Principles of Classical and Modern Radar Systems
"Monostatic Pulse Radar for Complex Targets"

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1 Task 1-Phase Shifters

The phase shifter vector and the associate transmitter(Tx) and receiver(Rx) manifolds are computed using the following equations:

$$\underline{\psi} = \frac{2 \cdot \pi}{\lambda} \cdot \underline{r}_x \cdot cos(\theta) \tag{1}$$

$$\underline{Tx}_{manifold} = exp(i \cdot \psi) \tag{2}$$

$$\underline{Rx}_{manifold} = exp(-i \cdot \psi) \tag{3}$$

The phase shifter vectors for the steering angles 40°,70°,and 120°are shown below in Table 1.

40°	70°	120°
206.4640	85.6002	180.0000
344.3520	147.1639	90.0000
122.2400	208.7275	360.0000
260.1280	270.2911	270.0000
38.0160	331.8547	180.0000
175.9040	33.4184	90.0000
313.7920	94.9820	360.0000
91.6800	156.5456	270.0000
229.5680	218.1092	180.0000
7.4560	279.6729	90.0000
145.3440	341.2365	360.0000
283.2320	42.8001	270.0000
61.1200	104.3637	180.0000
199.0080	165.9274	90.0000
336.8960	227.4910	360.0000
114.7840	289.0546	270.0000
252.6720	350.6182	180.0000
30.5600	52.1819	90.0000
168.4480	113.7455	360.0000
306.3360	175.3091	270.0000
84.2240	236.8727	180.0000
222.1120	298.4364	90.0000
0.0000	0.0000	0.0000
137.8880	61.5636	270.0000
275.7760	123.1273	180.0000
53.6640	184.6909	90.0000
191.5520	246.2545	0.0000
329.4400	307.8181	270.0000
107.3280	9.3818	180.0000
245.2160	70.9454	90.0000
23.1040	132.5090	0.0000
160.9920	194.0726	270.0000
298.8800	255.6363	180.0000
76.7680	317.1999	90.0000
214.6560	18.7635	0.0000
352.5440	80.3271	270.0000
130.4320	141.8908	180.0000
268.3200	203.4544	90.0000
46.2080	265.0180	0.0000
184.0960	326.5816	270.0000
321.9840	28.1453	180.0000
99.8720	89.7089	90.0000
237.7600	151.2725	0.0000
15.6480	212.8361	270.0000
153.5360	274.3998	180.0000

Table 1: Phase shifter vector in degrees

The array pattern for the steering angles 40°,70°,and 120°are plotted below.

