IWR1x Industrial mmWave Sensors
Portfolio Overview

May, 2018

mmWave Sensors – Technology Overview

What is mmWave sensing

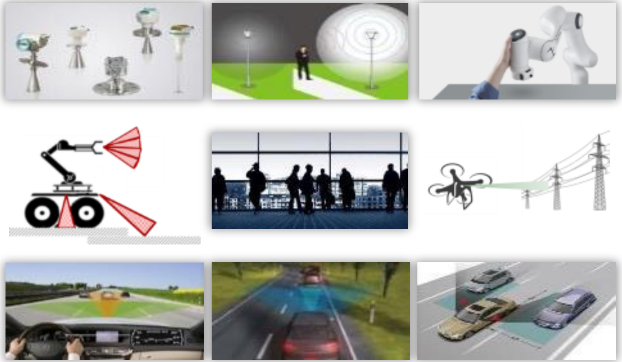
- mmWave is the band of spectrum between 30GHz and 300GHz
- Electromagnetic waves used for sensing, imaging and communications
- mmWave sensors measure with high accuracy **range**, **velocity** and **angle** of remote objects

Why Now?

- mmWave technology is robust against environmental influences such as bad light, weather conditions and extreme temperatures
- Range measurement with unprecedented accuracy (<1mm), detect very fine motions, penetration through materials like plastic, fabric, and drywall
- RFCMOS technology enables analog/digital integration in a single low-power, small, single-chip solution

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



TI Innovation – Long-Term Investment

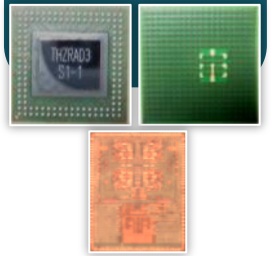
2010 — **Kickoff**

2011

Kilby Radar

160 GHz

single chip
embedded
antenna

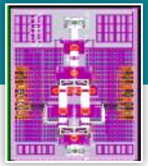


2012

Test Chip 1

77 GHz

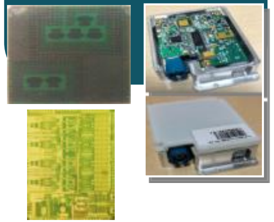
Module level
circuits



2013

Test Chip 2

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



2014

Test Chip 3

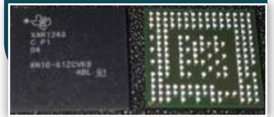
76-81 GHz
Module level
circuits
Final tune
Model matching

2015

AWR1443
IWR1443

76-81 GHz
Single Chip
Transceiver
Production intent

Sampling Now

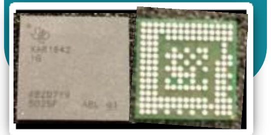


2018

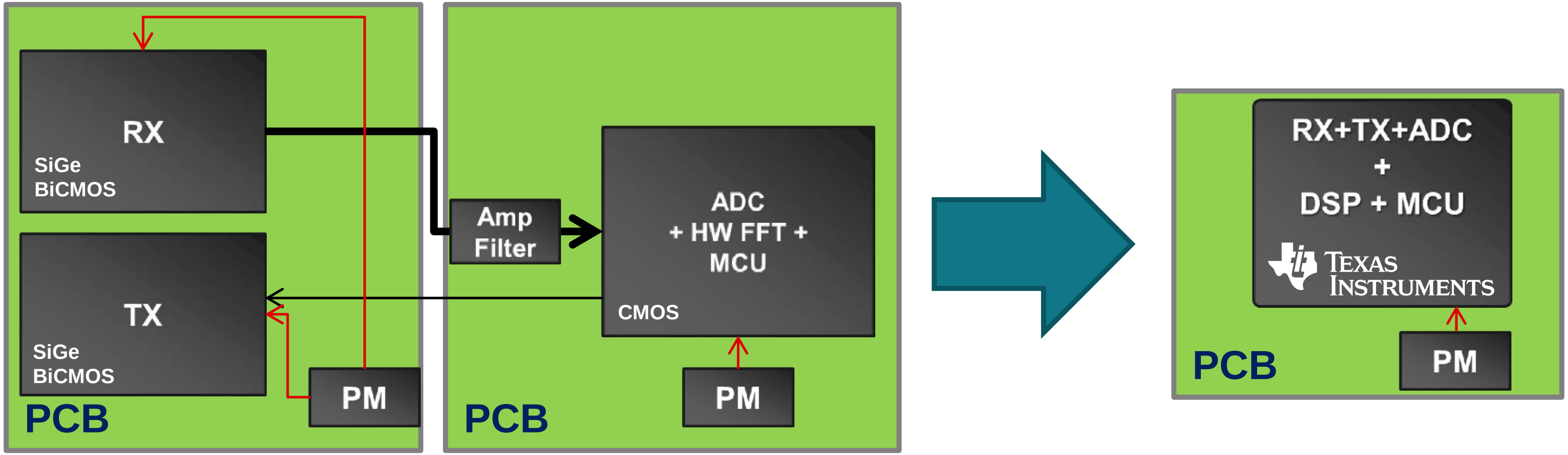
AWR1642
IWR1642

76-81 GHz
Single Chip
Radar
Production intent

Sampling Now



TI Innovation – Single-Chip 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 (SIL)
- High Resolution, less false positives
- Programmable core
- Lower Power

Industrial mmWave Sensors – Typical Performance

Typical Max Range	
80m – 150m	Large tank level probing Perimeter security (vehicles) Highway traffic flow monitoring
20m – 80m	Drone sense and avoid Street traffic flow monitoring Perimeter security (people)
5m – 20m	Small tank level probing Traffic intersection imaging Drone landing assistance
3cm – 5m	Gesture recognition Proximity sensing High-precision range sensing

Typical Device Performance	
Device Output	Raw ADC, Range, Velocity, Angle
Tuning Range	76-81 GHz
Minimum Range	3cm*
Angle Accuracy	1°
Max Relative Velocity	300 km/hr
Power Output	12dBm
Power Consumption	30mW – 2.7W**
Digital Performance	200MHz R4F 600MHz C674x DSP

* Requires bandwidth stitching
** Depends on duty cycle and chirp design

Performance Estimates – Detection with mmWave

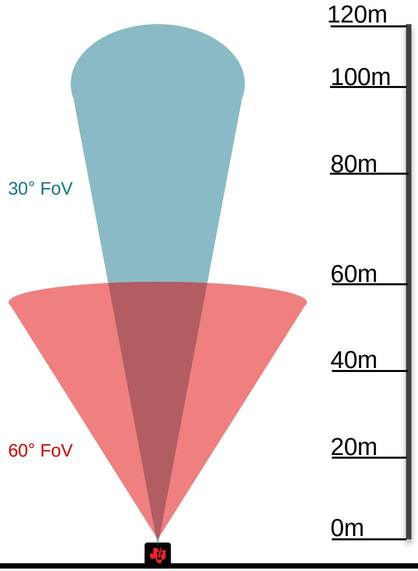
Max/Min Range is a function of antenna design and size of object to be detected

Measured with EVM Antenna Design (120° FoV)

Object	EVM Measured Range (m)									
	5	10	20	30	40	60	80	100	120	160
Car/Truck	●	●	●	●	●	●	●	●[1]	●[1]	●[1]
Motorbike	●	●	●	●	●	●	●			
Bicycle w/ Human	●	●	●	●	●	●				
Human	●	●	●	●	●					
Dog	●	●								

[1] xWR1642 EVM using long range chirp configuration from Traffic Monitoring TI Design (TIDEP-0090)
For more detailed information, view the object range detection application note.

Theoretical Antenna Design Performance



Estimated performance at 120m, 30° FoV

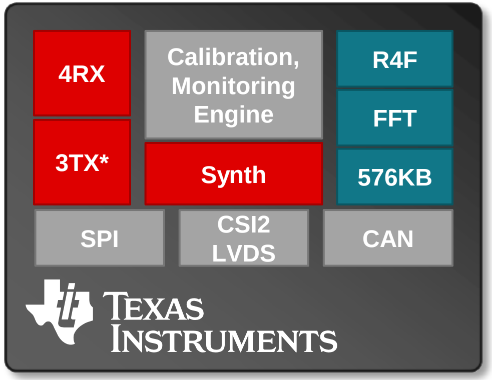
- Detection of **person** (RCS=0.1) and larger objects
- Detection of **motorcycle** (RCS=1.0) possible even with increased FoV to 60°

Estimated performance at 60m, 60° FoV

- Detection of **person** (RCS=0.1) and larger objects
- Detection of **motorcycle** (RCS=1.0) possible even with increased FoV to 120°

Industrial mmWave Sensors – 76-81 GHz

IWR1443

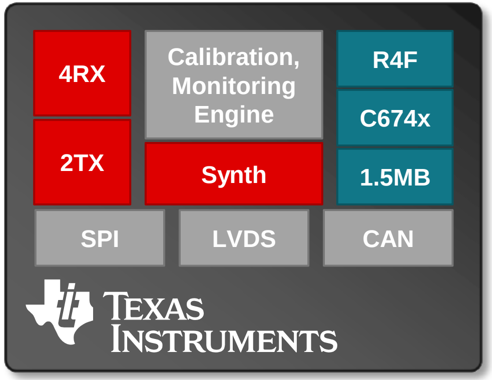


mmWave Sensor + HW Accelerator

- **Use Case**
  - Entry-level Single-chip Sensor
    - Power-optimized applications
    - HW acceleration for limited processing

* 2x TX simultaneously

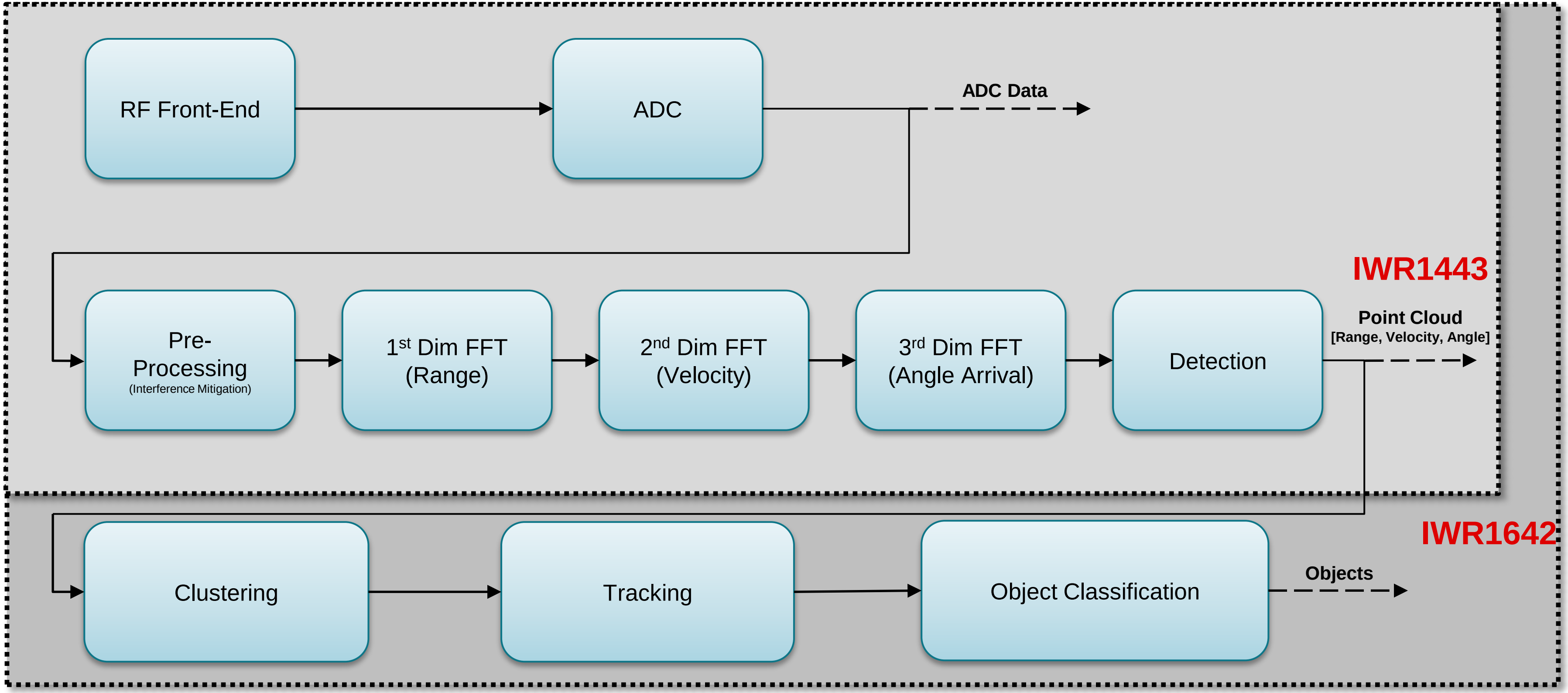
IWR1642



mmWave Sensor + DSP

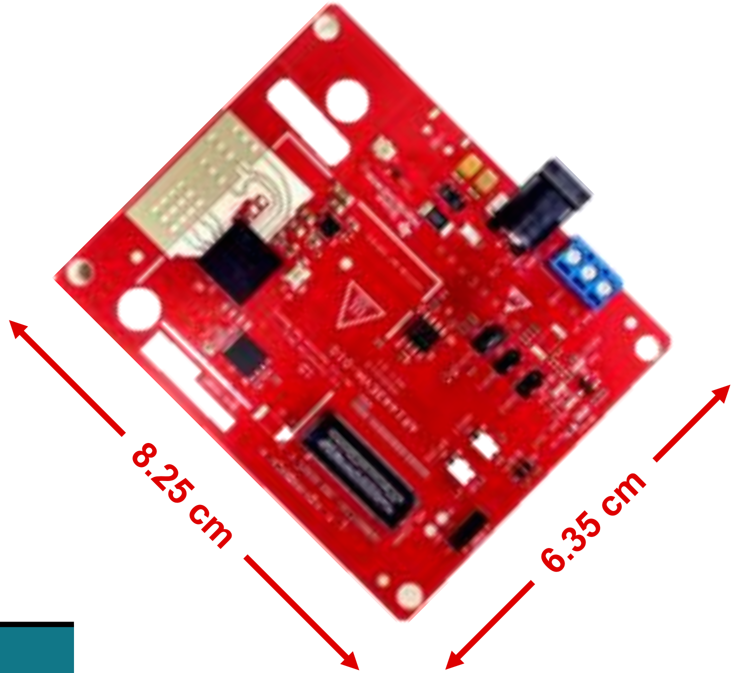
- **Use Cases**
  - Full functionality single-chip radar
    - Increased on-board memory for higher range and resolution measurement
    - On-chip DSP for advanced algorithms

IWR1xxx mmWave Signal Processing



IWR1x Evaluation Modules

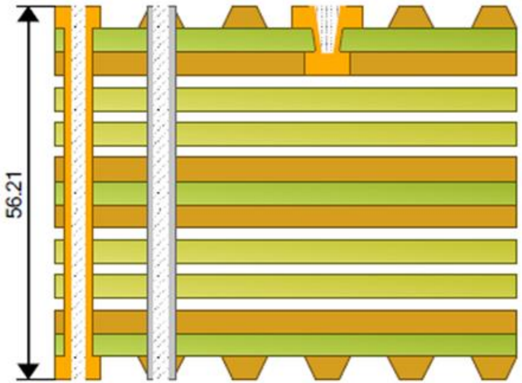
- Platform for out of the box evaluation and rapid prototyping
- Includes reference schematics, layout, and BOM
- Interfaces:
  - USB for debugging and emulation
  - High-speed interface for raw ADC capture
  - BoosterPack headers
- DevPack board for additional expansion



