

AWR1443 single-chip radar: for diverse proximity-sensing applications



Karthik Ramasubramanian
Radar Systems Manager

Jasbir Singh
SoC Architect

Texas Instruments

Abstract

The [AWR1443](#) millimeter wave (mmWave) sensor is a highly integrated 76–81-GHz radar device that serves as a single-chip radar solution suitable for proximity-sensing automotive radar applications.

The AWR1443 device includes the entire mmWave radio frequency (RF) and analog baseband signal chain for three transmitters and four receivers, as well as a customer-programmable microcontroller (MCU) and hardware accelerator for radar signal processing. Typical automotive applications include proximity-sensing applications such as door/trunk opener, ground clearance measurement and in-cabin applications.

In this white paper, we will cover the device's high-level architecture and features, and discuss various chirp configuration examples and potential applications.

Introduction

The use of radar technology in various automotive applications has grown tremendously in recent years. Typical applications include blind-spot detection (BSD), front/rear cross-traffic alert (F/RCTA), autonomous emergency braking (AEB) and adaptive cruise control (ACC). Looking beyond these applications, radar is a promising technology for new use cases that involve proximity-sensing and entry-level radar functionality. For instance, applications such as door/trunk opener, ground clearance measurement and in-cabin applications require accurate range measurement at close proximity (e.g., 20 m or less).

The benefits of radar technology include its robustness to dirt, mud, snow, fog and other environmental conditions and it can work in the dark without any ambient lighting. Also, compared to ultrasonic technology, radar covers better range (both in terms of minimum distance and maximum distance), can work behind bumpers, and has the ability to also accurately measure velocity and angle of an object. Compared to narrowband

24-GHz radar, the use of 76–81-GHz radar offers several advantages, such as high range resolution and accuracy due to the large 4-GHz bandwidth availability, smaller sensor size due to the high RF frequency and good velocity resolution due to the small wavelength.

The requirements on a radar device, in terms of radar data-cube memory and processing capability vary for different applications. This white paper introduces the AWR1443 mmWave sensor as a 76–81-GHz single-chip radar solution for proximity-sensing and entry-level radar applications and presents the relevant features, high-level architecture and potential use cases.

The AWR1443 radar sensor includes the entire mmWave radio-frequency (RF) and analog baseband signal chain for three transmitters and four receivers, as well as a customer-programmable microcontroller (MCU) and hardware accelerator for radar signal processing. This device is applicable as a single-chip radar for applications with modest requirements for memory, processing MIPS and application code size.

Other Texas Instruments devices like the [AWR1642](#) and [AWR1243](#) sensors + [TDA3x](#) processors offer higher levels of performance and flexibility via a programmable digital signal processor (DSP), thus addressing standard short-, mid- and long-range automotive radar applications.

The AWR1443 radar sensor includes three transmit and four receive chains, a 200-MHz user-programmable ARM® Cortex®-R4F processor and a radar hardware accelerator. As **Figure 1** shows, the device comprises three main subsystems: the RF/analog subsystem, the radio processor subsystem and the master subsystem.

The RF/analog subsystem includes the RF and analog circuitry: the synthesizer, power amplifier (PA), low-noise amplifier (LNA), mixer, intermediate frequency (IF) amplifier and analog-to-digital converter (ADC). This subsystem also includes a crystal oscillator and temperature sensors.

Two of the three transmit channels can operate simultaneously for transmit beamforming purposes as required, whereas all four receive channels can operate simultaneously. The device supports wide RF bandwidth covering 76–77-GHz and 77–81-GHz bands.

The radio processor subsystem includes the digital front end, ramp generator, and an internal processor for controlling and configuring low-level RF/analog and ramp generator registers based on well-defined application programming interface (API) messages from the master subsystem. [Note that this radio processor is TI programmed and takes care of RF calibration needs and some built-in self-test (BIST)/monitoring functions; the processor is not available directly for customer use.] The digital front end takes care of filtering and decimating the raw sigma-delta ADC output and provides the final ADC data samples at a programmable sampling rate.

