The 77GHz/60GHz CMOS mmWave Radar Sensing for Automotive and Industrial

2019/06/03

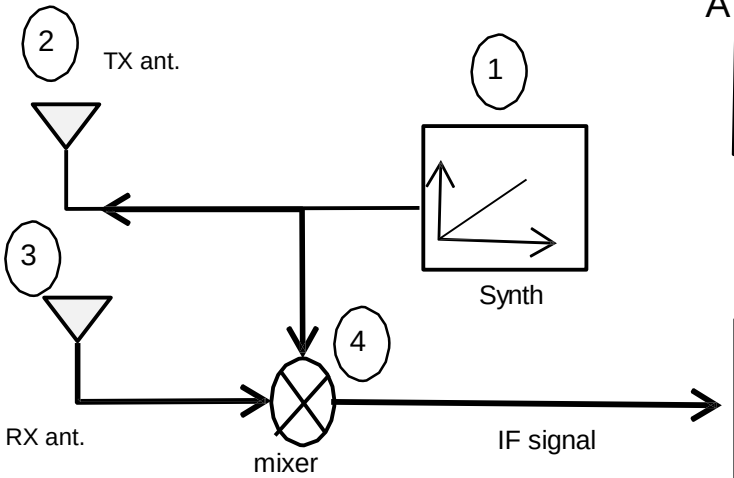
TI Jesse Wang

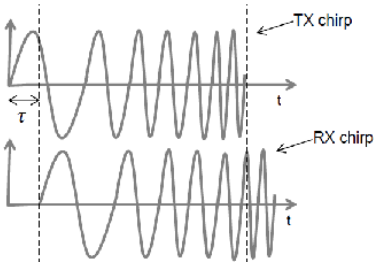
Agenda

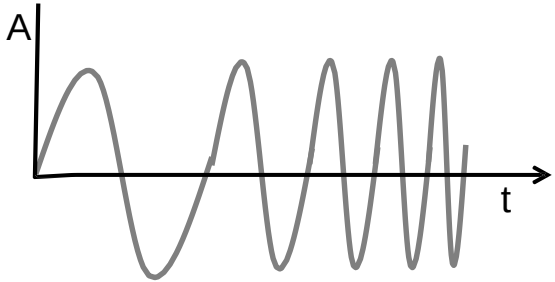
- mmWave Radar Sensor Technology Overview
- mmWave Radar Sensor Main Applications
  - Automotive
  - Industrial

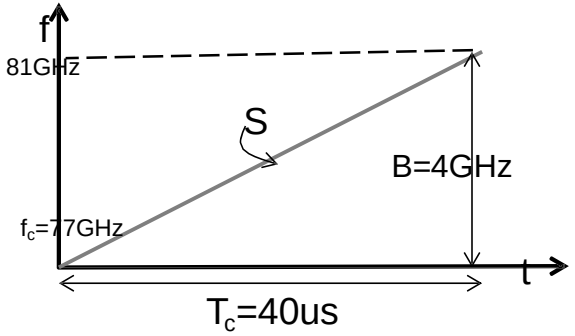
- mmWave Radar Sensor Technology

Basics of FMCW (Frequency Modulation Continue Wave)









1. A synthesizer (synth) generates a "**chirp**"
2. The chirp is transmitted by the TX antenna
3. The chirp is reflected off an object and the reflected chirp is received at the RX antenna.
4. The RX signal and TX signal are 'mixed' and the resulting signal is called an 'IF signal'.

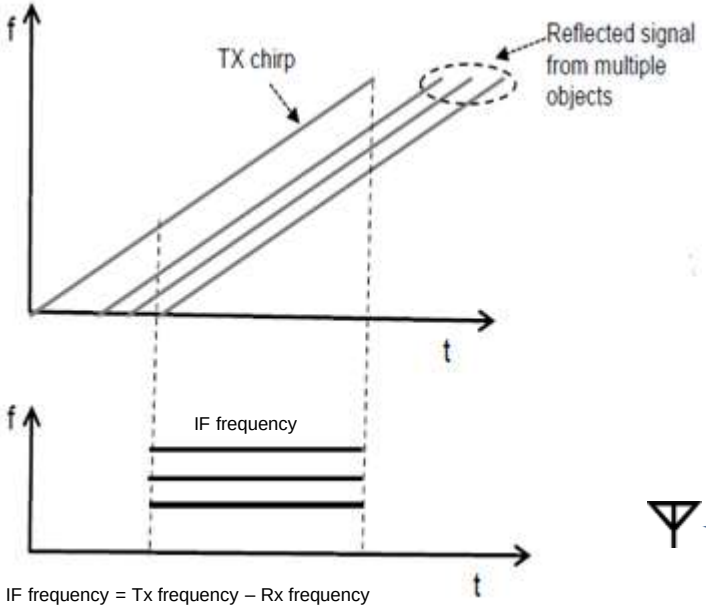
$$\mathrm{Tx} = \sin[w_1 t + \phi_1)]$$

$$\mathrm{Rx} = \sin[w_2 t + \phi_2)]$$

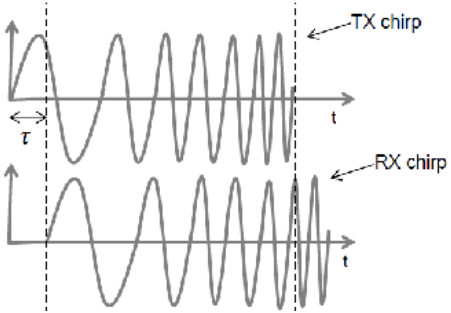
$$\mathrm{IF} = \sin\ [(w_1 - w_2)\, t + (\phi_1 - \phi_2)]$$

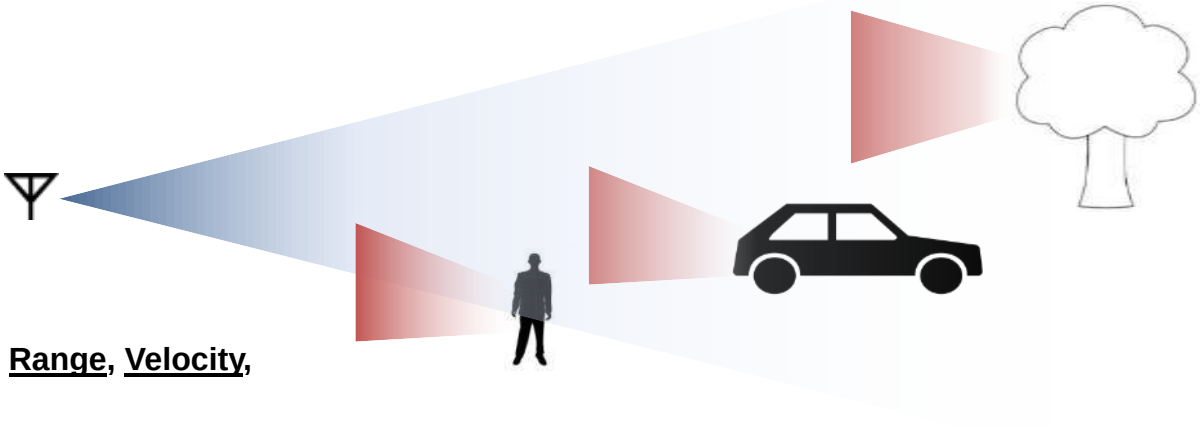
The fundamentals of millimeter wave sensors, http://www.ti.com/lit/wp/spyy005/spyy005.pdf

Basics of FMCW (Range Measurement)



