TI 设计：*TIDEP-0092*
使用 *AWR1642* 的短距离雷达参考设计

说明

TIDEP-0092 为使用 AWR1642 评估模块 (EVM) 开发短距离雷达 (SRR) 应用奠定了基础。该设计可实现在其高达 80m 的视野内估算物体的位置（在方位平面中）和速度。

资源

TIDEP-0092	设计文件夹
AWR1642	产品文件夹
TCAN1042	产品文件夹
TMP112	产品文件夹
LP87524	工具文件夹

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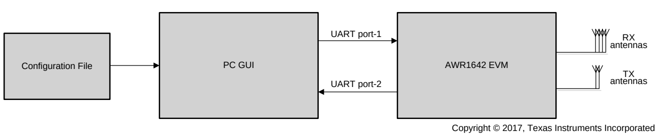
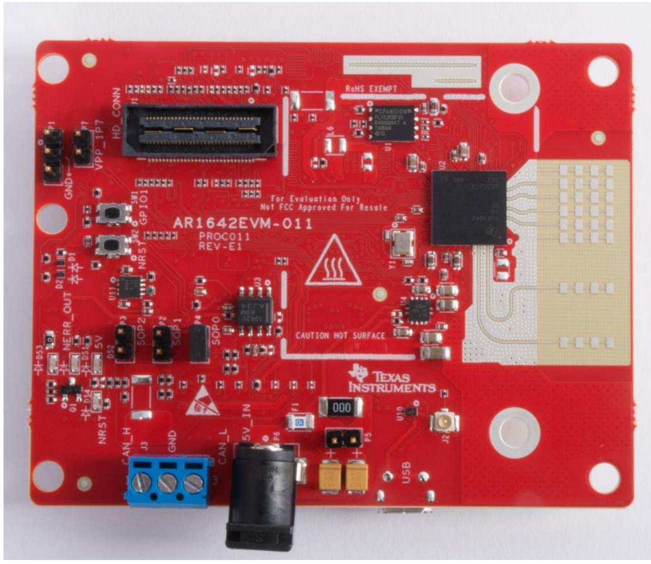
特性

- 适用于 SRR 应用的 单芯片雷达
- 通过 35cm 的距离分辨率检测距离高达 80m 的物体（如汽车和摩托车）
- 天线视野为 ±60º，且角度分辨率约为 15º
- 通过毫米波软件开发套件 (SDK) 提供了快速傅里叶变换 (FFT) 处理和检测源代码
- AWR1642 演示了设计
- 对雷达前端和检测配置进行了全面说明

应用

- 车道变换辅助系统 (LCA)
- 自主泊车
- 侧向来车警示系统 (CTA)
- 盲点监测系统 (BSD)





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1 System Description

Autonomous control of vehicles provides quality-of-life and safety benefits making the mundane but tense act of driving safer and less difficult. The quality-of-life features include the ability of a vehicle to park itself or to assist in situations where a lane change is required and with automatic cruise control—where a vehicle maintains a constant distance with respect to the car ahead of it. In the near future, cars are expected to drive themselves. Each of these features require a variety of sensors to detect obstacles and other cars in the environment as well as track their velocities and positions over time.

1.1 Why Radar?

Automotive 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 (autonomous breaking and collision avoidance). An important advantage of radars over camera and lidar-based systems is that radars are relatively immune to environmental conditions (such as the effects of rain, dust, and smoke). Additionally, radars can work in complete darkness or in bright day light (radars are not affected by glare).

1.2 TI SRR Design

The TIDEP-0092 is an introductory application that is configured for short range applications (that is to detect objects up to a distance of 80 m as well as estimate their velocities and positions). The TI Design can be used as a starting point to design a stand-alone sensor for a variety of SRR automotive applications. A range of more than 80 m can be achieved with the design of an antenna with higher gain than the one included in the AWR1642.

