**Simon Fraser University**
**School of Engineering Science**
**ENSC 380-3 Linear Systems**
**Spring 2000**

This course covers the modeling and analysis of continuous and discrete signals and systems using linear techniques. Topics include: review of the Laplace transform and methods for the basic modeling of physical systems; discrete and continuous convolution; impulse and step response; transfer functions and filtering; the continuous Fourier transform and its relation to the Laplace transform; frequency response and Bode plots; sampling; the z-transform.

*Prerequisite* ENSC 220, ENSC 320 (co-requisite), MATH 310

*Instructor* Jim Cavers ASB 9843 291-3281 cavers@sfu.ca

*Teaching Assistants* TBA

*Lab Engineer* TBA

*Text* S. Haykin and B. Van Veen, *Signals and Systems*, John Wiley, 1999..

*Relation of Lectures and Text* The text provides a good treatment of many specific topics. However, its range of examples is somewhat narrow, so I will use the lectures to introduce additional physical systems and examples.

*Class Notes* We can no longer afford to supply free class notes (copies of the instructor's transparencies). However, you will be able to purchase a set. Details will be announced in class. To keep the cost to you low, they will be copied 1/2 size, double sided.

*Classes* TBA

*Grades*

| | |
|---|---|
| 5 assignments 3% each | 15% |
| 1 midterm | 25% |
| 1 final | 45% |
| 1 lab | 15% |
| | ------- |
| Total | 100% |

*General Objectives* ENSC 380 develops the basic tools for analysis and design of linear dynamic systems. Building on your earlier exposure to electric circuits and mechanics, it introduces you to:

- basic ideas of linearity and linearization of systems;
- discrete time and continous time models.
- impulse response, step response and convolution as general time domain descriptions;
- transform analysis and transfer functions as general frequency domain descriptions;

The treatment encourages you to shift freely between time and frequency analysis, and to convert from one system description to another. Examples are taken from RLC circuits, simple mechanical systems, thermal systems and digital filters for communications and signal processing.

The lab component is intended to reinforce the analytical topics and give you direct experience of some systems. However, this is only a three-credit course, so the lab is limited in scope.

*Detailed Outline*

1. BASIC SYSTEM PROPERTIES
   - 1.1 Systems and Subsystems
   - 1.2 Causality
   - 1.3 Memory
   - 1.4 Time Invariance
   - 1.5 Discrete Time, Continuous Time
   - 1.6 Stability
   - 1.7 Linearity – the Big One
   - 1.8 The Concept of State
   - 1.9 Test Inputs
   - 1.10 Some Comments on Modeling

2. TIME-DOMAIN ANALYSIS OF SYSTEMS
   - 2.1 System Response by Superposition – Discrete Time
     Graphical solutions, difference property, summation property, unit step response, unit pulse response.
   - 2.2 Arbitrary Inputs – the Convolution Summation
     Analytical and graphical solutions, “flip, slide & sum”, the digital filter, associativity, commutativity.
   - 2.3 Response by Superposition – Continuous Time
     Graphical solutions, derivative and integral properties, unit step response, review of impulse function, impulse response.
   - 2.4 Arbitrary Inputs – Convolution Integral
     Analytical and graphical solutions, “flip, slide and integrate”, frequency response and transient response, associativity, commutativity.
   - 2.5 Discrete Time Approximation of Continuous Time Systems
     By impulse response invariance, digital filters.

3. FINITE ORDER SYSTEMS IN THE TIME DOMAIN

- 3.1 Differential and Difference Equation Representation of Some Systems
  Mechanical, thermal, electric, financial.
- 3.2 Review of Differential Equation Solution
  Homogeneous and particular, zero input and zero state responses, impulse response a sum of complex exponentials, root location and nature of time response.
- 3.3 Difference Equation Representation and Solution
  Homogeneous and particular, zero input and zero state responses, pulse response a sum of complex exponentials, root location and nature of time response.
- 3.4 Simulation Diagrams
  Discrete time and continuous time block diagrams that correspond to given difference or differential equations.
- 3.5 The State Variable Representation
  State variable description obtained from simulation diagram, discrete and continous time. No solution of the equations, just representation.
- 3.6 Analysis of Quasi-Linear Systems
  How to analyze systems in which the dynamics change at switching boundaries (e.g, thermostat). Differential equations, boundary conditions.

