# Modern Radar Techniques

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COLLINS
8 Grafton Street, London W1

Collins Professional Books
William Collins Sons & Co. Ltd
8 Grafton Street, London W1X 3LA

First published in Great Britain by
Collins Professional Books 1987



*British Library Cataloguing in Publication Data*
Modern radar techniques.
1. Radar
I. Scanlan, M.J.B.
621.3848 TK6575

ISBN 0-00-383190-6

Typeset by Katerprint Typesetting Services, Oxford
Printed and bound in Great Britain by
Mackays of Chatham, Kent

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# Preface

The six chapters of this book each contain a coherent account of an important radar topic, dealt with at review paper length and including a good bibliography. The topics have been chosen as having present-day relevance and future growth: Chapters 1 and 2 deal with important sub-systems, 3 and 4 with general topics important to every radar system designer and 5 and 6, by way of illustration, with two radar systems which seem to have been somewhat neglected elsewhere.

None of these topics is new; indeed, many of them have been foreshadowed or known for years, or even decades. Nor are they claimed to be comprehensive, since a number of other topics came to mind in the planning of this book. These particular six chapters were chosen to cover matters which are at least vaguely familiar to most radar engineers, but where more detailed knowledge in one place, written by an international authority, would be of most value. The treatment is designed to be readable, descriptive and informative, rather than rigorously mathematical.

It may help the reader to put the topics of this book in context if we look back more than 40 years to the earliest operational radar system, the British CH (Chain Home) system. CH used very roughly the same frequencies as the over-the-horizon radars of Chapter 5: it had a number of manually operated antijamming devices (Chapter 4 calls them ECCMs) including a measure of frequency agility; it had an electromechanical calculator which processed readings taken by an operator; and, being a flood-lit system, it avoided the problem of a fluctuating target cross section (Chapter 3) by having a long (virtually infinite) integration time. (At such a low frequency, we were blessedly ignorant of target statistics!)

Today's descendents of these facilities, as discussed in this book, are almost infinitely faster, more powerful and more adaptable. Over-the-horizon radar, using high-resolution Doppler processing, extracts valuable information from what was clutter to CH radar. Frequency agility is available on a pulse-to-pulse basis, if necessary, the new frequency being selected as free from jamming: ECMs are now more varied and sophisticated, and so are the ECCMs, as discussed in Chapter 4. A modern data processor (Chapter 1), allied to a phased array radar (Chapter 2), can search for, and track, hundreds of targets simultaneously: the system can null itself on jamming sources. With modern high frequency, narrow beamwidth radars, target fluctuation (Chapter 3) is a real problem, only alleviated by frequent searches of the target space, and by frequency agility and diversity. Chapter 3 makes it quite clear that radar detection is something of a statistical gamble: we can only calculate the odds and then bend them as far as possible in our favour.

To sum up then, this book deals with two major radar problems (Chapters 3 and 4); shows two ways in which modern electronic techniques can help (Chapters 1 and 2); and describes two radar systems (Chapters 5 and 6) which would have been unthinkable a decade or two ago.

Finally, it is my pleasant duty to express my warmest thanks to those who have contributed to this book. First in the list must be the authors, who have made time in their crowded schedules to write their chapters, and who have dealt with my nit-picking queries with patience and courtesy. Next must come Bernard Watson and Janet Murphy of Collins Professional Books, who have cajoled, chivvied and consoled authors and editor alike, as occasion required. I am also indebted to my secretaries, Sheila French and Pamela Betts, and to Louise Titford and Tracy Cooch of the M.R.C. drawing office, who have drawn most of the artwork. I have also to thank David Speake and John Williams, successive Directors of the Marconi Research Centre, for allowing me to use some of the facilities of M.R.C. in the preparation of this book. Last of all, I owe a debt to some dozens, or even hundreds, of individuals through the years who have contributed to the unconscious osmotic process by which I have acquired most of what I know about radar. Editing this book has crystallised for me many ideas which were vague and amorphous: I hope the book will do the same for many readers.

