JPL GPS Capabilities Overview

Stephen Lichten
Manager, Tracking Systems and Applications Section
Stephen.Lichten@jpl.nasa.gov

Jet Propulsion Laboratory (JPL), California Institute of Technology
JPL is managed by Caltech for NASA as a Federally Funded Research and Development Center (FFRDC)

- Work is also performed for other non-NASA agencies and private sector

Our Section is one of five in JPL's Telecommunications Science and Engineering Division

- 128 employees in the Section, 108 with B.S. or higher (74 Ph.D.'s)
- 11 Technical Groups
  - Five groups focused on GPS technology: two hardware groups and three analysis groups (~ 55 technical employees)
  - Two groups focused on precision Frequency/Timing systems and quantum technologies (~ 20 technical employees)

4 Supervisors here today

- Yoaz Bar-Sever (Orbiter and Radio Metric Systems)
- Larry Young (GPS Systems)
- Bob Tjoelker (Frequency and Timing Advanced Instrument Development)
- Frank Webb (Satellite Geodesy and Geodynamics Systems)
- Also here: Stephen Lichten (Manager) and Jim Zumberge (Deputy Manager)
Introduction (cont.)

- Diverse section with technologists, specialists, and scientists provides a "cradle to grave" capability in GPS-based systems and applications
  - Signal structure expertise; in-receiver algorithms and software; performance trades
  - Innovative GPS receiver design (multiple patents)
  - GPS receiver/transceiver spaceborne experiments and deployments
  - Orbit/trajectory estimation and user positioning algorithms & software (multiple patents)
  - Precise spacecraft-spacecraft tracking systems
  - GPS ground networks and automated data acquisition systems for precision ground and orbiting applications (operating on 24/7 basis)
  - User applications: real-time and non-real-time; navigation/positioning; geolocation and time transfer; tropospheric and ionospheric science; gravity science; geophysics

- Frequency and Timing unique core expertise
  - Responsible for 24/7 operation of mission critical NASA/JPL frequency and timing subsystems in global Deep Space Network
  - Advanced atomic clock technology development; innovative oscillators and resonators; precision time and frequency measurements (multiple patents)
  - Underlying fields include: quantum electronics, laser cooling, quantum optics, fundamental physics
  - Presently building advanced space clocks for future GPS (Linear Ion Trap clock) and Space Station (Laser cooled clocks) deployments
Other groups include specialists in: radio interferometry (ground and space); optical interferometry (space); antenna arraying; correlator systems; quantum science and technologies
Advanced GPS Receiver Technology (a)

TurboRogue
Commercial
Ground Receiver
(1992)

Ruggedized
A/D Converter
RS-422
(1995)

GPS/MET Class
Microlab-I
4/3/95
(Pegasus)
Wake Shield II & III
9/7/95 & 11/96
(Shuttle)

Engineering
Model

Ørsted Class
Low Power
Data Compression
(1996)

Ørsted
Denmark
2/23/99
(Delta)
Sun Sat
S. Africa
2/23/99
(Delta)

MIR-HMG
Russia/US
Cancelled
(Shuttle/MIR)

GeoSat Follow On
2/98
Ball/AOA
(Taurus)

Bit-Grabber Class
Ultra-Low Power Nav
RF Sampling @ LEO/GEO
CA/P/Y Ground Proc.

SNOE
2/98(Pegasus)

DoD Briefing
S. Lichten
December 2000
Advanced GPS Flight Receivers/Transceivers (b)

SAC-C Class
Hi-Performance PowerPC
CPU
Lower Power Multi-Antenna

- SRTM
  200 (Shuttle)
- SAC-C
  Argentina
  11/00
  (Delta II WITH EO1) 705 km
- CHAMP
  Germany
  7/15/00
  (COSMOS) 470-330 km/yr
- STRV-1c
  UK/US
  11/00
  (Ariane-5)
- Jason-1
  French/US
  3/01
  (Delta II with TIMED)

Raptor Class
Additional Functions Lower Power

- GRACE
  US/Germany
  8/01
  (Rockot)500-300 km
  3 gps ant, red bb and K, Ka RF

