Design Guide: TIDEP-01037

Low-Power In-Cabin Reference Design

Description

This design is a low-power and small form factor reference design based on AWRL6432, TI's single-chip 60GHz automotive radar sensor. The design uses high RF performance PCB material and is targeted for in-cabin sensing end applications like Child Presence Detection (CPD) and Intruder Detection (ID). The AWRL6432 device runs machine-learning-based presence and detection algorithms to detect and classify the vehicle occupants.

Resources

TIDEP-01037	Design Folder
AWRL6432	Product Folder
TCAN3404-Q1	Product Folder
TPS65036x-Q1	Product Folder

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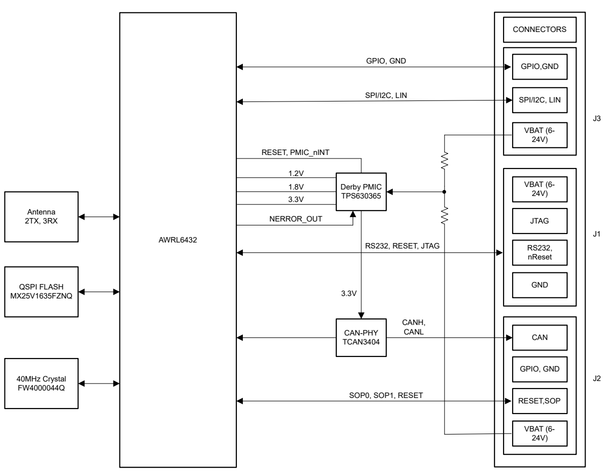
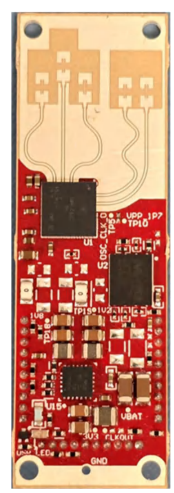
Features

- 12V automotive battery connection support
- Small form factor design (18mm × 55mm)
- Wide antenna FOV (120° × 120°) and 6.5dBi peak gain
- High-performance RO3003® material used as the substrate
- Onboard CAN PHY and LIN signal connections for directly interfacing with the automotive network
- 3.3V IO support

Applications

- Interior Cabin Sensing
- Child Presence Detection
- Occupancy detection
- Intruder detection
- Driver vital sign monitoring
- Seat belt reminder





1 System Description

This reference design is based on AWRL6432, TI's 60GHz mmWave radar sensor and a fully automotive compliant bill of material (BOM). The small form factor of the design allows an easy evaluation and integration into the end application system.

AWRL6432 device operation is based on Frequency-Modulated Continuous Wave (FMCW) technology. Using two TX antennas for transmitting and three RX antennas for receiving RF signals, this FMCW radar system can capture various data points associated with the distance, angle, and velocity of the reflected radar signal that can be translated into specific motion or presence being detected.

The AWRL6432 device is powered by three rails (3.3V, 1.8V, and 1.2V) in power-optimized topology (3.3V I/O). These power rails are generated by TPS65036x-Q1, a wide V_{IN}, Derby Power Management Integrated Circuits (PMIC) using the 12V battery voltage input. The usage of a single PMIC enables the design to have an extremely small form factor. The 12V input from the battery connects to the VBAT pin coming out in all the three connectors.

The reference design comes with an onboard Controller Area Network (CAN) physical layer (PHY) which helps in communicating with an external automotive network. This design also supports a serial peripheral interface (SPI) based raw data capture.

1.1 Key System Specifications

Table 1-1. Key System Specifications

PARAMETER		COMMENTS	MIN	TYP	MAX	UNIT
V_{IN}	Supply voltage	Battery Input	6(1)	12	24(1)	V

(1) Even though TPS65036x-Q1 supports a wide input voltage range of 4.0V to 35V, the recommendation is to operate the reference design under 6V to 24V for proper functional operation.

