Design Guide: TIDEP-01035

Video Surveillance Camera Reference Design using TI mmWave Radar

Description

This reference design highlights the IWRL6432AOP's ability to detect motion and presence for outdoor surveillance systems, such as home cameras, video doorbells and automatic controls. IWRL6432AOP detects people and objects at long ranges and high angles through efficient antenna design, consumes very little power by cycling into deep sleep modes, and filters out nearly all false alarms through advanced algorithms. A multi-stage architecture allows the radar to achieve all three attributes (long detection range, low power consumption, low false alarm rate) at the same time. Devices with the IWRL6432AOP can benefit from faraway detections, long battery life, and fewer false alarms.

Resources

TIDEP-01035	Design Folder
IWRL6432AOP	Product Folder
IWRL6432AOPEVM	Tool Folder

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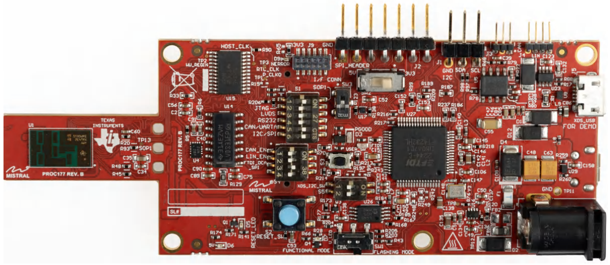
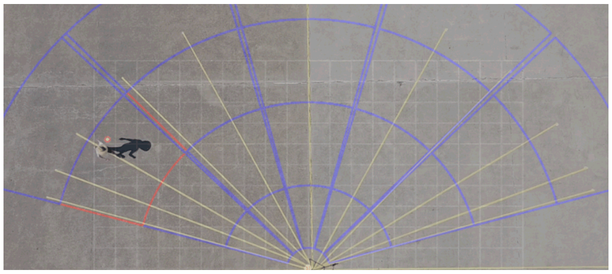
Features

- Demonstration hardware and software using the IWRL6432AOP to detect movement and awaken a video camera system
- Integrated antennas, fully programmable M4F running at 160MHz, dedicated Hardware Accelerator (HWA) at 80MHz for complex radar operations
- Default software providing long detection range, low power consumption and near-zero false alarm rates
- Detection experiment results
- Methodology for further measurement under different conditions

Applications

- Video Doorbell
- Wireless Security Camera
- Motion Detector
- Area Landscape Lighting
- Air Conditioner Outdoor Unit





1 System Description

As consumer technology becomes smaller and lower-power, video doorbells and video cameras are increasingly being powered by batteries instead of direct line-power. While this shift has made the process easier to put more surveillance devices in different places, the process has created a challenge to increase battery life of these devices. The most power-hungry event in typical operation for surveillance devices is recording and streaming video. Recording and streaming require the device to capture data over the camera, run image signal processing algorithms, and stream over WiFi to the cloud. To reduce the amount of time a device spends streaming data, smart surveillance systems have presence detection devices built onto them, which decrease the number of false alarms detected by the system, extending battery life without missing any true detection events.

Nearly all presence detection technologies face a tradeoff between low-power consumption, long detection range and low-false alarm rate. TI’s IWRL6432AOP mmWave radar balances these factors effectively through the high transmission power, multiple detection modes and seamless programmability on the M4F core and hardware accelerator (HWA).

1.1 Detection Theory

The radar equation found in *Programming Chirp Parameters in TI Radar Devices,* application note describes the tradeoff between long detection range, low power consumption, and low false alarm rate mathematically.

$$\mathrm{Range}_{\mathrm{max}}\ \text{based off SNR} = \sqrt[4]{\frac{P_T \times G_{RX} \times G_{TX} \times c^2 \times \sigma \times N \times T_R}{f_c^2 \times (4\pi)^3 \times kT \times NF \times SNR_{det}}} \tag{1}$$

P_T	Tx output power (mW)
G_{Rx} ,G_{Tx}	RX and TX Antenna gain (linear)
σ	Radar Cross Section of the object (sq. meters)
N	Number of chirps x Number of virtual antennas
T_r	Chirp time (seconds)
NF	Noise figure of the receiver (linear)
SNR_{det}	Minimum SNR required by the algorithm to detect an object (linear)
k	Boltzmann constant (J/K)
T_{det}	Ambient temperature (K)

P_t and T_r are functions of power consumption - as the functions increase, power consumption increases. SNR_{det} is a function of false alarm rate - as SNR_{det} increases, false alarm rate decreases. Keeping all the other terms constant, this yields the following relation, that detection range is proportionate to the product of power consumption and false positive rate.

$$\mathit{Detection\ Range} \propto \mathit{Power\ Consumption} \times \mathit{False\ Positive\ Rate} \tag{2}$$

This can also be understood through a broader lens through statistics. A known fact is that the noise of a radar system can be modeled as the magnitude of a complex Gaussian, which is known as a *Rayleigh Distribution*. If the received signal of a target of interest is modeled as a Gaussian, centered around some non-zero returned power, then the detection threshold for the amount of power returned to the radar system needs to be set somewhere between the two distributions. Detecting whether an object is present or not reduces simply to a hypothesis test of two distributions.

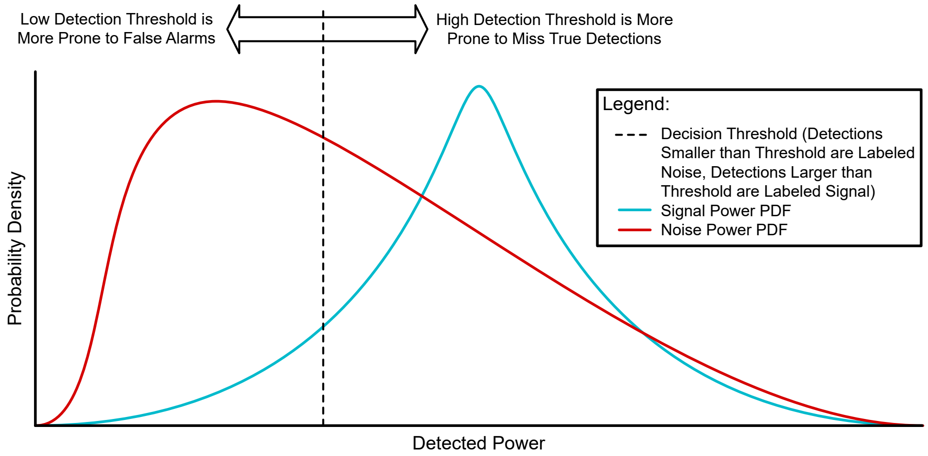


Figure 1-1. Signal and Noise Power Distributions

If the detection threshold is set lower, then there can be more false positive alarms (radar wakes up unnecessarily), but fewer false negatives (radar misses a real detection). Conversely, if the detection threshold is set higher, then there can be fewer false positive alarms, but the radar can experience some false negatives. Since the cost of missing a real detection can be quite high for surveillance systems, often the strategy is to make the detection threshold lower, and absorb some of the false alarms in exchange for the reduced likelihood of a missed real detection.

