Imperial College London
Electrical & Electronic Engineering

Monostatic Pulse Radar for Complex Targets

Principles of Classical & Modern Radar Systems Coursework

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1 Task 1 - Phase Shifters

Estimate the vectors of Tx and Rx phase-shifter for the following steering directions: 40, 70 and 120 degrees.

The equation for ψ for a given angle θ is provided below:

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

The equation for the phase shifters is then provided by the following:

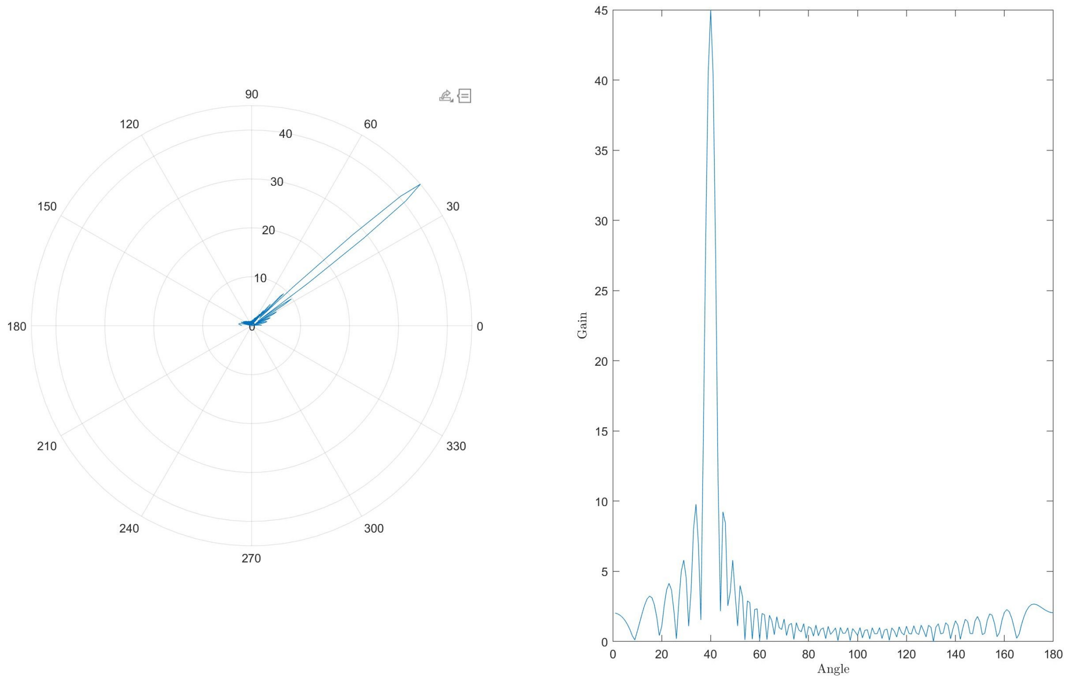
$$\text{phase shifter}_{Rx} = \exp\left(+j\ \psi\right)$$
$$\text{phase shifter}_{Tx} = \exp\left(-j\ \psi\right)$$

Using the above equations, the phase shifters are displayed on the next page in degrees.

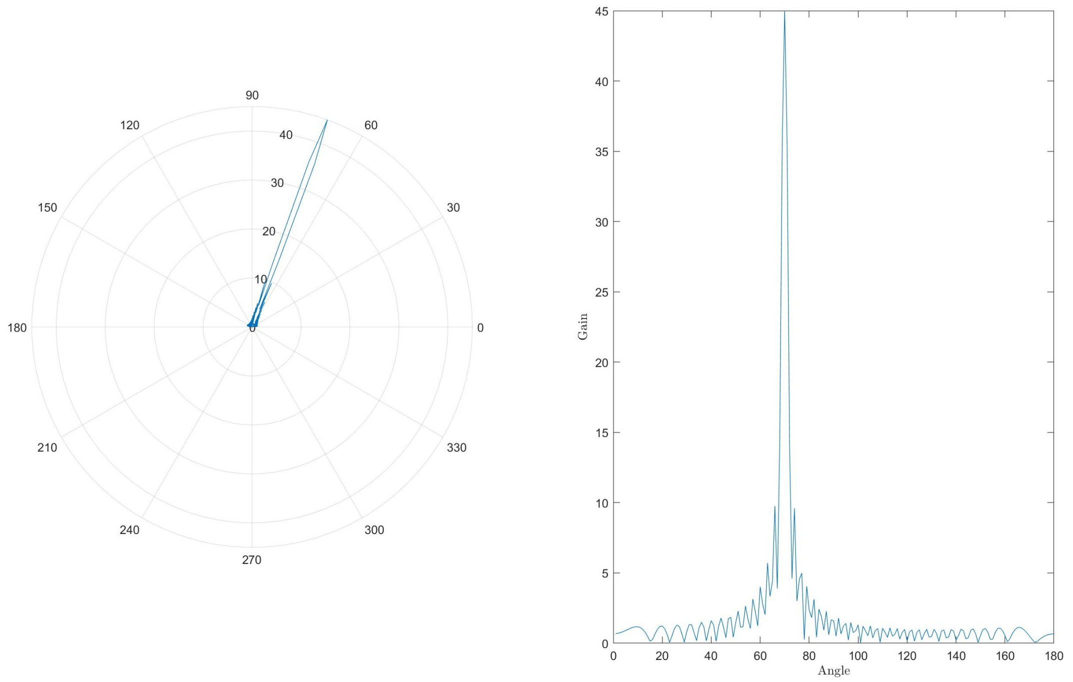
Phase Shifters - Rx			Phase Shifters - Tx		
40^o	70^o	120^o	40^o	70^o	120^o
206.4640	85.6002	180.0000	153.5360	274.3998	180.0000
344.3520	147.1639	90.0000	15.6480	212.8361	270.0000
122.2400	208.7275	0.0000	237.7600	151.2725	360.0000
260.1280	270.2911	270.0000	99.8720	89.7089	90.0000
38.0160	331.8547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