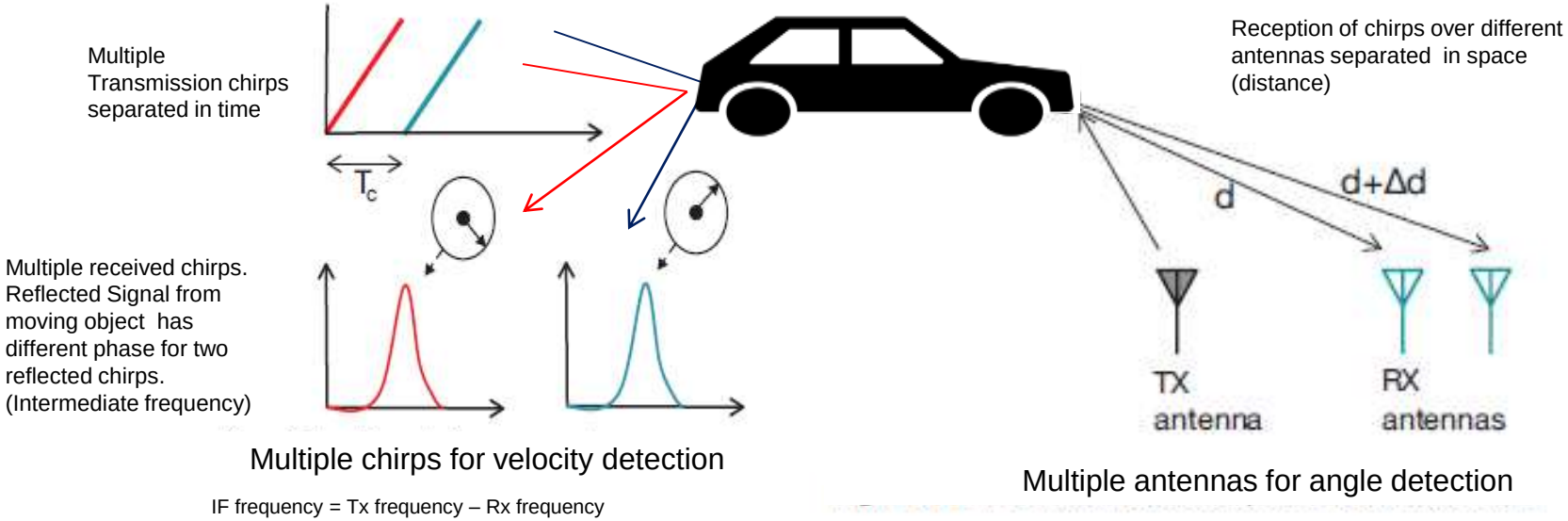
IF frequency = Tx frequency – Rx frequency





By working with FFT on these IF signals to get **Range**, **Velocity**, **Angle** information of detecting object

Basics of FMCW (Velocity and Angle Measurement)



Multiple chirps for velocity detection

IF frequency = Tx frequency – Rx frequency

Multiple antennas for angle detection

Velocity and Angle of object reflects in phase difference of IF signal.

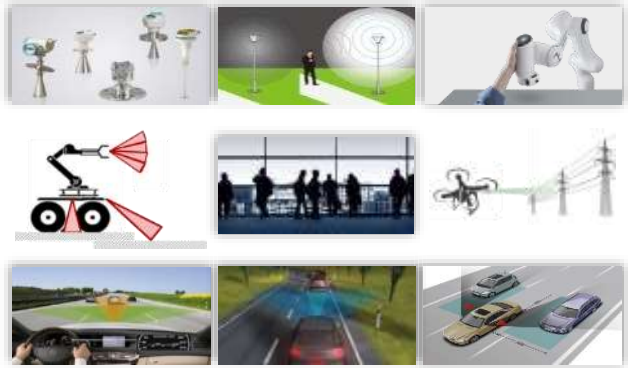
mmWave Sensors – Technology Overview

What is mmWave sensing

- mmWave is the band of spectrum between 30GHz and 300GHz
- Electromagnetic waves used for sensing, imaging and communications
- mmWave sensors measure with high accuracy **range**, **velocity** and **angle** of remote objects

When to use mmWave sensing?

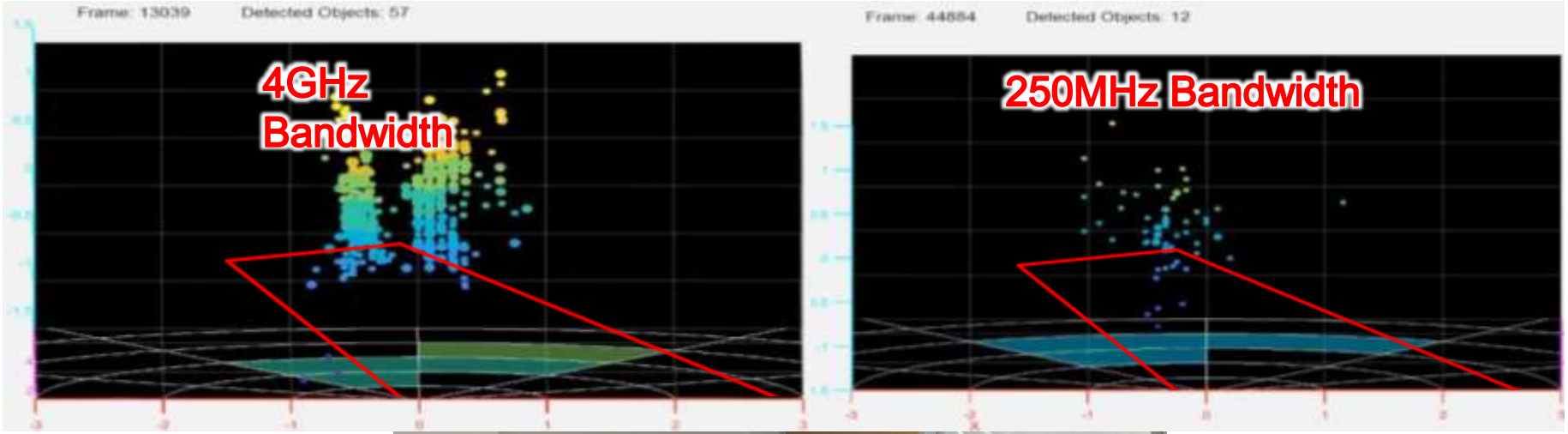
- High precision range measurement – tank level probing, displacement sensing, and vibration monitoring
- Smarter infrastructure – occupancy sensing, traffic monitoring, lighting control, gesture recognition
- Advanced navigation for drones and robotics – sense and avoid, landing assistance, collision avoidance, ground speed sensing
- Automotive - Adaptive cruise control, automatic emergency brake, lane change assist, and more



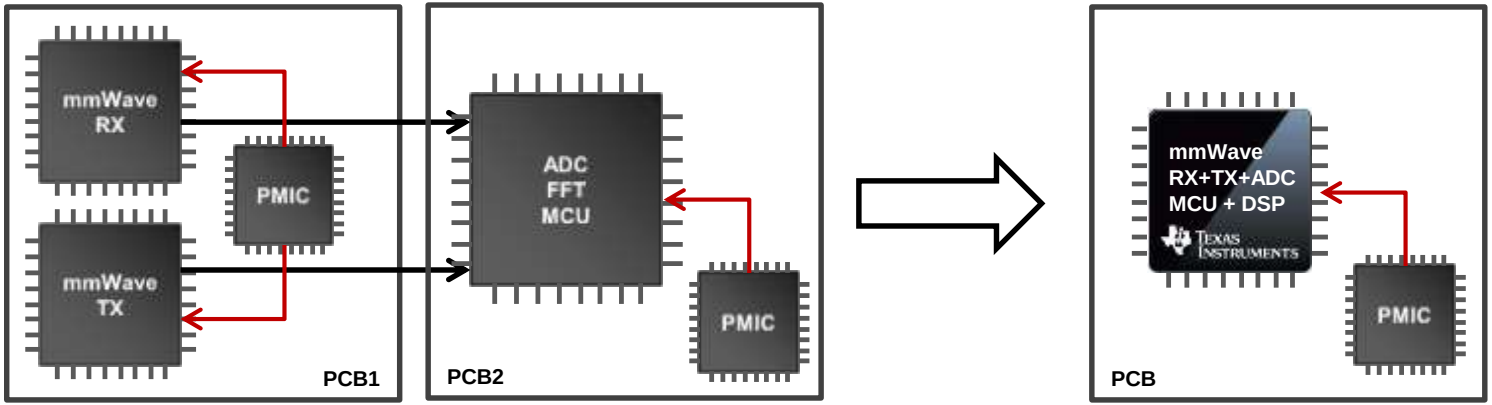
Why Now?

