



GPS Current Status & Future Enhancements

**4th International Telecoms Synchronisation Forum
Workshop: Tuesday 14 November 2006**

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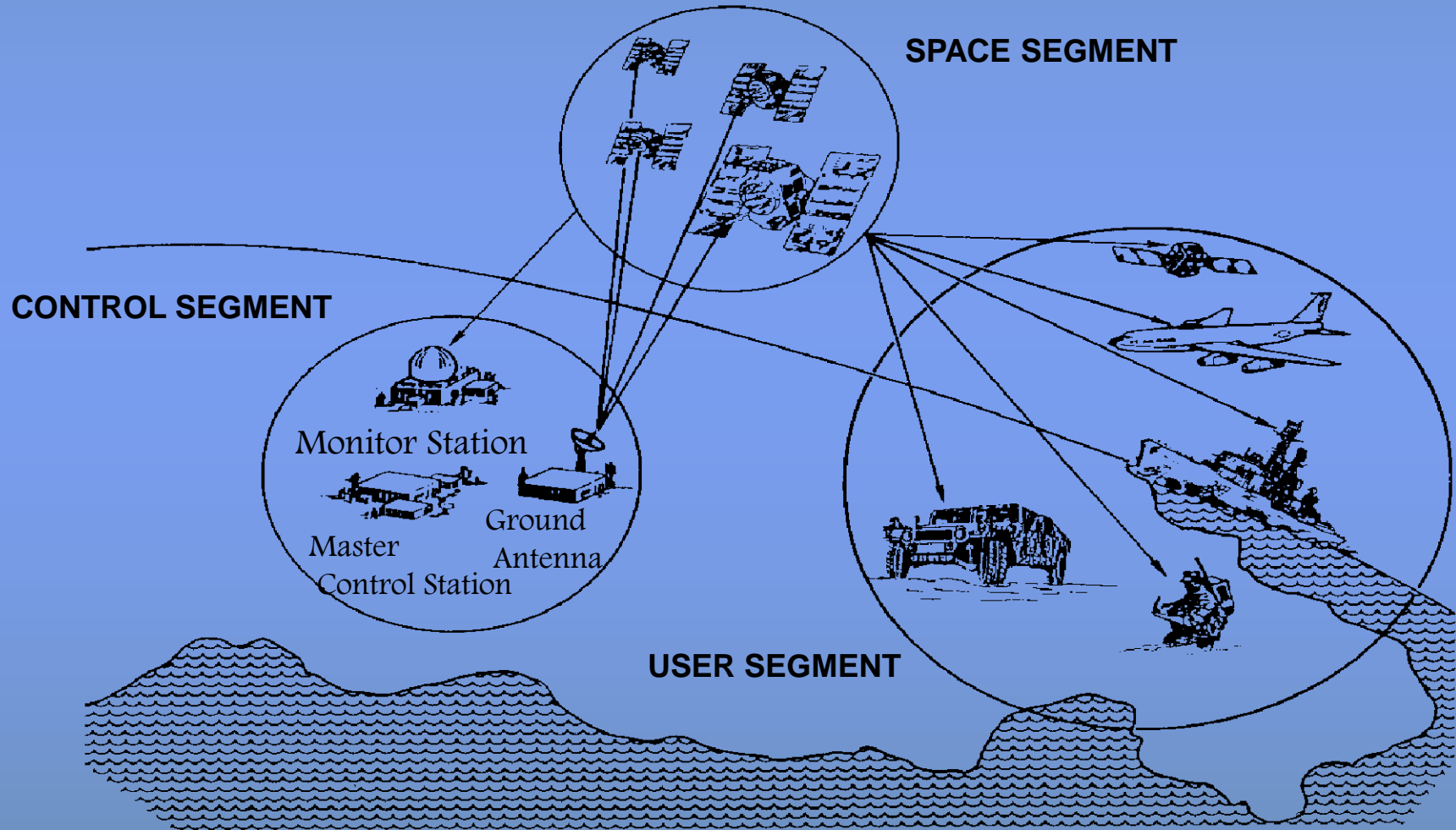
OVERVIEW

- **GPS Current Status**
- **GPS Future**
- **GPS-Galileo Interoperability**
- **Failure Modes**
- **Summary – Conclusions**

OVERVIEW

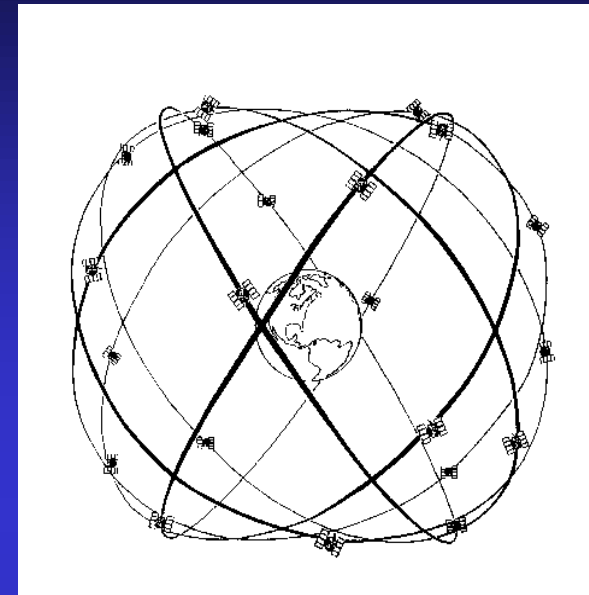
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GPS System Configuration - Three Major Segments



