Application Note

Getting Started with mmWave Sensors

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ABSTRACT

The mmWave radar sensors help solve vision-sensing challenges in automotive and industrial applications with high-performance sensors that can withstand tough environmental conditions. These fully integrated products enable sensing applications with long range, high resolution, and edge intelligence. This document helps users to fully understand the radar working principles and getting started with development. The contents of this document are structured in a systematic way to help users understand the development flow. Starting from selecting the sensor to production, the steps are described in this application note. The scope of this document aims to assist users at every stage of the design development. The application note also enlists all the collaterals by TI to aid the users in understanding the mmWave sensors and building custom designs. This application note only focuses on the automotive domain.

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1 Introduction

The application note is divided into the following sections to cover all aspects of mmWave sensors.

- **Discover Phase**: designed to help users understand the mmWave sensor, the requirements in the automotive industry, and to pick the appropriate product for application.
- **Evaluation Phase**: provides insights into the evaluation offerings that are provided by TI to perform the initial testing on the sensor and finalize the product selection.
- **Development Phase**: documents the software and hardware development aspects with the sensor. This section assists the users in developing custom projects with mmWave sensors.
- **Production Phase**: outlines the production aspects of the mmWave sensor.

Figure 1-1. Different Phases in mmWave Sensor Development

2 Terminology

This Terminology module provides a dictionary of terms and acronyms related to TI radar sensors.

3 Discover Phase

This phase provides information on what a mmWave sensor is, why a sensor is required, and, finally, on how to select a sensor from the portfolio offered by TI.

3.1 What is a mmWave Sensor?

Millimeter wave (mmWave) is a special class of radar technology that uses short-wavelength electromagnetic waves. Radar systems transmit electromagnetic wave signals that objects in the path then reflect. By capturing the reflected signal, a radar system can determine the range, velocity and angle of the objects.

mmWave radars transmit signals with a wavelength that is in the millimeter range. This is considered a short wavelength in the electromagnetic spectrum and is one of the advantages of this technology. Indeed, the size of system components such as the antennas required to process mmWave signals is small. Another advantage of short wavelengths is the high accuracy. An mmWave system operating at 76–81GHz (with a corresponding wavelength of about 4mm) has the ability to detect movements that are as small as a fraction of a millimeter.

A complete mmWave radar system includes transmit (TX) and receive (RX) radio frequency (RF) components: analog components (such as clocking), digital components (such as analog-to-digital converters (ADCs)), microcontrollers (MCUs), and digital signal processors (DSPs). TI devices implement a special class of mmWave technology called frequency modulated continuous wave (FMCW). As the name implies, FMCW radars transmit a frequency-modulated signal continuously to measure range and angle and velocity. This differs from traditional pulsed-radar systems, which transmit short pulses periodically.

TI Reference Collaterals

- The mmWave training curriculum provides foundational content and hands-on examples for users to learn the fundamentals of FMCW technology and mmWave sensors to start development quickly. The training can be accessed from mmWave training series.

Note

The training series is highly recommended for all users to understand the basic working principles of a FMCW radar.

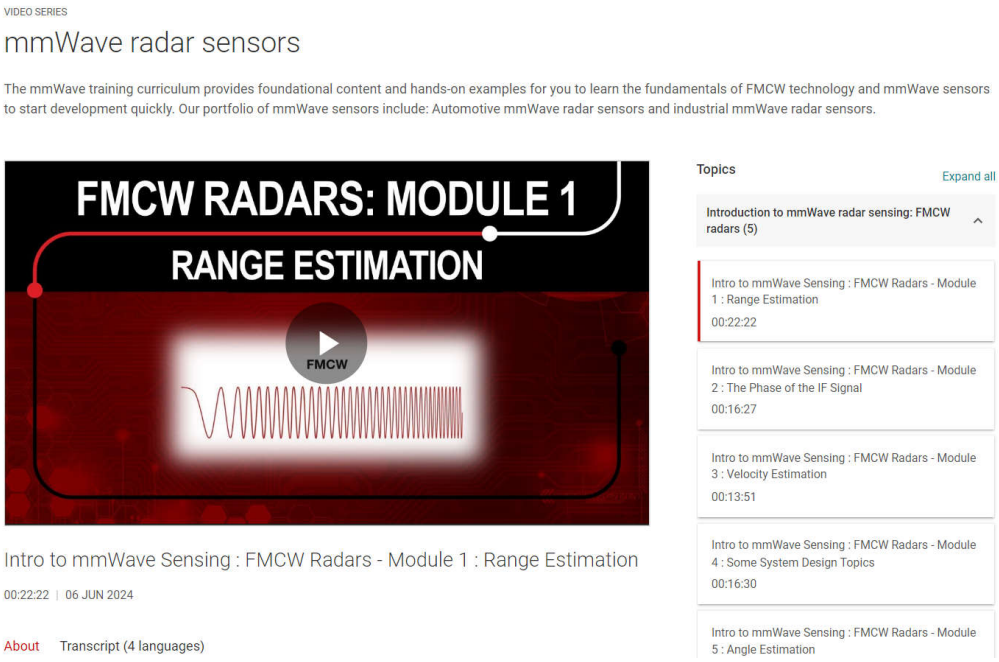

Figure 3-1. mmWave Training Series Landing Page

- The Radar Academy is a collection of training modules for all developers to learn about TI's radar sensor offering and the underlying mmWave Radar technology. The academy explores the technical foundation of mmWave sensing and demonstrates how this can be leveraged with TI's radar sensor portfolio. The training can be accessed from Radar Academy.

Note

Radar Academy is updated regularly by TI engineers and is highly recommended to all the users who want to learn and understand radar concepts and operating principles.

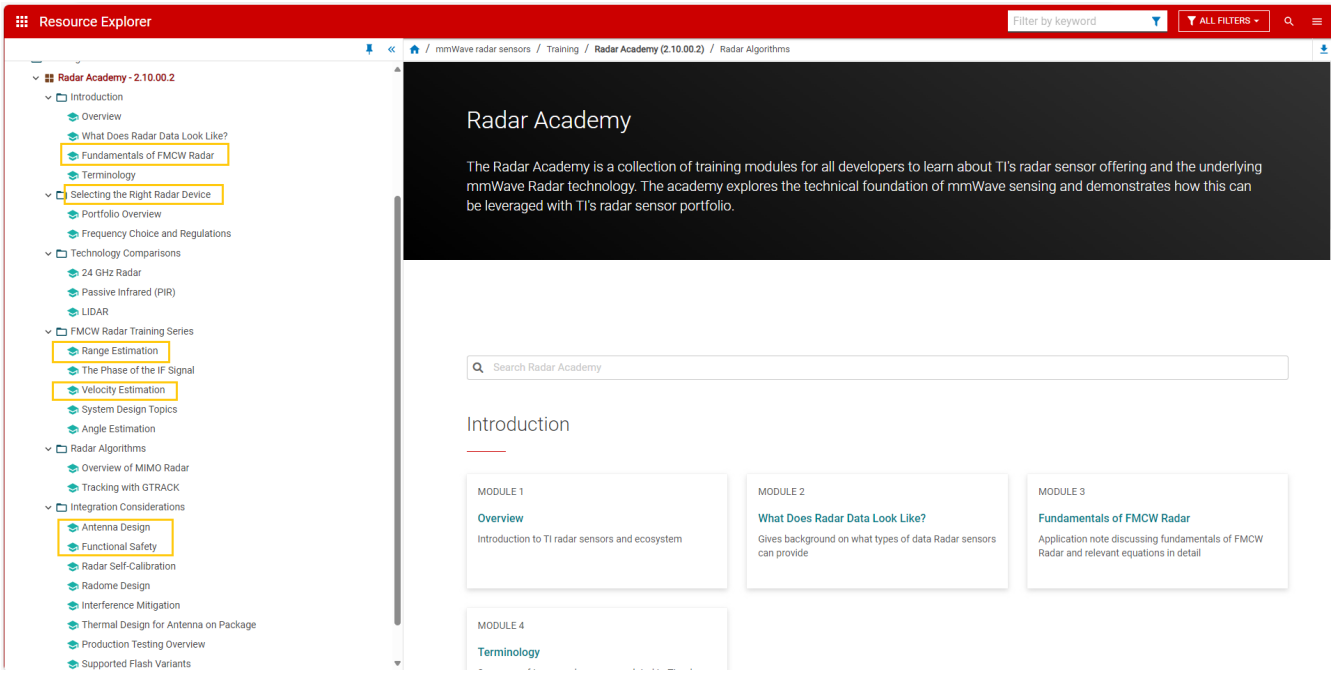

Figure 3-2. Radar Academy Landing Page

- TI has leveraged the traditional advantages of CMOS designs in terms of higher transistor density and low power to create a compelling family of mmWave devices. The CMOS MMIC Ready for Road – A Technology Overview application note enumerates some of these challenges, respective designs, and advantages of CMOS as leveraged in TI mmWave Sensing devices.
- The Moving from legacy 24GHz to state-of-the-art 77GHz radar white paper discusses the shift in the industry toward 77GHz radar and the various benefits users can achieve. TI has a family of highly integrated radar sensors that enables customers to leverage the benefits of the 77GHz frequency band for radar applications.

3.2 Why are mmWave Sensors Required in Automotive and ADAS?

As the level of autonomy in cars increases, choosing the right number and type of sensors becomes more complex. Traditional sensing options are available, but over the years, the application of radar within the automotive industry has positively evolved the definition of safety and efficiency.

Because radars can work in extreme environmental conditions such as rain, snow, dust, and bright sunlight and also provide precise distance and velocity information, radar is considered the most appropriate sensing modality to meet New Car Assessment Program (NCAP) requirements. Vehicle architectures are increasingly relying on smart radar sensors, with all processing occurring at the edge to send object lists to central electronic control units.

Radar sensing has become a cost-efficient sensing modality for required advanced driver assistance system (ADAS) functions and to meet the Society for Automotive Engineers vehicle autonomy levels 2+ and even 3+, as shown in the Figure 3-3.

