UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

Introduction to Electronic Defence (EEE 5120Z)

Project

Total marks: 30

The project will cover the student's understanding of Electronic Support in Electronic Defence. The project report must be self contained in a single document and submitted electronically via the course web page on **Amathuba** no later than **17:00 on 18 September 2024**.

Besides the technical content, the student's capability of writing a technical paper on the subject will also be evaluated.

This project will count 30% towards the final mark.

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1 Project Description

Modern ESM (Electronic Support Measures) receivers are required to operate in very dense Electro Magnetic Spectrum (EMS) conditions, in which typical EMS environments can reach pulse densities of up to 5 million pulses per second for hundreds of radiation sources. For ESM receivers to operate in such environments, the deinterleaving function forms a core part of the receiver to separate radiation sources and provide support for the radiation source identification.

For this project, the students will implement a PDW (Pulse Descriptor Word) generator and a simple ESM deinterleaver. The PDW generator will be used to generate input data to the ESM processor.

The PDW generator requirements are described in detail in Section 2, so that the generated PDW series have the desired features to test the deinterleaver with. The deinterleaver requirements are described in Section 3, and students will have greater flexibility in the implementation thereof.

2 Pulse Data Generation Requirements [10]

The student is required to generate his/her own data to be used for the evaluation of the pulse deinterleaver.

2.1 Pulse Descriptor Message Generator

When a radar pulse is intercepted by an ESM receiver, its parameters are extracted and stored in a Pulse Descriptor Word (PDW). A series of intercepted pulses will generate a series (or list) of PDWs. A PDW generator will produce a series of PDWs that would be created by a given receiver in an operational scenario. PDW generators are useful tools building scenario simulators for training or system testing.

The students will implement a simple PDW generator according to the instructions that follow – this generator will be used to create scenarios for the ESM deinterleaver in Section 3.

2.2 PDW structure

The PDW must contain the following fields:

- Time of Arrival (TOA);
- Angle of Arrival (AOA);
- Amplitude (Amp);
- RF Frequency (Freq), and
- Pulse Width (PW).

The characteristics of the PDW are shown in the Table 1, below. The PDW will be a n-tuple formed by the concatenation of the parameter values, for example: (TOA; AOA; Amp; Freq; PW). ***Importantly, the parameters must be in this order***.

Note: For simplicity, you do not need to store the values in your PDW with the exact number of bits from Table 1. It is necessary, though, to respect the resolution and range values from Table 1 when generating PDWs.

Table 1: PDW Structure

Parameter	**#bits**	**Resolution**	**Range**
TOA	24	500ns	<8.38s
AOA	8	1.40625°	360°
Amp	6	1dB	At least 50dB Sensitivity -50dBm
Freq	10	3.90625MHz	8-12GHz
PW	5	500ns	500 – 10µs
Size	**53**	**N/A**	**N/A**

2.3 Single radar

Implement a function to create the PDWs that would be generated by the interception of a single radar operating either in circular scan mode, bi-directional horizontal sector scan mode or lock-on (no amplitude variation due to scanning).

The parameters of the respective radars should be configurable in your PDW generator function.

2.4 Generate PDW lists

Use your PDW generator function to generate four separate PDW lists for the radar types specified in Table 2 for an observation window of 3 s. The lists shall be output in the format of a text file with a separator between PDWs, according to Section 3.5.

Note: PDWs in the list are ordered by TOA. Also consider that radar antenna beams are semi-cycled of the function: $f(\theta) = sin((\theta*\pi)/(2*beamwidth))$, where the beamwidth values are given in Table 2 as 3-dB Beamwidth. See Appendix A.1 for a more detailed description of using this function. Lastly, notice that absolute time for each radar starts at time = 0.

Table 2: PDW list

Radar Type	First intercept	AoA [deg]	Peak Amp [dBm]	Freq [GHz]	PRI [μs]	PW [ns]	Scan Pattern	Scan Period [s]	3dB Beam-width [deg]
Radar1	1μs	45	-20	9.47	100	1100	Circular	1.45	2.5
Radar2	11.5μs	86	-15	11.9	10	750	Sector*	1.07	1
Radar3	1.5μs	87	-33	9.42	130	3000	Circular	2	4
Radar4	75ms**	50	-30	9.35	9	500	Lock-on		

* Note: The sector scan of Radar2 is 10° wide and it illuminates the interceptor (ESM receiver) at 2° from the sector limit. First intercept is approaching this sector limit.

** Note: Radar4 stops transmitting at 200 ms.

2.5 Add uncertainty to the PDW values

Create a function to add uncertainty to the pulse parameters stored in the PDWs lists. The uncertainties will represent the errors that arise from propagation effects, measurement limited precision and accuracy, receiver noise etc.

For a matter of simplicity, implement the uncertainty of any of the parameters to have a 20% probability, that the value stored in a PDW is wrong by the value of the precision of that parameter. Note, this is not a realistic representation of a receiver, but rather a means to reduce complexity of the Project.

