Application Note

Transmitter Back Off and Receiver Gain Recommendation for xWRL6432AOP

Radar Systems and Applications

ABSTRACT

This application report provides information on how to select the transmitter power backoff and the receiver gain setting in the xWRL6432AOP radar device based on the end application and use case to avoid the increased receiver noise figure and the risk of receiver ADC saturation, and correctly program them on TI's xWRL6432AOP radar devices.

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1 Introduction

When determining overall system performance with FMCW radar sensors, many factors affect the range of detection. Range of detection is determined by chirp slope, IF bandwidth, and the signal-to-noise ratio (SNR) of the reflected energy from a detected object. The SNR in turn depends on EIRP (combination of TX power and TX antenna gain), EINF (combination of RX antenna gain and RX noise figure) and RCS of the target object. With the xWRL6432AOP device, there is limited isolation between transmit and receive antennas due to the close proximity of the antennas on the antenna-on-package (AOP) device.

This impacts the receiver performance in two ways:

- **Impact 1**: Increased receiver noise figure
  - Due to the noise riding on the TX- RX coupled signal the noise figure is increased.
- **Impact 2**: Risk of receiver ADC saturation
  - The TX - RX coupling causes a low frequency signal at the RX output which can be large enough to saturate the ADC if precautions are not taken.

2 Increased Receiver Noise Figure

The noise riding on the coupled signal can increase the noise figure of the receiver. Increased noise figure reduces the SNR of the detected object, leading to reduced detection range and accuracy. The effective isotropic noise figure therefore depends on two things:

1. TX Backoff
2. TX - RX Isolation

The TX - RX isolation depends on two factors:

- Transmit and Receive combination
- RF frequency

Figure 2-1 shows the dependencies of the effective isotropic noise figure (EINF) across different transmit and receive combinations and across different RF frequencies. The EINF is shown for two different TX backoff settings (0dB and 6dB). The change in noise figure between the two TX backoff settings show the impact of TX-RX coupling on noise figure for different RF frequencies.

