SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

NATIONAL SPACE-BASED POSITIONING, NAVIGATION, AND TIMING ADVISORY BOARD

Interim Meeting 24-B

July 1, 2020

Virtual Meeting

ADM (Ret. USCG) Thad Allen, *Chair*

Mr. James J. Miller, *Executive Director*

24-B Interim Virtual Meeting Agenda
National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board

Wednesday July 1, 2020

11:00-11:05	**BOARD CONVENES** *Call to Order, Logistics, & Announcements*	Mr. James J. Miller, *Executive Director, National Space-based PNT Advisory Board, NASA Headquarters*
11:05-11:15	Opening Remarks & Mtg Objectives *Submitted for the record:* ▪ **Statement by Capt. Sullenberger (145 KB PDF)** ▪ **Addendum 1 (1 MB PDF)** ▪ **Addendum 2 (36 KB PDF)**	ADM Thad Allen, USCG, Ret., *Chair, National Space-Based PNT Advisory Board*
11:15-11:40	GPS Modernization Update ***View PDF***	Lt Col Ken McDougall, *GPS Chief Engineer, GPS Integration Branch, GPS Program Office, Space and Missile Systems Center*
11:40-11:50	U.S. Space-Based PNT Policy	Col Curtis (Scraps) Hernandez, USAF, *Director, National Security Space Policy, National Space Council, Executive Office of the President*
11:50-12:00	Executive Order 13905: *Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services*	Dr. Seth Jonas, *Deputy Senior Director for Resilience Policy, National Security Council, Executive Office of the President*
12:00-12:10	PNT Beyond GPS: *PNT Resilience Research and Development*	Dr. Adam J. Balkcum, *Fellow and Policy Advisor, Office of Science and Technology Policy, Executive Office of the President*
12:10-12:15	**BREAK**	
12:15-12:55	FCC Order on Mobile Satellite Service Radio-Spectrum Repurposing: *The Message and Nine Takeaways* ***View PDF***	Dr. Bradford Parkinson, *1st Vice Chair, National Space-Based PNT Advisory Board*
12:55-1:10	A Proposed Response to Shifting Spectrum Landscape: *L-band Interference Monitoring - DOT Developments* ***View PDF***	Dr. Andrew Hansen, *Principal Technical Advisor, Volpe Center, U.S. Department of Transportation*
1:10-1:25	Assessment of NASA/JPL GNSS Signal Monitoring Capabilities: *Global Differential GPS System (GDGPS) Working Group* ***View PDF***	Maj Chris Bonniksen, USAF, Ret., *NASA Management Office Technical and Programmatic Oversight, NASA Headquarters*
1:25-1:30	**BREAK**	
1:30-3:00	PNT Board Round Table Discussion	All members, led by Chairs
3:00	**ADJOURNMENT**	

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Executive Summary

On July 1, 2020, the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board held its interim virtual meeting 24B. The PNT Advisory Board (PNTAB) has been sponsored by the National Aeronautics and Space Administration (NASA) since 2007. The GPS Program Office briefed on the status of the GPS modernization program, and representatives from the Executive Office of the President (EOP) provided updates on: U.S. PNT policy, Executive Order 13905 on Strengthening National Resilience Through Responsible Use of PNT Services, and efforts to develop a national plan for Resilient PNT Research and Development (R&D). The board discussed Federal Communications Commission (FCC) decision to repurpose the Mobile Satellite Services (MSS) frequency band adjacent to the Global Positioning System (GPS) primary frequencies, and unanimously approved a briefing with the key message and takeaways. The Department of Transportation (DOT) presented a proposal for L-band interference monitoring from 5G broadband terrestrial transmissions. Finally, NASA briefed on a new effort to assess the role it should have in the Global Differential GPS (GDGPS) system. This document summarizes the key briefing points and discussions at the meeting.

Action Items and Issues:

- Incorporate the revisions from board members, as approved, to the PNTAB briefing regarding the FCC decision, "The Message and Nine Takeaways," and post on www.gps.gov.
- John Betz and Todd Walker to draft a Terms of Reference for a new subcommittee to look into the NASA GDGPS Assessment. Additional board members volunteering for this subcommittee: Matt Higgins, Terry Moore, Frank van Diggelen, Penina Axelrad, Tim Murphy, and Gary Thompson.
- Gerhard Beutler sent Adm Allen some ideas on how an international group could be organized. He also noted some reorganization may be necessary in the science and international subgroup.
- Dana Goward sent Adm Allen a proposal for two small workgroups, one on terrestrial PNT characteristics and implementation and another to discuss the advantages of potential LEO systems.
- Thad Allen asked the international board members to draft a one-page summary of their perspectives for inclusion in the Meeting Minutes.
- Gary Thompson to send Thad Allen a summary of the implications of the FCC decision on the geodetic community.
- Thad Allen to include a briefing on Geodetic Datums at the next PNTAB meeting.

Meeting Notes

Board Convenes & Call to Order
Mr. James J. Miller
Executive Director, National Space-based PNT Advisory Board, NASA Headquarters

Mr. Miller introduced himself and welcomed the attendees to the National Space-based PNT Advisory Board (PNTAB) interim meeting 24-B. The PNTAB was established as part of the 2004 National Positioning, Navigation, and Timing (PNT) Policy. Today's session is chaired by Admiral Thad Allen (USCG, Ret.) along with the Honorable John Stenbit and vice-chairs Dr. Bradford Parkinson and Governor Geringer. For information on the board members please go to www.gps.gov, where you will also find all the briefings. The PNTAB is intended to provide independent advice to the U.S. government. The findings and recommendations are derived from experts representing the worldwide GPS user community. The PNTAB deliberations are governed by the regulations of the Federal Advisory Committee Act (FACA), which means the discussions are public and the meeting minutes will be posted on www.gps.gov within 90 days. As members deliberate, they must abide by the government ethics laws, which require them not to engage in any discussions may involve a potential or perceived conflict of interest. If a member does believe there is a potential conflict on a particular matter that is raised, please do not engage and a note of that recusal will be included in the record.

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Opening Remarks & Mtg Objectives
ADM Thad Allen, USCG, Ret.
Chair, National Space-Based PNT Advisory Board

Adm Allen noted a key issue for the board is the recent ruling by the Federal Communications Commission (FCC) that allocated spectrum to Ligado Networks for terrestrial broadcast. In lieu of opening remarks, Adm Allen read a statement that provided by Captain Chesley (Sully) Sullenberger, dated July 1, 2020 and posted on www.gps.gov:

> *Members of the Space Based Positioning, Navigation, and Timing Advisory Board: The FCC's decision to approve Ligado Networks' use of a portion of the L-band spectrum is ill-advised, and constitutes a dereliction of duty on the FCC's part. Frequency spectrum is a precious national asset and we are all obligated to protect it. Not only does this decision benefit just the shareholders of one company, but it is a dangerous decision that must be reversed. This land grab of public frequency spectrum and gifting it to a private company will harm not only aviation and everyone who relies on it, but anyone who depends on ATM or other financial transactions, emergency responders, modern farming, the emerging benefits of autonomous vehicles, and even the production of precision mapping and survey products. Testing and studies performed by DOD and DOT supported by nine federal agencies concluded Ligado's solution will cause interference both for civilian and military users. The decision impacts warfighter testing, training, exercises and homeland defense missions – putting national security at risk. Putting the narrow commercial interests of one company ahead of our national security and the needs of our country is wrongheaded and dangerous. Simply put, the FCC authorized Ligado terrestrial signal is much stronger than the GPS signal, and will overwhelm the ability to "hear" the GPS signal. Existing satellite communications users will have to replace equipment to accommodate the relocation of the satellite signals and provide additional interference filtering for the new terrestrial signals. This includes The Aircraft Communications Addressing and Reporting System (ACARS) which uses INMARSAT – ACARS will need to be upgraded or replaced as a result. This is a principal concern by the aviation industry and users. Another SATCOM concern is the interference from the Ligado cell phones with the aircraft Iridium satellite communications at frequencies above GPS."*
>
> *Contrary to Ligado's position, 1536-1559 MHz is not a "Guard Band." Rather, it is allocated and used for satellite voice and data communication as Mobile Satellite Services (MSS). MSS data communications are used to improve the performance of some high accuracy GPS receivers. The Ligado signal resides inside the larger MSS band that used to be a quiet zone. The band where*

FCC has authorized Ligado to transmit at 10 watts previously was limited to extremely low power satellites signals only.

MSS frequencies are also used for Aircraft Communications Addressing and Reporting System (ACARS), Aviation Controller Pilot Data Link Communications (CPDLC), Automatic Dependent Surveillance — Contract (ADS-C) position reporting, Pilot to Dispatch Communications and real-time engine health monitoring. Aircraft International Marine/Maritime Satellite (INMARSAT) equipment that operates in the MSS band where the Ligado terrestrial transmitters will operate will need to be upgraded or replaced at the Airlines' expense. Iridium and their aviation user communities have identified that Ligado cell phone transmissions overload Iridium cell phones since the cell phone power is so much greater than the Iridium satellite signals that the Iridium transceivers are attempting to receive in their authorized spectrum that is separated by only 1 MHz from the Ligado cell phones. Reportedly, there is no currently identified resolution to the Ligado interference with Iridium cell phones since the frequencies are so close together.

GPS receivers are very sensitive and require a very "quiet" neighborhood to function. Ligado's operations will act like a loud neighbor and overload the sensitive GPS satellite signal receivers. In fact, Ligado's proposed use will include adjacent band powers that are two Billion times greater than the power of the GPS signals that the receivers are "listening" for. This will overwhelm the GPS receivers and make them unable to "hear" the sensitive GPS signals that they need to receive and process.

Ligado's claims that receivers "can easily be made to coexist" are incorrect. Coexistence would require antenna replacements and extensive redesign and replacement of the receivers. Such replacements are often larger, heavier and have reduced performance that may be inadequate for many high precision applications needs. Many GPS receivers are deeply integrated into the application systems and would require system-level hardware/software redesign and recertification at high cost. Retrofits would take systems offline with corresponding operational as well as cost impacts.

For sound reasons, Ligado's terrestrial operations have never been tried before in the proposed band. No Mobile Satellite Service (MSS) ancillary terrestrial components (ATC) service has ever been deployed within this MSS band despite the FCC authorization for MSS ATC services. The FCC made it clear in 2003, when it adopted the original MSS ATC rules, that a stand-alone terrestrial service was not intended for the MSS band. In that 2003 MSS ATC Order, FCC stated: "We do not intend, nor will we permit, the terrestrial component to become a stand-alone service." The FCC's rules (47 CFR 25) include provision 25.255 that "if harmful interference is caused to other services by ancillary MSS ATC operations, either from ATC base stations or mobile terminals, the MSS ATC operator must resolve any such interference." The existence of 25.255 demonstrates that FCC is aware of the consequences of interference in this band.

The contention that Ligado Networks enables 5G is misleading. None of Ligado's bands are included in the 3GPP's consortium's 5G standards and the 10 MHz bandwidth is not consistent with most 5G providers and user needs for high bandwidth applications such as YouTube, FaceTime, Zoom, etc. There is currently not a deficit of frequency division duplexing (FDD) cellular handset spectrum in the L-band or below. FDD handset bands in L-band or below are currently underutilized.

Contrary to Ligado's assertion, the FCC Order and Authorization does not provide "total protection" to all GPS devices and users at the 1dB level. The DOT maintains that the FCC would need to reduce its authorization of Ligado operations from the currently-approved 10 watts to approximately one milliwatt (a factor of 10,000) to protect all existing GPS receivers.

Contrary to Ligado's assertion, the FAA did not conclude that 10 watts was sufficient to protect all aviation use of GPS. 10 watts protects only certain GPS receivers—those that are certified, Instrument Flight Rule (IFR) capable and outside a 250' horizontal assessment zone. Ligado

emissions can impact certified aviation GPS receivers when aircraft are within 250' (e.g., aircraft at terminals and helicopter or drone/UAV operations at lower altitudes). Significantly, 10 watts does not protect aviation VFR rated receivers used by drones/UAVs, many VFR aircraft, GPS handheld/electronic flight bag and some helicopter safety systems (H-TAWS/EGPWS). The 10 watt Ligado emission can impact VFR (non-certified) GPS receivers at distances up to one kilometer. High precision drones/UAVs used for mapping, survey, construction, and agriculture can be impacted at distances up to 3 kilometers. In light of all of these caveats, the FAA did not conclude that the 10 watts protects all aviation use of GPS.

Contrary to Ligado's assertion, the DOT testing did not solely rely on the 1dB degradation level metric to make determinations about harmful GPS interference. In fact, DOT's testing identified many receivers that completely failed at the FCC authorized 10 watt power level. During this testing, the GPS receivers lost lock on all visible satellites, rendering complete loss of GPS function, not just "harmful interference." Thus, these receivers were rendered completely nonfunctional at the 10 watt power level approved by the FCC for Ligado operations and even lower power levels in many instances. A direct correlation was also identified between the 1dB metric and important performance metrics such as the length of time needed for a GPS receiver to begin providing a position output. Even within Ligado Networks' sponsored NASCTN and Roberson & Associates testing, there is evidence that harmful interference will occur if the Ligado network is deployed: their studies also demonstrate loss-of-lock by some receivers during testing.

Of special note is a possible conflict of interest – a filing by Mr. Dennis Roberson, who serves on the TAC FCC Federal Advisory Committee. His firm – Roberson & Associates, a technology and management consulting company - was hired by Ligado's counsel – Covington and Burling LLP – to perform constrained testing of a very limited set of GPS receivers under less than representative test conditions.

Also of note is that Julius Knapp, Chief of the Federal Communications Commission's Office of Engineering, was well aware of the GPS receiver overload by adjacent band terrestrial use in 2012. Yet, the FCC Chairman holds firm that the Ligado decision was based upon sound FCC engineering (led by Mr. Knapp). Please refer to Mr. Knapp's statement (included) before the House Oversight and Investigations Subcommittee of the Energy and Commerce Committee from September 2012.

Wishful thinking and hoping that things will work out is not an effective strategy and cannot repeal the laws of physics. I urge you to reverse the FCC's decision approving Ligado's proposal.

Capt. Sully's letter included two Addendums, also posted on www.gps.gov.

[Ed. Note: the letter and addendums are also included in Appendix D of this report.]

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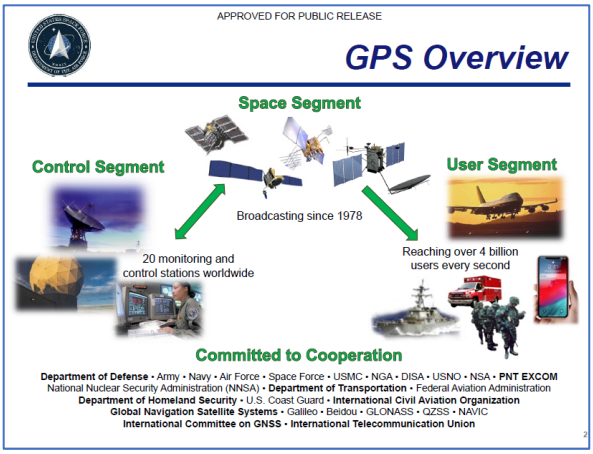
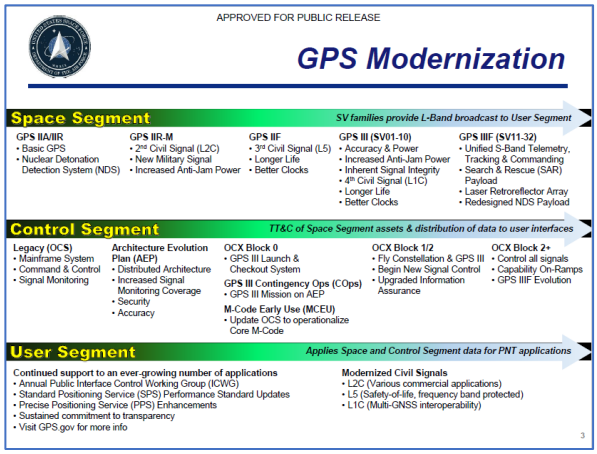
GPS Modernization Update
Lt Col Ken McDougall
GPS Chief Engineer, GPS Integration Branch, GPS Program Office, Space and Missile Systems Center

[The briefing slides are available at: https://www.gps.gov/governance/advisory/meetings/2020-07/mcdougall.pdf]

Lt Col Ken McDougall is the Chief Engineer for GPS. His briefing is on GPS, its current status, and modernization activities.

GPS Overview and Modernization:

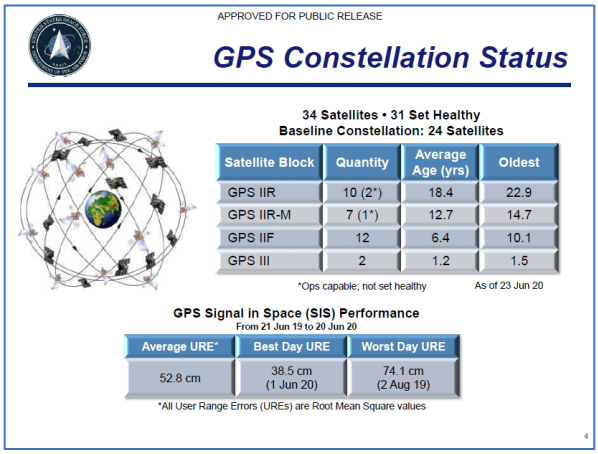




GPS is truly an enterprise system. We've had satellites that broadcast from space since 1978. Those signals reach billions of users worldwide. In order to operate the system, we also have ground segment that controls the GPS satellites and monitors the signals through over 20 stations worldwide. We are committed to our domestic and international partners. We partner with a number of agencies through agreements and various collaborations with other military services and government agencies. We are also active participants in many forums, including the International Committee on GNSS (ICG), Institute of Navigation (ION), and many others.