*M.J.B.*

# Authors' Biographies

**Billetter, D. R.**

Mr Billetter is presently a consultant in Woodland Hills, Ca. He was employed by ITT-Gilfillan prior to becoming a consultant, involved with advanced programs. He was previously at RCA where he was responsible for advanced aspects of the Aegis Weapon System and the AN/SPY-1 radar; he was also involved with several forward-looking programs for Air Defence and Ballistic Missile Defence. He was at SEMCOR Inc. for 3½ years working on advanced techniques for the use and control of phased array radars, primarily the SPY-1. Mr Billetter was initially at RCA for 18 years where he functioned as Program Manager, System Manager and in a broad spectrum of engineering roles.

Mr Billetter graduated from Lehigh University, Bethlehem, Pennsylvania in 1954 with a BSME degree. He completed most of the requirements toward an MSEE degree at Villanova University in Philadelphia, Pennsylvania.

**Cole, H. W.**

H. W. Cole, after service in the Royal Corps of Signals, worked for A. C. Cossor Ltd as a development, and later as a field commissioning, engineer. He joined Marconi Radar Systems Ltd in 1960 as a radar systems engineer, specialising in secondary radar. He was Development Programme Manager for Marconi's monopulse secondary surveillance radar system 'Messenger'. Author of many papers on radar and air traffic control, he represents Marconi on several professional bodies concerned with air traffic control. His book *Understanding Radar* was published by Collins in 1985.

**Forrest, J. R.**

J. R. Forrest graduated at Cambridge University in 1964 and then carried out research at Oxford University until 1967, and at Stanford University, Ca., until 1970. Between 1970 and 1984 he was at University College London, first as Lecturer, then Reader and finally Professor of Electronic Engineering. He built up a research group active in the topics of phased array radar, satellite communications and microwave opto-electronics. He has acted as a consultant to a number of organisations in Europe and the USA and has also worked on a number of government committees dealing with electronics, radar, telecommunications and professional engineering training. In 1984 he joined Marconi Defence Systems as Technical Director and was elected to the Fellowship of Engineering in 1985. In 1986, he was appointed Director of Engineering to the Independent Broadcasting Authority.

**Johnston, Stephen L.**
Stephen L. Johnston received the BEE degree with Honours in 1948 and the MSEE degree in 1949 from the Georgia Institute of Technology, Atlanta, Georgia. He was a research assistant at the Engineering Experiment Station at Georgia Tech from 1947 to 1950, entered Federal Civil Service in 1950 at the Joint Long Range Proving Ground, Patrick AFB, Florida, and was employed by the US Army Missile Command at Redstone Arsenal, Alabama from 1951 to 1980. He is now the Editor-in-Chief of the International Radar Directory and also a lecturer for George Washington University Continuing Engineering Education. Currently he is conducting short courses on his first book, *Radar Electronic Counter-Countermeasures*, and his second book, *Millimeter Wave Radar*. He is a Senior Member of the IEEE, and a past Associate Fellow of the AIAA. He has published and presented over 50 papers at numerous international technical symposia, both professional and government.

**Olin, Irwin D.**
Irwin Olin received a BSEE from the Newark College of Engineering and an MS from Rutgers University in the USA. His professional experience includes development of microwave components and antennas, radar systems design, and backscatter measurements and statistical analyses of radar targets and the sea. He has actively participated in an international committee on radar technology and served briefly as a Project Officer with the Ballistic Research Laboratory in Aberdeen, Maryland, and as an exchange scientist with the Royal Signals and Radar Establishment in Malvern, UK. Presently, Mr Olin is Associate Superintendent of the Radar Division of the Naval Research Laboratory in the USA.

