GPS at Geosynchronous Orbit

Coordinated through the Policy and Strategic Communications (PSC) Office, Space Communications and Navigation (SCaN) Program, NASA Headquarters

21 April 2010

Background

The U.S. space community uses the Global Positioning System (GPS) in a number of spacecraft and science instrument applications throughout the GPS Terrestrial Service Volume, which spans from the surface up to 3000 km altitude. Onboard the satellite, GPS may be used to determine satellite position as an input to navigation software that calculates and propagates the satellite's orbit. GPS may also provide accurate time synchronization for satellites as well as spacecraft attitude determination.

The development of the *Blackjack* family of GPS spaceborne science receivers has been led by Dr. Larry Young of the Jet Propulsion Laboratory (JPL) in support of NASA science missions including, for example, GPS occultation measurements for atmospheric research or observations of GPS signals reflected off the Earth's surface to measure sea level height. The Blackjack receiver family is continuously evolving and new capabilities include tracking signals from various Global Navigation Satellite Systems (GNSS) and supporting on-board navigation.

NASA is also working with the Air Force to define the GPS performance parameters that support navigation services in the GPS Space Service Volume (SSV), which covers the region in space between 3,000 km and Geostationary Earth Orbit (GEO) altitude (~36,000 km), as described in the GPS III Capabilities Development Document.

Beyond the GPS Terrestrial Service Volume

Navigation within the GPS Space Service Volume requires specialized GPS receivers capable of operating in a high-radiation environment and tracking weaker GPS signals. The *Navigator* is a space-qualified GPS receiver, being developed by a team led by Dr. Carl Adams at the NASA Goddard Space Flight Center (GSFC), designed to highly elliptical and geosynchronous orbits (Figures 1a and 1b). It has flown as part of a Remote Navigation Sensor experiment on the Hubble Space Telescope Servicing Mission-4 (HST SM-4), and is being used for benchmark performance testing for the geosynchronous GOES-R mission. The Magnetospheric Multi-Scale (MMS) mission consists of four identical spacecraft flying in formation in a High Earth Orbit (HEO) orbit to explore the interaction of Earth's magnetic field with the solar wind, which will operate in a 1.2 by 25 Earth radii elliptical orbit and use GPS for primary navigation. Navigator will also be a primary Navigation sensor for the Global Precipitation Measurement (GPM) mission, a prototype is being developed for the Air Force Research Lab's (AFRL) Plug-and-Play spacecraft, and is serving as the technological backbone of commercial GPS receiver designs for GOES-R, the AFRL Nanosatellite Guardian for Evaluating Local Space (ANGELS) GEO mission (receiver developed by Broad Reach Engineering), and the Orion vehicle (receiver developed by Honeywell). The *Navigator* is also being explored for possible navigation in trans-lunar orbits.

Significance of the Technology

Navigator enables autonomous on-orbit navigation in GEO and HEO regimes where typical GPS receivers fail to pick up a signal. A side benefit of the weak signal algorithm is that it requires no prior information and can rapidly acquire a position fix within minutes (less than 1 minute for strong signals). This is extremely useful during black out scenarios and cold-start situations. *Navigator* comes complete with an on-board orbit determination filter, known as Goddard Enhanced Onboard Navigation System (GEONS), to filter and propagate the solution providing high levels of accuracy combining the orbit knowledge with raw GPS measurements. Navigation accuracies on the 1-meter order are possible in GEO orbits using the increased acquisition and tracking sensitivity of *Navigator*.

