Radar Systems

Macmillan New Electronics Series

Series Editor: Paul A. Lynn

Paul A. Lynn, *Radar Systems*

A. F. Murray and H. M. Reekie, *Integrated Circuit Design*

Radar Systems

Paul A. Lynn

*BSc (Eng), DIC, PhD, MIEE, C Eng
formerly Reader in Electronic Engineering, University of Bristol*

Macmillan New Electronics
Introductions to Advanced Topics

M
MACMILLAN
EDUCATION

© Paul A. Lynn 1987

Softcover reprint of the hardcover 1st edition 1987

All rights reserved. No reproduction, copy or transmission of this publication may be made without written permission.

No paragraph of this publication may be reproduced, copied or transmitted save with written permission or in accordance with the provisions of the Copyright Act 1956 (as amended).

Any person who does any unauthorised act in relation to this publication may be liable to criminal prosecution and civil claims for damages.

First published 1987

Published by
MACMILLAN EDUCATION LTD
Houndmills, Basingstoke, Hampshire RG21 2XS
and London
Companies and representatives
throughout the world

Typeset by
TecSet Ltd, Wallington, Surrey

British Library Cataloguing in Publication Data
Lynn, Paul A.

Radar systems.—(Macmillan new electronics)

1. Radar

I. Title

621.3848'5 TK6575

ISBN 978-0-333-42544-2

ISBN 978-1-349-18748-5 (eBook)

DOI 10.1007/978-1-349-18748-5

Contents

<i>Series Editor's Foreword</i>	<i>vii</i>
<i>Preface</i>	<i>viii</i>
<i>List of Symbols</i>	<i>x</i>
<i>List of Abbreviations</i>	<i>xiii</i>
1 Introduction	1
1.1 Historical notes	1
1.2 Types of radar system	2
1.2.1 Transmission waveforms	2
1.2.2 Operating frequencies	6
1.2.3 Applications	7
2 The Radar Equation	11
2.1 Basis of the equation	11
2.2 Statistical aspects of radar detection	14
2.2.1 Target fluctuations	16
2.2.2 Receiver and system noise	18
2.2.3 Other system factors	25
2.2.4 Effects on the Radar Equation	27
3 Operational and Siting Factors	31
3.1 Radar clutter	31
3.2 Horizontal and vertical coverage	38
3.3 Air-traffic-control and marine radar	45
4 Radar Hardware	50
4.1 Transmitters, receivers and duplexers	50
4.2 Antennas	60
4.2.1 Parabolic reflectors	60
4.2.2 Phased arrays	65
5 Signal Processing and Display	70
5.1 Matched filtering and pulse compression	70
5.2 Clutter reduction	76
5.3 Digital signal processing	78
5.4 Moving target indication (MTI)	80
5.4.1 The basis of MTI	80
5.4.2 Delay-line cancellers	83
5.4.3 Pulse repetition frequency (PRF) stagger	87
5.4.4 Digital MTI	89
5.4.5 The MTI improvement factor	90

5.5 Moving target detection (MTD)	94
5.5.1 The basis of MTD	94
5.5.2 Adaptive MTD systems	96
5.6 Constant false-alarm rate (CFAR) processing	98
5.7 Plot extraction and display	102
6 Secondary Radar	109
6.1 The basis of secondary surveillance radar (SSR)	109
6.2 Monopulse SSR	114
6.3 Mode-S operation	118
7 Modern Surveillance Radar for Civil Air Traffic Control	120
7.1 Introduction	120
7.2 Britain	120
7.3 France	124
7.4 Germany	126
7.5 United States of America	128
<i>Bibliography</i>	<i>133</i>
<i>Problems</i>	<i>134</i>
<i>Answers to Problems</i>	<i>138</i>
<i>Index</i>	<i>139</i>

Series Editor's Foreword

The rapid development of electronics and its engineering applications ensures that new topics are always competing for a place in university and polytechnic courses. But it is often difficult for lecturers to find suitable books for recommendation to students, particularly when a topic is covered by a short lecture module, or as an 'option'.

