

Contents

Chapter 1 Introduction	1
1.1 Overview	1
1.2 U. S. Global Positioning System	2
1.2.1 GPS Services	4
1.2.2 GPS Modernization Program	5
1.3 Russian GLONASS System	7
1.4 Chinese BeiDou Satellite Navigation System	9
1.4.1 BeiDou Program History	10
1.4.2 BeiDou Services	12
1.5 European Galileo Satellite System	14
1.6 Augmentations	16
1.7 Organization of the Book	16
Review Questions	19
Chapter 2 Fundamentals of Satellite Navigation	21
2.1 Methods of Radionavigation	21
2.1.1 Trilateration	21
2.1.2 Hyperbolic Positioning	23
2.1.3 Doppler Positioning	24
2.2 Concept of Ranging Using TOA Measurements	26
2.2.1 Two-Dimensional Position Determination	26
2.2.2 Principle of Position Determination via Satellite-Generated Ranging Signals	29
2.3 Reference Coordinate Systems	31
2.3.1 Earth-Centered Inertial Coordinate System	31

2.3.2	Earth-Centered Earth-Fixed Coordinate System	32
2.3.3	World Geodetic System	33
2.3.4	Height Coordinates and the Geoid	36
2.3.5	GLONASS Coordinate Reference System	39
2.3.6	BeiDou Geodetic Reference System	40
2.3.7	Galileo Coordinate Reference System	41
2.4	Time References and GNSS Time	42
2.4.1	Time Scales; Astronomical and Atomic	43
2.4.2	GNSS System Time	48
2.5	Fundamentals of Satellite Orbits	54
2.6	Position, Velocity and Time Estimation	65
2.6.1	Determining Satellite-to-User Range	66
2.6.2	Calculation of User Position	69
2.6.3	User Velocity Estimation	73
2.6.4	Time Estimation	77
	Review Questions	77
Chapter 3	Functional Segments of GNSS	79
3.1	Overview of the GNSS System	79
3.1.1	Space Segment Overview	80
3.1.2	Control Segment Overview	81
3.1.3	User Segment Overview	82
3.2	Space Segment	82
3.2.1	GPS Space Segment	82
3.2.2	GLONASS Space Segment	88
3.2.3	BeiDou Space Segment	93
3.2.4	Galileo Space Segment	96
3.3	Control Segment	99
3.3.1	GPS Control Segment	99
3.3.2	GLONASS Control Segment	118
3.3.3	BeiDou Control Segment	118
3.3.4	Galileo Control Segment	119
3.4	User Segment	121
	Review Questions	122

Chapter 4 Stand-Alone GNSS Performance	123
4.1 Introduction	123
4.2 GNSS Error Sources	124
4.2.1 Satellite Clock Error	126
4.2.2 Ephemeris Error	127
4.2.3 Relativistic Effects	129
4.2.4 Atmospheric Effects	131
4.2.5 Receiver Noise and Resolution	146
4.2.6 Multipath and Shadowing Effects	146
4.2.7 Hardware Bias Errors	164
4.2.8 Pseudorange Error Budgets	166
4.3 Accuracy	168
4.3.1 Satellite Geometry and Dilution of Precision in GPS	168
4.3.2 Accuracy Metrics	174
4.3.3 Weighted Least Squares (WLS)	179
4.3.4 Additional State Variables	180
4.3.5 Kalman Filtering	181
4.4 Availability	181
4.5 Integrity	184
4.5.1 Discussion of Criticality	184
4.5.2 Sources of Integrity Anomalies	185
4.5.3 Integrity Enhancement Techniques	186
4.6 Continuity	200
Review Questions	201
Chapter 5 GNSS Signals	203
5.1 Introduction	203
5.2 Modulations for Satellite Navigation	203
5.2.1 Modulation Types	203
5.2.2 Multiplexing Techniques	206
5.2.3 Signal Models and Characteristics	207
5.3 GPS Signals	213
5.3.1 Legacy GPS Signals	213

5.3.2	Modernized GPS Signals	236
5.3.3	GPS Signal Summary	242
5.4	GLONASS Signals	243
5.4.1	GLONASS Frequencies	243
5.4.2	Modulation	245
5.4.3	Code Properties	245
5.5	BeiDou Signals	247
5.5.1	BeiDou Frequencies	247
5.5.2	Open Service Signals	248
5.5.3	Ranging Code	249
5.6	Galileo Signals	252
5.6.1	Frequencies and Signals	252
5.6.2	Modulation Schemes	255
5.6.3	SAR Signal Plan	265
5.7	Navigation Message Format	266
5.7.1	GPS Navigation Message	266
5.7.2	GLONASS Navigation Message	269
5.7.3	BeiDou Navigation Message	271
5.7.4	Galileo Navigation Message	275
	Review Questions	277
Chapter 6	GNSS Receivers	279
6.1	Introduction	279
6.2	GPS Receiver Architecture	281
6.2.1	Radio Frequency (RF) Front End	282
6.2.2	Frequency Down-Conversion and IF Amplification	284
6.2.3	Analog-to-Digital Conversion and Automatic Gain Control	286
6.2.4	Baseband Signal Processing	287
6.3	GPS Signal Acquisition	287
6.3.1	Tong Search Detector	293
6.3.2	M of N Search Detector	296
6.3.3	Direct Acquisition of GPS Military Signals	298
6.4	GPS Signal Tracking	301
6.4.1	Predetection Integration	303