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Department
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ECE432: Radar Systems

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Course Project

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❖ Objective

Range-Doppler ambiguity graphs of a target using Golay transmitted signal

- Perform matched filtering for range estimation in the time domain and frequency domain
- Perform 2D range-Doppler processing for a moving target
- Repeat exercise for multiple targets (three)
- Perform cell averaged CFAR-based detection of target parameters (amplitude, range, and Doppler)
- Repeat the above exercises for Doppler resilient Golay sequences

❖ Methodology

➢ Transmitted and Received Signals

For the Golay transmitted signal, 512 samples of Golay sequence in 1 PRI have been taken. The signal is then zero-padded to have a duty cycle of 50%, resulting in 1024 samples in 1 PRI. For the received signal, the transmitted signal is shifted according to the number of samples corresponding to the time delay.

➢ Range Estimation

We know that, td (time delay) = $2r_{tgt} / c$ (where r_{tgt} = range of target)
Given, dt = 1/BW
Sample delay, nd = round(td/dt)

- **Range Estimation in time domain**

Time domain Matched filtering was performed using the xcorr function.

- **Range Estimation in frequency domain**

We know that convolution in the time domain is equivalent to multiplication in the frequency domain. Firstly, the received and transmitted signals are converted from time to frequency domain, using the Fast Fourier Transform fft function. Then the received signal is multiplied to the conjugate of the transmitted signal. Finally, Inverse Fast Fourier Transform is performed using the ifft function.

➢ 2D Range Doppler Processing

For 2D Range Doppler Processing, the considered signal is a 2D array having M rows and N columns, in our case M = 1024 and N = 2048. The number of columns N represents the number of PRI in one CPI, also known as the slow time samples. The number of rows M represents the fast time samples in 1 PRI.

Range delay and doppler delay are computed to construct the received signal. Range delay is incorporated by shifting the signal according to the number of samples corresponding to the time delay. Doppler delay is incorporated by multiplying each column with $e^{j2\pi.fd.xTpri}$ where fd is the doppler frequency corresponding to the target's velocity, and x representing the column number starting from 0 to N-1.

➢ 2D Range Doppler For single target

2D Range Doppler processing is performed by doing Matched filtering across rows in a column and doing Doppler Processing across columns in a row. Doppler Processing was performed using Fast Fourier Transform(FFT). We know that for Matched filtering, if the input arguments consist of n samples, we get 2n-1 samples in the output. We also know that for FFT, if the input argument consists of n samples, we get n samples in the output. Thus, the dimensions after 2D Range Doppler processing were 2047 x 2048.

➢ 2D Range Doppler For Multiple targets

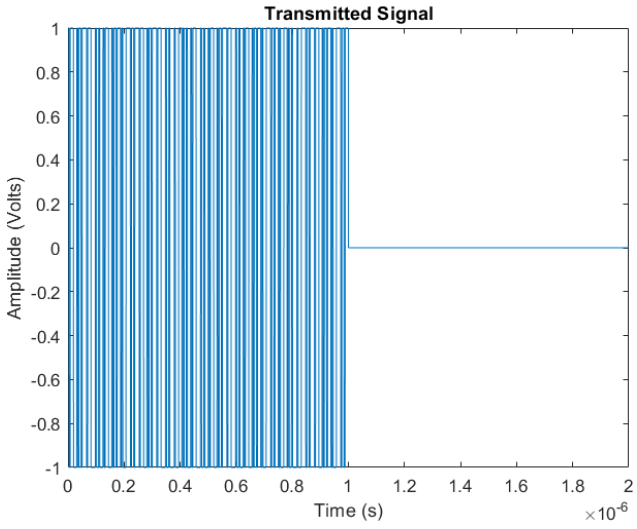
For 2D Range Doppler for multiple targets, we first fixed the target ranges, and velocities, like for 3 targets we made two array of target ranges and velocities and then we looped till 1 to 3, and in each iteration we are finding the 2d range doppler map for each target, we are superimposing(adding) the each 2d range doppler map to a matrix initialized to the same dimension and set to zero initially. Then Finally after the loop we are using imagesc to plot the superimposed 2d range doppler map.

