mmWave Radar – ADAS Applications

Chethan Kumar Y.B Abdulraheem Killedar

Embedded Processing → Radar, Analytics & Processors

Chethan Kumar Y. B

Hardware Applications Manager (SMTS) & Radar & Analytics Processors

- **Career**
  - Masters degree in Electronics Design and Technology from Indian Institute of Science
  - Joined TI as NCG and that was in the year 2000.

- **Expertise**
  - Started career as an Analog Design Engineer and held various positions with multiple groups within High Performance/High V Analog, Wireless and Embedded Processing organizations.
  - Rich experience on Analog and Mixed Signal Products in silico systems and applications functions.
  - Published multiple papers including best papers awards in vari internal and external conferences.
  - Has two granted patents and is pursuing a few more
  - Currently leads the Hardware applications team for the Auto R Product line

Likes adventure sports and is an avid badminton player

Abdulraheem Killedar

Hardware Applications Engineer- Radar and Analytics Processors

- **Career**
  - Masters Degree in Digital Electronics
  - Over a decade of experience in Semiconductor industry across TI, Marvel and ST Micro. Joined TI in 2011. Prior to joining the Radar team, managed Application, Verification & Validation teams in Processor BU for SoCs like AM335x/437x and TDA2/3
- **Expertise**
  - Comprehensive knowledge of “SoC Design cycle” spanning across IP/SoC-RTL Design, Design Verification, Emulation and Prototyping
  - Pre/Post Silicon AV&V of Digital, Mixed Signal SoCs and Applications Engineering
  - Proudly ramping (finding my way) on mmWave Sensing Applications

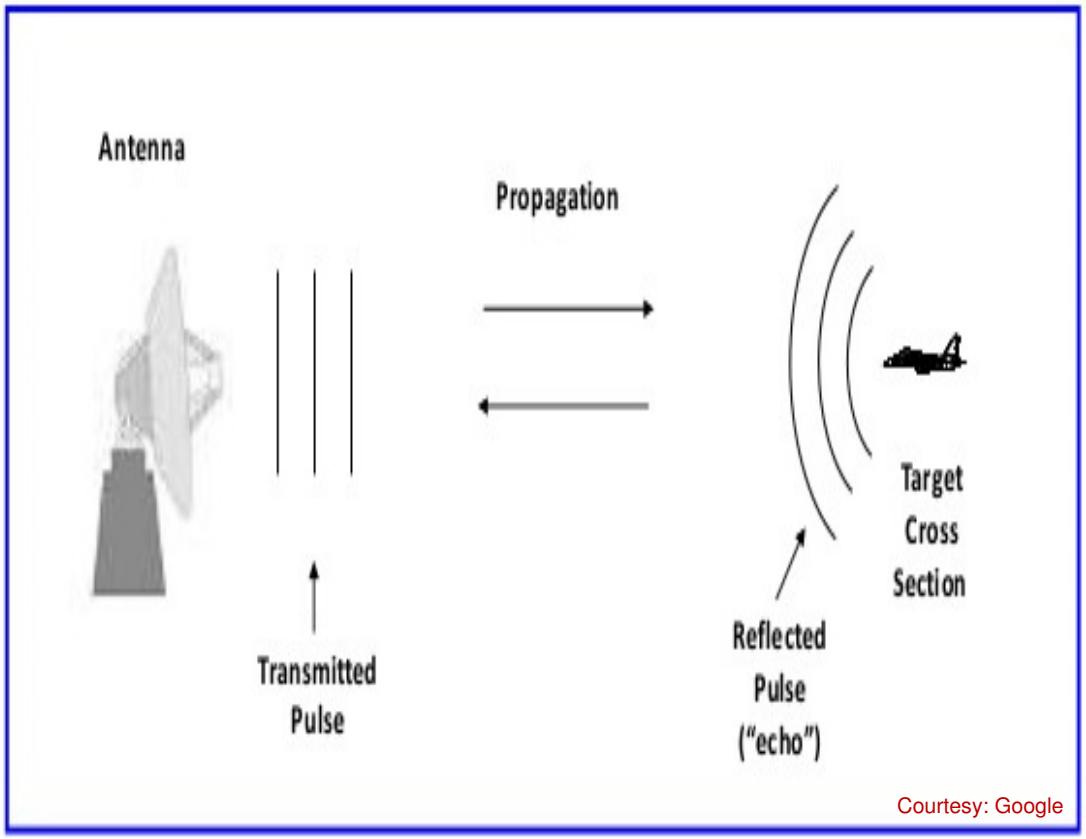
Likes Travelling to far away corners and spending time with his adorable daughter

Outline

- *What is RADAR??*
  - Introduction
  - Automotive RADAR applications and Challenges
  - Why mmWave?
  - Brief introduction to Frequency Modulated Continuous Wave RADAR(FMCW)
  - System Block diagram
- *TI's mmWave RADAR solutions*
  - TI mmWave Journey
  - Device Portfolio
  - Device Architecture
  - Sensor configuration with TI mmWave solutions
  - Applications
- *How to get started*
  - Introduction to EVMs
  - 3rd Party Sensor modules

What is RADAR??

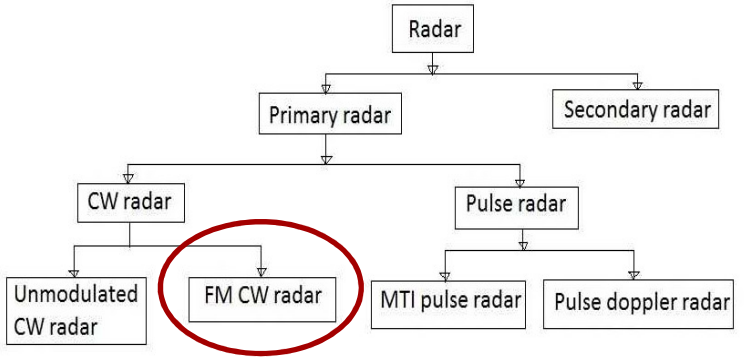
Yah we remember… seeing this in School ☺



Observables

- ❑ Range,
- ❑ Angle (Azimuth, Elevation)
- ❑ Velocity
- ❑ Size

Types



Applications: Military,Inductrial,**Automotive-ADAS** …….many more!!