Level 2+ 5 sensors	Front: 1 short range 1 medium range
	Rear: 1 short range 1 medium range 1 long range
Level 3+ 7 or more sensors	All of the sensors named above for front and rear Plus sensors on each side of the car for 360° coverage
Level 4 and beyond All sensing modalities	Front: Short- and medium-range sensors Rear: Short-, medium- and long-range sensors Sides: May include all sensing modalities including cameras, radar and lidar

Figure 3-3. Autonomy Levels and Corresponding Sensing Requirements

The Euro New Car Assessment Program (NCAP) recently updated the standards for radar to improve driver assistance features in new cars. NCAP standards vary by region. In the U.S., the NCAP is governed by the National Highway and Traffic Safety Administration (NHTSA). The Global NCAP is a centralized organization. However, all organizations have the same goal: to set standards that make cars and driving safer. The organizations provide ratings in the form of 0-5 stars to help consumers make informed new car buying decisions.

TI Reference Collaterals

- Texas Instruments, What ADAS Engineers Need to Know about the New NCAP Requirements for Radar technical article provides more detailed information.
- Texas Instruments, Meet corner radar NCAP regulations with TI's AWR2944 radar sensor video aids in comprehending NCAP regulations and TI's AWR2944 performance.

3.3 Understanding Frequency Choice and Regulations

TI's mmWave radar sensors are built to operate in one of two frequency bands: the 60GHz band or the 77GHz band. Depending on the local governmental regulations, radar products can be allowed to operate in one of these frequency bands. Typically, the 77GHz band is used for ADAS automotive applications, such as vehicle collision avoidance and fluid tank level sensing applications. The 60GHz band is often available for in-cabin automotive applications, such as child presence detection, and commercial applications, such as fall detection for the home.

TI Reference Collaterals

The Radar Academy module explains the TI mmWave regarding worldwide frequency regulation. This training can be accessed from Frequency Choice and Regulations.

3.4 What is Imaging Radar?

Imaging radar is enabled by a sensor configuration in which multiple low-power TI mmWave sensors are cascaded together and operate synchronously as one unit, with many receive and transmit channels to significantly enhance angular resolution and radar range performance. Angular resolution is the ability to distinguish between objects within the same range and the same relative velocity.

TI Reference Collaterals

The collaterals below capture all the details for the imaging radar.

- Imaging radar is the landing page of Imaging radar on TI.com. Users can access all the collaterals on imaging radar.
- The Imaging Radar: One Sensor to Rule Them All technical article explains what an imaging radar is and why an imaging radar is required in the automotive segment. TI devices like the AWR2243 and AWR1243 can be used in a cascaded system to meet the requirments for a imaging radar.
- ThemmWave Automotive Imaging Radar System - Long-Range Detection video shows the capability of TI imaging radar system. The mmWave automotive imaging radar system utilizes four AWR1243 sensors working as a single unit to achieve long detection range.

3.5 How to Check TI Portfolio and Select Product?

Automotive mmWave radar sensors shows the automotive mmWave sensors on TI.com and all the products. All the required information like product number, frequency range, number of transmitters and receivers, interface type, and so forth are provided to find the best product for the application.

The product can then be checked out by going to the specific product page for the selected device. The product page provides all the product details, technical documentation, design and development utilities and so forth, as shown below. Please note AWR2944 is used as a reference example.

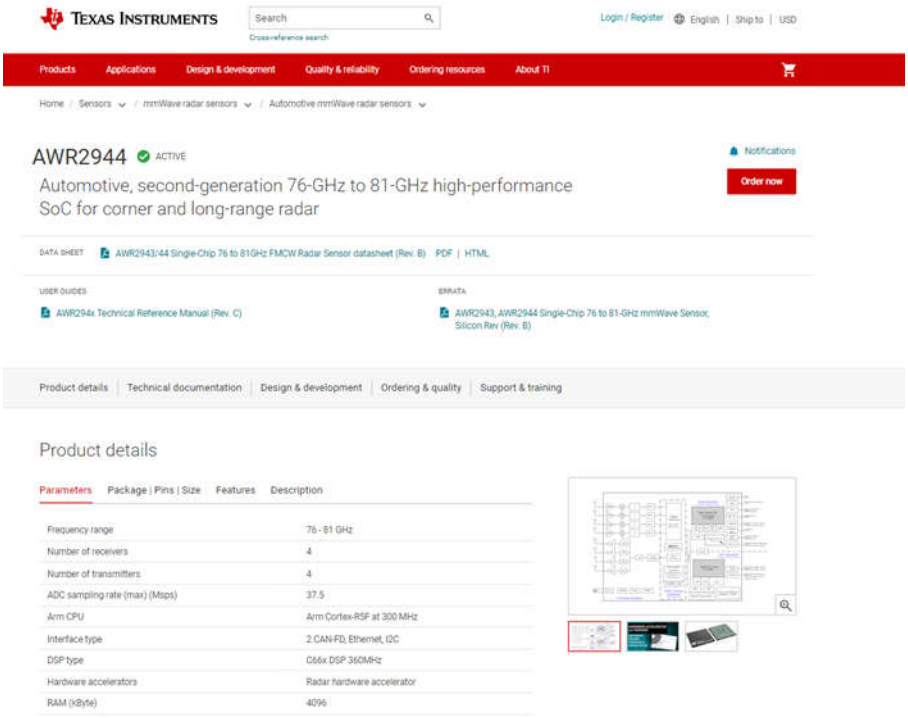

Figure 3-4. AWR2944 Product Page

TI Reference Collaterals

- Texas Instruments, Selecting the Right Radar Device, webpage

3.5.1 Selecting a Part Based on Application

Users can select a TI device based on the targeted application. Figure 3-5 through Figure 3-7 explains the process in a simplified way.