**Shearman, E. D. R.**
E. D. R. Shearman, after early work on HF communication in the Admiralty Signal Establishment, joined the DSIR Radio Research Station (now the SERC Rutherford-Appleton Labora-

tory), where he carried out research in ionospheric sounding, HF backscatter radar investigations and satellite instrumentation. In 1962 he joined the University of Birmingham, Department of Electronic and Electrical Engineering, where he led a research team active in radar, satellite communication and, more recently, remote sensing by radar. Until recently Head of the Postgraduate School, he is now a Research Professor, active in HF radar oceanography and microwave radar studies. In 1985 he was awarded the Faraday Medal of the IEE for contributions to the understanding of radio wave propagation and sea state sensing.

# Contents

CHAPTER 1

# Computers and Data Processing in Radar

DALE R. BILLETTER

The application of digital computers to radar has evolved from providing simple throughput processing of output data, to performing many of the classical radar functions as well as new functions. Computers (control processors) intimately control the operation of most modern radars.

While the control processor uses disciplines not historically associated with radar design, i.e. those of computer program design, it has become an inherent part of the radar, and is now the focal point of effective radar system operation.

## 1.1 Radar control

The radar control processor, as considered here, provides not only the control of radar operation but also tracking and automatic test and exercising. These functions may be allocated to different sets of programs and even to different hardware. In larger systems, of which the radar is only a part, the testing and exercising may be system functions which are supported by the radar control processor. Tracking may also be a system function. All of these functions will be considered to be resident in the radar control processor, but the three functions will be treated independently. The control processor allows the radar to function efficiently, coordinating the operation of the radar within restrictive constraints. Figure 1.1 presents an epitomised version of this function.

The radar control design as discussed here relates to a 3D search and tracking radar. The radar may employ a mechanically rotated antenna with electronic beam steering in only elevation or in both azimuth and elevation, or it may use fixed antennas with

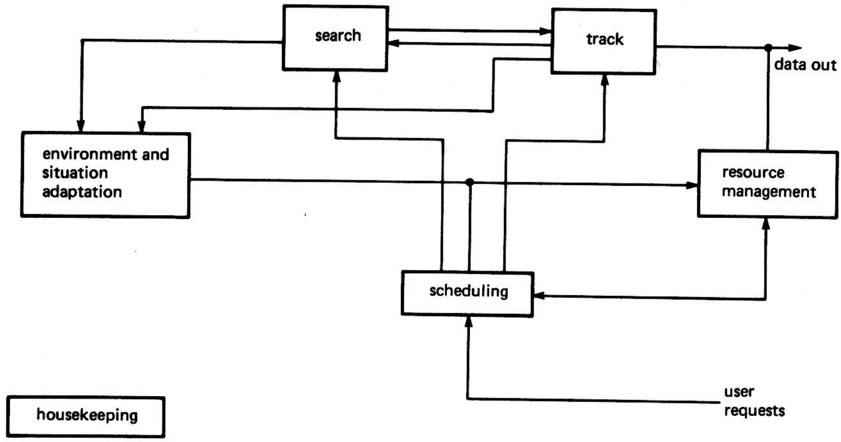


**Fig. 1.1** Functional control.

electronic beam steering in both dimensions. It is assumed that the radar generates separate beams for search and track[1]. The concepts presented here are also applicable to 2D search radars, but to a lesser degree.

The radar control design will not be constrained by the size of the radar processor. Recent advances in the state of the processing art provide relief in the form of faster and smaller computers. Historically, some of the very early phased array radars were restricted in terms of processor size and, therefore, in the ability to control the radar effectively and efficiently. In several cases, the advent of phased arrays has been the driving impetus for the development of larger and faster processors.

The control processor is involved in all aspects of the radar's operation[2,3]. Figure 1.2 is a simplification of the radar control process. The discussion in this chapter cannot delve into all aspects of the radar control process. Several volumes would be required to define adequately and thoroughly the control process design, which is far more complex and interrelated than is shown in either Fig. 1.1 or Fig. 1.2. The computer operation must deal with issues as they develop in real time, so that the programs cannot just start and run until complete. Interrupts will occur constantly and must be dealt with on a priority basis. The control design must be both adaptive and reactive.

