

Contents

Preface..... xv

Chapter 1 Global Positioning System (GPS) Signal 1

 GPS Signal Structure 1

 GPS and Trilateration 1

 Passive System 1

 Time 1

 Control 2

 Codes 2

 Wavelength and Frequency 3

 NAV Messages 3

 P and Coarse/Acquisition Codes 5

 Pseudorandom Noise 5

 P Code 5

 C/A Code 6

 Standard Positioning Service and Precise Positioning Service 6

 GPS Time 6

 Satellite Clocks 7

 GPS Week 8

 Julian Date 10

 Broadcast Ephemeris 10

 Atmospheric Correction 10

 Almanac 12

 Satellite Health 13

 Telemetry and Handover Words 13

 Production of a Modulated Carrier Wave 13

 EDM Ranging 13

 GPS Ranging 14

 Oscillators 15

 Chain of Electromagnetic Energy 16

 Phase Shift 17

 Two Observables 19

 Encoding by Phase Modulation 19

 Pseudoranging 22

 Propagation Delay 22

 Code Correlation 22

 Autocorrelation 23

 Correlation Peak 24

 Lock and the Time Shift 26

 Imperfect Oscillators 26

A Pseudorange Equation	27
One Percent Rule of Thumb	28
Carrier Phase Ranging	30
The Cycle Ambiguity Problem.....	30
Carrier Phase Comparisons.....	31
Beat	31
Doppler Effect	32
GPS and the Doppler Effect	32
Carrier Phase Approximation.....	33
Illustration of the Cycle Ambiguity Problem	35
Chapter 2 Biases and Solutions.....	41
Biases.....	41
A Look at the Error Budget.....	41
User Equivalent Range Error and User Range Error.....	41
Ionospheric Effect d_{ion}	42
Ionized Plasma.....	42
Ionosphere and the Sun.....	42
Ionospheric Stratification.....	43
Satellite Elevation and Ionospheric Effect.....	44
Magnitude of the Ionospheric Effect	44
Group Delay and Phase Delay	44
Different Frequencies Are Affected Differently	45
Broadcast Correction	45
Satellite Clock Bias dt	46
Relativistic Effects on the Satellite Clock	46
Satellite Clock Drift.....	46
Receiver Clock Bias dT	47
Typical Receiver Clocks	47
Orbital Bias d_p	47
Forces Acting on the Satellites	47
Tropospheric Effect d_{trop}	47
Troposphere	48
Multipath	50
Limiting the Effect of Multipath	51
Antenna Design and Multipath.....	51
Receiver Noise.....	53
Solutions	53
Some Methods of Data Collection.....	53
Static and Kinematic.....	53
Single-Point	53
Relative Positioning	55
Differencing.....	55
Between-Receiver Single Difference	56
Between-Satellites Single Difference.....	57

