TI Designs: TIDEP-0094

80-m Range Object Detection With IWR1642 mmWave Sensor Reference Design

Description

The TIDEP-0094 provides a foundation to evaluate object detection using the IWR1642 evaluation module (EVM). This design will allow the estimation of the position (in the azimuthal plane) and the velocity of objects in its field of view up to 84 m.

Resources

TIDEP-0094	Design Folder
IWR1642	Product Folder
TMP112	Product Folder
LP87524	Tool Folder
TPS7A88	Tool Folder
TPS7A8101	Tool Folder

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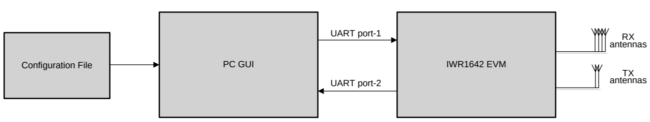
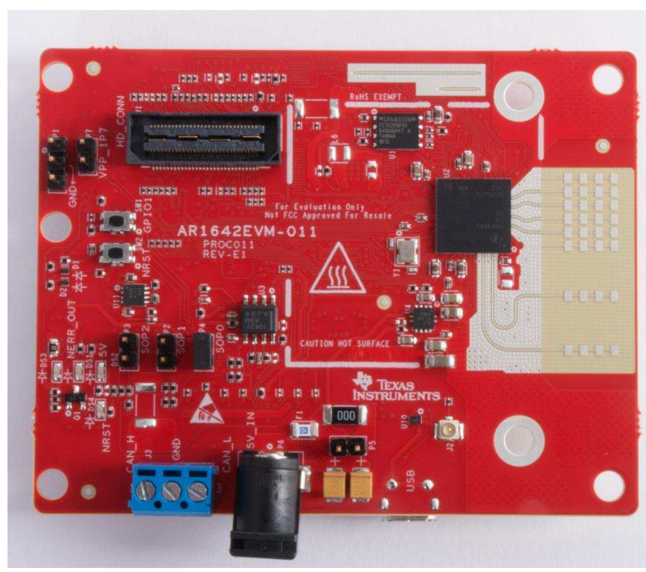
Features

- Detect Objects up to 84 m With Range Resolution of 37 cm
- Antenna Field of View ±60º With Angular Resolution of Approximately 15º
- Source Code for Fast Fourier Transform (FFT) Processing and Detection Provided by mmWave Software Development Kit (SDK)
- IWR1642 EVM Demonstrates Design
- Radar Front End and Detection Configuration Fully Explained

Applications

- Service Robots
- Logistics Robots
- Industrial Robots
- Industrial Transport
- Forklifts
- Drone Systems





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1 System Description

The goal of industrial systems is to increase productivity. Increasingly these systems intelligently interact with dynamic surroundings and the objects in them. Robots are quickly being deployed as costs are reduced and functionality is increased to automate mundane and tedious operations. Agriculture, construction, and heavy vehicles are increasing in intelligence to assist in operator productivity and enhance the safety towards autonomous operation. Forklifts are rapidly adding intelligence to detect obstacles, balance loads, and detect ground edges. Drones are disrupting entire industries from package delivery to forestry. All of these systems require a variety of sensors to detect obstacles in the environment as well as track object velocities and positions over time.

1.1 Why mmWave Sensors?

mmWave Sensors allow the accurate measurement of distances and relative velocities of obstacles. An important advantage of mmWave sensors over vision and LIDAR-based sensors are their relatively immunity to environmental conditions, such as rain, dust, smoke, fog, or frost. Additionally, mmWave sensors can work in complete darkness or in the glare of direct sunlight. Mounted directly behind enclosure plastics without external lenses, apertures, or sensor surfaces, the sensors are extremely rugged. TI's mmWave sensors are also small, lightweight, and produce designs that are three times smaller and half the weight of miniature LIDAR range finders.

1.2 80-m Range Object Detection TI Design

The TIDEP-0094 is an introductory application configured to detect objects up to a distance of 84 m as well as estimate their velocities and positions.

The TI Design can be used as a starting point to design a standalone sensor for a variety of Industrial applications. A range of more than 84 m can be achieved with the design of different chirp parameters, use of an external lens, or through design of an antenna with higher gain than the one included in the IWR1642 EVM.