Raptor Constellation:
4-D coherence, Bistatic Radar, Inter SC links

ST-3 Space Interferometer:
Autonomous Formation Flyer 3/05

DoD Briefing
S.Lichten
December 2000
GPS tracking maintains constant and precise knowledge of relative spacecraft positions & clocks
Demonstrated Orbit Accuracies

Geostationary
36000 km altitude (TDRS, INMARSAT)
15 m ground-based tracking

GPS
20000 km altitude
8 cm (< 40-cm real-time) operational automated processing

Lageos
6000 km altitude <10 cm 2-way laser ranging

TOPEX/POSEIDON
1336 km altitude
With GPS: < 2 cm radial (AS off)
< 3 cm (AS on) radial
< 10 cm 3D RSS operational automated processing

MicroLab/GPSMET
730 km altitude
With GPS L1/L2 < 10 cm

EUVE (Explorer)
500 km altitude
2-3 m with GPS L1 only

Shuttle Radar Topography Mission (SRTM): 230-km alt
45-cm orbit accuracy

CHAMP: 470-km alt
< 10-cm orbit accuracy

SAC-C: 705-km alt
< 10-cm orbit accuracy

FUTURE GOAL: < 1-cm Orbit Accuracy for LEOs

DoD Briefing
S.Lichten
December 2000
Linear fits to GPS-based clock estimates for pairs of masers worldwide (some separated by 1000’s of km) show rms scatter of better than 30 picosec
• GPS and/or LEO cross-link tracking maintain constant and precise knowledge of relative spacecraft positions & clocks
Spacecraft Cross-Link Sensors Under Development for Space Deployments

GRACE: JPL GPS Receiver with integrated camera and K-band spacecraft-spacecraft tracking, to provide 1-micron accuracy measurement of range change to improve knowledge of the Earth's gravity field by several orders of magnitude.

ST-3: Precision (1-cm) formation flying

Mars Network Node: Integrated Navigation and Telecommunications

ST-5: Constellation Communications and Navigation Transceiver (CCNT) for meter-level cross-link ranging and inter-spacecraft telecom in constellation of three spacecraft in GEO-transfer elliptical Earth orbit.

DoD Briefing

S. Lichten

December 2000
Global Positioning System (GPS) Measurements Applied to Geophysics and Natural Hazards

- NASA contributes about one-quarter of the ≈ 200 GPS tracking stations in the International GPS Service (IGS) global network.
- Analyses of their data is interpreted in terms of tectonic plate motions and geodynamics.
- High density deployment of GPS sites contributes to the assessment of earthquake hazards (southern California map).

DoD Briefing
S.Lichten

December 2000
Los Angeles is moving, literally

LOS ANGELES, August 4 — Scientists at the Jet Propulsion Lab in Pasadena, Calif., have made measurements that suggest that downtown Los Angeles is moving toward the San Gabriel Mountains, and that a new mountain range is being formed beneath Hollywood.
Shortening and Thickening of Metropolitan Los Angeles

residual velocity field

Mojave segment, San Andreas F.
best 25 mm/yr 20 km

DoD Briefing

S. Lichten

December 2000
Using Satellite Technology to Help Track Global Change Such As El Niño

- JPL receives daily GPS satellite tracking data and automatically determines TOPEX/Poseidon orbit "next-day" accurate to a few centimeters
- Calibrated TOPEX/Poseidon altimeter data provide accurate information on sea level changes
- Scientists infer ocean temperatures and determine that an El Nino event is occurring based on sea level rise in Pacific Ocean
- Advance preparations can save lives and property

DoD Briefing
S.Lichten
December 2000
Novel Science Applications

Atmospheric and Ionospheric Remote Sensing and Science

Bi-Static Ocean Reflectometry

Troposphere: vertically integrated precipitable water vapor
Task: GPS Wide Area Augmentation System (WAAS) Implementation

Task Purpose/Objectives:
- Deliver working prototype of real-time software for DOT/FAA's new GPS-based precision navigation system (WAAS) for aviation. Support its implementation and develop future enhancements.