Space Segment

- Nominal 24 satellite constellation
 - Semi-synchronous, circular orbits (~20,200 km/10,900 nautical miles altitude)
 - Repeating ground tracks (11 hours 58 minutes)
 - Six orbital planes, inclined at 55 degrees, four vehicles per plane
 - *designed for global coverage (at least 4 sats in view)*
- Redundant cesium and/or rubidium clocks on board each satellite
- In recent years there have been two to three replenishment launches per year



Control Segment

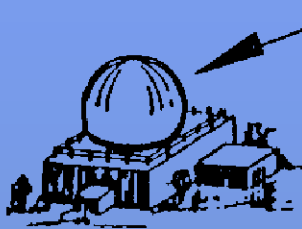
SPACE VEHICLE (SV)

Broadcasts the SIS PRN codes, L-band carriers, and 50 Hz navigation message stored in memory



SPACE-TO-USER INTERFACE

CONTROL-SPACE INTERFACE



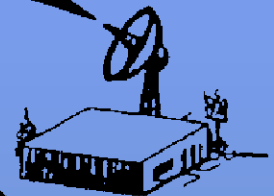
MONITOR STATION

- Sends raw observations to MCS



MASTER CONTROL STATION

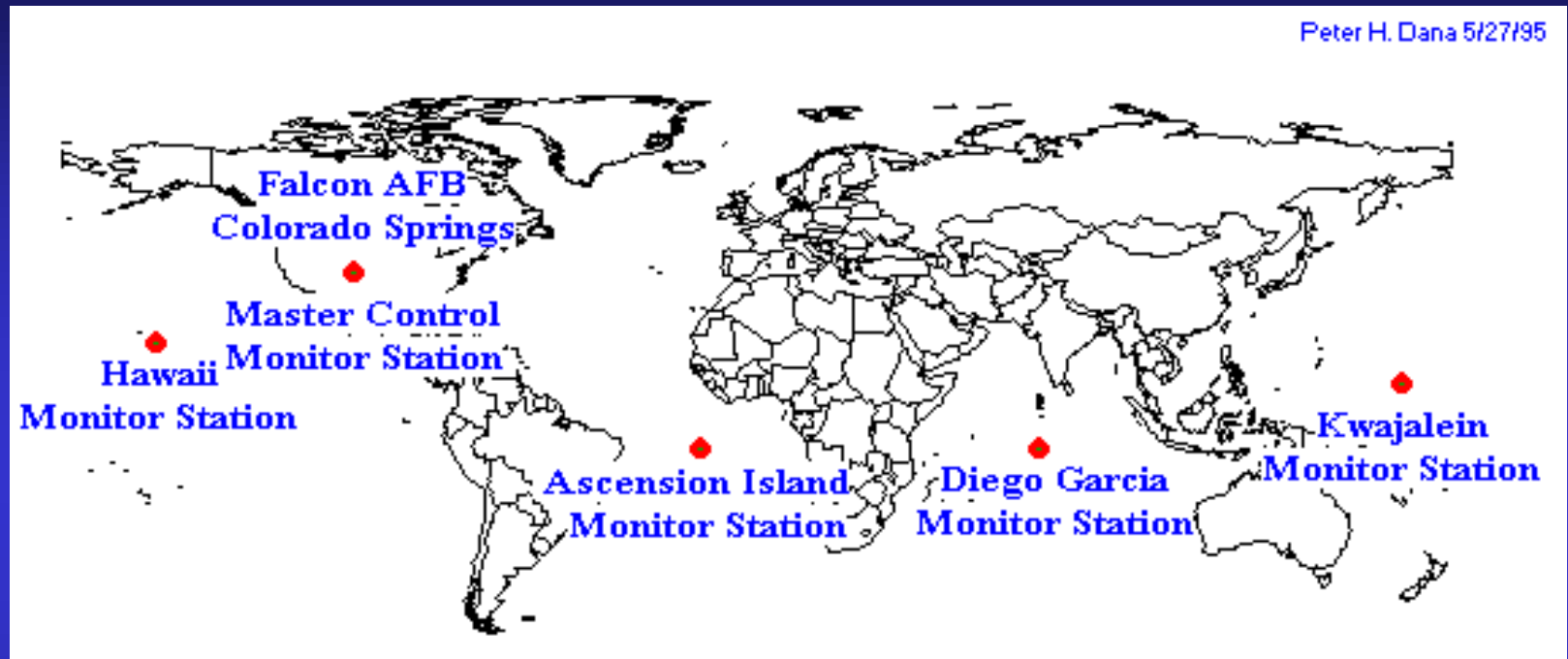
- Checks for anomalies
- Computes SIS portion of URE
- Generates new orbit and clock predictions
- Builds new upload and sends to GA



GROUND ANTENNA

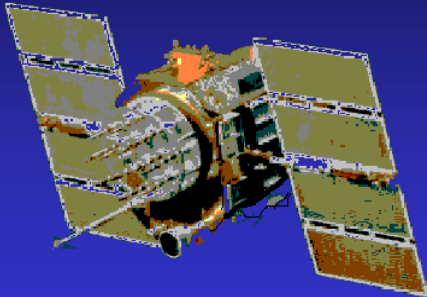
- Sends new upload to SV

Control Segment – Monitor Stations



- Existing GPS Monitor Stations
 - Hawaii, Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs

Current GPS Constellation Status



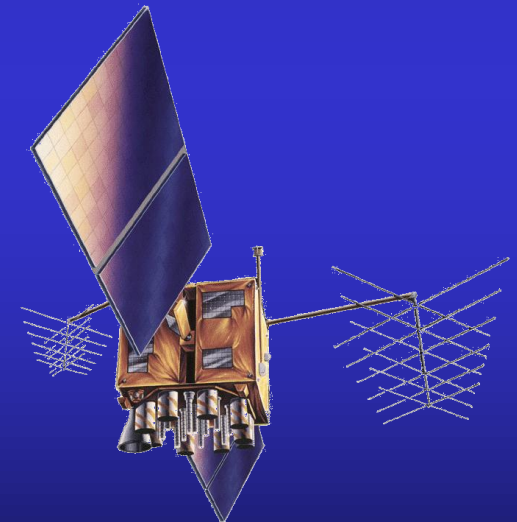
Block II/IIA

Built by Boeing Aerospace
Launched 1989 - 1997

- Currently 28 satellites operational
 - 14 Block IIA
 - 12 Block IIR
 - 2 Block IIR-M
- Next Block IIR-M launch scheduled for 14 November 2006 Today!

