Tracking Systems and Applications

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JPL
JPL’s Tracking Systems and Applications
Section (335)

- Technologies for precision spacecraft tracking, remote sensing, and science
  - GPS and spacecraft-spacecraft tracking systems technologies
  - Frequency and timing: advanced atomic clocks; oscillators and resonators
  - Quantum sciences and technologies
  - Radio interferometry, antenna arraying, and correlators
  - Earth and planetary science, astronomy, fundamental physics

- Sponsors: NASA, USAF, Navy, NRO, FAA, commercial partners

- Our Section is one of five in JPL’s Telecommunications Science and Engineering Division
  - 128 employees (11 technical groups), 108 with B.S. or higher (74 Ph.D.’s)
    - 5 groups focused on GPS technology (two hardware and three analysis groups)
    - 2 groups focused on Frequency/Timing systems and quantum technologies
    - 3 groups focused on RF and optical interferometry
    - 1 group focused on solid Earth, atmospheric, and ocean science
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
  - Numerous spaceborne experiments and deployments
  - Orbit/trajectory estimation and user positioning algorithms & software
  - Precise spacecraft-spacecraft tracking systems
  - GPS global ground networks and automated data acquisition systems for precision ground and orbiting applications (operating on 24/7 basis)
  - Real-time and non-real-time applications; 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 for NASA, USAF Research Lab and USNO
  - Underlying fields: quantum optics and electronics, laser cooling, fundamental physics
  - Presently building advanced space clocks for future GPS (Linear Ion Trap clock) and Space Station (Laser cooled clocks) deployments
Advanced GPS Receiver Technology (a)

**TurboRogue**
Commercial Ground Receiver (1992)

**GPS/MET Class**

**Ørsted Class**
Low Power Data Compression (1996)

- **Microlab-I**
  - 4/3/95 (Pegasus)
- **Wake Shield II & III**
  - 9/7/95 & 11/96 (Shuttle)
- **Engineering Model**

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

**Ørsted**
- **Denmark**
  - 2/23/99 (Delta)
- **Sun Sat**
  - S. Africa 2/23/99 (Delta)
- **MIR HMC**
  - Russia/US Cancelled (Shuttle/MIR)
- **GeoSat Follow On**
  - 2/98 Ball/IAA (Taurus)

**SNOE**
- 2/98 (Pegasus)

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Aerospace Corp. Briefing: S.Lichten  July 2001
Advanced GPS Flight Receivers/Transceivers (b)

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

**Completed**
- SRTM 2/00 (Shuttle)
- SAC-C Argentina 11/00 (Delta II with EO1) 705 km
- CHAMP Germany 7/15/00 (COSMOS) 470-330 km/yr

**LAUNCHED**
- STRV-1c UK/US 11/00 (Ariane-5)
- Jason-1 French/US 10/01 (Delta II with TIMED)

**Delivery 9/01**
- VCL Delivered 7/99
- Launch 7/01
- 30 cm

**Raptor Class**
- Additional Functions
- Lower Power

**And**
- ST5
- COSMIC 8 sats 1/03
- LCAP, PARCS

**GRACE**
- US/Germany 11/01
- (Rocket) 500-300 km
- 3 gps ant, red bb and K, Ka RF

**Raptor Constellation**
- 4-D coherence, Bistatic Radar, inter SC links

**Phase A**
- Delivery 2/04

**ICESAT**
- 12/99, 8/01
- Delta II 600 km polar

**FEDSAT**
- 12/99, 1/02
- on H2A with ADEOS II

**Starlight Space Interferometer**
- Autonomous Formation
- Flyer 3/06

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Aerospace Corp. Briefing: S.Lichten July 2001
Precision LEO Positioning and Timing

• GPS tracking maintains constant and precise knowledge of relative spacecraft positions & clocks
Demonstrated Orbit Accuracies With GPS

Geostationary
36,000 km altitude
(TDRS, INMARSAT)

15 m
ground-based tracking

GPS
20,000 km altitude

8 cm (< 40-cm real-time)
operational automated processing

MicroLab/GPSMET
730 km altitude

With GPS < 10 cm

TOPEX/POSEIDON
13,360 km altitude

With GPS: < 2 cm radial accuracy
operational automated processing

Recent (2000) JPL Blackjack Flight GPS Receiver Results

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
Ultra-Precise Time Transfer with GPS

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
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.

Starlight: Precision (1-cm) formation flying

Mars Network Node: Integrated Navigation and Telecommunications

ST-5: GPS-based Constellation Communications and Navigation Transceiver (CCNT) for cross-link ranging and inter-spacecraft telecom in constellation of spacecraft in GEO-transfer elliptical Earth orbit.
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)
Novel Science Applications

Atmospheric and Ionospheric Remote Sensing and Science

Bi-Static Ocean Reflectometry
Task: GPS Wide Area Augmentation System (WAAS) Implementation

Task Purpose/Objectives:
- Deliver real-time software prototype to DOT/FAA for new GPS-based precision navigation system (WAAS) for aviation.

