GPS Wing Program Update

Munich Satellite Navigation Summit

Munich, Germany

7 March 2007

Col Mark Crews, USAF
GPS Wing Chief Engineer

GPS Wing
Los Angeles AFB, CA

Overview

- **System Improvements & Modernization**
  - GPS Constellation Status
  - Next Steps for Space and Control Segments
- **Interoperability & International Collaboration**
- **Summary**

GPS Constellation Status as of 12 Feb 07

30 Healthy Satellites

Baseline Constellation: 24

- **15 Block IIA satellites operational**
- **12 Block IIR satellites operational**
- **3 Block IIR-M satellites operational**
  - 5 additional IIR-M satellites to launch

– **Since Dec 93, U.S. Government met/exceeded civil GPS service performance commitments**
  - SPS Performance Standard (PS)

– **U.S. committed to superior GPS service**

GPS Constellation Growing to 30+ Satellites

- **IIR-15(M) launched: Monday, 25 Sep 06**
  - Set healthy: Thursday, 12 Oct 06, SVN 52 - PRN 31
  - 17 days from launch to on-orbit ops
- **IIR-16(M) launched: Friday, 17 Nov 06**
  - Set healthy: 13 Dec 06, SVN 58 - PRN 12
- **PRNs 12 & 32 return to ops – allows growth to 32 SV constellation**
- **Larger constellation yields improved availability & accuracy**

PRN – Pseudo Random Noise (spreading code)
SVN – Space Vehicle Number

IIR-15(M) Launch & ISS View
25 September 2006

IIR-16(M) Launch
17 November 2006

GPS constellation – Delivering excellent performance

	Orbital Slot	SVN	PRN	Block	URE
A-plane	A-1	39	9	IIA	1.11
	A-2	25	25	IIA	2.61
	A-2	52	31	IIR	0.14
	A-3	38	8	IIA	0.36
	A-4	27	27	IIA	2.13
B-plane	B-1	56	16	IIR	0.45
	B-2	30	30	IIA	2.06
	B-3	44	28	IIR	0.68
	B-4	35	5	IIA	0.6
	B-5	58	12	IIR	0.16
C-plane	C-1	36	6	IIA	1.05
	C-2	33	3	IIA	0.36
	C-3	59	19	IIR	0.38
	C-4	53	17	IIR	0.21
	C-5	37	7	IIA	0.69

	Orbital Slot	SVN	PRN	Block	URE
D-plane	D-1	61	2	IIR	0.6
	D-2	46	11	IIR	0.22
	D-3	45	21	IIR	0.69
	D-4	34	4	IIA	1.29
	D-6	24	24	IIA	1.08
E-plane	E-1	51	20	IIR	0.33
	E-2	47	22	IIR	0.5
	E-3	40	10	IIA	0.45
	E-4	54	18	IIR	0.49
F-plane	F-1	41	14	IIR	0.17
	F-2	26	26	IIA	0.09
	F-3	43	13	IIR	0.43
	F-4	60	23	IIR	0.23
	F-5	29	29	IIA	0.52
	F-6	32	1	IIA	1.08

Average URE from 30 GPS SVs: 0.71 m

NASA JPL data on Wed Feb 21 17:46:02 2007 (UTC)

