

Radionavigation systems

Börje Forssell



Prentice Hall

New York London Toronto Sydney Tokyo Singapore

Contents

Preface	xiii
Part I: Terrestrial systems	1
1 The fundamentals of terrestrial navigation	3
1.1 The shape of the earth	3
1.2 Maps and coordinate systems/Datum	6
1.3 Distances and directions on the surface of the earth	13
1.3.1 Great circle course on a spherical earth	13
1.3.2 Loxodrome course	15
1.3.3 Distances and directions on an ellipsoidal earth	16
2 Error calculations	19
2.1 Lines of position	19
2.1.1 Errors in lines of position	19
2.2 The geometrical influence on two-dimensional position errors	21
2.2.1 Errors in measurements of distance and distance differences	21
2.2.1.1 Distance measurements	21
2.2.1.2 Measurements of distance differences	23
2.2.2 Error ellipses	30
2.2.2.1 Distance measurement error ellipses	35
2.2.2.2 Error ellipses for a hyperbolic navigation system	37
2.3 Accuracies	40
2.4 Two-dimensional position determination by means of more than two LOPs	45

3 Wave propagation	46
3.1 Free space propagation	46
3.2 Reflection from surroundings	48
3.3 The ground wave	52
3.4 Tropospheric influence	57
3.5 Ionospheric influence	61
System descriptions	69
4 Hyperbolic systems	69
4.1 Introduction	69
4.2 General	69
4.3 Phase measurements	70
4.4 OMEGA	73
4.4.1 General	73
4.4.2 Signal format	73
4.4.3 Wave propagation at VLF	76
4.4.3.1 General	76
4.4.3.2 Conditions in the lower part of the ionosphere	81
4.4.3.3 The directional dependence of the reflection coefficient of the ionosphere	83
4.4.3.4 Influence of the earth and the solution of the wave equations	85
4.4.4 Receivers	87
4.4.5 Transmitters	88
4.4.6 Accuracy	88
4.4.7 Differential OMEGA	91
4.4.8 Prospects	95
4.5 DECCA	96
4.5.1 Introduction	96
4.5.2 Frequencies	96
4.5.3 Receivers	97
4.5.4 Transmitter stations	105
4.5.5 Maps and corrections of the measurement result	107
4.5.6 Accuracy and coverage	107
4.5.7 Perspectives	112
4.6 LORAN-C	114
4.6.1 General	114
4.6.2 Signal format	115
4.6.3 Interference and use of pulse groups	118

4.6.4	Coded pulse groups	122
4.6.5	Receivers	123
4.6.6	Grouping of pulses for automatic search	131
4.6.7	Transmitters	136
4.6.8	Accuracy and range	138
4.6.9	Differential LORAN-C	140
4.6.10	Prospects	143
5	Direction finding	146
5.1	Introduction	146
5.2	Frequencies and transmitters	147
5.3	Directivity	148
5.4	Receiver antennae	149
5.4.1	Antennae for improved accuracy	154
5.4.1.1	The Adcock antenna	154
5.4.1.2	Doppler direction finders	156
5.5	Accuracies	158
6	Aircraft systems	160
6.1	Introduction	160
6.2	VOR	162
6.2.1	Operation	162
6.2.2	The receiver	163
6.2.3	Doppler VOR	164
6.3	DME	166
6.3.1	Principles of operation	166
6.3.2	Search procedure	167
6.3.3	The transponder	169
6.3.4	Accuracies/Use	170
6.3.5	DME/P	170
6.4	ILS	175
6.4.1	System principles	175
6.4.2	Markers	176
6.4.3	Angular information	177
6.4.4	Accuracy/Sources of error	180
6.5	MLS	182
6.5.1	Introduction	182
6.5.2	TRSB angular information	183
6.5.3	The data message	188
6.5.4	Use	188
6.5.5	Accuracies and coverage	188
6.5.6	Costs and perspectives	191