1.2 Multi-Pass Architecture

While a good detection system has all three of these qualities (low power, long range, low false alarm rate), the recommendation is to prioritize some over others in specific scenarios to extract the best overall system performance. The IWRL6432AOP navigates this balance by using multiple detection modes. This design guide assumes that three modes are used, but the logic can apply for two modes, or even more than three modes if necessary.

First pass mode is the default option for the radar. In first pass mode, the IWRL6432AOP operates in the lowest possible power configuration while still maintaining the ability to detect at long ranges. IWRL6432AOP does have some false alarms, even in low-noise conditions to achieve long range at the lowest possible power. For best results, the first pass mode need to be as low-power as possible, even at the expense of some false alarms.

When detections occur in first pass mode, the radar switches to second pass mode, which uses a higher-power chirp that reduces the false alarm rate of the radar, and achieves the same detection range as the first pass mode. There is no advantage for the second pass mode to detect objects at further ranges than the first pass mode, since the first pass mode is what triggers the second pass mode. The second pass mode do not have nearly as many false alarms as the first pass mode, but is acceptable to still wake up sometimes from winds, bushes and trees.

Finally, a third pass mode can be used to eliminate any false positives still detected in second pass mode. The third pass mode cannot have any false alarms if possible, since the third pass mode can be used to awaken the camera, which can draw 10-100 times more power than the radar.

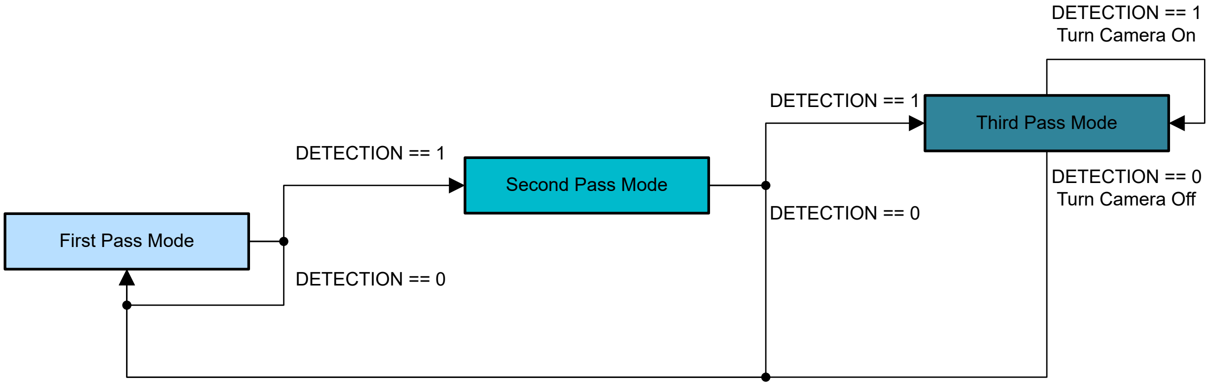


Figure 1-2. Multi-Pass Architecture State Machine

By cycling between the three power modes, the IWRL6432AOP is able to take advantage of the lowest-power consumption of the first pass mode when there is very little ambient motion, while also benefiting from the minimal false alarm rate of the third pass mode. The second pass mode serves to make sure that in times of high ambient movement in the scene, when first pass mode can be too sensitive to be effective, the radar still has a reasonably low power mode.

Table 1-1. Power, Range and False Alarm Rate for Each Mode

	First Pass Mode	**Second Pass Mode**	**Third Pass Mode**
Power Consumption	Low	Medium	High
False Alarm Rate	High, even in low-movement scenarios	Moderate, only when there is wind, trees, or bushes	Low
Detection Range	Equal	Equal	Equal
Percent of Time Spent in Mode	High	Medium	Small

2 System Overview

2.1 System Design Theory

The following three sections detail how each individual mode within the multi-pass architecture can achieve long detection range, low false alarm rates, and low power consumption. This process is accomplished through a combination of hardware, software, and algorithm design to maximize performance within each mode.

2.1.1 Long Detection Range

2.1.1.1 Antenna Design for Long Detection Range

The IWRL6432AOP device achieves very long detection range over a wide field of view through effective circuit and antenna design. As seen in the IWRL6432AOP, data sheet the IWRL6432AOP has a single transmitter Effective Isotropic Radiated Power (EIRP) of 15dBm. EIRP is the maximum of the sum of the conducted power and the antenna gain over the entire field of view of the antenna. EIRP refers to the maximum amount of power that the device can radiate, which is most typically at 0° in azimuth and elevation, referred to as bore sight. A large EIRP means that at bore sight, the radar can detect objects that are very far away.

While the EIRP gives the maximum radiated power, the IWRL6432AOP, data sheet also shows radiation plots of the RX and TX antennas across azimuth and elevation. The IWRL6432AOP exhibits a wide field of view (FOV) and achieves ±70 degrees in the azimuth and ±40 degrees in the elevation.

The combination of a high EIRP and a wide FOV make the IWRL6432AOP an effective radar in all environments. For example, in a crowded city, the distance from a home to the street can be short, but the sidewalk in front of the house can be quite long, which can benefit a short detection range and a wide field of view. However, in the countryside, there can be a long road leading up to the home, which can benefit a long detection range and a narrower field of view. To create a design that can work for all setups, video doorbell providers need to have both a wide-field of view and a long front-facing detection range. The IWRL6432AOP is able to achieve these specifications at a variety of power levels.

2.1.1.2 SNR Compensation for Long Detection Range

While a powerful transmit chain over a wide FOV gives the IWRL6432AOP the power to detect objects far away, the radar device can further increase the detection range by reducing the thresholds to detect points where the antenna signal starts to fade. This can be seen at long detection distances at boresight, and at wide detection angles too. In both cases, the video doorbell application reduces the detection SNR thresholds selectively to achieve greater detection distances.

