TI Designs: TIDEP-01011
77GHz ミリ波センサを使用した自動パーキング・システムのリファレンス・デザイン

TEXAS INSTRUMENTS

概要

TIDEP-01011 は DSP、MCU、ハードウェア・アクセラレータを内蔵した TI の 77GHz シングルチップ・ミリ波レーダー・センサ AWR1843 を使用した自動パーキング・システムのリファレンス・デザインです。このデザインでは、リファレンス・データ処理チェーンを C674x DSP 上で実行し、水平視野角 ±50 度、垂直視野角 ±15 度で、4cm〜40m の範囲にある物体を検出できます。本デモは、AWR1843BOOST 評価キットで開発しました。出力を可視化するために MATLAB ベースのリファレンスを提供しています。

リソース

|	
TIDEP-01011	デザイン・フォルダ
AWR1843	プロダクト・フォルダ
AWR1843BOOST	ツール・フォルダ
mmWave SDK	ソフトウェア開発キット

TI E2E™ Community

E2E™エキスパートに質問
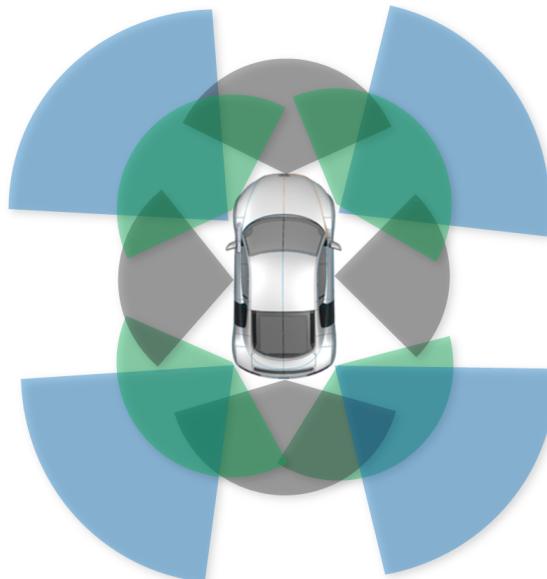
特長

- TI の 77GHz シングルチップ・ミリ波センサを使用した物体検出クラスタ化による、環境堅牢性の高い物体検出のデモ
- AWR1843 − 3Tx/4Rx RF フロント・エンド、ADC、DSP (C674x)、MCU (Cortex-R4F)、ハードウェア・アクセラレータを内蔵する TI の FMCW ミリ波 (76〜81GHz) シングルチップ・レーダー
- 完全なレーダー・データ処理機能を搭載
- UART インターフェイスによりポイント・クラウドおよび物体クラスタ化情報を出力
- データ処理アルゴリズムを C674x DSP 上で実行

アプリケーション

- 自動パーキング
- 駐車支援
- クロス・トラフィック・アラート
- 追突警戒レーダー
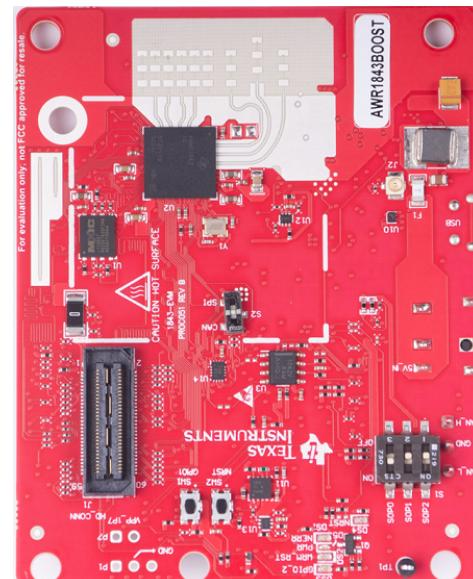
1 System Description

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-01011 is an introductory application that is configured for ultra-short range applications. 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

表 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Maximum range	40 m	This represents the maximum distance that the radar can detect an object, representing an RCS of approximately 10 m^2.
Range resolution	0.175 m	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	8.33 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.