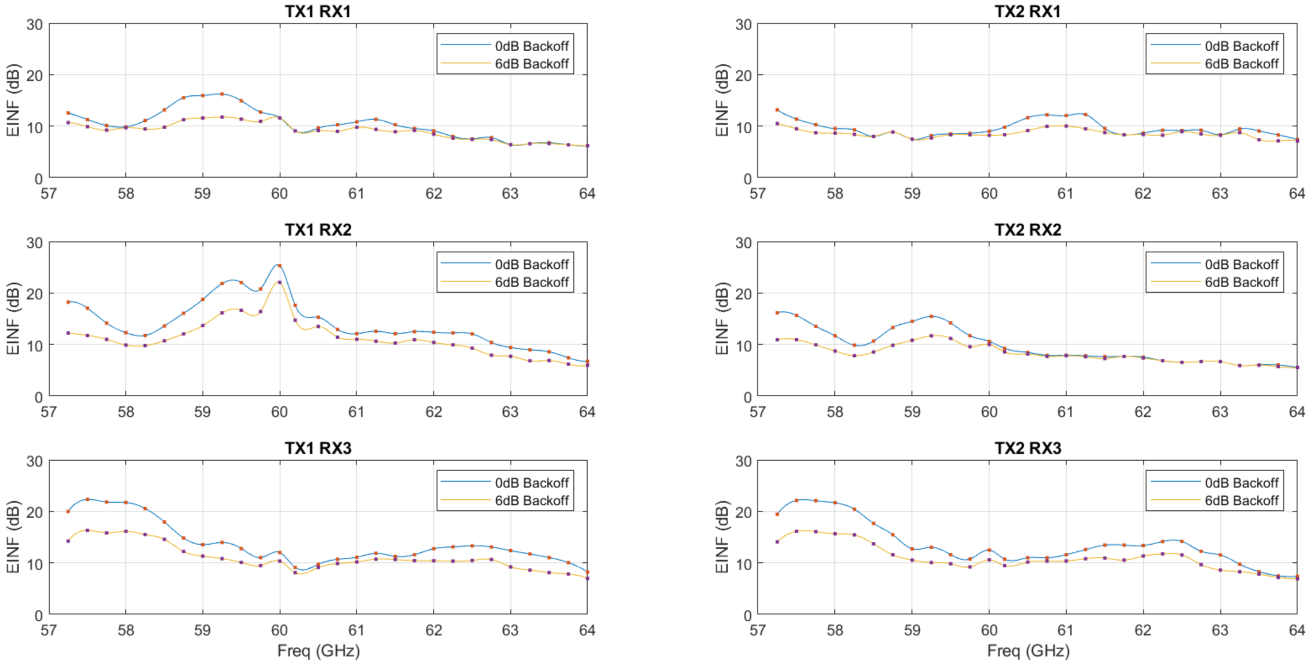

Figure 2-1. EINF With Single TX on Across Frequencies

These effects across transmit and receive pairs can be combined to show a total effect of all transmit and receive antennas across RF frequency. Figure 2-2 shows the noise figure averaged across different TX-RX combinations.

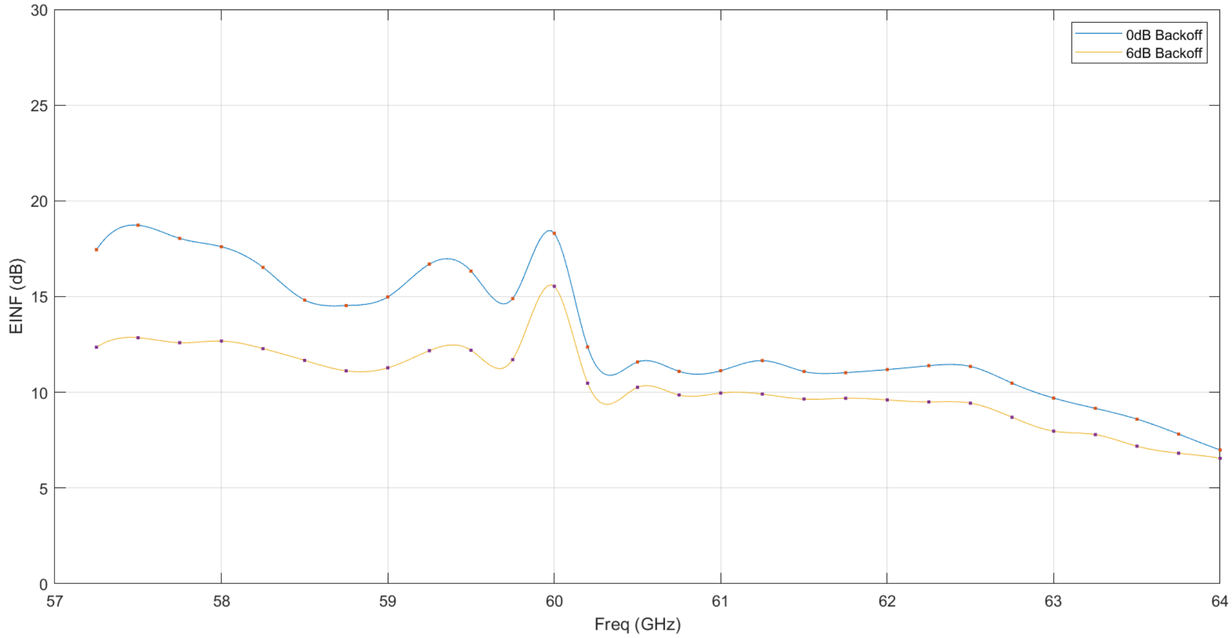

Figure 2-2. Average EINF With Single TX on Across Frequencies

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Note

Due to the increased noise figure at 60GHz, TI recommends avoiding narrow bandwidth chirps (< 0.5GHz) around 60GHz.

Maximizing detection range (or minimizing required integration time for a particular detection distance) relies on maximizing detection SNR. Based on the previously-mentioned noise figure profiles, this can be achieved in several ways.

