Preface

This second edition of *Fundamentals of Radar Signal Processing* shares with the first the goal of providing in-depth coverage of fundamental topics in radar signal processing from a digital signal processing perspective. The techniques and interpretations of linear systems, filtering, sampling, and Fourier analysis are used throughout to provide a modern and unified tutorial approach. The coverage includes a full range of the basic signal processing techniques on which virtually all modern radar systems rely, including topics such as target and interference models, matched filtering, waveform design, Doppler processing, threshold detection, and measurement accuracy. Introductions are provided to track filtering and the advanced topics of synthetic aperture imaging and space-time adaptive array processing to provide a bridge to more in-depth texts on these topics.

The first edition was published in 2005 with the intention of filling what I perceived to be a void in the technical literature on radar. There existed at that time a number of excellent books on radar systems in general (e.g., Skolnik, Edde) that provided an excellent qualitative and descriptive introduction to radar systems as a whole and could be enthusiastically recommended as first texts for anyone interested in the topic. Indeed, having worked on speech enhancement in graduate school, I read the first edition of Skolnik's *Introduction to Radar Systems* when I accepted a job in radar, hoping to avoid appearing completely ignorant on my first day at the new job. (It didn't work, through no fault of Skolnik.) Some of these texts (e.g., Peebles, Mahafza) provided greater quantitative depth on basic radar systems and some signal processing topics. At the same time, a number of good quality texts were available on advanced topics in radar signal processing, principally synthetic aperture imaging (Jakowatz et al., Carrara et al., Soumekh) and space-time adaptive processing (Klemm, Guerci). The problem, in my view, was the existence of a substantial gap between the qualitative systems books and the quantitative advanced signal processing books. Specifically, I believed the radar community lacked a current text providing a concise, unified, and modern treatment of the basic radar signal processing techniques mentioned above on which these more advanced methods are founded. It was my hope that this book would fill that gap.

The reception accorded the first edition since its publication has been gratifying. I have received many very kind and encouraging comments and it has been adopted for use by a number of universities and companies. I believe it has largely been successful in meeting its goals. Its success, however, also quickly brought to light many ways in which the book could be improved.

New books continue to appear, particularly the excellent *Principles of Modern Radar* series. I believe it remains true today, somewhat to my surprise, that most radar textbooks generally address either the entire radar system or very specialized processing topics, and that few attempt to address the full suite of basic signal processing concepts found in virtually every radar that form the basis for advanced techniques. That is, the gap still exists.

The goal of the text has therefore remained the same. The specific goal of the second edition is to strengthen that coverage, broaden it slightly, correct and improve the presentation, and provide additional resources that will increase its usefulness as a textbook as well as a professional reference.

This book was originally developed and used over several years in support of two courses at Georgia Tech. It was primarily developed as a product of ECE 6272, *Fundamentals of Radar Signal Processing*, a semester-length first-year graduate course. Elements of this book were also used in abbreviated and simplified form in the one-week professional education course of the same name taught periodically through Georgia Tech's Professional Education division. Since publication of the first edition, I have continued to use it for both courses. Through those experiences and just the passage of time I have learned more, both about the topics and how to convey them, and I have tried to incorporate that knowledge into the updated text.

There is one major change and many minor to moderate ones from the first edition. The major change is the addition of what is now Chap. 7, "Measurements and Tracking." This chapter introduces an important basic topic missing from the first edition, that of measurement accuracy. The Cramèr-Rao lower bound (CRLB) and maximum likelihood estimation are introduced and applied to measurements of time delay, frequency, phase, and angle using common techniques such as matched filtering with peak detection, leading edge pulse detection, the DFT, and monopulse angle measurement. Also included is an overview of basic track filtering covering α-β and Kalman filters. This chapter should have been in the first edition, and I am happy to remedy its absence now.

Changes to the other portions of the text are more modest. The review of basic digital signal processing concepts previously in Chap. 1 has been relocated to App. B and expanded slightly. An entirely new App. A has been added to reference basic information from random variables and random signals needed for this text, including common probability density functions (PDFs) in radar; estimators and the CRLB; and the effect of linear shift-invariant systems on random signals.