1.3 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Maximum range	84.375 m	This represents the maximum distance that the radar can detect an object representing an RCS of approximately 10 m^2.
Range resolution	36.6 cm	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	29.33 kph	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	0.46 kph	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

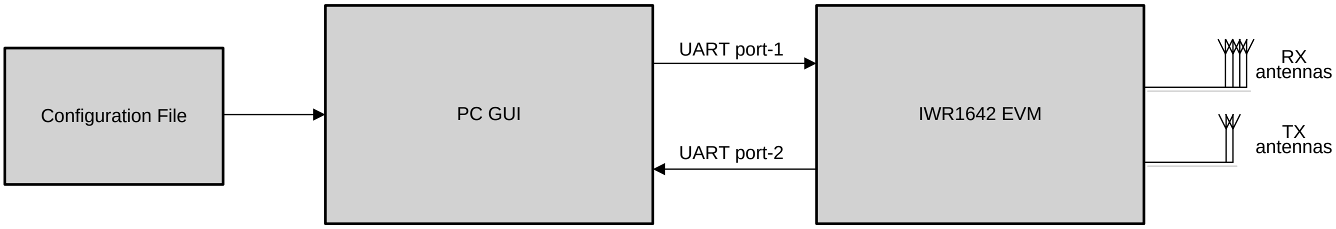

Figure 1. System Block Diagram

2.2 Highlighted Products

2.2.1 IWR1642 Single-Chip Radar Solution

The IWR1642 is an integrated single-chip, frequency modulated continuous wave (FMCW) sensor capable of operation in the 76 to 81 GHz frequency band. The device is built with TI's low-power, 45-nm RFCMOS processor and enables unprecedented levels of analog and digital integration in an extremely small form factor. The device has four receivers and two transmitters with a closed loop PLL for precise and linear chirp synthesis. The sensor includes a built-in radio processor (BIST) for RF calibration and safety monitoring. Based on complex baseband architecture, the sensor device supports an IF bandwidth of 5 MHz with reconfigurable output sampling rates. The presence of ARM® Cortex® R4F and Texas Instruments C674x DSP (fixed and floating point) along with 1.5 MB of on-chip RAM enables high-level algorithm development.

2.2.2 IWR1642

The IWR1642 has the following features:

1. IWR1642 mmWave sensor device
2. Power management circuit to provide all the required supply rails from a single 5-V input
3. Two onboard TX antennas and four RX antennas
4. Onboard XDS110 that provides a JTAG interface, UART1 for loading the mmWave sensor configuration on the IWR1642 device, and UART2 to send the object data back to the PC