2.1.1.3 Smart Detection Logic

As the motion and presence documentation in the MMWAVE-L-SDK shows, the IWRL6432AOP detects points with the following steps:

1. Compute range, Doppler, azimuth, and elevation FFTs on the incoming data
2. Compute the sum or maximum over the Doppler and elevation dimensions
3. Run CFAR on the range-azimuth heat map in the range dimension
4. Filter detected points to reject side-lobes (peaks in the same range bin caused by power from a different azimuth bin spilling over into adjacent azimuth bins)

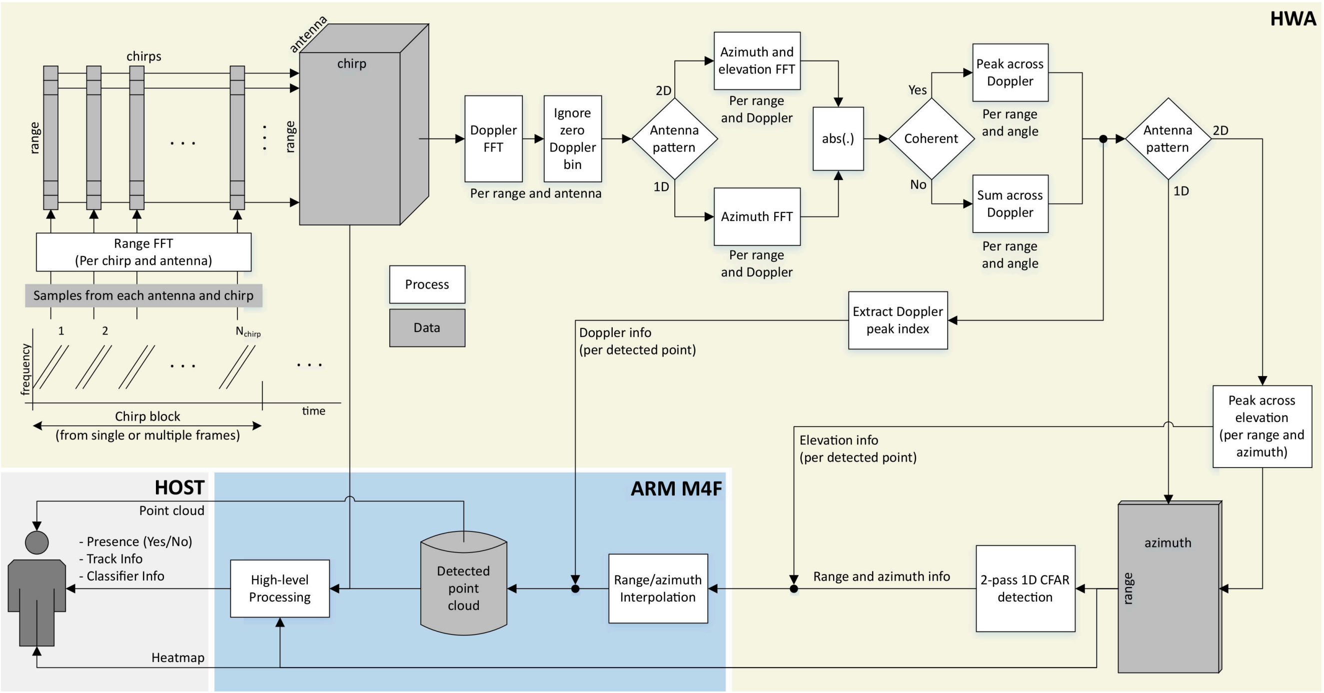


Figure 2-1. Motion and Presence Detection Block Diagram

After points are detected, the video doorbell reference design passes them into a state machine to determine whether presence is detected in a certain zone. This state machine is based off the MPD State Machine, which is also described in the MMWAVE-L-SDK. The state machine examines all the points, clusters them together using the DBSCAN algorithm, counting the number of points and SNR statistics on the points in the cluster. Based off that information, the state machine determines whether a zone is occupied or unoccupied. The following sequence illustrates how a zone transitions from the unoccupied to the occupied state. For a full description of the state machine flow, see the tuning guide, found in the docs/ folder of the MMWAVE-L-SDK.

Generally speaking, when people are closer to the radar, the number of points detected is a better indicator of presence than the SNR of the points. However, when targets are further away from the radar, the SNR of the detected points becomes a better indicator than the number of points. The video doorbell reference design provides ways to achieve robust detection at short and long ranges by favoring the number of detected points at short ranges, but favoring the detection SNR at long ranges.

2.1.2 Low Power Consumption

2.1.2.1 Efficient Chirp Design

Chirping, when the radar is transmitting and receiving signal, is the state that consumes the most amount of power on the IWRL6432AOP. The recommendation is to minimize this time as much as possible. However, chirping time also strongly dictates detection range and the minimum detectable velocity. Therefore, an effective low-power radar system needs to chirp for exactly long enough to detect objects at the desired range, velocity and false alarm rate, and absolutely no longer. Using the mmWave Sensing Estimator, engineers can calculate how long the radar needs to chirp for based off the detection range needed. Equation 3 in combination with appropriate estimates for SNR detection threshold and human radar cross sections can estimate the amount of integration time needed ($N \times T_R$) for detection at the range of interest. Make sure this is equal to the product of the chirp time (ADC samples / sampling rate) and the Number of chirps per TX in the mmwave Sensing estimator. Then, decrease the ramp end time to the minimum required. Constraints built into the mmWave Sensing estimator can require some extra time for the chirp to settle and become linear, so the ramp end time can always be slightly longer than the necessary chirping time. Minimizing the chirp within these limits can make sure that the device spends no unnecessary time chirping.

For example, to achieve 17 meters of detection range at a low power budget, an engineer can set the SNR detection threshold as 4dB, and estimate the RCS of a typical target to be -6dB sqm. The engineer can then calculate the required integration time (133 microseconds, or 4 chirps and 33.28µ sec each) to achieve these criteria.

$$R = \sqrt[4]{\frac{31.62 \times 10^{-3}\, W \times 3.16 \times \left(3\ \times 10^{8}\right)^{2}\left(\frac{m}{s}\right)^{2} \times 0.25 \times 4\ chirps \times 33.28 \times 10^{-6}\ \frac{sec}{chirp}}{\left(62.49 \times 10^{9}\right)^{2}(Hz)^{2}\ \times\ (4 \times \pi)^{3} \times 1.38\ \times 10^{-23}\left(\frac{J}{K}\right) \times 293.15\ K\ \times 41.68\ \times 2.51}} \tag{3}$$

Table 2-1. Sources of Variables in SNR Calculation

Data Sheet Parameters	Configuration File Parameters	Constants/Misc
P_T × G_{TX} = 15dBm = 31.62mW G_{RX}= 5dB = 3.16 linear NF = 16.2dB = 41.68 linear	SNR_{det} = 4dB = 2.51 linear F_c = 62.49GHz N = 4 chirps over 1 virtual antenna T_R = 33.28 µsec	C^2 = $(3E8)^2$ K = 1.28E-23 T = 293.15 K σ = -6dB = 0.25 (Since different people of different sizes have different radar cross sections, a suggestion is to select over a range to find the worst-case scenario.)

