AWRL6432: Intruder Detection Testing

Overview

Intruder detection testing shows that AWRL6432 enables high accuracy detection to reliably discern when there has been a breach into a vehicle and monitor the vehicle's proximity

Information in the following slides:

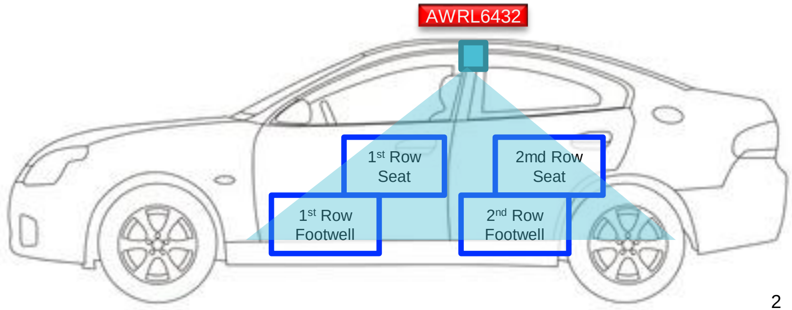
- Test setup details
- Performance and Test Results
- Processing Chain Overview

Requirements:

✓ 2-row coverage including dashboard
✓ Detection intrusion via window aperture
✓ Power consumption under 50mW
✓ Continuous cabin and close proximity monitoring

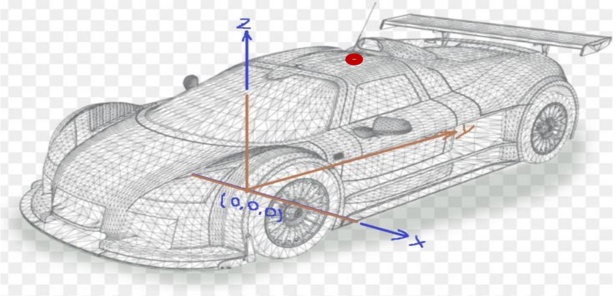
Key performance metric:

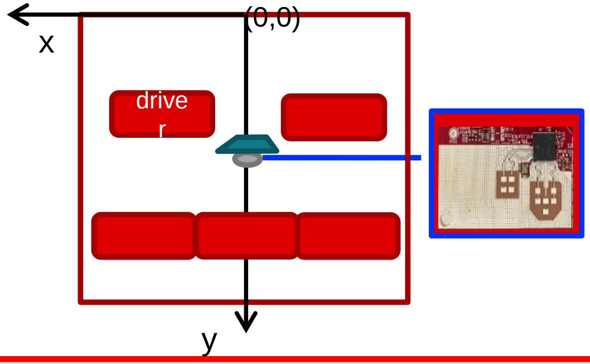
Parameter	Requirement	AWRL6432 Demo Results
Coverage	Full 2 row coverage	Full 2 row + dashboard
Intruder detection accuracy	>95%	98%
Detection delay	<10s	1s
Avg power	<50mW	**14.13mW**



Test Setup Details

- The data is collected with the TiREX demo – AWRL6432 Intruder Detection Demo
  - Frame rate: 250ms
  - Detailed Chirp configuration discussed in the next slide
- An intruder approached the vehicles and reached into vehicle via an open window. This was repeated at each of the four windows, and different surfaces were touched (e.g. seat, floor, dashboard).
- Overhead Mounting position details –
  - For all the test data, the sensor is mounted at (x = 0, y = 1.2m, z = 1.2m) and rotated 90 degrees to face the floor. The device was oriented so as to use the better FOV in azimuth to cover the width of the car.





Chirp Configuration Details

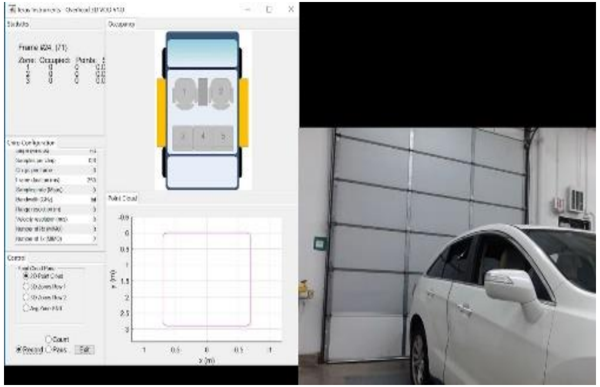
Chirp parameters and system performance	Values	Units
Starting frequency	58.1	GHz
Ramp slope	60.0	MHz/us
Number of samples per chirp	128	#
Number of burst	8	#
Sampling frequency	2.50	MHz
Idle time	7	us
ADC valid start time	10	us
Ramp end time	63.0	us
Chirp accumulation	2	#
Burst period	400	us
Valid sweep bandwidth	3072.11	MHz
Frame duration	250	ms
Maximum range, Rmax	2.8	m
Range resolution	4.9	cm