Part II: Satellite systems	193
7 Satellite orbits and geometry	195
7.1 Introduction	195
7.2 Kepler's laws	195
7.3 Distortion of the orbits	196
7.4 Coordinate systems	198
8 Satellite navigation principles	204
8.1 Frequency measurements	204
8.2 Time measurements	206
8.3 Measurement principles	206
9 Error calculations	209
9.1 Error sources	209
9.2 The geometrical influence on the accuracy	214
9.2.1 Frequency measurements	214
9.2.2 Time measurements	217
9.2.2.1 Calculation of geometrical dilution of position	217
System descriptions	225
10 TRANSIT	225
10.1 Introduction	225
10.2 The satellites	225
10.3 Navigation principles	229
10.3.1 Satellite signals	229
10.3.2 Position measurements	232
10.4 The receiver	235
10.5 The use of two carrier frequencies	242
10.6 The iteration procedure	244
10.7 Accuracy	245
10.8 Translocation	247
10.9 Fields of utilization/Future	249
11 Spread spectrum: coding of satellite signals	250
11.1 Introduction	250
11.2 Spread spectrum	251
11.2.1 Principles	251

11.2.2	Spreading functions	252
11.2.3	The correlation function	254
11.2.4	Generation of the codes (spreading functions)	258
11.2.5	The receiver	261
11.3	Spread spectrum in NAVSTAR/GPS	267
12	NAVSTAR/GPS	272
12.1	Introduction	272
12.2	Satellite orbits	272
12.3	The satellites	276
12.4	The control segment	278
12.5	The navigation message	281
12.5.1	Introduction	281
12.5.2	TLM and HOW	281
12.5.3	Data block 1	281
12.5.3.1	Clock corrections	284
12.5.3.2	Age of data/group delay	284
12.5.3.3	Corrections of ionospheric delays	286
12.5.4	Data block 2	287
12.5.4.1	Introduction	287
12.5.4.2	Parameter representation selection	289
12.5.5	Data block 3	292
12.6	Receivers	293
12.6.1	Introduction	293
12.6.2	Receiver types	294
12.6.3	Receiver description	297
12.6.4	Clock and frequency stability	303
12.6.5	Antennae	304
12.7	Differential GPS	306
12.7.1	Presumptions and possibilities	306
12.7.2	Work up to now	308
12.8	Interferometric use	311
12.9	Accuracy	315
12.10	Integration with other navigation systems	318
12.10.1	GPS and inertial navigation systems	318
12.10.2	GPS and LORAN-C	319
12.10.3	Other combinations	320
12.11	Perspectives	321
13	GLONASS	322
13.1	Introduction	322

x Contents

13.2 Satellite orbits	323
13.3 The navigation signals	324
13.4 The codes	325
13.5 The navigation message	326
13.6 Receivers	327
13.7 Accuracy	327
14 Other satellite navigation systems	328
14.1 Introduction	328
14.2 TSIKADA	329
14.3 STARFIX	330
14.4 GEOSTAR/LOCSTAR	330
14.5 NAVSAT	332
Appendix 1: Datum transformation	335
Appendix 2: Formulas from spherical trigonometry	338
A2.1 Theorems concerning right-angled spherical triangles	338
A2.2 Theorems concerning arbitrary spherical triangles	339
Appendix 3: The radii of curvature of an ellipsoidal surface	341
Appendix 4: The standard deviation of the error in a two-dimensional position	344
Appendix 5: Position determination by the method of least squares	346
Appendix 6: Errors in DECCA user lines of position due to phase errors caused by the master-to-slave, master-to-user and slave-to-user signal paths	352
Appendix 7: Satellites in orbit	356
A7.1 Derivation of Kepler's laws	356
A7.2 The orbital velocity	361
A7.3 Orbital coordinates as time functions	363
A7.4 Launching of satellites into a desired orbit	368
Appendix 8: A method of satellite selection in time measurement systems	371

Appendix 9: Basic Kalman filter equations	375
References	377
Index	387