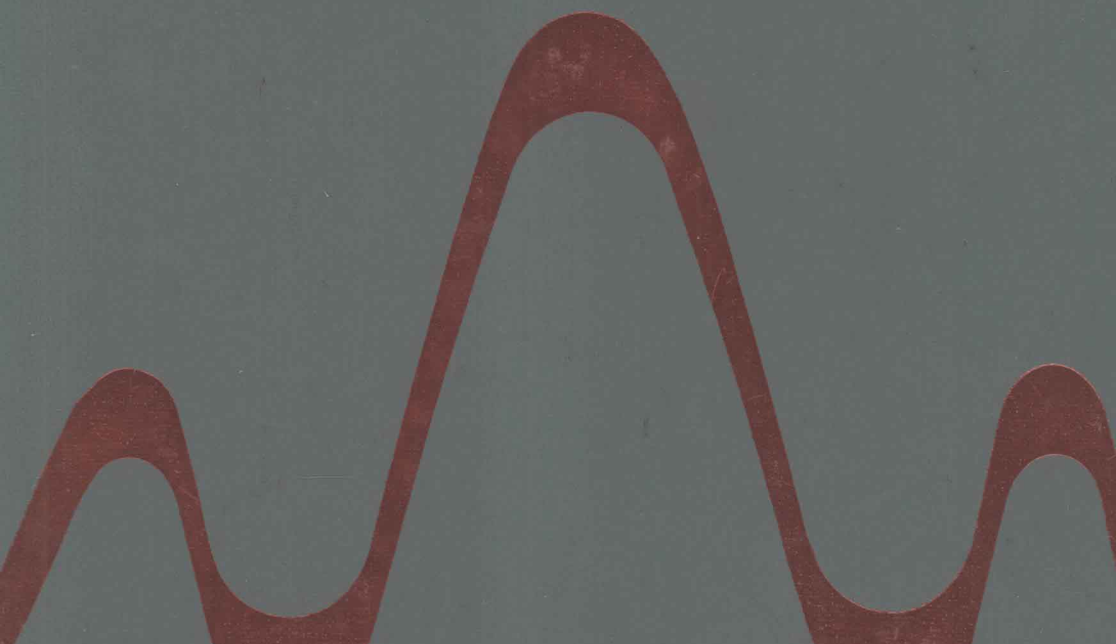
MODERN COMMUNICATIONS AND SPREAD SPECTRUM

George R. Cooper
Clare D. McGillem



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PREFACE

Although continuous evolution marks the technology and practice of communication engineering, a large segment of basic theory remains unchanged, and this provides the basis for evaluating new techniques and new systems. One of the main objectives of this text is to furnish an introduction to the basic principles of communication systems that is appropriate for a first-year graduate-level course. This proves to be more difficult than it might seem upon first consideration. The main problem is the diverse backgrounds of the students who are likely to take such a course. If the students have just completed their undergraduate program, they undoubtedly have had an introductory course in communication engineering that covers various modulation techniques. However, the degree of mathematical and statistical sophistication employed varies greatly with the undergraduate text used in the course, and with whether or not the students have had any previous exposure to the theory of probability and random processes. Compounding the problem is the likelihood that a number of students may be transferring from another specialty or another discipline, and although quite mature academically, may not be familiar with communication system principles.

The first seven chapters of this text are intended to address this problem. They were designed to cover topics relating to analog and digital communications in such a manner that they can be followed by students who have never taken a communications course and still provide sufficient breadth and depth of coverage to complement and extend the material normally presented in an undergraduate course. The text is written on the assumption that the reader understands something of modulation theory and is familiar with such techniques of linear system analysis as Fourier transforms and convolutions, and also is acquainted with probability and random processes. These techniques and concepts are reviewed as part of the text but it will be necessary for a student unfamiliar with them to do additional outside reading. It has been found that graduate students who are interested in this material generally will do the extra work necessary to overcome the lack of a previous communications course. The goal of this type of course is to bring the participating students to a more or less equal level of sophistication relative to the terminology, implementation, and analysis of communication systems so that subsequent courses can be based on a presumption that such an equality exists.

Because of the enormous variety of specialized modulation systems that have been developed over the years, it is not possible to provide coverage that is in any sense comprehensive. Rather the most widely used techniques and some of their variations are considered, and various systems are compared in terms of error probability, performance in the presence of noise, effects of system instabilities, and system complexity. The methods of analysis are intended to be correct and understandable, but no attempt has been made to demonstrate that they are mathematically rigorous.

A second purpose of this text is to provide a comprehensive introduction to the new and rapidly growing area of spread-spectrum communications. This material is presented at the same level as the first portion of the text, and is appropriate for a graduate-level course. The presentation is self-contained and offers a coherent development of the theory not previously available. References to a number of specialized topics are included to permit more in-depth study of spread-spectrum communications if desired.

