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Radar Homing Guidance for Tactical Missiles

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Preface

This book has its origin in a package of lectures given over a span of many years to the students of the Guided Weapons M.Sc. Course at the Royal Military College of Science, Shrivenham; the lectures formed part of a course of study covering the whole of guided weapons technology. Radar homing missiles have been in service in the armed forces of various countries throughout the world for at least 30 years and have been employed in many of the armed conflicts that have taken place since the end of the Second World War. Particularly noteworthy are the use of Surface to Air missiles in the Arab-Israeli conflicts and in Vietnam, and the devastating use of the Exocet sea-skimming anti-ship missile in the recent war in the Falkland Islands.

It may be asked why radar homing guidance has been singled out for special treatment; there are other forms of radar guidance and other forms of homing. The reason is that radar homing guidance combines two unique advantages: that of homing, in which the missile is theoretically certain to guide itself towards impact with the target, and that of radar which has the ability to penetrate rain, smoke, and dust. These advantages have encouraged much effort in development and in the growth of an extensive branch of radar technology which merits a treatment of its own.

Information pertaining to this subject has hitherto been rather scattered — in articles appearing in electronic engineering periodicals, in other works as part of a more general treatment, and in unpublished memoranda of a non-confidential nature within defence organisations. The purpose of this book is to collate this information sufficiently for the benefit of engineers working in this field; it is hoped that it will also prove to be of interest to engineers concerned with other branches of radar and telecommunications.

Treatment of the subject assumes no more than a knowledge of basic radar principles. It is mainly descriptive, supported by simple mathematical analyses and practical numerical examples; so far as security permits, the descriptions relate to actual systems. The introductory chapter gives a broad outline of the subject, including a general description of the homing process, operational aspects, and a selective catalogue of radar homers. It includes also a section on the basic principles of tracking radar upon which radar homing depends. Chapters 2, 3 and 4 describe features which are common to all applications; chapters 5, 6 and 7 deal with homing against airborne targets, and chapter 8 describes homing

against slow-moving surface targets such as ships and vehicles, and includes a section on the specialized topic of homing on to enemy radar. Electronic counter-measures, which have already proved themselves to be a significant factor in the radar war, are described in the context of the particular applications mentioned. The book includes a glossary of those terms which are, on the whole, peculiar to this subject.

In conclusion, my thanks go to Professor C. J. Harris, Head of the School of Electrical and Electronic Science, Royal Military College of Science/Cranfield, for his encouragement, advice and provision of many useful facilities; to my colleagues for the provision of material and for constructive criticism; to Karen for the typing and to Les Judd for the many diagrams. Last, but not least, I wish to thank my former students for their interest and enthusiasm, which prompted me to explore the subject in depth.

The Ministry of Defence has given approval for this book to be published.

Glossary of Terms

<i>All-the-way</i>	Use of the same system of guidance throughout missile flight.
<i>Autonomous</i>	Missile can guide itself without further assistance from parent station.
<i>Autopilot</i>	See <i>Control system</i> .
<i>Bistatic radar</i>	Transmitting and receiving antenna are at separate locations.
<i>Boost (phase)</i>	Initial acceleration of missile to cruising velocity; short, a few seconds at most; severe, many 10s of <i>g</i> .
<i>Chaff</i>	Metallized strips of paper etc., resonant at radar wavelength; intended to confuse.
<i>Conical scan</i>	Method of tracking in angle, using a single rotating antenna primary feed.
<i>Control system</i>	Controls the flight and attitude of the missile, usually by means of appropriate aerodynamic surfaces.
<i>Direct clutter</i>	Breakthrough from transmitter (active) or rear reference (semi-active) into signal receiver; has zero Doppler shift in coherent system.
<i>Ground spike</i>	Doppler shifted signal due to ground echoes in the seeker antenna main beam.
<i>Home-on-jam</i>	Switching from active or semi-active to passive homing on a source of electronic counter-measure (ECM).
<i>Homing eye</i>	The seeker antenna system.
<i>Homing head</i>	The seeker.
<i>Illuminator</i>	Transmitter providing the radiation scattered from the target as an echo; can be in the seeker (active) or at the parent station (semi-active).

<i>Incidence lag</i>	Non-alignment of the missile longitudinal axis with the heading.
<i>Inverse receiver</i>	The Doppler shift on the target echo is transferred to the reference channel.
<i>LATA</i>	Lateral acceleration (abbreviation).
<i>Lock-on</i>	Commencement of steady tracking of the target in all coordinates.
<i>Mid-course guidance (phase)</i>	A different and probably less precise form of guidance used during most of the missile flight.
<i>Monopulse receiver</i>	Radar receiver which derives a complete set of target co-ordinates from each pulse echo — that is, measurements are simultaneous.
<i>Monostatic radar</i>	Transmitter and receiver are co-located.
<i>Multi-path</i>	Propagation of radio waves by a direct path and one or more surface-reflected paths.
<i>Phased array</i>	Antenna in which the beam is steered electronically, without mechanical movement of the antenna.
<i>Pitch</i>	Movement of the missile or antenna in the local vertical plane (comparable to ‘elevation’).
<i>Range gate</i>	A gating pulse timed to coincide with the arrival of a pulse echo.
<i>Rear reference</i>	Direct transmission from the illuminator in semi-active homing to the missile in flight to provide synchronization.
<i>Rear reference spillover</i>	See <i>Direct clutter</i> .
<i>Resolution cell</i>	‘Space’ defined by the combined resolution in all co-ordinates.
<i>Roll</i>	Rotation of the missile about its longitudinal axis.
<i>Seeker</i>	The radar homing guidance installation in a missile.
<i>Sequential lobing</i>	Sequential sampling of the signals of a monopulse angle tracking antenna; equivalent electrically to conical scan.
<i>Squint</i>	Angle between sight line and missile longitudinal axis.
<i>Terminal guidance (phase)</i>	Precise guidance system taking over in the final stage of missile flight.
<i>Threshold detector</i>	Detector which takes cognizance of a signal only if its

