RF Measurements and Instrumentation

EEL 6935 Section 27878
Class Periods: Mon/Wed/Fri 8:30-9:20 AM (lectures)
Tue 6:15-8:10 PM and Wed 8:20-10:10 PM (labs)
Location: Online
Academic Term: Fall 2020

Instructor:
Name: Soumyajit Mandal
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Office Hours: Mon 9:20-10:20

Teaching Assistant/Peer Mentor/Supervised Teaching Student:
Please contact through the Canvas website
- Name: David Ariando, Email Address: dariando@ufl.edu

Course Description
This course will introduce modern instrumentation and measurement design principles. Students will simulate, build, and analyze the performance of electronic circuits and sensors, with a focus on radio frequency (RF) systems. They will also become familiar with FPGA programming and understand practical signal processing techniques. Finally, they will understand how to integrate hardware and software to build high-performance RF instruments. *Lecture and Lab. Credits 4.*

Course Pre-Requisites / Co-Requisites
- EEE 3308C – Electronic Circuits 1
- EEL 3112 – Circuits 2
- EEL 3701C – Digital Logic
- Permission of the instructor

Students should be familiar with analysis, design, and testing of analog and digital circuits (including frequency response concepts), and the fundamentals of logic design. Knowledge of FPGA programming using a hardware description language (such as Verilog or VHDL) is useful but not required.

Course Objectives
The first half of the course will introduce general concepts of measurement systems, including accuracy, precision, sensitivity, resolution, and safety issues. The second half will mainly focus on various specific techniques and applications that involve RF circuits and systems. Examples include radar, sonar, nuclear magnetic resonance (NMR), magnetic resonance imaging (MRI), and ultrasound.

In addition to theoretical material taught during the lectures, there will be laboratory assignments in which students build and test a complete RF-based scientific instrument. This will provide hands-on experience for understanding precision measurements and scientific instrumentation with an emphasis on sensor physics, sensor interface electronics, signal processing, and data analysis. The specific instrument considered may change from term to term. A typical example is a low-field NMR spectrometer. In this case, lectures will introduce the NMR phenomenon and its numerous uses in chemical analysis and imaging (i.e. MRI). Students will then implement a complete spectrometer by simulating and measuring coil properties; designing matching networks and analog front ends for processing RF signals; building and testing a high-performance transceiver on a printed circuit board (PCB); and programming an FPGA development board to control the system and acquire data.

Materials and Supply Fees
- Terasic DE0-Nano-SoC development board (cost: $90): https://www.terasic.com.tw/cgi-bin/page/archive.pl?Language=English&No=941

- BNC Adapter for Analog Discovery (cost: $20): https://store.digilentinc.com/bnc-adapter-for-analog-discovery/
- BNC Oscilloscope x1/x10 Probes (Pair) - 6 MHz / 100 MHz (cost: $20): https://store.digilentinc.com/bnc-oscilloscope-x1-x10-probes-pair/
- AURSINC NanoVNA vector network analyzer (cost: $70): https://tinyurl.com/y56maaed
- PowerBank +5V DC power supply (cost: $17): https://www.amazon.com/Updated-Compact-10000mAh-Technology-Portable/dp/B07YB9K7WJ
- Digilent Analog Discovery 2 (DAD2) board, or equivalent.

Required Textbooks and Software

Course lectures and notes as developed by the instructor.

Recommended Materials

- Alan Morris and Reza Langari, "Measurement and Instrumentation: Theory and Application" (2nd Edition), Academic Press, 2015. ISBN: 978-0128008843.
- David M. Pozar, "Microwave Engineering" (4th Edition), Wiley, 2011. ISBN: 978-0470631553.
- Mark Denny, "Blip, Ping, and Buzz: Making Sense of Radar and Sonar"(1st Edition), Johns Hopkins University Press, 2007. ISBN: 978-0801886652.
- Additional material to be provided on the course website.