We have three main segments in GPS. For the space segment, we are currently deploying the third generation of GPS satellites (GPS Block III, or GPS III). Yesterday we successfully launched our third GPS III satellite. GPS III satellites have increased accuracy and power, increased signal resiliency against jamming, inherent signal integrity, and are broadcasting for the first time the fourth civil signal (L1C). In addition, we have better atomic clocks on these satellites, which contribute to increased capabilities. The ground segment is also being updated as we accept new satellites with new capabilities. Unfortunately, OCX (modernized GPS control system) is still in development, so we had to incrementally release the OCX Block 0 in order to launch and check out the GPS III satellites, and then operationally accept them as the COps (contingency operations) as an evolution of the legacy OCX, which allows the OCS system to monitor and control the GPS III satellites. We also are developing OCX blocks 1 & 2, that will allow full control of the GPS III satellites, as well as block 2+ to support the GPS block IIIF satellites. Finally, we have the user segment. We are continuing to report the development of our civil signals. We recently published the 5th edition of the GPS SPS Performance Standard, including the new L2C signals specifications. We're also working on delivering operational uses for L2C, L5, and L1C through different interface specifications.

GPS Constellation Status and GPS III: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GPS Constellation Status

34 Satellites • 31 Set Healthy
Baseline Constellation: 24 Satellites

Satellite Block	Quantity	Average Age (yrs)	Oldest
GPS IIR	10 (2*)	18.4	22.9
GPS IIR-M	7 (1*)	12.7	14.7
GPS IIF	12	6.4	10.1
GPS III	2	1.2	1.5

*Ops capable; not set healthy As of 23 Jun 20

GPS Signal in Space (SIS) Performance
From 21 Jun 19 to 20 Jun 20

Average URE*	Best Day URE	Worst Day URE
52.8 cm	38.5 cm (1 Jun 20)	74.1 cm (2 Aug 19)

*All User Range Errors (UREs) are Root Mean Square values

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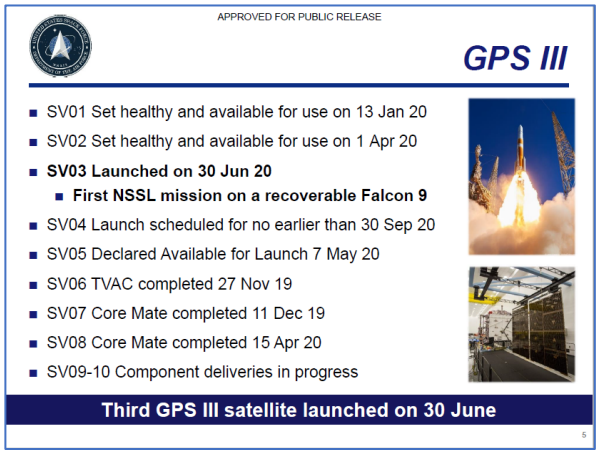
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GPS III

- SV01 Set healthy and available for use on 13 Jan 20
- SV02 Set healthy and available for use on 1 Apr 20
- **SV03 Launched on 30 Jun 20**
  - **First NSSL mission on a recoverable Falcon 9**
- SV04 Launch scheduled for no earlier than 30 Sep 20
- SV05 Declared Available for Launch 7 May 20
- SV06 TVAC completed 27 Nov 19
- SV07 Core Mate completed 11 Dec 19
- SV08 Core Mate completed 15 Apr 20
- SV09-10 Component deliveries in progress

Third GPS III satellite launched on 30 June

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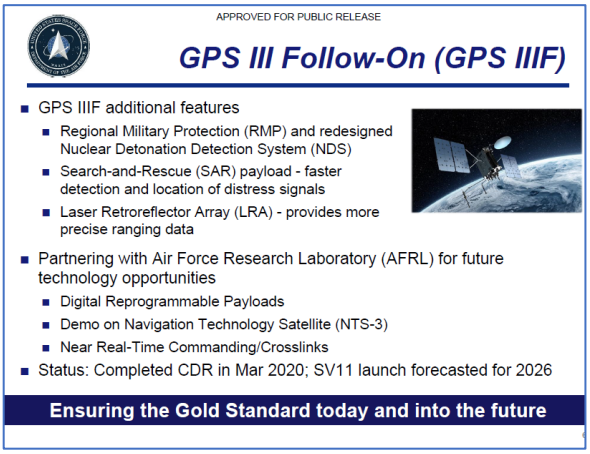
Currently we have 34 satellites in operation (not including yesterday's launch, which is not yet set as operational). Thirty-one of the satellites are set as 'healthy', and we have additional three residual satellites that are operationally capable but not set as healthy. The table shows the average age and design life of each GPS satellite block. Note we have several satellites that are well past their design life, which is a good thing, and we are expecting a similar trend with the new generation of GPS satellites having an even longer operational life. The current GPS Signal-in-Space performance as of June 2020 is right around half a meter.

As noted earlier, on June 30 we had a successful launch of GPS III SV03, which was launched on the first recoverable Falcon 9 launcher. Originally GPS III SV03 was scheduled to launch in April, but we didn't go through the launch because of the COVID-19 pandemic and while we set up new safety measures to support launches. GPS III SV04 is scheduled to launch no earlier than September 30, 2020 (originally scheduled to launch

GPS IIIF and OCX: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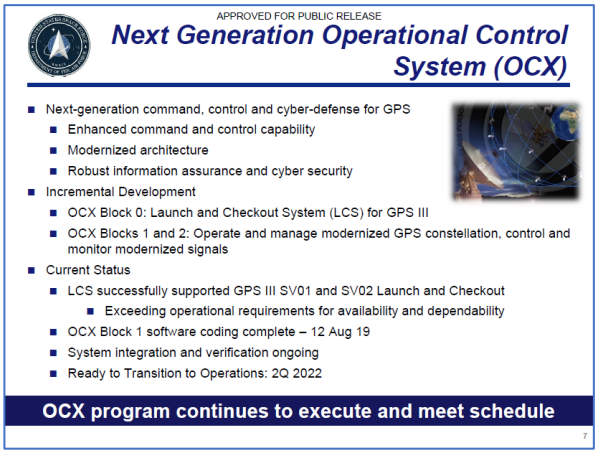
GPS III Follow-On (GPS IIIF)

- GPS IIIF additional features
  - Regional Military Protection (RMP) and redesigned Nuclear Detonation Detection System (NDS)
  - Search-and-Rescue (SAR) payload - faster detection and location of distress signals
  - Laser Retroreflector Array (LRA) - provides more precise ranging data

- Partnering with Air Force Research Laboratory (AFRL) for future technology opportunities
  - Digital Reprogrammable Payloads
  - Demo on Navigation Technology Satellite (NTS-3)
  - Near Real-Time Commanding/Crosslinks
- Status: Completed CDR in Mar 2020; SV11 launch forecasted for 2026

Ensuring the Gold Standard today and into the future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Next Generation Operational Control System (OCX)

- Next-generation command, control and cyber-defense for GPS
  - Enhanced command and control capability
  - Modernized architecture
  - Robust information assurance and cyber security
- Incremental Development
  - OCX Block 0: Launch and Checkout System (LCS) for GPS III
  - OCX Blocks 1 and 2: Operate and manage modernized GPS constellation, control and monitor modernized signals
- Current Status
  - LCS successfully supported GPS III SV01 and SV02 Launch and Checkout
    - Exceeding operational requirements for availability and dependability
  - OCX Block 1 software coding complete – 12 Aug 19
  - System integration and verification ongoing
  - Ready to Transition to Operations: 2Q 2022

OCX program continues to execute and meet schedule

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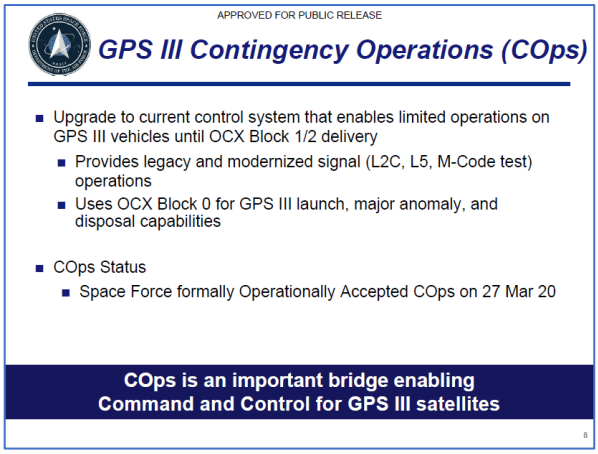
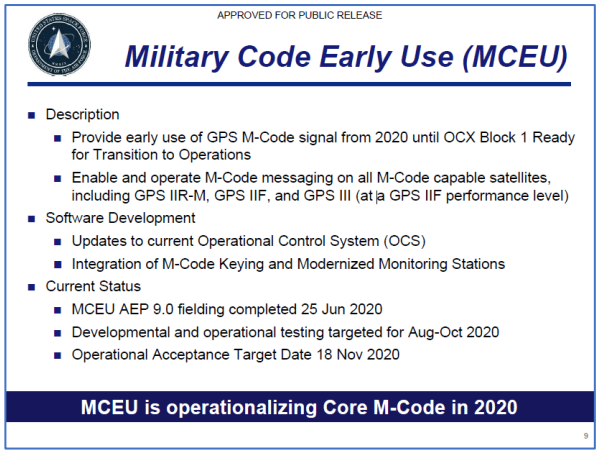
GPS IIIF is a contract that was awarded to Lockheed Martin in 2018 to develop 22 GPS satellite vehicles. In addition to the advances in GPS III, it will have the following features: regional military protection (RMP), a redesigned Nuclear Detonation Detection System (NDS), a Search and Rescue (SAR) payload, and Laser Retro-reflector Arrays (LRA) for more precise ranging data. In addition, this program has pre-planned technology insertion points for additional opportunities, some of which will be demonstrated on NTS-3. We have just completed a year-long bottom-up review of GPS IIIF. We forecast the launch of GPS III SV-11 [the first GPS IIIF satellite] in 2026, which is two years earlier than our original schedule.

For control of the GPS III satellites we are going to rely on OCX, a new design OCS which will enhance our ability to command and control the GPS constellation, which includes cybersecurity enhancements. An incremental development approach is being used, as described earlier. OCX Block 0 (LCS for GPS III) exceeded its operational requirements. OCX Blocks 1 & 2 are going to be delivered together. They will be able to manage and operate all modernized GPS satellites. Block 1 software coding was completed last year and is now undergoing system integration and verification, and we anticipate transition to operations in the second quarter of 2022.

GPS III COps and MCEU:

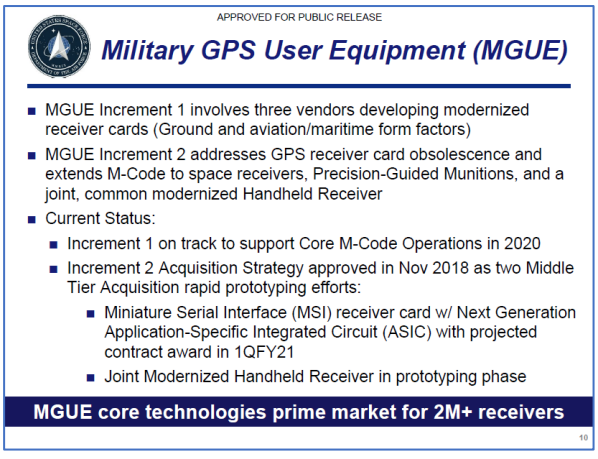




GPS III satellites are being controlled by the Contingency Operations (COps). This platform was accepted in March 2020. We needed to operationally accept this prior to entering GPS III SVs 01 and 02 into the operational constellation. This is an interim solution until delivery of OCX Blocks 1 and 2.

Military Code Early Use (MCEU) is a control system enhancement which will allow us to begin using the M-Code signal until OCX Block 1 is ready to fully transition into operations. It will allow us to use M-Code messaging as well as control M-Code signals. We are two satellites away from a full 24-satellite constellation for M-code. We are still targeting for operational acceptance this year later this year.

GPS MGUE:



Finally, Military GPS User Equipment (MGUE) has two increments. Increment 1 had three different vendors producing independent designs for military receiver and to include them in the platforms used by the services. Increment 2 addresses GPS receiver card obsolesce, and are smaller and better. Increment 1 on track to support operations later in 2020. Increment 2 is includes two main rapid prototyping efforts, first is the miniature serial

interface (MSI) receiver card for precision guided munition, and second is the joint handheld prototype receiver. The development is focused on delivering the core receiver technology, which will then transition to industry.

Q&A:

Brad Parkinson: My first question concerns the status of the GPS Space Service Volume (SSV). There is an agreement between the GPS Program Office (GPO) and NASA where they were going to participate in the Critical Design Reviews (CDR) in order to become aware of any changes to the antenna patterns. Do you know the status of that? Is this agreement working? Are NASA, and others, involved at the level they need to in order to successfully use the SSV?

- Ken McDougall: I'm aware of an activity to provide a standardized set of data. The work is on-going. I'll have to defer to NASA on whether the data that has been provided is useful.
- Brad Parkinson: The agreement went a step further than that. NASA was to attend the PDR and CDR for GPS IIIF? Did that happen?
- Ken McDougall: I believe it did, but I will verify.
- Brad Parkinson: My second question concerns the MGUE. I assume you're up to speed on what Qualcomm is doing with civil signals. They are accessing all GNSS signals and providing actual sampling of the signal that is coming down so that deep integration with inertial systems is possible. This is a very high anti-jamming capability. Do your MGUE chips have equivalent capabilities?
- Ken McDougall: I'll have to defer to MGUE card designers. I will get back to you on this.
- Brad Parkinson: Thanks. I'll appreciate if you get something back to the board. We have expressed many times that we should use all signals if they've been established as reliable, certainly Galileo, and other allied GNSS.
- Ken McDougall: The National Defense Authorization Act (NDAA) did mandate multi-GNSS use. It is included in the MGUE 2 baseline. I don't believe it will be incorporated in MGUE 1.
- Brad Parkinson: This board has gone on record many times that at least Galileo should be authorized. As such, we give accolades to the FCC for licensing use of Galileo E1 and E5 signals in the U.S. Thanks for the nice briefing.

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U.S. Space-Based PNT Policy
Col Curtis (Scraps) Hernandez, USAF
Director, National Security Space Policy, National Space Council, Executive Office of the President

[Note: there are no briefing slides for this presentation]

I spoke to this forum last summer on the endeavor to launch an effort to revise NSPD-39 and incorporate 15 years of challenges, experiences, applications, uses, and threats to our space-based PNT architecture. Following that update we launched a working group (WG) to revise that policy and come up with language would acknowledges the development in space-based PNT for U.S. participants, addresses the issues and concerns along with the changes that have occurred in the environment overall. This WG was organized along the lines of departmental [and agency] responsibilities that apply resources to address all those changes and ensure that space-based PNT would be applicable to future generations. I want to personally thank the participants in this WG, and am very grateful for their contribution and diligent work in constructing this. To that end, while this policy remains deliberative, I did want to provide a little envelope of input on its goal for policy guidance. The goal is to maintain U.S. leadership in the service provision and responsible use of GNSS, including GPS and foreign systems. With that as the guidance, the revision drafting was completed right prior to the end of the last calendar year. The document was submitted for White House deliberation prior to COVID-19 crisis taking off. With that in mind the final approval of the revision to the policy has been delayed, so we do not have anything published and I cannot provide further detail until the President has made a decision on the final policy. The policy did gain approval by departmental deputies and is ready for that final review by the White House staff. As will be spoken to by my colleague, Dr. Seth Jones, the policy complements and is consistent with the Executive Order (EO) 13905 for strengthening national resilience through responsible use of PNT services, and to that end the EO has incorporated into the policy. At this time, I wish I could provide more details on the contents of the policy, but I am unable as it is still under deliberation

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Executive Order 13905: Strengthening National Resilience Through Responsible Use of PNT Services
Dr. Seth Jonas, Deputy Senior Director for Resilience Policy
National Security Council, Executive Office of the President

[Note: there are no briefing slides for this presentation]

This EO really focuses on the applications of PNT services to critical infrastructure and other uses. The administration's goals include securing infrastructure vital to our national security and commercial industry. The national security strategy provides a vision to protect its people. Promoting U.S. resilience is a key factor in the administration's ability to meet this. Despite our best efforts, the government cannot prevent all dangers to its people. However, we can help the country remain resilient in the face of adversity. Improving risk management especially across the critical infrastructure sectors, is a priority to achieving a resilient posture. PNT services, such as GPS, are among the most used utilities in the world. The application of PNT data permeates our lives, yet largely goes and unseen. On daily basis people depend PNT services, ranging from the use of smartphone applications to critical infrastructure systems such as power grids and transportation networks. With this in mind the President took action by signing EO 13905 in February 2020. This will help secure critical infrastructure that relies on GPS. The EO directs federal departments and agencies to develop guidance to mitigate the risk of disruption to critical infrastructure that rely on PNT services. One of these ways is through the development of PNT profiles, which is one of several actions identified in order. These PNT profiles are a first step towards this goal, and through engagement across public and private sectors will seek to better understand how PNT services are used by infrastructure systems, networks, and assets. It will seek to identify which PNT services best suit the needs for each application, from commercial aviation to information technology systems. It will seek to improve the ability to detect disruption and manipulation of data from PNT services to ensure our infrastructure can rely on PNT data, and ultimately will seek to enable infrastructure owners and operators to manage the associated risks with their system networks and assets that depend on PNT services. As we have seen from collaborative work across critical sectors on the cybersecurity profiles, which are similar in nature to what we envision the PNT profiles to be, functional effective PNT profiles will need engagement from users and consumers of PNT data, and will be ever evolving and improving through pilot testing and observation, and will change as users of PNT data change. These profiles, and other actions called for in the EO, will inform and enable more resilient and secure national critical infrastructure and economy. The U.S. will benefit from this EO,

which will maintain uninterrupted access to essential services like electricity, communications, air travel, and a myriad of other services that we rely on daily and also utilize and rely on PNT services. We look forward to executive departments' and agencies' implementation of the EO, and engagement across the public and private sectors.