Automotive Radar Applications

Core Applications

Adaptive Cruise Control

Automatic Emergency Brake

Lane Change Assist

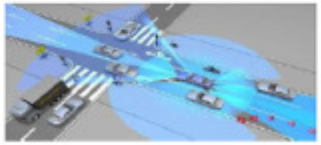
Blind spot detect

Emerging Applications

Parking and Proximity warning

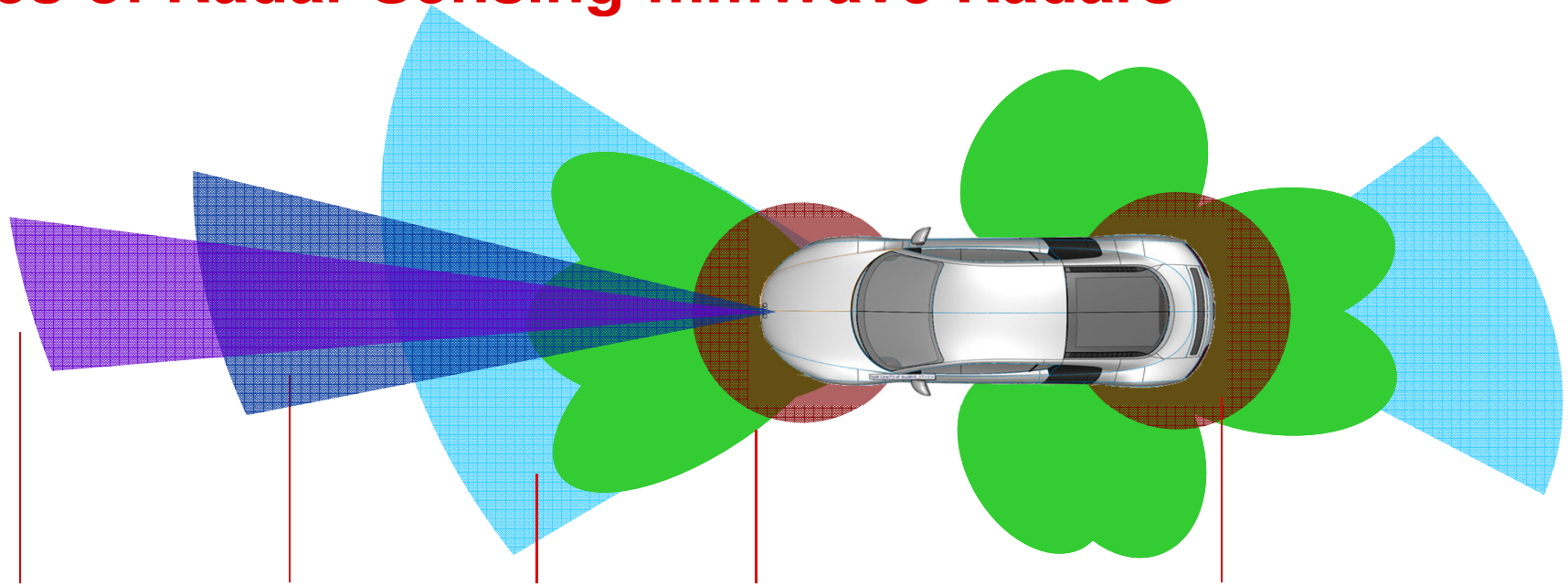
Surround sense

Urban Driving



Increased Demand for Accuracy and Miniaturization

Types of Radar Sensing-mmWave Radars



Long-Range Radar (LRR)
76-78 GHz

1 m – 250 m

MRR & IR

26 GHz
77-81 GHz
0.2 m – 160 m

Video

0 m – 80 m

Short-Range Radar (SRR)
24-26 GHz and
77-81GHz

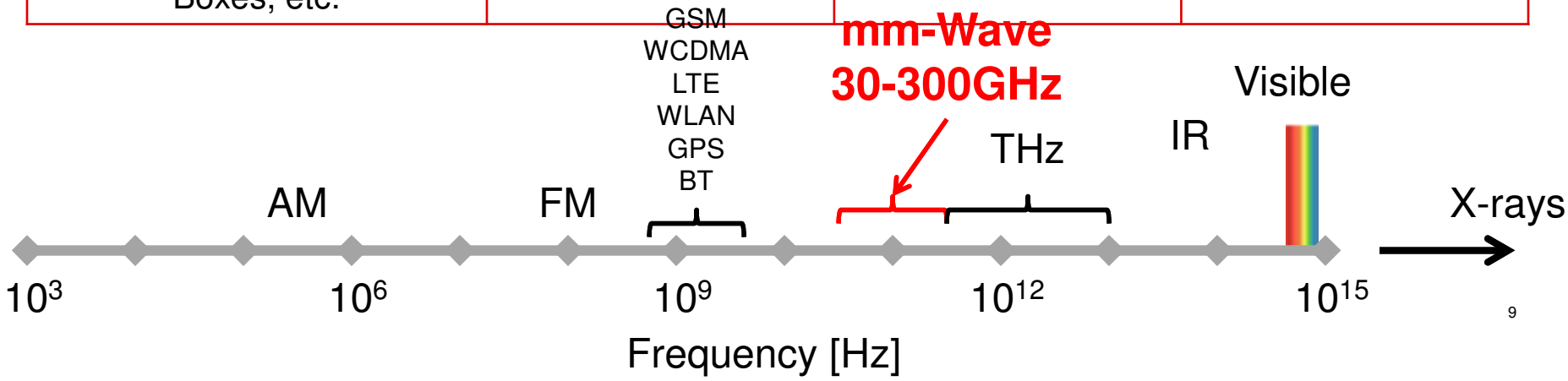
0.2 m – 80 m

Ultrasonic (US)
48 kHz

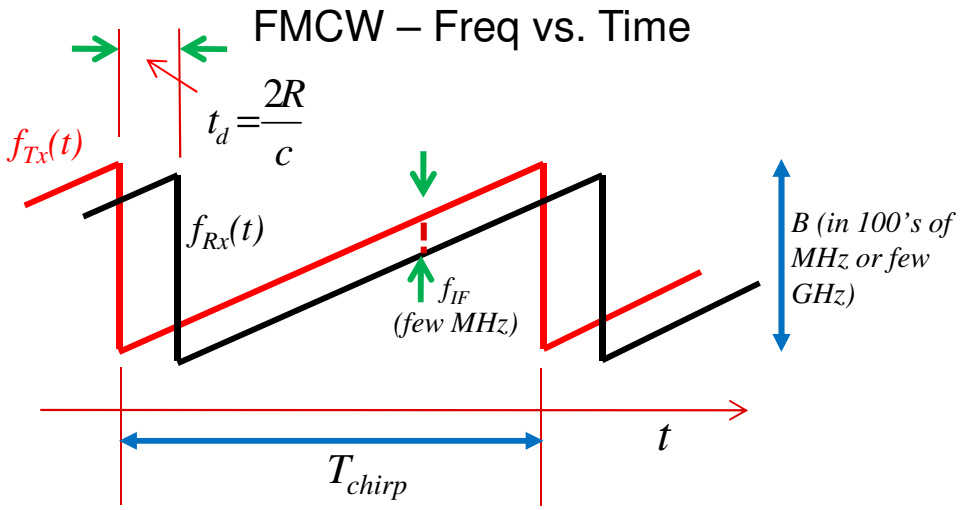
0.2 m – 3 m

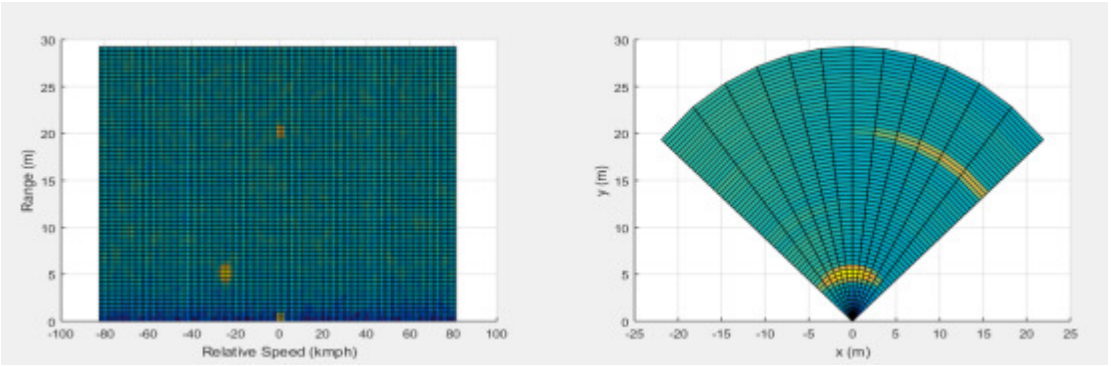
Why mm-wave?

Property	Microwave	mm-Wave	IR/Visible Light
Generation	Electronic	Electronic	Optics
Spatial resolution	~cm – m	~mm – cm	um
Coupling (antenna) size	PCB	Package	Package
Propagation Through Walls, Boxes, etc.	Yes	Yes	No



Frequency Modulated Continuous Wave FMCW Radar





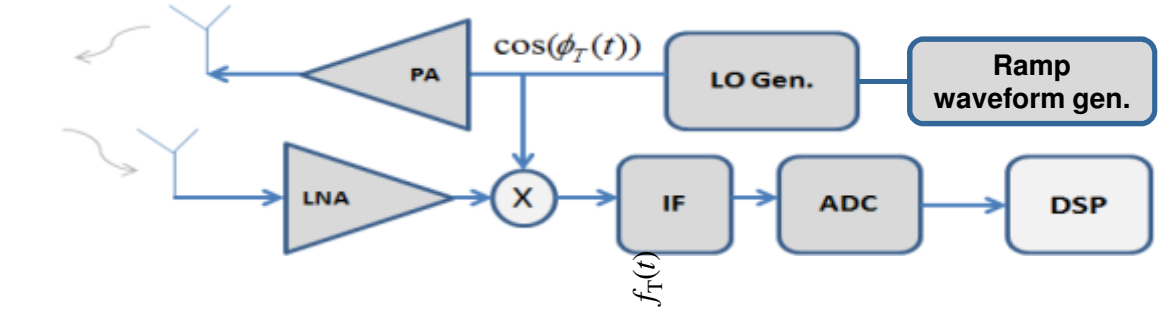
Key Features

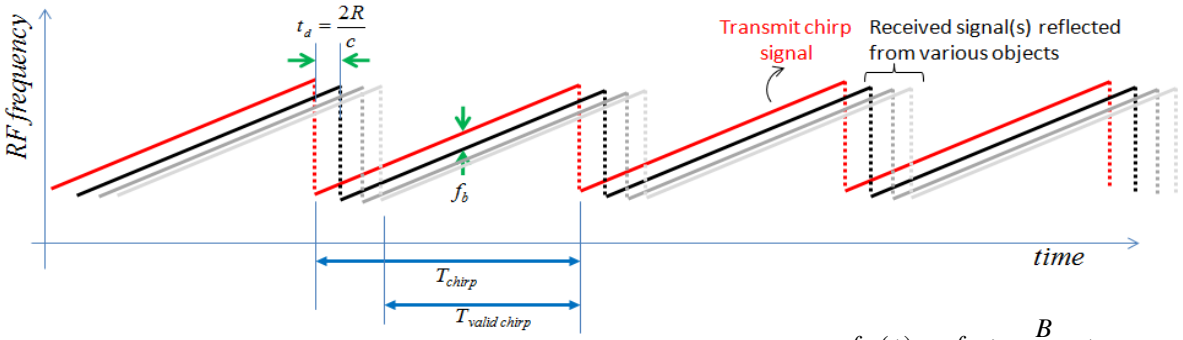
- ❑Ability to sweep wide RF bandwidth (GHz) while keeping IF bandwidth small (MHz)
  - Better range resolution. RF sweep bandwidth of 2 GHz can achieve 7.5cm range resolution, while IF bandwidth can still be <15MHz
- ❑ Lower peak power requirement

Performance

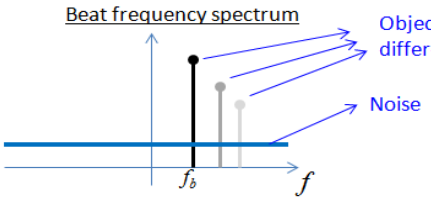
- ❑ Range precision ∝ RF (sweep) Bandwidth
- ❑ Velocity precision ∝ Dwell (frame) time
- ❑ Angle precision ∝ Number of Tx,Rx

System Block Diagram





FFT



$$f_T(t) = f_c + \frac{B}{T_{chirp}}t$$

$$\phi_T(t) = 2\pi f_c t + \pi \frac{B}{T_{chirp}} t^2$$

Beat freq = Round-trip delay * Slope

$$f_b = \frac{2RB}{cT_{chirp}}$$

How does it work?

- LO is ramped linearly to produce L-FMCW transmit signal
- Received signal (from object reflections) is mixed with the same ramping LO
- Baseband ADC output is post processed in DSP
- Beat frequency (fb)-**Range**
- Phase shift between successive chirps -**Doppler (relative velocity)**
- **Angle of arrival** is obtained using beamforming (multiple Tx, Rx)

Journey & the Offering !!

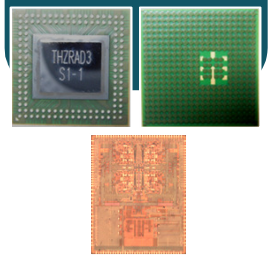
The last 7 years: TI mmWave Journey

2010 — Kickoff

2011 — Kilby Radar

160 GHz

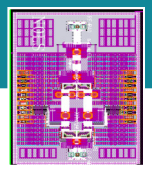
single chip
embedded
antenna



2012 — Test Chip 1

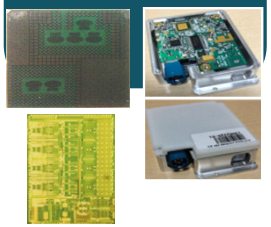
77 GHz

Module level
circuits



2013 — Test Chip 2

76-81 GHz
Single chip
Package variant 1
Package variant 2
Embedded
Antenna
Field Trials



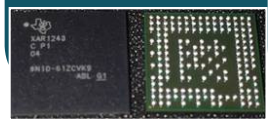
2014 — Test Chip 3

76-81 GHz
Module level
circuits
Final tune
Model matching

2015 — AWR1243

76-81 GHz
Single Chip
Transceiver
Production intent

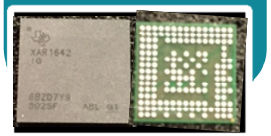
Sampling Now
PPAP Q1 2018



2016 — AWR1642

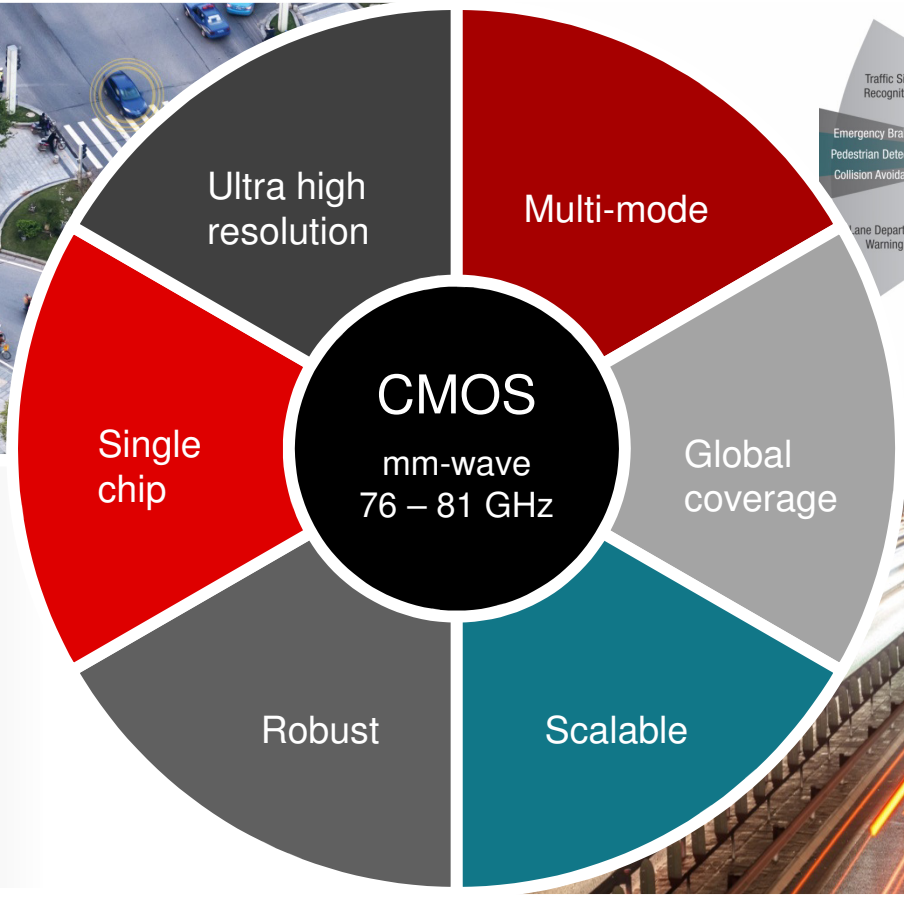
76-81 GHz
Single Chip
Radar
Production intent

