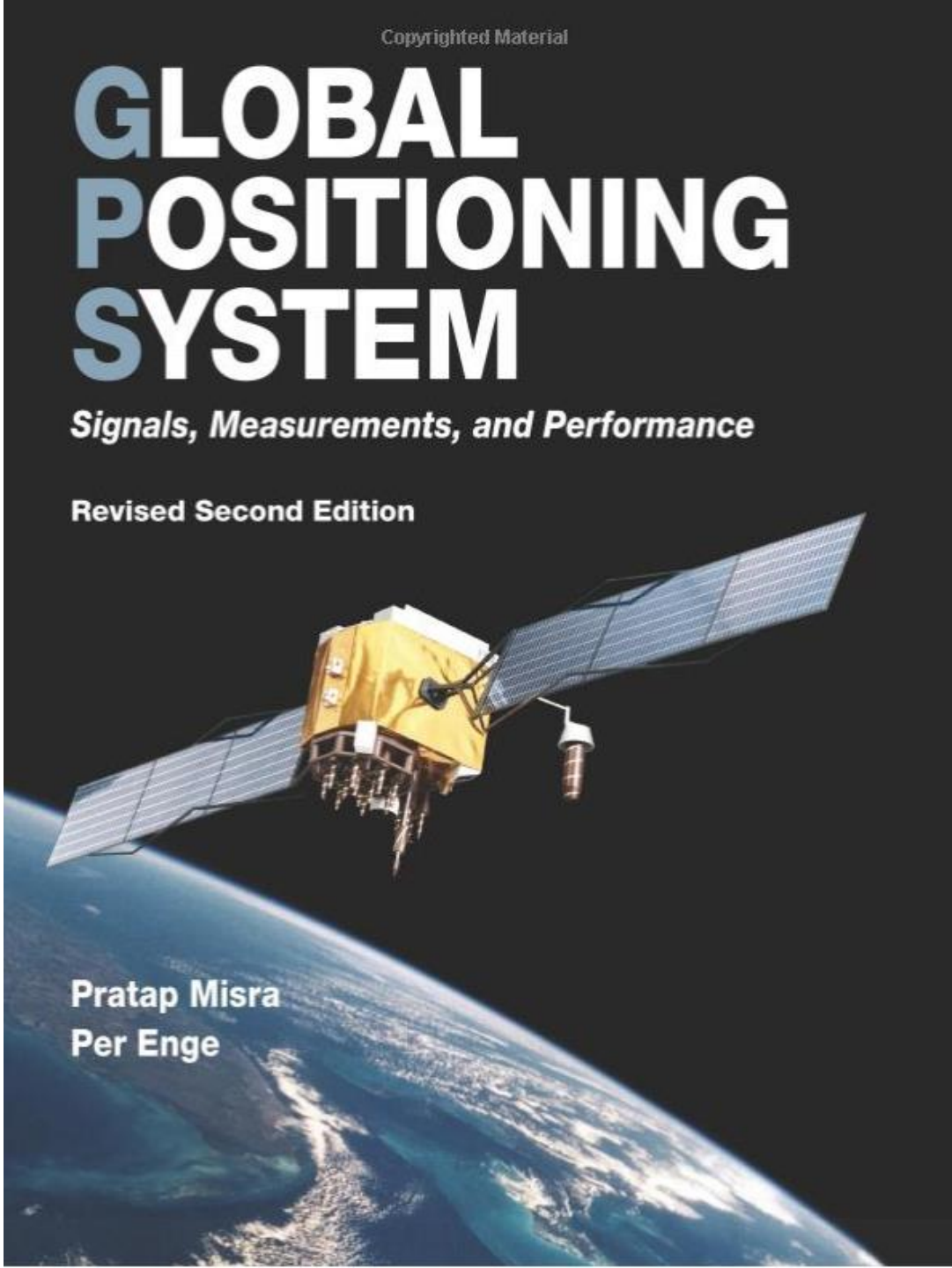
Global Positioning System: Signals, Measurements and Performance

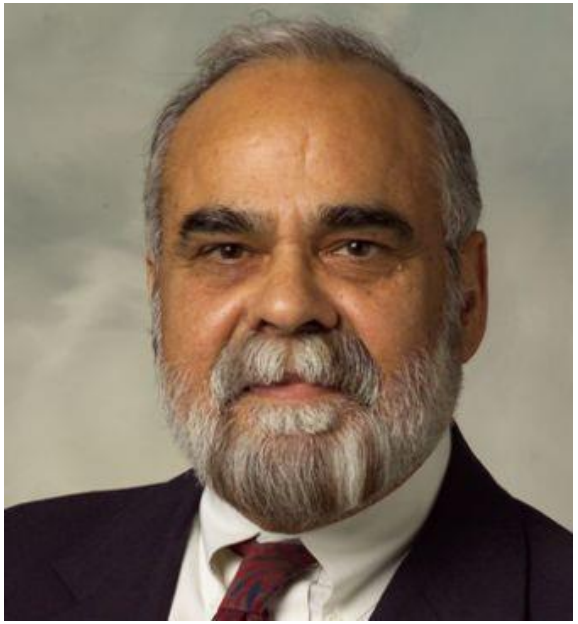
11th meeting of the
UN International Committee on GNSS
06-11 November 2016

Presentation to WG-C
Rick Hamilton



From the preface by Professor Pratap Misra (Tufts University) and Professor Per Enge (Stanford University)

Both authors are recipients of the prestigious Institute of Navigation (ION) Kepler Award



"GPS, in many ways, is like the Internet. Both are gifts of the U.S. Department of Defense to the civil world. Both continue to transform the way we do ordinary, everyday things as individuals and society, delivering wide-ranging economic and social benefits far beyond anything their designers could have dreamed of."