1.3 Key System Specifications

表 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

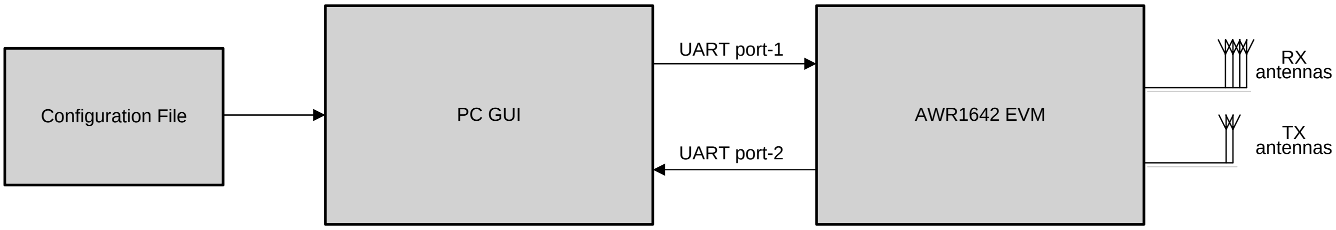

图 1. SRR System Block Diagram

2.2 Highlighted Products

2.2.1 AWR1642 Single-Chip Radar Solution

The AWR1642 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 AWR1642

The AWR1642 has the following features:

1. AWR1642 radar 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 radar configuration on the AWR1642 device, and UART2 to send the object data back to the PC

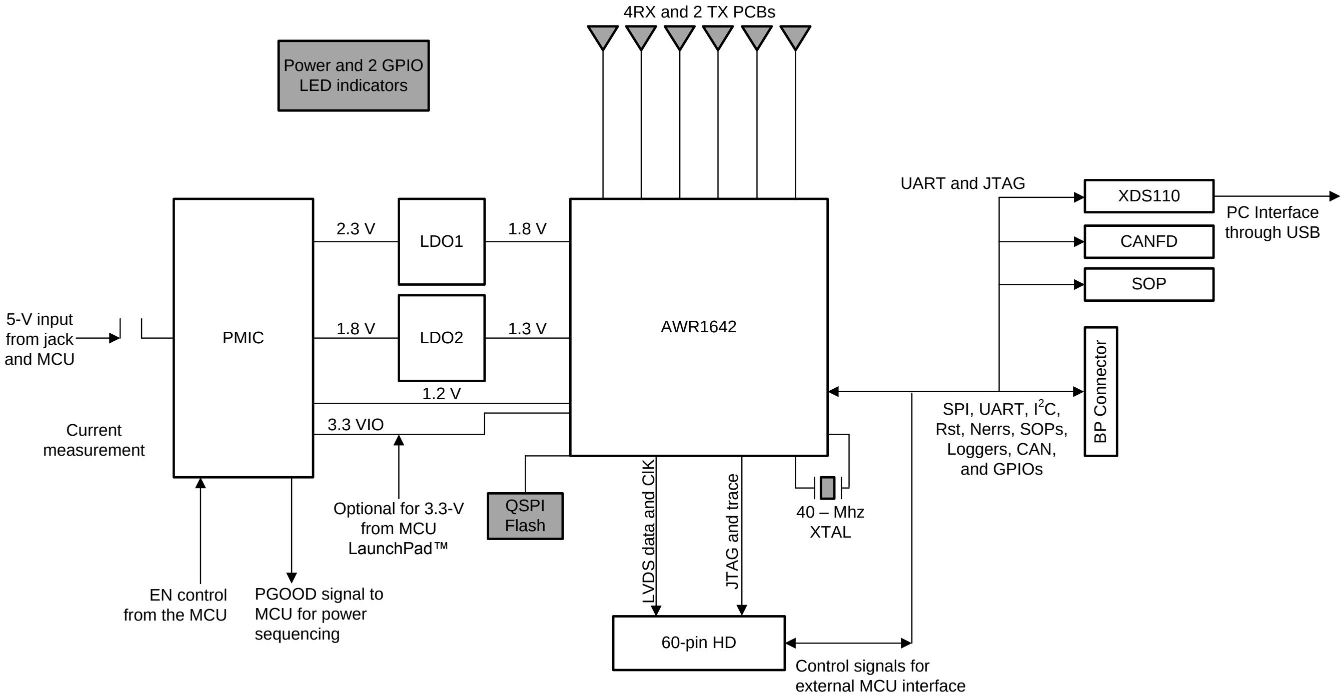

图 **2. AWR1642**

For more details on the hardware, see the *AWR1642 Evaluation Module (AWR1642BOOST) Single-Chip mmWave Sensing Solution*[1]. The schematics and design database can be found in the following documents: *AWR1642BOOST Design Database*[5] and *AWR1642BOOST Schematic, Assembly, and BOM*[6].

