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Preface

Goals of the Book

As the editors of *Principles of Modern Radar: Basic Principles* (*POMR*), we had two primary goals in mind when this book was conceived. Our first goal was to design *POMR* to become the "Radar 101" textbook of choice for the next generation of radar engineers, whether students in graduate engineering courses, new hires on the job, or retraining professionals in government and industry. Our second goal was to provide a breadth of topics and modern approach that would make *POMR* the most convenient and valuable starting point for today's professionals needing to study or review a particular subject. To accomplish these twin goals, we needed to make several key trade-offs in designing the book:

1. Focus on modern techniques and systems from the start rather than historical background and legacy systems.
2. Strike a careful balance between quantitative mathematical models and tools and qualitative motivation and insight.
3. Carefully proportion the breadth of topics versus the depth of coverage of systems and external phenomenology.
4. Draw on the knowledge of a range of subject experts—and accept the intense editing effort needed to integrate their contributions into a coherent whole—versus the less comprehensive coverage but inherently consistent style and notation of just one or two authors.

What follows is a description of how these trade-offs were struck to achieve our goals.

Many in the radar community will recognize that *POMR* has evolved from the professional education short course of the same name taught to thousands of students by Georgia Tech research faculty since 1969. Some may even remember that the short course produced an earlier book, now out of print, by the same name.[1] This book is a completely new text, developed from scratch by 15 scientists and engineers working today with the most modern systems and techniques in radar technology. Each of these contributing authors brings a wealth of research and teaching experience to bear in explaining the fundamental concepts underlying all radar systems.

There are, of course, several very good books currently in use for college- and professional-level courses in radar systems and technology, so it is fair to ask why one should consider *POMR*. We believe the answer is fourfold:

- Comprehensiveness.
- Qualitative versus quantitative balance.
- Emphasis on the most modern topics and methods.
- Radar community support.

[1] Eaves, J.L., and Reedy, E.K., *Principles of Modern Radar.* Van Nostrand Reinhold, New York, 1987.

Most importantly, *POMR* provides a breadth of coverage unmatched by currently available introductory radar textbooks: chapters on fundamental concepts, propagation and echo phenomenology for targets and interference, all major subsystems of a modern radar, and all basic signal processing functions so important to modern practice. Second, these topics are presented both qualitatively and quantitatively, at a consistent level appropriate for advanced undergraduate and beginning graduate students and readers. No competing book of which we are aware strikes such a carefully constructed balance. Some competitors provide the traditional fundamental concepts but offer little on modern signal processing. Some are almost entirely descriptive, lacking the mathematical analysis students need to undertake their own analysis and modeling. A few others are highly mathematical but have limited coverage and lack the qualitative interpretation needed to develop the understanding of students new to the field. *POMR* not only provides the basic mathematical tools but also supports those tools with the explanations and insights of its experienced authors.

POMR's focus on *modern* radar is evident in its choice of topics. For example, extensive coverage is given to increasingly popular phased array antennas due to their advanced capabilities. Coherent systems, a prerequisite to most interesting signal processing, are strongly emphasized throughout the text. Last and most importantly, because so much functionality in modern systems lies in the signal processing, a significant portion of the book is devoted to methods enabled by digital radar signal processing, from pulse compression and Doppler processing to tracking and imaging. This topic choice and organization results in coverage superior to any other "Radar 101" textbook, so that *POMR* provides the most solid foundation for students progressing to "Radar 102" texts on more advanced and specialized topics.

Finally, *POMR* benefits from an extraordinary vetting by the modern radar community. It is a joint effort among the text's highly experienced authors and editors; the publisher SciTech, with its radar focus and resulting contacts; and the volunteering global community of radar experts, mostly fellow radar instructors and radar authors. As a result, the 21 chapters have been reviewed for content and style by more than 50 radar professionals representing academia, the government and military, and commercial companies. Chapters were reviewed first in their draft versions and then again after revisions. *POMR*'s editors were assisted in integrating the many reviewer suggestions by "master reviewers," each of whom read most or all of the chapters and also "reviewed the reviews" to help coordinate the improvements and perfect the emphasis, topical flow, and consistency across chapters. This extensive process of peer review iterations within the radar community ensures that *POMR* meets the needs of students, educators, and professionals everywhere.