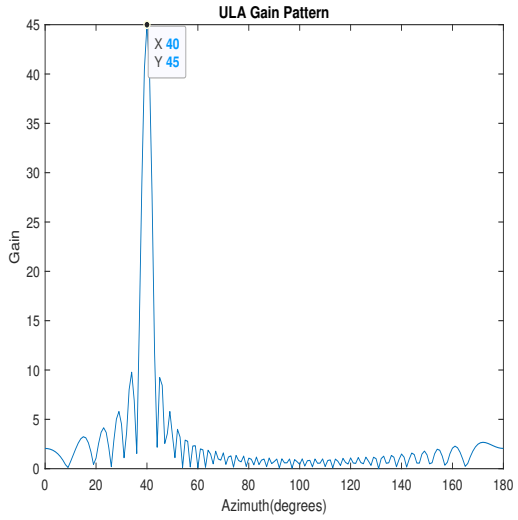

Fig. 1: Linear pattern plot for 40°

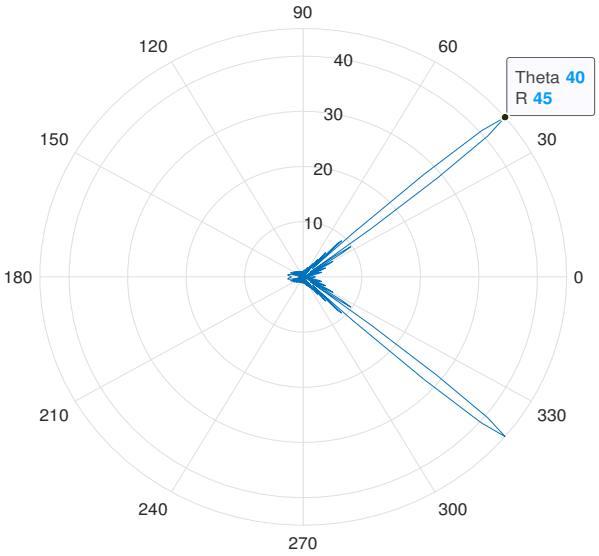

Fig. 2: Polar pattern plot for 40°

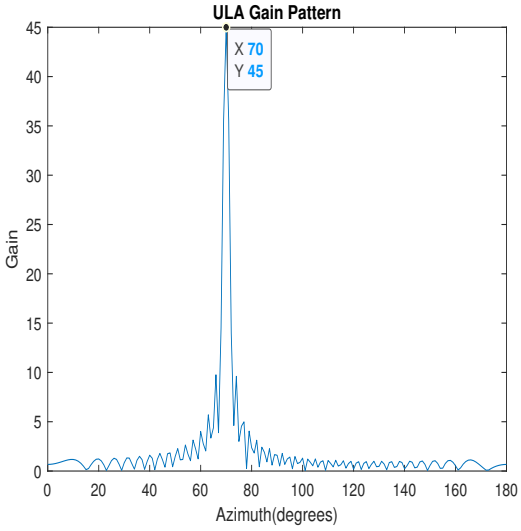

Fig. 3: Linear pattern plot for 70°

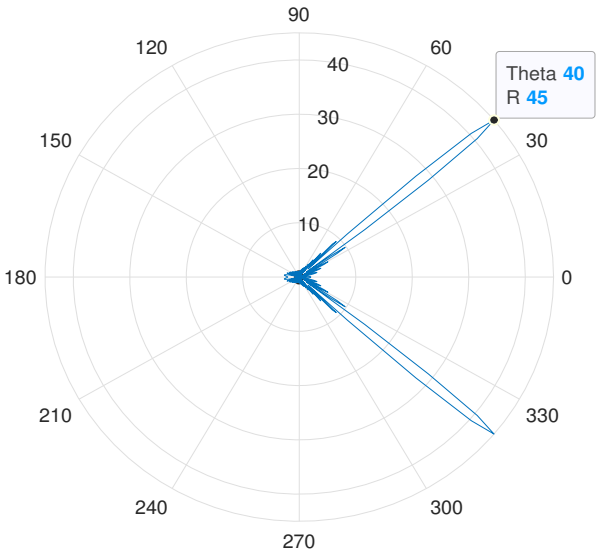

Fig. 4: Polar pattern plot for 70°

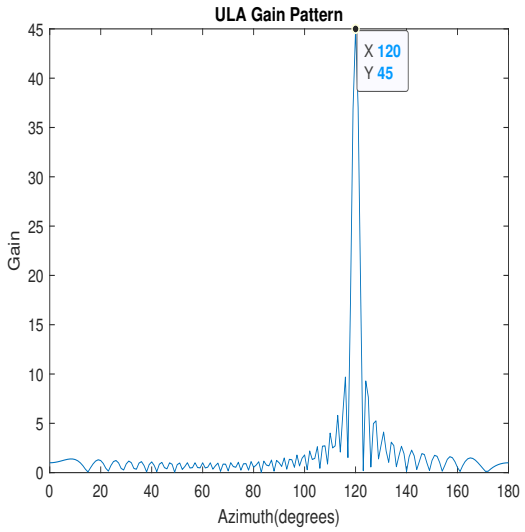

Fig. 5: Linear pattern plot for 120°

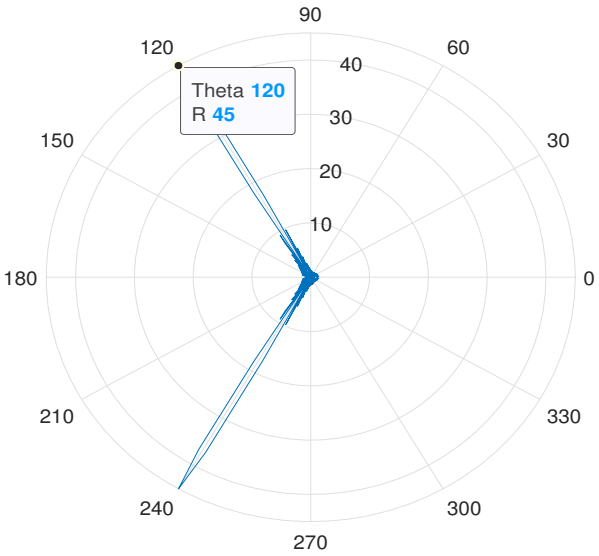

Fig. 6: Polar pattern plot for 120°

2 Task 2-Backscatter Modelling Function

The backscatter modelling function is provided in the submitted MATLAB files and follows the diagram shown in Figure 7.

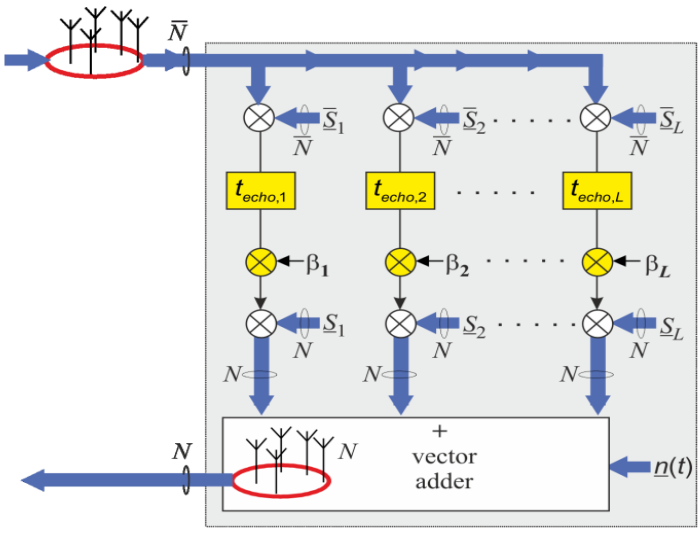

Fig. 7: Backscatter function diagram

3 Task 3-First Scan-No Targets

The noise samples at the baseband Rx ports are generated with the noise power defined in the following equation:

$$P_{noise} = k_B \cdot T_o * F_n * B \tag{4}$$

where:

- $k_B = 1.28 \cdot 10^{-3}\ m^2\ kg\ s^{-2}\ K^{-1}$
- $T_o = 290°\text{K}$
- $F_n = 3.1068$
- $B = \frac{1}{Tc} = 3.5714 \cdot 10^7$ Hz

The noise power is thus equal to $P_n = 4.1187 \times 10^{-13}$.
The magnitude of the noise snapshots at point Z for one Dwell-time is plotted in Figure 8.