- Reducing TX power (increasing power backoff) lowers the noise figure by reducing the amount of coupling between TX and RX antennas. This varies between TX and RX combination and across output frequency. However, the benefit by lowered noise figure is outweighed by the reduction in transmitted power, lowering the detection range.
- Choosing start and stop frequencies (bandwidth) of the FMCW chirp can help reduce coupling and lower the noise figure. As Figure 2-2 shows, the 61 to 64GHz band has lower coupling than the 57 to 61GHz band. Designing a chirp to utilize the 61 to 64GHz portion of the frequency band can help lower the noise figure. Local regulations and other considerations can drive frequency choice of the end application, but the previous graphs can be used for expected noise figure in different frequency bands.
- For applications which do not need all 6 virtual channels (TX and RX combinations), using TX2 can help reduce noise figure. The coupling is lowest for TX2 in the 59 to 64GHz band. For single TX applications need, use TX2 over TX1 to get best performance and maximum range.
- For two TX applications, use TDM MIMO mode instead of BPM MIMO mode.

3 Risk of Receiver ADC Saturation

The TX - RX coupling causes a low-frequency signal at the RX output which can be large enough to saturate the receiver ADC if precautions are not taken. The strength of the receiver ADC saturation depends on:

1. Coupled signal level at RX input:
    - TX backoff
    - RF frequency
    - Transmit and receive combinations under consideration
2. RX Gain setting
3. HPF attenuation:
    - Chirp slope and HPF cutoff frequency configurations

To mitigate this risk, the swing at the receiver output needs to be reduced. This is achieved by the recommendations in the following section.

4 TX Backoff and RX Gain Recommendations

Figure 4-1 and Figure 4-2 give the maximum allowed RX gain setting and minimum TX back off restrictions based on chirp slope (X-axis) and HPF setting (different colors). These are recommendations which minimize the effects of increased receiver noise figure and risk of receiver ADC saturation.

