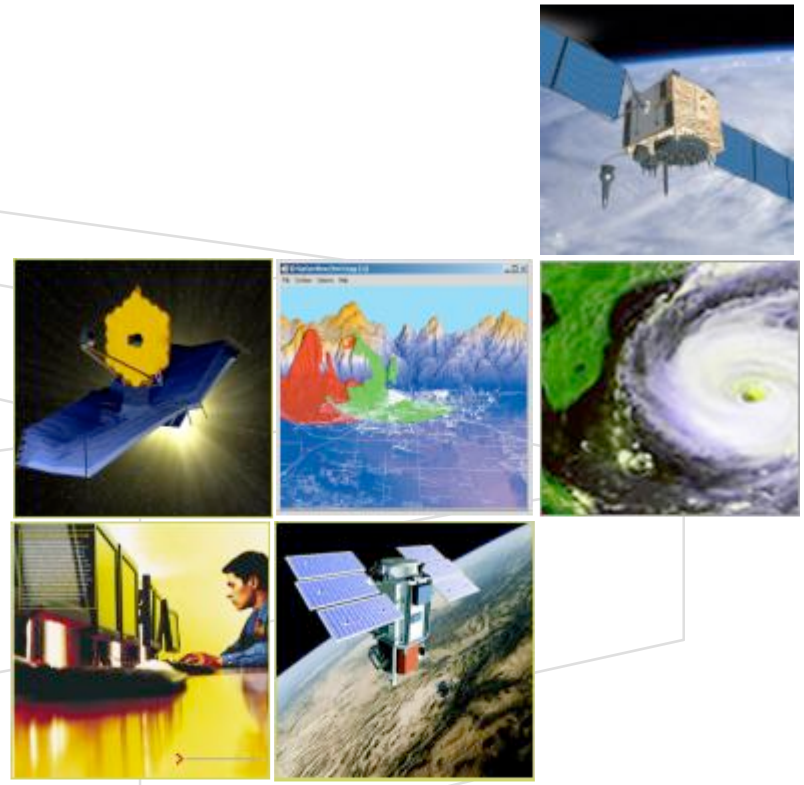
ITT Space Systems Division

Evolution of the GPS Navigation Payload – A Historical Journey



Stanford Center for Position, Navigation & Time (SCPNT)

October 2009

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Navigation Payloads have Supplied the Path for GPS Capability and Growth

1974-1983

Block I

12 Flight Payloads

GPS Signals
- Code Generators
- L1 Transmitter
- L2 Transmitter

1983-1988

Block II/IIA

28 Flight Payloads

GPS Transmitters
- L1
- L2
- Triplexer

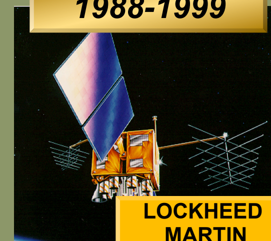
1987-1989

Payload Box Study

2 Breadboard Payloads

GPS Payload System
- Mission Computer
- Atomic Clocks
- Crosslink Transponder

1988-1999

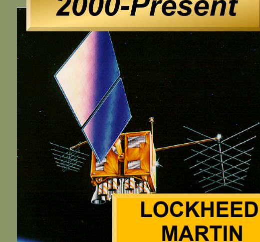


Block IIR

21 Flight Payloads

Fully Integrated GPS Payload
- On-Orbit Reprogramability
- Crosslink Ranging
- Self Navigation (AutoNav)
- Improved Accuracy (1m)
- Improved Time Keeping
- Improved Security

2000-Present

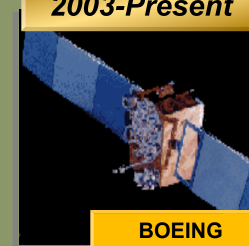


Block IIR M

8 Flight Payloads

GPS Modernization
- On-Orbit Signal Structure Changes
- Enhanced Signal Security Per NSA
- High Power GaAs Transmitters
- New High Power Military Unique Signals

