

Contents

Preface to the Fifth Edition	xvii
About the Author.....	xix
Chapter 1 The Signal	1
The Global Navigation Satellite System (GNSS)	
Signal.....	1
GNSS and Trilateration.....	1
A Passive System	1
Time	1
Control	2
Atmosphere	2
At Least Four	2
Satellite ID	2
Codes	3
Wavelength and Frequency	3
The NAV Messages.....	4
The Precise P(Y) and Coarse/Acquisition (C/A)	
Codes.....	7
P Code.....	8
The C/A Code	9
Standard Positioning Service (SPS) and Precise	
Positioning Service (PPS)	9
Time, UTC, and TAI.....	10
GPS Time.....	11
Satellite Clocks	11
GPS Week	12
Julian Date	13
The Broadcast Ephemeris	14
Atmospheric Correction.....	15
The Almanac.....	16
Satellite Health.....	18
Telemetry and Hand Over Words.....	18
The Production of a Modulated Carrier Wave	18
EDM Ranging	18
GNSS Ranging.....	19
Oscillators	20
A Chain of Electromagnetic Energy	21
Phase Shift	22

Two Observables	25
Encoding by Phase Modulation	25
Pseudoranging	27
Propagation Delay	28
Code Correlation	29
Autocorrelation	29
Correlation Peak	30
Lock and the Time Shift	33
Imperfect Oscillators	33
A Pseudorange Equation	34
A 1-Percent Rule of Thumb	35
Carrier-Phase Ranging	37
The Integer Ambiguity Problem	37
Carrier-Phase Comparisons	37
Beat	38
The Doppler Effect	38
GNSS and the Doppler Effect	40
A Carrier-Phase Approximation	40
An Illustration of the Integer Ambiguity Problem	43
Exercises	44
Answers and Explanations	46

Chapter 2 Biases and Solutions	49
Biases	49
A Look at the Error Budget	49
User Equivalent Range Error	49
The Ionospheric Effect, d_{ion}	50
Ionized Plasma	50
Ionosphere and the Sun	50
Ionospheric Stratification	51
The Ionospheric Effect	52
Group Delay and Phase Delay	52
Different Frequencies Are Affected Differently	53
Broadcast Correction	53
The Satellite Clock Bias, dt	55
Relativistic Effects on the Satellite Clock	55
Satellite Clock Drift	55
The Receiver Clock Bias, dT	56
Typical Receiver Clocks	56
The Orbital Bias, d_p	57
The Tropospheric Effect, d_{trop}	57

Multipath	59
Limiting the Effect of Multipath.....	61
Antenna Design and Multipath	62
Receiver Noise.....	63
Some Methods of Data Collection.....	64
Static and Kinematic	64
Single Point	64
Relative Positioning.....	66
Differencing	66
Between-Receivers Single Difference.....	67
Between-Satellites Single Difference.....	68
Double Difference	69
Triple Difference	70
Repairing Cycle Slips.....	72
Components of the Carrier-Phase Observable	73
Post-Processing.....	75
Correlation of Biases.....	75
Organization Is Essential	76
Control.....	77
Least-Squares Adjustment.....	77
Network Adjustment.....	78
Using an Online Processing Service	79
Summary	80
Exercises.....	81
Answers and Explanations	84
 Chapter 3 The Framework	 91
Technological Forerunners	91
Consolidation	91
Terrestrial Radio Positioning.....	91
Satellite Advantages.....	92
Optical Systems.....	93
Extraterrestrial Radio Positioning	94
Minitrack.....	94
Very Long Baseline Interferometry.....	95
TRANSIT.....	96
System 621B and Timation	98
NAVSTAR.....	98
Requirements	100
Secure, Passive, and Global	100
Expense and Frequency Allocation.....	100
Large Capacity Signal.....	100

