ASEN 5245 – Radar and Remote Sensing

Syllabus, Spring 2021 – Public version

Class Lectures:	Pre-recorded videos available via Canvas
Class Discussion:	Thursdays, 4:25 – 5:40 pm, 14-Januray through 29-April. No class 25-March Zoom: TBA
Office Hours:	Tuesdays, 4:25 – 5:40 pm Zoom: TBA Thursdays, 5:45 – 6:45 pm Zoom: TBA (and by appointment)
Web page:	Canvas (https://canvas.colorado.edu)
Instructor:	Christopher R. Williams
Phone:	303-492-4829 (It is better to contact me via email)
Email:	christopher.williams@colorado.edu

Outline

The subject of radar 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:

Title:	**Principles of Modern Radar, Volume I - Basic Principles**
Author(s) / Editor(s):	Richards, Mark A.; Scheer, James A.; Holm, William A.
Publisher:	SciTech Publishing
Copyright Date:	2010 with updates in 2015
ISBN:	978-1-891121-52-4
Electronic ISBN:	978-1-61344-155-8
Online:	www.Knovel.com

Principles of Modern Radar (POMR) is a required text, but it is not required that you purchase your copy as an electronic version is available online through an agreement between the University of Colorado and www.knovel.com. To access the text, you need to access the Knovel web site while your computer has a CU network address. There are two ways for your computer to get a CU network address. Either be physically on campus connected to the internet via the

campus's network, or use the CU VPN (Virtual Private Network) to access the CU network. To get VPN on your computer, see https://oit.colorado.edu/. You will need your CU username and identikey password to install the software and every time you login to the VPN. Once connected to the CU network via the VPN, browse to the Knovel website: www.knovel.com and search for 'Principles of Modern Radar'. You will see three volumes of this text. We will use volume 1. You can use the book online, or download individual chapters.

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.

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 Radar Analysis, 2nd Edition, by Majafza
- 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)

Several radar books are available online through an agreement between the University of Colorado and www.knovel.com.

Class Format

This class is scheduled to meet for two 75-minute sessions on Tuesdays and Thursdays (4:25-5:40 pm). To improved efficiency and adapt to different learning styles, the Tuesday class meeting will be replaced with pre-recorded technical lectures. The material in those lectures will be discussed and built upon during the Zoom lecture on Thursday afternoon. Benefits of pre-recorded technical lectures include watching them multiple times on your own schedule before we discuss the material on Thursday. There will be about 75 minutes of pre-recorded technical lectures every week which is the same duration as a Tuesday lecture. The Thursday lecture will

focus on answering your questions about the pre-recorded lectures, working through example problems, and having a discussion about radar systems.

Video Recording of Thursday Class

In addition to pre-recorded lectures, the Thursday afternoon classes will be recorded and posted on the class Canvas page. Please be aware that all conversations during the Thursday afternoon class may be recorded both on video and/or audio by the Zoom application.

Zoom Link for Thursday Class

The Thursday afternoon class will be conducted via Zoom. Connect to the Zoom meeting using:

- Zoom Meeting ID: TBA
- Join via web browser: TBA
- Join via Zoom app, use meeting ID: TBA

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

- https://oit.colorado.edu/services/network-internet-services/vpn

Slido Communication App

During the Thursday class, we will use a third-party app called Slido (https://www.sli.do/) to conduct polls to gauge learning of concepts and for you to submit questions. The app is designed to get user feedback and questions during panel discussions. When a user submits a question (you can choose to include your name or submit the question anonymously), your class-mates can vote the question up in priority. The questions with the most votes float to the top of the list and will be the next question discussed during class. I will use the polling feature to produce multiple-guess questions that you would answer in real time. I will use this information to gauge which material needs to be emphasized or rephrased in order to improve your understanding of the topic. The polling feature aggregates the responses and I do not see answers associated with any one person. This is not a graded activity, but an activity to guide the discussion to topics that need more attention. The Slido app is designed for phones, but can be used on computers via a web browser, like Google Chrome or Apple Safari.

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.

Access to the class Canvas web page will expire 2 weeks after the last day of class. Be prepared and download material throughout the semester so that you have a copy of class material after the semester ends.

Course Grading

75% Quizzes*

Seven (7) quizzes will be given during the semester, approximately 1 quiz every 2 weeks. Six (6) highest quiz scores will be used to determine your grade.

25% Final Exam*

Exam will be available on Canvas after the last lecture on Thursday, 29-April. Once started, you have 3.5 hours to complete the exam (3 hours allocated for the exam and 30 minutes to upload files to Canvas. The Final Exam must be submitted by the end of the class's scheduled Final Exam time: **Saturday, 1-May, 4:00 pm.**

100% Total

**Quizzes and Final Exam will be open book, open note, but time limited. You will have several days to start a quiz, but you will have a finite amount of time to complete it.*

Quiz Format and Planned Due Dates

Quizzes will be administered through Canvas. A quiz will be available on Canvas on Friday and will be due by 4 pm the following Thursday (before class). Once you start the quiz, you will have 1 hour and 15 minutes to complete the quiz. All quizzes will require an uploaded file to be submitted to Canvas. Your work can either be hand drawn using pen or pencil on paper, scanned, and then uploaded to Canvas. Or, your work can be done electronically and then uploaded to Canvas. The quizzes will require the sketching of diagrams and writing of equations. An hour is allocated to take the quiz and 15 minutes is allocated to upload scanned files to Canvas.