PCB Antenna	Max Range	FOV
3x TX / 4x RX	~60m	A: ±65º E: ±15º

IWR1x Evaluation Modules

- Platform for out of the box evaluation and rapid prototyping

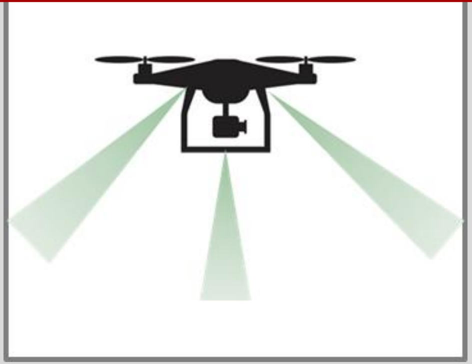


Layer	Stack up	Description	Type	Base Thickness	Processed Thickness	εr	Copper Coverage	Mask Thickness
1				0.689	2.067		100.000	
		Rogers 4835 4mil coreH/1 Low Pro	Rogers 4835	4.000	4.000	3.480		
2				1.260	1.260		73.000	
		Iteq IT180A Prepreg 1080	Dielectric	4.195	2.830	3.700		
		Iteq IT180A Prepreg 1080	Dielectric	4.195	2.830	3.700		
3				1.260	1.260		69.000	
		Iteq IT180A 28 mil core 1/1	FR4	28.000	28.000	4.280		
4				1.260	1.260		48.000	
		Iteq IT180A Prepreg 1080	Dielectric	4.195	2.691	3.700		
		Iteq IT180A Prepreg 1080	Dielectric	4.195	2.691	3.700		
5				1.260	1.260		72.000	
		Iteq IT180A 4 mil core 1/H	FR4	4.000	4.000	3.790		
6				0.689	2.067		100.000	

expansion

PCB Antenna	Max Range	FOV
3x TX / 4x RX	~60m	A: ±65º E: ±15º

Enabling Innovation in Industrial Applications

Factory Automation	Building Automation	Motor Drives & Industrial Transport	Medical
			

Enabling Innovation in Industrial Applications

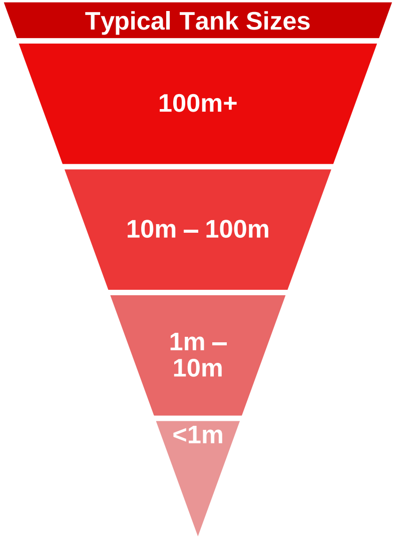
Factory Automation	Building Automation	Motor Drives & Industrial Transport	Medical

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

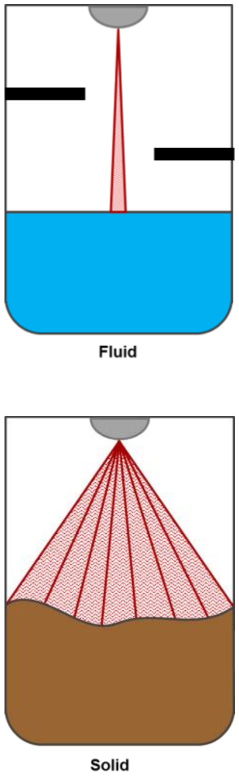
- **Ultra Accurate –** sub 100um accuracy with +/-15um precision
- **Long Range** – sense far away displacement at 100+ meters
- **Robust** – insensitive to environmental conditions such as dust and humidity, and can be easily packaged for hazardous environments

Level Transmitter - Overview

- **Highly-accurate, fully-integrated displacement sensing** for precision range measurement in Level Transmitter and other precision measurement markets
- Enable measurements of **fluid and solid levels** in **small (<1m) to large (100m+) banks**



Typical Device Performance		Level Sensing Benefit
Output	Raw ADC, Range, Velocity, Angle	Flexible interface to connect to existing systems
Tuning Range	76-81 GHz	Narrow beam to avoid clutter, smaller antenna and lenses
Chirp BW	4GHz (5GHz*)	Measure closer to the tank floor and ceiling
Power Output	Up to 12dBm	Detect in small and large tanks with the same platform
Power Consumption	25mJ/measurement	4-20mA two-wire interface capable
MIMO	4RX x 3 TX + cascading	Accurate surface mapping for solid level sensing



* Requires bandwidth stitching

mmWave Level Sensing Field Transmitter – TIDEP-0091

TIDesigns

Features

- Industry's first Single Chip 77Ghz FMCW radar with integrated RX, TX, ADC, MCU and FFT accelerator.
- 4Ghz chirp bandwidth (can be extended to 5Ghz*).
- Power optimized mmWave operation at low frame rate for usage in 4-20ma current loop powered applications.
  - Using MSP432 to duty cycles IR14xx power between measurements
- IR1443 EVM connects to MSP432 EVM using standard launch pad connectors.

Target Applications

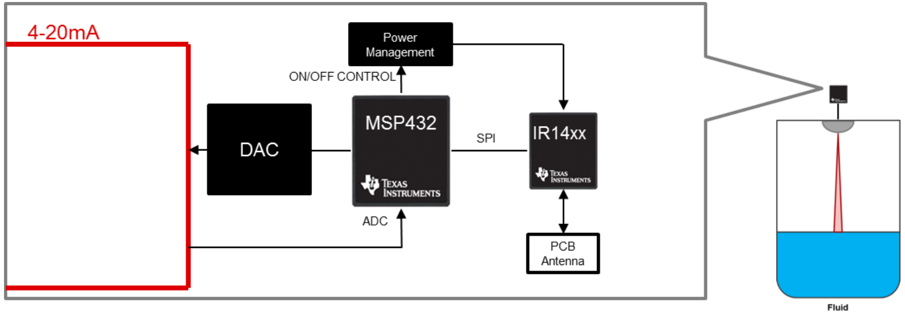
- Targeted at Level Sensing Applications such as
  - Industrial tank probing (fluid Level sensing).
  - Height sensing for industrial transport applications e.g. Forklifts, Drones and industrial robotics etc.

Benefits

- Single chip solution significantly reduces system Cost, Size, Weight , Power and design complexity.
- Wider bandwidth provides higher accuracy and less false positives.
- On-chip programmable R4F core enables customers to implement proprietary radar signal processing using HW FFT as required.
  - External MCU can be a low-cost device used only for power management, with primary radar signal processing performed on the IR14xx device.
- Etched antenna on the IR14xx EVM provides a complete mmWave radar evaluation platform.

Tools & Resources

- **TIDEP-0091 Tools Folder**
  - TI Design Guide
  - Relevant Design Files (integrated schematics, BOM,
  - mmWave level probing white paper
  - *Bandwidth stiching app note
- **Device Datasheets:**
  - IWR1443
  - MSP432



Texas Instruments

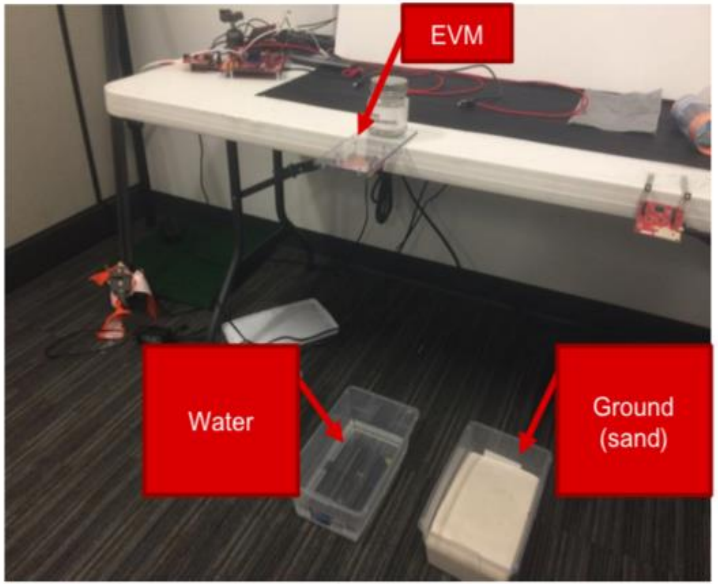
Summary of Capabilities 1642

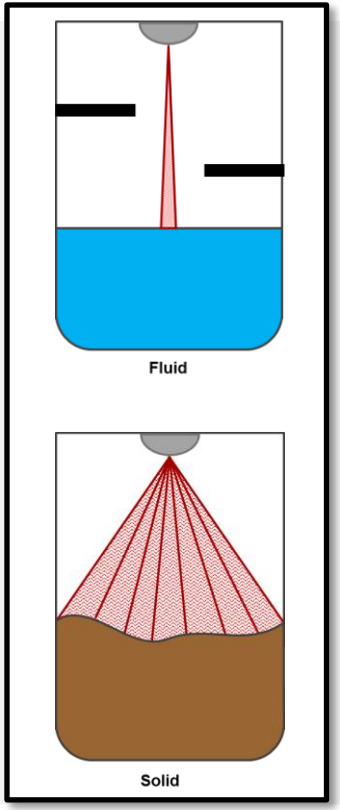
HW Setup Antenna	Target Material	Range Accuracy (mm)	Max Range (m)	TX power (dBm)	Active Chirp Time (msec)	Range x Zoom FFT	Range Resolution (cm)	Processing Time (msec)
IWR1642 EVM	water	0.01	10	12	1.2	512x512	4.3	<10
IWR1642 EVM	water	0.5	20 50 70	12	1.2 1.22 1.34	512x512 512x512 1024x1024	4.5 11.5 11.5	<10 <10 >10
IWR1642 EVM	water	1.0	50 100 140	12	1.22 1.22 1.31	512x512 512x512 1024x1024	11.5 22 22	<10 <10 >10
IWR1642 Horn	oil	0.01	20 45	4 10	1.2 1.23	512x512 1024x1024	4.5 5.0	<10 <10
IWR1642 Horn	oil	0.5	20 50 70	-10 -3 -1	1.2 1.22 1.34	512x512 512x512 1024x1024	4.5 11.5 11.5	<10 <10 >10
IWR1642 Horn	oil	1.0	50 100 140	-9 -3 -1	1.22 1.22 1.31	512x512 512x512 1024x1024	11.5 22 22	<10 <10 >10

- Accuracy of 0.01 mm to 1 mm with range of 20 m to 140 m
  - With horn antenna and oil we are range bound mostly by 5MHz IF BW, and the power constraints which translate to active chirping time and processing time constraints.
  - Secondary is memory constraint solved by custom/special FFT algorithm implementation.

Water vs Ground classification - Overview

- TI xWR 1443 mmWave radar sensor used to differentiate between water and ground.
- Fundamental principle: Detect extremely fine movement of the target using phase measurement.
- Ripples in water introduce measurable phase difference in the reflected signal which is used to classify water from a solid surface
- CCS project along with source code provided.





Enabling Innovation in Building Automation

Tank Level Probing	**Building Automation**	Motor Drives & Industrial Transport	Medical

Adding robust, small form-factor detection and sensing around buildings, cameras, and doors

- **Powerful –** range, velocity, and angle information
- **Robust** – insensitive to environmental and lighting conditions. Indoor/outdoor, smoke, rain.
- **Fully-Integrated** – single-chip radar for smaller design sizes, reduced HW complexity, and integrated processing
- **C674x DSP** – performance for advanced algorithms such as filtering and object classification

Why mmWave Sensors in Building Automation

Accurate Range, Velocity, Angle Info

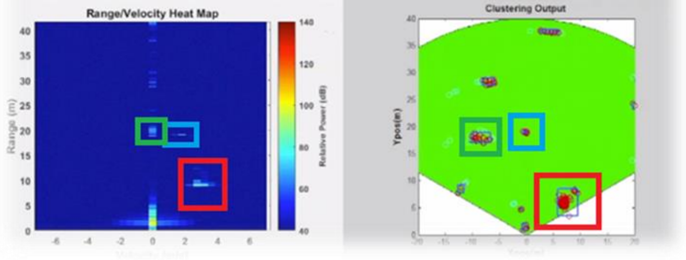
- mmWave can provide high-accuracy range, velocity, and angle information about objects in scene.
- Very sensitive to motion, detect heartbeat
- Sense distances short (5cm) and long (150m+)

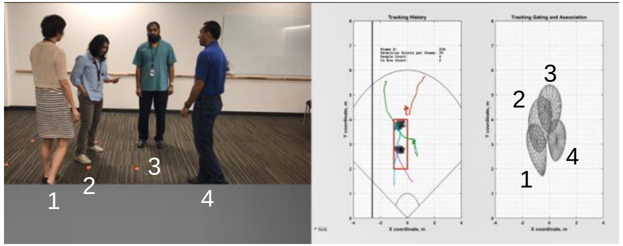
Environment Insensitivity

- mmWave is uniquely insensitive to the weather and lighting conditions.
- For robust indoor/outdoor sensing in all lighting, smoke, fog, rain

Added System Intelligence

- Integrated processing allows for smaller form-factors
- System intelligence with novel algorithms such as clutter removal and classification





Building Automation – Technology Comparison

Passive Infrared

Measures change in infrared light to detect motion

Pros:
- Simple, low power consumption (uA-mA)

Cons:
- Low sensitivity to motion
- False detection outdoors from sunlight, temperature
- Limited range (5-10m), no position/range information

Cameras

Video image processor analyzes imagery to determine people movement and behavior

Pros:
- Algorithms applied for variety of applications
- Video for recording and monitoring

Cons:
- False detection from shadows, occlusion, day/night cycles, changing environment.
- No position/range information
- Privacy considerations

Active Infrared (3D ToF,

Measurement of infrared light time of flight

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

Cons:
- Limited range in presence of sunlight (5-10m)
- Requires substantial processing to separate and classify relevant objects
- System complexity (optics, illumination, processing)

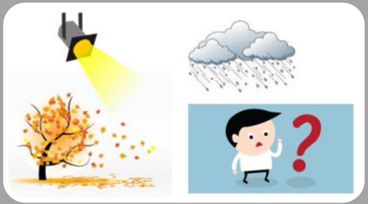
TI 77 GHz mmWave

TI's fully-integrated, single-chip 77GHz mmWave radar

Pros:
- High sensitivity to motion (breathing, typing)
- 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

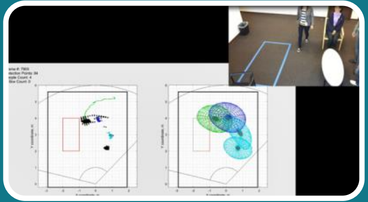
Cons:
- Lower angular resolution than camera or active infrared

Building Automation – Problems to Solve using mmWave



False Detection – Fine Motion

- Sensing systems to detect occupancy today are prone to false detection
- In security, all detection events must be responded to by a person (camera, guard, police)
- Costs $$$, false detection desensitize responders to real threats
- Need sensing systems that can ignore common false detection sources (environment, objects, movement outside ROI)



People Localization and Counting

- Locating and counting people can be done today, but requires complex and expensive technologies like stereo vision and 3D ToF
- Doing this accurately requires expensive processing and complex SW.
- Need for less expensive, higher accuracy solutions
- **TI mmWave on-board processing enables counting and tracking of multiple people in single-chip**

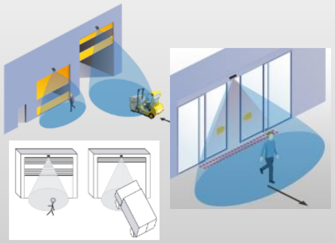
Motion Classification

- Classification of objects and motion such as determining if John, a forklift, or a dog has just moved into a ROI
- Can be done today, but requires complex and expensive technologies like vision processors.
- Need for less expensive solutions that require less complex SW implementations
- **TI mmWave range, velocity, angle, data along with point cloud size can be used for classification**

Vision for 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 vs Existing Technologies

- 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

Experiment – Fine Motion Detection (available now)

- Velocity information allows sensor to detect and localize even very small movements like breathing, talking, typing
- Onboard processing allows for ‘static clutter removal’, distinguish between animate and inanimate objects
- Showing enhanced capability versus other sensing technologies like **PIR** to help minimize false detection

Parameter	Config 1: Higher Range Resolution	Config 2: Higher Maximum Range
Num TX and RX	3TX, 4 RX	3TX, 4RX
Max range (m)	3.367	6.4
Range resolution (m)	0.053	0.125
Max velocity (m/s)	2.77	0.94
Velocity resolution (m/s)	0.022	0.03
Frame duration (ms)	100	150
Static clutter removal	Enabled	Enabled

Experiment Documentation and Report

Example Usage: Occupancy Detection

Detects: small movements like talking, typing, breathing

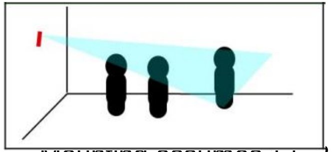
People Tracking and Counting Reference Design using mmWave Radar Sensor TIDEP-01000, Design Status: On ti.com

TI Designs

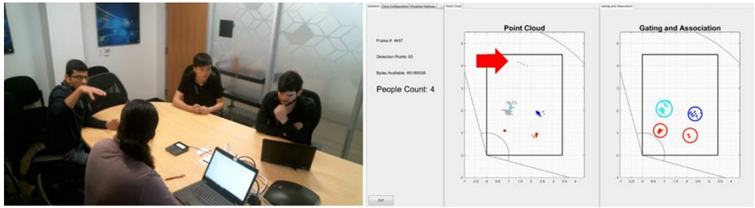
Base configurations of people counting TI Design support 6m and 14m operation.

