

**Global Positioning System:  
Signals, Measurements, and Performance 1st Edition  
Pratap Misra and Per Enge**

**Table of Contents**

Navtech Part #2500 (1st Edition)

for MORE INFO and to ORDER BOOK click [HERE](#)

**PART I-Fundamentals**

Chapter 1

Introduction ..... 3

|  |           |
|--|-----------|
| <b>1.1 A Brief History of Navigation</b> .....                           | <b>4</b>  |
| 1.1.1 Longitude and Time .....   | 6         |
| 1.1.2 Astronomical Methods .....   | 7         |
| 1.1.3 Twentieth Century Developments: Inertial Navigation and Radio..... | 8         |
| <b>1.2 Methods of Radionavigation</b> .....                              | <b>12</b> |
| 1.2.1 Trilateration .....  | 12        |
| 1.2.2 Hyperbolic Positioning .....                                       | 14        |
| 1.2.3 Doppler Positioning .....  | 15        |
| <b>1.3 Radionavigation Systems</b> .....                                 | <b>16</b> |
| 1.3.1 Terrestrial Radionavigation Systems: Loran and Omega ..            | 16        |
| 1.3.2 Satellite Navigation Systems: Transit, GPS, and GNSS .....         | 19        |
| <b>1.4 Summary</b> .....   | <b>25</b> |
| Problems   |           |
| References   |           |

Chapter 2

GPS: An Overview ..... 29

|   |           |
|---|-----------|
| <b>2.1 Objectives, Status, and Policies</b> .....                 | <b>30</b> |
| <b>2.2 System Architecture</b> .....                              | <b>32</b> |
| 2.2.1 Space Segment .....   | 32        |
| 2.2.2 Control Segment .....                                       | 34        |
| 2.2.3 User Segment .....  | 35        |
| <b>2.3 Signals</b> .....  | <b>36</b> |
| 2.3.1 Signal Structure .....                                      | 36        |
| 2.3.2 Anti-Spoofing(AS)and Selective Availability (SA) .....      | 40        |
| 2.3.3 Signal Power .....  | 41        |
| <b>2.4 Receivers and Measurements</b> .....                       | <b>42</b> |
| 2.4.1 Signal Acquisition and Tracking .....                       | 42        |
| 2.4.2 Estimation of Position, Velocity, and Time (PVT) .....      | 43        |
| 2.4.3 Evolution of Receiver Technology .....                      | 46        |
| <b>2.5 Augmentation Systems and Differential GPS (DGPS)</b> ..... | <b>46</b> |
| <b>2.6 Civil Applications</b> .....                               | <b>50</b> |

|  |            |
|--|------------|
| <b>2.7 Modernization Plans .....</b>                                 | <b>55</b>  |
| 2.7.1 Cost-Performance Curves .....                                  | 55         |
| 2.7.2 New Signals and Their Benefits .....                           | 57         |
| <b>2.8 Summary• .....</b>  | <b>59</b>  |
| Problems   |            |
| References   |            |
|  |            |
| Chapter 3  |            |
| GPS Coordinate Frames, Time Reference, and Orbits .....              | 69         |
| <b>3.1 Global Coordinate Systems .....</b>                           | <b>71</b>  |
| 3.1.1 Terrestrial and Inertial Reference Systems .....               | 71         |
| Conventional Terrestrial Reference System:                           |            |
| Conventional Inertial Reference System                               |            |
| 3.1.2 Geodetic Coordinates Geoid, and Darums .....                   | 75         |
| Ellipsoid and Ellipsoidal Coordinates; Definition of Height;         |            |
| Regional Datums and Map Projections                                  |            |
| 3.1.3 World Geodetic System 1984 (WGS 84) .....                      | 80         |
| <b>3.2 Time References and GPS Time .....</b>                        | <b>83</b>  |
| 3.2.1 Time Scales: Astronomical and Atomic .....                     | 84         |
| Solar and Sidereal Times; Atomic Time; Definition of Time Epoch      |            |
| 3.1.2 Stability Measures of Frequency Sources* ..                    | 88         |
| 3.2.3 GPS Time .....   | 91         |
| <b>3.3 GPS Orbits and Satellite Position Determination .....</b>     | <b>92</b>  |
| 3 3.1 Kepler', Laws* .....   | 93         |
| 3.3.2 Ideal Elliptical Orbits: Keplerian Elements .....              | 95         |
| 3.3.3 Satellite Position and Velocity .....                          | 97         |
| 3.3 4 Perturbed Keplerian Orbit, .....                               | 100        |
| 3.3.5 GPS Orbital Parameters .....                                   | 102        |
| 3.3.6 GPS Navigation Message .....                                   | 105        |
| <b>3.4 GPS Satellite Constellation and Visibility Displays .....</b> | <b>105</b> |
| <b>3.5 Summary .....</b>   | <b>109</b> |
| Appendix 3.A Coordinate Conversion .....                             | 115        |
| Problems   |            |
| References   |            |