2.3 System Design Theory - Chirp Configuration

2.3.1 Antenna Configuration

The TIDEP-0092 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 图 3. This technique improves the angle resolution by a factor of two (compared to a single TX configuration).

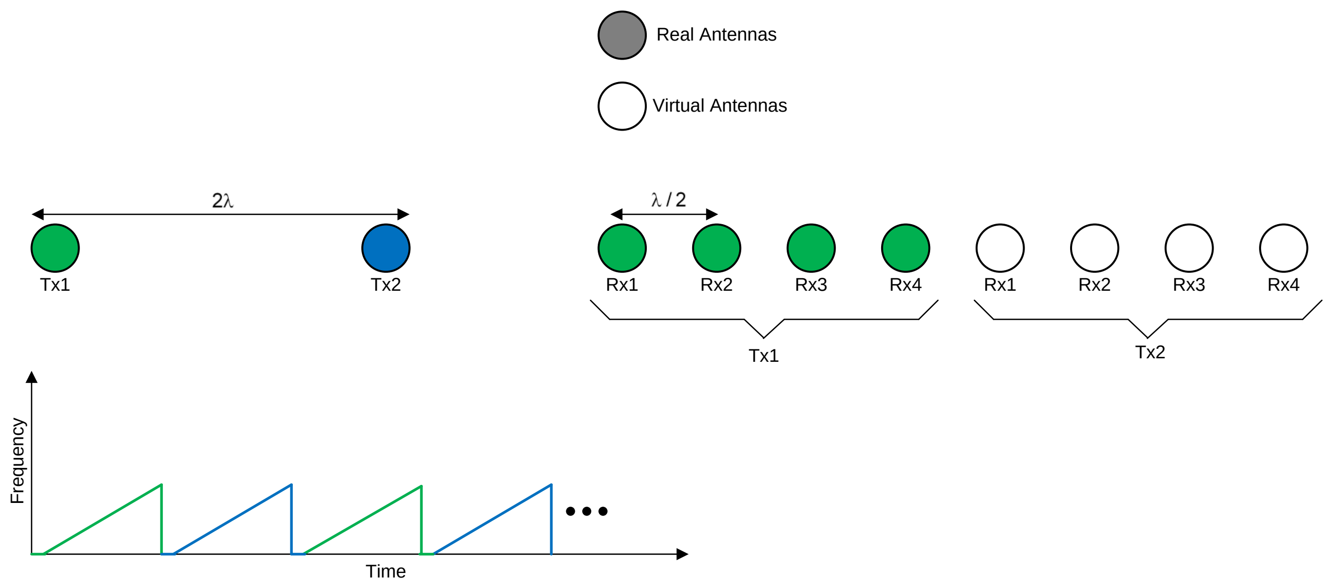

图 3. MIMO Antenna Configuration

2.3.2 Chirp Configuration and System Performance

To achieve the specific SRR use case with a visibility range of approximately 80 m and memory availability of AWR1642, the chirp configuration in 表 2 is used.

表 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 表 2 configuration is selected to achieve the system performance shown in 表 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 AWR1642). 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 SRR radar 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 SRR design but is targeted for a future release.

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

表 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 R1.0 distribution that represents the SRR TI Design allows the user to push the Radar 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 SRR 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 表 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 图 4 shows the processing data part to the SRR application.