2 System Overview

2.1 Block Diagram

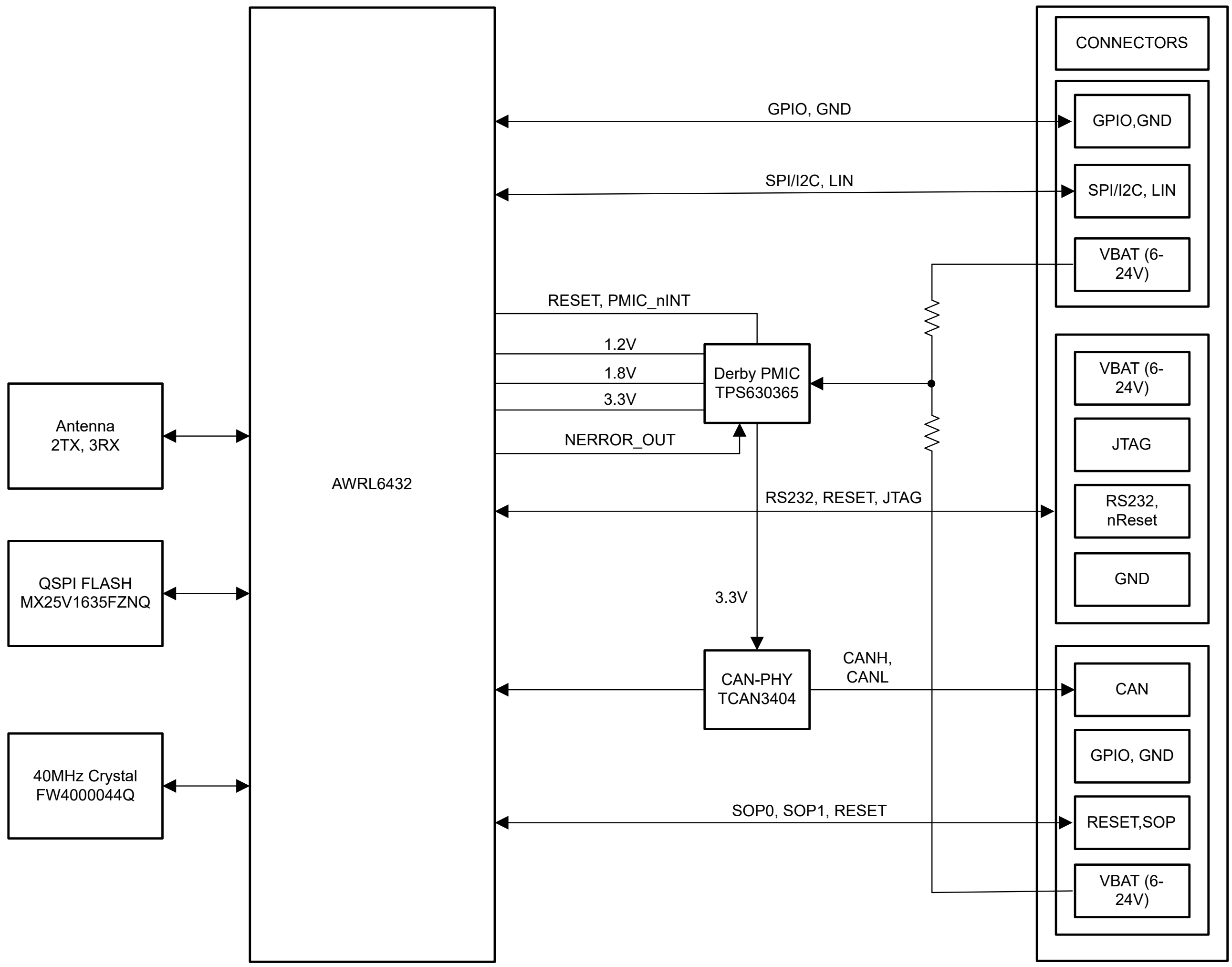


Figure 2-1. TIDEP-01037 Block Diagram

2.2 Design Considerations

This design is made to provide customers with a ready-to-use, small form-factor mmWave in-cabin radar sensor with a cost-optimized bill of materials. In this design, the AWRL6432 device powered by PMIC rails (3.3V, 1.8V, and 1.2V) eliminates the need for multiple DC-DC converters and enables the design to have an extremely small form factor. The antennas designed for this board are capable of providing 120°(Azimuth) × 120°(Elevation) field-of-view, 3.5GHz bandwidth and 6- to 7dBi peak gain with the high-performance Rogers® RO3003® material. This reference design also utilizes TI's low-cost, small form-factor, low-power Derby PMIC and CAN PHY. The onboard connectors (J1, J2, and J3) have various communication peripherals (UART, RS232, SPI, CAN, LIN, JTAG, I2C, GPIOs), SOPs, PWR, and GND being brought out, including a dedicated 10-pin connector (J1) for direct connection with LP-XDS110 which enables the ease of operation of the board. The onboard connectors used in the design have 1.27mm pitch, which also helps reduce the overall form factor of the board.

2.2.1 Power Topology

The reference design works in a power-optimized mode power topology with 3.3V IO support. In this mode, the device is powered by using three rails (3.3V, 1.8V, and 1.2V). The Derby PMIC (TPS65036x-Q1) has three step-down converters which provides the three rails. These converters operate in forced PWM mode; however, can be configured to operate in AutoPFM mode.

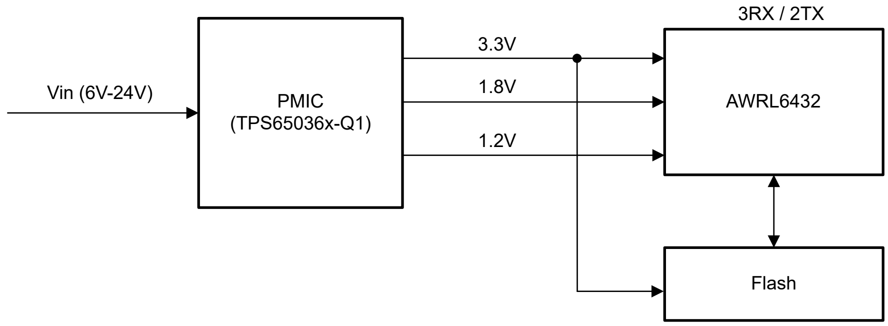


Figure 2-2. Power Topology

2.2.2 PCB and Form Factor

The goal of this reference design is to have a small compact radar module which is easy and ready to use for the in-cabin applications. With the mounting holes, the board measures roughly 18mm × 55mm (0.7in × 2.16in). Figure 2-3 and Figure 2-4 show the top view and bottom view of the PCB.