## **PART II-Estimation of Position, Velocity, and Time**

### Chapter 4

|  |     |
|--|-----|
| GPS Measurements and Error Sources ..... | 123 |
|--|-----|

#### **4.1 Measurement Models .....**

|                                     |     |
|-------------------------------------|-----|
| 4.1.1 Code Phase Measurements ..... | 124 |
|-------------------------------------|-----|

|  |     |
|--|-----|
| 4. t.2 Canter Phase Measurements ..... | 126 |
|--|-----|

|  |     |
|--|-----|
| 4.1.3 An Instructive Model for the Code and Carrier Measurements | 129 |
|--|-----|

|                                      |     |
|--------------------------------------|-----|
| 4.1.4 Error Sources and Model, ..... | 130 |
|--------------------------------------|-----|

#### **4.2 Control Segment Errors: Satellite Clock and Ephemeris ....**

|            |  |            |
|------------|--|------------|
| <b>4.3</b> | <b>Signal Propagation Modeling Errors</b>                          | <b>132</b> |
| 4.3.1      | Signal Refraction- Wave Propagation, and Dispersive Media          | 132        |
| 4.3.2      | Ionospheric Delay  | 137        |
|            | Phase Advance and Group Delay, Obliquity Factor                    |            |
|            | Delay Estimation with Dual-Frequency Measurements; Broadcast Model |            |
| 4.3.3      | Tropospheric Delay   | 145        |
|            | Dry and Wet Delays; Tropospheric Models: Mapping Functions         |            |
| <b>4.4</b> | <b>Measurement Errors</b>  | <b>150</b> |
| 4.4.1      | Receiver Noise   | 150        |
| 4.4.2      | Multipath  | 151        |
| 4.4.3      | Measurement Error Models   | 152        |
| <b>4.5</b> | <b>User Range Error (URE)</b>                                      | <b>153</b> |
| <b>4.6</b> | <b>Measurement Errors: Empirical Data</b>                          | <b>155</b> |
| <b>4.7</b> | <b>Combining Code and Carrier Measurements</b>                     | <b>157</b> |
| 4.7.1      | Signal-Frequency Measurement                                       | 157        |
| 4.7.2      | Dual-Frequency Measurements  | 160        |
| <b>4.8</b> | <b>Error Mitigation: Differential GPS (DGPS)</b>                   | <b>161</b> |
| 4.8.1      | Error Mitigation   | 162        |
| 4.8.2      | Local-Area DGPS and Relative Positioning                           | 164        |
| 4.8.3      | Wide-Area DGPS   | 169        |
| <b>4.9</b> | <b>Summary</b>   | <b>170</b> |
|            | Problems   |            |
|            | References   |            |