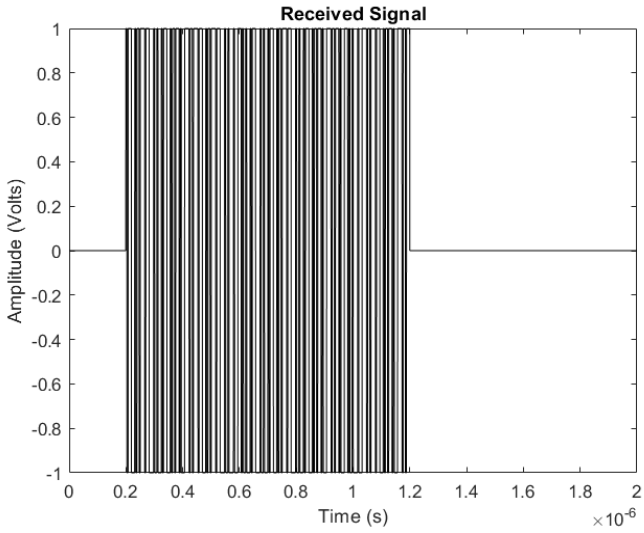
➢ CFAR

For CFAR, we first formed the CFARDetector2D object using a phased toolbox command, with parameters such as Training Band Size = [5,4], Guard Band Size = [4,4], false alarm rate probability as 1e-5. Now to find the object spots in the range doppler image, we have to make cut windows using the bands we have defined. For forming windows, we have looped over the start and ending of rows and columns to append all the possible windows into 2d array cutidx. Now we use the object we had created to find the detections map using the cuts we have created. After that, we plot the detections map using helperDetectionMaps by MATLAB to plot the detections.

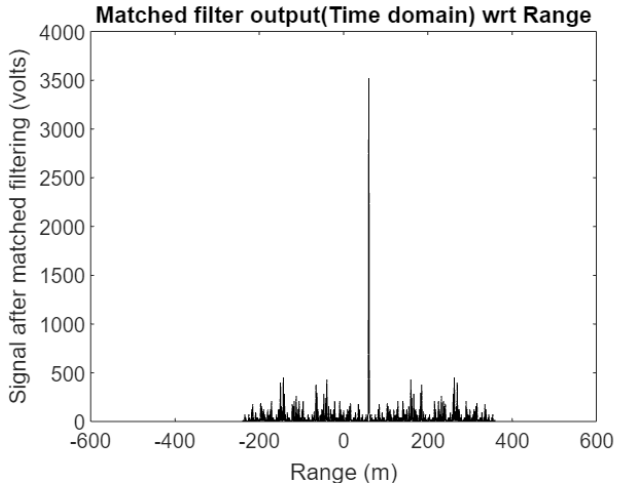
Results For Golay Sequence

- **Transmitted and Received Signal For Target at 60m Distance**





- **Time Domain Matched Filter**

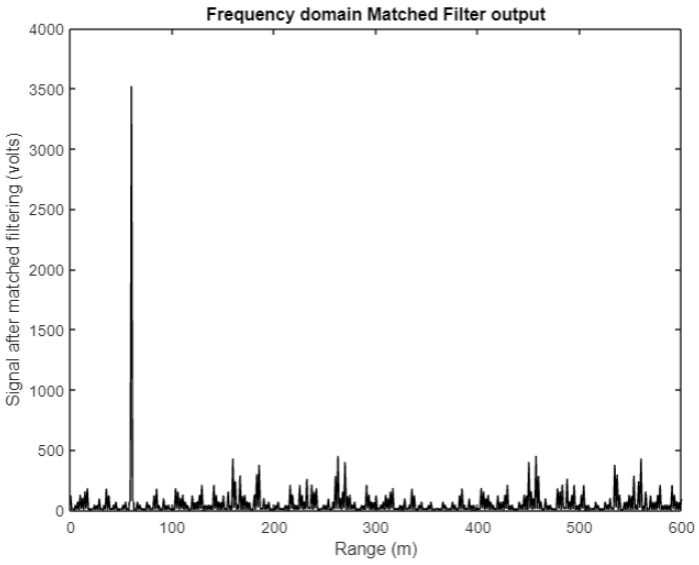


Peak-To-Side Lobe Ratio

Peak = 3520V
Side lobe = 427V
PSL Ratio = 3520:427 = 8.24
Ratio (in dB) = 20*0.916 = 18.32

After performing range estimation in Time domain using Matched filter by xcorr the range is coming out to be 59.923m, which is almost equal to 60m, which we have provided initially.

