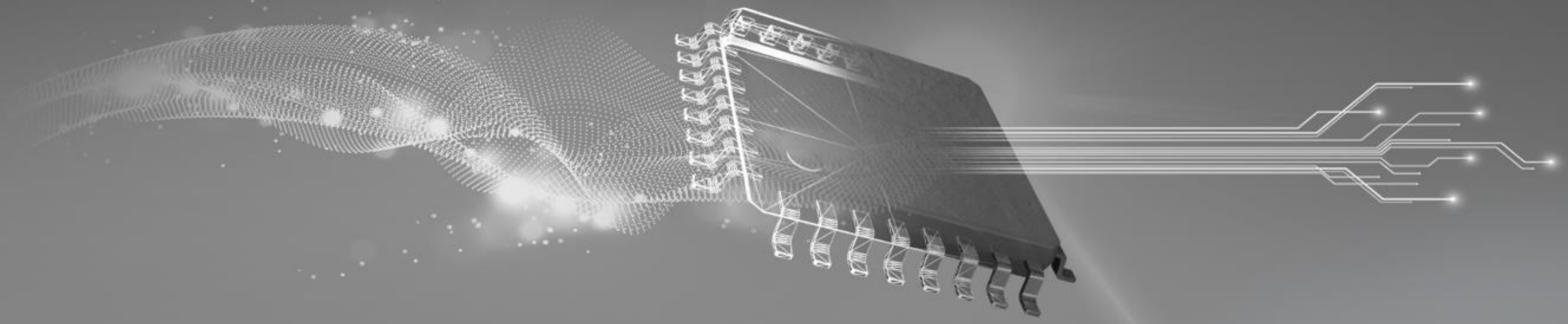
TI TECH DAYS



Texas Instruments AWR6843 60-GHz sensor for incabin sensing

Dave Woodall

Radar

mmWave Sensors – Technology Overview, TI Advantages and Applications

What is mmWave Technology

- mmWave sensors provide **range**, **velocity** and **angle** for detected objects with high accuracy
- mmWave technology **works in challenging environmental conditions** such as darkness, extreme bright light, dust, rain, snow and extreme temperatures

Texas Instruments mmWave Advantages

- **Single-chip, Low-power** sensing solution achieved through RFCMOS technology
- **Integrated processing** solutions remove the need for an external processor in the system
- **Scalable Portfolio –** SW re-use across Automotive & Industrial platforms, regardless of band
- **Antenna on Package** – Optimized solution simplifies design & manufacturing challenges
- **Imaging Radar –** Lidar-like performance at the right price point

mmWave Applications

Automotive



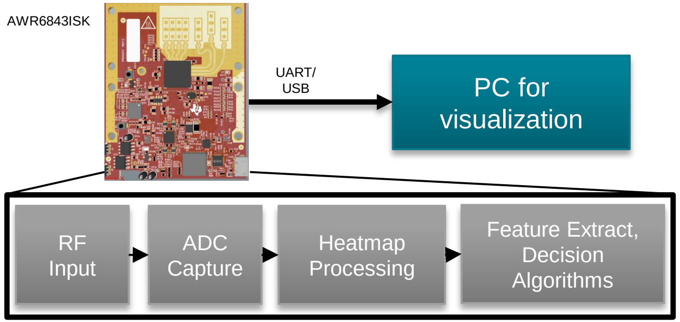
Industrial

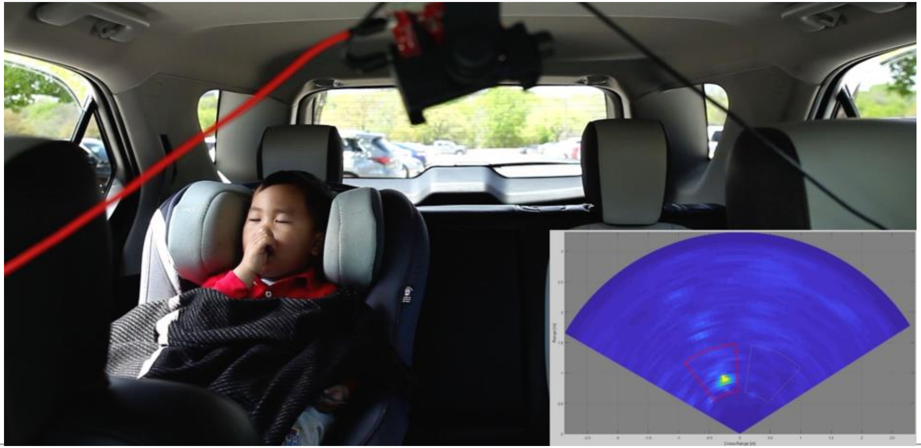


Front Mount Vehicle Occupancy Detection

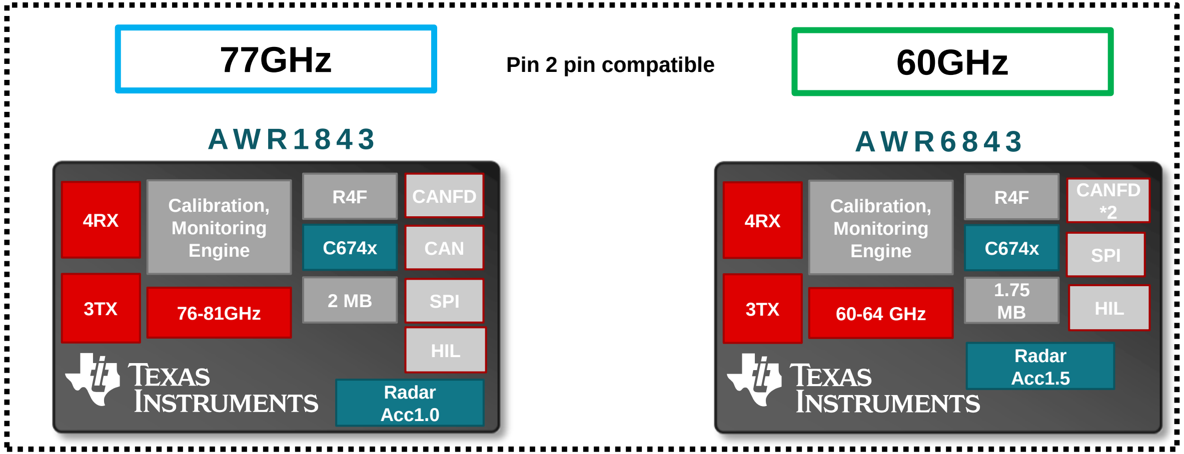
- Reference Design Number: TIDEP-01001: www.ti.com/tool/tidep-01001
- AWR6843 – TI's FMCW mmWave (60-64GHz) **Single chip Radar** with 3Tx/4Rx RF front End, ADC, DSP(C674x) and MCU(Cortex-R4F), FFT/CFAR accelerator.
- AWR1843 – TI's FMCW mmWave (76-81GHz) **Single chip Radar**
- Complete RADAR data processing on-board the device.
- Device outputs heatmap, feature and zone decision information.
- Chirping pattern provides ability to detect small movements, such as breathing and heart rate.