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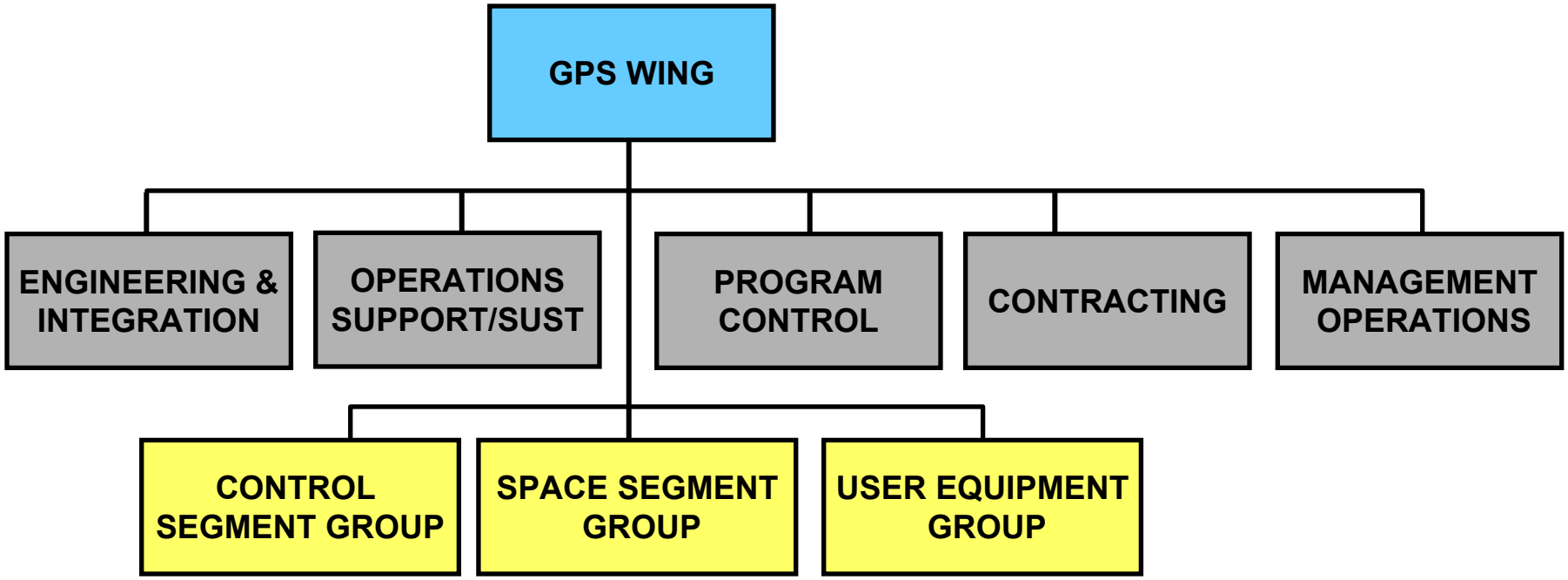
Modernizing the GPS Wing



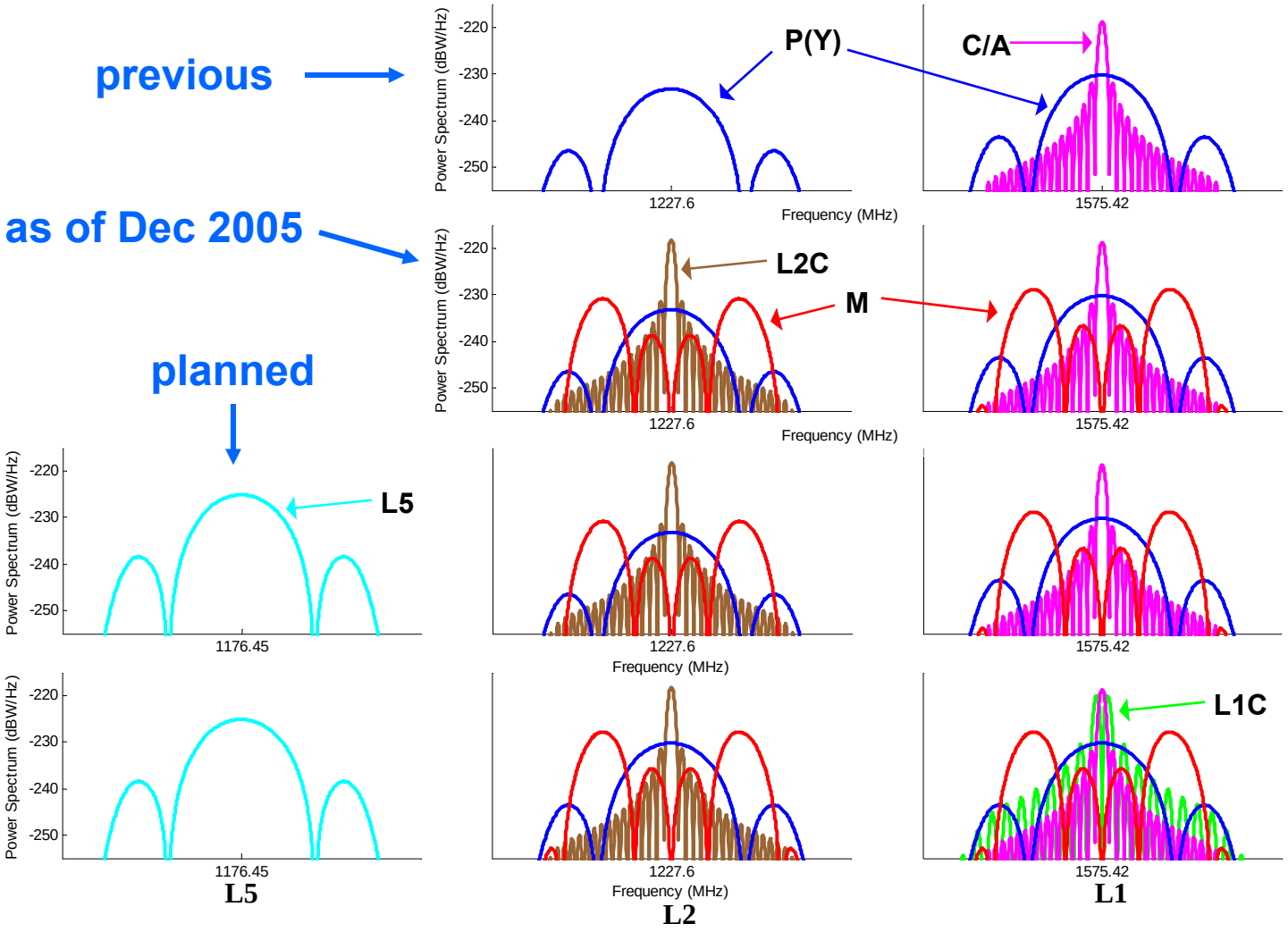
- **GPS Wing (GPSW) replaced GPS Joint Program Office (JPO)**
- **Aligns program office structure with Air Force organizations**
  - Wing-Group-Squadron: team-of-teams
- **Representatives from U.S. Dept of Transportation & NASA**

