

FRANK VAN DIGGELEN



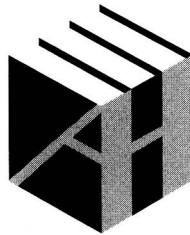
A-GPS

Assisted GPS, GNSS, and SBAS

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A-GPS: Assisted GPS, GNSS, and SBAS

Frank van Diggelen



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Foreword

More than 35 years have passed since some of us were fortunate enough to play a role in the design of GPS. Predecessor systems and designs, such as Transit, Timation, 621B, DNSS, and atomic clocks provided some of its foundations. Considered at first by some as a useless adventure of some technologists with little knowledge of real navigation, GPS has now become a household word and has many millions of users, mostly civilian, in aircraft, ships, surveying, construction, and most of all, cell phones and automobiles.

Assisted GPS (A-GPS) is one of the major contributors to the widespread use of GPS, especially for cell phones and other handheld units. A-GPS integrates GPS and communications, especially wireless and utilizes GPS chips with added low-cost processing power and many thousands of correlators. GPS satellites are limited in the amount of power they can provide to users on the ground many thousands of miles away. A-GPS provides important information, by means of these separate wireless communications channels, to substantially improve the processing power of the GPS receiver, so that they can operate successfully in disadvantaged locations and circumstances where buildings, trees, hills may partially degrade the GPS signals.

A-GPS—Assisted GPS, GNSS, and SBAS by Dr. Frank van Diggelen brings together a highly readable description of this technology and its theory and an emphasis on practical examples of its actual use or planned use in real-world applications, products, and chipsets. He complements this detailed description of A-GPS with a large number of Matlab code examples and an even larger number of informative figures and tables. He also translates the industry standards into a practical perspective. He concludes with a glimpse of the future of A-GNSS, in which new generations of GPS and other global-navigation satellites will be in orbit.

*Dr. James J. Spilker, Jr., Ph.D, NAE
Professor, Consulting
Department of Electrical Engineering
and Aeronautics and Astronautics
Cofounder, Stanford University
Center for Position, Navigation, and Time
March 2009*

Preface

This book is primarily intended for GNSS technical professionals involved in the study, research, design, or use of GPS/GNSS. However, much of the book is also intended to be accessible to a nontechnical audience. To achieve this dual-purpose, the book has been organized so that each chapter begins with an overview of the subject matter. The nontechnical reader, or anyone wishing to get a quick insight, can read the entire Chapter 1, and then Section 2.1, Section 3.1, and so on. This gives you approximately a 50-page summary, like an embedded study guide.

For the technical GPS professional the book is meant as a complete design guide to Assisted GPS: It is intended for engineers and scientists already thoroughly familiar with the basics of GPS.

The author has been involved in the development of commercial GPS receivers since before the initial operational capability of the GPS system. Over the last decade he has been exclusively employed in the design and implementation of A-GPS receivers deployed in tens of millions of personal navigation devices and mobile phones worldwide. Thus the book is written from the point of view of practical design of A-GPS for commercial use. It focuses on what is actually done in industry. Because of this you may notice that in some topics we deviate from the conventional approach described in many GPS texts, especially in the areas of signal processing for high sensitivity. This is mostly to reflect actual practice, but also comes with the express intent to show alternative approaches to certain topics already covered or touched on in earlier works. So if you find that certain expositions are not what you are used to, this is, I hope, the deliberate result of a new approach.

Although the book is intended to be practical, we do not shy away from theoretical detail where it is required. Chapters 4 and 5, dealing with navigation, are dense with linear algebra; and Chapter 6 (High Sensitivity) has much statistical analysis for digital signal processing. However, to make it easier to absorb the material, we provide worked examples in Matlab, including snippets of Matlab scripts that you can read, or copy and run for yourself, to illustrate certain concepts or replicate results.

This book evolved from a course on *Indoor GPS* (or high sensitivity A-GPS) first taught in March 2001. Chapter 6 is dedicated to high sensitivity receiver design, and is almost a book within a book. The rest of the book covers the other aspects of A-GPS, including: generation and analysis of the assistance data; the mathematics of GPS navigation, in particular coarse-time navigation; long term orbits; industry standards; government mandates; and future A-GNSS.