Demonstration using AWR6843 EVM





HW & SW Compatible AWR1843 (77 GHz) & AWR6843 (60 GHz)

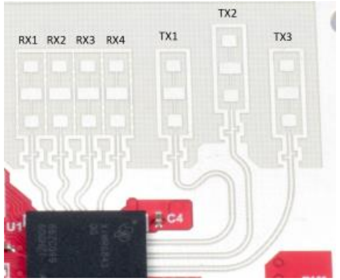


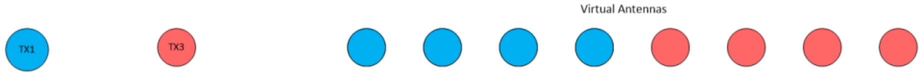
Function	AWR1843 (77GHz)	AWR6843 (60GHz)
Continuous Bandwidth	4GHz	4 GHz
I/F Bandwidth	10MHz	10MHz
RAM	2MB	1.75MB

- mmWave-SDK supports both 77GHz and 60GHz platform
- Common device architecture
- Same software API's for development
- Pin 2 Pin compatible
- Radar Accelerator 1.5 has **Memory Compression unit**
- AWR6843 in production!

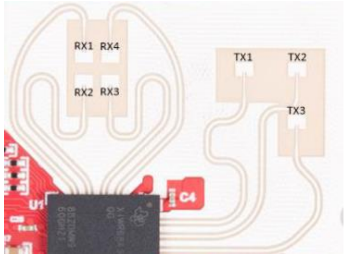
VOD Antenna Overview

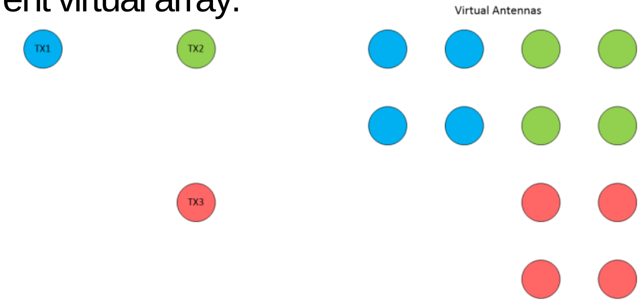
The Front Mount Vehicle Occupancy Detection demo was originally developed on the AWR1642BOOST EVM. With AWR6843 and 1843, we perform TDM MIMO with the azimuth antennas to create a 1x8 virtual antenna pattern:





IWR6843 AOP and ODS antennas create a different virtual array:



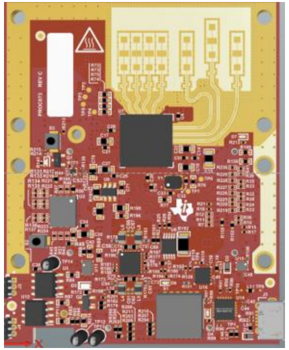


This antenna is used for the Overhead Mount VOD demo and “3D” algorithms make use of both azimuth and elevation data.

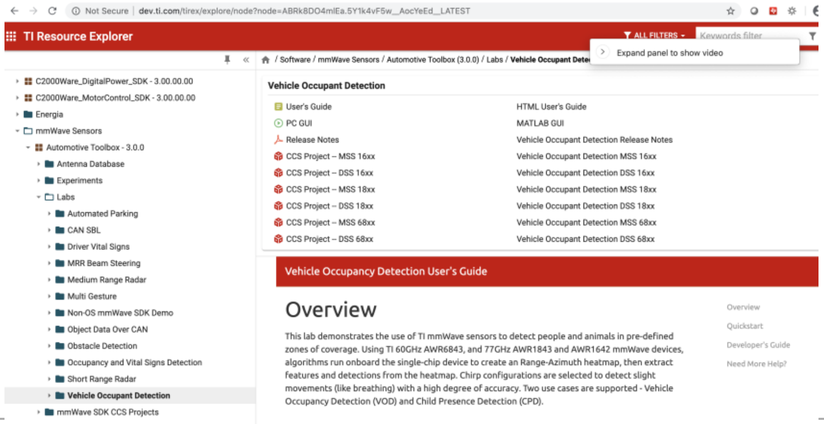
Front Mount Implementation Overview

Hardware

- AWR6843ISK
  - 4 RX, 3TX
  - DSP, ARM
  - RF Front end
  - FFT accelerator



Software



Key Performance Specifications

Parameter	Value
Max range	3.3 m
Max velocity	2.78 m/s
Range resolution	4.69cm
Velocity resolution	0.013 m/s
Field of View	120º Horizontal
Bandwidth	3.920 GHz

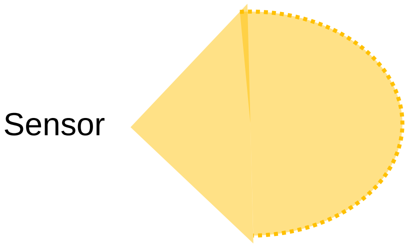
- mmwave_automotive_toolbox_3_x_x
  - Available in TI Resource Explorer
  - (within CCS, or http://dev.ti.com/tirex/explore)
- mmWave SDK
  - Installer here: www.ti.com/tool/mmwave-sdk

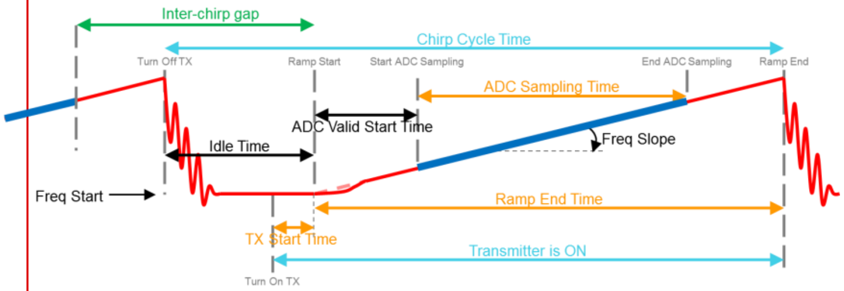
VOD Chirp Configuration Features

- TDM 2x4 MIMO
  - Suitable for applications which require a high angular resolution
  - Angular resolution determined by the virtual antenna.

