CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

A Brief History of GPS L5

Chris Hegarty

Stanford's 2010 PNT Symposium

November 10, 2010

CAASD

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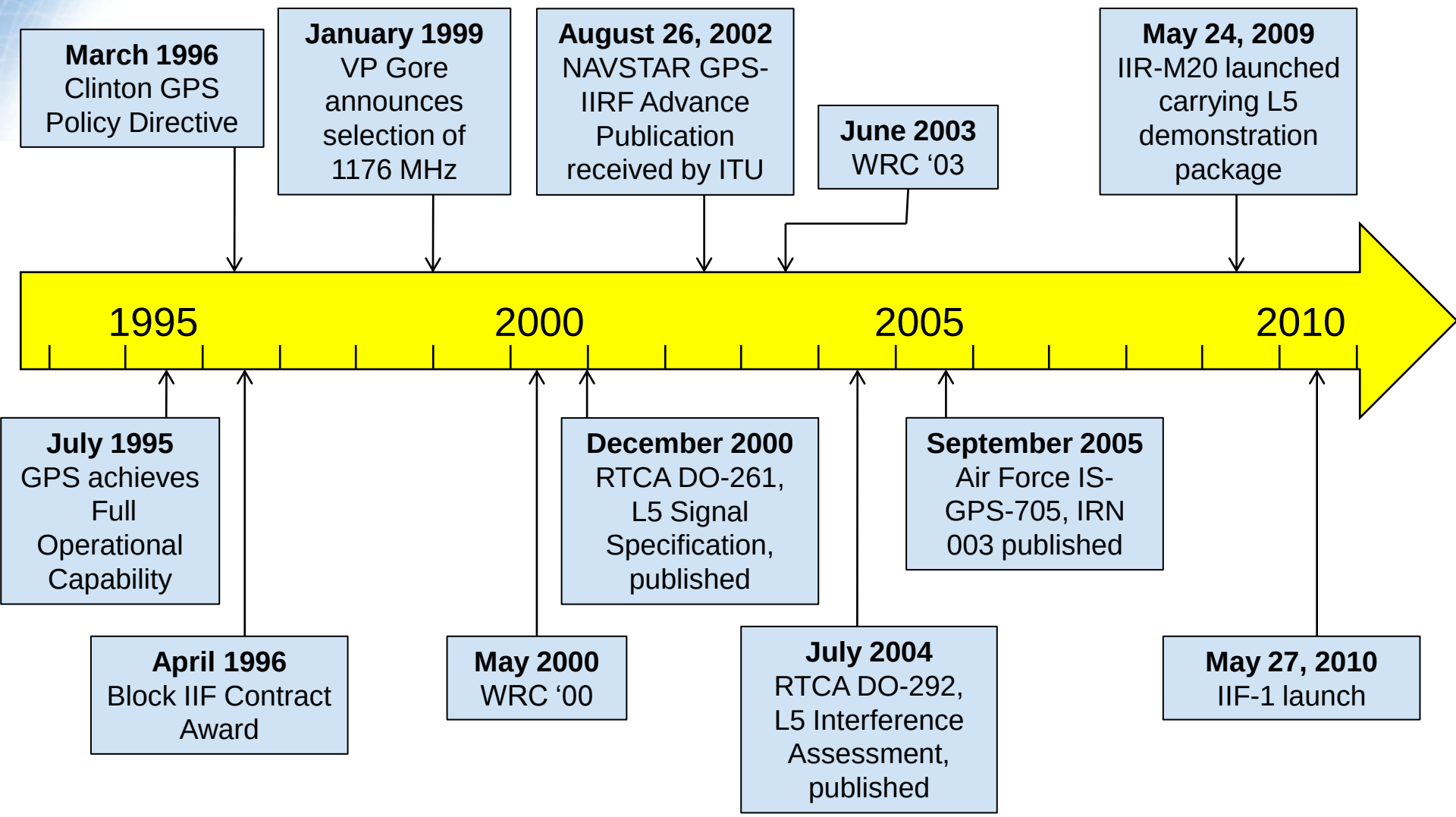
GPS L5 Milestones



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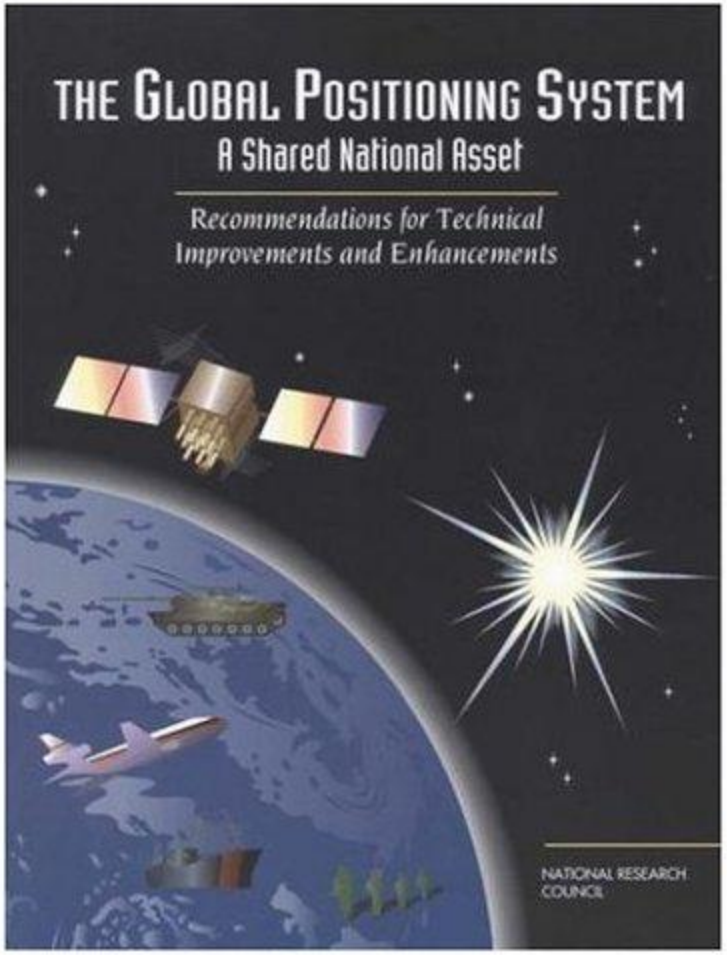
1995: GPS Fully Operational and a Clear Need for a Second Civil Signal



