TI Designs: TIDA-020011
Automotive mmWave Radar Gesture Control Reference Design

TEXAS INSTRUMENTS

Description

This reference design utilizes mmWave radar and a full automotive power design to provide a sleek, simple solution to capture hand gestures and improve the experience of the driver. The evolution of the automobile has led to the desire for simpler and easier interaction with the ever-increasing amount of hardware found within both the infotainment console and body of the vehicle. Beyond direct human interfacing with a system through the physical press of a button or a customized voice control, basic intuitive hand gestures allow the driver to control their vehicle with less distractions from the road.

Resources

TIDA-020011	Design Folder
AWR1642	Product Folder
LM53625-Q1	Product Folder
LP87702-Q1	Product Folder
TPS7A52-Q1	Product Folder
TCAN1042GV-Q1	Product Folder

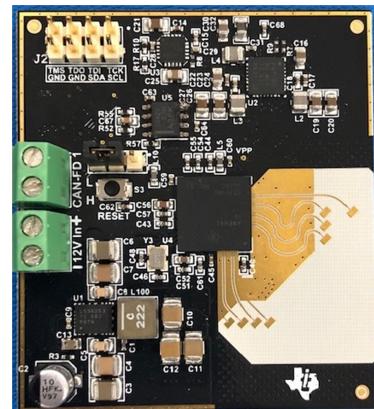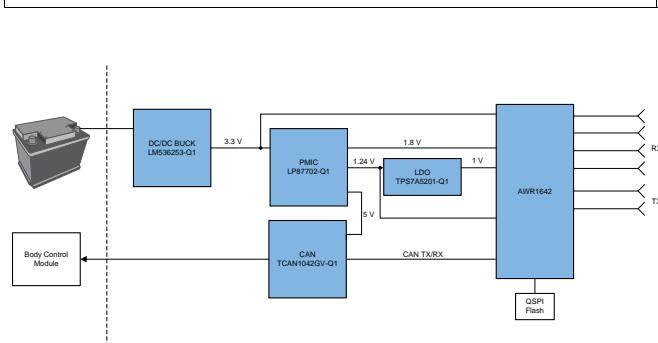ASK Our E2E™ Experts

Features

- 77-GHz radar-based gesturing
- CAN-FD gesture data output
- Wide operating voltage: 3.5 V to 42 V
- Small form factor: 50.3 mm × 56.7 mm
- This circuit design is tested and includes Gerbers, Schematics, and BOM

Applications

- HMI - Gesturing
- Obstacle Detection Sensor

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1 System Description

This reference design provides an example of a full radar-based gesture control system in a very small form factor that is implemented within the infotainment center console, the overhead console, or anywhere else where both size and performance are primary goals.

This system relies on the functionality of the AWR1642 device, a mmWave radar digital signal processor (DSP) and analog front end (AFE) that drives, senses, and analyzes 77- to 81-GHz signals. Using two TX antennas and capturing with four RX antennas, a frequency-modulated continuous wave (FMCW) radar system can capture various data points associated with the distance, angle, and velocity of the reflected radar signal to be translated into specific gestures being read.

The highly-integrated AWR1642 device relies on only a small selection of external components for power, flash memory, and CAN interface communication. The entire system interacts with the rest of an automotive system with only the battery power input and CAN-FD communication output. This design uses a wide input voltage buck converter, the LM536253-Q1 device, in conjunction with a multi-rail power management IC, the LP87702-Q1 device, and linear regulator, the TPS7A52-Q1 device, to power the entire system. The communication interface uses the TCAN1042GV-Q1 device.
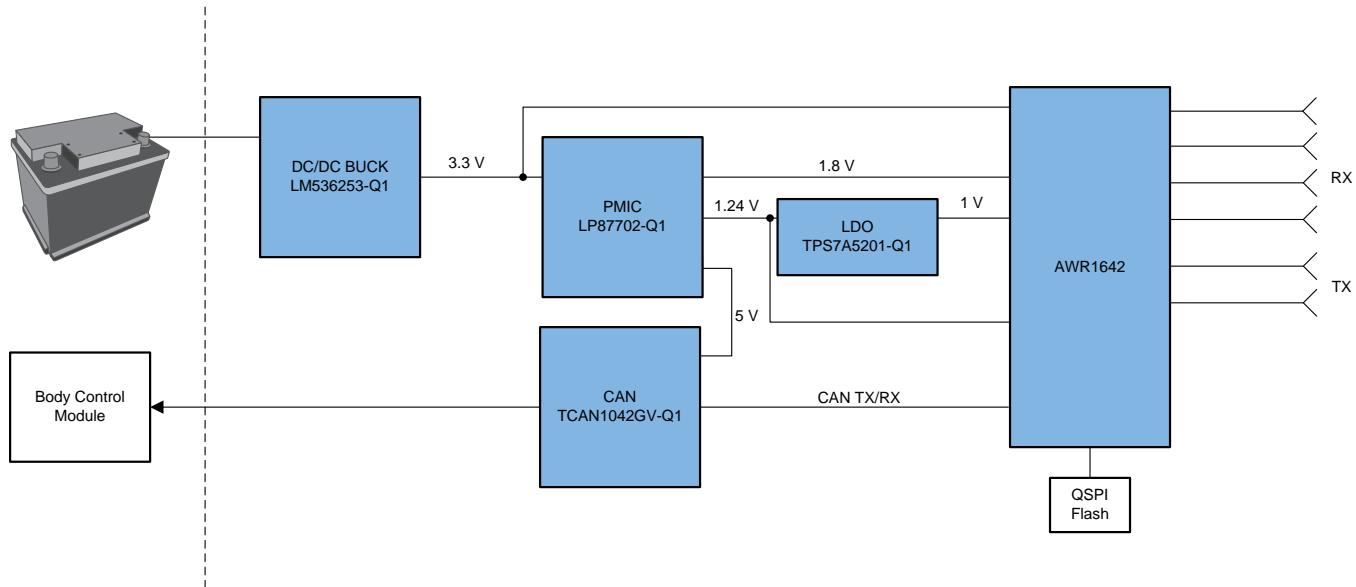
1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Power supply operating range	3.5 to 42 V	Section 2.3.2
Total Power Consumption (12 V, typical software operation)	Approximately 4.8 W	Section 2.3.2.1
CAN-FD Data Speed	5 Mbps maximum	Section 2.3.4
PCB Size	50.3 mm × 56.7 mm	Section 2.3.1
Operating distance for gestures	1 meter	