Tuning of parameters in TI Design enables variety of applications and environments

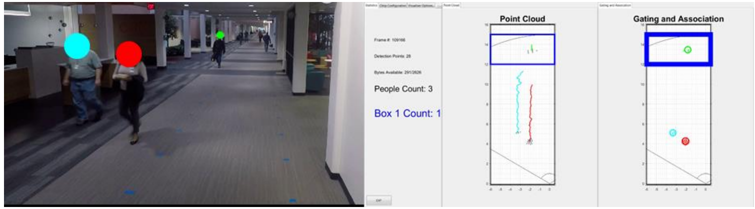
	Short Range Configuration	Long Range Configuration
HW / EVM	IWR1642 EVM *(IWR1642BOOST)*	
Field of View	120° Horizontal, 30° Vertical	
Max Range	**6m**	**14m**
Range Resolution	4.8cm	12cm
Max Velocity	5.17 m/s	5.25 m/s
Velocity Resolution	0.082 m/s	0.082 m/s
Algorithms Used	Static Clutter Removal, Group Tracking	Static Clutter Removal, Group Tracking
System Power	~2W	
Performance Metrics	Tracking accuracy of >93% Counting density of 3 persons per m^2	



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



Conference Room Scene showing **Static Clutter Removal** ignoring chairs and table, and reflections ignored at red arrow

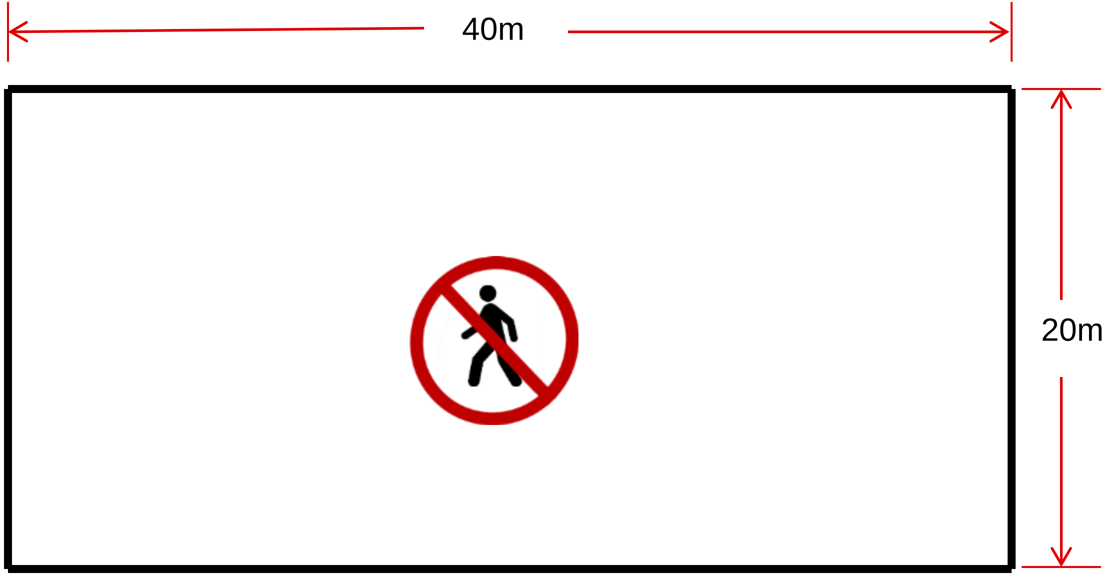


Hallway Scene showing person in GREEN tracked at **14m** with **Long Range Configuration** and **Group Tracking**

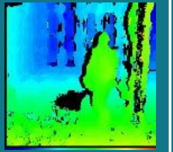
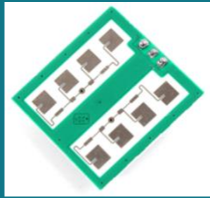
Example Sensing Problem in Security/Surveillance

Example: Construction Yard

Goal is to make sure no one is inside the fenced-off construction yard after-hours



Could this be solved with sensing today?

Technology	 **Passive Infrared (PIR)**	  **Vision / Stereo**	 **3D Time of Flight / LIDAR**	 **Ultrasound (Doppler)**	 **Microwave (Doppler)**
Principle	Detection of changes in infrared radiation	One or two camera sensors (emulate human eyesight)	Modulated IR light, measure transit time	Transmission and reception of ultrasonic waves (doppler)	Transmission and reception of microwaves (doppler)
Strengths	✓ Lower cost ✓ Low processing requirements ✓ Very low power ✓ Good for short range ✓ Sensitive to macro motion	✓ High angular resolution ✓ Ability for user to monitor the scene remotely ✓ Vision processing and algorithms ✓ Good for moderate ranges ✓ Thermal sensors available	✓ High angular resolution ✓ High distance accuracy ✓ Fast frame rate ✓ Good for short ranges, indoor applications	✓ Low processing requirements ✓ Lower cost ✓ Good for short range ✓ Motion sensor only- Sensitive to very small motions	✓ Robust to environment ✓ Good for moderate ranges ✓ Motion sensor only- Sensitive to very small motions

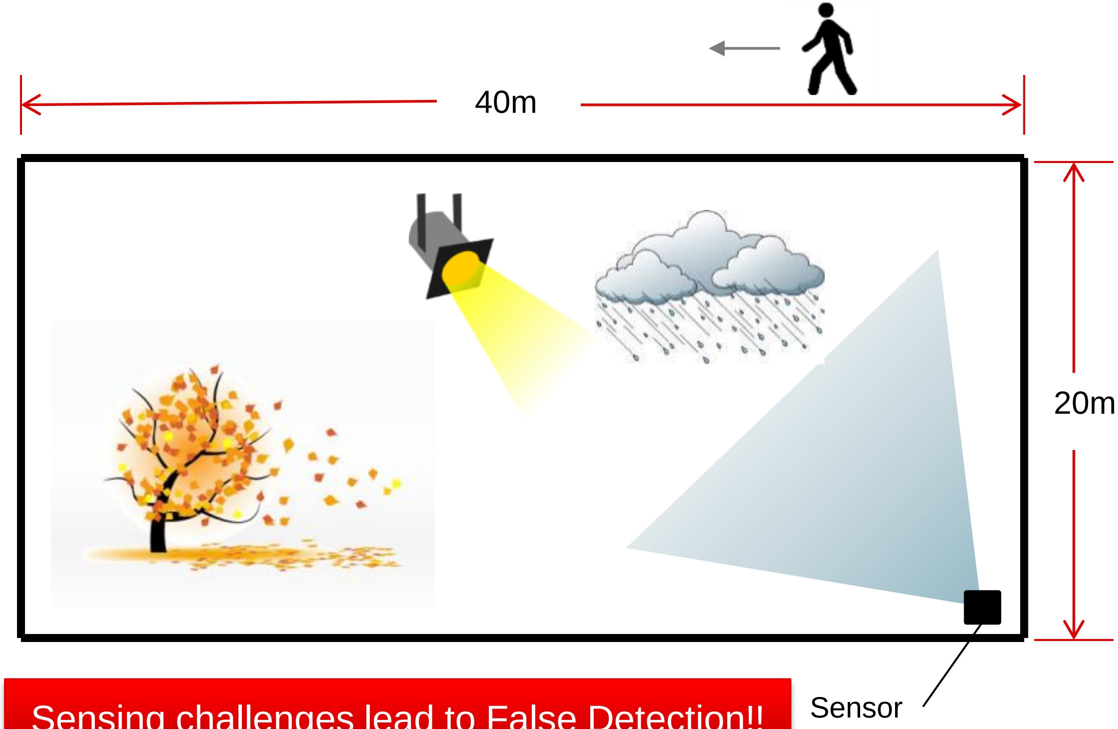
Example Sensing Problem – Key Sensing Challenges

Environment (Outdoors)
- Ambient Lighting
- Temperature, Humidity
- Rain/Fog

False Detection of Objects
- Leaves/Trees
- Background Clutter
- Animals versus Persons

Movement outside of zone
- People outside of fenced area
- Urban environments

Range and Sensing Distance
- Maximize coverage
- Minimize system cost



Sensing challenges lead to False Detection!!

False Detection costs $$ for our customers

- False detection costs our customers money – it’s a people problem
  - People must respond to phantom events
  - Security personnel to monitor cameras – verify false alarms are false
  - Send out security personnel or police to check out scene in person

- False detections prevent our customers from addressing real threats
  - Responders are desensitized to any detection/alarms
  - Time spent understanding false alarms

Customer collateral

The following information is available for you to send to customers

Content title	Content type	Link to content or more details
Video: Why TI mmWave for Security/Surveillance	90 second marketing focused video	http://www.ti.com/general/docs/video/watch.tsp?entryid=5432114959001
Video: mmWave in Factory Automation and Intelligent Lighting	Video demonstration of how mmWave can be used to detect position and motion in offices and factories	https://www.youtube.com/watch?v=I3ePEu0fRvg
TI Design: Object Detection and Tracking Reference Design Using Single-Chip mmWave Radar Sensor	Demonstrates how IWR1642 can be used for traffic monitoring applications. Shows example clustering and tracking algorithms	http://www.ti.com/tool/tidep-0090
Application Note: Introduction to the DSP Subsystem in the IWR16xx	Technical Application Note on how to port radar algorithms to the C674x	http://www.ti.com/lit/an/swra564/swra564.pdf
E2E Forums	Public E2E Forum available for customers and FAEs	https://e2e.ti.com/support/sensor/mmwave_sensors/

Enabling Innovation in Industrial Applications

Tank Level Probing	Factory & Building Automation	Motor Drives & Industrial Transport	Medical

Adding highly-integrated, flexible and scalable navigation assistance in Drones, Robotics, and Industrial Transport

- **Long Range** – sense far away objects at 100+ meters
- **Sensing Capability** – Able to detect hard-to-see obstacles such as metal wires and power lines
- **Robust** – insensitive to environmental conditions such as dust, fog, low light or dazzling sunlight
- **Radar/Vision Fusion** – make the system safer through complimentary sensing fusion

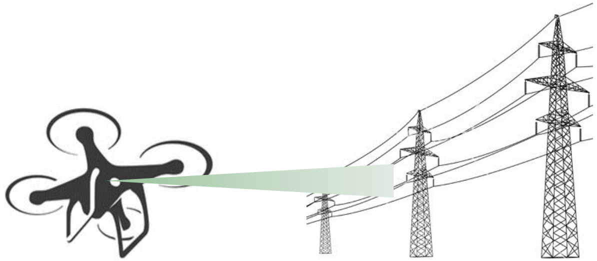
Drone Introduction

Autonomous Operation

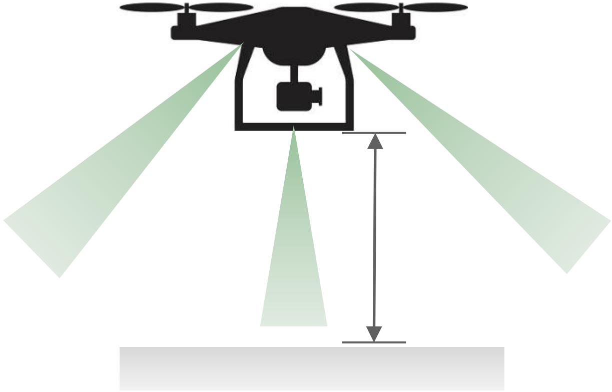
- Obstacle Detection and Avoidance: Power lines, buildings, trees etc..,
- Ground level ranging for: Positioning, Hovering, Object Tracking, Return and landing assist operations
- Long detection range of 150m+ and ability to track velocities up to 60m/sec means fast operation for higher productivity
- Insensitive to environmental conditions such as dust, fog, low light or dazzling sunlight
- Supplement existing sensors with Radar for added Safety/Redundancy
- Radar/Vision Fusion - make all sensors smarter

- **mmWave vs Other Sensing Technologies**

- Wind, motor EMI and foliage can defeat ultrasound
- Camera solutions need controlled lighting. Dust and Spray cover lenses. Cant operate at night
- LIDAR is expensive compared to mmWave. Mechanically complex, Dust and Spray cover lenses. Direct sunlight and water light sparkle defeat sensors. Can not detect glass obstacles



