# ECE 602: Lumped Linear Systems

## Course Run

ECE602: Lumped Linear Systems (2T2020a)

## Instructors


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## Audience

This course is designed for students from Electrical Engineering, Mechanical Engineering, Aeronautical and Astronautical Engineering, Civil Engineering, and Biomedical Engineering…to name a few.

## Course Description

This course provides an introduction to the fundamentals of modern control theory for linear dynamical systems. The course adopts the state-space method that builds upon the classical transfer function methods covered in undergraduate feedback control courses. The state-space framework is used in modeling and controller design for systems arising in many engineering and non-engineering disciplines.

## Course Learning Outcomes

After completing this course, you will be able to:

- Construct models for dynamical systems arising in various applications, such as: mechanical, electrical, pneumatic, hydraulic, economic, and biological systems
- Recognize various properties of given linear systems, such as: stability, controllability, observability, stabilizability, and detectability
- Design controllers so that a system satisfies given performance specifications
- Test and validate the controller design using simulation tools, such as MATLAB and Simulink



## Required Tools

***MATLAB***

You will need to have access to MATLAB in this course. To access MATLAB, you may either:

1. Purchase a student version of MATLAB for $99 (https://www.mathworks.com/academia/student_version.html)
2. Use MATLAB via Software Remote (https://goremote.itap.purdue.edu/). Note that there are a limited number of licenses for this, and during busy times students may not be able to use MATLAB via Software Remote.

## Prerequisites

It's highly recommended that you are familiar with Laplace transform and ordinary differential equations. Knowledge of undergraduate feedback control is not strictly needed for most topics, but will definitely increase your appreciation of some of the topics covered in this course.

Knowledge of linear algebra is **needed.** Although officially Purdue's MATH 511 is listed as a co-prerequisite of this course, in practice, students who took MATH 511 and this course in the same semester often found it challenging as the pace of the two courses may not be fully synchronized. Some references that can help you freshen up on linear algebra include:

- *Linear Algebra and Its Applications*, 4th ed., G. Strang, 2006.
- *Introduction to Linear Algebra*, 4th ed., G. Strang, Wellesley-Cambridge Press, 2009.

## Grading

This course will be graded based on the following criteria:

| Assessment Type | Description | % of Final Grade |
|---|---|---|
| FunWork | We're sure that these assignments will be a source of fun for you – thus, we have named them "FunWork" instead of your everyday, basic "homework". FunWork is assigned each week and may involve Matlab programming. | 30% |
| Midterm Exam 1 | The midterm exam will test your understanding of the course material. The midterm will be available to access for 48 hours (see the schedule below), but you will only have 1.5 hours to complete it once you have started. | 20% |
| Midterm Exam 2 | The midterm will be available to access for 48 hours (see the schedule below), but you will only have 1.5 hours to complete it once you have started. | 20% |
| Final Exam | The final exam will be comprehensive. The final exam will be available to access for 48 hours (see the schedule below), but you will only have 2.5 hours to complete the final exam once you have started. | 30% |

## Grading Scale

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|---|---|
| 98% - 100% | A+ |
| 90% - 98% | A |
| 84% - 90% | A- |
| 78% - 84% | B+ |
| 72% - 78% | B |
| 68% - 72% | B- |
| 63% - 68% | C+ |

| | |
|---|---|
| 63% - 68% | C+ |
| 58% - 63% | C |
| 53% - 58% | C- |
| 48% - 53% | D+ |
| 45% - 48% | D |
| 40% - 45% | D- |
| <40% | F |

## Course Schedule

| Week | Module | Assignments and Exams |
|---|---|---|
| **Week 1 & 2**<br>Aug 24 – Sept 6 | Welcome and Introduction<br>1. Systems<br>2. State Variables<br>3. State-Space Models<br>4. State-Space Models vs. Transfer Functions | • Required Gradescope Submission<br>  ○ Due Date: **Tuesday, 9/1 at 11:59 PM ET** *(9/2, 3:59 UTC)*<br>• FunWork 1<br>  ○ Due Date: **Saturday, 9/5 at 11:59 PM ET** *(9/6 at 3:59 UTC)* |
| **Week 3 & 4**<br>Sept 7 – Sept 20 | 5. Linear Algebra Review<br>6. Functions of Square Matrices<br>7. Matrix Exponential | • FunWork 2<br>  ○ Due Date: **Saturday, 9/19 at 11:59 PM ET** *(9/20 at 3:59 UTC)* |
| **Week 5 & 6**<br>Sept 21 – Oct 4 | 8. Solutions of Continuous-Time Autonomous LTI Systems<br>9. Solutions of Discrete-Time Autonomous LTI Systems<br>10. Solutions of Autonomous LTV Systems<br>11. Stability of Continuous-Time Linear Systems<br>12. Stability of Discrete-Time Linear Systems | • FunWork 3<br>  ○ Due Date: **Saturday, 10/3 at 11:59 PM ET** *(10/4 at 3:59 UTC)* |
| **Week 7 & 8**<br>Oct 5 – Oct 18 | 13. Stability of Nonlinear Systems Around Equilibrium Points<br>14. Solutions of Controlled Continuous-Time LTI Systems<br>15. Solutions of Controlled Discrete-Time LTI Systems<br>16. Solving Continuous-Time Dynamical Systems Numerically<br>17. Quadratic Forms | • **Midterm 1**<br>  ○ Exam Opens: **Tuesday, 10/13 at 12:00 AM ET** *(10/13 at 4:00 UTC)*<br>  ○ Exam Due: **Wednesday, 10/14 at 11:59 PM ET** *(10/15 at 3:59 UTC)*<br>  ○ Time Limit Once Started: 1.5 hours<br>• FunWork 4<br>  ○ Due Date: **Saturday, 10/17 at 11:59 PM ET** *(10/18 at 3:59 UTC)* |
| **Week 9 & 10**<br>Oct 19 – Nov 1 | 18. Lyapunov Stability Theory<br>19. Reachability and Controllability of Discrete-Time LTI Systems<br>20. Controllability of Continuous-Time LTI Systems<br>21. Separating the Controllable Part from the Uncontrollable Part of a Given System | • FunWork 5<br>  ○ Due Date: **Saturday, 10/31 at 11:59 PM ET** *(11/1 at 3:59 UTC)* |