Chapter 5

|                |     |
|----------------|-----|
| PVT Estimation | 175 |
|----------------|-----|

|            |   |            |
|------------|---|------------|
| <b>5.1</b> | <b>Position Estimation with Pseudoranges</b>                          | <b>176</b> |
| 5.1.1      | Linear Model for Position Estimation                                  | 178        |
| 5.1.2      | RMS Positioning Error   | 182        |
|            | Satellite Geometry, Dilution of Precision (DOP); Distribution of DOP; |            |
|            | What's DOP Good For?  |            |
| 5.1.3      | Price of an Inexpensive Receiver Clock                                | 188        |
| 5.1.4      | Other Performance Measures and Specifications                         | 189        |
| 5.1.5      | Empirical Positioning Results   | 192        |
|            | Position Estimates in Autonomous Mode; DGPS Position Estimates        |            |
| <b>5.2</b> | <b>Position and Velocity from Doppler Rates</b>                       | <b>196</b> |
| 5.2.1      | Velocity Estimation   | 196        |
| 5.2.2      | Position Estimation   | 198        |
| <b>5.3</b> | <b>Time Transfer</b>  | <b>198</b> |
| <b>5.4</b> | <b>Summary</b>  | <b>202</b> |
|            | Problems  |            |
|            | References  |            |

Chapter 6

|  |     |
|--|-----|
| Precise Positioning with Carrier Phase | 209 |
|--|-----|

|            |   |            |
|------------|---|------------|
| <b>6.1</b> | <b>Carrier Phase and Integer Ambiguity Resolution:<br/>A Simple Model</b> | <b>210</b> |
|------------|---|------------|

|            |   |            |
|------------|---|------------|
| <b>6.2</b> | <b>Carrier Phase Measurements and Precise Positioning .....</b>   | <b>214</b> |
| 6.2.1      | Carrier Phase Measurements .....  | 214        |
| 6.2.2      | Precise Positioning and Navigation .....  | 215        |
| <b>6.3</b> | <b>Elimination of Nuisance Parameters .....</b>   | <b>218</b> |
| 6.3.1      | Single Difference .....   | 218        |
|            | Estimation of Position and Change in Position:<br>The Relent` Geometric Diversity .....   | 223        |
| 6.3.2      | Double Difference . .....   | 223        |
| 6.3.3      | Triple Difference .....   | 225        |
| 6.3.4      | Integer Ambiguity Resolution and Position Estimation .....  | 226        |
| <b>6.4</b> | <b>Resolving Ambiguities One at a Time .....</b>  | <b>227</b> |
| 6.4.1      | Using Code Measurement, to Estimate Integers .....  | 227        |
| 6.4.2      | Dual Frequency Measurements: Wide Laning .....  | 230        |
| <b>6.5</b> | <b>Resolving Ambiguities as a Set .....</b>   | <b>233</b> |
| 6.5.1      | Linear Model for Position estimation.. .....  | 234        |
| 6.5.2      | Float Solution .....  | 236        |
| 6.5.3      | Search Techniques .....   | 236        |
|            | Constraints on the Integers: Local Minima Search (LMS) Algorithm*;<br>Correlation, among the Double-Difference Measurements; LAMBDA Method* |            |
| <b>6.6</b> | <b>Three-Frequency Measurements ..</b>  | <b>248</b> |
| <b>6.7</b> | <b>Summary .....</b>  | <b>250</b> |
|            | Problems  |            |
|            | References  |            |

## **PART III-Signals and Receivers**

### Chapter 7

|                   |     |
|-------------------|-----|
| GPS Signals ..... | 257 |
|-------------------|-----|

|            |   |            |
|------------|---|------------|
| <b>7.1</b> | <b>Time Domain Description .....</b>                        | <b>258</b> |
| <b>7.2</b> | <b>Fourier Transforms .....</b>                             | <b>263</b> |
| <b>7.3</b> | <b>Frequency Domain Description of GPS Signals .....</b>    | <b>264</b> |
| <b>7.4</b> | <b>Auto-correlation and Cross-correlation .....</b>         | <b>268</b> |
| <b>7.5</b> | <b>Maximal Length Linear Shift Register Sequences .....</b> | <b>271</b> |
| <b>7.6</b> | <b>Gold Codes of Length 31 and 1023 .....</b>               | <b>273</b> |
| <b>7.7</b> | <b>Pseudo-Random Noise (PRN) Sequences* .....</b>           | <b>277</b> |
| <b>7.8</b> |   |            |