- mmWave technology is **robust against environmental** influences such as bad light and weather conditions and extreme temperatures
- **RFCMOS** technology enables analog/digital integration in a small single chip, low-power solution
- Highly linear signal generation, ultrawide resolution, robust calibration/monitoring, and more for unprecedented accuracy in RF sensing

Bandwidth of 4GHz vs 0.25GHz – Sensor View



Single Chip Integration Enabled by CMOS



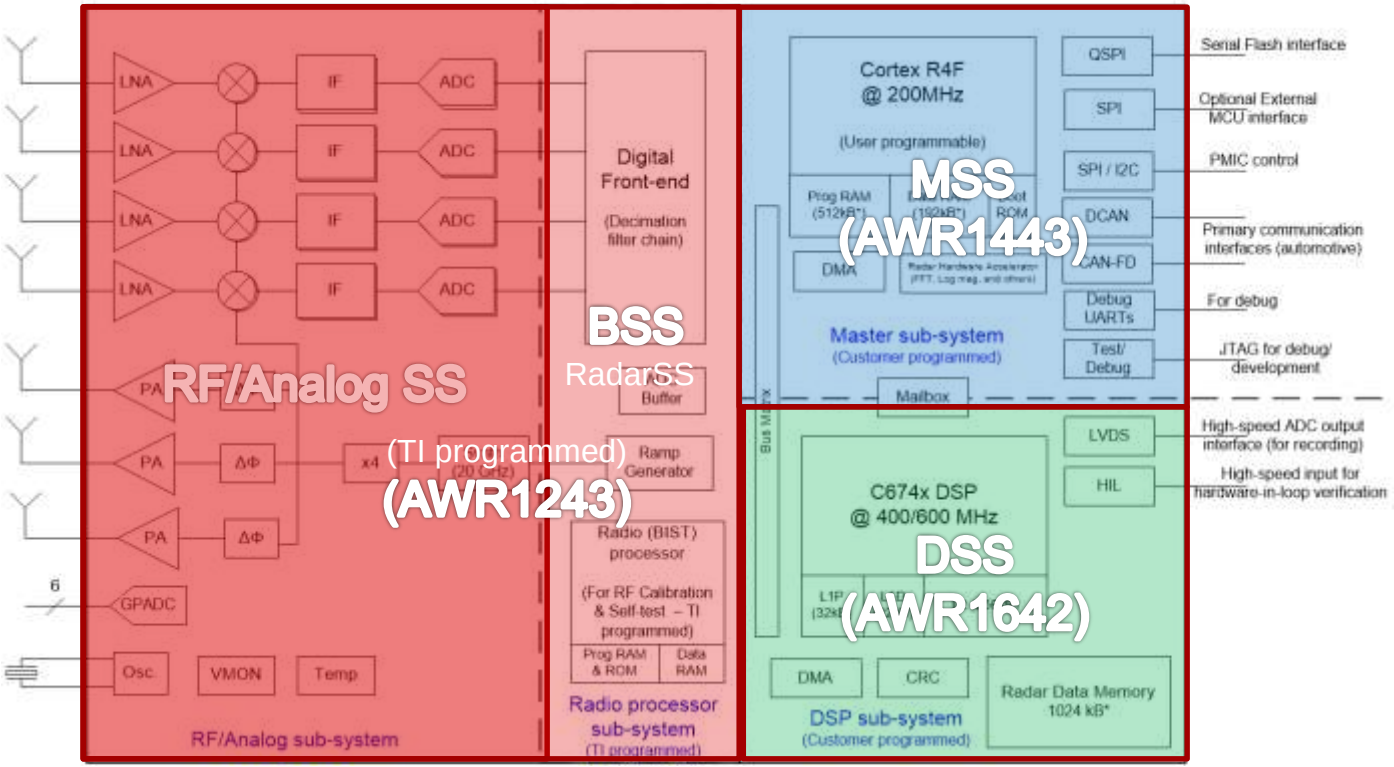
Discrete Multi-Chip mmWave Sensor

- Discrete solution – expensive
- Complex and critical signal routes
- Unconventional packaging
- Prone to noise
- Lack of system level observability
- Crude implementation of RF and Baseband safety

TI Single-Chip mmWave Sensor

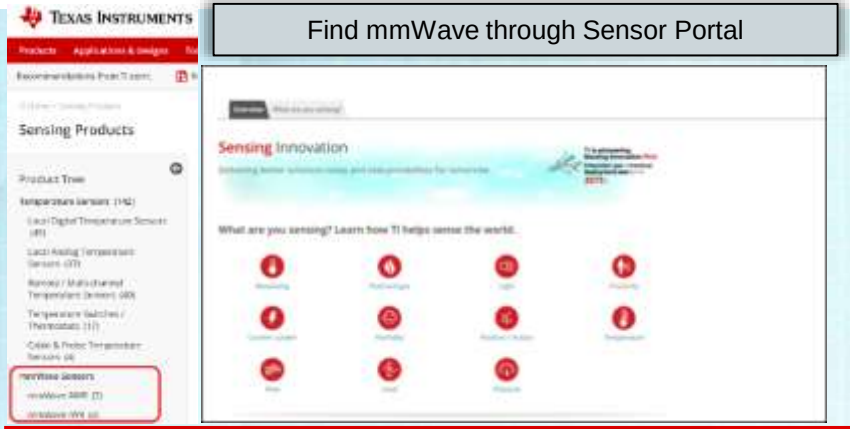
- Smaller in size
- Simpler design
- Built in monitoring and calibration (ASIL)
- High Resolution, less false positives
- Programmable core
- Lower Power

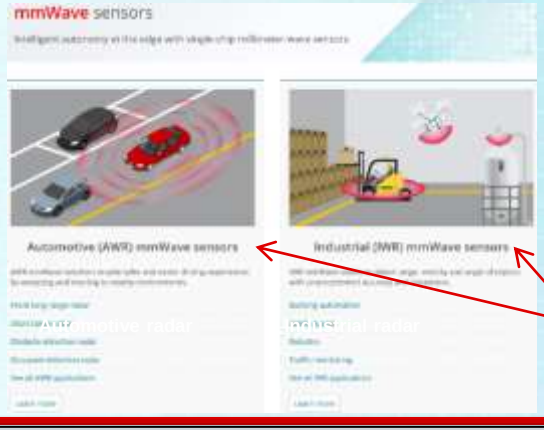
mmWave Single Chip Block Diagram – AWR1843



mmWave Sensors – Presence on ti.com

Find mmWave through Sensor Portal

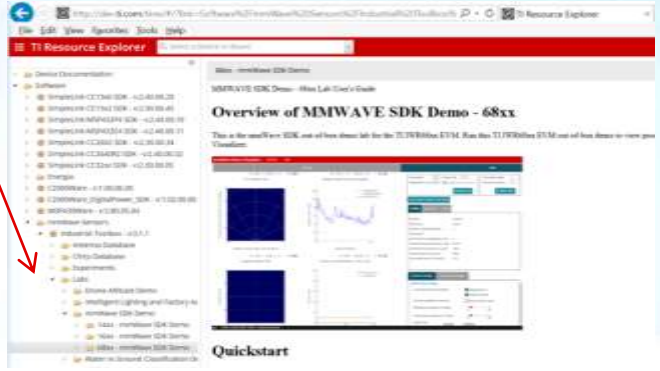




mmWave Portal:
Each title will drive to unique landing pages for Auto and Industrial

Get the training / E2E support

Plenty of example codes with applications in “TI Resource Explorer”



Training material, https://training.ti.com/mmwave-training-series
Sensor E2E forum, https://e2e.ti.com/support/sensors/f/1023