Double Difference 58

Triple Difference 59

 Repairing Cycle Slips 59

 Components of the Carrier Phase Observable..... 61

Post-Processing..... 62

 Correlation of Biases 63

 Organization Is Essential..... 63

Control..... 64

The First Position..... 64

Least-Squares Adjustment..... 66

Network Adjustment..... 66

Using a Processing Service 67

Summary 67

Chapter 3 Framework..... 77

 Technological Forerunners..... 77

 Consolidation..... 77

 Terrestrial Radio Positioning..... 77

 Satellite Advantages 78

 Optical Systems 79

 Extraterrestrial Radio Positioning..... 79

 Prime Minitrack..... 80

 Very Long Baseline Interferometry 80

 TRANSIT 81

 Linking Datums..... 82

 System 621B and Timation..... 82

 NAVSTAR 84

 Requirements 84

 Secure, Passive, and Global 84

 Expense and Frequency Allocation 85

 Large Capacity Signal 85

 Satellite Constellation..... 85

 The Perfect System? 85

 GPS in Civilian Surveying 86

 Federal Specifications..... 86

 Interferometry..... 86

 Civil Applications of GPS 87

 GPS Segments 87

 Space Segment..... 87

 GPS Constellation 88

 Orbital Period 88

 Four-Minute Difference..... 88

 Dilution of Precision..... 89

 Bad Dilution of Precision 90

 Good Dilution of Precision..... 90

Satellite Positions in Mission Planning 91

Satellite Blocks 93

Satellite Names 94

GPS Satellites 95

Control Segment..... 95

 Kalman Filtering 97

User Segment..... 98

Chapter 4 Receivers and Methods 107

Common Features of Global Positioning System (GPS) Receivers 107

 A Block Diagram of a Code Correlation Receiver 107

 Receivers for GPS Surveying 107

 Antenna 107

 Bandwidth..... 109

 Nearly Hemispheric Coverage..... 110

 Antenna Orientation 110

 Height of Instrument..... 111

 Radio Frequency (RF) Section..... 111

 Channels 112

 Multiplexing and Sequencing 112

 Tracking Loops..... 112

 Pseudoranging..... 113

 Carrier Phase Measurement..... 113

 Carrier Tracking Loop..... 113

 Doppler Shift 113

 Typical GPS Doppler Shift..... 114

 Continuously Integrated Doppler 115

 Integer Ambiguity..... 115

 Signal Squaring 116

 Microprocessor..... 116

 Control and Display Unit..... 117

 Storage 117

 Power 117

 Battery Power 117

 Receiver Categories 118

 Recreation Receivers 118

 Local and Network Accuracy 120

 Mapping Receivers 121

 Global Navigation Satellite System 122

 Surveying Receivers 122

Chapter 5 Coordinates 129

A Few Pertinent Ideas about Geodetic Datums for Global
Positioning Systems..... 129

- Plane Surveying..... 129
 - Development of State Plane Coordinate Systems..... 129
 - GPS Surveyors and Geodesy 130
- Some Geodetic Coordinate Systems 130
 - Three-Dimensional (3-D) Cartesian Coordinates 130
 - Polar Motion 131
 - Latitude and Longitude..... 134
- Elements of a Geodetic Datum..... 134
 - Deflection of the Vertical..... 134
- Geocentric, Geodetic, and Astronomic Latitude..... 135
 - Datums..... 136
 - Development of the Ellipsoidal Model 137
- Biaxial Ellipsoidal Model of the Earth 139
 - Role of an Ellipsoid in a Datum 139
- Regional Ellipsoids..... 139
 - Measurement Technology and Datum Selection 139
- Position Derived from GPS 141
 - Development of a Geocentric Model..... 141
- Geoid 142
 - Equipotential Surface 142
 - Geoidal Undulation..... 143
- Modern Geocentric Datum..... 143
 - World Geodetic System 1984 (WGS84) 144
- North American Datum 1983 144
 - NAD27..... 144
 - Development of the North American Datum 1983 (NAD83) ... 146
 - International Terrestrial Reference System 146
 - ITRF, WGS84, and NAD83..... 147
 - Management of NAD83..... 148
 - Transformations from NAD27 to NAD83 148
 - Densification and Improvement of NAD83 149
 - High-Accuracy Reference Networks 149
 - Continuously Operating Reference Stations..... 150
- State Plane Coordinates 151
 - NAD83 Positions and Plane Coordinates..... 151
 - Map Projection 151
 - Distortion..... 153
 - Decreasing Distortion..... 154
 - Secant and Cylindrical Projections 154
 - Origin of State Plane Coordinates..... 156
 - State Plane Coordinate System Map Projections 158
 - SPCS27 to SPCS83..... 159
 - Changes in Zones..... 159
 - State Plane Coordinates Scale and Distance..... 161
 - Geodetic Lengths to Grid Lengths 161
 - Universal Transverse Mercator Coordinates 168

Universal Transverse Mercator Zones of the World.....	169
Heights.....	172
Ellipsoidal Heights	172
Orthometric Heights.....	174
Spirit Leveling	174
Evolution of a Vertical Datum.....	174
Sea Level.....	174
Diurnal Tide	175
A Different Approach.....	176
Zero Point	177
Geoid	177
Geoid Models.....	179

Chapter 6 Static Global Positioning System Surveying.....	187
Planning	187
A Few Words about Accuracy.....	187
Standards of Accuracy	189
New Design Criteria.....	190
Lay of the Land	191
Maps	191
National Geodetic Survey (NGS) Control.....	192
NGS Control Data Sheets.....	192
Coordinates.....	195
Station Mark	195
Significance of the Information	195
Control from Continuously Operating Networks.....	195
NGS Continuously Operating Reference Stations.....	196
NGS CORS Reference Points.....	197
International Global Navigation Satellite System (GNSS)	
Service (IGS).....	197
Static Survey Project Design.....	197
Horizontal Control.....	197
Station Location.....	198
Vertical Control	199
Preparation	200
Plotting Project Points	200
Evaluating Access.....	201
Planning Offsets	201
Planning Azimuth Marks	201
Obtaining Permissions.....	202
Some GPS Survey Design Facts.....	202
Software Assistance	202
Position Dilution of Precision	202
Polar Plot.....	203
An Example	203