SPACE GENERATION ADVISORY COUNCIL

A Textbook for Use by the ICG Regional Centers for Space Science and Technology Education

- Coordination:
  - Civil GPS Service Interface Committee (CGSIC)
  - ICG Secretariat UNOOSA
- Funding:
  - National Aeronautic and Space Administration (NASA) with a very generous donation by the book's authors
- Purchase:
  - Space Generation Advisory Council (SGAC)
- Distribution:
  - SGAC Headquarters in Vienna, Austria

Second Edition

- This edition corrected, updated, revised, and expanded treatment of the GPS signals, measurements, and performance.
- But the basic objective remains unchanged:

  To offer an introductory textbook for students of engineering and applied sciences and a self-study guide for practicing engineers.

Prerequisites

- Some background in linear algebra, probability theory, signal theory, and linear system theory is required for this book.
- An ideal preparation would be an upper-division course in each of these areas.
- Vector-matrix notation is used throughout.
- The concepts of mean, standard deviation, covariance, and correlation of random variables are used without explanation.
- However, the results from signal theory and system theory are reviewed before beginning discussion of the GPS signals and receivers.

Part 1: Fundamentals.

"*These stars shine all the time radiating extraordinarily faint radio signals.*"

- Introduces the basic framework of a global satellite navigation system, including coordinate frames, time references, and orbits,
- Provides an overview of GPS, GLONASS, and Galileo,
- Begins study of the engineering principles of GPS with a discussion of the fundamentals.

- **Chapter 1:** Brief survey of the history of navigation from watching the heavens to measuring radio signals.
- **Chapter 2:** Offers an overview of GPS, describing briefly the system, signals, receivers, performance, and applications.
- **Chapter 3:** Gives a similar overview of the global navigation satellite systems now under development, including the GPS upgrade.
- **Chapter 4:** Examines three topics basic to GPS: Coordinate frames in which to specify a position, time scales, and satellite orbits.

PART II: Estimation of Position, Velocity and Time

"*Centimeter-to-decimeter-level accuracy is now being achieved in real time by users on the move who can stand still for a minute or two.*"

- A close look at the measurements provided by GPS and the algorithms for processing these measurements to obtain Position, Velocity and Time (PVT) estimates.

- **Chapter 5:** Discussion of the measurements, error sources, and error mitigation.
- **Chapter 6:** Algorithms for estimation of PVT based on measurements of pseudoranges and pseudorange rates.
- **Chapter 7:** Examination of precise relative positioning based on carrier phase measurements.

PART III: GPS Signals

"*GPS signals travel 20,000 kilometers from a medium earth orbit and arrive at the earth's surface with a power density of only 10^{-14} to 10^{-13} watts/m^2.*"

Electro-magnetic whispers:

- Enable high-precision ranging even in the presence of natural noise and modest amounts of man-made interference.
- Distinguish the direct (desired) signal from reflected signals.
- Allow satellites to simultaneously use same transmission frequencies.
- Carry all the ancillary data required for position fixing.

- **Chapter 8:** Review of signals and systems tools needed in the remainder of the book
- **Chapter 9:** Uses tools to provide time and frequency domain characterizations of GPS signal, introduces auto-correlation and cross-correlation functions and provides a random sequence analysis of GPS codes.
- **Chapter 10:** Analyzes GPS signal power and competing background noise.

PART IV: Receivers

"*Even though we might like to, we cannot simply connect the GPS antenna to a fast computer.*"

- Signal power must be increased by approximately ten orders of magnitude in power.
- Natural noise and man-made radio-frequency interference (RFI) must be removed to the extent possible.
- Signal conditioning is required to cope with rapid (1.5 billion cycles per second) variations.
- Must down-convert frequency to something more manageable and convert from an analog signal to a digital signal.

- **Chapter 11:** The process known as signal acquisition is described.
- **Chapter 12:** The continuous process of signal tracking, as estimates of receiver and satellite movements are updated, is described.
- **Chapter 13:** The growing portfolio of countermeasures to mitigate the deleterious effect of GPS signal obstructions or competing radio signals is described.

Summary

This book offers an instructor several options for a one-semester senior- or graduate-level course.

The two simplest options are:

- Chapters 1–7 for a course with emphasis on positioning and navigation algorithms, and
- Chapters 1, 2, 8–13 for a course with emphasis on signals and receivers.
- Students may download GPS measurements required for some homework exercises: www.GPStextbook.com.

In either case, the authors hope the instructor would apply and extend the basic ideas of positioning algorithms or receiver design to a specialized application, e.g., geodesy, aviation, land navigation, or assisted GPS.

Well wishes from authors:

"Pratap and I welcome you to the world of satellite navigation. Navigation is a global enterprise that connects distant corners of our lives. On one hand, these navigation satellites are very personal; we can use them to get to the market, or meet our friends, or communicate our position during an emergency. We can also rest assured that the ships at sea and aircraft in the sky are running true to their destinations, because they carry navigation radios. In addition, satellite navigation makes generous use of very elegant science and mathematics. Indeed, many of humankind's greatest science stems from the wish to know where we are. We hope that this book brings you joy, and that it helps to bring you closer to this worthy field of study and practice."

Per Enge

Pratap Misra