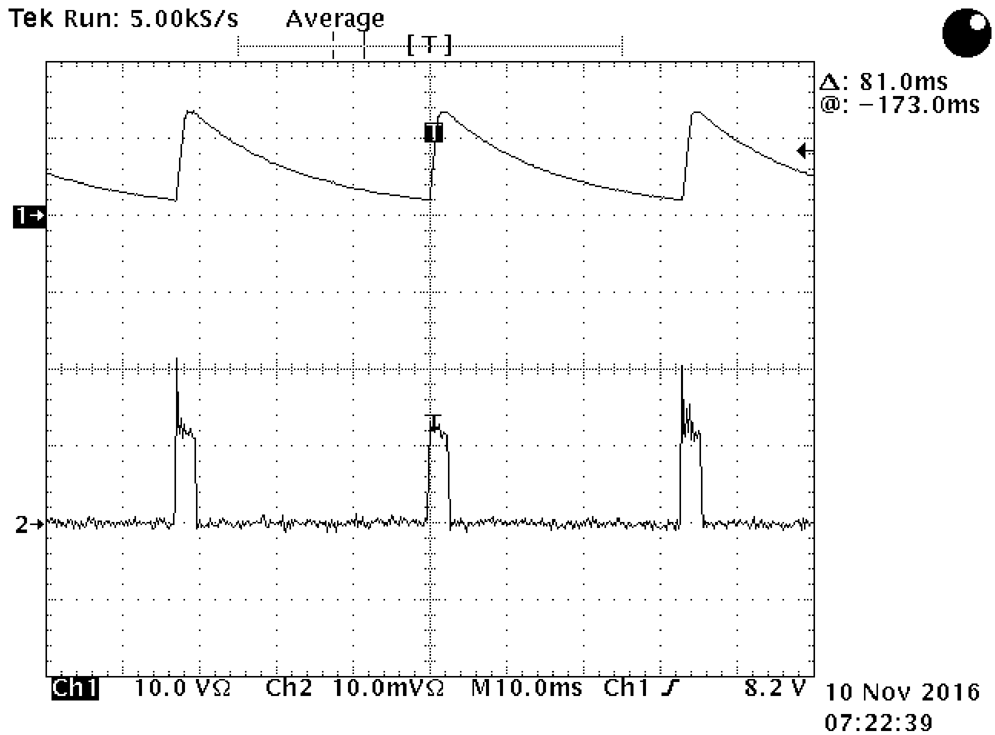

Figure 53. Matrix Switch Inputs—Low-Power Polling Mode

As the plot shows, the current consumption briefly rises when the device is sourcing wetting current and monitoring the inputs and then drops to under 10 µA of current for the non-active time. The average current consumption at room temperature with all 36 inputs active was 145 µA.

4.4.7 Light Control Arm Inputs Results

As determined in Section 2.9.3, the light control arm requires two inputs in comparator input mode, one input in ADC input mode that can handle three states and an additional input in ADC input mode that can handle four input states. IN19 through IN22 were used and Section 4.4.2 and Section 4.4.4 discuss how to set up both single-threshold comparator inputs and multi-threshold ADC inputs. Because both comparator mode input and ADC mode inputs were used for the light control arm, both the IN_STAT_COMP and IN_STAT_ADC1 registers are read to determine the input states.

IN19, IN20, and IN21 indicate the position of the knob and are independent of IN22; therefore, it is appropriate to first review the results of IN19-IN21 separately.

Figure 54 highlights the input status bits for IN19 and IN20 (IN_STAT_COMP_Reg) and IN21 (IN_STAT_ADC1_Reg). For this input state:

- IN19 and IN20 have a "10" status indicating that the input voltage on IN19 is below the set comparator threshold and the input voltage on IN20 is above the set comparator threshold.
- IN21 has a "11" status indicating that the input voltage is equal to or above THRES3C.