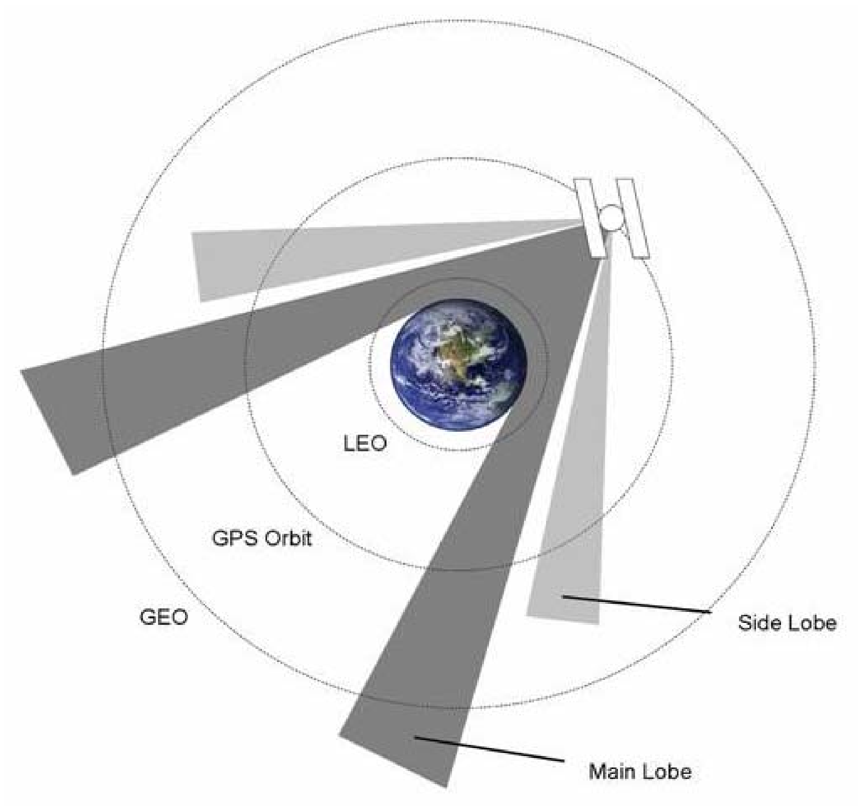


Figure 1a - Weak Signal GPS Space Environment

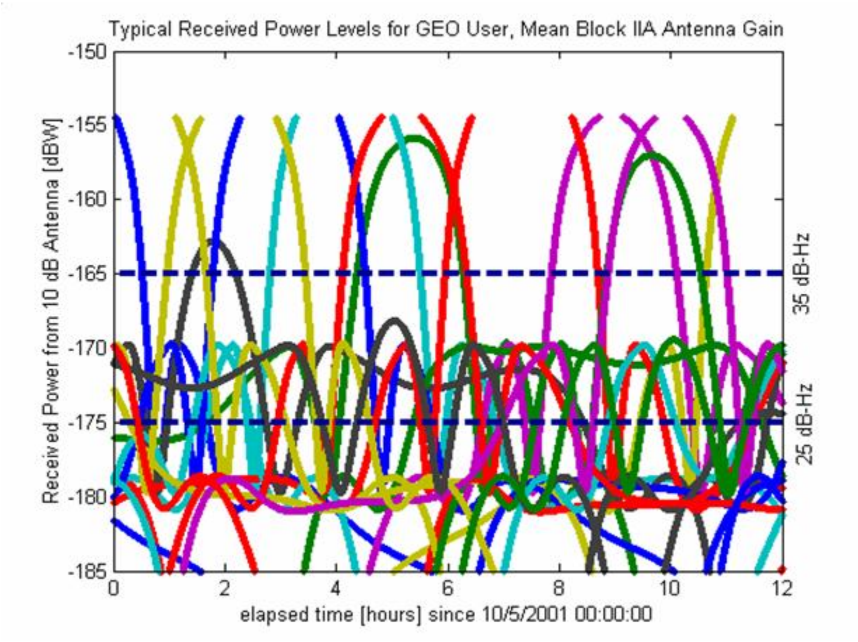
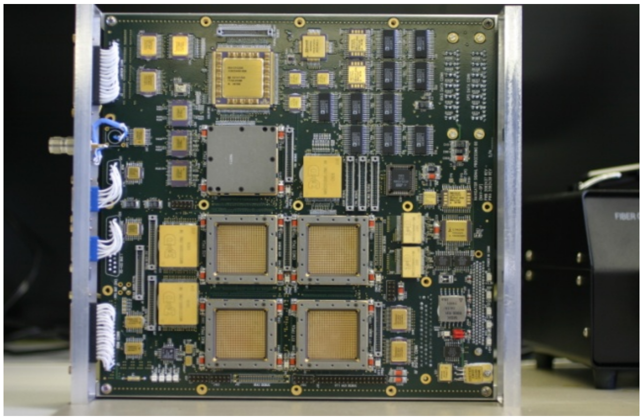


Figure 2b – GPS Signal Levels at GEO

Benefits At-A-Glance

- Able to acquire and track the much weaker side-lobe signals broadcast by GPS satellites. (signal power threshold of 25 dB-Hz vs. conventional 35-40 db-Hz receivers)
- 6U format processing card < 1 kg and uses 12-15 W on-orbit on average. (see Figure 2)
- Radiation tolerance > 100 kRad

- Data Interfaces: RS422, 1553, SpaceWire
- Provides up to 32 tracking channels, 4 antenna inputs (current design)



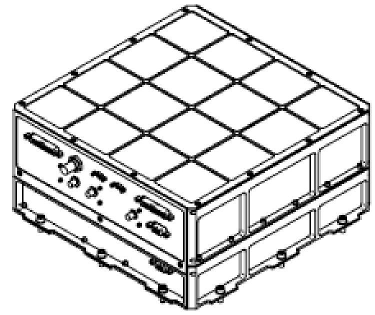


Figure 3 - Navigator GPS Receiver Signal Processing Card (NAV-SP) and Flight Enclosure

How the Technology Works

The technology works by using a special acquisition engine to find the GPS signals. The acquisition engine is built around Fast Fourier Transforms (FFT) and is embedded in a Field Programmable Gate Array (FPGA). This enables rapid processing allowing for extremely quick acquisitions. The acquisition process works by searching for all possible delays of the transmitted GPS signal while simultaneously searching through a large Doppler space. The results are buffered in 4 MB of Static Random Access Memory (SRAM) and are integrated over longer periods, allowing for weak signal reception.

Technology Origins

The acquisition algorithm was developed by Dr. Mark Psiaki at Cornell University (see M.L. Psiaki, "Block Acquisition of Weak GPS Signals in a Software Receiver," Proceedings of the 2001 ION GPS Conference). Greg Boegner and Luke Winternitz, both from GSFC, further developed and implemented the algorithm in real-time on a development board using Field Programmable Gate arrays.

Looking Ahead

Navigator is undergoing testing for the MMS mission via a Spirent STR4760 GPS simulator available in the Flying Formation Test Bed at GSFC. During that testing, *Navigator* flew in various low-Earth orbit, highly elliptical, and geosynchronous orbits. Future research on *Navigator* will include increasing the acquisition and tracking sensitivity to levels necessary to make GPS measurements at lunar distances (~ 15 dB-Hz signal acquisition power threshold), and adding additional sensor capabilities, such as Micro-Electro-Mechanical Systems (MEMS) inertial sensors.

Other enhancements could include a chip-scale atomic clock to further enhance GPS/GNSS signal acquisition. In addition, a small onboard mercury-ion atomic clock could be used to supplement the GPS signals at GEO by providing long-term time stability.

Additional information:

Feasibility of using GPS at GEO: http://www.emergentspace.com/publications.html#gps

Navigator Flight Receiver: http://techtransfer.gsfc.nasa.gov/ft_tech_gps_navigator.shtm

GEONS: http://techtransfer.gsfc.nasa.gov/ft_tech_geons.shtm