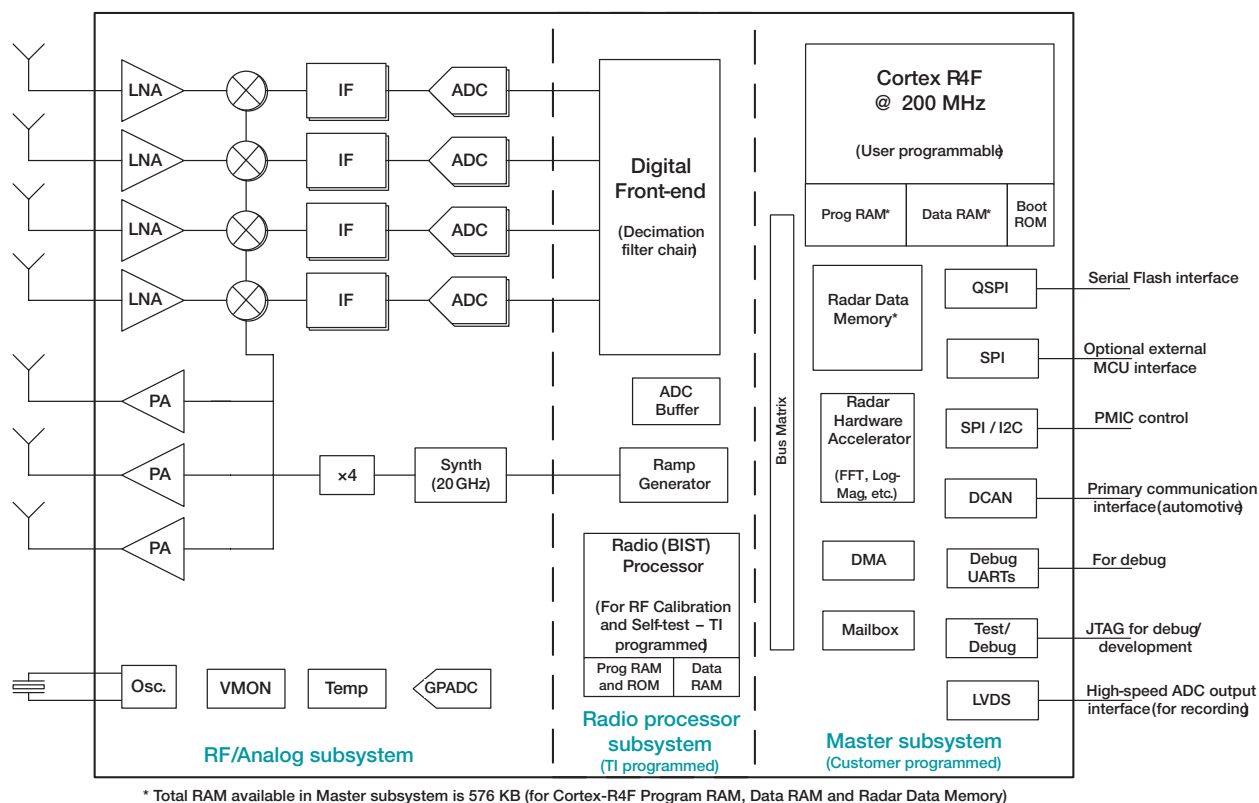


Figure 1. AWR1443 radar high-level architecture.

The master subsystem includes ARM's automotive-grade Cortex-R4F processor clocked at 200 MHz, which is customer programmable. This processor controls the overall operation of the device, implements the radar signal processing (assisted by the radar hardware accelerator) and configures the radar transmit/receive operations via well-defined API messages, which are written to the radio processor through a mailbox interface.

For proximity-sensing and entry-level radar applications, the AWR1443 device can function as an autonomous single-chip radar sensor. The device includes a quad serial peripheral interface (QSPI), which can download customer code directly from a serial Flash. An included (classic) controller area network (CAN) interface communicates directly from the device to a CAN bus. An I²C/serial peripheral interface (SPI) is available for power-management-integrated-circuit (PMIC) control when using the AWR1443 mmWave sensor as an autonomous sensor.

For more complex applications, the device can operate under the control of a low-cost external MCU, which communicates to and commands the device through an SPI interface, through which it downloads code as well. In this case, it is possible to use the AWR1443 device as a radar sensor, providing raw detected objects to the external MCU. The external MCU can provide additional functions (e.g., motor control) and can help reduce application code complexity residing in the AWR1443 device (for Automotive Open Systems Architecture [AUTOSAR], security features and so on). This configuration makes more memory available for the radar data cube inside the AWR1443 device and also eliminates the need to connect a separate serial Flash to the AWR1443 device. Furthermore, the external MCU can provide faster interfaces if required, such as CAN-flexible data rate (FD)

or Ethernet, for the radar sensor to connect to a central processing unit (CPU).

The total memory available in the master subsystem is 576 KB. This is partitioned between the R4F program RAM, R4F data RAM and radar data memory. The maximum usable size for the R4F is 448 KB and is partitioned between the R4F's tightly coupled memory interfaces, TCMA (320 KB) and TCMB (128 KB)

The remaining memory, starting at a minimum of 128 KB, is available as radar data memory for storing the radar data cube. It is possible to increase the radar data memory size in 64-KB increments, at the cost of a corresponding reduction in R4F program or data RAM size. The maximum size of radar data memory possible is 384 KB. **Table 1** lists a few example configurations.

