Design Guide: TIDEP-01026

Automated Parking Reference Design using 76-Ghz to 81-GHz AoP mmWave Sensor

Description

The TIDEP-01026 system reference design demonstrates the use of the AWR1843AOP, TI's 76-81 GHz single-chip Antenna-on-Package (AoP) mmWave Radar sensor with an integrated DSP, MCU, and hardware accelerator (HWA) for automated parking applications. This reference design provides a reference data processing chain that runs on the hardware accelerator and C674x DSP, capable of detecting objects at ranges from 4 cm up to 50 meters in a field of view (FOV) of ±70 degrees in azimuth and ±70 degrees in elevation plane. The demo was developed on the AWR1843AOP evaluation kit (EVM) using the mmWave Software Development Kit (SDK). A MATLAB-based reference GUI is provided for output visualization.

Resources

TIDEP-01026	Design Folder
AWR1843AOP	Product Folder
AWR1843AOPEVM	Tool Folder
mmWave SDK	Software Development Kit

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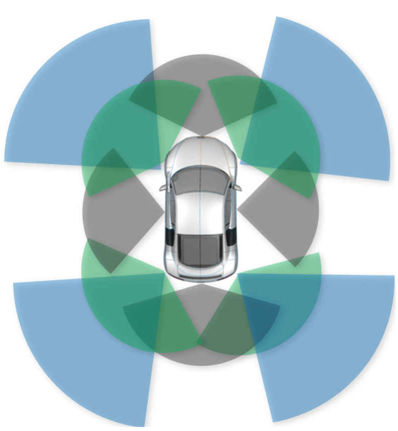
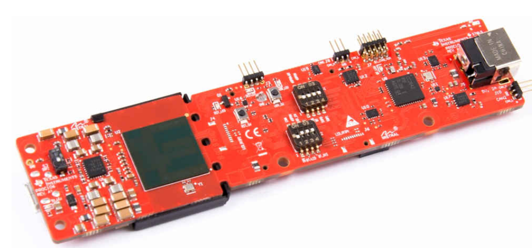
Features

- Demonstration of environmentally robust object detection with clustering of object detections using TI 76-81 GHz Antenna-on-Package single-chip mmWave Sensor
- AWR1843AOP – TI's FMCW mmWave (76 to 81-GHz) single-chip Antenna-on-Package radar with 3Tx/4Rx RF front end, ADC, DSP (C674x), MCU (Cortex-R4F), and hardware accelerator
- Antenna-on-Package provides FOV of ±70 degrees in azimuth and ±70 degrees in elevation
- Processing Chain uses ultra-short range and short range multi-modal configuration
- The data processing algorithms run on the HWA and C674x DSP

Applications

- Ultra Short Range Radar
- Medium Short Range Radar





1 System Description

Level 3 and higher autonomous driving is moving away from parking assistance to automated parking of cars, and mmWave sensors are increasingly being considered as a solution by car manufacturers and Tier1's. This is due to the advantages which the mmWave sensors provide compared to other sensing technologies. The mmWave sensors can be placed behind bumpers, with no need to drill holes inside bumpers, for an aesthetic solution. At a system level, the TI mmWave sensors can be re-purposed because of the multimodal nature. That is, when the car is in motion, the rear corner sensors can be used as a blind spot detector, and when the car is in parking mode, it can be used for parking. The number of sensors required for a 360-degree sensing around the car is also reduced. In addition, the mmWave sensors provide high-resolution detection in a wide field of view in azimuth, as well as the elevation plane in any challenging environmental conditions.

1.1 Why Radar?

Frequency-modulated continuous-wave (FMCW) radars allow the accurate measurement of distances and relative velocities of obstacles and other vehicles; therefore, radars are useful for autonomous vehicular applications (such as parking assist and lane change assist) and car safety applications (such as autonomous breaking and collision avoidance). An important advantage of radars over camera and light-detection-and-ranging (LIDAR)-based systems is that radars are relatively immune to environmental conditions (such as the effects of rain, dust, and smoke). Because FMCW radars transmit a specific signal (called a chirp) and process the reflections, they can work in either complete darkness or bright daylight (radars are not affected by glare). When compared with ultrasound, radars typically have a much longer range and much faster time of transit for their signals.

Additionally, radar sensors are easy to install, and provide accurate detections of several kinds of objects in any challenging environmental conditions such as rain, dust, smoke. They are multi-functional, as they can be used as blind-spot sensors in one mode and the configuration can be changed to work as a parking sensor in another. They enable detection in 3D space in azimuth and elevation plane, with a high-range resolution of less than 4 cm.

TIDEP-01026 uses a multi-modal configuration of the sensor. The first mode is configured to provide 3D location of objects at ultra-short range (0-10m) whereas the second mode is configured to provide 2D information of objects at short range (10-50m). This reference design can be used as a starting point to design a standalone sensor for a variety of automotive applications beyond automated parking.

1.2 Key System Specifications

Table 1-1. Key System Specifications

PARAMETER	SPECIFICATIONS SHORT RANGE	SPECIFICATIONS ULTRA-SHORT RANGE	DETAILS
Maximum range	55 m	10 m	This represents the maximum distance that the radar can detect an object, representing an RCS of approximately 10 m^2.
Range resolution	0.43m	0.076m	This is the ability of a radar system to distinguish between two or more targets on the same bearing, but at different ranges.
Maximum velocity	9.6 m/s	7.05 m/s	This is the native maximum velocity obtained using a two-dimensional FFT on the frame data. This specification will be improved over time by showing how higher-level algorithms can extend the maximum measurable velocity beyond this limit.
Velocity resolution	0.149 m/s	0.1 m/s	This parameter represents the capability of the radar sensor to distinguish between two or more objects at the same range, but moving with different velocities.