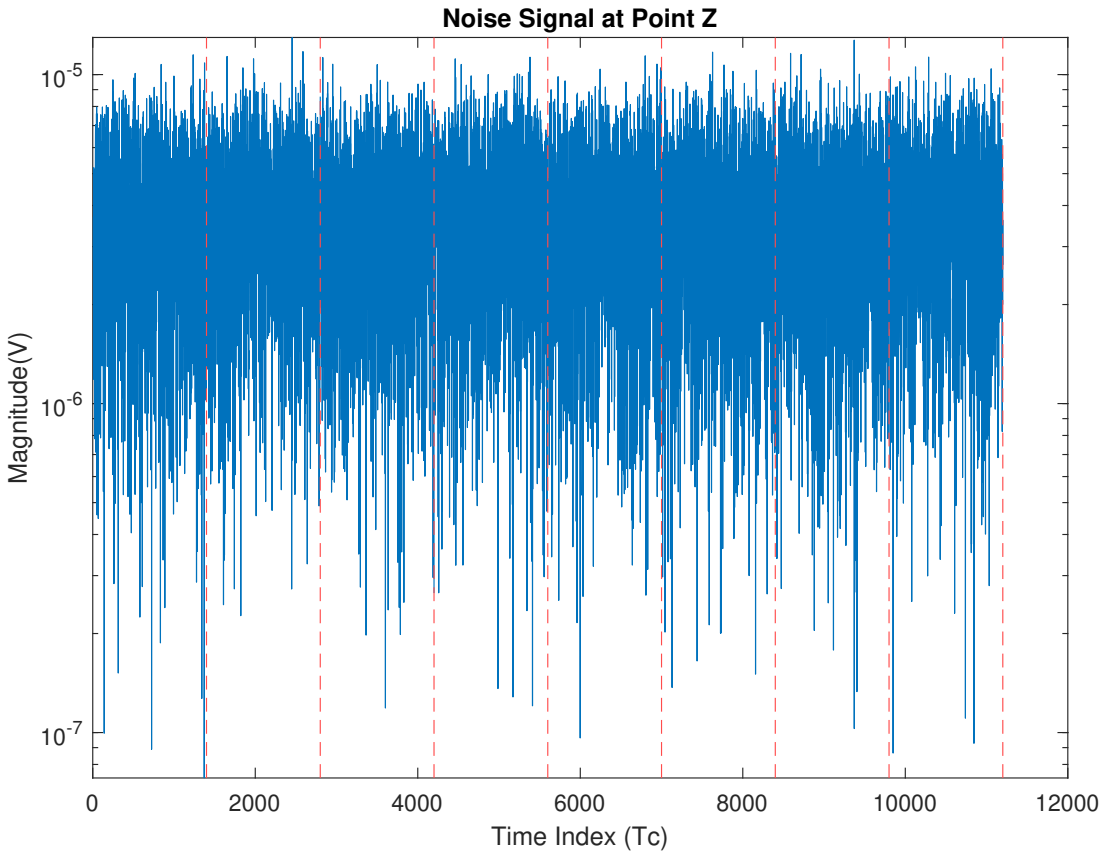

Fig. 8: Magnitude of noise samples at point Z

The power of the noise signal at point Z is estimated using the equation $P_{n,est} = \frac{1}{L} \cdot \underline{n}(t) \times \underline{n}^H(t)$ and is found equal to $P_{n,est} = 1.8842 \times 10^{-11}$. The magnitudes of the noise samples follow a Rayleigh distribution. This is confirmed by plotting the a theoretical Rayleigh Probability Density Function(PDF) with the estimated noise power as its parameter. The samples' histogram and the theoretical distribution are illustrated in Figure 9.

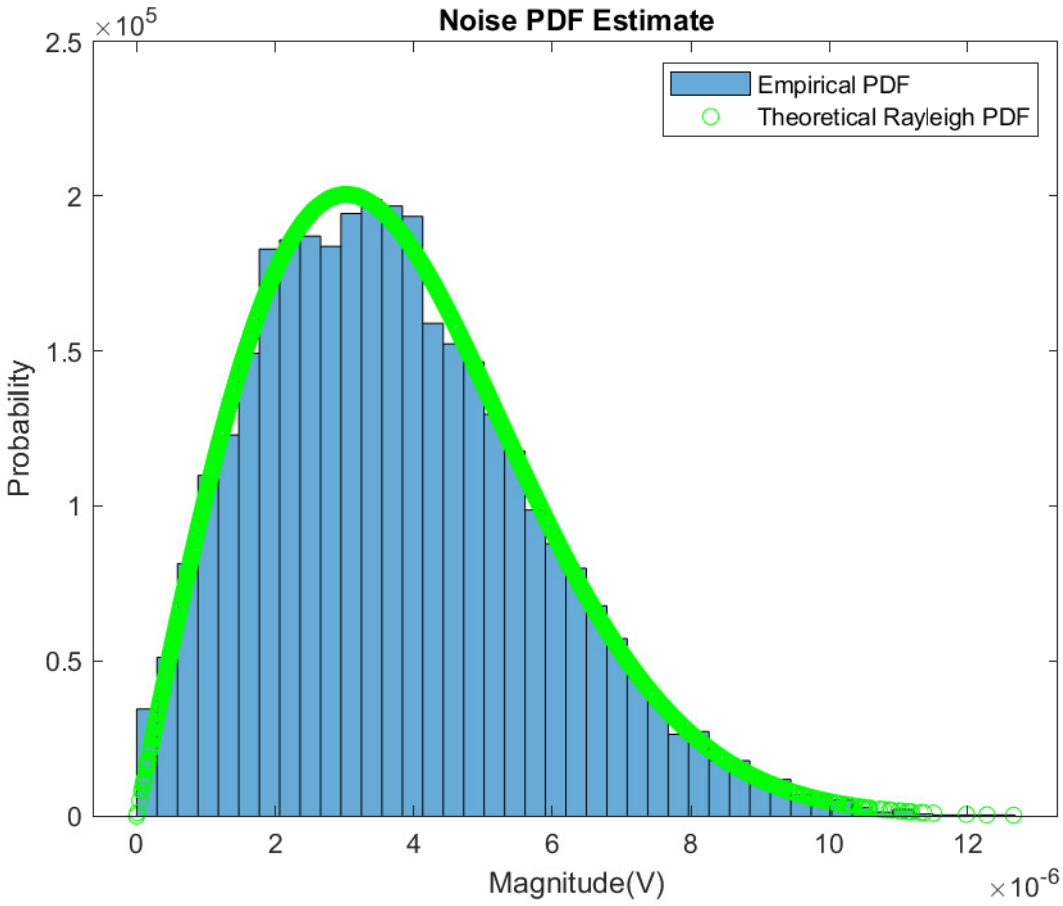

Fig. 9: Histogram of noise samples and Rayleigh PDF

The transmission of a pure noise signal allows us to determine a threshold value using the probability of false alarm, which is specified as $P_{FA} = 10^{-3}$. Because of the randomness of noise samples, the threshold varies between 2×10^{-6} V and 9×10^{-6} V.