Macmillan New Electronics offers introductions to advanced topics. The level is generally that of second and subsequent years of undergraduate courses in electronic and electrical engineering, computer science and physics. Some of the authors will paint with a broad brush; others will concentrate on a narrower topic, and cover it in greater detail. But in all cases the titles in the Series will provide a sound basis for further reading of the specialist literature, and an up-to-date appreciation of practical applications and likely trends.

The level, scope and approach of the Series should also appeal to practising engineers and scientists encountering an area of electronics for the first time, or needing a rapid and authoritative update.

Preface

The basic principles of radar do not change, but the design and technology of practical radar systems have developed rapidly in recent years. Advances in digital electronics and computing are having a major impact, especially in radar signal processing and display. I hope that this book will prove a useful introduction to such developments, as well as to the underlying principles of radar detection.

A short book on a huge subject must be selective. I have decided to concentrate on pulse radars used for Air Traffic Control, including secondary radar. In part this reflects personal experience. But I also believe that modern ATC radar, with all its recent advances in signal processing, provides an excellent framework for introducing many of the problems and solutions of radar engineering. Civil equipments of this type are also relatively accessible, for visits or for technical information.

Readers requiring practice in radar calculations will find a set of problems (with solutions) towards the end of the book. They relate to the quantitative material developed in chapters 2, 3 and 5.

I gratefully acknowledge information obtained from many sources. Most of the references listed at the end of the book have influenced me considerably. I have also received technical material and photographs from various radar manufacturers, and should like to thank:

Cossor Electronics Ltd (Harlow, England)
English Electric Valve Company Ltd (Chelmsford, England)
Marconi Radar Systems Ltd (Chelmsford, England)
Plessey Radar Ltd (Chessington, England)
Racal Avionics Ltd and Racal Marine Radar Ltd (New Malden, England)
AEG (Ulm, West Germany)
Hollandse Signaalapparaten (Hengelo, The Netherlands)
Thomson/CSF (Meudon-la-forêt, France)
Westinghouse Electric Corporation (Baltimore, USA)

Several national ATC authorities have been very helpful. I have used information supplied by the British Civil Aviation Authority and National Air Traffic Service in section 7.2 of the book; by the French ATC authority (Direction de la Navigation Aérienne) in section 7.3; by the West German ATC authority (Bundesanstalt für Flugsicherung) in section 7.4; and by the USA Federal Aviation Administration in section 7.5. It is also a personal pleasure to recall hospitality received during visits to radar sites near Gatwick, England; Evreux, France; and the ATC centre and radar near Hanover, Germany.

It is only fair to add that most of the information obtained from the above sources has been heavily condensed. I regret any errors of fact or balance which may have crept in. I am also very aware of topics which have had to be omitted altogether for lack of space, and trust that such omissions will not seriously detract from the book's value.

I should finally like to thank Jeana Price for all her careful work on the typescript.

4 Kensington Place
Clifton
Bristol BS8 3AH

Paul A. Lynn

List of Symbols

α	Weibull parameter
Δ	antenna difference pattern
$\delta[n]$	discrete unit impulse
ϵ	permittivity
η	clutter volume density
θ	phase or azimuth angle
θ_B	horizontal beamwidth
λ	wavelength
μ	permeability
ρ	reflection coefficient
ρ_A	antenna efficiency
Σ	antenna sum pattern
σ	target cross-section
σ_0	clutter area density
σ_{av}	average cross-section
σ_c	clutter cross-section
τ	pulse length
τ'	auxiliary time variable
ϕ	elevation, grazing, or phase angle
ϕ_B	vertical beamwidth
ψ_0	variance
$\psi_0^{\frac{1}{2}}$	standard deviation
ψ_d	phase difference
Ω	discrete frequency variable
ω	continuous frequency variable
A	antenna physical area
a	antenna aperture
A_c	clutter area
A_e	antenna effective area
$A[n]$	antenna aperture distribution (discrete)
$A(z)$	antenna aperture distribution (continuous)
B	bandwidth
C	clutter power
c	velocity of radio waves