2003-Present



Block IIF

12 Flight Payloads

GPS Modernization
- Flexible RF Power
- High Power GaAs Transmitters

An Instrumental Part of the Continuous Evolution of GPS

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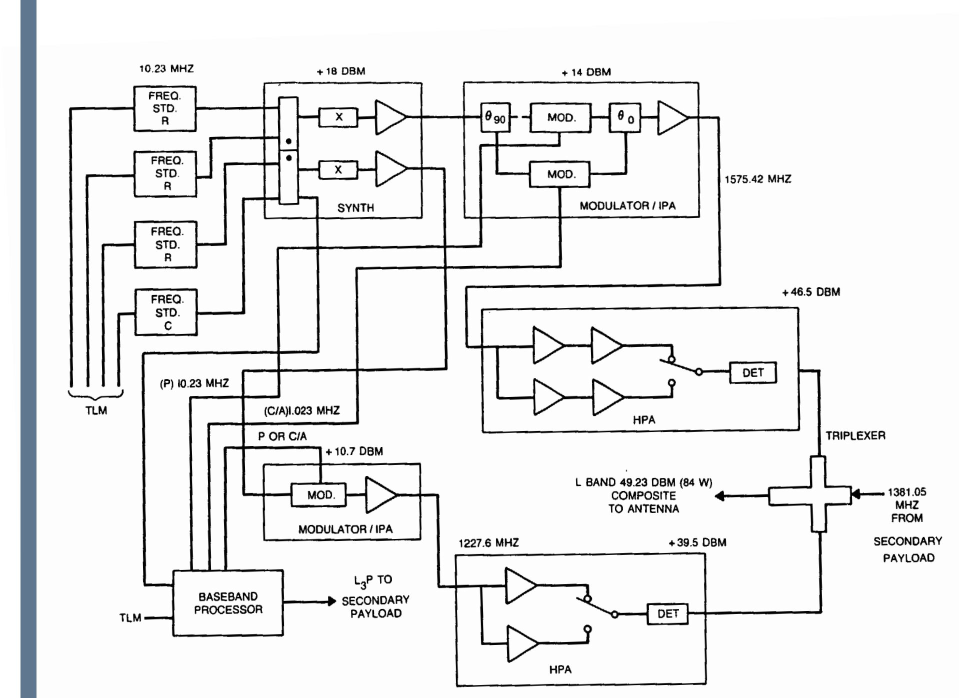
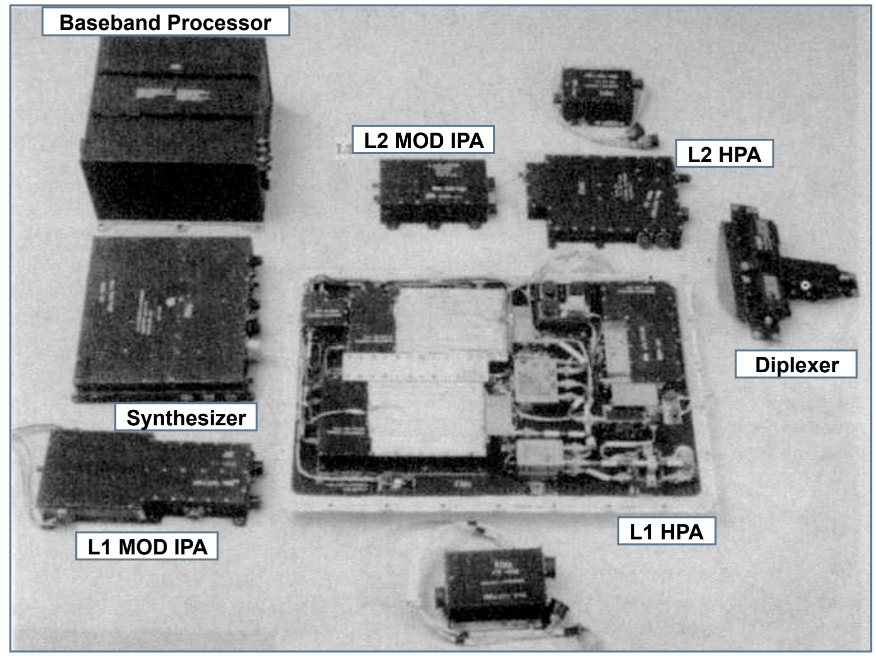
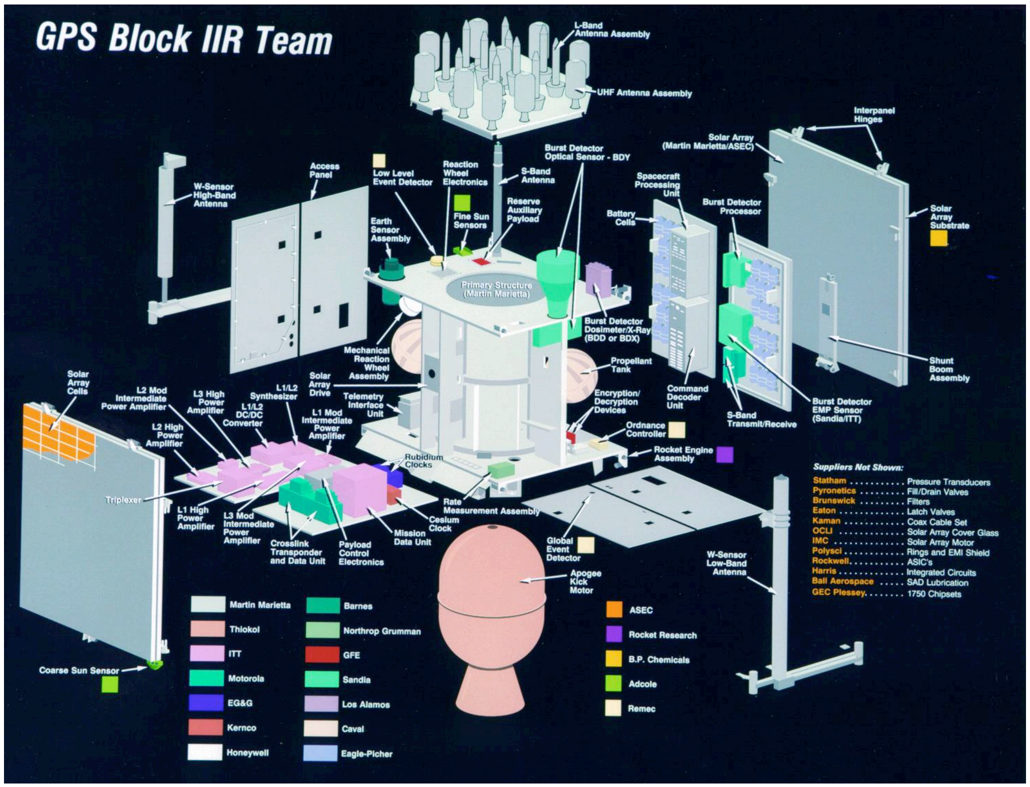
For GPS Block I and II, ITT's PRNSA Develops and Transmits the GPS L1&L2 Signals





ITT's Pseudo Random Noise Signal Assembly (PRNSA)

