



The Modernized GPS Civil Signals

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May 2014

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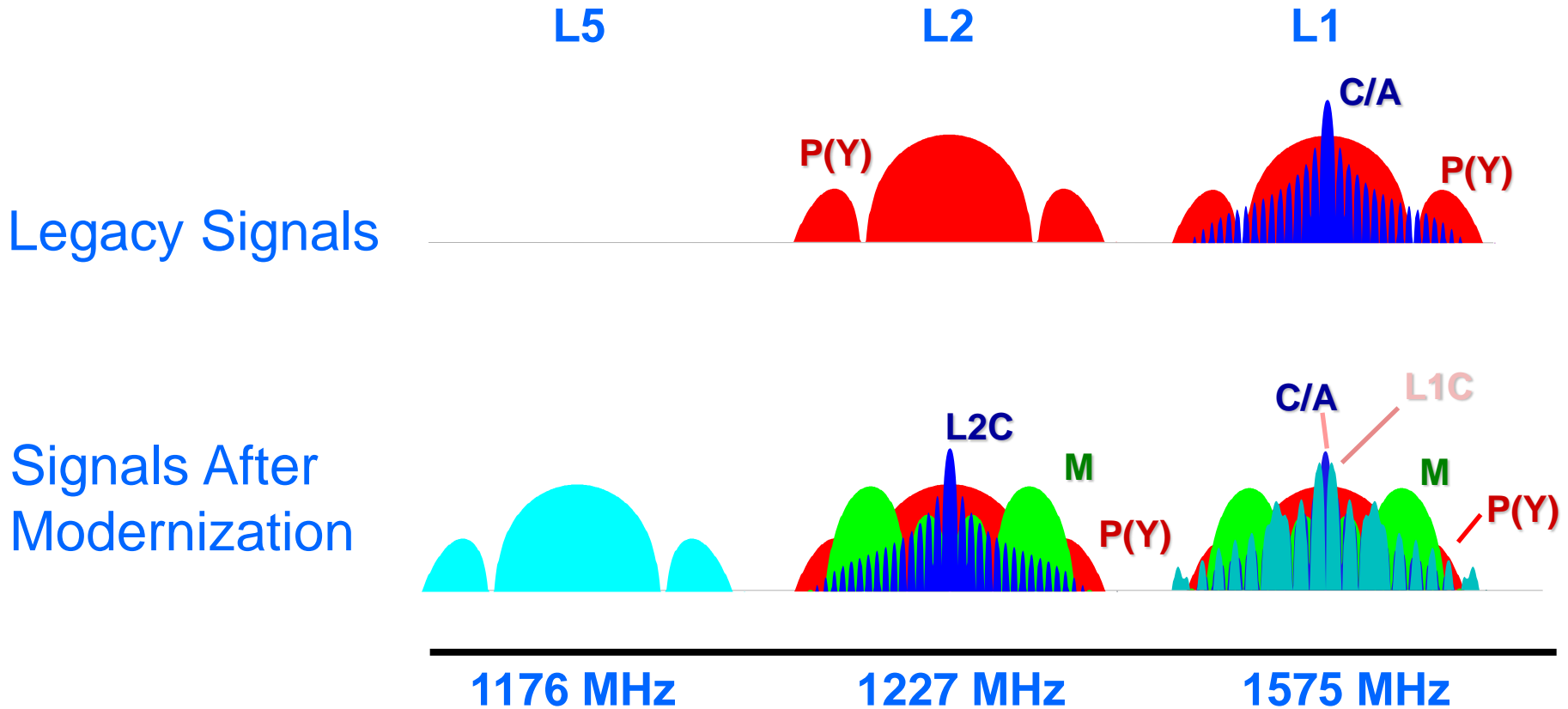
First – A Trivia Quiz...

GPS, Galileo, BeiDou, QZSS, IRNSS, and SBAS satellites utilize a frequency plan based around 10.23 MHz. Why?