Please read the Section 2.4 in this reference guide to understand how to compute the values provided in the table.

2 System Overview

The TI Automated Parking reference design is built around the AWR1843AOP evaluation board and the mmWave SDK demonstration software.

2.1 Block Diagram

2.1.1 Automated Parking Software Block Diagram

The Automated Parking reference design software is based on the mmWave SDK demonstration software. Advanced Frame configuration is used to configure two sub-frames. One sub-frame is configured for 3D detection with maximum range of 10m and the second sub-frame is configured for 2D detection with maximum range of 50m.

Each sub-frame has independent chirping acquisition and processing times as shown in Figure 2-1.

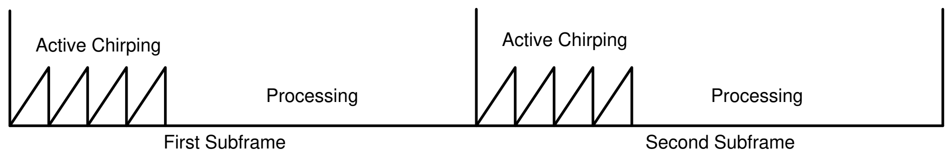


Figure 2-1. Multi-Mode Sub-Frames

For each sub-frame the data path processing and timing has the same structure as shown in Figure 2-2.

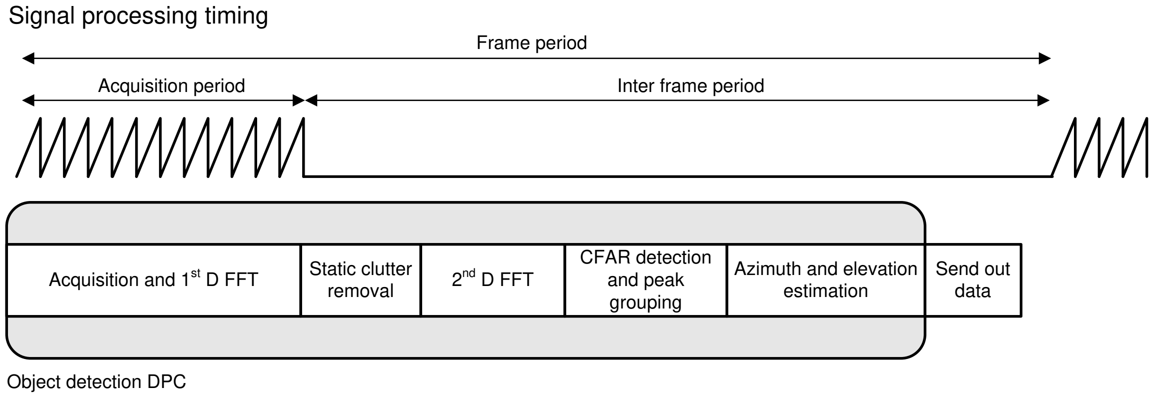


Figure 2-2. Datapath Processing and Timing

The processing chain consists of the following blocks, implemented on the HWA and the C674x DSP core of the AWR1843AOP.

- Range processing
  - For each antenna, 1D windowing, and 1D fast Fourier transform (FFT)
  - Range processing is interleaved with the active chirp time of the frame
- Doppler processing
  - For each antenna, 2D windowing, and 2D FFT
  - Then non-coherent combining of received power across antennas in floating-point precision
- Range-Doppler detection algorithm
  - Constant false-alarm rate, cell averaging smallest of (CASO-CFAR) detection in range domain, plus CFAR-cell averaging (CACFAR) in Doppler domain detection, run on the range-Doppler power mapping to find detection points in range and Doppler space
- Angle estimation
  - For each detected point in range and Doppler space, reconstruct the 2D FFT output with Doppler compensation, then a beamforming algorithm is applied to calculate the angle spectrum on the azimuth direction with multiple peaks detected. After that the elevation angle is estimated for each detected peak angle in azimuth domain.

2.2 Highlighted Products

2.2.1 AWR1843AOP Single-Chip Radar Solution

The AWR1843AOP device is an integrated single-chip FMCW radar sensor 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 and enables unprecedented levels of integration in an extremely small form factor by integrating a wide FOV antenna-on-package. The AWR1843AOP is an ideal solution for low-power, self-monitored, ultra-accurate automotive radar systems.

