SES 494/598: SIGNAL PROCESSING ON FIELD PROGRAMMABLE GATE ARRAYS (FPGAs)
FALL - 2024

Instructor Information

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Class Information

Dates: August 22, 2024 – December 6, 2025
Time: Tuesday|Thursday, 9:00AM – 10:15AM (MST)
Classroom: PSF-647

Inspiration for this Course

*Only a few times in ones academic life is a course like this offered. The inspiration for creating **Signal Processing on FPGAs** was inspired from my 20 year career at NASA Goddard Space Flight Center. I have witnessed that when the merging of talents between Scientists and Engineers happen, instrument measurement capabilities expand. The play space for this synergistic activity resides on the digital hardware platform called the Field Programmable Gate Array (FPGA). In this course, for the first time, the Engineers can see the science measurement and the Scientist can understand how that measurement is captured and digitally processed. Enjoy this new learning journey.*

Course Description

This is an exciting course which offers an experiential learning journey to explore science through the digital manipulation of signals on hardware (The FPGA). This is one of the first hybrid Science Electrical Engineering (SEE) courses to be offered in The School of Earth and Space Exploration. The onboard computer that resides in most NASA Spacecraft Missions (eg. JWST) is the Field Programmable Gate Array (FPGA). FPGAs are also found in your cell phones, cars, appliances, etc. Space-qualified FPGAs have been radiation-hardened to survive in the space environment. The future of remote sensing instruments is to process greater amounts of data in real-time acquiring it from the far reaches of the universe. There is an ever-growing need for skilled individuals to meet the tremendous workforce need in this microelectronic area. In this course, we will experientially explore the key attributes of Signal Processing on FPGAs for remote sensing and spaceflight applications. You will learn the key elements of how Signal processing algorithms are realized onto the FPGAs to enable high-speed, real-time, high-resolution science measurements. Engineers and Scientists who study this material will find themselves highly sought after in industry as well as advancing NASA/DoD space research.

Pre-requisites

The background assumed is calculus, experience in manipulating complex numbers, and differential equations. Prior exposure to the fundamentals of circuits and Signals and Systems (EEE 203 or equivalent) for electrical engineers or fundamentals of dynamics for mechanical engineers is helpful.

Course Topics

Listed below is a broad summary of course topics:

1. **The Science Signal** - How did we get here? Are we alone? These are fundamental questions that NASA aims to address in its astrophysics program. Answering these questions requires exquisite measurements across the electromagnetic spectrum, from the far-infrared, to the UV/optical / near-IR, to the X-ray. The type of detector used to obtain these exquisite measurements drives the DSP algorithm that resides on an FPGA. We will explore the Microwave Engineering detector that will be used in the in the future James Webb Telescope Mission: Microwave Kinetic Inductance Detectors (MKIDs).

2. **Discrete-Time Signals: Introduction and Basics** – understanding the characteristics of the incoming signal into your digital board. Students will explore through theory, simulation and hardware how scaling, shifting and mixing of an incoming signal affects the design on the FPGA.

3. **Basic Concepts of Sampling Theory** - We will explore analog-to-digital and digital-to-analog converters (ADC/DAC). Students will study sampling theory, quantization and how these parameters are modeled in Matlab/Simulink.

4. **Convolution** – understanding the theory of convolution (time domain multiplication). Students will explore the simulation and hardware implementation of convolution using Matlab and Simulink.

5. **Correlation/Autocorrelation** – Understanding correlation/autocorrelation theory and its applications in RADAR. Students will explore the simulation and hardware implementation of Correlation/Autocorrelation using Matlab and Simulink.

6. **Discrete Fourier Transform(DFT)/Fast Fourier Transform(FFT)** – Exploring theory and evolution of the FFT through its planetary application (eg. spectral analysis of molecular species on different planets to find evidence of life). The overall RADAR system (for example) will incorporate an FFT into the Simulink model and then we will deploy this onto an FPGA.

7. **Finite Impulse Response (FIR) Filters** – Understanding the theory of FIR filers and its different architectural realizations on the FPGA.

Course Objectives

After this course, you should be able to. . .

1. Understand how the science measurement drives the DSP algorithms on the the Field Programmable Gate Array (FPGA).

2. Develop a Digital Signal Processing System Block Diagram.

3. Understand how data is digitally acquired, mathematically transformed and processed, and information down-linked from Field Programmable Gate Array (FPGA).
4. Develop a Frequency Plan.
5. Understand the major DSP algorithms that primarily effect Digital Signal Processing Designs on Field Programmable Gate Array (FPGAs).
6. Apply introductory DSP theory to develop a Model-based design in Matlab Simulink of a science application (eg. RADAR).
7. Implement Fast, Efficient and Real-Time DSP Algorithms onto an FPGA.