Major Products and Deliverables:
- Real-Time GIPSY (RTG) software
- Real-time WAAS Ionospheric Software (WIS)
- New GPS and safety algorithms

Sponsor: DOT/FAA

Customer Relevance:
- Improve airline navigation accuracy by orders of magnitude; enhance aviation safety in U.S.
- Save $12B+ in next decade in fuel and airport costs

NASA Relevance:
- Real-time, autonomous space navigation
- Onboard science data product generation
- Real-time natural hazard monitoring
- Pathfinder for the Mars Network Infrastructure.
Established a global, real-time, differential GPS ground network

- Real-time user accuracies: 8 cms RMS horizontal, 20 cms RMS
  - ~10 times better than best available commercial and military systems
- State-space method => no need to be near reference station (global availability)
- 30-40 cms 3D (RSS) global GPS orbits, in real-time
- NASA, DoD and commercial applications being studied, including:
  - X33/RLV navigation (X33 flight demo planned)
  - Automated LEO navigation and onboard science data product generation
Frequency and Timing Research

- Linear Ion Trap frequency Standards (LITS): world's best for measuring times over ~ hours to weeks
  - New generation of atomic frequency standards was developed at JPL and is now being installed in NASA ground stations. Small size, high reliability also make it a natural choice to advance spacecraft capabilities to ultra-high stability levels ($10^{-15}$ or better).
  - Project underway to deploy LIT on a GPS satellite

- Projects underway to fly laser-cooled clocks on the Space Station

- Photonic research
  - Provide new capabilities for distribution, conversion & generation of ultra-stable RF & microwave signals.
  - These capabilities are essential to NASA's worldwide deep space antenna/communications system
  - Optical fiber with low thermal variability
  - Photonic frequency conversion that can entirely eliminate the need for an external downconverter.
  - OptoElectronic Oscillator: ultra-high stability in a small, room-temp package
Applications of JPL Technologies With Potential Interest for GPS III

- Studies of GPS signals & performance (propagation, jamming, codes ...)
- User equipment directed studies and research
- GPS system performance improvement (global network, 10-cm real-time user accuracy ...)
- "Truth systems" to validate operational performance
- Evaluation of GPS augmentations (space and/or ground)
- Prototypes (algorithms, software, hardware) for operational GPS enhancements (OCS, users ...)
- Precision clocks for long-term use in operational environments on ground or onboard GPS satellites

- JPL routinely contracts directly with non-NASA agencies and/or with private companies, and licenses its technologies (through Caltech).
JPL’s GPS Receiver Technology

Larry Young,
Dec 8, 2000
GPS System Building Blocks
(Today, Tomorrow)

■ Satellites
  ■ Lc, second civil link
  ■ Ls, science link
  ■ POD-friendly design (phase center, rad. Models)

■ Digital receivers
  ■ Sub mm precision
  ■ On-board multipath mitigation
  ■ Lower power/mass/cost
  ■ Additional capabilities (active ant array, ...)

■ Global tracking network
  ■ Data from >200 digital receivers
  ■ Automated 15-cm GPS orbits
  ■ Realtime 30-cm GPS orbits
JPL's GPS Receivers
Characteristics

- Developed to provide the highest accuracy observables
- Designed in consultation with users of science data
- Flexible design (software radio)
  - All tracking loops closed in software
  - Next receiver replaces ASICs with FPGAs to allow dynamic hardware reconfiguration
JPL's GPS Receivers Development

- Design hardware and algorithms
- Predict performance analytically
- Simulate receiver performance at the sample level, with $10^{-8}$ cycle precision
- Do bench testing to measure performance vs analysis
  - Ex. C/A measured range vs SNR varies according to analysis. An SNR-based correction was added to the C/A pseudorange.
JPL GPS Receiver History

- Ground GPS receiver development at JPL (*tectonic deformation, clk. sync., ion maps, ships/planes*)
  - 1979 **SERIES** (codeless pseudorange, directional), cm precision, sub-ns clk synch
  - 1986 **Rogue** + 1992 **TurboRogue** (code and codeless pseudorange and carrier), 0.1 mm precision, 0.01 ns clock-synch precision
JPL GPS Receiver History (contd)