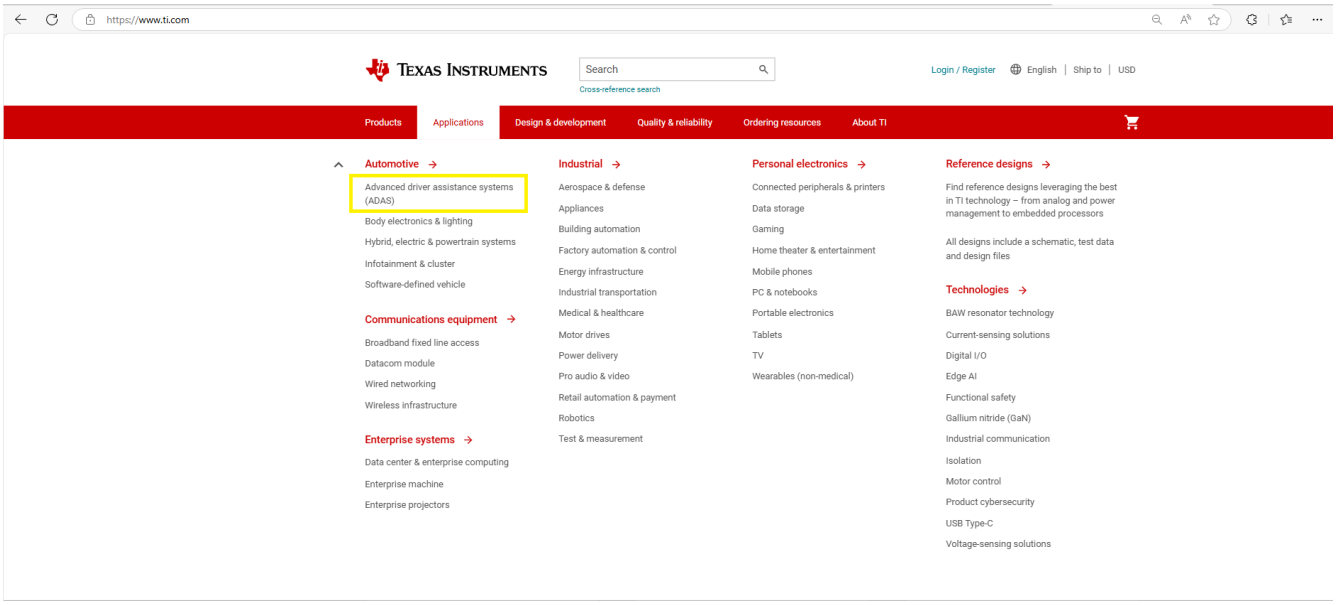

Figure 3-5. Selecting a Part Based On Application from TI.com

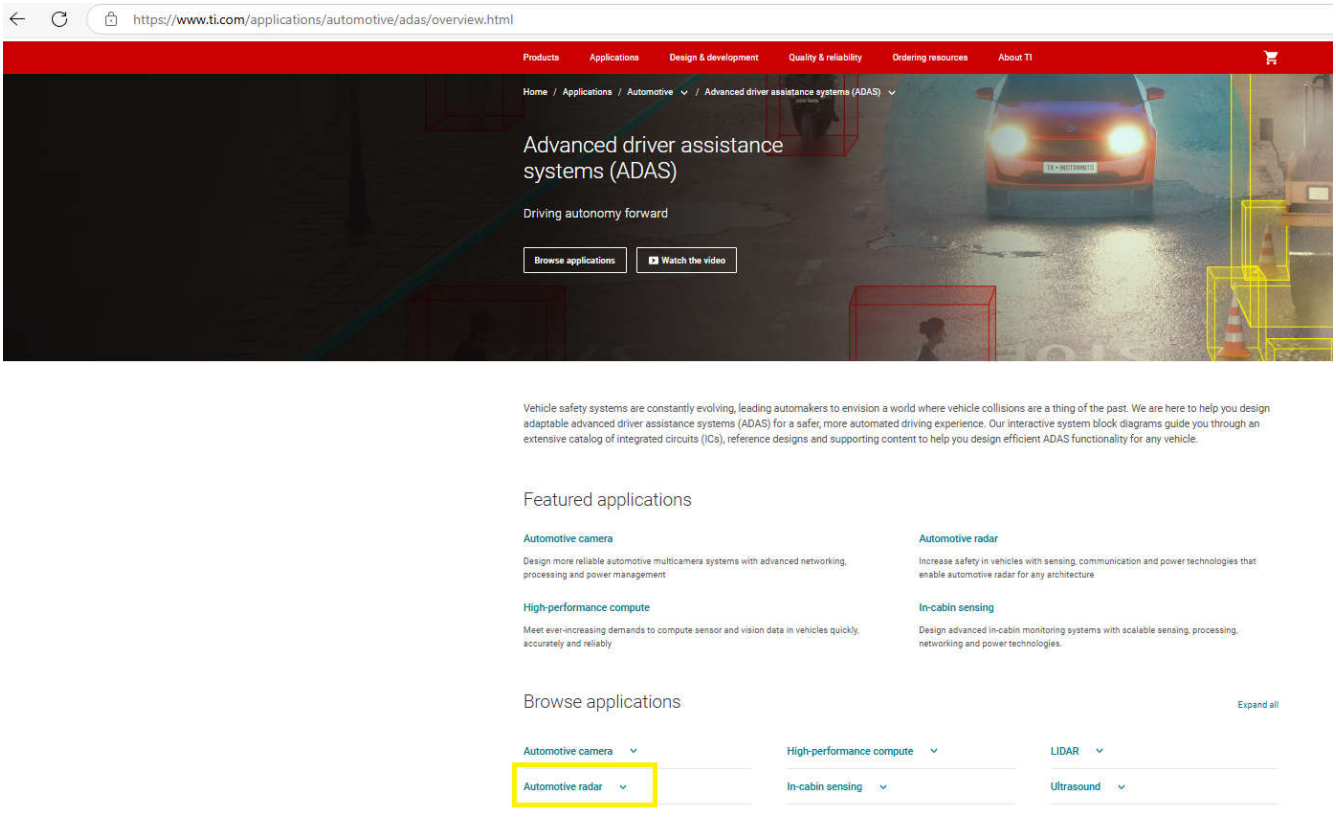

Figure 3-6. Selecting the Adas Technology for Which a Part is Required

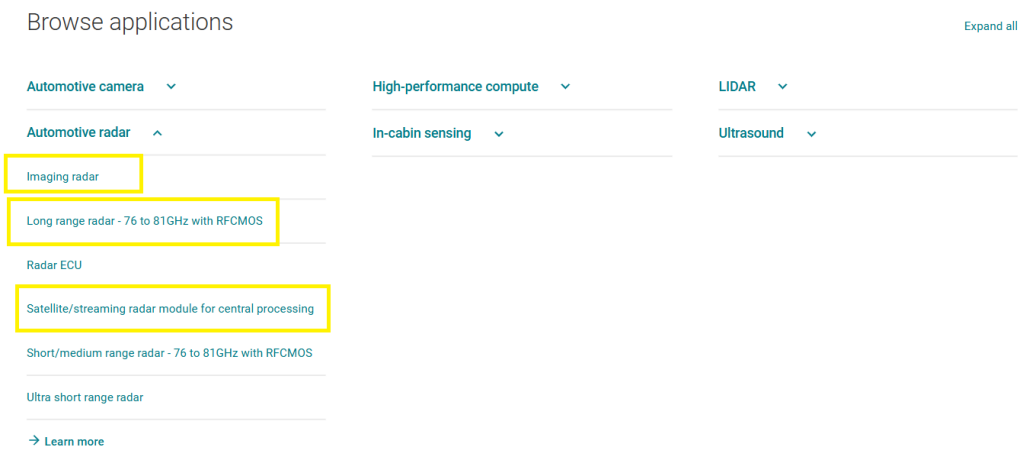

Figure 3-7. Choosing a Device Based on Application

4 Evaluation Phase

The evaluation offerings are categorized into hardware and software tools offerings. The following section provides more insights on them. This phase also describes about the various resources that are offered by our partners to help users in either getting started, in evaluation, or in development.

4.1 Hardware

To assist in user evaluation, a wide portfolio of Evaluation modules, capture boards are provided. TI recommends using the evaluation hardware to understand the mmWave sensors and to evaluate the performance of the sensors as per application requirements.

4.1.1 EVM

Evaluation Module (EVM) is an easy-to-use platform for evaluating any mmWave sensor. The EVM comes with a quick start guide to plug and play with the EVM with the preprogrammed OOB demo.

As an example, the AWR2944 website snips are provided for reference. The EVM can be ordered directly form the website for evaluation. The webpage also provides the design files for the EVM (containing the schematics, BOM, and so forth). The user's guide for the EVM along with other relevant documents are available on the EVM tool page on ti.com.

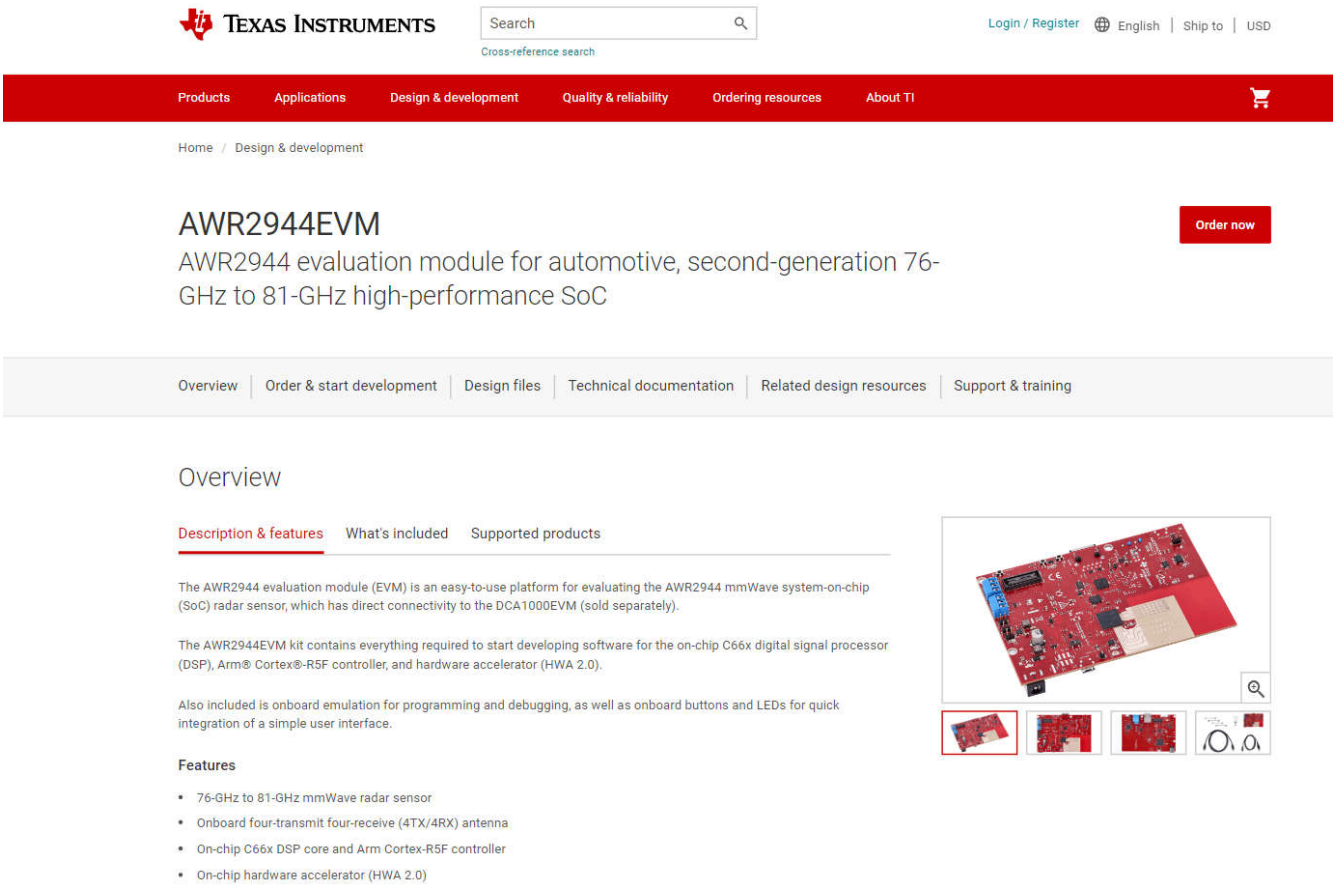

Figure 4-1. AWR2944EVM Tool Page

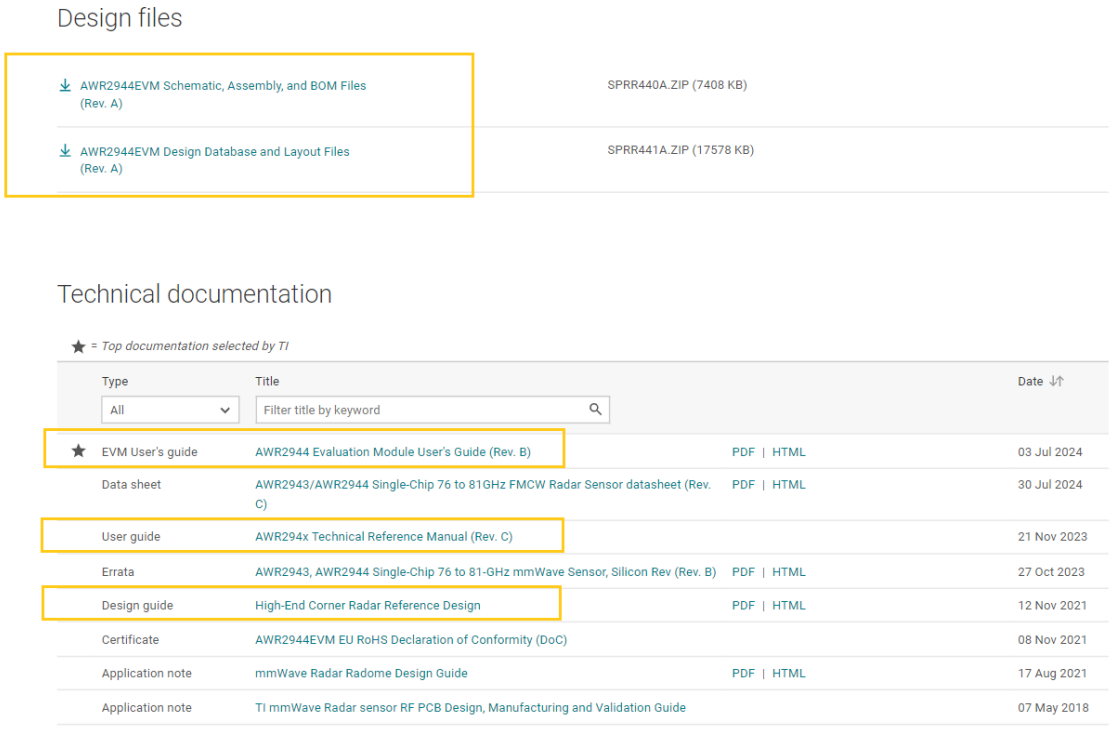

Figure 4-2. AWR2944EVM Technical Documentation

Note

Users can also check out other EVMs, boards offered by our partners to help in evaluation goals. The process is explained in Section 4.3.