Course Schedule

Week	Lectures (3 per week)	Lab session (1 per week)	Others
1	• Introduction to the course • Characteristics of sensors	• Introduction to the SoC development board, basic Verilog, and programming on the FPGA	
2	• Concepts of RF measurements • Concepts of NMR instruments	• Introduction to finite state machine and Modelsim debugging	
3	• Basics of frequency measurements • Phase-locked loops and frequency synthesizers	• Introduction the hard processor system (HPS), Platform Designer, and its communication interfaces	
4	• Review of transmission lines • Impedance matching	• Introduction to Linux system on the FPGA, and programming via Python	
5	• Introduction to feedback systems • Stability and compensation	• Programmable FPGA-based frequency generator	
6	• Fundamentals of electronic noise • Noise models of devices	• Coil design and impedance matching network	
7	• Noise analysis in circuits • Low-noise circuit design methods	• Simulation and testing of voltage regulators and DC power supplies	• Midterm exam
8	• Low-noise amplifier design • Midterm review	• Simulation and testing of the low-noise amplifier	
9	• Linear power amplifiers • Switching power amplifiers	• Simulation and testing of the complete receiver	
10	• Fundamentals of ADCs • Common ADC architectures	• Simulation and testing of the duplexer	
11	• Review of signal processing in MATLAB • Averaging and matched filtering	• Data acquisition with the ADC	
12	• Introduction to RF test equipment • RF calibration principles	• Implementing the NMR finite state machine	

13	• RF performance metrics • Board-level RF design	• HPS-based instrument system control in Linux	
14	• Antennas and wireless propagation • Introduction to amateur radio	• Testing of the complete instrument	

Online Course Recording

Our class sessions may be audio visually recorded for students in the class to refer back and for enrolled students who are unable to attend live. Students who participate with their camera engaged or utilize a profile image are agreeing to have their video or image recorded. If you are unwilling to consent to have your profile or video image recorded, be sure to keep your camera off and do not use a profile image. Likewise, students who un-mute during class and participate orally are agreeing to have their voices recorded. If you are not willing to consent to have your voice recorded during class, you will need to keep your mute button activated and communicate exclusively using the "chat" feature, which allows students to type questions and comments live. The chat will not be recorded or shared. As in all courses, unauthorized recording and unauthorized sharing of recorded materials is prohibited.

F2F Course Policy in Response to COVID-19

We will have face-to-face instructional sessions to accomplish the student learning objectives of this course. In response to COVID-19, the following policies and requirements are in place to maintain your learning environment and to enhance the safety of our in-classroom interactions.

- You are required to wear approved face coverings at all times during class and within buildings. Following and enforcing these policies and requirements are all of our responsibility. Failure to do so will lead to a report to the Office of Student Conduct and Conflict Resolution.
- This course has been assigned a physical classroom with enough capacity to maintain physical distancing (6 feet between individuals) requirements. Please utilize designated seats and maintain appropriate spacing between students. Please do not move desks or stations.
- Sanitizing supplies are available in the classroom if you wish to wipe down your desks prior to sitting down and at the end of the class.
- Follow your instructor's guidance on how to enter and exit the classroom. Practice physical distancing to the extent possible when entering and exiting the classroom.
- If you are experiencing COVID-19 symptoms (Click here for guidance from the CDC on symptoms of coronavirus), please use the UF Health screening system and follow the instructions on whether you are able to attend class. Click here for UF Health guidance on what to do if you have been exposed to or are experiencing Covid-19 symptoms.
- Course materials will be provided to you with an excused absence, and you will be given a reasonable amount of time to make up work. Find more information in the university attendance policies.

Attendance Policy, Class Expectations, and Make-Up Policy

This class will be presented online using Zoom and requires access to a working webcam and stable internet connection. I prefer that students keep their camera on during the class so that I can see you as I would during normal face-to-face classes. Studies show that if we can see each other's faces then we will have more engagement, more student success, and more faculty success. However, this is not a requirement. I understand if on certain days you can't have your camera on due to internet bandwidth limitations, other family members, health issues, or any other reasons.

Excused absences must be in compliance with university policies in the Graduate Catalog (http://gradcatalog.ufl.edu/content.php?catoid=10&navoid=2020#attendance) and require appropriate documentation.

Evaluation of Grades

Assignment	Total Points	Percentage of Final Grade
Homework assignments (7)	100 each	35%
Midterm exam	100	35%
Final presentation	100	30%
		100%

Homework assignments: Each assignment will consist of two parts: i) Problems based on the theoretical material presented during the lectures; each student will complete these individually. ii) Experiments to be performed in the lab. Verification of individual effort for the experiments will be carried out by the instructor and teaching assistant(s) during the weekly lab sessions.