- Flight GPS receiver development at JPL (*Precise Orbit Determination*, gravity, atmospheric occultation, bistatic radar, attitude, ...)
  - 1995 **TRSR** on GPS/MET, Wake Shield, Ørsted, SunSat,
  - 1998 **BitGrabber** on SNOE, STRV-1C
  - 2000 **BlackJack** on SRTM, CHAMP, SAC-C, JASON, GRACE, ICESat, FedSat, VCL, ST5

**Constellation flying**

- SAC-C, GRACE, ST3, ST5, Mars infrastructure
Architecture

Block Diagram TRSR Subsystem

Antennas

Bandpass Filter

Low Noise Amplifier

Osc. $F_0$

Downconverter Subassembly

Signal Processing ASIC

PowerPC 603e

Control Logic

SDRAM

Flash

Communication

I/O

N * 12 parallel tracking channels Nominal n=4

Power
JPL-Developed Digital Receiver Performance

- Limiting-Performance test results
- 29-m baseline measured on JPL mesa

- Repeatability over 5 successive days is 0.1 mm (0.7 arc sec)
Undersea Positioning
(Today, Tomorrow)

- GPS/acoustic buoy, multiple seafloor transponders
  - SIO/JPL demonstrated <10 cm repeatability for seafloor reference mark
  - Fixed site
  - Post-processed

- Multiple buoys to locate underwater vehicle
  - Develop algorithms to measure sound velocity
  - Produce sub-meter realtime kinematic positioning
Sub Decimeter Positioning Under 2.6 km of Ocean
BlackJack Derived Comm/Nav Transceivers

**AFF Class**
- Ka-band
- S/C to S/C Link
- no GPS (deep space)
- Nav + Comm
- Range + Bearing Angle
- Extreme Performance
- 1 kbps (no coding)
- 6 month mission

**ST-3 Space Interferometer**: Autonomous Formation Flyer (AFF)

**CCNT Class**
- S-band
- S/C to S/C Link
- "BitGrabber" GPS
- Nav + Comm
- Range
- Lower Performance
- 1 kbps + coding
- 6 month mission

**ST-5 NanoSat Constellation Trailblazer**: Constellation Communication and Navigation Transceiver (CCNT)

**MNN Class**
- UHF + X-band
- S/C to many S/C Links
- no GPS (@ Mars)
- Nav + Comm
- Range + Doppler
- High Performance
- 2 Mbps + coding
- 5-7 year mission

**Mars Network Project (Infrastructure)**:
Mars Network Node (MNN)
GRACE Mission
PROJECT OVERVIEW

SALIENT FEATURE
Launched from Plesetsk to a near-polar 500-km orbit:
- Separation is maintained to 220 km ± 50 km
The twin satellites are the instrument
- Accurate satellite-to-satellite range measurement
  Tones: ≤ 4µm @ > twice/orbit
  Noise: < 1µm/Hz-1/2
Launch & Mission Operations
- By Germany
Launch Date
- Fall 2001

SCIENCE
- A new model of the Earth’s gravity field every 30 days
- Enables monitoring of ocean heat transport
- Potential to track the storage of water in the Hydrologic Cycle

PERFORMANCE
- Minimum Science Mission – Geoid error < 10,000 microns for spatial scales of 285 km
- Expected performance – Geoid error < 350 microns for spatial scales of 285 km
- Expect to improve the knowledge by a factor of 1000 for spatial scales of 1000 km
Altimetry + Scatterometry; Ocean Reflections of GPS
(Today, Tomorrow)

- Ground and aircraft-based demos by JPL, Dassault, NASA-Langley, and U. of CO
- Two small satellite missions scheduled
  - TurboRogue receiver modifications to process data on-board
  - Receiver-controlled antenna array will be used
  - 100 MHz code on Ls will enable cm-level altimetry
  - 5 GHz Ls carrier will enhance scatterometry
GOLPE: GPS Occultation and Passive Reflection Experiment