- 512 Chirps/frame for high velocity resolution to detect slow movement like breathing
  - 256 TX1 chirps interlaced with
  - 256 TX3 chirps.
  - Large chirp cycle time = 290us

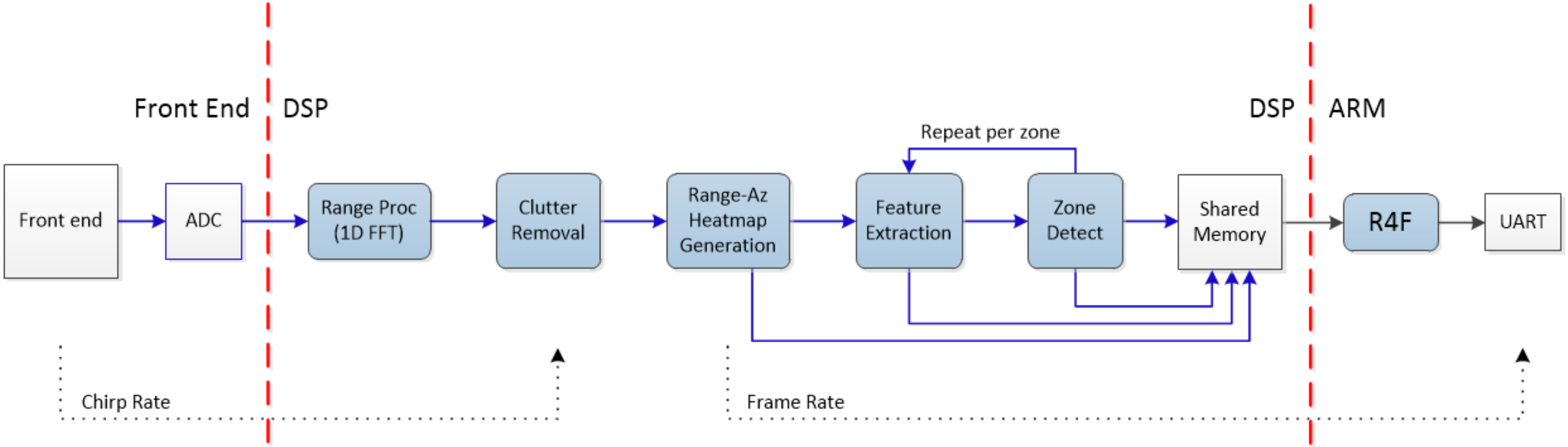
- Maximize range resolution while fitting in a 512KB radar cube:
  - num samples = 64
  - sample rate = 2200ksps
  - freq slope = 98 Mhz/us





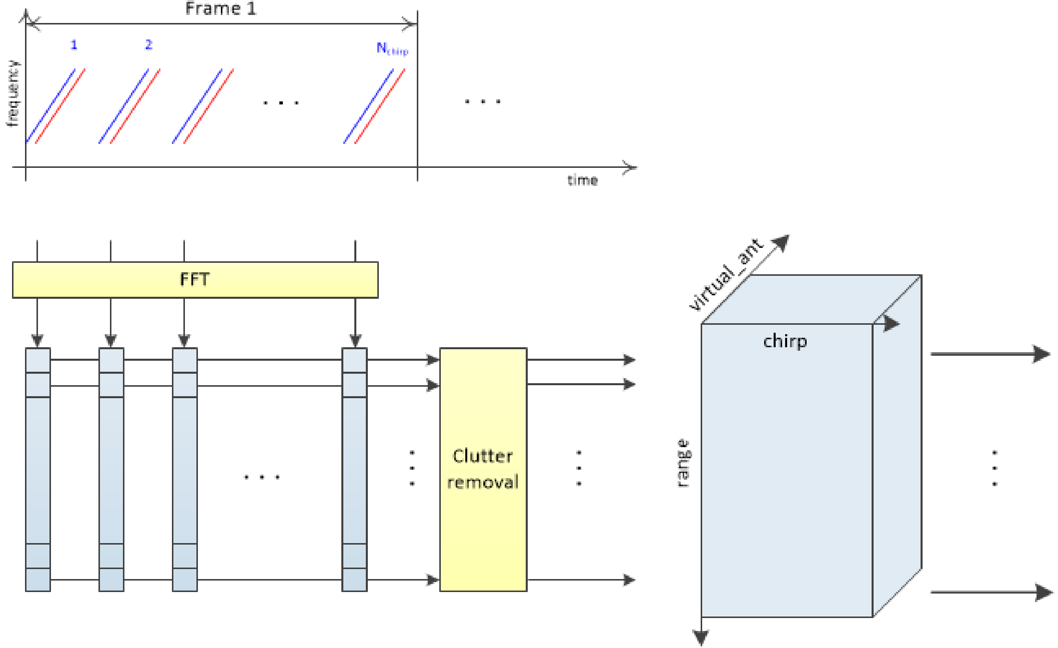
BLUE = Not a register. Shown for information only
BLACK = Fully configurable per chirp
ORANGE = Configurable per chirp to one of 4 pre-determined values, using single common control ("Chirp Profile")

Signal Processing Chain: Block Diagram



- Low level signal processing chain is implemented on the DSP (C674x).
- Low level signal processing chain outputs heatmap, feature parameters and zone decisions.
- R4F (MSS ARM) processor transfers outputs from shared memory to UART.
- All algorithms are fully documented in the design document. Go to www.ti.com/tool/tidep-01001.