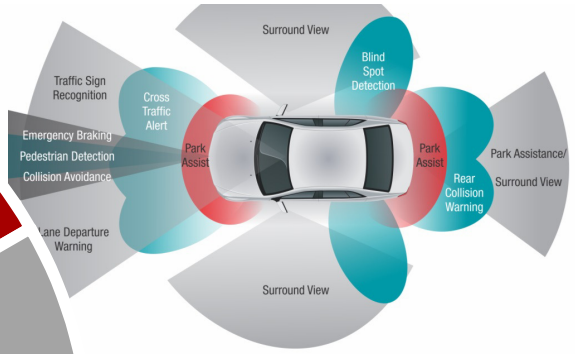
Sampling Now
PPAP Q4 2017



Smart, accurate radar sensors enable autonomous driving

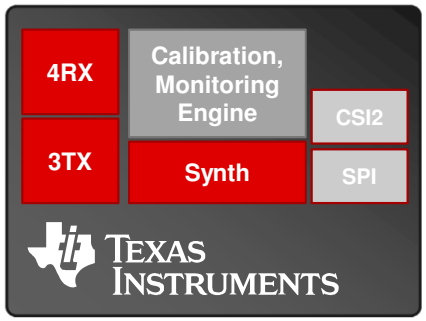
- **5cm resolution**
- **1° angular accuracy**
- **Ability to distinguish two closely placed objects**
- **300km/h max relative velocity detection**
- **Jammer avoidance from other radars**
- **Intelligent self monitoring**





76 – 81 GHz mmWave SoCs (Sampling)

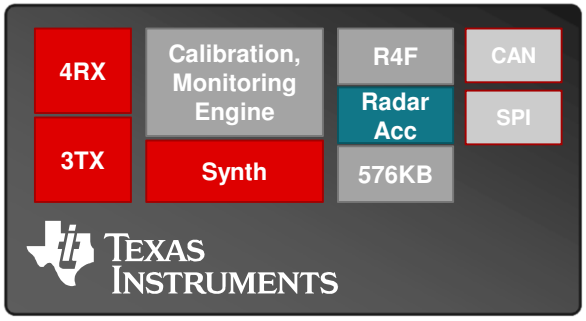
AWR1243



Radar Sensor

- **Use Cases**
  - Imaging Radar Sensor
    - 2x AR12 + External DSP
    - 4x AR12 + External DSP

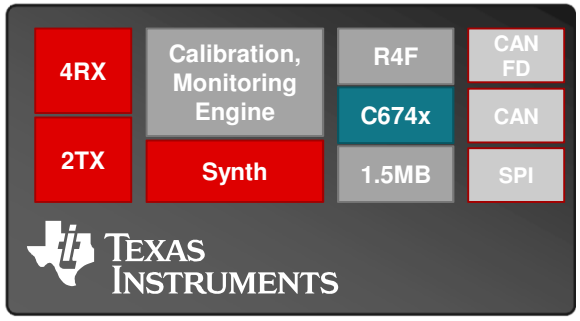
AWR1443



Radar Sensor + HW Accelerator

- **Use Cases**
  - Entry-level Single-chip Radar
    - Proximity warning, Blind spot

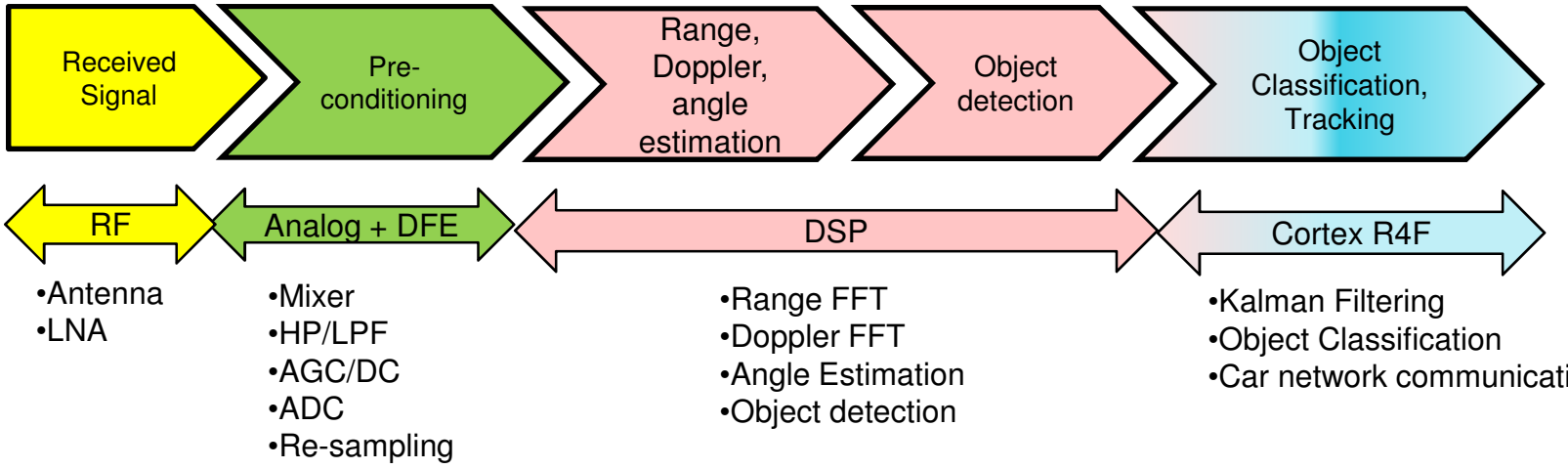
AWR1642



Single Chip Radar

- **Use Cases**
  - USRR Single Chip Radar
    - 160 Degree, 40m
  - SRR Single chip Radar
    - 120m Cross traffic Alert

Scaling from front-end only to full radar integration

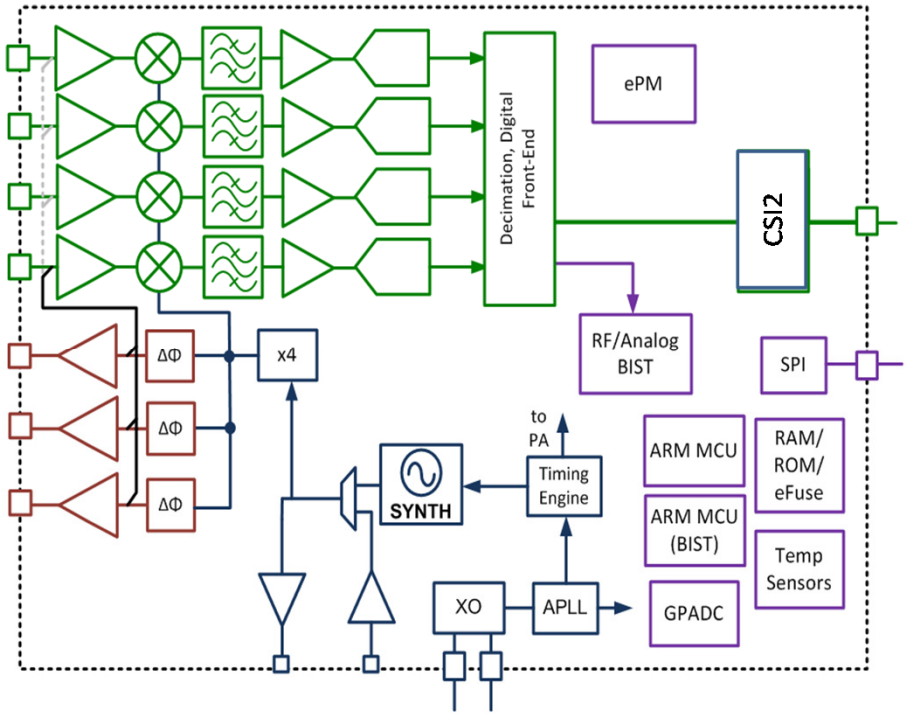


AWR12x

AWR14x

AWR16x

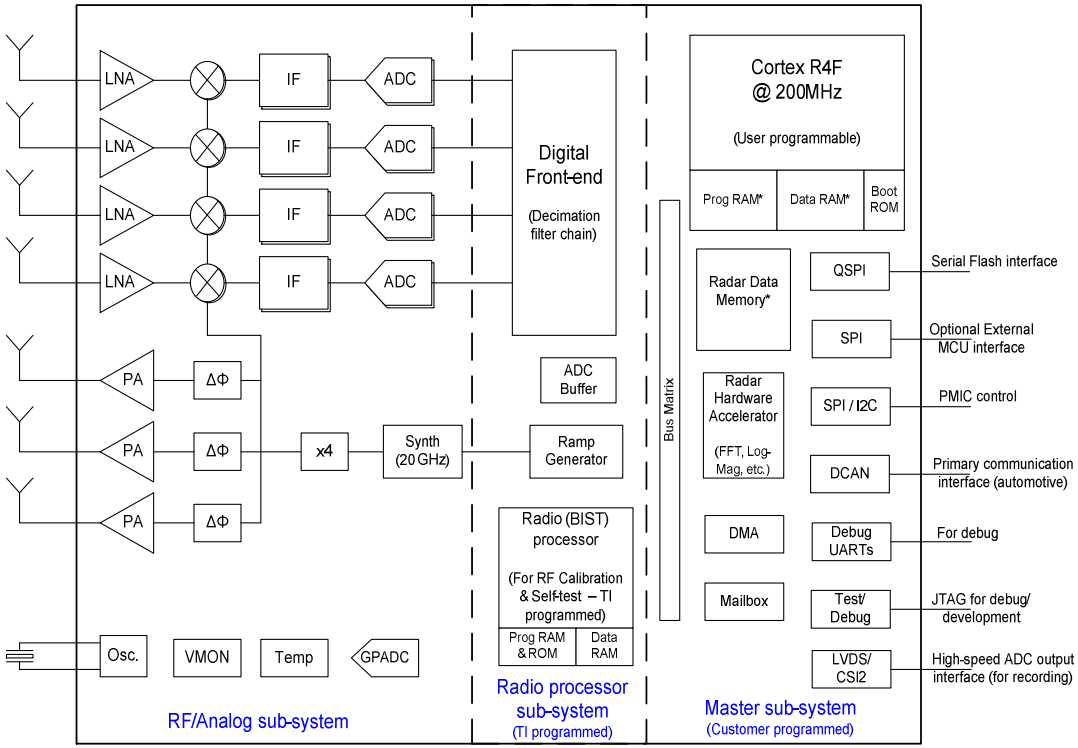
Architecture: AWR1243 Single Chip FMCW Transceiver



Overview

- Highly integrated 76-81GHz front-end
- 3 TX, 4 RX channels
- LVDS/CSI2 interface for ADC data output
- Multi-chip cascading support
- Built-in Radio (BIST) processor for RF calibration and safety monitoring
- Closed loop PLL for precise and linear chirp synthesis
- Complex baseband architecture for improved noise figure and interference tolerance
- Flexible Ramp Generator and Digital front-end supporting multiple chirp profiles
- Wide IF bandwidth (15MHz) and reconfigurable output sampling rates