- **Age Summary**

- All satellites have greatly exceeded original design lifetime
- 12 satellites are more than 10 years old
- Several are “single string”



Block IIR/IIR-M

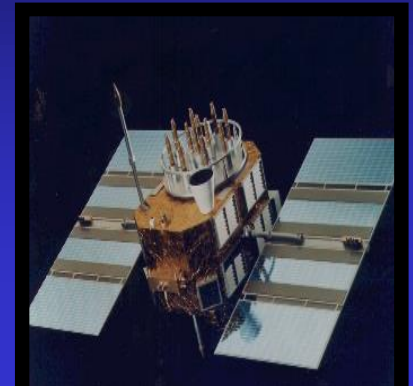
Built by Lockheed Martin
Launched 1997 - 2007

GPS Constellation Status

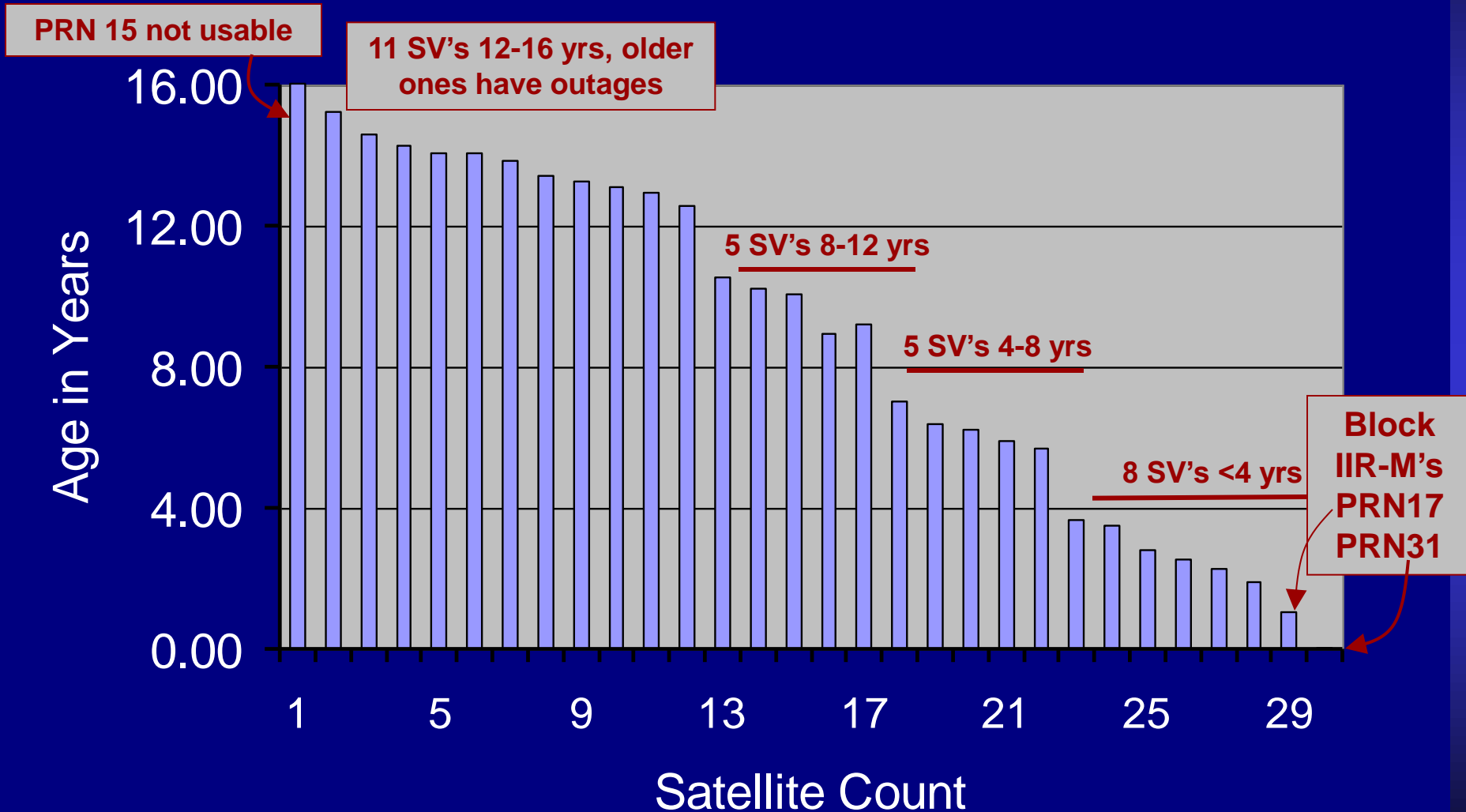
28 Operating Satellites

(to ensure 24)

- **14 Block IIA** satellites operational
- **12 Block IIR** satellites operational
 - Modernizing up to 8 Block IIR satellites
- **2 Block IIR-M** in orbit
 - PRN 17 launched Sep 2005
 - PRN 31 launched Sep 2006
- 3rd IIR-M launch currently scheduled Nov 2006
- **Continuously assessing** constellation health to determine launch need
- Global GPS civil service performance commitment **met continuously** since Dec 93