Therefore, by looking at Table 3, the designer can conclude that the light control arm is in the "Headlights and Fog Lights Off" position.

Figure 55 highlights the input status bits for IN19 and IN20 (IN_STAT_COMP_Reg) and IN21 (IN_STAT_ADC1_Reg). For this input state:

- IN19 and IN20 have a "11" status indicating that the input voltage on both IN19 and IN20 is above the set comparator threshold.
- IN21 has a "00" status indicating that the input voltage is below THRES3A.

Therefore, by looking at Table 3, the designer can conclude that the light control arm is in the "Automatic Headlight Control" position.

Figure 56 highlights the input status bits for IN19 and IN20 (IN_STAT_COMP_Reg) and IN21 (IN_STAT_ADC1_Reg). For this input state:

- IN19 and IN20 have a "01" status indicating that the input voltage on IN19 is above the set comparator threshold and the input voltage on IN20 is below the set comparator threshold.
- IN21 has a "11" status indicating that the input voltage is equal to or above THRES3C.

Therefore, by looking at Table 3, the designer can conclude that the light control arm is in the "Headlights On and Fog Lights Off" position.

Figure 57 highlights the input status bits for IN19 and IN20 (IN_STAT_COMP_Reg) and IN21 (IN_STAT_ADC1_Reg). For this input state:

- IN19 and IN20 have a "11" status indicating that the input voltage on both IN19 and IN20 is above the set comparator threshold.
- IN21 has a "10" status indicating that the input voltage is equal to or above THRES3B and below THRES3C.

Therefore, by looking at Table 3, the designer can conclude that the light control arm is in the "Headlights and Fog Lights On" position.

Expression	Type	Value
IN_STAT_ADC1_Reg	unsigned long	00000000000000000000001111000000b (Binary)
IN_STAT_COMP_Reg	unsigned long	00000000001000000000000000000000b (Binary)

Figure 54. Light Control Arm—Headlights and Fog Lights Off

Expression	Type	Value
IN_STAT_ADC1_Reg	unsigned long	00000000000000000000001100000000b (Binary)
IN_STAT_COMP_Reg	unsigned long	00000000001100000000000000000000b (Binary)

Figure 55. Light Control Arm—Automatic Headlight Control

Expression	Type	Value
IN_STAT_ADC1_Reg	unsigned long	00000000000000000000001111000000b (Binary)
IN_STAT_COMP_Reg	unsigned long	00000000000100000000000000000000b (Binary)

Figure 56. Light Control Arm—Headlights On and Fog Lights Off

Expression	Type	Value
IN_STAT_ADC1_Reg	unsigned long	00000000000000000000001110000000b (Binary)
IN_STAT_COMP_Reg	unsigned long	00000000001100000000000000000000b (Binary)

Figure 57. Light Control Arm—Headlights and Fog Lights On

Because IN22 independently indicates the momentary twist-forward position, momentary twist-backward position, and momentary push-button input on the end of the control arm, the designer can separately review the results of just the IN22. Bits 8 and 9 of the IN_STAT_ADC1 register are the only bits required to be read (the control arm was left in the "Headlights and Fog Lights Off") because the status of IN22 is the only parameter of concern.

Figure 58 highlights the input status bits for IN22. For this input state, the IN22 status bits have a value of "11" indicating that the input voltage is equal to or above THRES3C; therefore, by looking at Table 3, the designer can conclude that no momentary inputs are pressed.

Figure 59 highlights the input status bits for IN22. For this input state, the IN22 status bits have a value of "00" indicating that the input voltage is below THRES3A; therefore, by looking at Table 3, the designer can conclude that the control arm is in the "Momentary Twist Forward" position.

Figure 60 highlights the input status bits for IN22. For this input state, the IN22 status bits have a value of "01" indicating that the input voltage is equal to or above THRES3A and below THRES3B; therefore, by looking at Table 3, the designer can conclude that the control arm is in the "Momentary Twist Backwards" position.