Architecture: AWR1443 Single Chip Proximity Sensor

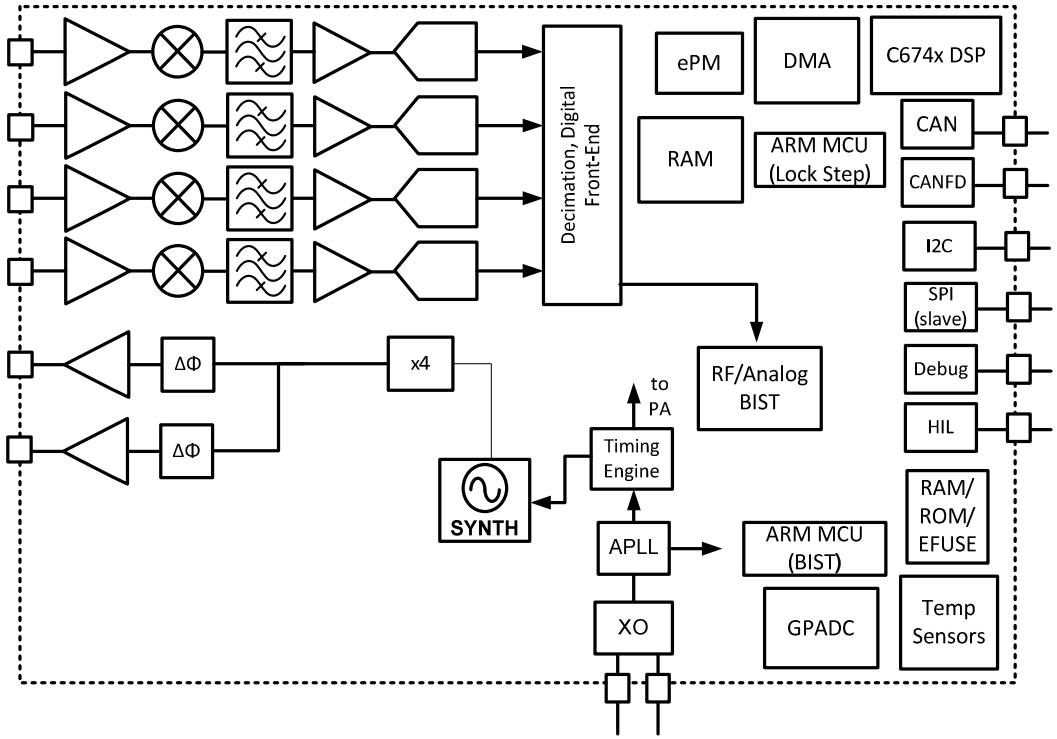


* Total RAM available in Master sub-system is 576 KB (for Cortex R4F Program RAM, Data RAM and Radar Data Memory)

Overview

- Single chip proximity Sensor
- IF bandwidth – 5MHz
- Highly integrated 76-81GHz radar frontend
- 3 TX, 4RX channels
- Multiple automotive interfaces
- Built-in Radio (BIST) processor for RF calibration and monitoring
- Programmable lock step R4F MCU
- Integrated hardware accelerators

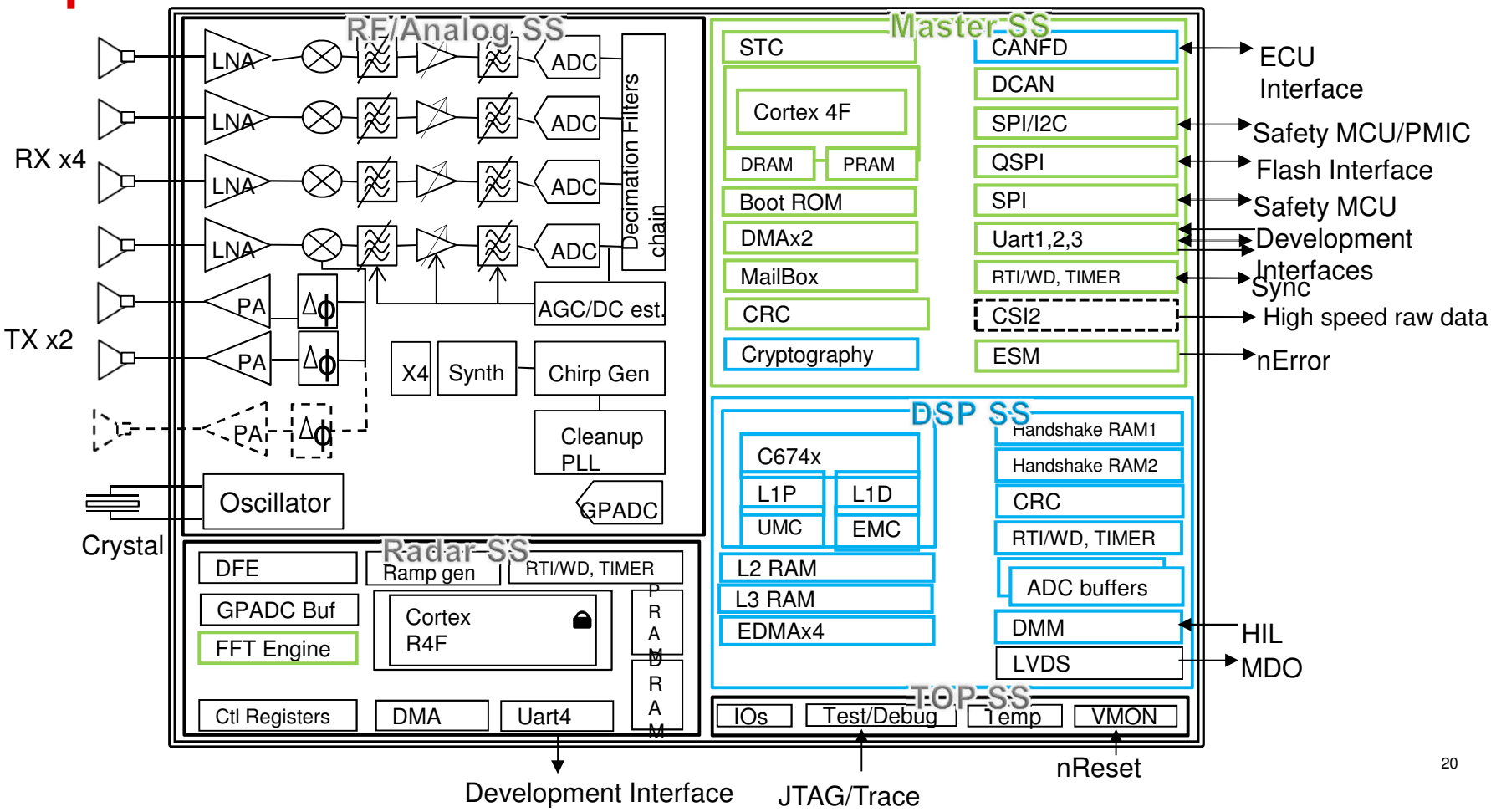
Architecture: AWR1642 Single Chip RADAR Sensor



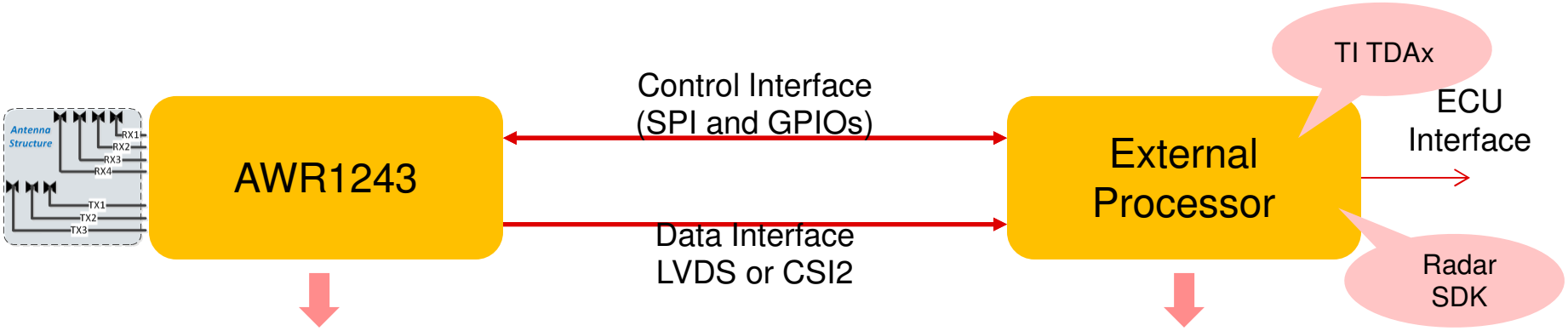
Overview

- Highly integrated 76-81 GHz radar frontend
- 2 TX, 4RX channels
- Multiple automotive interfaces
- Built-in Radio (BIST) processor for RF calibration and monitoring
- Programmable lock step R4F MCU
- High performance C67 DSP
- ASIL B capable

Comparison: AWR1642/AWR1443/AWR1243



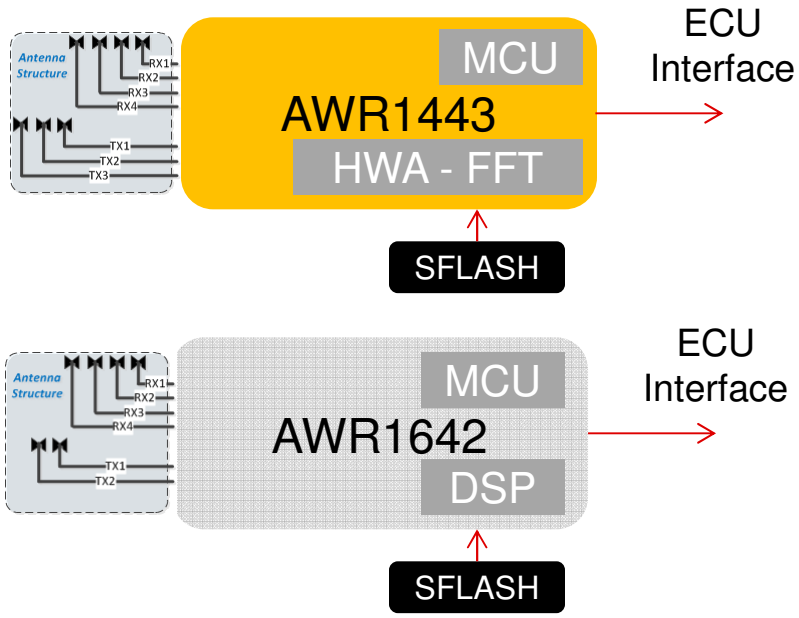
Software Offering - High Performance RADAR Front end



- Control is via messages over SPI
- mmWaveLink: TI offers driver with APIs that abstract these messages

Software Offering → mmWave Device Firmware Package (DFP)

Software Offering - Single Chip RADAR Sensor

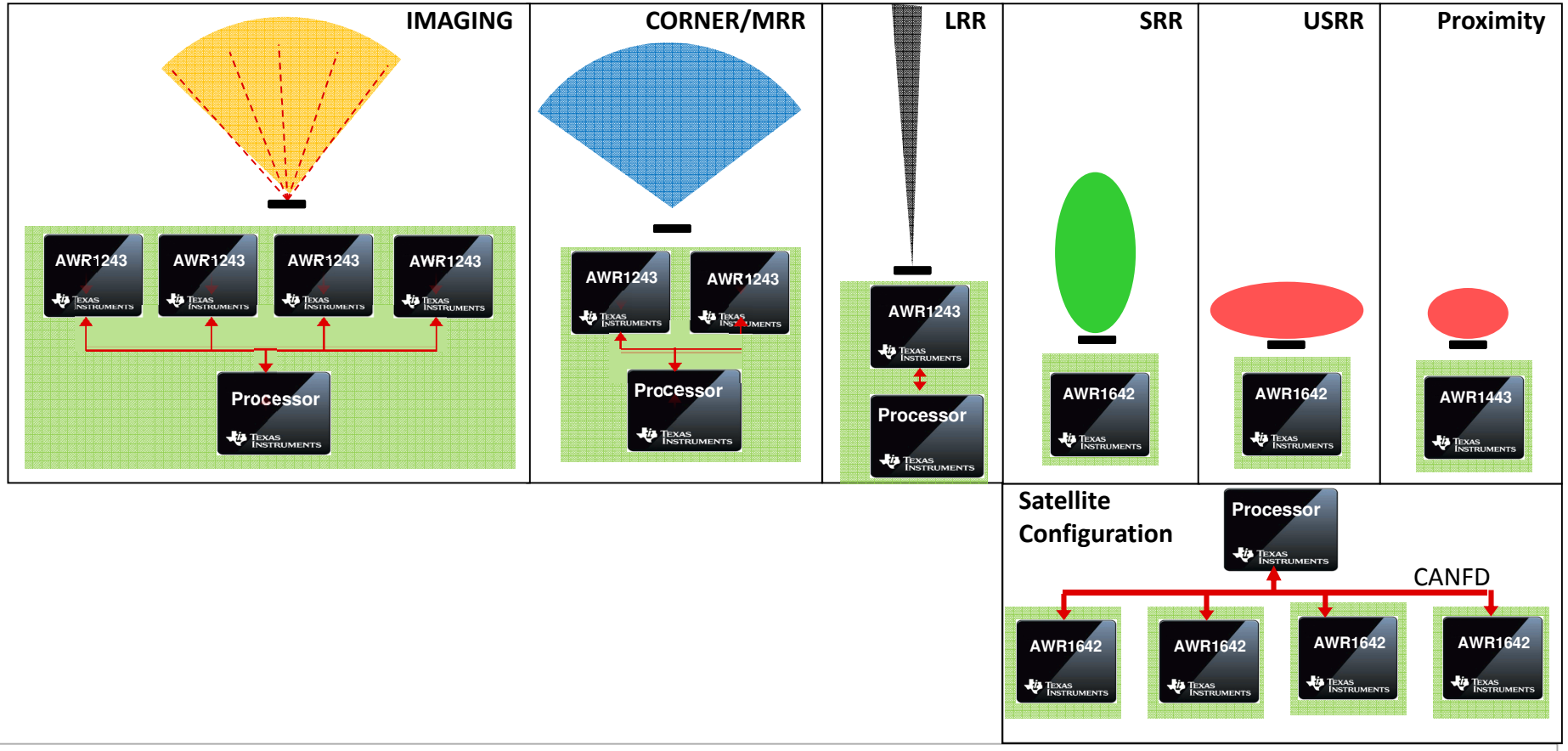


Platform Software

- RTOS
- Device Drivers
- APIs and Processing Libraries
- Sample Applications
- Tools (Image Creation, Flashing etc..)