Age of GPS Satellites as of 13Oct-2006



SPS Performance

source: GPS SPS Performance Standard, Department of Defense, Oct 2001

GPS SPS Global Time Transfer Performance -- June 2000

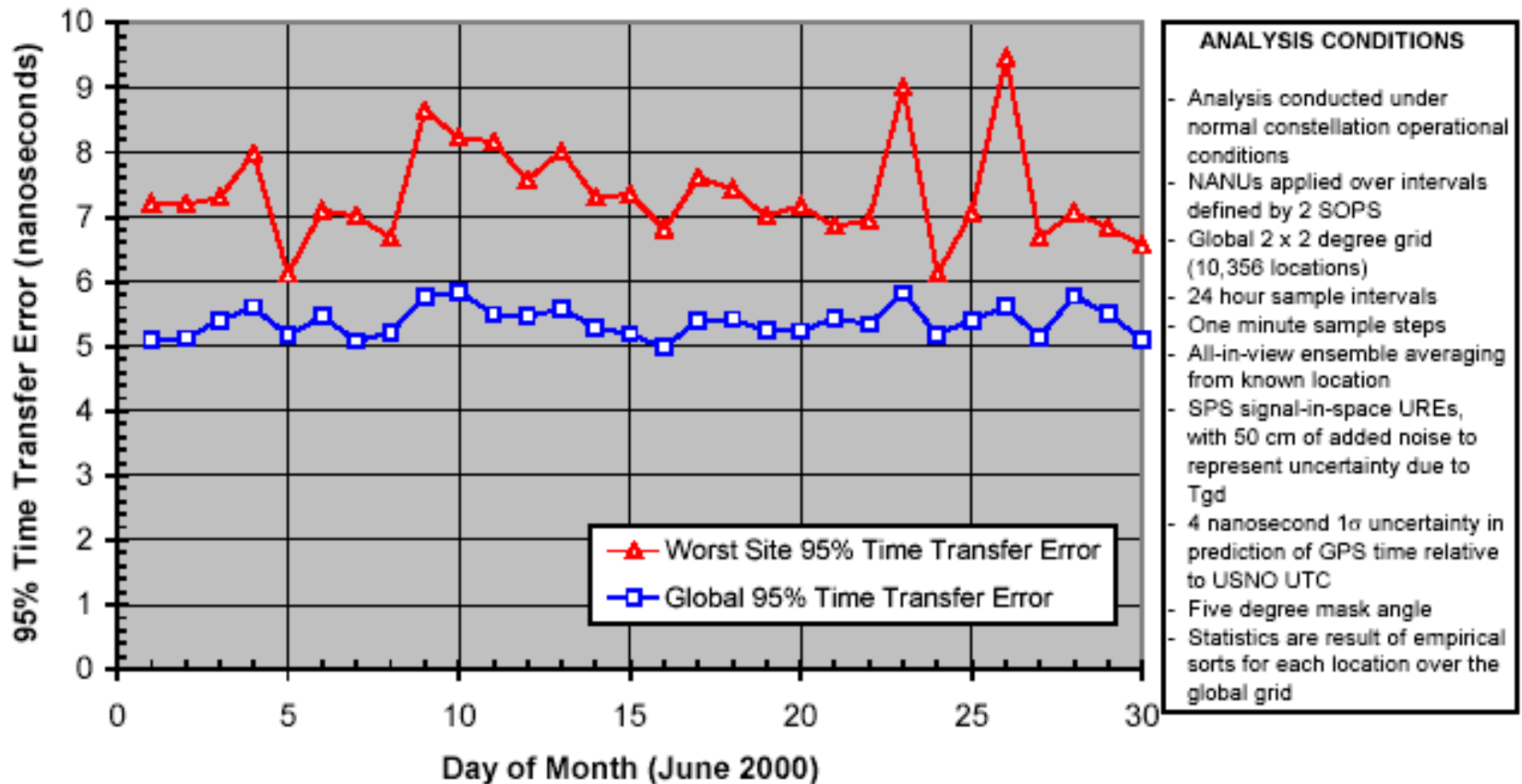
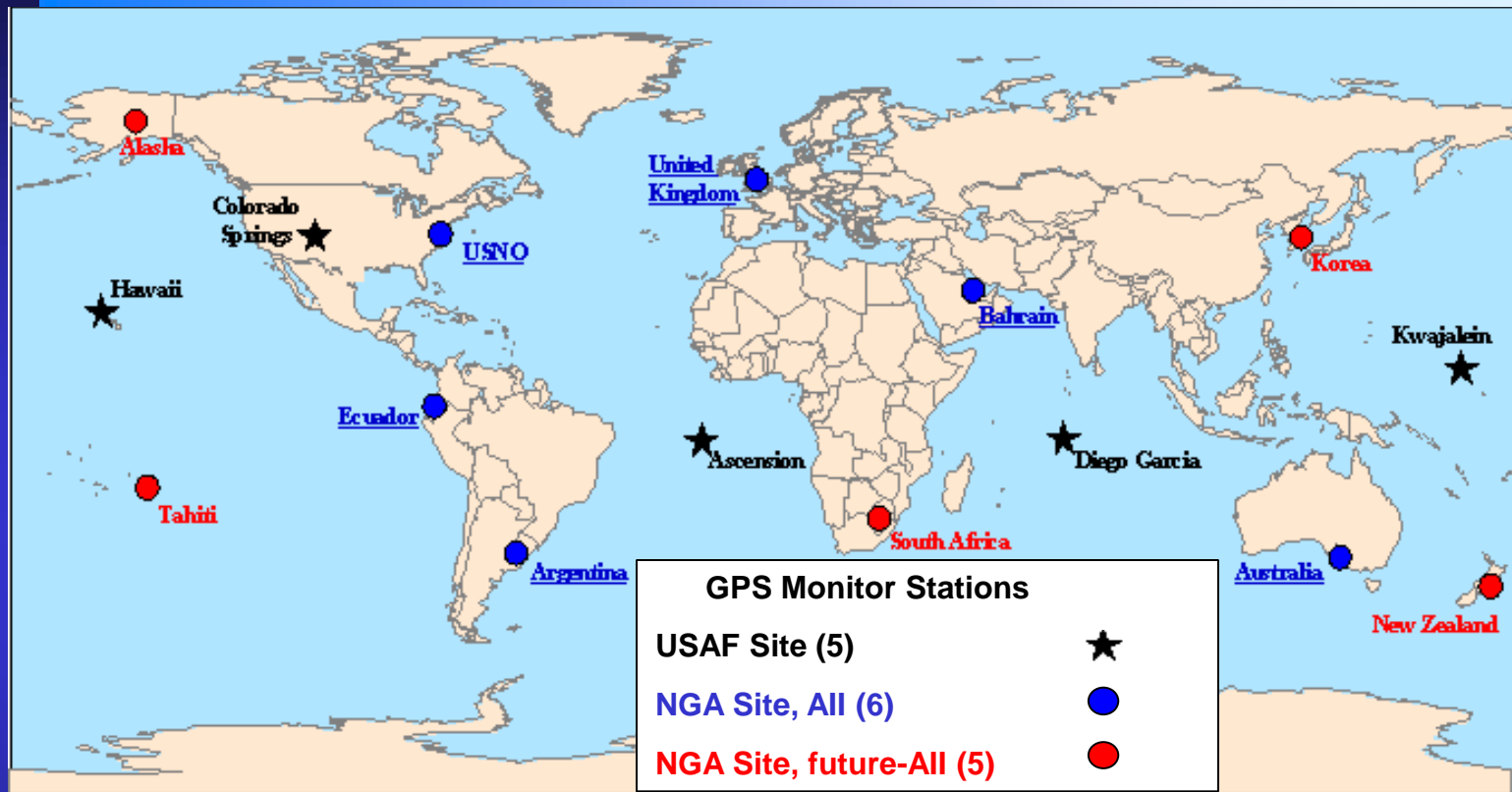