From a practical point of view, the function will perform the modification of all parameters in all PDWs according to the following rule (see Table 1):

- 10% chance of adding the value of the least significant bit (LSB) to the value stored;
- 10% chance of subtracting the value of the LSB from the value stored.

2.6 Add pulse loss to the PDW lists

Create a function to add the effect of pulse loss to PDW lists. The function must:

- accept as input a value between 0% and 100%;
- randomly discard pulses from the list in the percentage indicated in the input.

2.7 Merge PDW lists

Create a function to merge PDW lists. The function must:

- output a single list with the merged PDW ordered by TOA;
- check if there are overlapping pulses- in this case, output a single PDW with correct TOA, the value of the total width of overlapping pulses in PW and all other fields zeroed.

3 Deinterleaving Evaluation [20]

The students will implement the processor (deinterleaver) of a simple ESM receiver according to the following requirements.

This receiver will use scenarios created by the PDW generator as developed by the students in this project.

Refer to the to the reference book [Neri, 2006] on section 4.4.8.

3.1 Read the PDW list

The processor must read the PDW lists from the files created by the PDW generator in Section 2.

3.2 Clustering

The deinterleaver must create cells and cluster the PDWs according to the following instructions:

a) Use the scenario in Table 2 with uncertainties and 10% pulse loss;

b) Clustering must be made automatically;

c) Use the first 100 ms as the time slice for the analysis;

d) Use 2-dimention cells for clustering; choose any two 2 parameters (do not use amplitude or TOA) for clustering;

e) Choose the initial cell size. Remember that every time you add a PDW to a cell, its size is potentially increased;

f) Verify the cell size increase after every PDW is added.

The lists of PDWs corresponding to the clusters shall be output in the format of a text file with a separator between PDWs, according to Section 3.5. Be sure to name the two parameters that gives the least ambiguity for the clustering results.

3.3 Differential TOA analysis

The second step of the deinterleaver is the differential TOA (ΔTOA) analysis, that must be performed according to the following instructions:

a) Use the scenario in Table 2 with uncertainties (Section 2.5) and 10% pulse loss (Section 2.6);

b) Use the first 100 ms as the time slice for the analysis;

c) Choose the histogram bar width;

d) Construct Cumulative Difference (CDIF) histograms up to the 4^{th} level automatically for every cluster found in Section 3.2.

The ΔTOA histograms for each cluster shall be represented in the report, according to Section 3.5. *Bonus marks will be given for mentioning alternative deinterleaving algorithms that will improve the performance.*

3.4 Sequencing

The third step of the deinterleaver is the sequence extraction, that must be performed according to the following instructions:

a) Use the scenario in Table 2 with pulse loss and uncertainties;

b) From Section 3.3, choose the best PRI candidates for every cluster (can be made manually);

c) Use the full 3 s of time data for the sequence extraction;

d) Extract the sequences of PDWs relative to the four radars in Table 2 from the initial time up to the moment they cease to illuminate the receiver (end of first scan of each radar).

The lists of PDWs corresponding to the sequences extracted for each radar shall be output in the format of a text file with a separator between PDWs, according to Section 3.5.

3.5 Output Data

The following output data is required for the report:

3.5.1 PDW Lists

The following PDW lists must be present in the files attached to the submission and the file names must be listed in the report.

a) The four radar types (four independent PDW lists) in Table 2 with no uncertainty and no loss, full 3s range (Section 2.4);

b) The four radar types (four independent PDW lists) in Table 2 with added uncertainties and no loss, full 3s range (Section 2.5);

c) The four radar types (four independent PDW lists) in Table 2 with added uncertainties and 10% pulse loss, full 3s range (Section 2.6);

d) The radar type "Radar1" (only) in Table 2 with added uncertainties and 50% pulse loss, full 3s range;

e) The list for the merging of the lists in item c) above, full 3s range (Section 2.7);

f) The lists for each cluster (independent PDW lists for each cluster) found in the first step of deinterleaving, only in the 100-ms time slice (Section 3.2);

g) The lists for each sequence (independent PDW lists for each sequence) found in the sequence extraction, from TOA=0 to the moment the radar ceases to illuminate the receiver (only first scan period) (Section 3.4);

h) The list of PDWs discarded in the deinterleaving.

Note: Remember that all PDW lists shall be output in the format of a text file with a separator (e.g. CSV file) between PDWs.

3.5.2 PDW Graphs

a) Plot a graph of amplitude in dBm (vertical axis) versus TOA (horizontal axis) for every list in Section 3.5.1.

b) Plot the four CDIF ΔTOA histograms (for the first, second, third and fourth-grade histograms) for each cluster found in the deinterleaving (Section 3.3).

3.6 Literature Sources

The student is required to provide a list of all sources used for this project.

3.7 Programming Language

The student may use any scientific programming language (Matlab, Python, Octave etc.) to perform your simulations and plot generation.