*** New feature in AWRL6432**

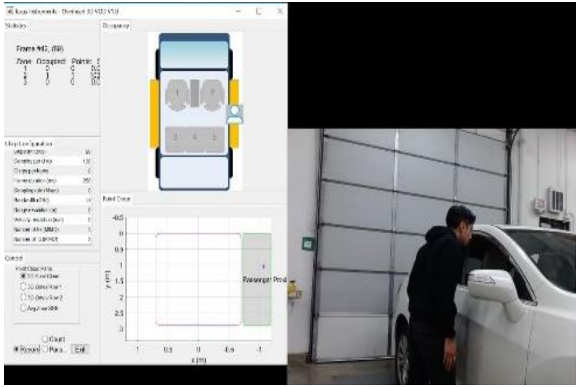
Intruder Detection Performance

	Test Case	Detection Rate
Driver Side	Front window, take from dashboard	95%
	Front window, take from seat	100%
	Front window, take from floor	100%
	Rear window, take from seat	100%
	Rear window, take from floor	100%
	Proximity zone occupied	90%
Passenger Side	Front window, take from dashboard	100%
	Front window, take from seat	100%
	Front window, take from floor	100%
	Rear window, take from seat	100%
	Rear window, take from floor	100%
	Proximity zone occupied	90%

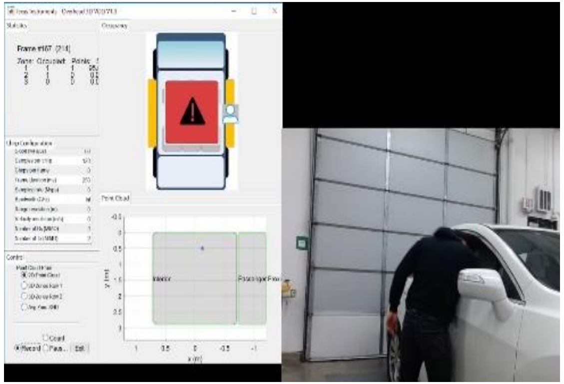
Intruder Detection Test Snapshots



No intruder present, zones all clear



Intruder looking into window, triggering proximity zone alert

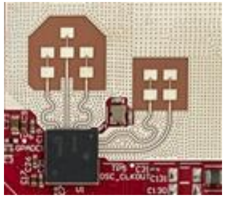


Intruder reaching into car to grab something off seat, triggering intruder alert

Performance Summary and Analysis

- Running AWRL6432 intruder detection demo with major chain
  - ✓ Using 2 chirp accumulation (accum = 2)
- ***Able to cover two-row and dashboard as well as close proximity monitoring with 98% of detection***
- The current signal chain is optimized for low power. For higher performance, tradeoffs can be made between system power vs accuracy, using a different signal chain design