Planned Quiz dates:

Quiz #	**Date Available**	**Due Date**	**Material "In Play"**
1	Friday, 22-Jan	4 pm, Thursday, 28-Jan	Weeks 01-02
2	Friday, 05-Feb	4 pm, Thursday, 11-Feb	Weeks 01-04
3	Friday, 19-Feb	4 pm, Thursday, 25-Feb	Weeks 01-06
4	Friday, 05-Mar	4 pm, Thursday, 11-Mar	Weeks 01-08
5	Friday, 19-Mar	4 pm, Thursday, 01-Apr	Weeks 01-10
6	Friday, 09-Apr	4 pm, Thursday, 15-Apr	Weeks 01-12
7	Friday, 23-Apr	4 pm, Thursday, 29-Apr	Weeks 01-14

Estimating Final Grades

There will be 7 quizzes given during the semester. The highest 6 scores will be used to determine 75% of your final grade. The dropping of one quiz score is to accommodate the possibility of a student or a family member being sick during the semester. The 6 quizzes will represent 6 hours of examination time. The Final Exam will be 3 hours in length and will represent 25% of your final grade. There will be a natural clustering of accumulated scores in the class based on how well the material is described and how well the quiz and Final Exam questions map actual learning into measurable quantities. Thus, a fixed percentile of 90%, 80%, 70%, etc. does not fit real-world grading statistics. A scaled K-means clustering approach will be used to determine natural clustering of accumulated scores that will then be mapped into letter grades of A, A-, B+, B, B-, etc.

Aerospace Engineering Sciences & University Policies: Spring 2021

"Spring Pause"

Due to public health concerns, the University decided to forego a "spring break" this semester and changed the Spring 2021 academic calendar. To provide a safe and supportive way to promote health, wellness, and learning without leaving campus, the week of March 22-26 has been declared a "spring pause" by the College of Engineering and Applied Sciences (CEAS). During this week, Engineering classes will not have any exams or assignments due. Engineering classes with interactive activities requiring your attendance will still occur and will be part of your final course grade. While March 25 is a wellness day with no University classes meeting that day, attendance is still required for all other Engineering class sessions that week. It is important for all Buffs to behave responsibly at all times, not just during the "spring pause", by not engaging in risky behavior that could be detrimental to yourself, your friends, your family, your colleagues, your neighbor, and the unknown person next to you in public.

Classroom Behavior

Both students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote or online. 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. For more information, see the policies on classroom behavior and the Student Code of Conduct.

Requirements for COVID-19

As a matter of public health and safety due to the pandemic, all members of the CU Boulder community and all visitors to campus must follow university, department and building requirements, and public health orders in place to reduce the risk of spreading infectious disease. Required safety measures at CU Boulder relevant to the classroom setting include:

- maintain 6-foot distancing when possible,
- wear a face covering in public indoor spaces and outdoors while on campus consistent with state and county health orders,
- clean local work area,
- practice hand hygiene,
- follow public health orders, and
- if sick and you live off campus, do not come onto campus (unless instructed by a CU Healthcare professional), or if you live on-campus, please alert CU Boulder Medical Services.

Students who fail to adhere to these requirements will be asked to leave class, and students who do not leave class when asked or who refuse to comply with these requirements will be referred to Student Conduct and Conflict Resolution. For more information, see the policies on

COVID-19 Health and Safety and classroom behavior and the Student Code of Conduct. If you require accommodation because a disability prevents you from fulfilling these safety measures, please see the "Accommodation for Disabilities" statement on this syllabus.

All students who are new to campus must complete the COVID-19 Student Health and Expectations Course. Before coming to campus each day, all students are required to complete the Buff Pass. For this class, students do not need to be on campus to complete the requirements for this class. Also, the instructor will not be on campus during the Spring semester.

Students who have tested positive for COVID-19, have symptoms of COVID-19, or have had close contact with someone who has tested positive for or had symptoms of COVID-19 must stay home. In this class, if you are sick or quarantined, you do not need to inform the instructor. The course grading with the dropping of one quiz is to accommodate the possibility of a student or a family member being sick during the semester.

Accommodation for Disabilities

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition, see Temporary Medical Conditions on the Disability Services website.

Preferred Student Names and Pronouns

CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred names and pronouns are listed on instructors' class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

Honor Code

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code. Violations of the policy may include: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code (honor@colorado.edu); 303-492-5550). Students found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found at the Honor Code Office website.

Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation

The University of Colorado Boulder (CU Boulder) is committed to fostering an inclusive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, or protected-class discrimination or harassment by members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or cureport@colorado.edu. Information about the OIEC, university policies, anonymous reporting, and the campus resources can be found on the OIEC website.

Please know that faculty and graduate instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, dating and domestic violence, stalking, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about options for reporting and support resources.

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, let the instructor know of any religious observances that interfere with due dates posted in this syllabus on or before 21-January-2021, which is before the first quiz is posted in Canvas on 22-January-2021.

See the campus policy regarding religious observances for full details.