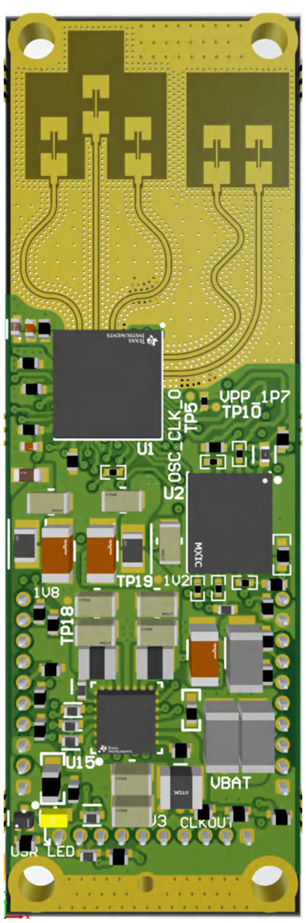


Image shown does not represent the actual size of the board.

Figure 2-3. PCB Top View

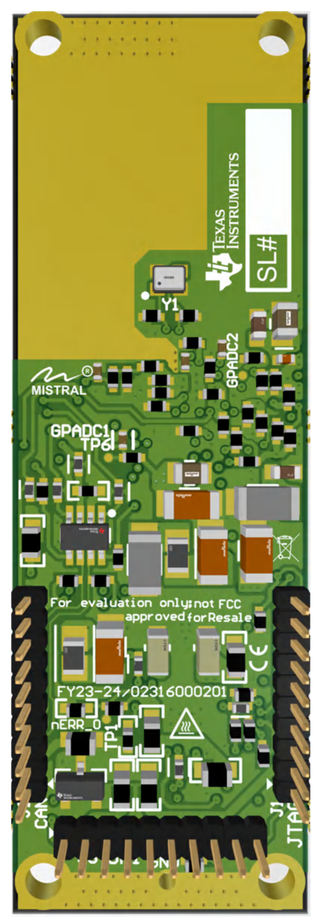


Image shown does not represent the actual size of the board.

Figure 2-4. PCB Bottom View

The in-cabin applications require the mounting of the radar device at an appropriate position to efficiently cover the region inside the cabin. Mounting positions like the center overhead mount, front mount, side-pillar mount, second-row overhead mount, and so forth, are explored by manufacturers to achieve the best coverage. This reference design is designed with a form factor to enable the radar to be fixed at the front overhead mount position for two-row coverage as shown in Figure 2-5.

Figure 2-5. Front Mount Sensor

2.2.3 Antenna

This reference design includes onboard etched-patch antennas for the three receivers and two transmitters. This antenna design provides a wide Field of View (FOV) in azimuth and elevation with high gain and good bandwidth coverage. Figure 2-6 shows the antenna design.

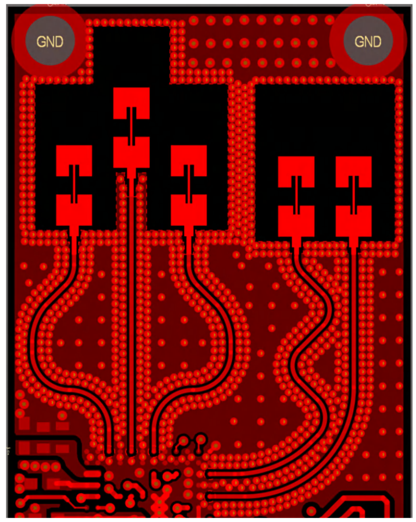


Figure 2-6. Altium Antenna Design

The antenna design uses RO3003 substrate material with a dielectric constant of 3 and a loss tangent of about 0.001 which makes the material highly efficient with reduced power losses. The antenna peak gain is greater than 6dBi across the operating frequency band of 57GHz to 60.5GHz. Figure 2-7 shows the S11 plots. Table 2-1 lists the performance parameters.

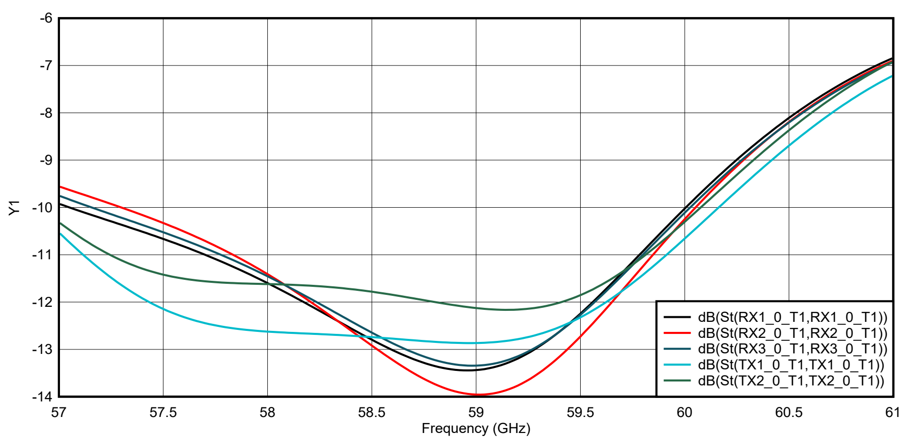


Figure 2-7. Antenna S11

Table 2-1. Performance Table

PARAMETERS	VALUES
Gain	> 6dBi
FOV	120°(Azimuth) × 120°(Elevation)
Bandwidth	3.5GHz

Figure 2-8 shows the radiation pattern of the RX2 antenna element in the horizontal plane (in black, Phi = 0°) and vertical plane at 59GHz (in red, Phi = 90°).