- **Frequency Domain Matched Filter**



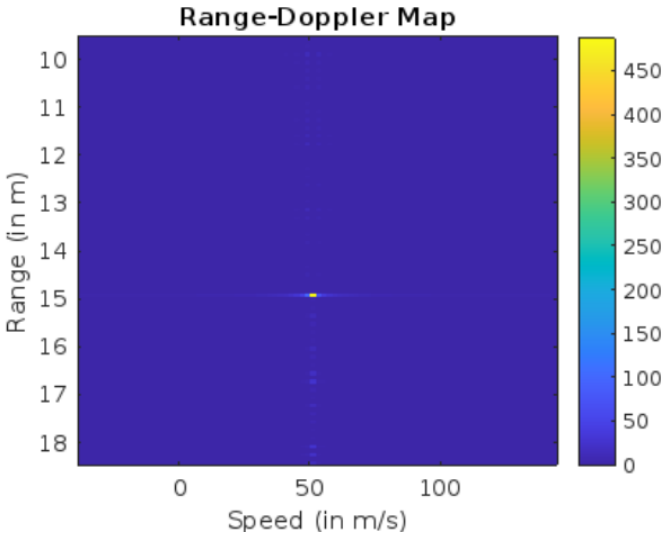
Peak-To-Side Lobe Ratio

Peak = 3520V
Side lobe = 427
PSL Ratio = 3520:427 = 8.24
Ratio (in dB) = 18.3223

After performing range estimation in frequency domain using Matched filter the range is coming out to be 59.923m, which is almost equal to 60m, which we have provided initially.

- **2D Range Doppler For single Target**

For a target with range 15m and velocity 50m/s.



Peak to side Lobe

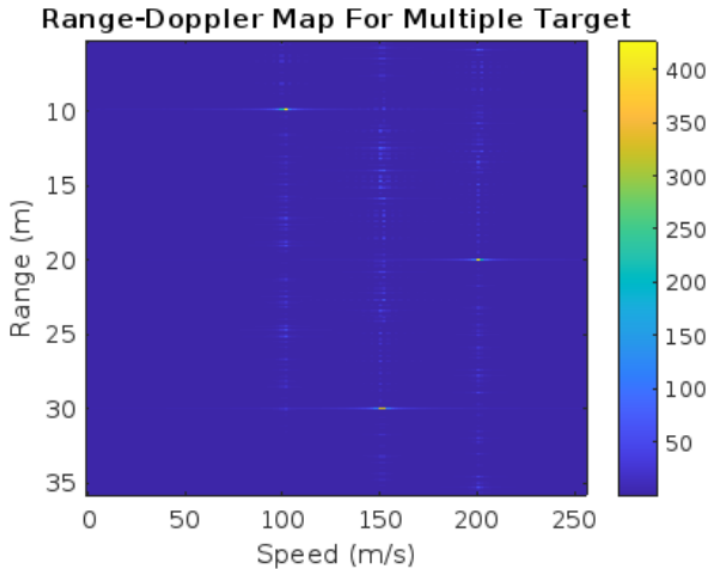
Value at bright spot: 488.358
Value at side lobe: 99.124

