Evolution of the GPS Navigation Payload – A Historical Journey

Stanford Center for Position, Navigation & Time (SCPNT)

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Navigation Payloads have Supplied the Path for GPS Capability and Growth

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<th>Period</th>
<th>Block</th>
<th>Payloads</th>
<th>GPS Signals</th>
<th>GPS Transmitters</th>
<th>GPS Payload System</th>
<th>Fully Integrated GPS Payload</th>
<th>GPS Modernization</th>
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<td>1974-1983</td>
<td>Block I</td>
<td>12</td>
<td>• Code Generators</td>
<td>• L1</td>
<td>• Mission Computer</td>
<td>• On-Orbit Reprogramability</td>
<td>• On-Orbit Signal Structure Changes</td>
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<td>• L1 Transmitter</td>
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<td>• Atomic Clocks</td>
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<td>• High Power GaAs Transmitters</td>
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<td></td>
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<td>• Triplexer</td>
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<tr>
<td>1983-1988</td>
<td>Block II/IIA</td>
<td>28</td>
<td>• Code Generators</td>
<td>• L1</td>
<td>• Mission Computer</td>
<td>• Improved Accuracy (1m)</td>
<td>• New High Power Military Unique Signals</td>
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<td>1987-1989</td>
<td>Payload Box Study</td>
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<td>• Code Generators</td>
<td>• L1</td>
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<td>1988-1999</td>
<td>Block IIR</td>
<td>21</td>
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<td>• Mission Computer</td>
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<td>Block IIR M</td>
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An Instrumental Part of the Continuous Evolution of GPS
For GPS Block I and II, ITT’s PRNSA Develops and Transmits the GPS L1&L2 Signals

ITT’s Pseudo Random Noise Signal Assembly (PRNSA)
IIR GPS Navigation Payload Represents an Evolution for the GPS Satellite

- GPS IIR Payload is Unique as It is
- Designed as a Completely Integrated System
- Occupies One Side of the Spacecraft on Two Panels
  - NAV
  - L-Band

The GPS Block IIR Space Vehicle
GPS IIR Satellite Navigation Payload

A Complete System From Atomic Reference Clocks Through Transmitted NAV Messages

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The MDU or Mission Data Unit Represents the “Heart” of the GPS Payload

- **Main MDU Function – Controlling the L-Band Signals**
  - Combines Uploaded Navigation Data with internally generated Ranging Codes and routes to the L-Band Transmitter System
  - Contains the FSU or Frequency Synthesizer Unit
    - Generates the 10:23 MHz Reference Frequency

- **Additional MDU Functions**
  - Encodes/Prepares NDS Data for L-Band Transmission to Ground and UHF Crosslink
  - Stores & Processes Message Data from OCS
  - Generates PRN Codes & Nav Data
  - Add Anti-Spoof (AS) to Signals for Authorized Users
  - Operate Through & Recovery through Radiation Environment
  - Operate Autonomously for 180 days without Ground Contact in Autonav Mode
  - Operate Accurately for 14 Days in a “Block II” (Non-Autonav) Mode

IIR Payload Flight Panels Under Test at ITT
MDU Controls the Total NAV Payload Operation from Atomic Frequency Standards Through Transmitted Signals

- **Mission Data Unit**
  - Central Processor
  - ADA HOL Used Throughout
  - Clock Frequency Synthesis from Multiple Standards
  - Integral Baseband Processor
  - Full Message Encoding and Message Processing

- **Crosslink Transponder Data Link**
  - RF Receive Transmit of Digital Data
  - Precision Inter Satellite Ranging
  - Frequency Hopped TDMA
  - Full Frame Modulation and Mode Control

- **Time Standard Assembly**
  - Multiple Atomic Frequency Standards for Reliability
  - Accommodates Various Clock Types (Cs, Rb)
  - RAD-Hard Upset Proof Design
  - Synthesized High Stability GPS Timing Signals
  - Automated Integrity Monitoring

- **L-Band Subsystem**
  - 25-30 Watt Transmitter
  - Bandwidth 20 MHz
  - Radiation Hardened
  - L1: 1 or 10 Mchip/s Quadraphase
  - L2, L3: 1 or 10 Mchip/s Biphase
  - Space Proven Design Operational on Block I and Block II