Power Line Detection

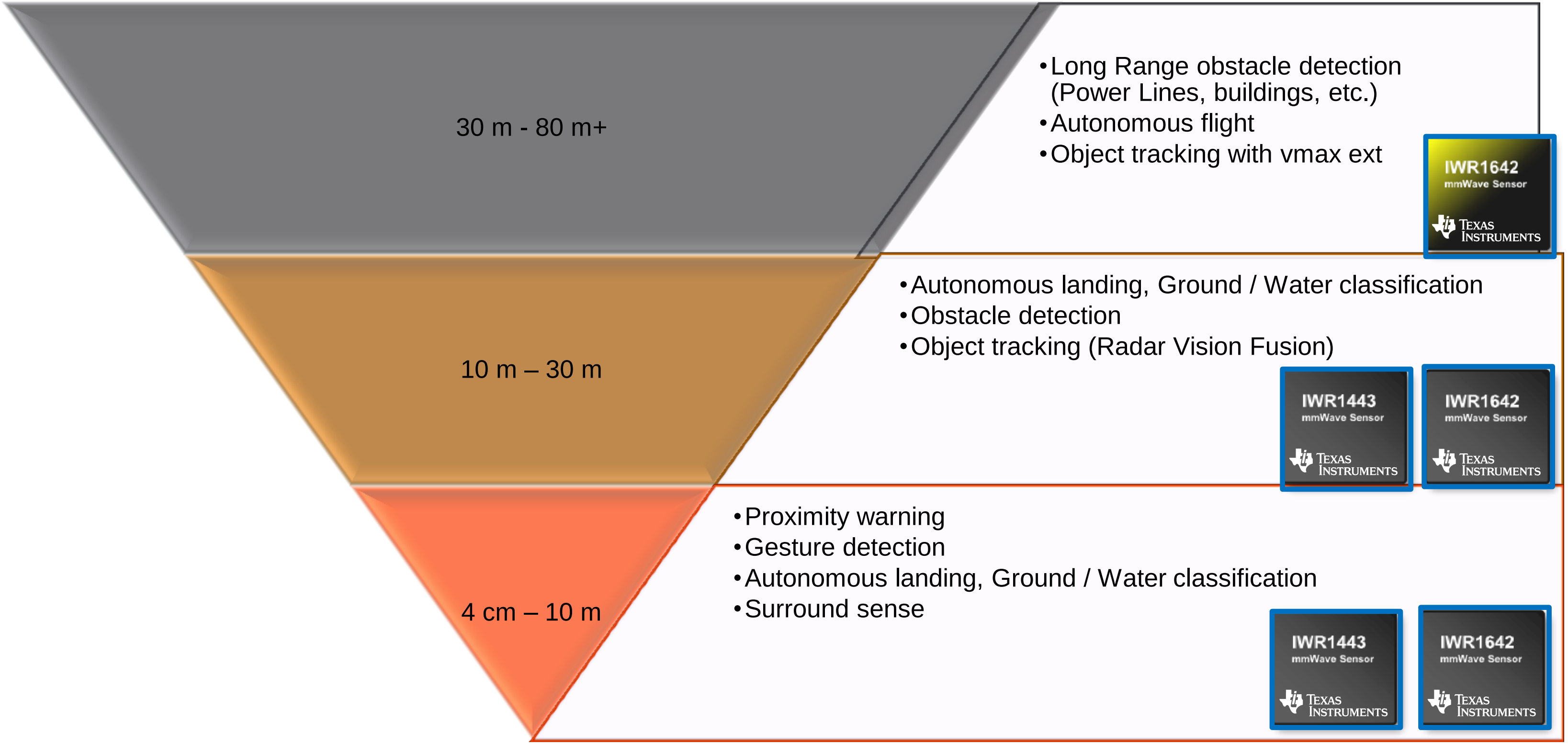


Autonomous Landing

Drones – Sensing Technology Comparison

Sensors	Detection Range	Detection Angle	Range Resolution	Detectable Information	Bad Weather	Night Operation	Detection Performance
 mmWave	Long	Narrow & Wide	Good	Velocity, Range, Angle	Good	Yes	Robust & stable
 Camera	Medium	Medium	Medium	Target Classification	Poor	No	Complexity to calculate object coordinates
 Lidar	Long	Narrow & Wide	Good	Velocity, Range, Angle	Poor	No	Poor in bad weather
 ultrasonic	Short	Wide	Good	Range	Poor	No	Short range applications

mmWave – Sensing for Drones



Drone Use Case Configuration

Use Case Requirement		IWR 1642 (with Vmax Extension)
Range	150 m	150 m
Range Resolution	0.8 m	0.8 m
Velocity	60 m/s (216 km/h OR 134 miles/h)	20 m/s (72 km/h) native & 60 m/s (w/ 3x Vmax Extension)
Velocity Resolution	0.5 m/s	0.5 m/s (1.8 km/h)
RCS	$10m^2$ at 150m	$10m^2$ at 168 m (with 13.5dB Tx/Rx antenna gain)
	IF Bandwidth	4.54 MHz
	Radar Cube Size	320 KB

Vmax Extension For Higher Velocity Detection

- Increasing attainable maximum velocity of reference design using algorithms
- Increase in maximum velocity by 3x (ideally no limit) of current chirp designs
  - For example 35km/hr → 105km/hr, 60km/hr → 180km/hr
- Results
  - Tested for 180km/hr (112 m/hr) in simulations so far

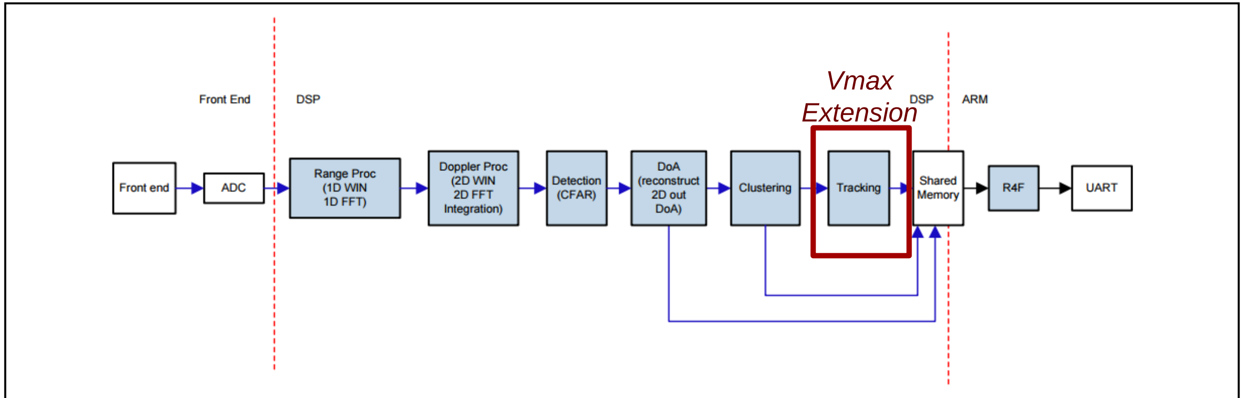
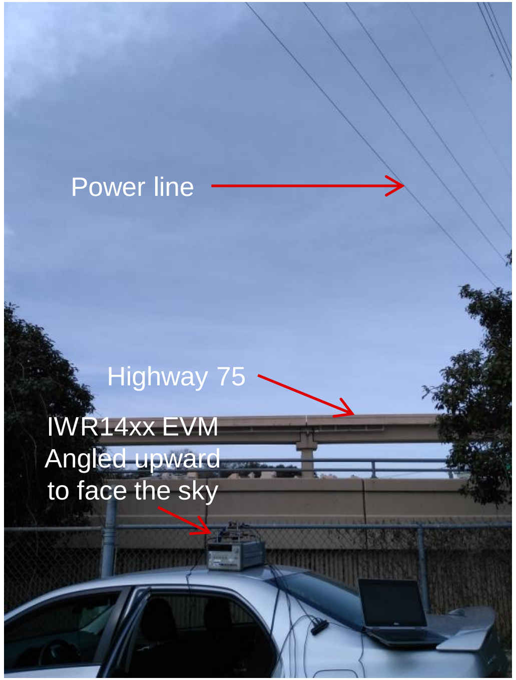
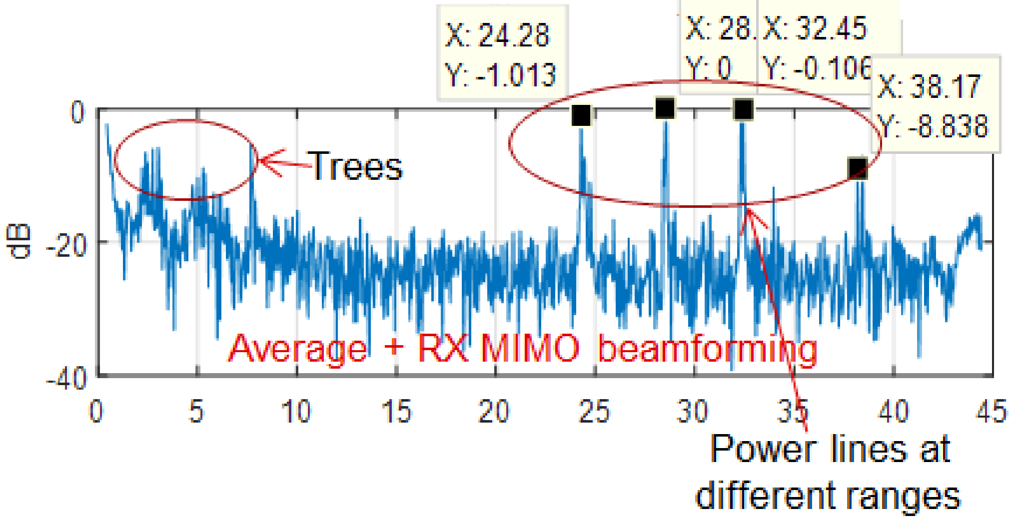


Figure 3. Application Software Block Diagram

- Processing chain based on Drone Use Case. **Vmax extension algorithm** is an incremental addition to the Tracking algorithm.

Power line detection





mmWave sensors glass wall detection

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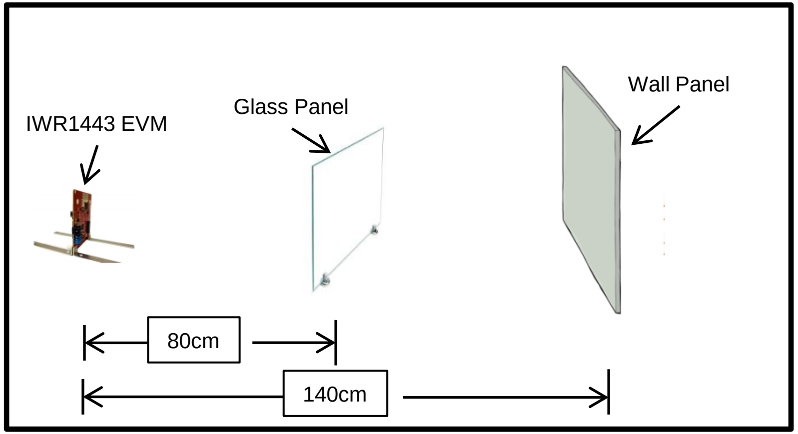
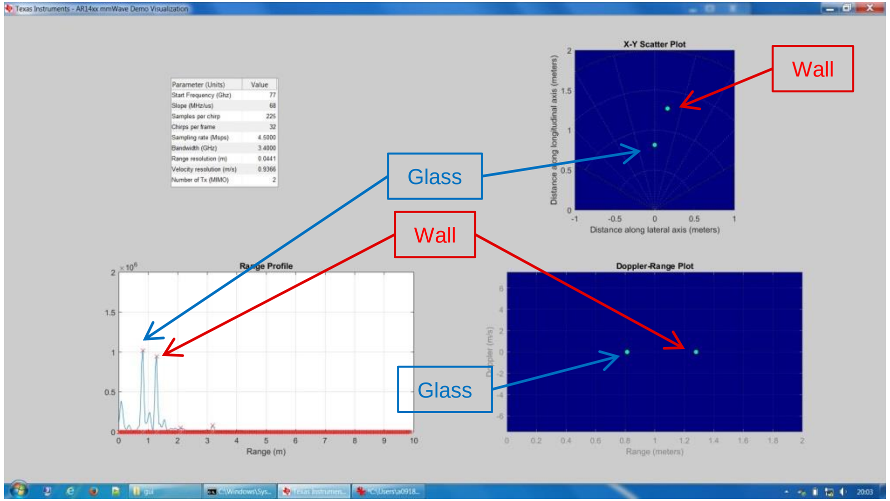
Below test results show mmWave sensors can detect glass obstacle as well as wall surfaces behind in the same scene.

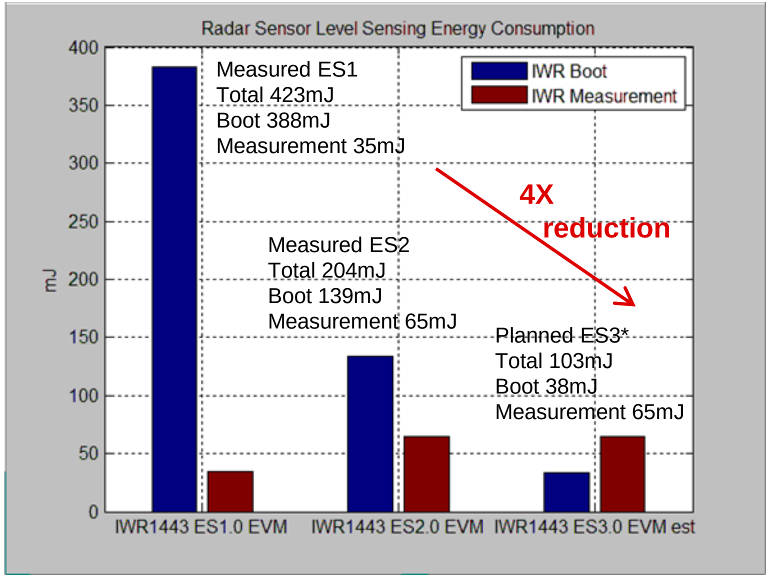




Measured Accuracy and Power

HW Setup Antenna	Target Material	Range Accuracy (mm)	Max Range (m)	TX power (dBm)	Active Chirp Time (msec)	FFT (1642)/ Sample freq Msps (1443)	Range Resolution (cm)	Processing Time (msec)
IWR1642 EVM	water	0.01	10	12	1.2	512x512	4.3	9
IWR 1443 EVM	water	0.5	8.2	12	0.22	5.08	4.0	440usec + active chirp time

	16xx	14xx
Equivalent FFT size	=RangeFFTsize^2 => ~260k	=16384 + quadratic interpolation
Implemented on	C674x	HWA and R4
High level steps	1. Range FFT, find peak 2. Zoom-in, find peak 3. Estimate freq then range	1. Range FFT, find peak 2. Zoom-in, find peak 3. Interpolation 4. Estimate freq then range
Accuracy	1mm @ 36dB det SNR 0.5mm @47dB det SNR ***0.1mm @57dB det SNR***	1mm @45dB line SNR 0.5mm @51dB line SNR ***Error floored @ ~0.2mm***
Memory usage	~30KB on DSP for 512 Range FFT	Negligible on R4
Processing latency	9ms for 512 Range FFT Size, >10ms for 1024 Range FFT	***440us*** on HWA Negligible on R4



Sense and Avoid Solution from Aerotenna

www.aerotenna.com

dronelife

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Aerotenna Demonstrates Collision Avoidance in Drones with Texas Instruments Sensors

Posted By: Frank Schroth on: August 07, 2017

Aerotenna has successfully demonstrated collision detection and avoidance in drones with the IWR1642 mmWave sensor from Texas Instruments (TI), and announced its commitment to feature TI mmWave sensors in its next-generation collision-avoidance solution, uSharp Patch D1. As a leading provider of autonomous flying solutions for drones, Aerotenna sees TI IWR1642 sensor real-time intelligence capabilities as ideal for advanced detection algorithms, clustering and object-classification algorithms required for flight in real- world

Unmanned Aerial

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Aerotenna Brings Texas Instruments Sensor into Drone Collision-Avoidance Tech

Posted by **Betsy Lillian** - August 4, 2017

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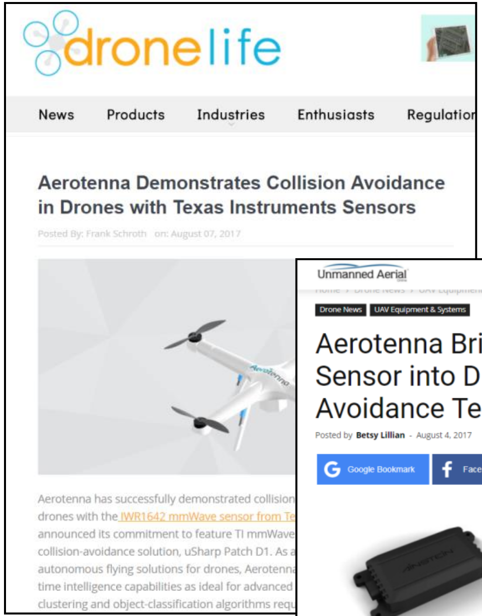
Kansas-based Aerotenna, a provider of radar-based collision avoidance sensors and real-time intelligence for drones, has successfully tested the IWR1642 mmWave sensor from Texas Instruments (TI) with its own technology.