Q&A:

- Brad Parkinson: I have one comment. As Dr. Jonas knows, the PNTAB has a Protect, Toughen, and Augment (PTA) construct. At the national level, I see a great deal a great deal of emphasis on 'augmenting' GPS, but I am concerned that 'toughening' is not being emphasized enough. A GPS receiver can be reasonably immune to almost any jamming with techniques that have been in use for a while. These techniques cost more, but should be part of the 'trick-bag' for critical applications. They cost a little more money, but for critical applications should be part of trick bag. I suggest you put that into your basket.
- Seth Jonas: Yes, those can and will likely be considered as part of the PNT profiles. I also wanted to mention that the National Institute of Standards and Technology (NIST) has issued a Request for Information (RFI) to develop timing profiles, and we welcome input from both the PNTAB and the public. This particular effort is on-going through July.
- J.J. Miller: How can the PNTAB, representing the wider user community, support our objectives?
- Seth Jonas: From an implementation perspective, the White House relies on coordination across the departments and agencies that have been identified in the EO as primary actors. I would encourage the PNTAB to engage the implementers of the EO in order to figure out how to support items such as the PNT profiles, which I are an excellent opportunity to provide inputs. Inputs from private and public sector, and experts across the board, will be essential to make implementation of the EO more effective.
- Thad Allen: The EO includes direction from the President on how it wants the government to operate on responsible use of PNT as it related to the processes and missions of government agencies, such as protection of critical infrastructure. I think it's incumbent on the PNTAB to truly represent the civil user community from where they sit, which is not necessarily a mission-based view of the PNT framework as, say, homeland security with the protection of critical infrastructure. So, yes, I would double down on what you [J.J. Miller] just said.

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PNT Resilience Research and Development
Dr. Adam J. Balkcum, Fellow and Policy Advisor
Office of Science and Technology Policy, Executive Office of the President

[Note: there are no briefing slides for this presentation]

A new interagency working group, PNT Research & Development (PNTRAD) WG, has been established to support one of the tasks in the EO. The PNTRAD WG still in its early stages of effort, and is looking forward to engage the wider PNT community to obtain a more complete understanding of the evolving PNT needs and challenge as specifically related to concepts, technologies, and concepts that can improve PNT resilience. The EO has a broad schedule tasks that are aimed towards improving the resilience of the critical infrastructure that is reliant on PNT. One of these tasks states that, within one year, the Office of Science and Technology Policy (OSTP) will coordinate the development of a national plan for R&D and initial testing for robust PNT services that are not dependent on GPS or GNSS, and which will approaches to use and integrate multiple PNT sources as a way to improve resilience. The emphasis for the PNTRAD WG will be on non-GNSS element and developing them into additional robust PNT services. As such, the plan will be more complementary than what the EXCOM is usually focused on [i.e. GPS], even though we will still have to account aspects related to GNSS services to ensure proper system integration, as GPS/GNSS will still be the primary source for PNT. The R&D plan specifically targets improving resilience of national critical infrastructure, and will be updated every four years. The PNTRAD was formed under the National Science and Technology Committee on Resilience. It consists of representatives from nine agencies with heavy stakes in PNT, as well as reps from pertinent White House components which are NSpC, OMB, and OSTP. Incidentally, some of the agencies with PNTRAD representatives helped craft the EO. Therefore, their continued involvement will help conserve consistency and allows for closer coordination with other efforts identified in the EO. The PNTRAD group will gather the information needed to identify gaps in knowledge and capabilities that can contribute to resilience improvement, and then determine the broad R&D activities that can help fulfill those gaps. A large part of the data will come from agencies themselves, but we also plan to engage the broader community. We are currently putting

together materials those materials and considering the approaches for such engagement. We will also use www.gps.gov to alert the user community on those efforts. As directed by the EO, we are required to have a plan finalized by February 2021. Since the plan has to be coordinated across the government, and requires multiple review, we are aiming towards having a complete draft several months before that. The final plan will be published in the OSTP's website documents page.

Q&A:

- John Betz: Clearly, these three briefings from the White House are doing a better job to defend against threats. Obviously, that will involve millions of users and their receivers, but I haven't seen the suppression of threats as part of the discussion. It seems seen the discussion is leading towards accepting the threats. We need to do more to recognize and remove threats, and not just to accept them and try to protect from them. What kind of trade-offs are being discussed?
- Seth Jonas: The PNT profiles mention doing a risk assessment, and then taking a risk-informed approach to address them. There are various actions we can take depending on what those risks are to the infrastructure, and to the extent such infrastructure relies on PNT. There will be a spectrum of situations. In some cases, it will be more appropriate suppress threats, and in other to accept them. Right now, the Department of Commerce (DOC), though NIST, is working to understand what the risk are for each application of PNT, and then will identify what makes more sense to address. It will be a whole-of-nation approach. I don't think we've sufficiently mapped out yet the risks to each application so that we can decide how to approach the risks.
- Brad Parkinson: Back to the 'toughening' idea, what has been already demonstrated, as a matter of fact 40 years ago, was the ability to take a GPS receiver, augment it with inertial sensors and directional antennas, and fly directly over very high-power jammer without the receiver being affected. The point is, there are techniques to toughen that should also be in the mix for considerations. Obviously, cost is a factor in individual GPS receivers, but the point I'm making is that as I read the EO my interpretation is that toughening of this space-based source of navigation appears to be excluded from what you are trying to do. I believe that the toughening of receivers should be in your 'trick bag' of solutions. Maybe I'm misreading?
- Seth Jonas: I defer to Scraps (Col Hernandez) on the perspective of provision of space-based PNT sources. There is awareness that the combination of the NDPS-39 review and this EO are intended to be developed and presented holistically.
- Scraps: You're correct. The draft updated policy mentions how the responsible agencies would approach this. Those issues are addressed in the upcoming policy, and they are cooperative and complementary with the EO.
- Brad Parkinson: Note I'm not talking about modifying the GPS signals to make them more robust, which is something that would take decades. I'm focusing on the receiver side and pointing out that toughening techniques exist, and I fervently hope that the government understands it's a system of systems that should be looked at. One impediment to toughening are our export laws. In many cases GPS manufacturers know how to do such toughening, but they are worried that if they do this then the government will not let them sell it freely. The unintended consequence is that this encourages foreign entities to develop and sell such toughening capabilities and freely sell the toughened receivers. This is why I believe the toughening aspect has to be part of this mix. I hope the people making policy realize that the quickest thing you can do is field new receivers. Such techniques are available now.
- Scraps: I agree with intent. The policy includes language to guide the direction of nation in that lane. I won't call specifically to toughen receivers, but it does call for agencies to take measures to protect the spectrum and receivers from intentional and unintentional disruptions.
- Dana Goward: I have two questions, one for Scraps and the other for Dr. Balkcum.
    - The first question is, the FCC is nominally charged with detection and monitoring, but it seems they have reduced their ability to do that. Will the new policy talk about responsibilities within Executive Branch (of which FCC is not) for interference detection, monitoring, and perhaps enforcement?
    - The second question is whether the emphasis on non-GNSS for R&D resilience mean that you won't be looking at options such as Low Earth Orbit (LEO) -based PNT? PNT in LEO is not generally considered a GNSS, and it has a potential for adding another layer of resilience. There are a number of countries that are either exploring or doing that right now in addition to terrestrial systems, so they have a complete architecture. So, will you be looking at LEO PNT as well?
- Scraps: The short answer is yes. We are looking at the language that specifically calls for that.

- Adam Balkcum: I would say that anything not considered as GNSS will be part of options for the PNTRAD plan.
- Jim Geringer: With China completing its constellation (BeiDou) they're now claiming to be the new GNSS Gold Standard. Is this issue being considered by the White House? This is a topic we may want to discuss later.
- Thad Allen: I think you raise a good point, Governor. Yes, I think we ought to discuss later. However, since we have the WH gentlemen here, we can ask what their thoughts are. We talk a lot about the Gold Standard, and the GNSS systems being developed are fairly distinct and some have better capabilities than others. I see a lot of aspirational comments about the U.S. wanting to be the Gold Standard, but I don't see us always "walking the walk" in terms of technology and how rapidly we can adapt. One of the things this body has talked a lot about is how we get our arms around, especially with the FCC's decision, the comments about us being Gold standards, but now as much walking the walk. One thing we've talked is how we get our arms around it, especially with FCC decision, the role of monitoring and feedback from a national level perspective.
- Dana Goward: Let me jump in on that. China is positioning itself as the new PNT Gold Standard since they've taken a comprehensive approach, including PNT at LEO, Geosynchronous Orbit (GEO), Medium Earth Orbit (MEO), High Earth Orbit (HEO), terrestrial, inertial, all integrated so their citizens and forces have all available when needed. Ironically, they're using a graphic from the U.S. National PNT Architecture Implementation Plan to demonstrate what this looks like. In summary, we know what needs to be done to remain the Gold Standards, but in my view, we are not doing what needs to be done.
- Scraps: That's definitively a challenge that we are paying attention to and trying to address. One of those mechanism is to use our international partnerships and leadership we've provided in the past to pave the way for continued leadership. Some of that is ensuring we have complementary and cooperative systems. Consistent with where we are going, including the EO, we can look like overall PNT would look like in this new technological regime.
- Frank van Diggelen: I wanted to mention something not apparent in discussion I've heard, nor in press. From point of view of most users, over 90% of GNSS use in in cellphones. Everyone uses all GNSS systems that are available, so it is a bit misleading from user perspective to talk about gold standards when, in fact, we are already using multiple constellations. In the U.S., BeiDou is disabled through the software.
- Brad Parkinson: To Frank van Diggelen, I have heard you also support dual frequency. Is this not true?
- Frank van Diggelen: Yes, high end phones support L1 and L5.
- Brad Parkinson: That is fabulous news.
- Matt Higgins: From a user perspective, it is the system of systems that needs to be 'gold', and each GNSS has different capabilities. There are also Galileo and BeiDou dual frequency chips. I agree with Frank on the issue of not focusing just on a single system and instead talking of a system of systems.

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Note: The following board members recused themselves by e-mail from any discussion regarding the topic of the FCC order on MSS radio-spectrum repurposing: John Stenbit, Scott Burgett, Joe Burns, Tim Murphy.

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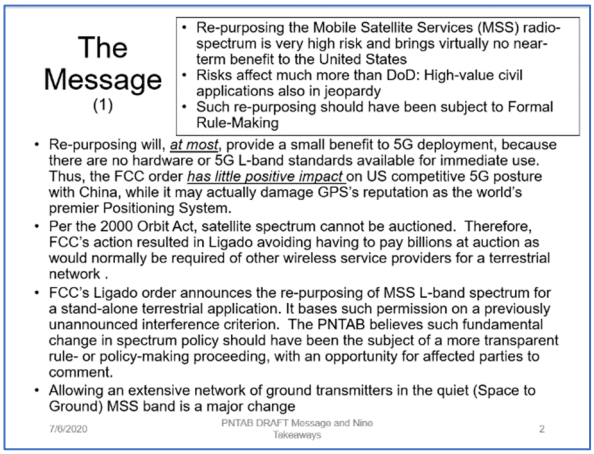
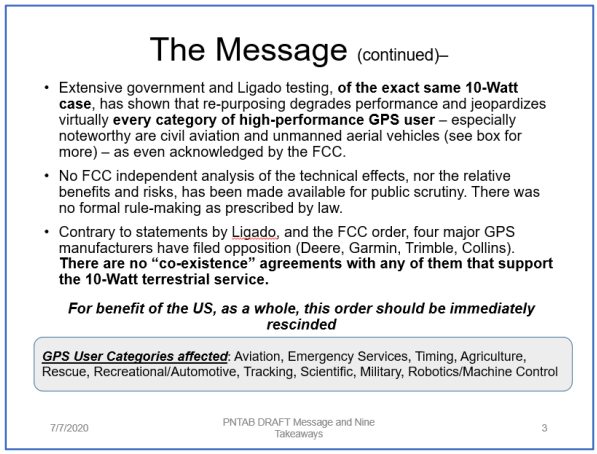
FCC Order on Mobile Satellite Service Radio-Spectrum Repurposing: The Message and Nine Takeaways
Dr. Brad Parkinson, 1st Vice Chair, PNT Advisory Board

Introduction: On Patriot's Day this year, I believe, the FCC issued an order which abruptly changed the whole character of the spectrum the GPS primary frequencies. This band is called the Mobile Satellite Services (MSS) band, which basically means it is reserved for the faint signals coming from satellites in space to the ground used both for communication and navigation. The FCC, in that order, authorized a single company to deploy a high-power terrestrial network to support, allegedly, 5G. This is something we as the board have been studying this issue for over 10 years. Expensive tests have been conducted at taxpayer expense by the Department of Transportation (DOT), and as a result of the technical data the PNTAB recommended to the PNT EXCOM that this be opposed. The PNT EXCOM twice voted unanimously to oppose this. The company brought the power they originally requested down to 10-Watt, and made many misleading claims such as saying we (the PNTAB) had never considered it, which is not true. This report confirms the tests that have been already been made. What I'm going to show is a draft that summarizes our position. It has two sections: the first is a message, and the second is what we call nine takeaways to respond to various claims that have been made. The slides being presented now is a DRAFT and, until voted upon by the PNT Advisory Board, edited, modified, etc., is not the board's official position. Our purpose is to make a public statement on how we feel about this and, at the same time, make available to those people that want to understand better on how and why this is happening. I also hope it will inform the administration and others. To board members: (1) if you notice a grammar issues, or typo, please send me an e-mail; (2) if you have a concern or amendment to the content in this briefing, please note it in real time and I'll try to amend the slide. At the end I hope we can vote up or down whether the revised briefing constitutes a position of the PNT Advisory Board.

Opening Statement: The FCC has made a grave error in authorizing a high-power, terrestrial communication-network in this spectrum adjacent to GPS, and as a matter of fact a radio band that the FCC had assured the GPS community it would exclusively be designated for faint radio signals coming from satellites.

The Message:





The text in the box is our message at the highest level, namely: (1) re-purposing the MSS radio-spectrum is very high risk and brings virtually no near-term benefit to the United States; (2) risks affect much more than DoD: High-value civil applications also in jeopardy; and (3) such re-purposing should have been subject to Formal Rule-Making. The point about risks affecting much more than the Department of Defense (DoD) is particularly important because there's been a focus on the DoD leading the charge in many cases because the civilian community does not have a single voice covering all its applications. In fact, the majority of the GPS receivers in jeopardy are civil receivers.

Now, let me go into a little bit of detail. The re-purposing will, at most, provide a small benefit to the 5G deployment, because there is no hardware or 5G L-band standards available for immediate use. Thus, the FCC order has little positive impact on U.S. competitive 5G posture with China and it actually damage GPS's reputation as the world's premier Positioning System because of the harm it does. We know that there is an Orbit Act that says satellite spectrum cannot be auctioned, which is the type of spectrum we are here. And so, the FCC's action had the consequence of

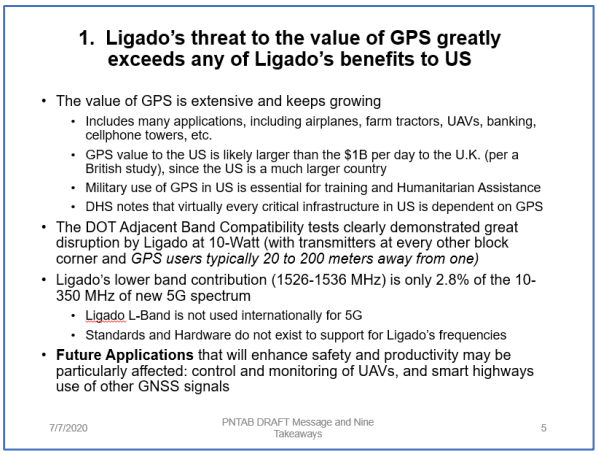
Ligado avoiding having to pay billions at auction as would normally be required. The FCC's order announced, in essence, the re-purposing of MSS L-band spectrum for a stand-alone terrestrial application, and they said it was ok because of something they called "interference criterion" which the PNT community has never endorsed. We believe it should have been the subject of a more transparent rule- or policy-making proceeding. And we do note again that this is a major change in spectrum policy.