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

Among many others, this was recommended by the National Research Council in 1995.

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1996: Block IIF Contract Award

- **April 1996 – Rockwell International (now Boeing) wins IIF contract**
- **Contract included option for second coded civil signal with several candidate frequencies**
  - **Required government selection of frequency by February 1997**

Source: Braschak et al., The Boeing Company, ION GNSS 2010.

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Civil Signal Frequency Options

- In 1996, joint Department of Defense/Transportation (DoD/DOT) effort initiated to recommend frequency
- 1996 also notable for 1st paper on benefits of three frequencies (Ron Hatch, *GPS World*, May issue)
- By January 1997, candidate list included: 1145, 1186, 1205, 1227, 1258, 1309, and 1329 MHz
- February 1997 - DoD/DOT determine that *none* of the candidate frequencies in IIF contract are acceptable
- Independent Review Team (IRT) help was solicited, and 970 MHz and 5 GHz were added

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The Issue with L2

- **Federal Aviation Administration (FAA) and other civil aviation advocates noted that L2 is NOT in a band allocated for aeronautical radionavigation services (ARNS)**
- **Further, the L2 band was heavily used worldwide for high-powered radars…**
- **…and in a significant number of countries also co-allocated for fixed and mobile services**
- **[Much later -- in April 2002 -- the International Civil Aviation Organization (ICAO) decided to NOT include L2C in their Standards and Recommended Practices (SARPs)]**

Interagency GPS Executive Board (IGEB)

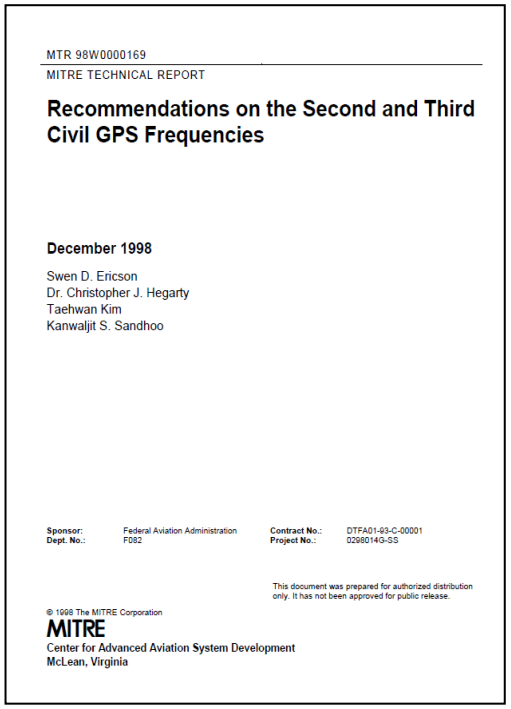
- March 1996 – Presidential Decision Directive formally established the IGEB to manage GPS and U.S. government augmentations
- March 1997 – first IGEB meeting
  - Principal issue on agenda – selection of frequency for 2nd civil signal
  - Decision postponed for a year to allow time for studies

White House Announcement – March 30, 1998

- **Vice President Gore 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"**
- **Announcement was made 3 days after the 3rd meeting of the IGEB**
  - **IGEB was origin of the announced decisions**
  - **Co-chairs: Mort Downey (Deputy Secretary, DOT) and Dr. Jacques Gansler (Undersecretary DoD for Acquisition and Technology)**
- **Interagency efforts ramp up to identify frequency**
  - **Emitters Working Group, Bandwidth Req't Team, Independent JTIDS Review Team (IJRT), etc etc**

And the Winner is…

- **1181.565 MHz !!??**
  - **Result of many, many staff-years of inter-agency studies**
- **GPS Joint Program Office in consultation with Boeing quickly recommended adjusting this candidate frequency (which they initially supplied) to 1176.45 MHz (=115 × 10.23 MHz)**
- **January 25, 1999 – VP Gore announces selection**
  - **"…implemented beginning with a satellite scheduled for launch in 2005...."**



MTR 98W0000169

MITRE TECHNICAL REPORT

Recommendations on the Second and Third Civil GPS Frequencies

December 1998

Swen D. Ericson
Dr. Christopher J. Hegarty
Taehwan Kim
Kanwaljit S. Sandhoo

Sponsor: Federal Aviation Administration
Dept. No.: F082
Contract No.: DTFA01-93-C-00001
Project No.: 02980143-SS