Software Offering → mmWave Software Development Kit

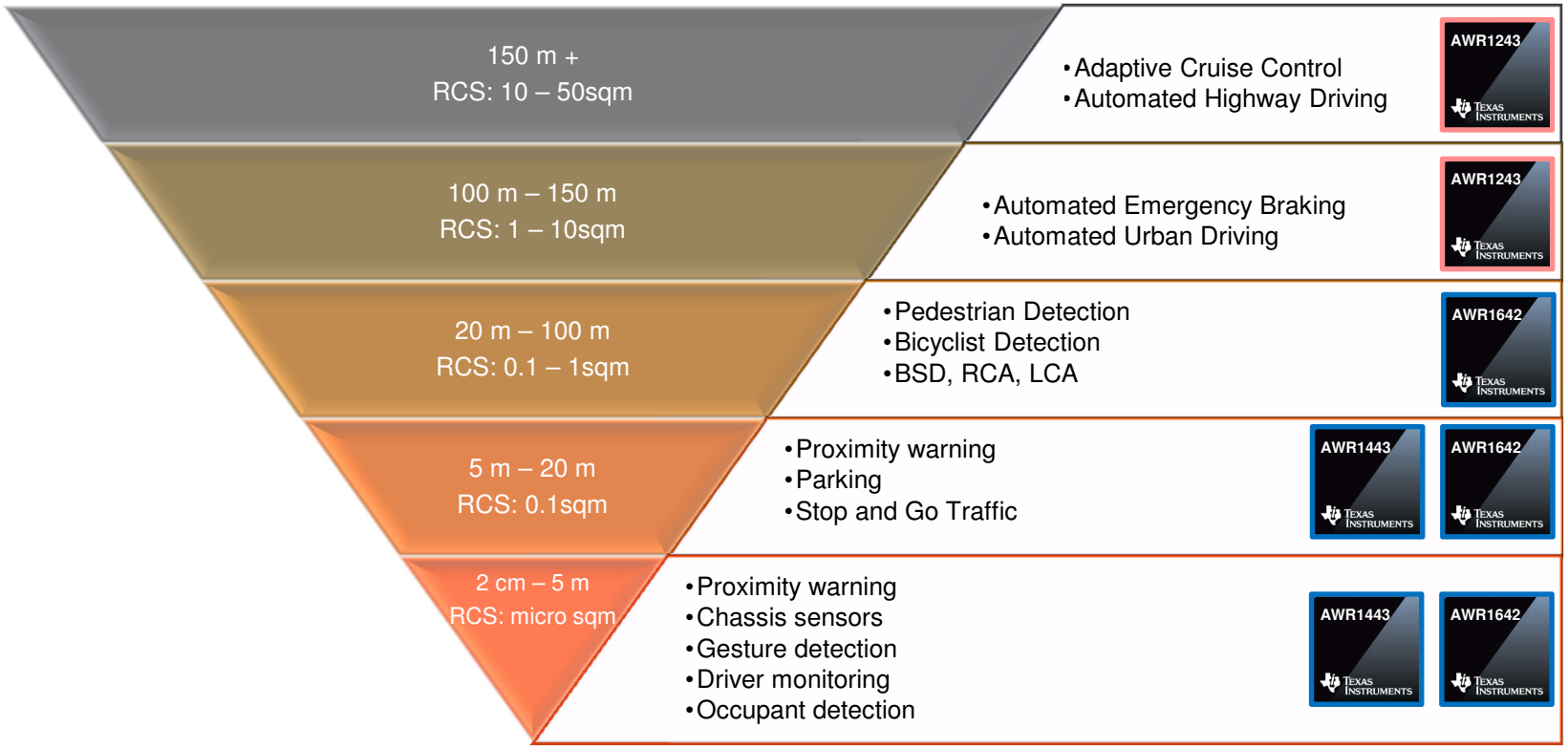
Sensor configuration with TI mmWave solutions