4 Task 4-Second Scan-One Target

According to the brief, the radar searches for targets in the range between 30°and 150°. An angle sweep in this range is thus performed. For each angle, the maximum of the received signal at point Z is found. The resultant vector is plotted in Figure 10.

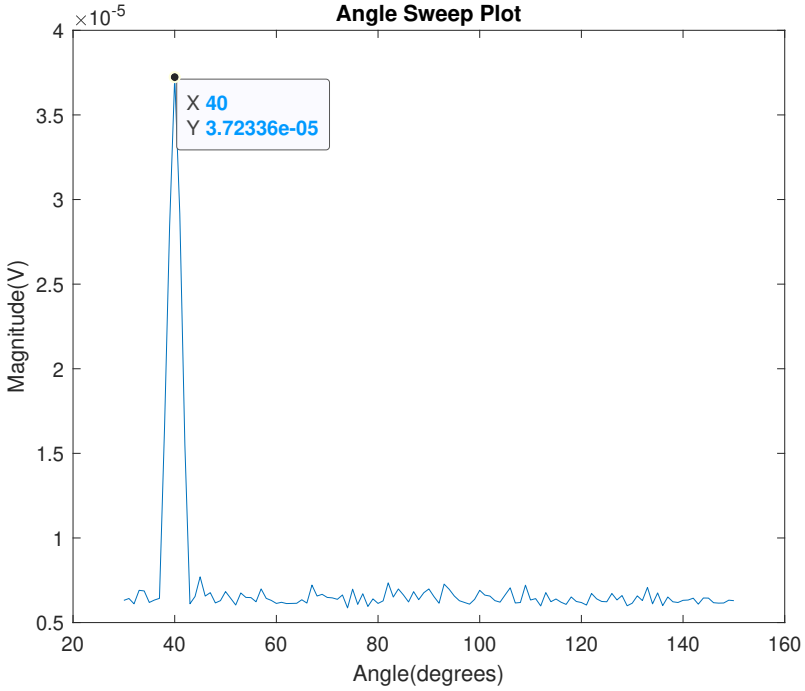

Fig. 10: Sweep for second scan

It can be concluded from this plot that there is a target present in the direction $\theta = 40°$. The received signal for this angle is plotted in Figure 11.

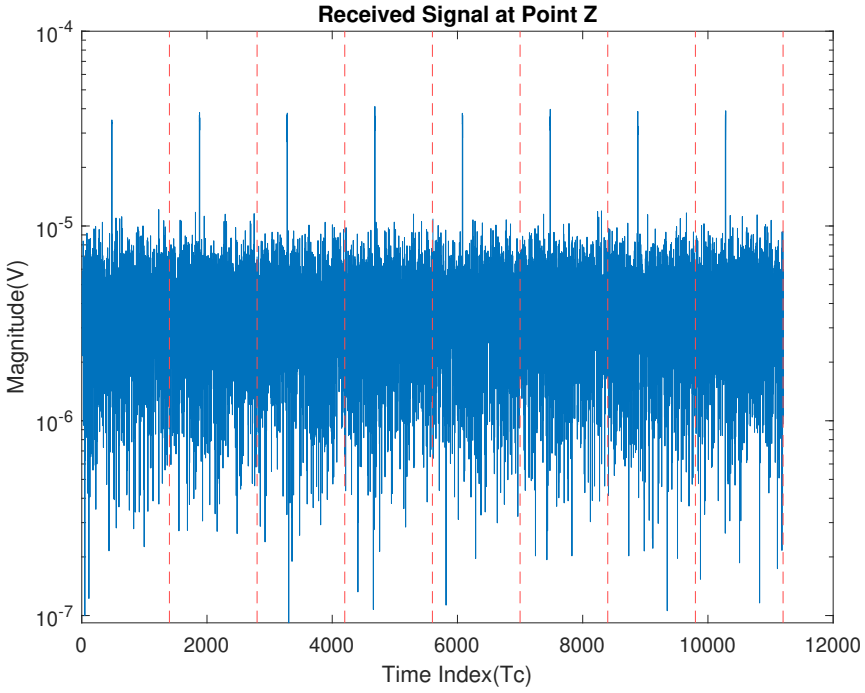

Fig. 11: Signal at point Z at angle 40°

Figure 12 shows the signal following matched filtering.

