Detection, Estimation, and Modulation Theory, Part III: Radar–Sonar Signal Processing and Gaussian Signals in Noise. Harry L. Van Trees

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Detection, Estimation, and Modulation Theory

Radar-Sonar Processing and Gaussian Signals in Noise

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To Diane

and Stephen, Mark, Kathleen, Patricia,
Eileen, Harry, and Julia

and the next generation—
Brittany, Erin, Thomas, Elizabeth, Emily,
Dillon, Bryan, Julia, Robert, Margaret,
Peter, Emma, Sarah, Harry, Rebecca,
and Molly

Preface for Paperback Edition

In 1968, Part I of *Detection, Estimation, and Modulation Theory* [VT68] was published. It turned out to be a reasonably successful book that has been widely used by several generations of engineers. There were thirty printings, but the last printing was in 1996. Volumes II and III ([VT71a], [VT71b]) were published in 1971 and focused on specific application areas such as analog modulation, Gaussian signals and noise, and the radar–sonar problem. Volume II had a short life span due to the shift from analog modulation to digital modulation. Volume III is still widely used as a reference and as a supplementary text. In a moment of youthful optimism, I indicated in the the Preface to Volume III and in Chapter III-14 that a short monograph on optimum array processing would be published in 1971. The bibliography lists it as a reference, *Optimum Array Processing,* Wiley, 1971, which has been subsequently cited by several authors. After a 30-year delay, *Optimum Array Processing,* Part IV of *Detection, Estimation, and Modulation Theory* will be published this year.

A few comments on my career may help explain the long delay. In 1972, MIT loaned me to the Defense Communication Agency in Washington, D.C. where I spent three years as the Chief Scientist and the Associate Director of Technology. At the end of the tour, I decided, for personal reasons, to stay in the Washington, D.C. area. I spent three years as an Assistant Vice-President at COMSAT where my group did the advanced planning for the INTELSAT satellites. In 1978, I became the Chief Scientist of the United States Air Force. In 1979, Dr. Gerald Dinneen, the former Director of Lincoln Laboratories, was serving as Assistant Secretary of Defense for C3I. He asked me to become his Principal Deputy and I spent two years in that position. In 1981, I joined M/A-COM Linkabit. Linkabit is the company that Irwin Jacobs and Andrew Viterbi had started in 1969 and sold to M/A-COM in 1979. I started an Eastern operation which grew to about 200 people in three years. After Irwin and Andy left M/A-COM and started Qualcomm, I was responsible for the government operations in San Diego as well as Washington, D.C. In 1988, M/A-COM sold the division. At that point I decided to return to the academic world.

I joined George Mason University in September of 1988. One of my priorities was to finish the book on optimum array processing. However, I found that I needed to build up a research center in order to attract young research-oriented faculty and doctoral students. The process took about six years. The Center for Excellence in Command, Control, Communications, and Intelligence has been very successful and has generated over $300 million in research funding during its existence. During this growth period, I spent some time on array processing but a concentrated effort was not possible. In 1995, I started a serious effort to write the Array Processing book.

Throughout the *Optimum Array Processing* text there are references to Parts I and III of *Detection, Estimation, and Modulation Theory*. The referenced material is available in several other books, but I am most familiar with my own work. Wiley agreed to publish Part I and III in paperback so the material will be readily available. In addition to providing background for Part IV, Part I is still useful as a text for a graduate course in Detection and Estimation Theory. Part III is suitable for a second level graduate course dealing with more specialized topics.

In the 30-year period, there has been a dramatic change in the signal processing area. Advances in computational capability have allowed the implementation of complex algorithms that were only of theoretical interest in the past. In many applications, algorithms can be implemented that reach the theoretical bounds.

The advances in computational capability have also changed how the material is taught. In Parts I and III, there is an emphasis on compact analytical solutions to problems. In Part IV, there is a much greater emphasis on efficient iterative solutions and simulations. All of the material in parts I and III is still relevant. The books use continuous time processes but the transition to discrete time processes is straightforward. Integrals that were difficult to do analytically can be done easily in Matlab®. The various detection and estimation algorithms can be simulated and their performance compared to the theoretical bounds. We still use most of the problems in the text but supplement them with problems that require Matlab® solutions.

We hope that a new generation of students and readers find these reprinted editions to be useful.

HARRY L. VAN TREES

Fairfax, Virginia
June 2001

Preface

In this book I continue the study of detection, estimation, and modulation theory begun in Part I [1]. I assume that the reader is familiar with the background of the overall project that was discussed in the preface of Part I. In the preface to Part II [2] I outlined the revised organization of the material. As I pointed out there, Part III can be read directly after Part I. Thus, some persons will be reading this volume without having seen Part II. Many of the comments in the preface to Part II are also appropriate here, so I shall repeat the pertinent ones.

