

# Space and Missile Systems Center



## Global Positioning Systems Directorate

Jun 2013 GPS Civil Navigation  
(CNAV) Testing Summary

13 Sep 2013

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# Purpose of CNAV Testing

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- Validate L2C/L5 interfaces/flush out issues
- Facilitate Operations Concept development
- Facilitate compatible civil receiver development
- Reinforce civil stakeholder role in L2C/L5 development
- Ensure readiness for Dual Frequency Civil Signal Initial Operational Capability



# Jun 2013 CNAV Testing Overview

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- Focused on basic PNT functionality
  - CNAV message types (MTs) 10, 11, and 3X were broadcast
- Began w/ three basic message types plus optional text
  - Initially uploaded MT-10,11,15,30 to only 2 SVs (SVN58, SVN65)
  - Gradually uploaded CNAV to all 10 capable SVs upon visibility
- Increased broadcast complexity – all ten capable SVs
  - Uploaded more MTs (MT-12,32,33,35) & varied sequence
- Reverted to default CNAV config & broadcast MT-0, all SVs

***Employed Low-Risk, Incremental Testing Approach***



# Jun 2013 CNAV Test Broadcast Schedule

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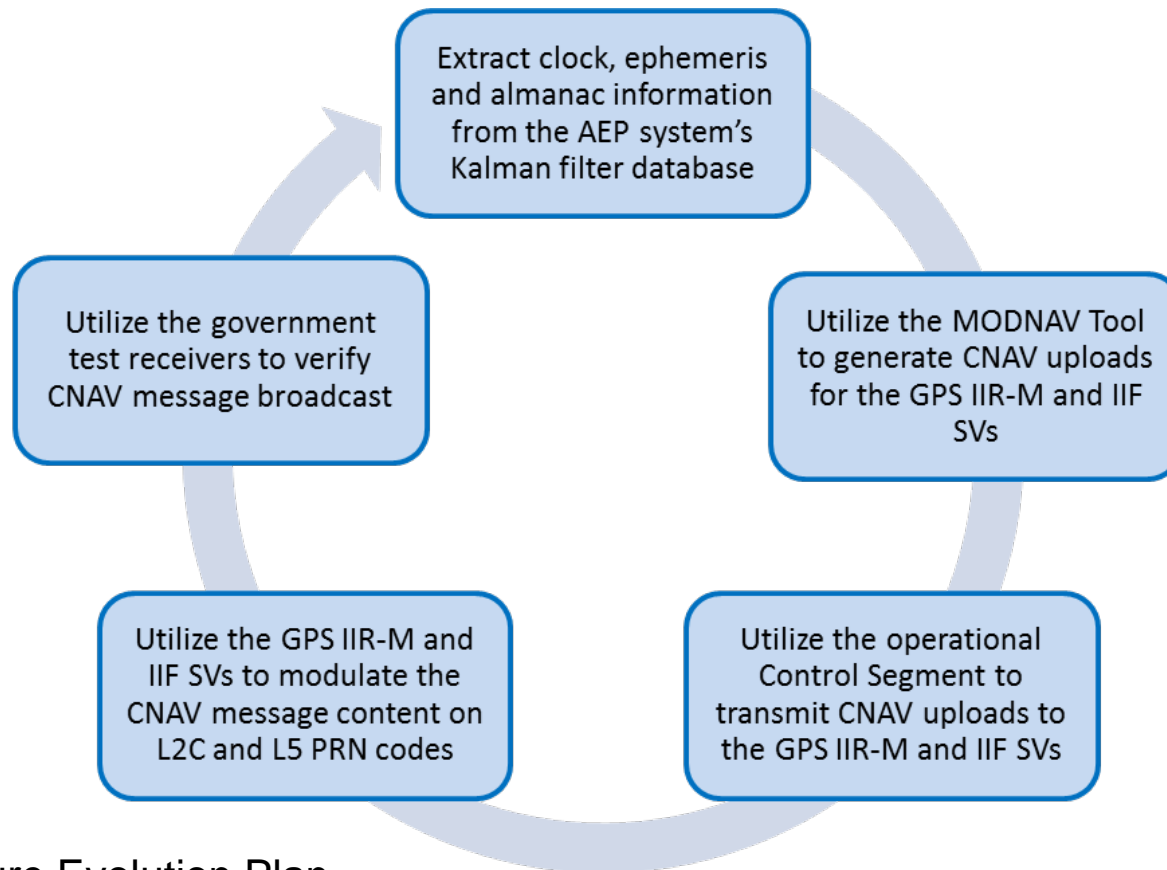
Test Scenario	SV Block Type	Message Types/ Sequence	Message Purpose/Description
#1 15 June	GPS IIR-M SVN58	10, 11, 30, 15	Minimum CNAV Message Subset to Support SV Position Determination - CNAV Channel status unhealthy
	GPS IIF SVN65	10, 11, 30, 15	Minimum CNAV Message Subset to Support SV Position Determination - CNAV Channel status unhealthy
#2 16 June	GPS IIR-M SVN58	10, 11, 30, 15	Minimum CNAV Message Subset to Support SV Position Determination - CNAV Channel status healthy
	GPS IIF SVN65	10, 11, 30, 15	Minimum CNAV Message Subset to Support SV Position Determination - CNAV Channel status healthy
#3 17-18 June	GPS IIR-M (All)	10, 11, 30, 15	Minimum CNAV Message Subset to Support SV Position Determination - CNAV Channel status healthy
	GPS IIF (All)	10, 11, 30, 15	Minimum CNAV Message Subset to Support SV Position Determination - CNAV Channel status healthy
#4 19 June	GPS IIR-M (All)	10, 11, 12, 30	Basic CNAV Message Subset includes Reduced Almanac CNAV Channel status healthy
	GPS IIF (All)	10, 11, 12, 30	Basic CNAV Message Subset includes Reduced Almanac CNAV Channel status healthy
#5 20-21 June	GPS IIR-M (All)	10, 11, 12, 30	Basic CNAV Message Subset includes Reduced Almanac CNAV Channel status healthy
	GPS IIF (All)	12, 30, 10, 11	Basic CNAV Message Subset includes Reduced Almanac CNAV Channel status healthy
#6 22-23 June	GPS IIR-M (All)	10, 11, 12, 30	Basic CNAV Message Subset includes Reduced Almanac CNAV Channel status healthy
	GPS IIF (All)	10, 11, 12, 30, 32, 33	Expanded CNAV Message Subset, includes Earth Orientation Parameters and GPS Time to Coordinated Universal Time (UTC)
#7 24-25 June	GPS IIR-M (All)	10, 11, 12, 30, 32, 33	Expanded CNAV Message Subset, includes Earth Orientation Parameters and GPS Time to UTC
	GPS IIF (All)	10, 11, 12, 30, 32, 33	Expanded CNAV Message Subset, includes Earth Orientation Parameters and GPS Time to UTC
#8 26 June	GPS IIR-M (All)	10, 11, 12, 30, 32, 33	Expanded CNAV Message Subset, includes Earth Orientation Parameters and GPS Time to UTC No Intrasignal Corrections (ISC) values broadcast
	GPS IIF (All)	10, 11, 12, 30, 32, 33	Expanded CNAV Message Subset, includes Earth Orientation Parameters and GPS Time to UTC No ISC values broadcast
#9 27-28 June	GPS IIR-M (All)	10, 11, 12, 15, 30, 32, 33, 35	Expanded CNAV Message Subset, includes GLONASS GALILEO Time Offset (GGTO) message; GGTO values not available "000"
	GPS IIF (All)	10, 11, 12, 15, 30, 32, 33, 35	Expanded CNAV Message Subset, includes GGTO message; GGTO values not available "000"