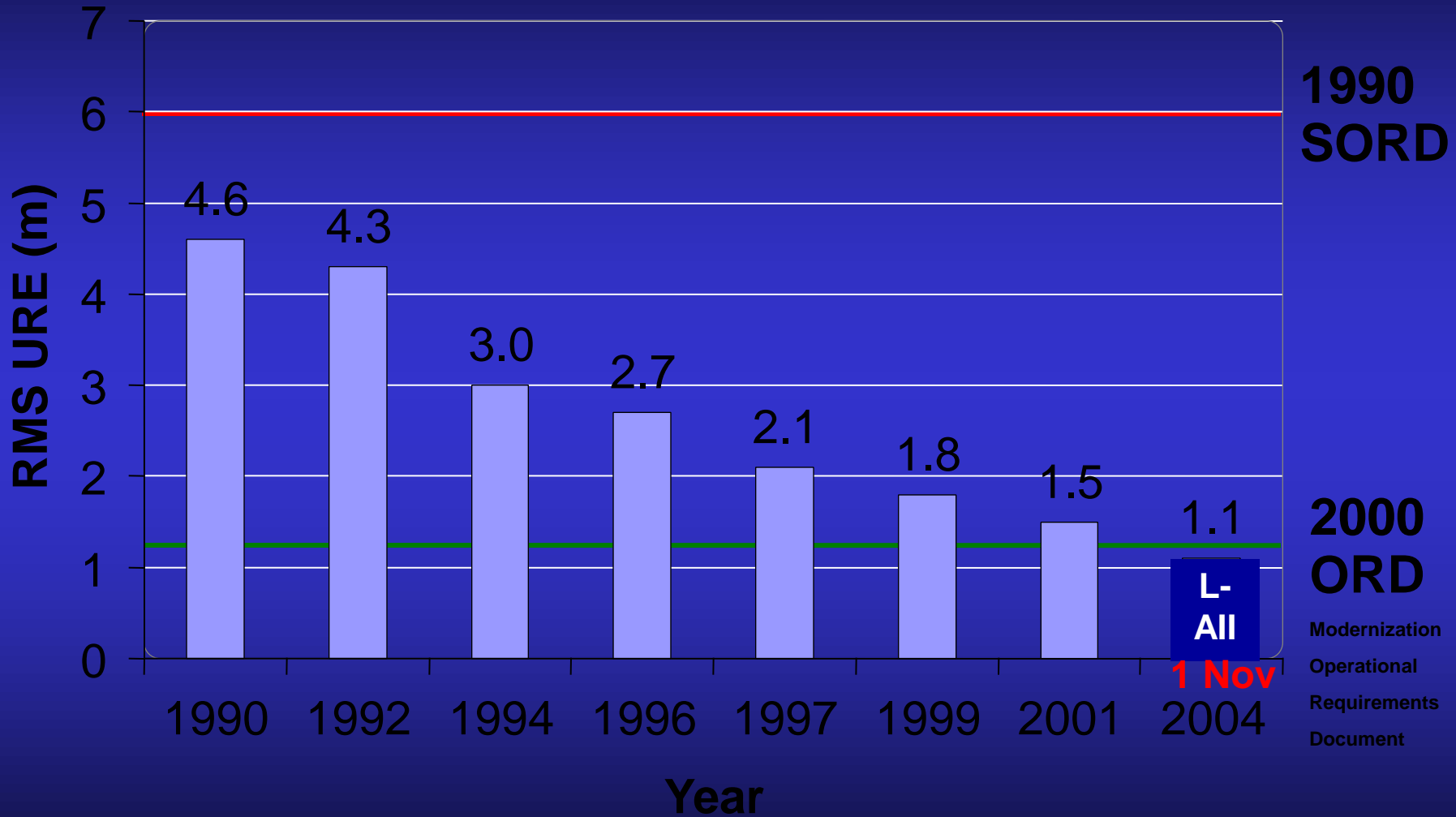
Figure A-5-10. Typical Example of GPS SPS SIS Time Transfer Performance – June 2000