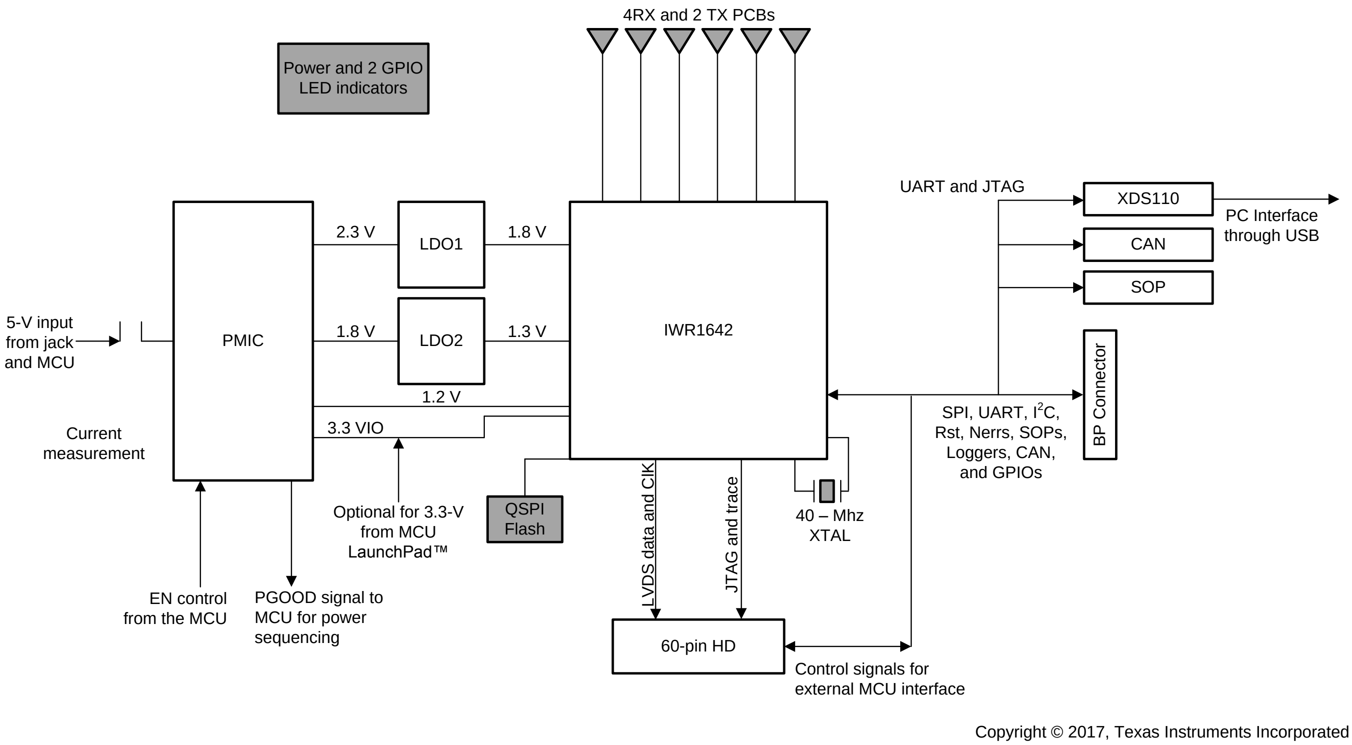

Figure 2. IWR1642

For more details on the hardware, see the *IWR1642 Evaluation Module (IWR1642BOOST) Single-Chip mmWave Sensing Solution* [1]. The schematics and design database can be found in the following documents: *IWR1642BOOST Design Database* [5] and *IWR1642BOOST Schematic, Assembly, and BOM* [6].

2.3 System Design Theory - Chirp Configuration

2.3.1 Antenna Configuration

The TIDEP-0094 uses four receivers and the two transmitters in the time division multiplexed MIMO configuration (that is, alternate chirps in a frame transmit on TX1 and TX2 respectively.). The MIMO configuration synthesizes an array of eight virtual RX antennas, as shown in Figure 3. This technique improves the angle resolution by a factor of two (compared to a single TX configuration).

