

Contents

| | |
|--|-------------|
| List of Contributors | xi |
| Preface | xiii |
| 1 Fundamentals of Bistatic Synthetic Aperture Radar | 1 |
| Antonio Moccia | |
| 1.1 Introduction | 1 |
| 1.2 BSAR Basic Geometry and Resolutions | 2 |
| 1.3 Scientific Applications of the BSAR | 8 |
| 1.3.1 Evaluation of the BRCS of Natural and Manmade Targets by Means of Multiangle Bistatic SAR Observations | 8 |
| 1.3.2 Acquisition of Terrain Elevation and Slope by Means of Range and Bistatic Scattering Measurements | 9 |
| 1.3.3 Acquisition of Velocity Measurements Due to the Simultaneous Measurement of Two Doppler Frequencies | 10 |
| 1.3.4 Stereoradargrammetric Applications Due to the Large Antenna Separation Involved | 10 |
| 1.3.5 Improvement of Image Classification and Pattern Recognition Procedures | 11 |
| 1.3.6 High-Resolution Measurements of Components of Sea-Wave Spectra | 11 |
| 1.3.7 Bistatic SAR Data Processing | 12 |
| 1.3.8 Position and Velocity Measurements | 13 |
| 1.3.9 Bistatic Stereoradargrammetry | 15 |
| 1.4 Summary | 20 |
| Abbreviations | 21 |
| Variables | 21 |
| References | 22 |
| 2 Spaceborne Bistatic Synthetic Aperture Radar | 27 |
| Antonio Moccia and Marco D'Errico | |
| 2.1 Introduction | 27 |
| 2.2 Key Design Issues in Spaceborne BSAR | 29 |
| 2.2.1 Basic Trade-offs in Spaceborne BSAR Configurations | 29 |
| 2.2.2 Impact of Bistatic Observation on Mission and System Design | 32 |

| | |
|---|-----------|
| 2.2.3 Payload–Bus Performance Trade-off | 35 |
| 2.2.4 BSAR Missions Functional/Technological Key Issues | 40 |
| 2.3 Mission Analysis of Spaceborne BSAR | 42 |
| 2.3.1 BSAR Orbit Design | 42 |
| 2.3.2 BSAR Attitude and Antenna Pointing Design | 49 |
| 2.4 Summary | 60 |
| Abbreviations | 60 |
| Variables | 60 |
| References | 62 |
| 3 Bistatic SAR for Earth Observation | 67 |
| A. Moccia and M. D’Errico | |
| 3.1 Introduction | 67 |
| 3.2 Bissat Scientific Rationale and Technical Approach | 68 |
| 3.3 Bistatic Payload Main Characteristics and Architecture | 70 |
| 3.3.1 Design Assumptions | 70 |
| 3.3.2 System Architecture | 70 |
| 3.3.3 Payload Operational Modes | 71 |
| 3.3.4 Signal Synchronization | 72 |
| 3.3.5 Science Data Handling and Telecommunication | 73 |
| 3.3.6 Antenna Characteristics | 75 |
| 3.3.7 Overall Budgets | 75 |
| 3.4 Orbit Design | 76 |
| 3.5 Attitude Design and Radar Pointing Design | 78 |
| 3.6 Radar Performance | 86 |
| 3.7 Summary | 91 |
| Abbreviations | 91 |
| Variables | 92 |
| Acknowledgements | 92 |
| References | 92 |
| 4 Spaceborne Interferometric and Multistatic SAR Systems | 95 |
| Gerhard Krieger and Alberto Moreira | |
| 4.1 Introduction | 95 |
| 4.2 Spaceborne SAR Interferometry | 97 |
| 4.3 Interferometric Mission Design | 101 |
| 4.3.1 Satellite Formation | 101 |
| 4.3.2 Phase and Time Synchronization | 106 |
| 4.3.3 Operational Modes for Bi- and Multistatic SAR Systems | 112 |
| 4.4 Mission Examples | 115 |
| 4.4.1 TanDEM-X | 115 |
| 4.4.2 Semi-active TerraSAR-L Cartwheel Configuration | 128 |
| 4.5 Advanced Multistatic SAR System Concepts | 137 |
| 4.5.1 SAR Tomography | 137 |
| 4.5.2 Ambiguity Suppression and Resolution Enhancement | 139 |
| 4.5.3 Multistatic SAR Imaging | 142 |

