

# ASEN 6024

## NON-LINEAR CONTROL DESIGN

**Course Description:** Analysis and design of continuous-time non-linear control systems. Begins with phase plane analysis of second order systems, then introduces several popular methods for the analysis and design of higher order non-linear systems. Central topics include Lyapunov stability theory, passivity theory, and frequency-domain approaches.

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**Prerequisites:** Graduate Linear Systems course (e.g. ASEN 5014 or equivalent).

**Textbook:** *Nonlinear Systems*, Hassan K. Khalil, 3<sup>rd</sup> Ed., Prentice Hall, 2002.

### Syllabus Outline

Topics	Weeks
Introduction: Non-linear vs. linear systems	2
Phase plane analysis of 2 <sup>nd</sup> order systems	2
Existence and uniqueness of solutions	1
<b>Midterm exam 1</b>	
Lyapunov stability theory	4
<b>Midterm exam 2</b>	
Input-Output stability theory	2
Passivity theory	2
Frequency domain analysis	1
Feedback linearization	1
<b>Final exam</b>	
<b>Total</b>	<b>15</b>

### Course Policies and Grading

- **Grading:** 3 exams---30% each, Homework---10%.
- **Homework:** Group work is encouraged, although individual understanding will be necessary to do well on exams. Homework will be checked (but not graded). Solutions will be posted and discussed in class.
- **Exams:** Take home, involving both analysis and computation. Work must be yours alone: honor system applies. Make up exams must be arranged in advance (at least two weeks).
- **Office hours:** Regular times (to be arranged) held by instructor. Other times are always available by appointment.

## Course Purpose and Learning Objectives

Nonlinearities are unavoidable in most high-performance control systems, and this course provides a foundation for treating these systems using the most popular techniques. This course builds on analysis and control design techniques developed in a graduate linear systems course. It will develop further analysis and control design techniques that apply to various types of non-linear systems.

The course begins with a comparison between 2nd order linear and non-linear systems using a phase plane analysis. This provides a survey of various behaviors that can arise in non-linear systems, and sets the stage for analysis and design tools to handle these types of systems.

A foundation for analysis is laid with a discussion of existence and uniqueness of solutions to non-linear ODE's. Then Lyapunov stability is treated in depth, showing how it can be used for analysis as well as control design. Input-Output stability theory is then addressed, including passivity theory and frequency domain analysis/design techniques (absolute stability, describing functions). Examples of their use in feedback systems are presented. Finally, feedback linearization is introduced.

As in the linear systems course (ASEN 5014), key ideas are the focus of the course, with mathematics used to expose these ideas. The required mathematics tools and vocabulary will be covered as needed. The theorem/proof format is avoided in favor of an exposition of useful "truths" and a demonstration of the underlying reasons. The course introduces standard viewpoints, methods, and terminology used in the applied and research literature. It is intended as a basis for students pursuing research in the control systems area, and as a resource (set of tools, insights) for the application of control systems in practice.

## 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 Conduct & Conflict Resolution policies](#).

## **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 all public health orders in place to reduce the risk of spreading infectious disease. 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 policy on [classroom behavior](#) and the [Student Code of Conduct](#). If you require accommodation because a disability prevents you from fulfilling these safety measures, please follow the steps in the “Accommodation for Disabilities” statement on this syllabus.

As of Aug. 13, 2021, CU Boulder has returned to requiring masks in classrooms and laboratories regardless of vaccination status. This requirement is a temporary precaution during the delta surge to supplement CU Boulder’s COVID-19 vaccine requirement. Exemptions include individuals who cannot medically tolerate a face covering, as well as those who are hearing-impaired or otherwise disabled or who are communicating with someone who is hearing-impaired or otherwise disabled and where the ability to see the mouth is essential to communication. If you qualify for a mask-related accommodation, please follow the steps in the “Accommodation for Disabilities” statement on this syllabus. In addition, vaccinated instructional faculty who are engaged in an indoor instructional activity and are separated by at least 6 feet from the nearest person are exempt from wearing masks if they so choose.

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, please notify the instructor via e-mail so accommodations can be discussed.

## **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](mailto: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 academic integrity policy. Violations of the Honor Code may include, but are not limited to: 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](mailto: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 on the [Honor Code 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 or against 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 email [cureport@colorado.edu](mailto:cureport@colorado.edu). Information about OIEC, university policies, [reporting options](#), 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 their rights, support resources, and reporting options.

## **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, there

are no in-class exams, and take-home exam and homework assignment due dates can be adjusted, if necessary. Please contact the instructor at least 1 week in advance of a potential conflict to discuss possible accommodations.

See the [campus policy regarding religious observances](#) for full details.