HAMISH MEIKLE

MODERN RADAR SYSTEMS

SECOND EDITION

Modern Radar Systems

Second Edition

Hamish Meikle

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Modern Radar Systems

Second Edition

For a listing of recent titles in the *Artech House Radar Series*,
turn to the back of this book.

To my wife, Monika

Foreword

The publication of the first edition of *Modern Radar Systems*, in 2001, made available to the radar community a valuable resource for understanding the principles of radar systems and their several subsystems. Radar theory was explained in words, equations, diagrams, and plots, notably including three-dimensional representations of complex signals that provide visualization of otherwise obscure concepts. Accurate, closed-form expressions were included to permit the radar engineer to calculate and plot the functions that affect radar performance.

Now, in an extensively revised and updated second edition, Hamish Meikle has refined the original discussions and added significant new material to cover areas of importance to all those working in radar design and analysis, including the statistical domain. Much of the new material reflects the evolution of radar, independent of the technology used, from early designs to more modern digital and solid-state circuits and subsystems.

Chapter 1 presents the fundamentals of radar, including both primary radar that receives echoes reflected from the target and secondary radar that relies on a transponder to generate the response. Monostatic and bistatic radar systems are defined and described. Before going into details of radar circuits and subsystems, Chapter 2 introduces the fundamental methods of vector presentation, modulation, polyphase signals and noise, and the probability distributions that are used to represent them. A new section covers the mathematical processes of convolution and correlation, essential for analysis of radar performance and increasingly used in modern digital signal processors.

The discussion of radar subsystems starts with Chapter 3 on transmitters, where new material has been included on solid-state devices that have begun to replace vacuum tubes in both modulators and RF power sources. The discussion of pulse compression has been updated to reflect current design practice, including waveforms such as the NRL P-codes, and references to recent publications have been added. Chapter 4 on waveguides and transmission lines now includes material on stripline technology, and the description of the many types of microwave components has been updated.

An expanded Chapter 5 describes antennas, including a discussion and plots of low-sidelobe monopulse patterns based on the Bayliss and Zolotarev distributions. A discussion on electronically scanned antennas using horn-fed lens or reflector arrays, as used in the U.S. Patriot system and many Russian radars, has been added. As in the first edition, a thorough discussion of losses associated with antennas has been included. New sections on sidelobe cancelers and adaptive arrays now appear, along with a section on aircraft antennas, including synthetic aperture systems. Chapter 6 covers factors outside the radar: propagation, scattering, and clutter. The mathematical basis of the Swerling target models is now described more thoroughly.

Continuing with radar subsystems, Chapter 7 is dedicated to the receiver, followed by Chapter 8 on matched and matching filters. A section has been added on the Dicke-fix receiver, an important counter to electronic jamming. In the discussion of pulse compression, the nonlinear FM technique is now covered as well as the linear FM technique, the effects of limiting before pulse compression are described, and the correlator processing method is presented. Additional data on discrete phase codes, including the polyphase codes, has been added to the material of the first edition.

Chapter 9 covers detectors, and Chapter 10 discusses analogue-to-digital conversion. Here, material on the techniques of conversion at intermediate frequency has been added. Signal processing is the subject of Chapter 11. New material includes detailed mathematics of the log-FTC circuit response to clutter and on the operation of range-cell-averaging constant-false-alarm-rate (CFAR) processing. A section on airborne MTI has been added, covering time-averaged coherent clutter airborne radar (TACCAR) and the displace-phase-center antenna (DPCA).

Threshold and detection issues are discussed in Chapter 12, with plots and graphs covering the steady target and the four Swerling models. Chapter 13 covers the determination of position, with equations for the errors for different measuring procedures. A section on the display of position has been added. Chapter 14 discusses radar performance, including the range equation, accuracy, resolution, stability considerations, and operation in jamming. Finally, chapters on statistics and transforms explain in more detail the mathematical techniques needed to perform radar system analysis. A section on moment generating functions has been added to Chapter 13. The transform discussion now includes material on convolution, the multiplication of the Fourier transform, supporting the earlier discussion in Chapter 2.

Those who have used the first edition in their work will welcome the new material included in this new edition. Those who have not previously discovered the unique advantages of Meikle's presentation are guaranteed new insight into the analysis of radar signals and circuits provided by the second edition of *Modern Radar Systems*.