PSLR = 488.358: 99.124 = 4.92
PSLR in dB = 13.847

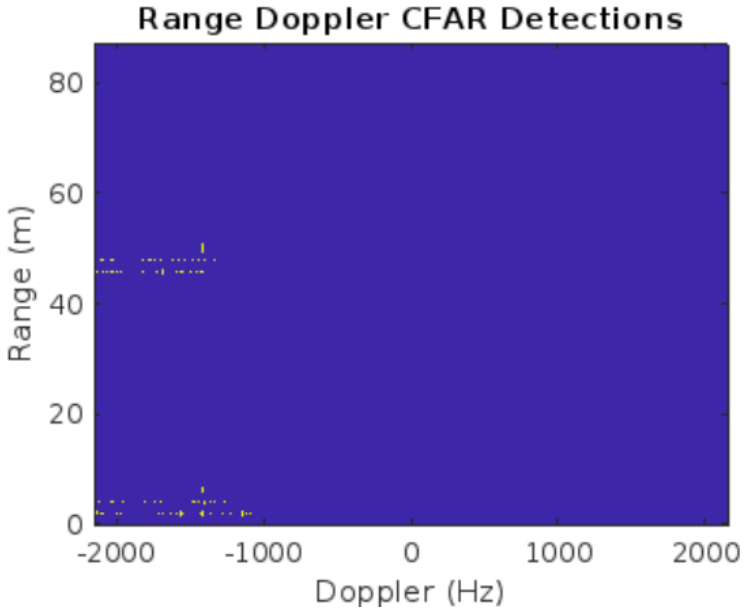
The bright spot is coming at speed 51.4282 m/s and range 14.9294m, considering the initial range and velocity we provided, the 2d range and doppler estimation is quite accurate.

- **2D Range Doppler For Multiple Target (three)**

    - For 3 targets with ranges 10m, 20m & 30m and velocities 100m/s, 200m/s & 150m/s.