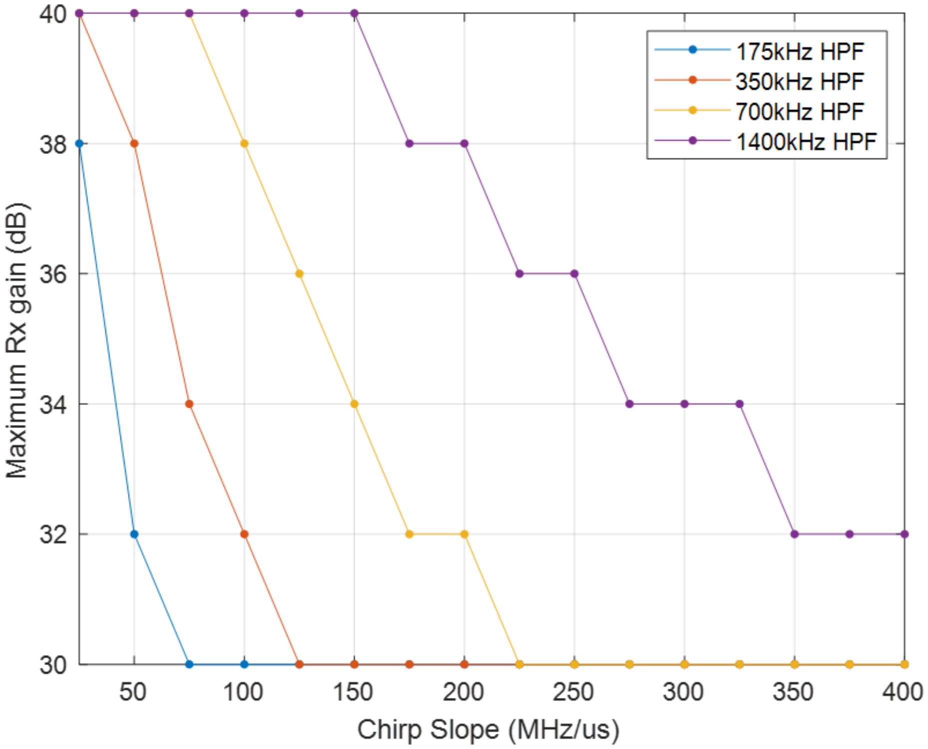


Figure 4-1. Maximum Allowed RX Gain Setting

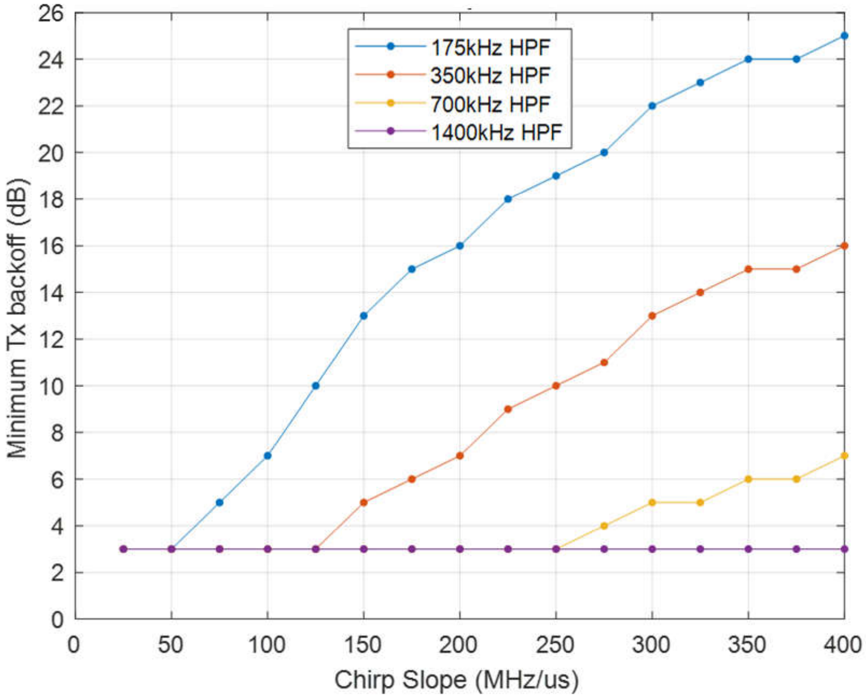


Figure 4-2. Minimum TX Backoff for 57 to 64GHz

TX backoff restriction can be relaxed as shown in Figure 4-3 for the following cases:

- Chirps contained within 61 to 64GHz for two TX applications
- Chirps contained within 59 to 64GHz for single TX applications (using TX2)