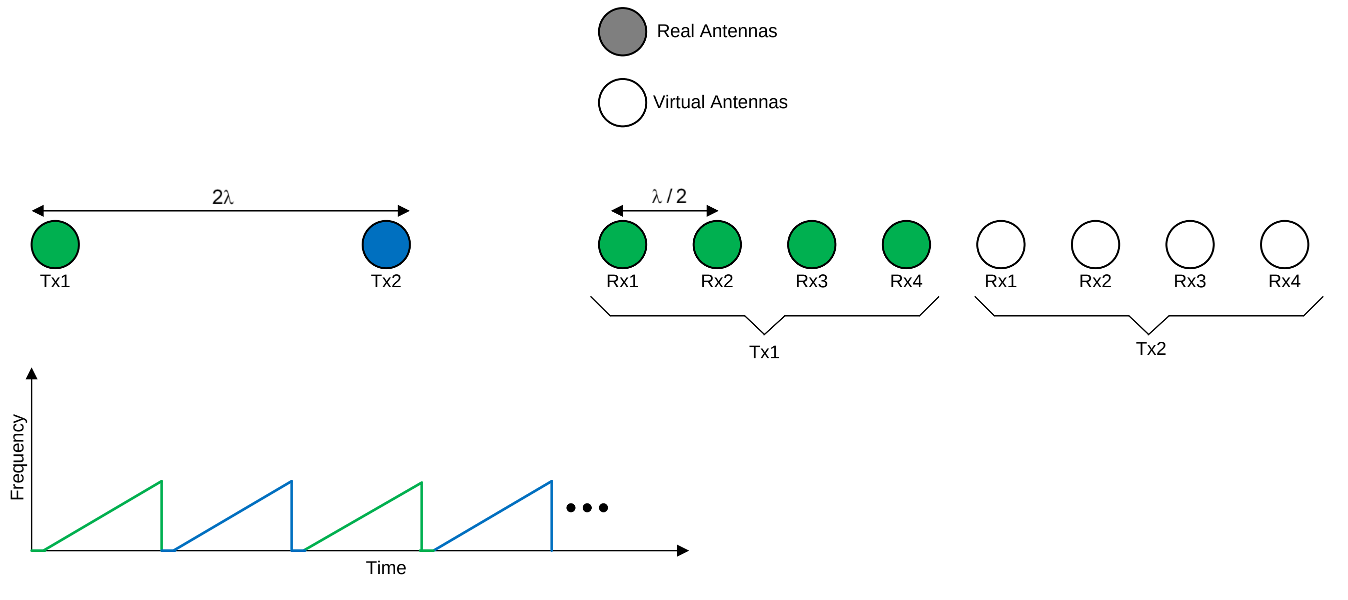

Figure 3. MIMO Antenna Configuration

2.3.2 Chirp Configuration and System Performance

To achieve the specific use case with a visibility range of approximately 80 m and memory availability of IWR1642, the chirp configuration in Table 2 is used.

Table 2. Chirp Configuration

PARAMETER	SPECIFICATIONS
Idle time (µs)	3
ADC start time (µs)	3
Ramp end time (µs)	56
Number of ADC samples	256
Frequency slope (MHz/µs)	8
ADC sampling frequency (ksps)	5000
MIMO (1→yes)	1
Number of chirps per profile	64
Effective chirp time (usec)	51.2
Bandwidth (MHz)	409.6
Frame length (ms)	7.552
Memory requirements (KB)	512

The Table 2 configuration is selected to achieve the system performance shown in Table 3. The primary goal was to achieve a maximum distance of about 85 m. Note that the product of the frequency slope and the maximum distance is limited by the available IF bandwidth (5 MHz for the IWR1642). Thus, a maximum distance of 85 m locks down the frequency slope of the chirp to about 8 MHz/µs. See the *Programming Chirp Parameters in TI Radar Devices* [2] application report for more details. The choice of the chirp periodicity is a trade-off between range resolution and maximum velocity. This design uses a range-resolution of about 0.3 m, which leaves a native maximum velocity of about 30 kmph (1). For details on the connection between the system performance and the chirp parameters, see the *Programming Chirp Parameters in TI Radar Devices* [2] application note. Through high-level algorithms, the maximum unambiguous velocity that can be detected is 90 kmph.

A larger maximum distance translates to a lower range resolution (due to limitations on both the L3 memory and the IF bandwidth). A useful technique to work around this trade-off is to have multiple configurations with each tailored for a specific viewing range. For example, it is typical to have the mmWave sensor alternate between two modes: a low resolution mode targeting a larger maximum distance (such as 85 m with 0.3-m resolution) and a high resolution mode targeting a shorter distance (such as 20 m with 4-cm resolution). This multi-mode capability is not implemented in the current TI design but is targeted for a future release.

(1) Though not implemented in the currentdesign, note that there are several approaches that can improve the maximum detectable velocity several multiples beyond this native maximum.

Table 3. System Performance Parameters

PARAMETER	SPECIFICATIONS
Range resolution (m)	0.366210938
Maximum distance (m)	84.375
Native maximum velocity (kmph)	29.33507171

2.3.3 Configuration Profile

The example in the mmWave SDK 1.0 distribution that represents the TI Design allows the user to push the mmWave sensor configuration using a *Profile Configuration* file.

The *mmWave SDK User's Guide* [7] describes the semantics of the following commands in detail. The following sequence of commands represent the configuration choices described in earlier sections representing sensor functionality.

```
sensorStop
flushCfg
dfeDataOutputMode 1
channelCfg 15 3 0
adcCfg 2 1
adcbufCfg 0 0 1 1
profileCfg 0 77 3 3 56 0 0  8 1 256 5000 0 0 30
chirpCfg 0 0 0 0 0 0 0 1
chirpCfg 1 1 0 0 0 0 0 2
frameCfg 0 1 64 0 100 1 0
lowPower 0 0
guiMonitor 1 1 1 0 0 1
cfarCfg 0 0 8 4 4 0 5000
cfarCfg 1 0 8 4 4 0 5000
peakGrouping  1 0 1 1 224
multiObjBeamForming 0 0.5
calibDcRangeSig 0 -5 8 256
sensorStart
```

The profile configuration defines the profile of a single chirp (as per Table 1). Subsequently, two chirp configurations are defined each one inheriting the same profile but associated with Tx1 and Tx2 respectively. Finally a frame configuration message constructs a frame with transmissions alternating between Tx1 and Tx2.