Chapter 2 attempts to improve the discussion of fluctuating target models. The traditional Swerling models do not apply in many situations today, both because finer-resolution radars require new PDFs and because the "scan-to-scan" and "pulse-to-pulse" terminology is a poor fit to processing based on coherent processing intervals (CPIs). However, the analysis strategy remains valid. I have therefore kept the presentation of the detector design and analysis strategy based on the Neyman-Pearson criterion largely intact while reducing reliance on the "scan-to-scan" and "pulse-to-pulse" terminology for discussing noncoherent integration issues. I have not abandoned these terms completely because the student still needs to understand them to interpret the literature and apply it to modern systems. The other change to Chap. 2 is a modest increase in the discussion of clutter reflectivity.

Chapter 3 has been renamed "Pulsed Radar Data Acquisition" but is largely unchanged. The discussion of acquiring a datacube for one CPI has been reorganized a bit to make the sequence clearer. Similarly, Chap. 4 on waveforms has been expanded only slightly, to add time-domain control of linear FM sidelobes and brief mentions of the stepped-chirp waveform, mismatched filters for binary phase codes, and continuous wave radar.

Chapter 5 on Doppler processing has been significantly expanded to include more explanation of the behavior of the pulse Doppler spectrum in the presence of range and Doppler ambiguities. A short mention of the pros and cons of the low, medium, and high PRF regimes has been added. Coverage of ambiguity resolution has been increased and a discussion of blind zones added. Also, the discussion of staggered pulse repetition frequencies for moving target indication has been redone in terms of pulse repetition intervals.

Chapter 6 on basic detection theory and Chap. 7 on constant false alarm rate (CFAR) thresholding have been combined into the new Chap. 6 but are otherwise little changed except for corrections and clarifications. Chapter 8 on synthetic aperture radar has likewise been corrected and clarified, with some additional information on interferometric SAR added. Finally, Chap. 9 on adaptive beamforming and space-time adaptive processing has also been corrected and clarified. The only significant change has been the elimination of most of the material on computational issues in STAP. (Perhaps a future third edition will have room for a new chapter that can address computational issues in all the radar signal processing techniques.) While SAR and adaptive interference suppression are extremely important in modern radar, the intent of this text is to introduce the basics and prepare the student to tackle some of the many fine books that address these topics in depth.

Throughout the text, I attempt to do a better job of identifying and bringing out common themes that arise again and again in radar signal processing, if sometimes in disguise. These include phase history, coherent integration, matched filtering, integration gain, and maximum likelihood estimation.

A one-semester course in radar signal processing can cover Chaps. 1 through 7, perhaps also skipping some of the later sections of Chaps. 2 and 3 for additional time savings. Such a course provides a solid foundation for more advanced work in detection theory, adaptive array processing, synthetic aperture imaging, and more advanced radar concepts such as passive and bistatic systems. A quarter-length course could cover Chaps. 1 through 5 and the non-CFAR portion of Chap. 6 reasonably thoroughly. In either case, a firm background in basic continuous and discrete signal processing and an introductory exposure to random variables and processes are advisable. In this edition, I have added homework problems to each chapter to improve the book's usefulness as an academic text. Solutions to the problems are available to instructors of courses using the text on request from the publisher.

Since publication of the first edition, I have collected and maintained a thorough list of every error reported to me by readers or that I have found myself and made it available on the textbook support website at http://www.radarsp.com. That website also provides additional support information such as occasional technical memo supplements on topics related to this book, and some simple MATLAB®-based software demos and projects that I have used in my classes. I have tried in this edition to eliminate all known errors without introducing new ones. Complete success is certainly impossible, but I sincerely hope I have mostly succeeded. (Being all new content, Chap. 7 and App. A remain particularly at risk for errors in this edition.) I invite readers to send any and all errata that they find to me at mrichards@gatech.edu. As always, I will make available at the website an errata document with all known errors in this edition.

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