The reason we are so opposed is that, contrary to some allegations, the DOT tested virtually the identical 10-Watt case, and showed that it degrades performance and jeopardizes virtually every category of high-performance GPS user. Noteworthy are civil aviation and unmanned aerial vehicles, but I'm also showing a list here of all the other applications that the advisory board is well familiar with [Aviation, Emergency Services, Timing, Agriculture, Rescue, Recreational/Automotive, Tracking, Scientific, Military, Robotics/Machine Control]. More applications are showing up all the time as people find new creative use for GPS signals. We have found no FCC independent analysis of the technical effects, nor the relative benefits and risks, at least in the public domain and there was no formal rule-making as prescribed by law. Now, this is a very important point, because Ligado and the FCC order has suggested that the major GPS manufacturers are in agreement with them. Contrary, the are no "co-existence" agreements with most of the major manufacturers supporting the 10-Watt terrestrial service. In fact, some of them went to great extent after the order was published to file a disagreement [editorial note: in later discussions it was decided to remove Collins from the third bullet]. So, the top-level message here is that for benefit of the US, as a whole, we believe this order should be immediately rescinded.

This completes the first section of the briefing with the top-level message. Now let me go to the nine key takeaways and, again, at this point this is just a draft for discussion and further amendment.

The Nine Takeaways:

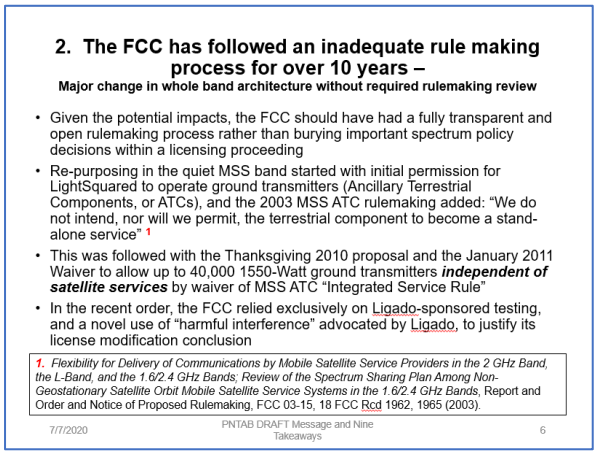
1. Ligado's threat to the value of GPS greatly exceeds any of Ligado's benefits to US



The first takeaway is that Ligado's threat to the value of GPS greatly exceeds any of Ligado's benefits to the U.S. This is a bold statement. Why do we say it? The value of GPS is extensive and keeps growing. It includes many applications that are not visible to the average person, such as farm tractors, UAVs, banking transactions, cellphone towers which rely on GPS time for synchronization. The value is very large. This was quantified by the UK, just for their country, at $1B per day. We have a study that suggested the value to the US was, I believe, approximately $66B per year [according to a preliminary study], but that study excluded many applications that the UK study did consider. There's a thought that maybe the military is just using GPS in wars overseas. Not so. The US military use is essential for training and humanitarian assistance. I'm not going to discuss much about the military, because it would necessitate a classified discussion. The military has however filed notice that they oppose the FCC decision. On the civilian side however, the Department of Homeland Security (DHS) has noted that virtually every critical infrastructure in US is dependent on GPS. The tests that were run by the DOT clearly demonstrated great disruption by Ligado at 10-Watt. What this order authorizes is to have a transmitter at virtually every other block corner (433-meter separation), and that will put GPS users between 20 and 200 meters away from a single tower. We also note an

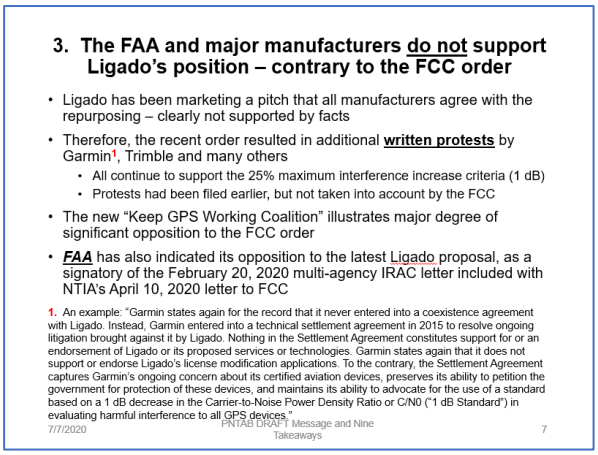
attempt to quantify [the value to 5G] this lower band contribution (1526-1536 MHz). That's less than 3% of approximately of the approximately 350 MHz of spectrum for 5G. In addition, this L-Band spectrum is not used internationally for 5G, for some very good reasons, as standards and hardware do not exist [for 5G use in L-band]. I worry a lot that the board has been so focused on this that we have not had time to discuss future applications for safety and productivity will also be affected. And here I'm talking about UAVs that will be flying in urban areas, where both their control and monitoring will undoubtedly use GPS. Smart highways will also use many sensors and GNSS signals, many of which share the same primary frequency as GPS.

2. The FCC has followed an inadequate rule making process for over 10 years



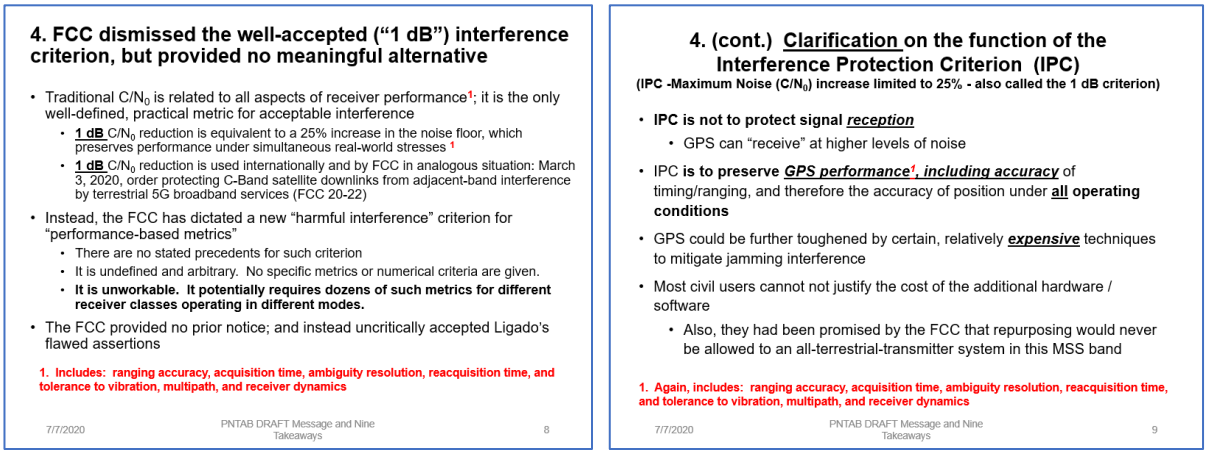
The second takeaway relates process, and that is that the FCC in our opinion has not followed an adequate rule making process for over 10 years; that any contemplation of change to this whole band architecture really should have had a formal rulemaking review looking at the risks and challenges. And we believe that review should have been transparent rather than burying the issue in a licensing proceeding. The process began with initial permission for LightSquared to operate ground transmitters simultaneous with satellite transmissions, and when they made that rule in 2003 giving LightSquared permission they stated, "We do not intend, nor will we permit, the terrestrial component to become a stand-alone service." In other words, they specifically ruled out the decision they have made with the latest order. The reference where this was stated is at the bottom of this chart. We also note that in the recent order, the FCC seemed to rely exclusively on the Ligado-sponsored testing and proposed a new use of "harmful interference" that had been advocated by Ligado as an alternative to the standard that has been traditionally used both in the US, and by the FCC itself incidentally, to avoid interference with an adjacent band. The filings by major GPS equipment manufacturers do not support Ligado's position. The FCC said manufacturers supported the order, but the filings go in the opposite direction.

3. The FAA and major manufacturers do not support Ligado's position – contrary to the FCC order



The third takeaway is that Ligado has been stating that all major manufacturers agreed with the repurposing, and that's not supported by the facts. The recent order resulted in additional written protests by Garmin[1], Trimble, and many others, and they all support the ordinary standard, and that is that an adjacent band transmitter should not raise the noise floor by more than 25%. In short hand we call that the 1dB maximum carrier to noise floor interference criteria. There are a lot of technical things involved, but I think everyone can understand the background noise if you are turning on your radio to a place where there are no stations and you hear this hiss (static). The point is that increasing that noise, or 'hiss', by more than 25% is deemed to be interference. Protests had already been filed earlier but apparently not taken into account by the FCC. The example at the bottom [of the slide] is pretty pertinent, "Garmin states again for the record that it never entered into a coexistence agreement with Ligado. Instead, Garmin entered into a technical settlement agreement in 2015 to resolve ongoing litigation brought against it by Ligado. Nothing in the Settlement Agreement constitutes support for or an endorsement of Ligado or its proposed services or technologies. Garmin states again that it does not support or endorse Ligado's license modification applications. To the contrary, the Settlement Agreement captures Garmin's ongoing concern about its certified aviation devices, preserves its ability to petition the government for protection of these devices, and maintains its ability to advocate for the use of a standard based on a 1 dB decrease in the Carrier-to-Noise Power Density Ratio or C/N_0 ("1 dB Standard") in evaluating harmful interference to all GPS devices." This is just an example of the typical responses that the FCC order has triggered. There has been a new coalition [Keep GPS Working Coalition] of users that also opposes the order. Also, the FAA was a signatory to the multi-agency Interdepartment Radio Advisory Committee (IRAC), the coordinating committee in the government for frequency matters, letter included with the National Telecommunications and Information Administration's (NTIA) April 10 letter to the FCC that specifically requested this not be done.

4. FCC dismissed the well-accepted ("1 dB") interference criterion, but provided no meaningful alternative



4. FCC dismissed the well-accepted ("1 dB") interference criterion, but provided no meaningful alternative

- Traditional C/N_0 is related to all aspects of receiver performance[1]; it is the only well-defined, practical metric for acceptable interference
  - **1 dB** C/N_0 reduction is equivalent to a 25% increase in the noise floor, which preserves performance under simultaneous real-world stresses [1]
  - **1 dB** C/N_0 reduction is used internationally and by FCC in analogous situation: March 3, 2020, order protecting C-Band satellite downlinks from adjacent-band interference by terrestrial 5G broadband services (FCC 20-22)
- Instead, the FCC has dictated a new "harmful interference" criterion for "performance-based metrics"
  - There are no stated precedents for such criterion
  - It is undefined and arbitrary. No specific metrics or numerical criteria are given.
  - **It is unworkable. It potentially requires dozens of such metrics for different receiver classes operating in different modes.**
- The FCC provided no prior notice; and instead uncritically accepted Ligado's flawed assertions

1. Includes: ranging accuracy, acquisition time, ambiguity resolution, reacquisition time, and tolerance to vibration, multipath, and receiver dynamics

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4. (cont.) Clarification on the function of the Interference Protection Criterion (IPC)

(IPC -Maximum Noise (C/N_0) increase limited to 25% - also called the 1 dB criterion)

- **IPC is not to protect signal *reception***
  - GPS can "receive" at higher levels of noise
- IPC **is to preserve *GPS performance[1], including accuracy*** of timing/ranging, and therefore the accuracy of position under **all operating conditions**
- GPS could be further toughened by certain, relatively ***expensive*** techniques to mitigate jamming interference
- Most civil users cannot not justify the cost of the additional hardware / software
  - Also, they had been promised by the FCC that repurposing would never be allowed to an all-terrestrial-transmitter system in this MSS band

1. Again, includes: ranging accuracy, acquisition time, ambiguity resolution, reacquisition time, and tolerance to vibration, multipath, and receiver dynamics

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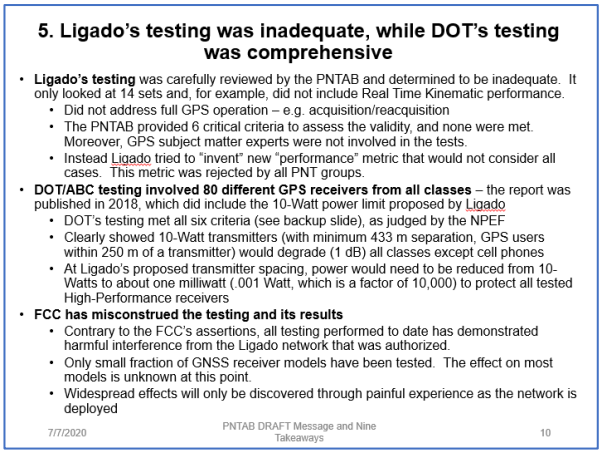
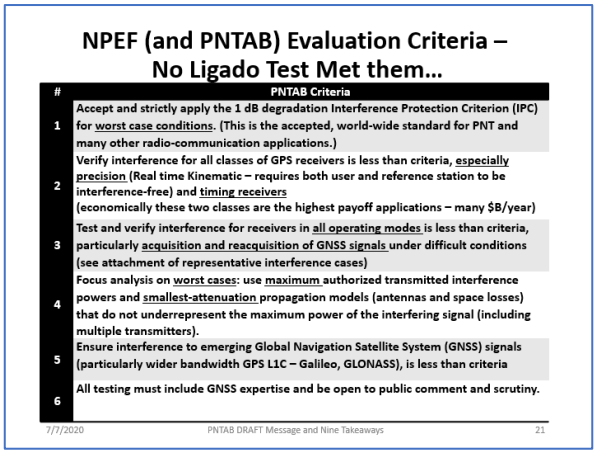
The fourth takeaway is that the FCC dismissed the well-accepted interference criterion, the 1 dB, but the alternative they provided is difficult to understand. The traditional C/N_0, i.e. the traditional 1 dB, is related to all aspects of receiver performance. It is the only well-defined, practical metric for acceptable interference, and if an adjacent band transmitter stays within that then you're assured all the functionality (such as ranging accuracy, acquisition time, ambiguity resolution, reacquisition time, and tolerance to vibration, multipath, and receiver dynamics) is ok. Instead, what Ligado has been advocating with this "performance metric" is something far different. The 1 dB C/N_0 criterion is already used by the FCC in a very analogous situation (though in C-Band). However, this new "harmful interference" criterion for "performance-based metrics" has no stated precedent. It is undefined and arbitrary, and would apply in different ways for every receiver class operating in a different mode. So, there are literally dozens of such metrics that may apply, and testing them all would be laborious. Also, receivers don't all operate in the same way, and the FCC did not really give us opportunity to publicly comment on them. They appeared to accept Ligado's assertions that this was fine, and yet the PNT community had pointed out in many cases it was not fine at all. Now, let's expand slightly on this Interference Protection Criterion, or IPC. The point is that a communication link is generally concerned about receiving the signal, but GPS isn't that. GPS is a timing signal, so a GPS receiver can typically receive a signal at a higher level of C/N_0, i.e. more interference than 25%, but the 25% is what guarantees the performance of the timing accuracy, reacquisition, and all the other parameters I just enumerated. The 25% means that GPS performance is preserved under all operating conditions. That's the reason this simple parameter is useful.

It should be useful to the FCC, and it is certainly useful to the PNT community in terms of what they think they can tolerate. Some people argue that if GPS is that bad, why don't we throw it out? No. It turns out that GPS can be toughened a lot more than that if you perhaps give up a little in ranging accuracy, but unfortunately those techniques are quite expensive. Civil users generally can't justify the cost of the additional hardware / software and, by the way, the FCC has already promised that this would never happen, that FCC that repurposing would never be allowed in this quiet neighborhood called the Mobile Satellite Services band.

