INTRODUCTION TO DIGITAL COMMUNICATION

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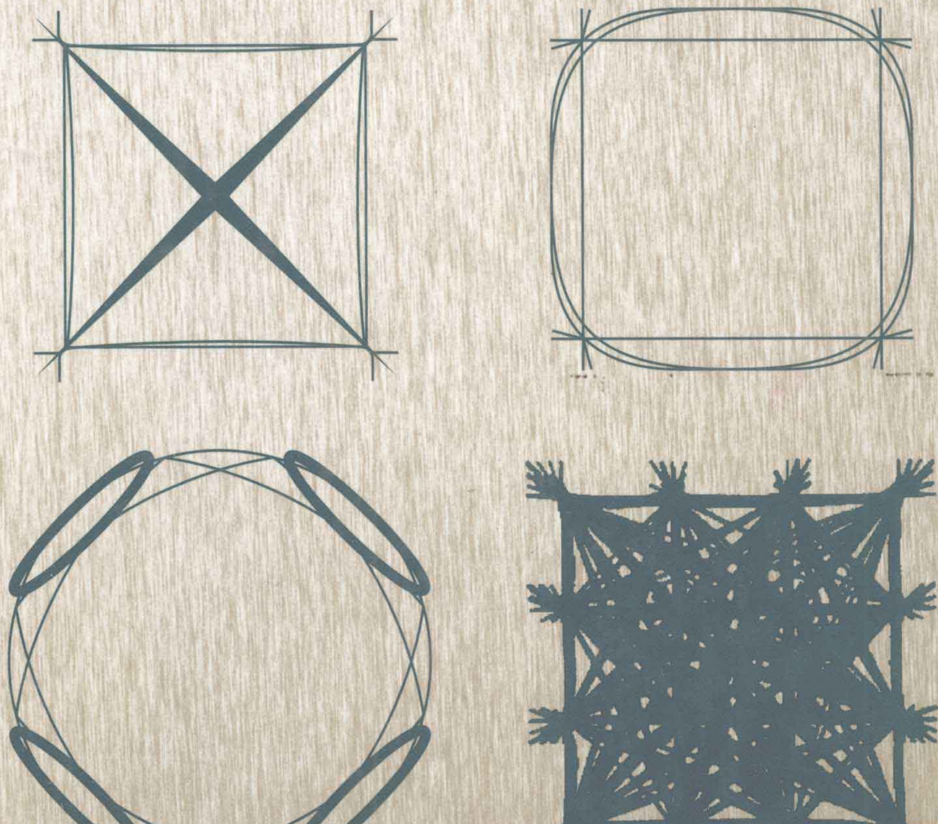

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DIGITAL COMMUNICATION

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Preface

The philosophy of this book remains the same as that of the first edition, in particular to provide an introduction to the essentials of digital communications based on sound mathematical underpinnings and anchored in the literature of the various topics considered. After providing a treatment of the basic theory of digital modulation and coding in the first eight chapters, the three additional specialized areas of spread spectrum, cellular, and satellite communications are given one-chapter overviews. The intent is to not only provide firm foundation in the basic theory of digital communications, but to give an introduction to three areas that have provided the basis of a number of applications in recent years and show avenues of research that are currently receiving much attention. For example, spread-spectrum communications includes the subareas of code families with good correlation properties, multiuser detection, and ultra wideband communications for resolving multipath channels. Cellular radio provides a host of research areas, such as capacity optimization of multiuser communication systems and means for accommodating mixed-rate traffic. Satellite communications has enjoyed a resurgence of interest with the proposed (with one realized) low-earth orbit mobile voice communication systems, satellite navigational systems, and small aperture antenna system applications. With this philosophy, we feel that both the needs of the practicing engineer in the communications industry and the senior/beginning graduate student are met. The former is provided with a means to review or self-study a topic of importance on the job, and the latter is provided background in basic theory with an introduction to possible topics for further research.

Virtually all electrical engineering programs include a course on linear systems in the junior year, and this book is written under that assumption. However, since the content of these linear systems courses varies from program to program, an overview of linear systems is included in Chapter 2. An additional reason for providing this information is to set notation and define special signals used throughout the book.

Another assumption of the authors is that the typical student taking a course using this book will have had a junior-level course on probability. Often such courses contain additional topics from statistics and random processes. However, since coverage of these topics varies from program to program, the necessary material on random processes for this book is included in Chapter 2. For those students that may not have had a prior course on probability, our recommendation is that one be taken before a course taught using this book is taken. However, for very diligent students who may not wish to do this, or whose probability course was taken in the distant past, Appendix A of this book provides a brief overview of the necessary topics from probability. This material may be reviewed in conjunction with Chapter 1 and will not be needed until the latter part of Chapter 2, where random processes are covered.

After an introduction to the general features of digital communication systems, Chapter 1 includes an overview of channel characteristics and an introduction to link power calculations. The latter subject is returned to in Chapters 10 and 11 in conjunction with a consideration of cellular radio and satellite communication links, respectively. The introduction of this subject in Chapter 1 provides a link between performance requirements of communication systems in terms of signal-to-noise ratio at the receiver input and the requirements of transmitter power implied by the performance desired and the channel attenuation characteristics.

As already mentioned, Chapter 2 is a review of signal and system theory, analog modulation, and random processes. In addition to providing definitions of basic signals and setting notation, a very simple simulation of noise through a linear system (Butterworth digital filter) is illustrated by an example. This sets the context for simulation of a simple digital communication system illustrated by example in Chapter 3. The student is then encouraged to do his or her own simulations in several problems of Chapter 3.