Option	R4F program RAM	R4F data RAM	Radar data memory
1	320 KB	128 KB	128 KB
2	256 KB	128 KB	192 KB
3	256 KB	64 KB	256 KB
4	128 KB	64 KB	384 KB

Table 1. Example memory configurations.

The master subsystem also includes a radar hardware accelerator to assist the R4F with frequently used radar signal-processing computations such as fast Fourier transform (FFT) and log magnitude. Let's explore this module.

Radar hardware accelerator

The radar hardware accelerator module enables offloading of certain frequently used computations in frequency-modulated continuous-wave (FMCW) radar signal processing from the R4F processor. FMCW radar signal processing involves the use of FFT and log-magnitude computations in order to obtain a radar image across the range, velocity and

angle dimensions. Some frequently used functions in FMCW radar signal processing occur within the radar hardware accelerator, while proprietary algorithms related to clustering or object tracking happen in the R4F processor.

The key features of the radar hardware accelerator are:

- Fast FFT computation, with programmable sizes (powers of 2) up to a 1,024-point complex FFT.
- Internal FFT bit width of 24 bits (each for I and Q) for good signal-to-quantization-noise ratio (SQNR) performance, with fully programmable butterfly scaling at every radix-2 stage for user flexibility.
- Built-in capabilities for simple pre-FFT processing: programmable windowing, basic binary phase modulation (BPM) removal and interference zeroing out.
- Magnitude (absolute value) and log-magnitude computation capability.
- Flexible data-flow and data-sample arrangement to support efficient multi-dimensional FFT operations and transpose accesses as required.
- Chaining and looping mechanism to sequence a set of accelerator operations with minimal intervention from the main processor.
- Constant false-alarm rate–cell averaging (CFAR-CA) detector, supporting linear and logarithmic modes.
- Miscellaneous other capabilities: FFT stitching, slow discrete Fourier transform (DFT) and complex vector-multiplication capability.

The radar hardware accelerator shown in **Figure 2** comprises four memories, each 16 KB, that send input data to and pull output data from the main accelerator engine. These memories are referred to as the radar hardware accelerator’s “local memories” and are separate from the 576 KB total RAM described in the previous section.

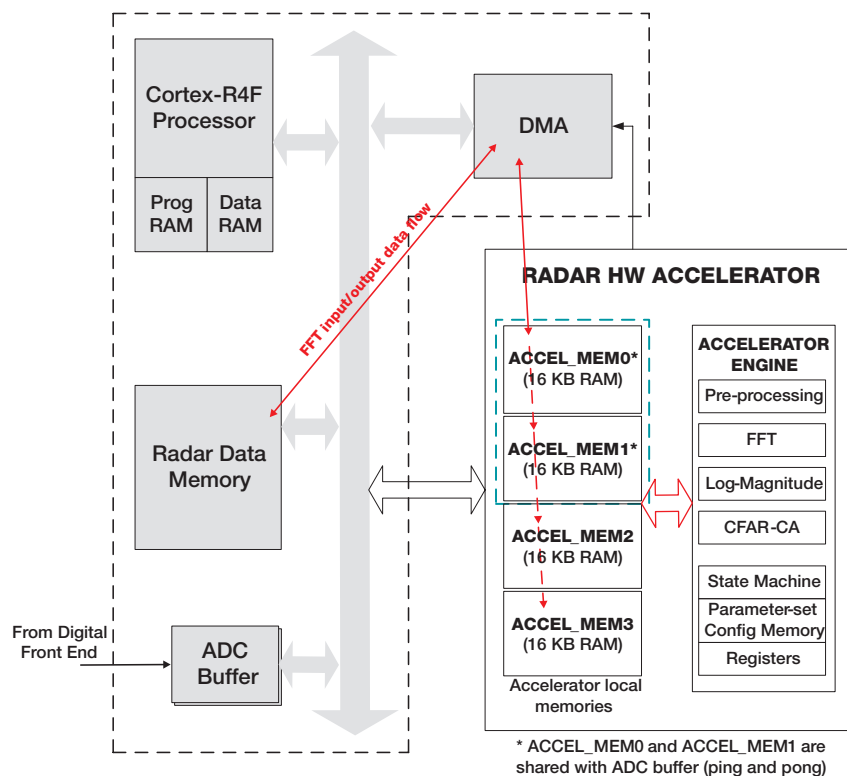


Figure 2. Radar hardware accelerator.

The general data flow is that the direct memory access (DMA) module brings in samples (such as FFT input samples) into the radar hardware accelerator's local memories so that the main accelerator engine can access and process these samples. Once the accelerator's processing is done, the DMA module reads the output samples from these local memories and stores them back in either radar data memory or R4F data RAM for further processing by the R4F processor. **Figure 2** shows where the red arrow indicates data movement from and to radar data memory into and out of the local memories for the FFT and other processing steps.