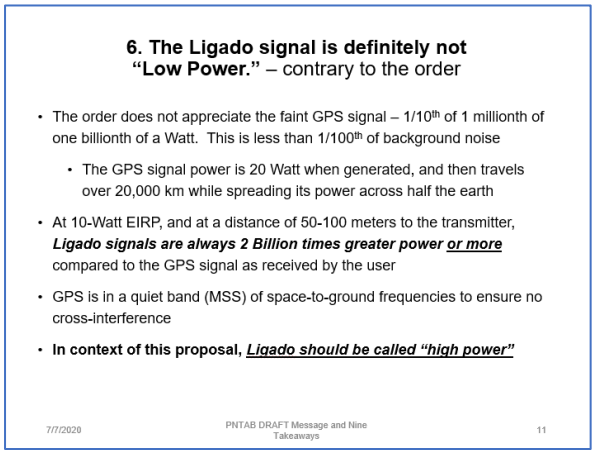
5. Ligado's testing was inadequate, while DOT's testing was comprehensive



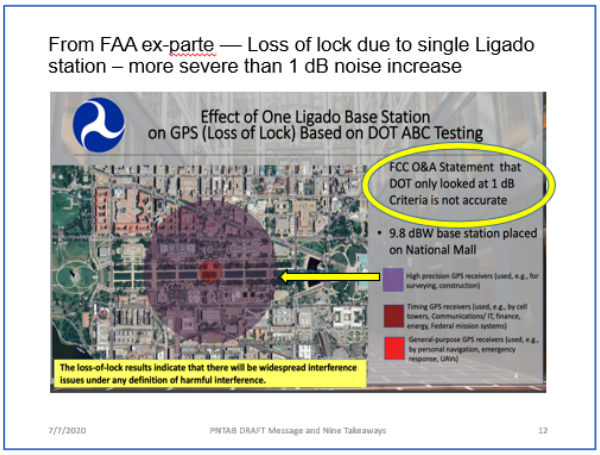


Now let's get to the credibility and amount of testing that was done. This takeaway is that Ligado's testing was inadequate, while DOT's testing was comprehensive. Ligado sponsored testing that was carefully reviewed by the advisory board, and it was clearly inadequate. As a matter of fact, in the backup slides, we have the six criteria we came up with. They looked at only 14 sets and, for example, they did not include what we call Real Time Kinematic (RTK) performance. RTK is the process used to control farm tractors, bulldozers, graders, etc., that require precision control in real time to get down to a few cm of accuracy. The testing that Ligado sponsored did not look at the full GPS operation, and frankly they tried to "invent" a brand new "performance" metric that would not consider all cases. As a matter of fact, it would be very difficult to even test all operating modes, and so this metric was rejected by all PNT groups. The testing that was adequate is the one done by the DOT, called the Adjacent Band Combability, or ABC, testing. The PNTAB reviewed the DOT/ABC study in depth report that was published in 2018 and which did include the 10-Watt power case proposed by Ligado. The DOT testing met all six criteria and was independently judged by the National PNT Engineering Forum (NPEF). It clearly showed that a 10-Watt transmitter (with minimum 433 m separation) would degrade all classes of receivers except for cell phones themselves. As a matter of fact, at Ligado's proposed transmitter spacing, their 10-Watt power would have to be reduced to about one milliwatt (.001 Watt), which is a factor of 10,000) to protect all of the High-Performance receivers from harmful interference from the proposed network. Even though the DOT tested some 80 receiver sets, that's still only a small fraction of receiver models, and the effect on models is unknown at this point. So, a lot of those effects, the widespread effects, are only going to be discovered after this network is allowed to be deployed.

6. The Ligado signal is definitely not "Low Power." – contrary to the order

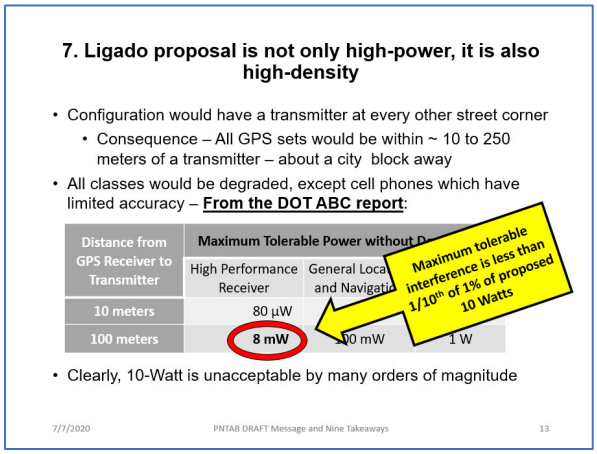


There have been references to the Ligado signal as being "low power." I'd like to correct that, and the example I'll show is that while the signal may be considered as "low power" for communications, the FCC order does not appreciate the faint GPS signal. The GPS signal is 1/10th of 1 millionth of one billionth of a Watt. As a matter of fact, if you listen to the background 'hiss' [of a radio not tuned to a station], the GPS signal is still just 1% of that. So, when you tune into the raw spectrum without a receiver, you're not even going to "see" the GPS signal. And it's a tribute to modern signal processing that your little handheld phone can did that signal out of the background. The GPS signal power at the satellite transmitter itself is 20-Watt, and the beam shaped it's focus on the Earth and that signal travels over 20,000 km while spreading that 20-Watt over the whole side of Earth that the GPS satellite is facing. That's the reason why the GPS signal is faint. As a matter of fact, if you compare that to the 10-Watt Effective Isotropic Radiated Power (EIRP) of a Ligado transmitter a distance of 50-100 meters, the Ligado signals are always 2 Billion times greater power or more compared to the GPS signal. So, I'd like to commend the people who designed the GPS sets of today. They have done an outstanding job dealing with a very faint signal, and aggravation of having this additional power (Ligado) intruding on their band, that is a very serious problem that has to be avoided. Again, the reason we are in this band (MSS) is because there is no cross-interference. Therefore, in the context of this proposal, Ligado should be called "high power."

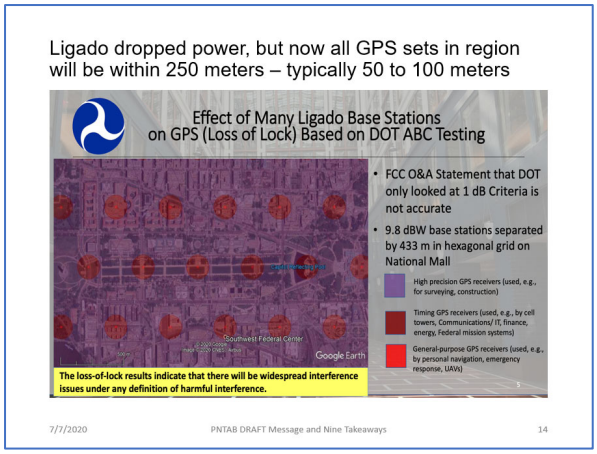


This is an example from the FAA protest to the FCC. The circles represent a single Ligado transmitter, and the purple area is even worse than a 1dB noise increase. It's where the high precision GPS receivers will actually lose lock. The darker circle is where timing receivers are starting to lose lock, and the red circle is where general purpose GPS receiver lose lock. Also, it must be pointed out that the loss of lock occurs way before the lock of performance. So, this is a much greater interference level than simply the 1dB.

7. The Ligado proposal is not only high-power, it is also high-density

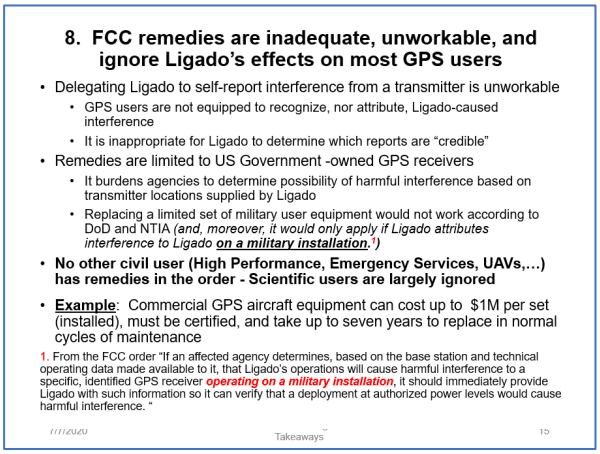


This takeaway is that the Ligado proposal isn't only high-power, but it's also very high density. The configuration would have a transmitter at every other street corner, so all GPS sets would be within 10 to 250 meters from a transmitter. Of course, the closer you get to a transmitter the greater the interference. But you can't get any further away than 250 m since at that point you're sort of between two Ligado transmitters (the overall transmitter distribution would be in a honeycomb pattern, with 433 m distance between transmitters). Note that all classes of GPS receivers would be degraded, except cell phones which have only limited accuracy. In this table, from the DOT ABC report, we can see the maximum tolerable power without incurring degradation. On the left we have two distances (10 and 100 m), and across we have the receiver categories. This is the maximum Ligado power that could be tolerated. Let's look at the high-performance receivers, which are the ones providing high economic value to the U.S., at 100 meters the maximum tolerable power to not interfere is 8 mW (.008 Watt). Clearly, the proposed 10-Watt transmitter power is not even close to what can be tolerated by the high-performance receivers.



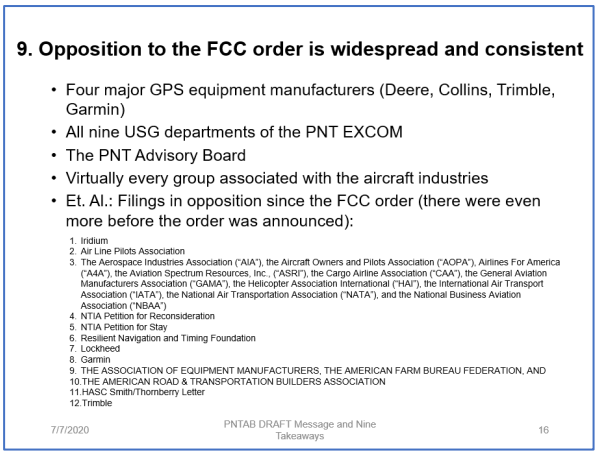
Ligado dropped the power from earlier initial proposals, but in turn this requires a denser network. As shown in this figure, again in the National Mall, the 1dB criterion is not met anywhere for a high precision GPS receiver.

8. FCC remedies are inadequate, unworkable, and ignore Ligado's effects on most GPS users



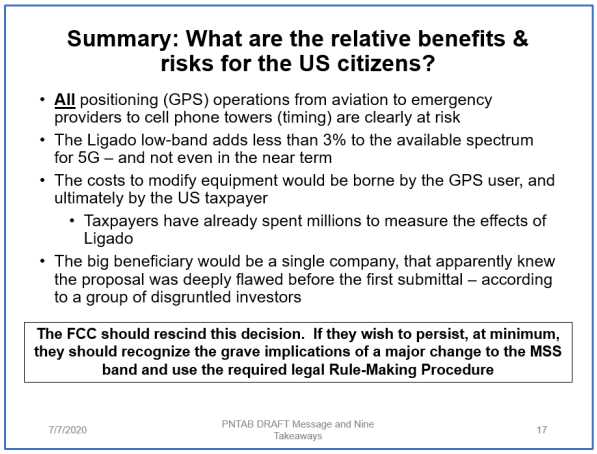
The FCC order said they had provided remedy. We carefully looked at those remedies, and have comments about those. What the FCC did is ask Ligado to set up an Interference Reception Center, and delegate to Ligado to "self-report." GPS users were supported to recognize, attribute to Ligado, and then call this center and say they're getting interference with, and then Ligado would make the determination whether the report was credible or not. One senses there is a "fox in with the chickens" here. The FCC also offered a remedy to replace US government-owned GPS receivers, but to do that the agencies have to determine the possibility of interference and base that on transmitter locations supplied by Ligado. According to DoD and NTIA, replacing a limited set of military user equipment would not work, and as I read this it seems to only apply in a military installation. But there is a problem with this because in many cases we use the military in times of national emergencies such as hurricane disaster relief. Also, I note that no other civilian user (high performance, emergency services, UAVs, etc.) has remedies in this order, and scientific users are largely ignored. We looked at the specific example for GPS equipment on commercial aircraft, which as I understand is a triple-redundant installation, and the cost of that (installed, certified, etc.) can rise up to $1M per set. And in the normal cycle of doing maintenance, it would take up to seven years to replace such a commercial aviation GPS set. You can sense why Garmin, defending its GPS aviation market, would be so concerned about this. You also find receivers in general aviation, and other places, that are going to be susceptible.

9. Opposition to the FCC order is widespread and consistent



The final takeaway is that opposition to this order is very widespread and very consistent. This includes major GPS equipment manufacturers, which have filed opposition, all nine U.S. government departments and agencies of the PNT EXCOM, of course the PNTAB, virtually every group associated with the aircraft industries, and many others.

Summary:



In summary, all positioning operators from aviation to emergency providers to cell phone towers (timing) are clearly at risk. The Ligado low-band adds less than 3% to the available spectrum [for 5G], and certainly can't even do that in the near term. This is hardly a pivotal case. The costs to modify equipment by this order would have to be borne by the GPS user, and ultimately by the U.S. taxpayer. I note that the taxpayer has already spent millions to measure these effects. The DOT testing regime was not funded by Ligado nor LightSquared. The big beneficiary is a single company. They apparently knew the proposal was deeply flawed before the first submittal, according to a group of disgruntled investors who filed a lawsuit and attached to that lawsuit the internal data that LightSquared already had, which was clearly aware of the serious problem. The bottom line at the end of the day is, in our opinion, that the FCC should rescind this decision. If they wish to persist, at a minimum, they should recognize the grave implications of a major change to the MSS band and use the required legal Rule-Making Procedure and allow everyone, including all the PNT community, to comment on what the impacts are and the relative value of doing this.

Discussion:

- Thad Allen: Given the time constraints I'll ask board members to provide very major comments. If there are small technical changes, we can take those offline.
- Terry Moore: I understand perfectly why the focus is on the impact to GPS. However, we discussed earlier that the real value is multi-constellation GNSS, but this briefing only mentions the impact to GPS. A large number of U.S.-based users also rely on those constellations. It's worse than just GPS. It's all of GNSS that will be affected as well.
- Brad Parkinson: You're absolutely right and I think it deserves a position here, particularly as it relates to Galileo since it is an authorized signal in the U.S. In the past the advisory board has highlighted this. I'll take an action item to insert somewhere here an amendment that makes that very point. I'll work with Terry and the others to make sure that point is made very clearly in here.
- Jim Geringer: I don't know if it is pertinent to your presentation, but several people are logged in to hear this presentation and I'd like to state as a matter of observation that I can't imagine any investor wanting to invest in this proposed 5G when they realize that there is extraordinary liability to them. Any viewer of television lately knows that there are individuals and firms threatening to sue or follow up on lawsuit awards for perceived and demonstrated damages, which from the way you've described this would be enormous liability up to include loss of life, not just economic activity. Any investor would have to assume such liability in a trial court. So, it befuddles me that any investor would even want to step forward on this knowing that they have no way to duck the liability on interference, particularly when there is a demonstrated injury to a party. This is just a statement. I'm not really asking to change your presentation, but because of the audience that we have it just seems ludicrous for someone to even considering investing in this.
- Brad Parkinson: Let me suggest that that's a conclusion a prospective investor could reach, and certainly has a lot of logic behind it, but I think it's probably outside the purview of our advisory board to formally endorse that. But, yes, people could reasonably reach that same conclusion.
- Thad Allen: This would impact all other satnav systems as well as GPS. But I'd also like to make the point that it will do on that inside the U.S., so that will limit the ability to use some of those higher precision

capabilities that are coming along with the modernization and expansion of GNSS. That will put U.S. industry at a disadvantage globally. It also erodes the Gold Standard concept of a system of systems that was mentioned earlier.

- Matt Higgins: I agree with Terry. An additional point is that I've been concerned for years many years that if LightSquared or Ligado went up in the U.S. then that would probably set a precedent for other such proposals all around the world. I realize that's not within the FCC's scope, but it is an important point I need to make. I'm not suggesting this should be on the slides, but it's a comment I needed to make.
- Brad Parkinson: This I think is something that we on the board have to take into consideration. I suspect it doesn't belong in here, except to the extent that Terry has already enunciated it. At the same time, the board has to recognize our purpose is to provide assured PNT for our users, not just GPS. Certainly, in the current context it is already done with multi-GNSS in the context of the Qualcomm chips. Throughout the rest of the world they get to use all four GNSS, and system providers can easily assure the integrity of the signal much like the FAA does with the systems that we already have. So, what I'm saying is that your point is very well taken and fits right in with the charter of this board, which is assured PNT. It's must broader than just assured GPS.
- John Betz: There's a minor tweak we need to make to the takeaway, which talks about the FCC remedies being inadequate. When you talk about replacing a limited set of military user equipment, and that it would only apply to interference in military installations, that's not what I read in the FCC order. The order says that the power would be turned down only if the DoD determines that the receiver cannot be adequately tested or replaced, and that replacement would have to be anywhere whether the receiver is operating on a military installation or not. So, there's an incomplete quote from the FCC there that could lead to misinterpretation. It's something we probably ought to clean up before the slides become final.
- Brad Parkinson. I have no objection. When I read the order, I read it the other way, but since to me it is not central to the overall argument one alternative is just to take the point out.
- John Betz: If you take out the parenthetical part of the sub bullet that'd take care of that, or perhaps adding some text to clarify there is a repair/replace for any military receiver it is operations or not within a military installation.
- Brad Parkinson: Let me suggest we remove those too, both footnote and the parenthetical. I don't think it detracts from what we are trying to say, and it there is any controversy in what the order means we don't want to cause confusion.
- Thad Allen: Are there other comments?
- James J. Miller: On behalf of Pat Diamond, who's having problems trying to get on the phone, he raises what I think is a good point. Given that the FCC has approved the use of Galileo, and that they accept many users will use GPS + Galileo for resiliency and robustness, perhaps the FCC should require Ligado to perform testing on Galileo receivers as well.
- Brad Parkinson: That's an excellent point. If you recall when we criticized Ligado's testing we brought that up. I thought they did preliminary testing of Galileo receivers. Brian (Ramsay), are you on?
- Brian Ramsay: I do not recall if there was preliminary testing of a Galileo receiver, at least not since the 2011 timeframe. Others expressed concerned about other GNSS, but the FCC's focus was on GPS.
- Karen Van Dyke: We did test multi-GNSS receivers, and that's included in the DOT agency report that other constellations will also be impacted.
- Brad Parkinson: That's great clarification and that should help in putting together a supplemental remark in this briefing. We'll update the briefing and send it out for board members to review. This should not be, in my opinion, and impediment to voting whether to approve this briefing subject to the edits we've discussed.
- James J. Miller: Adm Allen, are you on the line? It appears some folks got dropped off and are having problems getting back online.
- Brad Parkinson: In the interest of proceeding, I suggest we vote and ask that anyone in opposition please identify themselves and say no.
- James J. Miller: I'm in contact by text messaging with Adm Allen, and he suggests to do as the first vice chair has suggested. The question to the overall board is whether there are concerns or objections to adopting this presentation as a formal product of the board? If so, please state it now.
    - None were forthcoming.
- Brad Parkinson: Hearing none, this statement as amended is approved and we will put in the words to reflect the use of Galileo and other comments that have been made, and we will send it around to board members to review again. In the meantime, this summary of the PNTAB position is hereby approved.