Using the above phase-shifters, plot the array patterns for these three directions:

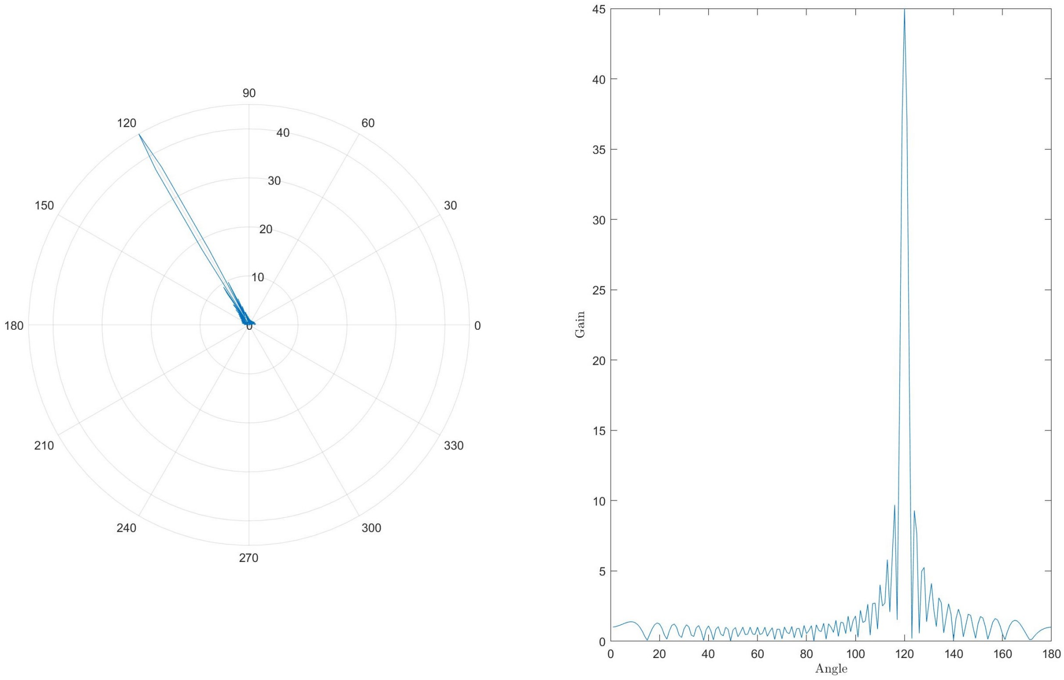
ULA Radar - Steering Angle of 40 degrees



ULA Radar - Steering Angle of 70 degrees



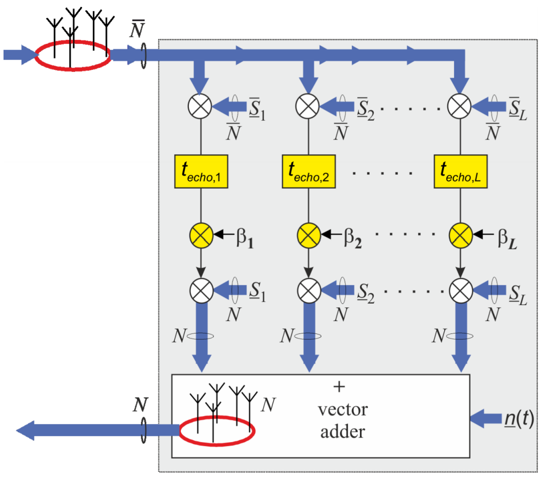
ULA Radar - Steering Angle of 120 degrees



2 Task 2 - Backscattering Function

Write a matlab function to generate the backscatter data for a given steering direction:

The backscattering function was written to according to the model provided in the figure shown below:



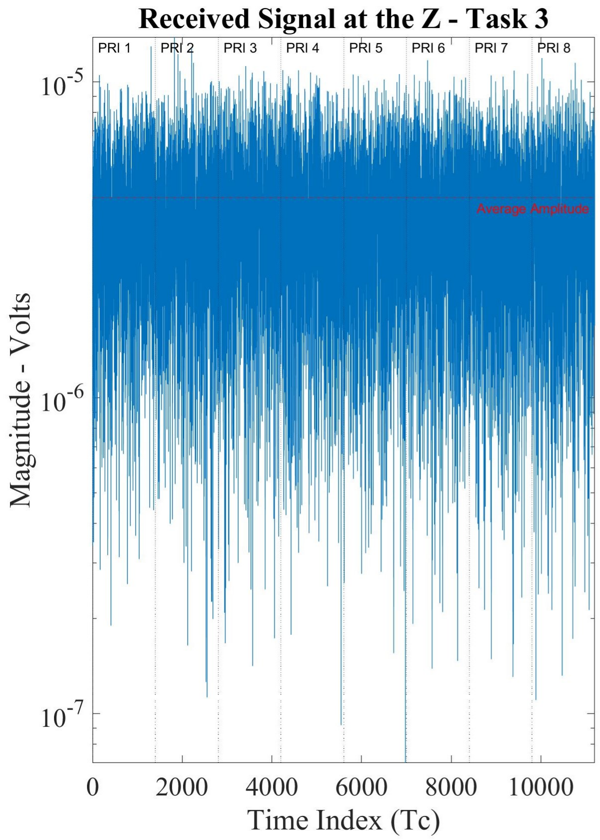
The full function has been provided in the matlab files, and is commented with explanations regarding what is taking place.