Aerotenna, which is powered by Ainstein, says it will now feature TI mmWave sensors in its next-generation collision-avoidance solution, uSharp Patch D1. With a multi-mode design, Aerotenna also offers uSharp Patch D1 as a low-cost option for automobile safety and self-driving features.

"Using TI's recently announced mmWave sensors in their sense-and-avoid solutions, Aerotennna will make it possible for drone developers to design products that

Sense and Avoid Solution from Aerotenna

www.aerotenna.com



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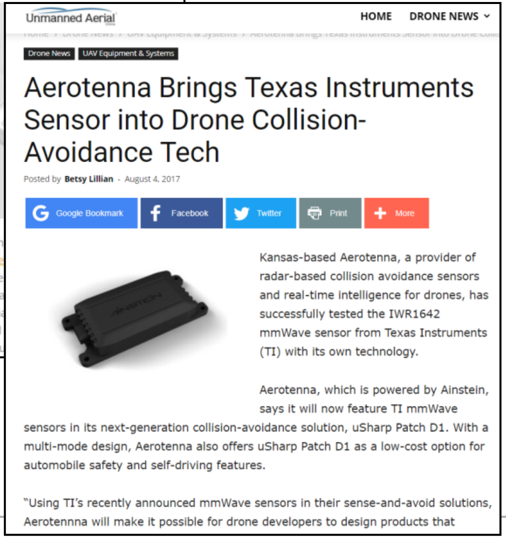

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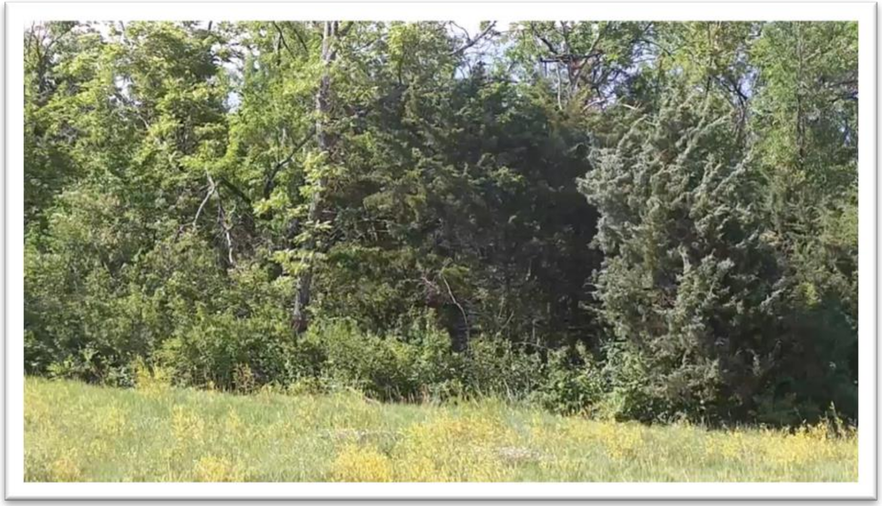
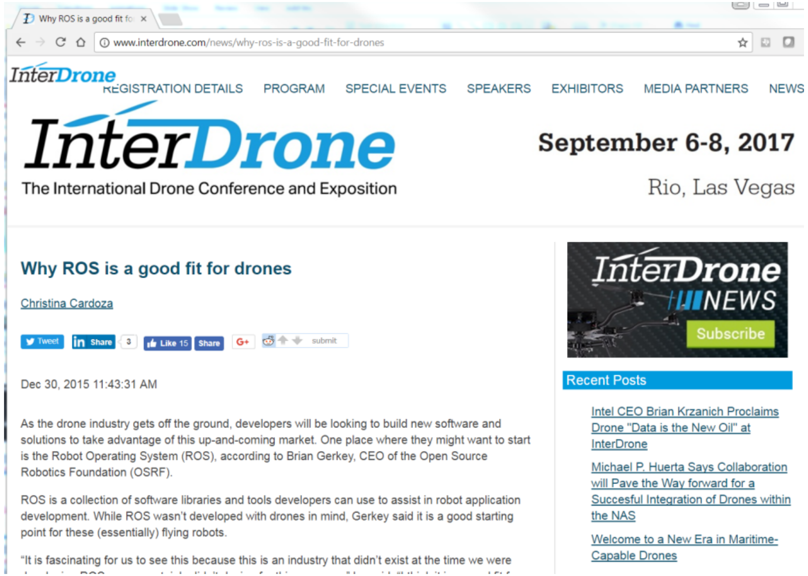


mmWave EVM driver for Robot OS (ROS)

Get to Prototype faster using mmWave EVMs with Robot OS



Why ROS is a good fit fo ×

www.interdrone.com/news/why-ros-is-a-good-fit-for-drones

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InterDrone

The International Drone Conference and Exposition

September 6-8, 2017

Rio, Las Vegas

Why ROS is a good fit for drones

Christina Cardoza

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Dec 30, 2015 11:43:31 AM

As the drone industry gets off the ground, developers will be looking to build new software and solutions to take advantage of this up-and-coming market. One place where they might want to start is the Robot Operating System (ROS), according to Brian Gerkey, CEO of the Open Source Robotics Foundation (OSRF).

ROS is a collection of software libraries and tools developers can use to assist in robot application development. While ROS wasn't developed with drones in mind, Gerkey said it is a good starting point for these (essentially) flying robots.

"It is fascinating for us to see this because this is an industry that didn't exist at the time we were

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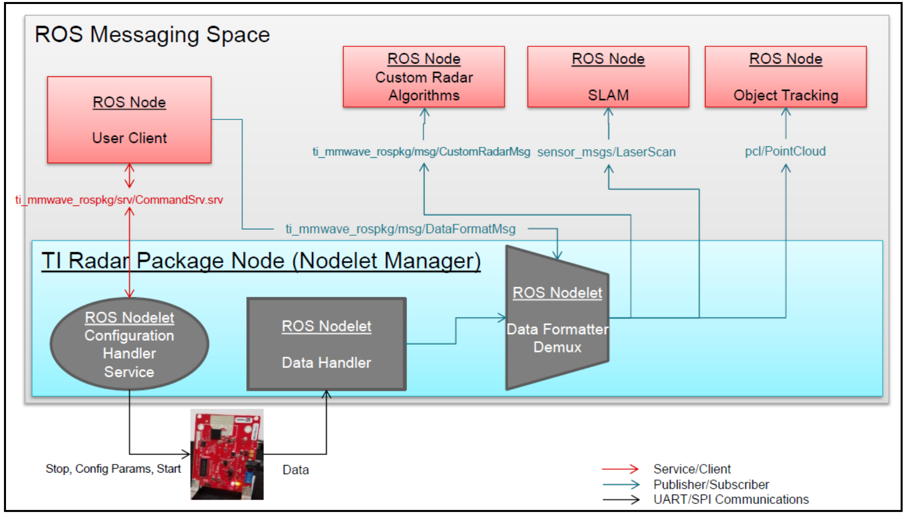
Michael P. Huerta Says Collaboration will Pave the Way forward for a Succesful Integration of Drones within the NAS

Welcome to a New Era in Maritime-Capable Drones



Robot OS (ROS) Introduction

- ROS – Robot OS http://www.ros.org/ is a set of open source software libraries and tools that help you build robot applications. From drivers to state-of-the-art algorithms, and with powerful developer tools for your robot project.

- Initial release 2007 (10 years). Active users estimated in 100k's users by ROS.org
  - Provided under BSD license.
  - Linux based written in C++ and Python
  - Services such as hardware abstraction, low-level device control, implementation of commonly used functionality, message-passing between processes, and package management.

- Robot specific capabilities that ROS provides
  - Standard Message Definitions for Robots
  - Robot Geometry Library
  - Robot Description Language
  - Pre-emptable Remote Procedure Calls
  - Diagnostics
  - Pose Estimation
  - Localization
  - Mapping
  - Navigation

TIDEP-0094: 80-Meter Range Object Detection with IWR1642 mmWave sensors

TIDesigns

Features

- Detect Objects up to 84 meters with Range Resolution of 37cm
- Antenna Field of View +/- 60 degrees with Angular resolution of Approximately 15 degrees
- Source Code for Fast Fourier Transform (FFT) processing and Detection provided by mmWave Software Development Kit

Applications

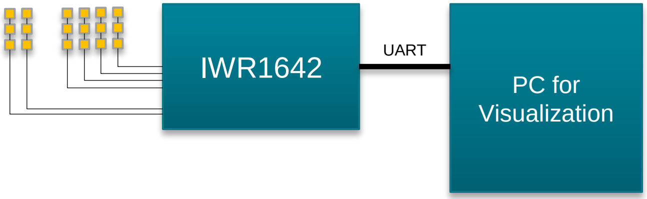
- Service robots
- Logistics robots
- Industrial robots
- Industrial Transport
- Forklifts
- Drone Systems

Tools & Resources

- **TIDA-0094 and/or Tools Folder**
- **Design Guide**
- **Design Files:** Schematics, BOM, Gerbers, Software, etc.
- **Device Datasheets:**
  - IWR1642
  - LP87524B-Q1
  - TPS7A8101-Q1
  - TPS7A8801RTJ
  - TPS79601DRB
  - TMP112AIDRL

Benefits

- Not sensitive to environmental conditions such as lighting, direct sunlight, smoke, fog, dust, frost or electric motor EMI
- Small form factor mounted behind enclosure plastics with no need for aperture results in rugged sensor
- Not only detect objects but also provide relative velocities and positions of objects
- Not as computationally complex as vision based systems, reducing processor requirements, lowering cost and power
- Range far exceeds acoustic based sensors



Customer collateral

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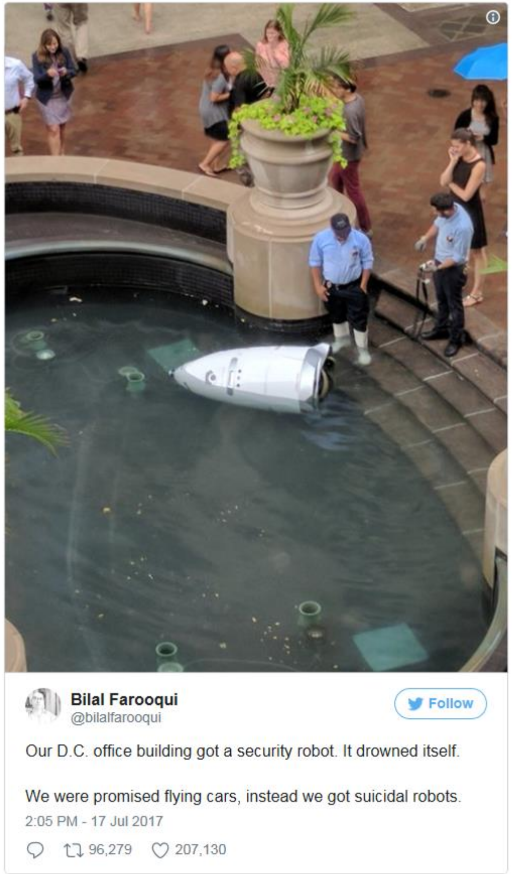
Content title	Content type	Link to content or more details
Video: Why TI mmWave for Drones	90 second marketing focused video	http://www.ti.com/general/docs/video/watch.tsp?entryid=5432149554001
White Paper	White Paper presenting mmWave strengths in Drones to sense power lines, trees and detect water from ground on landing	http://www.ti.com/lit/SPYY001
Demonstration Videos	Drone Assisted Landing	http://www.ti.com/general/docs/video/watch.tsp?entryid=5432082121001
	Water vs Ground Classification	http://www.ti.com/general/docs/video/watch.tsp?entryid=5432103016001
EVM Labs	Water vs Ground classification with EVM	http://dev.ti.com/tirex/#/?link=Software%2FmmWave%20Training%2FLabs%2FWater%20vs%20Ground%20Classification
Application Note: Algorithm Porting and Optimizing on C674x DSP Core	Technical Application Note on how to port radar algorithms to the C674x	http://www.ti.com/lit/pdf/swra564
Application Note: MIMO Radar	Technical Application Note	http://www.ti.com/lit/pdf/swra554
E2E Forums	Public E2E Forum available for customers and FAEs	https://e2e.ti.com/support/sensor/mmwave_sensors/f/1023

Why mmWave Radar sensors in Robotics?
Edge detection is important

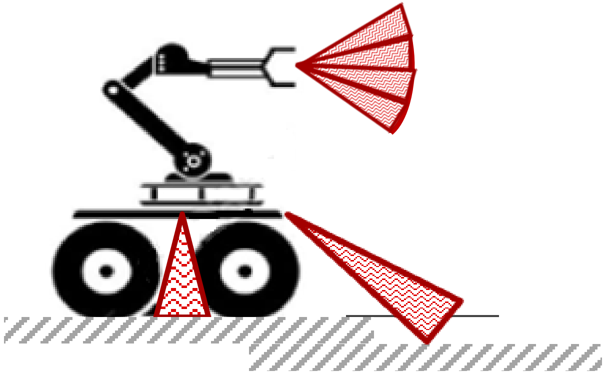


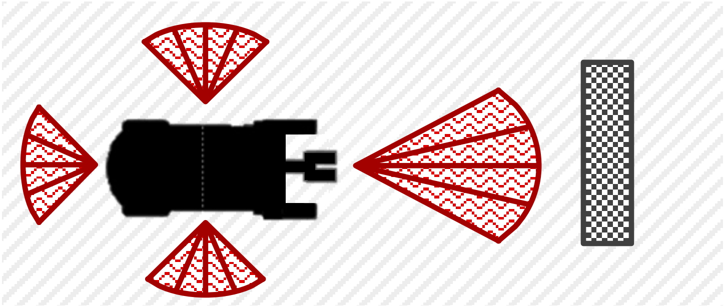
Isaac Asimov's "Three Laws of Robotics"

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

http://www.cbsnews.com/news/washington-dc-knightscape-k5-robot-falls-into-fountain/

mmWave – Robotics Applications





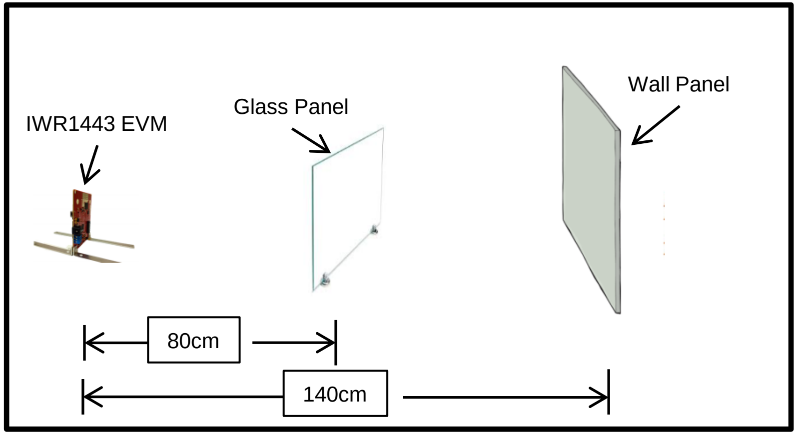
- **Ground speed sensing**
  - Use Doppler shift to calculate ground speed
    - High accuracy, useful in applications where wheels will slip on surface
- **Edge detection**
  - Accurately detect ground edges such as loading docks to avoid unrecoverable situations
- **Articulating ARM safety curtain**
  - Avoid collisions with objects or people

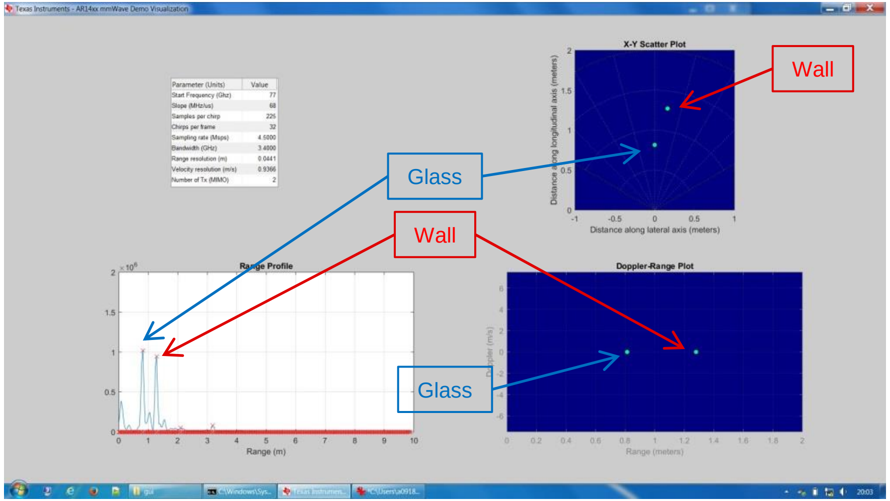
- **Surround obstacle sensing**
  - Sense and Avoid autonomous operation
  - Accurately track multiple approaching objects or people from all directions
  - Differentiate static objects (equipment, boxes, etc) vs. moving objects (robots, people, etc)
  - Augment other sensors with radar information for enhanced safety and reliability
  - Maintain a no-entry curtain or zone around the equipment

mmWave sensors wall detection

Use of glass in architecture is common. Floor to ceiling and partition glass is a problem for vision and IR based sensors in robotics.

