MultiCarrier Digital Communications
Theory and Applications of OFDM

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We dedicate this book
to our families...

Preface

Multi-carrier modulation, Orthogonal Frequency Division Multiplexing (OFDM) particularly, has been successfully applied to a wide variety of digital communications applications over the past several years. Although OFDM has been chosen as the physical layer standard for a diversity of important systems, the theory, algorithms, and implementation techniques remain subjects of current interest. This is clear from the high volume of papers appearing in technical journals and conferences.

Multi-carrier modulation continues to evolve rapidly. It is hoped that this book will remain a valuable summary of the technology, providing an understanding of new advances as well as the present core technology.

The Intended Audience

This book is intended to be a concise summary of the present state of the art of the theory and practice of OFDM technology. The authors believe that the time is ripe for such a treatment. Particularly based on one of the author's long experience in development of wireless systems (AB), and the other's in wireline systems (BS), we have attempted to present a unified presentation of OFDM performance and

implementation over a wide variety of channels.

It is hoped that this will prove valuable both to developers of such systems and to researchers and graduate students involved in analysis of digital communications.

In the interest of brevity, we have minimized treatment of more general communication issues. There exist many excellent texts on communication theory and technology. Only brief summaries of topics not specific to multi-carrier modulation are presented in this book where essential. As a background, we presume that the reader has a clear knowledge of basic fundamentals of digital communications.

Highlights of the Second Edition

During the past few years since the publication of the first edition of this text, the technology and application of OFDM has continued their rapid pace of advancement. As a result, it became clear to us that a new edition of the text would be highly desirable. The new edition provides an opportunity to make those corrections and clarifications whose need became apparent from continued discussions with many readers. However, the main purpose is to introduce new topics that have come to the forefront during the past few years, and to amplify the treatment of other subject matter.

Because of the particularly rapid development of wireless systems employing OFDM, we have introduced a section early in the text on wireless channel fundamentals. We have extended and modified our analysis of the effects of clipping, including simulation results that have been reported in a recent publication. These new results are restated here. A section on channel estimation has been added to the chapter on equalization. The chapter on local area networks has been greatly expanded to include the latest technology and applications. Two totally new chapters are added, on OFDM multiple access tech-

nology and on ultra wideband technology.

Organization of This Book

We begin with a historical overview of multi-carrier communications, wherein its advantages for transmission over highly dispersive channels have long been recognized, particularly before the development of equalization techniques. We then focus on the bandwidth efficient technology of OFDM, in particular the digital signal processing techniques that have made the modulation format practical. Several chapters describe and analyze the sub-systems of an OFDM implementation, such as clipping, synchronization, channel estimation, equalization, and coding. Analysis of performance over channels with various impairments is presented.

The book continues with descriptions of three very important and diverse applications of OFDM that have been standardized and are now being deployed. ADSL provides access to digital services at several Mb/s over the ordinary wire-pair connection between customers and the local telephone company central office. Digital Broadcasting enables the radio reception of high quality digitized sound and video. A unique configuration that is enabled by OFDM is the simultaneous transmission of identical signals by geographically dispersed transmitters. And, the new development of wireless LANs for multi-Mb/s communications is presented in detail. Each of these successful applications required the development of new fundamental technology.

Finally, the book concludes with describing the OFDM based multiple access techniques and ultra wideband technology.

Acknowledgements

The two authors of the first edition of this text are very pleased to include our colleague as an additional author, and gratefully acknowledge his extensive contributions in making this second edition possible.

The first edition of this text has been used for classes in University of California Berkeley, Stanford University, University of Cambridge, CEI-Europe and in other institutions. We are grateful to colleagues in the institutions where this book have been used. For the first edition, we acknowledge the extensive review and many valuable suggestions of Professor Kenji Kohiyama, our former colleagues at AT&T Bell Laboratories and colleagues at Algorex. Gail Bryson performed the very difficult task of editing and assembling this text. The continuing support of Kambiz Homayounfar was essential to its completion.

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Despite all our efforts to keep the text error free, for any that remain, any comments, corrections and suggestions received will be much appreciated for the future printings. We can be reached via e-mail at *bahai@stanford.edu, bsaltzberg@worldnet.att.net*, and *ergen@eecs.berkeley.edu*. We will post any corrections and comments at the Web site ***http://ofdm.eecs.berkeley.edu/*** in addition to the support materials that may be necessary to prepare a lecture or paper.