This yields the following configuration file

```
channelCfg 1 1 0
chirpComnCfg 13 0 0 256 1 37 2
chirpTimingCfg 50 24 0 25 62
frameCfg 8 0 811 1 333 0
cfarCfg 2 8 4 3 0 4.0 0 0.8 0 1 1 1
```

Engineers have to estimate some of the parameters in the equation, notably the SNR detection threshold, which can determine the false alarm rate, the radar cross section of the target, which can vary from person-to-person, and any miscellaneous losses due to radome, humidity, and temperature.

To decrease development time, TI recommends base lining performance with the candidate chirp configuration given in the video doorbell software, and scaling the integration time up or down based off the results. For example, if the configuration designed to yield 10 meters of detection range is only yielding 8 meters, then increasing the integration time by a factor of $(10/8)^4$= 2.44 is likely to give the desired result.

2.1.2.2 Deep Sleep Power Modes

The IWRL6432AOP consumes very little power through the deep sleep modes, which achieve <0.5mW power consumption when the radar is not being used. While *xWRL6432 Low Power Radar - Power Optimization Techniques,* application note covers this in extensive detail, this section can focus specifically on the ways to reduce power that do not affect detection range or false alarm rate.

The IWRL6432AOP device can save power in deep sleep by reducing the amount of memory retained in the Deep Sleep mode. On the IWRL6432, memory instances consume approximately 45µW or 64kB in power-down retention mode. If memory within a cluster is not retained, IWRL6432 can consume approximately 20µW/64kB. To further save power when memory is not retained, some memory clusters on the IWRL6432 are grouped together, and power switches are deployed on the corresponding SRAM power rails. If all the clusters in a group are not retained during Deep Sleep, switches for the group are opened, completely powering off the group, causing the memory to consume 0µW/kB while completely powered off (no retention).

These switches can be set in sysconfig. Table 2-2 explains which clusters correspond to which sections in memory.

Table 2-2. Memory Addresses for Each Cluster

Cluster No.	Memory Segment	Cluster Name	Size (kB)	Starting Memory Location	Notes
APPSS Cluster #1	RAM_1	RAM1A	64	0x00400000	
APPSS Cluster #3	RAM_1	RAM1B	64	0x00410000	
APPSS Cluster #4	RAM_1	RAM1C	128	0x00420000	
APPSS Cluster #2	RAM_2	RAM2A	16	0x00440000	
APPSS Cluster #5	RAM_2	RAM2B	112	0x00444000	
APPSS Cluster #5	RAM_3	RAM3	128	0x00460000	
APPSS Cluster #6	APP_SHMEM_1	Shared RAM 1	128	0x00480000	When accessed from HWA, starts at 0x60000000
APPSS Cluster #6	APP_SHMEM_2	Shared RAM 2	128	0x004A0000	When accessed from HWA, starts at 0x60000000

The linker.cmd file can be used to dictate where data is stored in memory. Efficient design can store the variables that get reset every frame, such as the major motion point cloud, in clusters that are NOT retained during deep sleep. However, other variables that are not reset every frame, such as the occupancy status in each detection zone, needs to be placed in memory banks that are retained during deep sleep. This is accomplished in the video doorbell demo by default.

2.1.2.3 Hardware Accelerator

The hardware accelerator on the IWRL6432AOP enables ultra-efficient computation of the most important operations needed for radar signal processing, which include windowing, FFT, Log-Mag and CFAR vector operations. Using the HWA decreases computation time significantly, allowing the radar sensor to spend more time in the deep sleep mode and less time in computation. Because the HWA uses streaming input and output, the number of cycles required for a sequence of FFTs is (1+NumFFT) * FFTSize, which is much faster than a typical O(NlogN) implementation. To illustrate some typical computation times for the IWRL6432AOP, *Radar Hardware Accelerator*, user's guide (Table 5) has been modified for the 80MHz HWA clock as shown in Table 2-3.

Table 2-3. FFT Computation Time (80MHz HWA Clock)

Example	FFT Size	Number of Back-to-Back Iterations	Number of Clock Cycles (Initial Latency + Computation)	Total Duration (assuming 80MHz clock)
1	256	4	256+ (256 × 4)	16 µsec
2	128	4	128 + (128 × 4)	8 µsec
3	8	64	8 + (8 × 64)	6.5 µsec

2.1.3 Low False Alarm Rate

2.1.3.1 Typical Causes of False Alarms

Rejecting false alarms is one of the principle benefits of using radar in surveillance systems. The most common causes of false alarms in residential environments include the following:

- Cars driving on the street
- Trees and bushes blowing in the wind
- Neighbors walking on the sidewalk
- Heaters or condensers nearby causing differences in temperature
- Small animals in the field of view
- Bug nests very nearby the radar

Typically in these systems, users are able to select a detection zone, where the user wants to detect movement, and exclusion zones, where the user does not want to detect movement. Therefore, this list of false alarms can be divided into two categories: false alarms from movement within the expected detection zone, and false alarms from movement outside the expected detection zone

Table 2-4. Sources of False Alarms

False Alarms Within the Detection Zone	False Alarms Outside the Detection Zone
• Trees and bushes blowing in the wind • Heaters or condensers nearby causing differences in temperature • Small animals in the field of view • Bug nests very nearby the radar	• Cars driving on the street • Neighbors walking on the sidewalk

2.1.3.2 False Alarms Outside the Detection Zone

The FMCW encoding scheme used by the IWRL6432AOP makes sure that localization is significantly more accurate than competing technologies. Since the IWRL6432AOP can achieve nearly 4cm of range resolution, and angle accuracy within 5°, the IWRL6432AOP easily rejects false alarms that come from outside the detection zone.

60GHz radar locates targets much more accurately than competing sensing technologies. PIR sensors have no inherent ability to estimate range without prior knowledge of the target PIR sensors are detecting. To a PIR sensor, an object that emits lots of energy at a long distance looks identical to an object emitting less energy at a shorter distance. Therefore, when a large car drives by a PIR sensor at a longer distance, the PIR can confuse the car for a comparatively smaller human walking by the PIR at a shorter distance. Since the IWRL6432AOP uses FMCW radar for localization, the estimate of distance is not based off the amount of received power to the device, rather, the distance is based off the estimated frequency of the received wave to the device, which is a much more reliable indicator. See *The Fundamentals of Millimeter Wave Radar Sensors,* marketing white paper for more information about how radar estimates distance.