Below test results show mmWave sensors can detect glass obstacle as well as wall surfaces behind in the same scene.





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TIDesigns	80m-Range Object Detection Reference Design With Integrated Single-Chip mmWave Sensor	http://www.ti.com/tool/TIDEP-0094
	Demonstrates how IWR1642 can be used for clustering and tracking algorithms	http://www.ti.com/tool/tidep-0090
Third Party support	D3 Engineering DesignCore Industrial mmWave Sensor Starter Kit	http://www.ti.com/devnet/docs/catalog/thirdpartydevtoolfolder.tsp?actionPerformed=productFolder&productId=25860
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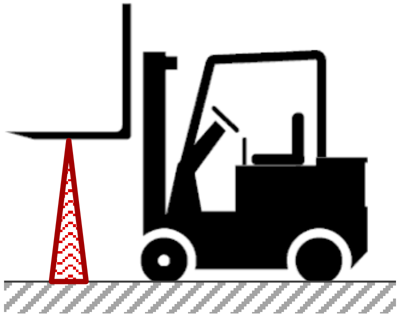
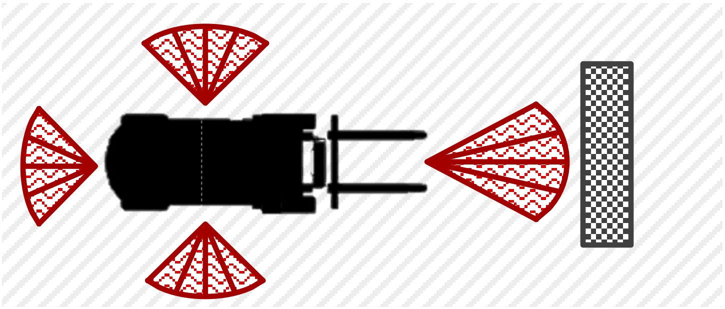
mmWave – Industrial Transport





- **Obstructed view detection**
  - Detect people and objects in an obstructed field of view
  - Robust against environmental conditions such as fog, smoke, and limited illumination
  - Differentiate static objects (equipment, boxes, etc) vs. moving objects (robots, people, etc)

- **Surround obstacle sensing**
  - Augment visual information with radar information
  - Detect approaching objects or people from all directions
  - Maintain a no-entry zone around the equipment

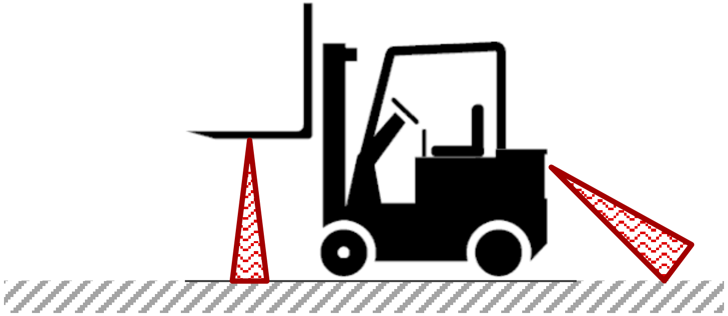
Material Handling – Obstacle Detection

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 – Sensing

Short Range (4 cm – 10 m)

- Proximity warning
- Autonomous loading
- Load balancing
- Edge detection, Ground / Water classification
- Surround sense

Mid Range (10 m – 30 m)

- Autonomous operation
- Obstacle detection
- Object tracking (Radar Vision Fusion)

Long Range (30 m – 80 m+)

- Long Range obstacle detection (Autos, Trucks, buildings, etc.)
- Autonomous Operation

Use case parameters

Sensor Performance

Parameter	Short Range	Mid Range	Long range
Range (typical)	4 cm – 10 m	10 m – 30 m	30 m – 80+ m
Max Velocity (typical)	5 m/sec	15 m/sec	25 m/sec
FOV Azimuth (typical)*	± 45° (90°)	± 30° (60°)	± 10° (20°)
FOV Elevation (typical)*	± 20° (40°)	± 30° (60°)	± 10° (20°)
Range Accuracy**	0.4 cm	0.6 cm	2 cm
Range Resolution	4 cm	6 cm	17 cm
Velocity Accuracy**	0.05 m/sec	0.05 m/sec	0.08 m/sec
Velocity Resolution	0.5 m/sec	0.5 m/sec	0.8 m/sec
Angular Accuracy**	0.5°	1°	1°

**Dependent upon Antenna Design.*
***Values may vary based on the target.*

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Enabling Innovation in Industrial Applications

Tank Level Probing	Factory & Building Automation	Motor Drives & Industrial Transport	**Medical**

Bringing highly-accurate, non-contact sensing and vital signs monitoring to the medical industry

- **Ultra Accurate –** sub 100um accuracy with +/-15um precision enables measurement of human breathing and heart rate from distance of 2m+.
- **Fully-Integrated –** single-chip radar for smaller design sizes, reduced HW complexity, and integrated processing

VITAL SIGNS MONITORING

Vital Signs Monitoring with mmWave Sensors

- Measures the chest wall displacement due to breathing and heart-beat
- The signal is dominated by the body surface movements as the RF penetration inside the body is very minimal at high frequencies (@ 94 GHz skin depth is 0.37 mm in human skin)

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

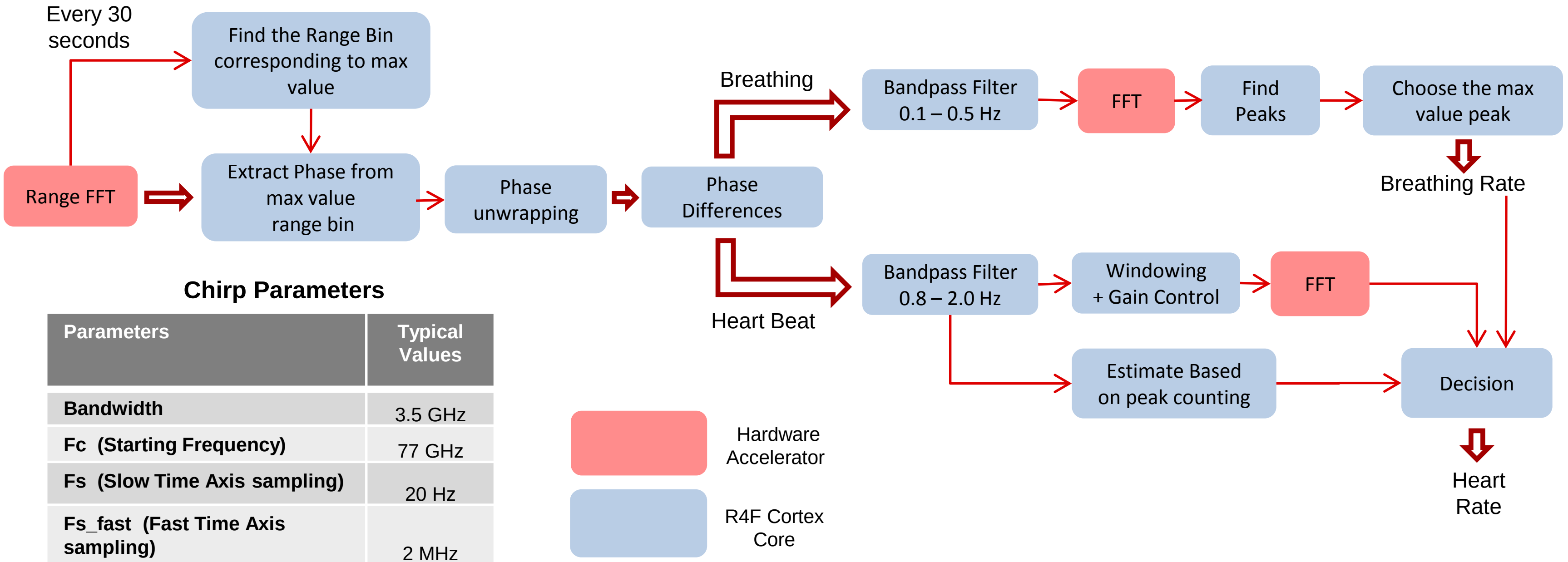
- To measure these small scale vibrations/displacements, we measure the change in phase of the FMCW signal with time at the target range bin

$$\Delta\phi_b = \frac{4\pi}{\lambda}\Delta R$$

- $\Delta\phi_b$ corresponds to the change in phase when the target moves a distance ΔR
- Note that a smaller wavelength will give better displacement sensitivity

Implementation on the IWR-1443

- Real-time implementation (20 fps) utilizing the on-chip hardware accelerator for the FFTs and the Cortex R4F core
- Processing done over a running window of *T* ~ 25 seconds. New estimates are updated every 1 second

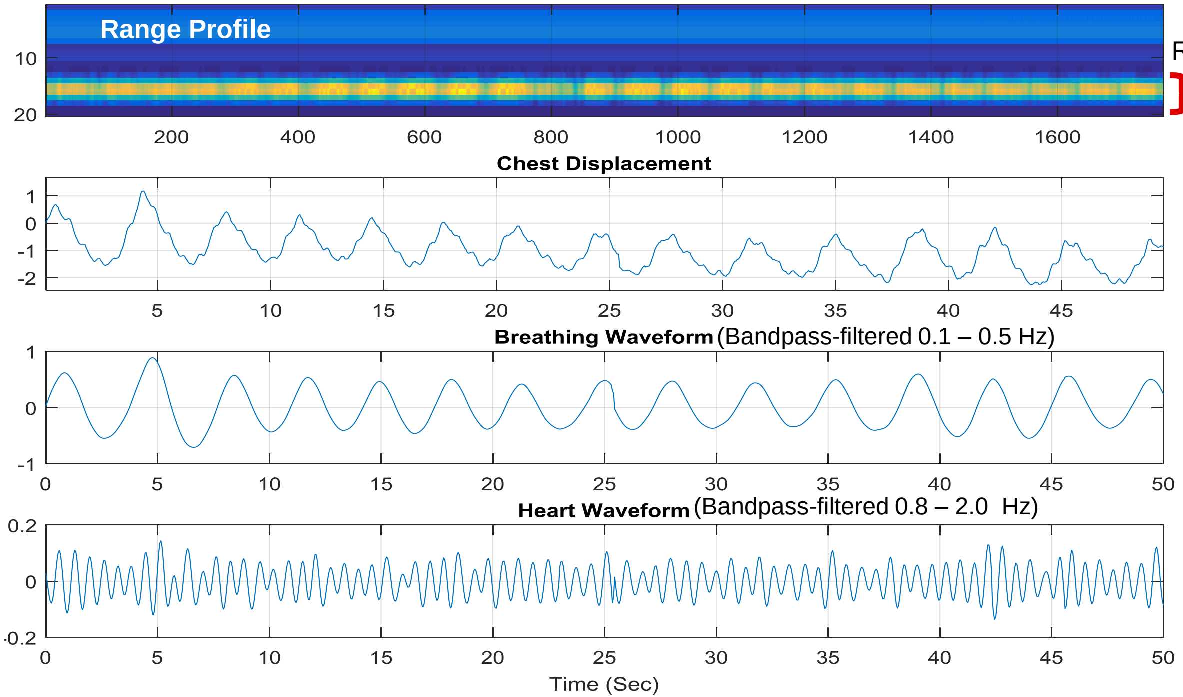


Chirp Parameters

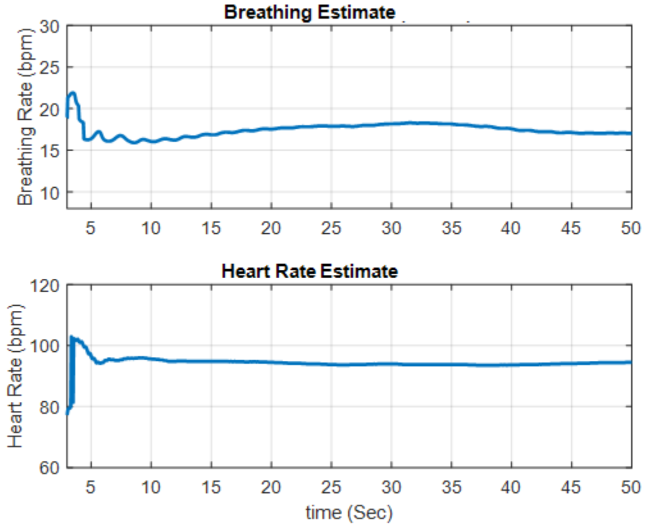
Parameters	Typical Values
Bandwidth	3.5 GHz
Fc (Starting Frequency)	77 GHz
Fs (Slow Time Axis sampling)	20 Hz
Fs_fast (Fast Time Axis sampling)	2 MHz
N (Samples per Chirp)	100
T_c (Chirp Duration)	50 us

Example Measurements

- Subject seated at a distance of 1.5 meters form the Radar and was asked to remain stationary



Range Bins corresponding to the subject



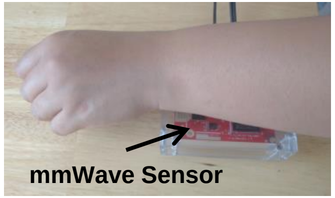
Human Vital Signs – Demo GUI

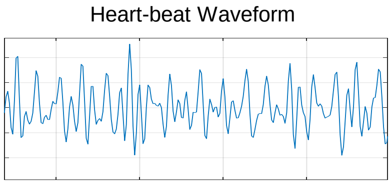
The demo requires the person to be aligned properly in front of the mmWave sensor and remain relatively still for at least 20 seconds before accurate measurements are obtained