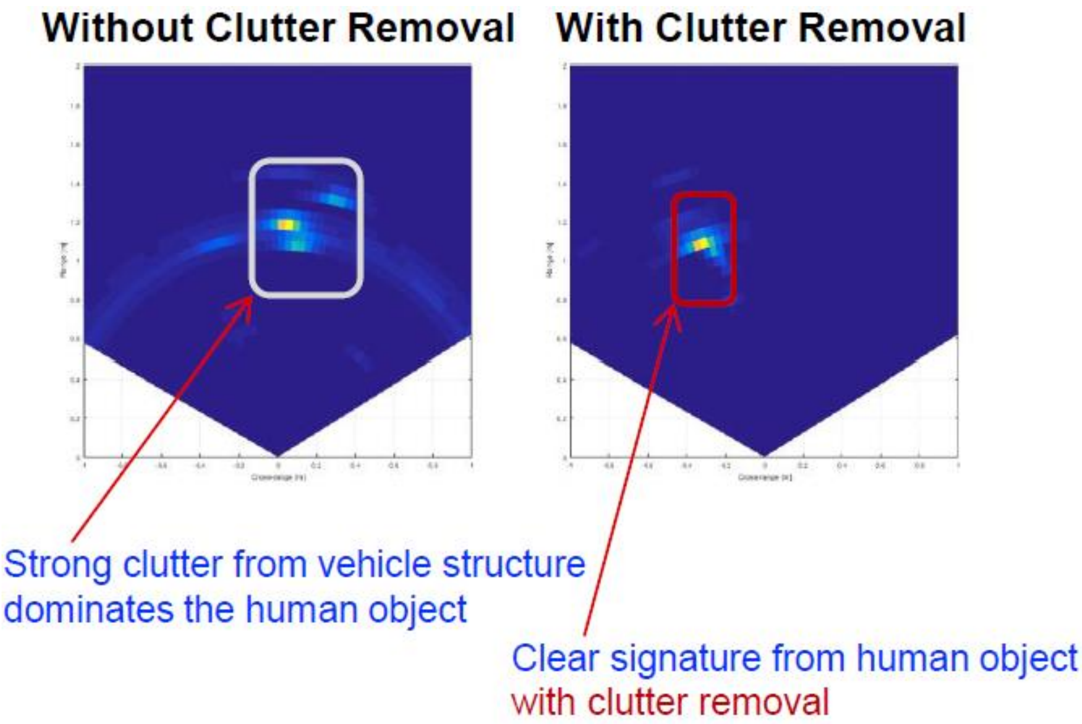
Front End and Range (Chirp) Processing



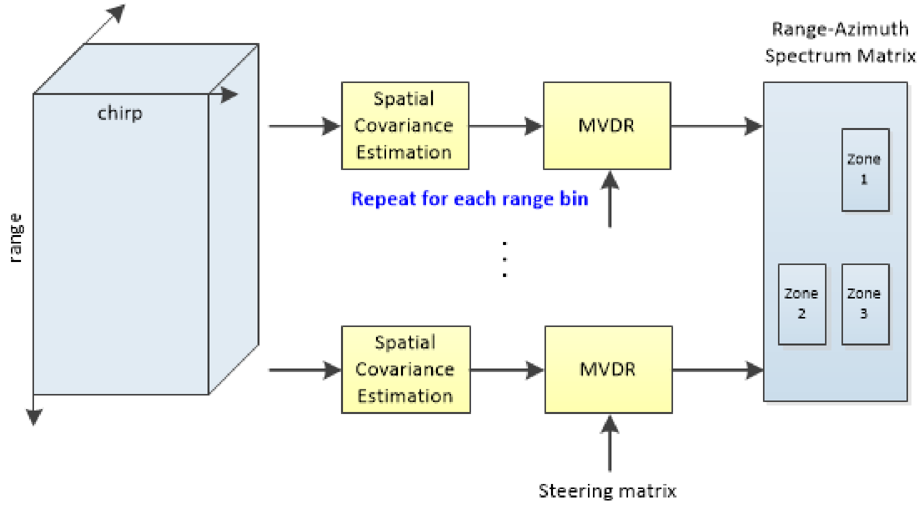
- Range processing performs FFT on ADC samples per antenna per chirp. FFT output is a set of range bins.
- Range processing results in local scratch buffers are DMA'd to the L3 radar cube.
- Static clutter removal is performed once radar cube is complete (following chirping).

Static Clutter Removal

- Non moving objects in the vehicle can create strong returns in the data:
  - Seat structure
  - Items left on seats or cargo area
- Clutter removal eliminates most static objects, improving the signal for moving objects.
- Static clutter removal is performed by subtracting the estimated DC component (average power) from each range bin.

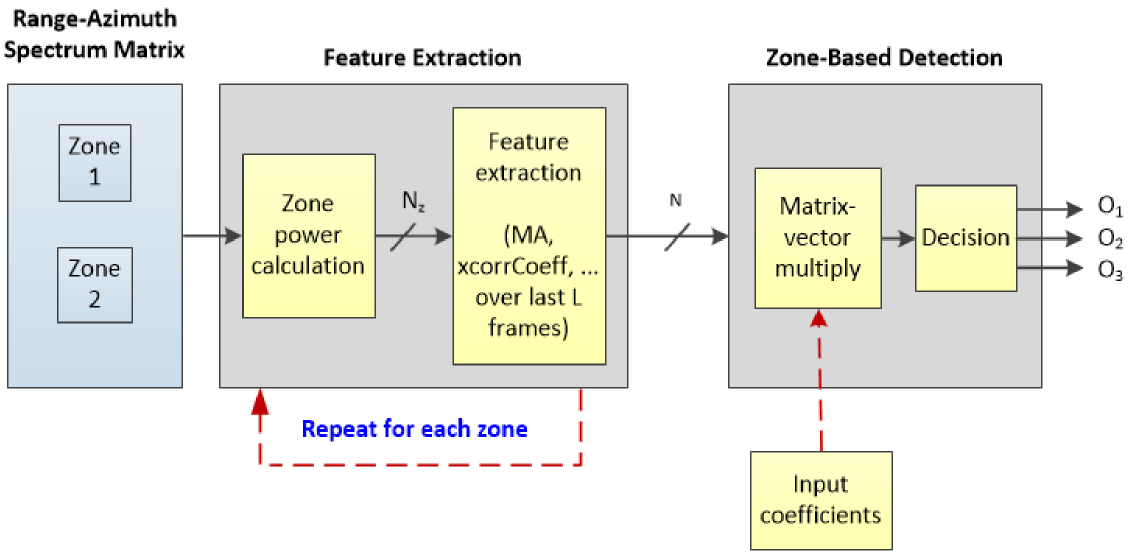


Range-Azimuth Heatmap Processing



- Perform a high resolution Direction-of-Arrival (DOA) Spatial Estimation to calculate a 2D heatmap for the frame:
  - Spatial Covariance estimation is performed by stacking range bins across antennas, per n^{th} range bin and k^{th} chirp.
  - DOA estimation uses MVDR (minimum variance distortionless response, or Capon beamforming) to compute the angular spectrum for each range bin.