Additionally, 60GHz radar localizes to a much higher degree of accuracy than lower-frequency radars at 2.4, 5, or 24GHz. Higher frequency radars can fit more antennas in a fixed area, enabling better angular resolution, better angular accuracy, and wider fields of view. The IWRL6432AOP fits 2 TX and 3 RX antennas within a 10.9mm × 6.7mm package size. Designs of this size can be impossible at lower frequencies because the designs can require larger antennas.

2.1.3.3 False Alarms Within the Detection Zone

The same SNR compensation technique to increase detection range over range and angle also serves to reject false alarms near the radar due to trees and bushes. Trees and bushes can be a persistent source of noise, especially in the areas where surveillance devices are installed. Assuming that stationary objects are rejected from the radar returns using the static clutter removal option, the RCS of trees and bushes, is often much smaller than that of a person. Therefore, at a given distance from the radar, points from a person walking and a tree blowing in the wind can be separated by SNR, (provided that the power degradation over range is accounted for).

2.1.3.4 Adaptive State Machine

Because the IWRL6432AOP is easily programmed, the IWRL6432AOP enables users to set higher and lower thresholds for zone occupancy based off the field of view. This allows users to set higher occupancy criteria for zones that can have consistent movement from trees, bushes, or animals. This can also be accomplished adaptively, where users or a computer vision algorithm can filter out the false alarms, giving the radar information about the problematic regions in the field of view. Through this information, the radar can learn more about the scene, and adjust the detection thresholds automatically in different regions.

3 Hardware, Software, Testing Requirements, and Test Results

TI has developed the following tests and the associated tools to measure the performance of the IWRL6432AOP. These instructions detail the procedure to measure the long detection range, low false alarm rate, and low power consumption of the device in typical application environments.

3.1 Hardware Requirements

Running the test suite requires the following materials:

- IWRL6432AOPEVM
- A tripod or mount to hold the device upright
- An open field or parking lot to test detection distances
- A PC to run the visualizer software
- A long USB cable to easily connect the IWRL6432AOPEVM to the PC

3.2 Software Requirements

Running the test suite requires the following software downloaded to the PC:

- MMWAVE-L-SDK (most recent version)
- Radar Toolbox (most recent version)
  - Video Doorbell prebuilt binary
  - Applications Visualizer executable
- Details on how to program the device and run the visualizer can be found in the user guides for the video doorbell example and the applications visualizer respectively.

3.3 Test Setup

TI recommends conducting the following series of tests to evaluate the performance of the radar for maximum range, low power consumption and minimal false alarm rate.

Table 3-1. Radar Surveillance Test Suite

Test ID	Test Name	Parameter Under Test	Results
1	Detection Range	Detection at long range	Detection Distance in meters
2	Empty Scene False Alarm Rate	Low False Alarm Rate	Percentage of time in each mode, number of false alarms
3	Power Consumption	Power Consumption	Power Consumption in mW

In each test, TI recommends mounting the radar as the radar is intended for operation, which can be at different heights and angles. Two common installations are a doorbell configuration, where the device is placed about one meter high and angled straight out to the horizon, and a video camera configuration, where the device is mounted higher and tilted slightly down to increase the camera's field of view.

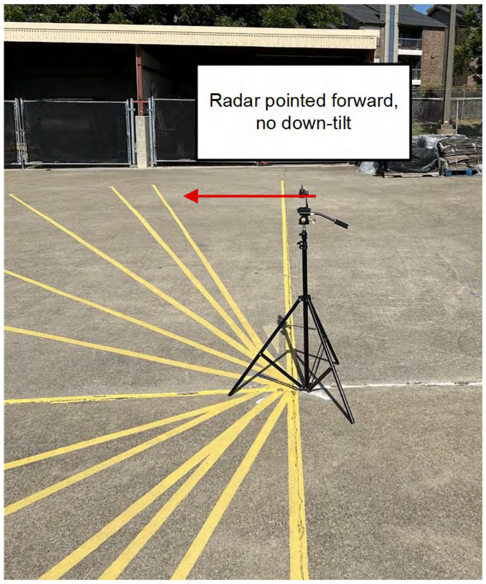


Figure 3-1. Radar Mounting Doorbell Configuration

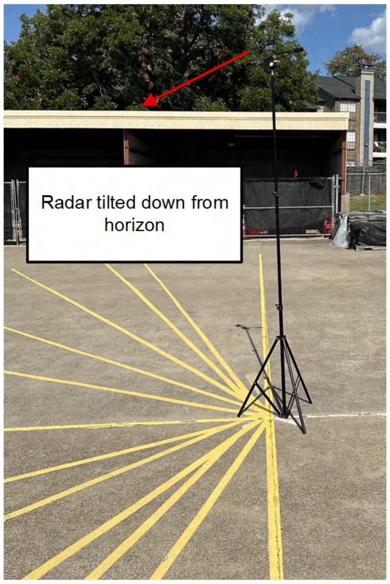


Figure 3-2. Radar Mounting Camera Configuration

3.3.1 Test 1 - Detection Range

In Test 1, a person approaches the radar from outside the detection range of the radar at a variety of angles. Person walks at a typical walking speed, the person keeps arms loose by their sides. The distance at which the person is detected, is noted by the radar. User repeats the test three times for each angle.