amplitude attains a given level for a given minimum duration.

Velocity gate

Narrow band filter tuned to accept the Doppler frequency of the target echo.

Yaw

Movement in the local horizontal plane (comparable to 'azimuth').

List of Symbols

<i>a</i>	aberration
<i>A</i>	antenna aperture area
<i>B</i>	bandwidth
<i>c</i>	velocity of electro-magnetic waves in free space, $3 \times 10^8 \text{ m s}^{-1}$
<i>C</i>	clutter power
<i>d, d'</i>	diameter; spacing
<i>E</i>	emissivity
<i>f</i>	frequency; function
<i>F</i>	Fourier transform
<i>g</i>	acceleration of gravity, 9.81 m s^{-2}
<i>G</i>	antenna gain
<i>h</i>	Planck's constant, 6.626×10^{-34} ; height
<i>J</i>	received jamming power
<i>k</i>	an integer; constant of proportionality; Boltzmann's constant, $6.626 \times 10^{-34} \text{ J K}^{-1}$
<i>K</i>	constant of proportionality
<i>L</i>	power loss factor
<i>M</i>	Mach number
<i>n</i>	an integer
<i>N</i>	noise power; an integer
<i>NF</i>	noise figure
<i>P</i>	transmitted power
<i>r</i>	radius; an integer
<i>R</i>	range
<i>s</i>	Laplace transform parameter
<i>t</i>	time
<i>T</i>	time constant; fixed time interval; temperature
<i>T₀</i>	ambient temperature, 290 K
<i>u</i>	velocity
<i>W</i>	fast Fourier transform (FFT) parameter
<i>x, y, z</i>	Cartesian coordinates
<i>Y</i>	transfer function
<i>Greek</i>	
α	geometrical angle; radome aberration slope
β	geometrical angle

γ	geometrical angle
δ	geometrical angle; incremental
$\tan \delta$	loss tangent
Δ	difference (finite)
ϵ	radome aberration angle
ϵ_r	relative permittivity
ζ	damping parameter
η	efficiency
θ	geometrical angle; θ_3 antenna half-power beamwidth
λ	wavelength; proportional navigation constant
π	3.1418
σ	radar echoing area; standard deviation
σ_0	radar echoing area per unit area of clutter
σ'	radar echoing area per unit area of diffusing surface
Σ	sum
τ	pulse duration
ϕ	phase angle; geometrical angle
ψ	angle with respect to space axes; geometrical angle
ω	angular velocity; pulsance ($2\pi f$)

Suffixes

a	atmospheric; aberrated sight line
c	carrier; rear reference spillover
C	clutter
D	boresight axis; Doppler
e	elapsed; earth
f	missile heading
g	glint
i	integrated
I	interferometer; illuminator
J	jammer
m	missile
n	natural
o	local oscillator
p	pitch
r	recurrence; receiver
R	receiver
s	target sight line; system
t	transmitted; target
T	target
y	yaw

List of Abbreviations

AAM	air to air missile
AC	alternating current
AFC	automatic frequency control
AFV	armoured fighting vehicle
AGC	automatic gain control
ARM	anti-radar missile
ASM	air to surface missile
CS	compressive strength
CW	continuous wave
DC	direct current
DFT	discrete Fourier transform
ECCM	electronic counter-counter-measures
ECM	electronic counter-measures
EM	electro-magnetic
ERP	effective radiated power
ESM	electronic support measures
FFT	fast Fourier transform
FM	frequency modulation
FMCW	frequency modulated continuous wave
FMICW	frequency modulated interrupted continuous wave
FS	flexural strength
GBJ	ground-based jammer
IF	intermediate frequency
IFA	intermediate frequency amplifier
LO	local oscillator
LOS	line of sight
MCOPS	millions of complex operations per second
MIC	microwave integrated circuit
PA	probability of acquisition
PN	proportional navigation
PRF	pulse recurrence frequency
PSR	phase-sensitive rectifier
RF	radio frequency
SAM	surface to air missile

SAW	surface acoustic wave
S:N	signal to noise ratio (power)
SOJ	stand-off jammer
SSJ	self-screening jammer
SSM	surface to surface missile
TGSM	terminally guided sub-munition
TIR	tracking and illuminating radar
TVM	target via missile
UTS	ultimate tensile strength
VCO	voltage-controlled oscillator
YIG	yttrium-iron-garnet