Course Materials

Below are the materials needed for this course:

1. **Required Textbook**

   Textbook: *Signals and Systems*, Alan Oppenheim and Alan S. Willsky, 2nd edition, Prentice Hall, 1983, ISBN 0-13-814757-4

2. **Supplementary Textbook(s) and Software**

   Listed below are books and resources that are highly encouraged to purchase, borrow, and/or download:

   (a) Textbook: *Digital Signal Processing Principles, Algorithms and Applications*, John G. Proakis and Dimitris G. Manolakis, 4th edition, Pearson, 2021. ISBN 978-81-317-1000-5

   (b) Textbook: *Microwave Engineering*, David M. Pozar, 4th edition, Wiley & Sons, Inc, 2012, ISBN 978-0-470-63155-3

   (c) Solved Problems: *Schaums Outline of Digital Signal Processing, 2nd Edition*, Monson H. Hayes, 2nd edition, McGraw Hill Education, 2012, ISBN-10 0071635092

   (d) Download Matlab and Simulink 2023b (*required*)

   (e) Download Xilinx Vivado Development Environment (see instructor for version) (*optional)*

Overview of Lectures

This schedule listed below is subject to change:

Table 1: Overview of Lectures and Topics (THIS IS SUBJECT TO CHANGE) ** Zoom Class Session

Lecture	Week	Date	Day	Topic
1	1	8/22	Th	Course Overview/ Syllabus Review
2		8/27	Tu	The origin of the Science Signal: Microwave Resonators

Table 1: Overview of Lectures and Topics (THIS IS SUBJECT TO CHANGE) ** Zoom Class Session

Lecture	Week	Date	Day	Topic
3	2	8/29	Th	The Science Signal: Microwave Kinetic Inductors
4	3	9/3	Tu	The Continuous-time Signal: Understanding the Complex Signal
5		9/5	Th	The Continuous-time Signal: Periodicity/Time Shifting/Scaling
6	4	**9/10	Tu	The Continuous-time Signal: Addition/Multiplication
7		**9/12	Th	The Continuous-Time Signal Time-Invariance
8	5	9/17	Tu	Analog-to-Digital/Digital-to-Analog Conversion (ADC/DAC): 1. Sampling of Analog Signals 2. The Sampling Theorem
9		9/19	Th	ADC/DAC: 1. Quantization of Sinusoidal Signals 2. Coding of Quantized Samples
10	6	9/24	Tu	Intro to Convolution and Properties
11		9/26	Th	Convolution Examples and Implementation on Hardware
12	7	10/01	Tu	Correlation/Autocorrelation
13		10/03	Th	SHEPS Experiential Learning Lab: Convolution on Hardware
14	8	10/08	Tu	Continuous-time Fourier Transform
15		10/10	Th	Continuous-time Fourier Transform Properties
n/a	9	10/15	Tu	**Fall Break (no class)**
Midterm		10/17	Th	**Midterm**
16	10	10/22	Tu	The Discrete-time Fourier Transform
17		10/24	Th	The Discrete-time Fourier Transform Properties
18	11	10/29	Tu	Fast Fourier Transform
19		10/31	Th	Fast Fourier Transform on Hardware
20	12	11/05	Tu	Continuous-time Filters Described by Differential Equations
21		11/07	Th	Discrete-time Filters Described by Difference Equations
22	13	11/12	Tu	Intro to Finite Impulse Response (FIR) Filters
23		11/14	Th	FIR Continued
24	14	11/19		Introduction Sampling Theory
25		11/21		Sampling Theory Continued
26	15	**11/26	Tu	Virtual SHEPS Experiential Learning Lab
n/a		11/28	Th	**Holiday (no class)**
27		12/3		Frequency Planning

Table 1: Overview of Lectures and Topics (THIS IS SUBJECT TO CHANGE) ** Zoom Class Session

Lecture	Week	Date	Day	Topic
28	16	12/5		Digital Spectrometer Design
Final Review		12/6		Last Day of Class:))
Final		**12/12**	**Th**	**7:30AM-9:20AM (timed online)**

The Keys to Success

The guidelines below are suggestions for integrating the theory and practical exercises in this course.

1. **Mindfulness** - During my 20 year tenure at NASA Goddard Space Flight center, I worked in a highly dynamic, fast-paced and (sometimes) stressful environment. I learned to manage my stress/anxiety with research-based stress management practices. We will begin each class with a 3-minute mindfulness activity. You are encouraged to participate but if you choose not to, please refrain from talking.