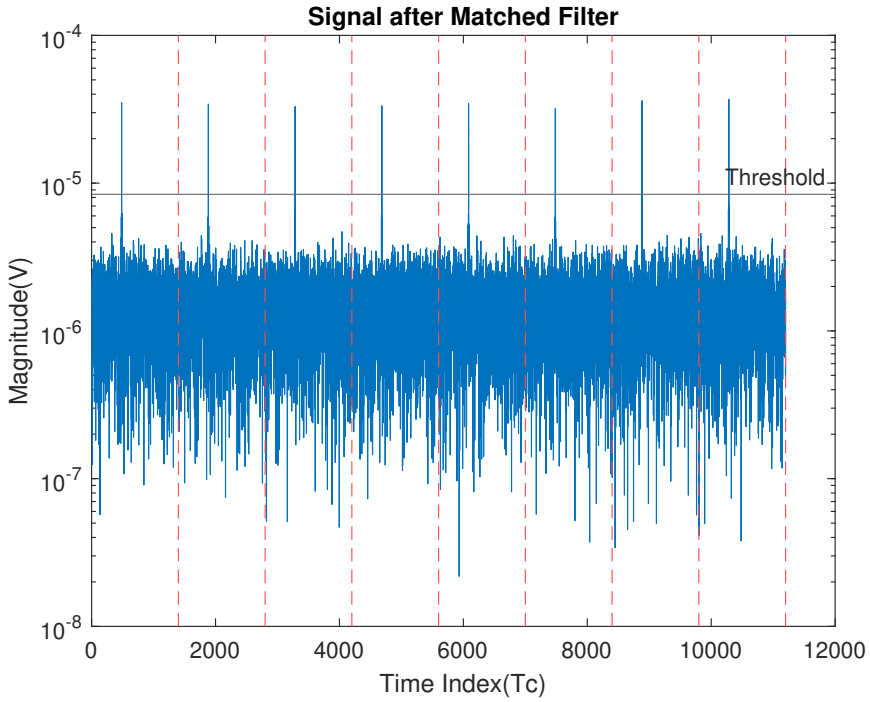

Fig. 12: Target 1 signal after matched filtering

The matched filter boosts the output signal's Signal-to-Noise Ratio (SNR) by reducing the effect of noise. Assuming only knowledge of the received signal at point Z, the parameters of target 1 are estimated. Given that $Tc = 28 \times 10^{-9}$, the range resolution is computed as $\Delta_R = \frac{cT_c}{2} = 4.2$ m. After matched filtering, a threshold in the range discussed in Section 3 is applied and the average of the signal across the 8 PRIs is found and plotted in Figure 13.

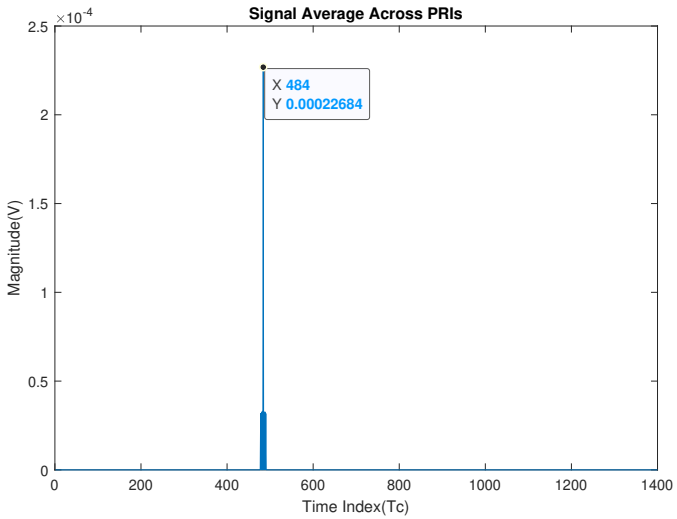

Fig. 13: Signal at 40°angle after matched filtering and thresholding

Matched filtering is implemented through discrete convolution, which introduces a delay of 7 (equal to the length of the modulation pulse). Therefore, t_{echo} is found equal to 1.3356×10^{-5} s. The estimated values for the round trip time,direction, range, and RCS are listed in Table 2.

Parameters	Target 1
t_{echo}	1.3356×10^{-5} s
Direction	40°
Range	2,003.4 m
RCS	1.03

Table 2: Task 4 Estimated Parameters

5 Task 5-Third Scan-Two Targets

The result of the angle sweep in the range [30°,150°] is depicted in Figure 14. It indicates that there are two targets present at angles $\theta_1 = 40°$and $\theta_2 = 70°$.

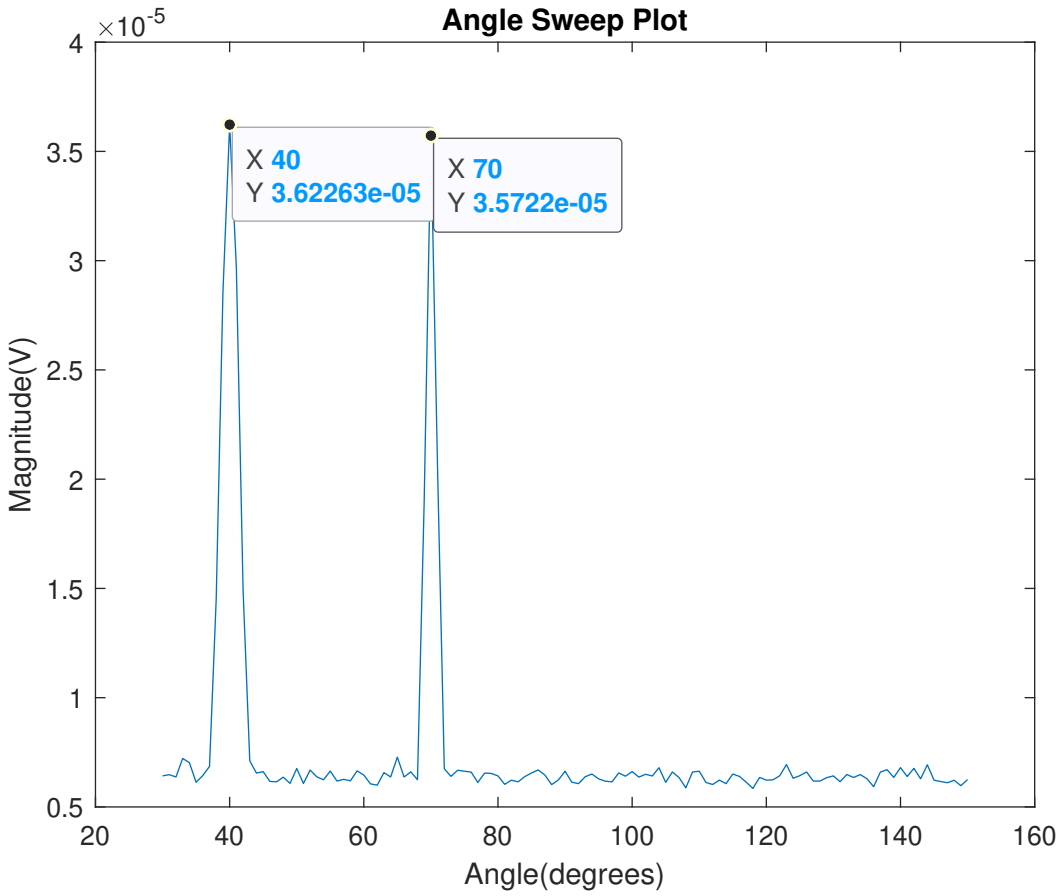

Fig. 14: Angle sweep for task 5

The signal at point Z for both directions is plotted in Figure 15.

