Gene H. Hostetter
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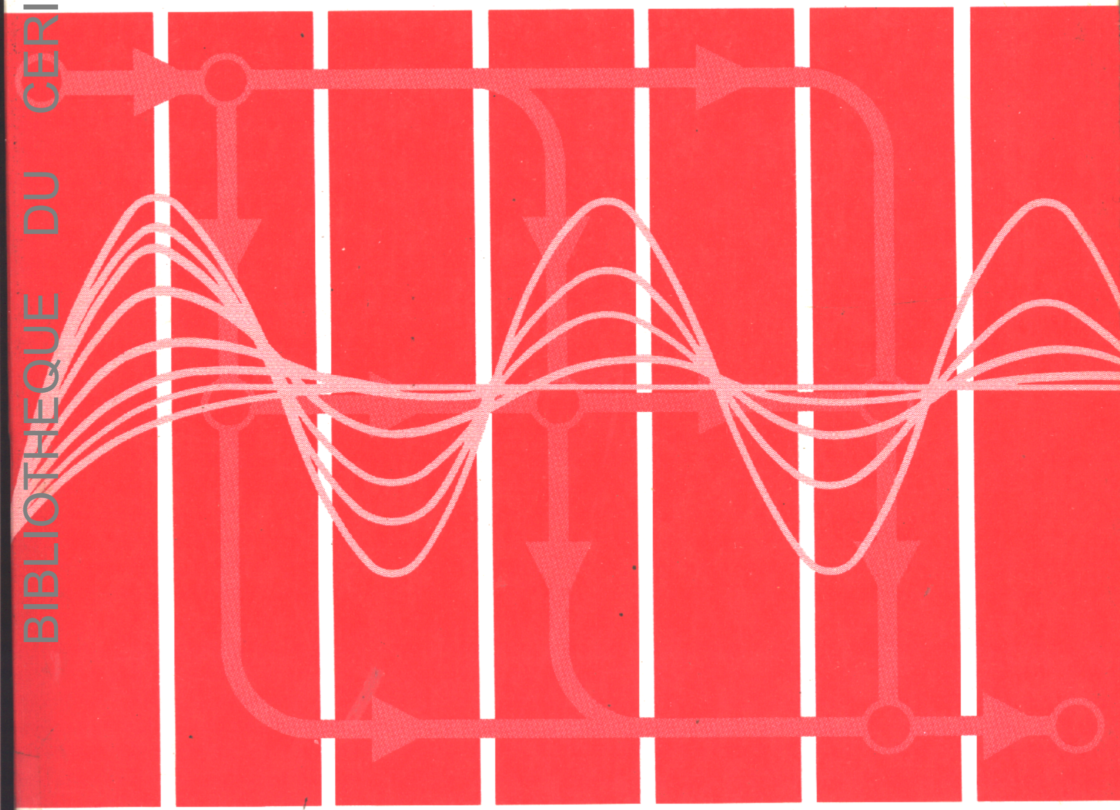
Design of Feedback Control Systems



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To
Donna, Kelly, and Kristen
Barbara
Val, Ted, and Rick

Preface

This is a design-oriented control systems text intended for use in an introductory academic course and for reference and self-study by electrical and mechanical engineers in industry. Laplace transforms and electrical and/or mechanical network analysis are the prerequisite subjects upon which this text builds. It is especially well suited for a one-term junior- or early senior-level first course in control systems.

The manuscript evolved over several years of combined effort to provide an interesting, relevant, and effective introductory control system design class at California State University, Long Beach. Much of the understanding and skill we once taught specifically as it applied to networks is here presented in a more general context, with a wider immediate applicability. When used as a prerequisite for a sequence of modern control courses, this material also greatly reduces the large amount of time and effort that would otherwise be expended in establishing (then parting from) classical concepts. And it serves to encourage broad interests, perspectives, and skills at an early stage.

The greatly increased availability of digital computers naturally poses questions as to the proper and best role of computers in design. As the creative aspect of system design continues to involve the *directed* use of analytical tools, the emphasis here is upon the understanding, practical experience, and judgment necessary to be a creative designer. The manner in which the analytic tools are employed (hand calculation, pocket calculator, or computer) is taken to be of secondary concern at this introductory stage.