2. **Attendance** - It is important that you come to class on time for the full duration of the class. If you are having an extenuating circumstance that prevents you from coming to class, it is your responsibility to communicate this with your Instructor.

3. **Timely Completion of Assignments** - Completing your weekly reading, homework and Matlab/Simulink assignments is essential for you to exercise the knowledge in this course. Please be sure to submit your work in a timely fashion on canvas. All assignments have been designed to provide you with the practical tools to be successful in your careers and your future academic life. It is strongly encouraged that you work on assignments early and meet with your Instructor if you have questions.

4. **Purchase your Book Immediately** - You will be responsible for completing assignments which will require you to have the assigned book for this course.

5. **Bring your computer to class** - We will be utilizing the Matlab/Simulink design tools during class to work on example problems.

6. **Late assignments** - Please make every effort to submit your work on time. Each lesson builds on the previous lesson so it is important to submit your work on time. A late submission penalty (10%) will apply in the case of late submissions. No assignment submission will be graded after 24 hours after the submission due date unless there is a valid excuse and/or accommodation.

Assignment/Labs/Exam Submission Guidelines

Please become familiar with the items below for all class submissions.

1. All assignments (unless otherwise stated) should be electronically submitted in canvas by the due date. All assignments are due in Phoenix, Arizona time (MST). Phoenix does not observe daylight savings time, so we are in the MST (Mountain Standard Time) time zone year round.

A late submission penalty (10%) will apply in the case of late submissions. No assignment submission will be graded after 24 hours after the submission due date unless there is a valid excuse and/or accommodation.

2. Homework/Labs should be completed independently. Collaboration and study groups are encouraged but your **homework submissions must be unique**.
3. Homework/Labs/Exams must be submitted as **ONE** PDF file.
4. Homework/Labs/Exams must be submitted in a neat organized manner to receive credit.
5. Filename on homework needs to be in the following manner:

   JAMISONHOOKS_HW1_08222024

6. Filename on Labs needs to be in the following manner:

   JAMISONHOOKS_LAB1_08222024

7. Filename on Midterm Exam needs to be in the following manner:

   JAMISONHOOKS_MID_08222024

8. Filename on Final Exam needs to be in the following manner:

   JAMISONHOOKS_FIN_08222024

Grading

Your course grade is determined by the following components:

Midterm	20%
Homework	20%
Quizzes	20%
Labs	20%
Final Exam	20%

Respect for Computers and Field Programmable Gate Arrays

The FPGA (and supporting computers) used in this class are expensive and should be respected. Mistakes happen whenever people work in the lab, and that is OK. However, if any students intentionally destroy or damage the hardware, they will be billed (which could be thousands of dollars).

Drop and Add Dates/Withdrawals

Please be aware of the limited timeline to drop or add courses. Consult with your academic advisor and notify your instructor to add or drop this course. If you are considering a withdrawal, review the following ASU policies:Withdrawal from Classes, Medical/Compassionate Withdrawal, and a Grade of Incomplete. Please consult the advisor before dropping the course. There are often

suggestions for improvement that you might not have considered.

Medical Withdrawals

- Medical withdrawals are available when the student's own serious illness or injury prevents them from continuing their classes. Both physical and mental health difficulties are covered.
- Compassionate withdrawals are available when other personal reasons (such as care of a seriously ill child or spouse or a death in the immediate family) prevent the student from continuing in classes.
- Students who do not meet the standards for medical or compassionate withdrawals may still be eligible for an academic record change to change their grade to a W in one or more classes. The effective date on an academic record change should reflect the last date of active participation in the class.
- Medical/Compassionate Withdrawal process is overseen by The College and the link to begin submitting a request along with required documentation is on this website.

Grade Appeals

Grade disputes must **first** be addressed by discussing the situation with the instructor. If the dispute is not resolved with the instructor, the student may appeal to the department chair per the University Policy for Student Appeal Procedures on Grades.

Absences

The conditions under which assigned work or tests can be made up, including:

- The instructor's general policy on absences.
- Information on excused absences related to religious observances/practices that are in accordance with ACD 304–04 "Accommodations for Religious Practices."
- Information on excused absences related to university-sanctioned events/activities that are in accordance withACD 304–02 "Missed Classes Due to University-Sanctioned Activities."