- A. Natural frequency of a rubidium or cesium atomic clock.**
- B. ITU devised frequency plan.**
- C. Somehow related to these individuals**

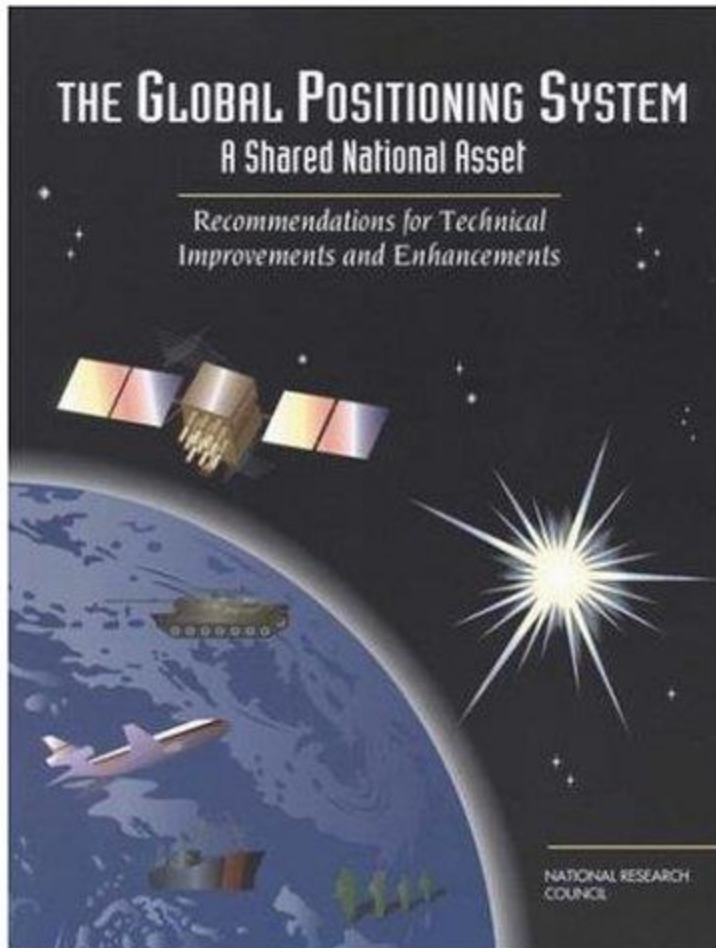


GPS Signal Modernization



- L2C** = Second civil signal (now on 12 satellites, 24 by ~2018)
- L5** = Third civil signal (now on 5 satellites, 24 by ~2021)
- L1C** = Fourth civil signal (first launch in 2016, 24 by ~2026)