IIR GPS Navigation Payload Represents an Evolution for the GPS Satellite



The GPS Block IIR Space Vehicle

- 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**

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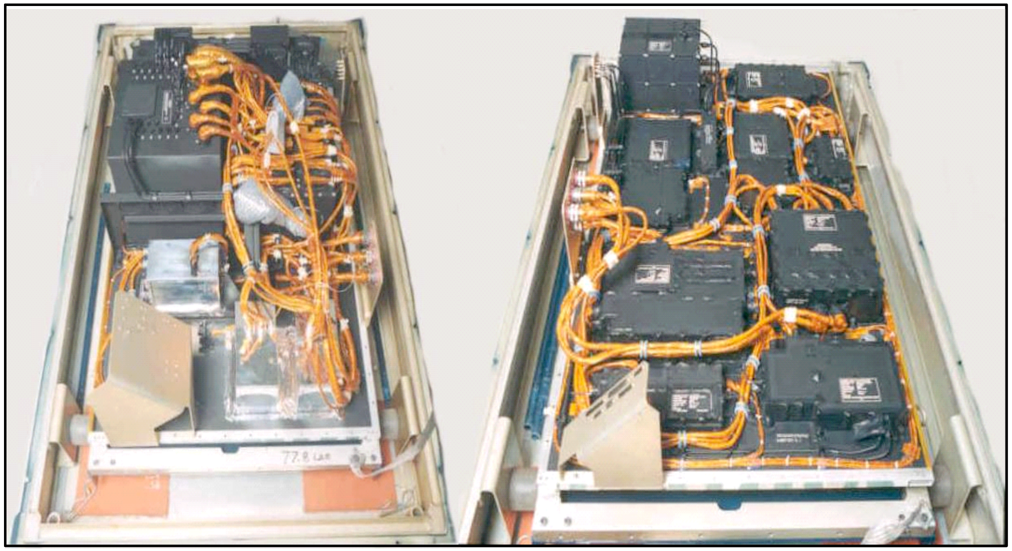
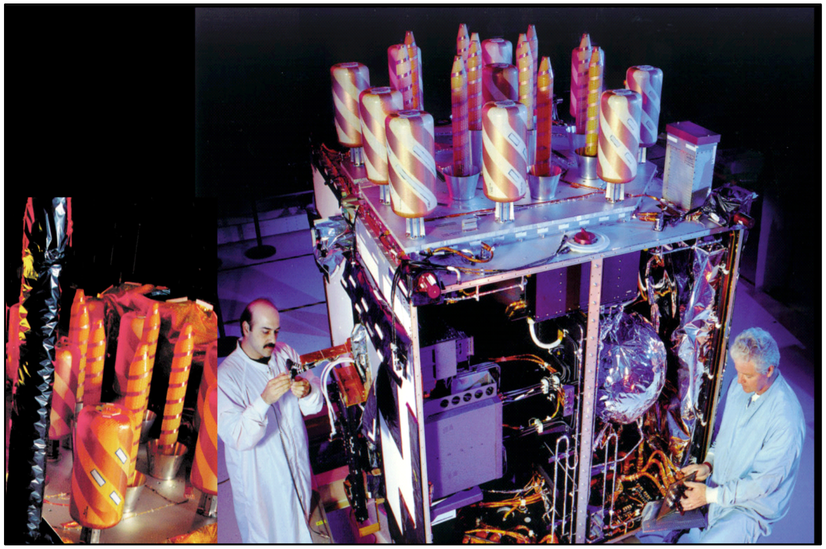
GPS IIR Satellite Navigation Payload





Lockheed Martin IIR Satellite Assembly

Navigation Panel **L-Band Panel**

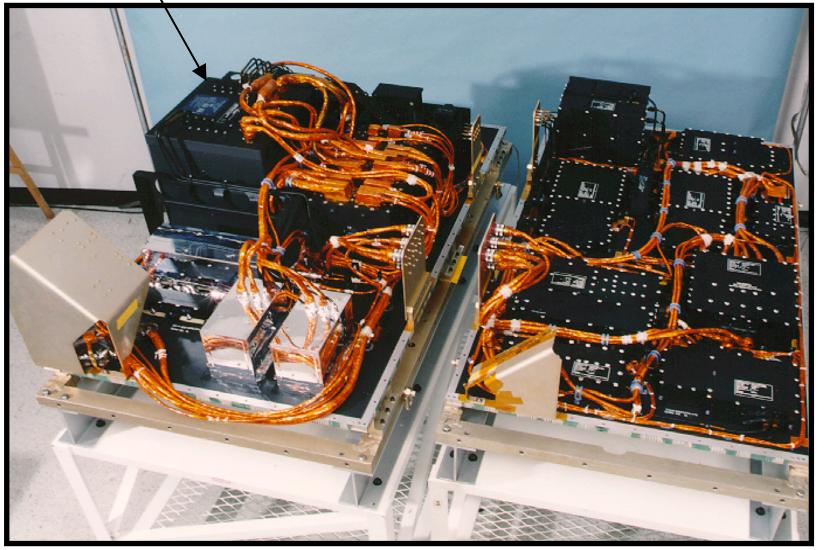
A Complete System From Atomic Reference Clocks Through Transmitted NAV Messages

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

- **Main MDU Function – Controling 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

