ASEN 5245 – Radar and Remote Sensing

Syllabus, Spring 2018

Class Lectures:	Pre-recorded and available via class web page
Class Discussion:	Thursdays, 5:00 – 6:30 pm, Humanities (HUMN) 1B80
Office Hours:	Thursdays, 6:30 – 7:30 pm, Humanities (HUMN) 1B80 Tuesdays, 3:30 – 5:00 pm, ECNT 422 (and by appointment)
Web page:	Canvas (https://canvas.colorado.edu)
Instructor:	Christopher R. Williams
Phone:	303-497-3829 (it is better to contact me via email)
Email:	christopher.williams@colorado.edu

Outline

The subject of radars is extremely broad and this course will introduce radar systems using three interconnected perspectives: theory, analysis, and synthesis. The theory portion will consist of pre-recorded lectures covering the mathematical basis and foundation of radar systems. This perspective is the dissemination and acquisition of fundamental radar knowledge needed for a professional to understand the operation of radar systems. The analysis portion will consist of processing and interpreting real radar observations from ground-based, airborne, and space-borne platforms. This perspective applies acquired theoretical knowledge to solve real-life atmospheric science problems. Finally, the synthesis portion will consist of simulating key attributes of radar systems to solidify the understanding between radar theory and application.

Course Objective

This course will introduce radar systems from a combined theoretical and applied perspective. Students will develop a quantitative understanding of radar system design and radar signal analysis, and apply these principles to specific applications in environmental remote sensing.

The subject of radars is extremely broad, and a wide range of topics will be treated in this course. It is unlikely that any student will be prepared for all topics, but the particular expertise of individual students will be cultivated through a semester project on a particular radar application. The course is intended for any graduate student with a solid background in mathematics, familiarity with electromagnetic waves and wave propagation, and a background in undergraduate signal analysis.

The applications of radar are endless from the detection of targets such as aircraft to the estimation of parameters such as refractivity, wind speed, temperature, rainfall rate, raindrop size

and the list goes on. The purpose of this class is to provide you with a fundamental understanding about how radar systems operate, their components, and their applications to environmental remote sensing.

By the end of the semester you will have a good understanding of how a radar system works and their application to environmental remote sensing. You will NOT be an expert in radar design, or construction, nor will you be able to go into Radio-Shack and buy the parts to construct your own backyard radar or a radar jammer so that you can avoid speeding tickets. Just a caveat here – It is illegal to transmit radio waves outside of a few specified bands (e.g., CB radio and the ISM bands) without a license from the FCC. So, if that is your intention, then you may want to consider another course. However, if you would like to learn how radar systems can be used to probe the environment and how physically useful information is extracted from such systems, then you are in the right place.

Prerequisites

The prerequisites for this class include a basic understanding of electromagnetic waves (Physics II), linear system theory including Fourier analysis and some basic understanding of statistics and/or probability. These are all topics that are typically covered in an undergraduate engineering curriculum. Some topics such as electromagnetic waves are covered in more detail by the electrical engineering curriculum however only a basic sophomore Physics II level understanding of the topic is expected for this course.

A working knowledge of MATLAB will be needed as functions written in MATLAB will be provided and homework assignments and projects may require code development in MATLAB. If you do not have a background in one these areas, you should expect to spend some extra time on the specific material.

There are many resources, including the library, at your disposal. If you have questions regarding your preparation for the class, you should contact the instructor. Additionally, because radar is abroad topic, it is not unexpected that students may need to do some additional work in specific topical areas to provide a firm base in the fundamentals.