4.1.2 DCA1000EVM

The DCA1000 evaluation module (EVM) is a capture design that provides real-time data capture and streaming through two-lanes (with AWR1642, AWR1843, AWR294x) and four-lanes (with AWR2243) low-voltage differential signaling (LVDS) traffic from TI AWR radar sensor EVMs. The data can be streamed out through 1Gbps Ethernet® in real-time to a PC running the MMWAVE-STUDIO tool for capture, and visualization, and then can be passed to an application of choice for data processing and algorithm development.

TI Reference Collaterals

- DCA1000 EVM is the landing page of the DCA1000EVM. Users can refer to the design files, technical documents, support and training resources and order the kit.
- DCA1000 Training Video describes how to capture and post process raw data using a mmWave EVM with the DCA1000 Capture Card and mmWave Studio

Note

The DCA1000, along with the MMWAVE-STUDIO, form a very sustainable combination to evaluate the TI offerings in mmWave sensors. The EVM can be used directly to run the pre-flashed OOB demo and the ADC data can be captured by using the DCA1000. This data can then be evaluated by any post processing algorithms for accuracy and correctness. TI highly recommends to use this setup for evaluation.

4.2 Software and Tools

TI provides a vast variety of software packages and tools to support user evaluation and development of the mmWave sensor. Though TI suggests to utilize all the software packages, IDEs, compiler packages and so forth, this does not bind or restrict the user to use all the tools, IDEs, debugger, compiler packages and so forth,.

For mmWave sensor evaluation and development, TI provides SDK, MCAL, SDL, CLANG compiler packages and many tools to evaluate the RF performance or assist in development like Radar Toolbox, mmWave Studio, Uniflash and so forth.

4.2.1 Software Development Kits (SDK)

Each TI radar sensor which includes an integrated MCU has an associated SDK available. The SDK contains all necessary software components to take full advantage of the processing capabilities of the radar sensor, such as kernels, drivers, and example code. SDK also contains unit tests for each driver which the user can modify or use to evaluate the use case and check if the application requirements are met.

Note

SDK is discussed in detail in the development phase section.

TI Reference Collaterals

- AWR1443, AWR1642, AWR1843, AWR6843: mmWave SDK
- AWR2944, AWR2944P, AWR2544: mmWave MCU Plus SDK

4.2.2 Radar Toolbox

The Radar Toolbox and Resource Explorer is a collection of tools and example code for a wide variety of applications. Users can find the example code for various applications and visualizers for viewing the output data. Figure 4-3 through Figure 4-6 provides an insight of the toolbox and the contents.

Note

The Toolbox is highly recommended by TI to be used for referencing, learning and understanding the development with mmWave sensors.

Note

The radar toolbox can be accessed by Radar Toolbox.

Figure 4-3 shows the landing page for the Radar Toolbox.

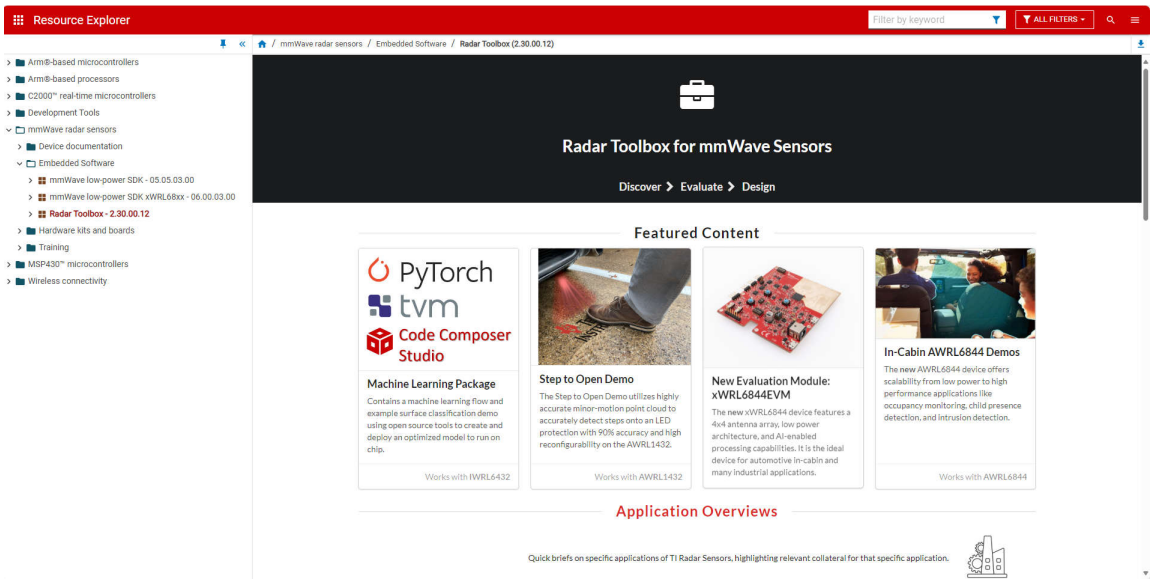

Figure 4-3. Radar Toolbox Landing Page

Figure 4-4 illustrates the various applications that are covered by the toolbox. TI provides reference code for most of the in demand applications in the automotive domain like the corner radar, front radar and so forth.

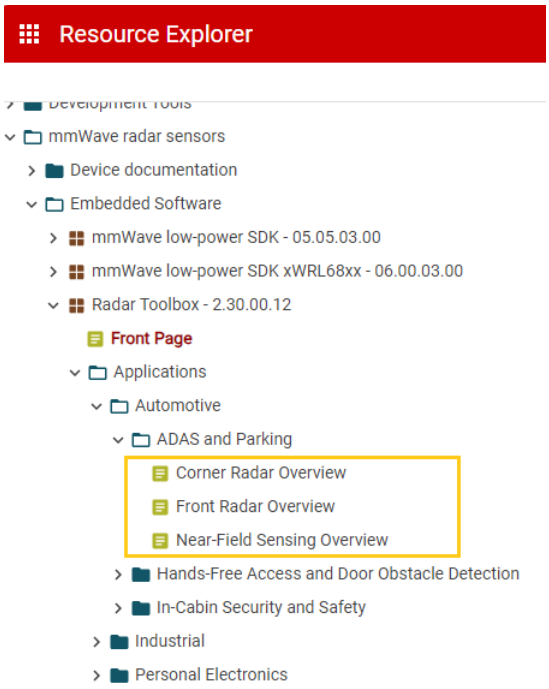

Figure 4-4. Radar Toolbox Application list

TI provides many example projects for users to perform the evaluation as per the application requirements and enter the development phase. The topics covered by the radar toolbox are Safety demos, HECR demo, MRR or SRR demos, and BSD.

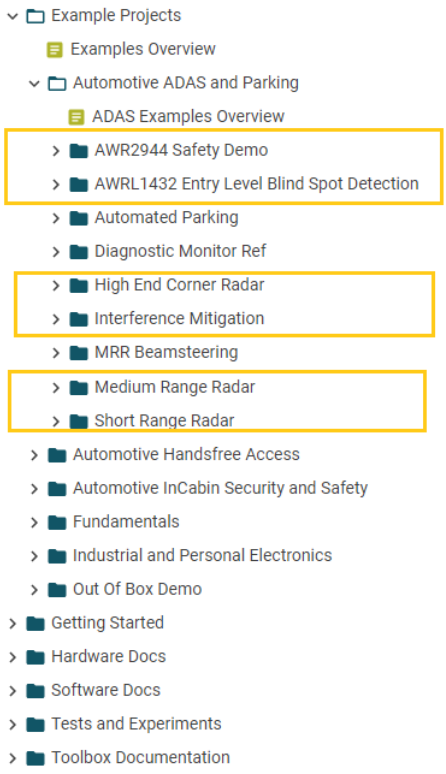

Figure 4-5. Radar Toolbox Example Projects List

A wide variety of tools are supported by TI. The most requested tools like JTAG flasher, or Studio CLI are available in the toolbox.

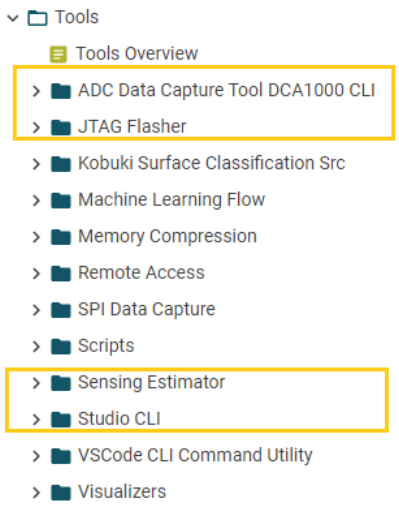

Figure 4-6. Radar Toolbox Tools List

4.2.3 mmWave DFP

mmWave–DFP is a device firmware package for TI's Radar transceiver devices. This package provides firmware, ROM patches and API that provides seamless control and configuration for the RF operation in real-time from an external host device and allows periodic schedule calibration and functional safety monitoring. This enables the RF transceiver to be self-contained and capable of adapting to dynamic conditions, such as temperature changes, and minimize external intervention an external host perspective.

Note

DFP is discussed in detail in the development phase section.

TI Reference Collaterals

- AWR1443, AWR1642, AWR1843, AWR6843: mmWave SDK
- AWR2944, AWR2944LC, AWR2544: mmWave MCU Plus SDK
- AWR1243, AWR2243: MMWAVE-DFP

4.2.4 mmWave Sensing Estimator

The mmWave Sensing Estimator is a graphical web tool designed to simplify chirp design for TI radar sensors. The tool enables rapid experimentation with a wide range of configurable exposed from the radar sensors, with performance metrics calculated and displayed in real-time.

TI Reference Collaterals

- Sensing Estimator directs to the sensing estimator web tool.
- mmWave Sensing Estimator Overview video gives an overview of the mmWave Sensing Estimator tool and shows how to use the tool to generate mmWave sensor chirp configurations for desired use cases.

4.2.5 mmWave Studio

mmWave studio is a stand-alone Windows® GUI that provides the ability to configure and control mmWave sensor modules and collect analog-to-digital (ADC) data for offline analysis. ADC data capture is intended to enable evaluation and characterization of radio-frequency (RF) performance, and PC development of signal-processing algorithms. MMWAVE-STUDIO provides the capability to evaluate and prototype chirp designs and experiment with advanced features of our radar devices. MMWAVE-STUDIO is intended for advanced users collecting ADC data directly and for fine-tuning low-level chirp parameters. This is not needed for typical evaluation of the radar demos. MMWAVE-STUDIO provides basic post-processing and visualization of ADC data, and post-processing examples based on MATLAB®, which can be used as getting-started reference.

