M. GHAVAMI · L. B. MICHAEL · R. KOHNO

Ultra Wideband

signals and systems in communication engineering

SECOND EDITION

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Ultra Wideband Signals and Systems in Communication Engineering

Second Edition

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Second Edition

Preface

In the two years since this book was first published, ultra wideband (UWB) has advanced and consolidated as a technology, and many more people are aware of the possibilities for this exciting technology. We too have expanded and consolidated materials in this second edition in the hope that 'Ultra Wideband: Signals and Systems in Communication Engineering' will continue to prove a useful tool for many students and engineers to come to an understanding of the basic technologies for UWB.

In this book we focus on the basic *signal processing* that underlies current and future UWB systems. By looking at signal processing in this way, we hope that this text will be useful even as UWB applications mature and change or regulations regarding UWB systems are modified. The current UWB field is extremely dynamic, with new techniques and ideas being presented at every communications and signal-processing conference. However, the basic signal-processing techniques presented in this text will not change for some time to come. This is because we have taken a somewhat theoretical approach, which we believe is longer lasting and more useful to the reader in the long term than an up-to-the-minute summary that is out of date as soon as it is published.

We restrict our discussion in general to *ultra wideband communication*, looking in particular at *consumer communication*. What we mean by this is that although there are many and varied specialized applications for UWB, particularly for the military, we assume that the majority of readers will either be in academia or in industry. In any case, as this is a basic text, aimed mostly at the upper undergraduate or graduate student, these basics should stand the reader in good stead to be able to easily understand more advanced papers and make a contribution in this field for themselves.

We are painfully aware of the depth and breadth of this field, and regretfully pass on interesting topics such as UWB radar, including ground penetrating radar, and most military applications. For the former there is already a great deal of information available, while for the latter most material is classified.

The introduction to this book presents a brief look at why UWB is considered to be an exciting wireless technology for the near future. We examine Shannon's famous capacity equation and see that the large bandwidth promises possibilities for high-data-rate communication. A quick overview of the regulatory situation is presented.

Chapter 1 presents the basic properties of UWB. We examine the power spectral density, basic pulse shape, and spectral shape of these pulses. The regulatory requirements laid down by the Federal Communications Commission are briefly described. Why UWB is considered to be a multipath resistant form is also examined, and such basic figures of merit such as capacity and speed of data transmission are considered. We finish the chapter with a look at the cost, size, and power consumption that is forecast for UWB devices and chipsets.

Chapter 2 examines in detail how to generate basic pulse waveforms for UWB systems, for the simple Gaussian pulse shape. An introduction to damped sine waves and the difference between them and Gaussian waveforms is presented. Armed with this information, the reader can now proceed to more complex waveforms and theory associated with UWB signals and systems. We examine how to design pulses to fit spectral masks, such as mandated by regulators, or to avoid interference to other frequency bands.

Chapter 3 looks at different signal-processing techniques for UWB systems. The chapter begins with a review of basic signal-processing techniques, including both time and frequency domain techniques. The Laplace, Fourier, and z-transforms are reviewed and their application to UWB is discussed. Finally, some practical issues, such as pulse detection and amplification, are discussed.

The wireless indoor channel, and how it should be modeled for UWB communications, is considered in Chapter 4. Following our basic pattern we define and explore basic concepts of wideband channel modeling, and show a simplified UWB multipath channel model which is amendable to both theoretical analysis and simulation. Path loss effects and a two-ray model are presented. A frequency domain autoregressive model is discussed and, finally, IEEE proposals for a UWB channel model are explained.

Chapter 5 takes a look at some of the fundamental communication concepts and how they should be applied to UWB. First, modulation methods applicable to UWB are presented. A basic communication system consisting of transmitter, receiver, and channel is discussed. Since most consumer communication systems do not consist of only one user, multiple access techniques are introduced. The simple capacity of a UWB system is derived. Since other wireless consumer communication systems have already become popular, a comparison between UWB and other wideband techniques is included. Finally, the chapter ends with a look at interference to and from UWB systems.

In Chapter 6, which is in many ways an extension of Chapter 2 but requiring many of the concepts presented in Chapters 3 to 5, more complex pulse shapes and

their use in a communication system are explained. An extensive treatment of the more complex orthogonal pulses, including Hermite pulses, prolate spheroidal wave functions, and wavelet packets is presented.

Chapter 7 is concerned with UWB antennas and arrays of antennas. This is considered one of the most difficult problems that must be overcome before the widespread commercialization of UWB devices takes place. Antenna fundamentals are first introduced, including Maxwell's equations for free space, antenna field regions, directivity, and gain. The suitability of conventional antennas for UWB transmission and reception is discussed in detail. More suitable impulse antennas are then introduced. Arrays of antennas and beamforming for UWB systems are given a brief treatment.

Positioning and location, using both traditional techniques and UWB, are discussed in Chapter 8. Traditional location systems are first introduced and their pros and cons discussed. The advantages of UWB, particularly the extremely precise positioning that is theoretically possible, are examined. Finally, several possible scenarios are discussed where the precise location capabilities and high data rate of UWB can be combined to produce some new and exciting applications.

New applications made possible by UWB technology are among the most exciting reasons to use UWB. Chapter 9 has a brief look at some applications that use UWB technology, as well as an overview of some chipsets and possible future UWB products. Emphasis is on consumer communication and medicine; however, military applications are also given a brief treatment.

Chapter 10, an additional chapter for the second edition, presents an introduction and overview of the main UWB standards bodies. In particular, the IEEE 802.15.3a and IEEE 802.15.4a efforts are summarized. The two main physical layer proposals for UWB, direct sequence UWB and multiband UWB, and their respective advantages are then presented in detail.

Chapter 11 presents advanced topics in UWB communication systems, and is also an addition for the second edition. This chapter looks at novel communication systems that have matured recently. In particular, UWB ad-hoc and sensor networks, UWB vehicular radars and the effects of interference with Wi-Max are examined.

For the reader who wants a fast-track understanding of UWB and some knowledge of the current situation, we recommend the introduction, Chapter 1 (Basic properties of UWB signals and systems), Chapter 9 (Applications), and Chapter 10 (UWB communication standards).

For students who want to look at UWB in more detail, they should then proceed to look at Chapter 2 (Generation of UWB waveforms), Chapter 3 (Signal processing techniques for UWB systems), and then Chapters 4 through to 8 as required. We have strived to make each chapter complete in itself as far as possible and provide as much basic theory as practicable, including derivations where appropriate. We have made constant reference to the literature, a significant part of which is covered here.

As an extra resource we have set up a companion website for our book containing a solutions manual, Matlab programs for the examples and problems, and a sample chapter. Also, for those wishing to use this material for lecturing purposes, electronic

versions of most of the figures from our book are available. Please take a look at `http://www.wiley.com/go/ghavami`.

We hope that you will find this book useful as both a reference, a learning tool, and a stepping stone to further your own efforts in this exciting field.

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