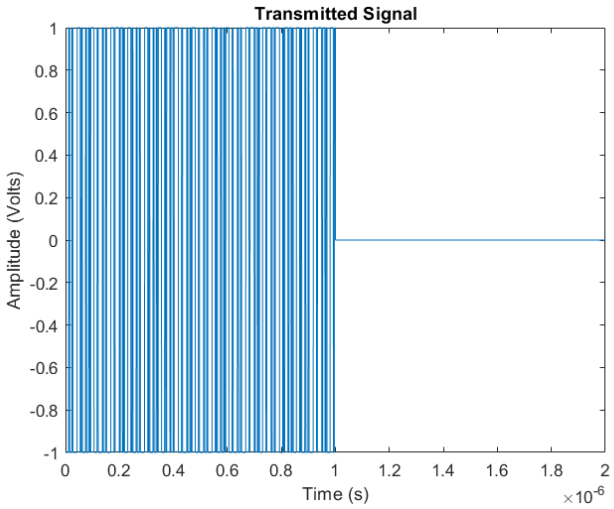


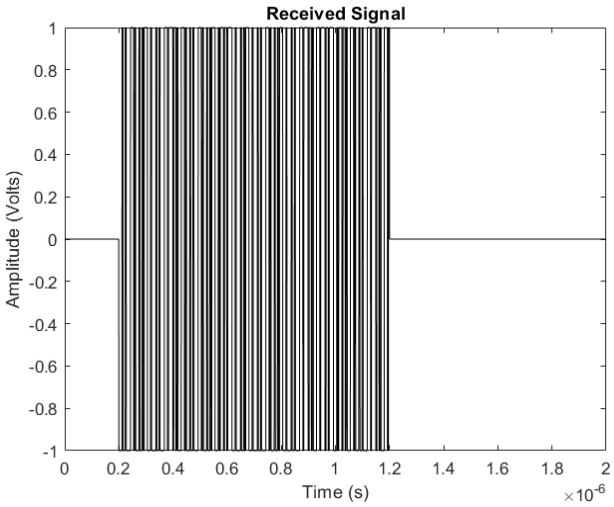
- **CFAR**



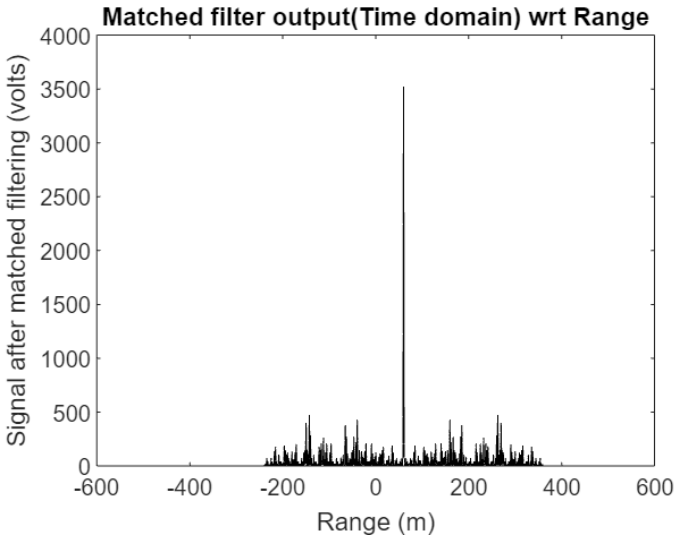
Results For Doppler Resilient Golay Sequence

- **Transmitted and Received Signal For Target at 60m Distance**





- **Time Domain Matched Filter**

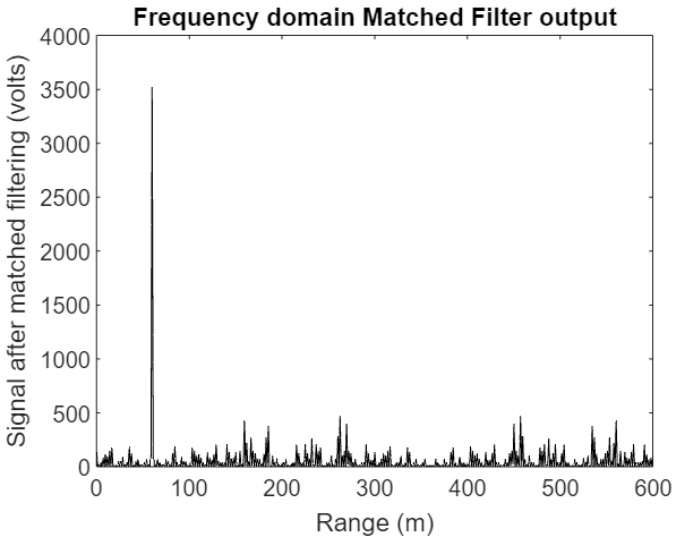


Peak-To-Side Lobe Ratio

Peak = 3520V
Side lobe = 393V
PSL Ratio = 3520:393 = 8.95
PSL Ratio in dB = 19.0430

After performing range estimation in Time domain using Matched filter by xcorr the range is coming out to be 59.923m, which is almost equal to 60m, which we have provided initially.

- **Frequency Domain Matched Filter**



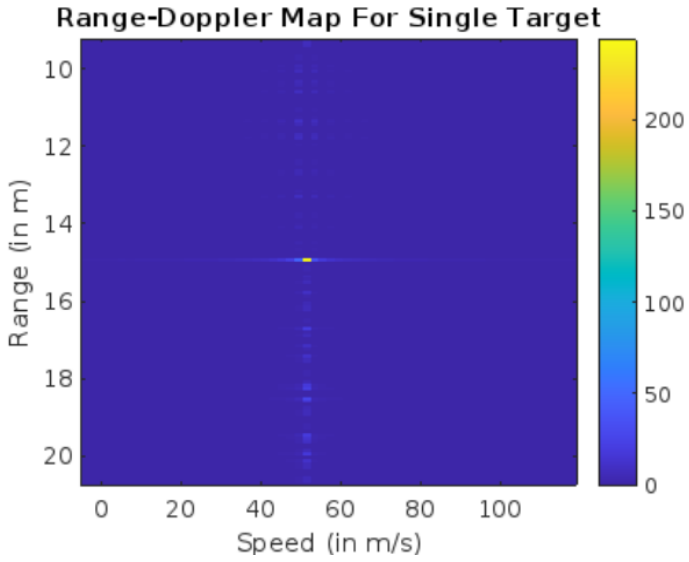
Peak-To-Side Lobe Ratio

Peak = 3520V
Side lobe = 393V
PSL Ratio = 3520:393 = 8.95
PSL Ratio in dB = 19.0430

After performing range estimation in Frequency domain using Matched filter the range is coming out to be 59.946m, which is almost equal to 60m, which we have provided initially.

