# Contents

**List of Figures** xiii

**List of Tables** xix

**Preface** xxi

**I Radar Basics** 1

**1 Introduction** 3
1.1 Uses for Radar . . . 3
1.2 A Brief History of Radar up to 1950 . . . 4
1.3 Rudimentary Imaging Methods . . . 5
1.3.1 Detection and Ranging . . . 5
1.3.2 High-Range-Resolution (HRR) Imaging . . . 5
1.3.3 Real-Aperture Imaging . . . 6
1.4 Synthetic-Aperture Radar . . . 8
1.5 A Brief History of Synthetic-Aperture Radar . . . 8
1.6 The Equations of Electromagnetic Wave Propagation . . . 10
1.7 Radar Frequency Bands . . . 11
1.8 Outline of a Typical Radar System . . . 12
1.9 Decibels . . . 14

**2 Radar Systems** 15
2.1 Stepped-Frequency Systems . . . 15
2.2 Pulsed Systems . . . 17
2.2.1 I/Q Demodulation and the Analytic Signal . . . 17
2.2.2 Filters . . . 18
2.2.3 The Quadrature Model . . . 20

**3 Introduction to Scattering** 21
3.1 One-Dimensional Scattering from a Fixed PEC Plate . . . 21
3.2 One-Dimensional Scattering from a Moving PEC Plate . . . 22

**4 Detection of Signals in Noise** 25
4.1 Detection of Signals Scattered from Fixed Targets . . . 25

4.1.1 Pulse Compression . . . 27
4.1.2 Phase Coding . . . 27
4.2 High-Range-Resolution Imaging . . . 30
4.2.1 Two Point-Like Targets . . . 31
4.2.2 A Distribution of Fixed Targets . . . 31
4.3 Detection of Signals Scattered from Moving Targets . . . 31
4.3.1 A Single Moving Point-Like Target . . . 32
4.3.2 Two Moving Point-Like Targets . . . 33
4.3.3 A Distribution of Moving Targets . . . 33

**5 The Radar Ambiguity Function** **35**
5.1 Basic Properties . . . 35
5.2 Resolution and Cuts through the Ambiguity Function . . . 37
5.2.1 Range Resolution . . . 37
5.2.2 Doppler Resolution . . . 37
5.3 Special Cases . . . 37
5.3.1 Resolution for a CW Pulse . . . 38
5.3.2 Resolution for Coherent Pulse Trains . . . 41
5.4 Application: Range-Doppler Imaging . . . 43
5.4.1 Range-Doppler Imaging of Rotating Targets . . . 43
5.4.2 Range-Doppler Synthetic-Aperture Radar . . . 46
5.5 Mathematical Issues Related to the Ambiguity Function . . . 48

**II Radar Imaging** **49**

**6 Wave Propagation in Two and Three Dimensions** **51**
6.1 Scalar Wave Propagation . . . 51
6.2 Basic Facts about the Wave Equation . . . 51
6.3 Introduction to Scattering Theory . . . 52
6.3.1 The Lippmann–Schwinger Integral Equation . . . 52
6.3.2 The Lippmann–Schwinger Equation in the Frequency Domain . . . 53
6.3.3 The Neumann Series . . . 53
6.4 The Born Approximation . . . 54
6.5 The Incident Field . . . 55
6.6 Model for the Scattered Field . . . 56
6.7 The Effect of Matched Filtering . . . 57

**7 Inverse Synthetic-Aperture Radar** **59**
7.1 The Far-Field Approximation . . . 59
7.2 The Far-Field Expansion in the Scalar Wave Born Approximation . . . 60
7.3 Inverse Synthetic-Aperture Imaging . . . 60
7.3.1 ISAR Systems . . . 61
7.3.2 Modeling Rotating Targets . . . 61
7.3.3 Radar Data from Rotating Targets . . . 61
7.3.4 The Data Collection Manifold . . . 62
7.3.5 The Polar Format Algorithm (PFA) . . . 62

7.3.6 ISAR Resolution . . . 63
7.3.7 ISAR in the Time Domain . . . 67
7.3.8 Range Alignment . . . 69

**8 Antennas** **73**
8.1 Examples . . . 73
8.2 Scalar and Vector Potentials . . . 74
8.3 Fields Far from the Antenna . . . 82
8.4 Examples . . . 85
8.4.1 A Short Linear Antenna . . . 85
8.4.2 Radiation from an Aperture . . . 85
8.4.3 A Linear Array of Short Linear Antennas . . . 86
8.4.4 Array Steering . . . 87
8.5 Antenna Properties . . . 87
8.5.1 Beamwidth . . . 87
8.5.2 Directivity . . . 88
8.5.3 Gain . . . 88
8.5.4 Radiation Efficiency . . . 88
8.5.5 Phase Center . . . 88
8.6 Antennas in Imaging . . . 89
8.6.1 Field from Antenna not at the Origin . . . 89
8.6.2 The Scalar Antenna Model . . . 89
8.6.3 Antenna Reception . . . 90

**9 Synthetic-Aperture Radar** **91**
9.1 Spotlight SAR . . . 92
9.2 Stripmap SAR . . . 93
9.2.1 The Stripmap SAR Point-Spread Function . . . 95
9.2.2 Resolution . . . 99
9.3 Understanding SAR Images . . . 102
9.3.1 The Radar Projection . . . 102
9.3.2 Shadows and Layover . . . 102
9.3.3 Color in SAR Imagery . . . 104
9.3.4 Singularities and Edges . . . 106
9.4 The Effects of Discrete Slow Time . . . 109
9.4.1 The Received Signal . . . 110
9.4.2 Image Formation . . . 110
9.5 Other Imaging Algorithms . . . 111

**10 Related Techniques** **113**
10.1 Motion Compensation . . . 113
10.2 Moving Target Indicator (MTI) Images . . . 113
10.3 Interferometric SAR . . . 114
10.3.1 Stereometry . . . 115
10.3.2 Interferometry . . . 117

**11 Open Problems** **121**
11.1 Problems in Waveform Design . . . 121

11.1.1 Problems in Coding . . . . . 121
11.1.2 Problems in Ambiguity Theory . . . . . 122
11.1.3 Design of Waveform for Particular Purposes . . . . . 122
11.2 Problems Related to Antennas . . . . . 123
11.3 Problems Related to Synthetic-Aperture Imaging . . . . . 123

**Bibliography** **127**

**Index** **137**