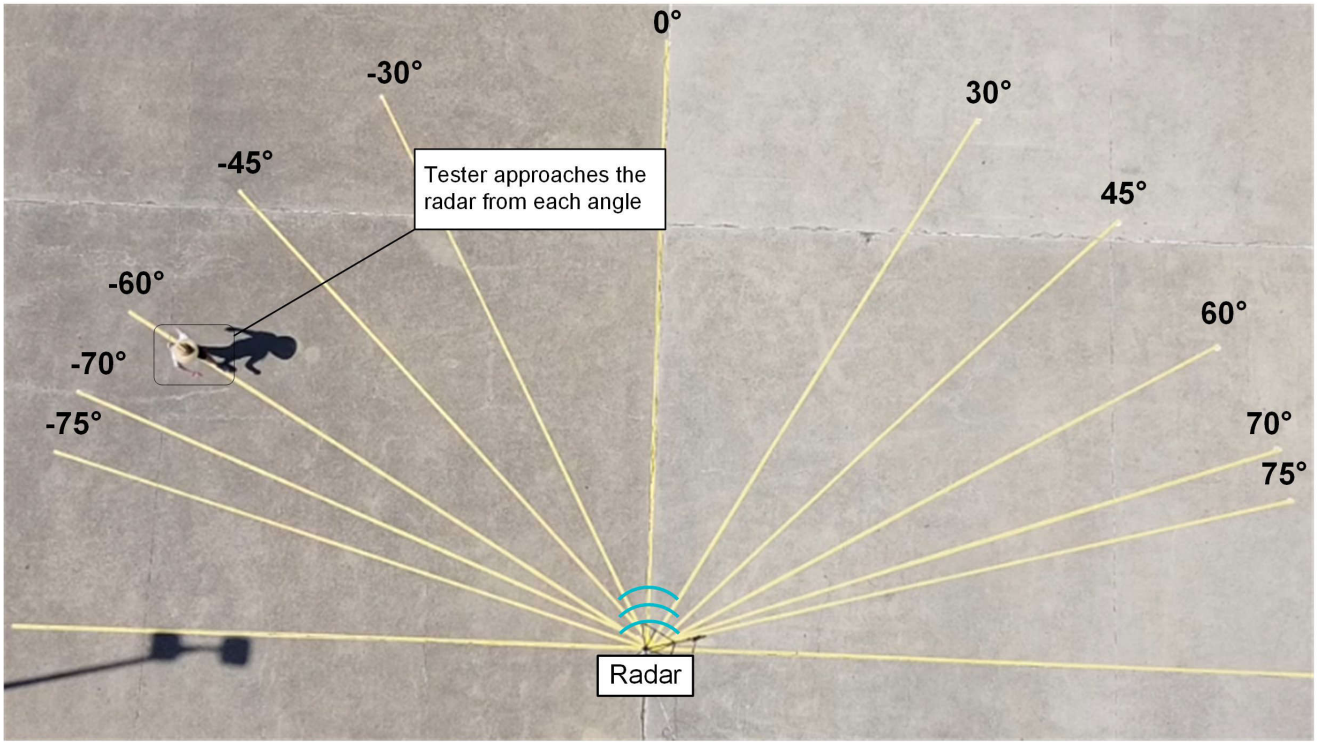
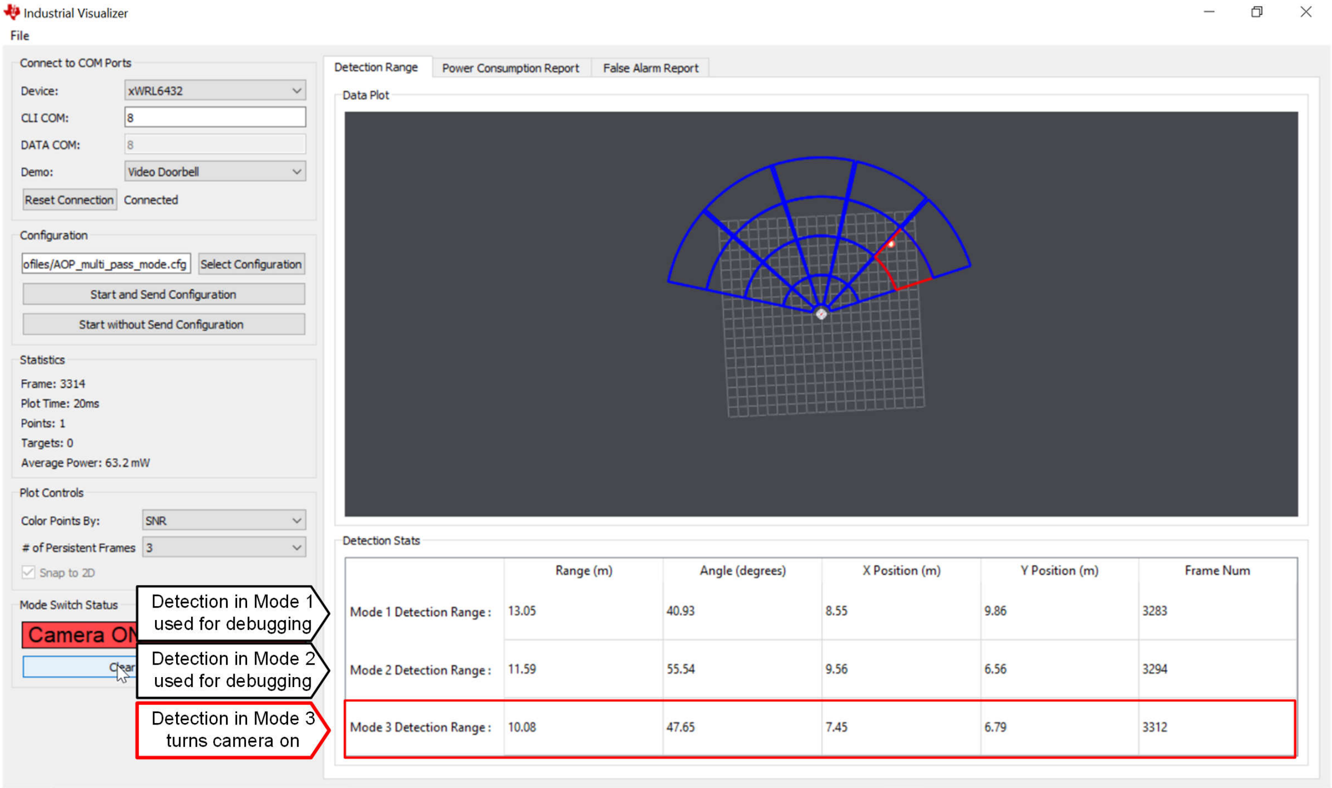


Figure 3-3. Detection Range Test - Bird's Eye View

The Detection Range pane in the Industrial Visualizer tool makes this measurement easy by labeling the detection distances of the different detection modes. For the overall detection distance, use the Mode 3 Detection Range (which is designed to turn on the video camera in a fully designed system).