2   System Overview

2.1   Block Diagram

Figure 1. TIDA-020011 Block Diagram

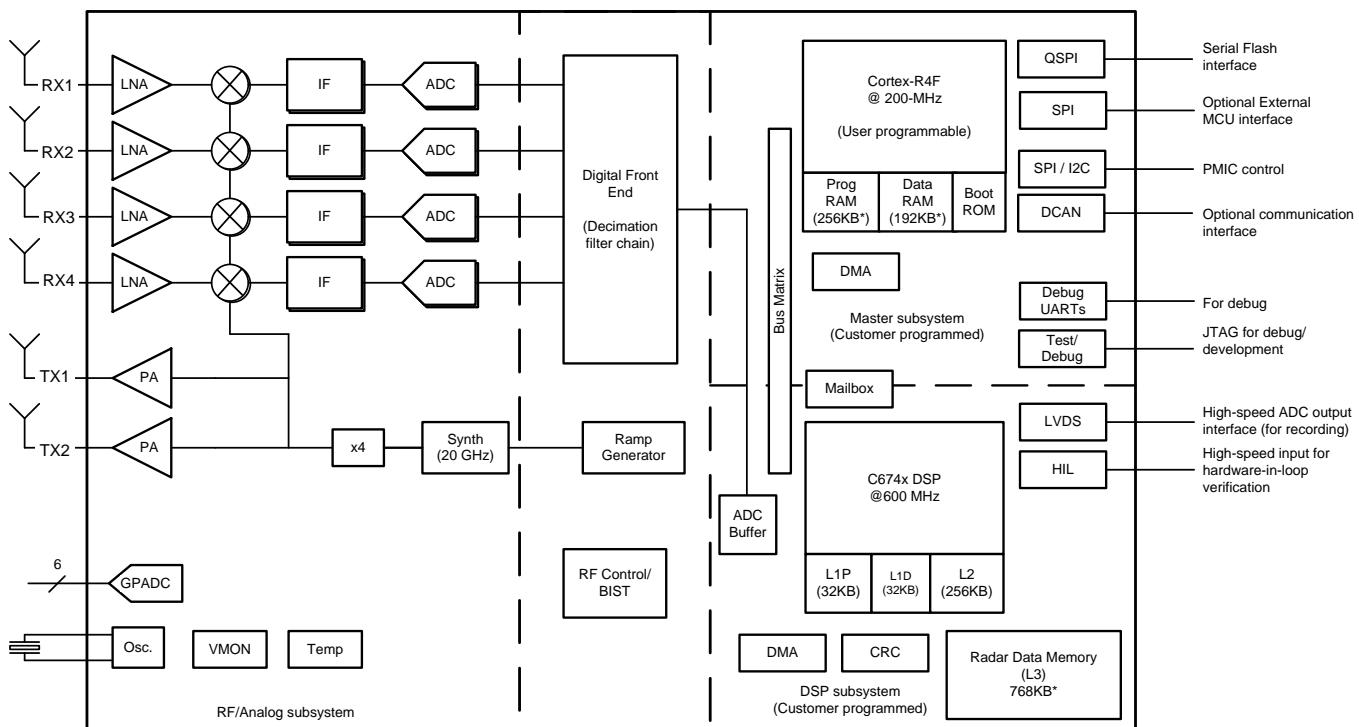Copyright © 2018, Texas Instruments Incorporated

2.2 *Highlighted Products*

2.2.1 AWR1642

The AWR1642 device is an integrated single-chip FMCW radar sensor capable of operation in the 76- to 81-GHz band. The device is built with TI's low-power 45-nm RFCMOS process and enables unprecedented levels of integration in an extremely small form factor. The AWR1642 is an ideal solution for low-power, self-monitored, ultra-accurate radar systems in the automotive space.

The AWR1642 device is a self-contained FMCW radar sensor single-chip solution that simplifies the implementation of Automotive Radar sensors in the band of 76 to 81 GHz. It is built on TI's low-power 45-nm RFCMOS process, which enables a monolithic implementation of a 2TX, 4RX system with built-in PLL and A2D converters. It integrates the DSP subsystem, which contains TI's high-performance C674x DSP for the Radar Signal processing. The device includes an ARM R4F-based processor subsystem, which is responsible for radio configuration, control, and calibration. Simple programming model changes can enable a wide variety of sensor implementation (Short, Mid, Long) with the possibility of dynamic reconfiguration for implementing a multimode sensor. Additionally, the device is provided as a complete platform solution including reference hardware design, software drivers, sample configurations, API guide, and user documentation.
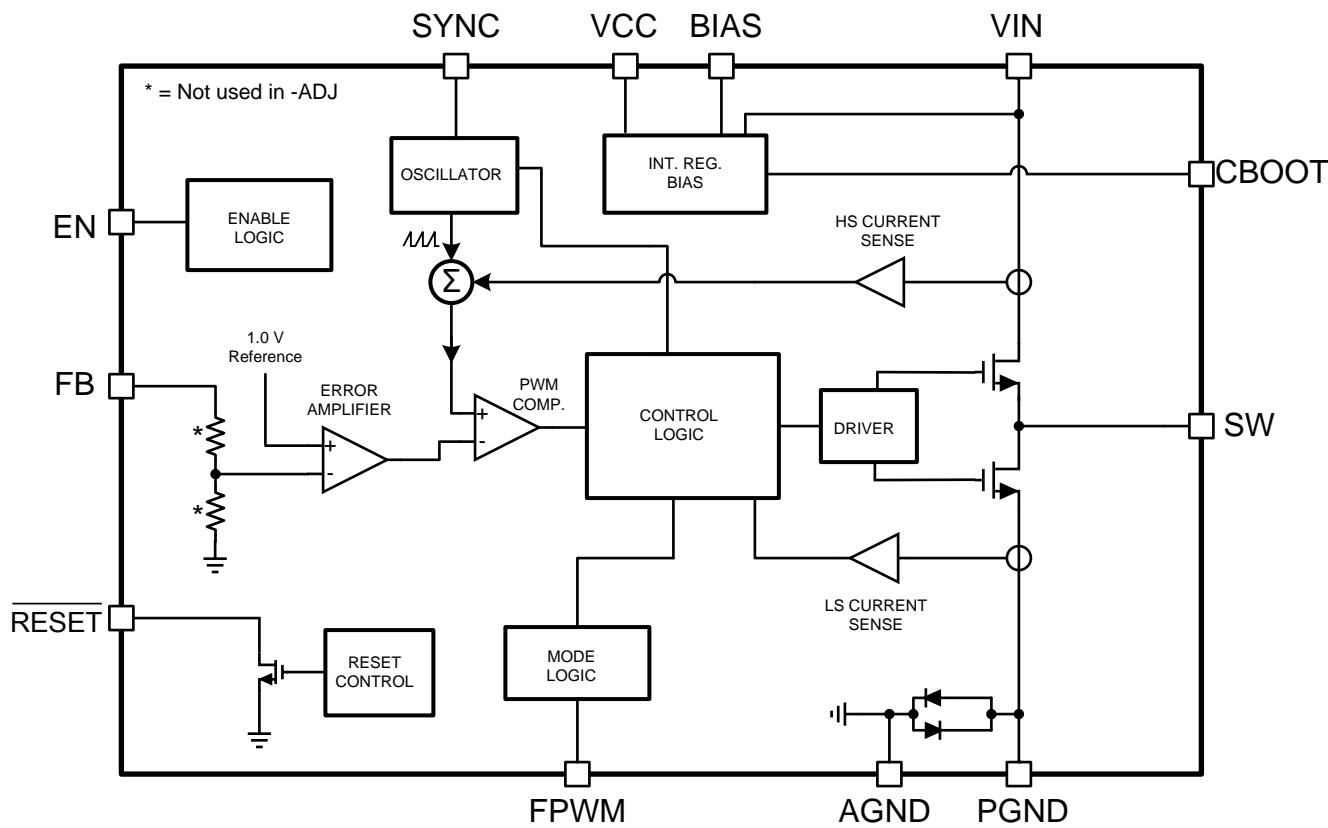
Figure 2. AWR1642 Block Diagram

