

## **Linear Control Systems**

**EEL 4657** All Sections

**Class Periods:** Tuesday (8:30 AM – 10:25 AM), Thursday Period 9 (9:35 AM - 10:25 AM)

**Location:** Online

**Academic Term:** Fall 2020

### ***Instructor:***

Zoleikha A. Biron, Ph.D.

[z.biron@ece.ufl.edu](mailto:z.biron@ece.ufl.edu)

(352)-392-5965

Office Hours: Thursday, 11 AM, Zoom

### ***Teaching Assistant/Peer Mentor/Supervised Teaching Student:***

Please contact through the Canvas website

- Miaomiao Hu, [mhu1@ufl.edu](mailto:mhu1@ufl.edu), TBA
- Office Hours: Thursday, 4 PM, Zoom

### ***Course Description***

**EEL 4657- Linear Control Systems** - Pre-requisites: Circuits II and Signals and Systems. Theory and Design of Linear Control Systems

### ***Course Pre-Requisites / Co-Requisites***

EEL 3112, EEL 3135, and EEL3744

An undergraduate course in electrical circuits and signals and systems provides a desirable background for some of the material to be covered in the course. Specifically, it would be helpful for students to have a sound grasp of the concepts of transfer functions, time and frequency response, and Laplace Transform analysis.

A basic knowledge of z-transforms and solving difference equations would also be helpful in the discrete-time material. In addition, matrices and linear algebra concepts will be used in the introduction of the state variables approach that is covered in this class. Knowledge of microprocessors will also be useful in implementing controlling analog controllers in digital form.

## ***Course Objectives***

EEL 4657 is an introductory course on the analysis and design of Linear Control Systems. The material presented emphasizes the classical analysis and design control systems to achieve overall system stability and acceptable performance. The class of Linear Time Invariant (LTI) Single-input Single Output (SISO) systems is of primary focus, although a more general introductory treatment is also given in terms of state space and transfer matrix representations of Multi-input Multi-output (MIMO) systems. This course is built on material covered in pre-requisite or co-requisite courses such as EEL 3112 (Electrical Circuits II) and EEL 3135 (Signals and Systems), as well as mathematical preliminaries with particular emphasis on the solution of ordinary differential equations using Laplace transform techniques. The course also exhibits control systems as a multidisciplinary subject finding application in electrical, chemical, mechanical, biomedical, and other branches of engineering.

The goal of the course is to provide access to the basic design and analysis tools used in practical control systems as well as to give an exposure of the student to the general area of linear systems theory which appears so very often in all branches of engineering. We consider such topics as the philosophy, benefits and costs of negative feedback, stability, robustness and performance specifications as well as system analysis and design for Single-input Single-output systems. The major tools of classical analysis, The Root Locus, the Nyquist Diagram and the associated Nyquist Stability Criterion and Bode Plots are developed and illustrated. While the main results are developed for continuous time systems using the mathematical formalism of the Laplace transform, we also provide an introductory coverage of discrete-time systems using the Z-transform. Throughout our discussion of the classical theory, we interweave hints of the more rigorous design methods of both the state-space as well as the optimal frequency domain approaches. For example, in dealing with differential equations and Laplace transforms, MIMO systems are presented as quite simple extensions of SISO systems within the state-space setting, leading naturally to the generalization of SISO transfer functions to MIMO transfer matrices. We also introduce the notion of an optimization over the set of all stabilizing controllers to attain the best possible performance or robustness measures. The treatment of these latter aspects at this point is very general and non-rigorous; the intent is purely motivational for an appreciation of more advanced material the student may encounter later.

Lab schedules and details for the laboratory section of the class will be provide in class and online. Labs will typically begin during the second week of the semester. MATLAB/Simulink will be used to integrate with laboratory velocity and position motor systems and with a ball and beam rig. Students will be required to implement Lead/Lag and PID controllers using a microprocessor, students are familiar with from EEL3744 (Microprocessor Applications).