D	Earth's effective diameter
d	distance or horizontal range
$E_i(n)$	integration efficiency
$E(\phi)$	electric field distribution
F	frequency spectrum
f	frequency in hertz
f_o	transmitter frequency
f_c	intermediate frequency
f_d	doppler frequency
f_l	stalo frequency
F_n	noise figure
f_p	pulse repetition frequency
f_r	beat frequency
G	antenna gain
G'	receiver or amplifier gain
h	height
$h[n]$	impulse response (discrete)
$h(t)$	impulse response (continuous)
$H(\Omega)$	frequency response of digital system
I	in-phase MTI channel or MTI improvement factor
I_0	Bessel function of zero order
k	Boltzmann's constant or integer variable
l	length
L_s	loss factor
N	integer number or variable
n	hits-per-target or integer variable
p	probability density
P_{av}	average transmitter power
P_d	detection probability
P_{fa}	false-alarm probability
P_r	received power
P_t	transmitter power
Q	quadrature MTI channel
R	range
r	rainfall rate
R'	path length
R_{max}	maximum range
S	signal power
S_{min}	minimum detectable signal
(S/C)	signal-to-clutter power ratio
$(S/N)_1$	input $S:N$ ratio
T	interpulse interval, sampling period, or delay time
t	time
T_0	absolute temperature or time interval/delay

t_0	time delay
v	velocity
v_1	input voltage
v_2	output voltage
V_c	clutter volume
v_r	radial velocity
$v(t)$	voltage signal
$v_e(t)$	envelope voltage signal
V_T	threshold voltage
W	power spectral density
X_k	discrete spectral coefficient
$x[n]$	input signal (discrete)
$x(t)$	input signal (continuous)
$y[n]$	output signal (discrete)
$y(t)$	output signal (continuous)

List of Abbreviations

ACF	autocorrelation function
ADC	analog-to-digital converter
ADT	automatic detection and tracking
ARSR	air-route surveillance radar
ASDE	airfield surface detection equipment
ASMI	airfield surface movement indicator
ASR	airfield surveillance radar
ATC	air traffic control
BITE	built-in test equipment
CFAR	constant false-alarm rate
COHO	coherent oscillator
CPI	coherent processing interval
CRT	cathode ray tube
CW	continuous wave
DAC	digital-to-analog converter
DFT	discrete Fourier Transform
DPSK	differential phase-shift keying
DVST	direct-view storage tube
ERP	effective radiated power
FET	field-effect transistor
FFT	fast Fourier Transform
FIR	flight information region
FM-CW	frequency-modulated continuous wave
FTC	fast time constant
GCA	ground-controlled approach
IAGC	instantaneous automatic gain control
ICAO	International Civil Aviation Organisation
IF	intermediate frequency
IFF	interrogation, friend or foe
LO	local oscillator
LTI	linear time-invariant
LVA	large vertical aperture
MTBF	mean time between failures
MTD	moving target detector
MTI	moving target indicator

NM	nautical mile
OBA	off-boresight azimuth
OTH	over the horizon
PAR	precision approach radar
PCR	pulse compression ratio
PDF	probability density function
PPI	plan-position indicator
PPS	pulses per second
PRBS	pseudo-random binary sequence
PRF	pulse repetition frequency
PSD	phase-sensitive detector
RADAR	radio detection and ranging
RHI	range-height indicator
RPM	revolutions per minute
SAW	surface acoustic wave
SCV	subclutter visibility
SD	standard deviation
SSR	secondary surveillance radar
STC	sensitivity time control
TR	transmit-receive
TWT	travelling wave tube
ZVF	zero-velocity filter