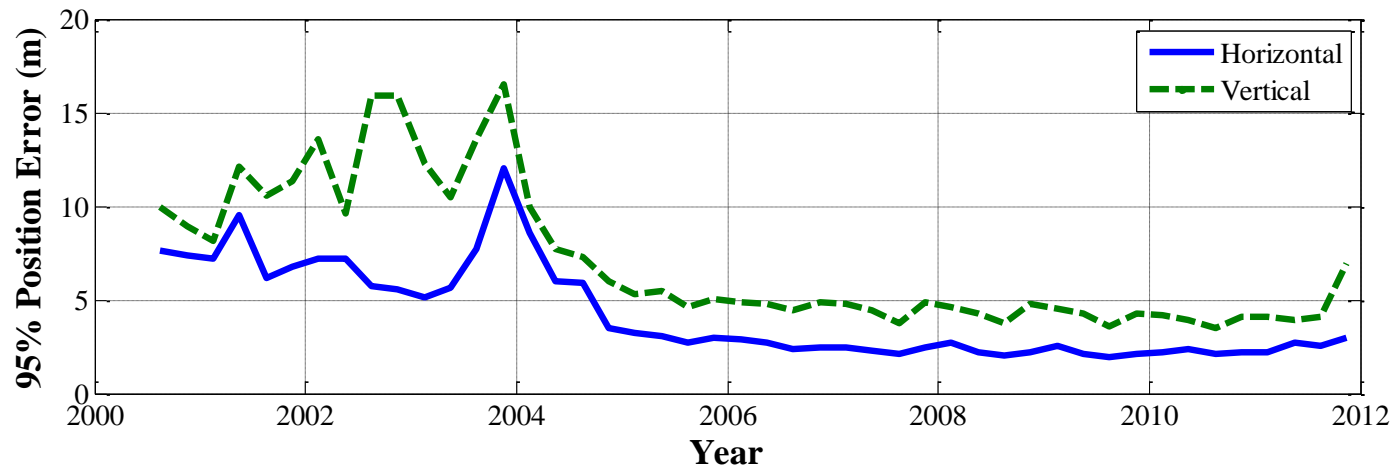
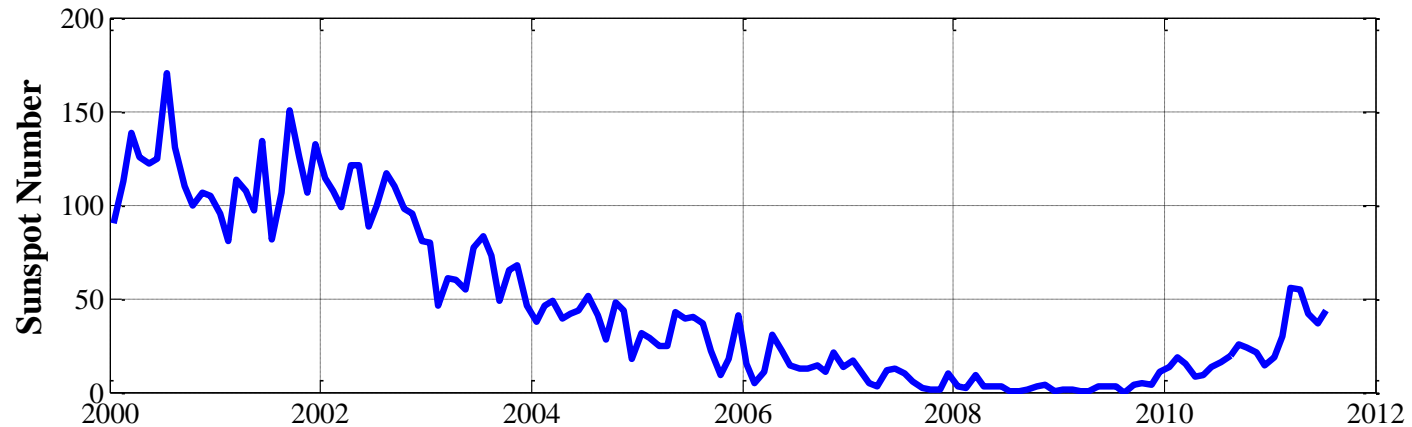
1995: GPS Fully Operational and a Clear Need for a Second Civil Signal



Source: National Academies Press, www.nap.edu.

- Among many others, this was recommended by the National Research Council in 1995
- Second civil signal would support:
 - Ionospheric delay correction
 - Carrier-phase widelane observable
- Simplest implementation would be to duplicate C/A-code on L2

Mid-Latitude GPS L1 C/A-code Accuracy



Source data from the Federal Aviation Administration's Global Positioning System (GPS) Quarterly Standard Positioning Service (SPS) Performance Analysis Reports.

The Issue with L2 for Aviation

- L2 is NOT in a band allocated for aeronautical radionavigation services (ARNS)
- This band is used worldwide for high-powered radars and, in some areas, also co-allocated for fixed and mobile services
- In April 2002 the International Civil Aviation Organization (ICAO) decided to NOT include L2 in their Standards and Recommended Practices (SARPs)



Source: Microsoft.

A Third Civil Signal

- **March 30, 1998 – U.S. Vice President announces:**
 - **New civil signal on L2**
 - **“A third civil signal will also be added with a decision on the frequency to be made in August”**
- **January 25, 1999 – Selection announced as 1176.45 MHz**



Source: Microsoft.