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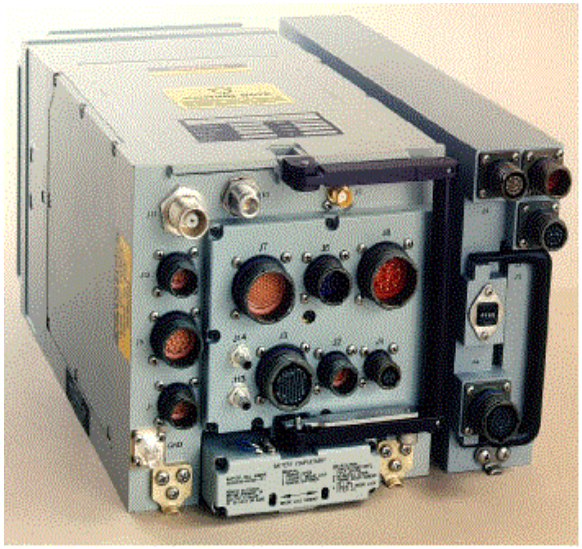
Center for Advanced Aviation System Development
McLean, Virginia

Two Challenges with 1176.45 MHz

DME/TACAN

- Over 1700 U.S. ground beacons
- 1 MHz channels across 960-1215 MHz
- EIRP = 100 W - 10000 W
- 3.5 μs pulse width (1/2 voltage)
- 2700 - 3600 pulse pairs/s



JTIDS/MIDS

- Thousands of terminals (many airborne)
- Hops over 51 3 MHz channels from 969-1206 MHz
- 6.4 μs pulse width
- For uncoordinated exercises:
  - Peak power = 200 W
  - 396,288 pulses/12 s in 200 nmi radius

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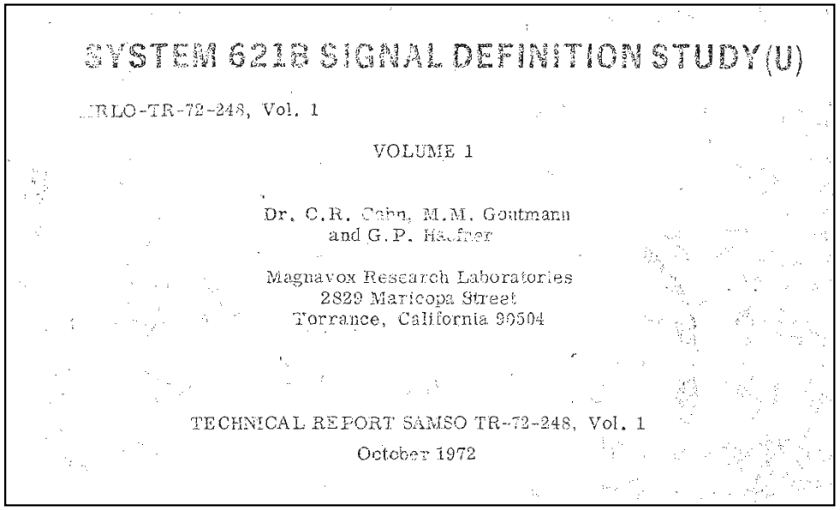
Initial L5 Signal Design

- Various modulations were explored in 1998 prior to the L5 frequency selection
  - By “Bandwidth Requirements Group” et al.
  - Binary Phase Shift Keying (BPSK) with a range of chip rates and “split spectrum” (a.k.a. binary offset carrier)
- BPSK with rectangular chips and 10.23 MHz chip rate became favored option
- Important design milestone:
  - Spilker, J.J., Jr., and A.J. Van Dierendonck, “Proposed Third Civil GPS Signal at 1176.45 MHz In-Phase/Quadrature Codes at 10.23 MHz Chip Rate,” 28 February 1999
  - 10.23 MHz chip rate, quadrature data and dataless components, 10230-length codes, 50 bps data with rate ½ convolutional forward error correction

L5 Dataless Component

- **Resulted from input from Tom Stansell, Charlie Cahn, and Rich Keegan**
  - **In Feb 12, 1999 memo to A.J. Van Dierendonck**
  - **Other suggestions not used (e.g., 2-ms code)**
  - **Half-power split recommended by Charlie Cahn and later (for final design) by Tom Morrissey (Zeta)**
- **Idea goes back much further though**
  - **Assessed in 621B studies by Charlie Cahn et al.**
  - **Used for Transit**



SYSTEM 621B SIGNAL DEFINITION STUDY(U)