- Thad Allen rejoined the meeting after the vote.

[The revised briefing, as approved by the PNTAB vote, is available at:
https://www.gps.gov/governance/advisory/meetings/2020-07/parkinson.pdf]

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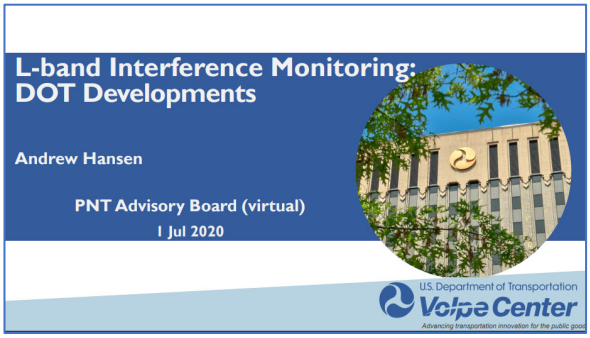
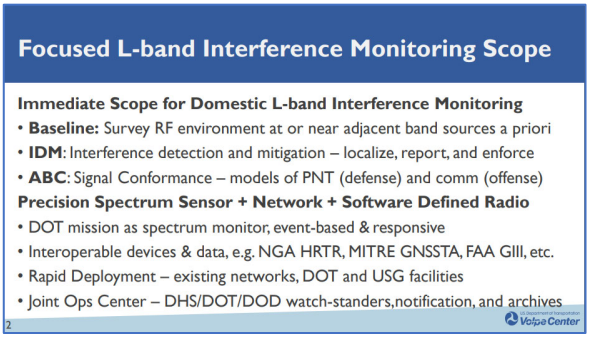
A Proposed Response to Shifting Spectrum Landscape: L-band Interference Monitoring
Dr. Andrew Hansen, Principal Technical Advisor
Volpe Center, U.S. Department of Transportation

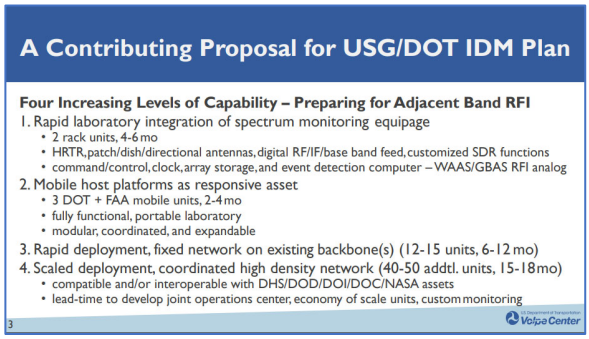
Charts 1 & 2:





This briefing falls under the 'protect' component of PTA. The focus is to scope a proposal for L-band interference monitoring should the FCC decision stand. It follows a three-pronged approach to protect the L-band, including: (1) conduct a baseline survey of the RF environment in as many places as possible where transmitters are going to be installed; (2) provide some level of detection and mitigation of harmful interference, including localizing, reporting, and enforcing what protections we have; and (3) develop models not only for defense of PNT equities, but also in ensuring conformance with the authorization. We do that by understanding what tools we can bring to table. This briefing focuses on what DOT can provide. It is not comprehensive as in what the Administration could bring as a whole. The DOT's approach includes an array of RF sensors at or near the transmitters, a network that connects to the sensors, and some level of software defined radio (SDR) to help us on trigger on events that we need to respond to. We do not envision a uniform network. There is already a strong set of candidate devices already in use across the executive branch. We are attempting to get as much interoperable data as possible exchanged. We also need rapid deployment since the FCC order has timelines that are quite short. Lastly, we need an operational Concept of Operations (CONOPS) and mechanisms to feed the information up to those that need it and also be able to record that information.

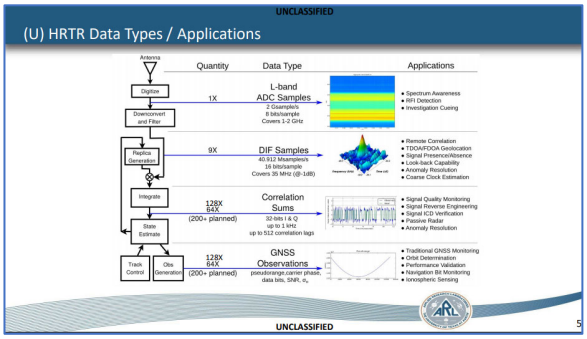
Charts 3 & 4:



As shown on chart 3, an actual proposal is starting to coalesce under the assumption that there will be some level of resource ask for this process. In preparing for an RFI we have formed up four phases, each with an increasing

capability level (see chart 3). The timeline for Phases 1-3 was set in order to be ahead of the actual installation of the transmitters. Phase 4 is a compatible and interoperable high-density network with assets from various agencies along with a joint operations center. The FAA has been in the business of spectrum engineering for quite some time. They already work with enforcement on the FCC side with a VHF/UHF band mobile unit (see chart 4). We expect a direct upgrade to L-band.

Charts 4 & 5:



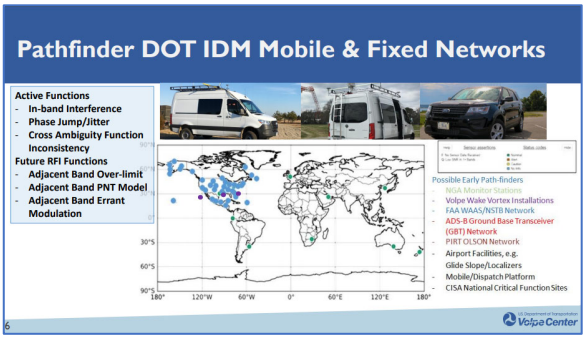


Chart 5 shows the kinds of information we are trying to get. It starts with the SDR sensor and, generally, four categories of information that we're asking that sensor to bring forward for us, and make it useful in the interference detection. The first level is acquisition of L-band raw samples. The second level down are intermediate frequency samples, which can be useful since it allows us not to have to send back huge amounts of raw data. These samples give clear indication of the effects of PNT function later on in the chain. The third level is actual correlation sums of the data coming across the PNT signal, sending that information back, and potentially triggering on it. The final level are the actual GNSS observables that typical applications rely upon to develop their PVT (Position, Velocity, and Time) or PNT solution. Chart 6 shows how we bring this together. We're expecting to have pathfinder mobile units (the photos show units already available to us at the DOT), and the map shows potential candidate early pathfinder networks. On the left we can see the functions that are already available, and also a transition to future RFI functions. Ms. Van Dyke has already been moving us with weekly meetings to stand this up.

Q&A:

- Terry Moore: Are you planning to record all the raw RF samples, which could potentially be terabytes in size that need to be stored and moved? By the way, there is a European Space Agency (ESA) project, "GNSS Big Data," that is looking precisely at recording raw samples, how they can be stored, and how they can be processed.
- Andrew Hansen: The intent is to move those event-driven detect functions out to the centers, and having window buffers for that RF information that is too much to backhaul. The current mechanism to monitor GNSS functions has already been implemented. If high rate information is needed, then local archives can be accessed on specific windows but not the an entire 24-hour recording.
- John Betz: This proposal looks like it would be useful for a lot of purposes, but it is not clear to me how this applies to enforcement of the FCC order on Ligado. In the order it seems that a couple of things have to happen. First of all, real GNSS receiver has to experience harmful interference in terms of some performance-based metrics, so it's not just a question on whether your SDR has identified a problem or not. The second thing that it has to be attributed to the Ligado downlink, and thirdly the evidence needs to be provided in a way that Ligado can judge as credible per the FCC order. At some point we need to discuss how this capability will help address the FCC order on Ligado.
- Andrew Hansen: The majority of what I have presented is about a screening function that can be effective. You're exactly right that we would have to demonstrate harm and send it to Ligado and the FCC for remedy, whether legal or otherwise. It depends on higher powers to give us direction, and where a PNTAB recommendation would be quite useful, on how to use a screening network like this one to identify hot spots and then, if directed, to field actual receivers in those hot spots to further solidify the case with actual evidence. That's why a joint operations center is critical, as the network alone cannot make the case.

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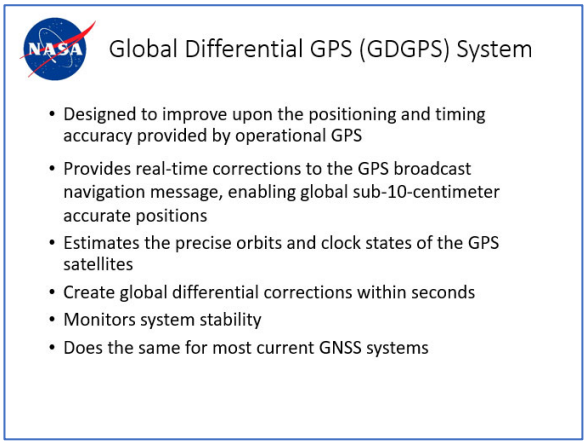
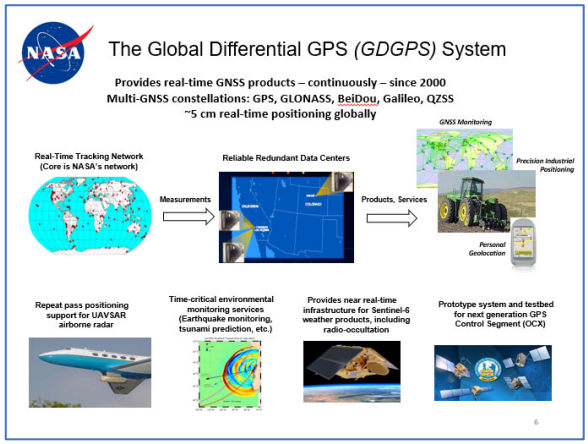
Global Differential GPS System (GDGPS) Working Group
Maj Chris Bonniksen (USAF, Ret.), NASA Management Office Technical and Programmatic Oversight

We're here for two reasons: (1) let the PNTAB know we are doing an evaluation of the Global Differential GPS (GDGPS) System that is resident at the Jet Propulsion Laboratory (JPL); and (2) use the advice part of the PNTAB and make sure that as we look at this capability we're also taking the right things into account outside of what is just NASA.

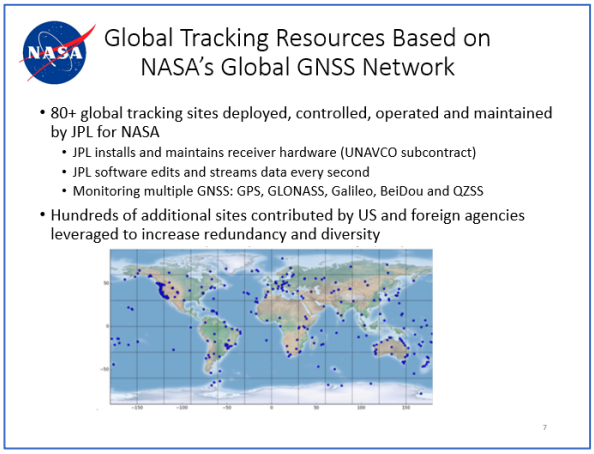
Overview of GDGPS:

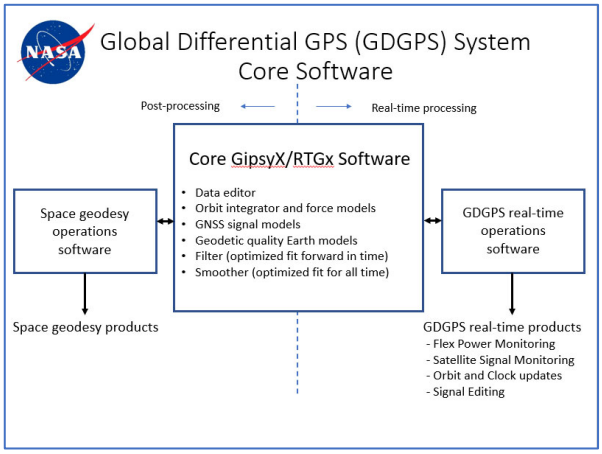




GDGPS was originally designed to improve upon the positioning and timing accuracy provided by operational GPS. It does sub-decimeters accuracy by providing real-time corrections to the GPS broadcast navigation message. It provides estimates of the precise orbits and clock states of the GPS satellites, and this is a real-time correction that comes out. It also monitors system stability: Are the satellites working the way they're expected to? Are there errors that are starting to show up? And it does this for most of the current GNSS systems (GPS, GLONASS, Galileo, and BeiDou). This is done through a network of reference sites, the core of which is a NASA network. There are a large number of reference sites that are done through agreements with universities, agencies, both U.S. and foreign. The information comes into the data canter, and then products and services are pushed out to users either through differential corrections or as specific products for those who are paying customers.

NASA Global GNSS Network (GGN) and GDGPS System Core Software:

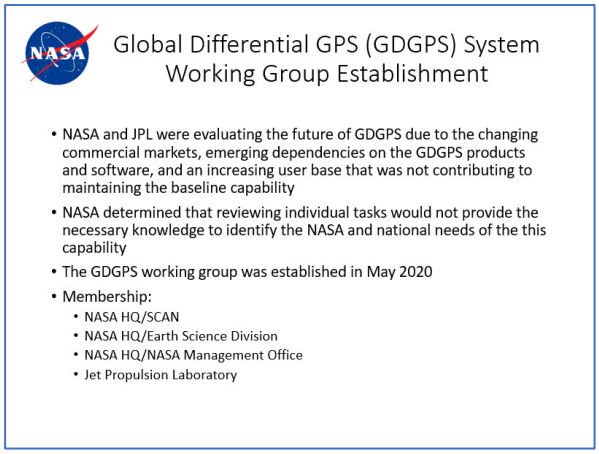


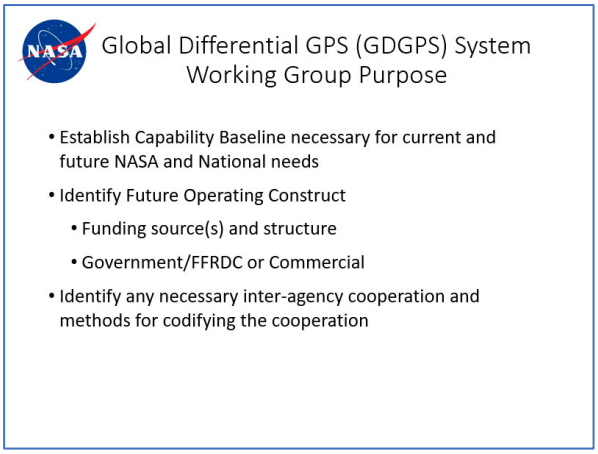


What it really comes down are the ~80 sites run by NASA as part of its Space Geodesy Project. GDGPS attaches a box to those and gets a real-time feed of what is coming to those receivers. It also gets feeds from hundreds of

additional sites, but what those additional sites provide is redundancy. One of the big things that comes out of this system is the core software. It supports both post processing work as well as real time. This is software that has to be maintained, because as the satellite signals change/adjust and adjust, that's put into these models. This software is modified in real-time to maintain currency. The real-time products include monitoring of the flex power activities on GPS, and also a satellite signal editing function where it looks at bad data that is coming out, such as clock drifting, which is then edited out prior to the corrections coming in, in addition to specific products requested by customers.

