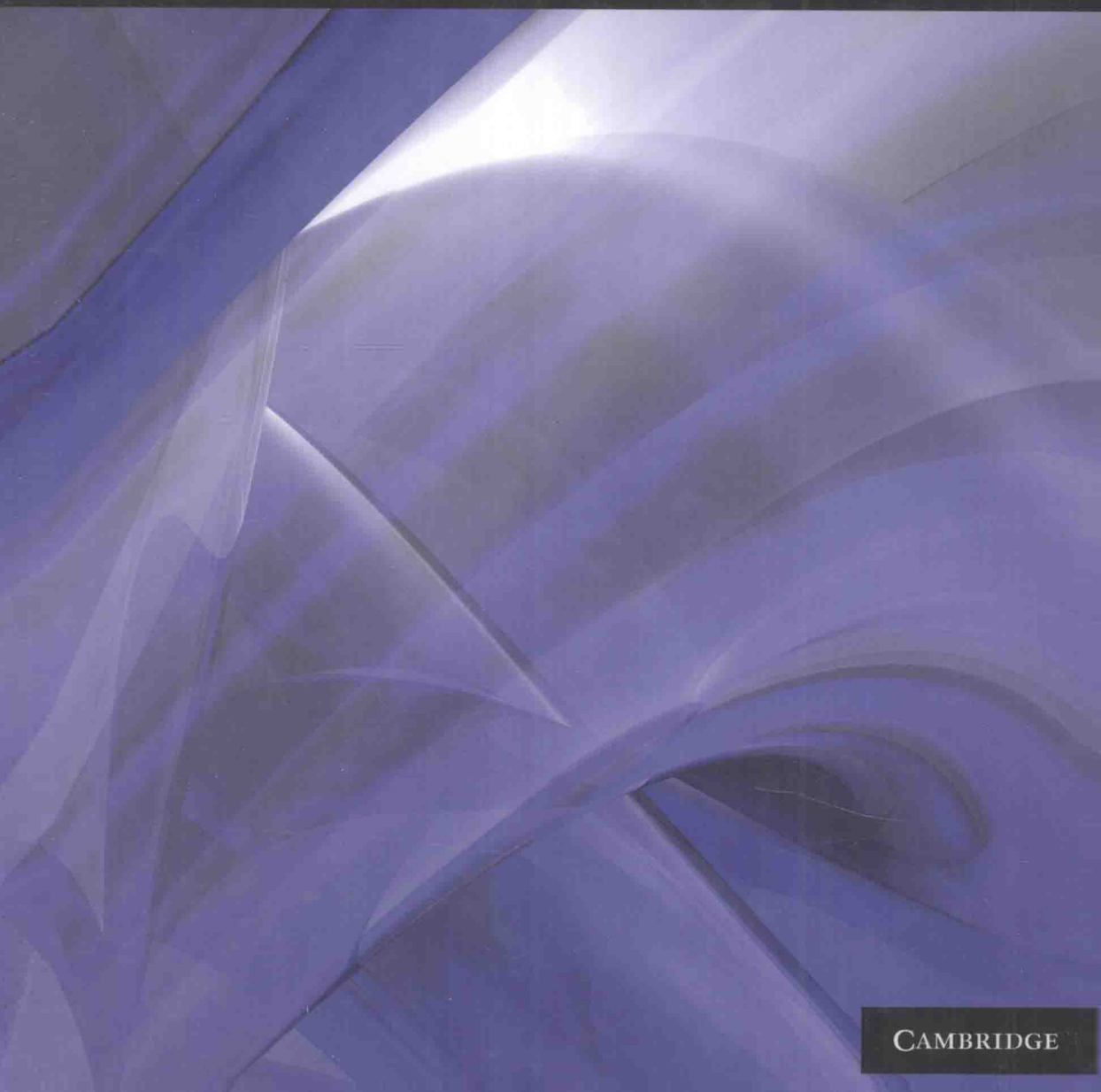
Signal Processing and Optimization for Transceiver Systems

P. P. Vaidyanathan, See-May Phoong
and Yuan-Pei Lin



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SIGNAL PROCESSING AND OPTIMIZATION FOR TRANSCEIVER SYSTEMS

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SIGNAL PROCESSING AND OPTIMIZATION FOR TRANSCEIVER SYSTEMS

Presenting the first complete treatment of MIMO transceiver optimization, this self-contained book provides all the mathematical information needed to understand transceiver optimization in a single volume. It begins with a review of digital communication fundamentals, and then moves on to a detailed study of joint transceiver optimization, starting from simple single-input single-output channels all the way to minimum bit error rate transceivers for MIMO channels. Crucial background material is covered, such as Schur-convex functions, matrix calculus, and constrained optimization, together with eight appendices providing further background material on topics such as matrix theory, random processes, and sampling theory. A final ninth appendix provides a grand summary of all the optimization results. With 360 illustrations, over 70 worked examples, and numerous summary tables provided to aid understanding of key concepts, this book is ideal for graduate students, practitioners, and researchers in the fields of communications and signal processing.