ERLO-TR-72-248, Vol. 1

VOLUME 1

Dr. C.R. Cahn, M.M. Goutmann
and G.P. Haefner

Magnavox Research Laboratories
2829 Maricopa Street
Torrance, California 90504

TECHNICAL REPORT SAMSO TR-72-248, Vol. 1

October 1972

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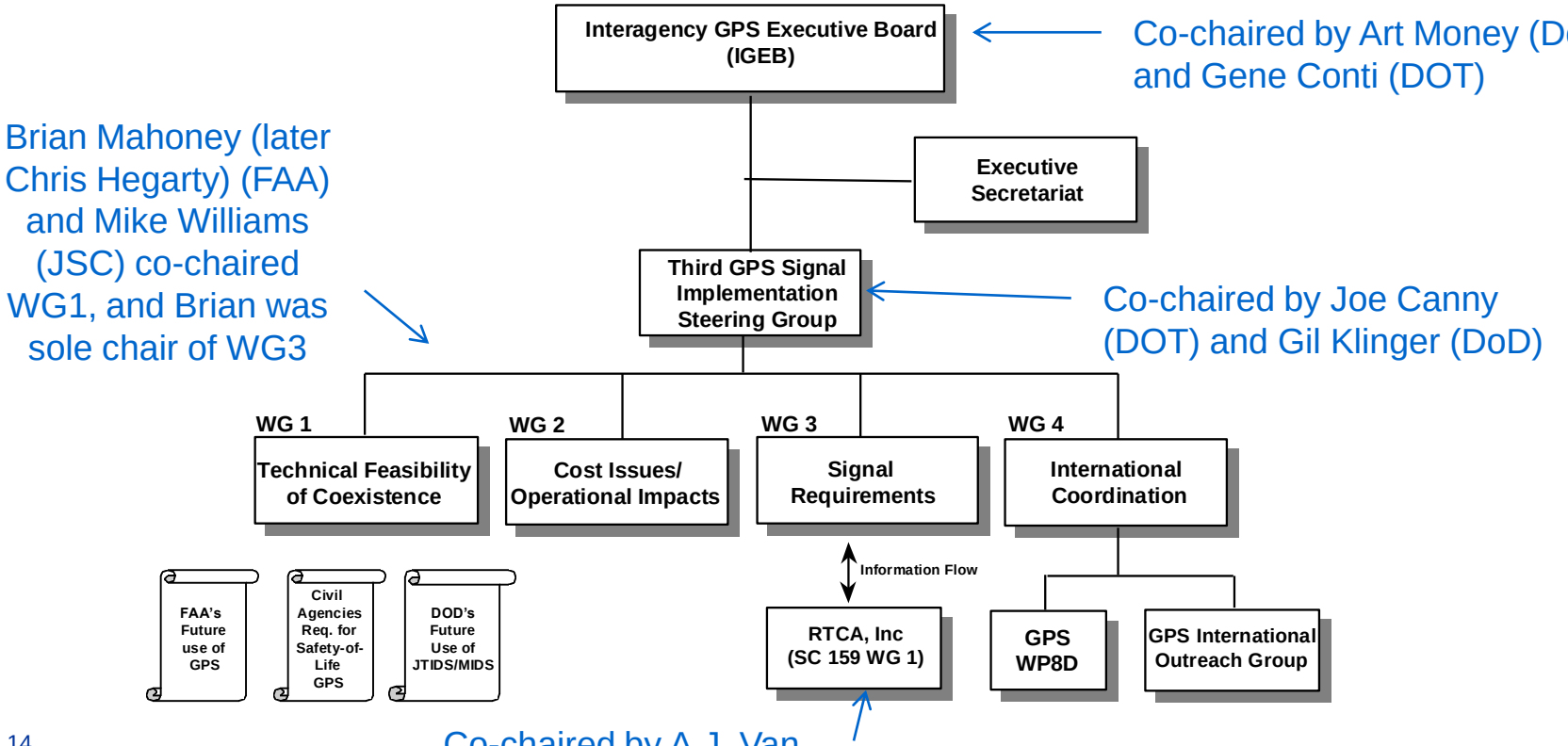
L5 Implementation

- **In February 1999, IGEB established Third Civil Signal Implementation Steering Group**
  - **IGEB Working Groups established**
  - **RTCA Special Committee 159 Working Group 1 was requested to develop L5 Signal Specification**



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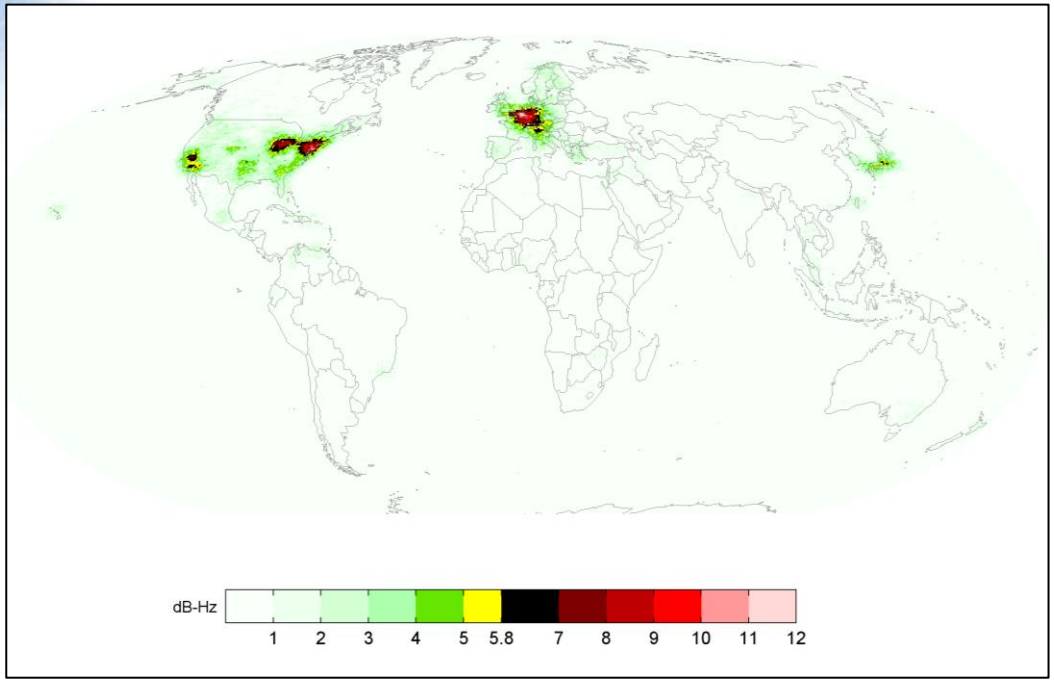
Validating Co-existence of L5 with DME, TACAN, and Link 16