There are several benefits of an antenna-on-package technology:

- Small form factor: Antenna on the PCB takes up almost ~30% of the board space. With the antenna now integrated on the package, the size of the sensor reduces by ~30% compared to conventional sensors. This helps in easy vehicle integration.
- Faster design cycle: Developer need not spend time on simulation and characterization of the antenna parameters.
- Lower PCB cost: Low cost FR4 based PCB can be chosen for design instead of expensive roger's material-based PCB

The AWR1843AOP has the following features:

- AWR1843 radar device
- Antenna-on-Package with three TX antennae and four RX antennae
- Power management circuit, to provide all the required supply rails from a single 5-V input
- Built-in calibration and self-test (monitoring):
  - ARM Cortex-R4F-based radio control system
  - Built-in firmware (ROM)
  - Self-calibrating system across frequency and temperature
  - On-chip memory: 2 MB RAM

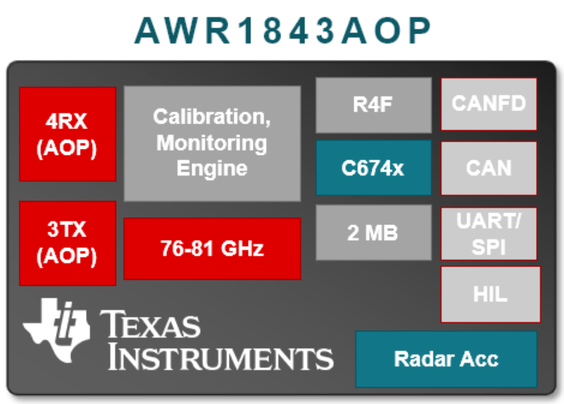


Figure 2-3. AWR1843AOP Block Diagram

For more details on AWR1843AOP please see the product folder.

2.2.2 mmWave SDK

The mmWave SDK has two broad components: the mmWave Suite and mmWave demos. The mmWave Suite is the foundational software part of the mmWave SDK, and includes smaller components:

- Drivers
- OSAL
- mmWaveLink (BSS interface API)
- mmWaveLib (C674x-optimized library)
- mmWave API (high-level control API)
- BSS firmware
- Board setup and flash utilities

The mmWave SDK demos provide a suite of demonstrations that depict the various control and data processing aspects of an mmWave application. Data visualization of the demonstration's output on a PC is provided as part of these demonstrations.

2.3 System Design Considerations

2.3.1 Usage Case Geometry and Sensor Considerations

The AWR1843AOP combines the AWR1843 silicon with a wide FOV antenna-on-package.

The AWR1843 is a radar-based sensor that integrates a fast FMCW radar front end with both an integrated ARM R4F MCU and TI C674x DSP for advanced signal processing.

The key performance parameters of the AWR1843AOP radar front end depend on the following:

- Configuration of the transmit signal
- Configuration and performance of the RF transceiver
- The design of the antenna array
- Available memory and processing power.

The key performance parameters at issue are listed with brief descriptions.

- Maximum Range
  - Range is estimated from a beat frequency in the de-chirped signal proportional to the round trip delay to the target. For a given chirp ramp slope, the maximum theoretical range is determined by the maximum beat frequency that can be detected in the RF transceiver. The maximum practical range is then determined by the SNR of the received signal and the SNR threshold of the detector.
- Range resolution
  - This is defined as the minimum range difference over which the detector can distinguish two individual point targets, which is determined by the bandwidth of the chirp frequency sweep. The higher the chirp bandwidth, the finer the range resolution.
- Range Accuracy
  - This is often defined as a rule of thumb formula for the variance of the range estimation of a single point target as a function of the SNR.
- Maximum velocity
  - Radial velocity is directly measured in the low-level processing chain as a phase shift of the dechirped signal across chirps within one frame. The maximum unambiguous velocity observable is then determined by the chirp repetition time within one frame. Typically this velocity is adjusted to be one-half to one-fourth of the desired velocity range, to have better tradeoffs relative to the other parameters. Other processing techniques are then used to remove ambiguity in the velocity measurements, which experience aliasing.
- Velocity resolution
  - This is defined as the minimum velocity difference over which the detector can distinguish two individual point targets that are also at the same range. This is determined by the total chirping time within one frame. The longer the chirping time, the finer the velocity resolution.
- Velocity accuracy
  - This is often defined as a rule of thumb formula for the variance of the velocity estimation of a single-point target as a function of the SNR.
- Field of view
  - This is the sweep of angles over which the radar transceiver can effectively detect targets. This is a function of the combined antenna gain of the transmit and receive antenna arrays as a function of angle and can also be affected by the type of transmit or receive processing, which can affect the effective antenna gain as a function of angle. The field of view is typically specified separately for the azimuth and elevation.
- Angular resolution
  - This is defined as the minimum angular difference over which the detector can distinguish two individual point targets that also happened to have the same range and velocity. This is determined by the number and geometry of the antennas in the transmit and receive antenna arrays. This is typically specified separately for the azimuth and elevation.

- Angular accuracy
  – This is often defined as a rule of thumb formula for the variance of the angle estimation of a single point target as a function of SNR.

2.3.2 AWR1843AOP Antenna

The AWR1843AOP antenna supports four receivers and three transmitters. This antenna was designed to achieve wide FOV in both azimuth and elevation. For more information regarding the FOV performance and the radiation patterns of the AWR1843AOP antenna please see the AWR1843AOP EVM User's Guide.

When the system operates in time-division multiplexed (TDM) MIMO mode, a non-uniformed, synthesized array of 12 antennas is achieved, as shown in Figure 2-4. The TDM mode of operation is achieved by transmitting chirps using TX1, TX3, and TX2 in an alternate fashion. With 4 synthesized antennas in azimuth direction and three in elevation direction this antenna provides an angular resolution of 29 degrees in azimuth and 38 degrees in elevation.