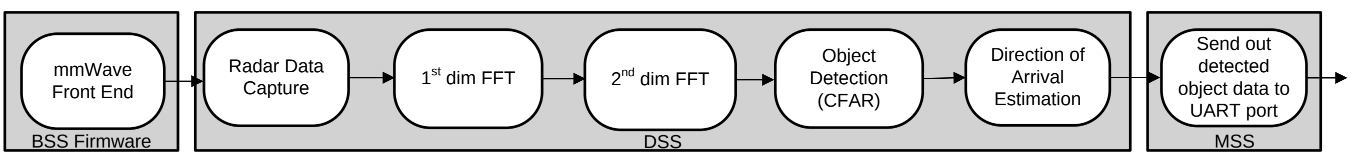

图 **4. SRR Data Path or Processing Chain**

2.3.5 Chirp Timing

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

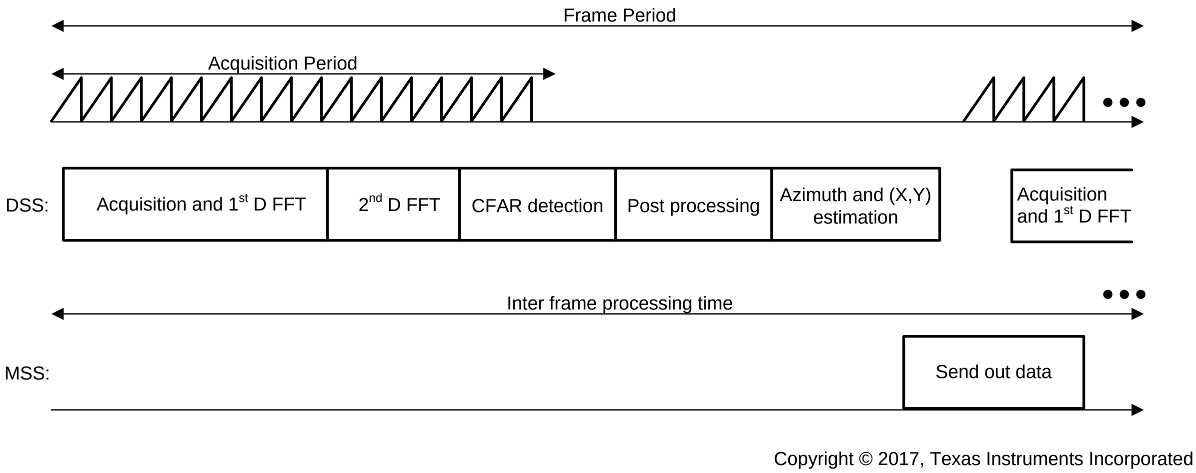

图 5. Top Level Data Path Timing

As seen in 图 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 C67x DSP subsystem (DSS) for processing.
- Processing during the chirps as seen in 图 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 图 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 AWR1642 BoosterPack™ from Texas Instruments is an easy-to-use evaluation board for the AWR1642 mmWave sensing devices.

The short range radar application runs on the AWR1642 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 *AWR1642 Evaluation Module (AWR1642BOOST) 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 AWR1642 core design includes:

- AWR1642 device, a single-chip, 77-GHz radar 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

表 4 summarizes the time complexity of key building blocks in the processing chain (running on C674x DSP hosted in the AWR1642).

表 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 节 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 on the SRR system where a single small vehicle and motorcycle were driven away from the system while the results were being logged.