TI Resource Explorer, http://dev.ti.com/tirex/#/

Texas Instruments

- mmWave Radar Sensor Applications

Automotive

mmWave sensing applications

Automotive

Adaptive Cruise Control

Automatic Emergency Brake

Lane Change Assist

Blind Spot Detection

Beyond Automotive

Level Probing

Precision Measurement

Vibration Monitoring

Building Automation

Occupancy Sensing

Gesture Recognition

Traffic Monitoring

Perimeter Surveillance

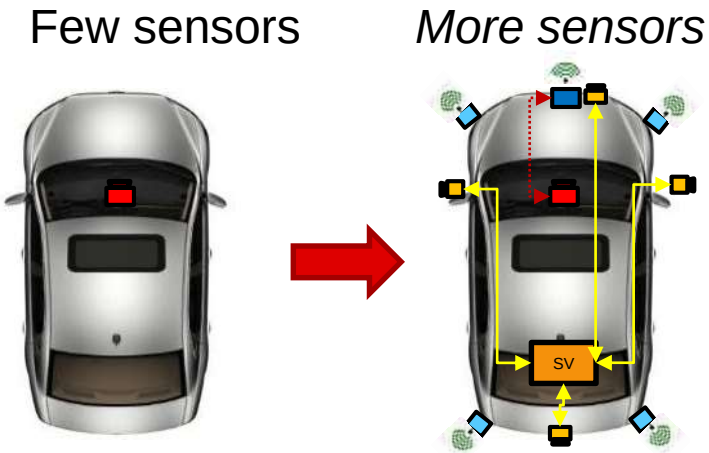
Vital Sign Monitoring

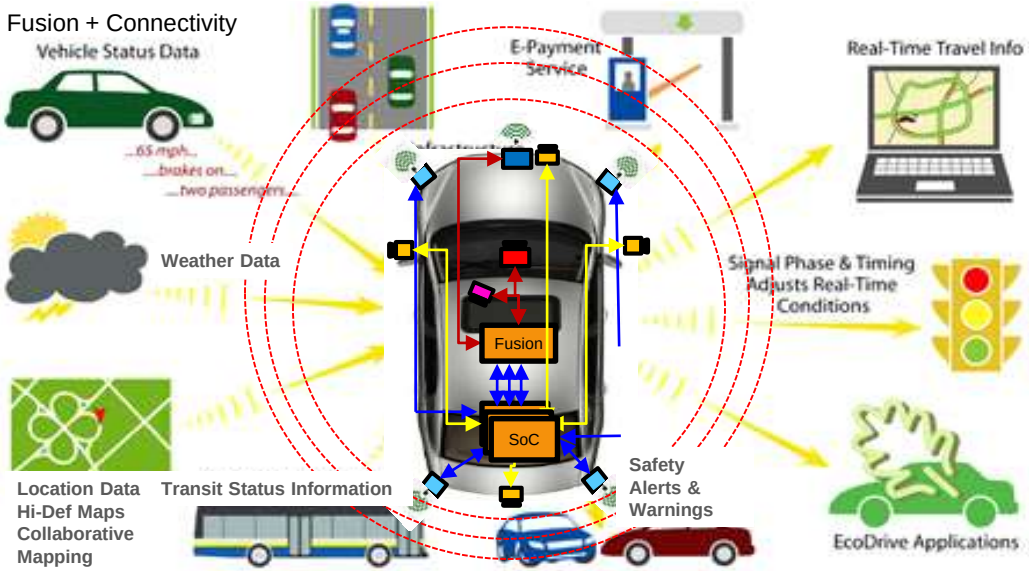
Factory Automation

Drones

Industrial Transport & Robots

ADAS to Autonomous





ADAS – Driver Assist to Limited Driver Substitution

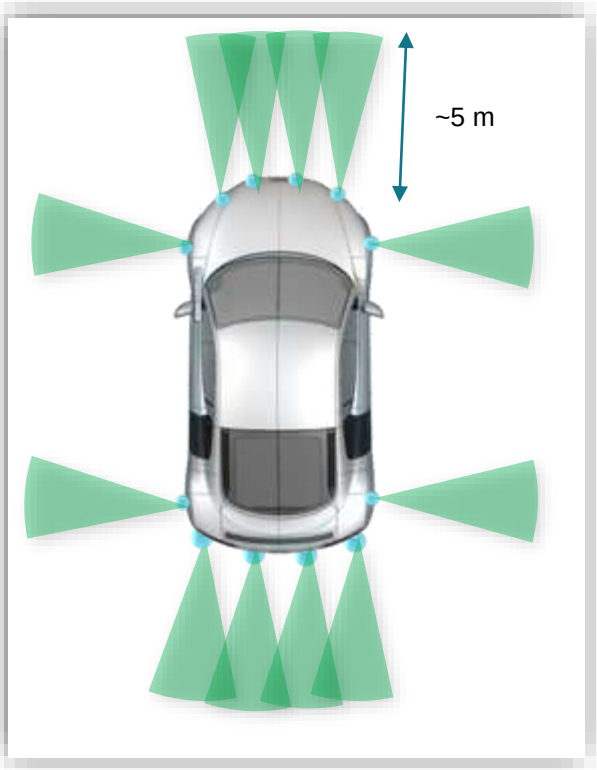
- Discrete signal processing with 1-4 sensors per SoC and limited fusion on big ARM SoCs
- Traditional Detection and Classification moving to Deep Learning
- Isolated compute provides security

Autonomous driving through connected/collaborative technology

- Shift towards centralized signal processing
- Multi-Modal Sensor Fusion provides Robustness and Redundancy
- Heavy use of Deep Learning
- Connected compute needs active security

ADAS → **Autonomous Driving**

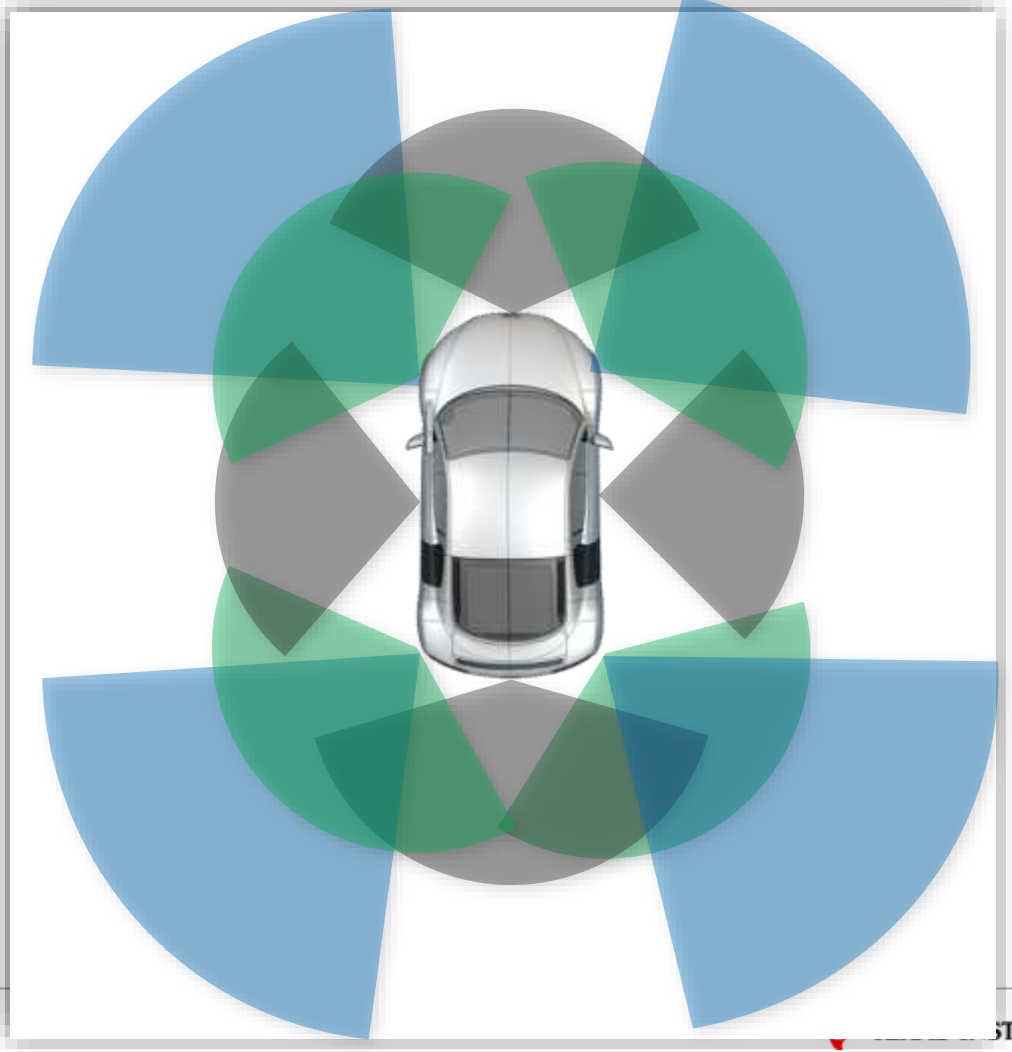
Parking Sensor today



- 12 Ultrasonic sensors
- No 360 deg coverage
- Doesn't work when covered with mud, snow
- Limited range (15 cm to 5 m)
- Holes in bumper
- Color needs to match

Why Radar Sensors

- Reduced number of sensors
- Extended range ~ 40m
- Wide field of view
- Must for Automated Parking



Automotive mmWave Sensors

TI's AWR portfolio of 76-81 GHz mmWave sensors scales from high performance front-end to single chip solutions that integrate a DSP and MCU

Mid and long range radar
Adaptive cruise control, emergency braking, highly automated highway driving

Ultra short and short range radar
Blind spot, rear collision avoidance / warning, lane change assist, pedestrian/bicyclist detection, collision avoidance, cross traffic alert, 360 degree view, park assist

Proximity sensing
Occupant detection, body sensor, in cabin gesture recognition, driver monitoring

AWR mmWave Sensors

TI's mmWave technology enables highly precise sensing applications across ADAS, body and chassis and infotainment systems by analyzing and reacting to dynamic operating conditions

