Radar Range-Performance Analysis

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To My Children and Grandchildren

Preface

In this book I have gathered material that has been available only in scattered sources, with new material added where appropriate and possible. Although the subject is a limited one, in the sense that there is no attempt to cover the entire field of radar technology, the range of topics is broad, as can be noted by perusal of the chapter headings. The intent is to analyze in detail the theory and practice of predicting the range performance of radars designed for surveillance—that is, for the detection of targets, as distinct from radars whose primary purpose is to track targets after their initial detection or to provide various types of information about targets.

In chapter 1 the basic equations for the maximum range of a radar are derived. Although these equations have been derived elsewhere, the derivation is included for two reasons. First, it is so fundamental to the subject of the book that it would be inappropriate to ask the uninitiated reader to look for it elsewhere. Second, some aspects of the derivation are (in the author's opinion) not well explained elsewhere or commonly are, at any rate, not well understood. This is especially true of the equations that include non-free-space effects. Confusion also often exists concerning some aspects of such quantities as system noise temperature, minimum detectable signal-to-noise ratio, and loss factors.

In addition to the "basic" radar range equation for monostatic radars with noise as the limiting factor in detection, equations are developed for more general cases such as bistatic radar and for detection in the presence of clutter and jamming. Equations that would apply in more specialized types of radar, for example, laser radar and synthetic-aperture mapping radar, are presented in chapter 9.

Chapters 2 through 7 discuss in detail the evaluation of individual factors in the radar equations. Chapter 8 is devoted to the practical problems and techniques of radar maximum-range calculation, including the use of digital computers and graphical methods. Finally chapter 9 treats a number of the more important special types of radar.

The subject of the maximum range of a radar has received much attention since the earliest days of radar, and many excellent analyses of aspects of the subject have been published. The earliest one known to me was that of Norton and Omberg, titled "The Maximum Range of a Radar Set." It was published first as a security-classified U.S. Army Signal Corps report in 1943 and later in the January 1947 issue of *Proceedings of the I.R.E.* This paper discussed many details of the subject in a sophisticated manner. However, at that time the modern theories of signal detection were not established, and many of the techniques employed in present-day radar systems were unknown.

The basic ideas of modern radar-detection theory were introduced in the

classic paper of D.O. North, "An Analysis of the Factors which Determine Signal/Noise Discrimination in Pulsed-Carrier Systems." Like the Norton-Omberg paper, it was first published as a security-classified (RCA Laboratories) report, in 1943, and it was republished in the July 1963 issue of *Proceedings of the IEEE.* These ideas were expanded by J.I. Marcum in his Rand Corporation reports of 1947 and 1948, and further extended by P. Swerling in 1954, also in a Rand report. These works of Marcum and Swerling were republished in *I.R.E. Transactions on Information Theory* of April 1960.

Since then there have been many individual contributions to the development of radar maximum-range theory, and it is hoped and intended that adequate recognition has been given to them at appropriate points throughout the book. I apologize for the unintentional omissions that have probably occurred. Special recognition is due to the books of the M.I.T. Radiation Laboratory Series, published after World War II to document the monumental works of that laboratory. In particular volume 13 of the series, *Propagation of Short Radio Waves,* edited by Donald E. Kerr is a most valuable contribution to the subject of the present book. Many of the important features of the theory of radar maximum range under non-free-space conditions are based on material contained in that book.

Chapter 2 was written at the author's request by Dr. Lowell Brooks, a former associate at the Technology Service Corporation (TSC). It had become evident to me, through this association, that his knowledge of that subject was much more up to date than mine, and I am grateful that he agreed to undertake this task. I am also grateful to many others at TSC who helped with advice, criticism, and in some cases review of a chapter. I especially thank Fred Nathanson, Joe Frank, Gerald Rose, Peter Tong, and Wayne Rivers. I also thank Isadore Katz of the Johns Hopkins University Applied Physics Laboratory for his review of chapter 5.

I am greatly indebted to many persons at the Naval Research Laboratory who helped and encouraged me during my 31½ years of employment there, notably Robert J. Adams and Robert C. Guthrie, who headed the Search Radar Branch and the Radar Division, respectively, and Merrill Skolnik who is the present head of the Radar Division. They contributed in many ways to my acquisition of the knowledge that made this book possible. I am also indebted to the management of that laboratory for creating an environment favorable to scientific self-development. The advice and encouragement of Maurice W. Long of the Georgia Institute of Technology Engineering Experiment Station is also gratefully acknowledged.

Preface to the Artech House Edition

In the five and a half years (approximately) that this book was in print under the aegis of the original publisher, it was favorably received by the radar community, at least by those who were aware of its existence. I hope that this republication by Artech will come to the attention of a larger potential readership.

I am grateful for the opportunity that this republication provides to correct those errors that inevitably seem to occur in a first edition, which have been brought to my attention by diligent readers. No doubt some still remain undiscovered, but I am reasonably sure that the important ones have now been corrected, along with minor ones. I am especially indebted to the following persons who read the book with unusual care, and took the trouble to tell me of the errors that they discovered: Dr. Menachem Levitas of Technology Service Corporation, Silver Spring, Maryland; Major Russell D. Smith, National Defence Headquarters, Ottawa, Ontario, Canada; Professor Nadav Levanon of Tel Aviv University, Tel Aviv, Israel; and Mr. Paul Steichen of Technology Service Corporation. I am also grateful to those other persons who took the trouble to write to me about specific errors that they noticed.

The book was originally intended to be a reference source for practicing engineers and scientists, and a text for independent study by newcomers to the field of radar engineering. Since its publication, however, it has been used as a text for teaching intensive short courses, and a need has been expressed for sets of problems to test students' understanding of the material. Therefore, I have prepared sets of problems for each chapter. These problems, with answers, will be available from Artech House as a separate publication.

In my preface to the original publication of this book, I acknowledged my indebtedness to many persons and sources of information, and I wish here to reaffirm those acknowledgements. What I have attempted to do in the book is to assemble in a single source information that was formerly available only from many scattered sources, to update it and augment it where appropriate, and to integrate it into a cohesive whole. Although a fair amount of the material is from my own previous writings, much of it is from other sources, some of them now regrettably out of print. I thank David K. Barton for his assistance in preventing this book from sharing that fate.

Lamont V. Blake
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