

Design Guide: TIDEP-01010

Area Scanner Using mmWave Sensor With Integrated Antenna-On-Package Reference Design



Description

The TIDEP-01010 leverages TI's single-chip millimeter-wave (mmWave) technology to implement an area scanner capable of detection and localization in 3D space. Crucial to applications deployed in industrial facilities, mmWave sensing technology is inherently robust to heat, water, dust, and poor lighting conditions.

This reference design uses the IWR6843 mmWave sensor and integrates a complete radar processing chain onto the device. The processing chain includes the analog radar configuration, analog-to-digital converter (ADC) capture, low-level FFT, and signal processing. This reference design is intended to be built on top of the TI mmWave SDK for a cohesive software experience, including APIs, libraries, and tools for evaluation, development, and data visualization. The reference design can be evaluated using either the IWR6843ISK or IWR6843AOPEVM evaluation modules. The IWR6843 antenna-on-package variant of mmWave sensors enables reduced design and manufacturing costs, simplified system design, smaller sensor footprint, and eventually faster time to market.

Resources

TIDEP-01010	Design Folder
IWR6843AOPEVM	Tool Folder
IWR6843ISK	Tool Folder
MMWAVEICBOOST	Tool Folder
IWR6843	Product Folder
mmWave SDK	Tool Folder

Features

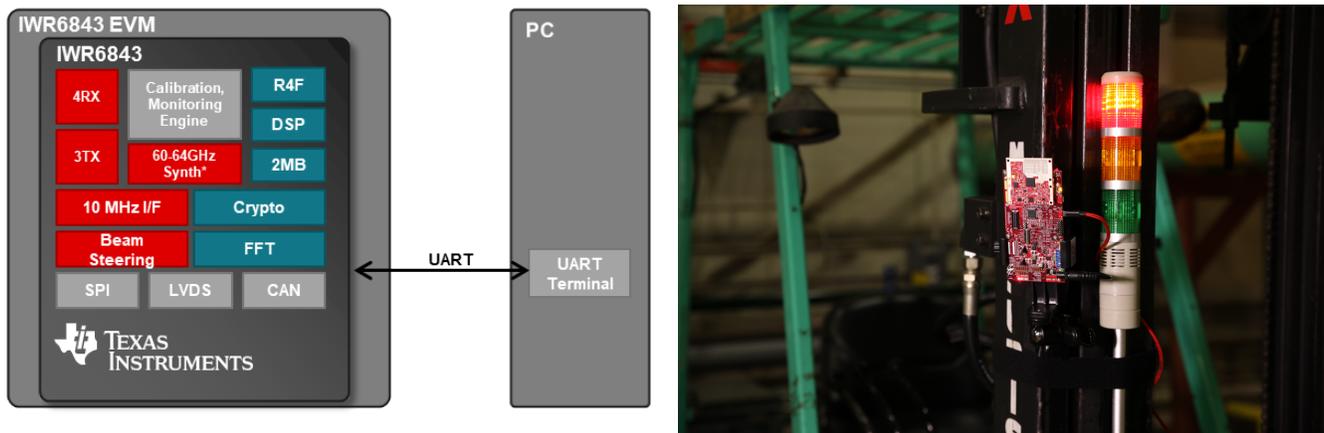
- Demonstrates environmentally robust area scanner using TI's single-chip mmWave sensor
- Detection and localization of people and objects across a 3D space
- Using a single device, supports sensing across
 - Range of 0 m to 10 m
 - An azimuth field of view (FOV) up to 120° if using the IWR6843ISK
 - A 130° FOV in both azimuth and elevation if using the IWR6843AOP
- References the processing chain source code provided, based on the mmWave software development kit (SDK)
- Based on proven EVM hardware designs, enabling quick time to market and out-of-the-box demonstrations

Applications

- [Area Scanner Safety Guard](#)
- [Proximity Sensor](#)
- [Light Curtain Safety Guard](#)



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1 System Description

The TIDEP-01010 provides a reference for creating a area scanner or safety guard application using TI's IWR6843, based on 60-GHz mmWave radio-frequency complementary metal-oxide semiconductor (RF-CMOS) technology. Frequency-modulated continuous-wave (FMCW) radars enable accurate measurement of distances and relative velocities. Thus, radars are useful for detection of occupancy and whether an object or person has entered a space of interest.

