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SPREAD SPECTRUM Communications Handbook

Electronic Edition

THE engineering reference on the workings of spread spectrum—the basis of CDMA

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SPREAD SPECTRUM COMMUNICATIONS HANDBOOK

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PREFACE

In the nine years since the publication of the first edition of *Spread Spectrum Communications*, the world's political situation has changed considerably. The U.S. Department of Defense has reduced its support for the development of new communication systems as well as their acquisition. One might question the need for a second edition of a book written about robust techniques for anti-jamming (AJ) and low-probability-of-intercept (LPI) communications.

However, while it is already painfully clear that the close of the Cold War has not ended warfare, the past decade has also ushered in a new era of mobile communications. The qualities that make spread-spectrum techniques useful in military communications—fine time-resolution, low power-density, privacy, and a high immunity to interference—are also extremely desirable in today's mobile communications systems. Encouraged by enlightened FCC actions, spread-spectrum technology is being transferred from the Department of Defense to the arena of commercial mobile cellular communications. The emerging markets for spread-spectrum systems have the potential to dwarf those of the past.

Are the design techniques for military communication systems truly applicable to the commercial environment? Does yesteryear's jammer have anything to teach us about managing multiple-user noise in a spread-spectrum multiple-access radio network? The answer—an unqualified "yes"—is attested to by the successes of companies that are penetrating the commercial marketplace with spread-spectrum products.

This revised edition contains new material on the emerging commercial applications of spread-spectrum techniques as well as minor modifications to the book's original fourteen chapters. We believe that since it is based on sound engineering principles and is not bound to a particular implementation technology, it will retain its usefulness for the foreseeable future.

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PREFACE TO FIRST EDITION

Not more than a decade ago, the discipline of spread-spectrum (SS) communications was primarily cloaked in secrecy. Indeed, most of the information available on the subject at that time could be found only in documents of a classified nature.

Today the picture is noticeably changed. The open literature abounds with publications on SS communications, special issues of the *IEEE Transactions on Communications* have been devoted to the subject, and the formation of an annual conference on military communications, MILCOM, now offers a public forum for presentation of unclassified (as well as classified) papers dealing with SS applications in military systems. On a less formal note, many tutorial and survey papers have recently appeared in the open literature, and presentations on a similar level have taken place at major communications conferences. Finally, as further evidence we cite the publication of several books dealing either with SS communications directly or as part of the more general electronic countermeasures (ECM) and electronic counter-counter measures (ECCM) problem. References to all these forms of public documentation are given in Section 1.7 of Chapter 1, Part 1.

The reasons for this proliferation can be traced to many sources. While it is undoubtedly true that the primary application of SS communications still lies in the development of enemy jam-resistant communication systems for the military, largely within the confines of classified programs, the emergence of other applications, in which both the military and civilian sectors are involved, as playing a role of ever-increasing importance. For example, to minimize mutual interference, the flux density of transmissions from radio transmitters must often be maintained at acceptably low radiation levels. A convenient way to meet these requirements is to spread the power spectrum of the signal before transmission and despread it after reception—the nonhostile equivalent of the military low-probability-of-intercept (LPI) signal design.

Another instance in which SS techniques are particularly useful in a nonanti-jam application is in multiple-access communications in which many users share a single communication channel. The assignment of a unique SS sequence to each user allows him or her to transmit simultaneously over the common channel with a minimum of mutual interference, simplifying the network control requirements.

Extremely accurate positioning can be computed by using signals from several satellites in synchronous and asynchronous orbits. Satellites transmitting pseudorandom noise sequences modulated onto the transmitted carrier signal provide the means for accomplishing the required range and distance determination at any point on the earth.

Finally, SS techniques can improve the reliability of transmission in frequency-selective fading and multipath environments. Spreading the bandwidth of the transmitted signal over a wide range of frequencies reduces its vulnerability to interference and often provides some diversity gain at the receiver.

At the heart of all these potential applications lies the increasing use of digital forms of modulation for transmitting information, driven by the tremendous advances made over the last decade in microelectronics. This trend no doubt will continue, and thus it should not be surprising that more and more applications for spread-spectrum techniques will continue to surface. Indeed, the state-of-the-art is advancing so rapidly (e.g., witness the recent improvements in frequency synthesizers boosting frequency hop rates from the Khops/sec to the Mhops/sec ranges over SS bandwidths in excess of a GHz) that today's primarily theoretical concepts will be realized tomorrow.

Unclassified research and developments in spread-spectrum communications have arrived at a point of maturity necessary to justify a textbook on SS communications that goes far beyond the level of those available on today's market. Such is the purpose of *Spread Spectrum Communications.* Contained within the fourteen chapters of its three volumes is an in-depth treatment of SS communications that should appeal to the specialist already familiar with the subject as well as the neophyte with little or no background in the area. The book is organized into five parts, within which the various chapters are for the most part self-contained. The exception is Chapter 3, Part 1, which deals with basic concepts and system models and serves as a basis for many of the other chapters that follow. As would be expected, the more traditional portions of the subject are treated in the first two parts, while the latter three parts deal with more specialized aspects. The authors envision that an introductory one-semester course in SS communications taught at a graduate level in a university might cover all or parts of Chapters 1, 3, 4, 5 of Part 1, Chapters 1 and 2 of Part 2, and Chapters 1 and 2 of Part 4.

In composing the technical material presented in *Spread Spectrum Communications,* the authors have intentionally avoided referring by name to specific modern SS systems that employ techniques such as those discussed in many of the chapters. Such a choice was motivated by the desire to offer a unified approach to the subject that stresses fundamental principles rather than specific applications. Nevertheless, the reader should feel confident that the broad experience of the four authors ensures that the material is practical as well as academically inspiring.

In writing a book of this magnitude, we acknowledge many whose efforts should not go unnoticed. Credit is due to Paul Green for originally suggesting

the research that uncovered the material in Chapter 2, Part 1, and to Bob Price for the tireless sleuthing which led to much of the remarkable information presented there. Chapter 5, Part 1 benefited significantly from the comments of Lloyd Welch, whose innovative research is responsible for some of the elegant sequence designs presented there. Per Kullstam helped clarify the material on DS/BPSK analysis in Chapter 1, Part 2. Paul Crepeau contributed substantially to the work on list detectors. Last but by no means least, the authors would like to thank James Springett, Gaylord Huth, and Richard Iwasaki for their contributions to much of the material presented in Chapter 4, Part 5.

Several colleagues of the authors have aided in the production of a useful book by virtue of critical reading and/or proofing. In this regard, the efforts of Paul Crepeau, Larry Hatch, Vijay Kumar, Sang Moon, Wei-Chung Peng, and Reginaldo Polazzo, Jr. are greatly appreciated.

It is often said that a book cannot be judged by its cover. The authors of *Spread Spectrum Communications* are proud to take exception to this commonly quoted cliche. For the permission to use the historically significant noise-wheel cover design (see Chapter 2, Part 1, Section 2.2.5), we gratefully acknowledge the International Telephone and Telegraph Corp.

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