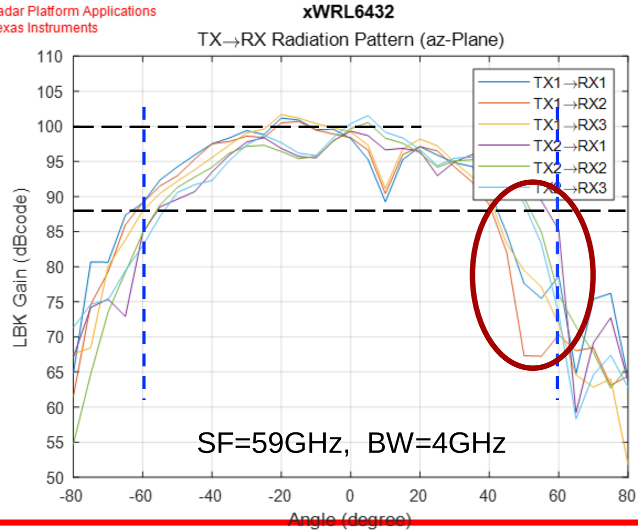
xWRL6432 Antenna Radiation Pattern



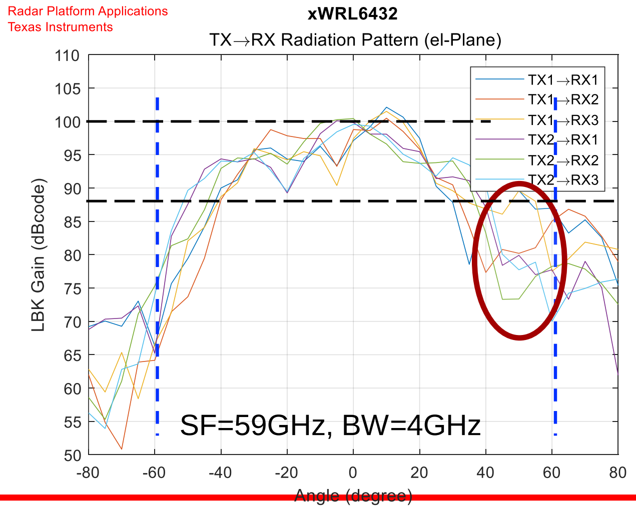
- Lower cost PCB material (FR4) results in lower antenna gain
  - PCB materials like Rogers can improve the performance further
- 2 patch antenna design results in narrower FOV for elevation.
- TX1 FOV is impacted by the crystal oscillator metal case (highlighted in the red cycle)

Antenna Design can be improved for in-cabin sensing applications compared to the reference design

Azimuth FOV (-60~60)



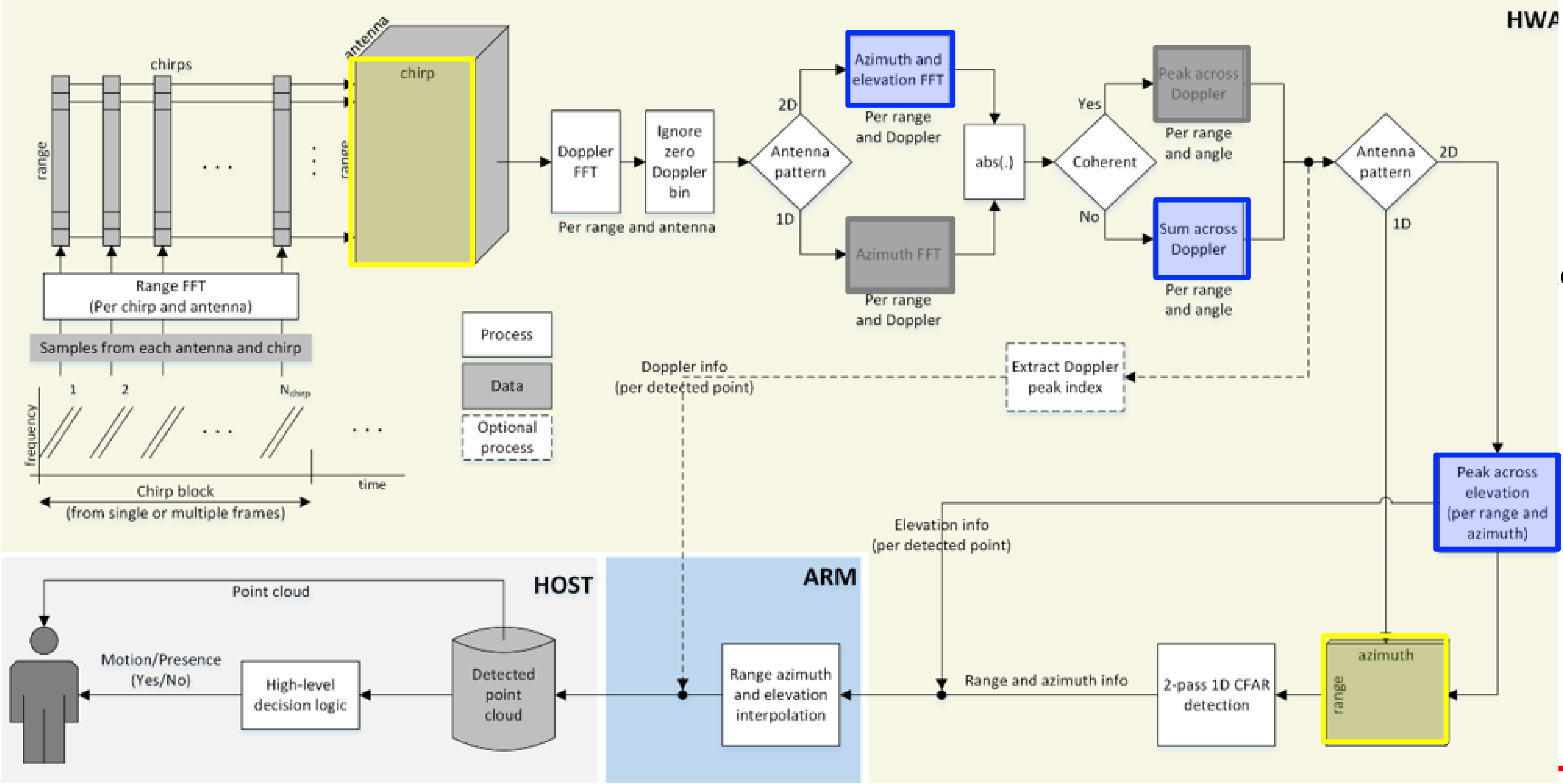
Elevation FOV (-40~40)



AWRL6432 Intruder Detection Processing Chain Details

Signal Chain Overview

- Frame processing is controlled by the ARM core, using HWA.