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To Usha, Vikram, Sagar, and my parents
— P. P. Vaidyanathan

To our families
— See-May Phoong and Yuan-Pei Lin

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Preface

Digital communication systems have been studied for many decades, and they have become an integral part of the technological world we live in. Many excellent books in recent years have told the story of this communication revolution, and have explained in considerable depth the theory and applications. Since the late 1990s particularly, there have been a number of significant contributions to digital communications from the signal processing community. This book presents a number of these recent developments, with emphasis on the use of filter bank precoders and equalizers. Optimization of these systems will be one of the main themes in this book. Both multiple-input multiple-output (MIMO) systems and single-input single-output (SISO) systems will be considered.

The book is divided into four parts. Part 1 contains introductory material on digital communication systems and signal processing aspects. In Part 2 we discuss the optimization of transceivers, with emphasis on MIMO channels. Part 3 provides mathematical background material for optimization of transceivers. This part can be used as a reference, and will be useful for readers wishing to pursue more detailed literature on optimization. Part 4 contains eight appendices on commonly used material such as matrix theory, Wiener filtering, and so forth. Thus, while it is assumed that the reader has some exposure to digital communications and signal processing at the introductory level, there is plenty of review material at the introductory level (Part 1) and at the advanced level (Parts 3 and 4). The material in Parts 2 and 3 will be useful for students wishing to pursue advanced work in the field, which is still a very active area for research. A detailed outline of the book can be found in Sec. 1.5 of Chap. 1.

Some of the material herein has been tested in the classroom, and a considerable part has benefited students at an advanced level. While many of the results in Part 2 can be regarded as results which appeared since the late 1990s, the mathematical foundation for this material is much older. Starting with the days of Shannon and Nyquist, there have been many giants in the field who contributed to this strong foundation since the 1940s. However, because of technological advances and the directions in which applications evolved, such as wireless communication and DSL technology, some of the theoretical problems have been revisited and some new problems solved by researchers in recent years. This freshness and novelty in the midst of old grandeur can clearly been seen from the combination of topics covered in Parts 1, 2, and 3 of the book.

We have endeavored to come up with a text that will be useful in the classroom, and which will serve as a research reference for advanced students. The writing style is in the form of an easy-to-read text book with detailed theory, plenty of examples, discussions, and homework problems. It is self-contained for students with an introductory background in signal processing and communications.

Acknowledgements

The wonderful environment provided by the California Institute of Technology, and the generous support from the Office of Naval Research and the National Science Foundation, have been crucial in developing the material covered in this book. As mentioned in the introductory and historical review sections of this book, many great minds have been involved in making the fields of communication and signal processing what they are today. Without their fundamental contributions this book would have been impossible.

Many graduate students have participated in extensive discussions relating to the material in this book. It is my pleasure to thank them here, and especially acknowledge the extensive discussions I have had with Chun-Yang Chen and Ching-Chih Weng regarding the material in Part 2 of the book.

For a project of this magnitude, long hours of hard work and concentration are absolutely essential. I have to thank Usha for creating the peaceful atmosphere which is crucial for the success of such a project. She has shown infinite patience during the long evenings and weekends of my absorption in this book. Her total unconditional love and sincere support, and the enthusiasm and love from Vikram and Sagar, are much appreciated!

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Part 1 Communication fundamentals

1

Introduction

1.1 Introduction

Digital communication systems have been studied for many decades, and they have become an integral part of the technological world we live in. Many excellent books in recent years have told the story of this communication revolution, and have explained in considerable depth the theory and applications. Since the late 1990s particularly, there have been a number of significant contributions to digital communications from the signal processing community. This book presents a number of these recent developments, with emphasis on the use of filter bank precoders and equalizers. Optimization of these systems will be one of the main themes in this book. Both multiple-input multiple-output (MIMO) systems and single-input single-output (SISO) systems will be considered. It is assumed that the reader has had some exposure to digital communications and signal processing at the introductory level. Many text books cover this prerequisite, and some are mentioned at the beginning of Sec. 1.5.

Before we describe the contents of the book we first give an introductory description of analog and digital communication systems in the next few sections. The scope and outline of the book will be described in Sec. 1.5.

1.2 Communications systems

Figure 1.1(a) shows the schematic of a simple analog communication system. Here we have a message signal $s(t)$ which is transmitted over a channel to produce the signal $y(t)$ at the receiver end. In many practical systems the channel can be modeled as a linear time invariant, or **LTI**, system followed by an additive noise source $q(t)$. This is shown in Fig. 1.1(b), where the channel impulse response is indicated as $h(t)$.

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