TI Reference Collaterals

- MMWAVE-STUDIO directs to the MMWAVE-STUDIO product page. All the resources can be found on this page.

Note

MMWAVE-STUDIO connects directly to our sensor modules and requires the DCA1000EVM for streaming of ADC data to PC for capture. This combination is highly recommended by TI to be used by all users to capture raw ADC data and perform various post processing algorithms on the data.

4.2.6 Code Composer Studio™

Code Composer Studio™ is an integrated development environment (IDE) for TI's microcontrollers and processors. CCS comprises a suite of tools used to develop and debug embedded applications. Code Composer Studio includes an optimizing C/C++ compiler, source code editor, project build environment, debugger, profiler and many other features. The intuitive IDE takes you through each step of the application development flow. Familiar tools and interfaces make getting started simple.

Some salient features of the CCS are mentioned below.

- Code Composer Studio includes C/C++ compilers tailored to get maximum performance and best code size for TI devices. The TI Arm Clang compiler combines LLVM and Clang with TI added features such as link time optimization to provide exceptional code size for TI Arm®-based microcontrollers.
- Resource Explorer provides access to the resources needed for embedded development. Quickly access examples, training, software development kits and documentation tailored to the device being used. Resource Explorer is included with Code Composer Studio and is also available in the cloud on the TI Developer Zone.
- SysConfig is an intuitive and comprehensive tool for configuring pins, peripherals, drivers, radios and other components. SysConfig simplifies configuration challenges and accelerates software development.
- EnergyTrace™ is an analysis tool that measures and displays the energy profile of microcontroller and wireless connectivity applications and helps optimize for ultra-low-power consumption.
- Code Composer Studio provides many advanced debug capabilities. The runtime object view provides insight into the status of RTOS objects such as tasks, stacks, timers and semaphores.
- Code Composer Studio has a complete scripting environment allowing for the automation of tasks such as testing and performance benchmarking.

TI Reference Collaterals

CCSTUDIO directs to the landing page of CCSTUDIO. All the resources are provided on the landing page for the users.

Note

There is no mandate to use the CCS as the only IDE and debugging option. Users can prefer to use an IDE of choice and any debugger. No device restriction is present.

4.2.7 UniFlash

UniFlash is a software tool for programming onboard flash on TI mmWave sensors. UniFlash provides both graphical and command-line interfaces. The UniFlash tool can be used to program the flash with the final app image.

TI Reference Collaterals

- Texas Instruments, UNIFLASH, webpage

Note

TI supports multiple interfaces for flashing the onboard memory on a EVM. Interfaces like UART, JTAG, Ethernet and CAN are supported and TI also provides the tools to support the flashing. The path below in the SDK provides all the details and TI recommends to go through the contents to understand all the flashing utilities available form TI. The file path is provided with reference to AWR2944 device. Users can select the folder corresponding to the device as well. The tools usage remain the same.

`ti/mmwave_mcuplus_sdk_xx_xx_xx_xx/mcu_plus_sdk_awr294x_xx_xx_xx_xx/docs/api_guide_awr294x/TOOLS_FLASH.html`

4.3 Find and Select the Right Partner Resource

Our partners offer specialized products and services to help users solve problems. Search our partner directory to identify and connect with experts in our technology for your needs to get to market faster.

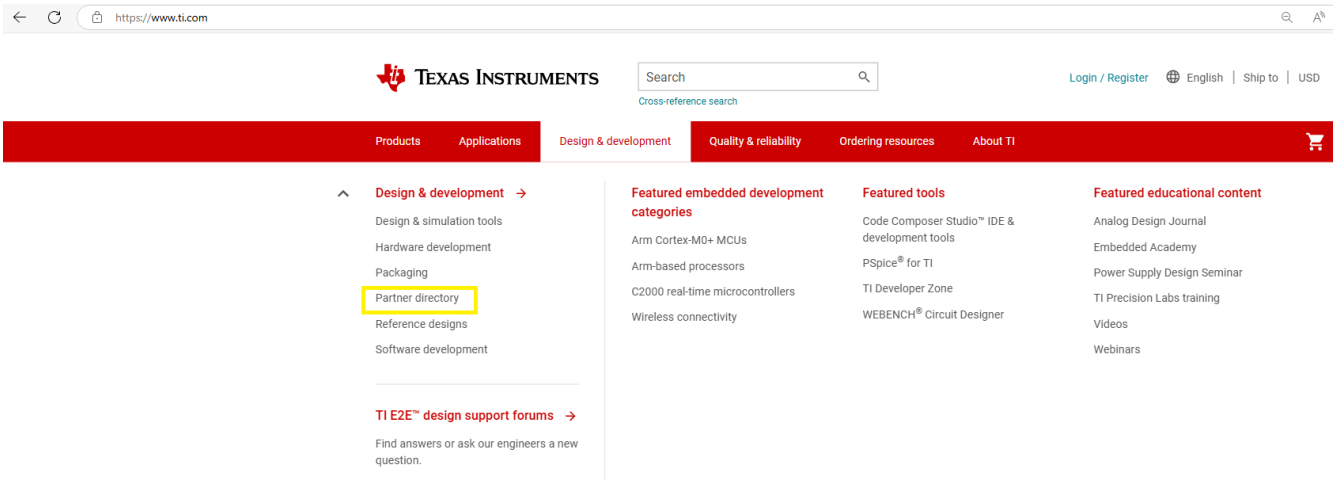

Figure 4-7. Locating Partner Directory

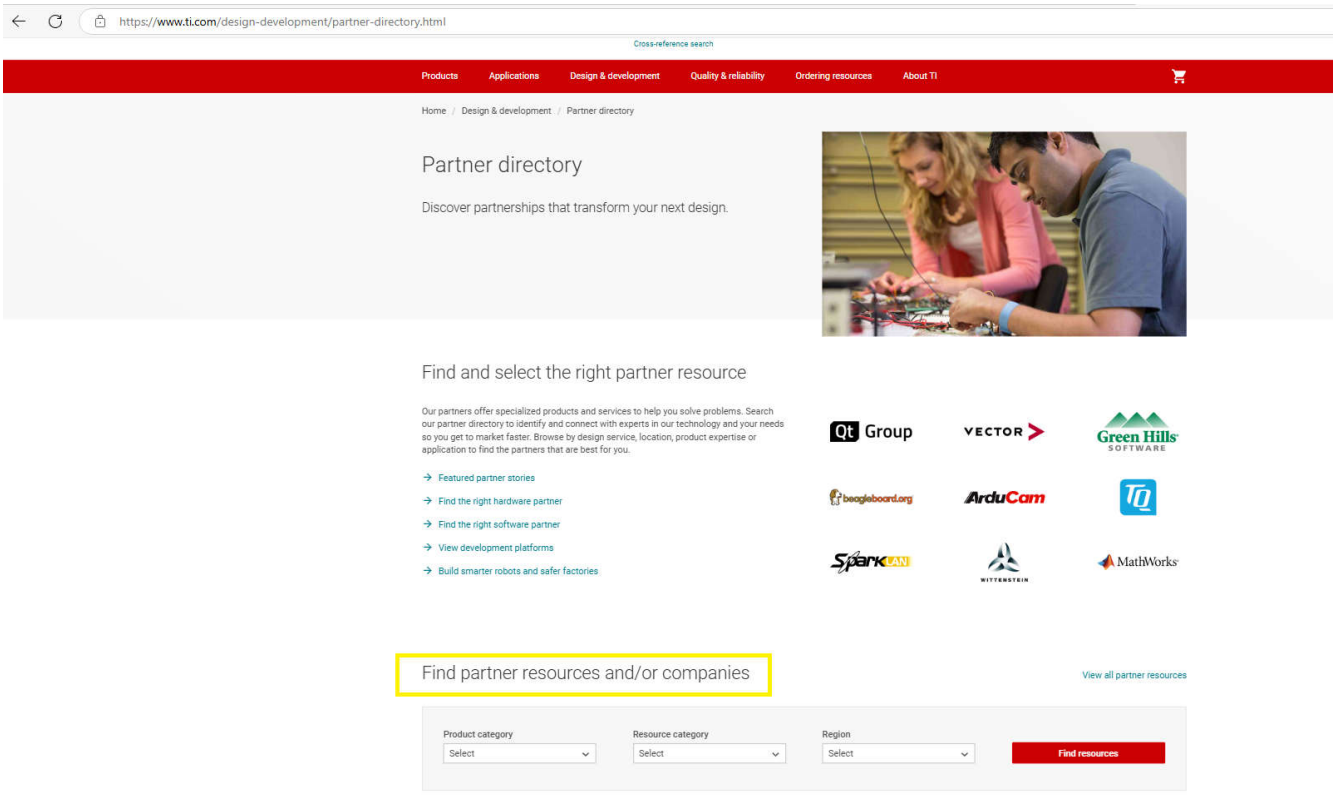

Figure 4-8. Exploring the Search Tab

The search tab allows users to perform a region based resource search for hardware, software development and other relevant resources. Be sure to check the page out to address any development requirements.

5 Development Phase

The development phase can be broadly classified into 7 aspects

- Primary and Secondary Bootloader
- SDK
- Compilers
- RF front end configurations and mmWave DFP
- Safety Aspects
- Security Aspects
- Signal Processing Chain
- MCAL, Autosar
- Hardware Module Design

Let's discuss all the aspects in detail to understand better. For every aspect a set of documents is also be mentioned which helps design/develop that phase better.

5.1 Primary and Secondary Bootloader

Bootloaders play a crucial role in most embedded devices. A bootloader is a small piece of software that runs before the main application code on an embedded device. The main purpose is to initialize the hardware, set up the memory, and load the application code from a storage device, such as a flash memory, into the RAM. A bootloader can also provide other features, such as updating the firmware, debugging, or communicating with other devices.

There are two main types of bootloaders: primary and secondary. A primary bootloader is the first code that executes when the device is powered on or reset. This is usually stored in a read-only memory (ROM) or a protected area of the flash memory. A primary bootloader is responsible for performing the basic hardware initialization and jumping to the secondary bootloader or the application code. A secondary bootloader is the code that follows the primary bootloader. This is usually stored in a flash memory or an external storage device. A secondary bootloader is responsible for loading the application code from the storage device into the RAM and transferring the control to application. A secondary bootloader can also perform more complex tasks, such as checking the integrity of the application code, verifying the digital signature, or allowing the user to select different firmware versions. Please refer the below app notes for a profound understanding of the mmWave bootloaders.