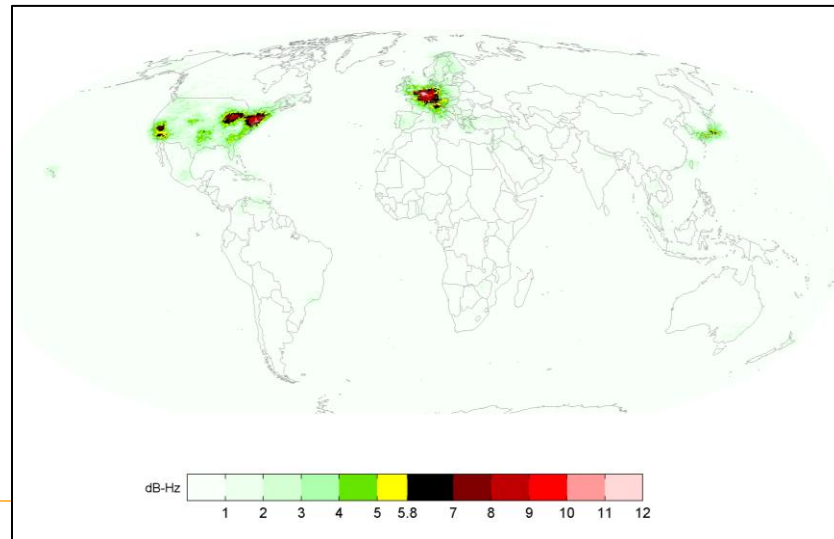
A Challenge with 1176.45 MHz



Distance Measuring Equipment (DME)

- Thousands of ground beacons worldwide (over 1700 in the United States)
- 1 MHz channels across 960-1215 MHz
- EIRP = 100 W - 10000 W
- 3.5 ms pulse width (1/2 voltage)
- 2700 - 3600 pulse pairs/s

Predicted Signal-to-Noise Degradation at 40,000'
(far less impact for users on the ground)



Site of GPS L5 High-level Design Finalization



Photo courtesy of Dr. A.J. Van Dierendonck.

L5 Design Features

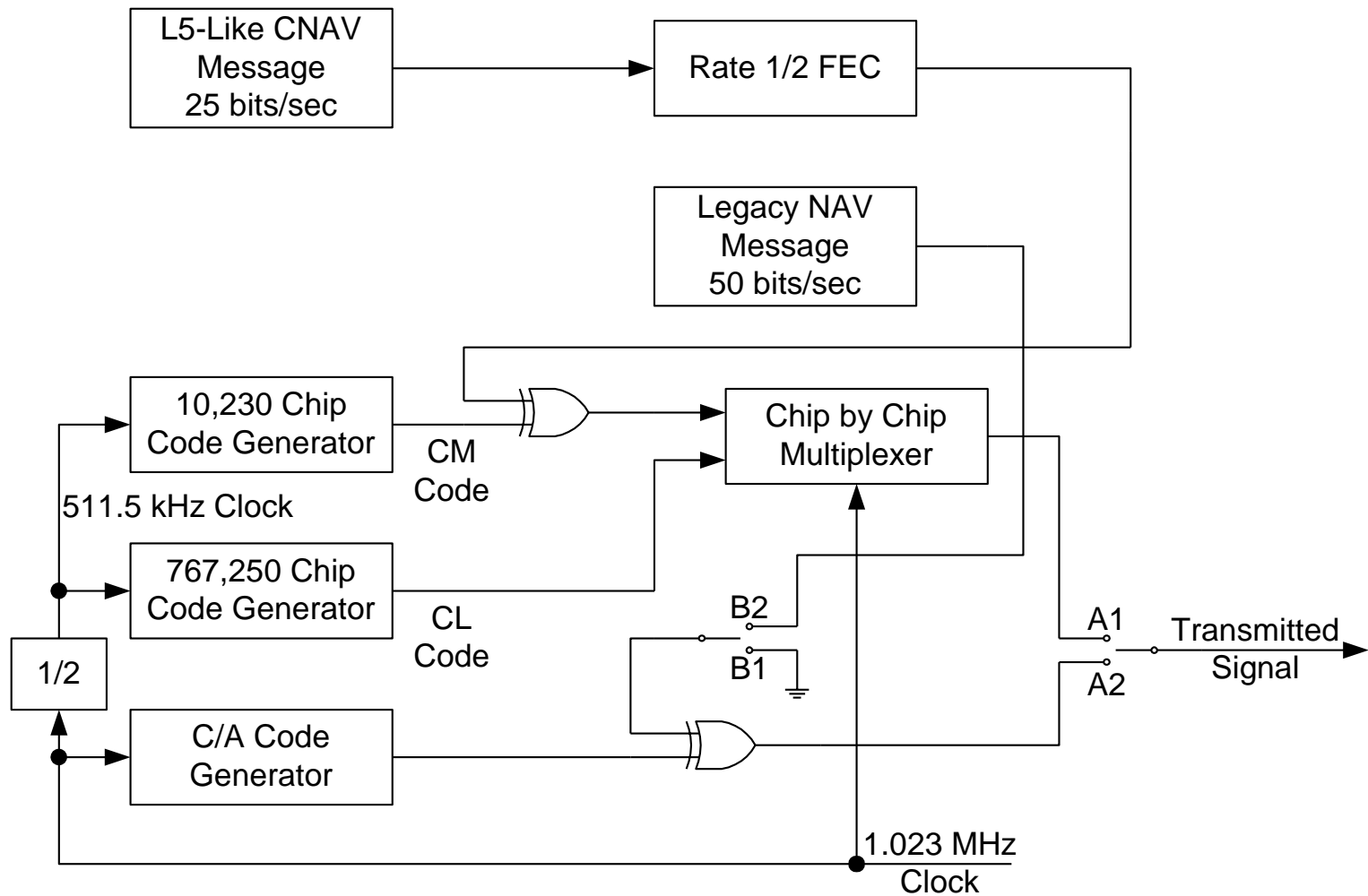
- L5 = 1176.45 MHz (within ARNS band)
- Much higher power than C/A (≥ -154.9 dBW)
 - In part to overcome DME interference
- Wide bandwidth (10.23 MHz chipping rate) enables precise ranging and robustness against narrowband interference
- Long (10230-chip) PRN codes and secondary (Neuman-Hofman codes) reduce cross correlation effects
- Half-power pilot component enables robust tracking in challenged environments
- Flexible 50 bps messages with robust error detection and forward error correction
- Specification: IS-GPS-705