* Up to 512KB of Radar Data Memory can be switched to the Master R4F if required

2.2.2   LM53625-Q1

The LM53625-Q1, LM53635-Q1 synchronous buck regulator is optimized for automotive applications, providing an output voltage of 5 V, 3.3 V, or an adjustable output. Advanced high-speed circuitry allows the LM53625-Q1 and LM53635-Q1 devices to regulate from an input of 18 V to an output of 3.3 V at a fixed frequency of 2.1 MHz. Innovative architecture allows this device to regulate a 3.3-V output from an input voltage of only 3.55 V. All aspects of the LM53625-Q1 and LM53635-Q1 devices are optimized for automotive and performance-driven industrial customers. An input voltage range up to 36 V, with transient tolerance up to 42 V, eases input surge protection design. The automotive-qualified Hotrod QFN package with wettable flanks reduces parasitic inductance and resistance while increasing efficiency, minimizing switch node ringing, and dramatically lowering electromagnetic interference (EMI). An open-drain reset output, with built-in filtering and delay, provides a true indication of system status. This feature negates the requirement for an additional supervisory component, saving cost and board space. Seamless transition between PWM and PFM modes and low quiescent current (only 15 µA for the 3.3-V option) ensure high efficiency and superior transient responses at all loads.
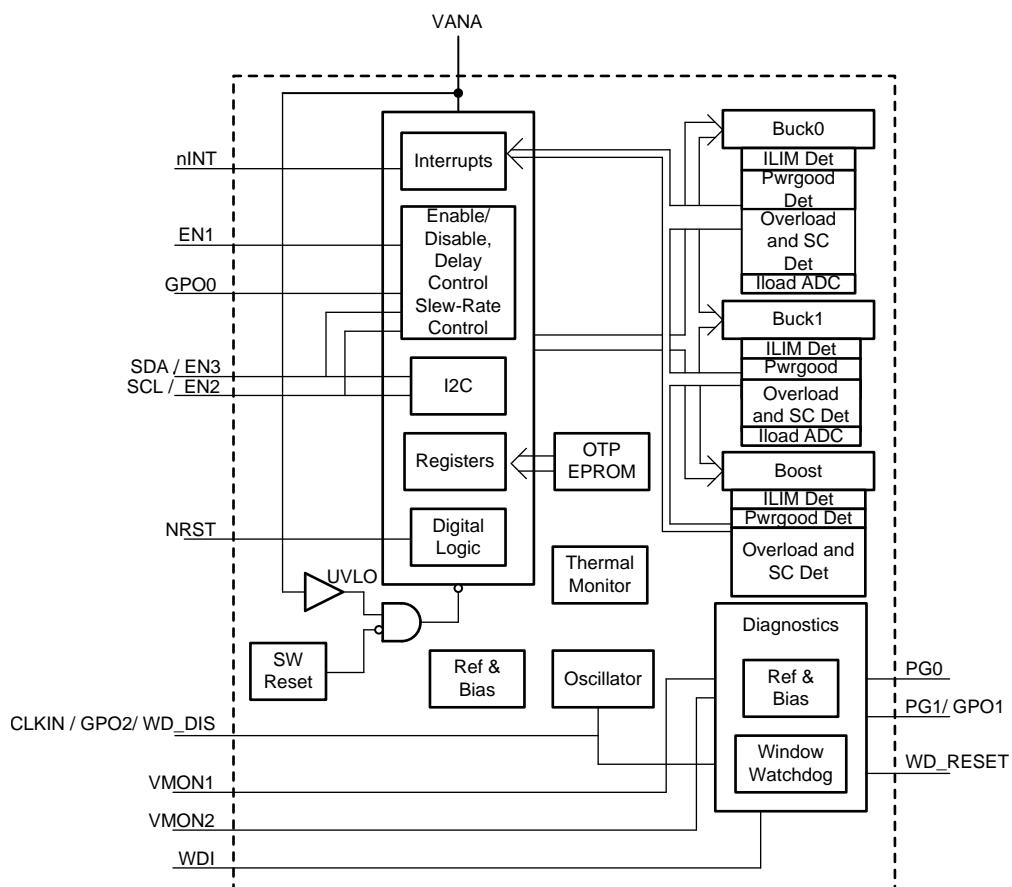
Figure 3. LM53625-Q1 Block Diagram

2.2.3 LP87702-Q1

The LP87702-Q1 device meets the power management requirements of the latest platforms, particularly in automotive radar and camera and industrial radar applications. The device contains two step-down DC/DC converters, a 5-V boost converter and bypass switch, two voltage monitoring inputs for external power supplies, and window watchdog. An I2C-compatible serial interface and enable signals control the device.

The automatic PWM, PFM (AUTO mode) operation gives high efficiency over a wide output current range for buck converters. The LP87702-Q1 device uses remote voltage sensing for buck converters to compensate IR drop between the converter output and the point-of-load, thus improving the accuracy of the output voltage. In addition, the switching clock can be forced to PWM mode and also synchronized to an external clock for minimal disturbances.

The LP8770 device has internal circuitry specifically designed to support current measurement, eliminating the need for an external resistor. Programmable start-up and shutdown sequences synchronized to the enable signal are supported, including general purpose digital outputs. During start-up and voltage change, the device controls the output slew rate for minimum output voltage overshoot and inrush current.