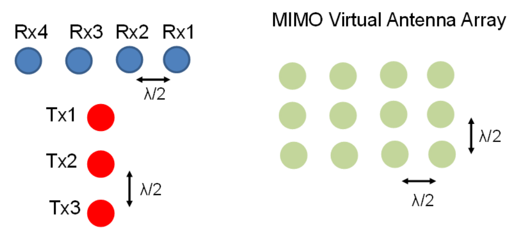


Figure 2-4. AWR1843AOP Antenna Virtual Array

2.3.3 Processing Chain

The TIDEP-01026 uses the mmWave SDK processing chain. This processing chain is described in detail in the mmWave SDK documentation.

The reader is invited to review this detailed documentation located at:

C:\ti\mmwave_sdk_03_05_00_04\docs\mmwave_sdk_module_documentation.html

2.4 Chirp Configuration Profile

The AoP automated parking demo uses multi-mode advanced chip configurations. There are two sub-frames being used, one for ultra-short range detection (0-10m) and the second one for short range detection (10-50m).

The two sub-frames are configured in the configuration file provided with the software package: \profiles\parking_advframe.cfg.

To understand the syntax of the commands in detail the reader is invited to read the mmWave SDK User Guide, section *3. 4. Configuration (.cfg) File Format*.

The User Guide is provided in: C:\ti\mmwave_sdk_03_05_00_04\docs\mmwave_sdk_user_guide.pdf

Table 2-1 provides a summary of the configuration

Table 2-1. Chirp Configurations

CONFIGURATION PARAMETER	ULTRA-SHORT RANGE	SHORT RANGE
Frame Duration	50 ms	50ms
ADC sampling rate	3.6MSPS	6.2MSPS
Chirp valid sweep bandwidth	280MHz	1.8GHz
Number of samples per chirp	128	128
Number of chirps per frame	128	128

The reader is invited to review following E2E FAQ for details on how to compute maximum range, range resolution, maximum unambiguous velocity and velocity resolution.

Computing Maximum Range, Velocity, and Resolution mmWave System

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

The AWR1843AOPEVM from Texas Instruments is an easy-to-use evaluation board for the AWR1843AOP mmWave sensing devices.

The AoP automated parking application runs on the AWR1843AOP EVM and connects to a Matlab GUI running on a PC connected to the EVM over USB.

For details regarding usage of this board, see AWR1843AOP Evaluation Module (AWR1843AOPEVM) SingleChip mmWave Sensing Solution.

3.1.1 Hardware

The AWR1843 core design includes:

- AWR1843 device: A single-chip, 77-GHz radar device with an integrated DSP
- Power management network using low-dropout linear regulators (LDOs), a power management integrated circuit (PMIC), and a DC/DC supply.
- LP87524J
- Power can be taken from USB port or the 2.1mm barrel jack.
- The EVM also hosts a device to assist with onboard emulation and UART emulation over a USB link with the PC

3.1.2 Software and GUI

The Automated Parking demo is using the mmWave SDK Demo with Advanced Multi Mode configuration.

The mmWave SDK can be downloaded from here. When installing the SDK, please select all the other tool components as well.

To download the AWR1843AOP Automated Parking demo, use the following TI Resource Explorer (TI Rex) here. The demo is provided in the Software section in the Automotive Toolbox. A MATLAB GUI is provided in the software package.

Details on how to run the pre-built binaries and how to rebuild the demonstration application are provided in the Automated Parking User Guide included in the release package.

3.2 Testing and Results

3.2.1 Test Setup

The AWR1843AOP EVM was used for testing. The EVM was placed vertically with USB connector at the top as shown in Figure 3-1. For some use cases the EVM had a 0 degree rotation (boresight), for some other use cases it had a 45 degree rotation. The EVM rotation is described for each use case.

The software used for testing was described in previous sections. The software is available in the TI Resource Explorer in the Software section as part of the mmWave Automotive Toolbox.

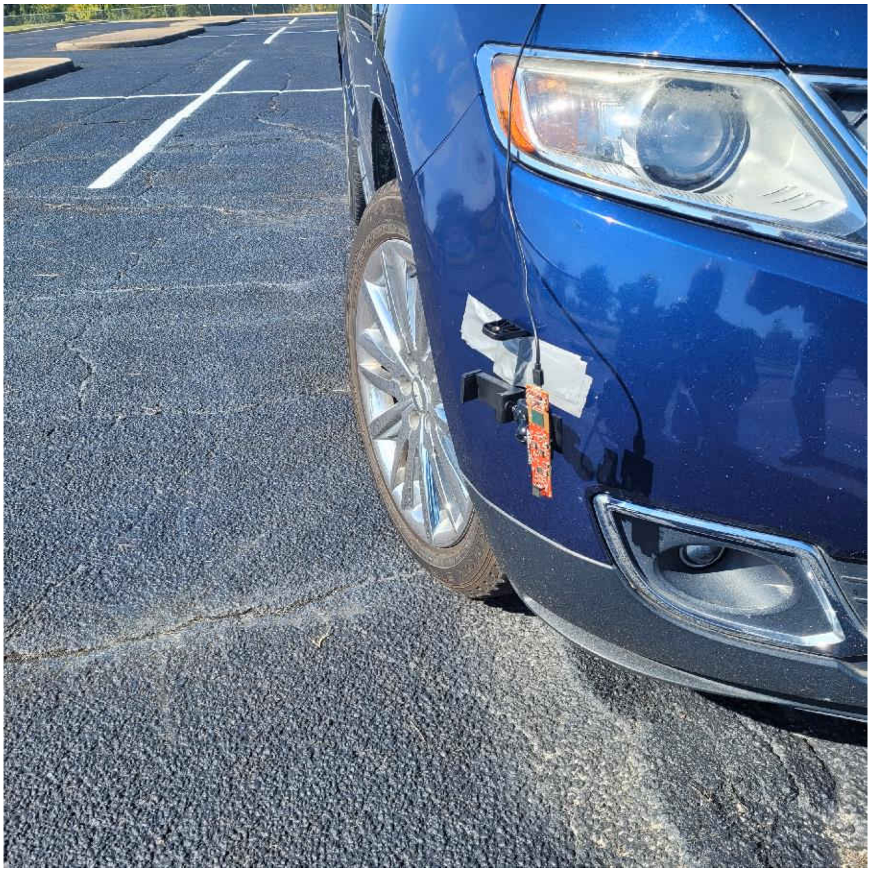


Figure 3-1. AWR1843AOP EVM Setup.