Predicted Signal-to-Noise Degradation at 40,000’

Prototype L5 Receiver with Analog Pulse Blanking

See, e.g.: (1) Hegarty, Kim, Ericson, Reddan, Morrissey, and Van Dierendonck, “Methodology for Determining Compatibility of GPS L5 with Existing Systems and Preliminary Results,” Proceedings of The Institute of Navigation Annual Meeting, Cambridge, MA, June 1999, (2) Hegarty, Van Dierendonck, Bobyn, Tran, Kim, and Grabowski, “Suppression of Pulsed Interference through Blanking,” ION Annual Meeting, June 2000.

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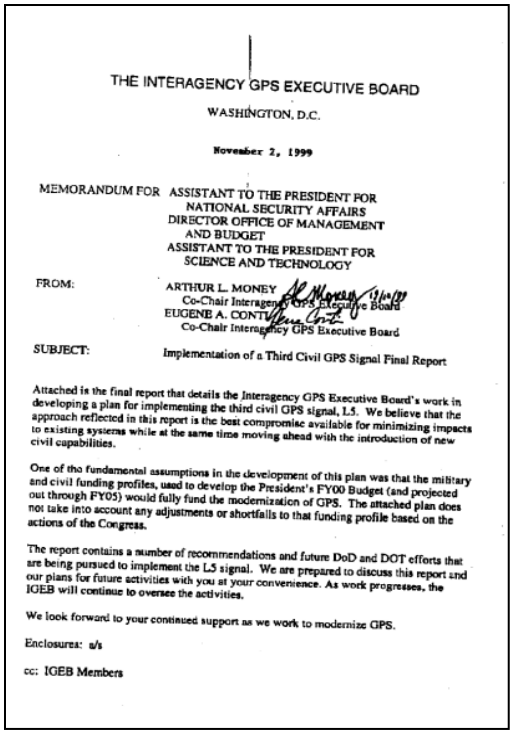
November 1999 - Third Civil Signal Implementation Report



THE INTERAGENCY GPS EXECUTIVE BOARD

WASHINGTON, D.C.

November 2, 1999

MEMORANDUM FOR ASSISTANT TO THE PRESIDENT FOR NATIONAL SECURITY AFFAIRS
DIRECTOR OFFICE OF MANAGEMENT AND BUDGET
ASSISTANT TO THE PRESIDENT FOR SCIENCE AND TECHNOLOGY

FROM: ARTHUR L. MONEY
Co-Chair Interagency GPS Executive Board
EUGENE A. CONTI
Co-Chair Interagency GPS Executive Board

SUBJECT: Implementation of a Third Civil GPS Signal Final Report

Attached is the final report that details the Interagency GPS Executive Board's work in developing a plan for implementing the third civil GPS signal, L5. We believe that the approach reflected in this report is the best compromise available for minimizing impacts to existing systems while at the same time moving ahead with the introduction of new civil capabilities.

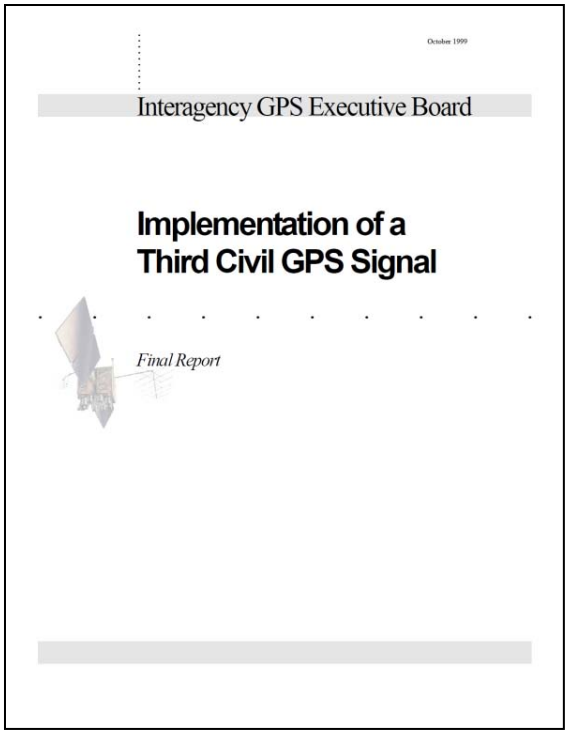
One of the fundamental assumptions in the development of this plan was that the military and civil funding profiles, used to develop the President's FY00 Budget (and projected out through FY05) would fully fund the modernization of GPS. The attached plan does not take into account any adjustments or shortfalls to that funding profile based on the actions of the Congress.

The report contains a number of recommendations and future DoD and DOT efforts that are being pursued to implement the L5 signal. We are prepared to discuss this report and our plans for future activities with you at your convenience. As work progresses, the IGEB will continue to oversee the activities.

We look forward to your continued support as we work to modernize GPS.