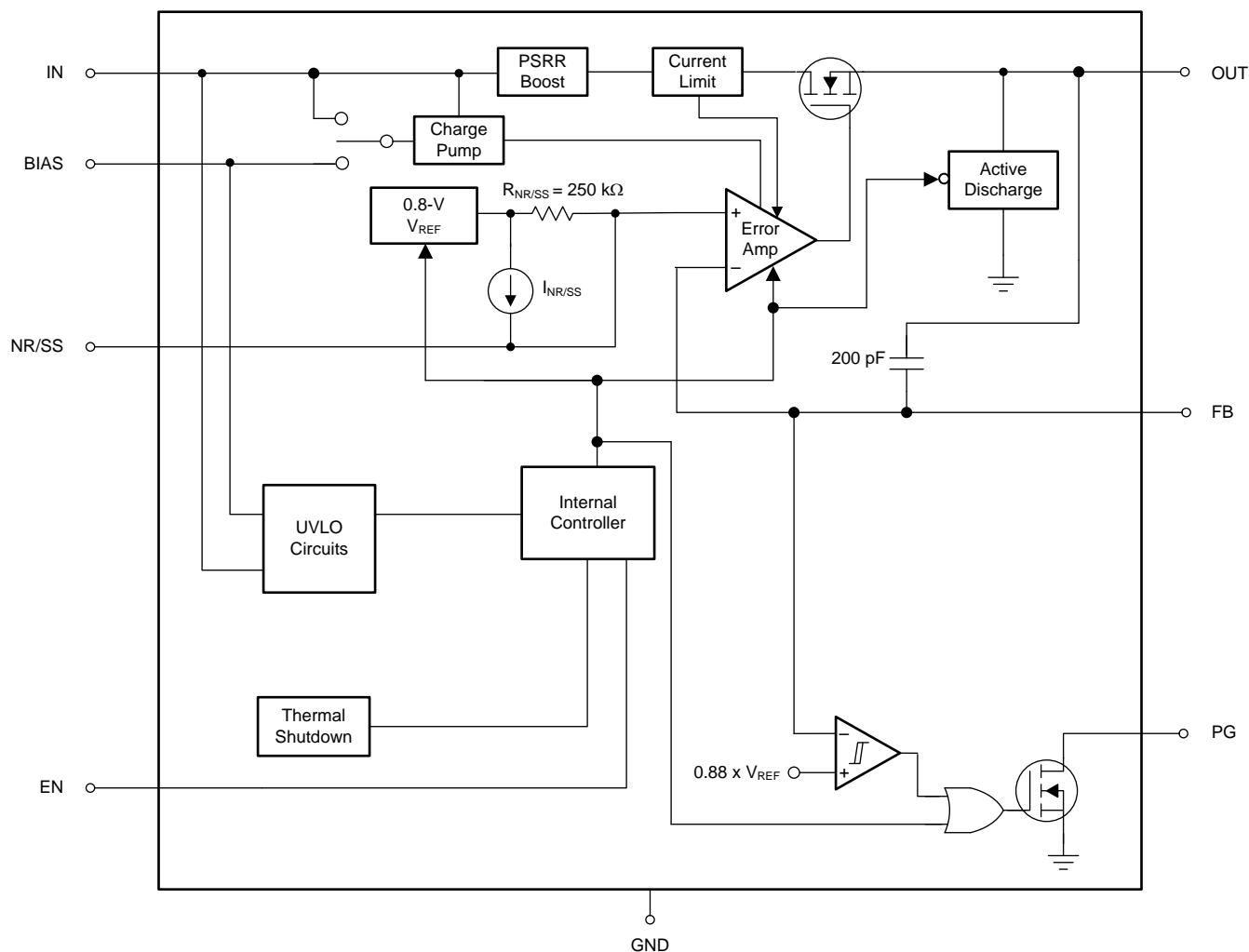**Figure 4. LP87702-Q1 Block Diagram**

2.2.4   TPS7A52-Q1

The TPS7A52-Q1 device is a low-noise (4.4 μV_{RMS}), low-dropout linear regulator (LDO) capable of sourcing 2 A with only 115 mV of maximum dropout. The device output voltage is adjustable from 0.8 V to 5.2 V using an external resistor divider.

The combination of low-noise (4.4 µVRMS), high-PSRR, and high output current capability makes the TPS7A52-Q1 device ideal to power noise-sensitive components such as those found in radar power and infotainment applications. The high performance of this device limits power-supply-generated phase noise and clock jitter, making this device ideal for powering RF amplifiers, radar sensors, and chipsets. Specifically, RF amplifiers benefit from the high-performance and 5.0-V output capability of the device.

For digital loads [such as application-specific integrated circuits (ASICs), field-programmable gate arrays (FPGAs), and digital signal processors (DSPs)] requiring low-input voltage, low-output (LILO) voltage operation, the exceptional accuracy (1% over load and temperature), remote sensing, excellent transient performance, and soft-start capabilities of the TPS7A52-Q1 provides optimal system performance.

The versatility of the TPS7A52-Q1 device makes it a component of choice for many demanding applications.
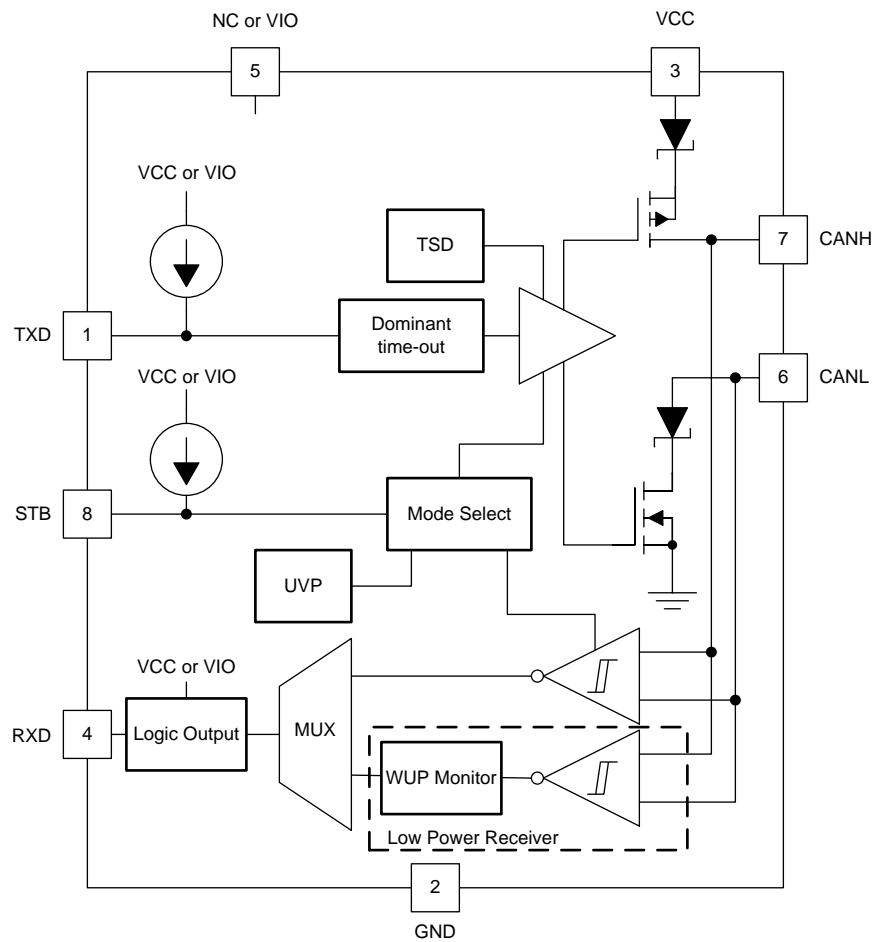
Figure 5. TPS7A52-Q1 Block Diagram

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2.2.5 TCAN1042GV-Q1

This CAN transceiver family meets the ISO11898-2 (2016) High Speed CAN (Controller Area Network) physical layer standard. All devices are designed for use in CAN FD networks up to 2 Mbps (megabits per second). Devices with part numbers that include the "G" suffix are designed for data rates up to 5 Mbps, and versions with the "V" have a secondary power supply input for I/O level shifting the input pin thresholds and RXD output level. This family has a low power standby mode with remote wake request feature. Additionally, all devices include many protection features to enhance device and network robustness.