Organization of Content

POMR is organized into four major parts: *Overview, The Radar Environment, Radar Subsystems*, and *Signal and Data Processing.* In teaching a technology area as broad as radar, it is difficult to design a topical sequence that proceeds in a straight line from start to finish without looking ahead or doubling back. The *Overview* section solves this problem by taking readers through a high-level first pass that familiarizes them with a range of fundamental radar concepts and issues, setting the stage for a more detailed examination in the remaining parts. Chapter 1 introduces basic concepts such as properties of electromagnetic waves, target and clutter echoes, monostatic and bistatic radar, and detection in noise. It also illustrates the scope of radar technology by describing a wide range of military and commercial applications. Finally, Chapter 1 introduces some radar cultural information such as the “band” terminology (e.g., L-band, X-band) and the AN Nomenclature for U.S. military systems. Chapter 2 delves into that most fundamental mathematical model in radar, the radar range equation. The basic point target range equation is derived, and its implications are explored. The chapter then develops several of the common variants tailored to specific radar modes. Chapter 3 provides a closer look at the most fundamental radar task of search and detection, describing search processes and introducing the idea of statistical detection and the resulting importance of probabilities in evaluating radar performance.

Part 2, *The Radar Environment*, is one of the truly distinguishing features of *POMR*. Few, if any, introductory radar texts provide the breadth and depth of discussion of propagation effects and target and clutter characteristics found here. Chapter 4 introduces all major electromagnetic propagation phenomenology of importance to radar, from simple attenuation in various weather conditions to more complex issues such as refraction, diffraction, multipath, ducting, and over-the-horizon propagation. Chapter 5 summarizes the extensive data on modeling the reflectivity and Doppler characteristics of atmospheric, land, and sea clutter and presents many of the common mean reflectivity and statistical models needed for clutter analysis. Chapter 6 introduces the mechanisms of scattering and reflection and the concept of radar cross section for targets, while Chapter 7 describes the common statistical models for radar cross section needed to evaluate detection performance. Chapter 8 delves more deeply into Doppler shift, concentrating on typical characteristics of Doppler spectra for stationary and moving targets and radar platforms.

Part 3, *Radar Subsystems*, describes each of the major subsystems of a typical modern radar system. Chapter 9 describes radar antenna technology, starting with basic antenna concepts and relations and then describing classic monopulse and mechanically scanned antennas. Half of this chapter is devoted to modern phased arrays, with detailed discussion of array patterns, wideband effects, and array architectures. Chapter 10 describes radar transmitter technology, including high-powered thermionic (tube-type) noncoherent and coherent transmitters, as well as solid-state transmitter technology. Again, significant coverage is devoted to transmitter modules and feed architectures for modern phased arrays. This chapter also addresses spectrum allocation and transmitter reliability issues, topics not found in other introductory textbooks. Chapter 11 presents radar receiver technology, beginning with the most basic types and extending to multistage superheterodyne receivers. Noise and dynamic range issues are discussed, and both classical analog synchronous detectors as well as the increasingly popular direct sampling digital receiver techniques for coherent systems are described. The coverage of coherent exciters in Chapter 12 is unique in an introductory textbook but important in understanding the architecture of modern systems. Exciter performance issues are presented, followed by a discussion of the technology available to implement modern coherent radar exciters. The importance of maintaining low phase noise for pulse-Doppler systems is also explained. Another topic unique to this textbook is Chapter 13, which discusses radar digital signal processor technology. Metrics and procedures for estimating processor loading are introduced, followed by discussion of alternative implementation technologies such as custom integrated circuits, reconfigurable hardware, and exciting new techniques such as the use of graphical processing units for real-time signal processing.