L2C Design Features

- **L2 = 1227.6 MHz**
- **Minimum received power = -160 dBW (IIR-M/IIF)**
- **Designed to maximize performance for commercial mass-market users**
 - **1.023 MHz overall chipping rate**
 - **25 bps (50 sps) navigation data**
 - **Very long PRN codes with 50% power pilot**
 - **Moderate code (CM) = 10230 chips, modulated by data**
 - **Long code (CL) = 767,250 chips, NOT modulated by data**
- **Specification: IS-GPS-200**

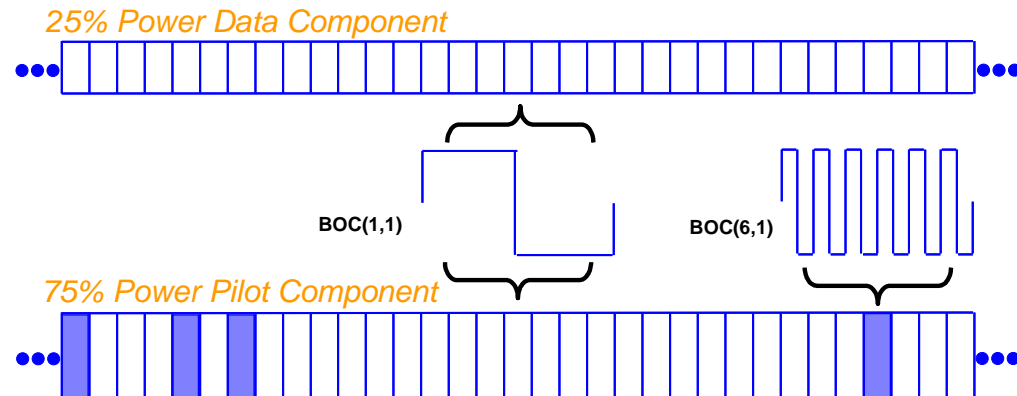
IIF L2C Signal Generation



Source: Fontana et al., The New Civil L2 Signal, ION GPS 2001.

