UW EE P 592 Fall 2025 - Radar Signals and Systems

Homework #3 Due Thursday Oct. 23th at 4:30pm via Canvas PDF upload of your Jupyter notebook.

***** Reminder *** Late HW is not accepted as the solutions will be posted to Canvas at that time.**

[Final Project Proposal - prepare written turn-in due Thurs 10/30, we will also discuss in class that day] It's time to start brainstorming about final project ideas. Given a small Doppler radar with capabilities similar to HW #1's coding exercise, please prepare a short written description of a proposed project. Please be sure to address the following design considerations:

(1) What are the targets you are considering for detection and processing? How will you estimate their RCS?

(2) How will you simulate the expected Doppler returns for these targets?

(3) How will you gather real-world data for this scenario?

(4) What interface will you provide for visualizing or otherwise interpreting the processed data? example: providing a real-time graphical readout of bicycle speed

(5) What is the rough timeline / key milestones that you will use to track your progress?

Part A: Please do the following problems from Skolnik 3rd Ed.

NOTE: For the following problems, you can use either pencil and paper, or write short Python programs. If you use pencil and paper, please paste a photo or screenshot directly into your Jupyter Notebook PDF as a markdown cell. Or, typeset the equations using LaTeX math blocks (MathJax) directly in Jupyter. See the examples here:

https://www.ibm.com/docs/en/watson-studio-local/1.2.3?topic=notebooks-markdown-jupyter-cheatsheet
https://jupyter-notebook.readthedocs.io/en/stable/examples/Notebook/Typesetting%20Equations.html

[Problem 6.4 - Individual Effort]

a) What is the minimum width τ of a rectangular pulse that can be used with an X-band radar (9375 MHz) if it is desired to achieve a 10 kt radial velocity accuracy (based on the Doppler frequency measured by a single pulse) when $2E/N_0$ = 23 dB ? NOTE: a velocity of 10 kt corresponds to ~ 5.144 m/s
b) What is the minimum range (in nautical miles, 1 nmi = 1852 m) that corresponds to this pulse width?
c) In part (a) of this question, what should be the value of $2E/N_0$ (in dB) to achieve a 10 kt radial velocity accuracy if the pulse width can be no longer than 10 μs?
d) What would be the minimum pulse width in (a) if the radar operated at W-band (94 GHz)?
e) Comment on the utility of accurately measuring the velocity with a single short pulse.

<u>Note Regarding Turn-Ins for Coding Exercises</u>: All plots must have a minimum text font size of 12 pt and a minimum line width of 2 pt. Be sure to label your axes with the appropriate quantities and units. Plots with unlabeled axes will receive zero credit. Be sure your code includes a comment containing your name and email address, and is well commented throughout. For binary file turn-ins, please submit these as .zip files uploaded to Canvas. Your file name should have the format firstname_lastname_assignment number_problem number.zip.
An example: mike_hegg_hw3_problem1.zip

[Coding Exercise 3 - Individual Effort] Consider a small bistatic continuous wave Doppler radar device with radar parameters unchanged from HW #1. *Note, when simulating the radar's IF output, do not make any assumptions about receiver sensitivity (e.g. do not threshold your simulated IF output, just let it occupy the full dynamic range of the .wav file).*

a. Roadside speed warning signs often use a small Doppler radar such as the one described above to provide a digital readout of the speed of an approaching car (for example near a school zone or a crosswalk). Write a small Python program that implements a speed readout sign, according to the following requirements:

(A1) The program should accept our "standard" wav file as its input (16 bit samples, 8 kHz sampling rate, up to 30 seconds in length).

(A2) The program should first plot a spectrogram of the given wav file data. This spectrogram dataset contains the frequency domain data that can be used to implement the speed readout sign.

(A3) At t = 1 s, and at every second thereafter, the program should print out the speed (in both m/s and MPH) of the <u>strongest</u> target within view of the radar, and the associated target power (in arbitrary units) in the following manner:

t = 1 s, v = 15.64 m/s, v = 35.00 MPH, target power 720
t = 2 s, v = 17.88 m/s, v = 40.00 MPH, target power 600
etc.

(A4) If there are two or more targets within view of the radar, the program should report the speed of the <u>strongest</u> target regardless of whether other targets are moving faster.