In area scanner or light curtain safety-guard applications, where it is important to have precisely defined "keep-out" zones, the ability of radar to accurately localize detected objects can be used to implement multiple detection zones and trigger corresponding responses. A single radar deployed to equipment with a critical "keep-out" perimeter could implement a multi-stage response, so that when an object or person first approaches the perimeter, a moderate warning flag is raised. Then, if the perimeter is breached, a critical response is triggered.

With the widespread growth of factory automation, there is a greater need for smarter incident management solutions that can detect the movement of people and objects around heavy machinery while maintaining productivity. Using TI's 60-GHz mmWave sensors, both presence detection and the ability to gauge the object's trajectory and speed are enabled. Thus, a system can be created that can dynamically adjust the safety zone's size depending on the object's speed of approach, alert before a safety zone is breached while also ignoring objects whose trajectory is not towards the zone.

An important advantage of radars over camera and light-detection-and-ranging (LIDAR)-based systems is that radars are relatively immune to challenging environmental conditions common in industrial facilities such as dust and smoke. Because FMCW radars transmit a specific signal (called a chirp) and process the reflections, they can work in both complete darkness and bright daylight (radars are not affected by glare). When compared with ultrasound, radars typically have a much longer range and faster transit time for their signals.

The IWR6843AOP variant features a short-range, wide field of view antenna-on-package (AOP), achieving unprecedented levels of integration in an extremely small form factor.

The AoP sensor design addresses three main challenges for robotics or factory automation:

- Wide 3D coverage with a single sensor: The AoP antenna's wide FoV configuration provides a 130-degree view in the azimuth and elevation, which provides true 3D sensing enabling detection of the object height and filtering out ground clutter. This maximizes a sensor's accuracy and measurement performance. The wide azimuth area coverage reduces the number of sensors used for area scanning and hence reduces overall system cost.
- Small form factor: The smaller form factor of AoP sensors means that they can fit into smaller enclosures, which is important for sleek, small autonomous robot designs such as autonomous guided

vehicles, delivery robots, and smaller robotic arms in factories for sense-and-avoid applications.

- **Fast time to market:** By eliminating expensive PCB substrates and RF expertise, AoP sensors simplify the design and manufacturing process, enabling in-house designs and reducing time to market.

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Field of view (FOV)	IWR6843 ISK: 120° azimuth, 40° elevation	The field of view of the sensor is determined by the antenna design of the EVM. Both EVMs enable a 3D point cloud with elevation information with the IWR6843ISK featuring greater azimuth resolution while the IWR6843AOP features wider, symmetrical FOV in azimuth and elevation.
	IWR6843 AOP: 130° azimuth, 130° elevation	
Frame rate	10 Hz	This parameter defines the data output and visualizer update rate.
Maximum range	12.79 m	The maximum range is defined by the radar chirp characteristics, and can be configured to suit application requirements. The maximum range defined for this reference design is with respect to the dimensions of the testing site.
Range resolution	0.125 m	Range resolution is the ability of a radar system to distinguish between two or more targets on the same bearing but at different ranges.
Maximum velocity (m/s)	1.6 m/s	This is the native maximum velocity obtained using a two-dimensional FFT on the frame data. Additional processing that can extend the maximum trackable velocity by 3x the chirp maximum velocity
Velocity resolution	0.05 m/s	This parameter represents the capability of the radar sensor to distinguish between two or more objects at the same range that are moving with different velocities.