GPS Modernization – Spectrum

previous

as of Dec 2005

planned



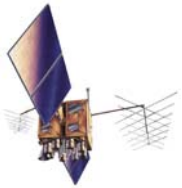
ARNS Band

RNSS Band

ARNS Band

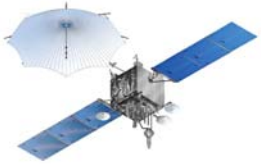
Block IIA, 1990

Block IIR-M, 2005



Block IIF, 2008

Block III, 2013



(artist's concept)

GPS Evolutionary "System-of-Systems" Programs

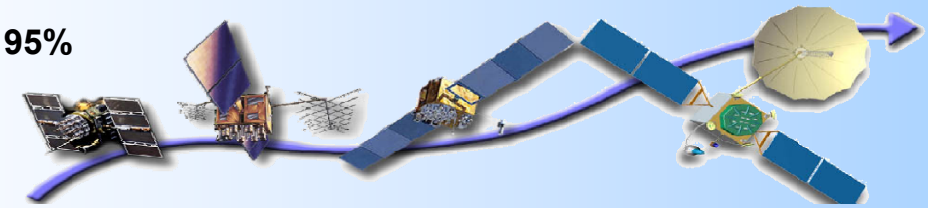
Space Segment

Legacy (Block IIA/IIR)
- Std Service (≤ 6 meters RMS SIS SPS URE)
  - Single frequency (L1)
  - Coarse acquisition (C/A) code navigation
- Precise Service (≤ 2.6 m 95% URE PPS at Zero AOD)
  - Y-Code (L1Y & L2Y)
  - Y-Code navigation

Modernized (Block IIR-M)
- 2nd civil signal (L2C)
- M-Code signals (L1M, L2M)
- Anti-jam flex power

Modernized (Block IIF)
- 3rd civil signal (L5)

GPS III (Block III)
- Increased accuracy
- Increased A/J power
- Signal integrity
- Search and Rescue
- L1C civil signal common w/Galileo, QZSS, & possibly GLONASS



Ground Segment

Legacy
- TT&C
- L1 & L2 monitoring

Upgraded (AEP)
- IIR-M IIF TT&C
- WAGE, AII, LADO
- NMCS/AMCS

Modernized (OCX V1)
- New Architecture
- Signal Monitoring

GPS III (OCX V2)
- GPS III TT&C
- Real-Time C2

GPS Block IIF Status

Key Milestones	Current Forecast
- SV1 thermal vacuum test	Aug 07
- SV1 delivered to CCAFS	Dec 07
- 1st IIF launch ready	May 08