L1C Design Overview

- New civil signal on L1 carrier, designed for GNSS interoperability
- Planned for GPS III space vehicles
- Modulation
 - Multiplexing of binary offset carrier (BOC) symbols referred to as time-multiplexed BOC (TMBOC)
 - Chipping rate = 1.023 MHz
 - Squarewave subcarrier = 1.023 MHz and 6.138 MHz
 - 50 bps (100 sps) data
 - Length-10230 PRN codes
- Specified in IS-GPS-800





EUROPEAN COMMISSION
DIRECTORATE-GENERAL FOR ENERGY AND TRANSPORT

Director-General

Brussels, 10 JUN. 2007
TREN/G5/MR/EAD(2007) 316635

Ms. Claudia A McMurray
Assistant Secretary for Oceans, Environment and Science
U.S. Department of State
Washington DC 20520
USA

Dear Ms McMurray,

In line with Article 11 paragraphs 5, 6 and 7 of the *Agreement on the promotion, provision and use of GALILEO and GPS satellite-based navigation systems and related applications* (the Agreement), I would like, on behalf of the European Community and its Member States, to notify you of our decision to change the Galileo Open Service, Safety of Life Service and Commercial Service signal from that described in the second bullet of paragraph (1) of the Annex to the Agreement to the Multiplex Binary Offset Carrier (MBOC) modulation. The description of the MBOC modulation is attached to this letter. I would also like to inform you that the European Community and its Member States would welcome the United States changing concurrently its signal structure from that described in the last sentence of the third bullet of paragraph (1) of the Annex to the MBOC modulation.

Yours sincerely,

Matthias Ruete



United States Department of State
Assistant Secretary of State for Oceans and
International Environmental and Scientific Affairs
Washington, D.C. 20520

JUL 25 2007

Dear Mr. Ruete:

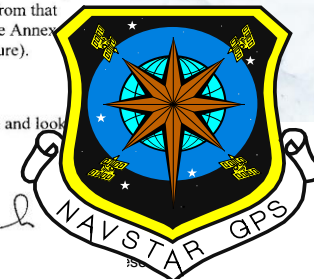
Thank you for your letters dated June 22 and July 18, 2007, regarding the adoption of the Multiplex Binary Offset Carrier (MBOC) modulation for certain Galileo signal structures. Your July 18 letter specifically notifies the United States, in accordance with Article 11, paragraphs 5, 6, and 7 of the *Agreement on the Promotion, Provision and Use of GALILEO and GPS Satellite-Based Navigation Systems and Related Applications* ("Agreement"), of the European Commission's decision to change the signal structures specified in bullet two of paragraph (1) of the Annex to the Agreement.

On behalf of the United States of America, and in accordance with the language of Article 11 paragraph 6 of the Agreement, I am pleased to inform the European Community and its Member States 1) that the United States will not oppose the adoption and implementation of the alternative signal structure specified in your notification; and 2) that, as a result of the close cooperation and collaboration fostered by the parties in Working Group A on radio frequency compatibility and interoperability for civil satellite-based navigation and timing services, the United States has decided to change its signal structure from that described in the last sentence of the third bullet of paragraph (1) of the Annex to the aforementioned Agreement to the MBOC modulation (see Enclosure).

We are very happy about the progress we have made in this area and look forward to continuing our mutually beneficial cooperation.

Sincerely,

Reno L. Harnish, Acting



Summary of Modernized GPS Civil Signal Features*

- **Longer pseudorandom codes**
 - Improves cross-correlation performance
- **Dataless (pilot) components**
 - One-half or more of signal energy devoted to component with no navigation data modulation
 - Enables more robust tracking
- **Wider bandwidth (L5 and L1C)**
 - Improves performance in noise and multipath
- **Robust forward error correction**
 - Convolution or low-density parity check encoding
- **Improved navigation data**
 - Greater precision
 - Stronger and more efficient error detection
 - Flexible messaging

Trivia Quiz Answer

GPS, Galileo, BeiDou, QZSS, IRNSS, and SBAS satellites utilize a frequency plan based around 10.23 MHz. Why?

A. Natural frequency of cesium or rubidium or cesium or rubidium atomic clocks

B. ITU devised a standard

C. Somehow related to these individuals



Dr. Robert Gold



Dr. Jim Spilker



Dr. Charlie Cahn