2 System Overview

2.1 Block Diagram

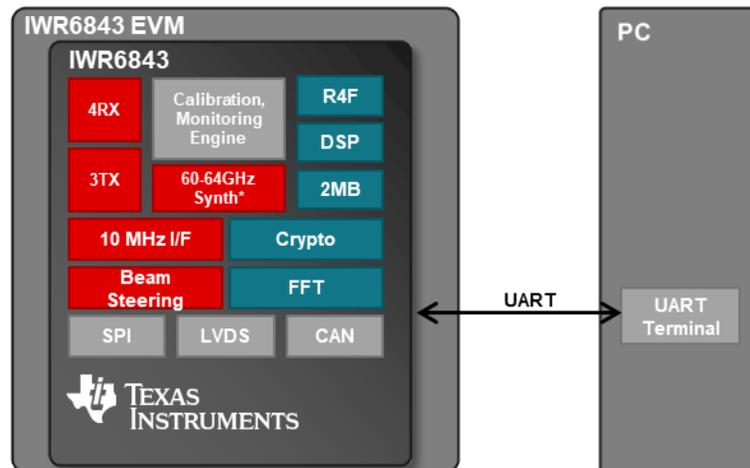


Figure 1. Area Scanner Using mmWave System Block Diagram

2.2 Highlighted Products

This reference design can be implemented using either the IWR6843ISK or IWR6843AOP EVM. Using either EVM, objects within the sensor's field of view are detected and represented as 3D point clouds. Each point within the point cloud has an X, Y, and Z location coordinate as well as associated doppler and SNR information.

2.2.1 IWR6843ISK or IWR6843AoP EVM

The IWR6843ISK and IWR6843AoPEVM are both easy-to-use evaluation module for the IWR6843 mmWave sensing device. The IWR6843 family of single-chip device features a 60-GHz mmWave Radar transceiver, on-chip C67x DSP core and low-power ARM R4F controllers. For the IWR6843ISK variant, antennas are etched on the PCB while the IWR6843AOP variant integrates the 4 receiver and 3 transmitter antennas on the device package.