Final presentations: Each person will present the results of lab assignments. The presentations are expected to show understanding of the topics covered in the lab assignments throughout the semester.

Mid-term: This in-class exam will test knowledge of the material from lectures covered throughout the first half of the semester.

This course is co-listed with an undergraduate class (EEL4930). The two courses will share the lectures and lab sessions, and the combined total enrollment is capped at 27 students (9 groups). The homework assignments and exams for the graduate section will involve additional work and more advanced concepts than the undergraduate section. Grading for the homework and projects will also be different for the graduate and undergraduate sections. The graduate and undergraduate sections will be graded separately; the graduate section will have additional problems and different weights for all problems.

Grading Policy

Percent	Grade	Grade Points
93 - 100	A	4.00
90 - 92	A-	3.67
87 - 89	B+	3.33
83 - 86	B	3.00
80 - 82	B-	2.67
77 - 79	C+	2.33
73 - 76	C	2.00
70 - 72	C-	1.67
67 - 69	D+	1.33
63 - 66	D	1.00
60 - 62	D-	0.67
0 - 59	E	0.00

More information on UF grading policy may be found at:
http://gradcatalog.ufl.edu/content.php?catoid=10&navoid=2020#grades

Students Requiring Accommodations

Students with disabilities who experience learning barriers and would like to request academic accommodations should connect with the disability Resource Center by visiting https://disability.ufl.edu/students/get-started/. It is important for students to share their accommodation letter with their instructor and discuss their access needs, as early as possible in the semester.

Course Evaluation

Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and

respectful manner is available at https://gatorevals.aa.ufl.edu/students/. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via https://ufl.bluera.com/ufl/. Summaries of course evaluation results are available to students at https://gatorevals.aa.ufl.edu/public-results/.

University Honesty Policy

UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code (https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-code/) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

Commitment to a Safe and Inclusive Learning Environment

The Herbert Wertheim College of Engineering values broad diversity within our community and is committed to individual and group empowerment, inclusion, and the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture.

If you feel like your performance in class is being impacted by discrimination or harassment of any kind, please contact your instructor or any of the following:

- Your academic advisor or Graduate Program Coordinator
- Robin Bielling, Director of Human Resources, 352-392-0903, rbielling@eng.ufl.edu
- Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, taylor@eng.ufl.edu
- Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, nishida@eng.ufl.edu

Software Use

All faculty, staff, and students of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

Student Privacy

There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see: https://registrar.ufl.edu/ferpa.html

Campus Resources:

Health and Wellness

U Matter, We Care:
Your well-being is important to the University of Florida. The U Matter, We Care initiative is committed to creating a culture of care on our campus by encouraging members of our community to look out for one another and to reach out for help if a member of our community is in need. If you or a friend is in distress, please contact umatter@ufl.edu so that the U Matter, We Care Team can reach out to the student in distress. A nighttime and weekend crisis counselor is available by phone at 352-392-1575. The U Matter, We Care Team can help connect students to the many other helping resources available including, but not limited to, Victim Advocates, Housing staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. In case of emergency, call 9-1-1.

Counseling and Wellness Center: http://www.counseling.ufl.edu/cwc, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

Sexual Discrimination, Harassment, Assault, or Violence
If you or a friend has been subjected to sexual discrimination, sexual harassment, sexual assault, or violence contact the **Office of Title IX Compliance**, located at Yon Hall Room 427, 1908 Stadium Road, (352) 273-1094, title-ix@ufl.edu

Sexual Assault Recovery Services (SARS)
Student Health Care Center, 392-1161.

University Police Department at 392-1111 (or 9-1-1 for emergencies), or http://www.police.ufl.edu/.

Academic Resources

E-learning technical suppor*t*, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu. https://lss.at.ufl.edu/help.shtml.

Career Resource Center, Reitz Union, 392-1601. Career assistance and counseling. https://www.crc.ufl.edu/.

Library Support, http://cms.uflib.ufl.edu/ask. Various ways to receive assistance with respect to using the libraries or finding resources.

Teaching Center, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring. https://teachingcenter.ufl.edu/.

Writing Studio, 302 Tigert Hall*,* 846-1138. Help brainstorming, formatting, and writing papers. https://writing.ufl.edu/writing-studio/.

Student Complaints Campus*:* https://care.dso.ufl.edu.

On-Line Students Complaints*:* http://www.distance.ufl.edu/student-complaint-process.