Choosing the Window	206
Ionospheric Delay	206
Naming the Variables	209
Compatible Receivers	209
Receiver Capabilities and Baseline Length	210
Drawing the Baselines.....	211
Horizontal Control.....	211
Julian Day in Naming Sessions	211
Independent Lines.....	211
Redundancy	212
Forming Loops	213
Finding the Number of Sessions.....	213
Ties to the Vertical Control	215
Static GPS Control Observations	216
Equipment.....	216
Conventional Equipment	216
Safety Equipment.....	216
Communications	217
GPS Equipment	217
Auxiliary Equipment	218
Information	218
Station Data Sheet	220
Station Name	221
Rubbings	221
Photographs	221
Quad Sheet Name	221
To-Reach Descriptions.....	222
Flagging and Describing the Monument	222
Visibility Diagrams	223
An Example	223
Drawing Obstructions.....	224
Working around Obstructions	224
Approximate Station Coordinates	226
Multipath.....	226
Point Offsets	226
Look for Multipath.....	227
Monumentation.....	227
Logistics	228
Scheduling	228
Observation.....	228
Arrival.....	228
Setup	229
Height of Instrument.....	229
Observation Logs.....	229
Weather	231
Daily Progress Evaluation	231

Chapter 7	Real-Time Global Positioning System Surveying	241
	Real-Time Kinematic (RTK) and Differential GPS (DGPS).....	241
	General Idea	241
	Radial GPS	242
	Correction Signal.....	243
	DGPS.....	245
	Local and Wide Area DGPS	245
	Wide Area Augmentation Systems (WAAS)	246
	Geographic Information Systems (GIS) Application	247
	Real-Time Kinematic (RTK).....	248
	Integer Cycle Ambiguity Fixing.....	249
	Wireless Link	249
	Vertical Component in RTK	251
	Some Practical RTK Suggestions.....	252
	Real-Time Network Services.....	253
	Real-Time GPS Techniques.....	255
	Offsets.....	255
	Dynamic Lines	256
	Planning.....	257
	A Few RTK Procedures	257
	Site Calibration	258
	Precise Point Positioning (PPP).....	259
	Post Processed (PP-PPP)	260
	Real-Time Service (RTS-PPP)	261
	PPP Disadvantage.....	261
 Chapter 8	 Global Positioning System Modernization and Global	
	Navigation Satellite System.....	265
	Global Positioning System (GPS) Modernization	265
	Satellite Blocks	265
	Block I, Block II/IIA, Block IIR, and Block III Satellites	265
	Block I.....	265
	Block II	267
	Block IIA	267
	Block IIR	268
	Block IIR-M.....	268
	Block IIF.....	269
	Block III.....	269
	Power Spectral Density Diagrams	271
	dBW/Hz	271
	L1 Legacy Signals	274
	New Signals.....	275
	M Code	275
	L2 Signal	276

L2C	277
Civil-Moderate (CM) and Civil-Long (CL)	277
Phase-Locked Loop	278
Practical Advantages	279
CNAV	280
L5	281
L5 Carrier	281
GPS Modernization Is Underway	282
Ionospheric Bias	283
Correlation Protection	283
L1C Another Civil Signal	283
Global Navigation Satellite System (GNSS)	284
GLONASS	285
Uragan-M	286
GLONASS-K	286
GLONASS Signals	286
Code Division Multiple Access	287
Frequency Division Multiple Access (FDMA)	288
GLONASS Time	289
GLONASS Ephemeris	289
Galileo	289
Galileo's Ground Segment	291
Galileo's Signals and Services	291
Governance of Galileo	291
Interoperability between GPS, GLONASS, and GALILEO	292
Frequency Coincidence	294
BeiDou	294
BeiDou's Signals and Services	295
BeiDou's Control/Ground Segment	297
Quasi-Zenith Satellite System (QZSS)	297
QZSS Control/Ground Segment	298
IRNSS	299
The Future	300
Interoperability	301
GPS–Galileo–GLONASS Constellations	301
Inconsistency	301
Glossary	305
References	329
Index	331