SPREAD SPECTRUM COMMUNICATIONS

Volume II

Marvin K. Simon
Jim K. Omura
Robert A. Scholtz
Barry K. Levitt

COMPUTER SCIENCE PRESS

SPREAD SPECTRUM COMMUNICATIONS

Volume II

Marvin K. Simon
Jet Propulsion Laboratory

Jim K. Omura
University of California

Robert A. Scholtz
University of Southern California

Barry K. Levitt
Jet Propulsion Laboratory

COMPUTER SCIENCE PRESS

Printed in the United States of America.

Computer Science Press
11 Taft Court
Rockville, Maryland 20850

1 2 3 4 5 6 Printing   Year 89 88 87 86 85

Library of Congress Cataloging in Publication Data
Main entry under title:

Spread spectrum communications (V.II)
Bibliography: p.
Includes index.
1. Spread spectrum communications—Collected works.
I. Simon, Marvin.
TK5102.5.S6662 1985 621.38′0413 84-4959
ISBN 0-88175-014-X (Vol. II)
ISBN 0-88175-017-4 (Set)

SPREAD SPECTRUM COMMUNICATIONS

Volume II

ELECTRICAL ENGINEERING
COMMUNICATIONS AND SIGNAL PROCESSING

Raymond L. Pickholtz, Series Editor

Anton Meijer and Paul Peeters
Computer Network Architectures

Marvin K. Simon, Jim K. Omura, Robert A. Scholtz, and Barry K. Levitt
Spread Spectrum Communications, Volume I

Marvin K. Simon, Jim K. Omura, Robert A. Scholtz, and Barry K. Levitt
Spread Spectrum Communications, Volume II

William W Wu
Elements of Digital Satellite Communication, Volume I

Also of interest:

Victor B. Lawrence, Joseph L. Lo Cicero, and Laurence B. Milstein, editors
IEEE Communication Society's Tutorials in Modern Communications

Wushow Chou, Editor-in-Chief
Journal of Telecommunication Networks

Contents to Other Volumes

VOLUME III CONTENTS

PART 5 SPECIAL TOPICS

Chapter 4 Low Probability of Intercept Communications

PREFACE

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, in addition to which 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, Volume I.

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

Another instance where SS techniques are particularly useful in a non-anti-jam application is in the area of multiple-access communications wherein many users desire to share a single communication channel. Here the assignment of a unique SS sequence to each user allows him or her to simultaneously transmit over the common channel with a minimum of mutual interference. This often simplifies the network control requirements to coordinate users of the available channel capacity.

Still another example is the requirement for extremely accurate position location using several satellites in synchronous and asynchronous orbits. Here, 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 offer the advantage of improved reliability of transmission in frequency-selective fading and multipath environments. Here the improvement stems from the fact that spreading the information bandwidth of the transmitted signal over a wide range of frequencies reduces its vulnerability to interference located in a narrow frequency band 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, which itself is driven by the tremendous advances that have been made over the last decade in microelectronics. No doubt this trend 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 in a particular situation will be realized in practice tomorrow.

Unclassified research and developments in spread-spectrum communications have reached 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 to this is that Chapter 3, Volume I dealing with basic concepts and system models is a basis for many of the other chapters that follow it. 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 the more specialized aspects. Thus the authors envision that an introductory one-semester course in SS communications to be taught on a graduate level in a university might cover all or parts of Chapters 1, 3, 4, 5 of Volume I, Chapters 1 and 2 of Volume II, and Chapters 1 and 2 of Volume III.

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 feed confident that the broad experience of the four authors ensures that the material is practically significant as well as academically inspiring.

In writing a book of this magnitude, we acknowledge many whose efforts should not go unnoticed either by virtue of a direct or indirect contribution. Credit is due to Paul Green for originally suggesting the research that uncovered the material in Chapter 2, Volume I, and Bob Price for tireless sleuthing which led to much of the remarkable information presented there. Chapter 5, Volume I benefitted 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, Volume II. 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 contribution to much of the material presented in Chapter 4, Volume III.

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, Volume I, Section 2.2.5), we gratefully acknowledge the International Telephone and Telegraph Corp.

Marvin K. Simon
Jim K. Omura
Robert A. Scholtz
Barry K. Levitt

To

Sidney, Belle, Anita, Brette, and Jeffrey Simon
Shomatsu and Shizuko Omura
Lolly, Michael, and Paul Scholtz
Beverly Kaye

for a variety of reasons known only to the authors

VOLUME II
CONTENTS

PART 3 OTHER FREQUENCY-HOPPED SYSTEMS