Program Description

- 2 Rubidium + 1 Cesium clock
- 12 year design life
- Launch options: Atlas V or Delta IV
- Satellite launch weight < 3720 lb
- SPS signals: L1C/A, L2C, L5
- PPS signals: L1-L2P(Y), L1-L2M

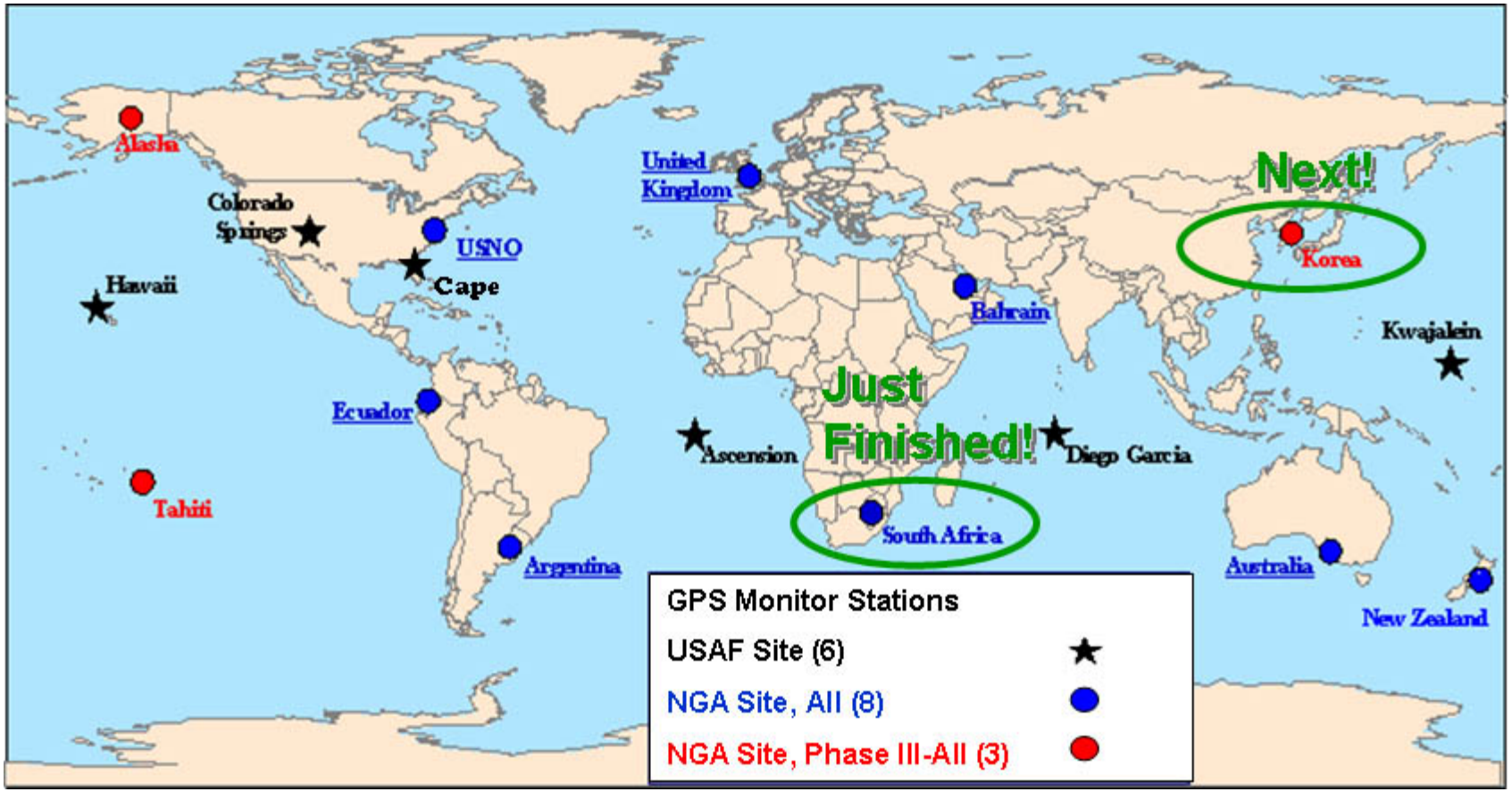
Program Status

- SV1 integration tests successful
- SV1 thermal vacuum upcoming test on track

SV1 launch
Atlas V

SV2 launch
Delta IV

Modernizing the operational control segment (OCS): Legacy Accuracy Improvement Initiative (L-AII)