Automotive Radar Sensing Applications

Adaptive Cruise Control

Automatic Emergency Brake

Lane Change Assist

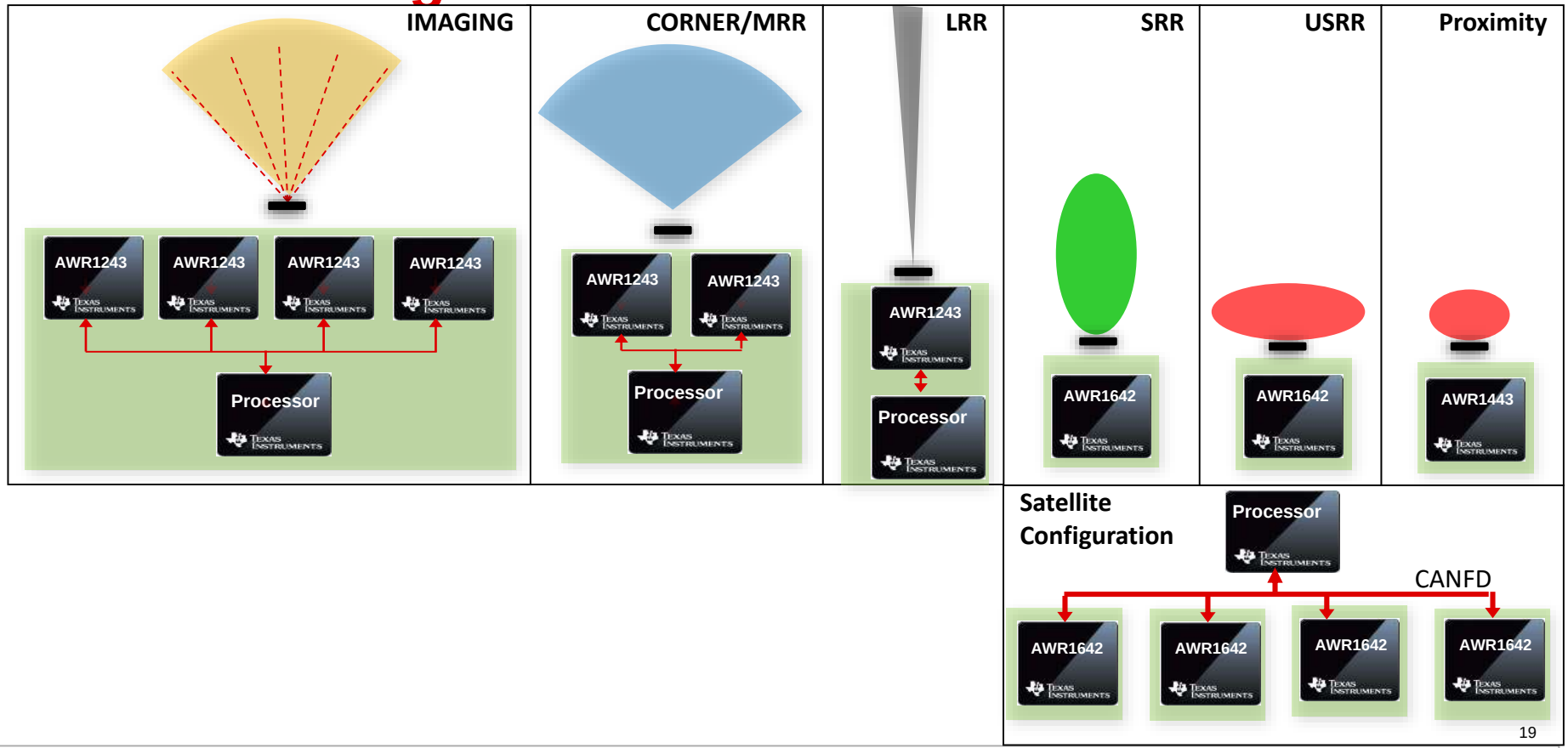
Blind Spot Detection

Imaging Radar

Automatic Parking

In-Cabin Sensing, Near-Field Sensing

Sensor configuration with TI mmWave solutions

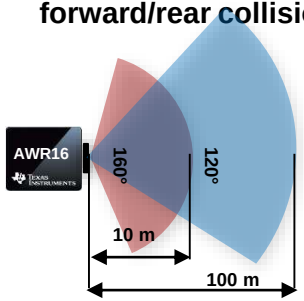


Enabling Innovation in ADAS – AWR1642

Ultra short / Short range (USRR/SRR)

Imaging / cascading radar

- **Small, low power single chip solution – AWR1642**
- **Cost optimized BOM – cheaper PCB, better yield**
- **Single chip radar, monolithic processing through RF/analog samples to object detection**
- **Power consumption as low as 2W leads to lighter housing**
- **Blind spot detection, pedestrian/bicyclist detection, park assist, lane change assist, forward/rear collision avoidance**



Parameter	Far Range	Near Range
Max Range	100 m	10 m
Range Resolution	40 cm	4 cm
Max Velocity	90 kmph*	30 kmph
Velocity Resolution	1 kmph	1 kmph
RCS	1 Sq m (Pedestrian, pole)	0.1 Sq m (Traffic cone, wire mesh)
Horizontal FOV	120 deg	160 deg
Vertical FOV	10 deg	30 deg

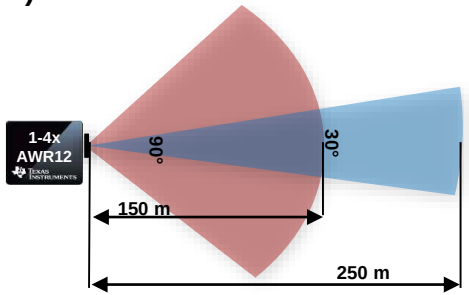
Enabling Innovation in ADAS – AWR1243

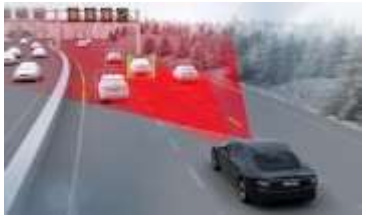
Ultra short / Short range (USRR/SRR)

Imaging / cascading radar

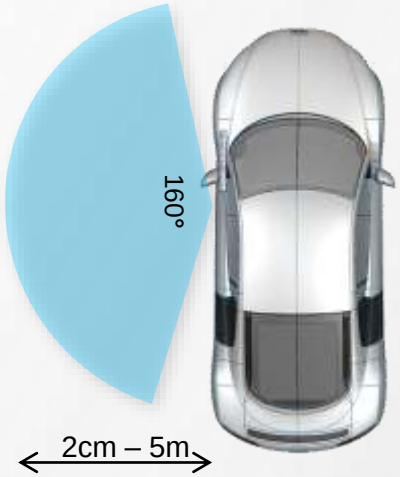
- **High performance, low power radar front end – AWR1243**
- **15 MHz IF bandwidth for 200+m range and 300km/hr unambiguous max velocity**
- **Built-in circuitry for seamless cascading of multiple AWR1243**
- **Angular resolution as low as 0.6° in the azimuth and vertical direction**
- **Urban driving, automated highway driving, full-range radar (FRR)**

Parameter	Long Range	Mid Range
Max Range	250 m	170 m
Range Resolution	2m	40 cm
Max Velocity	300 kmph	300 kmph
Velocity Resolution	1 kmph	1 kmph
RCS	10-50 Sqm (Car, truck)	5-10 Sqm (Motorbike, car)
Horizontal FOV	30°	90°
Vertical FOV	10°	30°





Near range 3D obstacle detection (Body & Chassis)



Why 77GHz radar

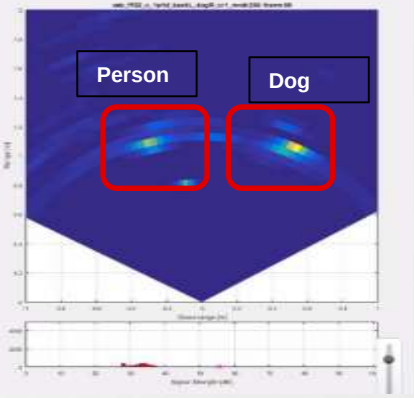
- Sense obstacle in the vicinity of car door to avoid collision and damage
- Single chip and small form factor that can go even "**inside**" a door-handle OR side-mirror OR door-cladding – Scalable to multiple locations
- Works under bright sunlight, pitch darkness, snow, fog
- Detection in elevation and azimuth directions with sub mm range accuracy
- Offers more range than any comparable sensing technology
- Easy algorithm implementation on single chip

Occupant detection (Body & Chassis)

AWR1642

RF MCU DSP

Texas Instruments



Why radar

- Detection of life forms and Child left behind in a car
- Pick up micro doppler signatures from sub mm movements
- Single chip solution with a small form factor, cost optimized BOM
- Ability to place the sensor at any place in the car
- Measurement with **high accuracy**
- Flexibility to implement several high level algorithms
- Works under bright light or no light conditions
- Ultra low power consumption