Figure 6. TCAN1042GV-Q1 Block Diagram

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2.3 System Design Theory

2.3.1 PCB and Form Factor

An important design goal was to minimize the total PCB area to exhibit the small form factor that can be easily integrated into a larger overall system like an interior control module. The total PCB size is 50.29 mm × 56.65 mm (1.98 in × 2.23 in) for a total area of 2848 mm^2 (4.42 in^2).
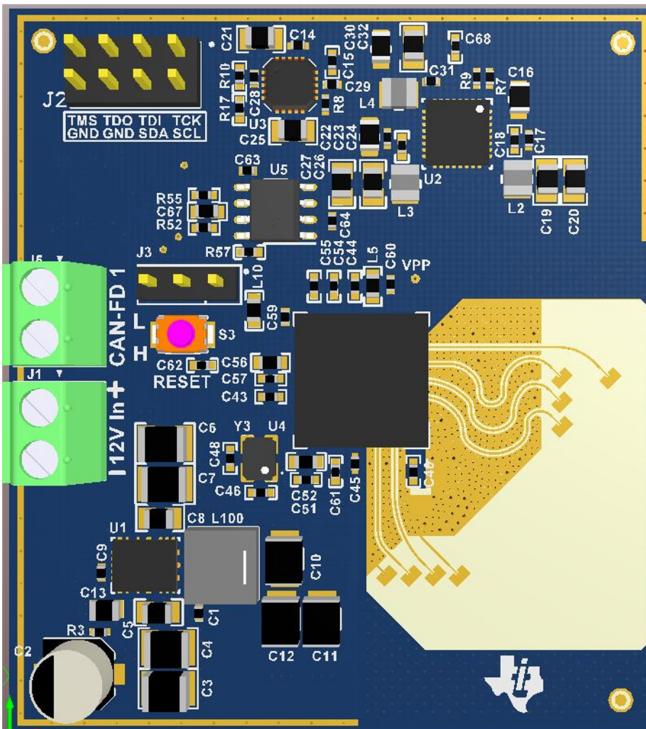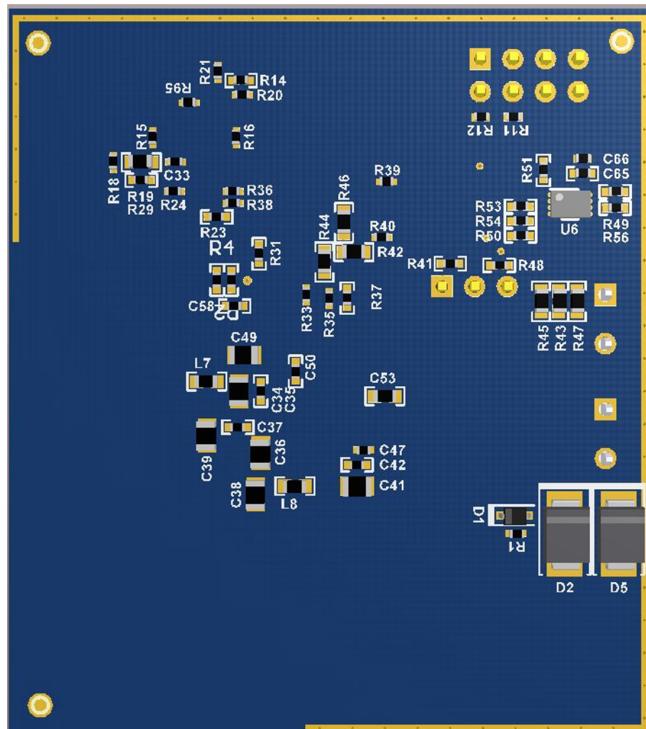
Figure 7. 3D Rendering of Top Side of PCB

Figure 8. 3D Rendering of Bottom Side of PCB

2.3.2 Power Supply Topology

The system power supply was designed to operate off of a 12-V automotive battery. The AWR1642 requires four voltage rails: 3.3 V for digital IO, 1.8 V for analog stages and clocking, 1.24 V for digital stages, and 1 V for radar antenna drivers. Additionally, the TCAN1042GV-Q1 CAN-FD physical layer requires a 5-V supply.

To tolerate typical automotive battery voltages, a wide input voltage buck converter is used to generate 3.3 V as an initial power stage for the rest of the system. From there, a multi-rail power management IC (PMIC) generates the 5-, 1.8-, and 1.2-V rails for the system. To generate a clean, low-noise supply for the sensitive radar driver stage, a 1-V linear regulator is used.

2.3.2.1 *AWR1642 Power Supply Considerations and Best Practices*

It is important to recognize the current requirements for each rail powering the AWR1642 device. provides a reference for possible peak current found on each rail. Design of the LP87702-Q1 device should take into consideration the power requirements of each of these rails.

Table 2. Power Rail Current Requirements

POWER RAIL	PEAK CURRENT
1.24 V	1000 mA
1.8 V	850 mA
1 V	2000 mA
3.3 V	Depends on the interfaces used on the AWR1642

The 1.24-V rail requires special attention. Typically this rail operates at 1.2 V for the AWR1642 device. The voltage has been increased slightly to provide enough dropout headroom for the 1-V LDO operating off of this rail. This also means that current requirements for the 1.24-V rail must also consider the amount of the current the 1-V rail needs.

One of the key concerns when using the switching regulators for the power supply is to prevent the switching frequency of the regulator from coupling onto the analog circuitry through the supply or ground. At a 4-MHz switching frequency, the AWR1642 device can tolerate approximately 35.5-μV_{RMS} ripple on the 1.8-V supply to keep the spur in the RX spectrum of less than –120 dBm (at the LNA input). The following steps offer ways to reduce the supply ripple level:

- Use LC filtering on the analog and RF supplies (1.8 V and 1 V).

- Some of the output voltage ripple of a switching buck regulator is caused by the inductor ripple current charging and discharging the output capacitor. Minimize this inductor ripple current by using a high switching frequency, in this case 4 MHz. The recommended inductance for LP87702-Q1 buck regulators is 0.47 µH.

- A higher output capacitance reduces the output voltage ripple and also improves load step behavior. Use ceramic capacitors with low to minimize ripple. The R_{ESR} is frequency dependent (as well as temperature dependent); make sure the value used for the selection process is at the switching frequency. Use the point-of-load capacitors to further decrease the ripple voltage and improve load transient performance.

- Use the LC filter to continue filtering the output from the regulator. Place a series ferrite bead on the supply path, along with the decoupling capacitors of the supply, so that they can act as an LC filter to reduce the ripple amplitude. Choose the values such that the corner frequency of the LC filter is much lower than the switching frequency. For example, in this design, the LP87702 device switches at a 4-MHz frequency. The LC filter is designed with the part number BLM18KG121TH1 to provide a cutoff frequency of approximately 120 kHz with the decoupling capacitors on the 1.8-V supply rail.