Legacy Accuracy Improvement Initiative (L-All)



- USAF working with National Geospatial-Intelligence Agency (NGA) to incorporate NGA ground stations into GPS network
 - Reduce range error and improve accuracy
 - Initially six NGA sites will be added
 - By 2006, 5 more NGA sites will be added to L-All

URE Performance History

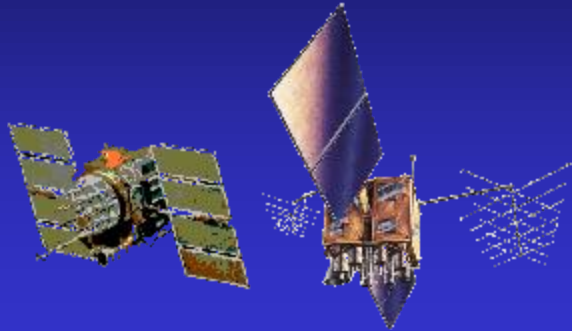


OVERVIEW

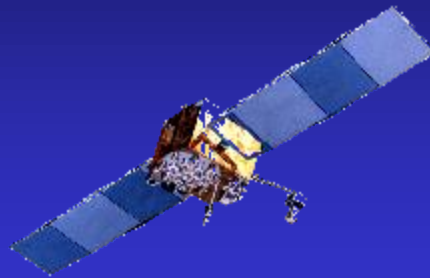
- **GPS Current Status**
- **GPS Future**
 - **Modernization**
 - **New Signals**
 - **New Monitor Stations & Ground Antennas**
 - **GPS III**
- **GPS-Galileo Interoperability**
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GPS Modernization Plan

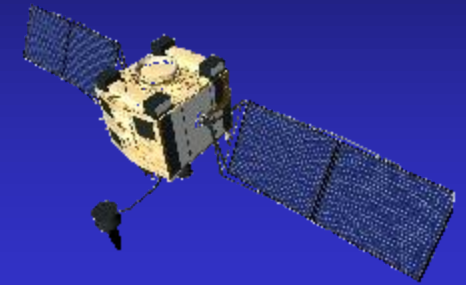
Block IIA/IIR



Block IIR-M, IIF

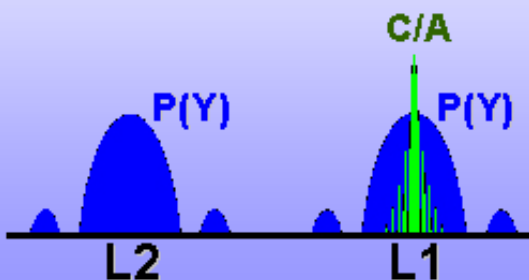


Block III



IIA / IIR: Basic GPS

- C/A civil signal (L1C/A)
- Std Service, 16-24m SEP
- Precise Service, 16m SEP
 - L1 & L2 P(Y) nav

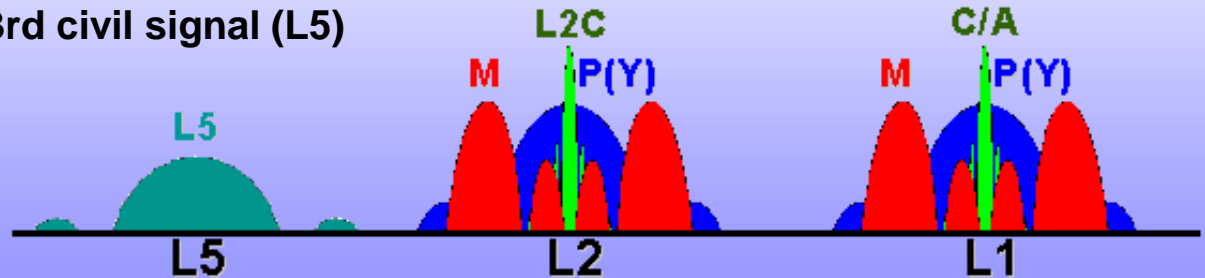


IIR-M: IIA/IIR capabilities &

- 2nd civil signal (L2C)
- **New military code**
- **Flex A/J power (+7dB)**

IIF: IIR-M capability plus

- 3rd civil signal (L5)



III: IIF capabilities &

- Improved civil signal (L1C)
- Increased accuracy (4.8-1.2m)
- Evaluating integrity improvements
- Navigation surety
 - Increased A/J power (+20 dB)

Monitoring Civil Signals

- Current C/A code monitored indirectly
 - Needed to lock on P-code at monitor stations
 - Depends on common hardware in SV
 - Clock
 - Some electronics
- Has been prioritized by PNT-ExCom
 - Planned to come on line in 2009