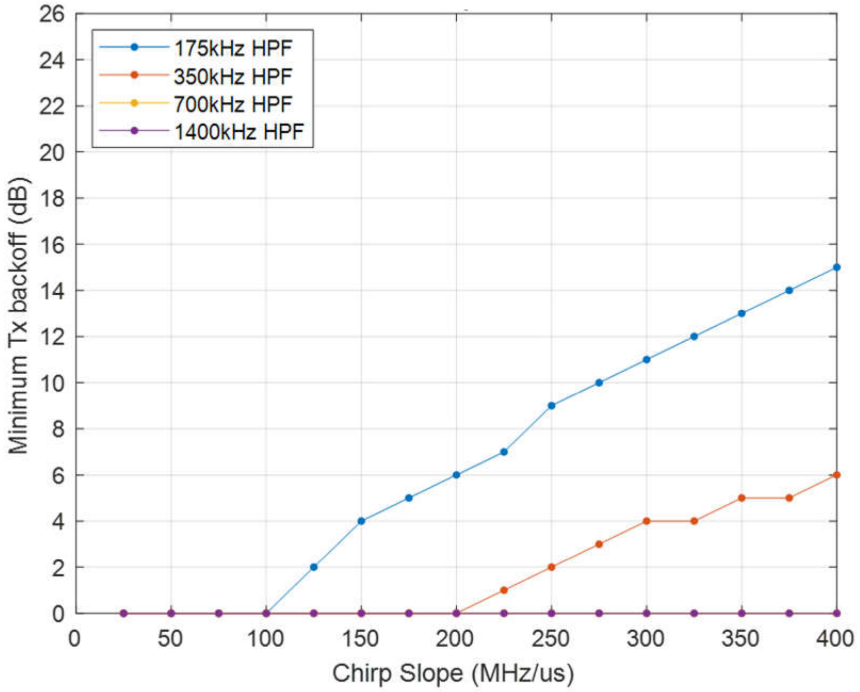
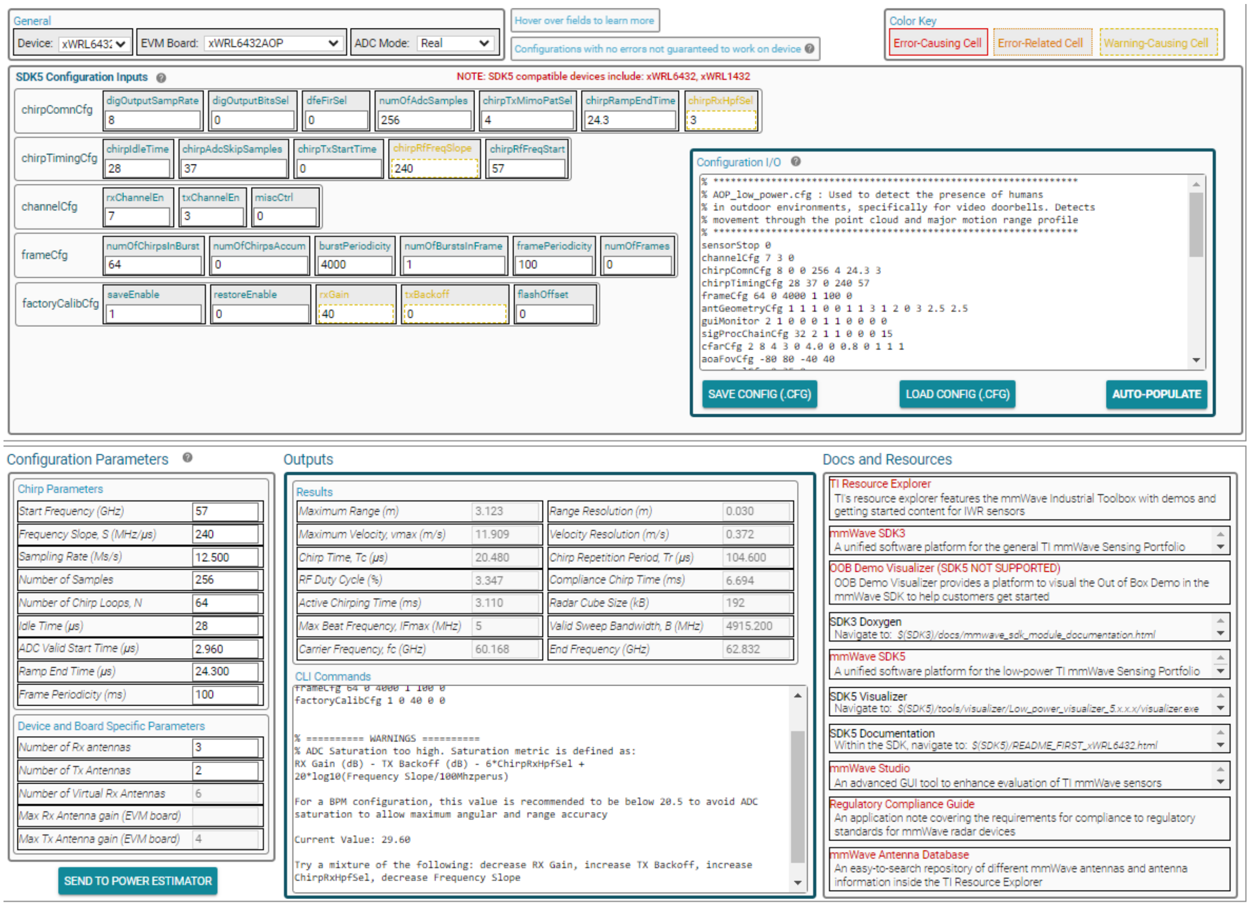


Figure 4-3. Minimum TX Backoff for 61 to 64GHz

Using the previously-shown constraints makes sure that the best possible SNR is achieved and also the receiver ADC is not saturated.