Academic integrity

Academic honesty is expected of all students in all examinations, papers, and laboratory work, academic transactions and records. The possible sanctions include, but are not limited to, appropriate grade penalties, course failure (indicated on the transcript as a grade of E), course failure due to academic dishonesty (indicated on the transcript as a grade of XE), loss of registration privileges, disqualification and dismissal. For more information, see this.

Accommodating students with disabilities

Students who feel they will need disability accommodations in this class but have not registered with the Disability Resource Center (DRC) should contact DRC immediately. The DRC Tempe office

is located on the first floor of the Matthews Center Building. DRC staff can also be reached at (480) 965-1234 (V) or (480) 965-9000 (TTY). For additional information, visit: here.

Expected classroom behavior

Respectful and professional behavior with your classmates is essential for a healthy learning environment.

Please arrive at class 10 minutes before the start of the lecture so that you can be prepared. Under no circumstances should you allow your cell phone to ring during class. I strongly encourage you to refrain from the following disruptive behaviors: ringing cell phones, listening to your mp3/iPod player, text messaging, constant talking, eating food noisily, and/or reading a newspaper. These behaviors will not be tolerated.

Policy against threatening behavior

All incidents and allegations of violent or threatening conduct by an ASU student (whether on- or off campus) must be reported to the ASU Police Department (ASU PD) and the Office of the Dean of Students. If either office determines that the behavior poses or has posed a serious threat to personal safety or to the welfare of the campus, the student will not be permitted to return to campus or reside in any ASU residence hall until an appropriate threat assessment has been completed and, if necessary, conditions for return are imposed. ASU PD, the Office of the Dean of Students, and other appropriate offices will coordinate the assessment in light of the relevant circumstances.

Reporting Title IX violations

Title IX is a federal law that provides that no person be excluded on the basis of sex from participation in, be denied benefits of, or be subjected to discrimination under any education program or activity. Both Title IX and university policy make clear that sexual violence and harassment based on sex is prohibited. An individual who believes they have been subjected to sexual violence or harassed on the basis of sex can seek support, including counseling and academic support, from the university. If you or someone you know has been harassed on the basis of sex or sexually assaulted, you can find information and resources here.

As a mandated reporter, I am obligated to report any information I become aware of regarding alleged acts of sexual discrimination, including sexual violence and dating violence. ASU Counseling Services is available if you wish to discuss any concerns confidentially and privately. ASU online students may access 360 Life Services

Policy on Sexual Discrimination

Arizona State University is committed to providing an environment free of discrimination, harassment, or retaliation for the entire university community, including all students, faculty members, staff employees, and guests. ASU expressly prohibits discrimination, harassment, and retaliation by employees, students, contractors, or agents of the university based on any protected status: race, color, religion, sex, national origin, age, disability, veteran status, sexual orientation, gender identity, and genetic information.

As a mandated reporter, I am obligated to report any information I become aware of regarding alleged acts of sexual discrimination, including sexual violence and dating violence. ASU Counseling Services is available if you wish discuss any concerns confidentially and privately.

Copyrighted materials

All the content in this course, including lectures, are copyrighted materials. Students may not share outside the class, upload, sell or distribute course content or notes taken during the conduct of the course (see ACD 304-06). Students may not upload to any course shell, discussion board or website used by the course instructor or other course forum, material that is not the student's original work, unless the student first complies with all applicable copyright laws. The instructor reserves the right to delete materials on the grounds of suspected copyright infringement (see ACD 304-10).

Prohibition of Commercial Note Taking Services

In accordance with ACD 304-06 Commercial Note Taking Services, written permission must be secured from the official instructor of the class in order to sell the instructor's oral communication in the form of notes. Notes must have the notetaker's name as well as the instructor's name, the course number, and the date.

Course Evaluation

Students are expected to complete the course evaluation. The feedback provides valuable information to the instructor and the college and is used to improve student learning. Students are notified when the online evaluation form is available.

Syllabus Disclaimer

The syllabus is a statement of intent and serves as an implicit agreement between the instructor and the student. Every effort will be made to avoid changing the course schedule but the possibility exists that unforeseen events will make syllabus changes necessary. Please remember to check your ASU email and the course site often.

Inclusion Statement

This class is a place where all will be treated with respect, welcoming individuals of all ages, backgrounds, beliefs, ethnicities, genders, gender identities, gender expressions, national origins, religious affiliations, sexual orientations, ability – and other visible and nonvisible differences. All members of this class are expected to contribute to a respectful, welcoming, and inclusive environment for every other member of the class.

Preferred Name/Pronoun Statement

Any request to be addressed by an alternate name or gender pronoun will be honored in this course. Please advise of this preference early in the semester so appropriate changes can be made to the course records.