Part 4, *Signal and Data Processing*, concentrates on the increasingly sophisticated techniques used to extract ever more information from radar signals using advanced digital signal and data processing. The first half of Part 4 deals with signal processing basics, detection, and clutter rejection. It begins in Chapter 14 with a succinct summary of digital signal processor fundamentals such as sampling, quantization, and data acquisition, followed by a thorough review of discrete Fourier analysis, including windowing and interpolation. Other sections refresh the reader on digital filters, properties of random signals, and the all-important matched filter concept and its connection to data integration. Chapter 15 returns to the topic of threshold detection first introduced in Chapter 3. Here, much more attention is given to details of coherent and noncoherent integration and alternative ways of using the available data. Neyman-Pearson detection and the Swerling models are introduced, leading to optimum detectors for radar signals. Albersheim's and Shnidman's equations are presented as convenient computational aids. Chapter 16 continues the discussion by introducing constant false alarm rate (CFAR) threshold detection, a practical requirement in real interference environments. The properties, performance, and shortcomings of the basic cell-averaging CFAR are discussed in depth, and then many of the common "robust" and "adaptive" CFAR variants are introduced and compared. Chapter 17 covers two major forms of Doppler processing for clutter reduction: moving target indication (MTI), and pulse-Doppler processing. The discussion of MTI includes blind speeds, staggered pulse repetition frequencies, and airborne MTI. The sections on pulse-Doppler processing introduce the important topics of blind zones and ambiguity resolution. This chapter also includes a brief discussion of the pulse-pair processing method widely used in weather radar.

In the second half of Part 4, the focus turns to postdetection position measurements and tracking as well as high-resolution techniques. Chapter 18 addresses position measurements in range, angle, and Doppler. Basic concepts of precision and accuracy lead to the introduction of the Cramèr-Rao lower bound on precision. Several estimators of range, Doppler shift, and angle are then introduced, and their performance is evaluated. This chapter leads naturally into an introduction to tracking algorithms in Chapter 19. After a discussion of basic parameter estimation and some of the data association and resolution problems that complicate radar tracking, a number of tracking algorithms are introduced, from the basic $\alpha - \beta$ tracker to the Kalman filter. Chapters 20 and 21 introduce the techniques needed to achieve high-resolution radar imaging. Chapter 20 describes pulse compression for high-range resolution. The matched filter is investigated in more depth and is then applied to the most common wideband waveforms, including linear frequency modulation or "chirp" and phase-coded waveforms ranging from Barker codes to a variety of polyphase codes. Methods of range sidelobe control are described, and the ambiguity function is introduced as a means of designing and understanding waveform properties. Finally, Chapter 21 provides an overview of synthetic aperture radar (SAR) imaging. SAR data collection is described, and general, widely applicable resolution and sampling equations are derived. While the range of SAR image formation algorithms is too extensive and too advanced for an introductory textbook, descriptions are given of the two extremes: Doppler beam sharpening, one of the simplest imaging algorithms; and backprojection, the current "gold standard" for advanced imaging. The chapter closes with a discussion of the unique phenomenology of SAR imaging, including layover, shadows, and speckle. Collectively, the extensive coverage of signal processing in Part 4 of *POMR* provides an excellent springboard to study of more advanced topics such as advanced SAR, space-time adaptive processing, and multiple-input multiple-output radar.

An appendix reviews two basic electrical engineering topics that are important for understanding radar but not deemed necessary for inclusion within the chapters: Maxwell's equations and the use of decibels in describing radar values.

Features and Resources

POMR has been designed to ease the task of learning or teaching. Some of the features available to all readers include the following:

- Every chapter written by experts having "hands-on" experience in the design and development of radar systems.
- Every chapter reviewed by independent radar experts and edited by technical and publishing experts for content accuracy, level consistency, and readable style.
- Consistent notation and terminology employed throughout.
- Numerous illustrations integrated throughout, all newly drawn, clearly labeled, and carefully captioned.
- Table of common symbols and notation provided for quick reference.
- Table of acronyms, so plentiful in radar, presented alphabetically.
- Extensive, professionally prepared index facilitates reference use.
- At least 12 problems included in every chapter—over 250 total—to check and advance the student's understanding and capability. Answers to the odd-numbered problems are provided.

Several aids are available to adopting course instructors, with more being developed. The following aids can be obtained through request to SciTech at **pomr@scitechpub.com**:

- All problem answers and detailed solutions.
- All illustrations in the text in Microsoft PowerPoint sets or in high-resolution JPEG image formats for construction of custom viewgraphs.
- Copies of all equations in Microsoft Equation Editor format.

Several additional aids—tutorial simulations in MATLAB®[2] worked examples, additional problems for homework or exams—are expected to be available, and more are being developed and contributed by the radar community.