### Chapter 8

|   |  |            |
|---|--|------------|
| Signal-to-Noise Ratio and Ranging Precision ..... | 283  |            |
| <b>8.1</b>  | <b>Signal Path Loss and Transmit Antenna Gain .....</b>        | <b>284</b> |
| <b>8.2</b>  | <b>Received Signal Power and Receiver Antenna (Iain .....</b>  | <b>287</b> |
| <b>8.3</b>  | <b>White Noise and Friis Formula .....</b>                     | <b>291</b> |
| <b>8.4</b>  | <b>Noise Analysis of a GPS Receiver .....</b>                  | <b>296</b> |
| <b>8.5</b>  | <b>Delay Lock Loops and Ranging Precision .....</b>            | <b>298</b> |
| <b>8.6</b>  | <b>Ranging Precision in the Presence of White Noise* .....</b> | <b>304</b> |

|  |            |
|--|------------|
| <b>8.7 Ranging Precision in the Presence of Signal Reflections (Multipath)</b> | <b>308</b> |
| 8.7.1 Long-Delay Multipath   |            |
| 8.7.2 Short-Delay Multipath .  |            |
| 8.7.3 Multipath-Limiting Antennas.   |            |
| <b>8.8 Summary</b>   | <b>313</b> |
| Problem,   |            |
| References   |            |
|  |            |
| Chapter 9  |            |
| GPS Receivers  | 317        |
| <b>9.1 Signal Conditioning</b>   | <b>321</b> |
| 9.1.1 Frequency Down Conversion  | 322        |
| 9.1.2 Direct Conversion  | 323        |
| 9.1.3 Image Frequencies  | 324        |
| 9.1.4 Sampling   | 325        |
| <b>9.2 Signal Acquisition</b>  | <b>331</b> |
| 9.2.1 Inphase and Quadrature Processing and Doppler Removal                    | 334        |
| 9.2.2 Ambiguity Function   | 335        |
| 9.2.3 Ambiguity Function for a Length 31 Gold Code                             | 336        |
| <b>9.3 Laplace Transforms and Convolution*</b>                                 | <b>338</b> |
| 9.3.1 Basic Definitions and Properties   | 338        |
| 9.3.2 Convolution  | 341        |
| <b>9.4 Using Feedback for Code and Carrier Tracking</b>                        | <b>344</b> |
| <b>9.5 Code Tracking Using a Delay Lock Loop</b>                               | <b>346</b> |
| 9.5.1 Discriminator Functions to Measure Code Tracking Error                   | 346        |
| 9.5.2 Linear Models for the Delay Lock Loop                                    | 349        |
| 9.5.3 Whit, Nome Performance of the Delay Lock Loop                            | 351        |
| 9.5.4 Step Response of Unaided Delay Lock Loop                                 | 353        |
| 9.5.5 Rate Anted Delay Lock Loop   | 353        |
| 9.5.6 Constructing the Whole Pseudorange Measurement                           | 354        |
| <b>9.6 Carrier Tracking Loop and Navigation Data Recovery</b>                  | <b>356</b> |
| 9.6.1 Discriminator Functions to Measure Carrier Tracking Error                | 357        |
| 9.6.2 Navigation Data Recovery   | 358        |
| 9.6.3 Linear Model and Noise Analysis for the Phase Lock Loop                  | 359        |
| 9.6.4 Dynamic Performance of the Phase Lock Loop                               | 360        |
| 9.6.5 Steady State Error for the Phase Lock Loop                               | 362        |
| <b>9.7 Summary</b>   | <b>363</b> |
| Appendix 9.A   |            |
| Receiver Techniques to Mitigate Radio Frequency Interference (RFI)             | 364        |
| Appendix 9.B   |            |
| External Assistance to Mitigate RFI and Increase Signal Sensitivity            | 365        |
| Problems   |            |
| References   |            |
| Appendix A. GPS Data Sets on the CD  | 375        |
| Guttorm R. Opshaug and Dr. Keith Alter   |            |
| Index  | 385        |

for MORE INFO and to ORDER BOOK click [HERE](#)