5 Chirp Configuration Recommendations Using Sensing Estimator

If there is doubt about whether the chirp configuration is following the proper recommendations mentioned in this application note, use the sensing estimator to check the chirp settings. The *Advanced Chirp Design and Tuning* tab can check a chirp configuration to see if the settings comply with the graphs the previous sections. See Figure 5-1 for an example of the warnings given in the sensing estimator.



Device: xWRL643
EVM Board: xWRL6432AOP
ADC Mode: Real

chirpComnCfg	digOutputSampRate	digOutputBitsSel	dfeFirSel	numOfAdcSamples	chirpTxMimoPatSel	chirpRampEndTime	chirpRxHpfSel
	8	0	0	256	4	24.3	3

chirpTimingCfg	chirpIdleTime	chirpAdcSkipSamples	chirpTxStartTime	chirpRfFreqSlope	chirpRfFreqStart
	28	37	0	240	57

channelCfg	rxChannelEn	txChannelEn	miscCtrl
	7	3	0

frameCfg	numOfChirpsInBurst	numOfChirpsAccum	burstPeriodicity	numOfBurstsInFrame	framePeriodicity	numOfFrames
	64	0	4000	1	100	0

factoryCalibCfg	saveEnable	restoreEnable	rxGain	txBackoff	flashOffset
	1	0	40	0	0

```
% ***************************************************************
% AOP_low_power.cfg : Used to detect the presence of humans
% in outdoor environments, specifically for video doorbells. Detects
% movement through the point cloud and major motion range profile
% ***************************************************************
sensorStop 0
channelCfg 7 3 0
chirpComnCfg 8 0 0 256 4 24.3 3
chirpTimingCfg 28 37 0 240 57
frameCfg 64 0 4000 1 100 0
antGeometryCfg 1 1 1 0 0 1 1 3 1 2 0 3 2.5 2.5
guiMonitor 2 1 0 0 0 1 1 0 0 0 0
sigProcChainCfg 32 2 1 1 0 0 0 15
cfarCfg 2 8 4 3 0 4.0 0 0.8 0 1 1 1
aoaFovCfg -80 80 -40 40
```

Chirp Parameters	
Start Frequency (GHz)	57
Frequency Slope, S (MHz/μs)	240
Sampling Rate (Ms/s)	12.500
Number of Samples	256
Number of Chirp Loops, N	64
Idle Time (μs)	28
ADC Valid Start Time (μs)	2.960
Ramp End Time (μs)	24.300
Frame Periodicity (ms)	100

Device and Board Specific Parameters	
Number of Rx antennas	3
Number of Tx Antennas	2
Number of Virtual Rx Antennas	6
Max Rx Antenna gain (EVM board)	
Max Tx Antenna gain (EVM board)	4

Results			
Maximum Range (m)	3.123	Range Resolution (m)	0.030
Maximum Velocity, vmax (m/s)	11.909	Velocity Resolution (m/s)	0.372
Chirp Time, Tc (μs)	20.480	Chirp Repetition Period, Tr (μs)	104.600
RF Duty Cycle (%)	3.347	Compliance Chirp Time (ms)	6.694
Active Chirping Time (ms)	3.110	Radar Cube Size (kB)	192
Max Beat Frequency, IFmax (MHz)	5	Valid Sweep Bandwidth, B (MHz)	4915.200
Carrier Frequency, fc (GHz)	60.168	End Frequency (GHz)	62.832