2.3.4 Data Path

The block diagram in Figure 4 shows the processing data part to the SRR application.

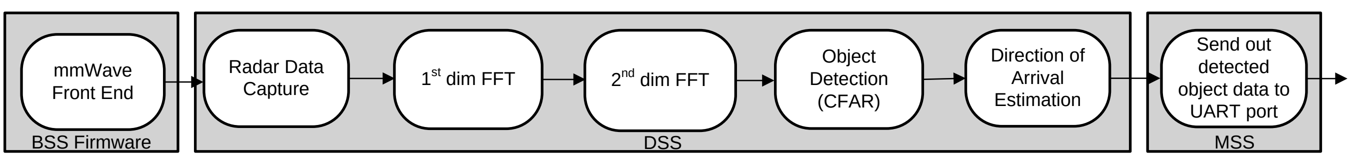

Figure 4. Processing Chain

2.3.5 Chirp Timing

Figure 5 shows the timing of the chirps and subsequent processing in the system.

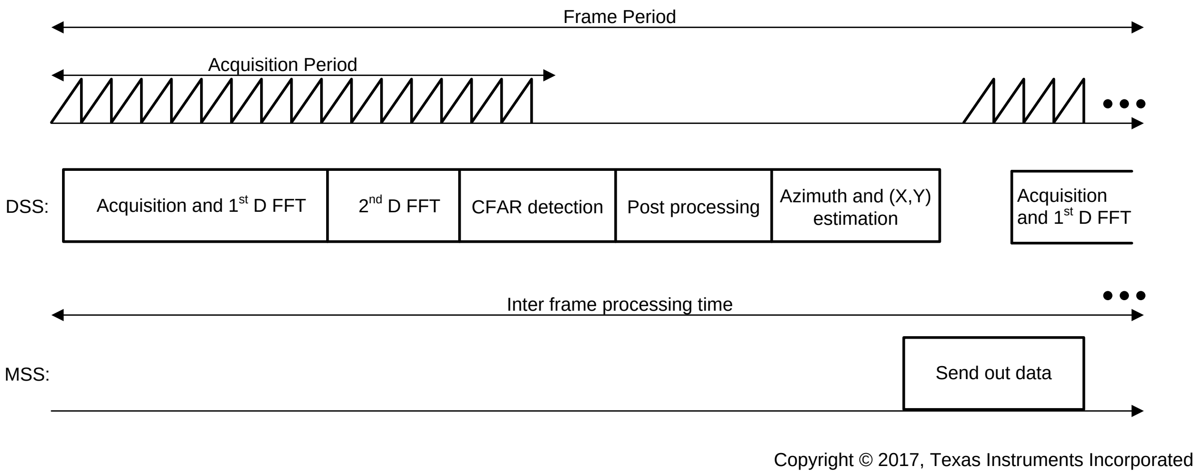

Figure 5. Top Level Data Path Timing

As seen in Figure 5, the data path processing is described below.

- The RF front end is configured by the BIST subsystem (BSS). The raw data obtained from the various front end channels is taken by the C674x DSP subsystem (DSS) for processing.
- Processing during the chirps as seen in Figure 5 consists of:
  - 1D (range) FFT processing performed by the C674x that takes input from multiple receive antennae from the ADC buffer for every chirp (corresponding to the chirping pattern on the transmit antennae)
  - Transferring transposed output into the L3 RAM by EDMA
- Processing during the idle or cool down period of the RF circuitry following the chirps until the next chirping period, shown as *Inter frame processing time* in Figure 5. This processing consists of:
  - 2D (velocity) FFT processing performed by C674x that takes input from 1D output in L3 RAM and performs FFT to give a (range, velocity) matrix in the L3 RAM. The processing also includes the CFAR detection in Doppler direction. CFAR detection in range direction uses the mmWave library.
  - Peak grouping if enabled
  - Direction of arrival (azimuth) estimation to map the X-Y location of object

For more details on the application flow and processing, see the *mmWave SDK User's Guide* [7].

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

The IWR1642 BoosterPack™ from Texas Instruments is an easy-to-use evaluation board for the IWR1642 mmWave sensing devices.

