Coursework EE327
Principles of Classical and Modern Radar
“Monostatic Pulse Radar for Complex Targets”

Professor A. Manikas
Chair of Communications and Array Processing
Department of Electrical & Electronic Engineering
Imperial College London

19th February 2022. [v20.4]

Contents

1 Aim

The aim of this coursework is to design a PC-based *Monostatic Pulse Radar* which employs the same phased array at both the radar's Tx and Rx for detecting, localising and estimating various parameters of multiple complex targets.

2 Essential Software

- PC (operating system Windows 10 or Mac OS)
- MATLAB or Python
- There is a personal data file that should be downloaded from the provided shared Box directory link (see GTA).

3 Background and Radar Description

With reference to Figure 1, consider a digital monostatic radar operating at the middle of the Ku-band. The radar generates at point-A of the Tx a pulsed-signal of amplitude A and duration $T_p = 7T_c$ (where $1/T_c$ is the clock frequency) with pulse repetition interval PRI= $200T_p$. The radar employs an array of 45 isotropic antennas with Cartesian coordinates given by the following matrix:

$$[\underline{r}_1, \underline{r}_2, ..., \underline{r}_k, ...\underline{r}_{45}] =, \begin{bmatrix} -22d, & -21d, & ... & +22d \\ 0, & 0, & ... & 0 \\ 0, & 0 & ... & 0 \end{bmatrix} \in R^{3\times 45} \tag{1}$$

where $d = \frac{\lambda}{2}$.

The radar is employed as a surveillance radar which is electronically rotated for detecting and localising multiple targets. As shown Figure 1, the radar uses vectors of phase shifters $\exp(j\overline{\underline{\psi}}) \in C^{45\times 1}$ and $\exp(j\underline{\psi}) \in C^{45\times 1}$ to electronically steer both the Tx and Rx mainlobes towards any direction θ (azimuth), with θ in the sector $30° \leq \theta \leq 150°$, on the (x-y) plane. Figure-3 illustrates the sector with an example where the main lobe is steered towards 144°.

In particular, in a single-scan, the Tx and Rx mainlobes are sequentially steered towards the directions $(30°, 31°, 32°, ..., 150°)$ where, for each steering direction, the radar transmits several pulses for a period known as "dwell time". As this is shown in Figure 2, the "dwell time" is assumed to be 8×PRIs and the radar employs "pulse compression" to increase its range resolution as well as the Signal-to-Noise Ratio (SNR) at the Rx's input.

Furthermore, in this assignment:

- The basic radar system parameters are given in Table- 1;
- Three complex targets are considered, having different locations (directions and ranges) and different radar cross sections. The parameters of the targets are given in Table-2;
- With reference to Figure 1, it is assumed that there are no weight vectors $\overline{\underline{w}}$ and $\underline{w}$, i.e.,

$$\overline{\underline{w}} = \underline{w} = \underline{1}_{45}. \tag{2}$$

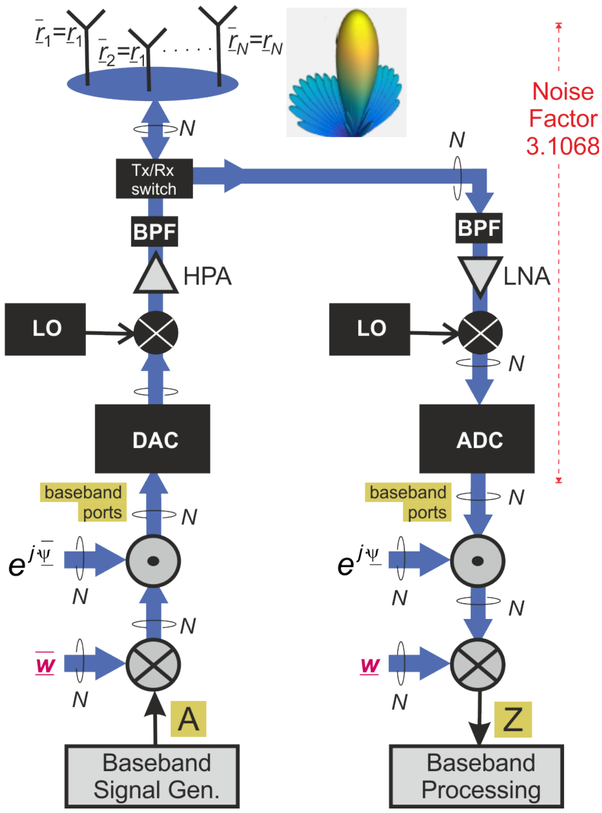

Figure 1: Monostatic Phased Array: System Modelling.