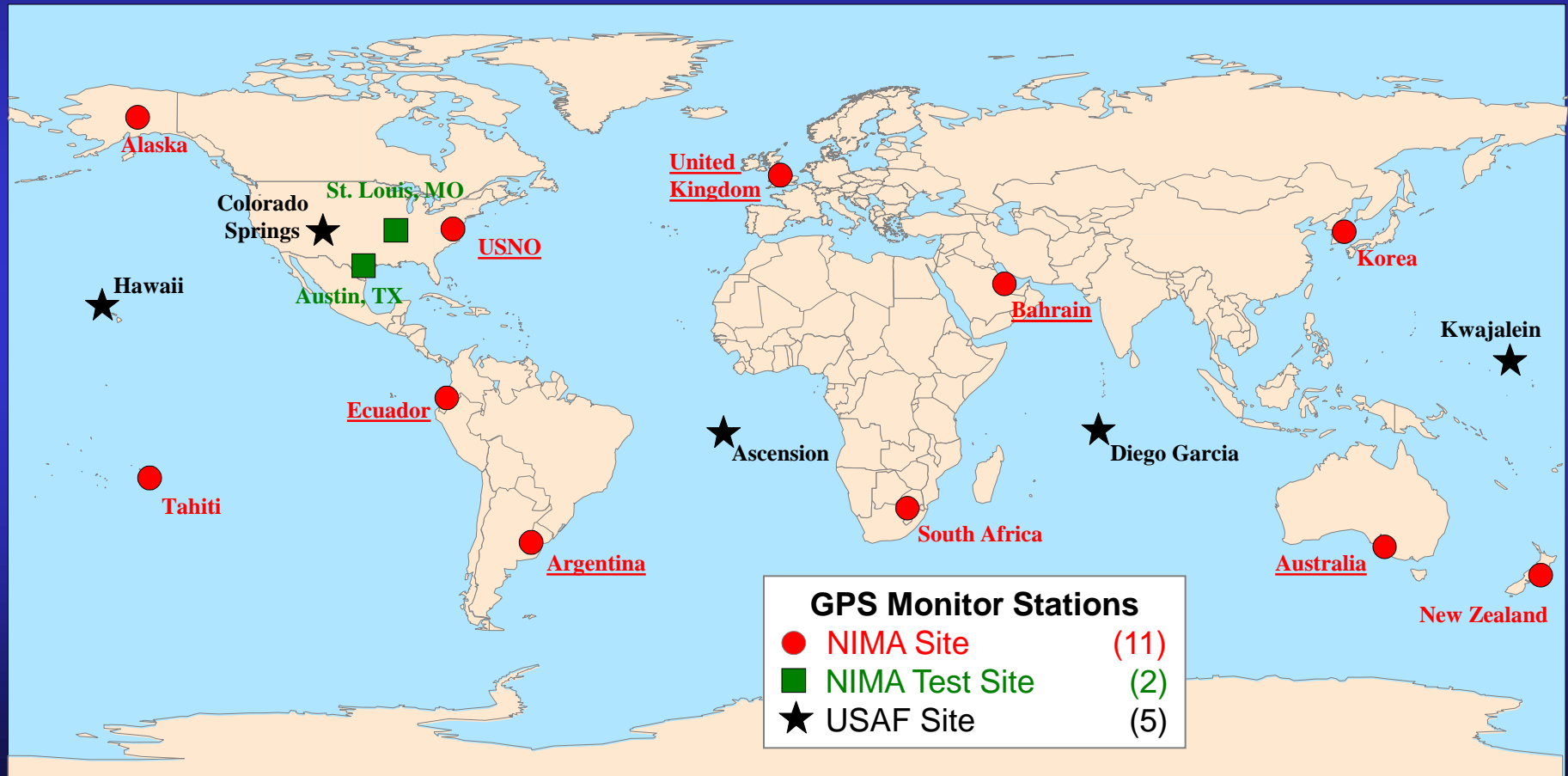
Ground Control Modernization

- **Replace existing Master Control Station mainframe computer with a distributed architecture**
- **Build fully mission capable Alternate Master Control Station (AMCS)**
- **Add IIF command and control functionality**
- **Legacy Accuracy Improvement Initiative**
 - Additional information from National Geospatial-Intelligence Agency sites decreases “**Age of Data**”, thus increasing accuracy in GPS satellite orbital position and clock data

GPS Future Monitor Station Network

- Six stations added to existing five in 2005
 - UK, Australia, Bahrain, Argentina, Equador, USNO
- Additional five to be added in ~ 2007

Developing GPS Monitor Station Network



GPS Modernization Schedule

Activity	Implementation Date
SA set to zero	May 2000
GPS IIR-M Enhancements <ul style="list-style-type: none">- New L2 Civil (L2C) Signal- M-code on L1 & L2	Launches: September 2005, September, November 2006, ...
GPS IIF Enhancements <ul style="list-style-type: none">- New L2 Civil (L2C) Signal- M-code on L1 & L2- L5	1 st launch currently scheduled for 2008
GPS III Enhancements <ul style="list-style-type: none">- New L2 Civil (L2C) Signal- M-code on L1 & L2 with greater power- L5- Future Capabilities	1 st launch ~ 2012
OCS Enhancements	On-going

GPS III

- Concept Definition completed in 2005
- Development contract to be awarded summer 2007
- GPS-III (2013 ? -): New features are being considered to increase reliability and accuracy
 - Faster time to alert or correct failures
 - More accuracy
 - More availability
 - Increased signal strength

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Galileo / GPS Time Offset (GGTO) ICD

- Scope:
 - The purpose of the Galileo / GPS Time Offset (GGTO) ICD is to provide a starting point for developing a detailed ICD that will allow precise estimation of the GGTO and inclusion of the offset between GPS and Galileo system time in each system's **navigation message**
- Goal:
 - An objective of **three nanoseconds** (one meter) accuracy for the GGTO message has been accepted