CONTENTS

vii

| | |
|--|------------|
| 4.5.4 Along-Track Interferometry and Moving Object Indication | 143 |
| 4.5.5 Multibaseline Change Detection | 144 |
| 4.6 Discussion | 145 |
| Abbreviations | 147 |
| Variables | 148 |
| References | 150 |
| | |
| 5 Airborne Bistatic Synthetic Aperture Radar | 159 |
| Pascale Dubois-Fernandez, Hubert Cantalloube, Bernard Vaizan, Gerhard Krieger and Alberto Moreira | |
| 5.1 Bistatic Airborne SAR Objectives | 159 |
| 5.2 Airborne Bistatic SAR Configurations | 160 |
| 5.2.1 Time-Invariant Configurations | 161 |
| 5.2.2 General Bistatic Configurations | 162 |
| 5.2.3 MTI Applications | 163 |
| 5.2.4 Examples of Resolution Performances | 163 |
| 5.3 Airborne Bistatic SAR Processing Specificity | 166 |
| 5.3.1 Changes in the SAR Synthesis Process | 166 |
| 5.3.2 Motion Compensation Issues | 177 |
| 5.3.3 Geometrical Distortion Model for Airborne Bistatic SAR Images | 185 |
| 5.3.4 Miscellaneous Processing Issues | 188 |
| 5.4 Open-Literature BSAR Airborne Campaigns | 197 |
| 5.4.1 Michigan BSAR Experiment | 197 |
| 5.4.2 QinetiQ BSAR Experiment | 198 |
| 5.4.3 FGAN BSAR Experiment | 198 |
| 5.5 The ONERA-DLR Bistatic Airborne SAR Campaign | 198 |
| 5.5.1 Preparing the Systems | 199 |
| 5.5.2 The Campaign | 205 |
| 5.5.3 Processing the Bistatic Images | 206 |
| 5.5.4 Calibration of the Bistatic Images | 207 |
| 5.6 A Selection of Results from the Campaign | 208 |
| 5.6.1 Quasi-Monostatic versus Monostatic | 208 |
| 5.7 Summary | 210 |
| Abbreviations | 210 |
| Variables Used in Section 5.3 | 210 |
| References | 211 |
| | |
| 6 Space-Surface Bistatic SAR | 215 |
| Mikhail Cherniakov and Tao Zeng | |
| 6.1 System Overview | 215 |
| 6.2 Spatial Resolution | 217 |
| 6.2.1 Monostatic SAR Ambiguity Function | 218 |
| 6.2.2 Resolution in BSAR | 223 |
| 6.3 SS-BSAR Resolution | 228 |
| 6.3.1 SS-BSAR Ambiguity Function | 228 |
| 6.4 SS-BSAR Resolution Examples | 237 |

| | |
|---|------------|
| 6.5 Summary | 243 |
| Abbreviations | 243 |
| Variables | 243 |
| Acknowledgement | 245 |
| References | 245 |
| 7 Passive Bistatic Radar Systems | 247 |
| Paul E. Howland, Hugh D. Griffiths and Chris J. Baker | |
| 7.1 PBR Development | 248 |
| 7.2 Sensitivity and Coverage for Passive Radar Systems | 251 |
| 7.2.1 The Bistatic Radar Equation | 251 |
| 7.2.2 Target Bistatic Radar Cross-Section | 253 |
| 7.2.3 Receiver Noise Figure | 254 |
| 7.2.4 Effective Bandwidth and Integration Gain | 255 |
| 7.2.5 Performance Prediction | 256 |
| 7.2.6 Sensitivity Analysis Conclusions | 260 |
| 7.3 PBR System Processing | 260 |
| 7.3.1 Narrowband PBR Processing | 260 |
| 7.3.2 Wideband PBR Processing | 268 |
| 7.3.3 Multistatic PBR | 273 |
| 7.4 Waveform Properties | 274 |
| 7.4.1 Introduction | 274 |
| 7.4.2 Range and Doppler Resolution – ‘Self-Ambiguity’ | 275 |
| 7.4.3 Range and Doppler Resolution – ‘Bistatic and Multistatic Ambiguity’ | 283 |
| 7.4.4 Influence of Waveform Properties on Design and Performance | 285 |
| 7.4.5 Conclusions of Waveform Properties | 287 |
| 7.5 Experiments and Results | 288 |
| 7.5.1 Experimental Overview | 288 |
| 7.5.2 Expected System Performance | 288 |
| 7.5.3 Data Collection | 291 |
| 7.5.4 Adaptive Filtering of the Signal | 292 |
| 7.5.5 Target Detection by Cross-Correlation | 295 |
| 7.5.6 Long-Integration Time | 296 |
| 7.5.7 Use of Decimation to Improve Efficiency | 299 |
| 7.5.8 An FMCW-Like Approach | 301 |
| 7.5.9 Constant False Alarm Rate (CFAR) Detection | 303 |
| 7.5.10 Direction Finding | 304 |
| 7.5.11 Plot-to-Plot Association | 304 |
| 7.5.12 Target State Estimation | 306 |
| 7.5.13 Plot-to-Target Association (Multiple Illuminator Case) | 306 |
| 7.5.14 Verification of System Performance | 308 |
| 7.6 Summary and Conclusions | 309 |
| Abbreviations | 309 |
| Variables | 310 |
| References | 311 |