- mmWave Radar Sensor Applications

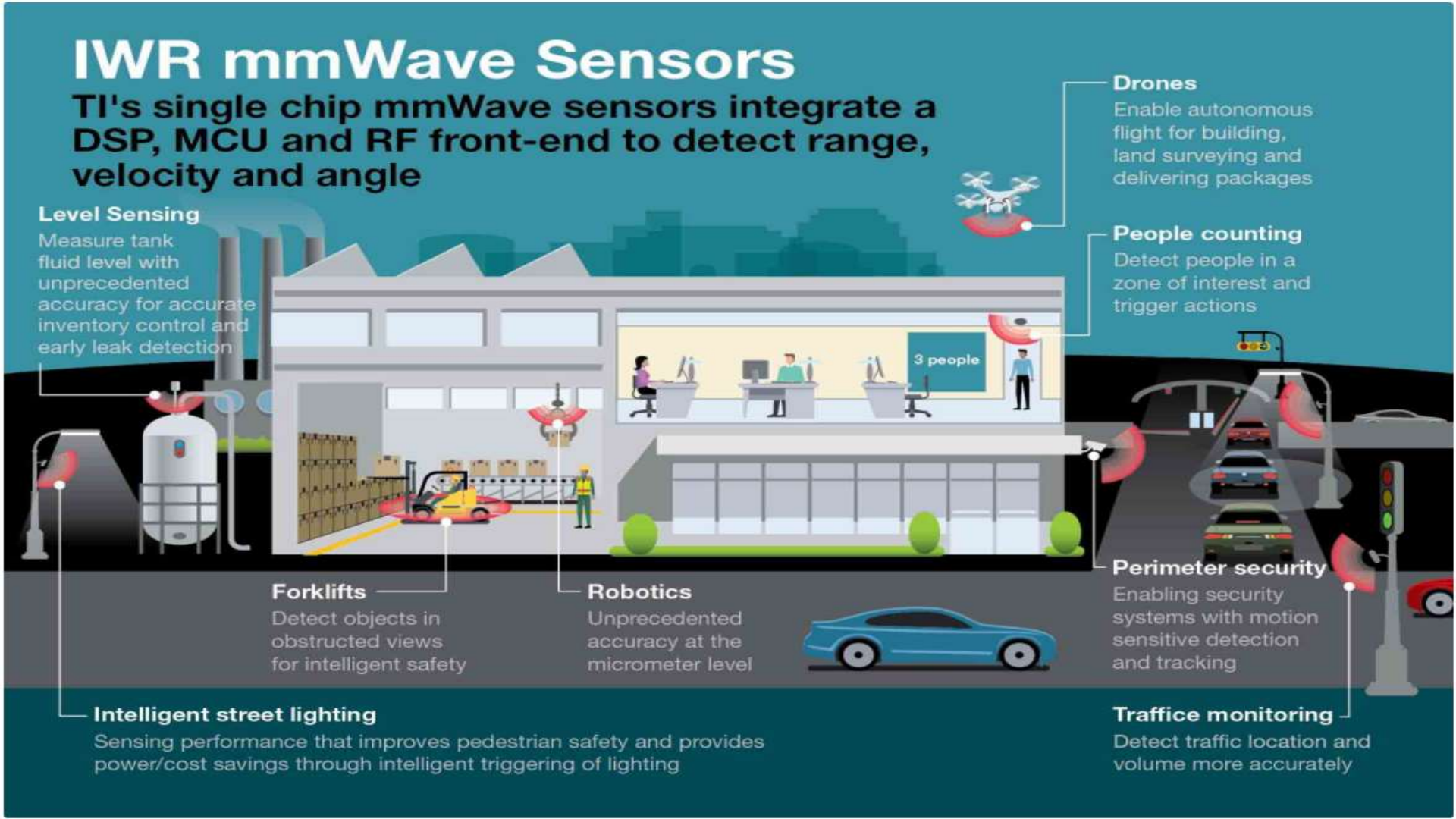
Industry

Object Range Detection

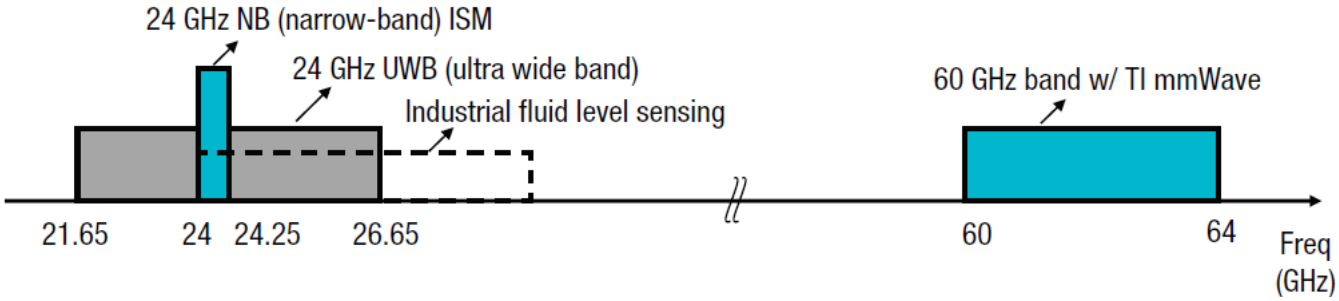
Object	EVM measured range (m)								
	1	10	20	30	40	60	80	120	160
Truck	✓	✓	✓	✓	✓	✓	✓	✓	✓
Car	✓	✓	✓	✓	✓	✓	✓	✓	
Motor bike	✓	✓	✓	✓	✓	✓	✓		
Human	✓	✓	✓	✓	✓				
Metal chair	✓	✓	✓	✓					
Large dog	✓	✓							
Coins (quarters)	✓								

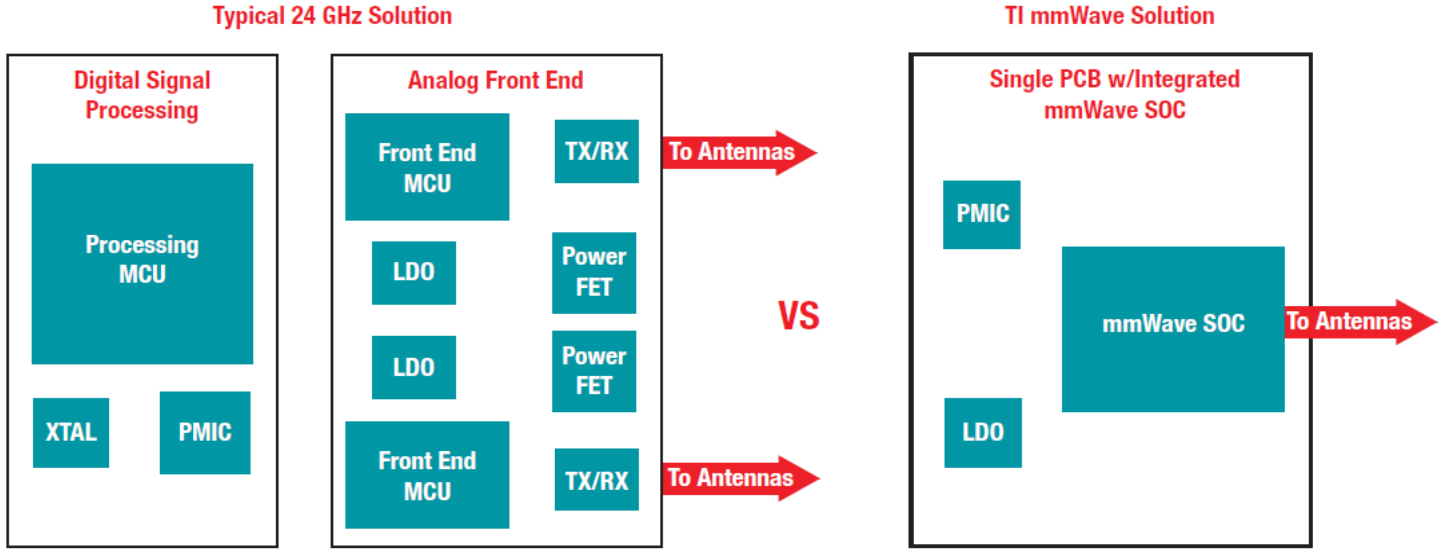
IWR mmWave Sensors

TI's single chip mmWave sensors integrate a DSP, MCU and RF front-end to detect range, velocity and angle



Leverage 77GHz investment on 60GHz platform





https://e2e.ti.com/blogs_/b/industrial_strength/archive/2018/11/07/leveraging-the-60-ghz-rf-band-for-intelligent-industrial-mmwave-sensing