Figure 61 highlights the input status bits for IN22. For this input state, the IN22 status bits have a value of "10" indicating that the input voltage is equal to or above THRES3B and below THRES3C; therefore, by looking at Table 3, the designer can conclude that the "Momentary End Button" is pressed.

Expression	Type	Value
IN_STAT_ADC1_Reg	unsigned long	00000000000000000000001111000000b (Binary)

Figure 58. Light Control Arm—No Momentary Inputs

Expression	Type	Value
IN_STAT_ADC1_Reg	unsigned long	00000000000000000000000011000000b (Binary)

Figure 59. Light Control Arm—Momentary Twist Forward

Expression	Type	Value
IN_STAT_ADC1_Reg	unsigned long	00000000000000000000000111000000b (Binary)

Figure 60. Light Control Arm—Momentary Twist Backward

Expression	Type	Value
IN_STAT_ADC1_Reg	unsigned long	00000000000000000000001011000000b (Binary)

Figure 61. Light Control Arm—Momentary End Button

4.4.8 Wiper Control Arm Inputs Results

As determined in Section 2.9.4, the wiper control arm has a total of six input states, which can be determined using one five-threshold ADC mode input. IN23 was used for this control arm and Section 4.4.4 addresses how to set up a multi-threshold ADC input. Because only one ADC mode input was used for the wiper control arm, bits 10 through 12 in the IN_STAT_ADC1 register are the only bits required to read to determine what state the control arm is in.

Figure 62 highlights the input status bits for IN23 when they have a "101" status. This readout indicates that the input voltage is equal to or above THRES9; therefore, by looking at Table 4, the designer can conclude that the wiper control arm is in the "wiper off" position and the push-button is not pressed.

Figure 63 highlights the input status bits for IN23 when they have a "100" status. This readout indicates that the input voltage is equal to or above THRES8 and below THRES9; therefore, by looking at Table 4, the designer can conclude that the wiper control arm is in the "wiper off" position and the push-button is pressed.

Figure 64 highlights the input status bits for IN23 when they have a "011" status. This readout indicates that the input voltage is equal to or above THRES3C and below THRES8; therefore, by looking at Table 4, the designer can conclude that the wiper control arm is in the "wiper on and wash" position and the push-button is not pressed.

Figure 65 highlights the input status bits for IN23 when they have a "010" status. This readout indicates that the input voltage is equal to or above THRES3B and below THRES3C; therefore, by looking at Table 4, the designer can conclude that the wiper control arm is in the "wiper on and wash" position and the push-button is pressed.

Figure 66 highlights the input status bits for IN23 when they have a "001" status. This readout indicates that the input voltage is equal to or above THRES3A and below THRES3B; therefore, by looking at Table 4, the designer can conclude that the wiper control arm is in the "wiper on" position and the push-button is not pressed.

Figure 67 highlights the input status bits for IN23 when they have a "000" status. This readout indicates that the input voltage is below THRES3A; therefore, by looking at Table 4, the designer can conclude that the wiper control arm is in the "wiper on" position and the push button is pressed

Expression	Type	Value
spiReceive	unsigned long	00000000000000000001010000000000b (Binary)

Figure 62. Wiper Control Arm—Off Position

Expression	Type	Value
spiReceive	unsigned long	00000000000000000001000000000000b (Binary)

Figure 63. Wiper Control Arm—Off Position With Button Pressed

Expression	Type	Value
spiReceive	unsigned long	00000000000000000000110000000000b (Binary)

Figure 64. Wiper Control Arm—Wiper and Wash Position

Expression	Type	Value
spiReceive	unsigned long	00000000000000000000100000000000b (Binary)

Figure 65. Wiper Control Arm—Wiper and Wash Position With Button Pressed

Expression	Type	Value
spiReceive	unsigned long	00000000000000000000010000000000b (Binary)

Figure 66. Wiper Control Arm—Wiper On Position

Expression	Type	Value
spiReceive	unsigned long	00000000000000000000000000000000b (Binary)

Figure 67. Wiper Control Arm—Wiper On Position With Button Pressed

5 Design Files

5.1 Schematics

To download the schematics, see the design files at TIDA-01237.