The purpose behind four separate 16-KB memories inside the radar hardware accelerator is to enable a “ping-pong” mechanism, both for the input and for the output, such that DMA write (and read) operations can happen in parallel to the accelerator's main computational processing. The presence of four memories enables such parallelism.

The radar hardware accelerator is designed to provide good performance as well as user flexibility for implementing various computational operations. Two types of registers configure operations: “parameter sets” and static (common) registers. The purpose of parameter sets is to enable the pre-programming of a complete sequence of accelerator operations (with appropriate source and destination memory addresses and other configurations specified for each operation in that sequence), such that the accelerator can perform them with minimal intervention from the R4F processor. A state machine built in to the accelerator handles the loading of one parameter-set configuration at a time and sequences pre-programmed operations, thus reducing the need for frequent interruptions to the R4F processor. The operating clock frequency of the radar hardware accelerator is 200 MHz. The internal architecture of the accelerator engine is such that a steady-state

FFT throughput of 200 MSPS is possible—one FFT input and one FFT output every clock cycle, after an initial latency. A detailed user guide provides further information about the capabilities and usage procedure for the accelerator.

AWR1443 device use cases

As we mentioned, the AWR1443 device can act as a single-chip radar for proximity-sensing and entry-level automotive radar applications. Let's illustrate how.

In **Table 2**, we show a proximity-sensing or ultrasonic upgrade example using the AWR1443 device. In this example, two chirp configurations in alternating frames cover near range (up to 4.5 m) at very high resolution and full range (up to 16 m) at normal resolution.

For proximity-sensing applications, the availability of sweep bandwidth up to 4 GHz using the wide 77–81-GHz band achieves high-range resolution.

Proximity sensing/ultrasonic upgrade example

(Alternating frames with different chirp configurations for near range and full range)

Sweep bandwidth	3.75 GHz	500 MHz
Range resolution	4 cm ← High resolution	30 cm ← Normal resolution
Maximum unambiguous range	4.5 m ← Near range	16 m ← Full range
Ramp slope	100 MHz/μs	25 MHz/μs
Chirp duration	37.5 μs valid (+120 μs inter-chirp)	20 μs valid (+15 μs inter-chirp)
Number of chirps	64	128
Maximum unambiguous relative velocity	±22 kmph	±100 kmph
Maximum beat frequency	3.0 MHz	2.66 MHz
ADC sampling rate (I, Q)	3.33 MSPS (complex)	3 MSPS (complex)
Frame time	64 × 157.5 μs = 10 ms	128 × 35 μs = 4.5 ms
Range FFT size	128 (complex)	64 (complex)
Radar data memory	128 × 64 × 4 RX × 4 Bytes = 128 KB	64 × 128 × 4 RX × 4 Bytes = 128 KB

Table 2. Example chirp configuration for ultrasonic upgrade.

Such high-range resolution provides better minimum distance measurement capability compared to ultrasonic sensors.

The availability of three transmit and four receive channels in the AWR1443 device also facilitates elevation estimation. Specifically, transmitting additional chirps or frames (beyond the azimuth scan shown in **Table 2**) enables the use of one or more TX channels for elevation scanning.

The example shown in **Table 2** uses the lowest configuration of radar data memory, starting at 128 KB. As we mentioned earlier, it is possible to increase the radar data memory in steps of 64 KB, up to a maximum of 384 KB, in order to achieve higher performance (in terms of larger range, range resolution, maximum velocity, velocity resolution, etc.) at the cost of a correspondingly reduced program memory for the R4F.

Summary

The use of radar in automotive applications is growing rapidly. New applications are emerging that go beyond the traditional short-range, mid-range and long-range use cases. The AWR1443 device enables you to leverage the superior performance of radar technology for emerging proximity-sensing applications in the automotive space. The potential applications include door protection, ground clearance measurement and in-cabin occupant detection. With the upcoming regulatory support for 77–81-GHz band across the globe for automotive radar, future radar sensors can achieve very high range resolution and accuracy required for sensing at close proximity. Being a single-chip solution, the [AWR1443](#) mmWave sensor is well-suited for such applications and enables you to implement a radar-based proximity sensor in a compact form factor and in a cost-effective manner.

Important Notice: The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI's standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer's applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company's products or services does not constitute TI's approval, warranty or endorsement thereof.

The platform bar is a trademark of Texas Instruments. All other trademarks are the property of their respective owners.

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ("TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products (<http://www.ti.com/sc/docs/stdterms.htm>), [evaluation modules](#), and [samples](http://www.ti.com/sc/docs/sampterm.htm) (<http://www.ti.com/sc/docs/sampterm.htm>).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2017, Texas Instruments Incorporated