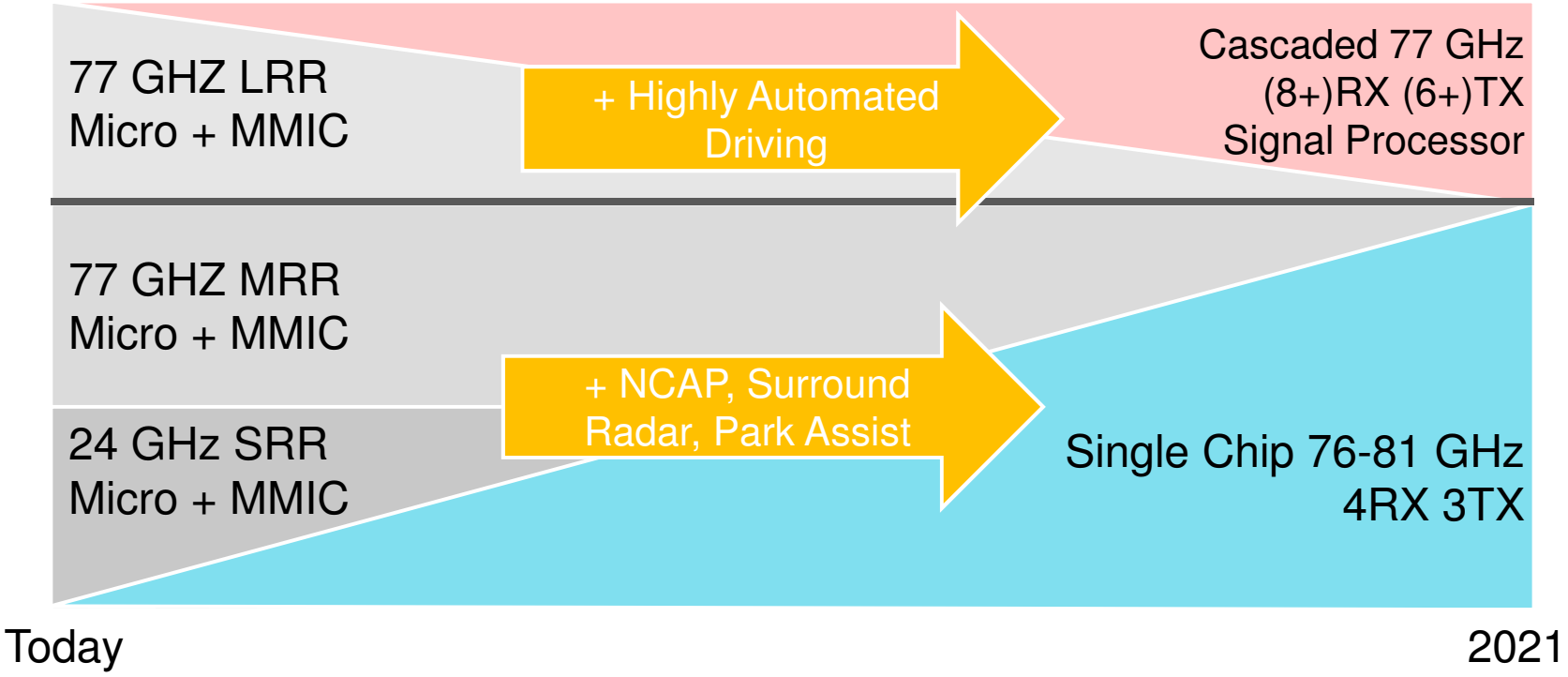
Applications

Single chip solution

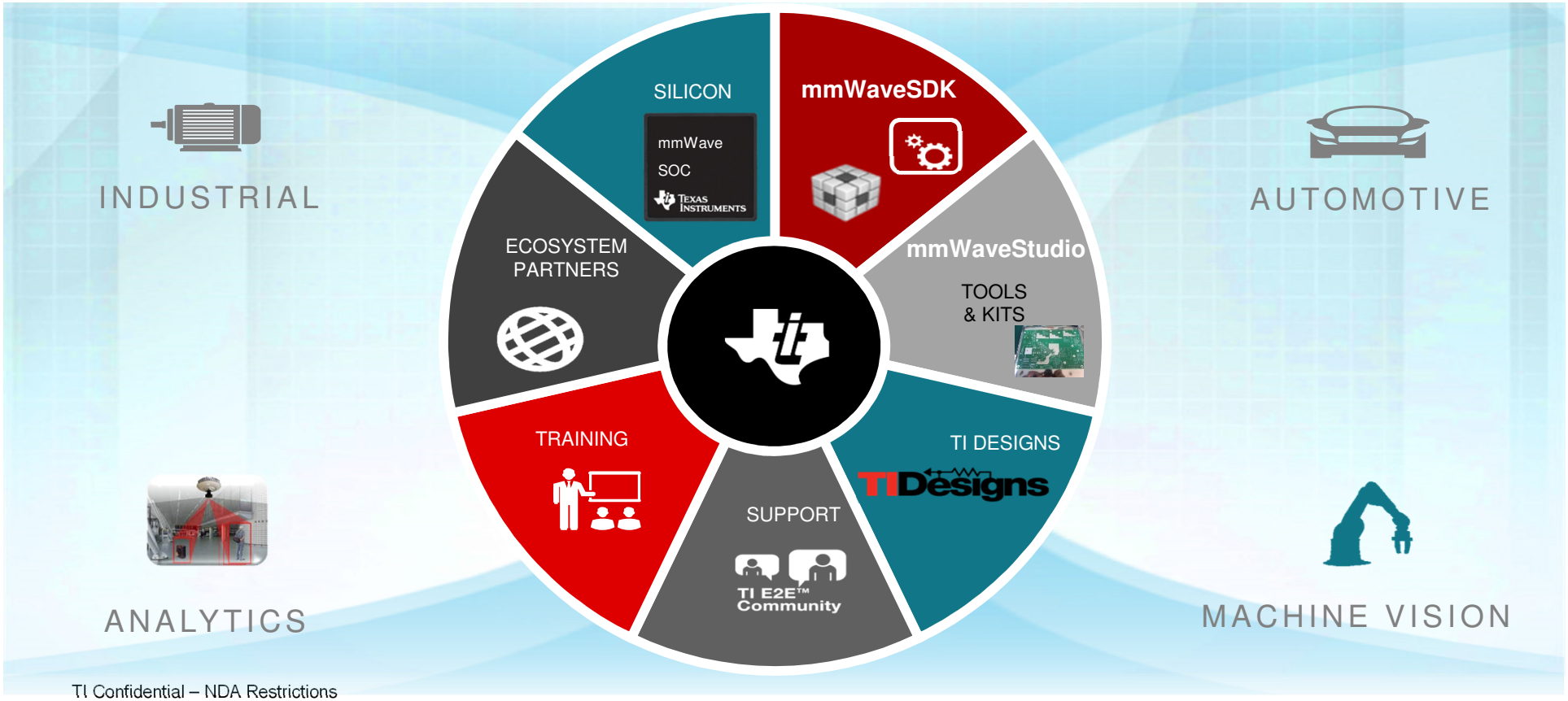
Works with external MCU/DSP



Trend in Radar sensors

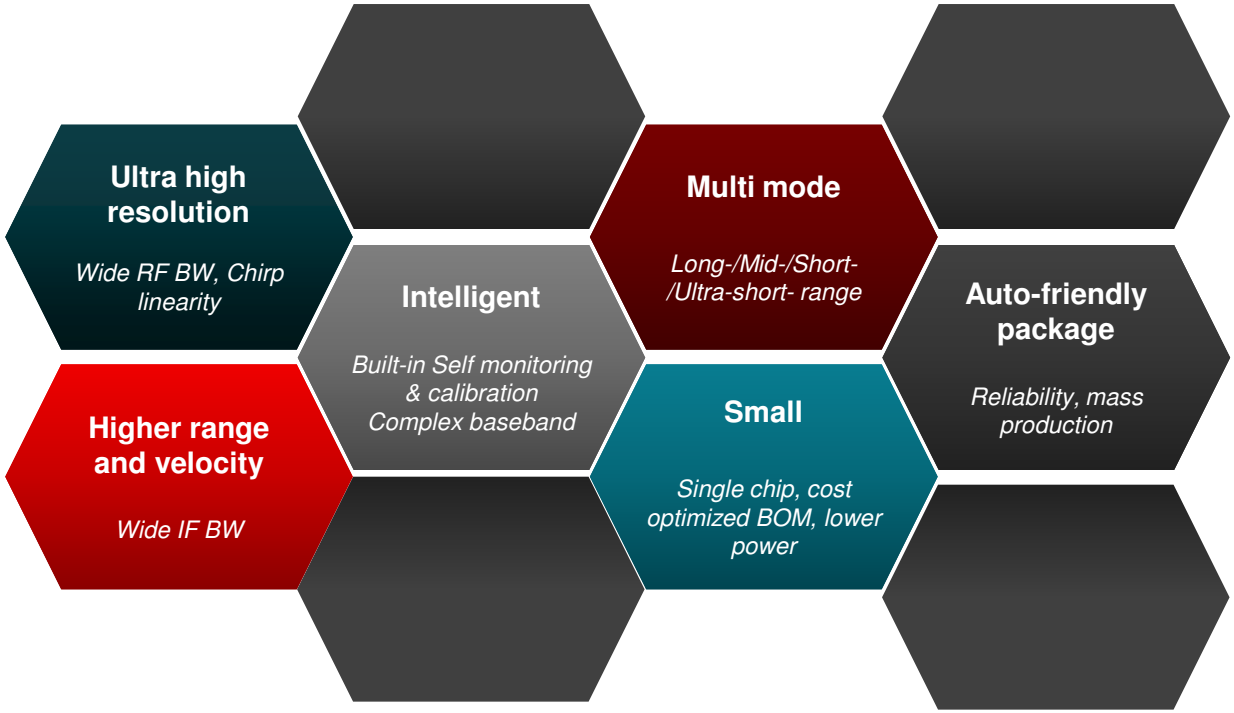


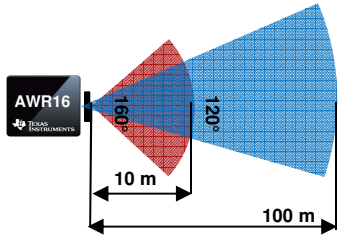
Delivering mmWave sensing solutions



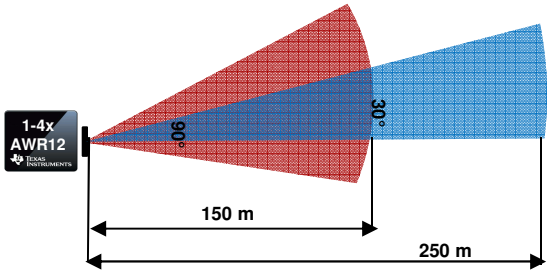
Delivering the most precise sensors in CMOS

Enabling Level 2 and above





- < 5cm range resolution
- 0.01% chirp linearity



- < 1° angular resolution
- 300km/hr max relative velocity

Competing Technologies!

Competing Technologies

Adapted from Kunert, MOSARIM W23 at EuMW 2012	24GHz NB Radar	24GHz UWB Radar	76-81GHz Radar	Mono Video	Stereo Video	Far/Near IR Sensor	Laser Scanner	Ultrasonic
Range < 2m								
Range > 100m								
Angular resolution								
Object separation/discrimination								
Object classification								
Direct velocity measurement								
Operation in dust/fog/snow								
Dazzling sunlight								
Day and night								
Sensor blockage due to dirt								
Mounting/surface cover constraints								
Regulatory constraints								
Effect on vehicle aesthetics								
Sensor data fusion capability								

Stereo Camera

- ❑ Object Classification
- ❑ Better Angular resolution
- ❑ High Processing bandwidth

Lidar

- ❑ Best in class angular resolution
- ❑ Slower scan ~20Hz
- ❑ Expensive

Ultrasonic

- ❑ Cost Effective
- ❑ Large sensors,
- ❑ Can't be placed under bumper

Technology comparison

Technology comparison			
	CMOS	**SiGe BiCMOS**	**III-V (GaAs)**
Speed	Fast	Fast	Very Fast
Breakdown	Low	Med	High
Power Gain	Med	Good	Very Good
Temp. Behavior	Poor	Good	Good
Logic Density	Very High	High	Very Low
Wafer Cost	Low	Low	High

Basic Transistor Comparison

	CMOS	SiGe	GaAs/III-V
Max operating frequency	>100GHz	>100GHz	>100GHz
Logic integration	Very High (>>10X SiGe)	Medium	Low
A2D integration	Yes	No	No
Wafer cost	Lowest	Medium	High
RF Power output	Medium/Low	Medium	High
Power dissipation – RF circuitry	Low	Medium	Medium
Power – data converters	Very Low	Medium	High
Power - logic	Very Low	Medium	High

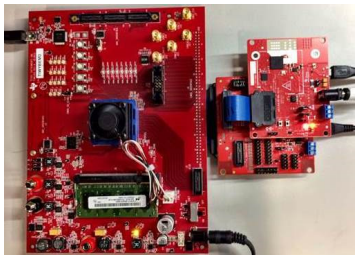
Lets get started & WIN….

Hardware Platforms

AWR1443/AWR1642 EVM

- Enables evaluation of single chip radar
- Proximity sensor demo on AWR1443 EVM
- SRR demo on AWR1642 EVM

AWR1243 + TSW1400

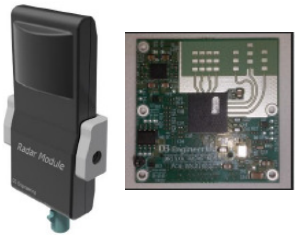


- Enables RF performance evaluation
- Raw ADC capture into PC and then post process
- mmWave Studio to visualize object range/velocity/angle

AWR1243 + TDA3x

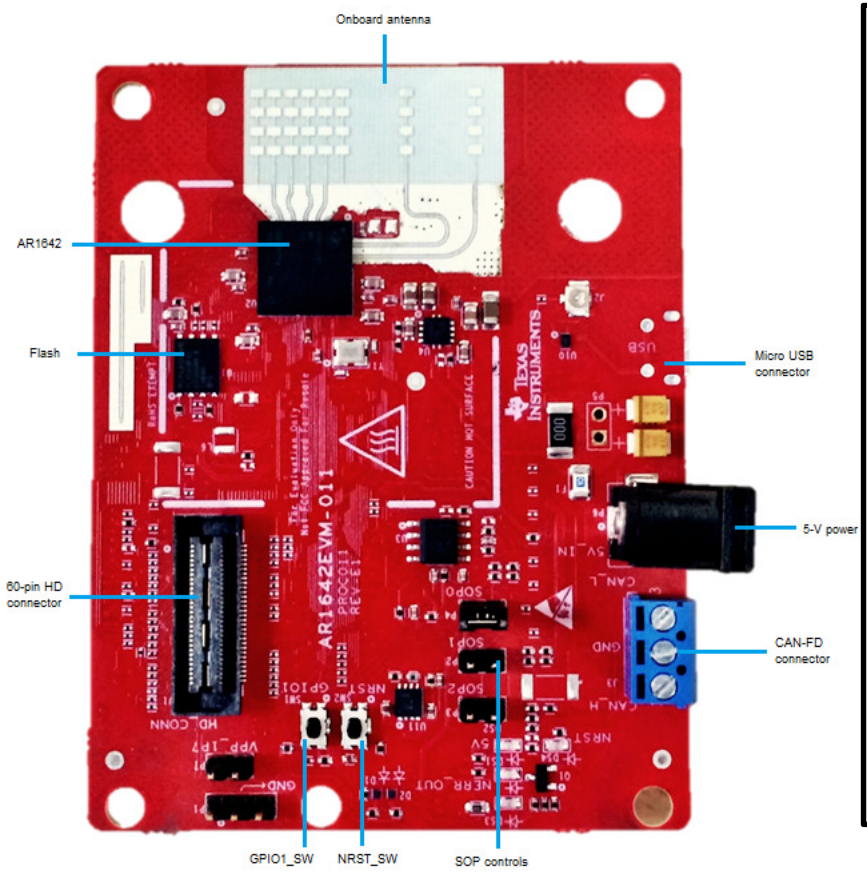
- Enables radar algorithm and MRR/LRR application development on TDA3x
- Enables vehicle validation/demonstration

AWR1443/AWR1642 Sensor module



- Enables radar algorithm and proximity/SRR application development on AWR1443/ AWR1642
- Enables vehicle validation/demonstration

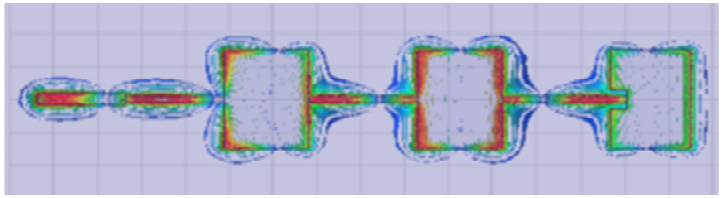
EVMs-AWR1243/AWR1443/AWR1642



Key Features

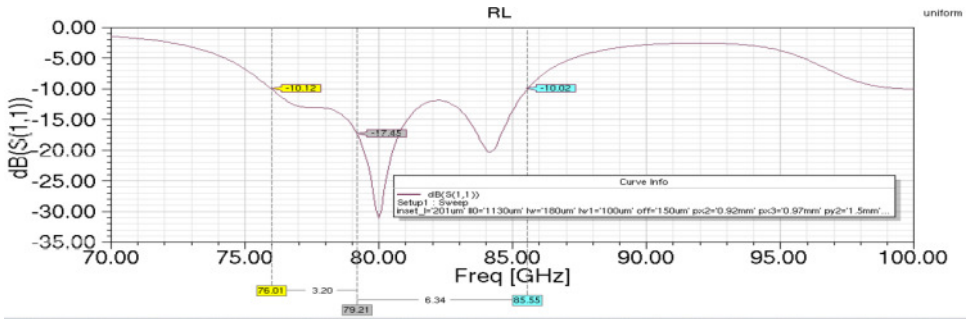
- The Booster Pack
- Rogers RO4835 material
- Antenna on board
- XDS110 based JTAG emulation
- On board QSPI flash for application code storage.
- UART through USB to PC for debug logging.
- On-board CAN transceiver for AWR1443 & CAN/CANFD for AWR1642.
- Provision for ADC raw data transfer over LVDS/CSI.
- leverages the Launchpad ecosystem
- 5V power jack to power the board