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01237.

5.3 PCB Layout Recommendations

Because of the inherently low frequency of signal switches and the low power requirements of this design, very few layout constraints require consideration. However, the following subsections list the best-practice board layout.

5.3.1 Board Size

The TIDA-01237 was designed to be used as a daughter card for the MSP430 LaunchPad. Additionally, onboard multi-switch detection on a single input, LED lighting, 6×6-matrix-configuration switch inputs, multiple headers for easy access to input pins, and indicator lights were added for ease of evaluation. For this reason, the width and length of the board has grown considerably but the small solution size of the TIC12400-Q1 device and all required circuitry is highlighted in silkscreen with a box and dimensions of 0.69 in by 0.72 in (17.5 mm by 18.18 mm), as previously listed.

The length of the TIDA-01237 board is quite a bit longer than the LaunchPad board but has been intentionally left off center so the user has access to the RESET and P1.3 push-buttons and allow an easy view of the red and green indicator LEDs, even after the TIDA-01237 board has been mounted on top of the MSP430. Therefore, two standoffs with rubber feet are used on the top end of the board so the board assembly does not tip over.

The dimensions of the TIDA-01237 board are 3 in × 5.25 in (76.2 mm × 133.35 mm). The tallest component on the board is the terminal block J1, which is 19-mm high, which amounts to an assembled board height of about 0.8 in (20.5 mm).

5.3.2 Board Layer Stackup

The board has been designed using two layers. Both top and bottom layers have signals and power traces routed. Additionally, a majority of the bottom layer has been used for a large, low-impedance ground plane. See Figure 68 for the stackup. The board uses standard 1-oz copper foil and the total board thickness is approximately 63 mils.

Layer Name	Type	Material	Thickness (mil)	Dielectric Material	Dielectric Constant
Top Overlay	Overlay				
Top Solder	Solder Mask/...	Surface Mat...	0.4	Solder Resist	3.5
Top Layer	Signal	Copper	1.4		
Dielectric1	Dielectric	Core	59.2	FR-4	4.8
Bottom Layer	Signal	Copper	1.4		
Bottom Solder	Solder Mask/...	Surface Mat...	0.4	Solder Resist	3.5
Bottom Over...	Overlay				

Figure 68. TIDA-01237 Board Layer Stackup

5.3.3 Voltage Regulator Layout Recommendations

For the layout of the TPS7B6733-Q1 device, place the input capacitor (C3) and output capacitor (C1) close to the device, as Figure 69 shows. Minimize equivalent series inductance (ESL) and equivalent series resistance (ESR) to maximize performance and ensure stability. Place every capacitor as close as possible to the device and on the same side of the printed-circuit board (PCB) as the regulator. Do not place any of the capacitors on the opposite side of the PCB where the regulator has been installed. TI strongly discourages the use of long traces because they can impact system performance negatively and even cause instability.

