Preface and Acknowledgments

This monograph on stability theory presents a novel and conceptually simple view of nonlinear, multiloop feedback system stability theory based on the "topological separation" of function spaces—a view sufficiently general to encompass both Lyapunov and input-output stability concepts. The main objective of the book is to address the issues that arise in designing feedback systems that are robust against the destabilizing effects of unknown-but-bounded uncertainty in component dynamics. I believe this is the first and only book to provide a completely general mathematical formulation of these issues and to methodically develop techniques for the quantitative analysis of multiloop feedback system robustness. The book is also a significant contribution to stability theory per se because the stability definitions and problem formulations in chapter 2 capture for the first time the essential features of stability problems with a sufficient degree of simplicity and abstraction to enable a completely unified treatment of the concepts and results of Lyapunov and input-output stability. I am hopeful that this book will prove to be timely in providing a rigorous methodology for addressing such inherently "feedback" aspects of system design as robustness and sensitivity at a time when researchers are beginning to recognize that such methodology is mandatory if complex systems are to be designed using modern system theory.

Included in chapter 2 are new multiloop generalizations of the circle stability criterion. Potential applications include nonlinear feedback design, the validity of modeling approximations, hierarchical control system design, and stability margin analysis for multiloop feedback systems. The results interface with modern multivariable feedback design techniques to provide a theoretical basis for the computer-aided design of multiloop feedback systems to meet specifications calling for a robust tolerance or bounded uncertainty in plant dynamics. The theory is applied in chapters 3 and 4 to characterize the stability margins of optimal linear-quadratic Gaussian estimators and controllers. Continuous-time linear-quadratic state-feedback regulator designs are found to be inherently robust, having an infinite gain margin and at least $\pm 60°$ phase margin at each control input channel; sampled-data designs are found to approximate this robustness provided certain conditions are satisfied. Analogous results apply to a constant-gain extended Kalman filter (CGEKF) for which no on-line covariance computations are required. A separation-type result is established for nonlinear systems, proving that nondivergent estimates can, unconditionally, be substituted for true values in nonlinear feedback controllers without inducing instability. The results have applications to gain scheduling for adjustable set-point nonlinear output-feedback regulator designs.

This book is aimed at researchers and advanced graduate students in the areas of feedback control engineering circuits and systems. It will also appeal to mathematicians having an interest in applications of functional analysis to engineering problems.

This book is based on my Ph.D. thesis, which I submitted to the Massachusetts Institute of Technology in August 1977 under the title "Robustness and Stability Aspects of Stochastic Multivariable Feedback System Design." I am grateful to Professor Michael Athans for his guidance, encouragement, and support during the course of this research. As my thesis supervisor, his insight, observations, and suggestions helped establish the overall direction of the research effort and contributed immensely to the success of the work reported here. I thank my thesis readers, Professor Alan S. Willsky, Professor Nils R. Sandell, and Dr. David A. Castanon for their encouragement and for their detailed comments and suggestions during the final phases of the preparation of the thesis. For making possible exchanges with several English scholars, I thank Professor Alistair G. J. MacFarlane of Cambridge University who kindly arranged for me to visit England while the thesis research was in progress. Discussions during my visit with Professor MacFarlane, Dr. A. I.

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