# Jun 2013 CNAV Test Process Flow

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## Test Process Flow



AEP: Architecture Evolution Plan  
MODNAV: Modernized Navigation  
PRN: Pseudo-Random Noise



# CNAV Testing Accomplishments

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- Executed first CNAV Live-Sky Test Broadcast with Civil Input
  - Demonstrated CNAV messaging on GPS IIR-M & GPS IIF SVs
  - Validated 8 of 15 CNAV Message Types
  - Coordinated effort between SMC, Aerospace, Draper, FAA, JPL, MITRE, NASA, NGA, SPAWAR, & SRI
  - Leveraged FAA's civil receiver monitoring & International Space Station's Space Communication and Navigation Testbed

***First CNAV Live-Sky Broadcast Test Successfully Executed***



# Valuable Results from Early Testing

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1. Observed GPS IIF L5 Signal Inversion – Characterized GPS IIF SV behavior affecting receiver accuracy & broadcasting non-compliant signal-in-space
2. Observed Premature GPS IIF Broadcast – Verified issue broadcasting non-compliant CNAV signal-in-space that could potentially affect receiver Time-to-First-Fix performance
3. Observed Invalid GPS IIR-M Broadcast – Verified issue providing erroneous information to receivers & non-compliant CNAV signal-in-space



# Issue 1: L5 Signal Inversion

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SVNs 62,63,65 transmit L5 signals with inverted I5 & Q5 phase relationship

- I5 should lead Q5 by  $90^\circ$  in phase (per Interface Specification)
- SVN 66 L5 signal correct, due to inverted wire (per photographic evidence)
- Photographs of other SVs (on-orbit & in production) all show wiring IAW instructions

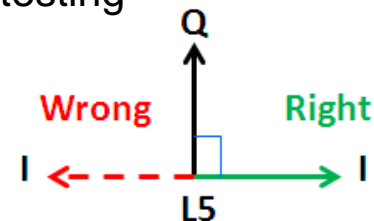
Cause: GPS IIF SV modulator I5 & Q5 lead/lag relationship opposite of expectations

Impact: High (if present after CNAV is operational)