Course Content

The course is divided into several sections, which consist of the following topics:

Radar fundamentals
Radar basics; pulsed radar; target ranging; range ambiguity; pulse-to-pulse motion; signal, noise and loss; target detection; receiver components and processing; Doppler radar; Doppler velocity ambiguity

Radar sensitivity
Radar power equation: derivation and application for point targets; Radar power equation for area targets; Radar power equation for volume targets; radar power losses; radio and receiver noise

Radar Antenna
Directivity; gain; illumination; antenna patterns; aperture antennas; phased array antennas

Scattering Processes
Radar cross section; Rayleigh; Mie; geometric; Bragg; rough surfaces; polarization, propagation

Radar Signals
Transmitter/signal generating characteristics; pulsed waveform; continuous waveform; pulse modulation and compression; complex signals including I and Q signals; digital filtering; Doppler spectrum

Remote Sensing Applications including data analysis
Tracking radars; scanning weather radar; vertically pointing cloud and precipitation radar; airborne radars; space borne radars (e.g., TRMM, GPM, and CloudSat); synthetic aperture radar (SAR)

Texts

Required Text:

Introduction to Radar Analysis, Second Edition. Bassem R. Majafza. CRC Press, ISBN: 9781498761079.

This textbook was published in *November 2017* and is available for purchase at University bookstores and through online retailers. I will be adapting my lectures to the notation used in this textbook.

It is difficult to find a textbook that covers the topic of radar from a remote sensing perspective. Additionally, many radar texts are written as reference books for practicing engineers and not specifically designed as a textbook for students. As reference books, they do not clearly develop subjects from first principles and do not provide problems that can worked by the student. Furthermore, many radar textbooks are written specifically for electrical engineers and assume a

significant depth of understanding in electromagnetics and wave propagation, which are not required for this course. Introduction to Radar Analysis by Majafza appears to provide a good balance between depth and breadth.

Depending on your specific background, you may need to draw from other supplementary material to provide more clarity or depth to a topic. One complication of supplying supplemental material is that the notation may change. Since this is a graduate course, you should be able to figure out changes in notations used in different books. Many books on radar fundamentals are available through the Engineering Library and through www.knovel.com. Some good references include:

- Introduction to Airborne Radar, 2nd edition, by Stimson
- Radar Principles, by Peyton Z. Peebles, Jr.
- Radar System Principles, by Harold R. Raemer
- Radar Handbook, by Skolink
- Introduction to Radar Systems, by Skolink
- Tools of Radio Astronomy, by Rohlfs and Wilson
- Modern Radar System Analysis, by Marton
- Radio Techniques for Probing the Terrestrial Ionosphere, by Hunsucker
- Fundamentals of Applied Electromagnetics, by Fawwaz T. Ulaby
- Elements of Engineering Electromagnetics, 6th edition, by Rao
- Antenna Theory – Analysis and Design, 3rd edition, by Constantine A Balanis (2005)

There are many other textbooks in the library, however, they are usually checked out. If you are interested in finding one of the other books, you should put a recall request into the library. Be prepared as it can take a couple weeks for the books to be recalled.

Several books are available online through an agreement between the University of Colorado and www.knovel.com. Once connected to the internet via a CU connection (either physically on the CU campus or via a CU VPN connection [see http://www.colorado.edu/oit for the latest on VPN services] using your CU username and identikey password), browse to the secure website www.knovel.com and search their collection of radar books.

Class Format

The class format will consist of both pre-recorded lectures and in person discussions. The pre-recorded lectures will cover technical aspects of radar systems. The students are expected to watch the pre-recorded lectures (approximately 2 hours per week) prior to attending the Thursday evening class. During the Thursday evening class, we will discuss salient features of the pre-recorded lectures and address any questions raised by the students.

Video Recording of Thursday Evening Class

In addition to pre-recorded lectures, the Thursday evening classes will be recorded and posted on the class web page. Please be aware that all conversations during the Thursday evening class may be recorded both on video and/or audio by the distant learning studio equipment.