| | |
|--|------------|
| 8 Ambiguity Function Correction in Passive Radar: DTV-T Signal | 315 |
| Mikhail Cherniakov | |
| 8.1 Introduction | 315 |
| 8.2 DTV-T Signal Specification | 317 |
| 8.2.1 Scattered Pilot Carrier | 318 |
| 8.2.2 Continuous Pilot Carrier | 318 |
| 8.2.3 Transport Parameter Signalling Carrier | 319 |
| 8.2.4 Guard Intervals | 320 |
| 8.3 DTV-T Signal Ambiguity Function | 320 |
| 8.3.1 The DTV-T Signal Model | 321 |
| 8.3.2 AF of DTV-T Signal Random Components | 322 |
| 8.4 Impact of DTV-T Signal Deterministic Components on the Signal Ambiguity Function | 322 |
| 8.4.1 Autocorrelation Function ($\omega_d = 0$) | 324 |
| 8.4.2 Complex Envelope Spectrum ($\tau = 0$) | 324 |
| 8.4.3 Ambiguity Function of the DTV-T Signal | 325 |
| 8.4.4 Experimental Confirmation of the Modelling Results | 325 |
| 8.5 Mismatched Signal Processing | 327 |
| 8.5.1 Receiver Stricture | 327 |
| 8.5.2 Signal Pre-processing in the Receiver | 328 |
| 8.5.3 Pilot Carrier Equalization | 330 |
| 8.5.4 Pilot Carrier Filtering | 332 |
| 8.6 Summary | 335 |
| Abbreviations | 336 |
| Variables | 336 |
| References | 337 |
| 9 Passive Bistatic SAR with GNSS Transmitters | 339 |
| Mikhail Cherniakov and Tao Zeng | |
| 9.1 Global Navigation Satellite Systems | 340 |
| 9.2 Power Budget Analysis | 343 |
| 9.3 Analysis of the Signal-to-Interference Ratio | 345 |
| 9.3.1 SIR at the Antenna Output | 345 |
| 9.3.2 Analysis of the SIR Improvement Factor | 345 |
| 9.3.3 Simulation Results | 351 |
| 9.4 Results Discussion | 354 |
| 9.5 Experimental Study of the SS-BSAR | 354 |
| 9.6 Summary | 358 |
| Abbreviations | 359 |
| Variables | 359 |
| References | 360 |
| 10 Ionospheric Studies | 363 |
| John D. Sahr | |
| 10.1 Introduction | 363 |

| | |
|---|------------|
| 10.2 The Ionosphere and Upper Atmosphere | 365 |
| 10.2.1 Gross Structure of the Ionosphere | 366 |
| 10.2.2 Ionospheric Models | 370 |
| 10.2.3 Fine Structure, Field-Aligned Density Irregularities | 370 |
| 10.2.4 Radio Interaction with the Ionosphere | 373 |
| 10.3 Bistatic, Passive Radar Studies | 378 |
| 10.3.1 Bistatic Radar Observations of the Ionosphere | 378 |
| 10.3.2 The Manastash Ridge Radar | 378 |
| 10.4 Trends for Ionospheric Research | 383 |
| Abbreviations | 383 |
| Variables | 384 |
| Acknowledgements | 385 |
| References | 385 |
| Index | 389 |