MDU



IIR Payload Flight Panels Under Test at ITT

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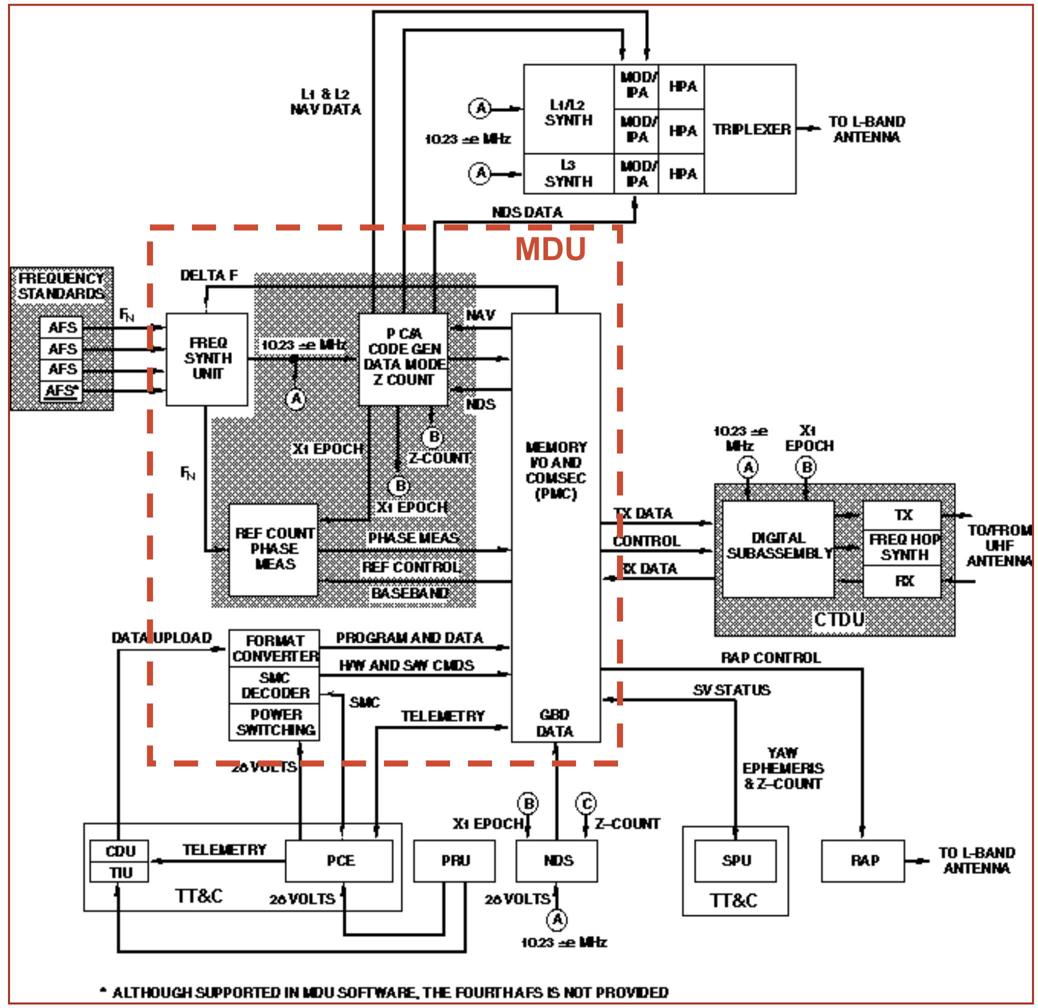
MDU Controls the Total NAV Payload Operation from Atomic Frequency Standards Through Transmitted Signals

- **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



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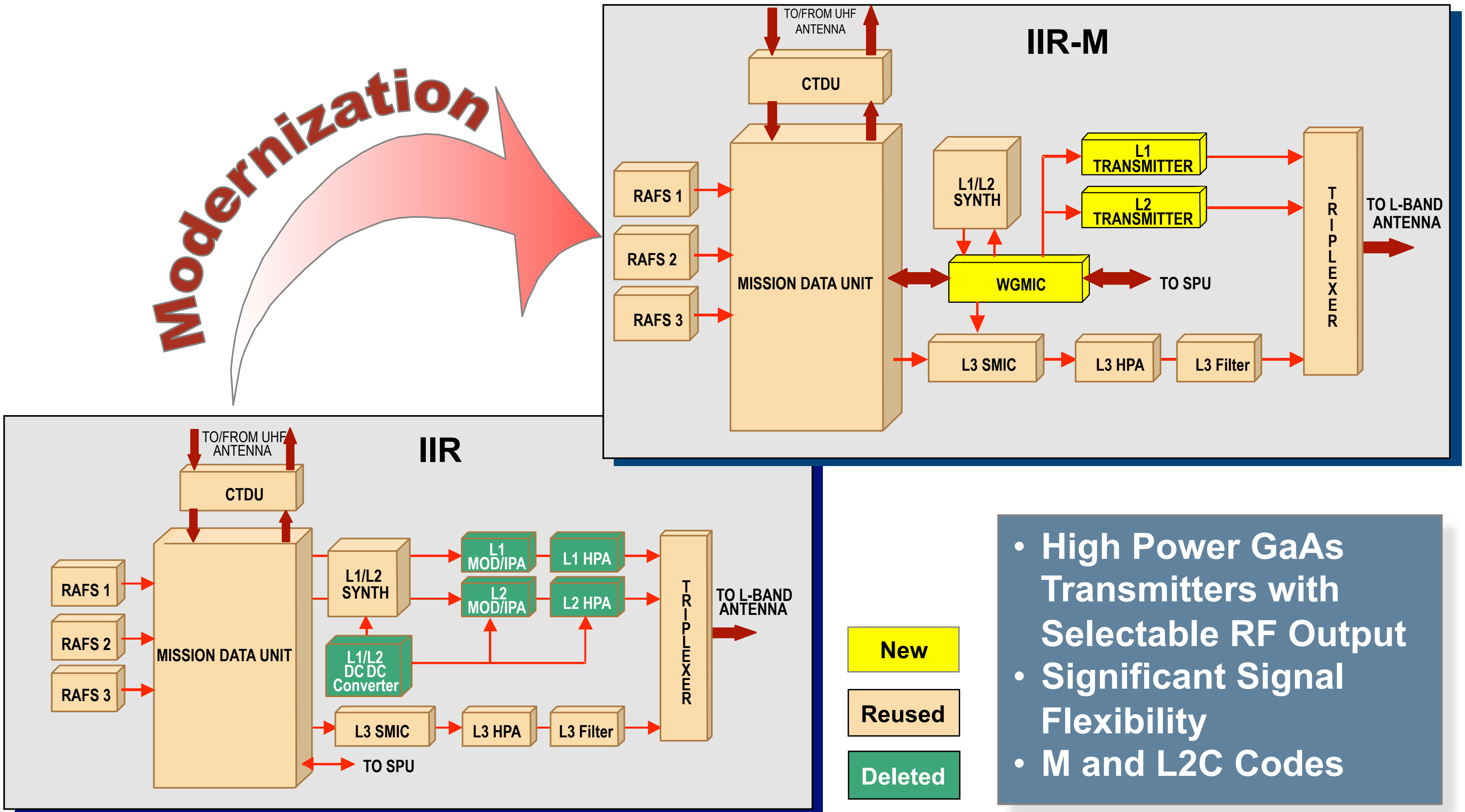
Modernizing the Block IIR Navigation Payload – Adding the New Signals