Table 1: Basic Radar Parameters

Parameter, symbol	Value
Amplitude, A	$150V$
Uncompressed pulse duration, T_p	$196ns$
Compressed pulse duration, T_c	$28ns$
Pulse compression	$[\ -1,\ \ -1,\ \ -1,\ \ +1,\ \ +1,\ \ -1,\ \ +1\ ]$
range bins, M	199
Detection criterion	constant false-alarm probability 10^{-3}

Table 2: Target Parameters

	Target-1 (constant)	Target-2 (complex)	Target-3 (complex)
direction, θ	$\theta_1 = 40°$	$\theta_2 = 70°$	$\theta_3 = 120^0$
ranges, R	$R_1 = 2$km	$R_2 = 3$km	$R_2 = 2.5$km
target RCS	$RCS_1 = 1m^2$	$RCS_2 = 5m^2$ (average)	$RCS_3 = 4.5m^2$(average)
complexity	constant RCS	scatterers of similar amplitudes	scatterers with one much larger than others

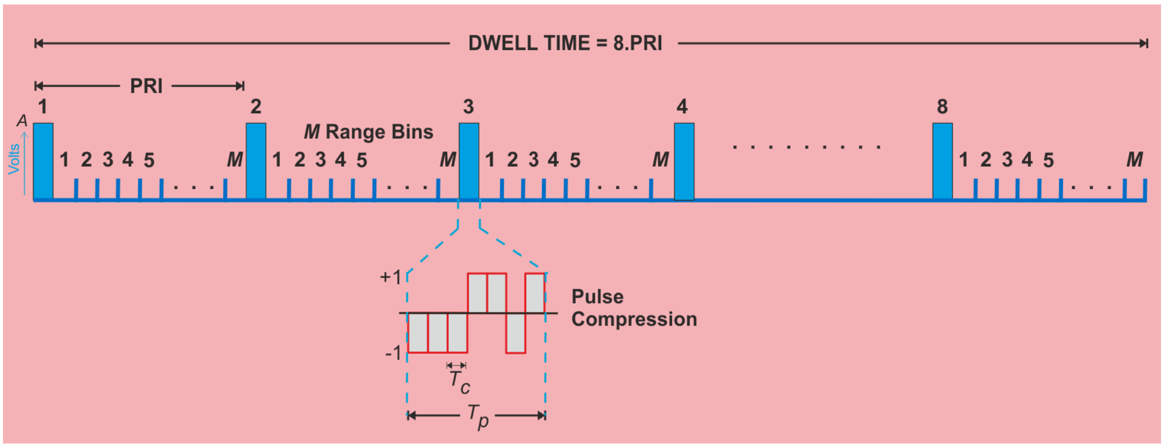

Figure 2: Transmitted Baseband Waveform (Single Direction). $T_c = 28$ns, $A = 1$kV, $M = 199$.

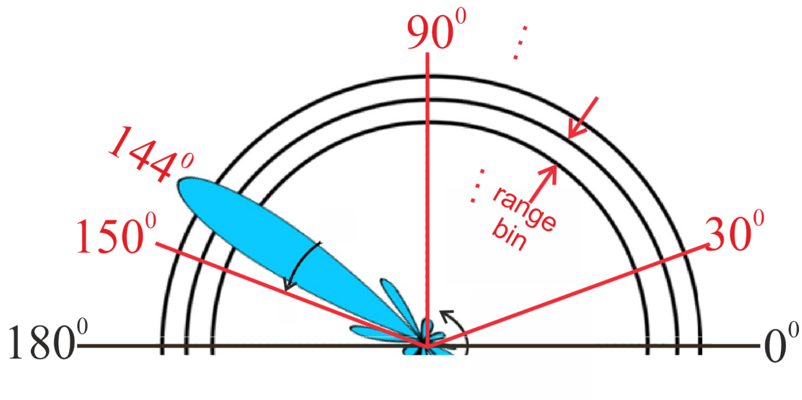

Figure 3: Single Scan Sector

4 Tasks

Task-1: Phase Shifters

- Estimate the vectors of Tx and Rx phase-shifter for the following steering directions 40°, 70° and 120°. [3 marks]
- Using the above phase-shifters, plot the array patterns for these three directions. [3 marks]

Task-2: Matlab backscatter modelling function

- Write a matlab function to generate the backscatter data for a given steering direction. The data should be generated according to the modelling of Figure 4 in conjunction with the appropriate Swerling target modelling (magnitude). [6 marks]
- N.B.:
  - This function is important and should be utilised in Tasks 3-6.
  - For each direction the radar transmits/receives for a period of 8×PRIs as this is shown in Figure 2, with the ADC providing 1 sample per T_c.