- Each SV tracked by three or more monitor stations over 99% of time
- Zero age-of-data URE improved from ~46 cm to ~27 cm
- L-AII SIS URE improved from ~1.25 m to ~1.05 m

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GPS-GLONASS Working Group 1 (WG-1)

- **GPS-GLONASS meetings**
  - Dec 04 in Washington D.C., USA
  - Oct 05 in Moscow, Russia
  - Dec 05 in Moscow, Russia
  - Jun 06 in Cocoa Beach, Florida, USA
  - Dec 06 in Yaroslavl, Russia
- **Exploring opportunities for enhanced interoperability and compatibility of civil signals**

U.S. – Russian Federation
WG-1 Joint Statement (14 December 2006)

Both parties made "significant progress" understanding benefits to users of a common approach

United States – Russian Federation
GPS/GLONASS Interoperability and Compatibility Working Group (WG-1)

Yaroslavl, Ring Premier Hotel, 14 December, 2006

Joint Statement

Working Group 1 met on December 13-14, 2006, in Yaroslavl, Russia, and discussed a range of issues. This was the third meeting of the working group. The meeting was highly successful and resolved many questions regarding interoperability and compatibility between the GPS and GLONASS systems. Both sides noted that concerning the question of the use FDMA and CDMA significant progress was made in understanding the benefit to the user community of using a common approach. The Russian side noted that a decision in this regard would be made by the end of 2007.

Both sides agreed that the planned International Satellite Forum 2007 to be held April 9-10, 2007, in Moscow will be a unique opportunity to demonstrate the benefits of GLONASS and GPS interoperability in the Russian Federation for civil applications.

Co-chair
Mark Crews

Co-chair
Vladimir Klimov

GPS & Galileo Working Group A (WG A) on Radio Frequency Compatibility & Interoperability

- **GPS-Galileo WGA meetings**
  - Mar 05 in Brussels, Belgium
  - Jun 05 in El Segundo, California, US
  - Oct 05 in Rome, Italy
  - Mar 06 in Stockholm, Sweden
  - Oct 06 in El Segundo, California, US
- **GPS-Galileo opportunities for civil signal capability**
  - L1C & L5 compatible/interoperable
  - Working GPS-Galileo Time Offset

WGA 22 March 2006 MBOC Recommendation
EC & US Joint Statement 24 March 2006

GPS-Galileo Working Group A (WG A)
Recommendations on L1 OS/L1C Optimization

1. BACKGROUND

The purpose of this document is to recommend a jointly optimized signal for the Global Positioning System (GPS) L1 Civil (L1C) and the Galileo L1 Open Service (OS), consistent with Article 11, Paragraph 7 of the June 2004 "Agreement on the Promotion, Provision and use of Galileo and GPS Satellite-Based Navigation Systems and Related Applications" (the "Agreement").

2. SPREADING MODULATION DESCRIPTION

We intend to design signals for L1 OS and L1C that have an identical power spectral density (PSD) when computed using all signal components including pilot and data. This normalized (unit power) PSD (hereinafter "the MBOC PSD"), specified without the effect of bandlimiting filters and payload imperfections, is given by

$$\Phi(f) = \frac{10}{11} BOC(1,1) + \frac{1}{11} BOC(6,1)$$

where $BOC(m,n)$ is the normalized PSD of a sine-phased Binary Offset Carrier modulation with subcarrier frequency $m \times 1.023$ MHz and spreading code chip rate $n \times 1.023$ MHz.

We understand that the Galileo and GPS systems may employ different time series, including different spreading symbols, to produce the MBOC PSD. Nonetheless, it is desirable for both Galileo and GPS to transmit time series using the same spreading symbols, and spreading codes from the same family.

Following the meeting in Stockholm on the 20-22nd of March, it was established that, when implemented by both GPS and Galileo, the MBOC PSD is fully compliant with the criteria of the Agreement. In addition, WG A established that the performance of MBOC signals surpasses that of CBCS* as previously defined.

3. RECOMMENDATIONS

3.1 WG A recommends that no further consideration be given to CBCS*.

3.2 WG A recommends that selection of the MBOC PSD completes the modulation optimization process described in Article 11, Paragraph 7 of the Agreement.