3.2.2 Test Results

The following sections present the test results for multiple use cases. At a range shorter than 10m, most detection points are provided by the sub-frame configured for ultra-short range. For detections beyond 10m, all detection points are provided by the sub-frame configured for short range. For parking application short range is considered to be up to 50m.

3.2.2.1 Use Case – Vehicle, Bicycle, Pedestrian Detection

In this test we use the capabilities of the short range (10m-50m) sub-frame to detect vehicles, bicycles and pedestrians. The processing chain is configured to perform 2D MIMO detection (azimuth only, 1 Tx enabled at a time) with a maximum range of 50m. We perform tests at boresight and at 45 degrees angle. The sensor is placed at bumper height and it is static.

Table 3-1 and Table 3-2 summarize the results.

Table 3-1. Static Detection Vehicle, Bicycle, Pedestrian

STATIC	0 deg	45 deg
Car	40m	25m
Bicycle	20m	15m
Pedestrian	15m	10m

Table 3-2. Dynamic Detection Vehicle, Bicycle, Pedestrian

DYNAMIC	0 deg	45 deg
Car	50m	35m
Bicycle	25m	20m
Pedestrian	20m	15m

3.2.2.2 Use Case – Traffic Cone, Grocery Cart, Sign Pole, Pipe, Shrub

In this test, we use the capabilities of the ultra-short range (0m-10m) sub-frame to detect traffic cones, grocery carts, sign poles, pipes, and shrubs. The processing chain is configured to perform 3D MIMO detection (azimuth and elevation, 1 Tx enabled at a time) with a maximum range of 10m. We perform tests at boresight and at 45 degrees angle. The sensor is placed at bumper height and it is static.

Table 3-3 and Table 3-4 summarize the results.

Table 3-3. Static Detection Traffic Cone, Grocery Cart, Sign Pole, Pipe, Shrub

STATIC	0 deg	45 deg
Traffic Cone	4m	2m
Grocery Cart	2m	1m
Sign Pole	4m	2m
Pipe	1.5m	1m
Shrubs	4m	2m

Table 3-4. Dynamic Detection Traffic Cone, Grocery Cart, Sign Pole, Pipe, Shrub

DYNAMIC	0 deg	45 deg
Traffic Cone	8m	4m
Grocery Cart	4m	2m
Sign Pole	8m	4m
Pipe	3m	2m
Shrubs	8m	4m

Figure 3-2 shows a traffic sign pole used for testing. For this test we wanted to emphasize the detection in elevation.

Figure 3-3 shows the elevation view of the traffic sign pole.