*Although supported in MDU software, the fourth map is not provided.*
Modernizing the Block IIR Navigation Payload – Adding the New Signals

- High Power GaAs Transmitters with Selectable RF Output
- Significant Signal Flexibility
- M and L2C Codes

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Autonav Gives Satellites the Ability to Self-Navigate

**AUTONAV**
Regularly computes new estimates of Keplerian states and clock states

**CROSSTLINK RANGING**

Initial upload ephemeris (180 day)

Each spacecraft can navigate autonomously by:
- Crosslink ranging
- Exchanging time tagged nav parameters
A Key Part of the AUTONAV Function is Provided By a VHF Crosslink

CROSSLINKS AND AUTONAV

- Each GPS IIR Satellite has a Redundant Crosslink Transponder Data Unit (CTDU) supplying a dual function for AUTONAV
  - Supplies a Precise Inter-Satellite Ranging Signal
  - Exchanges the AUTONAV State Vector between satellites
- The CTDU is a Time Division Multiple Access (TDMA) Frequency Hopped Spread Spectrum Communication System incorporating a 5 mChip/s Pseudorandom Code. Output power is 108 Watts.

CTDU Configuration Utilizes Dual Frequency for Elimination of Plasmasphere Delays
Autonav as an Aid To GPS Clock Performance

- AUTONAV Synchronizes Constellation Clocks by Processing Inter-Satellite Pseudoranges and Exchanged State Vectors in their Kalman Filters
- Constellation Time Synchronization Diverges within 3 days (AUTONAV OFF), but rapidly converges when AUTONAV turned on (Figure 1)
- One hundred Monte Carlo simulations for a 12 Satellite IIR Constellation shows 95 percentile less than 1.3 meters residual value. All trials < 0.85 meters (Figure 2)
Block IIR Pioneered Improved Reference Frequency Generation

- ΔF Commands Used to Discipline the VCXO for Precise 10.23 MHz Generation
- Having Access to Two Time References Allows for Failure Detection
- Employed a “Natural” Reference Frequency to Implement Multiple Clock Technologies

Hardware Functions
- RAFS
- 13.4 MHz
- 1.5 Sec Reference Epoch
- Reference Epoch Generator
- Phase Meter
- System Epoch Generator
- 1.5 Sec System Epoch
- 10.23 MHz
- VCXO

Software Functions
- Phase Difference Prediction
- Predicted Phase
- Sum
- TKS Loop Filter
- Delta F Command

10/22/09

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### RAFS-IIR & RFS-IIF

<table>
<thead>
<tr>
<th></th>
<th>RAFS-IIR</th>
<th>RFS-IIF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>13.4 MHz</td>
<td>10.23 MHz</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>11.6 lbs</td>
<td>13.55 lbs</td>
</tr>
<tr>
<td></td>
<td>5.26 kg</td>
<td>6.15 kg</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td>226.6 in³</td>
<td>290.7 in³</td>
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<td></td>
<td>3.7 liters</td>
<td>4.8 liters</td>
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</table>

2008 IEEE International Frequency Control Symposium
RAFS-IIR physics package
- Lamp buffer gas was Krypton
- Krypton buffer gas lines are close to Rubidium pumping lines and can not be easily filtered from reaching the photodetector and generating shot noise

RFS-IIIF physics package
- Lamp buffer gas is Xenon
- Xenon buffer gas lines are far away from the Rubidium pumping lines and can be easily filtered by means of a spectral filter (a thin film interference filter)
Physics Package Improvements

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RAFSMOD EDU Performance

RAFSMOD EDU Stability

Allan and Theo Deviation

Log Fit to Frequency Data Removed

Averaging Time, \( \tau \), Seconds

Threshold

Objective

2008 IEEE International Frequency Control Symposium

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Are We There Yet?

Future of the Navigation Payload

- Reduced Obsolescence Through
  - Signal Flexibility
  - Reprogramability
  - Flexibility for Mixed Constellation Use
  - Improved
    - Integrity
    - Accuracy
    - Failure Detection
    - Power Requirements
    - Payload Size and Weight

Technology Will Continue to Drive GPS Innovation