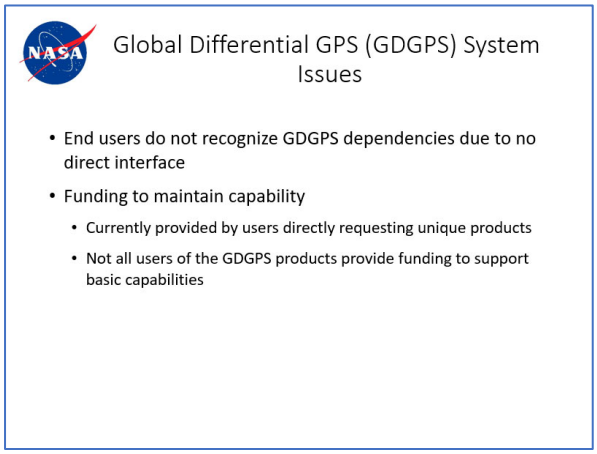
GDGPS WG Establishment and Purpose:

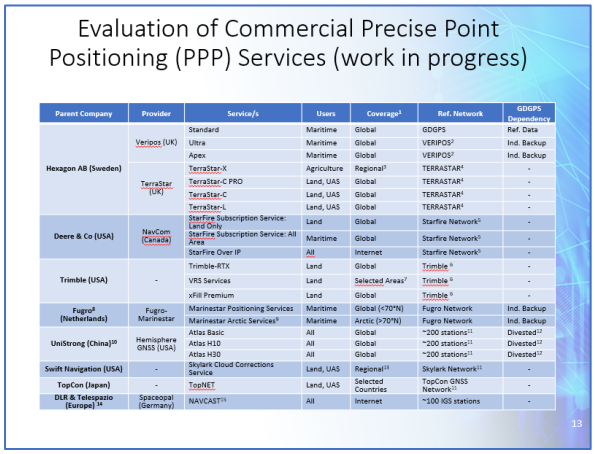




The GDGPS WG was set up because markets are changing, with increasing dependency on GDGPS and its products, and there is also an increasing user base that isn't necessarily helping to maintain the core capability. So, NASA decided to review what's going on with this system. We've been looking at individual tasks as most of what is done, as far as GDGPS products, comes from the commercial market place and we tend to review those as one-off activities. Some of those tend to come to NASA as a commercial request for a government customer, but we have to treat them all as strict commercial requests. Therefore, we wanted to look at a larger picture as we decide how to move forward. In May we established a working group including NASA HQ offices with vested interests in GDGPS as well as JPL and its subject matter experts. What we need now is to determine whether we have the right baseline as we move into the future. Also, as we move into the future, how do we operate this? Should this continue to be a Federally Funded Research and Development Center (FFRDC) capability, or should we move out and let the commercial marketplace provide the need? If we stay within the government, are there any interagency cooperative agreements we need to tee up so folks get what they need and remain vested in its continuation?

Issues and Initial Findings:

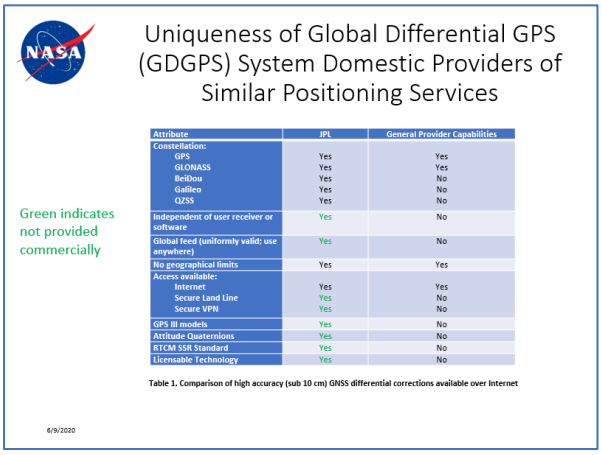




Parent Company	Provider	Service/s	Users	Coverage[3]	Ref. Network	GDGPS Dependency
Hexagon AB (Sweden)	Veripos (UK)	Standard	Maritime	Global	GDGPS	Ref. Data
		Ultra	Maritime	Global	VERIPOS[2]	Ind. Backup
		Apex	Maritime	Global	VERIPOS[2]	Ind. Backup
	TerraStar (UK)	TerraStar-X	Agriculture	Regional[3]	TERRASTAR[4]	-
		TerraStar-C PRO	Land, UAS	Global	TERRASTAR[4]	-
		TerraStar-C	Land, UAS	Global	TERRASTAR[4]	-
		TerraStar-L	Land, UAS	Global	TERRASTAR[4]	-
Deere & Co (USA)	NavCom (Canada)	StarFire Subscription Service: Land Only	Land	Global	Starfire Network[5]	-
		StarFire Subscription Service: All Area	Maritime	Global	Starfire Network[5]	-
		StarFire Over IP	All	Internet	Starfire Network[5]	-
Trimble (USA)	-	Trimble-RTX	Land	Global	Trimble [6]	-
		VRS Services	Land	Selected Areas[7]	Trimble [6]	-
		xFill Premium	Land	Global	Trimble [6]	-
Fugro[8] (Netherlands)	Fugro-Marinestar	Marinestar Positioning Services	Maritime	Global (<70°N)	Fugro Network	Ind. Backup
		Marinestar Arctic Services[9]	Maritime	Arctic (>70°N)	Fugro Network	Ind. Backup
UniStrong (China)[10]	Hemisphere GNSS (USA)	Atlas Basic	All	Global	~200 stations[11]	Divested[12]
		Atlas H10	All	Global	~200 stations[11]	Divested[12]
		Atlas H30	All	Global	~200 stations[11]	Divested[12]
Swift Navigation (USA)	-	Skylark Cloud Corrections Service	Land, UAS	Regional[13]	Skylark Network[11]	-
TopCon (Japan)	-	TopNET	Land, UAS	Selected Countries	TopCon GNSS Network[11]	-
DLR & Telespazio (Europa) [14]	Spaceopal (Germany)	NAVCAST[15]	All	Internet	~100 IGS stations	-

Many people, including within NASA, don't realize they are relying on GDGPS. Many of our satellites are using software that was created, and is maintained, for this system to get the accuracy levels required in science applications. We need to make sure that the end user knows it needs it. Currently funding is not consistent with requests and expectations for the system. We have gone out to find out what is in the commercial market place, who is doing it, and what type of service are they providing.

Identifying GDGPS's Uniqueness:

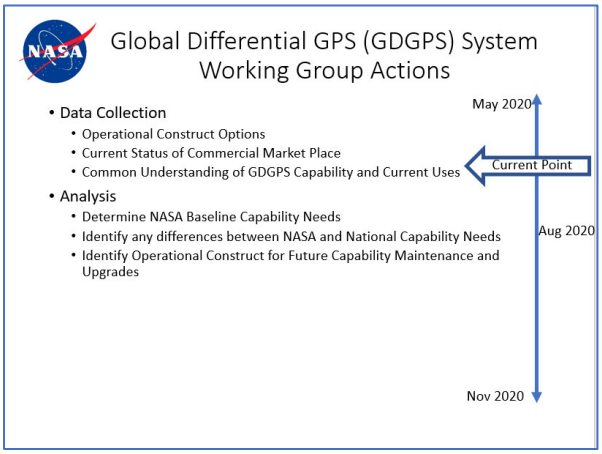


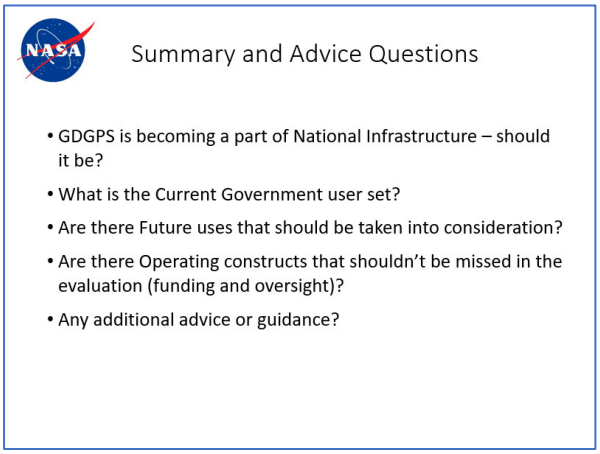
Attribute	JPL	General Provider Capabilities
Constellation:		
GPS	Yes	Yes
GLONASS	Yes	Yes
BeiDou	Yes	No
Galileo	Yes	No
QZSS	Yes	No
Independent of user receiver or software	Yes	No
Global feed (uniformly valid; use anywhere)	Yes	No
No geographical limits	Yes	Yes
Access available:		
Internet	Yes	Yes
Secure Land Line	Yes	No
Secure VPN	Yes	No
GPS III models	Yes	No
Attitude Quaternions	Yes	No
RTCM SSR Standard	Yes	No
Licensable Technology	Yes	No

Table 1. Comparison of high accuracy (sub 10 cm) GNSS differential corrections available over Internet

Based on where are today, here (above) is a comparison of what is in JPL's GDGPS system and what comes out of that based on our initial assessment of what we believe today's marketplace is doing. Green shows things that are not provided commercially. You'll see that there are areas where the GDGPS corrections are not tied to end user equipment. It is agnostic to the receiver and/or end unit.

Actions, Summary, and Questions for Advice:





We're in the process of doing our data collection. This WG would be ending in the October/November timeframe because we need to be able to know where we're going before our next budget cycles. Our questions are: Should GDGPS become part of the national infrastructure? Are there future uses that we are not doing today but that the PNTAB things are coming down the pipe and that we should take into account? If we need to continue, what is the funding and oversight? If there is any additional guidance you may have, please let us know.

Q&A:

- Thad Allen: I would like to offer having a conversation offline so I can better understand the GDGPS baseline from an appropriations standpoint, and how you get authorization to handle user fees, etc. I make an offer to be personally involved in WG effort.
- Tim Murphy: On slide with the initial evaluation of commercial Precise Point Positioning (PPP) services, I noted one that is using GDGPS as reference for one of its levels of service. Are all the other services using GDGPS?
- Chris Bonniksen: No, those are not using GDGPS as in requesting formal products. They may, however, depend on the extended network of stations not owned nor operated by NASA.
- Brad Parkinson: Do you provide a feed to any of the cellphone operators? I suspect all have the ability to listen to the satellites and pass along corrections for integrity. Is there any formal relationship? Are there phone apps that make GPS more accurate?
- Chris Bonniksen: I am not aware of any. Some services take and repackage our data with some additional enhancements. Those tend to have a formal relationship because they also want some guarantee of data availability and connectivity to their centers.
- Brad Parkinson: What is NASA's annual budget for GDGPS?
- Chris Bonniksen: GDGPS is not a program of record on the budget. We provide a support function to other programs of record.
- Thad Allen: Getting clarity on the multiple funding sources will be important.
- Chris Bonniksen: Currently most of funding comes through Space Act agreements rather than as directly appropriated funds.
- Thad Allen: I think we need to develop this so we have a baseline of how the GDGPS enterprise. I have a cousin that's a soybean farmer, and he acquires services more than just geospatial information. It is fascinating how GDGPS inputs are put into that and packaged as a service.
- Chris Bonniksen: The majority of commercial entities we found are subscriber services, which comes with their own receivers/antennas and additional benefits of subscribing to that service.
- Thad Allen: What happens if we lose the GDGPS signal, do those systems stop working?
- Chris Bonniksen: Yes.
- Brad Parkinson: It seems this suffers from same reasons we have potholes. Supporting infrastructure is not something that people step up to do. It requires a much broader strategic look at things. I think we are the appropriate place to do this. Another observation is that this, in the greater scheme of things, is not very

expensive system. Therefore, if it does everything it says then supporting it might be a very interesting thing to do.

- Thad Allen: I agree
- Gary Thompson: Is the national geodetic survey involved with your group?
- Chris Bonniksen: We have been briefed by Dave Stowers (JPL), who runs the NASA part of GDGPS. If there's someone we should contact, that's part of what we're looking for.
- Gary Thomson: I recommend contacting national geodetic network and who manages it. I'll provide the contact information.
- Matt Higgins: In Australia, lots of local governments run Continuously Operating Reference Stations (CORS) networks. That data can also be provided to a lot of these commercial services. To answer Brad's earlier question, you could do monitoring on your cellphone if you had free access to this data. This model varies a lot around the world.
- Tim Murphy: What is the competition doing with other GNSS. Are there analogs in Europe and/or China?
- Chris Bonniksen: There are lots of spot/regional corrections we're are aware of, but nothing that provides global corrections pole to pole. The person that talked about the big data project would have more info.
- Terry Moore: There is plan within Galileo for a high accuracy service (HAS) that will provide two levels of decimeter PPP globally, with level at a different convergence rate. The plan is to conduct trials later this and start operations next year.
- Matt Higgins: Also, the PPPF technique allows for less stations to get global coverage. The Galileo high accuracy service will be delivered directly from Galileo satellite. It is not a separate augmentation service. It's a significant game changer, which is why I always point out the lack of FCC authorization for the Galileo E6 signal in the U.S.
- Tim Murphy: This is significant. For GPS to remain the Gold Standard we need something like GDGPS as part of the core infrastructure.
- Matt Higgins: Also, Galileo is not the only system doing this.
- Thad Allen: We need to drill down.

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PNT Board Round Table Discussion

- Thad Allen: We can now go around the table to hear from PNTAB members.
- James Miller: Are there any outstanding points sticking out, such as Todd Walker and John Betz looking at GDGPS capabilities, and are there board members that want to start a subgroup?
- John Betz: In past few weeks we've begun informally setting up a PNTAB subgroup to look at the GDGPS questions that Christine introduced. We're still in fact finding mode. There is some budgetary stuff we're still studying. Once we've established those facts, then we'll be in a position to draft some recommendations for the board to consider. Todd and I are willing to add a couple members to the subgroup. Please contact me afterwards if you're interested.
- Thad Allen: Are there any comments? I'll go down the list and ask people.
- Penny Axelrad: I'd like to volunteer for it.
- John Stenbit: I don't want to volunteer, but I think it's a good idea.
- James Miller: Frank, would you be interested in this? I had Yoaz brief the FCC separately.
- Frank van Diggelen: Yes, I'm definitely interested in that.
- John Betz: We're not just looking at the differential aspect, but also how they will end up used for applications such as assisted GDGPS.
- Tim Murphy: I'd like to support that group as well.
- James Miller: Maybe Gary Thompson is also interested?
- Gary Thompson: Yes.
- Terry Moore: I also offer to participate if you want an international flavor.
- Matt Higgins: What is purpose of group? Evaluating whether GDGPS should continue?
- John Betz: It's more than that. It really had to do has to do with what form should GDGPS continue under, one being not at all, another being finding a home for it, what organization/funding it should have, etc. My first objective is to draft a Terms of Reference (TOR) to coordinate that with PNTAB leadership and Christine

and others at NASA as well as to make sure we have a common agreement on what questions we are supposed to answer.

- Matt Higgins: Ok, then add me on. Typically, the government does the infrastructure, and then industry does the data delivery.
- James Miller: Working through the summer and fall will be really helpful to give the GDGPS WG a helpful perspective.
- Thad Allen: Let's move now to other comments.
- Penny Axelrad: I found the discussion about the FCC useful. I also appreciate the information on addressing interference, GPS monitoring, and the GDGPS discussion.
- Gerhard Beutler: I sent you [Thad Allen] some ideas on how an international group could be organized, but that should happen at face-to-face meeting. Also, I think some reorganization may be necessary in the science and international subgroup. I really liked Brad's briefing very much. This issue is very important to high accuracy users of GPS and all GNSS. This not only affects GPS, but virtually all GNSS.
- Scott Burgett: I was well informed today, and don't have anything further to add
- Sergio Camacho-Lara: I think we made good progress on Brad's proposal regarding the message and key nine takeaways. On GDGPS I think there should be some consideration for a group on how to interact with science users, who typically don't have much budget to work with.
- Gerhard Beutler: I have one more point. I think the GDGPS world and link to science community is very important, and that's where the International GNSS Service (IGS) would come into play. Many of stations are used for CORS and are also available through IGS.
- Frank van Diggelen: I want to reiterate that 90% of GPS receivers are integrated in cellphones. The best approach is to enable all GNSS constellations in these phones, and only disable specific constellations if required by law (such as BeiDou in the U.S.).
- Dana Goward: I sent a proposal for two small workgroups, one on terrestrial PNT characteristics and another to discuss the advantages of potential LEO systems. I'm happy to take that discussion through e-mail. [Ed. note: see Appendix E for proposal]
- Thad Allen: We got some emails with statements before meeting. We can put those on www.gps.gov and include them in the meeting notes.
- Matt Higgins: I have a couple of points. I'm not clear on the next step with Ligado.
- That Allen: We generally think there are three things can happen now and, quite frankly, as PNTAB we have no official standing to move forward on those other than giving advice. First, there are many requests to FCC to reconsider, including follow-up requests from DOT and DoD (classified). The second one is a legal challenge. The third one is for Congress to act since they treat the FCC as a regulatory entity. In this regard, there will be language in the NDAA to require an independent review of the FCC decision, perhaps by the National Academy of Science.
- Matt Higgins: As I mentioned earlier, other countries are watching. I have been asked about this. It will be good to have some discussion and, at some point, how the Australian GNSS community needs to keep an eye on this.
- Thad Allen: There are other issues going on in the world of diplomacy and politics, where countries' positions are provided to the country teams (ambassadors, etc.) for the purpose of establishing what their position is. We haven't talked about that, but we may want to think about it if the discussion matures.
- Matt Higgins: I can't speak for the Australian government, but there may be opportunities to bring this up at U.S.-Australia bilateral meetings. The next comment I had was in regards to Dana Goward's paper. Both proposals are interesting. I was not aware of multi-level PNT strategy. Is there public information available? If there is, I'd be interested to be involved in the discussion. There is a need to get more structure around multi-GNSS and what that means to the U.S. For example, Australia would like to get access to the Galileo High Accuracy Service (HAS), which requires access to the E6 signals that is not licensed in the U.S.
- Larry James: Regarding the issue Brad raised regarding the SSV, I believe we need to continue working on that, and also working with the U.S. Space Force. I also support the dialogue on GDGPS.
- Terry Moore: My thoughts are aligned with what others have been saying in last few minutes. The issue of multi-GNSS is recurring. We need subcommittee for multi-GNSS.
- Thad Allen: Multi-GNSS is a key focus area in terms of defining what constitutes the Gold Standard.
- Tim Murphy: I'd like to echo previous points on multi-GNSS. So far, we've been only been able to get the Galileo E1 and E5 signals approved for use in the U.S. It'd be nice to have a policy and plan to get other

GNSS constellations approved. It seems silly to me to "turn off" the use of all GNSS constellations. We're missing on free performance at no cost. Also, as Brad said early on, we're not doing enough to toughen GPS receivers. I'd like to reiterate the point I made earlier about PNT technologies and U.S. export laws.