表 **1. Key System Specifications (continued)**

PARAMETER	SPECIFICATIONS	DETAILS
Velocity resolution	0.131 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.

2 System Overview

2.1 Block Diagram

As described in 図 1, the implementation of the automated parking processing chain consists of the following blocks, implemented as DSP code executing on the C674x core of the AWR1843.
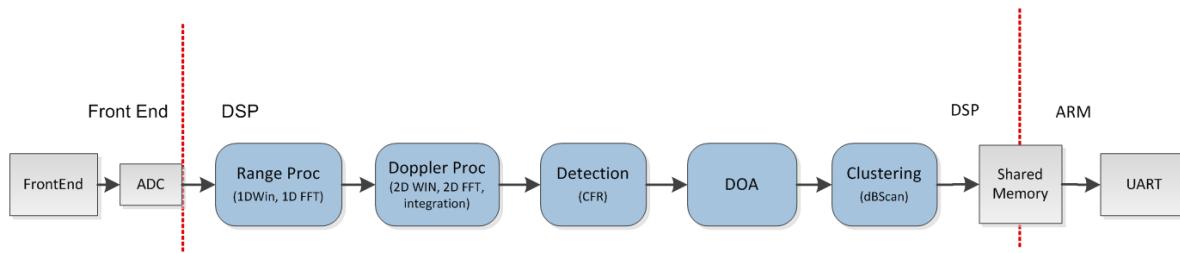

図 1. TIDEP-01011 Block Diagram

- 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.
- Clustering
    - Collect all detected points and perform DBSCAN-based clustering algorithm for every fixed number of frames. The reported output includes the number of clusters and properties for each cluster, like center location and size

After the DSP finishes frame processing, the results consisting of range, doppler, 3D location, and clustering are formatted and written in shared memory (L3RAM) for R4F to send all the results to the host through UART for visualization.

2.2 Highlighted Products

2.2.1 AWR1843 Single-Chip Radar Solution

The AWR1843 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, which enables a monolithic implementation of a 3TX, 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 a BIST processor subsystem, which is responsible for radio configuration, control, and calibration. Additionally, the device includes a user-programmable ARM R4F based for automotive interfacing. The Hardware Accelerator block (HWA) can perform radar processing and help save MIPS on the DSP for higher level algorithms.

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. The AWR1843 is an ideal solution for low-power, self-monitored, ultra-accurate radar systems in the automotive space.

2.2.2 AWR1843BOOST Features

The AWR1843BOOST has the following features:

- AWR1843 radar device
- Power management circuit to provide all the required supply rails from a single 5-V input
- Three onboard TX antennas and four RX antennas
- Onboard XDS110 that provides a JTAG interface, UART1 for loading the radar configuration on the AWR1843 device, and UART2 to send the object data back to the PC
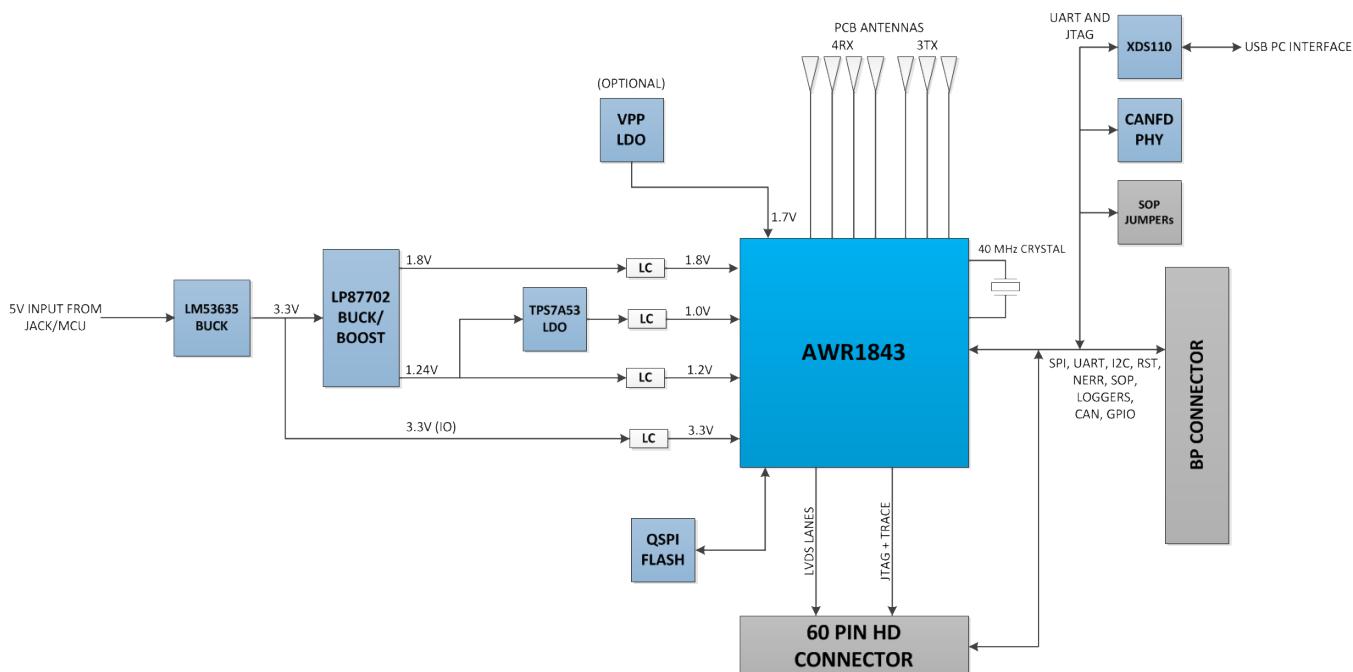

図 2. AWR1843 EVM Block Diagram

For more details on the hardware, see the AWR1843 Evaluation Module (AWR1843BOOST) Single-Chip mmWave Sensing Solution. The schematics and design database can be found in the following documents: AWR1843 Evaluation Board Design Database and AWR1843BOOST Schematic, Assembly, and BOM.

2.2.3 mmWave SDK

The mmWave SDK is split in 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 Theory

2.3.1 Usage Case Geometry and Sensor Considerations

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 configuration of the AWR1843 radar front end depends on the configuration of the transmit signal and the configuration and performance of the RF transceiver, the design of the antenna array, and the available memory and processing power. This configuration influences key performance parameters of the system.

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 may 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.

When designing the frame and chirp configuration for the automated parking application, the device uses the IF bandwidth and trades off the max range, max velocity, and range resolution. An example chirp design is listed in 表 3. In automated parking demo code, the chirp configuration is configured at pa_config_chirp_design_USRR20.h. Users must change this file and re-compile to apply a different chirp configuration.

2.3.2 Antenna Configuration

TIDEP-01011 uses four receivers and three transmit antennas, as shown in 図 3. When the system operates in time-division multiplexed (TDM) MIMO mode, a non-uniformed, synthesized array of 12 antennas is achieved, as shown in 図 3. The TDM mode of operation is achieved by transmitting chirps using TX1, TX3, and TX2 in an alternate fashion. With 8 synthesized antennas in azimuth direction, this antenna fashion provides a finer azimuth angle resolution and can also be used for elevation angle estimation.