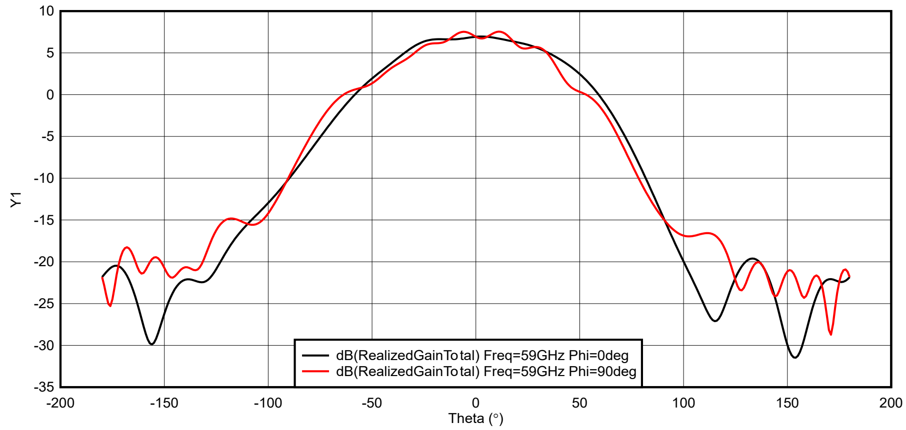


Figure 2-8. Antenna Pattern

2.3 Highlighted Products

2.3.1 AWRL6432BGAMFQ1

This integrated, single-chip frequency-modulated continuous wave (FMCW) radar sensor is capable of operation in the 57- to 63.9GHz band. The device is built with TI's low-power 45nm Radio Frequency Complementary Metal-Oxide-Semiconductor (RFCMOS) process and enables unprecedented levels of integration in an extremely-small form factor (SFF). AWRL6432 is designed for low-power, self-monitored, ultra-accurate radar systems in the automotive space for applications like child presence detection, intrusion monitoring, gesture detection, and occupancy detection.

2.3.2 TCAN3404DDFRQ1

The TCAN3404-Q1 device is an automotive electromagnetic compatibility (EMC)-compliant 3.3V Controller Area Network Flexible Data-Rate (CAN FD) transceiver PHY. The device is data-rate agnostic making them backward compatible for supporting classical CAN applications while also supporting CAN FD networks up to 8Mbps. The device has a standby mode support which puts the transceiver in low current-consumption mode. Upon receiving a valid wake-up pattern on the CAN bus, the device signals to the microcontroller through the RXD pin. The MCU can then place the device in normal mode using the STB pin. TCANC3404-Q1 supports ultra-low power shutdown mode where most of the internal blocks are disabled. This feature is optimized for battery-powered applications.

2.3.3 TPS65036x-Q1

The TPS65036x-Q1 device is a highly integrated power management IC for automotive applications. This device combines three step-down converters and one low-dropout (LDO) regulator. The BUCK1 step-down converter has an input voltage range up to 35V. All converters can operate in a forced fixed-frequency PWM mode or an AutoPFM mode and support optional spread spectrum modulation (SSM) for EMI reduction. The TPS65036x-Q1 supports low-power mode with control from the pin or I2C.

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Hardware Requirements

3.1.1 Getting Started With Hardware

This reference design can be powered up by connecting the VBAT pin (J2.2 or J3.2) to a battery power (DC supply – typically 12V). The other option is to place the R10 resistor and power up the device using the J1.2. In both the ways, the LP-XDS110 can be used for interfacing the AWRL6432 device with the PC. LP-XDS110 has access to the onboard XDS110 (TM4C1294NCPDT) emulator which provides the following interfaces to the PC:

- JTAG for Code Composer Studio™ (CCS) connectivity
- Application or user universal asynchronous receiver-transmitter (UART) (configuration and data communication to the PC)

3.1.1.1 Power Up Option

Figure 3-1 shows the connections for power up.

