

LINEAR SYSTEMS I

ECE230A — FALL 2002



Course summary

The purpose of this course is to provide the students with the basic tools of modern linear systems theory: stability, controllability, observability, realization theory, state feedback, state estimation, separation theorem, etc. For time-invariant systems both state-space and polynomial methods are studied. The students will also be introduced to the computational tools for linear systems theory available in MATLAB.

The intended audience for this course includes, but is not restricted to, students in circuits, communications, control, signal processing, physics, and mechanical and chemical engineering.

[Recommended readings](#) and [homework](#) are available on the web.

Instructor

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Prerequisites

ECE 210A Matrix Analysis and Computation

Graduate level-matrix theory with introduction to matrix computations. SVD's, pseudo-inverses, variational characterization of eigenvalues, perturbation theory, direct and iterative methods for matrix computations.

Course's Web Page

The [syllabus](#), [homework](#), solutions to homework, and all other information relevant to the course will be continuously posted at the course's web page. The URL is

<http://www.ece.ucsb.edu/~hespanha/ece230a/>

Assessment format

Homework – 30%

Mid-term exam – 30%

Final exam – 40%

Textbook

The main textbook is:

[1] C.-T. Chen. *Linear Systems Theory and Design*. Oxford Univ. Press, 3rd ed., 1999. (ISBN 0-19-511777-8)

Other recommended textbooks are:

[2] P. Antsaklis, A. Michel. *Linear Systems*. McGraw Hill, 1997.

[3] G. Dullerud, F. Paganini. *A Course in Robust Control Theory*. Springer, 1999. (ISBN 0-387-98945-5).

[4] W. Rugh. *Linear System Theory*, 1996.

The classes will follow Chen's book [1] closely. Antsaklis' book [2] will be used for topics not covered by [1] (see syllabus below). Dullerud's book [3] will be the textbook for ECE230B. All students are strongly encouraged to

review linear algebra. Chapter 3 of [1] provides a brief summary but a review of a Linear Algebra textbook (such as [5] below) is preferable, especially if one goes through a few exercises.

[5] Gilbert Strang *Linear Algebra and Its Applications*, 1988.

Study Guide

The following is a tentative schedule for the course. If revisions are needed they will be posted on the course's web page. The rightmost column of the schedule contains the recommended reading for the topics covered on each class. *Students are strongly encouraged to read these materials prior to the class.*

Class	Content	Reference
Lect #1 9/23/04	Introduction and course overview SYSTEMS REPRESENTATION System representation: input-output, block diagrams Basic system properties: causality, linearity, finite-dimensionality, time-invariance Continuous vs. discrete-time Examples	Secs 2.1-2.2 and 2.5-2.6 of [1]
Lect # 2 9/28/04	Forced responses <ul style="list-style-type: none"> • Impulse response • Transfer function State-space linear systems: <ul style="list-style-type: none"> • Impulse response and transfer function 	Secs 2.2-2.3 of [1]
Lect #3 9/30/04	<ul style="list-style-type: none"> • Elementary realization theory for LTI systems • Equivalent state-space representations The discrete-time case	Secs 4.3-4.4 [1]
Lect #4 10/5/04	Where do state-space linear systems come from? <ul style="list-style-type: none"> • Local linearization around equilibrium • Local linearization around trajectory • Feedback linearization 	Sec 2.4 of [1]
Lect #5 10/7/04	Solutions state-space linear time-varying (LTV) systems <ul style="list-style-type: none"> • Solution to homogeneous linear systems—Peano-Baker series • State-transition matrix • Properties of the state transition matrix • Solution to nonhomogeneous linear systems—variations of constants formula The discrete-time case	Sec 4.5 of [1] Sec 1.13 of [2]
Lect #6 10/12/04	Solutions state-space linear time-invariant (LTI) systems <ul style="list-style-type: none"> • Matrix exponential (definition and properties) • Computation of matrix-exponentials using the Laplace transform • The importance of the determinant of A 	Sec 3.5-3.6 [1]

Class	Content	Reference
Lect #7 10/14/04	Solution to state-space linear time-invariant (LTI) systems (cont.) <ul style="list-style-type: none"> • Jordan normal form • Computation of matrix-exponentials using the Jordan normal form • Poles with multiplicity larger than one (block diagram interpretations) • The discrete-time case 	
Lect #8 10/19/04	STABILITY Input-output stability of LTI systems <ul style="list-style-type: none"> • Definition • Time-domain condition • Frequency-domain condition 	Secs 5.1-5.2 of [1]
Lect #9 10/21/04	Internal stability of continuous-time LTI systems <ul style="list-style-type: none"> • Definitions • Eigenvalues condition (block diagram interpretation of multiplicity) • Lyapunov Theorem (LMI) 	Secs 3.9, 5.3-5.4 of [1]
Lect #10 10/26/04	Preview of optimal control <ul style="list-style-type: none"> • Linear quadratic regulator problem • Algebraic Riccati equation • Optimal state-feedback control • Stability 	Sec 4.2C of [2]
Lect #11 10/28/04	<i>Midterm exam</i>	
11/2/04	CONTROLLABILITY AND STATE FEEDBACK Reachability and controllability subspaces for LTI systems <ul style="list-style-type: none"> • Definition • Controllability Gramian • Controllability matrix • Cayley-Hamilton Theorem • Physical examples & block diagrams • Gramian-based control (minimum energy) The discrete-time case	Sec 6.1-6.2 of [1] Section 3.2 of [2] Section 2.2 of [3]
Lect #12 11/4/04	Controllable systems <ul style="list-style-type: none"> • Definition • Controllability matrix test • Popov-Belevitch-Hautus (PBH) test • Eigenvector/eigenvalues test • Lyapunov test (LME) • Lyapunov test-based control 	
Lect #13 11/9/04	Canonical decompositions <ul style="list-style-type: none"> • Invariance with respect to equivalence transformations • Controllable canonical form for single-input systems • Controllable decomposition 	Sec 6.4 of [1]
11/11/04	<i>Veterans day</i>	

Class	Content	Reference
Lect #14 11/16/04	Stabilizability <ul style="list-style-type: none"> • Definition • Popov-Belevitch-Hautus (PBH) test • Eigenvector/eigenvalues test • Lyapunov test (LMI) • Lyapunov test-based control Eigenvalue assignment <ul style="list-style-type: none"> • Controllable case • Stabilizable case Discrete-time case	
Lect #15 11/18/04	<p style="text-align: center;">OBSERVABILITY AND OUTPUT FEEDBACK</p> Motivation for observability—output feedback Observability and constructability subspaces for LTI systems <ul style="list-style-type: none"> • Definition • Observability Gramian • Gramian-based reconstruction • Duality • Physical examples & block diagrams Observable and detectable systems <ul style="list-style-type: none"> • Definitions • Dual tests Eigenvalue assignment	Sec 6.3 of [1] Section 3.3 of [2] Section 2.3 of [3]
Lect #16 11/23/04	State estimation Stabilization through output feedback—separation theorem	Secs 8.4-8.5 and 8.7-8.8 of [1] Sec 4.3C of [2]
11/25/04	<i>Thanksgiving day</i>	
Lect #17 11/30/04	Kalman decomposition Theorem Minimal realizations <ul style="list-style-type: none"> • Definition • Connection with controllability/observability • Equivalence of minimal realizations 	Sec 6.4 of [1] Secs 7.1-7.2 of [1]
Lect #18 12/2/04	<i>TBA</i>	
12/10/04	<i>Final exam.</i>	