UW EE P 592 Fall 2025 - Radar Signals and Systems

Homework #1 Due Thursday Oct. 9th 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.**

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 1.2 - Individual Effort] A ground-based air-surveillance radar operates at a frequency of 1300 MHz (L-band). Its maximum range is 200 nautical miles for the detection of a target with a radar cross section of 1 square meter ($\sigma = 1\ \mathrm{m}^2$). Its antenna is 12 m wide by 4 m high, and the antenna aperture efficiency is $\rho_a = 0.65$. The receiver minimum detectable signal is $S_{min} = 10^{-13}$W. Determine the following:

a. Antenna effective aperture A_e (square meters) and antenna gain G, numerically and in dB, where G (in dB) = $10\log_{10} G$
b. Peak transmitter power required to achieve the maximum range
c. Pulse repetition frequency required to achieve a maximum unambiguous range of 200 nautical miles
d. Average transmitter power, if the pulse width is $2\mu s$
e. Duty cycle
f. Horizontal beamwidth of the antenna (in degrees) use 4/mn

[Problem 1.4 - Individual Effort] The moon as a radar target may be described as follows: average distance to the moon is 3.844×10^8 m, experimentally determined radar cross section is 6.64×10^{11} m^2 (a mean value over a range of radar frequencies), and its radius is 1.738×10^6 m.

a. What is the round-trip time (in seconds) of a radar pulse to the moon and back?
b. What should the pulse repetition frequency (PRF) be in order to have no range ambiguities?
c. For the purpose of probing the nature of the moon's surface, a much higher PRF could be used than that found in (b). How high could the PRF be if the purpose is to observe the echoes from the moon's front half?
d. If an antenna with a diameter of 60 ft and aperture efficiency of 0.6 were used at a frequency of 430 MHz with a receiver having a minimum detectable signal of 1.5×10^{-16} W, what peak transmitted power is required? Does your answer surprise you? If so, why?

e. The radar cross section of a smooth perfectly reflecting sphere of radius a is πa^2. What would be the radar cross section of the moon if it were a sphere with a perfectly smooth, conducting surface? Why might the measured radar cross section of the moon (given above) be different from this value?

<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_hw1_problem1.zip

[Coding Exercise 1 - Individual Effort] Consider a small bistatic continuous wave Doppler radar device similar to the one demonstrated in Lecture 1. This small radar has a frequency of 10.5 GHz, a transmitter power of 10 mW, an antenna gain of 9 dBi for both transmitting and receiving antennas, and a minimum detectable signal of -60 dBm.

a. Write a short Python program to plot the maximum range of this radar as a function of target RCS, for target RCS between $0.01\ \mathrm{m}^2$ (approximating a bird), up to $100\ \mathrm{m}^2$ (approximating a car). Ensure that your turn-in PDF includes the source code and the resulting plot.

b. A bicycle with RCS $2\ \mathrm{m}^2$ moves away from the radar at an initial speed of 4.5 m/s and acceleration of 0.1 $\mathrm{m/s}^2$, and at the same time a car with RCS $100\ \mathrm{m}^2$ moves away from the radar at an initial speed of 26.8 m/s and an acceleration of 0.5 $\mathrm{m/s}^2$. Both targets start 1 m from the radar and move away in a straight line.

Write a short program that produces a simulated sampled radar IF output as a .wav file. This .wav file should have a sampling rate of 8 kHz, using 16 bit samples, with a duration of 15 s. The simulator should model the changing Doppler frequencies due to the bike and the car, and should also model the change in strength of the radar return as the bike and car move away from the radar. Note, the "gain" of the radar receiver is not specified so please normalize the maximum valued sample to full-scale within the .wav file. Turn in your source code and the resulting .wav file.

c. Write a short program that ingests the .wav file produced above, and plots a spectrogram of the sampled radar IF signal. Turn in your source code and a PDF of the resulting plot. Be sure to label your axes appropriately!

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

<u>Policy on Group Work and Academic Integrity</u>

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

1.2 a.) $A = 12 * 4 = 48 M$ $\quad \lambda = \frac{c}{f} = \frac{3E8}{1.3*10^9} = 0.231$

$A_e = A * \rho_a = 48 * 0.65 = 31.2 m^2$

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi (31.2)}{0.231} = 7362$$

$G(dB) = 10\log_{10}(G) = 10\log_{10}(7362) = 38.67 dB$

$R = 200 * 1852 = 370400$

b.) $$P_t = \frac{S_{min}(4\pi^3)R^4}{G^2 \lambda^2 \sigma} = \frac{(1E{-}13)(1984.4)(1.885E22)}{(7362)^2 (0.231)^2 (1)}$$

$= 1.3 MW$

c.) $$R_{unamb} = \frac{C}{2*PRF}$$ PRF

$$PRF = \frac{C}{2*R_{unamb}}$$

$$= \frac{3E8}{2*370400} = 404.97 Hz$$

d.) Duty cycle $= \tau * PRF = 2E{-}6 * 405 = 0.00081$

$P_{avg} = P_t *$ duty cycle $= 1.29E{-}6 * 0.00081 = 1044.9 W$ or $1.0449 kW$

e.) Duty cycle $= \tau * PRF = 2E{-}6 * 405 = 0.00081$

f.) $\lambda = 0.231$ $D_{horizontal} = 4m$ (use height)

is $d = 12$ or 4?

$$\theta_{3db} = \frac{0.886\lambda}{d} = \frac{0.886 * 0.231}{4} = 0.0512 \text{ radians}$$

$$\theta_{3db} = 0.0512 \text{rad} \left(\frac{180}{\pi}\right) = 2.93^{\circ} \rightarrow \text{horizontal beamwidth}$$

1.4 a.) $t = 2 * \frac{d}{c} = 2 * \frac{3.844E8}{3e8} = 2.563s$

b.) $PRF_{max} = \frac{1}{t} = \frac{1}{2.563} = 0.39\ Hz$

c.) $d_{min} = d - r = 3.844E8 - 1.738E6 = 3.82662E8$

$t_{min} = \frac{2d_{min}}{c} = \frac{2 * 3.827E8}{3E8} = 2.551s$

$\Delta t = t - t_{min} = 2.563 - 2.551 = 0.012s$

$PRF_{front} = \frac{1}{\Delta t} = \frac{1}{0.012} = 83.3\ Hz$

d.) $d = 60\ ft \to 18.288m$ $\quad \lambda = \frac{c}{f} = \frac{3E8}{430E6} = 0.698$

$\eta = 0.6$

$f = 430\ MHz$

$S_{min} = 1.5E-16\ W$

$\sigma = 6.64E11$

$R = 3.844E8$

$S_{min} = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4}$

$A_e = \frac{\eta \pi D^2}{4} = \frac{0.6\pi(18.288)^2}{4} = 157.55$

$G = \frac{4\pi A_e}{\lambda} = \frac{4\pi(157.55)}{0.698} = 4064$

$P_t = \frac{(4\pi)^2 R^4 P_r}{G A_e \sigma} = \frac{(4\pi)^2 (3.844E8)^4 (1.5E-16)}{(4064)(157.55)(6.64E11)} \approx 810W$

Yes, this is suprising as it's quite low. I would've thought it would take more power/gain (like telescopes NASA uses) for better SNR, but this shows that only modest power is needed to detect the moon