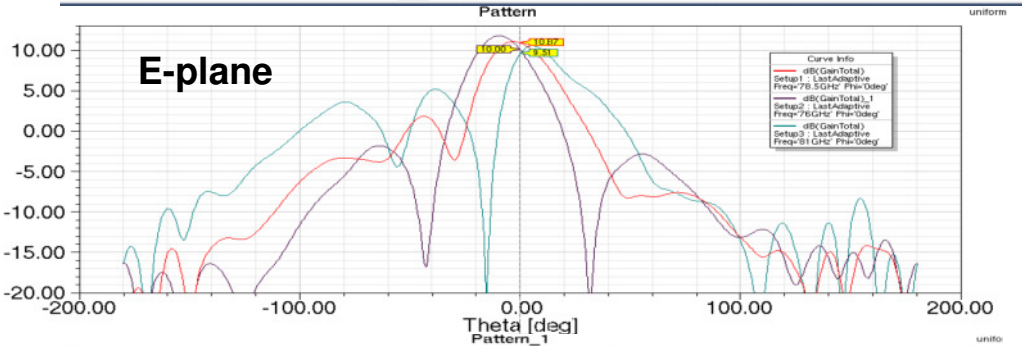
Antenna element on RO4835- 3-element series-fed inset

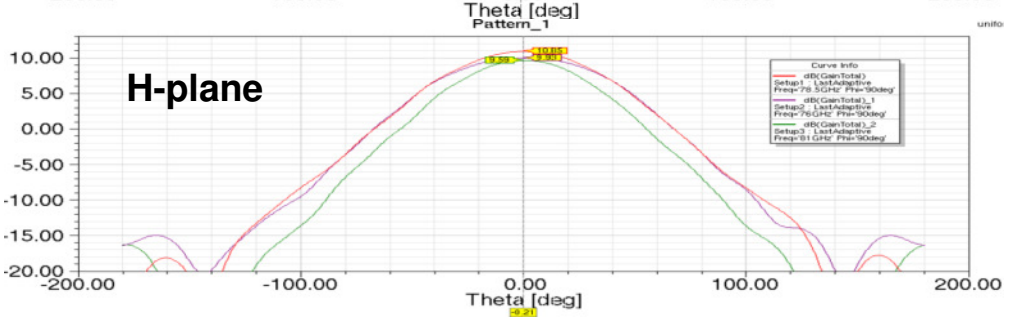


Substrate	RO4835, 4mil
Antenna length	6.5mm
BW (RL>10dB)	76-85GHz

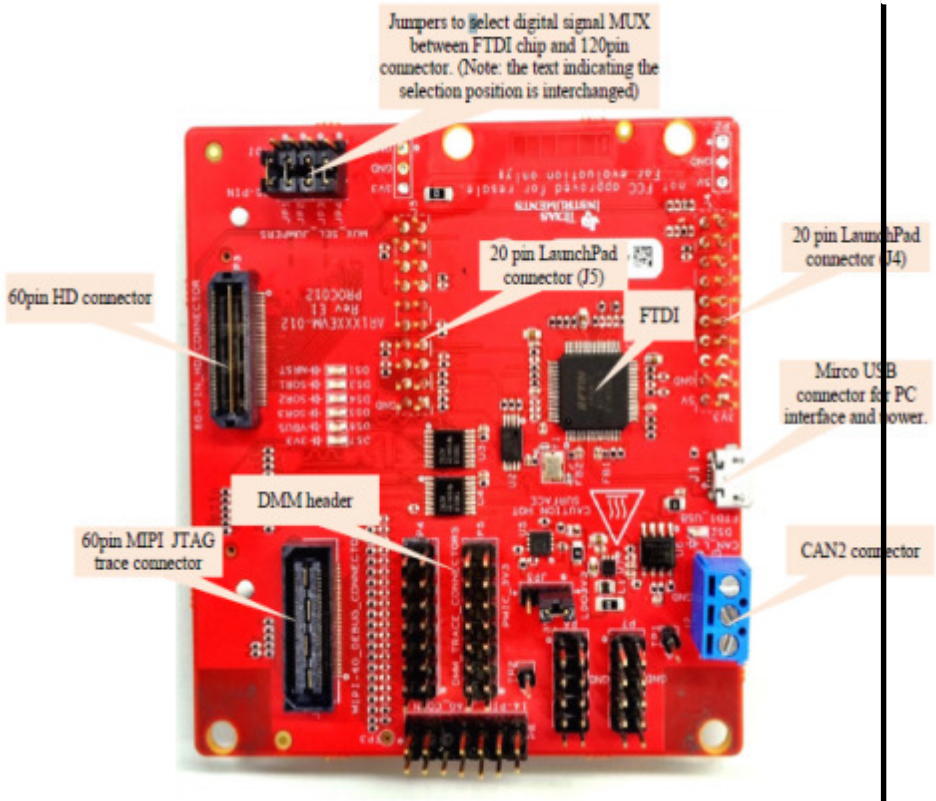
Frequency (GHz)	76	78.5	81
Peak Angle (EL,AZ) (deg)	2.5,0	9,0	17.5,0
Peak Directivity (dBi)	12.8	12.1	11.6
Peak Gain (dBi)	11.7	11.1	10.5
Radiation Efficiency (%)	78	78	78
Side lobe Level (dB)	13.5	9.2	5.3
H-plane Beamwidth (deg)	66	65	61
E-plane Beamwidth (deg)	24.4	27.1	23.1







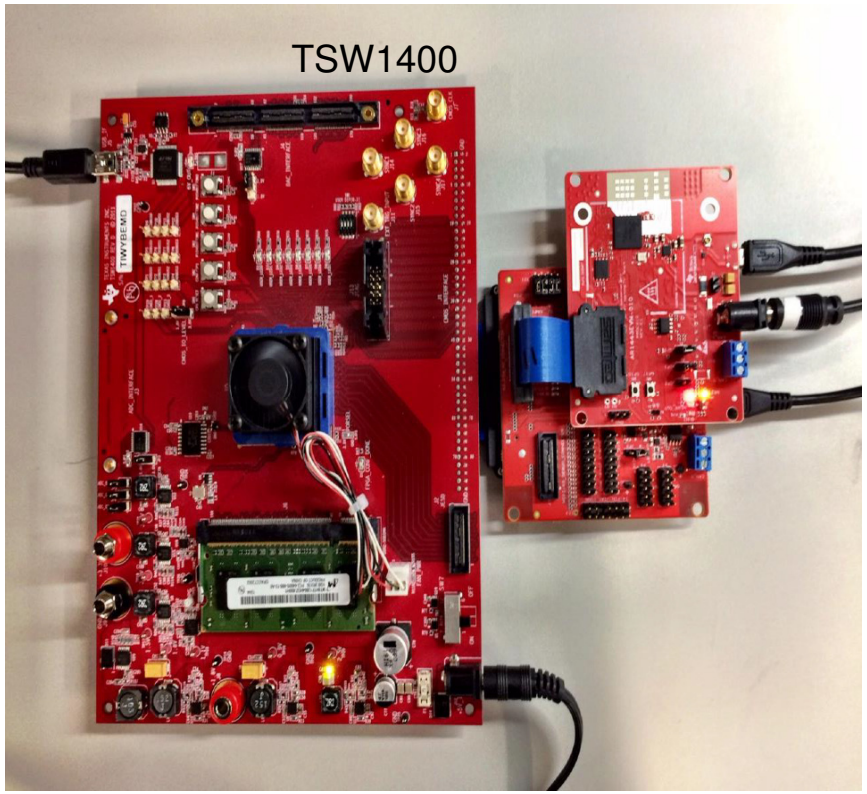
Debug Devpack



Key Features

- Micro USB Powered.
- PC interface through on board FTDI for SPI, GPIO controls & UART loggers
- 120pin connector to interface with TDA3 EVM (via DIB and VAB boards) and the TSW1400
- 20 pin LaunchPad connectors for Control signals to/from the AWR1443 EVM
- 60 pin high density (HD) connector to get the high speed ADC data over CSI or LVDS interface from the Booster-Pack..
- 60pin MIPI connector for JTAG trace (for AWR1642 ONLY)
- Header for DMM interface (for AWR16XX device ONLY).
- Second CAN connector (for AWR1642 device ONLY).

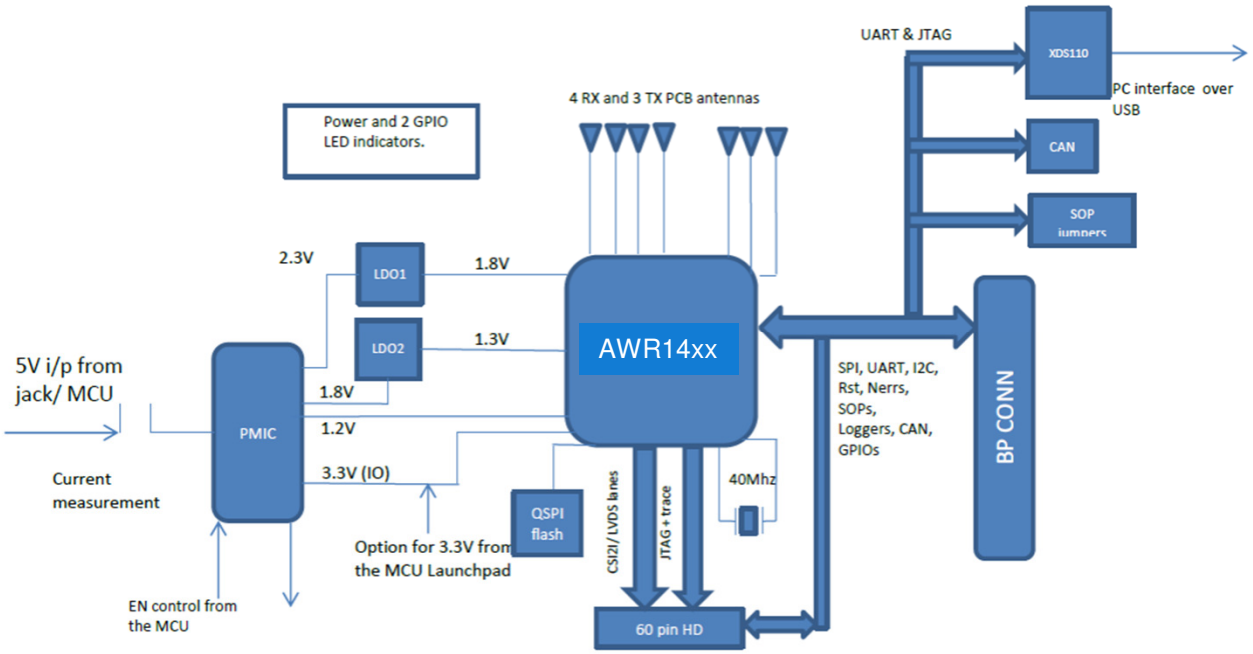
ADC data capture solution: TSW1400



Key Features

- ❑ Altera Stratix IV based FPGA generic ADC data capture board.
- ❑ Supports 900MBPS Serial LVDS capture on 7 Pairs of LVDS pins.
- ❑ 512MB of on board storage space
- ❑ Supports capture and post processing in RT3 directly.
- ❑ Supports single-tone, multi-tone signal performance analysis
- ❑ Supports up to 16 converter channels simultaneously
- ❑ Capability to feed CMOS parallel data using DAC interface.