> **NOTE:** The IR drop across the inductor must be kept as low as possible, for which TI recommends a very-low DC resistance inductor. From the data sheet, the BLM18KG121TH1 has a DC resistance (DCR) of 25 mΩ.
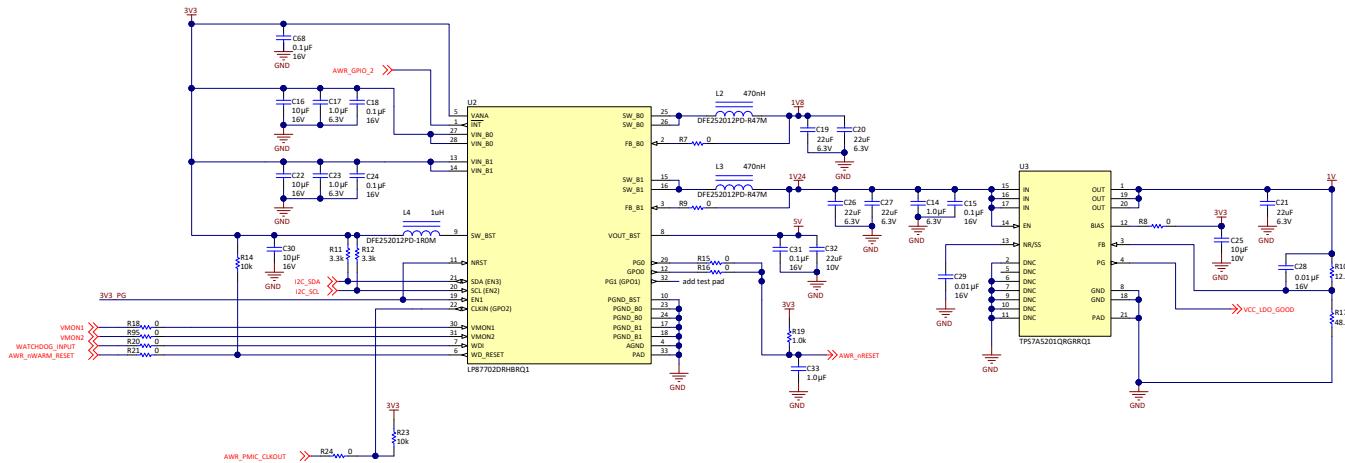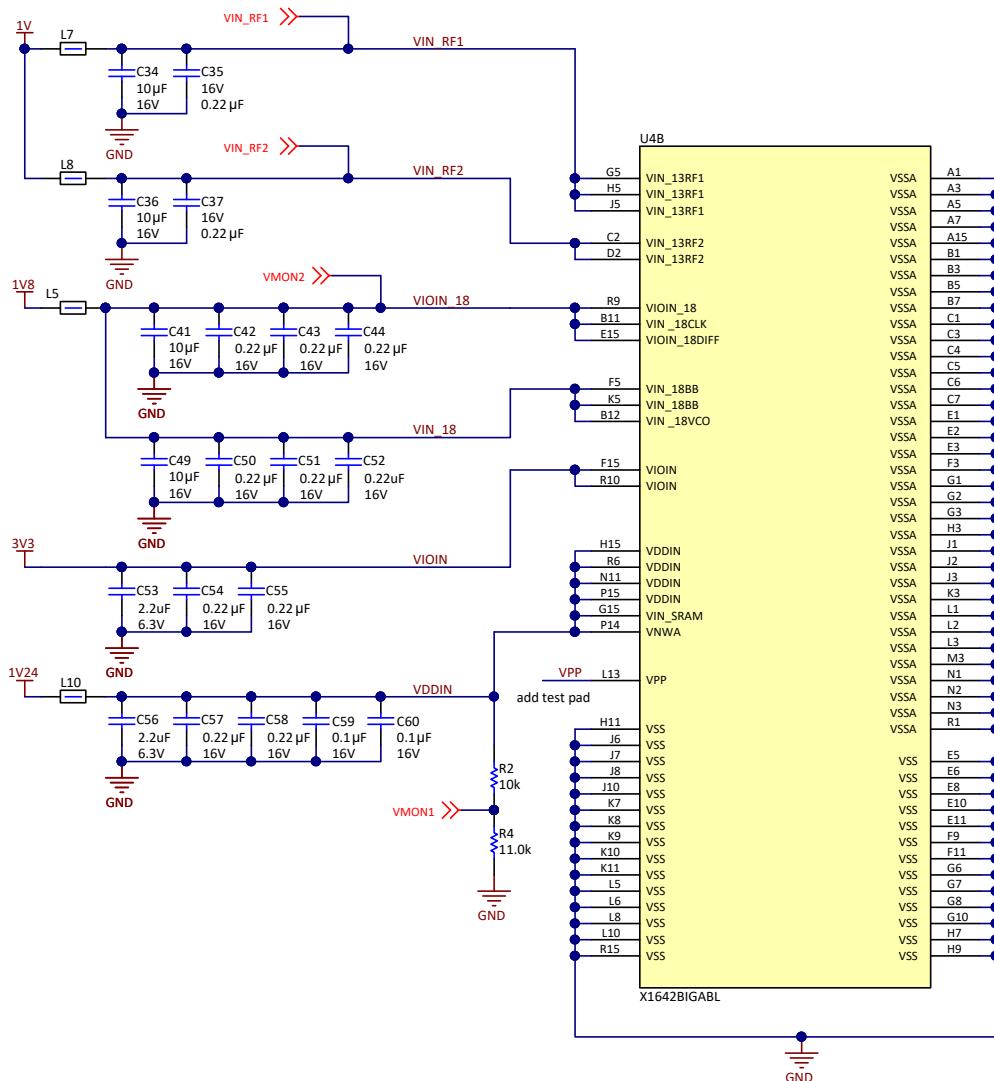
Figure 9. Schematic of PMIC and LDO

Figure 10. Schematic of Power Filtering and Decoupling at AWR1642

2.3.2.2 *Wide Input Voltage Buck*

To handle the possibly widely-varying automotive battery supply, a wide-input buck converter is used to generate a consistent 3.3-V rail from which the rest of the design generates the rest of the necessary power supply voltages. Start-stop and cold-crank conditions necessitate a system that can withstand a battery voltage of 6 V to 36 V. The LM53625-Q1 device allows for full operation across this battery range and can withstand typical automotive system transients.