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|---|---|---|
| **Week 11 & 12**<br>Nov 2 – Nov 15 | 22. Observability of Continuous-Time LTI Systems<br>23. State-Space Realizations of Transfer Functions<br>24. Bounded-Input Bounded-Output (BIBO) Stability | • **Midterm 2**<br>○ Exam Opens: **Tuesday, 11/10 at 12:00 AM ET** *(11/10 at 5:00 UTC)*<br>○ Exam Due: **Wednesday**, **11/11 at 11:59 PM ET** *(11/12 at 4:59 UTC)*<br>○ Time Limit Once Started: 1.5 hours<br>• FunWork 6<br>○ Due Date: **Saturday, 11/14 at 11:59 PM ET** (11/15 at 4:59 UTC) |
| **Week 13 & 14**<br>Nov 16 – Nov 29 | 25. Canonical Forms of Single-Input-Single-Output (SISO) Systems<br>26. State Feedback Control<br>27. State Observer Design<br>28. Observer-Based Feedback Controller | • FunWork 7<br>○ Due Date: **Saturday, 11/28 at 11:59 PM ET** (11/29 at 4:59 UTC) |
| **Week 15 & 16**<br>Nov 30 – Dec 12 | 29. Linear Quadratic Regulation (LQR) Problems (additional module for your knowledge, but material not covered on Final Exam) | • **Final Exam**<br>○ Exam Opens: **Thursday, 12/10 at 12:00 AM ET** *(12/10 at 5:00 UTC)*<br>○ Exam Due Date: **Friday, 12/11 at 11:59 PM ET** *(12/12 at 4:59 UTC)*<br>○ Time Limit Once Started: 2.5 hours |



## Course Help

To get help with course content, comment in the discussion forums located in each unit. By commenting in the unit discussion forums, the course team will be able to respond to your question more quickly.

## Discussion Guidelines

Please follow the Discussion Guidelines when contributing to discussions in this course. Here are a few of the key points you should remember:

- Do not use offensive language. Present ideas appropriately.
- Be cautious in using Internet language. For example, do not capitalize all letters since this suggests shouting.
- Avoid using vernacular or slang language. This could possibly lead to misinterpretation.
- Do not hesitate to ask for feedback.
- Be concise and to the point.
- Think and edit before you push the “Send” button.

## Technical Help

For general questions about using the edX platform, please refer to these resources:

- Learner Help Center: https://support.edx.org/hc/en-us
- To get help with a technical problem, visit the *Contact Us* link in the *Connect* section at the bottom of the page to contact edX Support.

## Accessibility Information

Purdue University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability, you are welcome to let us know so that we can discuss options. You are also encouraged to contact the Disability Resource Center at: drc@purdue.edu or by phone: 765-494-1247.

The **Office of Institutional Equity**, which is responsible for ensuring Americans with Disability Act compliance, can be contacted with any accessibility concerns at:

Ernest C. Young Hall, 10th Floor
155 S. Grant Street
West Lafayette, IN 47907-2114
Phone: (765) 494-7253
Email: equity@purdue.edu
TTY: (765) 496-1343
Website: http://www.purdue.edu/ethics/oie/

Frequently Asked Questions (FAQs) and answers are found here:
https://www.purdue.edu/oie/Equal_Access_Opportunity/Web_Accessibility/FAQs.php

- Purdue's Disability Resource Center Website
- Purdue's Web Accessibility Policy
- edX's Website Accessibility Policy
- MATLAB's Accessibility Policy
- Proctortrack's Web Accessibility Policy



## Academic Integrity

Academic integrity is one of the highest values that Purdue University holds. Individuals are encouraged to alert university officials to potential breaches of this value by either emailing or by calling 765-494-8778. While information may be submitted anonymously, the more information that is submitted provides the greatest opportunity for the university to investigate the concern.

The Purdue Honor Pledge

*"As a Boilermaker pursuing academic excellence, I pledge to be honest and true in all that I do. Accountable together - we are Purdue"*

## Nondiscrimination Statement

Purdue University is committed to maintaining a community that recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. Link to Purdue's nondiscrimination policy statement.