- Precise Orbit Determination
- Long Wavelength Gravity Recovery
- Atmospheric & Ionospheric Imaging
- Ocean Altimetry & Scatterometry

GPS Satellites

SAC-C

Ocean Reflection

Occultation
SPACE-BORNE GPS REFLECTION DATA

Shuttle Radar Laboratory

SIR-C/X-SAR
SHUTTLE RADAR LABORATORY
DATA SET

Some data were gathered in High Resolution mode during April and October, 1994 Shuttle Missions

- Sampling Rate: 89.99424 Mb/sec (1 byte samples)
- Bandwidth: 40 Mhz (1220-1260 Mhz)
- Antenna Gain: 60 db with ~27 km Ground Swath Width
- Polarization: Vertical
- Two seconds before and after each data take were in a listen only mode
Specular Point Distribution for Data Take 120.7
Estimate of Bistatic Cross Section for Galapagos

Reflected GPS Signal
Observed on SRL-2
Data Take 120.7
4 sec average
Climate/Weather from GPS
(Today, Tomorrow)

- GPS/MET
  - demonstration of 1 K accuracy temperature profile
  - about 200 profiles per day

- Constellation of 100 microsatellites
  - satellite hardware and operations costs low
  - about 50,000 globally distributed profiles/day
GPS/MET

Status
• Pegasus Launch 4/3/95
• About one software version per month
• Receiver remains healthy after 27 months

TurboRogue Firsts

• First Occultation Measurements of Earth's atmosphere
• First true cold start of GPS receiver in orbit (4/12/95).
• First Autonomous Scheduling of Science Observations
• First single antenna GPS attitude determination

Problems (through 1st year on orbit)
• AS
  • Data Outages
    Many Space Craft Resets
    Many Space Craft Power Problems
    Many Receiver Resets (SEU's)
    Many Communication Errors
    10-20 Space Craft attitude problems
      - Single Antenna Attitude Determination
    6-7 Commanding Errors
    7 Uploads (1 lasting 90 minutes)
    2 Software Errors
  • 1 Latch-Up
    ~48 hour duration, affected only one channel,
Science Link, Ls
(Today, Tomorrow)

Ls

- Special session on Ls at American Geophysical Union mtg, Ls design presented @ AGU, Talk @ JPL seminar,
- Desired attributes
  - Precise ion-free pseudorange
  - Tri-laning for robust carrier ambiguity resolution
  - Low multipath
- Future appl.: altimetry, scatterometry, bistatic radar...
- Strawman design for freq., range code, constant-amplitude modulation scheme
Error in Ion-Free GPS Pseudorange vs Wideband Ls Frequency
(sys. noise errors are 20, 1 cm for C/A, Ps)
(multipath errors are 10, 2 cm for C/A, Ps)
Two Concepts for Enhancing GPS
(Today, Tomorrow)

→ Upgrade existing constellation to enable <50 cm (expect 20 cm) stand alone user positioning
  ■ Augment GPS constellation to improve robustness, availability, and add new C-band frequency signal

■ Significantly enhance GPS cross-links with continuous phase and range to maintain precise time transfer across entire constellation

■ Could support 10-cm real-time non-differential user accuracy while requiring global monitor network of only ~ 20 ground sites
Summary

- GPS receivers
- GPS antennas
- On-receiver data processing
- GPS signal design
- New applications for GPS
JPL's relevant expertise in GPS performance analysis and software

Presenter: Yoaz Bar-Sever

Contents:
Core capabilities and activities
Strategic software tools
Selected contribution to GPS performance
GPS III study topics
Core capabilities and activities - orbit determination

Precise orbit determination (scientific, military and commercial)
- GPS, Topex, SRTM, Ikonos, SAC-C, Jason, OV3, PARCS, ...