Maintaining regulation and stopping the power supply from becoming unstable is critical in automotive power supplies around the minimum drop-out and high V_{IN} conditions. System-related conditions like cold crank or even load dump from faulty alternators can affect the regulation and output power. Support for low dropout requires that the device output does not oscillate. This oscillation translates into high-frequency noise and can cause disturbances elsewhere in the system. The LM53625-Q1 device is used here because it is designed to support very-low T_{MIN-ON} and $T_{MIN-OFF}$ conditions. Stable control of the power supply is critical and smooth operation into and out of a desired regulation range is required, as this controls the noise that is generated.
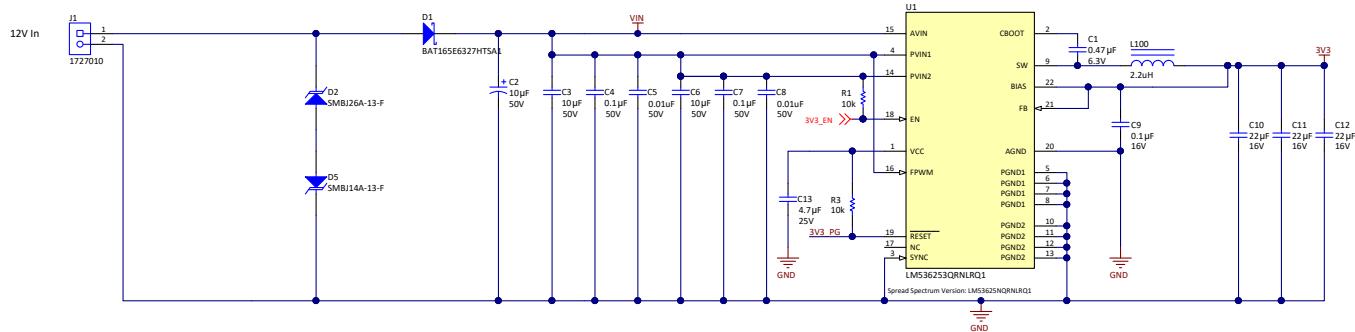
2.3.2.2.1 *Reducing EMI*

In an effort to minimize the amount of noise that could possibly be generated by the system. Several methods are used to reduce the EMI generated by the system power supplies.

The LM53625-Q1 device utilizes a pinout that allows for symmetrical placement of decoupling components to minimize series resistance and inductance to ground, reducing noise and potential ringing on the switch node. The package for the LM53625-Q1 is also designed to minimize losses possibly found from bond wires that can lead to inefficiency and additional sources of EMI.

A final benefit to this device is its utilization of spread-spectrum technology to allow for a reduced EMI effect generated by the primary switching frequency of the supply. By modulating the central frequency, the harmonics generated at the switch node are reduced and the peak EMI amplitudes are lowered.

Each of these features are discussed in more detail in the data sheet of the device.

Figure 11. LM53625-Q1 Schematic

2.3.3   AWR1642 Antenna Design

This design utilizes an etched-antenna that allows for accurate location of objects in a three-dimensional space. Within the cabin of the automobile, the antenna should have a fairly wide field-of-view, high angle resolution, and good accuracy in both the elevation and azimuth directions. A non-uniform receiver array (NURA) with 2 transmit (TX) and 4 receive (RX) antennas allows for a virtual array of 3 × 4 to be generated. Figure 12 and Figure 13 is a representation of the virtual antenna array and Figure 14 is an image of the antenna as represented on the printed circuit board (PCB).

Figure 12. NURA Antenna Design Theory
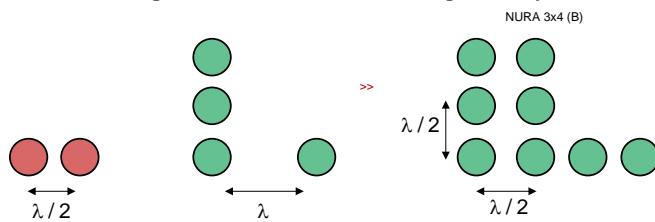
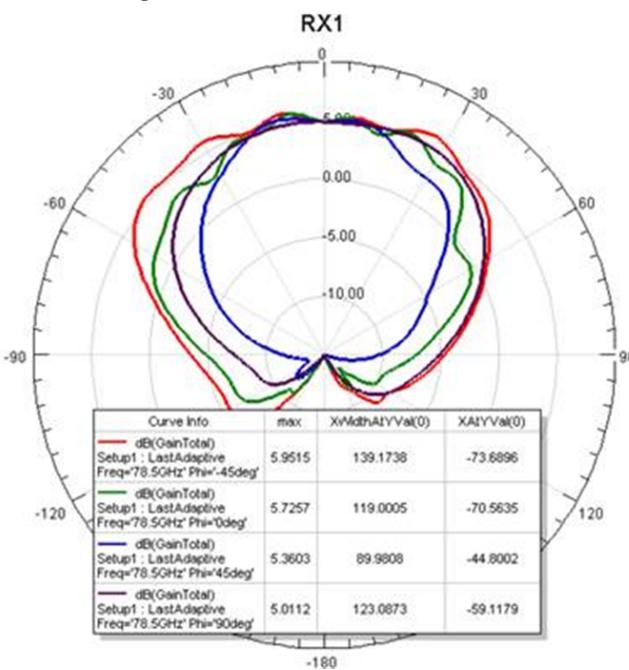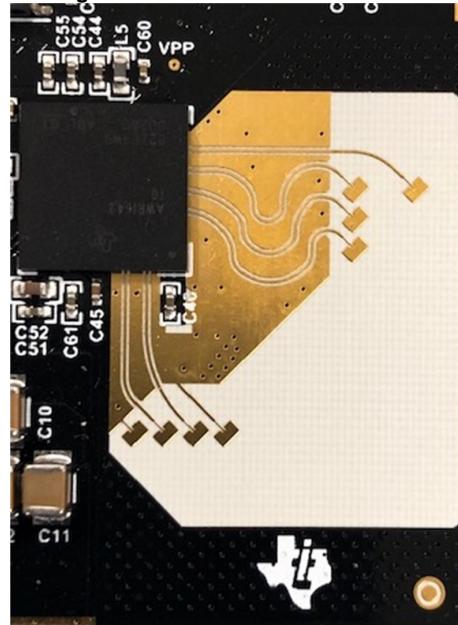**Figure 13. Simulation Pattern of Antenna**