Major Products and Deliverables:
- Real-time software for GPS orbits, clocks, and ionosphere maps
- New GPS and safety algorithms

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.
Ionospheric Research At JPL

Goal: Mitigate impact of ionosphere on COMM, NAV and SURVEILLANCE systems

Capabilities:
- Accurately characterize ionospheric behavior
- Real-time input/output
- Tailored products

Technical Expertise:
- Global snapshots of TEC in near real-time
- Data analysis for space-borne GPS receivers
  - Vertical electron density profiles & tomography
  - CHAMP, SAC-C & GRACE missions in FY’02
- Advanced global modeling development (GAIM)
  - Broad range of outputs (e- density, winds, etc.)
  - Broad range of inputs (TEC, UV images, etc.)
- GPS Global Network
  - Real-time processing
  - Scintillation monitoring

Possible Joint Developments:
- Near real-time prediction of Total Electron Content
  - Accuracy study by Aerospace Corp.
  - Tailored development to further boost performance
- Joint analysis of space-borne GPS data
  - IOX instrument on PicoSat (L. 9/2001)
  - CORISS instrument on C/NOFS (L. 2003)
- Scintillation monitoring and prediction
- Improved global electron density specification
  - Tailor GAIM towards applications of interest
  - Accommodate new data types
- Transfer software

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Aerospace Corp. Briefing: S.Lichten  July 2001
Precise Real-Time Global GPS Navigation

- Established a **global**, **real-time**, GPS ground network
  - Real-time user accuracies: 8 cms RMS horizontal, 20 cms RMS
    - ~ 10 times better than best available commercial and military systems
  - 30-40 cms 3D (RSS) global GPS orbits, in **real-time**
  - *Winner of the 2000 NASA Software of the Year Award!*
- JPL's initial implementation utilizes Internet for communications; the system is being commercialized by Navcom who is adding GEOs to the network
- NASA, DoD and commercial applications being studied, including:
  - RLV navigation
  - Automated LEO navigation and onboard science data product generation

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Aerospace Corp. Briefing: S.Lichten July 2001
# JPL's New Global Global Capability Supports 10-20 cm User Accuracy, Anywhere, Real-Time

## Revolutionary new capability: decimeter real time positioning, anywhere, anytime

<table>
<thead>
<tr>
<th>Capability</th>
<th>JPL’s IG DG</th>
<th>Un-augmented GPS</th>
<th>Others (WADGPS services)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coverage:</strong></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><strong>Accuracy:</strong></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><strong>Dissemination method</strong></td>
<td>Internet/broadcast</td>
<td>Broadcast</td>
<td>Broadcast</td>
</tr>
<tr>
<td><strong>Targeted users</strong></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)
Frequency, Timing and Quantum Sciences and Technologies


R&D
(Science and Technology) → Development Implementation → Evaluation Testing → Products & Service

Major research and technology development:

- Linear Ion Trap Standards (LITS)
- *GPS LITS: Space version of LITS*
- Cryogenic Sapphire oscillators (CSO)
- Stabilized Optical Fiber microwave link (FODA)
- *Opto-Electronic Oscillator (OEO)*
- Micro spheres
- Trapped single ion experiment
- Laser Cooling and Atomic Physics (LCAP)
- *Space clocks - Primary Atomic Clock in Space (PARCS), Rubidium Atomic Clock Experiment (RACE)*
- *Bose-Einstein Condensate (BEC) generation*
- *Quantum Interferometer Gravity Gradiometer (QUIGG)*
Antenna Arraying and Interferometry

- Developed Low Rate (<250 sym/sec) Telemetry system arraying up to 7 antennas, for the Galileo Mission
- Completing a follow-on High Rate (6 Mega-sym/sec) Telemetry system arraying up to 8 antennas, for DSN
- Developed prototype Ka Band Array Feed and Signal Processing system for DSN 70m antenna enhancement
- VLBI (Very Long Baseline Interferometry) Correlators
  - Developed a narrowband (250 kHz) system in both H/W and later in S/W, primarily for spacecraft navigation
  - Developed a wideband (28-channel, 4 MHz, 4 station) H/W system used for Geodesy, Astrometry, Astronomy
  - Developed a real-time wideband (14-channel, 4 MHz, 2 station) correlator of same design as above system, together with a 800 Mbit/sec fiber optic channel for interconnecting antennas
  - Are in process of implementing a replacement wideband (16-channel, 16 MHz, 4 station) H/W system to be used for Space VLBI in addition to the above applications.
  - Developing a real-time wideband (8-channel, 16 MHz, 2 station) correlator of same design as above, with a 1 Gbit/sec fiber optic channel, to replace the above real-time system.
Advanced Microwave Sensing
(Interferometric Imaging from Space)

- JPL/Section 335 participated in study of advanced interferometric imaging capabilities from space platforms
  - Sponsored by NRL Code 7214 and another DoD organization
  - Examined feasibility & assessed technical issues for such systems

- Study Goals
  - Covertly detect, characterize, locate, and track all man-made earth-based and air-borne sources of RF energy and communications
  - Monitor & map all natural sources of RF energy and changes to them due to natural and human activities
  - Provide 24/7 day/night, all weather surveillance capability, precise geolocation, & penetration

- Overview & Program Planning
  - Develop concept arrays for detection and characterization of possible targets
  - Different array architectures were evaluated for performance, costs, and operational issues
  - Technology issues and tradeoffs were defined

- Issues Affecting Space Operations
  - A number of issues were investigated for orbit and cluster configurations, antenna and receiver designs, and communications and on-board data processing/compression
Selected References

Ionospheric electron density profiles obtained with the global positioning system: Results from the GPS/MET experiment, Hajj GA, Romans LJ, Radio Science v33: (1), 175-190, JAN-FEB, 1998