The MIMO configuration synthesizes an array of twelve virtual RX antennas: 8 antennas in the azimuthal plane and 4 antennas in the elevation plane, as shown in 図 3. This technique improves the angle resolution by a factor of two when compared to a single TX configuration.
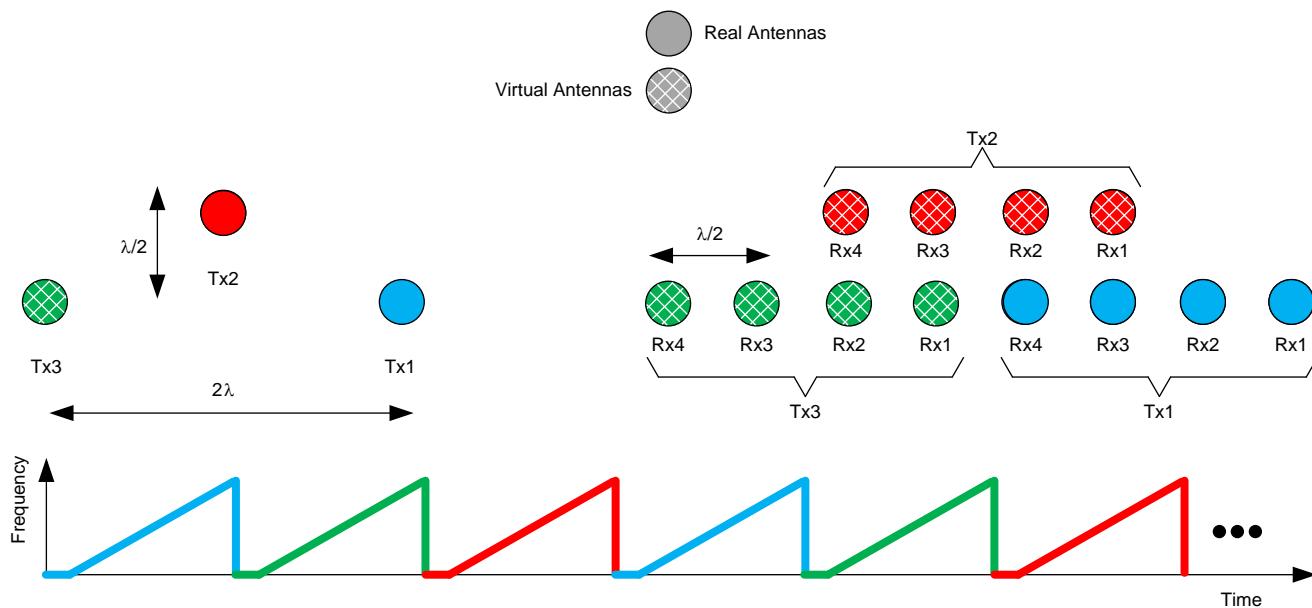

図 3. Antenna Configuration

2.3.3 Processing Chain

The processing chain for TIDEP-01011 is shown in 図 4.

An example processing chain for automated parking, using the ultra short range chirp and frame design, is implemented on the AWR1843 EVM.

The main processing elements involved in the processing chain consist of the following:

- Front End
  - Represents the antennas and the analog RF transceiver implementing the FMCW transmitter and receiver and various hardware-based signal conditioning operations. This must be properly configured for the chirp and frame settings of the use case.
- ADC
  - The ADC is the main element that interfaces to the DSP chain. The ADC output samples are buffered in ADC output buffers for access by the digital part of the processing chain.
- EDMA controller
  - This is a user-programed DMA engine employed to move data from one memory location to another without using another processor. The EDMA can be programed to trigger automatically, and can also be configured to reorder some of the data during the movement operations.
- C674x DSP
  - This is the digital signal processing core that implements the configuration of the front end and executes the low-level signal processing operations on the data. This core has access to several memory resources as noted further in the design description.
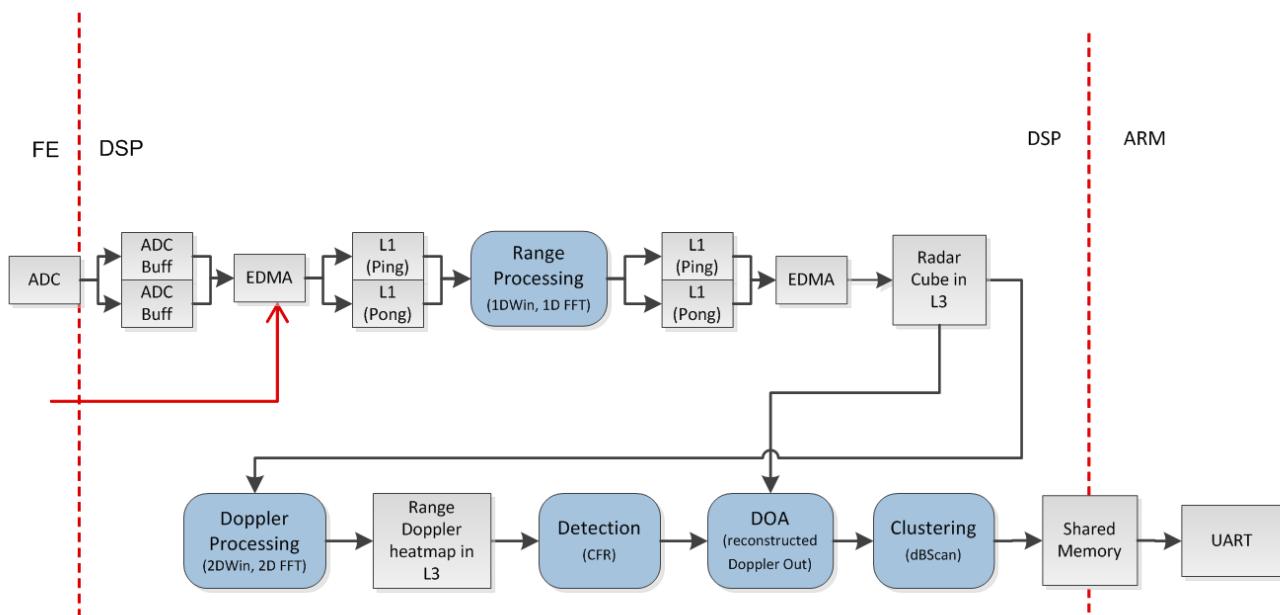

図 4. Processing Chain

A signal processing chain is implemented on the DSP. There are several physical memory resources used in the processing chain, which are described in 表 2.

表 2. Signal Processing Chain

SECTION NAME	SIZE (KB) AS CONFIGURED	MEMORY USED (KB)	DESCRIPTION
L1D SRAM	16	16	Layer one data static RAM is the fastest data access for DSP, and used for most time-critical DSP processing data that can fit in this section.
L1D cache	16	Used as cache	Layer one data cache caches data accesses to any other section configured as cacheable. The L2, L3, and HSRAM are configured as cacheable.
L1P SRAM	16	16	Layer one program static RAM is the fastest program access RAM for DSP, and used for most time-critical DSP program that can fit in this section.
L1P cache	16	Used as cache	Layer one cache caches program accesses to any other section configured as cacheable. The L2, L3, and HSRAM are configured as cacheable.
L2	256	185	Local layer two memory is lower latency than layer three for accessing, and is visible only from the DSP. This memory is used for most of the program and data for the signal processing chain.
L3	1024	835	Higher latency memory for DSP accesses primarily stores the radar cube and the range-Doppler power map. It is a less time-sensitive program. Data can also be stored here.
HSRAM	32	Currently unused	Shared memory buffer between the DSP and the R4F relays visualization data to the R4F for output over the UART in this design.

2.3.4 Chirp Configuration Profile

When designing the frame and chirp configuration for the park assistant application, TI used the IF bandwidth and traded off the max range, max velocity, and range resolution. An example chirp design is listed in 表 3. In park assistant demo code, the chirp configuration is configured at pa_config_chirp_design_USRR20.h.