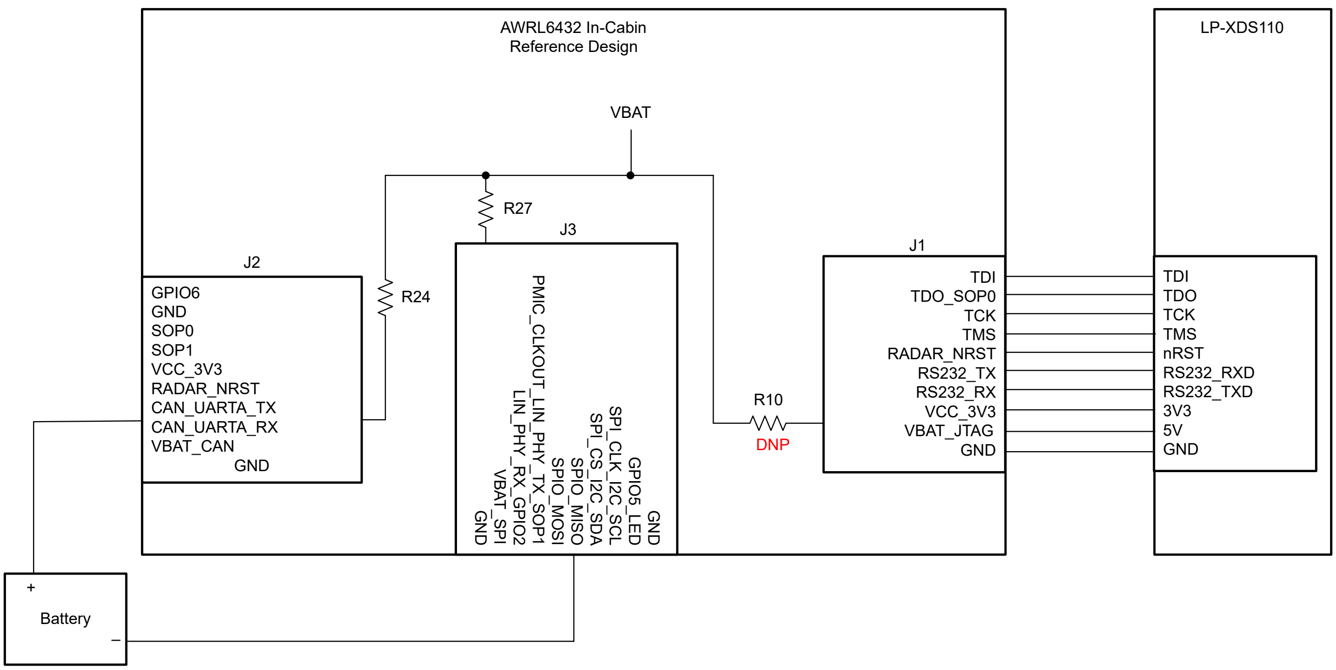


Figure 3-1. Connections for Power Up

Use the following steps for powering up the reference design for the power-up option:

1. Connect the VBAT (J2.2 or J3.2) pin to a 12V DC supply. In Figure 3-1, VBAT is supplied to J2.2.
2. Connect the GND pin of the DC supply to the GND pin of the reference design or to the GND pin of LP-XDS110 to provide the common GND across the setup
3. Put a jumper on the 2-3 pin of the LP-XDS110 P9 connector to make sure the 3.3V IO supply is provided by the reference design to the LP-XDS110
4. Connect the J1 connector with the bottom 10 pins of the LP-XDS110 using a female-to-female connector. See Figure 3-1.
5. Power up the LP-XDS110 using a USB Type-C® cable
6. Make sure the Sense-on-Power (SOP) lines are in correct configuration while powering up the device. See Section 3.1.2 for proper SOP configurations.
7. nRESET can be issued through the LP-XDS110 reset switch since the J1.6 pin connects to the LP-XDS110 nRST pin

Alternatively, VBAT can also be provided from J1.2 after populating the R10 resistor.

3.1.2 Sense-on-Power (SOP)

The AWRL6432 device has three different boot mode (SOP mode) configurations, *Application mode* (Functional mode), *Device management mode* [Quad Serial Peripheral Interface (QSPI) flashing mode], and *Debug mode* (Development mode). Exercise the SOP mode configurations in Table 3-1 first. After the correct SOP mode is set, an nRESET must be issued to register the SOP setting.

Connector pins J1.8 and J1.7 are dedicated for SOP0 and SOP1, respectively. By default, SOP0 is pulled high and SOP1 is pulled low in the reference design. Therefore, the device boots up in *Application (Functional) mode* when J1.8 and J1.7 are not connected externally. Connect J1.8 to GND to switch the device to *Device management mode* (QSPI flashing mode). Similarly, connect the J1.7 to VCC_3V3 to switch the device to Debug Mode (Development mode).

Table 3-1. Different SOP Modes

SOP MODE	PMIC_CLK_OUT, TDO	COMBINATION (SOP1, SOP0)	CONNECTION REQUIRED FOR SOP1	CONNECTION REQUIRED FOR SOP0
SOP_MODE1	Device management mode (QSPI flashing mode)	00	NC	GND
SOP_MODE2	Application mode (Functional mode)	01	NC	NC
SOP_MODE4	Debug Mode (Development mode)	11	VCC_3V3	NC

3.1.3 AWRL6432 Initialization: Board Programming

Once the board is powered with the VBAT (typically 12V) connection, a program must be loaded into the external flash. The radar toolbox provides the application binaries, chirp configuration, and GUI to run the Kick-to-Open demonstration (see Section 3.2 for more details). TI also provides the mmWave low-power Software Development Kit (L-SDK). This is a unified software platform for the AWRLx family of mmWave sensors, which enable evaluation and development. *mmWave Radar Visualizer User's Guide* covers the use of this design environment. Use the following steps for loading an application image file:

1. Download and install the UniFlash software, available from UNIFLASH: UniFlash flash programming tool. Proceed to the next step after installation.
2. Connect the board with the PC using the power-up options mentioned in Section 3.1.1.1.
3. Open the UniFlash software. Select *mmWave* from the *Category* header, select *AWRL6432* from the field of available devices, and then click the *Start* button (see Figure 3-2).