Demo Youtube Video:
https://www.youtube.com/watch?v=2-3x0cbDOEQ

Other configurations

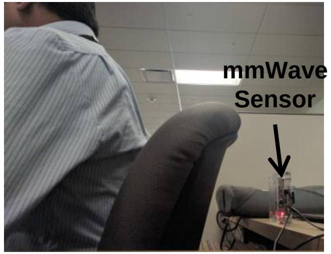
Wrist-based

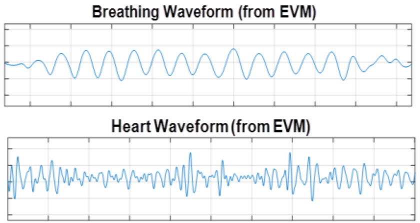




- "Contact-based" Ballisto-cardiography
- Heart-rate only, No Breathing signature

Measurements from the Back



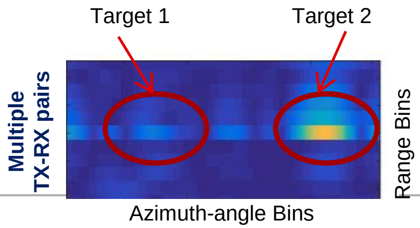


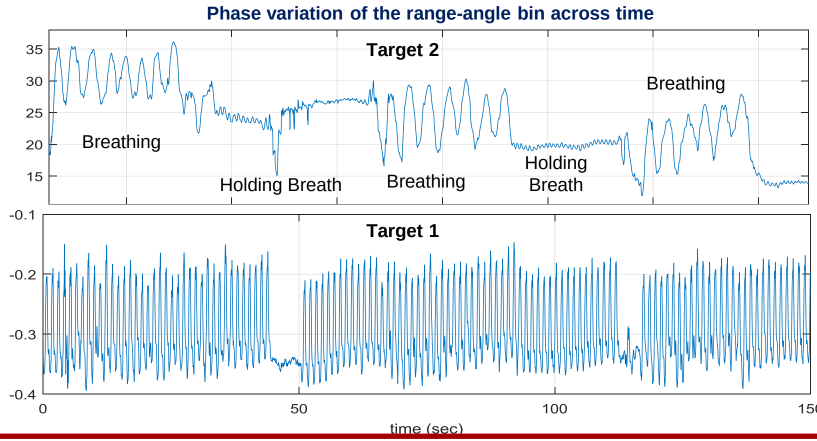
- Both breathing and heart-rate measurements possible. Breathing signal is relatively weak

Multiple-object vital signs

- Using FMCW waveforms and multiple receive channels to isolate objects in range-angle domain

- Target 1 : Corner reflector vibrating (50 um with f = 0.85 Hz)
- Target 2 : A person sitting still and periodically holding his breath

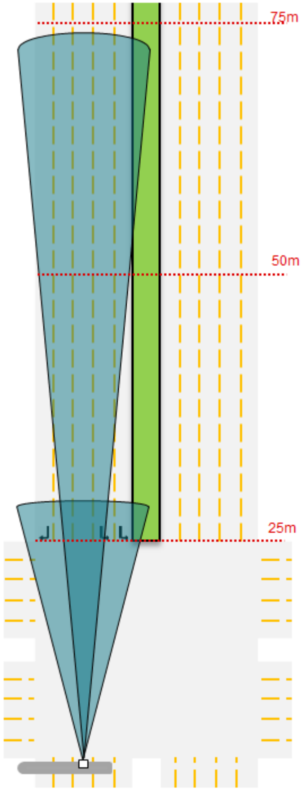




mmWave in Traffic Monitoring

Value of TI mmWave in Traffic Monitoring

- **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



Traffic Monitoring – Technology Comparison

Inductive Loop Sensors

Use of insulated wire inside cuts in roadway. Changes in wire induction measured when vehicle passes over

Pros:
- Well understood application

Cons:
- Disruption of traffic for installation/repair
- Short maintenance cycles
- Detection only around intersection
- Poor detection of two wheel vehicles

Cameras

Video image processor analyzes imagery to determine traffic behavior

Pros:
- Powerful algorithms for variety of applications
- Video for recording and monitoring

Cons:
- Complex signal processing needed to disregard shadows, occlusion, day/night cycles.
- Vulnerability to changing environments

24GHz Radar (SiGe, BiCMOS)

Discrete components assembled to create a 24GHz radar

Pros:
- Insensitive to weather, changing environments
- Radar has extended range over camera (60m+)
- Inherent ability to measure speed accurately

Cons:
- Lower angular resolution than camera
- Limited integration - design complexity
- Lower range/velocity performance versus 77GHz

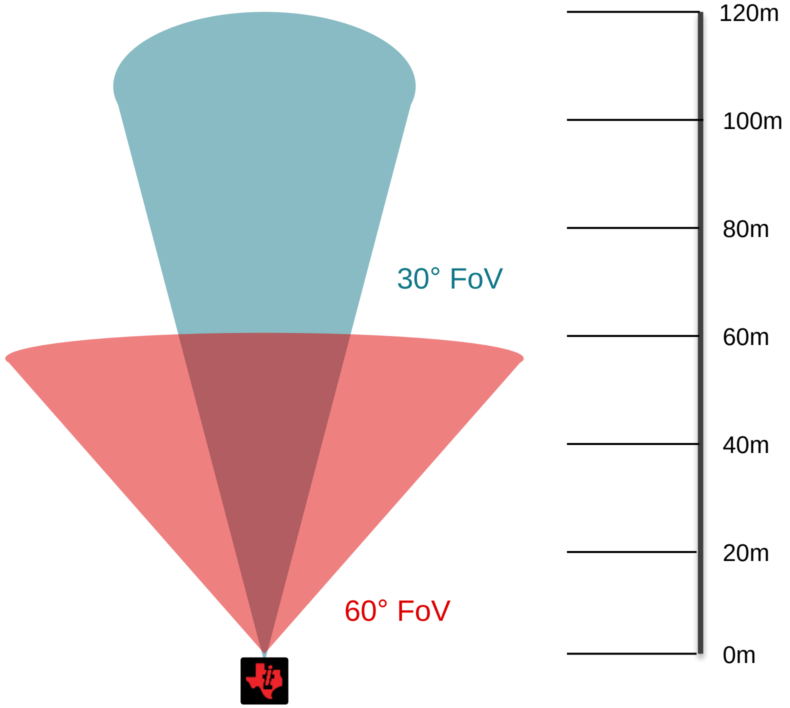
TI 77 GHz mmWave Radar

TI's fully-integrated, single-chip 77GHz mmWave radar

Pros:
- Larger RF BW means higher range resolution
- Radar has extended range over camera (60m+)
- Insensitive to weather, changing environments
- Inherent ability to measure speed accurately
- >3x higher velocity resolution vs 24GHz
- Smaller size, integrated processing

Cons:
- Lower angular resolution than camera

Performance Estimates – Detection with mmWave



Max/Min Range and accuracy are a function of antenna design and size of object to be detected

Estimated performance at 120m, 30° FoV

- Detection of **person** (RCS=0.1) and larger objects
- Detection of **motorcycle** (RCS=1.0) possible even with increased FoV to 60°

Estimated performance at 60m, 60° FoV

- Detection of **person** (RCS=0.1) and larger objects
- Detection of **motorcycle** (RCS=1.0) possible even with increased FoV to 120°

Traffic Monitoring Object Detection and Tracking Reference Design Using Single-Chip mmWave Radar Sensor: *TIDEP-0090*

TIDesigns

Features

- Demonstration of environmentally robust object detection, clustering, and tracking using TI single-chip mmWave sensor
- IWR1642 mmWave sensor used to pinpoint the location of objects in a 90-100° field of view over a range of 5m to 70m and up to 175m+
- Measurement bandwidth of 76-77GHz
- IWR1642 has onboard DSP processor used to cluster objects and track their range and velocity over time. Output of device is simplified object data with range, velocity, and angle information.
- Based on proven EVM hardware enabling quick time to market and out-of-the-box demonstration.

Benefits

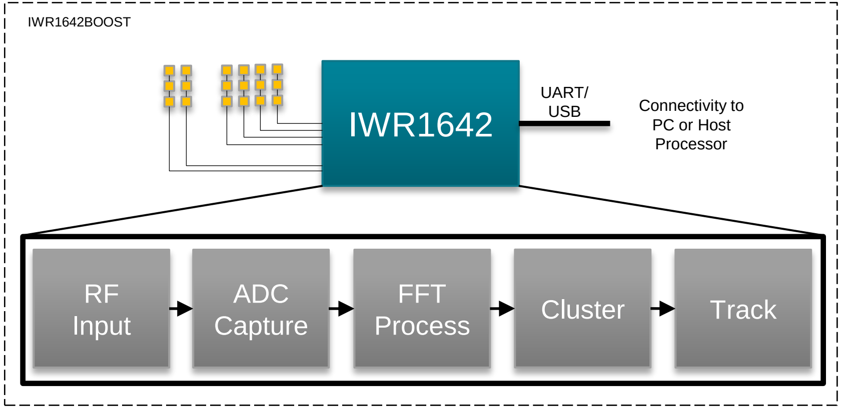
- All mmWave sensing, radar processing and advanced algorithms performed on single chip
- mmWave radar can precisely determine object location and speed
- mmWave offloads host processor in an intersection detection system – minimize need for expensive video analytics for object localization, speed estimation, and classification
- mmWave radar advantage over cameras is that it can be used for sensing in challenging environments such as nighttime, fog, smoke.

Target Applications

- Traffic Enforcement
- Intersection Monitoring
- Road-Railway Sensors
- Intelligent Lighting Sensors
- Security/Surveillance

Tools & Resources

- **Tool Folder Link TIDEP-0090**
- **Device Datasheets Links:**
  - IWR1642



Traffic Monitoring Object Detection and Tracking Reference Design Using Single-Chip mmWave Radar Sensor: *TIDEP-0090*

TIDesigns

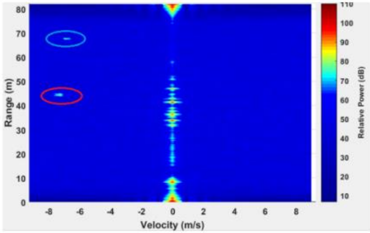
Table 1. Performance Parameters of Two Example Chirp Designs on the IWR1642

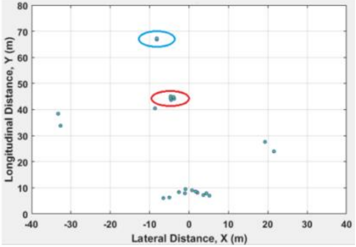
KEY INPUT PARAMETERS		
PERFORMANCE PARAMETERS	MEDIUM-RANGE MIMO EXAMPLE	LONG-RANGE NON-MIMO EXAMPLE
Antenna pattern	Two Tx, four Rx in azimuth plane	One Tx, four Rx in azimuth plane
Maximum range	70 m	120 m, 199 m[1]
Range resolution	0.4 m	1.0 m
Maximum velocity[2]	34 km/h[2]	70 km/h[2]
Velocity resolution	1.5 km/h	1.2 km/h
Frame duration	40 ms	40 ms
ADC sampling rate	5 MSPS	5 MSPS
DERIVED CHIRP DESIGN PARAMETERS		
Chirp valid sweep bandwidth	375 MHz	150 MHz
Chirp time	41.09 µs	39.69 µs
Chirp repetition time	104 µs	51 µs
Number of samples per chirp	206	199
Nfft_range	256	256
Number of chirps per frame	46	117
Nfft_doppler	64	128
Radar cube size	368 KB	468 KB

(1) Design goal 120 m; final parameters support theoretical maximum of 199 m.

(2) Additional processing can extend the maximum trackable velocity by 3x the chirp maximum velocity.

Example chirp designs implemented in TIDEP-0090 for different traffic monitoring application distances and speeds





Detection, clustering, and tracking of vehicles verified at 70m, 120m, and 175m

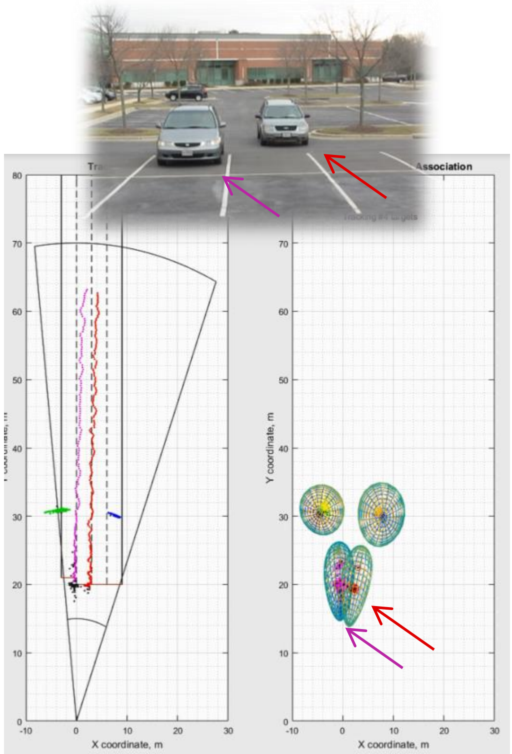
New Algorithms – Available now !

"Vmax Extension"

- Increasing attainable maximum velocity of reference design using algorithms
- Increase in maximum velocity by approx. 3x of previous medium and long range chirp designs
  - Single Lane : 195 km/hr
  - Multi Lane : 80 km/hr

"Advanced Tracker"

- Improvement to current tracker implementation to allow separation of multiple objects that are too close together to resolve with basic FFT processing
- Allows for monitoring within more dense urban environments



Advanced Tracker separates two cars as they approach intersection "stop bar" and come to stop (red and pink)

Industrial Radar – Path of Development

Discover

"I am looking for a new sensor for my project"

- Tools focused on showcasing mmWave sensor capabilities and potential
- Enable Proof of Concept validation of use cases

TI.com Portal

White Papers & Videos

mmWave Experiments

Evaluate

"I have purchased an EVM to evaluate mmWave sensors"

- Tools & SW focused on shortening evaluation time by simplifying getting started and providing reference software to start with

OOB Demo + Visualizer

mmWave Labs

Chirp Database

Design

"I have selected mmWave sensors for my project"

- Tools & SW that provide building blocks to develop unique mmWave sensor applications
- Enable rapid development, test and deployment

mmWave SDK & LIB

IWR1xxxBOOST EVM

App Notes, TID & Training

Sensing Estimator

mmWave Studio

mmWave Sensors Forum (e2e)

Product Evolution for Radar for Transport

Name	IWR1642 Out-of-Box	Traffic Monitoring TI Design (Available Now)		Traffic Monitoring TI Design v2 (4Q2018)	
HW	IWR1642 EVM	IWR1642 EVM		IWR1642 EVM	
Configuration	Out-of-Box	Medium Range (MIMO)	Long Range (Non-MIMO)	Medium Range (MIMO, Vmax)	Long Range (Non-MIMO, Vmax)
Applications	Generic	Stop-bar Monitoring	Intersection Monitoring	Dense Urban, Parking Lot	Highway Monitoring
Angular Resolution	15 degrees	15 degrees	30 degrees	15 degrees	30 degrees
Maximum Range	Up to 37m	70m	120m, 199m	70m	120m, 199m
Maximum Velocity	Up to 64km/h	34km/h	70km/h	100km/h	210km/h
Range Resolution	Down to 3.9cm	0.4m	1.0m	0.4m	1.0m
Velocity Resolution	Down to 1.8km/h	1.5km/h	1.2km/h	1.5km/h	1.2km/h
Frequency Range	76-81GHz	76-77GHz	76-77GHz	76-77GHz	76-77GHz
Algorithms	None	Basic Clustering, Tracking	Basic Clustering, Tracking	Vmax extension, Adv Group Tracking	Vmax extension, Adv Group Tracking