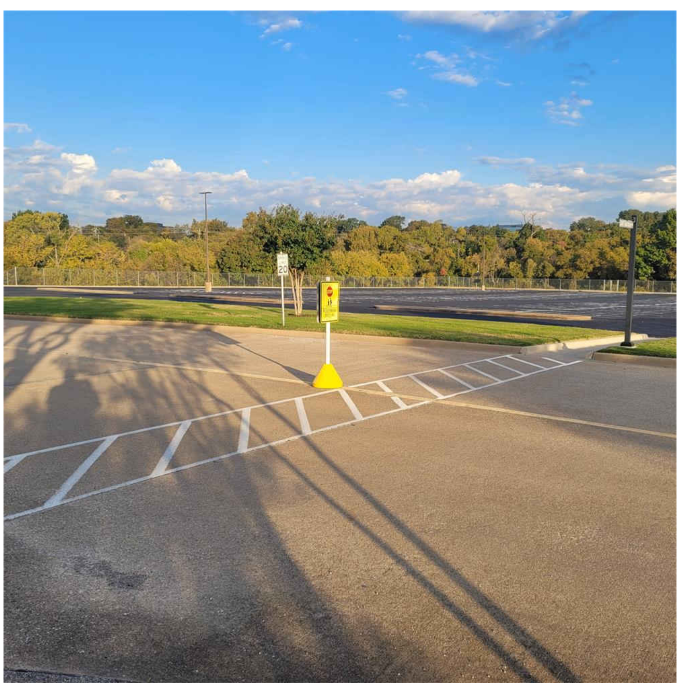


Figure 3-2. Traffic Sign Pole

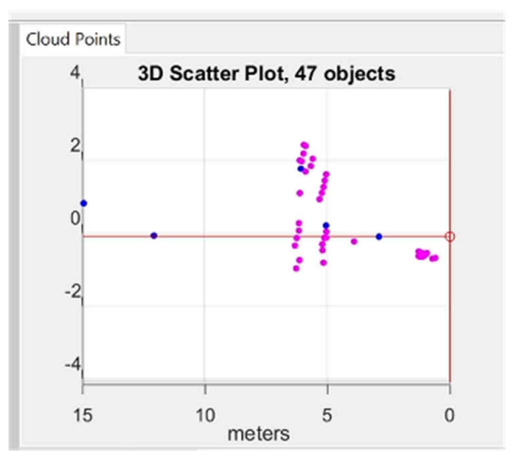


Figure 3-3. Detection Point Cloud of Traffic Sign Pole – Elevation View

3.2.2.3 Use Case – Pedestrian Standing in Empty Parking Space

In this test we use the capabilities of the ultra-short range (0m-10m) sub-frame to detect a pedestrian standing in an empty parking space. The adjacent parking spaces are occupied. The processing chain is configured to perform 3D MIMO detection (azimuth and elevation, 1 Tx enabled at a time) with a maximum range of 10m. The sensor is placed at bumper height at 45 degrees. Testing is performed with both static and moving sensor. The setup is shown in Figure 3-4.

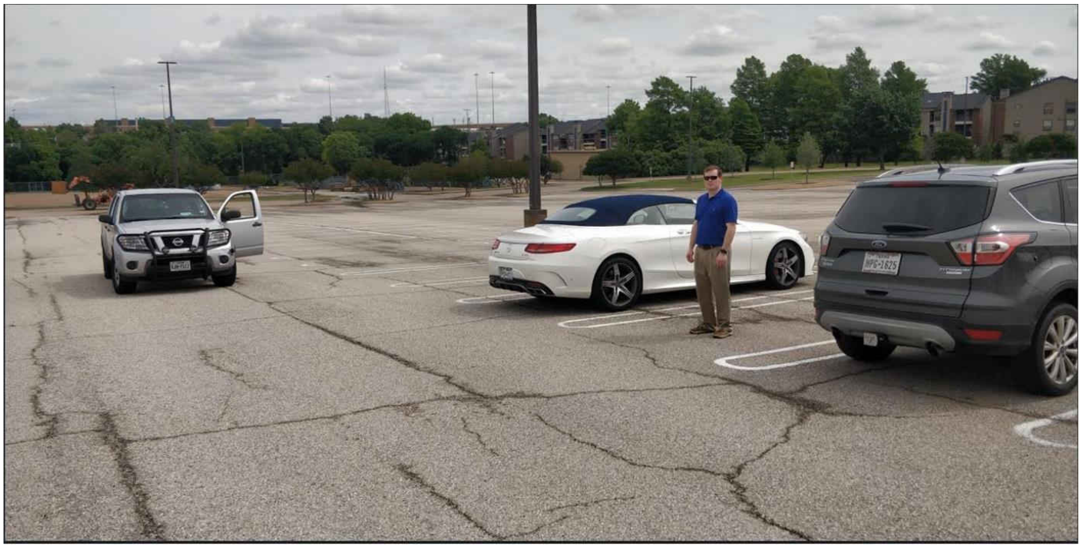


Figure 3-4. Pedestrian Standing in Empty Parking Space

Figure 3-5 shows the point cloud for static detection. The sensor, the car, and pedestrian in the parking space are all static. This is the most challenging detection case.

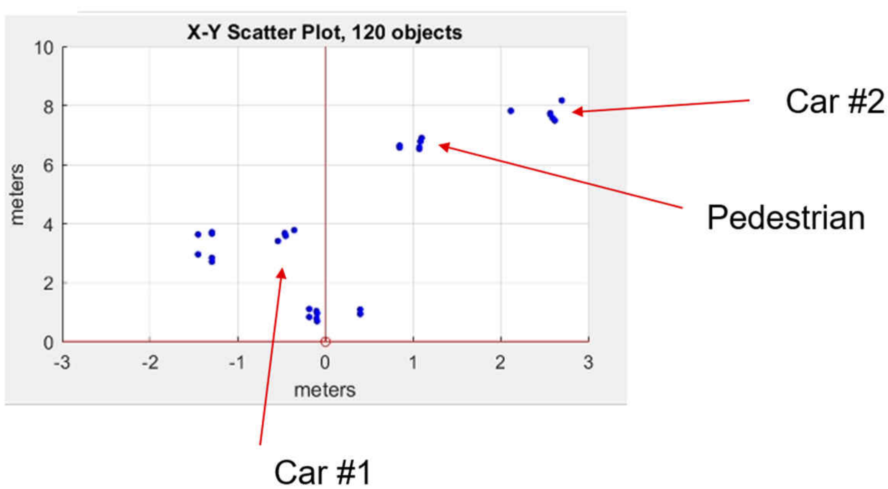


Figure 3-5. Detection Point Cloud of Pedestrian Standing in Empty Parking Space

When there is movement in the scene, the detection is better because Doppler information is used to detect movement.

3.2.2.4 Use Case – Pedestrian Standing Next to Car

In this test we use the capabilities of the ultra-short range (0m-10m) sub-frame to detect a pedestrian standing next to a car. The processing chain is configured to perform 3D MIMO detection (azimuth and elevation, 1 Tx enabled at a time) with a maximum range of 10m. The sensor is placed at bumper height at 45 degrees. Testing is performed with both static and moving sensor. The setup is shown in Figure 3-6.