At the time Part I was published, in January 1968, I had completed the "final" draft for Part II. During the spring term of 1968, I used this draft as a text for an advanced graduate course at M.I.T. and in the summer of 1968, I started to revise the manuscript to incorporate student comments and include some new research results. In September 1968, I became involved in a television project in the Center for Advanced Engineering Study at M.I.T. During this project, I made fifty hours of videotaped lectures on applied probability and random processes for distribution to industry and universities as part of a self-study package. The net result of this involvement was that the revision of the manuscript was not resumed until April 1969. In the intervening period, my students and I had obtained more research results that I felt should be included. As I began the final revision, two observations were apparent. The first observation was that the manuscript has become so large that it was economically impractical to publish it as a single volume. The second observation was that since I was treating four major topics in detail, it was unlikely that many readers would actually use all of the book. Because several of the topics can be studied independently, with only Part I as background, I decided to divide the material into three sections: Part II, Part III, and a short monograph on *Optimum Array Processing* [3]. This division involved some further editing, but I felt it was warranted in view of increased flexibility it gives both readers and instructors.

In Part II, I treated nonlinear modulation theory. In this part, I treat the random signal problem and radar/sonar. Finally, in the monograph, I discuss optimum array processing. The interdependence of the various parts is shown graphically in the following table. It can be seen that Part II is completely separate from Part III and *Optimum Array Processing*. The first half of *Optimum Array Processing* can be studied directly after Part I, but the second half requires some background from Part III. Although the division of the material has several advantages, it has one major disadvantage. One of my primary objectives is to present a unified treatment that enables the reader to solve problems from widely diverse physical situations. Unless the reader sees the widespread applicability of the basic ideas he may fail to appreciate their importance. Thus, I strongly encourage all serious students to read at least the more basic results in all three parts.

	Prerequisites
Part II	Chaps. I-5, I-6
Part III	
Chaps. III-1 to III-5	Chaps. I-4, I-6
Chaps. III-6 to III-7	Chaps. I-4
Chaps. III-8-end	Chaps. I-4, I-6, III-1 to III-7
Array Processing	
Chaps. IV-1, IV-2	Chaps. I-4
Chaps. IV-3-end	Chaps. III-1 to III-5, AP-1 to AP-2

The character of this book is appreciably different that that of Part I. It can perhaps be best described as a mixture of a research monograph and a graduate level text. It has the characteristics of a research monograph in that it studies particular questions in detail and develops a number of new research results in the course of this study. In many cases it explores topics which are still subjects of active research and is forced to leave some questions unanswered. It has the characteristics of a graduate level text in that it presents the material in an orderly fashion and develops almost all of the necessary results internally.

The book should appeal to three classes of readers. The first class consists of graduate students. The random signal problem, discussed in Chapters 2 to 7, is a logical extension of our earlier work with deterministic signals and completes the hierarchy of problems we set out to solve. The last half of the book studies the radar/sonar problem and some facets of the digital communication problem in detail. It is a thorough study of how one applies statistical theory to an important problem area. I feel that it provides a useful educational experience, even for students who have no ultimate interest in radar, sonar, or communications, because it demonstrates system design techniques which will be useful in other fields.

The second class consists of researchers in this field. Within the areas studied, the results are close to the current research frontiers. In many places, specific research problems are suggested that are suitable for thesis or industrial research.

The third class consists of practicing engineers. In the course of the development, a number of problems of system design and analysis are carried out. The techniques used and results obtained are directly applicable to many current problems. The material is in a form that is suitable for presentation in a short course or industrial course for practicing engineers. I have used preliminary versions in such courses for several years.

The problems deserve some mention. As in Part I, there are a large number of problems because I feel that problem solving is an essential part of the learning process. The problems cover a wide range of difficulty and are designed to both augment and extend the discussion in the text. Some of the problems require outside reading, or require the use of engineering judgement to make approximations or ask for discussion of some issues. These problems are sometimes frustrating to the student but I feel that they serve a useful purpose. In a few of the problems I had to use numerical calculations to get the answer. I strongly urge instructors to work a particular problem before assigning it. Solutions to the problems will be available in the near future.

As in Part I, I have tried to make the notation mnemonic. All of the notation is summarized in the glossary at the end of the book. I have tried to make my list of references as complete as possible and acknowledge any ideas due to other people.

Several people have contributed to the development of this book. Professors Arthur Baggeroer, Estil Hoversten, and Donald Snyder of the M.I.T. faculty, and Lewis Collins of Lincoln Laboratory, carefully read and criticized the entire book. Their suggestions were invaluable. R. R. Kurth read several chapters and offered useful suggestions. A number of graduate students offered comments which improved the text. My secretary, Miss Camille Tortorici, typed the entire manuscript several times.

My research at M.I.T. was partly supported by the Joint Services and by the National Aeronautics and Space Administration under the auspices of the Research Laboratory of Electronics. I did the final editing

while on Sabbatical Leave at Trinity College, Dublin. Professor Brendan Scaife of the Engineering School provided me office facilities during this period, and M.I.T. provided financial assistance. I am thankful for all of the above support.

Harry L. Van Trees

Dublin, Ireland,

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[1] Harry L. Van Trees, *Detection, Estimation, and Modulation Theory, Pt. I*, Wiley, New York, 1968.
[2] Harry L. Van Trees, *Detection, Estimation, and Modulation Theory, Pt. II*, Wiley, New York, 1971.
[3] Harry L. Van Trees, *Optimum Array Processing*, Wiley, New York, 1971.

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