Customer collateral

The following information is available for you to send for customers

Content title	Content type	Link to content or more details
IWR1642 Product Folder	Containing Datasheets, Technical Reference Manual, and more	http://www.ti.com/product/iwr1642
Video: Why TI mmWave for Traffic Monitoring	90 second marketing focused video	https://www.youtube.com/watch?v=2N2raw103fA&feature=youtu.be
White Paper: Robust traffic and intersection monitoring using mmwave sensors	White Paper presenting Traffic Monitoring market, challenges, and role of TI mmWave	http://www.ti.com/lit/pdf/spyy002
TI Design: Object Detection and Tracking Reference Design Using Single-Chip mmWave Radar Sensor	Demonstrates how IWR1642 can be used for traffic monitoring applications	http://www.ti.com/tool/tidep-0090
Application Note: Introduction to the DSP Subsystem in the IWR16xx	Technical Application Note on how to port radar algorithms to the C674x	http://www.ti.com/lit/an/swra564/swra564.pdf
E2E Forums	Public E2E Forum available for customers and FAEs	https://e2e.ti.com/support/sensor/mmwave_sensors/

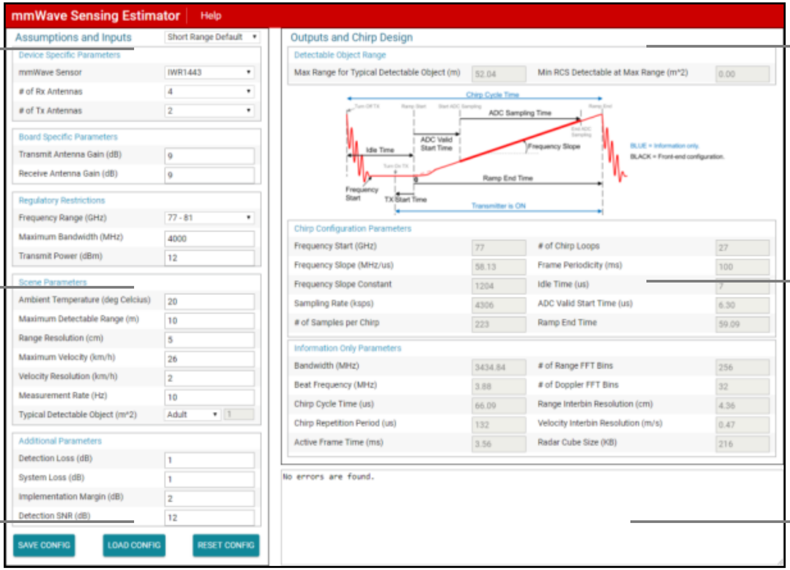
Sensing Estimator

Prototype chirp designs rapidly with real-time feedback!

Load sensible default values to quickly start from a valid configuration.

Input system level parameters about the scene the sensor needs to detect. Experiment with different parameters to design the perfect chirp.

Enables saving and reloading of the work for future adjustment.



Estimates maximum range for different size objects

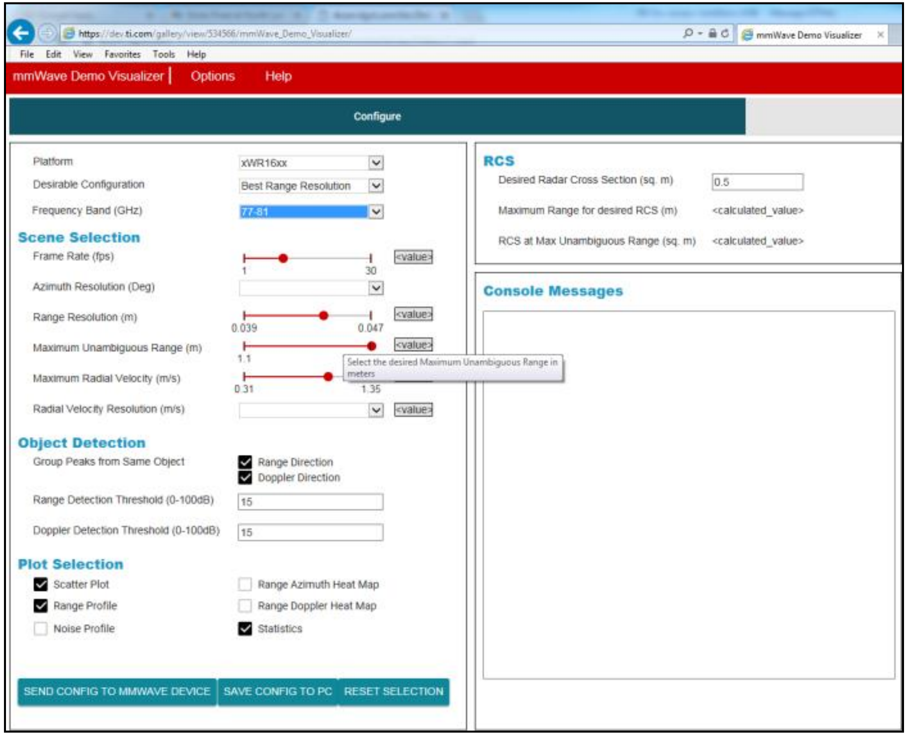
Calculates the chirp parameters instantly on input changes.

Detects outs of bounds inputs and provides tips on how to get back into bounds.

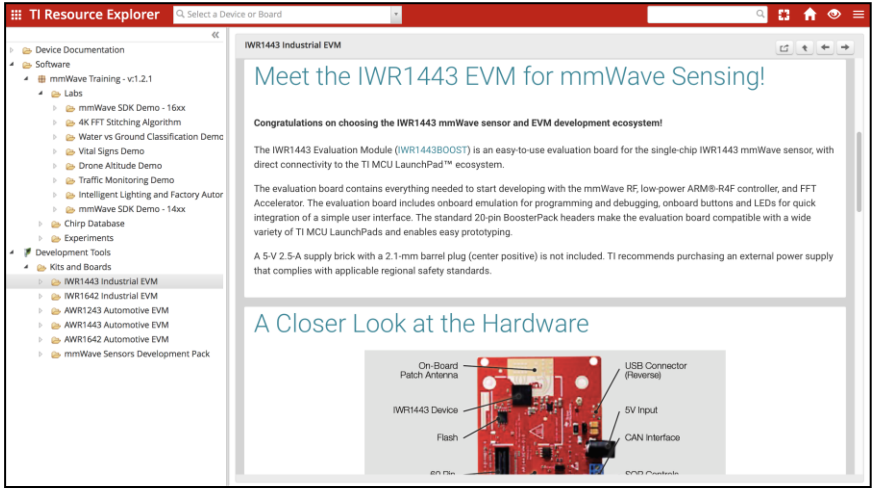
Link: [mmWave Sensing Estimator]

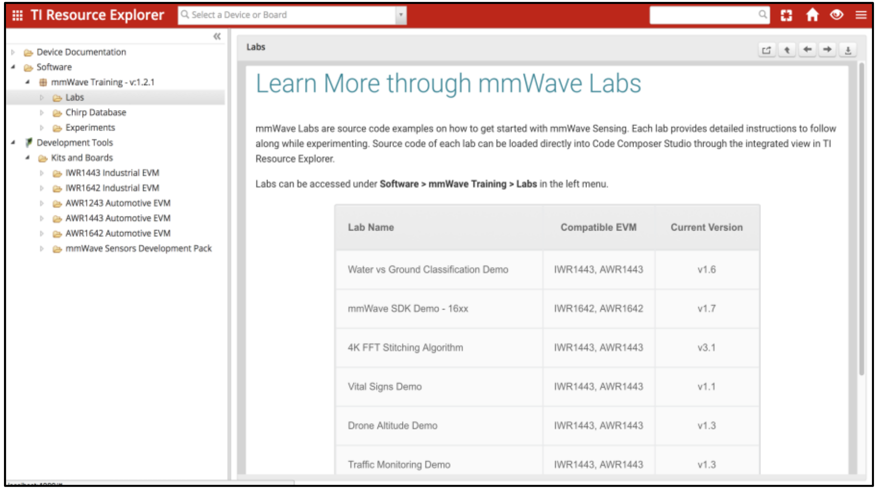
EVM Out of Box Demo

- EVM comes pre-loaded with the Proximity Demo (Out of Box Demo)
- Quickly demonstrates Range, Velocity and Angle measurement
- Configuration and Visualization done through a Web based GUI
  - https://dev.ti.com/mmWaveDemoVisualizer
- Quick setup: Simply connect the EVM to the PC and use the Web GUI
- Out of box Demo Video
  - http://www.ti.com/startIWR1443



Industrial mmWave –TIREX Landing Pages



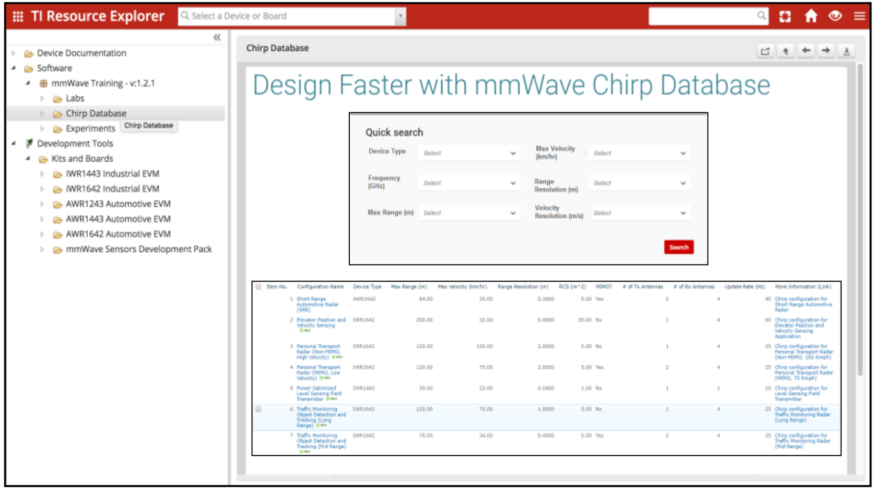


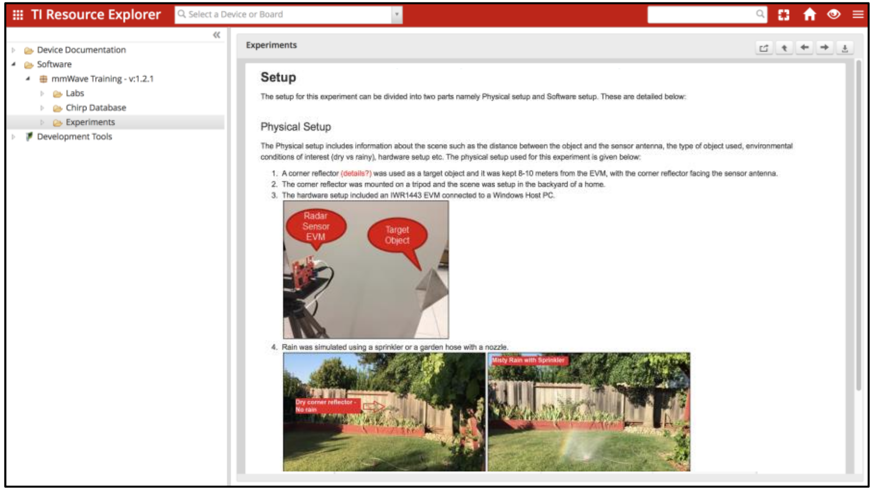
CCS will detect the EVM connected to the PC and load the appropriate landing page in TIREX. Landing Page will introduce features of the EVM, out of box experience and available labs.

mmWave Labs are pre-made CCS projects for all demos and algorithms that the customer can start with immediately to accelerate their evaluation and development.

Visit TI REX

Industrial mmWave –TIREX Chirp and Experiments





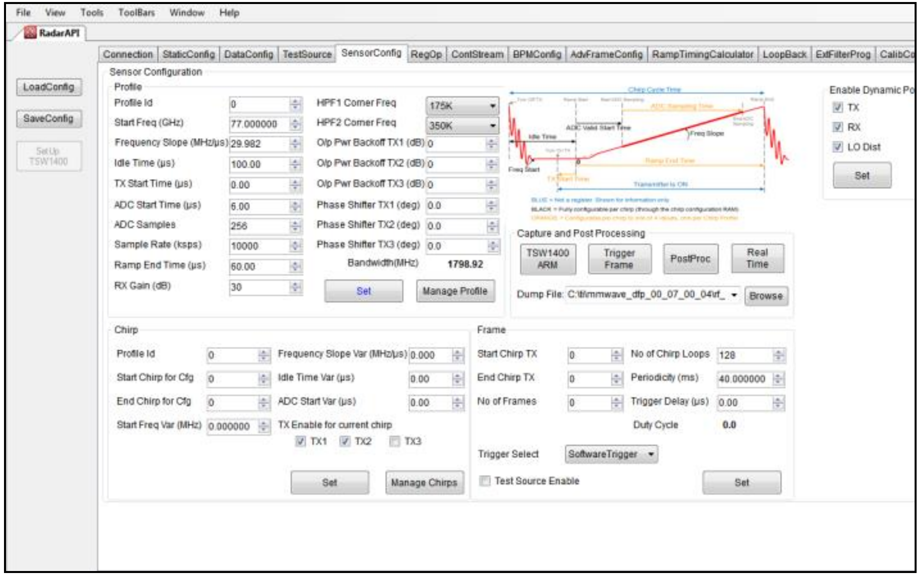
Chirp Database is a searchable repository of mmWave RF configurations that customers can use to get started designing their own system quickly.

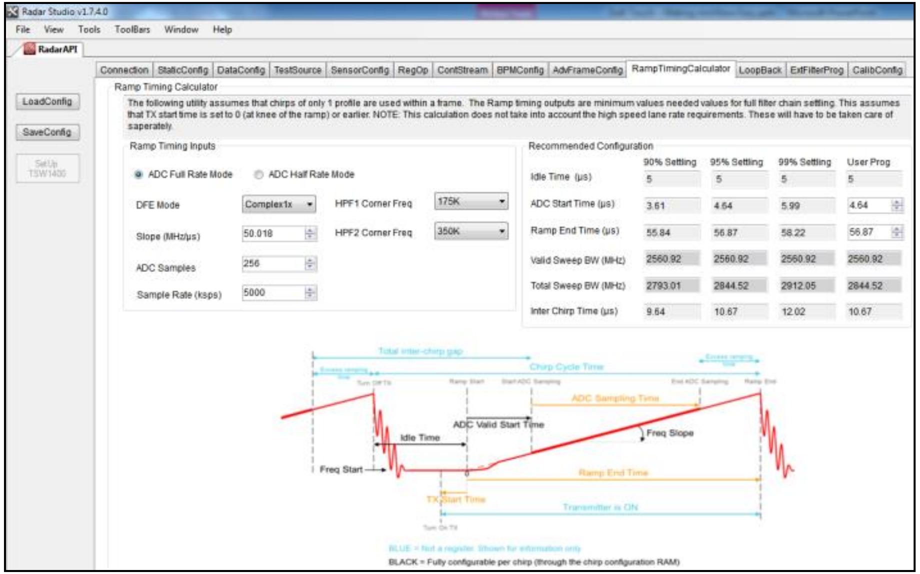
Experiments are replicatable tests that TI engineers have performed to characterize the ability of mmWave sensors in different environments with different objects.

Visit TI REX

Texas Instruments

mmWave Studio





- **Tool for RF Front-End configuration, Raw ADC data capture and Post processing.**
- Ability to configure the sensor without the need for a user application, including data path configuration (LVDS or CSI2).
- Advanced features such as Ramp timing calculator for fine tuning the sensor configuration for performance
- Interfaces with TSW1400 data capture card for a single tool data capture solution.
- Scripting interface for characterization and performance evaluation.

TEXAS INSTRUMENTS