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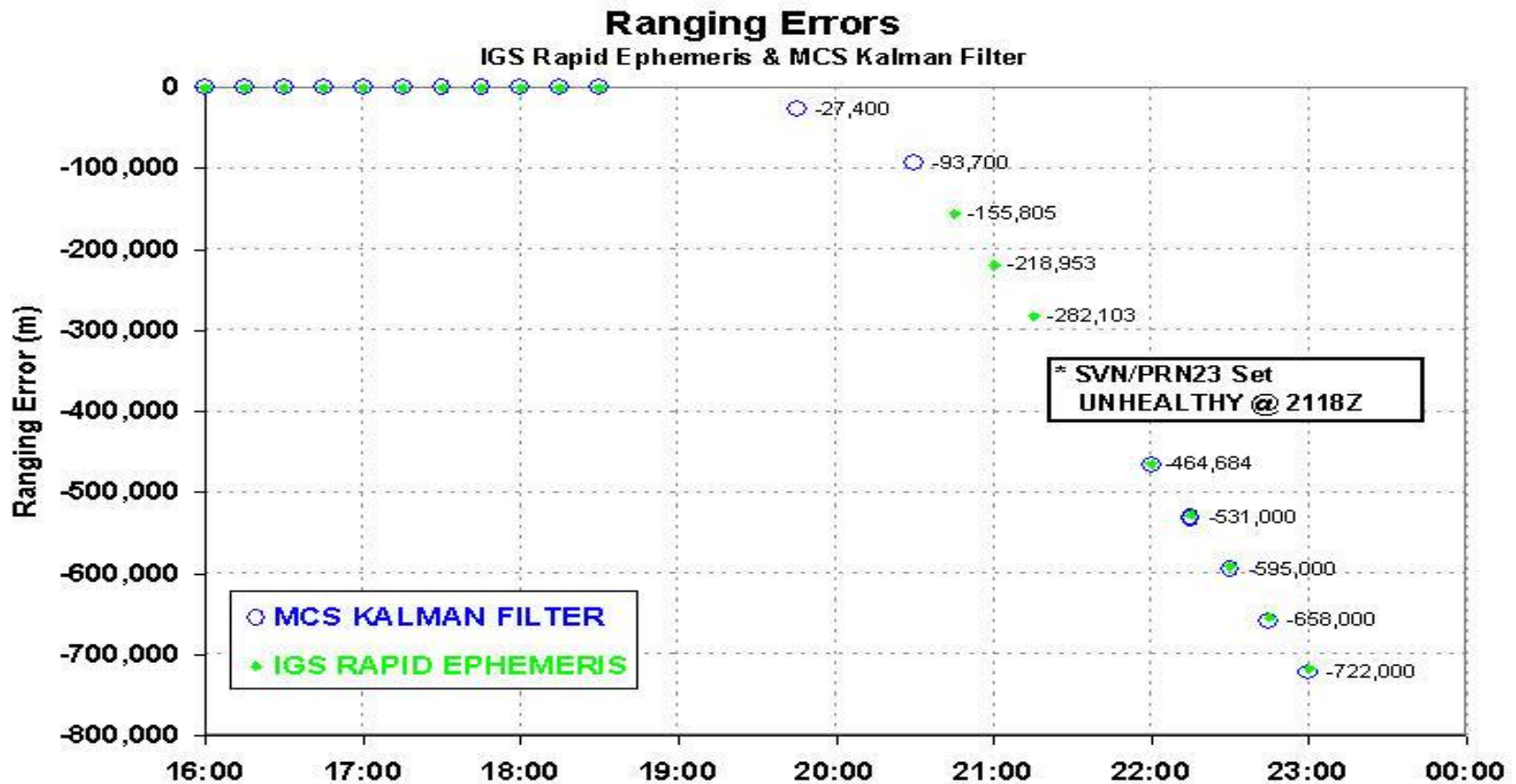
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Failure Modes

- Satellite failure modes can produce signals with large errors
 - Receiver Autonomous Integrity Monitoring (RAIM) should compare all satellite signals and discard errors
 - System design should compare GPS-based clock to local signals
- Receiver problems
 - Satellites set unhealthy should not be used
 - Firmware errors and wrong interpretations of specs
 - Ionosphere/troposphere models
 - Leap seconds
- Jamming: intentional and unintentional

PRN/SVN 23 Anomaly: Jan 1, 2004

Due to failed atomic frequency standard



Non-Standard Code Problems

- “The SV will transmit intentionally ‘incorrect’ versions of the C/A and the P(Y) codes where needed to protect the users from receiving and utilizing anomalous NAV signals as a result of malfunction ...”-ICD200
- 18March97 PRN 5 jumped forward 2 hours, 20 minutes and remained in standard code.
- Several wireless base station transmitters failed in the U.S.

GPS is Vulnerable to Jamming

- GPS signals can be easily jammed
- Incident of a synthesizer accidentally jamming aircraft
 - Transmitter accidentally left on near New York, two weeks Dec 1997 – Jan 1998
 - Jammed aircraft within 300 km
- Most telecom receivers can go into holdover for at least a week with few ill effects

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Summary

- Civil GPS service continues to **exceed** performance standards
- **GPS Modernization is underway**
 - **IIR-M** launch with **L2C** and M-code
 - Enhancements will continue through GPS III
- US and EU cooperation has made great progress at ensuring compatibility and interoperability between GPS and Galileo
 - **GPS/Galileo Timing Offset ICD**

Meeting the interoperability challenge will entail simultaneous cooperation and competition over a sustained period of time

Conclusions

- Global GPS civil service performance commitment met continuously since Dec 93
- Future:
 - GPS: new signals, more accuracy, yet backward compatible, more integrity information
 - New/other systems: GLONASS, Galileo, QZSS
- GPS failure modes: they exist **and** there are precautions
- Resources are available