All project files must be included in the submission in their original formats. The students will provide a copy of the contents of all these files (code, scripts etc.) in PDF and attach as an appendix of the report (see Section 4).

4 Project Report Formatting

The report is required to have the following format:

- An electronic copy of the project report must be compiled in the portable document format (pdf).
- The first page of project report must be a title-page.
- The second page must be the signed declaration of originality (see appendix).
- Use the IEEE article style with a single column and 11 pt font size.
- The main body of the report may not exceed 20 pages (excluding, title pages, the appendix etc.).

- Include a list of references (IEEE format) when consulting other sources of information or when substantiating any claims.
- Include an appendix where the code, scripts etc. are documented.
- The report must be self-contained with additional information provided in relevant appendices.
- Number all pages, including the pages where the code is provided.
- Both technical and language correctness will be taken into account.

5 Appendix

A.1 Radar Mainlobe representation

As stated in Section 2, one way of creating a radar antenna beam is by using the function:

$f(\theta) = sin((\theta*\pi)/(2*beamwidth))$

where θ is the angle in degrees, [0 to 360°] and the "beamwidth" is also given in degrees. The amplitude in dB is then given as 20*log10(f(θ)). As an example, the amplitude of a radar mainlobe, with a 2° 3-dB beamwidth, is presented in Figure 1. Notice, the width of the mainlobe is twice the 3-dB beamwidth and the antenna boresight is in the middle of the lobe.

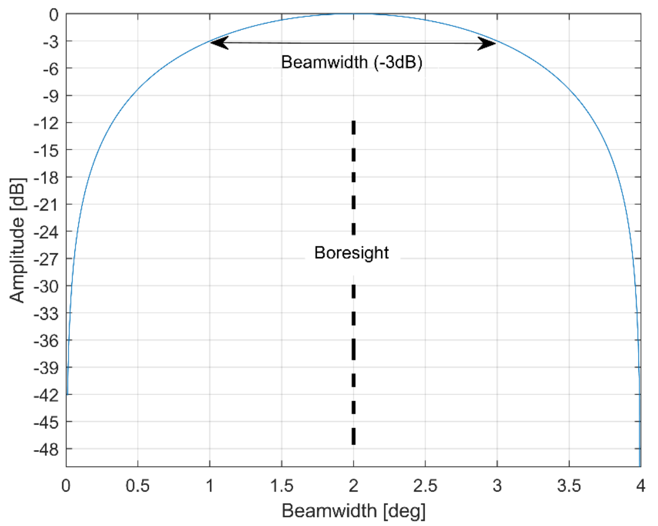

Figure 1: Example of a 2° Beamwidth (3dB Beamwidth).

When the function above is plotted as a function of the scan period (See Table 2), the parameter θ is then given in seconds, [0 to Scan Period]. As such, this function can be used to create a time series of pulse amplitude values that is shaped by the radar beam and also used to register only PDWs that are above the receiver sensitivity. As an example, suppose a radar has an antenna 3-dB beamwidth of 2° and the circular scan period is 2.7 s. Then, an ESM receiver with a sensitivity of -21dB, will detect/create all the PDWs from "Point 1" in time as seen in Figure 2. "Point 1" is known as the first interception time.

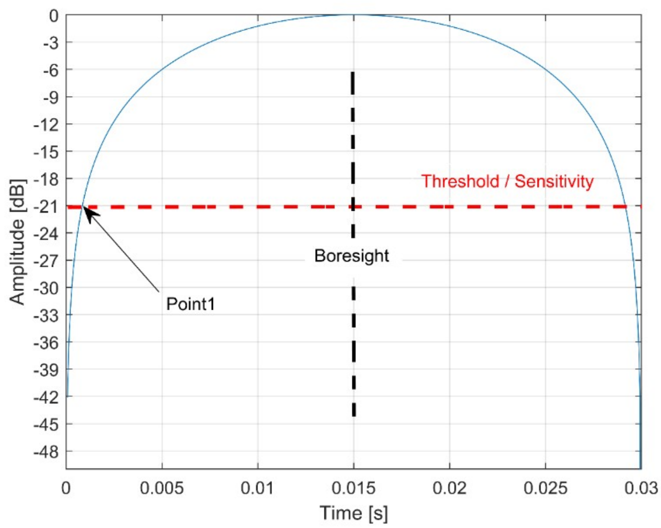

Figure 2: PDW detection and interception time.

A.2 Declaration of Originality

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DECLARATION OF ORIGINALITY

Introduction to Electronic Defence
EEE 5120Z

Project

Total number of pages submitted (including this one):_______

Declaration:

1. The use of information from outer sources has been duly referenced and cited. Information sources have been used only as support to this work and do not represent the core content of this work.
2. This project is my own work. There were no direct contributions from other people; I have not copied someone else's work, totally or in part; I have not practiced plagiarism in this work.
3. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work.

Student Name:_________________________

Signature:_____________________________ **Date:**_________________________