UNDERSTANDING RADAR SYSTEMS

Simon Kingsley
Department of Electronic and Electrical Engineering
University of Sheffield

Shaun Quegan
Department of Applied and Computational Mathematics
University of Sheffield
CONTENTS

Preface xi
Acknowledgements xiii

1 Fundamentals 1
   1.1 What is radar? 1
   1.2 A simple radar explained 3
   1.3 Overview of radar frequencies 4
   1.4 Antenna gain 6
   1.5 The radar equation 11
   1.6 Accuracy and resolution 15
   1.7 Integration time and the doppler shift 18
   1.8 Summary 22
   1.9 References 23
   1.10 Further reading 23
   1.11 Problems 23

2 Designing a surveillance radar 25
   2.1 Radar and surveillance 25
   2.2 Antenna beamwidth considerations 26
   2.3 Pulse repetition frequency and unambiguous range and velocities 28
   2.4 Pulse length and sampling 31
   2.5 Radar cross-section 33
   2.6 Clutter 38
   2.7 Noise 41
   2.8 Final design 43
   2.9 Summary 45
   2.10 References 46
   2.11 Problems 46
## 3 Tracking radar

3.1 Introduction 48
3.2 Sequential lobing 49
3.3 Conical scanning 49
3.4 Monopulse radar 50
3.5 Tracking accuracy 54
3.6 Frequency agility 55
3.7 The tracking process 56
3.8 Radar guidance 58
3.9 Summary 60
3.10 References 60
3.11 Further reading 60
3.12 Problems 60

## 4 Radar detection theory

4.1 Introduction 62
4.2 The basis for decision making—probability theory 66
4.3 The effects of the receiver on the noise distribution 73
4.4 The distribution of signal plus noise 78
4.5 The signal-to-noise ratio 79
4.6 Detection and false-alarm probabilities 81
4.7 The correlation receiver 84
4.8 The matched filter 90
4.9 Key elements of signal detection 91
4.10 Detection using multiple observations 91
4.11 Modifications for intermediate-frequency input to the receiver 94
4.12 Target fluctuations—the Swerling cases 95
4.13 Summary 99
4.14 References 101
4.15 Problems 101

## 5 Signal and data processing

5.1 Introduction 104
5.2 Properties of clutter 106
5.3 Moving-target indicator processing 107
5.4 Fast Fourier transform processing 112
5.5 Thresholding 115
5.6 Plot extraction 118
5.7 Plot–track association 119
5.8 Track initiation 120
5.9 Tracking 122
5.10 Summary 125
5.11 References 126
5.12 Problems 127
6 Designing radar waveforms 128
6.1 Introduction 128
6.2 Bandwidth and pulse duration 129
6.3 Range and doppler accuracy—the uncertainty relation 131
6.4 Resolution 134
6.5 The ambiguity function 138
6.6 Examples of the ambiguity function 142
6.7 Pulse compression 145
6.8 Chirp 145
6.9 Phase coding 150
6.10 Summary 154
6.11 References 156
6.12 Problems 156

7 Secondary surveillance radar 159
7.1 Introduction 159
7.2 Basic principles 162
7.3 Problems with secondary surveillance radar 164
7.4 Multipath 166
7.5 Mode S and the future 168
7.6 Summary 169
7.7 References 169
7.8 Problems 169

8 Propagation aspects 171
8.1 Introduction 171
8.2 The radar horizon 172
8.3 Atmospheric effects 173
8.4 Diffraction by the terrain 178
8.5 Battlefield radar systems 179
8.6 Ionospheric effects 181
8.7 Summary 187
8.8 References 189
8.9 Problems 189