## ***Materials and Supply Fees***

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### ***Required Textbooks and Software***

- a. **Title:** Linear Control Systems – A Neo-classical Approach (in preparation)  
**Author:** Haniph A. Latchman  
**Publication Date:**  
**ISBN number:**  
Available Online as a PDF for all students  
Please do not place on any Internet site.
- b. **Title:** Automatic Control System, Tenth Edition  
**Author:** Farid Golnaraghi, Benjamin Kuo

### ***Recommended Materials***

- a. **Title:** Modern Control Systems  
**Author:** R.C. Dorf and R.H. Bishop  
**Publisher:** Prentice Hall  
**Publication Date:** 2010  
**Edition:** 12

## **Course Outline**

- 1.0 Introduction and Background
  - 1.1 Open-loop Vs Closed-loop Control Systems
  - 1.2 Control Objectives
  - 1.3 Mathematical Representation of Systems
  - 1.4 System Classification
  - 1.5 Control Strategies
  - 1.6 History of Control Theory and Control Systems
- 2.0 Linear Systems Theory and Classical Control
  - 2.1 Introduction
  - 2.2 A Motivational Example - Automotive Cruise Control
  - 2.3 The Laplace transform
  - 2.4 A State-space Approach
  - 2.5 A Direct Transfer Function Approach
  - 2.6 Transfer Function Model Standardization and Simplification
  - 2.7 Block Diagram Reduction
  - 2.8 Signal Flow Diagram and Mason's Rule
  - 2.9 Relationship Between Transfer Function and State-space Models
- 3.0 s-Domain Analysis and Performance Criteria
  - 3.1 Stability Definitions and Conditions
  - 3.2 Negative Feedback Analysis and Stability Testing
  - 3.3 Transient Time Response: The Effect of Pole Locations
  - 3.4 Second Order Time Response Characteristics
  - 3.5 Steady State Response and System Type
- 4.0 Classical s-domain Design Methods
  - 4.1 Constant Gain Controllers
  - 4.2 The Root Locus
  - 4.3 An Example
  - 4.4 1st Order Lag Controllers
  - 4.5 1st Order Lead Controllers
- 5.0 Frequency Domain Analysis and Performance Criteria
  - 5.1 The Nyquist Stability
  - 5.2 Gain and Phase Margins
  - 5.3 Performance Specifications in the Frequency Domain
  - 5.4 Robustness and Robustness Margins
  - 5.5 The Critical Direction
- 6.0 Frequency Domain Design Methods
  - 6.1 1st Order Lag Design
  - 6.2 1st Order Lead Design
- 7.0 State Variable Analysis and Design Methods
  - 7.1 Observability Controllability and Minimality
  - 7.2 Stability Criteria
  - 7.3 State Feedback and Output Feedback
  - 7.4 State Observers

## **Attendance Policy, Class Expectations, and Make-Up Policy**

### **Class Attendance**

Class attendance is not required but all students are responsible for all material and information disseminated during class sessions as such information may not be posted on websites or otherwise. Quizzes are administered daily; make-up quizzes are only allowed in exceptional circumstances such as documented medical emergency – these should be discussed with the Instructor.

### **Assignments**

Homework and other assignments will be given periodically and will be due within the first 5 minutes of class on the designated due date. Use regular-size paper, staple the sheets together, and put your name and homework number at the top.

Late homework will be accepted only in exceptional circumstances which need to be discussed with the Instructor for approval. Homework assignments will not be given over the phone. Graded homework will be returned in class or during office hours.

### **Exams**

The midterm exam will be given in October (time and location TBA). The midterm will be closed-book and closed-notes.

The final examination will be comprehensive, but with emphasis on material covered since the midterm exam.

For the final exam, students will be allowed one side of one sheet of letter-sized paper, written in their own original handwriting. The date of the final exam is Tuesday, 12/15/2020 at 7:30 AM - 9:30 AM. Final exams are decided by the registrar's office and can be confirmed online at <http://www.registrar.ufl.edu/soc/>.