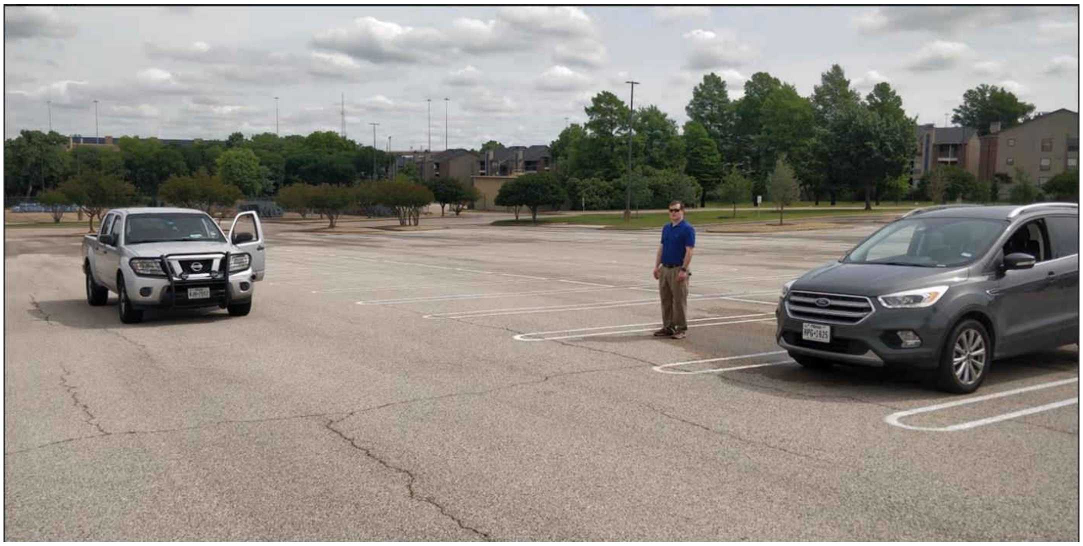


Figure 3-6. Pedestrian Standing Next to Car

Figure 3-7 shows the point cloud for static detection. The sensor, the car, and pedestrian in the parking space are all static. This is the most challenging detection case.

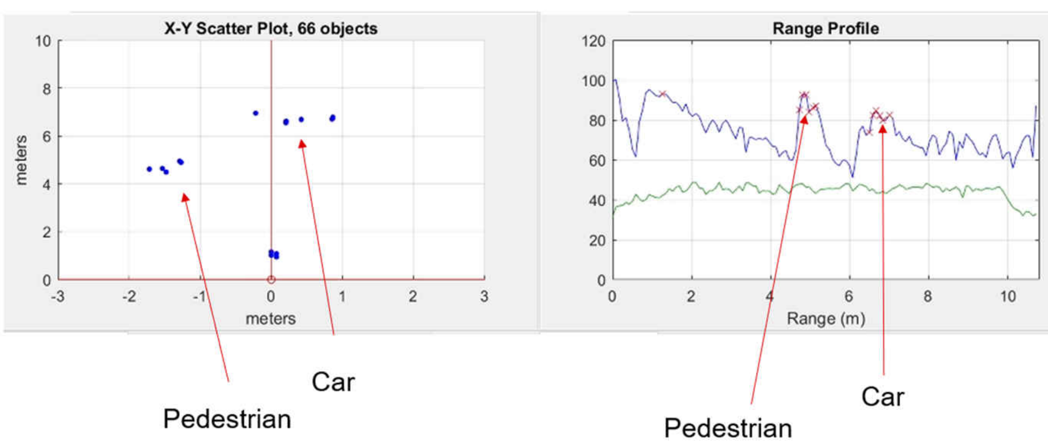


Figure 3-7. Point Cloud for Static Detection

When there is movement in the scene, the detection is better because Doppler information is used to detect movement.

3.2.2.5 Use Case – Empty Parking Space

In this test we wanted to analyze the point cloud for empty parking space detection. We use the capabilities of the ultra-short range (0m-10m) sub-frame. The processing chain is configured to perform 3D MIMO detection (azimuth and elevation, 1 Tx enabled at a time) with a maximum range of 10m. The sensor is placed at bumper height at 45 degrees. Testing is performed with moving sensor, the car driving through a parking lot. The detected point cloud is shown in Figure 3-8.

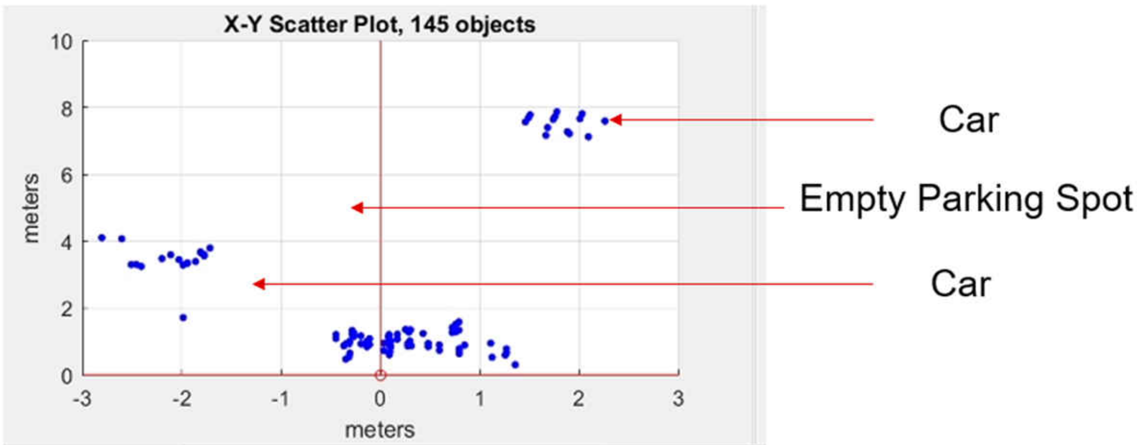


Figure 3-8. Detection Point Cloud of Empty Parking Space

3.2.2.6 Use Case – Cross Traffic Alert

The purpose of this test was to detect a moving object (vehicle, bicycle, pedestrian) coming from the side of the car. We use the capabilities of the short range (10m-50m) sub-frame. The processing chain is configured to perform 2D MIMO detection (azimuth only, 1 Tx enabled at a time) with a maximum range of 50m. The sensor is placed at bumper height at 45 degrees and it is static.