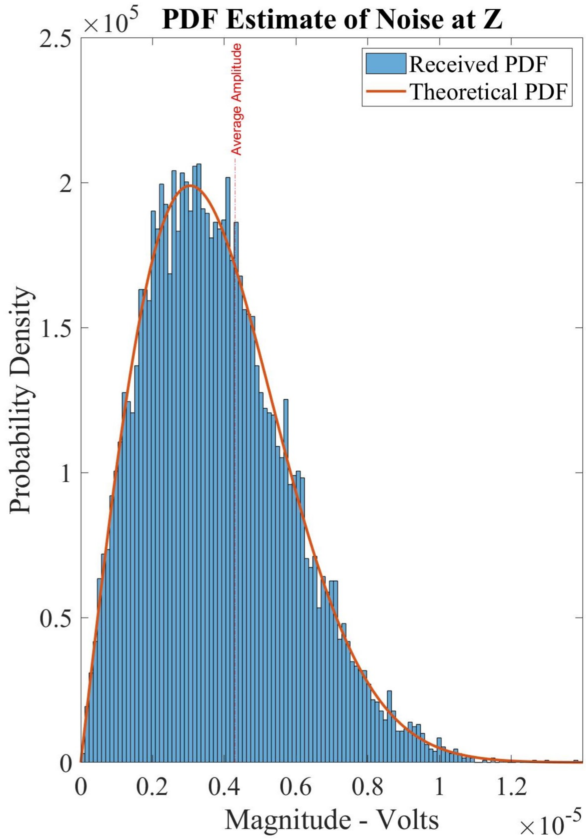
3 Task 3 - First Scan, No Targets

Within this section, no targets are present and so only noise is received.

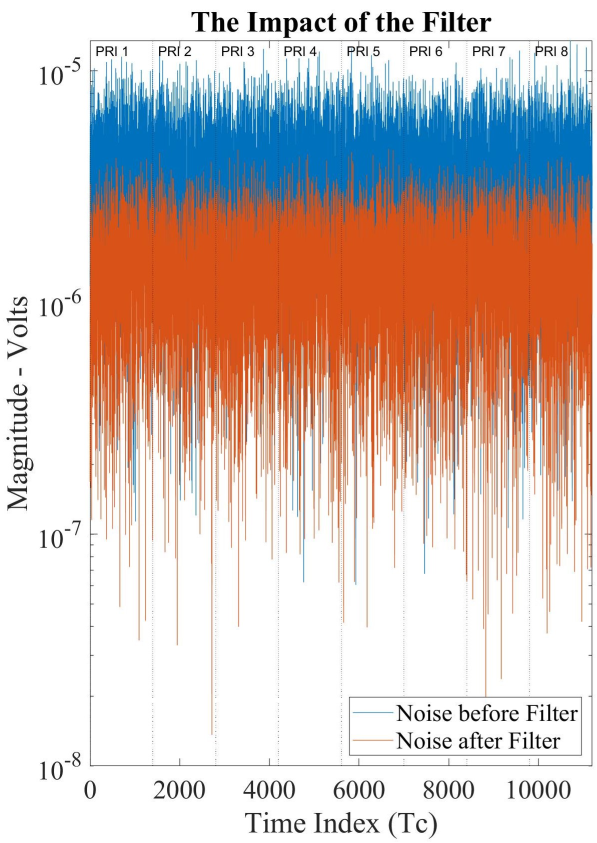
$$n(t) = \sqrt{\frac{P_n}{2}}\,(\,randn(45, 11200) + j\;randn(45, 11200))$$