Publication of this first edition of *POMR* is just the first step in the development of a comprehensive set of resources for introducing radar systems and technology to a new generation of radar engineers. A website has been established to provide to readers these supporting materials, a complete and up-to-date list of reported errata, and an evolving set of new supplements. Visit the website periodically to check for the latest supplements and announcements:

http://www.scitechpub.com/pomr

[2]MATLAB is a registered trademark of The MathWorks, Inc. For MATLAB product information and cool user code contributions, go to http://www.mathworks.com, write The MathWorks, Inc., 3 Apple Hill Dr., Natick, MA 01760-2098 or call (508) 647-7101.

Companion Publications

Several remarkable publications are planned to complement, augment, and extend the material in *POMR: Basic Principles*:

Principles of Modern Radar: Advanced Techniques and Applications edited by William L. Melvin and James A. Scheer (2011)

Building on *POMR: Basic Principles*, this sequel provides extensive coverage of both advanced techniques in radar and a wide variety of specific modern applications that integrate the fundamental technologies into complete systems. Examples of advanced techniques include advanced waveforms, stripmap and spotlight synthetic aperture imaging, space-time adaptive processing, multiple-input, multiple-output radar, polarimetry, target protection, and electronic protection. Applications discussed include airborne pulse-Doppler radar, space-based radar, weather radar, air traffic control, and passive and bistatic systems. Together, the two *POMR* volumes will provide integrated and comprehensive coverage of modern radar, from basic concepts to advanced systems, all in a coherent and consistent style and notation.

Radar Pocket Guide: Key Facts and Figures by G. Richard Curry (2010)

A quick reference in shirt pocket size to the very most important and commonly used facts, figures, and tables in real-world radar engineering practice.

Acknowledgments

Principles of Modern Radar could not have come into being without the dedicated efforts of many people. Each of our authors dedicated much personal time to contributing his or her individual chapters and then again to working with the entire *POMR* team to integrate the pieces into a whole that is greater than just the sum of those parts.

The authors were greatly aided by the reviewers and master reviewers. The complete list of reviewers is given in the "Publisher's Acknowledgments" section and so won't be repeated here, but every one of them had a direct hand in improving the final product in coverage, style, and correctness. Without their ability and willingness to critique the book based on their expert knowledge and their own experience with other introductory radar textbooks, we could not have achieved the level of consistency and coherency across such broad coverage and multiple authors. The authors and editors are greatly indebted to them for their efforts.

The entire *POMR* project might not have succeeded without the vision, support, and encouragement of SciTech Publishing and its president, Dudley Kay. SciTech is a wonderful asset to the radar community, and we hope this new book will add to that strength. Editorial assistant Katie Janelle managed the massive review process so important to *POMR*'s completion and quality. Production of a book is a complex endeavor requiring the efforts of many accomplished and dedicated staff. Robert Lawless is the production manager for *POMR*, responsible for managing the workflow and bringing together all the many pieces into the final product. Kristi Bennett, our copy editor, deserves great credit for bringing clarity, precision, and consistency to the writing styles of 15 authors. Freelancer Kathy Gagne conceived the eye-catching cover design. Brent Beckley has done an excellent job in marketing and promoting *POMR* so that it will reach and serve, we

hope, a large audience. All of the SciTech team has been professional and, at the same time, a pleasure to work with every step of the way.

Errors and Suggestions

We have tried to bring the radar community a carefully constructed and truly valuable new introductory textbook and professional reference in *POMR*, but we recognize that there are always some residual errors and inconsistencies. In addition, experience in using *POMR* and new developments in the rapidly evolving field of radar will inevitably bring to light a need to clarify or expand some topics and introduce new ones.

The extensive review process used to develop *POMR* raised and resolved many, many such issues. Those that remain are the responsibility of the editors. We welcome the assistance of *POMR* readers in identifying errata and in making recommendations for improvements in future printings and editions. All identified errata will be posted in a timely fashion on the *POMR* SciTech web site (http://www.scitechpub.com/pomr), accessible to all users.

One of our hopes for *POMR* is that it will be adopted for use in university, professional education, and in-house training classes. There is nothing like teaching the material to newcomers to the field to quickly identify areas where the book could be improved. We invite all instructors using *POMR* to help us design the next edition by letting us know of your experience in using it and how it can be improved in the future.

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