- **2D Range Doppler For single Target**

For a target with range 15m and velocity 50m/s.



Peak to side Lobe Ratio

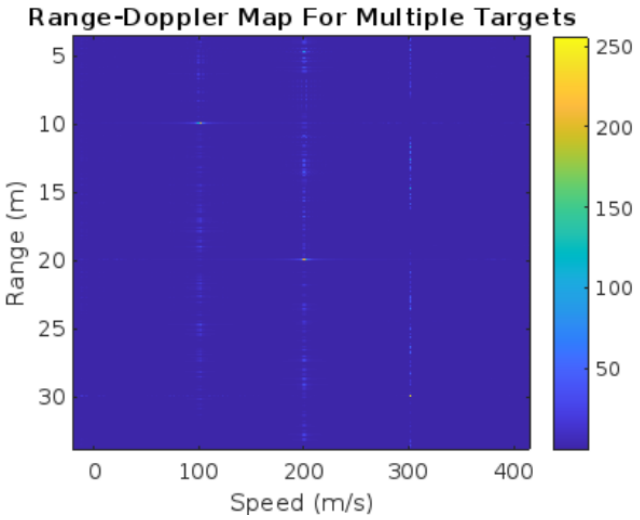
Value at bright spot: 244.179V
Value at side lobe: 49.56

PSLR = 244.179: 49.164 = 4.96
PSLR in dB = 13.8708

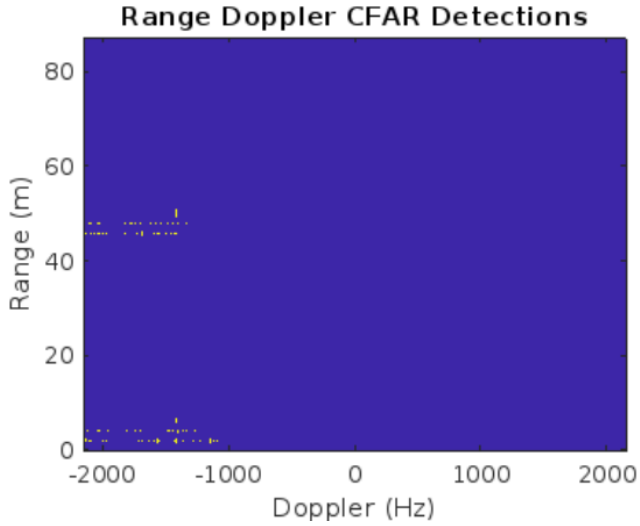
The bright spot is coming at speed 51.4282 m/s and range 14.9294m, considering the initial range and velocity we provided, the 2d range and doppler estimation is quite accurate.

- **2D Range Doppler For Multiple Target**

For 3 targets with ranges 10m, 20m & 30m and velocities 100m/s, 200m/s & 300m/s.



- **CFAR**



❖ Conclusion:

From the results for both golay sequence and doppler resilient golay sequence, The peak to side lobe ratio for golay sequence is lower in comparison to the doppler resilient golay sequence implying that the doppler resilient golay sequence has strong main lobe in comparison to the side lobes hence, it has good accuracy and higher resolution of radar measurements. Hence it indicates a good performance.

We saw how 2D range-Doppler processing is used in radar signal processing to detect moving targets in both range and velocity dimensions. Thus, having applications in surveillance and target-tracking radar systems.

We also looked into how the Range Doppler map can be further processed using CFAR (Constant False Alarm Rate) detection, to detect and track moving targets while minimizing the number of false alarms by coming up with an appropriate threshold. Overall, CFAR improves the performance of 2D range-Doppler processing by reducing false alarms, increasing the probability of detection, and improving the detection of weak targets in cluttered environments.

❖ Resources

1. https://in.mathworks.com/help/phased/ug/constant-false-alarm-rate-cfar-detection.html
2. https://in.mathworks.com/help/phased/ref/phased.cfardetector2d-system-object.html#bvevmd6-3