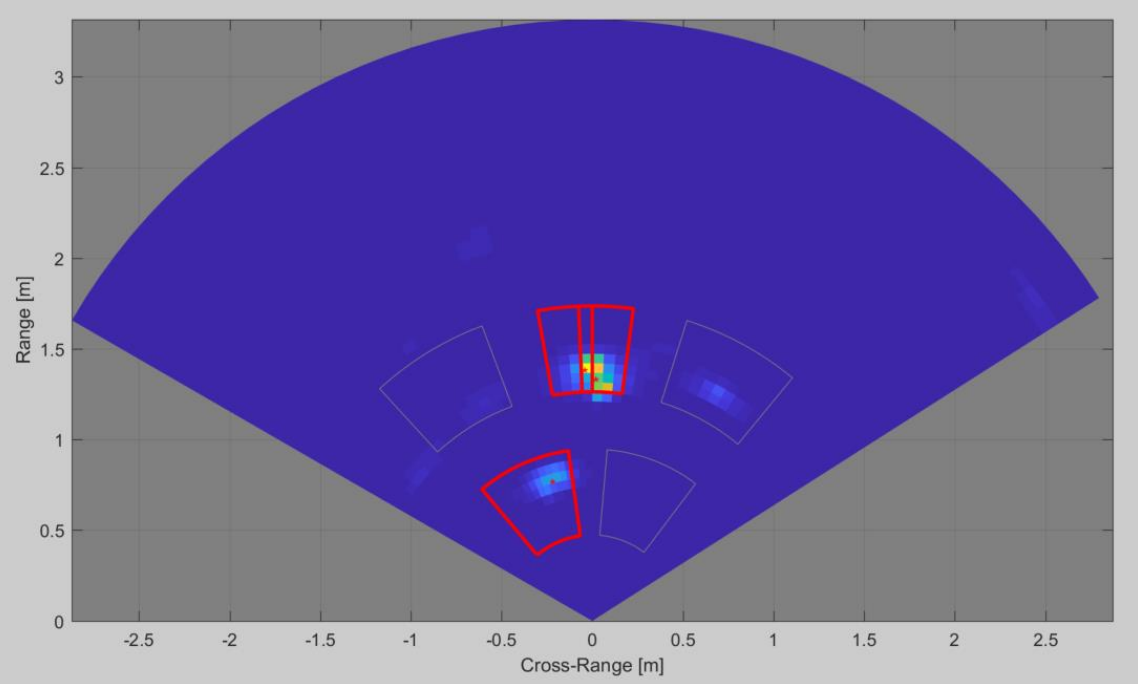
Zone Processing (Feature Extract and Detection)



- Each frame, scan the heatmap within each defined zone of interest and compute a feature vector:
  - Zone power determined from max 5x5 region, moving-average zone power (for L (window length), frames).
  - Moving-average power ratio (for L frames), Correlation coefficient of zone power.
- Perform matrix multiplication with the input coefficients and the feature vector. This yields an array of flags, one flag per zone, a ‘1’ indicating ‘zone occupied’, and ‘0’ indicating ‘empty’.

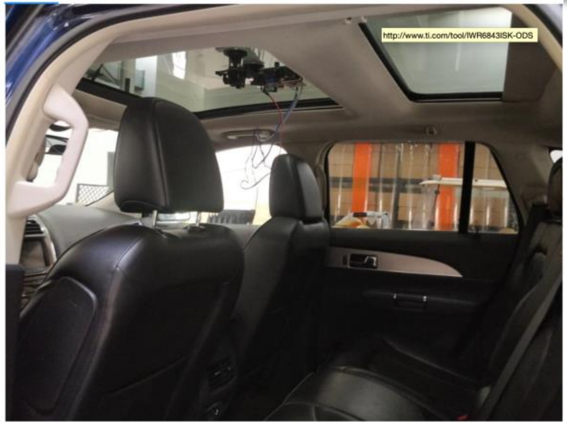
Example Heatmap with Zone Detections

- Large values means more movement, shown with brighter colors.
- Here, 2 front and 3 back zones are defined.
- Static objects are removed.

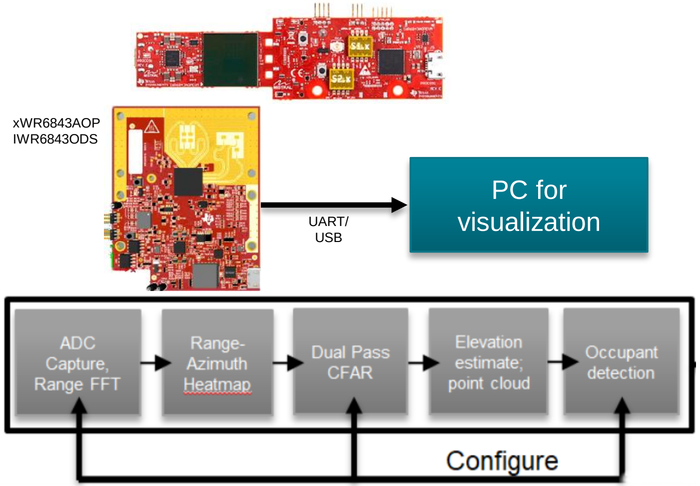


Overhead Mount Vehicle Occupancy Detection Reference Design

- Reference Design Number: tbd:
- AOP and ODS – TI's FMCW mmWave (60-64GHz) **Single chip Radar** with 3Tx/4Rx RF front End, ADC, DSP(C674x) and MCU(Cortex-R4F), FFT/CFAR accelerator.
- Range processing performed on HWA.
- Device outputs 3D point cloud (currently), plan is to also output zone decision information.
- Chirping pattern provides ability to detect small movements, such as breathing and heart rate.