### **Labs**

Labs will be completed on a weekly basis. Your lab grade will be out of 100 and will be used to calculate your final course grade as shown under Grading. The following is a list of the lab topics. The Module Fundamentals is due for each module on the last week of that module. A quiz will be given at the beginning of each lab. The lab will be held by Zoom and students will use MATLAB/Simulink to develop and implement different controllers virtually. Students will demonstrate their results during their designated lab section and will be evaluated by their TA. At-home labs should be completed before the deadline. Reporting to lab without being able to demonstrate will result in a 50% penalty for that lab, assuming completion by the end of the lab section.

At the end of each module, a module report putting together the contents of all the sections of the module will be due the following week. For example, the Module Fundamentals for Module 1: Modeling is due on the next week of labs, while the Module Report for Module 1 is due on the second week of labs. Students will submit these assignments via Canvas.

Late lab assignments will be accepted only in exceptional circumstances which need to be discussed with your TA for approval.

#### **Labs will be held Online (in two of the following sections)**

<b>Section</b>	<b>Meeting Time</b>	<b>TA</b>
308	T, 11-E1 (6:15 PM – 8:10 PM)	TBA
335	W, 11-E1 (6:15 PM – 8:10 PM)	TBA
336	R, 11-E1 (6:15 PM – 8:10 PM)	TBA
338	R, E2-E3 (8:20 PM – 10:10 PM)	TBA

### **Module 1: System Modeling**

1.1: Introduction of Simulink: Blocks, Simulation time, Model development

1.2: Modeling of Motor Speed System with State Space, Transfer Function

### **Module 2: PID Control**

2.1: Step and Ramp Response of Motor Speed System using PID controller

2.2: PID Controller tuning and Sampling time effect

### **Module 3: Lead/Lag Control**

3.1: Development, Simulation, and Implementation of lag Controller for Motor Speed System

3.2: Development, Simulation, and Implementation of Lead Controller for Motor Speed System

### **Module 4: Cascade Control Scenarios**

4.1: Development and Simulation of Cascade Control System

4.2: Stabilization of Aircraft Pitch System

### ***Evaluation of Grades***

<b>Assignment</b>	<b>Total Points</b>	<b>Percentage of Final Grade</b>
Homework sets	100 each	15%
Quizzes	100 each	10%
Labs	100 each	15%
Midterm Exam	100	25%
Final Exam	100	35%
		100%

### ***Grading Policy***

<b>Percent</b>	<b>Grade</b>	<b>Grade Points</b>
90.0 - 100.0	A	4.00
85.9 - 89.9	A-	3.67
81.8 - 85.8	B+	3.33
77.7 - 81.7	B	3.00
73.6 - 77.6	B-	2.67
68.5 - 72.5	C+	2.33
64.4 - 68.4	C	2.00
60.3 - 64.3	C-	1.67
56.2 - 60.2	D+	1.33
52.1 - 56.1	D	1.00
48.0 - 52.0	D-	0.67
0 - 47.9	F	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 requesting accommodations should first register with the Disability Resource Center (352-392-8565, <https://www.dso.ufl.edu/drc>) by providing appropriate documentation. Once registered, students will receive an accommodation letter which must be presented to the instructor when requesting accommodation. Students with disabilities should follow this procedure 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](mailto:rbielling@eng.ufl.edu)
- Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, [taylor@eng.ufl.edu](mailto:taylor@eng.ufl.edu)
- Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, [nishida@eng.ufl.edu](mailto: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](mailto: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](mailto: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 support**, 352-392-4357 (select option 2) or e-mail to [Learning-support@ufl.edu](mailto: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://www.dso.ufl.edu/documents/UF\\_Complaints\\_policy.pdf](https://www.dso.ufl.edu/documents/UF_Complaints_policy.pdf).

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