CLI Commands

```
frameCfg 64 0 4000 1 100 0
factoryCalibCfg 1 0 40 0 0


% ========== WARNINGS ==========
% ADC Saturation too high. Saturation metric is defined as:
RX Gain (dB) - TX Backoff (dB) - 6*ChirpRxHpfSel +
20*log10(Frequency Slope/100Mhzperus)

For a BPM configuration, this value is recommended to be below 20.5 to avoid ADC
saturation to allow maximum angular and range accuracy

Current Value: 29.60

Try a mixture of the following: decrease RX Gain, increase TX Backoff, increase
ChirpRxHpfSel, decrease Frequency Slope
```

TI Resource Explorer
TI's resource explorer features the mmWave Industrial Toolbox with demos and getting started content for IWR sensors

mmWave SDK3
A unified software platform for the general TI mmWave Sensing Portfolio

OOB Demo Visualizer (SDK5 NOT SUPPORTED)
OOB Demo Visualizer provides a platform to visual the Out of Box Demo in the mmWave SDK to help customers get started

SDK3 Doxygen
Navigate to: *$(SDK3)/docs/mmwave_sdk_module_documentation.html*

mmWave SDK5
A unified software platform for the low-power TI mmWave Sensing Portfolio

SDK5 Visualizer
Navigate to: *$(SDK5)/tools/visualizer/Low_power_visualizer_5.x.x.x/visualizer.exe*

SDK5 Documentation
Within the SDK, navigate to: *$(SDK5)/README_FIRST_xWRL6432.html*

mmWave Studio
An advanced GUI tool to enhance evaluation of TI mmWave sensors

Regulatory Compliance Guide
An application note covering the requirements for compliance to regulatory standards for mmWave radar devices

mmWave Antenna Database
An easy-to-search repository of different mmWave antennas and antenna information inside the TI Resource Explorer

Figure 5-1. Sensing Estimator With Chirp That Causes ADC Saturation

To evaluate the chirp configuration manually, consider the following settings:

1. TX Backoff
2. RX Gain
3. HPF setting
4. Frequency Slope

First, look at the HPF setting and Frequency Slope to make sure the requirements for RX gain are met. In the example pictured in Figure 5-1, *HPF setting* = 1400kHz and *Frequency Slope, S (MHz/μs)* = 240. This means the maximum RX gain is 36 (see Figure 4-1). In this case, the decision is made to change the RX gain to 36 or below to make sure that the maximum receiver gain constraint is met.

Next, look at the TX backoff for the frequency range. Here the frequency range is 57–63GHz so use the data in Figure 4-2. This shows the minimum TX backoff as 3. In this case, the decision is to change the TX backoff to 3 or above to make sure the minimum back off constraint is met.

With the changes of RX gain from 40 to 36 and the TX backoff from 0 to 3, there is little or no risk of ADC saturation and the errors in the sensing estimator are cleared.

6 Summary

The receiver ADC saturation can significantly impact radar functionality and leads to the loss of crucial information from the reflected signal of the target object. Additionally, a higher noise figure degrades the overall performance of the radar by reducing the SNR, which consequently affects both the range and angle resolution. The recommendations provided for selecting transmitter power backoff and receiver gain settings for the xWRL6432AOP radar device are intended to create the best possible performance. These guidelines address how improper settings can result in higher EINF due to noise in the TX-RX coupled signal and the risk of receiver ADC saturation from low-frequency signals at the RX output. Recommendations are provided to achieve the most favorable settings on xWRL6432AOP radar devices based on the end application, thus enhancing radar performance by managing the impact of these issues.

7 References

1. Texas Instruments, *Programming Chirp Parameters in TI Radar Devices Application Report*
2. Texas Instruments, *IWRL6432AOP Single-Chip 57 to 64GHz Industrial Radar Sensor Antenna-On-Package (AOP) Data Sheet*
3. Texas Instruments, *IWRL6432AOP Device Silicon Errata*
4. Texas Instruments, *mmWave Sensing Estimator*

8 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (August 2024) to Revision B (November 2024)	Page
• Updated *References* section	7

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