The results are summarized in Table 3-5.

Table 3-5. Dynamic Detection at 45 Degrees Cross Traffic Alert

DYNAMIC	45 deg
Car	35m
Bicycle	20m
Pedestrian	15m

3.2.2.7 Use Case – Parking Block, Curb Detection

In this test we wanted to analyze the point cloud for curb and parking block detection. We use the capabilities of the ultra-short range (0m-10m) sub-frame. The processing chain is configured to perform 3D MIMO detection (azimuth and elevation, 1 Tx enabled at a time) with a maximum range of 10m. The sensor is placed at bumper height at 0 degrees. Testing is performed with moving sensor, the car driving towards the curb or parking block. The environment is shown in Figure 3-9.

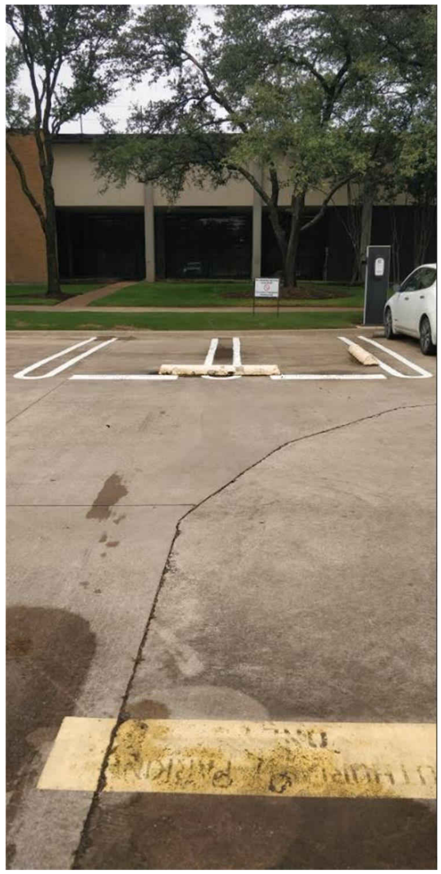


Figure 3-9. Parking Block

The detected point cloud is shown in Figure 3-10.

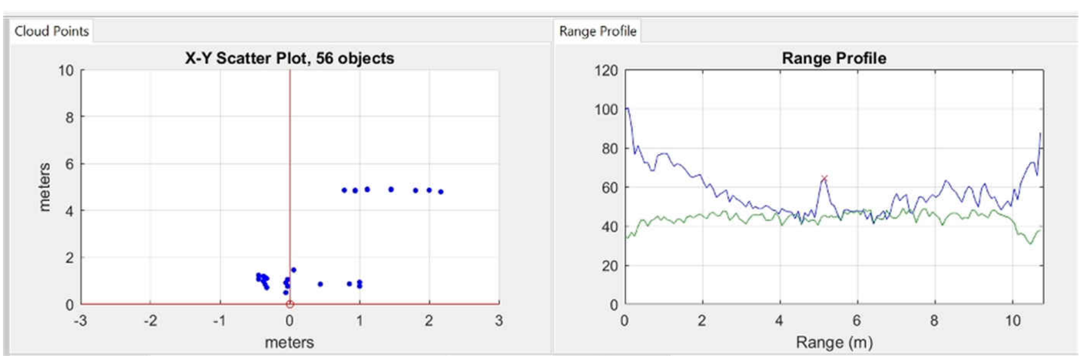


Figure 3-10. Detection Point Cloud of Parking Block

4 Design Files

The design files for TIDEP-01026 include the design database and the schematic, assembly, and BOM.

4.1 Design Database

Find the hardware files for TIDEP-01026.

4.2 Schematic, Assembly, and BOM

Find the schematic, assembly files, and BOM for TIDEP-01026.

5 Software Files

Download the software for TIDEP-01026. The software is found under the following folder structure:

- Software
  - mmWave Sensors
    - Automotive Toolbox
      - Labs
        - Automated Parking

6 Related Documentation

1. Texas Instruments, *AWR1843AOPEVM evaluation module for single-chip 76-GHz to 81-GHz automotive radar sensor*
2. Texas Instruments, Programming Chirp Parameters in TI Radar Devices
3. Texas Instruments, AWR1843AOP 76-GHz to 81-GHz Automotive Radar Sensor Integrating Antenna on Package, DSP and MCU
4. Texas Instruments, AR14xx/16xx/18xx Technical Reference Manual
5. Texas Instruments, AWR1843AOPEVM Design Database
6. Texas Instruments, AWR1843AOPEVM Schematic, Assembly, and BOM
7. Texas Instruments, mmWave SDK User's Guide

6.1 Trademarks

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265