

Understanding GPS: Principles and Applications Second Edition

Elliott Kaplan and Christopher Hegarty ISBN 1-58053-894-0 Approx. 680 pages Navtech Part #1024

This thoroughly updated second edition of an Artech House bestseller brings together a team of leading experts who provide you with a current and comprehensive treatment of the Global Positioning System (GPS). The book covers all the latest advances in technology, applications, and systems. The second edition includes new chapters that explore the integration of GPS with vehicles and cellular telephones, new classes of satellite broadcast signals, the emerging GALILEO system, and new developments in the GPS marketplace.

This single-source reference provides both a quick overview of GPS essentials and an indepth treatment of advanced topics. The book guides you in developing new applications and shows you how to evaluate their performance. It explains all the differential GPS services available to let you decide which is best for particular applications. You learn how to build GPS receivers and integrate them into navigational and communications equipment. Moreover, this unique volume helps you determine how technology is affecting the marketplace and where best to invest your company's resources.

Author Bio

Elliott Kaplan is a principal engineer at the MITRE Corporation, Bedford, Massachusetts. He is the New England Section Officer of the Institute of Navigation.. He earned his M.S. in electrical engineering from Northeastern University.

Christopher Hegarty is a senior principal engineer at the MITRE Corporation, Bedford, MA. He received a D.Sc. in electrical engineering from The George Washington University and currently serves as editor of the Institute of Navigation's quarterly journal, *NAVIGATION*, and as a member of RTCA, Inc.'s Program Management Committee.

Contents

Pref	ace	XV
Acknowledgments		xvii
_	-	
	APTER 1	
Intro	oduction	1
1.1	Introduction	1
1.2	Condensed GPS Program History	2
1.3	GPS Overview	3
	1.3.1 PPS	4
	1.3.2 SPS	4
1.4	GPS Modernization Program	5
1.5	GALILEO Satellite System	6
1.6	Russian GLONASS System	7
1.7	Chinese BeiDou System	8
1.8	Augmentations	10
1.9	Markets and Applications	10
	1.9.1 Land	11
	1.9.2 Aviation	12
	1.9.3 Space Guidance	13
	1.9.4 Maritime	14
1.10) Organization of the Book	14
	References	19
СН	APTER 2	
	damentals of Satellite Navigation	21
	-	
2.1	Concept of Ranging Using TOA Measurements	21
	2.1.1 Two-Dimensional Position Determination	21
	2.1.2 Principle of Position Determination Via	2.4
2.2	Satellite-Generated Ranging Signals	24
2.2	Reference Coordinate Systems	26
	2.2.1 Earth-Centered Inertial Coordinate System	27
	2.2.2 Earth-Centered Earth-Fixed Coordinate System	28
	2.2.3 World Geodetic System	29
2.2	2.2.4 Height Coordinates and the Geoid	32
2.3	Fundamentals of Satellite Orbits	34
	2.3.1 Orbital Mechanics	34
2.4	2.3.2 Constellation Design	43
2.4	Position Determination Using PRN Codes	50
	2.4.1 Determining Satellite-to-User Range	51
	2.4.2 Calculation of User Position	54

2.5	Obtaining User Velocity	58
2.6	Time and GPS	61
	2.6.1 UTC Generation	61
	2.6.2 GPS System Time	62
	2.6.3 Receiver Computation of UTC (USNO)	62
	References	63
CH	APTER 3	
GPS	System Segments	67
3.1	Overview of the GPS System	67
	3.1.1 Space Segment Overview	67
	3.1.2 Control Segment (CS) Overview	68
	3.1.3 User Segment Overview	68
3.2	Space Segment Description	68
	3.2.1 GPS Satellite Constellation Description	69
	3.2.2 Constellation Design Guidelines	71
	3.2.3 Space Segment Phased Development	71
3.3	Control Segment	87
	3.3.1 Current Configuration	88
	3.3.2 CS Planned Upgrades	100
3.4	User Segment	103
	3.4.1 GPS Set Characteristics	103
	3.4.2 GPS Receiver Selection	109
	References	110
CH	APTER 4	
	Satellite Signal Characteristics	113
4.1	_	113
4.2	Modulations for Satellite Navigation	113
	4.2.1 Modulation Types	113
	4.2.2 Multiplexing Techniques	115
	4.2.3 Signal Models and Characteristics	116
4.3	Legacy GPS Signals	123
	4.3.1 Frequencies and Modulation Format	123
	4.3.2 Power Levels	133
	4.3.3 Autocorrelation Functions and Power Spectral Densities	135
	4.3.4 Cross-Correlation Functions and CDMA Performance	140
4.4	Navigation Message Format	142
4.5	Modernized GPS Signals	145
	4.5.1 L2 Civil Signal	145
	4.5.2 L5	147
	4.5.3 M Code	148
	4.5.4 L1 Civil Signal	150
4.6	Summary	150
	References	150