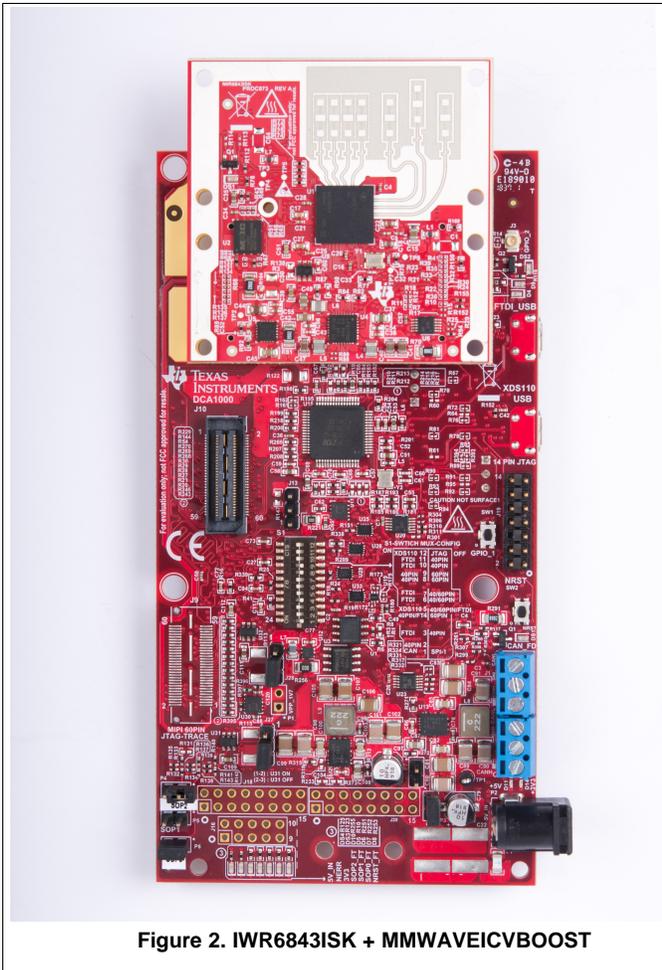


Figure 2. IWR6843ISK + MMWAVEICVBOOST

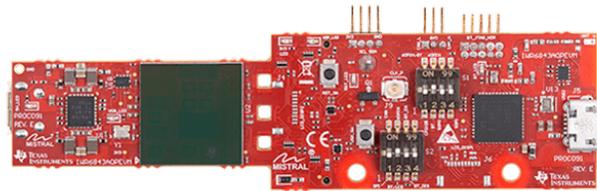


Figure 3. IWR6843AOPEVM

2.2.1.1 Key Features of IWR6843

- FMCW transceiver:
 - Integrated PLL, transmitter, receiver, baseband, and A2D
 - 60- to 64-GHz coverage with 4-GHz continuous bandwidth
 - Four receive channels
 - Three transmit channels
 - Option for integration of 4 receiver and 3 transmitter antenna-on-package (AOP)
 - Ultra-accurate chirp engine based on Fractional-N PLL
 - TX power: 10 dBm
 - RX noise figure: 14 dB
 - Phase noise at 1 MHz: -92 dBc/Hz
- Built-in calibration and self-test:
 - Arm® Cortex®-R4F-Based Radio Control System (RCS)
 - Built-in firmware (ROM)
 - Self-calibrating system across frequency and temperature
- On-Chip programmable core for embedded-user application:
 - Integrated Arm® Cortex®-R4F Microcontroller clocked at 200 MHz
 - On-Chip Bootloader supports Autonomous mode (Loading User application from QSPI Flash memory)

- Integrated peripherals:
 - Internal Memories With ECC
 - ARM-R4F microcontroller for object detection, and interface control
 - Supports autonomous mode (loading user application from QSPI flash memory)
 - Radar Hardware Accelerator (FFT, Filtering, and CFAR processing)
 - C674x DSP for advanced signal processing (IWR6843 or IWR6843 AOP only)
 - I2C
 - Two SPI ports
 - CAN-FD interface
 - Up to six general-purpose ADC ports

2.2.2 MMWAVEICBOOST

The MMWAVEICBOOST is an add-on board used with TI's mmWave sensor in all Starter Kits, to provide more interfaces and PC connectivity to the mmWave sensors. The MMWAVEICBOOST board provides an interface for the mmWave Studio tool to configure the radar device and capture the raw analog-to-digital converter (ADC) data using a capture board, such as the DCA1000 evaluation module (EVM). It also provides an interface to the MSP43xx boards through 40-pin LaunchPad™ / BoosterPack™ connectors.

2.3 System Design Theory

2.3.1 Operation

The IWR6843 is loaded with a flashed image that, when booted and initialized, receives a chirp configuration specified using the area scanner visualizer. In the area scanner visualizer, the location and dimension of the zones to monitor are set as well as other visualization properties. Then, using the visualizer, the chirp configuration is loaded and sent to the sensor to start monitoring the area of interest for zone occupancy.

The strongest reflections reported by the radar device are reported as detected objects to the host PC through the UART. The detected objects collectively form a point cloud representation of the scene as seen by the sensor. If an object generates a point cloud of at least 15 points within an area, the area is considered breached and the visualizer updates to highlight the occupied area.

2.3.2 Use Case Considerations

This reference design is intended to demonstrate the detection of people or objects moving into a zone for an indoor environment. Given this use case, the system implements static clutter removal so that other permanent fixtures in the scene, such as walls, do not trigger a zone occupancy detection. The use case drove the design of the chirp configuration in with primary considerations being achieving high doppler resolution with sufficient range resolution and maximum velocity for localizing and tracking human movement, including walking.

Table 2. Chirp Configuration

KEY INPUT PARAMETERS	
Antenna pattern	Three Tx, Four Rx
Maximum range	12.79 m
Range resolution	12.5 cm
Maximum velocity	1.6 m/s
Velocity resolution	0.05 m/s
Frame duration	100 ms

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

- One of the following mmWave EVM options:
 - IWR6843ISK and MMWAVEICBOOST Boards
 - IWR6843AOP EVM and optionally, MMWAVEICBOOST for debugging
- If using MMWAVEICBOOST, a 5-V, 3.0-A power supply
- A PC for Code Composer Studio™ (CCS) and the demonstration UART terminal

3.1.2 Software

For this reference design, software is provided for the IWR6843 device and the host PC.