Device: xWRL6432
CLI COM: 8
DATA COM: 8
Demo: Video Doorbell
Connected

ofiles/AOP_multi_pass_mode.cfg

Frame: 3314
Plot Time: 20ms
Points: 1
Targets: 0
Average Power: 63.2 mW

Color Points By: SNR
# of Persistent Frames 3
☑ Snap to 2D

Detection in Mode 1 used for debugging

Detection in Mode 2 used for debugging

Detection in Mode 3 turns camera on

	Range (m)	Angle (degrees)	X Position (m)	Y Position (m)	Frame Num
Mode 1 Detection Range :	13.05	40.93	8.55	9.86	3283
Mode 2 Detection Range :	11.59	55.54	9.56	6.56	3294
Mode 3 Detection Range :	10.08	47.65	7.45	6.79	3312

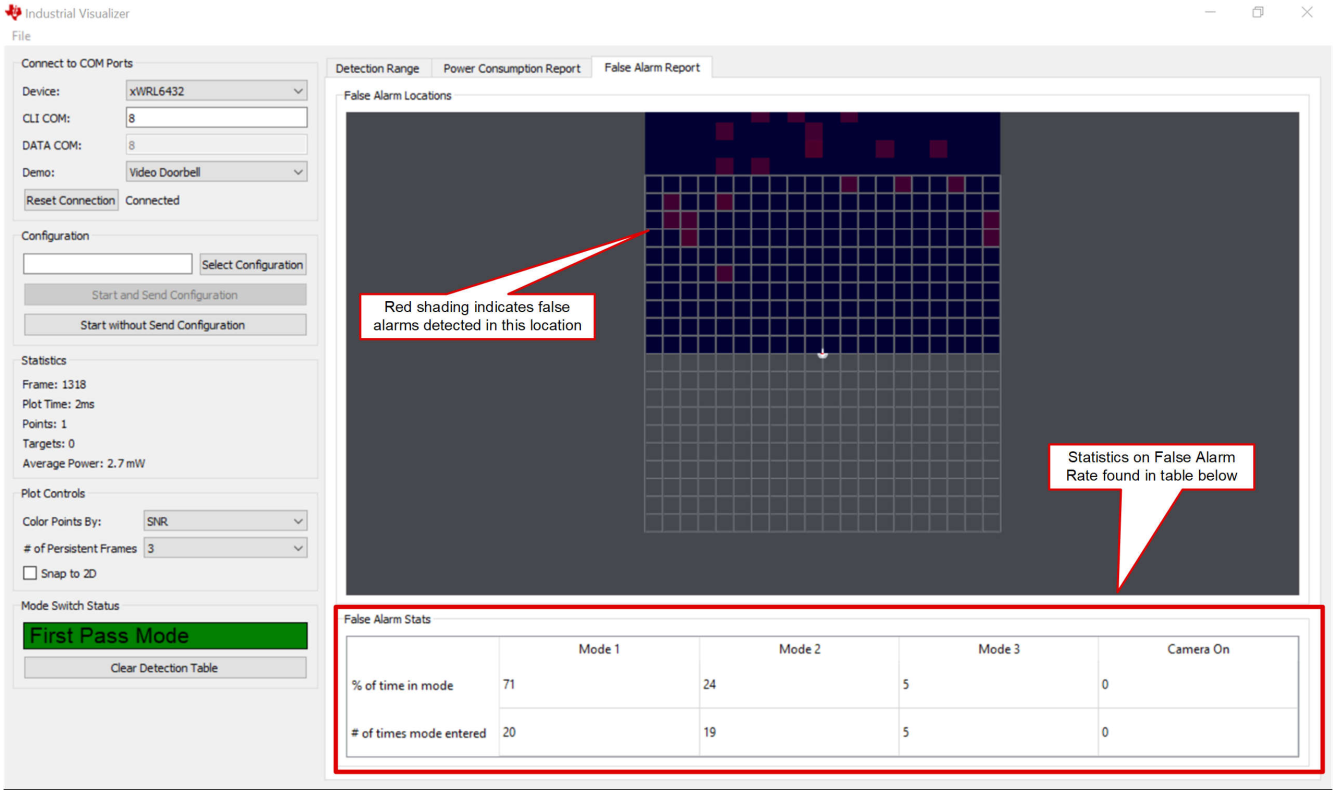
Figure 3-4. Detection Range Test - Visualizer View

3.3.2 Test 2 - False Alarm Rate

This test occurs in a large empty space, which can be a parking lot, open field, or a large room. Mount the radar and test setup securely to prevent the equipment from moving in the wind. Note the percentage of time spent in each mode, and the number of times the radar falsely awakens the camera.

Figure 3-5. False Alarm Rate Test - Empty Scene

The False Alarm screen in the Industrial Visualizer displays the relevant information in the table on the bottom. The shading on the top indicates the proportion of the false alarms that originate from that region (more red = higher percentage of false alarms).



Device: xWRL6432
CLI COM: 8
DATA COM: 8
Demo: Video Doorbell
Connected

Statistics
Frame: 1318
Plot Time: 2ms
Points: 1
Targets: 0
Average Power: 2.7 mW

Color Points By: SNR
# of Persistent Frames 3
☐ Snap to 2D

Red shading indicates false alarms detected in this location

Statistics on False Alarm Rate found in table below

	Mode 1	Mode 2	Mode 3	Camera On
% of time in mode	71	24	5	0
# of times mode entered	20	19	5	0

Figure 3-6. False Alarm Rate Test - Visualizer View

Testing performance in more crowded environments can lead to more false alarms. TI has found that a combination of velocity, SNR and height filters work particularly effectively in denser scenes.

3.3.3 Test 3 - Power Consumption

The power consumption measurement need to be conducted in a typical operating environment for the video doorbell if possible. TI recommends measuring the power consumption for each mode individually, and estimating total power consumption based off the expected time in each mode during typical operation.

To limit the amount of debugging information coming off the radar during a power measurement, TI provides a couple of predefined symbols that can be defined or not to enable power measurement in the different states. Table 3-2 shows which symbols to define to measure power in each mode.