3.3 WG A recommends the following actions:

a) Each party promptly informs the other party if it identifies an issue that prevents the implementation of the MBOC PSD.

b) The parties jointly prepare and exchange notifications of their intent to implement the MBOC PSD in accordance with the notification procedures described in Article 11 of the Agreement as soon as possible.

JEREMIE GODET
European Community WG A Co-Chair
Date 22 March 2006

MARK CREWS, Col, USAF
United States WG A Co-Chair
Date 22 March 2006

WGA recommended MBOC for L1C

.:: JOINT STATEMENT 24 MARCH 2006 ::.

Joint Statement on Galileo and GPS Signal Optimization
By the European Commission (EC) and the United States (US)
Brussels 24 March 2006

In June 2004, the EC and US signed the Agreement on the Promotion, Provision and use of Galileo and GPS Satellite-Based Navigation Systems and Related Applications on the compatibility and interopcrability of the Galileo and GPS satellite navigation systems. A central element of the Agreement was a common baseline signal structure that could be optimized for greater performance.

On 20-22 March 2006 in Stockholm, Sweden, the GPS-Galileo expert group on radio frequency compatibility and interoperability successfully produced a jointly-optimized common signal after 21 months of cooperative effort. The working group also verified that this signal satisfies all compatibility requirements and recommends this signal for broadcast by both the Galileo and GPS constellations.

Following this recommendation, the EC and US will promptly assess relevant programmatic aspects of implementing the joint-optimization. Subject to this assessment, the EC and US intend to formally notify each other of their intent to implement the jointly-optimized common signal.

Once implemented, the common signal will be jointly broadcast by up to 60 satellites from both the Galileo and GPS constellations.

The EC and US will continue to work together on GPS-Galileo compatibility and interoperability in order to raise the state-of-the-art in navigation, positioning, and timing services for users worldwide.

Heinz Hilbrecht
Head of the EU delegation

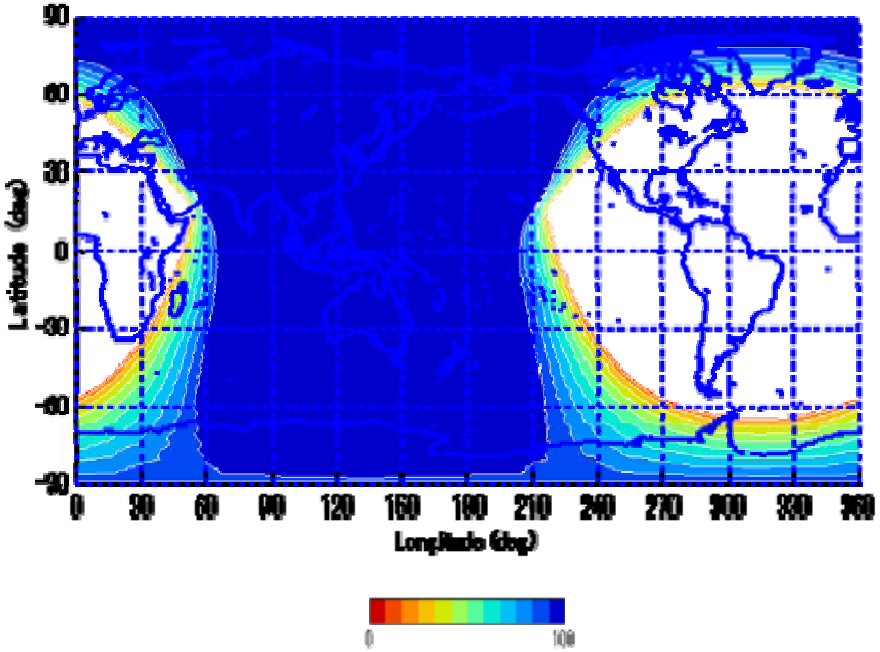
Ralph Braibanti
Head of the US delegation