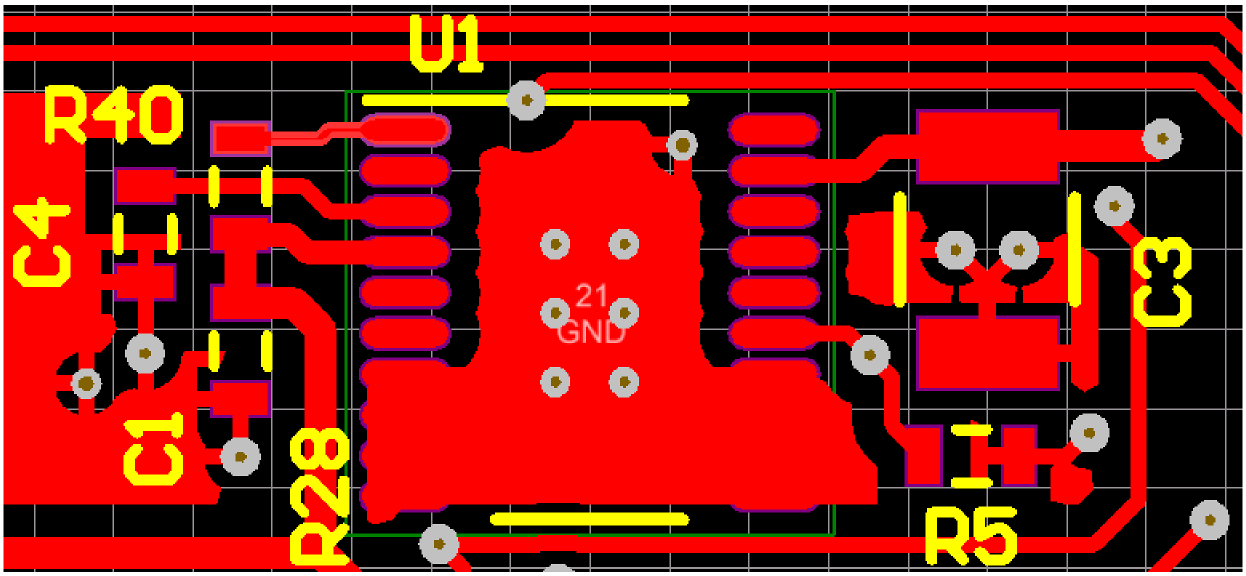

Figure 69. Voltage Regulator Capacitor Placement

5.3.4 LaunchPad™ Connectors

The connectors J2 and J3 are placed in accordance with the rules for building a BoosterPack™ Plug-in Module, which are available on the LaunchPad Build Your Own Board website. The location of the J2 and J3 connectors is such that the RESET and P1.3 push-buttons on the LaunchPad are accessible when the TIDA-01237 board has been mounted on top of the LaunchPad board, as Figure 24 shows.

5.3.5 Layout Prints

To download the layer plots, see the design files at TIDA-01237.

5.4 Altium Project

To download the Altium project files, see the design files at TIDA-01237.

5.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01237.

5.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01237.

6 Related Documentation

1. Texas Instruments, *TIC12400-Q1 Datasheet Title Here*, TIC12400-Q1 Datasheet (Base Lit #)
2. Texas Instruments, *TIC10024-Q1 Datasheet Title Here*, TIC10024-Q1 Datasheet (Base Lit #)
3. Texas Instruments, *TPS7B67xx-Q1 450-mA High-Voltage Ultra-Low I_Q Low-Dropout Regulator*, TPS7B67xx-Q1 Datasheet (SLVSCB2)
4. Texas Instruments, *DRV5023 -Q1 Automotive Digital-Switch Hall Effect Sensor*, DRV5023-Q1 Datasheet (SLIS163)
5. Texas Instruments, *LMT87/LMT87-Q1 SC70/TO-92, Analog Temperature Sensors with Class-AB Output*, LMT87/LMT87-Q1 Datasheet (SNIS170)

6.1 Trademarks

7 Terminology

Body control module—An automotive electronic control unit responsible for monitoring and controlling vehicle loads. Some examples include interior lighting, exterior lighting, heating ventilation and air conditioning (HVAC), powered windows, and powered door locks.

MSDI— Multi switch detection interface. A type of device that aggregates a number of inputs and communicates switch state information back to a central microcontroller.

8 About the Author

JOHN GRIFFITH is a systems engineer at Texas Instruments. As a member of the Automotive Systems Engineering team, John specializes on body control modules and gateway modules, creating end-equipment block diagrams, and reference designs for automotive customers. John earned his bachelor of science and master of science in electrical engineering from Rochester Institute of Technology in Rochester, New York.