4. FREQUENCY DOMAIN (FOURIER) ANALYSIS OF SYSTEMS
- 4.1 Consider the Complex Exponential
  De Moivre, pictorial view, rectangular and polar representations of sinusoids, phasors, negative frequency (mostly review).
- 4.2 Frequency Response of Systems
  Frequency response obtained from the convolution integral when input is complex exponential.
- 4.3 The Fourier Series
  Complex Fourier series and Fourier pair, frequency makeup of periodic signals, synthesis of periodic signals, existence and Gibbs
- 4.4 Properties and Applications of Fourier Series
  Response of linear systems to periodic inputs, multiplication/convolution, symmetries, representation of impulse train in time, time/frequency inverse scaling, resolution/bandwidth.
- 4.5 Summary of Fourier Series
- 4.6 The Fourier Transform
  Transform from limit as representation interval increases, Fourier transform pair, frequency content of signals, frequency response linked to impulse response, multiplication/convolution, duality, rectangular pulses, sinc functions, linear phase shifts (delays, offset tones), time/frequency scaling, symmetries, transform of periodic signals, Parseval, impulse train.
- 4.7 Windowing
- 4.8 Sampling
- 4.9 Fourier Wrapup
  Windowing, resolution/extent.
- 4.10 Sampled Signals and Fourier Representations
  Sampling by multiplication with impulse train, periodic spectra, sampling theorem, aliasing, antialiasing and reconstruction filters, interpretation through duality.

5. LAPLACE TRANSFORM ANALYSIS
- 5.1 Motivation

Variant of Fourier transform that simplifies initial conditions, permits analysis of unstable signals and systems.

5.2 Laplace Transform and Region of Convergence

Forced convergence of Fourier transform, generalization to s-plane, region of convergence for exponentials, sinusoids.

5.3 Inversion of Laplace Transforms

Review: partial fractions or residues (without complex variables background), initial and final value theorems.

5.4 Pole-Zero Diagrams and Time Functions Characteristics

5.5 Laplace Transform, Convolution and Transfer Functions

Multiplication/convolution in general systems.

5.6 Frequency Response From Laplace Transform

Substitution s=jw. Vectors on s-plane.

6. COMPLEX SYSTEMS AND FEEDBACK CONTROL

6.1 DC Machines

Basic models of dc motors and generators for examples of control.

6.2 Block Diagrams

Overall transfer function from series, parallel and feedback connections.

6.3 Open Loop Control

Deficiencies: sensitivity, regulation, effect of elementary nonlinearities.

6.4 Closed Loop Responses

Altered dynamics, improved regulation, response time, steady state error, size of error signal, classification (type 1, 2, etc)

6.5 Proportional-Integral Control

Introduction to PI, steady state error, size of error signal, stability.

6.6 Elementary Nonlinearities in the Loop

Basic discussion of limiter, clipper, dead zone and how to analyze in time domain.

6.7 Stability

Routh-Hurwitz, Bode plots (gain, phase margins)

7. Z-TRANSFORM ANALYSIS OF DISCRETE TIME SYSTEMS

7.1 What is it For?

Notational convenience in application of Laplace to discrete time systems.

7.2 From Laplace to Z

Laplace transform a weighted impulse train with change of variable; power series representation of a sequence; geometric sequences, behaviour in time, pole location and region of convergence.

7.3 Some Properties of Z-Transform

Time shift and initial values; multiplication/convolution.

7.4 Frequency Response

Frequency response from z-transform; normalized frequency.

7.5 More Properties

Initial and final value theorems.

7.6 Inversion of Z-Transforms

Fourier series method, power series method, long division method, residue method, partial fractions.

7.7 Solving Difference Equations by Z-Transform

Transformation of difference equation, initial conditions, zero state and zero input responses.

7.8 Links Between Laplace Transform s and Z-Transform z

Mapping between planes; another view of periodicity of discrete-time frequency response.