Virtual Access to Thursday Evening Class

On-line virtual access to the Thursday evening class is available to remote students via Zoom, a live video conferencing service administered through the University of Colorado. The Zoom meeting ID for ASEN 5245 is: **618393858**. Here is how to connect to the Zoom meeting ID:

- Join via web browser: https://cuboulder.zoom.us/j/618393858
- Join via Zoom app (using meeting ID): 618393858
- Join via phone: 1-646-558-8656 or 1-408-638-0968

Additionally, if you need help with getting Zoom up and running, please visit the following link:

- http://www.colorado.edu/oit/services/conferencing-services/web-conferencing-zoom

Extreme Weather

Safety is the highest priority. If extreme weather is forecasted for Boulder on Thursday evening, we may conduct our Thursday evening class via the Zoom conferencing tool.

Class Web Page – Canvas

All class communications, including outgoing assignments, incoming submissions, pre-recorded lectures, recorded Thursday evening classes, and class announcements and discussions, will be conducted through the class web page posted on the University of Colorado Canvas service. Access to this web page will be made available to you via your registration confirmation. Also, all email communication will be using @colorado.edu addresses.

Course Grading

25% Homework, quizzes, reading assignments, and class engagement/participation

50% Mid-term Exams (2):

*Exam #1 – take-home, covering weeks 1-5
4 hour exam, available Friday 23-Feb to Wednesday 28 Feb 12noon

*Exam #2 – take-home, covering weeks 1-11
24 hour exam, available Friday 6-April to Wednesday 11-April 12noon

25% *Final Exam:

Comprehensive Radar Systems exam – take-home exam: covering weeks 1-15
48-hr exam, available after last class on Thursday 3-May and due before end of scheduled final exam on Saturday 5-May at 7:30-10:00 pm

100% Total

**Exams will be open book, take-home, but time limited. You will have several days to start the exam, but once you start, you will have a limited amount of time to complete the exam.*

The College of Engineering and Applied Science grading policies can be found at http://www.colorado.edu/engineering/academics/policies/grading.

Aerospace Engineering Sciences & University Policies 2017

Accommodation for Disabilities

If you qualify for accommodations because of a disability, please submit to your instructor a letter from Disability Services in a timely manner so that your needs can be addressed. Disability Services determine accommodations based on documented disabilities. Information on requesting accommodations is located on the Disability Services website (www.colorado.edu/disabilityservices/students). Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition or injury, see Temporary Injuries guidelines under the Student tab on the Disability Services website and discuss your needs with your instructor.

This course requires the use of the Zoom conferencing tool which is currently **not** accessible to users using assistive technology. If you use assistive technology to access the course material, please contact your faculty member immediately to discuss.

Religious Holidays

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. In this class, you must let the instructor know of any such conflicts within the first two weeks of the semester so that I can work with you to make reasonable arrangements. See campus policy regarding religious observances for full details.

Classroom and On-Campus Behavior

Students and faculty each have responsibility for maintaining an appropriate learning environment, not only while in class, *but also while working outside of class such as in labs and study areas*. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. Class rosters are provided to the instructor with the student's legal name. I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. For more information, see the policies on classroom behavior and the student code.

Discrimination and Harassment

The University of Colorado Boulder (CU Boulder) is committed to maintaining a positive learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct, discrimination, harassment or related retaliation against or by any employee or student. CU's Sexual Misconduct Policy prohibits sexual assault, sexual exploitation, sexual harassment, intimate partner abuse (dating or domestic violence), stalking or related retaliation. CU Boulder's Discrimination and Harassment Policy prohibits discrimination, harassment or related retaliation based on race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political

philosophy. Individuals who believe they have been subject to misconduct under either policy should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127. Information about the OIEC, the above referenced policies, and the campus resources available to assist individuals regarding sexual misconduct, discrimination, harassment or related retaliation can be found at the OIEC website.

Honor Code

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the academic integrity policy. Violations of the policy may include: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, resubmission, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code Council (honor@colorado.edu; 303-735-2273). Students who are found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code Council as well as academic sanctions from the faculty member. Additional information regarding the academic integrity policy can be found at the Honor Code Office website.

Other Policies

Please be respectful of others during class time. This includes turning off your cell phone before class and not talking during class unless you have the floor. Details about all of the university policies can be found on the web at http://www.colorado.edu/policies/index.htm.