CHA	APTER 5	
Satel	lite Signal Acquisition, Tracking, and Data Demodulation	153
5.1	Overview	153
5.2	GPS Receiver Code and Carrier Tracking	155
	5.2.1 Predetection Integration	158
	5.2.2 Baseband Signal Processing	159
	5.2.3 Digital Frequency Synthesis	161
	5.2.4 Carrier Aiding of Code Loop	162
	5.2.5 External Aiding	164
5.3	Carrier Tracking Loops	164
	5.3.1 Phase Lock Loops	165
	5.3.2 Costas Loops	166
	5.3.3 Frequency Lock Loops	170
5.4	Code Tracking Loops	173
	Loop Filters	179
5.6	Measurement Errors and Tracking Thresholds	183
	5.6.1 PLL Tracking Loop Measurement Errors	184
	5.6.2 FLL Tracking Loop Measurement Errors	192
	5.6.3 C/A and P(Y) Code Tracking Loop Measurement Errors	194
	5.6.4 Modernized GPS M Code Tracking Loop Measurement Errors	199
5./	Formation of Pseudorange, Delta Pseudorange, and Integrated Doppler	200 201
	5.7.1 Pseudorange5.7.2 Delta Pseudorange	201
	5.7.3 Integrated Doppler	218
5.8	Signal Acquisition	218
5.0	5.8.1 Tong Search Detector	223
	5.8.2 <i>M</i> of <i>N</i> Search Detector	227
	5.8.3 Direct Acquisition of GPS Military Signals	229
5.9	Sequence of Initial Receiver Operations	231
	Data Demodulation	232
5.11		233
	5.11.1 Signal-to-Noise Power Ratio Meter	233
	5.11.2 Phase Lock Detector with Optimistic and Pessimistic Decisions	
	5.11.3 False Frequency Lock and False Phase Lock Detector	235
5.12		235
5.13	e e	237
5.14	Codeless and Semicodeless Processing	239
	References	240
CHA	APTER 6	
	ference, Multipath, and Scintillation	243
6.1	Overview	243
6.2	Radio Frequency Interference	243
0.2	6.2.1 Types and Sources of RF Interference	244
	6.2.2 Effects of RF Interference on Receiver Performance	247
	6.2.3 Interference Mitigation	278
6.3	Multipath	279
0.0	11 unit putit	

	6.3.1 Multipath Characteristics and Models	281
	6.3.2 Effects of Multipath on Receiver Performance	285
	6.3.3 Multipath Mitigation	292
6.4	1	295
	References	297
CH	APTER 7	
	ormance of Stand-Alone GPS	301
7.1	Introduction	301
7.2	Measurement Errors	302
	7.2.1 Satellite Clock Error	304
	7.2.2 Ephemeris Error	305
	7.2.3 Relativistic Effects	306
	7.2.4 Atmospheric Effects	308
	7.2.5 Receiver Noise and Resolution	319
	7.2.6 Multipath and Shadowing Effects	319
	7.2.7 Hardware Bias Errors	320
= 0	7.2.8 Pseudorange Error Budgets	321
7.3	1	322
	7.3.1 Satellite Geometry and Dilution of Precision in GPS	322
	7.3.2 Accuracy Metrics	328 332
	7.3.3 Weighted Least Squares (WLS)7.3.4 Additional State Variables	333
	7.3.5 Kalman Filtering	334
7.4	-	334
/ • I	7.4.1 Predicted GPS Availability Using the Nominal 24-Satellite	551
	GPS Constellation	335
	7.4.2 Effects of Satellite Outages on GPS Availability	337
7.5	GPS Integrity	343
	7.5.1 Discussion of Criticality	345
	7.5.2 Sources of Integrity Anomalies	345
	7.5.3 Integrity Enhancement Techniques	346
7.6	Continuity	360
7.7	Measured Performance	361
	References	375
CH	APTER 8	
Diff	erential GPS	379
8.1	Introduction	379
8.2	Spatial and Time Correlation Characteristics of GPS Errors	381
	8.2.1 Satellite Clock Errors	381
	8.2.2 Ephemeris Errors	382
	8.2.3 Tropospheric Errors	384
	8.2.4 Ionospheric Errors	387
	8.2.5 Receiver Noise and Multipath	390
8.3	Code-Based Techniques	391
	8.3.1 Local-Area DGPS	391