The short range radar application runs on the IWR1642 EVM and connects to a visualization tool running on a PC connected to the EVM over USB.

Details regarding usage of this board can be found in the *IWR1642 Evaluation Module (IWR1642BOOST) Single-Chip mmWave Sensing Solution* [1].

Details regarding the visualization tool can be found in the *mmWave SDK User's Guide* [7].

3.1.1 Hardware

The IWR1642 core design includes:

- IWR1642 device, a single-chip, 77-GHz mmWave sensor device with an integrated DSP
- Power management network using an LDO and PMIC DCDC supply (TPS7A88, TPS7A8101-Q1, LP87524B-Q1)
- The EVM also hosts a device to assist with on-board emulation and UART emulation over a USB link with the PC

3.1.2 Software

Associated software is hosted as the *mmWave Demo* in mmWave SDK distribution.

3.2 Testing and Results

3.2.1 Test Setup

Table 4 summarizes the time complexity of key building blocks in the processing chain (running on C674x DSP hosted in the IWR1642).

Table 4. Software Algorithm Processing Characteristics

	CYCLES	TIMING (µs) (AT 600 MHz)	SOURCE AND FUNCTION NAME
128-point FFT (16 bit)	516	0.86 µs	DSPLIB (DSP_fft16x16)
256-point FFT (16 bit)	932	1.55 µs	DSPLIB (DSP_fft16x16)
128-point FFT (32 bit)	956	1.59 µs	DSPLIB (DSP_fft32x32)
Windowing (16bit)	0.595N + 70	0.37 µs (for N=256)	mmwavelib (mmwavelib_windowing16x16)
Windowing (32 bit)	N + 67	0.32 µs (for N=128)	mmwavelib (mmwavelib_windowing16x32)
Log2abs (16 bit)	1.8N + 75	0.89 µs (for N=256)	mmwavelib (mmwavelib_log2Abs16)
Log2abs (32 bit)	3.5N + 68	0.86 µs (for N=128)	mmwavelib (mmwavelib_log2Abs32)
CFAR-CA detection	3N + 161	0.91 µs	mmwavelib (mmwavelib_cfarCadB)
Max of a vector of length 256	70	0.12 µs	DSPLIB (DSP_maxval)
Sum of complex vector of length 256(16 bit I,Q)	169	0.28 µs	—
Multiply two complex vectors of length 256 (16 bit)	265	0.44 µs	—

This system was used in field tests and a few observations are shown in Section 3.2.2, where a small size car is continuously visible up to 80-m distance and a motorcycle is detected up to 50-m away.

3.2.2 Test Results

The following results were obtained by performing field tests where a single small vehicle and motorcycle were driven away from the system while the results were being logged.