Enclosures: a/s

cc: IGEB Members



October 1999

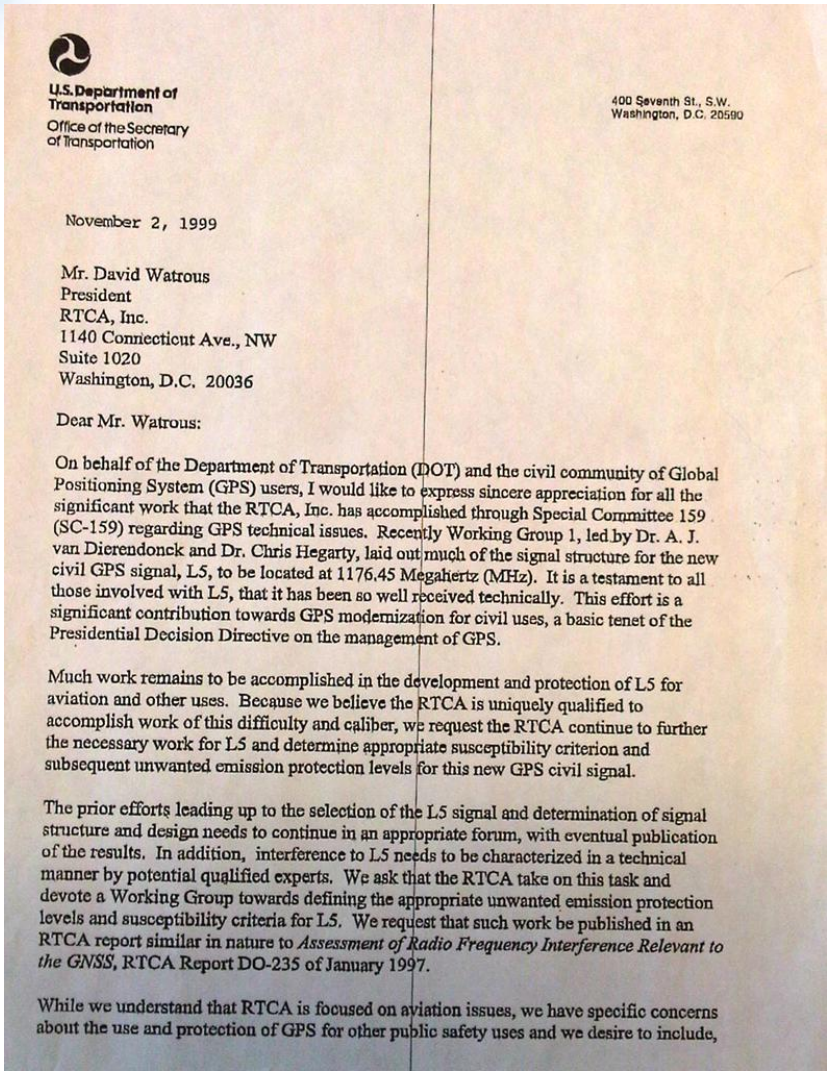
Interagency GPS Executive Board

Implementation of a Third Civil GPS Signal

Final Report

- **Delivered to the White House on November 2, 1999 by IGEB**
- **Key elements:**
  - **10.23 MHz chip rate, 50 bps, -154 dBW, QPSK with ½ power pilot**
  - **FAA to reassign DME/TACAN frequencies as needed**
  - **DoD to remap up to 7 Link 16 frequencies**

November 1999 – Thanks from DOT and More Work for RTCA



U.S. Department of Transportation
Office of the Secretary of Transportation

400 Seventh St., S.W.
Washington, D.C. 20590

November 2, 1999

Mr. David Watrous
President
RTCA, Inc.
1140 Connecticut Ave., NW
Suite 1020
Washington, D.C. 20036

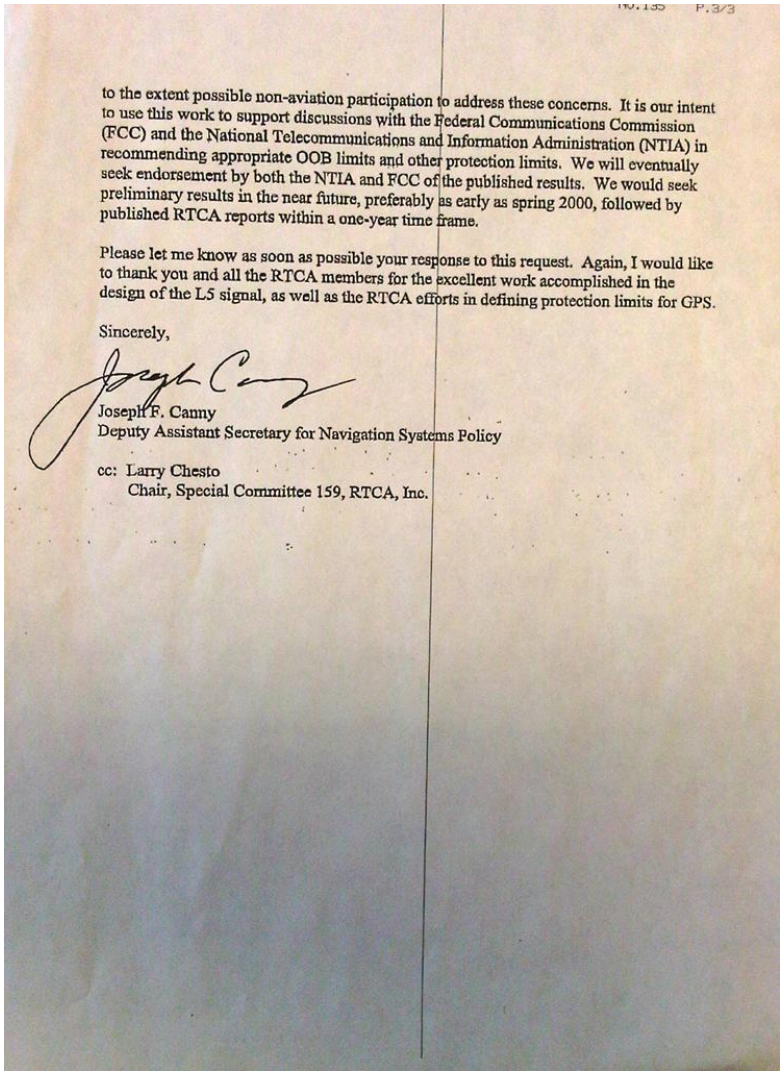
Dear Mr. Watrous:

On behalf of the Department of Transportation (DOT) and the civil community of Global Positioning System (GPS) users, I would like to express sincere appreciation for all the significant work that the RTCA, Inc. has accomplished through Special Committee 159 (SC-159) regarding GPS technical issues. Recently Working Group 1, led by Dr. A. J. van Dierendonck and Dr. Chris Hegarty, laid out much of the signal structure for the new civil GPS signal, L5, to be located at 1176.45 Megahertz (MHz). It is a testament to all those involved with L5, that it has been so well received technically. This effort is a significant contribution towards GPS modernization for civil uses, a basic tenet of the Presidential Decision Directive on the management of GPS.

Much work remains to be accomplished in the development and protection of L5 for aviation and other uses. Because we believe the RTCA is uniquely qualified to accomplish work of this difficulty and caliber, we request the RTCA continue to further the necessary work for L5 and determine appropriate susceptibility criterion and subsequent unwanted emission protection levels for this new GPS civil signal.

The prior efforts leading up to the selection of the L5 signal and determination of signal structure and design needs to continue in an appropriate forum, with eventual publication of the results. In addition, interference to L5 needs to be characterized in a technical manner by potential qualified experts. We ask that the RTCA take on this task and devote a Working Group towards defining the appropriate unwanted emission protection levels and susceptibility criteria for L5. We request that such work be published in an RTCA report similar in nature to *Assessment of Radio Frequency Interference Relevant to the GNSS*, RTCA Report DO-235 of January 1997.

While we understand that RTCA is focused on aviation issues, we have specific concerns about the use and protection of GPS for other public safety uses and we desire to include,



to the extent possible non-aviation participation to address these concerns. It is our intent to use this work to support discussions with the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA) in recommending appropriate OOB limits and other protection limits. We will eventually seek endorsement by both the NTIA and FCC of the published results. We would seek preliminary results in the near future, preferably as early as spring 2000, followed by published RTCA reports within a one-year time frame.

Please let me know as soon as possible your response to this request. Again, I would like to thank you and all the RTCA members for the excellent work accomplished in the design of the L5 signal, as well as the RTCA efforts in defining protection limits for GPS.

Sincerely,

Joseph F. Canny
Deputy Assistant Secretary for Navigation Systems Policy

cc: Larry Chesto
Chair, Special Committee 159, RTCA, Inc.

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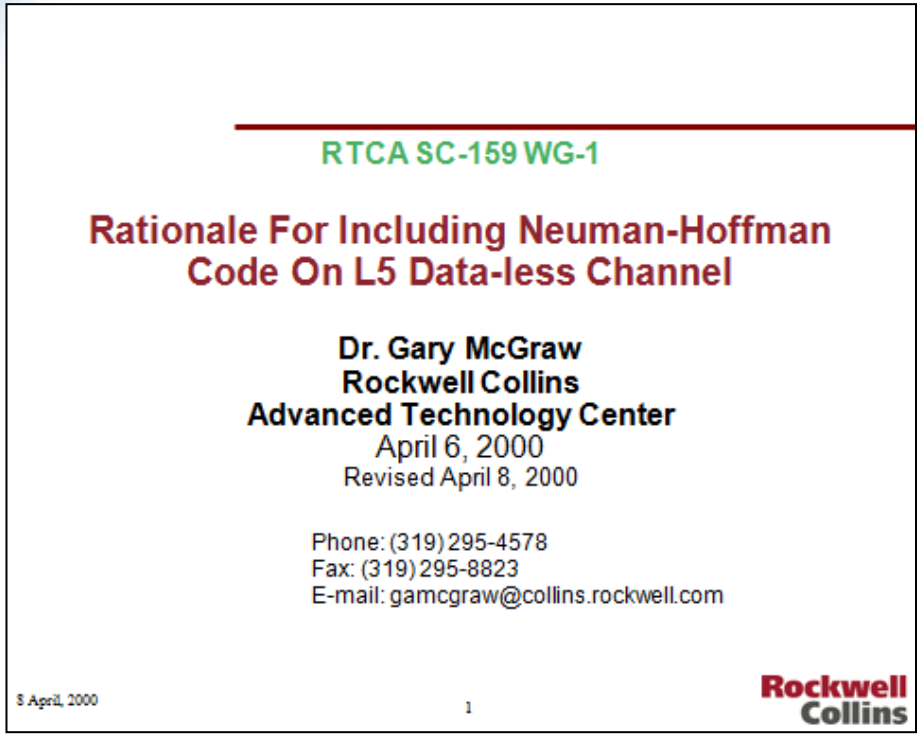
Neuman-Hofman Synchronization Codes