Routine and automatic GPS orbit determination processes
- Precise (better than 10 cm 3D RMS) with 3 day latency
- Rapid (20 cm 3D RMS) with 12 hours latency
- Real time (30 cm 3D RMS)
- 48 hour orbit prediction (50 cm median 3D error over last 24 hours)

Routine and automatic daily orbit determination for Topex
Core capabilities and activities - reference networks

- Operating and maintaining NASA’s global GPS network (GGN)
  - Dual frequency geodetic receivers
  - Real time global sub-net
  - Sub-cm routine daily positioning of hundreds of sites world wide

NASA’s Global GPS Network

GPS orbit determination by-products:
- Earth orientation parameters
- Determination of terrestrial reference frame
- Global ionospheric maps
Core capabilities and activities - real time systems

1995
- White Paper (WADGPS)
- Real Time GIPSY (RTG)

1996
- RTG is licensed to SATLOC
- RTG is licensed to Raytheon (WAAS)
- NASA-FAA Inter-Agency Agreement

1997
- 2nd RTG license to Raytheon (MSAS-Japan)

1998
- Internet-based Global Differential GPS (IGDG)

1999
- Global Differential GPS with IGDG operational

2000
- IGDG wins NASA Software of the Year Award

Initial ground positioning
Demonstrated 50-cm (97)

Automobile positioning
Demonstrated 80-cm (98)

Aircraft real-time Wide Area Differential navigation:
NASA SAR plane (98) and FAA/WAAS (99)
Demonstrated 40-cm vertical, 30-cm horizontal (98)

Internet-based Global Differential (IGDG) (00)
Real time ground positioning
Demonstrated 10 cm horizontal, 20 cm vertical accuracy

X-33/RLV IGDG real-time positioning demo (01)
Goal: sub-meter accuracy

Real-time autonomous positioning and navigation for Earth orbiters (00-01)
Goal: sub-10-cm accuracy
**Revolutionary new capability:**

decimeter real time positioning, anywhere, anytime

<table>
<thead>
<tr>
<th>Capability</th>
<th>JPL’s IGDG</th>
<th>Un-augmented GPS</th>
<th>Others (WADGPS services)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Seamless</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Usable in space</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Accuracy:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinematic applications</td>
<td>0.1 m horizontal</td>
<td>5 m</td>
<td>&gt; 1 m</td>
</tr>
<tr>
<td></td>
<td>0.2 m vertical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orbit determination</td>
<td>0.01 – 0.05 m (goal)</td>
<td>1 m</td>
<td>N/A</td>
</tr>
<tr>
<td>Dissemination method</td>
<td>Internet/broadcast</td>
<td>Broadcast</td>
<td>Broadcast</td>
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<tr>
<td>Targeted users</td>
<td>Dual-frequency</td>
<td>Dual-frequency</td>
<td>Single-freq.</td>
</tr>
</tbody>
</table>

For more info: [http://gipsy.jpl.nasa.gov/igdg](http://gipsy.jpl.nasa.gov/igdg)
Advanced tracking systems for spacecraft and constellations
• Next generation constellation tracking system (CETDP)
• GRACE (orbit determinations and gravity recovery)
• Constellation Communications and Navigation Transceiver (ST-5 CCNT)
• Interferometry-based deep space radio metric tracking

Constellation design
• Mars infrastructure network (comm. and navigation)
• Galileo
• Constellation design tools (visualization and analysis)
Core capabilities and activities - remote sensing

GPS-based remote sensing and science
- Altimetric missions calibration/validation
- Atmospheric sounding (ground-based and occultations)
- Global ionospheric maps
- Geodesy
- Earth orientation monitoring
- Bi-static ocean altimetry and scatterometry
- Radio science propagation calibration (Cassini)

TOPEX calibration site on Harvest oil platform
GPS Inferred Positioning System/Orbit Analysis and Simulation Software

- General tracking systems analysis and orbit determination/positioning
- Uncompromised modeling accuracy: cm-level accuracy demonstrated (ground and space)
  - Earth/Sun/Moon/planets (and tidal) gravity perturbations, solar pressure, thermal radiation, drag, empirical models etc.
  - Earth orientation, tides, ocean loading, general relativity, plate motion, troposphere, etc.
  - Unique GPS kinematic and dynamic models developed in-house (yaw, solar pressure)
- Unparalleled flexibility: space-space and ground-space tracking, range, Doppler, phase, angles, GPS, DORIS, SLR, 1-way, 2-way, 3-way data types
- Unique filter/smoothen is without equal in estimation capabilities and accuracy
- Hundreds of licensed government, industry, and academic users worldwide
Strategic software tools - GIPSY-OASIS