(A5) If there is no target present in view of the radar, the program should report "t = x s, no target". To implement this feature in a robust manner that's invariant to the unspecified radar receiver gain, you can assume that the spectrogram bin corresponding to a Doppler shift of 3900 Hz will never be occupied with target Doppler. That is, at each 1 s reporting interval, if there is no spectrogram bin with power exceeding that of the average of the 3900 Hz spectrogram bins across the entire wav file duration, the program should report "no target". The program should print out this threshold power in the following manner *before* reporting the speedometer readouts:

Average noise power at 3900 Hz: 10 units

b. Configure your target simulator to produce a test wav file (15 s duration) that simulates a car moving away from the radar at an initial velocity of 26.8 m/s and an acceleration of 0.5 m/s^2, along a straight line starting at 1 m from the radar. For this first test, assume that the car has infinite RCS and thus the target power does not decrease with distance. Run your digital speed warning sign against this wav file and turn in the resulting spectrogram and speed warning sign output.

c. Now, re-enable target power scaling (restore car RCS to 100 m^2), and additionally add AWGN at -60 dBFS noise power to simulate an imperfect radar receiver. Run your digital speed warning sign against this wav file and turn in the resulting spectrogram and speed warning sign output. Note, it's fine if your speed warning sign outputs "no target" if at a given distance, the target is weaker than the AWGN happens to be, given the particular random numbers comprising your AWGN samples.

NOTE: You should use the scipy functions scipy.io.wavfile.write and scipy.io.wavfile.read to read/write .wav files, as documented here:
https://docs.scipy.org/doc/scipy/reference/generated/scipy.io.wavfile.write.html

Policy on Group Work and Academic Integrity

Preparation and delivery of Homework shall be individual effort. You are encouraged to study and consult with others, but all homework solutions must be your own. Any use of outside resources (e.g. assistance given by others, Web searches, other online resources) must be identified and annotated alongside your solution.

At all times, students are expected to adhere to the University of Washington Student Code of Conduct, Washington Administrative Code (WAC) 478-121, and are expected to properly credit the work of others in all assignments and interactions with the instructor and other members of the class. Any suspected instances of academic misconduct will be reported in accordance with these policies.
https://www.engr.washington.edu/current/policies/academic-integrity-misconduct

6.4 a.) $\delta f = \dfrac{1}{\alpha \left(2E/N_0\right)^{1/2}}$ Skolnik 6.22

$$\delta f = \frac{\sqrt{3}}{\pi \tau \left(2E/N_0\right)^{1/2}}$$ Skolnik 6.24

$$\delta v_r = \frac{c}{2 f_0 \delta f_d}$$

$$\delta f_d = \frac{2 f_0 \delta v_r}{c} = \frac{(2)(9.34\,E9)(5.144)}{3E8} = 321.5\,Hz$$

$$\tau = \frac{\sqrt{3}}{\pi \delta f \left(2E/N_0\right)^{1/2}} = \frac{\sqrt{3}}{\pi (321.5)(\sqrt{199.53})} = 1.213E-4$$

$$\boxed{\tau_{min} = 121.3\,\mu s}$$

b.) $\delta R = [c/2]\,\delta T_R$ $T_R = \tau$

$$R_{min} = \frac{(3E8)(121.3E-6)}{2} = 18195\,m$$

$$\frac{18195\,m}{1852} = \boxed{9.82\,nmi}$$

c.) $\delta_f = \frac{\sqrt{3}}{\pi \tau (2E/N_0)^{1/2}}$ $\delta_{vr} = 5.144\,m/s$

$$\frac{2E}{N_0} = \left[\frac{\sqrt{3}}{\pi \tau \delta_f}\right]^2 = \left(\frac{\sqrt{3}}{\pi(10E\text{-}6)(5.144)}\right)^2 = (171.5)^2 = 29{,}412$$

$$10\log(29412) = \boxed{44.7\,dB}$$

d.) $f_0 = 94E9$, $\delta_{vr} = 5.144\,m/s$, $\frac{2E}{N_0} = 23\,dB$

$$\delta f_d = \frac{2(94E9)(5.144)}{3E8} = 3223.7\,Hz$$

$$\tau = \frac{\sqrt{3}}{\pi(3223.7)(14.13)} = 1.21E\text{-}5 \text{ or } \boxed{12.1\,\mu s}$$

At 10x freq the pulse width is 10x shorter

e.) Single pulse has limited applicability. If we look at Skolnik 6.24 we can see that freq. accuracy improves with longer τ and higher SNR. From a and c, reducing the pulse width by approx 12x requires a 21.7 dB increase in signal energy since $\delta f \propto \frac{1}{\tau}$, and the SNR $\left(\frac{2E}{N_0}\right) \propto \frac{1}{\tau^2}$ making short pulse measurements expensive in transmit power