New
Reused
Deleted

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

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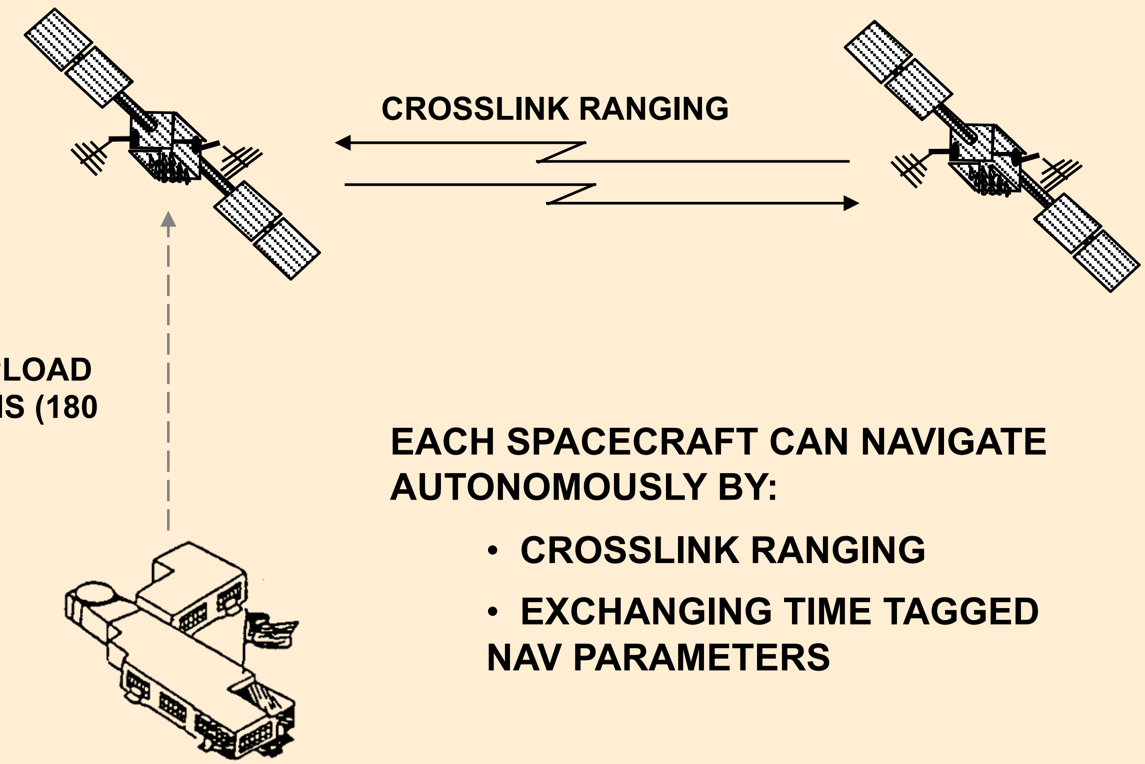
Autonav Gives Satellites the Ability to Self-Navigate

AUTONAV

REGULARLY COMPUTES NEW ESTIMATES OF KEPLERIAN STATES AND CLOCK STATES



EACH SPACECRAFT CAN NAVIGATE AUTONOMOUSLY BY:

- **CROSSLINK RANGING**
- **EXCHANGING TIME TAGGED NAV PARAMETERS**

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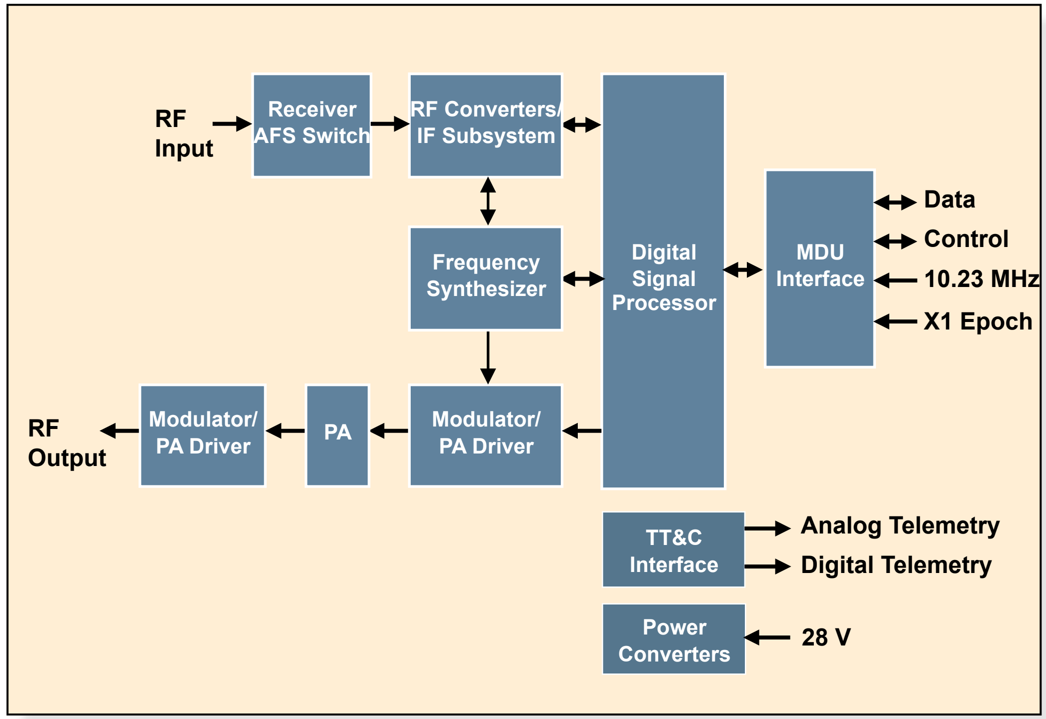
A Key Part of the AUTONAV Function is Provided By a VHF Crosslink