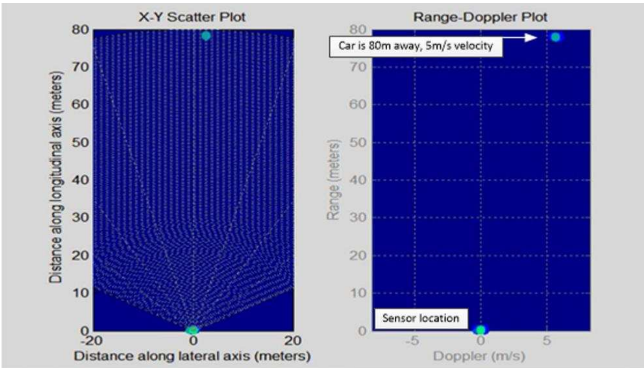

Figure 6. Small Car Test at 80 m

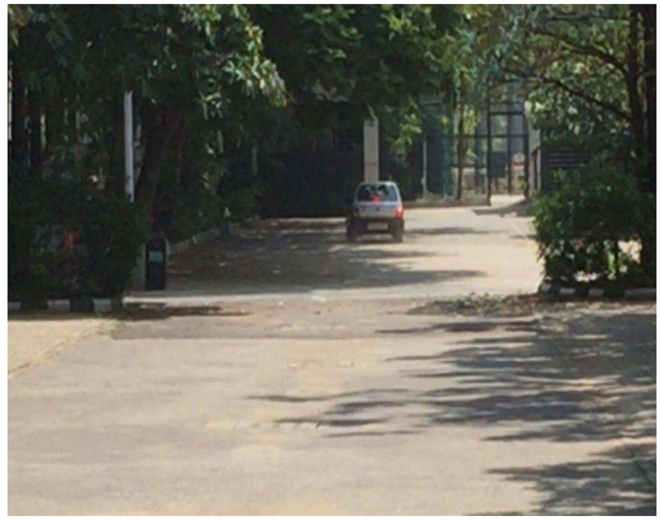

Figure 7. Small Car Test at 80 m

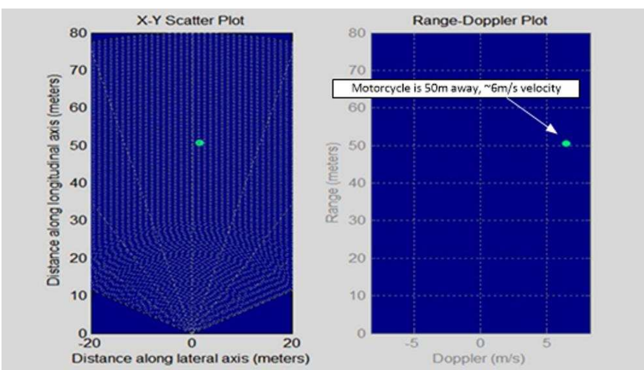

Figure 8. Motorcycle Test at 50 m

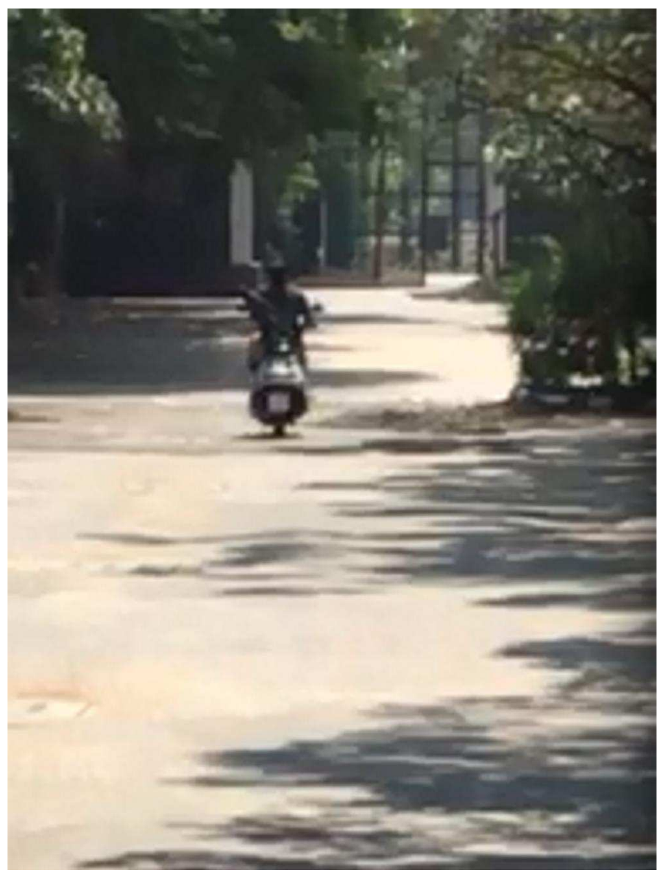

Figure 9. Motorcycle Test at 50 m

4 Software Files

To download the software files, see the design files at TIDEP-0094 .

5 Related Documentation

1. Texas Instruments, *IWR1642 Evaluation Module (IWR1642BOOST) Single-Chip mmWave Sensing Solution* , User's Guide (SWRU521)
2. Texas Instruments, *Programming Chirp Parameters in TI Radar Devices*, Application Report (SWRA553)
3. Texas Instruments, *IWR1642 Single-Chip 77- and 79-GHz mmWave Sensor*, IWR1642 Datasheet (SWRS212)
4. Texas Instruments, *IWR14xx/16xx Technical Reference Manual*, Technical Reference (SWRU522)
5. Texas Instruments, *IWR1642 Evaluation Board Design Database*, Schematic (SPRR255)
6. Texas Instruments, *IWR1642BOOST Schematic, Assembly, and BOM*, Schematic (SPRR256)
7. Texas Instruments, *mmWave SDK User's Guide*, Tools Folder