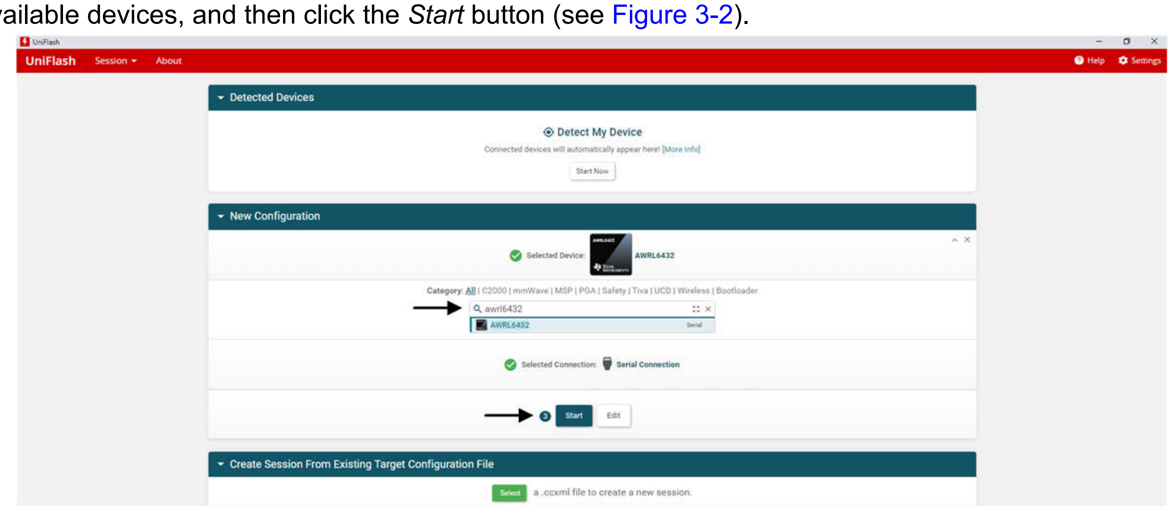


Figure 3-2. UniFlash Configuration

4. Click the *Browse* button and navigate to the application image file to load. The file path and name is <RADAR_TOOLBOX_INSTALL_DIR>\radar_toolbox latest version\source\ti \examples\InCabin_Sensing\AWRL6432_Life_Presence_Detection_Demo_Capon2D \prebuilt_binaries\AWRL6432_LifePresenceDetection_Capon2D.Release.appimage. After the name of the file populates the field, click on the *Settings & Utilities* menu on the left side of the program (see Figure 3-3).

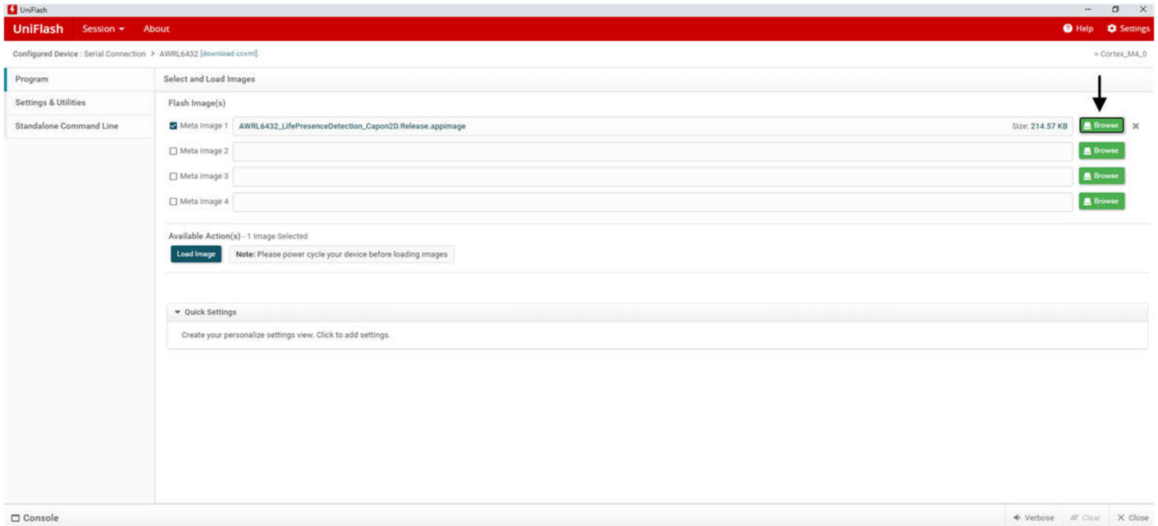


Figure 3-3. UniFlash Settings

5. After connecting the LP-XDS110 into the USB port, open the Microsoft® Windows® *Device Manager*. Find the *XDS110 Class Application/User UART* port and note the COM port number. The example in Figure 3-4 shows this COM port to be COM20.

