Preface

This third edition of *Fundamentals of Radar Signal Processing* (FRSP) shares with the first two editions the goal of providing an in-depth tutorial in the fundamental techniques of radar signal processing. The full spectrum of foundational methods on which virtually all modern radar systems rely is covered, including topics such as target and interference models, matched filtering, waveform design, Doppler processing, threshold detection, and measurement accuracy. Chapters or sections on tracking, adaptive array processing, and synthetic aperture imaging introduce those more advanced techniques and provide a bridge to dedicated texts.

The book is written from a digital signal processor's viewpoint; the techniques and interpretations of linear systems, filtering, sampling, Fourier analysis, and random processes are used throughout to provide a consistent and unified tutorial approach. Students should have a firm foundation in these areas to obtain the most benefit. The mathematical level is appropriate for college seniors and first-year graduate students and is leavened by extensive interpretation. Because this text concentrates on the signal processing, it does not address many other aspects of radar technology such as transmitter and receiver hardware technology or electromagnetic wave propagation. Familiarity with basic radar systems, perhaps from studying one of the books mentioned below, will ~~also~~ help prepare the reader to get the most out of this text.

This book first came about in 2005 because I could not identify an appropriate textbook for Georgia Tech's ECE 6272, Fundamentals of Radar Signal Processing, a semester-length first-year graduate course I taught. There existed at that time a number of books on radar systems in general (e.g., Skolnik, Edde) that provided good qualitative and descriptive introductions 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 classic *Introduction to Radar Systems* when I first 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 provided greater quantitative depth on basic radar systems and some signal processing topics. At the same time, a number of good texts were available on advanced topics in radar signal processing, principally synthetic aperture imaging and space-time adaptive processing. The problem, in my view, was the existence of a substantial gap between the systems books and the advanced signal processing books. Specifically, I believed the radar community lacked a current text providing a unified, modern treatment of the basic radar signal processing techniques mentioned above. The closest was probably Levanon's *Radar Principles*, which I used for early offerings of ECE 6272, but it was not comprehensive enough.

It was my hope that this book would fill that gap, and I believe it has largely been successful in doing so. However, it has now been over 16 years since the first edition was published. While new books continue to appear, particularly the excellent *Principles of*

Modern Radar series, to my surprise none has emerged that covers basic radar signal processing techniques with similar depth and breadth. In the meantime, radar technology and applications have continued to evolve, and rather rapidly. For instance, the last 10 years have seen a tremendous increase in the number of short-range continuous wave (CW) radars fielded, especially in the automotive industry. At the same time, complex new methods such as multi-input, multi-output (MIMO) processing, compressed sensing, artificial intelligence, and "deep learning" have crossed over from other application realms into advanced radar.

To continue meeting its goals, this text must also evolve. The second edition (2014) made one major addition, adding the chapter on measurement accuracy and the introduction to tracking, in addition to many more minor updates. This edition likewise has one major change. The first two editions assumed pulsed radar throughout, even though a number of the topics are also applicable to CW systems. In this edition, CW radars are now included explicitly, with an emphasis on "fast-chirp" linear frequency-modulated CW (FMCW) radars, the most common variety in current usage. Although data acquisition for pulsed and FMCW radars is very different, much of the basic processing that follows is essentially the same, a commonality that I have tried to emphasize in this edition.

Each chapter has one or two other significant updates and many small ones. Chapter 1 now includes a discussion of virtual antenna elements to set the stage for virtual arrays in Chap. 9. The discussion of Doppler shift in Chap. 2 has been simplified from that in previous editions. Also in Chap. 2, the K distribution has been added to the discussion of PDFs for describing target and clutter fluctuations.

The first portion of Chap. 3 has been significantly restructured and expanded to introduce FMCW radar, describing how range profiles are acquired and some of the range ambiguity and blind zone considerations in comparison to the pulsed case. The coherent processing interval is emphasized as a common data structure for both pulsed and FMCW, and so a common starting point for understanding subsequent processing steps.

The impact of incorporating FMCW continues in Chap. 4 with a brief discussion of CW waveforms in general before homing in on the fast-chirp linear FMCW variant of most interest. This chapter also now includes more information on mismatched filters for phase-coded waveforms and closes with a new comparison of frequency-modulated and phase-modulated waveforms.

Chapter 5 adds an introduction to the keystone transform for combatting range migration and introduces along-track interferometry (ATI) as a complement to DPCA for detecting ground movers in clutter. Chapter 6 has a new example of the effect of spiky interference on detection performance. Also new is the use of binary integration gain as an alternative way to quantify the impact of *M*-of-*N* processing.

Chapter 7 adds a brief section on the optimum combination of two noisy measurements to improve the motivation and understanding of the prediction-correction structure of most track filters. In Chap. 8, the sequence of SAR image formation algorithms has been extended to include the range migration algorithm, a workhorse in current practice, and a very basic introduction to the important emerging class of backprojection algorithms.

Chapter 9 now introduces the idea of virtual arrays (VAs), essential to the understanding of MIMO array systems. While MIMO processing itself is beyond the scope of this text, the discussion of VAs provides a base for its study in more specialized references. Also, both phase and time delay steering of arrays are now discussed and compared explicitly. The two appendices are largely unchanged except for the addition of the K distribution to the PDFs, discussed in App. A. Finally, some additional homework problems have been added to most chapters to improve the book's usefulness as an academic text.

Throughout the text, I once more 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 and processing gain, and maximum likelihood estimation.

Several ancillary FRSP materials are available from the publisher. An errata list and a collection of MATLAB® demonstrations of various fundamental radar signal processing operations are available to all readers at www.mhprofessional.com/Richards3e. For instructors of classes using this book as a text, there is a solution manual for the end-of-chapter problems and a collection of MATLAB® mini-projects with sample solutions. While not directly related to FRSP, a series of technical memos on additional radar signal processing topics can be found by the reader at the author's website www.radarsp.com.

A one-semester course in radar signal processing can cover Chaps. 1 through 7, perhaps skipping some of the later sections of Chaps. 2 and 3 for 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.

I have tried in this edition to eliminate all known errors in the second edition, but because there is significant new material, there are likely new errors. I invite readers to help me keep the errata sheet up to date by sending any and all errors they find to me at mrichards@ieee.org.

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