The software required for the target IWR6843:

- [Latest mmWave SDK](#). The SDK automatically installs the required component versions. These components are listed in the SDK's release notes in the /docs folder of the software package. Install the SDK and all required components before installing and building the demonstration source.
- [Code Composer Studio \(CCS\)](#). See the SDK release notes for the required version.
- [Latest mmWave Industrial Toolbox](#). Using CCS, access and install the mmWave Industrial Toolbox through the Resource Explorer. The Industrial Toolbox contains a quick start guide with precompiled binaries for the device, the source code, and a detailed user's guide to run the demo as presented in this reference design. When installed, the material specific to the reference design is located at under the labs directory in Area Scanner.

The software required for the host PC:

- [Latest mmWave Industrial Toolbox](#). The Area Scanner visualizer is packaged in the Industrial Toolbox. The /gui folder includes the compiled executable and source code for the visualizer.

The application software used in this reference design is from the mmWave SDK version 3.0.0.8 and mmWave Industrial Toolbox version 3.0.0. TI recommends getting the latest version of the demo software from the mmWave Industrial Toolbox.

3.2 Testing and Results

The following results are using the IWR6843ISK with a MMWAVEICBOOST board. Similar results can also be achieved for the IWR6843AOP EVM using the configuration provided in the software download.

3.2.1 Test Setup

Use case testing for implementing an area scanner and safety guard around equipment was carried out using a IWR6843 EVM. The EVM was mounted to a forklift located in a warehouse dock as depicted in [Figure 4](#). The EVM was oriented towards the area of concern where people could walk into the scene and approach the equipment.

A tower stack light was controlled by the output of the IWR6843 EVM. The top red light was used to indicate the critical zone had been breached, the middle yellow light was used to indicate that an object was in a cautionary zone, and the bottom green light was used to indicate that an object was detected in the area but outside either the critical or cautionary zones. The tower stack light was configured to be off entirely if the mmWave sensor had no detections in the field of view.

Figure 4. IWR6843 EVM Mounting and Test Scene



3.2.2 Test Results

To test the area scanner implementation, a person walked towards the IWR6843EVM while the output of the visualizer as well as the tower stack light was recorded. The ability of the mmWave based area scanner system to detect the person within the areas specified are summarized in [Table 3](#)

Table 3. Area Configurations and Summary of Testing Results

Area	Configured to be Triggered by Detections Located Within:	Indicator Triggered by Person Walking Into Area:
Critical Area Indicator (Red)	1-m radius from EVM	Yes
Cautionary Area Indicator (Yellow)	1-m to 3-m radius from EVM	Yes
Acceptable Area Indicator (Green)	>3-m radius from EVM	Yes

The images below depict the system as implemented, as well as the output of the mmWave sensor to the visualizer. The visualizer plots the detected points and highlights the 1-m radius block area in which a person or object is detected. The point cloud illustrates the 3D data provided from the mmWave sensor, enabling X and Y localization as well as points in the elevation plane, to enable estimating the vertical extent of the object.