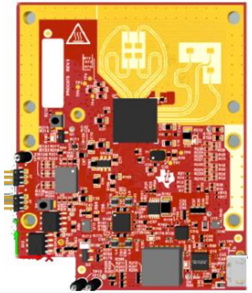
Demonstration using IWR6843AOPEVM



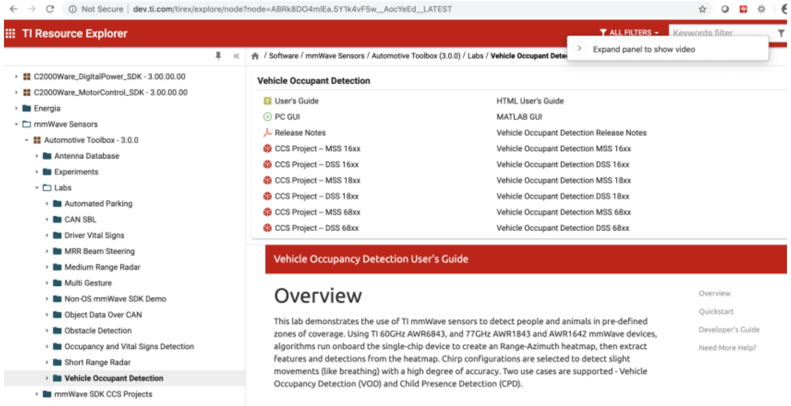
Overhead Mount Implementation Overview

Hardware

- AOP/ODS
  - 4 RX, 3TX
  - DSP, ARM
  - RF Front end
  - FFT accelerator



Software

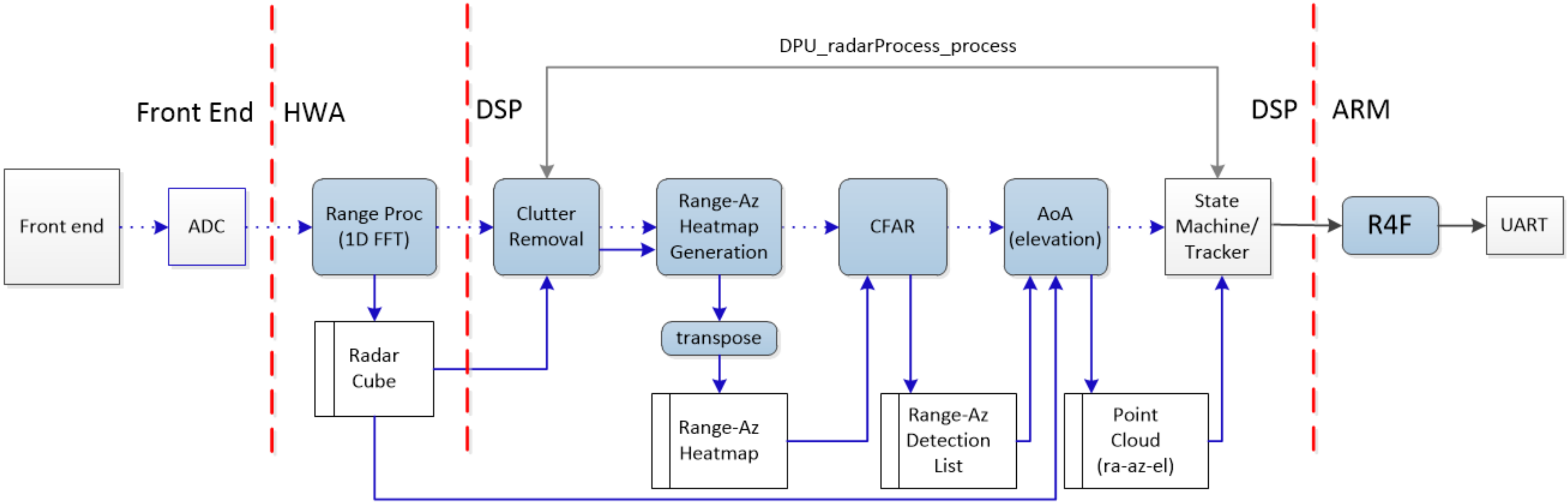


Key Performance Specifications

Parameter	Value
Max range	3.0 m
Max velocity	2.78 m/s
Range resolution	5.32cm
Velocity resolution	0.0154 m/s
Field of View	120º Horizontal
Bandwidth	2.8218 GHz

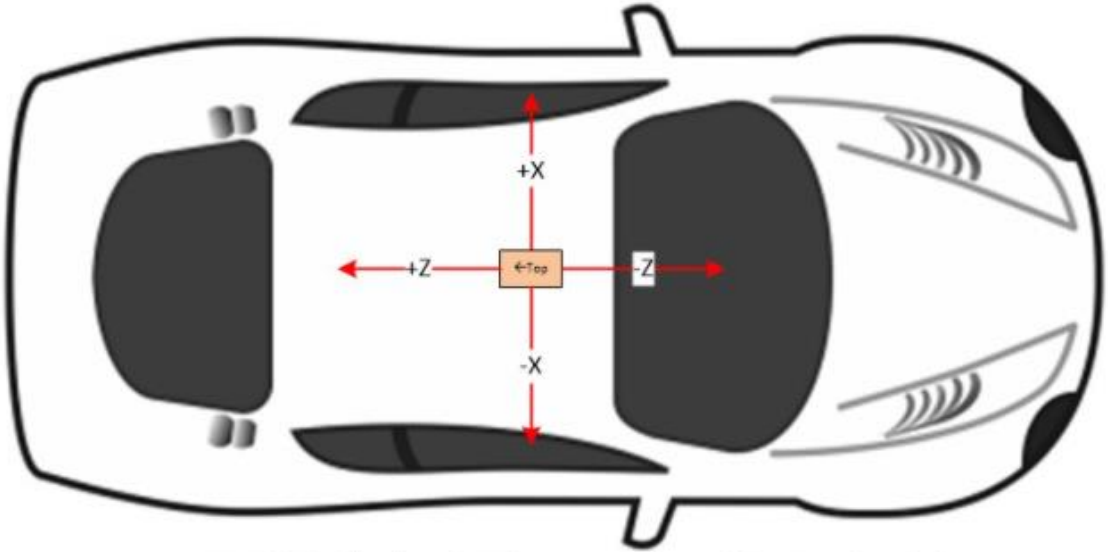
- mmwave_automotive_toolbox_3_1_x
  - Available in TI Resource Explorer
  - (within CCS, or http://dev.ti.com/tirex/explore)
- mmWave SDK
  - Installer here: www.ti.com/tool/mmwave-sdk

Signal Processing Chain: Overhead Block Diagram



- Range/Chirp processing chain is performed on the Hardware Accelerator (HWA).
- Frame rate signal processing implemented on DSP (C674x) and outputs point cloud and zone decisions.
- R4F (MSS ARM) processor transfers outputs from shared memory to UART.