表 3. Chirp Profile

Configuration Parameter	Value
Frame Duration	50 ms
ADC sampling rate	10 MSPS
Chirp valid sweep bandwidth	858 MHz
Chirp Slope	40 MHz/µs
Chirp time	25.6 µs
Chirp repetition time	115.8 µs
Number of samples per chirp	256
Number of chirps per frame	64
Radar cube size	192 KB

3   Hardware, Software, Testing Requirements, and Test Results

3.1   Required Hardware and Software

The AWR1843 BoosterPack™ from Texas Instruments is an easy-to-use evaluation board for the AWR1843 mmWave sensing devices.

The automated parking application runs on the AWR1843 EVM and connects to a visualization tool running on a PC connected to the EVM over USB.

For details regarding usage of this board, see AWR1843 Evaluation Module (AWR1843BOOST) 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 (TPS7A53-Q1, TPS796, LP87702-Q1, and LM53625-Q1)
- 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 mmWave SDK can be downloaded from here. The installation program also installs all required tool components.

To download the automated parking software, use the following TI Resource Explorer (TI Rex) here. 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 in TI-Rex.

3.2 Testing and Results

3.2.1 Test Setup

図 5 shows the physical setup used to test the automated parking demo. A car was parked next to a curb. A second car was used with the AWR1843 sensor attached to the back. The EVM was placed at a height of approximately one meter off the ground on the rear of the vehicle. Additionally, two traffic cones were placed in front of the second car. The traffic cones have a height of 30 inches.
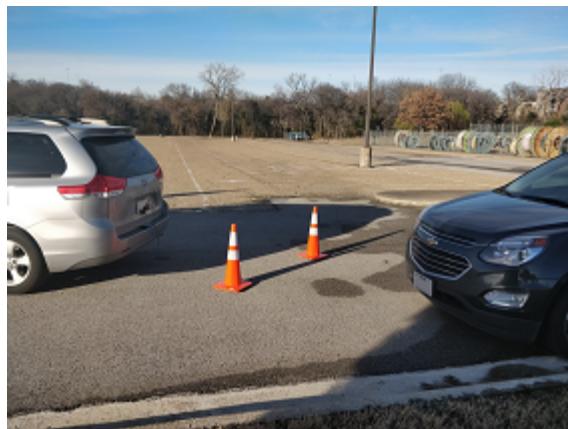
図 5. Test Physical Setup

3.2.2 Test Results

By default, detected objects and clusters are displayed. Detected objects are shown as dots in the 3D space, and clusters are shown as boxes. Cluster box sizes are obtained from the DSP's clustering algorithm.