	The Satellite Constellation	101
	The Perfect System?	101
	GPS in Civilian Surveying	102
	Federal Specifications	102
	Interferometry	102
	GPS Segments	103
	The Space Segment	103
	GPS Constellation	104
	Orbital Period	104
	Dilution of Precision	104
	Satellite Positions in Mission Planning	107
	Satellite Blocks	110
	Satellite Names	110
	GPS Satellites	110
	The GPS Operational Control System (OCS)	111
	Kalman Filtering	114
	The User Segment	116
	Exercises	118
	Answers and Explanations	120
Chapter 4	Receivers and Methods	127
	Common Features of GPS Receivers	127
	Receivers for GNSS Surveying	127
	The Antenna	127
	Bandwidth	128
	Nearly Hemispheric Coverage	129
	Antenna Orientation	130
	Receiver Processes	131
	Channels	132
	Tracking Loops	133
	Pseudoranging	133
	Carrier-Phase Measurement	134
	Carrier Tracking Loop	134
	Doppler Shift	134
	Typical GPS Doppler Shift	135
	Continuously Integrated Doppler	136
	Integer Ambiguity	136
	Signal Squaring	137
	The Microprocessor	138
	The Control and Display Unit (CDU)	138
	The Storage	138

The Power.....	139
Battery Power.....	139
Receivers.....	139
Local and Network Accuracy	140
Mapping Receivers.....	141
Surveying Receivers.....	142
Exercises.....	143
Answers and Explanations	145
Chapter 5 Coordinates	149
A Few Pertinent Ideas about Geodesy for GNSS	149
Plane Surveying	149
Development of State Plane Coordinate Systems	149
GNSS Surveyors and Geodesy.....	150
Some Geodetic Coordinate Systems	150
Three-Dimensional Cartesian Coordinates.....	150
Polar Motion	151
Latitude and Longitude.....	153
Elements of a Geodetic Datum.....	155
The Deflection of the Vertical.....	155
Geocentric, Geodetic, and Astronomic Latitude.....	157
Datums and Reference Frames	157
Development of the Ellipsoidal Model.....	158
Biaxial Ellipsoidal Model of the Earth	161
The Role of an Ellipsoid in a Datum.....	161
Regional Ellipsoids.....	161
Measurement Technology and Datum Selection.....	161
Position Derived from GNSS	163
The Development of a Geocentric Model	163
The Geoid.....	164
An Equipotential Surface.....	165
Geoidal Undulation	165
The Modern Geocentric Datum	166
World Geodetic System 1984.....	166
North American Datum 1983	167
NAD27.....	167
The Development of the North American Datum 1983.....	169
High Accuracy Reference Networks.....	169
Continuously Operating Reference Stations	170
A Step Forward.....	171

	The International Terrestrial Reference Frame	172
	Frame Reference Epoch	173
	World Geodetic System (WGS84)	174
	ITRF, WGS84, and NAD83	175
	The North American Terrestrial Reference Frame 2022 (NATRF2022)	175
	State Plane Coordinate Systems	177
	Distortion.....	180
	Decreasing Distortion	182
	Secant and Cylindrical Projections	183
	State Plane Coordinate System Map Projections	185
	SPCS27 to SPCS83	186
	State Plane Coordinates Scale and Distance	188
	Geodetic Lengths to Grid Lengths.....	188
	Universal Transverse Mercator Coordinates	196
	Universal Transverse Mercator Zones of the World	197
	Heights.....	201
	Ellipsoidal Heights	201
	Orthometric Heights	203
	Spirit Leveling	203
	Evolution of a Vertical Datum.....	203
	Sea Level.....	203
	A Different Approach	205
	The Zero Point.....	206
	The Geoid.....	207
	Geoid Models.....	209
	North American-Pacific Geopotential Datum of 2022	210
	Exercises.....	214
	Answers and Explanations	216
Chapter 6	Static GNSS Surveying	221
	A Few Words about Accuracy.....	221
	Standards of Accuracy	223
	New Design Criteria.....	224
	The Lay of the Land.....	225
	National Geodetic Survey (NGS) Control.....	225
	NGS Control Data Sheets	225
	Coordinates	230
	The Station Mark	230
	Significance of the Information	230