Field Transmitters with TI mmWave Sensors

Adding highly-accurate, fully-integrated displacement sensing for precision range measurement in Tank Level Probing and other precision measurement markets

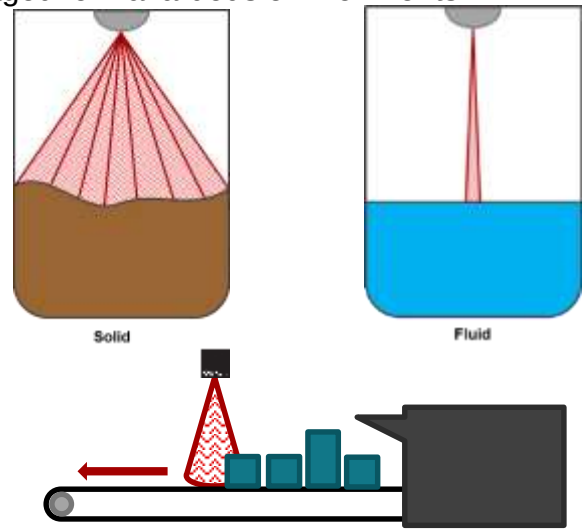
- Flexible, single-chip sensors enable low-power design for Fluid and Solid level sensing
- Highly-linear chirp generation for improved measurement accuracy

Typical Tank Sizes

- 80m+
- 10m – 80m
- 3cm – 10m

Typical Device Performance	
Output	Raw ADC, Range, Velocity, Angle
Tuning Range	76-81 GHz
Chirp BW	4GHz
Power Output	12dBm
Power Consumption	30mW – 2.7W *

- **Ultra Accurate –** sub 100um accuracy with +/-15um precision
- **Long Range** – sense far away displacement at 100+ meters
- **Robust** – insensitive to environmental conditions such as dust and humidity, and can be easily packaged for hazardous environments



* Depends on duty cycle and chirp design

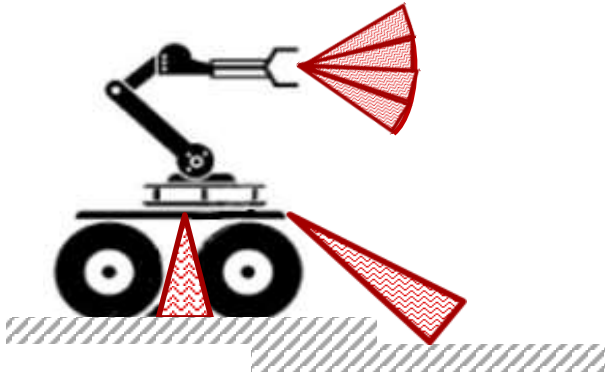
Industrial Transport / Robotics – Obstacle Detection

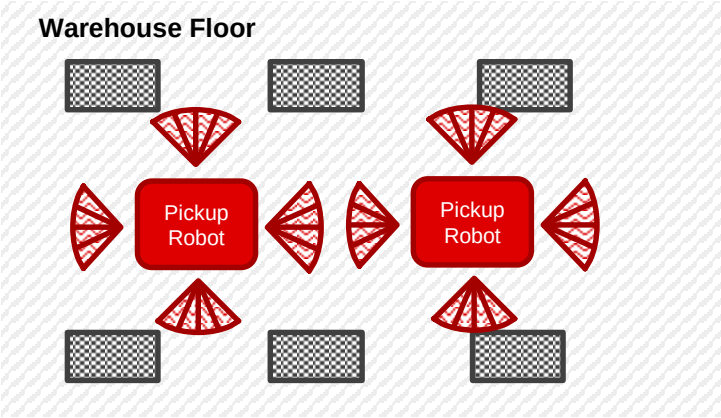
Warehouse Use Case	
Typical Range	~ 5 m
Typical Velocity	< 5 m/sec

Typical Device Performance	
Range accuracy	2 cm
Range resolution	10 cm (@2 GHz chirp BW)
Velocity accuracy	1 cm/sec
Velocity resolution	5 cm/sec
Angle accuracy	1°

Interference Rejection : The 2025 Parking lot

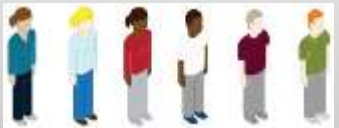
- FMCW inherently robust to interference
- Chirp based timing randomization
- Binary phase modulation





mmWave in Building Automation


Motion Detectors

People Counting

Automated Doors & Gates

IP Network Camera

GOAL: Robust, small form-factor detection and sensing of people near buildings, cameras, and doors

Advantages

- Robust to false detection/movements with integrated processing
- Radar information can give position and velocity – easy background subtraction, movement classification
- Robust to environment – lighting, temperature, moisture
- No camera or lens for privacy-conscience applications
- Sparse data set requires lower processing requirements

Challenges

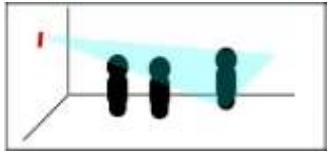
- **Angular resolution** of radar is poor, complex scenes require algorithms to decipher
- **Power consumption** for wireless, battery-powered sensors
- **Cost** pressure versus incumbent technologies such as 24GHz, ultrasonic, and PIR

Wall Mounted People Tracking and Counting Reference Design using mmWave Radar Sensor **TIDEP-01000, Design Status: On ti.com**

TIDesigns

Base configurations of people counting TI Design support 6m and 14m operation.
Tuning of parameters in TI Design enables variety of applications and environments

	Short Range Configuration	Medium Range Configuration	
HW / EVM	IWR6483 ISK EVM		
Field of View	120° Horizontal, 30° Vertical		
Max Range	6m	14m	
Example Area	6m x 6m	6m x 14m 14m x 14m	
Range Resolution	4.8cm	12cm	
Max Velocity	5.17 m/s	5.25 m/s	
Velocity Resolution	0.082 m/s	0.082 m/s	
Algorithms Used	Static Clutter Removal, Group Tracking, False Detection Mitigation	Static Clutter Removal, Group Tracking, False Detection Mitigation	
System Power	~1.5W		
Location accuracy	Person location within <16cm		
Counting density	3 persons per square meter		
Demonstrated accuracy	+/- 0 persons	+/- 1 persons	+/- 2 persons
3 people in scene	>95% of frames	100% of frames	100% of frames
5 people in scene	>51% of frames	>85% of frames	100% of frames
7 people in scene	>59% of frames	>85% of frames	>98% of frames
9 people in scene	>14% of frames	>43% of frames	>84% of frames



Mounting assumes 1.5-2.5m elevation, with 10 degree downtilt

L: Conference Room with **Static Clutter Removal** for chairs and table
R: Hallway Scene person in GREEN tracked at **14m** with **Medium Range Configuration** and **Group Tracking**

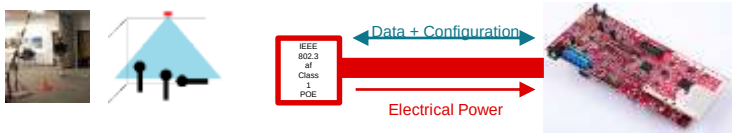
1. Discover mmWave offering for people tracking and counting page here
    1. Watch Video: People Counting Applications & Benefits
    2. (Nov) Watch Video: Intelligence at the Edge
2. Evaluate the performance
    1. Order IWR6843 EVM here
    2. Download People Counting Lab
    3. Download Indoor False Detection Mitigation Lab
3. Design custom boards with IWR6843 silicon
    1. Reference IWR6843 datasheet, errata and TRM
    2. Review IWR6843 EVM schematics and layout

Ceiling Mounted People Tracking and Counting Reference Design using mmWave Radar Sensor and POE

TIDEP-01009, **Design Status: Available 4Q18**

Base configurations of ceiling mounted people counting TI Design support 8m radial operation.
Tuning of parameters in TI Design enables variety of applications and environments

	Example Configuration
HW / EVM	IWR6843 ODS EVM IWR6843 Power Over Ethernet Adaptor
Field of View	160° Horizontal, 160° Vertical
Max Range	*8m – radial
Example Area	12m x 12m
Range Resolution	12cm
Max Velocity	5.25m/s
Velocity Resolution	0.082m/s
Algorithms Used	Static Clutter Removal, Group Tracking
System Power	*TBD
Performance Metrics	*TBD – expected similar to wall people counting



Mounting and sensing distance assumes 3m elevation
POE enables simplified integration with existing infrastructure