Geostationary 36000 km altitude (TDRS, INMARSAT)

5-25 m ground-based tracking

A small sample of GIPSY’s track record

GPS

>10 cm operational automated processing

>10 cm altitude

Lageos

6000 km altitude

<10 cm 2-way laser ranging

TOPEX 1336 km altitude

With GPS:

< 2 cm (AS off) radial
< 3 cm (AS on) radial
< 10 cm 3D RSS (AS off)

operational automated processing

EUVE (Explorer) 500 km altitude

2-3 m with GPS L1 only

MicroLab/GPSMET 730 km altitude

With GPS L1/L2 < 10 cm

Performance Analysis and Software for GPS III

12/8/00
• Optimized for real-time, autonomous radio metric data processing, orbit determination, and user positioning
• Compact - currently 50,000 lines of ANSI C code
• Designed to run in personal computers, small workstations, or flight computers (including processors embedded in GPS receivers)
• Retain the precision of the venerable GIPSY-OASIS software
• Minimize load size (400 kbytes) with fast throughput for flight CPUs
• Widely portable

• Unparalleled track record: WAAS prototype, commercial differential system, used for orbit determination (on the ground) of SNOE (Student Nitric Oxide Experiment) spacecraft, 30 cm real time GPS orbit determination.
  - Scheduled to fly on SAC-C GPS receiver (2001)
  - Scheduled to fly on the RLV/X33
  - Scheduled to fly on ST-5 constellation (2003) and perform constellation state determination using crosslinks and GPS
Visualization and Analysis Package for ORbiting Systems

Powerful constellation design and analysis tool with unique capabilities:
• Analysis of navigation, communications and radio science performance
• Robust Monte-Carlo simulation capabilities
• Ground-space and space-space links
• Innovative and stunning visualization capabilities

Primary tool for design and analysis of the Mars Network
Selected contributions to GPS operations/performance

- Explained unpredictable behavior of GPS satellites during eclipse season
- Efforts led to altering of GPS yaw attitude in orbit (1994)
- Developed and implemented in GIPSY a new model for GPS yaw attitude which directly contributed to improved GPS orbit determination.

GPS solar pressure (Bar-Sever, JPO/CZSF Report, 1997)
- Developed methodology to estimate solar radiation pressure in orbit to account for actual s/c behavior
- Developed new GPS solar radiation model significantly improving on the ROCK/T20 model. Allows for continuous tuning as satellite age
Selected contributions to GPS operations/performance

GPS antenna phase center (Bar-Sever., FAWG meeting, 1999)

- Estimated GPS transmit antenna phase center offset using ground-based observations. Reveal significant non-nominal value, including 1.5 m off-nominal value for SVN 43 (Block IIR)
- Analysis efforts on-going.

Tgd estimation
- Identified inaccuracies in the broadcast Tgd value
- Estimated values were delivered to 2SOPS and implemented in the broadcast message (1999)
Potential GPS III studies

Autonomy
- On board navigation software
- Utilization of cross links for navigation and communications  
  - Distributed onboard computing
- Limitation of orbit prediction capabilities
- Mitigation of Earth-fix orbit uncertainties

Improve navigation message
- New information for enhanced accuracy (e.g., attitude)
- Data compression schemes

Constellation design and coverage analysis
- Assess combination of LEO, MEO, GEO with VAPORS, GIPSY

System performance analysis and simulation
- GIPSY provides unique value to assess complex system

In orbit performance assessment
Potential GPS III studies

In orbit performance assessment
  • Using ground network

In orbit model enhancement and tuning
  • spacecraft never behave nominally. Successful approach demonstrated

Effective ground segment
  • Achieve best accuracy, economy, and safety with new paradigm: IGDG++

End-user software
  • Continuous phase smoothing
  • Atmospheric modeling/estimation
  • heading/windup