WGA produced jointly-optimized common signal

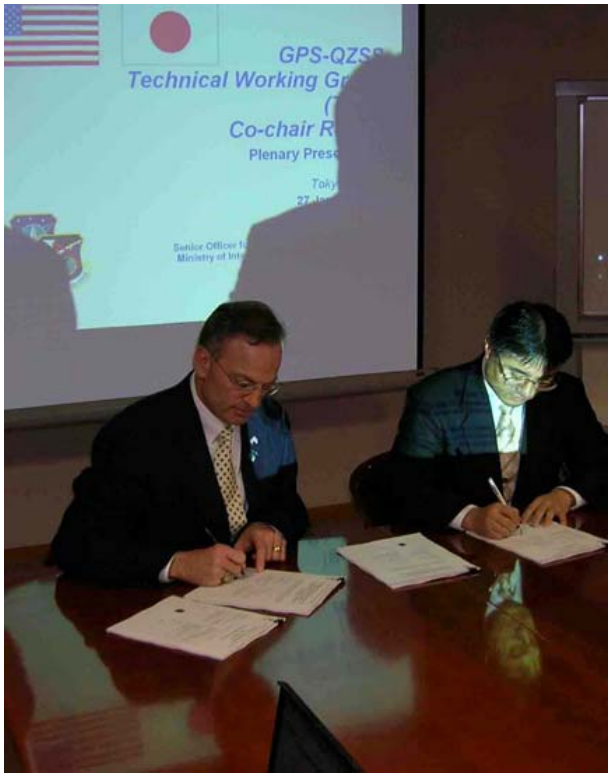
GPS-QZSS Technical Working Group (TWG)

- **Civil system for Asia-Pacific region**
- **Enhances civil GPS services**
- **First QZSS launch expected in 2009**
- **GPS-QZSS technical meetings**
  - Nov 04 in Washington, DC, US
  - July 05 in Hawaii, US
  - January 06 in Tokyo, Japan
  - Aug 06 in Hawaii
- **GPS & QZSS success in designing "common" signals**
  - Five of six QZSS signals use same signal structures, frequencies, spreading code families, data message formats as GPS or SBAS signals
- **Draft interface specification (IS) for QZSS released in January 2007**
  - IS-GPS-200, IS-GPS-705, & IS-GPS-800 are baseline documents

% Time that at Least 1 of 3 QZSS Satellites Is Visible



GPS/QZSS Agreement – 27 January 2006
Unprecedented Compatibility & Interoperability



- **QZSS designed to work with & enhance civil services of GPS**
  - Availability enhancement
  - Performance enhancement
- **GPS & QZSS have established that their signals are RF compatible**

MODELS AND METHODOLOGY FOR GPS/QZSS RADIO FREQUENCY COMPATIBILITY ANALYSES

The purpose of this document is (1) to set forth the Radio Frequency compatibility criteria that GPS and QZSS must comply with; and (2) to set forth the methodology and assumptions used to determine whether the signals comply with these criteria.

Issue	Rev 01	
Prepared by:		
Sean Lenahan, Lt, USAF GPS Signal Modernization Navstar GPS Joint Program Office		Satoshi Kogure Associate Senior Engineer Satellite Applications Center, JAXA Japan Expert Working Group Co-Chair
Checked by:		
Approved by:		
Mark C. Crews, Col, USAF NAVSTAR GPS Chief Engineer, Navstar GPS Joint Program Office		Takaharu Koide Senior Officer for Satellite Development Program Space Communications Policy Division Information and Communications Policy Bureau Ministry of Internal Affairs and Communications Japan Technical Working Group Co-Chair
Signature		Signature
Date 27 January 2006		Date 27 January 2006

GNSS Civil Signal Interoperability

	Characteristic	*Interoperability Benefit*
GLONASS-GPS	• Common time and reference frames, or broadcast offsets	• Navigation solutions can use measurements from different systems
?	• Common carrier frequencies	• Common antenna and receiver front end—lower power and cost; common carrier tracking for higher accuracy
	• Similar spreading modulation spectra	• Common-mode dispersive errors removed in navigation solution for higher accuracy
GPS (L1C and L5)–GALILEO (E1 OS and E5a)		
	• Common spreading code lengths and common code family	• Lower crosscorrelation sidelobes for better weak-signal reception; common receiver processing for acquisition and tracking
	• Common data message structure and encoding	• Common receiver processing for data message decoding and processing
GPS-QZSS		

Summary

- **Continuing success in GPS sustainment & modernization**
  - New capabilities delivering enhanced performance
  - Developments on track to enhance space and control segments
- **International Collaboration**
  - Excellent cooperation with civil service providers
  - Improving RNSS interoperability/compatibility for GNSS