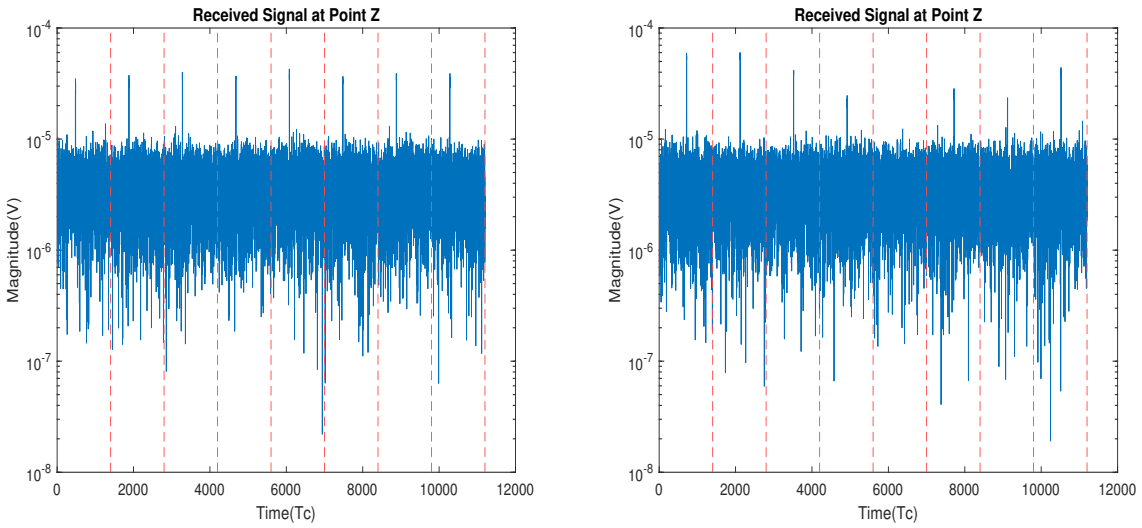

Fig. 15: (a)Point Z-40°angle (b)Point Z-70°angle

The round trip time is found in the same way as Task 4 for both targets. The second target features scatterers of similar amplitudes, which leads to a RCS value that varies across PRIs. Therefore, the estimated RCS value for the second target varies in every trial. The RCS values obtained at the time of writing are shown in Figure 16. Table 3 lists the estimated parameter values for targets 1 and 2.

Parameters	Target 1	Target 2
t_{echo}	1.3356×10^{-5} s	2.002×10^{-5} s
Direction	40°	70°
Range	2,003.4 m	3,003 m
RCS	1.03	5.1541

Table 3: Task 5 Estimated Parameters

```
Estimated RCS are:
    1.0030
    5.1541
```

Fig. 16: Task 5 RCS estimates

6 Task 6-Fourth Scan-Three Targets

The result of the angle sweep in the range [30°,150°] is depicted in Figure 17. It is evident that there are three targets present at angles $\theta_1 = 40°$, $\theta_2 = 70°$, and $\theta_3 = 120°$.

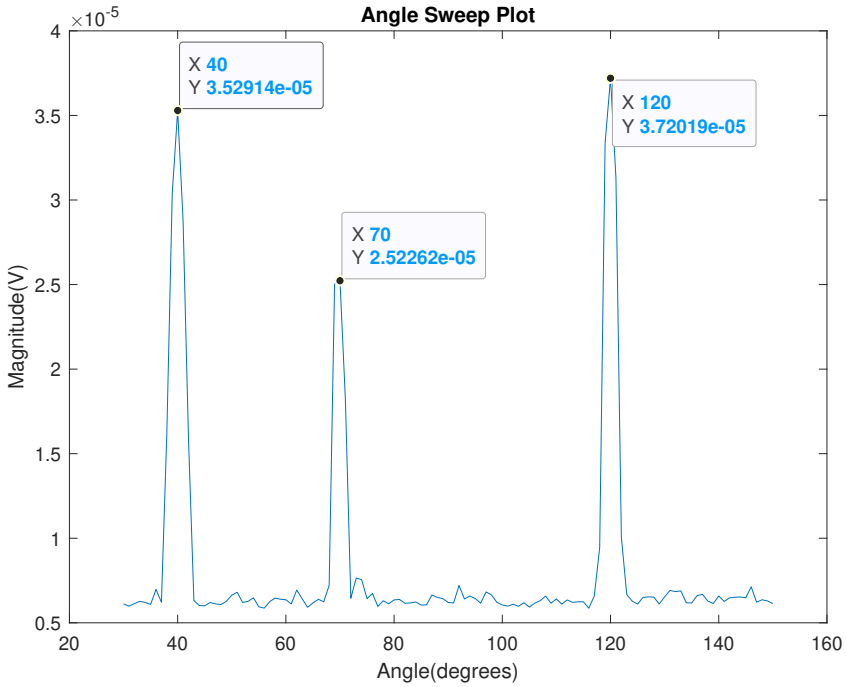

Fig. 17: Angle sweep for task 6

The signal for each target direction is plotted in Figure 18, 19 and 20.