Figure 5. Acceptable Area

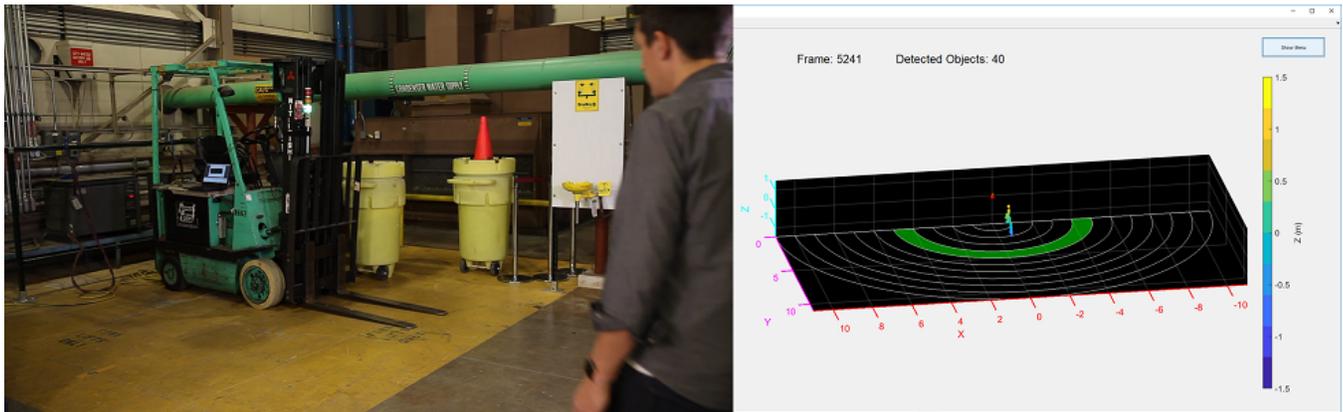


Figure 6. Cautionary Area

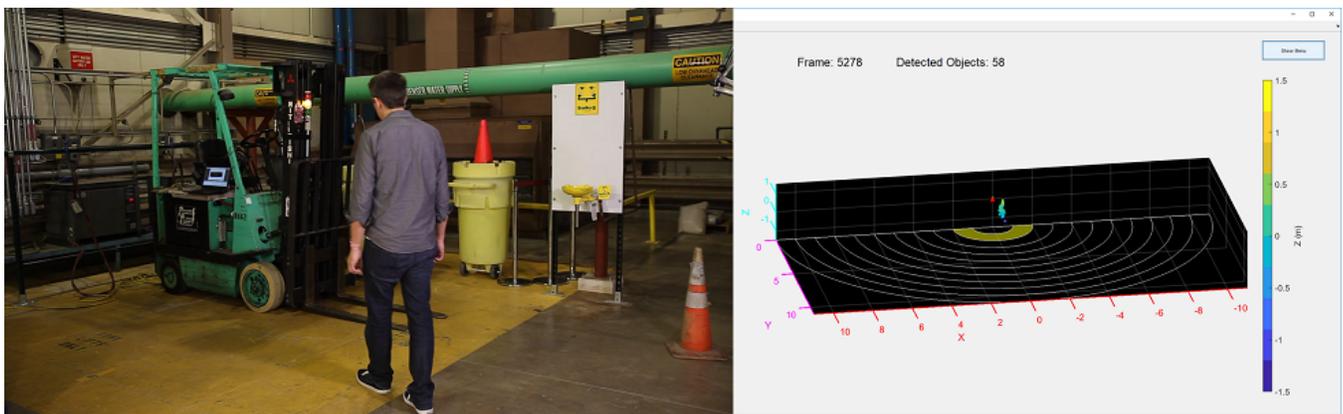
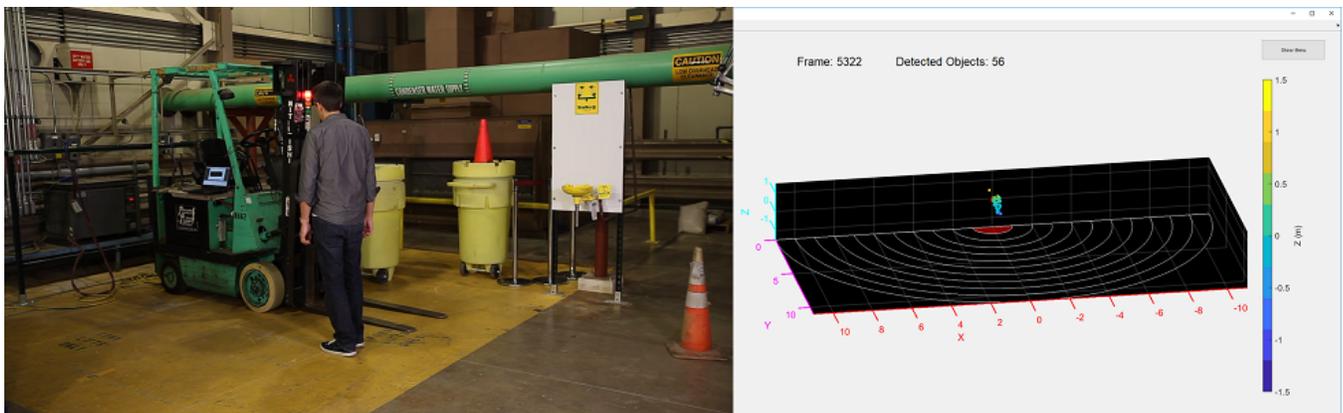