Much of the control design centres around the establishment of priorities. Many different sets of priorities must be developed and they will rarely be either compatible or static. Priorities must be

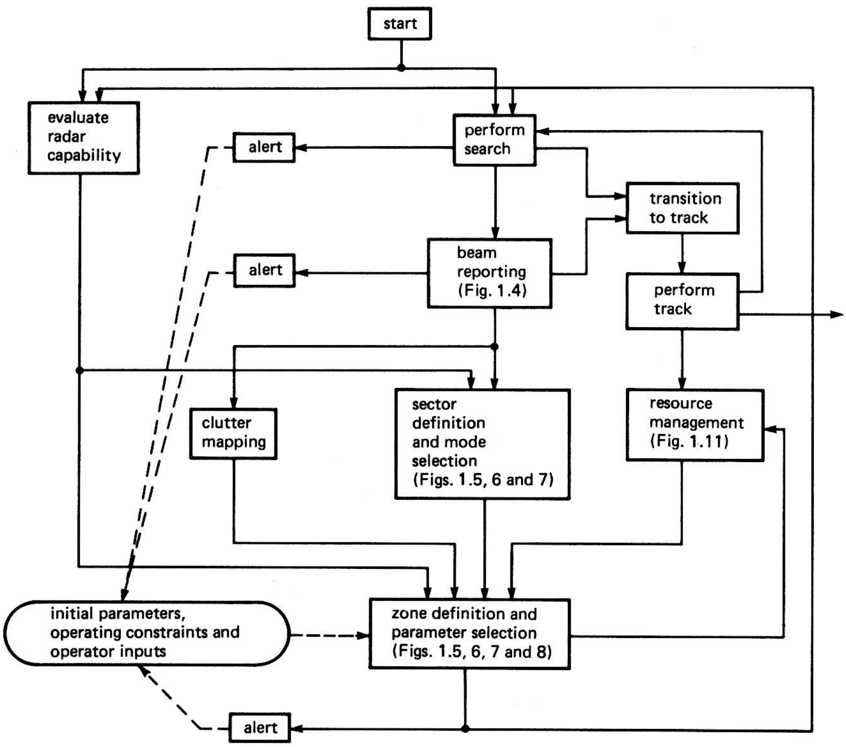


**Fig. 1.2** The control process.

established for spatially distributed radar functions, for targets being tracked, for control functions, and for interrupts. The list continues. An early establishment of the various priorities facilitates and simplifies the control design process. These initial priorities must be established as functions of prior events. Section 1.1.7 describes the use of priorities and the relationship to other events and timing. Some of the priorities must have dual values: the value of starting the event and the value of continuing the event once started. The initial priority of a burnthrough, for example, may be low but once started the priority of continuing may be very high.

The interrelationships of the functions are far more extensive than is shown in the example and are the subject of many tradeoffs. An example of this is the connections shown between the search and track functions in Fig. 1.1 and Fig. 1.2. The track function starts with a detection of a target in the search function. The detection is usually a complex operation involving more than just a threshold crossing; verification beams may be used to confirm the existence of a true target and to reject false targets. These same verification beams may also be the initial beams used to establish a track. The interface between the search and track functions is often vague and arbitrary. Targets which are being tracked must be excluded from the search process or redundant tracks will be initiated. This exclusion is often referred to as *crossgating*[2]. At least two forms of crossgating are possible, *pre-detection* and *post-detection.*

Pre-detection crossgating involves the blanking of known targets in each search beam. This requires a look-up of all targets which may occur in a search beam and the generation of blanking gates before the beam is generated. New targets, or target splits, may be obscured until they are outside of the crossgate. Post-detection crossgating involves the comparing of all targets seen in an ungated search beam with existing target tracks in the vicinity of the beam. New targets may be incorrectly associated with old targets. The amount of processing involved and the relative merits of the two techniques varies, depending upon the type of validation used, the number of targets which exist, the operating environment and many other issues. This is an obvious candidate for a tradeoff study.