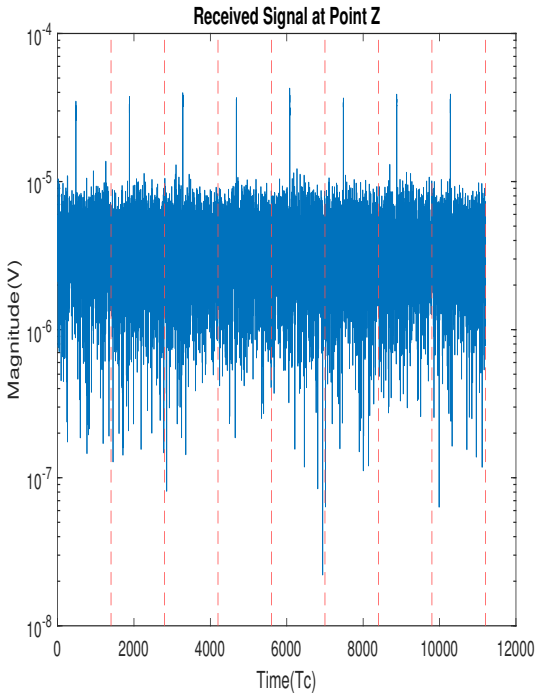

Fig. 18: Point Z-40°angle

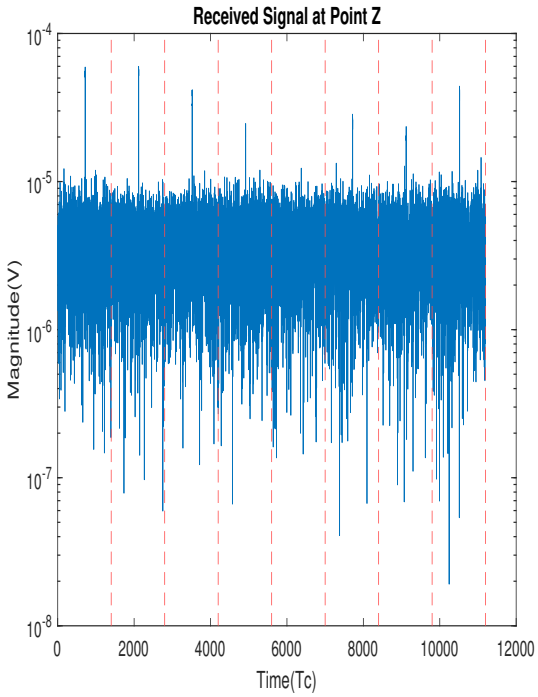

Fig. 19: Point Z-70°angle

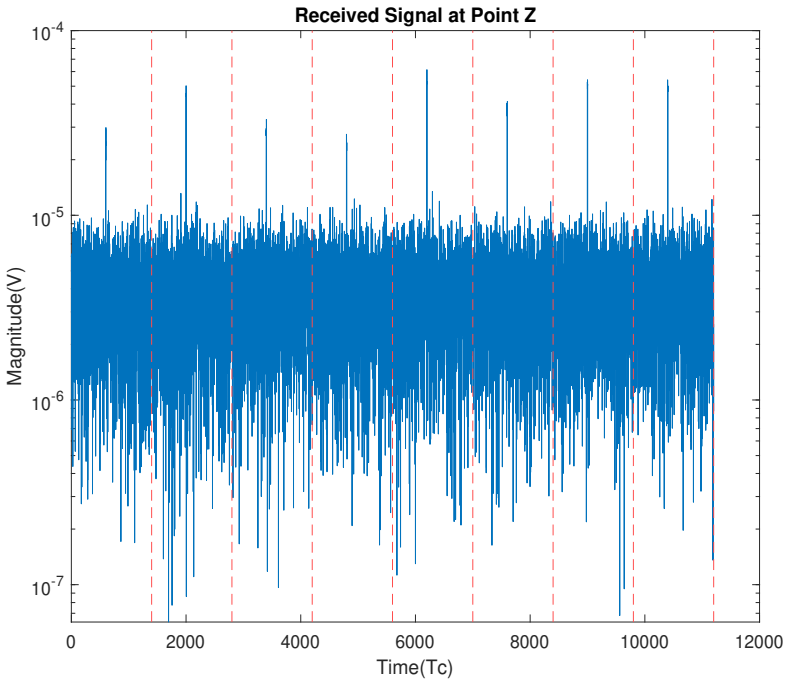

Fig. 20: Point Z-120°angle

Target 3 has a scatterer of much larger size than the rest, which means that RCS varies across PRIs. Hence, the estimated RCS value for target 3 is not constant across trials. A close estimate of the third target's RCS is shown in Figure 21.Table 4 shows the estimated parameter values for the three targets.

Parameters	Target 1	Target 2	Target 3
t_{echo}	1.3356×10^{-5} s	2.002×10^{-5} s	1.6685×10^{-5}s
Direction	40°	70°	120°
Range	2,003.4 m	3,003 m	2,500.3 m
RCS	1.03	5.1541	4.4730

Table 4: Task 6 Estimated Parameters

```
Estimated RCS are:
    1.0067
    3.1070
    4.4730
```

Fig. 21: Task 6 RCS estimates

7 Task 7-Radar Data- Multi-target Detection and Parameter Estimation

Using the provided backscatter data, a full angle sweep is first performed to identify targets' directions. From the plot in Figure 22, it can be seen that there are targets present in the direction $\theta = 137°$.