Note

The example drivers provided in the SDK for booting process must be referred by developers. The example codes adds a lot of insights for the users and provides a basic framework for custom boot driver development. Please use the below path. (AWR2944 device is used for reference)

```
ti\mmwave_mcuplus_sdk_04_xx_xx_xx\mcu_plus_sdk_awr294x_xx_xx_xx_xx\examples\drivers\boot
```

TI Reference Collaterals

- Texas Instruments, AWR1642, AWR1843 Bootloader Flow application note for bootloader for GEN1 devices.
- Texas Instruments, AWR1642, AWR1843 Application Startup Sequence application note provides more insights on the startup sequence for GEN1 devices.
- Texas Instruments, AWR294x, AWR2544 Primary and Secondary Bootloader application note for bootloaders for GEN2 devices.

5.2 SDK

Figure 5-1 shows the SW modules in the SDK.

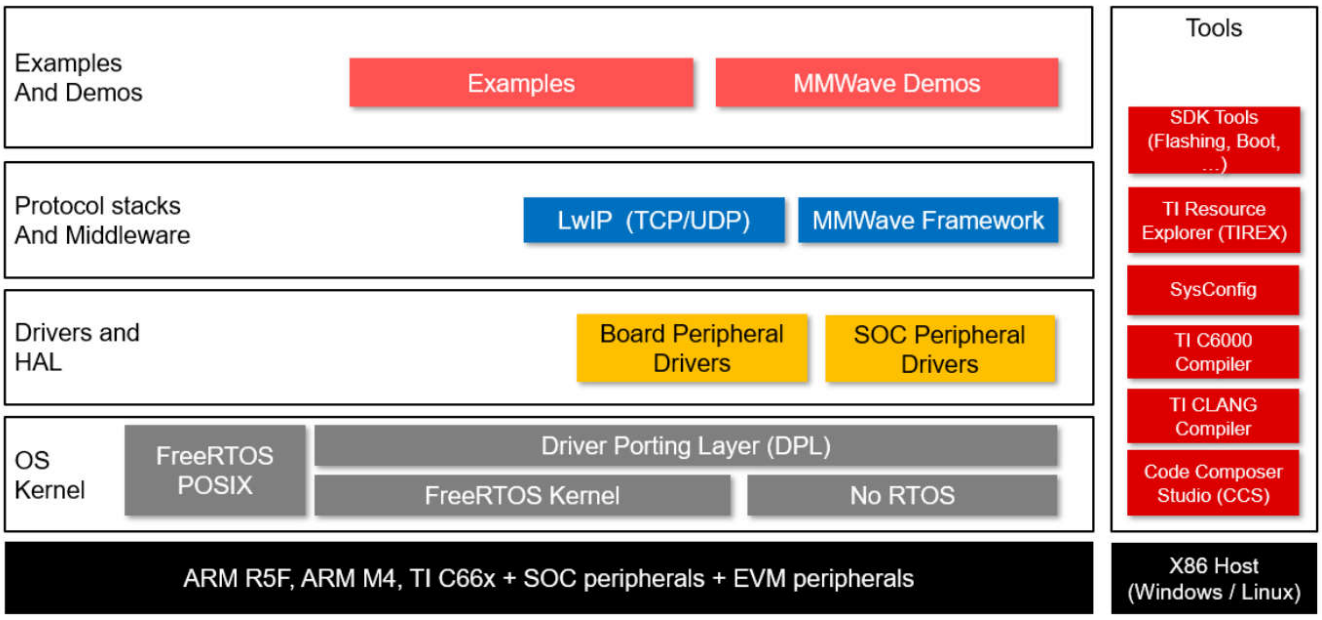

Figure 5-1. Software Block Diagram

Please use the file path below to refer to the readme document of the SDK. Users are encouraged to read through all the modules in Figure 5-1 to form a better understading on each of the blocks. AWR2944 has been used as a reference here.

`ti/mmwave_mcuplus_sdk_xx_xx_xx_xx/mcu_plus_sdk_awr294x_xx_xx_xx_xx/docs/api_guide_awr294x/index.html`

The mmWave SDK is split into two broad components: mmWave Suite and mmWave Demos.

mmWave Suite

mmWave Suite is the foundational software part of the mmWave SDK and encapsulates these smaller components:

- Drivers (part of the MCU PLUS SDK): device drivers library and APIs for peripherals within the SOC. Examples include, I2C, GPIO, UART.
- DPL (part of the MCU PLUS SDK): APIs used by drivers to abstract the OS environment. Examples include, Semaphore, HW interrupts, mutex, clock.
- mmWaveLink and Firmware (part of the device firmware package - dfp)
- mmWave API
- Data processing layer (manager, processing units)
- Board setup and flash utilities

mmWave Demos

SDK provides demos that depict the various control and data processing aspects of a mmWave application. Data visualization of the demo output on a PC is provided as part of these demos. These demos are example code that are provided to customers to understand the basics of the mmWave devices and the SDK. The demos also help users get started on developing custom applications.

Note

The best way to get started with the mmWave SDK is to start running one of the various demos that are provided as part of the package. TI mmWave EVM comes pre-flashed with the mmWave OOB demo. Sucessfully running the OOB demo is a paramount step to begin development on the mmWave sensors and is highly recommended for new developers.

The demos (source and pre-built binaries) are placed at `mmwave_mcuplus_sdk_<ver>/ti/demo/<platform>/mmw/` folder.

Note

The millimeter wave demo shows some of the radar sensing and object detection capabilities of the SoC using the drivers in the mmWave SDK (Software Development Kit). This allows users to specify the chirping profile and displays the detected objects and other information in real-time. A detailed explanation of this demo is available in the demo docs folder and can be browsed by using this file path: `mmwave_mcuplus_sdk_<ver>/ docs/mmwave_sdk_module_documentation.html`. This demo ships out detected objects and other real-time information that can be visualized using the TI Gallery App mmWave_Demo_Visualizer.

Note

The MMWAVE MCUPLUS SDK User's Guide is an important document for all users. The document provides deep insights on getting started with the SDK, running the OOB demo, SDK radar processing chain, optimization techniques, and various debugging techniques to aid the users. The path for the document is provided below.
`C:\ti\mmwave_mcuplus_sdk_xx_xx_xx_xx\mmwave_mcuplus_sdk_xx_xx_xx_xx\docs`

TI Reference Collaterals

- AWR1443, AWR1642, AWR1843, AWR6843: mmWave SDK
- AWR2944, AWR2944P, AWR2544: mmWave MCU Plus SDK

5.3 Compilers

TI provides two sets of compilers

- TI CLANG Compilers: CLANG based ARM compiler from TI for ARM core
- TI C6000 Compilers: DSP core compiler from TI

TI Arm Clang Compiler

The tiarmclang compiler is based on the open source LLVM compiler infrastructure and the Clang front-end. tiarmclang compiler uses the TI Linker and C runtime, which provide additional benefits for stability and reduced code size. Benefits of tiarmclang include:

- Excellent C/C++ standards support
- Source-based code coverage
- Improved code size over armcl/gcc
- GCC compatibility
- Comprehensive documentation: Getting Started Guide, Migration Guide and Compiler Tools User Manual
- Compiler Qualification Kit to assist qualifying the compiler to functional safety standards such as ISO 26262 and IEC 61508.

TI C6000 Compiler

The TI C6000 C/C++ Compiler and Assembly Language Tools support development of applications for TI C6000 Digital Signal Processor platforms, including the C66x multi-core, C674x and C64x+ single-core digital signal processors. Salient features of the C6000 are listed below.

- Supports the C++14 Standard ISO/IEC 14882:2014.
- Reduced compilation time and memory usage when compiling OpenCL-C kernels.
- Improved OpenCL-C vector type performance.

Note

User are not mandated by TI to use any specific compiler set. Compiler packages and tools can be selected and used based on user preference from TI or a 3rd party.

5.4 RF Front-end Configurations and mmWave DFP

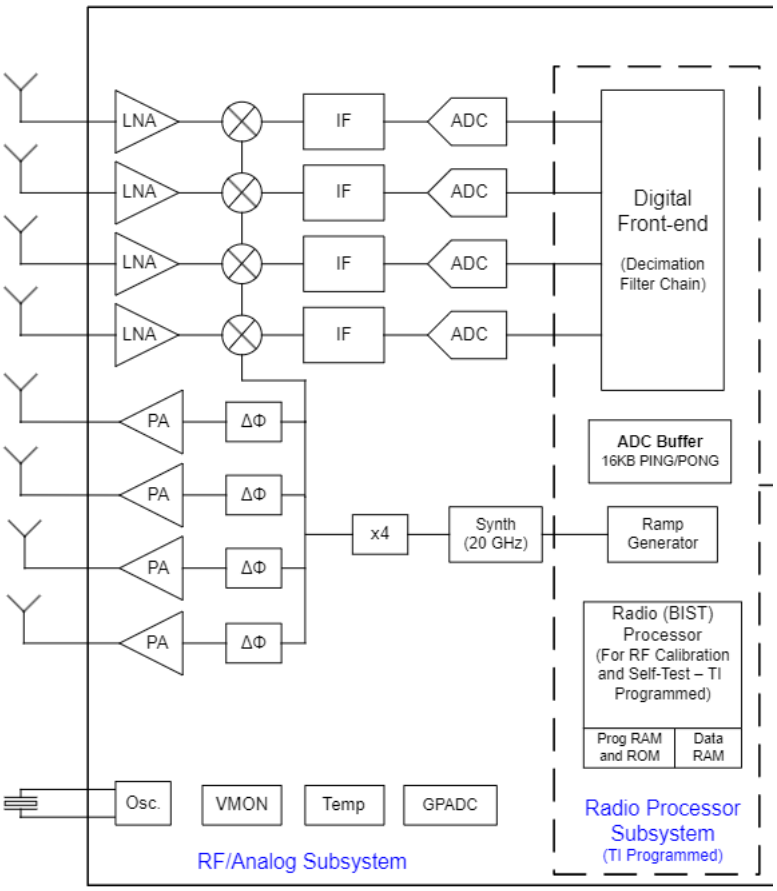

Figure 5-2. General Functional Block Diagram for Radar

Figure 5-2 is a general functional block diagram of the Radar sub-system of a TI mmWave sensor. The sub-system is a mix of analog and digital components. The mmWave DFP is a device firmware package for TI mmWave sensors which provides firmware, ROM patches and API. These provide seamless control and configuration for the RF operation in real-time and allow periodic scheduling of calibration and functional safety monitoring. This enables the RF transceiver to be self-contained and capable of adapting to dynamic conditions, such as temperature changes, and minimize external intervention an external host perspective.