Particular emphasis will be placed on the management of the radar's operation throughout this chapter. Attention will be paid to environmental adaptation in selecting radar parameters to optimise the performance of the radar under a given set of environmental conditions. Considerable attention must be paid to the resource management of the radar throughout the determination of the radar's parameters. The particular aspects of radar control design covered in this chapter are indicated by the references in Fig. 1.2 to other figures in this chapter. It will be assumed that the radar has the ability to perform its basic functions of search and track.

The control design set forth does not represent an actual control design; it is certainly not a complete design. The discussions which follow will highlight certain aspects of the control design and illustrate how the control design is to be implemented.

### 1.1.1 UTILISING THE OPERATOR

The role chosen for the operator will, to a very high degree, dictate the control design. Computers are far more capable of making routine decisions than are human beings. The human being, however, is far superior when reasoning is required. The degree of superiority of the operator depends on his abilities and his training. The role of the operator may be considerably different for different radar applications as well as for different levels of manpower available to operate the radar. Where decisions are to be highly automated, proper decision criteria have to be defined and provisions made to obtain the necessary data to allow the computer to make the proper decision. The same statement applies to decisions made by an operator, but the decision criteria and the information provided need not be as explicit. The human being is capable of resolving conflicts or areas of indecision, although often arbitrarily and not always properly. The human being knows the type of information required and can seek more information from superiors or by drawing upon past experience. The computer is certainly capable of determining when it does not have adequate information or criteria for making a decision; it can then only request assistance.

Radars designed for scientific or information gathering applications will usually be operated by a higher skill level of personnel than tactical radars which are used in a hostile environment. The information gathering radar can benefit from the use of the operator, in that unforeseen situations or sources of data may arise in which the operator is called upon to use his inherent intelligence, his background and his training to optimise the radar. While the tactical radar could benefit from such training and high level skilled personnel, these are usually not available. The tactical radar must, therefore, be designed to impose the minimum requirements on the operator associated with his skill level. The fully automated radar eliminates the need for operators and is desirable in that human beings need not be put in threatening or inhospitable locations. This is possible for relatively simple radars such as early warning radars, with the processing now available. The tactical radar, on the other hand, which experiences continually changing environments and situations, is far more difficult to automate fully in that the decision criteria are more difficult to specify and obtaining the information required to facilitate fully automated decisions can consume a large amount of the available radar resources. In this case, the operator's role may be one of providing rules of operation, monitoring the operation of the radar and resolving conflicts which occur. In designing a fully or highly automated radar, it is exceedingly important that a situation not be allowed to occur where a conflict or decision point is reached which will result in the radar ceasing to operate. This is true whether an operator is available to resolve such difficulties or not. Certainly, when the operator is available he should be used; but it should not be necessary that the operator make a decision for the radar to continue to operate and provide at least some level of performance.

The role assumed for the operator throughout this discussion will be one of monitoring the control process of the radar, providing inputs to define how the control processor should function, and resolving conflicts. The control program will request assistance from the operator but will not cease to function if the operator does not intervene.

### 1.1.2 IMPLEMENTING OPERATING DOCTRINE

The constraints on the operation of the radar control processor are provided through the insertion of operating doctrine. The operating doctrine will not necessarily always be the same. Dependent upon the preferences of the user or higher echelons of command, different degrees of automation and flexibility may be allowed within the control processor. Some users will recognise the need for, and prefer, a high degree of automation; other users will not have the same degree of faith in the computer. The situation may change with time as the situation or capabilities of operating personnel change. A good control design must be capable of providing different levels of automation and flexibility as dictated by the user. Provisions must be included for the insertion of operating doctrine which can change the manner in which the control program will work. Changes may also be brought about by changes in the status of the equipment, either the classical radar equipments or the control processor itself. Varying degrees of automation are possible. The control processor may sense changes in the status of the equipment and adapt to them, or it may be preferable to have the status of the equipment displayed to an operator who will then make decisions as to how the control processor should operate. The operator should be able to override any automated decisions made by the control processor. Varying levels of displayed information may be desired, depending upon how active a role the operator is to have.