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

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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)

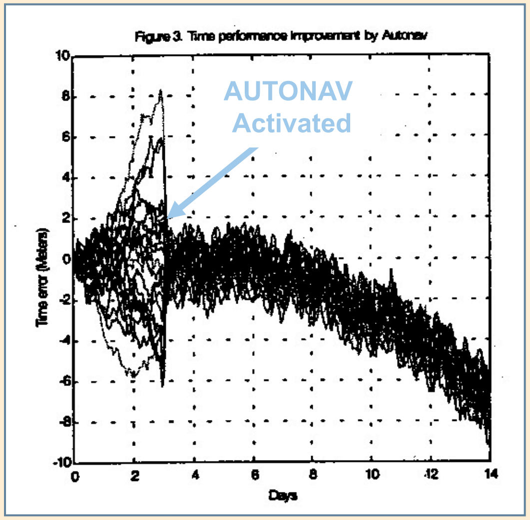

Figure 1 – Time Synchronization Improvement with AUTONAV

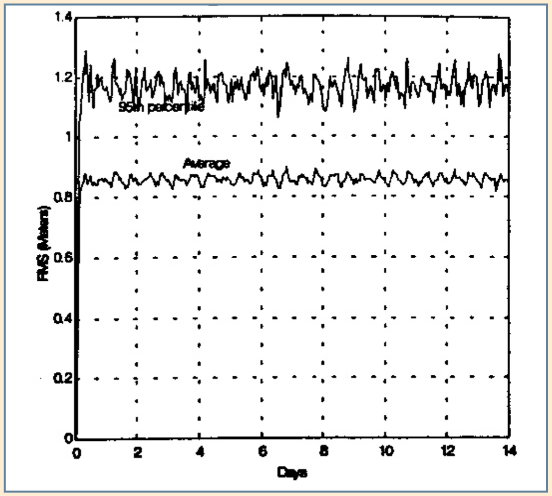

Figure 2 – Residual Clock Errors with AUTONAV Constellation

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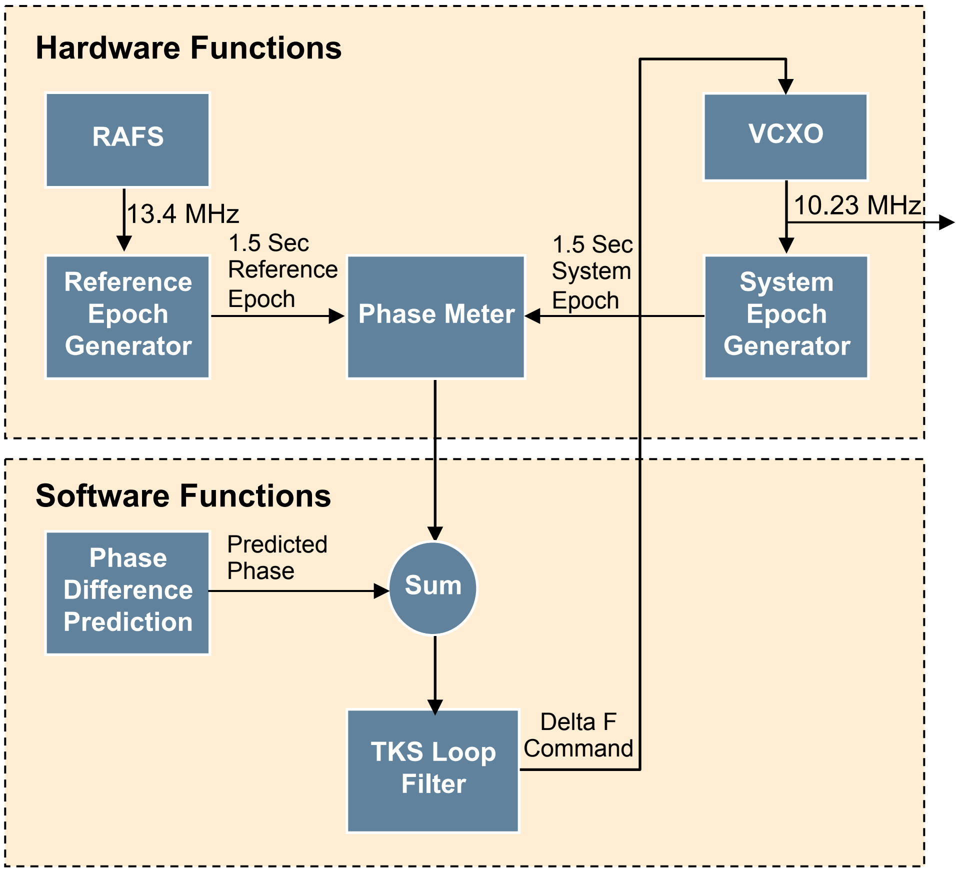
Block IIR Pioneered Improved Reference Frequency Generation