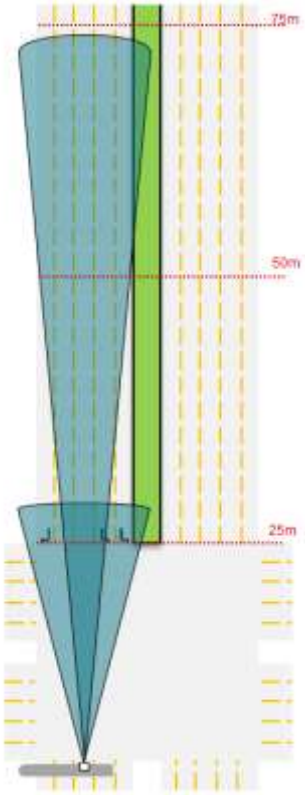
Ability to detect height of people and classify as standing/sitting/laying down (YELLOW – standing, BLUE – sitting)

1. Discover mmWave offering for people tracking and counting page here
2. Evaluate the performance
   1. (4Q18) Order IWR6843 ODS EVM + MMWAVEICBOOST
   2. (4Q18) Order mmWave POE Board
   3. (4Q18) Download Overhead People Counting Lab
3. Design custom boards with IWR6843 silicon
   1. Reference IWR6843 datasheet, errata and TRM
   2. Review IWR6843 EVM schematics and layout

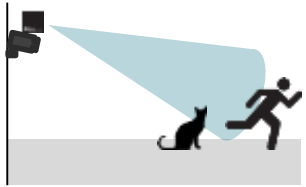
*Awaiting Further characterization

TI mmWave in Traffic Monitoring TIDEP-0090

- **RFCMOS - Fully-Integrated design**
  - All mmWave sensing, radar processing and advanced algorithms can be performed on single chip
- **High Performance**
  - mmWave radar can precisely determine object location and speed
  - Can minimize or eliminate need for expensive video analytics for object localization, speed estimation, and classification
  - Detection/measurement of objects at 100m+, velocities <200km/hr, across multiple lanes
- **Insensitive to Environment**
  - Insensitivity to challenging environments such as fog, smoke, and changing lighting conditions.
- **Flexibility of Solution**
  - TI mmWave supports multiple data output types to allow for greater flexibility and optimization in your system design



Surveillance/Security – Application Usage



Low Power State → Motion Detected and classified by Radar → Video Stream Turned ON

Intelligent Motion Detection

- Only turn on camera if radar **detects and verifies** motion
- Reduce false detection, less false alarms
- Result is system resource conservation:
  - Reduce Power Consumption
  - Reduce Network Bandwidth – more cameras in system
  - Reduce Video Storage – less server storage required

Vision Fusion / PTZ Control

- Use of both camera vision and radar combined to determine position and velocity of people
- Use radar to identify targets even in rain, fog, dust, and other extreme conditions
- Locate and track targets for PTZ and focus control

Safety Guards – Technology Comparison

Ultrasonic

Transmission and reception of ultrasonic waves

Pros:
- Simple, low cost
- Low processing requirements

Cons:
- Low sensitivity to motion
- No or very low angular resolution
- Sensitive to wind, movement or vibrations/
- Limited range

Vision

Video image processor analyzes imagery to determine object detection

Pros:
- Video for recording and monitoring
- Rich point cloud information
- High angular resolution

Cons:
- Privacy considerations
- High processing requirements
- Difficult to get position / range information
- Poor low-light performance, sensitive to environmental conditions

Active Infrared (3D ToF, LIDAR)

Measurement of infrared light time of flight

Pros:
- High angular resolution provides rich dataset similar to camera
- High distance accuracy

Cons:
- Limited range in presence of bright light (5-10m)
- Requires substantial processing to separate and classify relevant objects
- System complexity (optics, illumination, processing)
- Historically expensive, mechanically complex

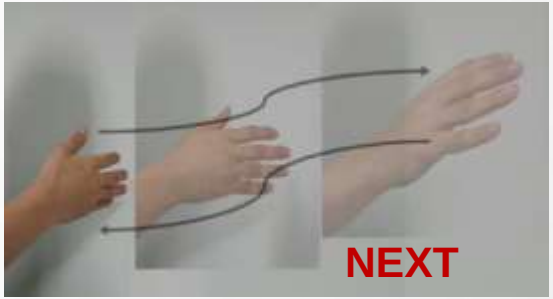
TI mmWave Radar

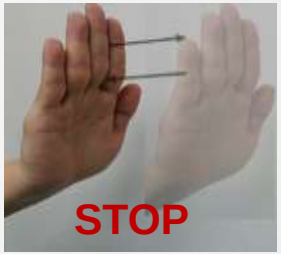
TI fully-integrated, single-chip mmWave sensor

Pros:
- Velocity tracking for smart incident management
- Simple static and dynamic object separation
- Onboard DSP processing for single-chip tracking, classification of objects
- Extended range for person detection (50m+)
- Insensitive to weather, changing environments

Cons:
- Lower angular resolution than camera or active infrared

Gesture detection (Body & Chassis)





What can radar detect

- Touchless Interactions
- Virtual Tool gestures - Button-Press, Slider, Dial

Why radar

- Single chip solution with a small form factor, cost optimized BOM
- Ability to place the sensor at any place/angle in the car
- Enables recognition of fine motions with high accuracy
- Not affected by Light conditions
- Flexibility to implement several high level algorithms
- Ultra low power consumption and easy installation

Driver vital sign detection

Typical vital sign parameters

Vital Signs	Amplitude	Frequency
Breathing Rate (Adults)	1- 12 mm	0.1 – 0.5 Hz
Heart Rate (Adults)	0.2 – 0.5 mm	0.8 – 2 Hz

- Detection of driver heart rate and breathing rate with high accuracy
- Code available on ti.com for static use case
- Simple implementation on single chip sensor

Keysight's E8740A Automotive Radar Solution

>5GHZ UP TO 110GHZ SIGNAL ANALYSIS AND FLEXIBLE SIGNAL GENERATION

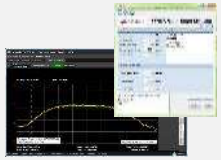
Radar Target Simulator

E8708A – 79 GHz w/ 4GHz BW

Radar Target simulator for Automotive radar functional test

- 4 GHz Bandwidth
- Range from 5m to 450m, 1m step
- 4 static targets
- Options for OBW and PWR
- Options for dual or single antenna

OBW and Power measurement



Signal Analysis Solution (Tx)

E8740A-010 Radar RF SA

Leading cost effective Auto Radar RF test tool

- 10 Hz to 26.5 GHz, 60 GHz to 90 GHz
- FMCW RF analysis

E8740A-020, 030 Basic SA

Optimum choice for Auto radar signal quality test

- 60 GHz to 90 GHz,
- 2.5 GHz BW, >5GHz BW FMCW Quality analysis

E8740A-040, 050 Advanced SA

Benchmark for demanding applications

- 10 Hz to 26.5 GHz, 60 GHz to 90 GHz
- 2.5 GHz BW , >5GHz BW FMCW Quality analysis

E8740A-060 Performance SA

Wide-open performance

- 3 Hz to 110 GHz
- >5 GHz BW for FMCW Quality analysis
- DANL-171dBm/Hz@1GHz, -150dBm/Hz up to 110GHz
- 2.4 mm, 1 mm input

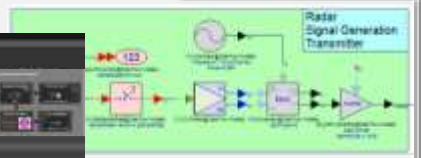
Spurious Emissions tests

E8740A-090 Emissions test solution

Conformance test

- 0 to 330 GHz
- Operating frequency range, peak power, unwanted emission, mean power, and more
- 2.4 mm, 1 mm input

89600 VSA software
Comprehensive demodulation & vector signal analysis
X-Series applications
Ready-to-use RF measurements
FMCW X-App for RF testing
Pre-defined RF test setting for standard
Integrated S/W platform for automotive radar testing



Signal Generation Solution (Rx)

E8740A-070 Performance SG

Wide-open performance

- 60 GHz to 90 GHz
- >5 GHz 3dB BW
- FM, PM, FMCW, pulse sequence, MFSK, custom OFDM

E8740A-080 Interference solution

Flexible wideband interference signal generation

- Full test set-up for ETSI interference test
- 60 GHz to 90 GHz
- >5 GHz 3dB BW
- CW, FMCW, pulse, MFSK, custom OFDM, 5G backhaul,….

SystemVue
W1908 Auto radar library measurements
Signal Studio
N7608C Pulse/FCM/FMCW/MFSK signal creation
Integrated S/W platform for RX/interference test sequence
KS83RX0A Automation platform for automotive radar

Thank You & Questions