9 Radar studies of the atmosphere 190
9.1 Introduction 190
9.2 Scattering mechanisms 191
9.3 Mesosphere–stratosphere–troposphere radar 197
9.4 Meteor wind radar 200
9.5 Other radar studies of the atmosphere 203
9.6 Summary 203
9.7 References 204
9.8 Problems 205
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Over-the-horizon radar</td>
<td>206</td>
</tr>
<tr>
<td>10.1</td>
<td>Introduction</td>
<td>206</td>
</tr>
<tr>
<td>10.2</td>
<td>Surface-wave radar</td>
<td>207</td>
</tr>
<tr>
<td>10.3</td>
<td>Skywave radar</td>
<td>212</td>
</tr>
<tr>
<td>10.4</td>
<td>Skywave propagation and frequency management</td>
<td>215</td>
</tr>
<tr>
<td>10.5</td>
<td>The over-the-horizon radar equation</td>
<td>220</td>
</tr>
<tr>
<td>10.6</td>
<td>Problems with high-frequency radar</td>
<td>223</td>
</tr>
<tr>
<td>10.7</td>
<td>Summary</td>
<td>223</td>
</tr>
<tr>
<td>10.8</td>
<td>References</td>
<td>224</td>
</tr>
<tr>
<td>10.9</td>
<td>Further reading</td>
<td>224</td>
</tr>
<tr>
<td>10.10</td>
<td>Problems</td>
<td>225</td>
</tr>
<tr>
<td>11</td>
<td>Radar remote sensing</td>
<td>226</td>
</tr>
<tr>
<td>11.1</td>
<td>High-frequency radar scattering from the sea</td>
<td>226</td>
</tr>
<tr>
<td>11.2</td>
<td>Measuring ocean currents</td>
<td>230</td>
</tr>
<tr>
<td>11.3</td>
<td>Measuring waves</td>
<td>231</td>
</tr>
<tr>
<td>11.4</td>
<td>The future of high-frequency remote sensing</td>
<td>233</td>
</tr>
<tr>
<td>11.5</td>
<td>Microwave scatterometry</td>
<td>234</td>
</tr>
<tr>
<td>11.6</td>
<td>Radar altimetry</td>
<td>237</td>
</tr>
<tr>
<td>11.7</td>
<td>Synthetic aperture radar</td>
<td>240</td>
</tr>
<tr>
<td>11.8</td>
<td>Summary</td>
<td>252</td>
</tr>
<tr>
<td>11.9</td>
<td>References</td>
<td>254</td>
</tr>
<tr>
<td>11.10</td>
<td>Further reading</td>
<td>254</td>
</tr>
<tr>
<td>11.11</td>
<td>Problems</td>
<td>254</td>
</tr>
<tr>
<td>12</td>
<td>Ground-probing radar</td>
<td>257</td>
</tr>
<tr>
<td>12.1</td>
<td>Introduction</td>
<td>257</td>
</tr>
<tr>
<td>12.2</td>
<td>Designing ground-probing radar systems</td>
<td>258</td>
</tr>
<tr>
<td>12.3</td>
<td>Carrier-free radar</td>
<td>260</td>
</tr>
<tr>
<td>12.4</td>
<td>Antenna designs</td>
<td>264</td>
</tr>
<tr>
<td>12.5</td>
<td>Data processing</td>
<td>267</td>
</tr>
<tr>
<td>12.6</td>
<td>Summary</td>
<td>269</td>
</tr>
<tr>
<td>12.7</td>
<td>References</td>
<td>269</td>
</tr>
<tr>
<td>12.8</td>
<td>Problems</td>
<td>270</td>
</tr>
<tr>
<td>13</td>
<td>Multistatic radar</td>
<td>271</td>
</tr>
<tr>
<td>13.1</td>
<td>Introduction</td>
<td>271</td>
</tr>
<tr>
<td>13.2</td>
<td>Multistatic concepts</td>
<td>272</td>
</tr>
<tr>
<td>13.3</td>
<td>The bistatic radar equation</td>
<td>275</td>
</tr>
<tr>
<td>13.4</td>
<td>Multistatic target location</td>
<td>277</td>
</tr>
<tr>
<td>13.5</td>
<td>Bistatic doppler</td>
<td>280</td>
</tr>
<tr>
<td>13.6</td>
<td>Applications</td>
<td>283</td>
</tr>
<tr>
<td>13.7</td>
<td>Summary</td>
<td>284</td>
</tr>
<tr>
<td>13.8</td>
<td>References</td>
<td>285</td>
</tr>
</tbody>
</table>
13.9 Further reading 285
13.10 Problems 285

14 Electronic warfare 286
14.1 Objectives and definitions 286
14.2 Noise jamming and the radar equation 288
14.3 Types of electronic countermeasures and electronic counter-countermeasures 290
14.4 Stealth applications 292
14.5 Summary 294
14.6 References 294
14.7 Problems 294

15 Recent developments 296
15.1 Introduction 296
15.2 Phased arrays 297
15.3 Digital beamforming 308
15.4 Active arrays 310
15.5 Multifunction radar 311
15.6 Multihead radar 312
15.7 High-resolution radar techniques 314
15.8 Summary 316
15.9 References 317
15.10 Further reading 317
15.11 Problems 317

16 The future of radar 319
16.1 Introduction 319
16.2 Developing the concept of bandwidth 320
16.3 Adaptivity 322
16.4 Summary 325
16.5 Reference 325

Appendices 326
I Symbols, their meaning and SI units 326
II Acronyms and abbreviations 330
III Useful conversion factors 333
IV Using decibels 335
V Solutions to problems 337

Bibliography 364

Index 367