Table 3-2. Symbols to Define to Measure Power in Each Mode

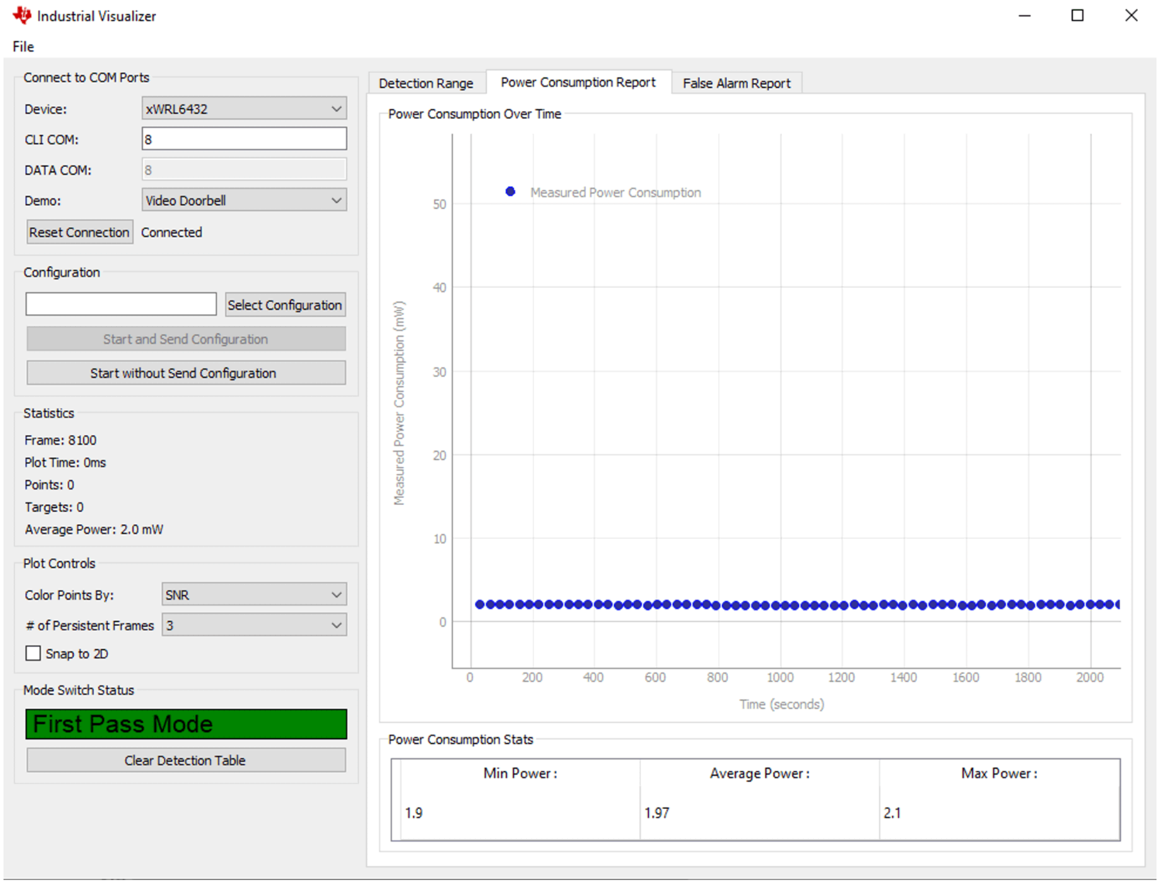
Measure Mode 1 Power	Measure Mode 2 Power	Measure Mode 3 Power
REMOVE_TRACKER LOW_MEM POWER_REDUCTION_MODS POWER_MEASUREMENT_CFG STAY_IN_FIRST_PASS_MODE	REMOVE_TRACKER LOW_MEM POWER_REDUCTION_MODS POWER_MEASUREMENT_CFG STAY_IN_SECOND_PASS_MODE	REMOVE_TRACKER LOW_MEM POWER_REDUCTION_MODS POWER_MEASUREMENT_CFG STAY_IN_THIRD_PASS_MODE

Each symbol does the following.

Table 3-3. Low Power Mode Symbol Definitions

Symbol	Usage
REMOVE_TRACKER	Removes the tracker from the project to save memory
LOW_MEM	Reduces the size of the radar cube to the minimum needed for all three modes to save memory, requires user to change the linker file
POWER_REDUCTION_MODS	Removes the GPIO from the example to reduce power consumption. Requires user to also remove GPIO in sysconfig
POWER_MEASUREMENT_CFG	Only outputs power consumption every 100 frames to reduce UART impact on power consumption
STAY_IN_FIRST_PASS_MODE	Keeps the demo from switching out of first pass mode for easier debugging
STAY_IN_SECOND_PASS_MODE	Keeps the demo from switching out of second pass mode for easier debugging
STAY_IN_THIRD_PASS_MODE	Keeps the demo from switching out of third pass mode for easier debugging

When each mode is running, the power consumption tab in the industrial visualizer displays power consumption as a function of time.



Device: xWRL6432
CLI COM: 8
DATA COM: 8
Demo: Video Doorbell
Connected

Frame: 8100
Plot Time: 0ms
Points: 0
Targets: 0
Average Power: 2.0 mW

Color Points By: SNR
# of Persistent Frames 3
☐ Snap to 2D

First Pass Mode

Min Power :	Average Power :	Max Power :
1.9	1.97	2.1

Figure 3-7. Power Consumption Test - Visualizer View

3.4 Test Results

Using the executable and visualizer tools found in the Reference Design folder, TI was able to achieve the following results for each of the tests specified. Results need to be replicable using the same software and tools, and can be improved upon with subsequent updates to the software.

Table 3-4. Test 1 - Detection Range

Angle (degrees)	Detection Distance (Average over 5 trials)
-70	6.06
-60	9.72
-45	12.02
-30	13.39
0	14.37
+30	11.97
+45	9.82
+60	8.69
+70	8.62

Table 3-5. Test 2 - False Alarm Rate

Parameter	Value
Length of test (seconds)	1800 (30 min)
Environment	Open Parking Lot
Number of Times the Camera turns On	0
Percentage of Time in Camera On	0%
Percentage of Time in Mode 3	8%
Percentage of Time in Mode 2	17%
Percentage of Time in Mode 1	75%

Table 3-6. Test 3 - Power Consumption

Average Power Consumption (mode 1)	Average Power Consumption (mode 2)	Average Power Consumption (mode 3)
1.97mW	4.4mW	30.5mW

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDEP-01035.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDEP-01035.

5 Tools and Software

Tools

TI Resource Explorer	Radar Toolbox

Software

mmWave software development kit (SDK) for xWRL1432 and xWRL6432	The mmWave low-power software development kit (SDK) is a collection of software packages that enable application evaluation and development on our low-power mmWave sensors. This tool includes MMWAVE-L-SDK and companion packages to support customer design needs.

6 Document Support

1. Texas Instruments, *IWRL6432AOP Single-Chip 57- to 64GHz Industrial Radar Sensor Antenna-On-Package (AOP)*, data sheet.
2. Texas Instruments, *xWRL6432 Low Power Radar - Power Optimization Techniques*, application note.
3. Texas Instruments, *Programming Chirp Parameters in TI Radar Devices*, application note.
4. Texas Instruments, *Radar Hardware Accelerator*, user's guide.
5. Texas Instruments, *The Fundamentals of Millimeter Wave Radar Sensors*, marketing white paper.

7 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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