Figure 7. Critical Area



3.2.3 Observations and Conclusions

Using the IWR6843 EVM, the system demonstrated the ability to define and detect whether a human had entered into three distinct areas. A tower stack light was also integrated with the sensor as a visual warning indicator. With three transmitters on the IWR6843, elevation information is enabled and 3D point clouds are generated. When the person is closer to the sensor, a rich and dense point cloud with elevation information representative of the sensed object's height is generated. The area scanner system supports configuration and customization for specific use cases. The size of the areas are fully configurable by configuring the radial limits of each area. The detection range can be extended or reduced by designing and loading a different chirp configuration. The [mmWave Sensing Estimator](#) tool can be used to design a chirp configuration based on an application's sensing requirements.

4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDEP-01010](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDEP-01010](#).

4.3 Altium Project

To download the Altium Designer® project files, see the design files at [TIDEP-01010](#).

4.4 Gerber Files

To download the Gerber files, see the design files at [TIDEP-01010](#).

4.5 Assembly Drawings

To download the assembly drawings, see the design files at [TIDEP-01010](#).

5 Software Files

To download the software files, see the [Area Scanner lab in the latest mmWave Industrial Toolbox](#).

6 Related Documentation

1. Texas Instruments, [IWR6843 Data Sheet](#)
2. Texas Instruments, [IWR6843 Evaluation Module \(IWR6843ISK + mmWaveICBoost\) Single-Chip mmWave Sensing Solution](#), user's guide
3. Texas Instruments, [IWR68xx/16xx/14xx Industrial Radar Family](#), technical reference manual
4. Texas Instruments, [mmWave SDK](#), tools folder

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from B Revision (July 2019) to C Revision	Page
<ul style="list-style-type: none"> • Changed Figure 2: IWR6843AOPEVM..... 4 	4
Changes from A Revision (June 2019) to B Revision	Page
<ul style="list-style-type: none"> • Changed title from "Area scanner using mmWave reference design" to "Area Scanner Using mmWave Sensor With Integrated Antenna-On-Package Reference Design" 1 • Changed "IWR6843AOP" to "IWR6843AOPEVM"..... 1 • Added "The IWR6843 antenna-on-package variant of mmWave sensors enables reduced design and manufacturing costs, simplified system design, smaller sensor footprint, and eventually faster time to market."..... 1 • Added "Range of 0 m to 10 m" 1 • Changed "a field of view up to 120°" to "An azimuth field of view (FOV) up to 120° if using the IWR6843ISK"..... 1 • Changed "and range of 0 m to 10 m" to "A 130° FOV in both azimuth and elevation if using the IWR6843AOP" 1 	1
Changes from Original (November 2018) to A Revision	Page
<ul style="list-style-type: none"> • Changed SK evaluation module (EVM) to MMWave sensor 1 • Added IWR6843AOPEVM tool folder..... 1 • Changed IWR-6843ISK to IWR6843ISK 1 • Changed AOP image to show AOP ES2..... 2 • Added IWR6843AOP description 2 • Added IWR6843 ISK: 3 • Changed Field of view detail information 3 • Added specifications 3 • Added highlighted products introduction 4 • Changed IWR6843ISK +MMWAVEICBOOST to IWR6843ISK or IWR6843AoP EVM 4 • Deleted MMWAVEICBOOST are part of mmWave EVMs hardware. The boards combine to form the IWR6843 Industrial starter kit from Texas Instruments, an easy-to-use evaluation module for the IWR6843 mmWave sensing device. This board contains a 60-GHz mmWave Radar transceiver, in which antennas are etched and act as a radar front-end board. 4 • Deleted paragraph 6 • Added MMWAVEICBOOST subsection 6 • Deleted System Design Theory description 6 • Changed Operation description 6 • Deleted Industrial mmWave Starter Kit (IWR6843 EVM) 7 • Changed "5-V, 3.0-A power supply for the IWR6843 EVM" to "If using MMWAVEICBOOST, a 5-V, 3.0-A power supply" 7 • Added Testing and Results description 8 • Changed Software Files text 11 	11

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