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Motion Detection Chains

- Range FFT is saved in RadarCube in L3
  - Major chain: collect one frame of data
  - Minor chain: collect chirps across several frames (sliding window)
- For each range bin, Doppler FFT, azimuth FFT and elevation FFT are calculated
  - Have a memory limitation of 32KByte inside HWA for this Doppler-azimuth-elevation 3D FFT output
    - If numAzimBin = 16, numElevBin = 8; then numChirp for Doppler FFT can not exceed 64,
  - Zero Doppler is removed, rest of the Doppler bins are combined non-coherently ➔ Azimuth and Elevation heatmap per range bin
  - Record the peak elevation value per azimuth bin. Store elevation peak index and Doppler peak index

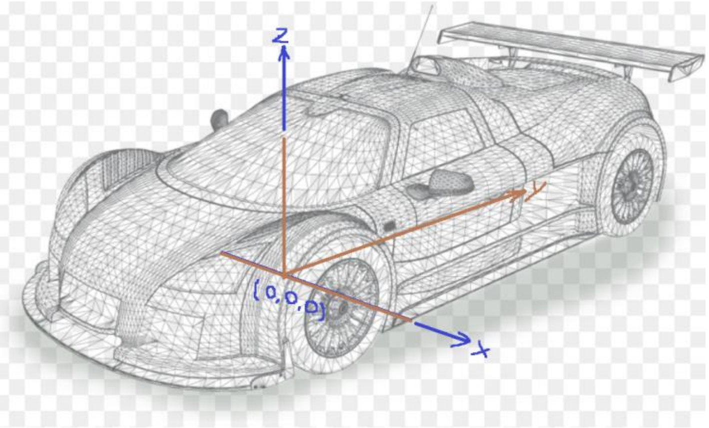
  ➔Create range-azimuth heatmap
- Run CFAR on Range-Azimuth heatmap
- Collect the point cloud (range, azimuth, elevation, Doppler and SNR info)
  - Peak interpolation in Range, azimuth

High Level Decision Logic

- Transform the point cloud into the car-coordinate.
- Define zones in car-coordination
- Map the point cloud into zones.
- Run per zone-based state machine to make a decision on whether a zone is occupied or not.
- Declare presence detection if any zone is occupied.

Frame Processing: Point Cloud Transformation

- The detected point cloud is all relative to the sensor.
  - The sensor position can change, but the seating zone for a car is fixed given a car.
  - For simplicity, in the visualizer, we define the seating zone based on the car coordinates, and transform the point cloud from sensor coordinates to the car coordinates.
- To support different position and different mounting angle, "sensorPosition" CLI command is used
  - Indicates the mounting offset in (x, y, z) and mounting rotation angle in y-z plane, x-y plane and x-z plane



CLI command	Parameters (in command order)
sensorPosition	offset in x direction, in meter
	offset in y direction, in meter
	offset in z direction, in meter
	Clockwise rotation angle in y-z plane, in degree
	Clockwise rotation angle in x-y plane, in degree
	Clockwise rotation angle in x-z plane, in degree

Frame Processing: Zone Definition and Assignment

- Zone definition through CLI commands to interior of the vehicle as well as proximity zones just outside the doors of the vehicle

  % zone 1 (car interior)
  - cuboidDef 1 1 -0.72 0.72 0.0 2.9 0.3 1.3

  % zone 2 (passenger proximity)
  - cuboidDef 2 1 -1.20 -0.73 0.0 2.9 0.0 1.3

  % zone 3 (driver proximity)
  - cuboidDef 3 1 0.73 1.20 0.0 2.9 0.0 1.3
- Zone assignment occurs when a point cloud detection resides within at least one of the zone’s cuboids.
- Cuboid rules:
  - Cuboids (for the same zone) may overlap or be disjoint.
  - Zones should not overlap, and usually 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.
- Detections not matching any zone are discarded.
- The result is a list of point cloud detections mapping into each zone.

Frame Processing: Occupancy State Machine

- The Occupancy State Machine examines the detection to zone mapping and makes yes/no occupancy decisions each frame.
- Decisions can be further processed by application software.
- 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 commands.