	8.3.2 Regional-Area DGPS	394
	8.3.3 Wide-Area DGPS	395
8.4	Carrier-Based Techniques	397
	8.4.1 Precise Baseline Determination in Real Time	398
	8.4.2 Static Application	418
	8.4.3 Airborne Application	420
	8.4.4 Attitude Determination	423
8.5	Message Formats	425
	8.5.1 Version 2.3	425
	8.5.2 Version 3.0	428
8.6	Examples	429
	8.6.1 Code Based	429
	8.6.2 Carrier Based	450
	References	454
CH	APTER 9	
	gration of GPS with Other Sensors and Network Assistance	459
9.1	Overview	459
9.2	GPS/Inertial Integration	460
	9.2.1 GPS Receiver Performance Issues	460
	9.2.2 Inertial Sensor Performance Issues	464
	9.2.3 The Kalman Filter	466
	9.2.4 GPSI Integration Methods	470
	9.2.5 Reliability and Integrity	488
	9.2.6 Integration with CRPA	489
9.3	Sensor Integration in Land Vehicle Systems	491
	9.3.1 Introduction	491
	9.3.2 Review of Available Sensor Technology	496
	9.3.3 Sensor Integration Principles	515
9.4	Network Assistance	522
	9.4.1 Historical Perspective of Assisted GPS	526
	9.4.2 Requirements of the FCC Mandate	528
	9.4.3 Total Uncertainty Search Space	535
	9.4.4 GPS Receiver Integration in Cellular Phones—Assistance Data	
	from Handsets	540
	9.4.5 Types of Network Assistance	543
	References	554
CH	APTER 10	
	ILEO	559
10.1	GALILEO Program Objectives	559
10.2	6	559
	10.2.1 Open Service (OS)	560
	10.2.2 Commercial Service (CS)	562
	10.2.3 Safety of Life (SOL) Service	562
	10.2.4 Public Regulated Service (PRS)	562
	10.2.5 Support to Search and Rescue (SAR) Service	563

10.3 GALII	LEO Frequency Plan and Signal Design	563
10.3.1	Frequencies and Signals	563
10.3.2	Modulation Schemes	565
10.3.3	SAR Signal Plan	576
10.4 Interop	perability Between GPS and GALILEO	577
10.4.1	Signal in Space	577
10.4.2	Geodetic Coordinate Reference Frame	578
10.4.3	Time Reference Frame	578
10.5 System	n Architecture	579
	Space Segment	581
	Ground Segment	585
10.6 GALII	LEO SAR Architecture	591
10.7 GALII	LEO Development Plan	592
Referen	ces	594
CHAPTER 1	1	
	e Navigation Systems	595
	ussian GLONASS System	595
	Introduction	595
	Program Overview	595
	Organizational Structure	597
	Constellation and Orbit	597
	Spacecraft Description	599
	Ground Support	602
11.1.7	* *	604
11.1.8	Reference Systems	605
11.1.9		606
	System Accuracy	611
	Future GLONASS Development	612
	Other GLONASS Information Sources	614
11.2 The C	hinese BeiDou Satellite Navigation System	615
11.2.1	- · ·	615
11.2.3	Program History	616
11.2.4	Organization Structure	617
	Constellation and Orbit	617
11.2.6	Spacecraft	617
11.2.7	RDSS Service Infrastructure	618
11.2.8	RDSS Navigation Services	621
11.2.9	RDSS Navigation Signals	622
11.2.10	System Coverage and Accuracy	623
11.2.11	Future Developments	623
11.3 The Ja	panese QZSS Program	625
11.3.1	Introduction	625
11.3.2	Program Overview	625
11.3.3	Organizational Structure	626
11.3.4	Constellation and Orbit	626
11.3.5	Spacecraft Development	627

11.3.6 Ground Support	628
11.3.7 User Equipment	628
11.3.8 Reference Systems	628
11.3.9 Navigation Services and Signals	628
11.3.10 System Coverage and Accuracy	629
11.3.11 Future Development	629
Acknowledgments	630
References	630
CHAPTER 12	
GNSS Markets and Applications	635
12.1 GNSS: A Complex Market Based on Enabling Technologies	635
12.1.1 Market Scope, Segmentation, and Value	638
12.1.2 Unique Aspects of GNSS Market	639
12.1.3 Market Limitations, Competitive Systems, and Policy	640
12.2 Civil Navigation Applications of GNSS	641
12.2.1 Marine Navigation	642
12.2.2 Air Navigation	645
12.2.3 Land Navigation	646
12.3 GNSS in Surveying, Mapping, and Geographical Information Systems	647
12.3.1 Surveying	648
12.3.2 Mapping	648
12.3.3 GIS	649
12.4 Recreational Markets for GNSS-Based Products	650
12.5 GNSS Time Transfer	650
12.6 Differential Applications and Services	650
12.6.1 Precision Approach Aircraft Landing Systems	651
12.6.2 Other Differential Systems12.6.3 Attitude Determination Systems	651 652
12.7 GNSS and Telematics and LBS	652
12.7 Gross and Telematics and EBS 12.8 Creative Uses for GNSS	654
12.9 Government and Military Applications	654
12.9 Military User Equipment—Aviation, Shipboard, and Land	655
12.9.2 Autonomous Receivers—Smart Weapons	656
12.9.3 Space Applications	657
12.9.4 Other Government Applications	657
12.10 User Equipment Needs for Specific Markets	657
12.11 Financial Projections for the GNSS Industry	660
References	661
APPENDIX A	
Least Squares and Weighted Least Squares Estimates	663
Reference	664
APPENDIX B	
Stability Measures for Frequency Sources	665
B.1 Introduction	665

B.2 Frequency Standard Stability	665
B.3 Measures of Stability	667
B.3.1 Allan Variance	667
B.3.2 Hadamard Variance	667
References	668
APPENDIX C	
Free-Space Propagation Loss	669
C.1 Introduction	669
C.2 Free-Space Propagation Loss	669
C.3 Conversion Between PSDs and PFDs	673
References	673
About the Authors	675
Index	683