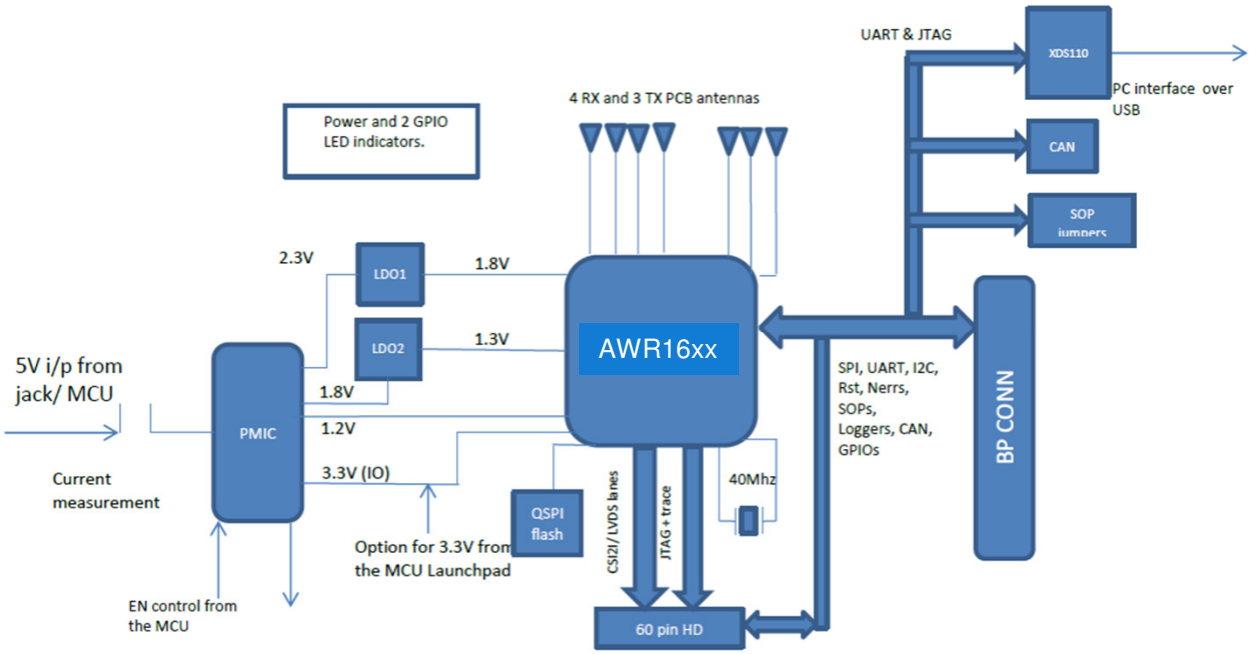
System Block Diagram – Proximity Sensor



Associated Reference Designs
Ref Des #1 TBD

TI Products in this System
Device #1 AWR1443
Device #2 LP87524B-Q1
Device #3 TPS7A8801
Device #4 TPS7A8101

System Block Diagram – Short Range Sensor



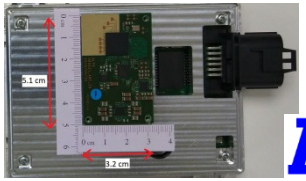
Associated Reference Designs
Ref Des #1 TIDEP0092

TI Products in this System
Device #1 AWR1642
Device #2 LP87524B-Q1
Device #3 TPS7A8801
Device #4 TPS7A8101

mmWave Sensing Ecosystem

Hardware solutions

D3



ALPS

CBCline

Software and Tools

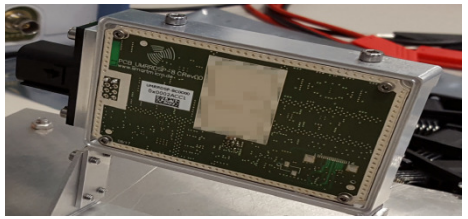
VECTOR

LATTICE SEMICONDUCTOR

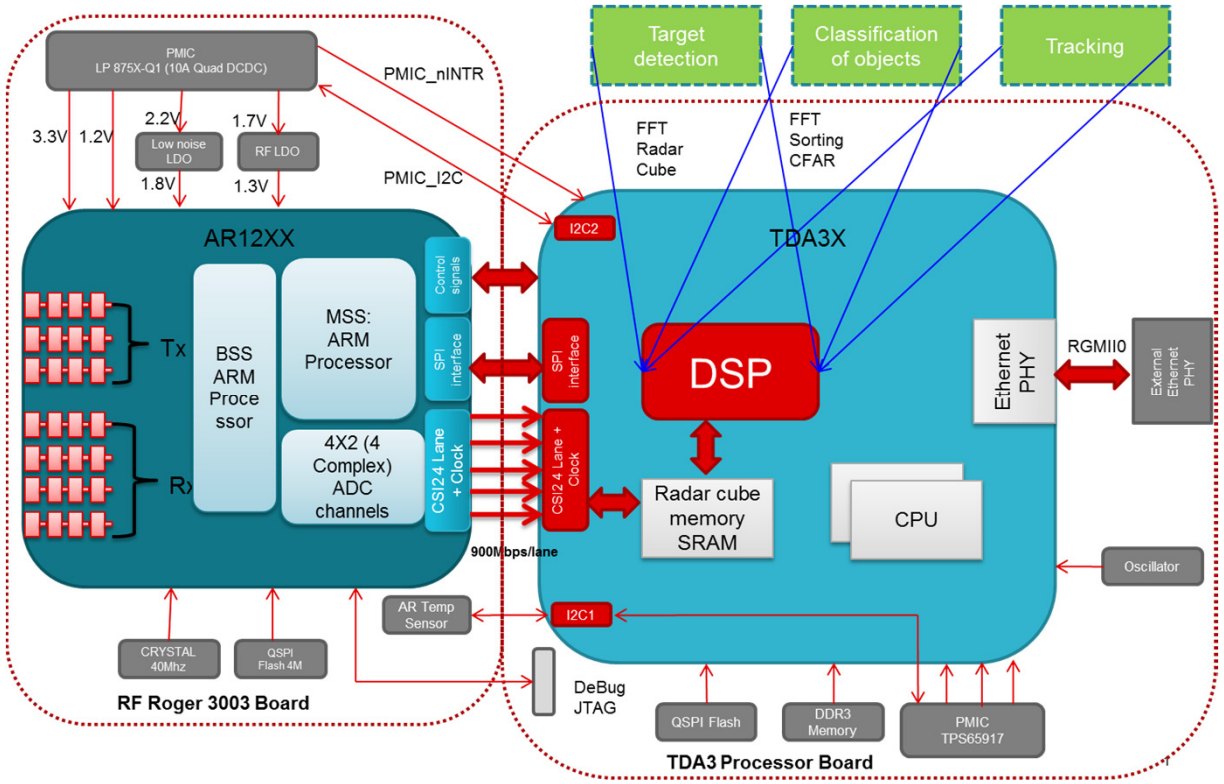
LAUTERBACH DEVELOPMENT TOOLS

Turnkey solutions

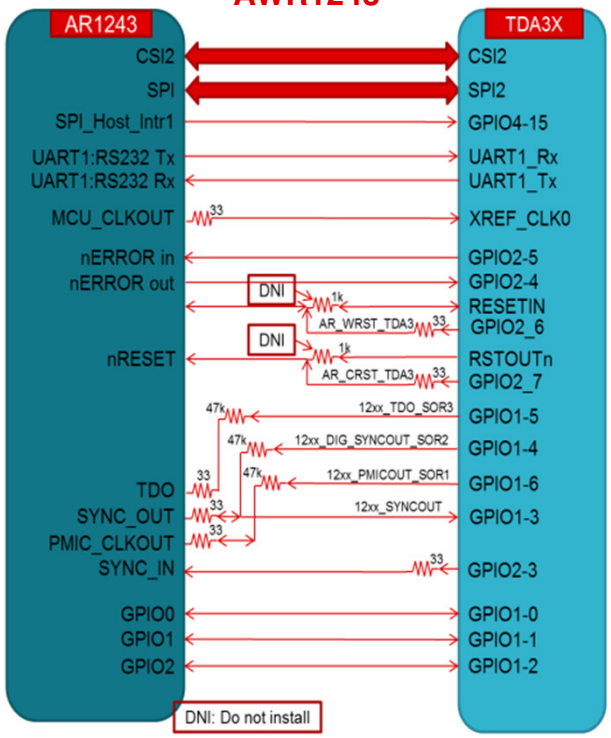
smartmicro
SMART MICROWAVE SENSORS GMBH



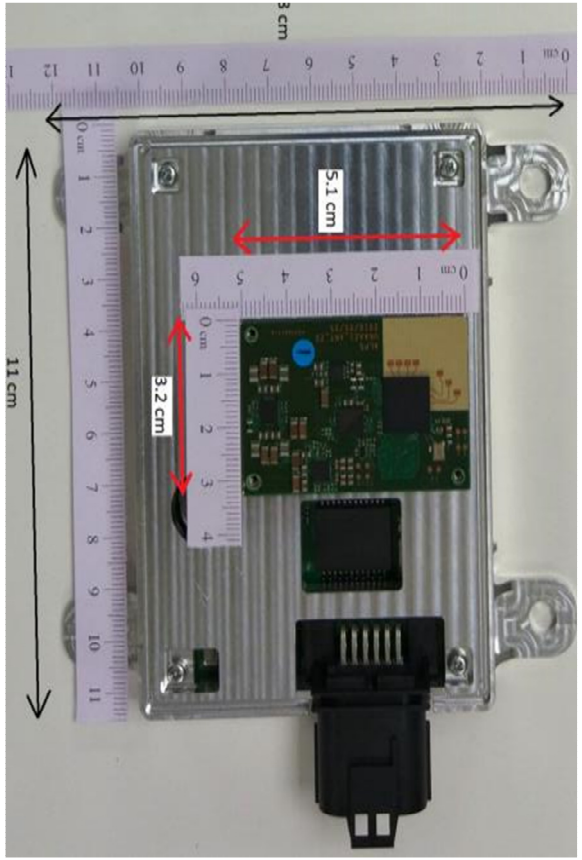
3rd Party Module – AWR1243+TDA3x : High level Architecture

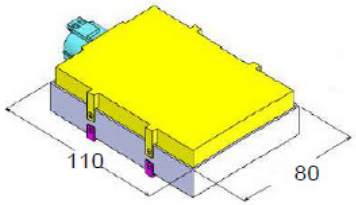


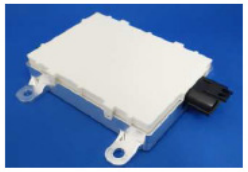
Signals between TDA3X and AWR1243

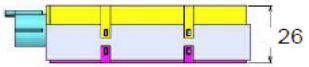


3rd Party Modules ALPS : Sensor Module

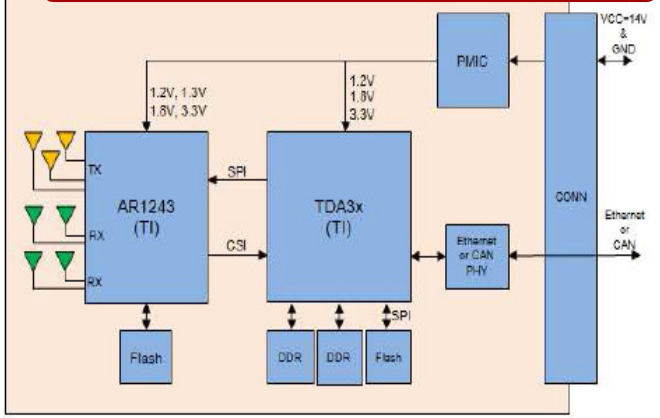








Simplified block diagram



Key Features

- Supports Radar system development on TDA3X + AWR1243 Platform
- Supports Multiple antenna configuration: 2 Flavors of RF Boards
- RJ45 Connector based Ethernet support
- 60 pin MIPI connector with Trace debug capability
- Single Power supply Module with Aluminum casing acting as heatsink

Design kit availability

	AWR1243	AWR1443	AWR1642
Silicon	√ (PPAP) June 2018	√ (PPAP) June 2018	√ (PPAP) Jan 2018
EVM • TI(Ecosystem partner) built reference HW	√	√	√
RF tool • Signal Path analysis, Radiative measurements	√	√	√
HDK • Reference Schematic/Layout, BOM, RF Model, Thermal Model	√	√	√
SDK • Firmware, Device drivers, Operating system, Development environment	√	√	√

Thank you

Back up