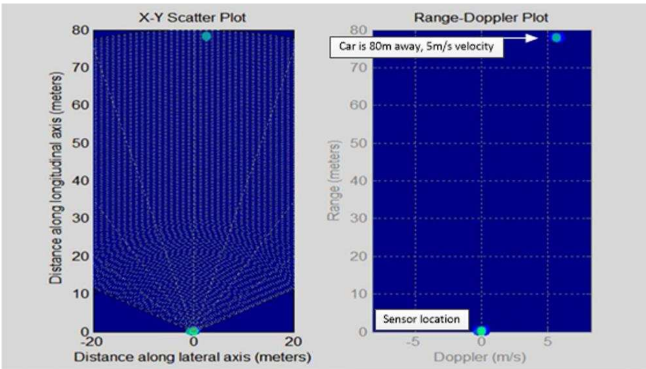

图 6. Small Car Test at 80 m

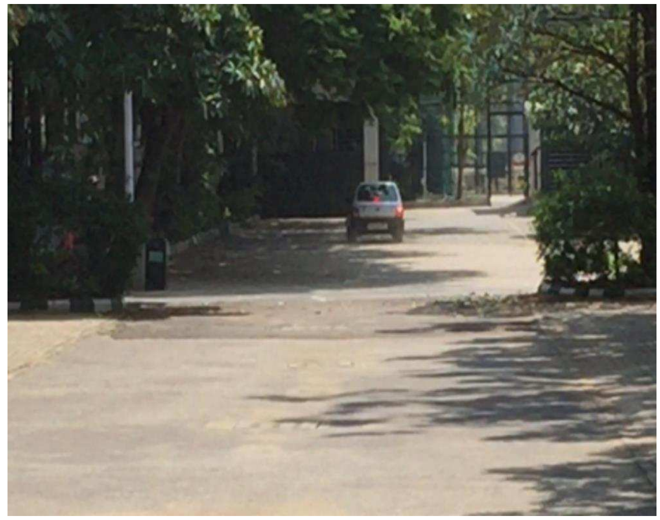

图 7. Small Car Test at 80 m

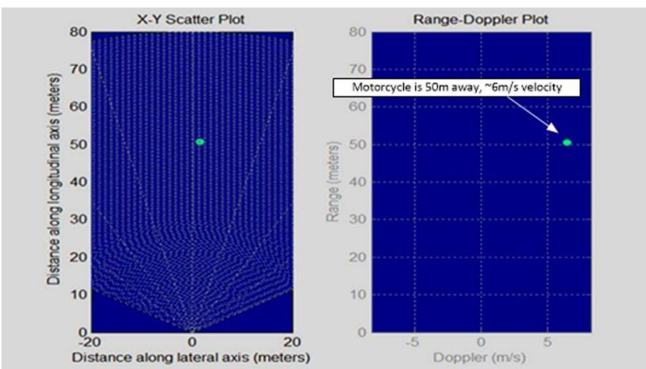

图 8. Motorcycle Test at 50 m

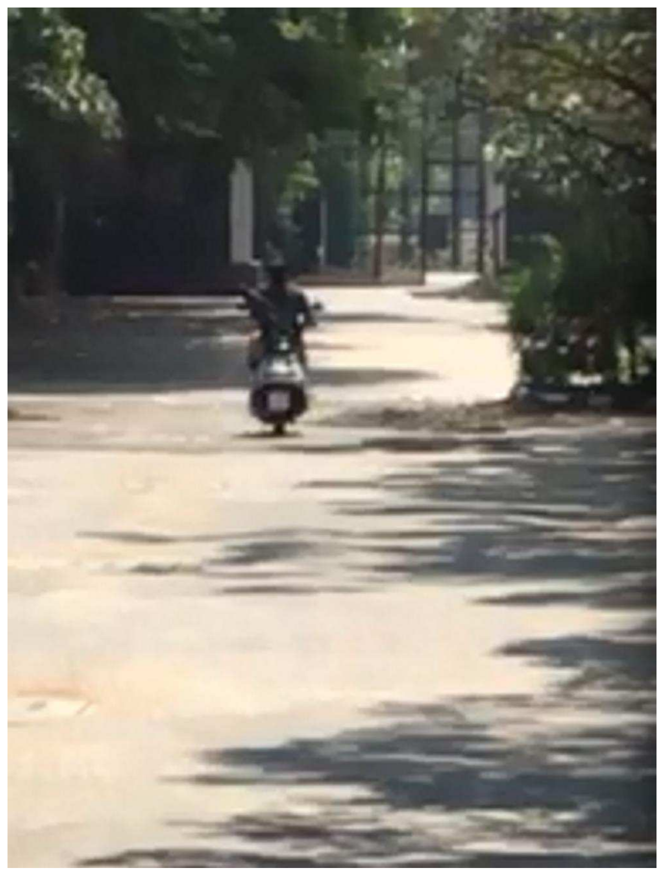

图 9. Motorcycle Test at 50 m

4 Software Files

To download the software files, see the design files at TIDEP-0092.

5 Related Documentation

1. Texas Instruments, *AWR1642 Evaluation Module (AWR1642BOOST) Single-Chip mmWave Sensing Solution*, User's Guide (SWRU508)
2. Texas Instruments, *Programming Chirp Parameters in TI Radar Devices*, Application Report (SWRA553)
3. Texas Instruments, *AWR1642 Single-Chip 77- and 79-GHz FMCW Radar Sensor*, AWR1642 Datasheet (SWRS203)
4. Texas Instruments, *AR14xx/16xx Technical Reference Manual*, Technical Reference (SWRU520)
5. Texas Instruments, *AWR1642 Evaluation Board Design Database*, Schematic (SPRR261)
6. Texas Instruments, *AWR1642BOOST Schematic, Assembly, and BOM*, Schematic (SPRR251)
7. Texas Instruments, *mmWave SDK User's Guide*, Tools Folder
8. Texas Instruments, *AWR1642 mmWave sensor: 76–81-GHz radar-on-chip for short-range radar applications*, Marketing White Papers (SPYY006)

6 About the Author

ANIL MANI is a system engineer at Texas Instruments where he is responsible for designing algorithms for the radar processing chain. Anil has been with TI since 2008 and has been involved in the design of various products related to wireless communication.

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