- Older, simple (~3M) L5 receivers process the phase-inverted signal with ~13cm error
- Advanced (~100K) L5 receivers used for scientific applications may not use the signal

Way Ahead:

- Prototype software fix demonstrated - will upload to on-orbit GPS IIF SVs in Dec 2013
- Confirmed inversion w/ GPS IIF SVs on Boeing factory floor (SVs 3,6) Jul 2013
- Remaining GPS IIF SVs 7-12, will be characterized during nominal factory testing
- Updated test setups to properly detect phase polarity



**L5 Inversion Root Cause ID'd & Issue to Be Resolved w/Software Patch**





# Issue 2: Premature GPS IIF Broadcast

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## Premature Broadcast of CNAV Messages (GPS IIFs only)

- Message Type-11 and 3X data sets incorrectly transitioning before 2-hr epoch
- MT-10,11,3X must all use same epoch time to provide PNT solution
- MT-10 data set transitions correctly at two-hour epoch
- Issue confirmed by University of Texas and NASA's ISS analysis

## Cause: Boeing GPS IIF software issue

- Issue confirmed previously; fix action is a known software change

## Impact: *Low* (if present after CNAV is operational)

- Renders CNAV signal non-compliant with IS-GPS-705 and IS-GPS-200
- Potentially affects receiver's Time-to-First-Fix performance

## Way Ahead:

- Software fix will be fielded mid-2014

***This Issue is a "Minor Annoyance" & Will Be Resolved With Software Patch***



# Issue 3: Invalid GPS IIR-M Broadcast

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Anomalous broadcast of invalid CNAV on GPS IIR-M SVs (post-test only)

- Broadcast random undefined message types & invalid data from IIR-M memory
- Government validated & verified asset confirmed the erroneous broadcast
- GPS World Article reported phenomena

Cause: MODNAV tool specified incorrect number of bits defining refresh count

- ICD misinterpretation led to software coding error for refresh count
- Truncated number of bits caused unpredictable message generation behavior
- Issue unexpected and previously unseen

Impact: *High* (if present after CNAV is operational)

- Renders CNAV signal non-compliant with IS-GPS-705 and IS-GPS-200
- Provides erroneous information to receivers (undefined, but properly-formatted)

Way Ahead:

- New CNAV MT-0 upload files were generated and uploaded to the GPS IIR-M SVs
- All GPS IIR-M SVs now broadcasting CNAV MT-0 correctly from all four memory slots
- MODNAV tool fix already coded and implemented

***This issue is resolved & will not affect future CNAV broadcasts***



# Preliminary CNAV Test Results

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- CNAV User Range Error results from all SVs were within GPS Standard Positioning Service Performance Standard (GPS-SPSPS) (< 4m RMS)
- LNAV-to-CNAV Position-Velocity-Time comparisons skewed
  - Caused by differing K-points, upload generation & activation times; analysis ongoing
- Future CNAV Live Sky Broadcasts
  - Implement direct connect to AEP for MODNAV Tool
    - Enable time-synchronized comparisons of LNAV & CNAV
  - Implement GPS IIF software fixes to correct issues

***CNAV URE performance met GPS-SPSPS requirements***



# Summary

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- Executed first CNAV Live-Sky Test Broadcast
  - Demonstrated GPS CNAV messaging capabilities
  - Validated 8 of 15 defined CNAV Message Types
  - Successfully collaborated with several organizations
- Obtained valuable information from early testing
  - Issue root causes & resolutions identified



# Backup

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# CNAV Message Types

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Msg Type	CNAV Message Title	Function/Purpose
0	Default	Default message (transmitted when no msg data is available)
10	Ephemeris 1	SV position parameters for the transmitting SV
11	Ephemeris 2	SV position parameters for the transmitting SV
12	Reduced Almanac	Reduced almanac data packets for 7 SVs
13	Clock Differential Correction	SV Clock differential correction parameters
14	Ephemeris Differential Correction	SV Ephemeris differential correction parameters
15	Text	Text, 29 eight-bit ASCII characters
30	Clock, IONO & Group Delay	SV Clock Correction Parameters, Ionospheric and Group Delay correction parameters (Inter-Signal Correction parameters)
31	Clock & Reduced Almanac	SV Clock Correction Parameters, Reduced almanac data packets for 4 SVs
32	Clock & EOP	SV Clock Correction Parameters, earth orientation parameters; ECEF-to-ECI coordinate transformation
33	Clock & UTC	SV Clock Correction Parameters, Coordinated Universal Time (UTC) Parameters
34	Clock & Differential Correction	SV Clock Correction Parameters, SV clock and Ephemeris differential correction parameters
35	Clock & GGTO	SV Clock Correction Parameters, GPS to GNSS Time Offset parameters.
36	Clock & Text	SV Clock Correction Parameters, Text, 18 eight-bit ASCII characters
37	Clock & Midi Almanac	SV Clock Correction Parameters, Midi Almanac parameters

**Shaded Messages Were Broadcast in Jun 2013 Live Sky**