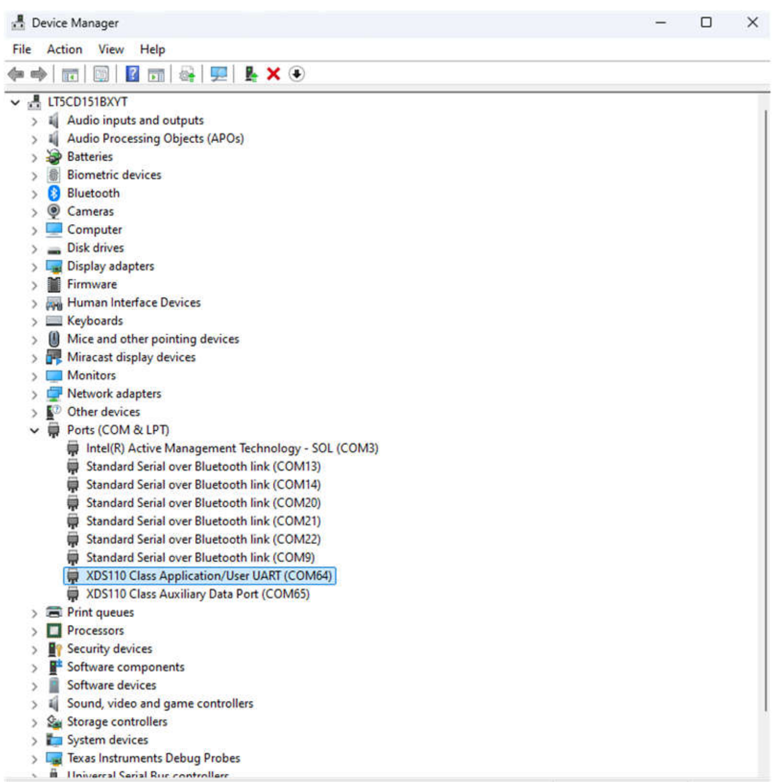


Figure 3-4. Determine COM Port

6. Return to the UniFlash software and enter the noted COM port number from the device manager. Then click the *Program* menu on the left side of the window to go back to the previous menu (see Figure 3-5).

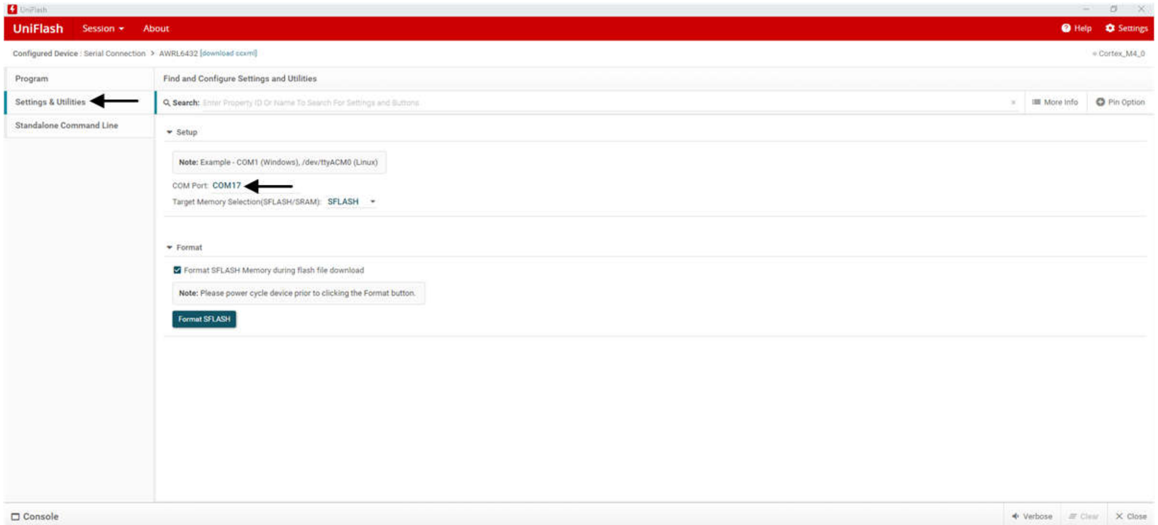


Figure 3-5. Enter COM Port

7. Reset the AWRL6432 device by pressing the reset button on the LP-XDS110. Then select *Load Image*. This action loads the program into the flash. To execute the program, change the SOP settings into functional mode. The program then runs.