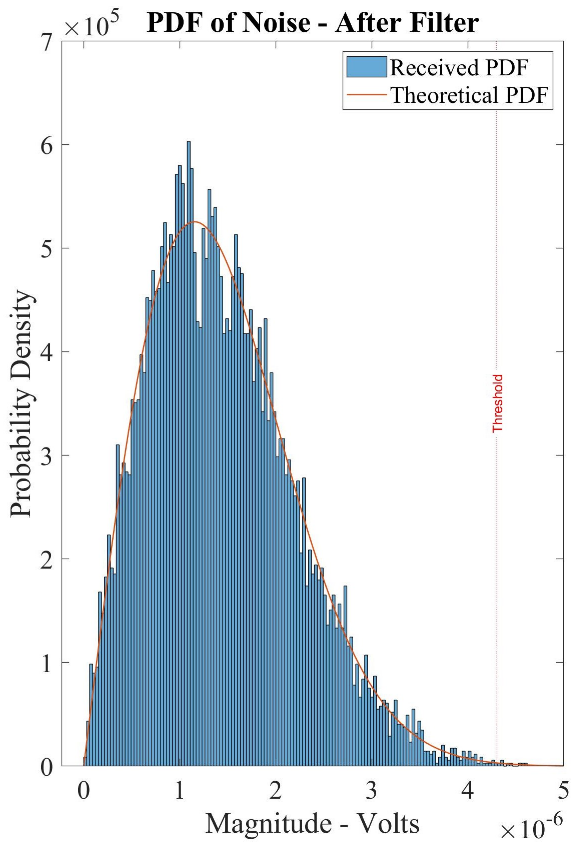
Added noise at the is calculated with method above. The subsequent matrix is what is seen at the baseband port of the receiver. Here, $P_n = K_b\ F_n\ T_o\ B$, where K_b is the Boltzmann constant, F_n is the noise factor (equal to 3.1068 according to the specification), T_o is the noise reference temperature ($290^\circ\ K$), and B is the bandwidth. The received signal at Point Z is shown below:





The noise power was calculated by taking the inner product of the received signal with itself (multiply the received vector with its transpose to get a singular value), and then dividing this number by the total number of elements present (11200). This gave an power of approximately 1.85×10^{-11}, which is equivalent to 45 P_n. Using this, one can then obtain the theoretical probability density function of the received noise as being a Rayleigh distribution, with b equal to $\sqrt{\frac{45\ P_n}{2}}$. This was used to then verify the received empirical pdf using the histogram function on MATLAB. As can be seen, the empirical Rayleigh PDF is good estimate when compared to the theoretical PDF.

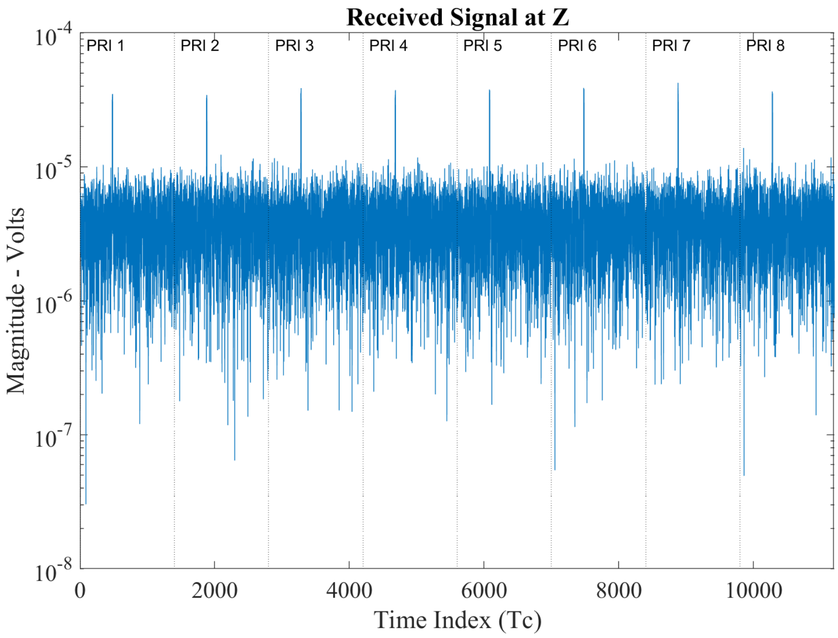




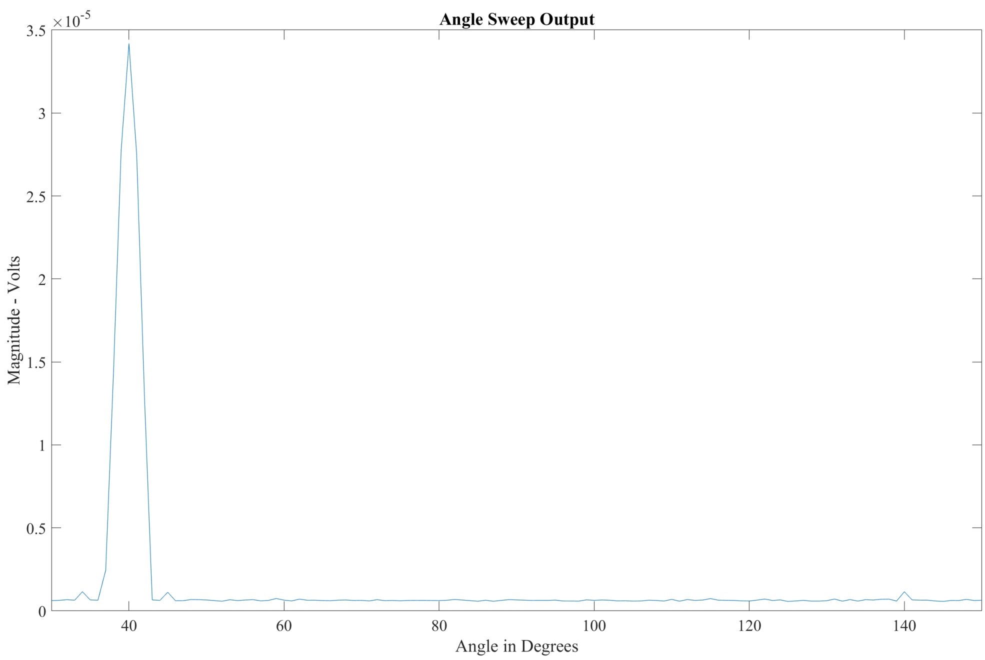
It can be noted that the noise distribution changes after the matched filter. As can be seen in the figure below, the power of noise reduces after the filter. However, the pdf remains a Rayleigh distribution. This is as expected, given the real and imaginary parts of the noise are normally distributed, which will remain the same after any LTI system. Like before, the noise power was derived and a theoretical pdf was hypothesised, and was similar to the empirical pdf that was obtained. Lastly, the false alarm magnitude was obtained as per the specification, by finding the value where where the CDF of the theoretical Rayleigh distribution was equal to 0.999.