This text is designed to guide the reader in gaining the following:

1. A review of the fundamentals of electrical, translational mechanical, rotational mechanical, and electromechanical networks
2. Confidence in the use of Laplace transform methods in system response calculation and an understanding of commonly used response components
3. Familiarity with the use of transfer functions for linear, time-invariant systems, including asymptotic stability concepts and multivariable relations
4. Capability with block diagram manipulations, signal flow graphs, and the use of Mason's gain rule
5. Thorough acquaintance with Routh-Hurwitz polynomial testing and the ability to determine root distributions, to test adjustable systems, and to axis-shift to find relative stability
6. Appreciation of the feedback concept and its importance to tracking and other systems; familiarity with steady state error concepts and calculation and an acquaintance with

system parameter sensitivity, susceptability to disturbances, and the use of performance indices

7. A thorough understanding of root locus methods, including those for adjustable systems other than the unity subtractive feedback type
8. Experience with classical compensation methods and real understanding of the principles guiding compensator design
9. Good comprehension and ability with frequency response methods, including those for systems involving delay elements and unstable components; appreciation of the powerful approach of incorporating experimental data
10. Competence with polar response plots and Nyquist methods
11. Familiarity with basic state variable concepts, including simulation diagrams, time-domain vector-matrix equations and solutions, transfer function matrices, stability, diagonalization, observability, and controllability; an introduction to state feedback design
12. Acquaintance with digital control concepts, sampling, and discrete-time system models at a level suitable for easy transition to study of computer and microprocessor-based

Quarter System Schedule

Week	*Chapters*	*Topics*
1	1	Introduction to the course System equations and terminology Review of Laplace transform Transfer functions
2	2–3	Block diagrams and signal flow graphs System response Stability and Routh-Hurwitz testing
3	4	Steady state errors Sensitivity and disturbance rejection Performance indices, optimality, and design
4, 5	5	Root locus construction and examples System compensation Design using root locus methods
		Midterm Examination
6, 7	6	Bode plot construction Frequency response examples Gain and phase margins Design using frequency response methods The Nyquist criterion
8, 9	7	State variable system models Controllability and observability Time-domain response Response computation
10	8	Digital control concepts Sampling Discrete-time system models Introduction to digital control system design

Semester System Schedule

Week	*Chapters*	*Topics*
1, 2	1	Introduction to the course System equations and terminology Review of Laplace transform Transfer functions
3	2	Block diagrams and signal flow graphs Response of first-, second-, and higher-order systems
4	3	Stability and Routh-Hurwitz testing
5, 6	4	Steady state errors Sensitivity and disturbance rejection Performance indices, optimality, and design
7, 8	5	Root locus construction and examples System compensation Design using root locus methods
		Midterm Examination
9, 10	6	Bode plot construction Frequency response examples Gain and phase margins Design using frequency response methods The Nyquist criterion
11, 12	7	State variable system models Controllability and observability Time-domain response Response computation
13, 14	8	Digital control concepts Sampling Discrete-time system models Introduction to digital control system design

real-time systems such as that given in B. C. Kuo, *Digital Control Systems* (New York: Holt, Rinehart and Winston, 1980), G. F. Franklin and J. D. Powell, *Digital Control of Dynamic Systems* (Reading, Mass.: Addison-Wesley, 1980), and similar texts

Along the way, it is hoped that the reader will learn much about the iterative process of engineering design. We have found the large number of example systems included here to be invaluable to this learning process.

Suggested class textbook schedules for quarters and semesters are given in the accompanying tables. For some classes—for example, for an introductory controls course early in an engineering program—the range of material available here is more than should be covered in a single term. The text is designed so that it is easy to abbreviate or delete topics to achieve a desired emphasis. In a course emphasizing transition to modern control theory, the compensation material of Secs. 5.7 through the end of Chap. 5 may be omitted with no penalty in understanding of the later topics. In a course emphasizing the classical viewpoint, Chap. 7 on state space methods and Sec. 8.8, which ties these ideas to the digital domain, may be omitted without disturbing the flow of topics. Chapter 8 may be easily omitted or abridged as desired.

We sincerely hope that you or your students will enjoy reading and using this text as much as we have enjoyed its development. Our students have enthusiastically contributed to it as have our colleagues, especially L. Bailin, G. H. Cain, E. N. Evans, H. J. Lane, C. S. Lindquist, M. Santina, R. Rountree, and S. Wolf. Special thanks are due to Cynthia Klepadlo, who supervised the manuscript typing and the drafting of many of the original figures and to Mohammed Santina, who tirelessly compiled the problem solutions.

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