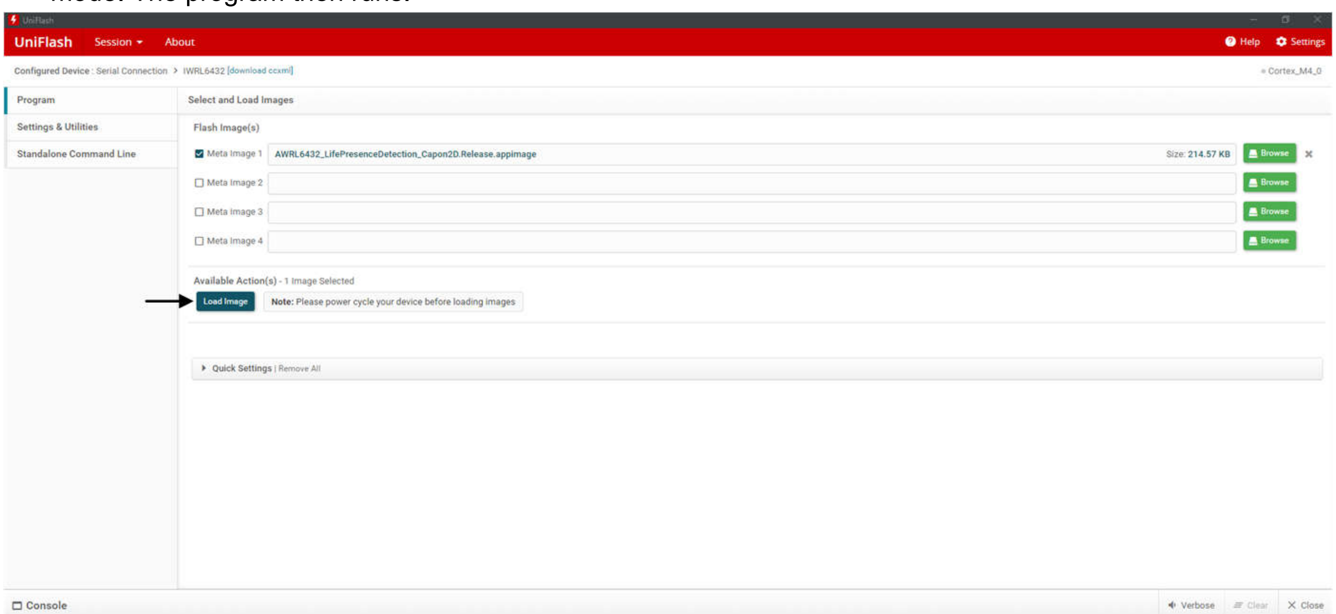


Figure 3-6. Load Image

Alternatively, the AWRL6432 device can be flashed through Visualizer. See details at *mmWave Radar Visualizer User's Guide*.

3.2 Test Setup

Follow the *Getting Started With Hardware* section for powering up the device and configuring the device in different SOP modes.

Install the latest Radar Toolbox present under *mmWave radar sensors* → *Embedded Software* in the TI Resource Explorer.

See the AWRL6432_Life_Presence_Detection_Capon2D_users_guide located at `\radar_toolbox latest version\source\ti\examples\InCabin_Sensing\AWRL6432_Life_Presence_Detection_Demo_Capon2D\docs` to run the LPD demonstration.

The *Life Presence Detection* capability on this reference design uses the low-power mode (Low Power Deep Sleep) on AWRL6432 along with a Capon2D chain algorithm implemented in the user application code space, which allows detection of adults and children in car seats and also children in the footwell in a two-row car.

3.3 Test Results

This section demonstrates the detection of adults in a two-row car. Figure 3-7 and Figure 3-8 illustrate the display in the GUI of the detection of an adult in the front row and the detection of an adult in the second row. For reference, the live captured images are also included in the following displayed images, along with the GUI images.

Figure 3-7. Adult Detection in Driver Seat

Figure 3-8. Adult Detection in Second-Row Seat

4 Design and Documentation Support

4.1 Design Files

4.1.1 Schematics

To download the schematics, see the design files at TIDEP-01037.

4.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDEP-01037.

4.1.3 Layout Prints

To download the layer plots, see the design files at TIDEP-01037.

4.1.4 Altium Project

To download the Altium Project, see the design files at TIDEP-01037.

4.1.5 Gerber Files

To download the Gerber Files, see the design files at TIDEP-01037.

4.2 Tools and Software

Tools

Radar Toolbox for mmWave Sensors	The Radar Toolbox is a collection of demonstrations, software tools, and documentation designed to assist in the evaluation of TI Radar Devices.
UNIFLASH	UniFlash is a software tool for programming on-chip flash on TI microcontrollers and wireless connectivity devices and onboard flash for TI processors. UniFlash provides both graphical and command-line interfaces.
MMWAVE-L-SDK	mmWave software development kit (SDK) for xWRL1432 and xWRL6432: The mmWave low-power software development kit (SDK) is a collection of software packages that enable application evaluation and development on TI's low-power mmWave sensors. This tool includes MMWAVE-L-SDK and companion packages to support customer design needs.

4.3 Documentation Support

1. Texas Instruments, *TPS65036x-Q1 Automotive Camera, Radar and MCU PMIC Data Sheet*
2. Texas Instruments, *TCAN340x-Q1 3.3V Automotive CAN FD Transceivers with Standby Mode and ±58V bus Standoff Data Sheet*
3. Texas Instruments, *AWRL6432 Single-Chip 57- to 64GHz Automotive Radar Sensor Data Sheet*

4.4 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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