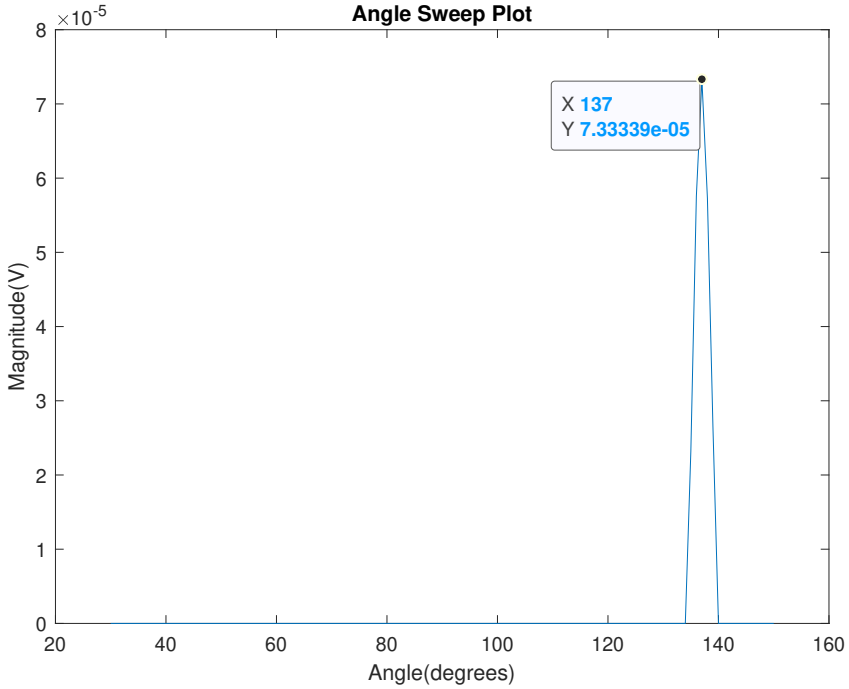

Fig. 22: Task 7 angle sweep

The received signal at point Z and the signal obtained after applying the matched filter and the threshold, and averaging across PRIs is shown in Figure 23 and 24.

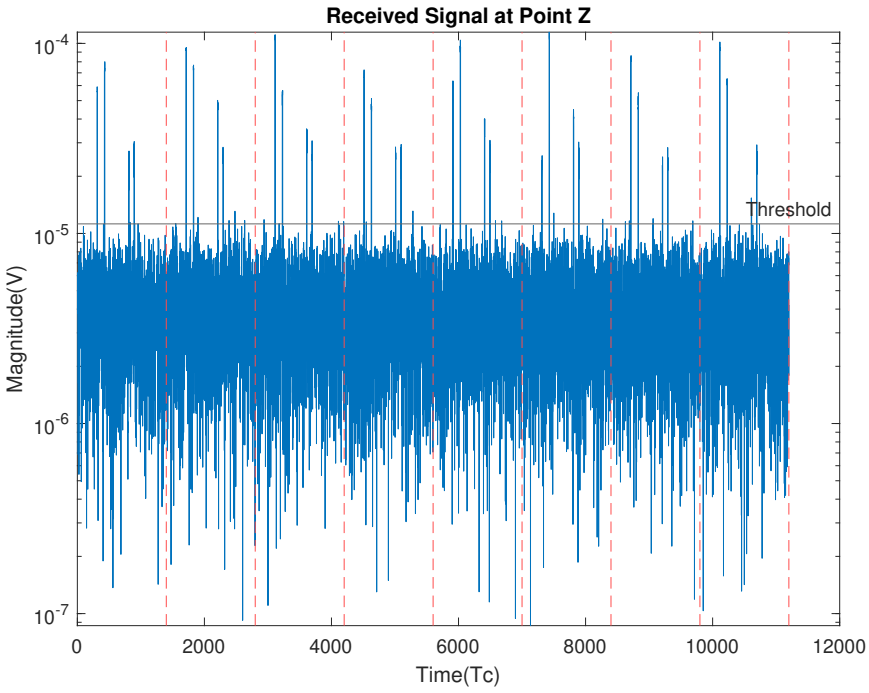

Fig. 23: Received signal at point Z-137°angle

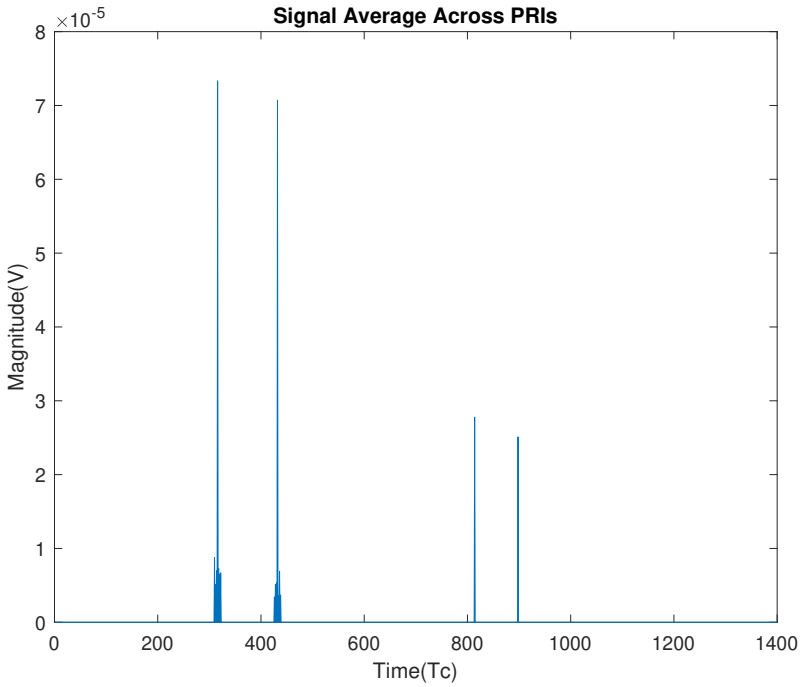

Fig. 24: Received signal averaged across PRIs

From Figure 24, it can be concluded that there are 4 targets present. Table num lists the estimated parameter values for each target.

	Target 1	Target 2	Target 3	Target 4
t_{echo}	8.652×10^{-6} s	1.19×10^{-5} s	2.2596×10^{-5} s	2.4948×10^{-5} s
Direction	137°	137°	137°	137°
Range	1,297.8 m	1,785 m	3,389.4 m	3,742.2 m
RCS	0.8203	2.7305	5.4763	6.6429