4 Task 4 - Second Scan, One Target

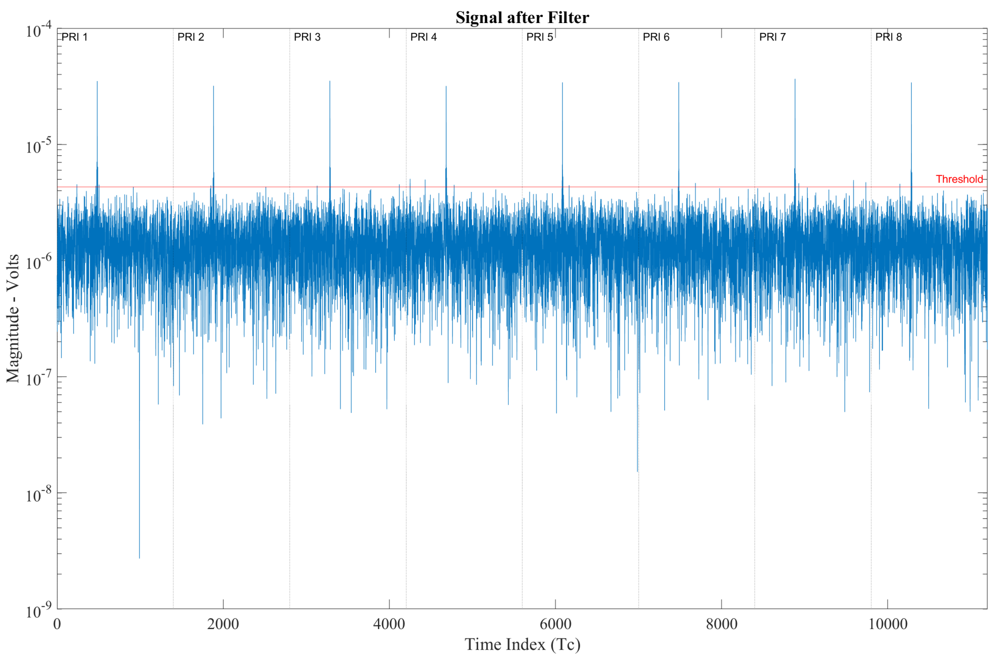
In this section, a single target (Target 1) is present at 40^o. Backscatter data was generated using the function made for Task 2, and the received signal at Point Z is plotted below:



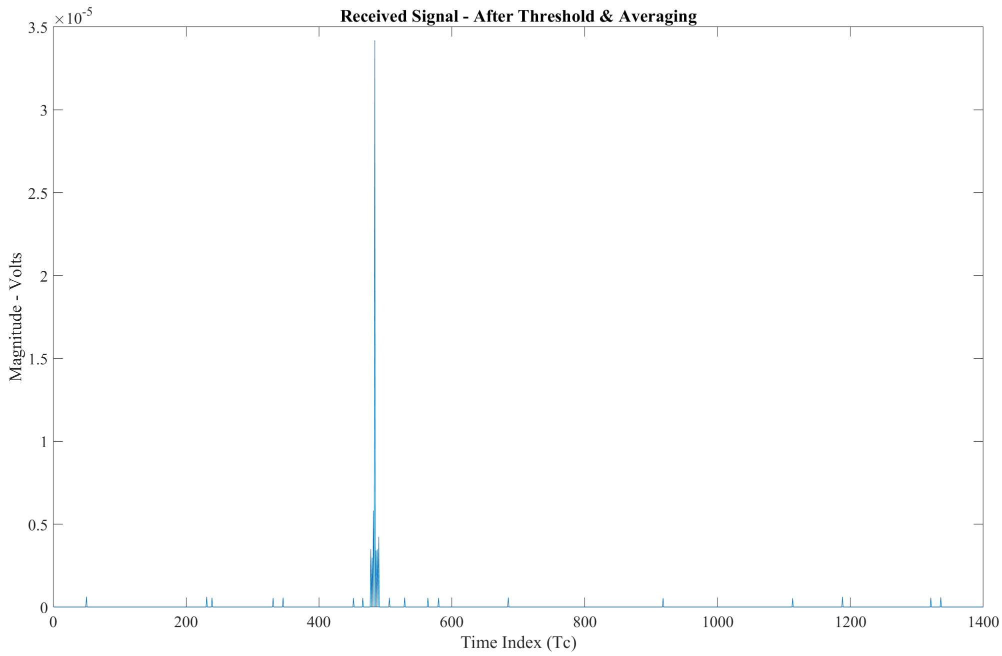
From this moment on, the target characteristics are assumed to be unknown. Using the backscatter data, a full angle sweep was modelled, and the peak amplitude at each angle was plotted:



From this, it was concluded that a target was present at 40^o. A closer look was taken at the backscatter data at this angle. The received information at this angle after the filter is plotted below:



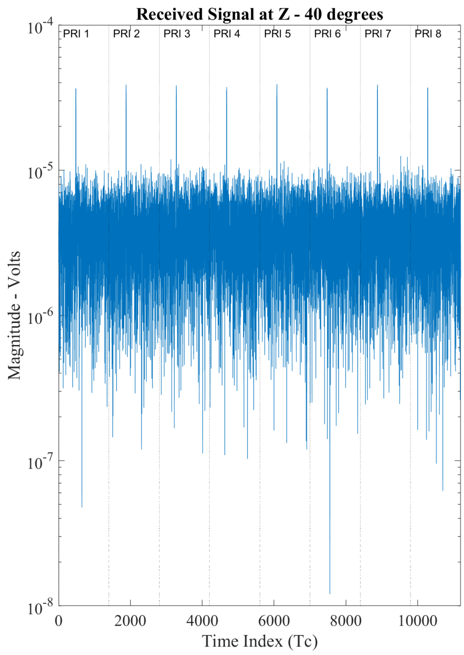
The signal is then evaluated against the threshold, before the data is averaged across the eight PRI. The final plot is shown below:

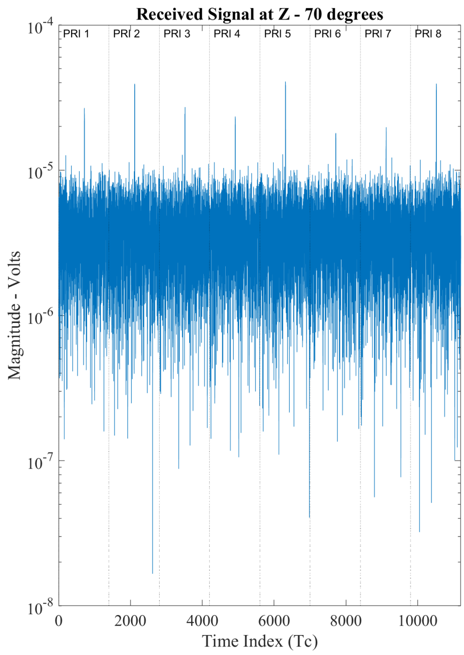


It is clear that there is one distinct target at this angle. The range was estimated with t_{delay} (this was calculated as the index of the greatest value within of the correlation pattern of the received signal, and subtracting it by seven (the convolution produces a peak seven time indexes after the beginning of the recevied pulse). For this target, **the range was estimated to be approximately 2003m**. Using this estimated range and the peak amplitude, **the RCS was estimated to be approximately 1.01**.

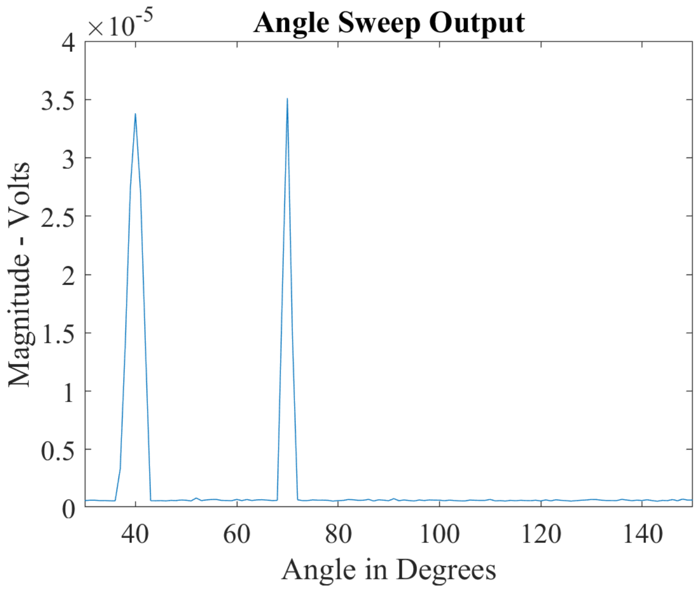
5 Task 5 - Third Scan, Two Targets

In this section, two targets (Targets 1 and 2) are present at 40^o and 70^o respectively. Backscatter data was generated using the function made for Task 2, and the received signals at Point Z for azimuths 40^o and 70^o are plotted below:





From this moment on, the target characteristics are assumed to be unknown. Using the generated backscatter data, a full angle sweep was modelled, and the peak amplitude at each angle was plotted:

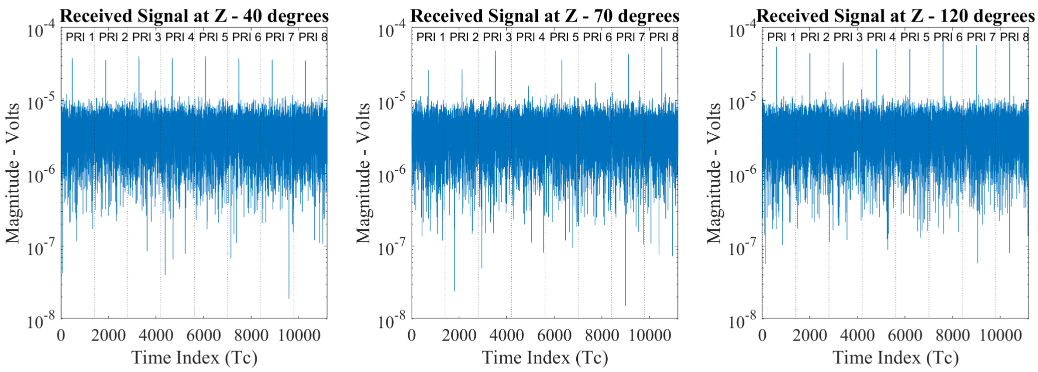


From this, it was concluded that there are targets present at 40^o and 70^o. The received information at 70^o was passed through the filter, before being evaluated against the threshold, and finally averaged across the eight PRI, as in Task 4. The same process was repeated for the target at 40^o. The received amplitudes and their estimates are shown in the table below:

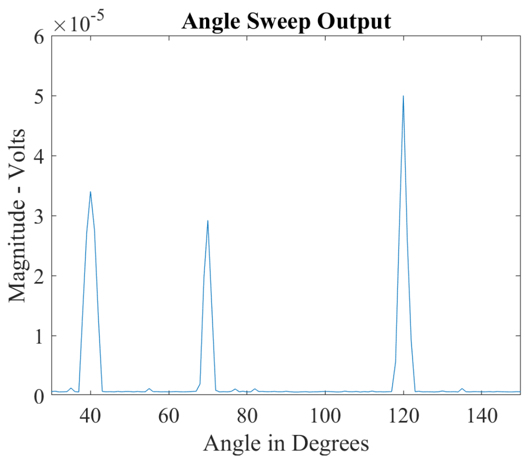
Target	Angle(^{o})	Received Amplitude (V)	Estimated Range(m)	Estimated RCS (m^2)
1	40	3.38×10^{-5}	2003.4	0.99
2	70	3.51×10^{-5}	3003	5.39

6 Task 6 - Fourth Scan, Three Targets

In this section, all three targets (Targets 1,2 and 3) are present at 40^o, 70^o, and 120^o respectively. Backscatter data was generated using the function made for Task 2, and the received signals at Point Z for azimuths 40^o 70^o and 120^o are plotted below:



From this moment on, the target characteristics are assumed to be unknown. Using the generated backscatter data, a full angle sweep was modelled, and the peak amplitude at each angle was plotted:

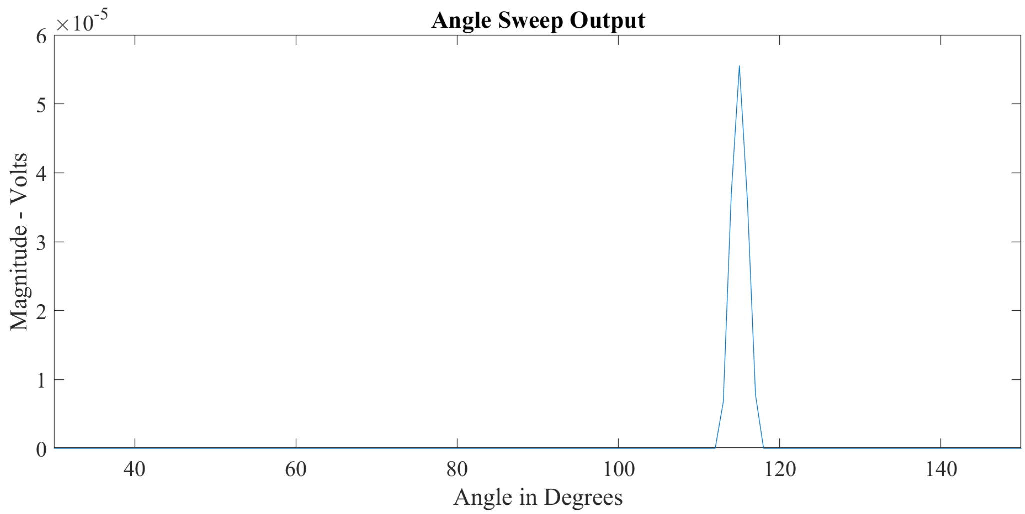


From this, it was concluded that there are targets present at 40^o and 70^o and 120^o. The received information at each angle was passed through the filter, before being evaluated against the threshold, and finally averaged across the eight PRI. The final results are shown in the table below:

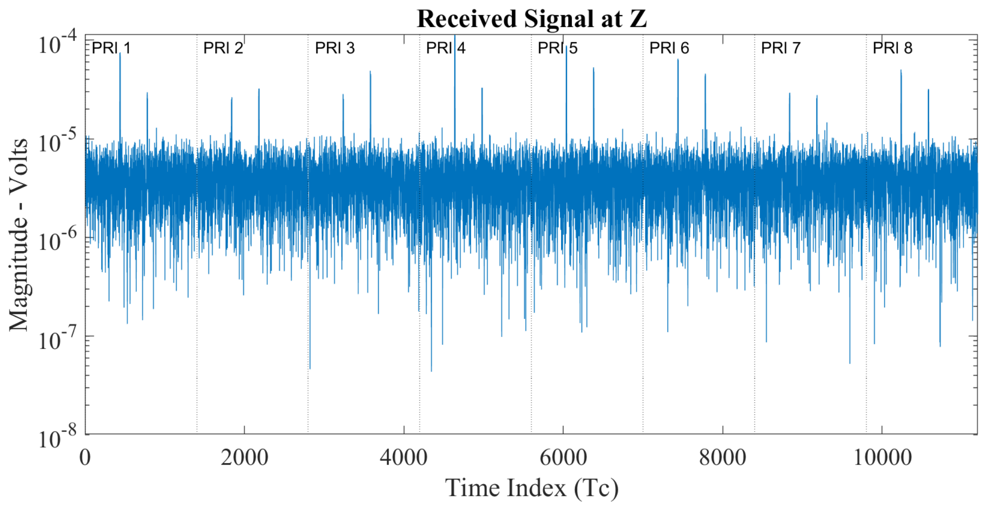
Target	Angle(^{o})	Received Amplitude (V)	Estimated Range(m)	Estimated RCS (m^2)
1	40	3.40×10^{-5}	2003.4	0.99
2	70	2.92×10^{-5}	3003	3.73
3	120	5.00×10^{-5}	2503.2	5.28

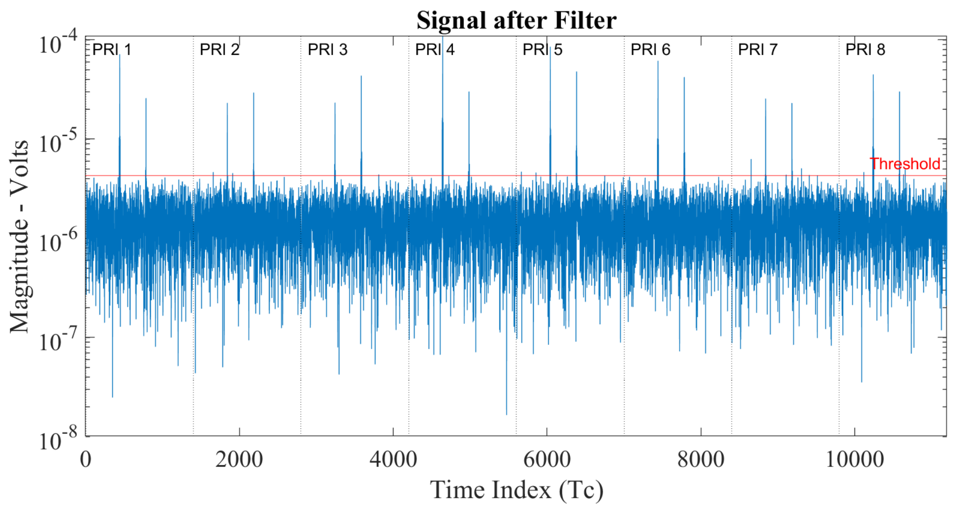
7 Task 7 - Personal Data

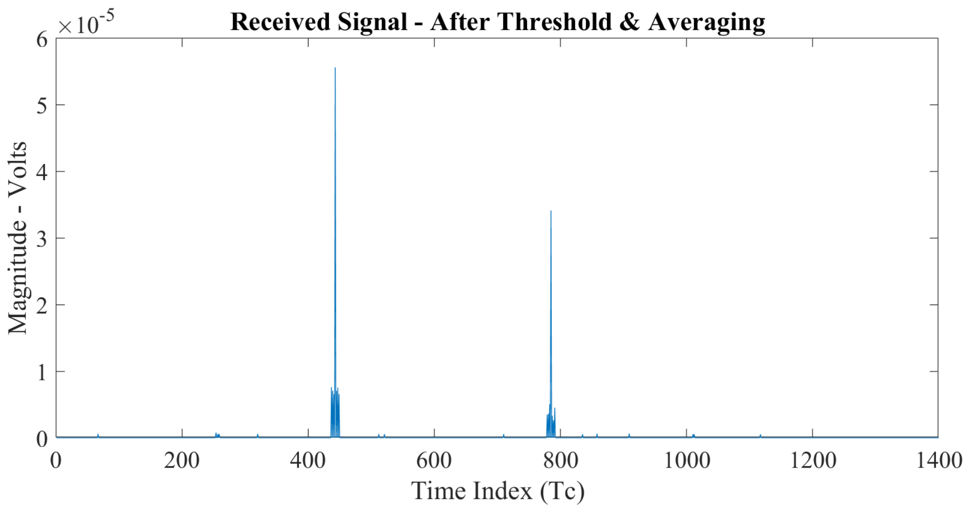
For the final task, my personal backscatter data was inspected, and the presence of targets, their location and RCS have been estimated. Like before, the backscatter data was taken and a full azimuth sweep plotting maximum the maximum amplitudes at each angle was plotted:



It is clear there is a target/are targets present at 115^o. A closer look was taken at the data at this angle, and the resultant signals at each stage have been plotted below.







From the final result, we can see that there are two targets at the same angle. From the final signal, t_{echo} for the first target was estimated to be $12.2\mu s$ and $21.8\mu s$ for the second target. The estimated range and RCS are shown below:

Target	Angle(^{o})	Received Amplitude (V)	Estimated Range(m)	Estimated RCS (m^2)
1	115	5.56×10^{-5}	1831.2	1.8671
2	115	2.92×10^{-5}	3267.6	7.1267