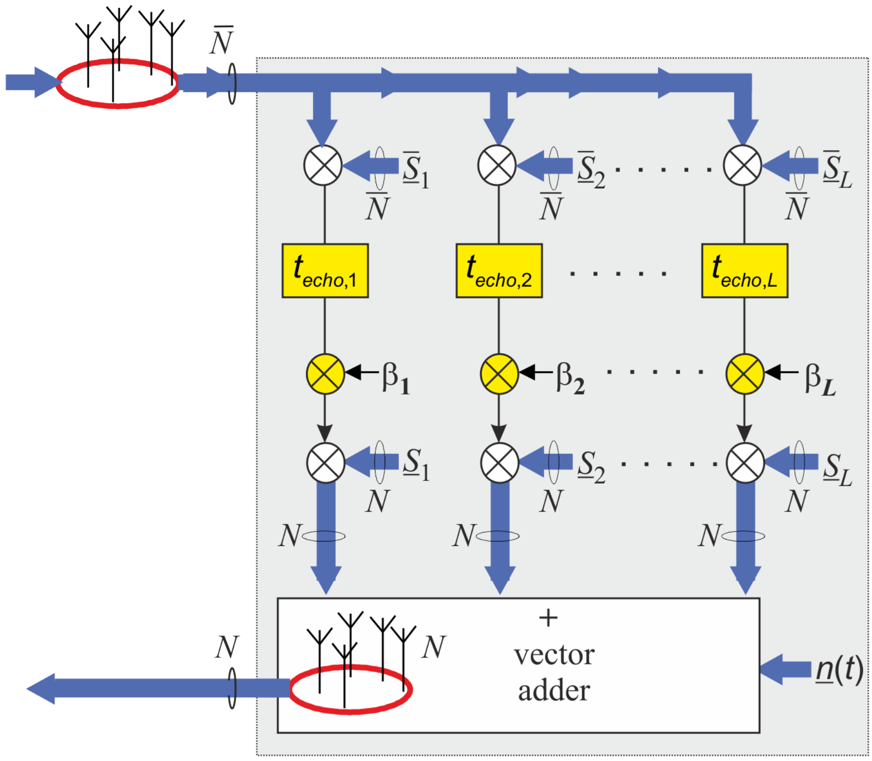

Figure 4: MIMO backscatter multi-target modelling

Task-3: 1st scan - no targets

- Assume that during the first scan there are no targets and thus the radar receives only noise.

  - Generate the noise samples/snapshots at the baseband ports of the Rx (see Figure 1). The "Noise-Figure" of the whole chain from each antenna and up to the ADC (included) of the chain is 3.1068. [4 marks]
  - Plot the magnitude (Volts) of noise snapshots for one Dwell-time. [2 marks]
  - Estimate and plot the probability density function of the noise data samples. [3 marks]
  - Estimate the noise power at Point-Z in Figure 1. [3 marks]

Task-4: 2nd scan - one target

- Assume that during the 2nd scan there is a single target (Target-1) with the parameters given in Table-2.

  - Initially, assuming that the Target-1 parameters are known, generate synthetic backscatter-data for this scan at the baseband ports. [3 marks]
  - Plot the backscatter-data at Point-Z for the dwell-time that corresponds to the direction of the Target-1. [2 marks]
  - Then forget that the parameters of Target-1 are known. Using only your generated backscatter random numbers at Point-Z, detect and estimate the parameters of this target. [5 marks]

Task-5: 3rd scan - two targets

- Assume that during the 3rd scan there are two targets (Targets-1 and 2) with their parameters given in Table-2.
  - Initially, assuming that the two targets parameters are known, generate synthetic backscatter-data for this scan at the baseband ports. [3 marks]
  - Plot the backscatter-data at Point-Z for the dwell-time that corresponds to the directions of the two targets. [2 marks]
  - Then forget that the parameters of the two targets are known. Using only your generated backscatter random numbers at Point-Z, detect and estimate the parameters of these two targets. [5 marks]

Task-6: 4th scan - three targets

- Assume that during the 4th scan all three targets of Table-2 are present. For all three targets, and in a similar fashion to the Task-5,
  - generate backscatter data at the baseband ports, [3 marks]
  - plot the data for the three target directions at Point-Z and, then, [2 marks]
  - detect and estimate the three target parameters. [5 marks]

Task-7: radar data - multi-target detection and parameter estimation

- The received data of a scan of the above radar is saved in your personal data file in the shared Box directory. Using your functions designed in the previous tasks with your own personal data file:
  - detect all the targets (if any) present and for the detected targets estimate their t_{echo}, locations (azimuth and range) and RCS. [6 marks]

5 Deliverables

1. The MATLAB file(s) - with brief comments. That is:
   - your script files where the system parameters are defined and a number of MATLAB functions (with comments) are called.
   - your functions that are used by your script files
2. A pdf file with the results, supported by 2-5 lines of brief comments per result.
3. Comments, if any, of how to run the programs to observe the results.
4. Please upload a zip file (including all the files) named by your login name (e.g., kl209.zip).

6 References

1. Lecture Notes on E327 Principles of Classical and Modern Radar
2. Your own references, if any.

7 Deadline

- Week S11: Friday 5:30pm, 25th March 2022.