In Chapter 3, the subject of digital data transmission is introduced. The receiver structure assumed is that of a linear filter followed by a threshold detector. Optimization of the receiver filter through maximization of peak signal-to-root-mean-square noise ratio at its output leads to the concept of the classic matched filter receiver. The data transmission schemes considered are binary. Although the channel is initially considered to be of infinite bandwidth, optimum systems for the strictly bandlimited case are eventually considered. Equalization methods for compensating for intersymbol interference introduced by bandlimiting in the channel are next considered. The chapter ends with a brief consideration of signal design for bandlimited channels and noise effect in pulse-code modulation systems.

The purpose of Chapter 4 is to provide a sound theoretical basis for the digital modulation systems introduced in Chapter 3, as well as to extend the results in several directions. The approach used is that of Bayes's detection couched in the language of signal space. The background noise is assumed to be additive and white, which allows the use of any orthogonal basis function set that spans the signal space, giving a very clear geometric picture of the digital signal reception process. As an extension of Chapter 3, Chapter 4 considers M-ary digital data transmission and the explicit treatment of modulation schemes suitable for practical channels. The concepts of equivalent bit error probability and bandwidth efficiency in terms of bits per second per hertz of bandwidth are introduced in order to provide a basis of comparison of M-ary systems. The chapter ends with several example design problems and a basic introduction to orthogonal frequency division multiplexing.

Building on the ideal systems covered in Chapter 4, Chapter 5 takes up several topics that can be considered degradation sources for those ideal systems. Synchronization methods at various levels (i.e., carrier, bit, and frame) are discussed, and the degradation imposed by imperfect carrier synchronization is characterized. Fading channel effects are characterized and diversity transmission for combating them is discussed. The chapter ends by discussing envelope plots, eye diagrams, and phasor plots as means to characterize communication system performance and their generation by computer simulation is illustrated.

Chapters 6 through 8 take up the subject of coding, with the elements of information theory and block coding considered in Chapter 6 and the elements of convolutional coding considered in Chapter 7. Theoretical foundations are provided, but the major underlying objective of Chapters 6 and 7 is always one of system applications. All coding techniques considered in Chapters 6 and 7 are characterized in terms of their ability to lower the signal-to-noise ratio required to achieve a desired probability of bit error (power efficiency) and the bits per second that can be supported per hertz of bandwidth (bandwidth efficiency). Chapter 8 provides a brief treatment of another error control scheme called automatic repeat request (ARQ), which utilizes a feedback channel.

Chapter 9 contains an overview of spread-spectrum communications. The important concept of multiuser detection is considered where, when signals from multiple users are being received, the detection process takes into account their statistical characteristics and the improvement of detector performance over what could be obtained if the other-user signals were treated as noise.

Chapter 10 deals with cellular radio communications. The cellular concept is introduced along with the major degradations experienced in such systems including other-user interference and multipath fading. First- and second-generation cellular systems are discussed and provide an excellent example of a case where the move has been made from analog to digital transmission for several reasons.

Chapter 11 treats satellite communications as an example where digital communications concepts and applications have come into extensive use over the years. The concepts are illustrated with several design examples. Characteristics of several low-earth orbit satellite communication systems for mobile phone communications are summarized.

The first edition of this book has been used successfully to teach courses on digital communications to ambitious undergraduates and first-year graduate students for several years. Typically, after the introduction provided in Chapter 1 is covered, basic digital modulation theory and coding (Chapters 3–7) are covered after spending some time on signal, system, and random process review. The use of computer simulation is emphasized from the start, with the assignment at about mid-semester of a computer simulation project to be worked on throughout the semester. Weekly problem sets are assigned and graded. An in-class closed-book midterm examination is given to encourage students to become intimately familiar with basic random process, modulation and digital detection principles (usually, this occurs at the end of Chapter 3). Depending on the scope of the computer project and the initiative shown by the class, a final examination may or may not be given.

We wish to thank the many persons who have contributed either directly or indirectly to this book. These include our colleagues at various locations throughout the world. We specifically thank David Kisak of SAIC for his careful review and constructive criticism of Chapters 6 through 8, Nick Alexandru for his corrections of several examples in the first edition, Jerry Brand of Harris Corporation and John Haug of Motorola for their reading and constructive criticism of Chapter 10. The Office of Naval Research is acknowledged as indirectly supporting the writing of this book through research grants to Rodger Ziemer, as well as the National Science Foundation, which provided research and development time while he was a program officer there during the production of the second edition. We also thank the reviewers of the book for their helpful comments and suggestions, a majority of which have been incorporated. In particular, we acknowledge the input of Professor Vijay K. Jain, University of South Florida; Professor Peter Mathys, University of Colorado at Boulder; Professor Laurence B. Milstein, University of California at San Diego; Professor Peyton Z. Peebles, Jr., University of Florida; and Professor William Tranter, Virginia Tech for the first edition. And we would also like to acknowledge the input of Mohammad Maqusi, Texas Tech University, and Richard J. Kozick, Bucknell University for this second edition.

Any errors or shortcomings that remain are the responsibility of the authors.

Most importantly, we thank our wives, Sandy Ziemer and Ann Clark, for their patience during the writing of both the first and second editions of the book, and the second author thanks his daughter Diane Peterson for love and support during this project. The first author wishes to specifically mention his children, Amy Ziemer-Nilson and Mark Ziemer, who apparently paid more attention to his writing activities than he thought—both are now published authors themselves!

Rodger Ziemer
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January 17, 2000

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