The mmWave device firmware package (DFP) is split in three broad components: mmWave Firmware, mmWaveLink and mmWave RF evaluation.

mmWave Firmware

mmWave Firmware is responsible for configuring RF and analog, digital front end in TI mmWave radar devices and consists of the following component:

- Radar SS firmware

All the services of Radar SS firmware are available to user programmble cores or sub-system like the Main SS or DSP SS (if applicable for the device) using the APIs in the mmWaveLink framework.

mmWavelink

The mmWaveLink framework acts as driver for the Radar sub-system. The mmWaveLink framework exposes a suite of low-level APIs that allow applications to enable, configure, and control the Radar SS. The mmWaveLink framework provides a well-defined platform and OS abstraction for the application to plug in the communication driver and OS routine callbacks to communicate with the TI mmWave devices.

mmWave RF Evaluation

For mmWave RF and system evaluation purpose, mmWave Studio Tool which is designed to communicate with all variants of TI mmWave devices for RF and system performance evaluation can be used. The RF evaluation provides the firmware that is to be programmed onto the sensor to use the studio tool.

Note

The DFP user's guide is an important document that helps users comprehend the front-end configurations and advane features of the device. The user's guide provides more information on the link test example which can be used by the developers to check a reference implmentation of using the mmWavelink framework, and most of the mmWave DFP APIs. The example code provides a framework on using most of the device front end features and must always be checked by developers. The user guide can be found at the following path:

```
ti\mmwave_mcuplus_sdk_04_xx_xx_xx\mmwave_dfp_02_xx_xx_xx\docs
```

Note

The ICD (Interface Control Document) define interface control specifications for TI’s mmWave sensors. This is a must read document for both front end and SOC devices to understand the communication protocol with the radar sub system. The ICD path is as follows:

```
ti\mmwave_mcuplus_sdk_04_xx_xx_xx\mmwave_dfp_02_xx_xx_xx\docs
```

TI Reference Collaterals

- AWR1443, AWR1642, AWR1843, AWR6843: mmWave SDK
- AWR2944, AWR2944LC, AWR2544: mmWave MCU Plus SDK
- AWR1243, AWR2243: https://www.ti.com/tool/MMWAVE-DFP

5.5 Safety Aspects

The automotive radar sensors are safety capable and ASIL B qualified by Technischer Überwachungsverein (TÜV) SÜD. This section describes the functional safety of radar sensors.

What is Functional Safety?

Functional safety is the reduction of unnecessary risk due to hazards caused by the malfunctioning behavior of E/E systems. The goal is to reduce the risk to an acceptable risk level.

Why Functional Safety?

As the automotive markets become more autonomous, the automotive manufacturers(OEMs, Tier1, Silicon supplier) face an increasing need to meet stricter functional safety standards. Global NCAP sets these standards to make cars and driving safer. These standards are designed to minimize equipment failures and physical injury. Meeting the standards increases consumer confidence, proves reliability and robustness of the vehicle in the market.

To address the potential failures, TI millimeter-wave (mmWave) radar devices are designed, implemented, and tested according to a hardware and software development process. The hardware and software development process are certified from Technischer Überwachungsverein (TÜV) SÜD to comply with ISO 26262 and IEC 61508. TI mmWave radar devices which are specifically designed for automotive applications are also certified by TÜV-SÜD to comply with the ISO 26262.

mmWave Safety Deliverables

TI provides various deliverables for functional safety development at customer end. The comprehensive list is provided below.

Table 5-1. Safety Deliverables

Name	Confidentiality	Type	Accessibility
Device safety manual	NDA required	Document	Secure resources
Safety Analysis Report FMEDA	NDA required	Document	Secure resources
Device data sheet	No NDA required	Document	ti.com
Monitoring application note	NDA required	Document	Secure resources
Device firmware package	No NDA required	Software package	ti.com
MCAL (applicable for selected devices)	NDA required	Software package	Secure resources
Safety compiler qualification kit	No NDA required	Software package	ti.com
Safety diagnostics library (applicable for selected devices)	No NDA required	Software package	ti.com

All the safety related documents are mostly available by NDA process. To maintain confidentiality, the functional safety is not be discussed in detail in the document and information is only provided to get started with the functional safety development.

Note

Please check Section 8 to get started with the process.

Note

TI's radar mmWave integrated chips (ICs) include hardware and firmware elements to enable monitoring of the mmWave, analog and digital sections. These built-in features are exposed to users through firmware APIs. The monitoring application note aims to help users build the software to program and use APIs to achieve the end-product's safety goals. For this, this application note describes monitoring mechanisms, explains the programming options offered by the APIs, illustrates example post-processing of the monitoring reports produced by these APIs, and illustrates the reports in example programming conditions in TI's internal labs. The monitoring application note must be referred to implement various available monitoring.

Note

The Safety Compiler Qualification Kit was developed to assist customers in qualifying custom use of the TI ARM, C6000, C7000 or C2000/CLA C/C++ Compiler to functional safety standards such as IEC 61508 and ISO 26262. Please refer to the link provided in the section below for all the details on the qualification steps and process.

Note

The mmWave sensors provides various safety mechanisms and features, as well as recommendations for usage of these safety mechanisms and features. The Software Diagnostic Library (SDL) provides interfaces to these safety mechanisms and features. The SDL provides these interfaces to assist in the development of software applications involving Functional Safety. The Software Diagnostics Library consists of different blocks for Error Capture and Safety Mechanisms. Error response is managed by the Application based on the device Safety requirements. The interface for the Application is in the form of software APIs. The SDL driver libraries can be directly used by the users to implement functional safety measures in the custom application. Please refer to the SDL package for further details.

TI Reference Collaterals

- Texas Instruments, Design guide for Functional Safety Compliant Systems Using mmWave Radar Sensors, functional safety information
- Texas Instruments, Understanding Functional Safety in Automotive and Industrial Sensing Applications, technical article
- Texas Instruments, Safety compiler qualification kit, webpage
- Texas Instruments, Reference Designs in Radar Toolbox, webpage
- Texas Instruments, Enabling Functional Safety for mmWave Sensors, video

5.6 Security Aspects

Cybersecurity is gaining importance in the wake of increase in the number of cyber crimes. Providing a secure execution environment is a key objective of mmWave High Security (HS) devices. Security in mmWave devices must encompass the specific needs of vertical markets like automotive and the broad market customer needs.

The key security goals being addressed by the device are

- A method to prevent malicious code or outside influences (peripherals or JTAG) from modifying customer software and data
- A method to verify only customer software runs on the device
- Protection against theft of IP

All the security related documents are available through NDA process. To maintain confidentiality, the security is not discussed in detail in the document and only the above overview is provided.

Note

Please check the Additional Resources section to get started with the process.

5.7 Signal Processing Chain

This section describes the signal processing chain of the radar sensors in detail. At this point, the user is well versed with the basic working and functionality of the FMCW radars. If not, then refer to the FMCW training series before proceeding to the next section.

5.7.1 How Can FMCW Radars Be Used?

A FMCW radar uses chirps for the radar detection and ranging. A chirp is a sinosoid of linearly varying frequency. In mmWave sensors, users can configure the chirp as required to meet the system performance parameters like range, range resolution, maximum detectable velocity, field of view and so forth.

The Programming Chirp Parameters in TI Radar Devices application note provides information on how to select the right chirp parameters in a fast FMCW Radar device based on the end application and use case, and program them on TI's radar devices.

The MIMO Radar application note introduces the basic principles of the MIMO radar and the different design possibilities. The document also provides an in depth explanation of the TDM-MIMO strategy.

Using the path shown below in the device specific MCU Plus SDK package, users can find an in depth explanation of the DDM-MIMO Strategy.

`ti\mmwave_mcuplus_sdk_04_xx_xx_xx\mmwave_mcuplus_sdk_04_xx_xx_xx\ti\datapath\dpc\objectdetection\objdethwaDDMA\docs\doxygen\html\index.html`

The Interference Mitigation on the AWR294x Transceiver application note describes the mechanisms of interference and methods to mitigate interference, using algorithms designed for and hardware hooks designed into the TI family of radar devices.

TI Reference Collaterals

- Texas Instruments, Programming Chirp Parameters in TI Radar Devices, application note
- Texas Instruments, MIMO Radar, application note
- Texas Instruments, Interference Mitigation on the AWR294x Transceiver, application note

5.8 MCAL and Autosar

Microcontroller Abstraction Layer (MCAL) is the lowest software layer of the AUTOSAR stack. MCAL contains software modules with direct access to hardware and is responsible for system initialization. The AUTOSAR-compliant drivers, provided by TI, is part of the MCAL on top of which the application can be built further. MCAL also implements notification mechanisms to support the distribution of commands, responses and information to processes.

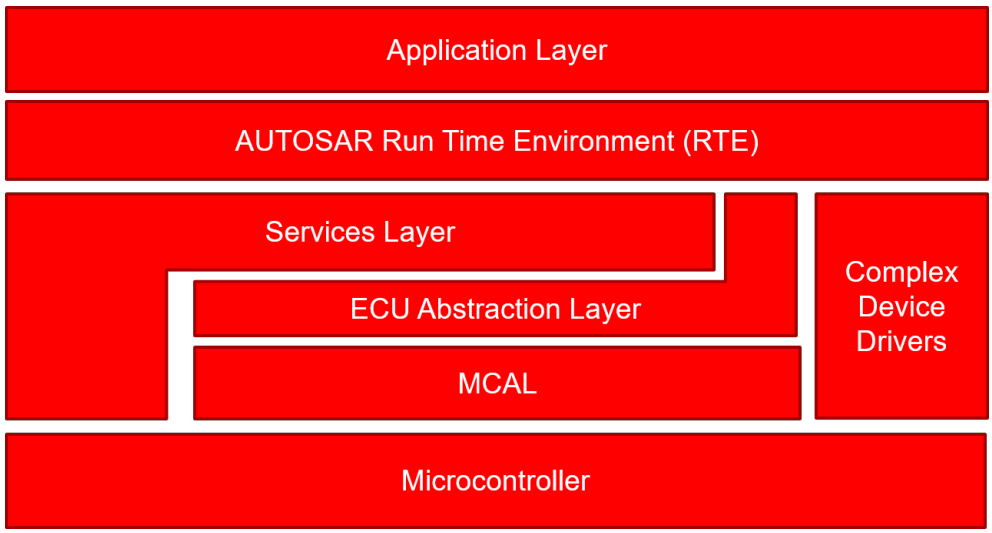

Figure 5-3. Autosar Stack

TI provides the MCAL drivers for the AUTOSAR to run on the SOCs. Customers need to procure the other AUTOSAR SW stack from third parties or internally. These SOCs are expected to be used in safety-critical systems and hence needs to be compliant to ISO26262 specifications. The targeted compliance for the AUTOSAR MCAL is ASIL-B. The MCAL drivers implement the Software specification mentioned in AUTOSAR 4.3.1 release.