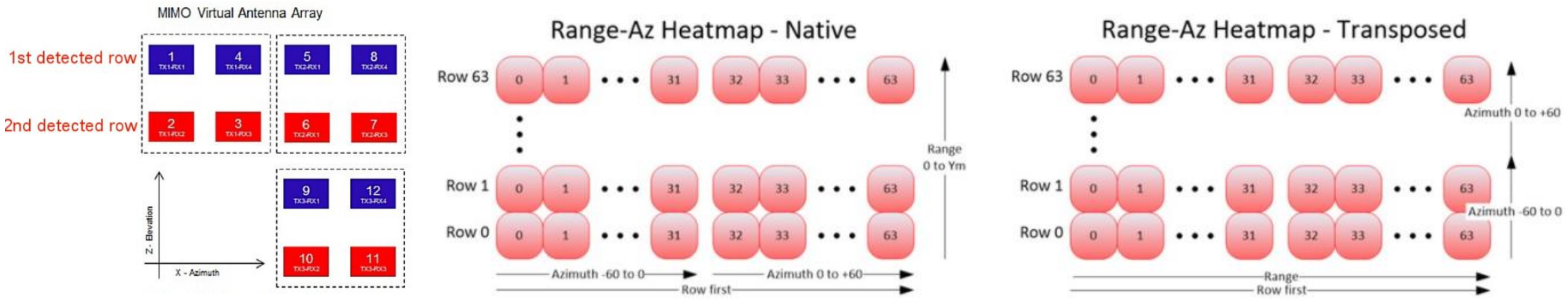
Signal Processing Chain: Coordinate Transform



Y = 0 is the floorboard, +Y increases to the roof (antenna location)

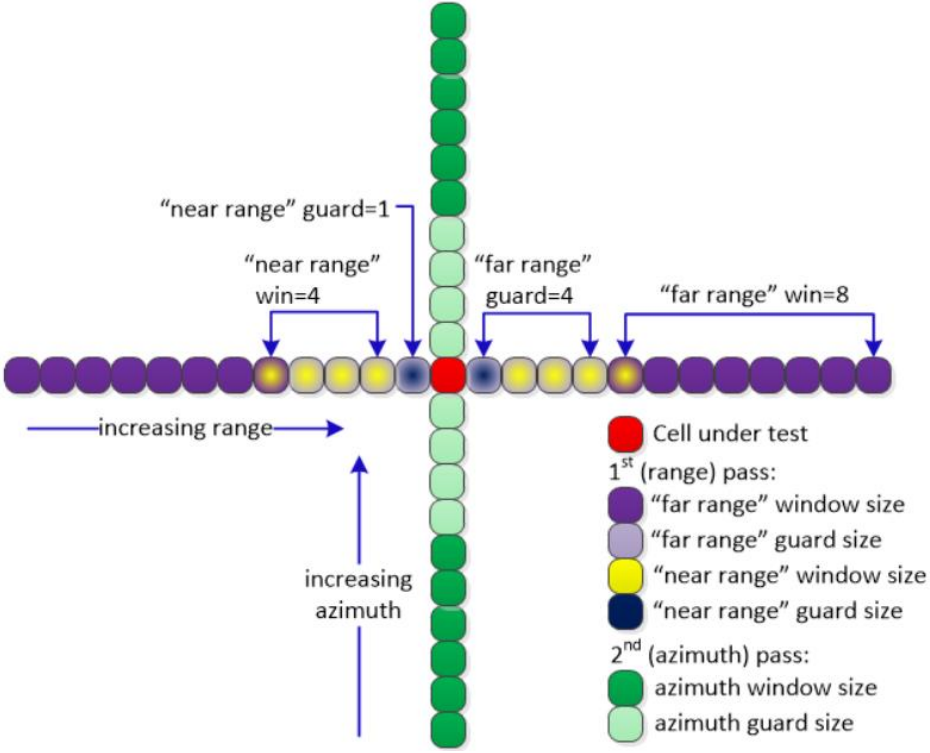
- Typically, a vertical mounting yields Y as positive range, Z as elevation (-values below sensor).
- With a horizontal mounting, Y becomes elevation (zero is the floor), and Z is range (+values to the rear, -values to the front). X remains azimuth angle.

Range-Azimuth Heatmap Processing



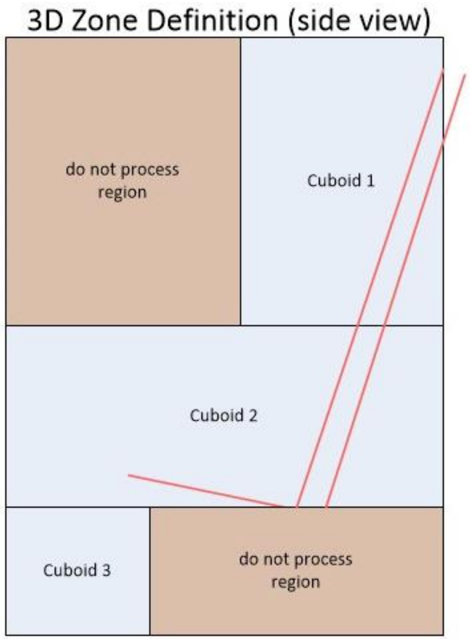
- Algorithm for the Ra-Az heatmap are the same as described for the Front Mount VOD demo, with these exceptions:
  - Two rows of azimuth oriented virtual antennas are located (if two exist), and MVDR is calculated on each row. The values in each row are squared and summed to form the final heatmap row. This is to improve SNR.
  - The heatmap row is natively per each range bin. This is transposed so that each row contains all range values per azimuth bin.

Dual-pass CFAR Processing

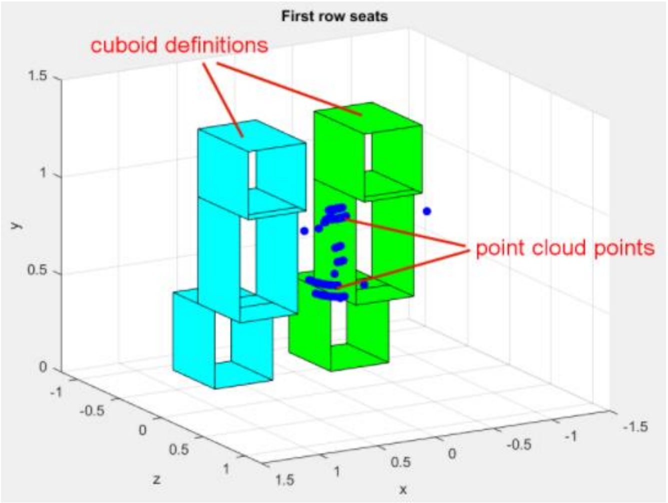


- The CFAR variant used is CASO (Cell Averaging Smaller Of), with a few improvements:
  - In the first (range) pass, two window averages are created on both sides of the cell under test:
    - Near Range, mostly in the guard area of the Far windows
    - Far Range
  - This gives a total of 4 averages. The smallest of these is found and thresholded, and compared to the peak.
- These initial detections (in range) are kept for the second pass search in the azimuth dimension.
- Multiple peaks may be found in both range and azimuth.

