# EE 351 Feedback-Control Systems

**Designation:** Elective

**Catalog Description:** Analysis/design of feedback systems. Compensator design via root locus and Bode analysis. Routh/Nyquist stability. State space representation and introduction to MIMO formulation. Controllability/observability. Application to physical dynamic systems such as industrial robots.

**Credits:** 3

**Pre-requisites:** EE 315 “Signal and Systems Analysis” or ME 375 “Dynamics of Machines and Systems” or instructor consent.

**Class Schedule:** Three 50-minute lectures per week.

**Class Information:**
This is an undergraduate-level course on linear dynamical systems and control. It builds on an introductory undergraduate course in signals and systems such as EE 315, and emphasizes frequency domain techniques for the analysis of dynamical systems and the synthesis of control laws meeting given design specifications. To follow the course, a working knowledge of Laplace transformation is required.

**Topics Covered:**
• Introduction to Control Systems (1 hours): The general approach to designing a feedbackcontrol system, objectives of feedback-control, examples.
• Mathematical Models of Systems (4 hours): Differential equations of physical systems such as electromechanical systems, transfer functions, block diagram models, signal-flow graph models.
• State Variable Models (3 hours): Concept of state variables, state space equations for linear systems, modeling of physical systems is state-space, relationship between state-space models and transfer functions, solutions to state-space equations.
• Transient and Steady-State Response Analysis (8 hours): Stability, Routh-Hurwitz criterion, transient response of first and second order systems to test inputs, dominant poles for higher order systems, effects of zeros on transient response, steady-state errors in unity feedback systems,integral and derivative control action for improving transient and steady-state performance.
• Root Locus Method (4 hours): Concept of root locus, procedures for constructing root-locus, examples.
• Control System Design by Root Locus Method (4 hours): Lead and lag controller design by root locus.
• Frequency Response Analysis (10 hours): Steady-state response to sinusoidal inputs, Bode diagrams, steady-state error constants and stability based on Bode diagrams, Nyquist plots and Nyquist stability criterion, phase and gain margins, time domain specifications based on frequency response characteristics.
• Control System Design Based on Frequency Response (4 hours): Lead and lag controller design using Bode diagrams.
• Control System Design by Polynomial Approach (4 hours): Diophantine equation, forcing pole-zero cancellations and integration in the feedback loop, reference tracking and

disturbance rejection by internal model principle.

**Textbook and Other Required Materials:** R. C. Dorf and R. H. Bishop, *Modern Control Systems, 11th Edition*, Prentice-Hall, 2008.

**Course Objectives and Relationship to Program Objectives:**
This is the first course on control systems and it covers basic linear systems and control design techniques. Students should be able to model physical systems, analyze dynamical linear systems, and understand the basic properties of feedback. They should be able to design control systems using the root locus and frequency response methods. They should be able to use modern design tools including computer aided design (CAD) tools such as Matlab/Control Systems design toolbox. [Program Objectives addressed by this course: 1, 2.]

**Course Outcomes and Their Relationship to Program Outcomes**
The following are course outcomes and the Program Outcomes (numbered 1-11 in square brackets "[ ]") they address:

- The students should be able to (*i*) use ordinary differential equations and Laplace transformation to model physical systems, (*ii*) obtain dynamic responses of linear systems and determine their stability, (*iii*) construct root-locus and Bode plots, and apply Nyquist criterion in the context of controller design, (*iv*) obtain and manipulate state-space representation of dynamical systems using linear algebra, and (*v*) become fluent in classical control systems design. [1]
- The students should be able to translate a set of performance specifications given in words to a formal description of a design problem, and then design a suitable feedback-controller using design tools, followed by simulation and verification using software tools. [3,5,11]
- The students should know the techniques for relaxing the constraints or redesigning the controller for achieving closed-loop specifications either in the time-domain or in the frequency domain. They should also know how constraints in the time domain affect the frequency response of the system and vice versa and how to apply these concepts to design. [3,5,11]
- Students should know how to debug their controller design, which requires them to iterate on their initial design. [3,5,11]
- Students should be able to design controllers, assess their design through the constraint specifications, and decide whether their initial design is acceptable or can be improved. [3,5,11]

**Contribution of Course to Meeting the Professional Component**
Engineering topics: 100%

**Computer Usage:** The computer-aided design (CAD) tool Matlab/Control Systems design toolbox is used in approximately one third of the homework assignments.
**Design Credits and Features:** At least 15% of the lecture material covers design techniques and principles for control systems. Approximately one third of the homework assignments have a problem, which requires the Matlab/Control Systems design toolbox. There are 0.5 design credits.

**Instructor(s):** G. Arslan, T. Kuh, A. Kavcic.
Person(s) Preparing Syllabus and Date: G. Arslan. December 2, 2008.