Control from Continuously Operating Networks	230
NGS Continuously Operating Reference Stations.....	231
NGS CORS Reference Points	232
International CORS.....	232
Static Survey Project Design	232
Horizontal Control	232
Station Location	233
Vertical Control.....	233
Plotting Project Points.....	235
Evaluating Access	235
Planning Offsets.....	237
Planning Azimuth Marks.....	237
Obtaining Permissions	237
Some GNSS Survey Design Facts	238
Position Dilution of Precision	238
Polar Plot.....	239
An Example	239
Choosing the Window	241
Naming the Variables.....	243
Receivers	243
Drawing the Baselines.....	245
Horizontal Control	245
Julian Day in Naming Sessions.....	245
Independent Lines	245
Redundancy	247
Forming Loops.....	249
Finding the Number of Sessions	249
Ties to the Vertical Control	250
Static GNSS Control Observations.....	250
Equipment	251
Conventional Equipment	251
Safety Equipment.....	251
Communications.....	252
GNSS Equipment.....	252
Auxiliary Equipment	253
Information	254
Station Data Sheet	254
Station Name.....	256
Photographs.....	257
To-Reach Descriptions	257
Flagging and Describing the Monument.....	258

Visibility Diagrams	258
Working around Obstructions	260
Approximate Station Coordinates	260
Multipath	262
Point Offsets	262
Monumentation	263
Logistics	263
Scheduling	263
Observation	264
Setup	265
Height of Instrument	265
Observation Logs	266
Weather	266
Daily Progress Evaluation	268
Exercises	268
Answers and Explanations	270
Chapter 7 Real-Time GNSS Surveying	275
Real-Time Kinematic (RTK) and Differential GNSS	275
The General Idea	275
Radial GNSS	276
The Correction Signal	277
DGNSS	278
Local and Wide Area DGPS	280
Wide Area Augmentation System	280
GIS Application	282
Real-Time Kinematic	283
Wireless Link	285
The Vertical Component in RTK	287
Some Practical RTK Suggestions	287
Real-Time Network Services	289
Real-Time GPS Techniques	291
Dynamic Lines	292
Planning	293
A Few RTK Procedures	294
Site Calibration	294
Precise Point Positioning	296
PPP Disadvantage	298
Exercises	298
Answers and Explanations	300

Chapter 8	GPS Modernization and Global Navigation Satellite System (GNSS).....	303
	GPS Modernization.....	303
	Satellite Blocks.....	303
	Block I, Block II/IIA, Block IIR, and Block III	
	Satellites.....	303
	Block I.....	304
	Block II.....	306
	Block IIA.....	306
	Block IIR.....	307
	Block IIR-M.....	307
	Block IIF.....	308
	Block III.....	308
	Power Spectral Density Diagrams.....	310
	dBW/Hz.....	310
	L1 Legacy Signals.....	314
	New Signals.....	314
	The M-Code.....	314
	L2C.....	316
	L5.....	318
	Practical Advantages.....	319
	L1C Another Civil Signal.....	320
	The New Navigation Messages.....	321
	GPS Evolution.....	323
	Global Navigation Satellite System.....	324
	GLONASS.....	325
	Satellites.....	325
	Signals and Services.....	327
	Code Division Multiple Access.....	327
	Frequency Division Multiple Access.....	328
	Control Segment.....	330
	Time Management.....	331
	Galileo.....	331
	Satellites.....	332
	Signals and Services.....	333
	Control Segment.....	336
	Time Management.....	336
	BeiDou.....	337
	BDS-1.....	338
	BDS-2.....	338
	BDS-2 Signals and Services.....	338

BDS-3.....	340
BDS-3 Signals and Services.....	340
BeiDou Message Services.....	341
BeiDou Augmentation Services.....	341
BeiDou's Control/Ground Segment	342
BeiDou Time Management.....	342
The Quasi-Zenith Satellite System.....	343
Satellites.....	343
Signals and Services	344
Control Segment.....	345
Time Management	345
NavIC	346
Satellites.....	346
Signals and Services	347
Control Segment.....	347
Time Management	348
Progress	348
Exercises.....	351
Answers and Explanations	353
Glossary	357
References	415
Index.....	417