- Δ F 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

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RAFS-IIR & RFS-IIF

RAFS-IIR

13.4 MHz

Weight

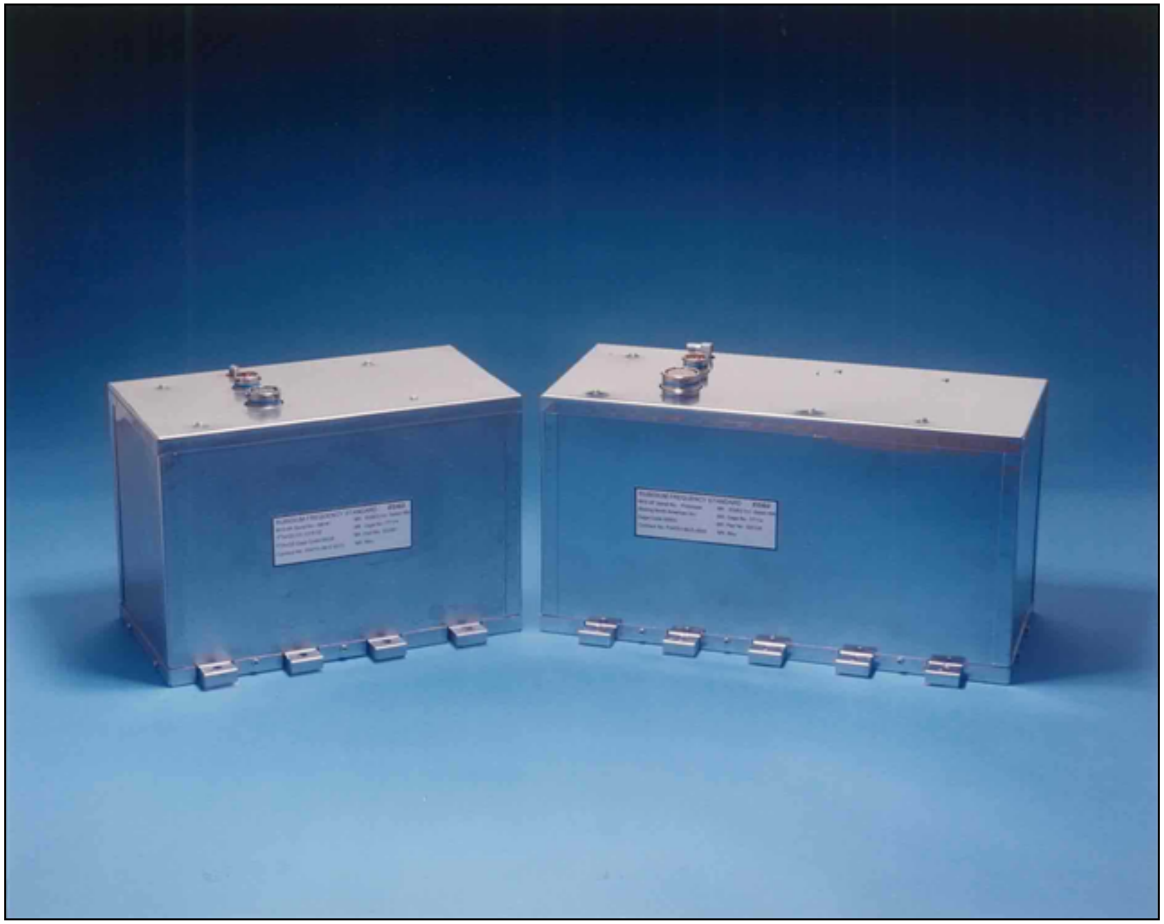
11.6 lbs

5.26 kg

Volume

226.6 in^3

3.7 liters



RFS-IIF

10.23 MHz

Weight

13.55 lbs

6.15 kg

Volume

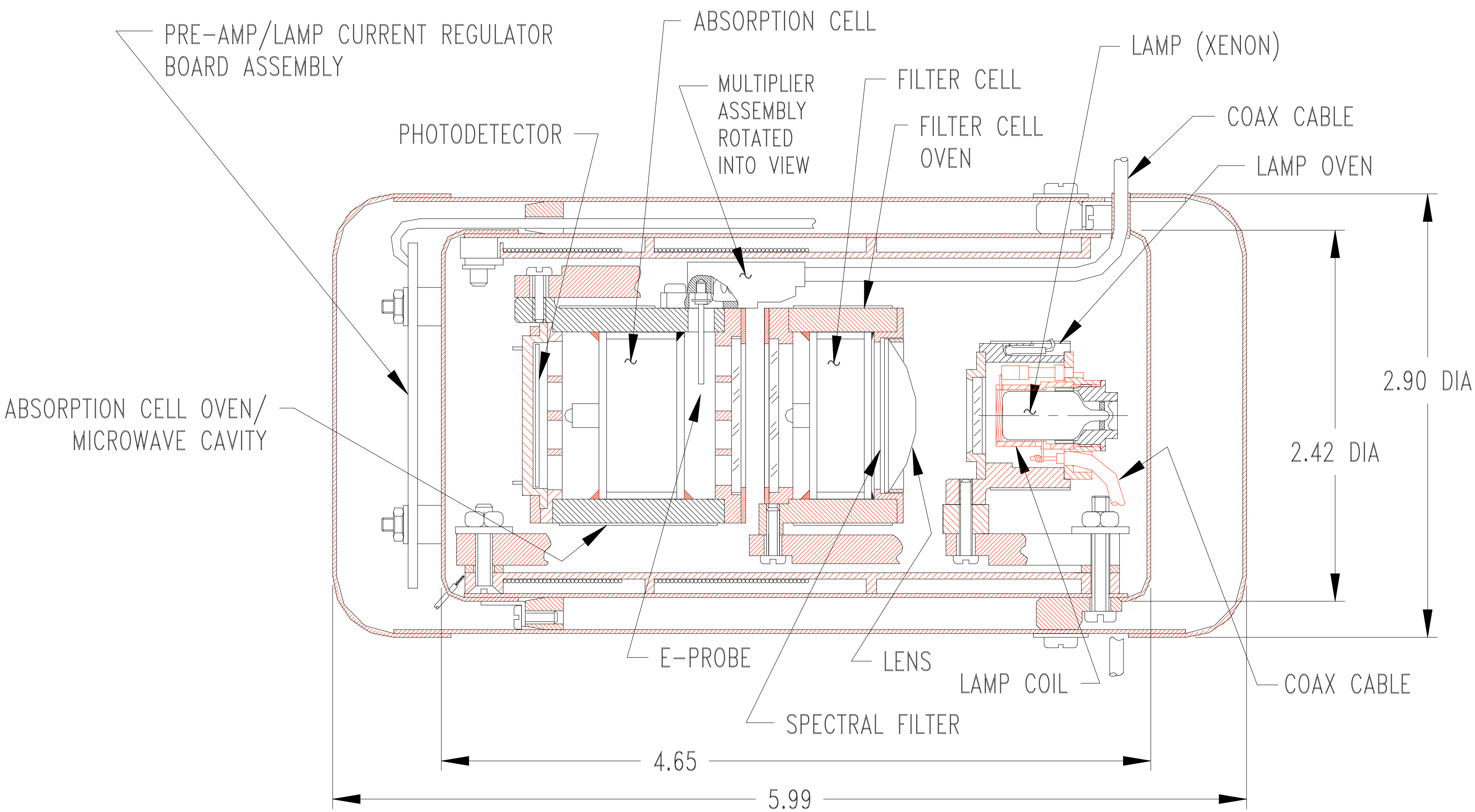
290.7 in^3

4.8 liters

Physics Package Improvements

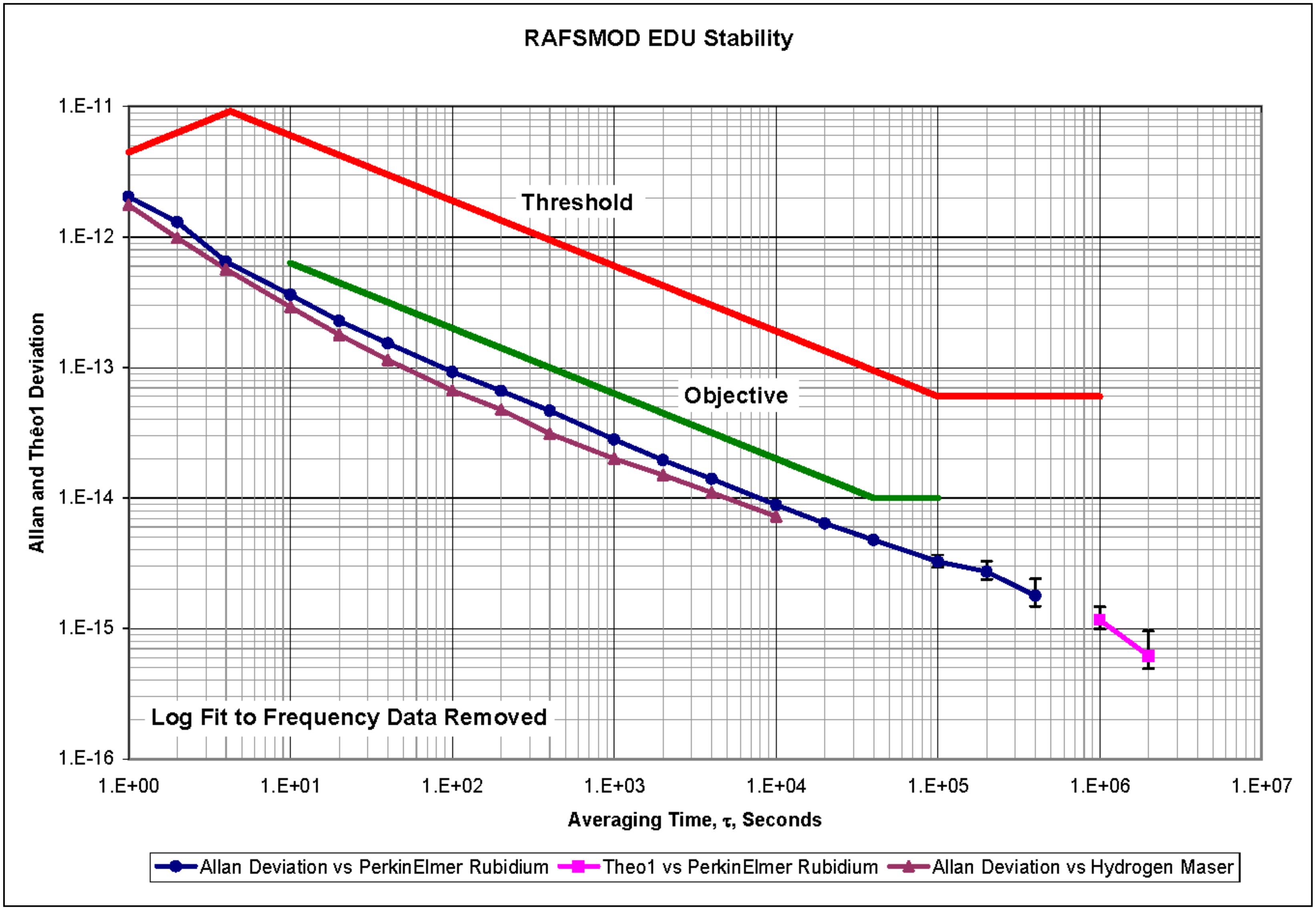
- **RAFS-IIR physics package**
  - Lamp buffer gas was Krypton
  - Krypton buffer gas lines are close to Rubidium pumping lines and can not be easily filtered from reaching the photodetector and generating shot noise
- **RFS-IIF physics package**
  - Lamp buffer gas is Xenon
  - Xenon buffer gas lines 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



GPS PHYSICS PACKAGE WITH SPECTRAL FILTER

RAFSMOD EDU Performance



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