As part of the emphasis on the practical approach, the book includes an appendix with tables of conversion factors and rules of thumb that A-GNSS designers and

researchers will use in their everyday work. These tables include cross references to the relevant sections where each topic is analyzed. I have these tables at my desk for everyday reference, and I hope you find them equally helpful.

I will be grateful to readers who point out errors and offer ideas for improvement at www.frankvandiggelen.com.

Acknowledgments

I have been lucky to work with many excellent GPS engineers. However three in particular stand out for their unusual combination of brilliance, knowledge, and time spent teaching me: Dr. Alison Brown (Navsys), Charles Abraham, and Sergei Podshivalov (Ashtech, Global Locate, Broadcom). Without them this would be a very thin book indeed!

The material in this book began with a class taught for NavtechGPS, in 2001. Carolyn McDonald, Keith McDonald, Franck Boynton, F'Lynne Didenko, and Yelena Teterina of NavtechGPS have all helped me prepare and present this course over the years. My colleagues at Global Locate were the first guinea pigs we tested the notes on over a series of lectures. There were 20 attendees at those lectures, and most of them are still working with me today: Alex Usach, Chris Lane, Charles Abraham, David Lundgren, Don Fuchs, Emre Tapucu, Huan Phan, Javier de Salas, John Pavan, Keith Evans, Phong Van, Scott Pomerantz, Serge de la Porte, Sergei Podhsivalov, and Vinny Hyunh.

After Broadcom acquired Global Locate in 2007 the seed of an idea germinated: turn the course notes into a book. Thanks to the enthusiastic support (at Broadcom) of Scott Pomerantz, Bob Rango, Nambi Seshradi, Henry Samueli, and Mark Walsh (Artech House), that seed blossomed into the complete work.

I was extremely fortunate to collaborate with the Stanford University GPS group; over a series of lectures through the summer of 2008 we tested and discussed each chapter. Many ideas and perspectives in the book are thanks to this group: Alan Chen, Alex Ene, Dr. David De Lorenzo, Prof. David Powell, Di Qiu, Godwin Zhang, Jiwon Seo, Prof. Kai Borre (Aalborg University), Prof. Nobuaki Kubo (Tokyo University of Marine Science and Technology), Shankar Ramakrishnan, Dr. Todd Walter, Tom Langenstein, Tsung-yu Chiou, and Dr. Y.C. Chao. Special thanks to Prof. Per Enge and Dr. Sherman Lo for organizing the lectures, Dr. Juan Blanch for the improved proof of the extra state theorem in Chapter 5, Dr. Grace Gao for much input on Chapters 3, 6, and 10, and Prof. James Spilker for advice and input on every chapter, and teaching me the importance of good graphics with full, descriptive, captions.

Thanks also to Dr. Farshid Alizadeh (Skyhook Wireless) for contributions to Chapter 7.

The cellular industry standards are sometimes an impenetrable alphabet soup of changing acronyms, and I am deeply indebted to Javier de Salas (Broadcom), and Dr. Jari Syrjärinne (Nokia), for contributing everything good about industry standards in Chapter 9, including the description of the ME-PE architecture and interface.

It is often difficult to wade through early drafts and half-formed explanations, and I am grateful to my colleagues who have done so. Thanks to Dr. Jason Goldberg

for many fruitful discussions around Chapter 6; Emre Tapucu for various discussions during lunchtime runs; Dr. Roberto Zanutta for his DR expertise; Randall Silva for Talon NAMATH and his excellent general GPS knowledge; Richard Najarian for researching government mandates; Dr. Hongming Li, Vijay Venkatasubramanian, Matt Riben, and Dr. Premal Medhani for their input on orbit analysis and SBAS; and Kathy Tan for diligently reading and improving Chapter 4.

Finally, and most importantly, the greatest thanks belong to my wonderful wife, Alison, and our two children, Lewis and Tanera, who have endured endless weekends, mornings, and evenings in the production of this book—they now know far more about GPS than they ever meant to!

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