Note

The MCAL packages are shared to users only after an NDA is established. This document does not discuss the MCAL any further to maintain confidentiality.

5.9 Hardware Module Design

TI provides the following collaterals to aid in hardware module design.

TI Reference Collaterals

- Texas Instruments, Antenna Design lists several factors to consider when designing an antenna which can allow designers to maximize the achievable performance for specific application.
- Texas Instruments, TI mmWave Radar sensor RF PCB Design, Manufacturing and Validation Guide application note helps sensor designers design, manufacture, and validate a new mmWave Sensor board.
- Texas Instruments, Flash Variants Supported by mmWave Sensor application note describes the flash variants supported by TI mmWave Sensor.
- Texas Instruments, mmWave Radar Radome Design Guide application note provides an introduction to radome design and highlights key issues for designing a mmWave radome whilst considering the radar sensor performance.
- Texas Instruments, Addressing 3 power design challenges for corner radar systems, technical article
- Texas Instruments, Reliability advantages of TI flip-chip BGA packaging, marketing white paper
- Texas Instruments, Thermal Design Guide for Antenna on Package mmWave Sensor application note helps in the thermal design aspect of TI Antenna on package mmWave sensor products.
- Texas Instruments, Integration Considerations, webpage
- Texas Instruments, Hardware Design Checklist is a design checklist for the AWR2944.
- Texas Instruments, System Performance Measurement With the mmWave Sensor application note discusses system performance measurement results using the high performance mmWave sensor.
- Texas Instruments, Best Practices for Placement and Angle of mmWave Radar Devices, application bried

6 Production Phase

TI ECS samples can be used for customer evaluation or for A sample build. For A samples, customers are able to use engineering samples (FCS) which are tri-temp tested. Customers need an RF freeze of the silicon before the B samples. The RF frozen devices are used for B samples. The B samples can be used for FOT (field operational testing) for collecting 1 million mile data. The DV samples must be the final silicon. The PV samples are RTMed, PPAPed devices.

In the following phase, the pointers assist in the mmwave sensor development.

- Calibration
- Production testing
- FCC and RED compliance
- Safety certification
- Quality process and customer returns
- Security key (OTP) writing

6.1 Calibration

The device calibration can be divided into two parts:

- Factory calibration
- Antenna calibration

Factory calibration is performed to mitigate the process and temperature effects on the radar analog performance. The Factory Calibration Flow can be understood by referring to the ‘Section: Factory Calibration’ in the mmwave_dfp_user_guide.pdf.

All the related application notes for calibration are shown below, which provides an in depth explanation of all the calibrations in the mmWave sensors.

TI Reference Collaterals

- Texas Instruments, Self-Calibration in TI’s mmWave Radar Devices, application note
- Texas Instruments, Cascade Coherency and Phase Shifter Calibration, application note

6.2 mmWave Production Testing

The mmWave Production Testing Overview application note is a guide to testing radar sensors built using TI’s radar chips. This document is a high-level guide to help set up testing of radar sensor units during production. The document describes generic requirements of radar testing; the actual test set up and software required to run the tests varies depending on the actual application of the radar. The user is expected to design the test software and determine the appropriate limits for any tests based on the application of the radar.

6.3 FCC and RED Compliance

The TI mmWave Radar Device Regulatory Compliance Guide application note covers the requirements for compliance to regulatory standards for mmWave radar devices. Radio Equipment Directive (RED), a standard for equipment sold in Europe, and Federal Communications Commission (FCC), the standard for the United States, are reviewed in detail. The tools provided by TI for these tests, common issues, and resolutions to these issues are also covered.

6.4 Functional Safety Certification

The collaterals assist in the safety certification.

- Texas Instruments, Functional Safety Page TI Resource Explorer, webpage
- Texas Instruments, Functional safety technologies, webpage
- Texas Instruments, How to apply the TI Compiler Qualification Kit for functional safety development, webpage

6.5 Quality Process and Customer Returns

TI's comprehensive semiconductor quality policies and procedures, from new product qualifications and process change notifications to timely resolution of customer cases, can all be found at TI.com/quality

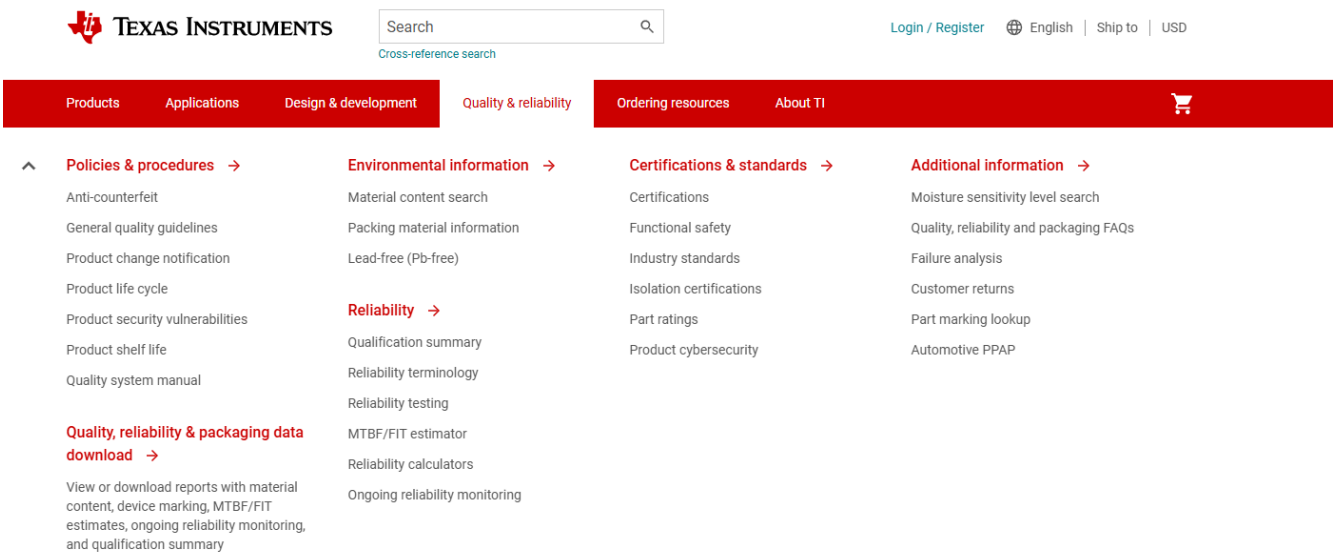

Figure 6-1. Quality policies and procedures

6.5.1 Customer Return Process

In the event that a customer experiences issues with a TI product, including embedded software, TI has an established customer return process to address non-conformance requests through the Customer Return Portal (CRP) on TI.com. Once a request has been accepted, a thorough and timely analysis of the reported problem is undertaken, including execution of appropriate corrective action.

6.5.2 Reference

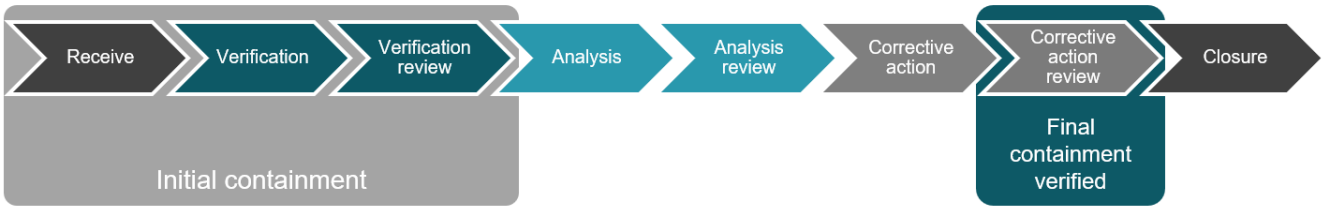

Figure 6-2. Customer Return Management Flow

Please follow these guidelines to initiate your request your customer return

TI product issue	TI point of contact
A potential shipping, packing or labeling issue	Contact TI customer support
Need technical application support or debugging guidance	Ask our engineers
Observed nonconformance to data sheet electrical, mechanical or functional specifications	Contact TI customer quality via CPR (customer product return)
RMA and field returns	Follow TI's guidelines for handling customer returns

6.6 OTP KeyWriter

HS-FS (Field Securable): This is the state in which device leaves TI factory where customer keys are not programmed. In this state, device protects the ROM code, TI keys and certain security peripherals. HS-FS devices do not enforce secure boot process.

HS-SE (Security Enforced): This is the state of the device after customer keys are programmed. HS-SE devices enforces secure boot.

OTP (One Time Programmable) KeyWriter is the software tool to provision customer keys into the device eFuse to enforce secure boot and establish root of trust. This package is also available to customers under NDA. Please check the Additional Resources section to get started with the process.

7 Summary

The application note provides an introduction to mmWave sensors and describes the functionality of the sensor. The document also introduces the imaging radar and also covers the frequency regulations and standards in different parts of the world. Next, the application note describes the evaluation process for the sensors and provides the necessary information required in different aspects of the development. Finally, the production phase is also explained for the user. Various sources are also provided to assist the user at any stage of the development.

8 References

References are provided throughout the document.

- Texas Instruments, TI E2E Community Forum - the TI E2E community is the best platform to raise a technical query. A TI engineer evaluates the query and provide a resolution for the issue. There is a high chance that similar queries have already been answered on the community. Use the community to get answers to all the queires users have or raise a new query for a TI verified answer.
- If a user needs more information about local TI FAE support, and is unable to reach out to our various teams, wants to evaluate some samples or connect with our marketing team, or has any non technical query, then reach out to TI at **tiradar_support@list.ti.com**. A TI representative evaluates the issue and takes appropriate action to resolve.

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