A third purpose of this text is to furnish a reference source for practicing engineers from which they can gain ready access to many of the analytical results available for the analysis of communication systems. This should prove particularly valuable with regard to the material on spread-spectrum communications.

Relevant problems are included at the end of each chapter, and answers to a a number of them can be found at the end of the book.

George R. Cooper
Clare D. McGillem

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CHAPTER

ONE

BASIC COMMUNICATION PRINCIPLES

1-1 INTRODUCTION

Communication systems of all types have many functional elements in common. Because of this it is often possible to adapt methods of analysis or implementation from one system to another. A very general type of communication system is illustrated in block diagram form in Fig. 1-1. Not all of the elements shown here would be present in every system, and there may be special elements in some systems (e.g., a diversity receiver) not represented here. However, most systems will contain most of the elements shown in Fig.1-1.

To permit the easy identification of where various specialized subsystems (discussed in detail later in the text) fit into an overall system, it is helpful to consider briefly the nature and function of each of the elements in the generalized system. The signal source and transducer together form the message source. The message

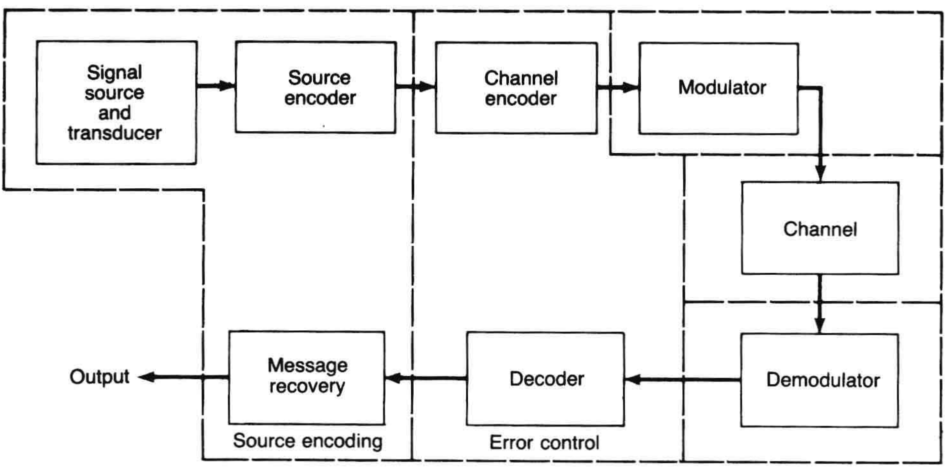

Figure 1-1 Generalized communication system.

might be an acoustic voice signal converted to an electrical waveform by a microphone, an optical image transduced by a television camera, or a measurement of some physical quantity converted to an electric signal by an appropriate sensor. Once the message is available, the source encoder modifies its structure for utilization in the particular communication system being used. This may include such operations as sampling and quantizing, companding, encrypting, or any of a variety of processes for dimensionality reduction.

The output of the source encoder goes to the channel encoder, which modifies the signal in such a way as to make its transmission through the channel more efficient. An example of a channel encoder is a processor that accepts a stream of binary signals and puts them into a series of groups with additional control symbols added so that the occurrence of an error during transmission and reception can be detected, or even corrected if desired. The channel encoder adds controlled redundancy to the transmitted message in order to accomplish error-free transmission through the channel. This added redundancy requires that extra information be transmitted along with the message and thus leads to a trade-off between speed of transmission (or bandwidth for a fixed speed) and error performance.

The modulator converts the encoded message into a signal suitable for transmission through the channel. For communications applications this channel can take many forms, ranging from free space to water to glass fibers. Generally the encoded message will be attached to a high-frequency carrier for transmission through the channel. The particular method of modulating the carrier with the message as well as the physical characteristics of the carrier itself are strongly dependent on the channel characteristics. In this book it is assumed that the channel is the atmosphere surrounding the earth and that the carrier is a radiated electromagnetic wave in the radio-frequency (RF) spectrum. However, many of the principles governing this type of carrier and channel carry over into other carriers such as acoustic or light waves and other channels such as water or waveguides. System noise is generally assumed to be part of the channel characterization. In the case of radio communications, this noise includes receiver noise generated within the system as well as external noise such as interference, intentional or otherwise, that may be present. To model a channel properly, it is necessary to be able to predict, either deterministically or probabilistically, what output will occur for a given input.

The remainder of the system in Fig. 1-1 demodulates and decodes the received signal and delivers it to the user. The design of these components is strongly dependent on the characteristics of the transmission system, but there are still a number of trade-offs that must be made among such things as cost, immunity to jamming, and ease of operation before a final design is possible.

In the following chapters, many of the alternatives available to the system designer are discussed. Performance is the principal criterion for comparing different approaches. The performance criteria considered include energy efficiency, peak-to-average power requirement, and error performance for various channels. The primary emphasis is on digital communications. However, to permit comparison with alternate and competitive analog communication systems, the