The corresponding output from the GUI visualizer is shown in 図 6.
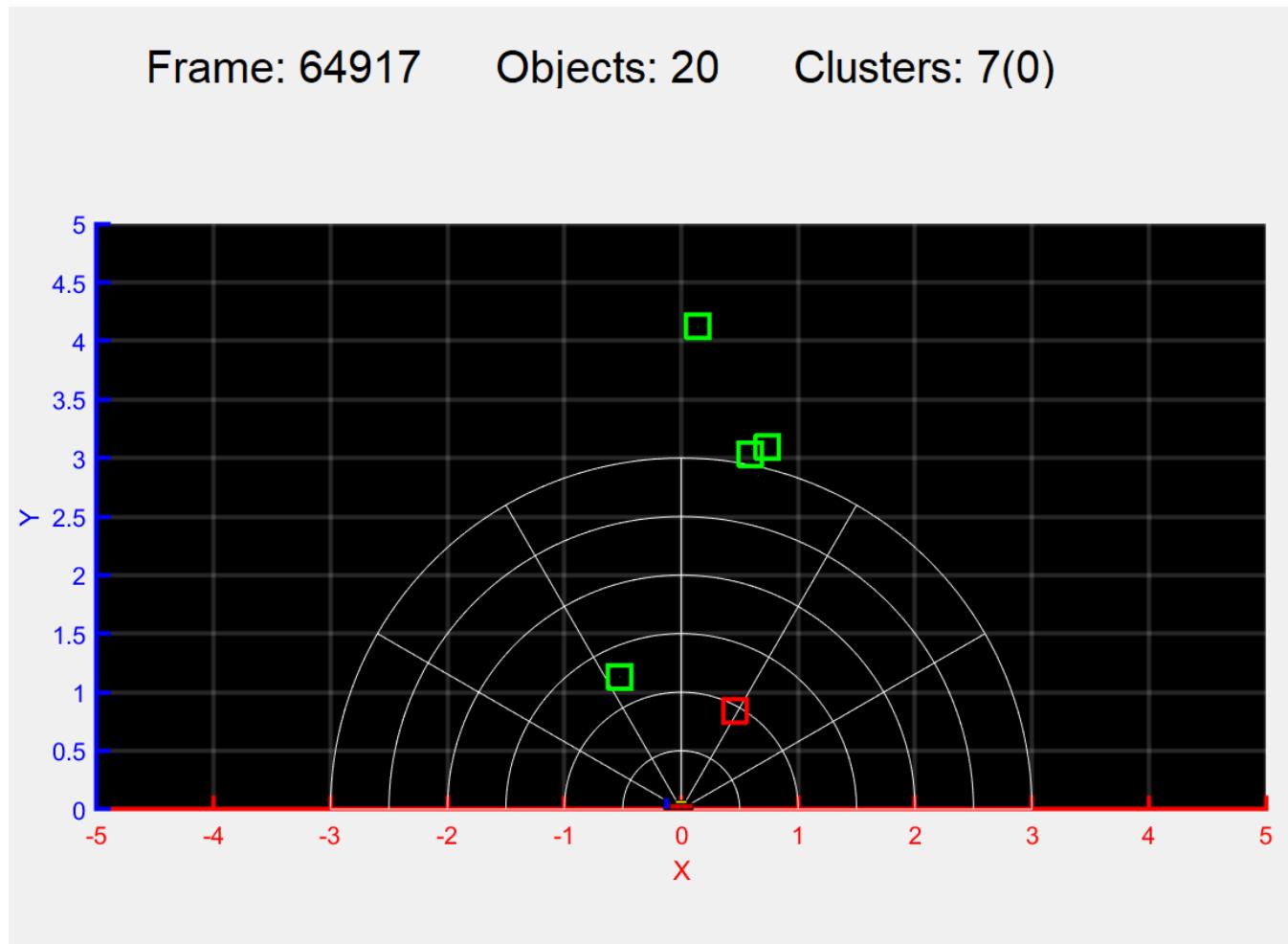
図 6. GUI Visualizer Output

As seen in 図 6, the AWR1843 can detect the two traffic cones as separate objects. The AWR1843 also detects multiple points on the parked car and clusters them together.

The detected object (dot) colors are determined by their Z distance (height) from the antenna. Cluster colors are red if the center is within 1 meter of the antenna, and green if outside 1 meter.

4   Design Files

The design files for TIDEP-01011 include the design database and the schematic, assembly, and BOM.

4.1   Design Database

Find the hardware files for TIDEP-01011 here.

4.2   Schematic, Assembly, and BOM

Find the schematic, assembly files, and BOM for TIDEP-01011 here.

5   Software Files

Download the software for TIDEP-01011 here. The software is found under the following folder structure:

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

6   Related Documentation

1. *Texas Instruments, AWR1843 Evaluation Module (AWR1843BOOST) Single-Chip mmWave Sensing Solution*
2. Texas Instruments, Programming Chirp Parameters in TI Radar Devices
3. Texas Instruments, AWR1843 Single-Chip 77- and 79-GHz FMCW Radar Sensor
4. Texas Instruments, AR14xx/16xx/18xx Technical Reference Manual
5. Texas Instruments, AWR1843 Evaluation Board Design Database
6. Texas Instruments, AWR1843BOOST Schematic, Assembly, and BOM
7. Texas Instruments, mmWave SDK User's Guide

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