Figure 14. Antenna as Found on PCB

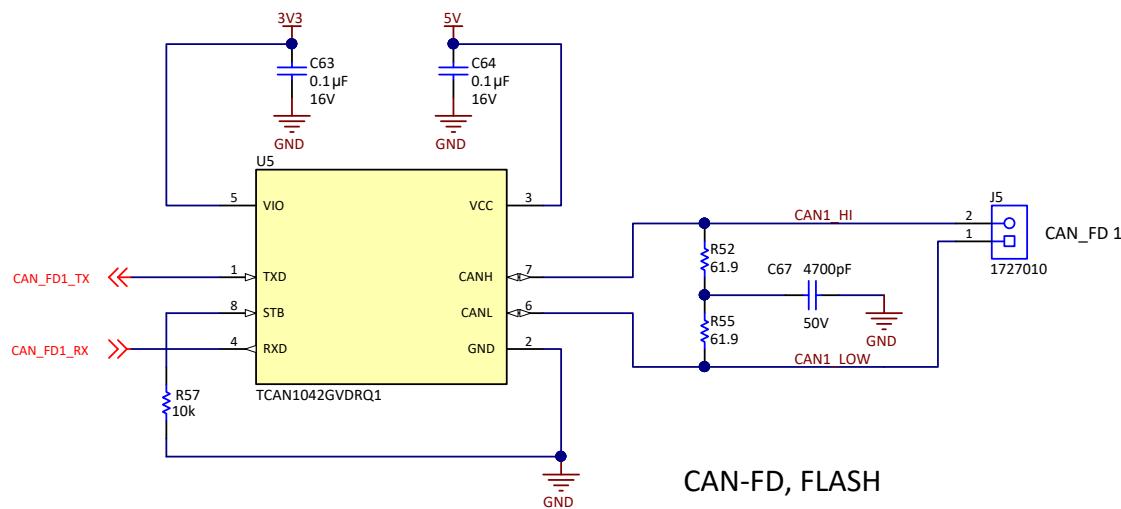Copyright © 2018, Texas Instruments Incorporated

2.3.4   Communication Interface

Upon recognition of a gesture, the device sends a message out to the rest of the automotive system with a CAN transceiver. In this design, the AWR1642 provides the appropriate data to a CAN physical layer transceiver to generate the appropriate signal for the CAN standard.

The TCAN1042GV-Q1 device has a very straightforward design and component choices are minimal. Multiple terminal options can be used, and this design uses a split termination method to provide an EMI reduction on the system and the CAN network.

Figure 15. CAN Interface Schematic

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3   Hardware, Software, Testing Requirements, and Test Results

3.1   Required Hardware and Software

3.1.1   Hardware

There are two terminals to connect to for operation of this reference design:

- The terminal marked J1 is the power supply input, for applying a typical automotive 12-V battery supply or similar. The silkscreen indicates the correct polarity for applying this voltage.
- Terminal J5 is the CAN-FD output. Upon capture of a gesture, the AWR1642 device sends out a specific 12-byte message that corresponds to that gesture.

3.1.2   Software

This reference design utilizes reference software available in the *TI Resource Explorer for the AWR1642*. More information about the software including source code and programming is found in this resource.

In this reference software, each gesture is associated with a specific 12 byte CAN message. A message is sent every 60 ms at 921600 baud and can be one of seven different results. If no gesture event is captured, a "Background" message is sent. Each message has 4 bytes of a Magic Word, 0x01020304, then 4 Bytes for the Gesture ID, then finally 4 Bytes of zeroes that are reserved for other use.

For orientation of the antenna to capture these gestures, the jumper terminals should be on the left side of the board, and the antenna array to the right.

Table 3. Reference Software Gesture Data Output

GESTURE TYPE	GESTURE ID
Background	0x0000 000F
Left	0x0000 0001
Right	0x0000 0002
Down	0x0000 0003
Up	0x0000 0004
Clockwise Twirl	0x0000 0005
Counterclockwise Twirl	0x0000 0006

3.2   Testing and Results

3.2.1   Test Setup

Testing was performed using the reference software and a data analyzer to capture the output results. Gestures were performed and the output data was captured to verify accuracy.

Additionally, this design has been used to send UART data to other automotive reference designs. Those designs can successfully interpret the data being sent and appropriately change operation based on a defined gesture operation. This design was additionally tested as part of a larger demonstration depicting how to control systems like interior matrix LED lighting and SPD-Smartglass™ drivers with a gesture-based system. Figure 16 provides an image of this demonstration as a whole and the three different systems (gesture control, smartglass driver, and LED matrix controller) all communicating together.

**Figure 16. TIDA-020011 Controlling a Larger Demonstration Featuring
LED Matrix Control and SPD-Smartglass™**

3.2.1.1   Programming

Programming can be performed using the pin header J2 and XDS100 JTAG debugger tool. With the appropriate connection between the XDS100 and this board, programming can be completed with the UniFlash programming tool found at dev.ti.com.

4   Design Files

4.1   Schematics

To download the schematics, see the design files at TIDA-020011.

4.2   Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-020011.

4.3   PCB Layout Recommendations

Use the AWR1642 Checklist for Schematic Review, Layout Review, Bringup/Wakeup for more guidance on specific schematic, layout, and bringup.

4.3.1   PCB Layer Stackup Recommendations

To design with radar, a non-typical PCB material must be used to achieve the proper dielectric properties for a 77-GHz antenna. Rogers Corporation RO4000® LoPro® ceramic allows for lower variation in the etched antenna and a better dielectric for the antenna. Figure 17 shows the layer stackup of this design. Additional guidelines and recommendations for the antenna layout is found in TI mmWave Radar sensor RF PCB Design, Manufacturing and Validation Guide.

Figure 17. Layer Stackup

Layer Name	Type	Material	Thickness (mil)	Dielectric Material	Dielectric Constant	Pullback (mil)	Orientation	Coverlay Expansion
Top Overlay	Overlay							
Top Solder	Solder Mask/Co...	Surface Material	0.4	Solder Resist	3.5			0
Layer 1 - Top Lay...	Signal	Copper	1.4				Top	
Dielectric 1	Dielectric	Core	4	RO4835LowPro	3.38			
Layer 2 - GND	Signal	Copper	1.4				Not Allowed	
Dielectric 2	Dielectric	Prepreg	10	IT 180A	4.2			
Layer 3 - Signal (...	Signal	Copper	1.417				Not Allowed	
Dielectric 3	Dielectric	Core	10	IT 180A	4.2			
Layer 4 - GND / ...	Signal	Copper	1.417				Not Allowed	
Dielectric 4	Dielectric	Prepreg	6	IT 180A	4.2			
Layer 5 - PWR / ...	Signal	Copper	1.4				Not Allowed	
Dielectric 5	Dielectric	Core	10	IT 180A	4.2			
Layer 6 - Bottom...	Signal	Copper	1.4				Bottom	
Bottom Solder	Solder Mask/Co...	Surface Material	0.4	Solder Resist	3.5			0
Bottom Overlay	Overlay							

4.3.2   Layout Prints

To download the layer plots, see the design files at TIDA-020011.

4.4   Altium Project

To download the Altium Designer® project files, see the design files at TIDA-020011.

4.5   Gerber Files

To download the Gerber files, see the design files at TIDA-020011.

4.6   Assembly Drawings

To download the assembly drawings, see the design files at TIDA-020011.

5   Software Files

To download the software files, see the design files at TIDA-020011.

6   Related Documentation

1. Texas Instruments, *Automotive 77-GHz Radar Module Reference Design With Object Data Output*
2. Texas Instruments, *TI mmWave Radar sensor RF PCB Design, Manufacturing and Validation Guide*

6.1   *Trademarks*

E2E is a trademark of Texas Instruments.
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7   About the Author

MATT SULLIVAN is a automotive systems engineer focused on body electronics and lighting. He graduated from the University of Southern California with a B.S.E.E. in 2012.