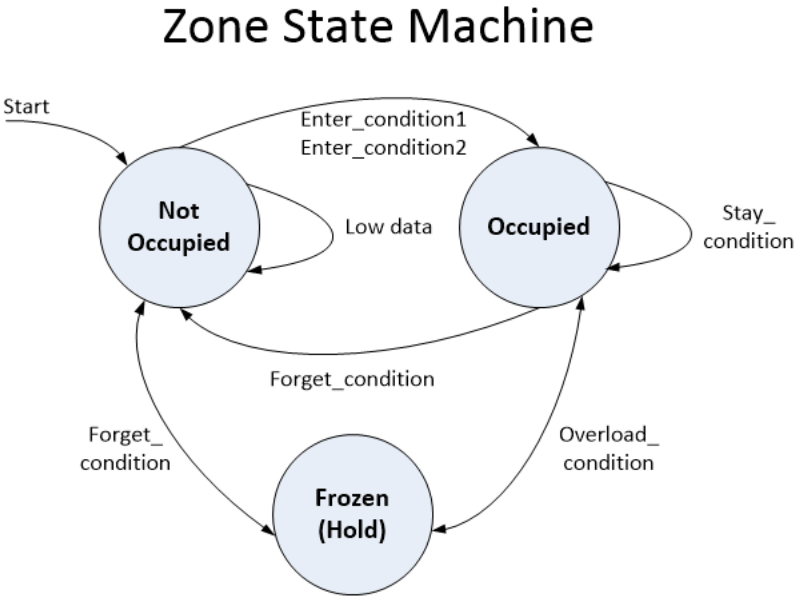
Zone Definition and Assignment



- Following CFAR, standard AoA (Angle of Arrival) processing is performed to estimate elevation for each range-azimuth CFAR output, yielding a point cloud with range, azimuth and elevation coordinates.
- To estimate the spaces where we look for occupants, we may define one, two or three cuboid volumes in our coordinate space, to represent the head-chest, lap, and leg-foot areas of the zone. Zone assignment occurs when a point cloud detection resides within at least one of the zone's cuboids.
- Detections not matching any zone are ignored.
- Cuboids may overlap or be disjoint.
- Zones should not overlap, and will perform better with some amount of space between them.
- Some zones, such as intruder spaces and cargo areas can be represented with a single cuboid.

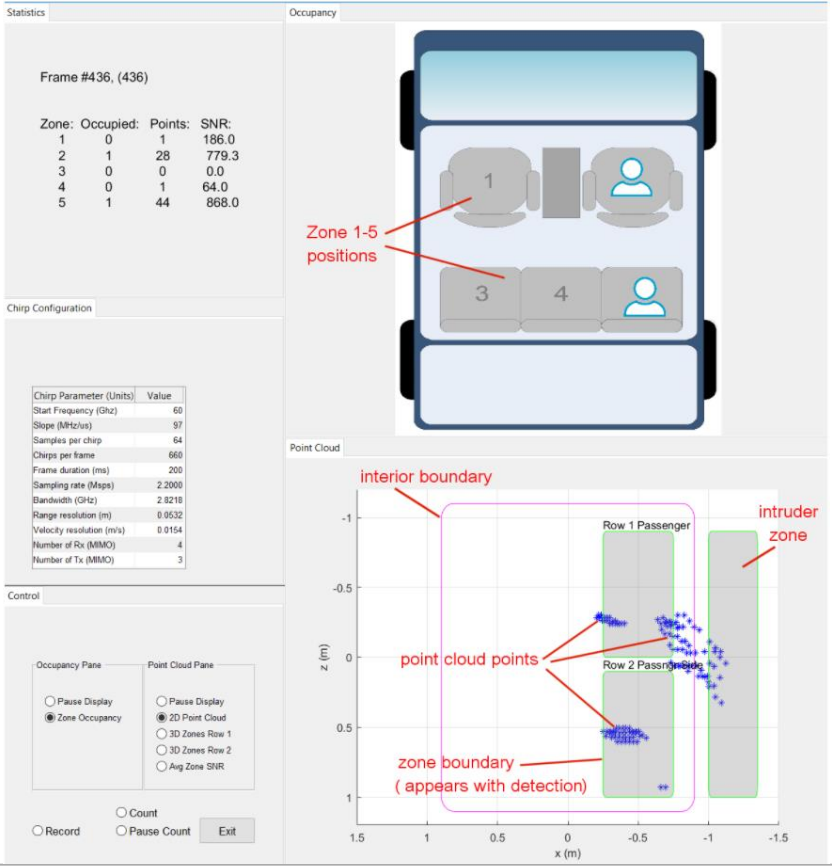


Zone State Machine Processing



- The Zone State Machine is the processing that examines the detections within each zone and makes yes/no occupancy decisions each frame.
- Entry conditions:
  - small number of detections with a high average SNR, *or*
  - larger number of detections with smaller average SNR.
- Stay condition:
  - num detections with thresholded SNR
- Forget condition:
  - exceeds number of frames failing the Stay condition
- Overload condition:
  - High energy level (vehicle entry, exit, or someone changing seats). This causes all zone states to be frozen until the overload subsides.
- All parameters are configurable via CLI interface.
- This is not a perfect science, and the state machine is evolving over time. We encourage customers to build upon our rules to fine-tune the processing to fit their needs.

GUI Display



- The Matlab GUI presents the output in 5 sub-windows:
  - Statistics: Shows frame number, list of zones with number of points and avg SNR.
    - Will show detection counts when enabled.
  - Chirp Configuration: Shows the CLI chirp configuration transformed into readable format.
  - Control: Button controls
  - Occupancy: A fixed display showing one to five zones mapped in a vehicle space.
  - Point Cloud: Several displays that show frame by frame detections within mapped zone boundaries.

Learn more about TI mmWave Sensors

- Learn more about AWRxxxx devices, please visit the product pages
  - AWR6843: http://www.ti.com/product/AWR6843
- Get started evaluating the platform with xWR1x EVMs, purchase EVM at
  - AWR6843 EVM: http://www.ti.com/tool/AWR684ISK
  - IWR6843AOPEVM: https://www.ti.com/tool/IWR6843AOPEVM
- VOD Video: https://training.ti.com/vehicle-occupant-detection-using-mmwave-sensors
- VOD Blog: http://e2e.ti.com/blogs_/b/behind_the_wheel/archive/2018/04/30/detecting-vehicle-occupancy-with-mmwave-sensors
- Automotive toolbox on TIREX: http://dev.ti.com/tirex/#/DevTool/AWR1642%20Automotive%20EVM/?link=Software%2FmmWave%20Sensors%2FAutomotive%20Toolbox
- Ask questions on TI's E2E forum @ http://e2e.ti.com

IMPORTANT NOTICE AND DISCLAIMER