RTCA SC-159 WG-1

Rationale For Including Neuman-Hoffman Code On L5 Data-less Channel

Dr. Gary McGraw
Rockwell Collins
Advanced Technology Center
April 6, 2000
Revised April 8, 2000

Phone: (319) 295-4578
Fax: (319) 295-8823
E-mail: gamcgraw@collins.rockwell.com

8 April, 2000 1 Rockwell Collins

- 10-bit Neuman-Hofman code added to data component in early 1999
- 20-bit NH-code for dataless component formally proposed by Dr. Gary McGraw, Rockwell Collins, at RTCA SC-159 WG-1 meeting on April 6, 2000
- European Commission comments on ICD-GPS-705 in January 2003 led to complete relook
  - And other L5 design elements
  - Undertaken by a subgroup, co-chaired by Chris Hegarty and Bryan Titus, of the GPS System Engineering Forum

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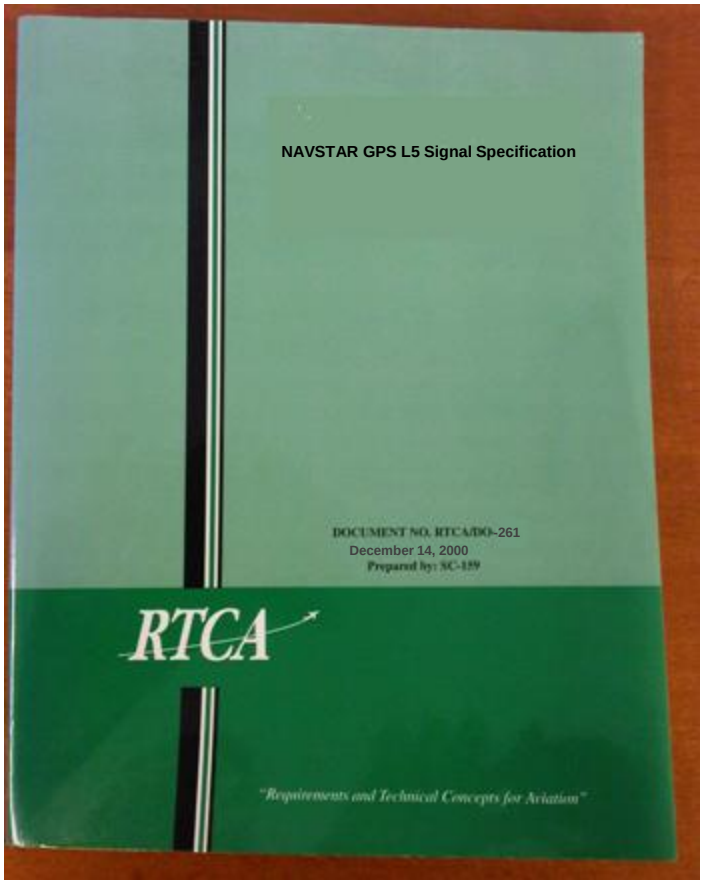
RTCA GPS L5 Signal Specification



- Published on December 14, 2000
- Later converted into first ICD-GPS-705, then subsequently IS-GPS-705 by Air Force
- Some updates made by Air Force
  - Improved Clock and Ephemeris messages (although note that flexible 300-bit messages with 24-bit cyclic redundancy code was RTCA contribution)
  - Handling of group delays
  - Softening of some low-level requirements

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May 27, 2010 - First IIF Launch

Source: www.losangeles.af.mil (photo by Pat Corkery, ULA)

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L5 Trivia

1. Who was the FAA spectrum manager who firmly insisted that L5 be in an ARNS band?
2. What was special about the initially selected I5 PRN 29 and Q5 PRN 32?
3. Which co-chair of the IGEB Third Civil Signal Implementation Steering Group was known for berating all for lack of progress and doling out candy when others fought?
4. What historic L5 document was drafted by a group of Irishmen (one honorary) in a gazebo in Long Beach?
5. Why is the IIF L5 power specified as an non-integer value (-154.9 dBW)?
6. Why were 210 PRNs selected for L5, C/A, L2C, and L1C?
7. Why was the U.S. ITU filing for GPS III named “USRSR”?

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L5 Trivia - Answers

1. Gerry Markey
2. They were the same code (this was fixed in March ‘02)
3. Gil Klinger
4. IGEB WG3 Final Report, written in 1999 by Mahoney, Hegarty, Morrissey, Reddan, and Van Dierendonck.
5. An Air Force Cost as an Independent Variable (CAIV) activity led to a specification of -154 dBW minimum power averaged over azimuth and out of a 0 dBic antenna. DOT protested and this was changed to true minimum out of a 3 dBil at worst normal orientation (as for C/A)
6. WAAS PRN mask limitation. 210 L5 PRNs were selected by Rick Niles, MITRE, for SC-159 in 2002. The Air Force (assisted by Aerospace, ARINC, and MITRE) selected 210 PRNs for C/A, L2C and L1C in years to follow.
7. After Rick Reaser