David K. Barton
Hanover, New Hampshire
February 2008

Preface to the second edition

As with the first edition, the chapters are arranged in the order that the signals pass through the radar hardware and, as far as possible, the section numbers have not been changed. This leads to pulse compression being divided between two chapters, Chapters 3 and 8. In reworking, a number of errors from the first edition have been corrected.

An important domain in radar is the statistical domain. This edition extends the Fourier transform treatment introduced in the first edition into the statistical domain for the calculation of probabilities of detection for wanted echo signals surrounded by thermal noise or clutter.

The second edition continues to use simple, civil language, using military terms only when appropriate and very few of the abbreviations that are beloved by the military community.

Again I would like to thank the staff of Artech House and their reviewers for their encouragement, support, and suggestions for the improvement of this book.

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Preface to the first edition

A radar is placed among its surroundings in space. It sends, receives, and processes signals in time. These signals are also described by their spectra and statistical distributions. The radar engineer must be able to think in all four of the domains, know their relationships, and be able to move freely between them using the shortest and most dependable routes.

The creative talents of engineers are primarily to look into the future, grab an idea, and create the three-dimensional drawings so that production can start today. This book is an attempt to support thinking in many domains and dimensions.

The main theme is to convey the shapes of the phenomena so that an engineer can place numbers on them and apply them to radar. The Maple V program has been used as the calculating engine to present the values and shapes in three dimensions for a better, more complete understanding, especially with vectors. To this end, in addition to amplitude and phase or x and y (I and Q) graphs, three-dimensional space curves are shown which emphasize the vector relationships involved. In practice purely real or purely imaginary simplifications seldom occur.

Radar has attracted electrical engineers, physicists, mathematicians, and later software specialists, each of whom brought their own terminology. Many have forgotten whence the techniques came: electrical engineering. The unity of thought and terminology throughout electrical engineering fell apart as engineers started to specialize; and worse still, electrical engineering training has followed this trend. The growing value of software in products is tending to change software for systems into systems for software (Appendix A).

Radar literature is peppered with abbreviations which often leads to woolly thinking and are roundly condemned by psychologists as a method of distinguishing those within the privileged, knowing circle from those without [1]. The author has tried to avoid them here, but they are included in parentheses (round brackets) for those who are more familiar with the abbreviations alone.

Radar technology grew up during the Second World War (1939-1945) and was refined during the Cold War (1946-1989). The language that developed is full of belligerent terms, and those who use them today are mostly ignorant of their origins. This is especially the case for those with a limited knowledge of English who do not know the principal English meaning. I was horrified once to learn that the surveillance radars at a civilian airport had to be "boresighted" and that the monopulse azimuth accuracy enhancement gave an "off-boresight-error" in civil secondary radar. Boresights are cross-wire sights mounted by hand in the bores or barrels of guns to provide the fundamental sighting reference. In field guns they are used to realign the main sights should they become displaced. In anti-aircraft gunnery, the boresight mounted in the barrel of the master gun is pointed at the alignment telescope of the fire control radar which is the reference. The gun azimuth is then set to the back bearing of the radar azimuth, and the elevations, set by spirit levels, are checked. I thought of the approach controller at the destination airport shepherding a passenger aircraft full of happy, carefree holiday-makers home using the representation of the "target" by his radar. At this time, the boresights would have been removed to allow the "target" to be engaged accurately. In the case of a miss, there was always the "execute" button on the console. To avoid such misunderstandings, demilitarized language is used in this book.

Having used W. A. Skillman's book on radar calculations [2] later, the version for personal computers, I thought that a more transparent book could be written using Maple V on a computer as the calculating engine. The graphics available in Maple bring the phenomena to life and give them shape.

I started to write useful Maple V worksheets with the "book of the disk" containing explanations. This was to give the look and feel on the computer display for the phenomena described using stereo images. I was advised that the market would be too small because too few people use the Maple V program. Here the Maple V program has carried out hard mathematical work and provided the diagrams in three dimensions. If demand calls for it, the "disk of the book" containing the Maple worksheets could be published. That would give hands-on experience in the handling of the shapes and sizes of the phenomena described in parallel to using published results.

When writing such a book, limits must be set. For that reason no techniques using Monte Carlo methods, covariance matrices, or adaptive characteristics are described.

I would like to thank Mr. David Barton for his many useful comments and suggestions including the name for the title and Mr. Robert Schmidt for his advice in the beginning. I would also like to thank Waterloo Maple Incorporated who kindly sent me an update of their program.

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February 2001

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