- James Miller: Maybe we need a brief on trade applications at the next PNTAB meeting.
- Brian Ramsay: I have nothing further to add.
- Russell Shields: The area I'm most interested in is automated driving, where substantial emphasis has been pushed forward because of the COVID-19 pandemic. At some point it may be useful for PNTAB to look further into what's happening in the automated vehicle space and where it's going. I would note that I have friends in car companies in other parts of world who are using multi GNSS receivers, and there is a belief that other GNSS services will be less impacted by Ligado than GPS is.
- Gary Thompson: There are important implications to the geodetic community, such as how we update datums. It is important to get users educated, particularly developers of technology and equipment. Some users could be blindsided and have catastrophic impact.
- Thad Allen: Please send me by e-mail a summary of the implications to the geodetic community.
- James Miller: For Gary, we can easily draft a finding and identify some user groups need to be educated and informed. We can take that offline and develop a finding for the next meeting.
- Thad Allen: That might be interesting to also pass on to the PNT ESG and PNT EXCOM.
- Todd Walker: I have nothing to add. I agree on the importance of accessing other GNSS signals and easing the ITAR restrictions on technologies to toughen receivers.
- Jim Geringer: Looking beyond the FCC issue, there are lots of other issues the board can examine, such as systems-of-systems, multi-GNSS, etc. Part of what we bring to the PNT ESG and PNT EXCOM is our next round of potential taskings. Issues such as multi-GNSS will require engagement with PNT EXCOM departments and agencies, in particular the Dept. of State. Another important issue is GDGPS, and I can envision additional taskings on that topic. How should we prepare for future PNT ESG and EXCOM meetings?
- Thad Allen: The PNT ESG meets next week. I can provide some high-level points of today's meeting. Had we not had the Ligado issue, today we would have focused on the workplan for the PNTAB.
- James Miller: From a science perspective, we are always going to be interesting in all GNSS. However, Galileo is our allied system, and non-allied GNSS are not going to get as warm of a welcome from the PNTE EXCOM or other federal government departments.
- Brad Parkinson: I have two additional issues. First, some has called to my attention that one of the GPS manufacturers that opposes Ligado may, in fact, not be as fervent as we would have hoped. I will remove that name from our briefing. Second, I strongly endorse this multi GNSS focus, and I'll ask our aviation friend to help us on the issue regarding certification. It appears certification is a very long process, and to my knowledge GPS are not certified to extend into the multi-GNS regime. I'd like for us to be briefed on the context of getting multi-GNSS on our airplanes and use that in combination with toughening techniques. We need a briefing on those techniques, and what the barriers are.
- TA: I can raise that at the ESG meeting next week.
- Brad Parkinson: I have also noticed that the FCC, unless something comes in as an Ex Parte, it looks like it never even happened. I think we need pressure from the PNT EXCOM to help get our concerns into an Ex Parte.
- James Miller: I'd like to remind everyone to please send me an e-mail if you had to recuse from a conversation.

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The meeting was adjourned at 3:08 PM

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Appendix A: PNT Advisory Board Membership

***Special Government Employees**:* Experts from industry or academia who temporarily receive federal employee status during meetings	
Thad Allen (Chair), Booz Allen Hamilton, retired USCG	John Stenbit (Deputy Chair), former Assistant Secretary of Defense
Bradford Parkinson (1st Vice Chair), Stanford University	James E. Geringer (2nd Vice Chair), ESRI, former Governor of Wyoming
Penina Axelrad, Univ. of Colorado Boulder	John Betz, MITRE
Scott Burgett, Garmin International	Joseph D. Burns, Sensurion Aerospace
Pat Diamond, Diamond Consulting	Frank van Diggelen , Google
Dorota A. Grejner-Brzezinska, Ohio State University	Larry James, Jet Propulsion Laboratory
Timothy A. Murphy, The Boeing Company	Jeff N. Shane, International Air Transport Association
T. Russell Shields, RoadDB	Gary W. Thompson, North Carolina Geodetic Survey
Todd Walker, Stanford University	
***Representatives**:* Individuals designated to speak on behalf of particular interest groups, including foreign representatives	
Gerhard Beutler, International Association of Geodesy (Switzerland)	Sergio Camacho-Lara, UN Regional Education Center of Science & Space Technology (Mexico)
Dana Goward, Resilient Navigation & Timing Foundation (U.S.)	Matt Higgins, International GNSS Society (Australia)
Terry Moore, Nottingham Geospatial Institute (U.K.)	Refaat M. Rashad, Arab Institute of Navigation (Egypt)
Subject Matter Experts:	
Kirk Lewis, Institute for Defense Analyses	Tom Powell, The Aerospace Corporation
Martin C. Faga, consultant, retired MITRE	Brian Ramsay, retired MITRE
Executive Director:	
James J. Miller, NASA	

Appendix B: Attendance (WebEx)

Members

Thad Allen
Penina Axelrad
John Betz
Gerhard Beutler
Scott Burgett
Joe Burns
Sergio Camacho-Lara
Pat Diamond
Martin Faga
Jim Geringer
Dana Goward
Dorota Grenjner-Brzezinska
Matt Higgins
Larry James
Kirk Lewis
JJ Miller
Terry Moore
Tim Murphy
Brad Parkinson
Tom Powell
Brian Ramsay
Refaat Rashad
Russ Shields
John Stenbit
Gary Thompson
Frank van Diggelen
Todd Walter

Speakers

Dr. Adam J. Balkum
Maj Christine Bonniksen, USAF, Ret.
Dr. Andrew Hansen
Col Curtis "Scraps" Hernandez, USAF
Dr. Seth Jonas
Lt Col Ken McDougall

NASA Staff

Barbara Adde
Amanda Allen
Charlene Chen
Alexandra Doten
Jason Kim
A.J. Oria
Sarah Salem
Julie Wang
Rebecca Zia
Lesha Zvosec

Other Attendees

Adam Pastrich
ADanesi
Aliza Margolies
Allison Craddock
Alyssa King
Amanda vonDeak
Amy Chaput
Andrew Roy
Annette Rivas
Anthony Russo
Arun Raghupathy
Ashu Pande
B Harvey
Barbara Clark
Ben Corbin
Benjamin Phillips
Bradford Arnold
Brian Carroll
Brian Humphreys
Brian Zane
Bridge Littleton
Charlene King
Charles Fletcher
Charles Hautau
Charles Popeck
Charles Toth
Cheney
Chi Mai
Chris Hegarty
Christopher Shepherd
Clifford Ledford
Corrie James
Craig Richard Jimenez
Cynthia Moore
Daniel Olmes
Danny
Darrell Pennington
Dave Howard, DOE
Dave Stowers
David
David Choi, MITRE
David Grossman
David Sambrano
David Tucker
David Turner
Dee Ann Divis
Diane Rausch
Dirk Neumann
DJ
Don Wilkerson
Doug Willey
Duke Buckner
Ed Powers
F. Joshua Krage
Francine Vannicola
Frank Bauer, NASA
Ganesh
George Fan
Glenn O'Grady
Greg Greg Danforth
Greg Wolff
Guy Buesnel
Harold "Stormy" Martin
HTS
Ignacio Alcantarilla
Medina
Indrani Graczyk
Ingrid Bartinque
Ismael Garcia
James Aviles
Jay Tallon
Jeff Auerbach, DOS
Jeff Foust
Jeff Hebert
Jennifer Warren
Jennifer Wharram
Jerome Vogedes
Jimmy Durden
Joe Rolli
John Anton
John Barry
John Church
John Franklin
John Hudiberg
John Lavrakas
John Palmer
John Pottle
Jonathan Hardis
Jonathan Krautmann
Jonathan Webster-Jones
Joseph Lazio
Josh Nimetz
Joshua Arnold
Jules McNeff
Justin Huebner
Justin Wymore
K. Alexander
Karen Van Dyke, DOT
Karl Kovach
Karl Shallberg
Kelly O'Rourke
Kent Kyatt
Kirk Vespestad
Kristina Miller
Larry Hothem
Lauren Bartels
Leslie Deutsch
Lt Col Stephen Lyon, NCO
Luis Moratinos
Lisa Valencia
Logan Scott
Lukasz Bonenberg
Mark Crews
Mark Rentz
Mary Lynne Dittmar
Matt Jones
Merrilee Fellows
Michael Barron
Michael Striffolino
Michael Weinhoffer
Mike Van Dooren
Milton R. Clary
Misty Finical
Mitch Narins
Narasimha Prasad
Natalia Saidoglu
Nate Goubeaux
Paul Kim
Peter Cash
Peter Markus
Rachel Wallner
Rafael Figuroa
Randy Brudzinski
Randy Kenagy
Raul Pineiro
Ravi Jain
Rene Balanga
Rich Foster
Richard Rogers
Rick Hamilton
Rob Reis
Robert Crane
Robert Holcomb
Robert Lilley
Roger Aitken
Scott Roberts
Sean Donnelly, DOT
Sean Memmen
Shawn Ryan
Serge Plattard
Stephanie Booth
Steve Mackey
Steve Malys
Steve Moran
Todd Kawakami
Tom Jaeger
Tony Snodgrass
Tupper Hyde
Victor Sparrow
Valerie Green
William Notley
Zhang Wq

Appendix C: Acronyms and Definitions

ACARS	Aircraft Communications Addressing and Reporting System
ATC	Ancillary Terrestrial Component
BeiDou	China's GNSS
C/N_0	Signal Carrier-to-Noise Ratio
CDR	Critical Design Review
COps	Contingency Operations
CORS	Continuously Operating Reference Stations
CPDLC	Controller Pilot Data Link Communications
dB	decibel
DHS	Department of Homeland Security
DOC	Department of Commerce
DoD	Department of Defense
DOT	Department of Transportation
EIRP	Effective Isotropic Radiated Power
EO	Executive Order
ESA	European Space Agency
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FCC	Federal Communications Commission
FDD	Frequency Division Duplexing
FFRDC	Federally Funded Research and Development Center
Galileo	European Union's GNSS
GDGPS	Global Differential GPS
GEO	Geosynchronous Orbit
GGN	NASA Global GNSS Network
GLONASS	Russia's GNSS
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HAS	Galileo High Accuracy Service
HEO	High Earth Orbit
Hz	Hertz
ICG	International Committee on GNSS
IGS	International GNSS Service
INMARSAT	International Marine/Maritime Satellite
IPC	Interference Protection Criterion
ION	Institute of Navigation
IRAC	Interdepartment Radio Advisory Committee
JPL	Jet Propulsion Laboratory
L1C	GPS 4th Civil Signal
LEO	Low Earth Orbit
LRA	Laser Retro-reflector Array
m	meter
MCEU	Military Code Early Use
MEO	Medium Earth Orbit
MGUE	Military GPS User Equipment
MSI	Miniature Serial Interface
MSS	Mobile Satellite Services
NASA	National Aeronautics and Space Administration
NDAA	National Defense Authorization Act
NDS	Nuclear Detonation Detection System
NIST	National Institute of Standards and Technology
NPEF	National PNT Engineering Forum
NSPD	National Security Presidential Directive
NTIA	National Telecommunications and Information Administration

OCS	GPS Operational Control Segment
OCX	GPS Modernized Operational Control Segment
OSTP	Office of Science and Technology Policy
PNT	Positioning, Navigation, and timing
PNTAB	PNT Advisory Board
PPP	Precise Point Positioning
PTA	Protect, Toughen, Augment
PVT	Position, Velocity, and Time
R&D	Research and Development
RFI	Request for Information
RMP	Regional Military Protection
RTK	Real-Time Kinematic
SAR	Search and Rescue
SDR	Software Defined Radio
SSV	GPS Space Service Volume
SV	GPS Satellite Vehicle
TOR	Terms of Reference
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
USAD	U.S. Air Force
USCG	U.S. Coast Guard
VHF	Very High Frequency
W	Watt
WG	Working Group

Appendix D: Statement by Capt. Chesley "Sully" Sullenberger

Capt. Chesley "Sully" Sullenberger
July 1, 2020

Members of the Space Based Positioning, Navigation, and Timing Advisory Board:

The FCC's decision to approve Ligado Networks' use of a portion of the L-band spectrum is ill-advised, and constitutes a dereliction of duty on the FCC's part. Frequency spectrum is a precious national asset and we are all obligated to protect it. Not only does this decision benefit just the shareholders of one company, but it is a dangerous decision that must be reversed.

This land grab of public frequency spectrum and gifting it to a private company will harm not only aviation and everyone who relies on it, but anyone who depends on ATM or other financial transactions, emergency responders, modern farming, the emerging benefits of autonomous vehicles, and even the production of precision mapping and survey products. Testing and studies performed by DOD and DOT supported by nine federal agencies concluded Ligado's solution will cause interference both for civilian and military users. The decision impacts warfighter testing, training, exercises and homeland defense missions – putting national security at risk.

Putting the narrow commercial interests of one company ahead of our national security and the needs of our country is wrongheaded and dangerous.

Simply put, the FCC authorized Ligado terrestrial signal is much stronger than the GPS signal, and will overwhelm the ability to "hear" the GPS signal.

Existing satellite communications users will have to replace equipment to accommodate the relocation of the satellite signals and provide additional interference filtering for the new terrestrial signals. This includes The Aircraft Communications Addressing and Reporting System (ACARS) which uses INMARSAT – ACARS will need to be upgraded or replaced as a result. This is a principal concern by the aviation industry and users. Another SATCOM concern is the interference from the Ligado cell phones with the aircraft Iridium satellite communications at frequencies above GPS.

- Contrary to Ligado's position, 1536-1559 MHz is not a "Guard Band." Rather, it is allocated and used for satellite voice and data communication as Mobile Satellite Services (MSS). MSS data communications are used to improve the performance of some high accuracy GPS receivers. The Ligado signal resides inside the larger MSS band that used to be a quiet zone. The band where FCC has authorized Ligado to transmit at 10 watts previously was limited to extremely low power satellites signals only.
- MSS frequencies are also used for Aircraft Communications Addressing and Reporting System (ACARS), Aviation Controller Pilot Data Link Communications (CPDLC), Automatic Dependent Surveillance — Contract (ADS-C) position reporting, Pilot to Dispatch Communications and real-time engine health monitoring. Aircraft International Marine/Maritime Satellite (INMARSAT) equipment that operates in the MSS band where the Ligado terrestrial transmitters will operate will need to be upgraded or replaced at the Airlines' expense. Iridium and their aviation user communities have identified that Ligado cell phone transmissions overload Iridium cell phones since the cell phone power is so much greater than the Iridium satellite signals that the Iridium transceivers are attempting to receive in their authorized spectrum that is separated by only 1 MHz from the Ligado cell phones. Reportedly, there is no currently identified resolution to the Ligado interference with Iridium cell phones since the frequencies are so close together.
- GPS receivers are very sensitive and require a very "quiet" neighborhood to function. Ligado's operations will act like a loud neighbor and overload the sensitive GPS satellite signal receivers. In fact, Ligado's proposed use will include adjacent band powers that are two Billion times

greater than the power of the GPS signals that the receivers are "listening" for. This will overwhelm the GPS receivers and make them unable to "hear" the sensitive GPS signals that they need to receive and process.

- Ligado's claims that receivers "can easily be made to coexist" are incorrect. Coexistence would require antenna replacements and extensive redesign and replacement of the receivers. Such replacements are often larger, heavier and have reduced performance that may be inadequate for many high precision applications needs. Many GPS receivers are deeply integrated into the application systems and would require system-level hardware/software redesign and recertification at high cost. Retrofits would take systems offline with corresponding operational as well as cost impacts.
- For sound reasons, Ligado's terrestrial operations have never been tried before in the proposed band. No Mobile Satellite Service (MSS) ancillary terrestrial components (ATC) service has ever been deployed within this MSS band despite the FCC authorization for MSS ATC services. The FCC made it clear in 2003, when it adopted the original MSS ATC rules, that a stand-alone terrestrial service was not intended for the MSS band. In that 2003 MSS ATC Order, FCC stated: "We do not intend, nor will we permit, the terrestrial component to become a stand-alone service." The FCC's rules (47 CFR 25) include provision 25.255 that "if harmful interference is caused to other services by ancillary MSS ATC operations, either from ATC base stations or mobile terminals, the MSS ATC operator must resolve any such interference." The existence of 25.255 demonstrates that FCC is aware of the consequences of interference in this band.
- The contention that Ligado Networks enables 5G is misleading. None of Ligado's bands are included in the 3GPP's consortium's 5G standards and the 10 MHz bandwidth is not consistent with most 5G providers and user needs for high bandwidth applications such as YouTube, FaceTime, Zoom, etc. There is currently not a deficit of frequency division duplexing (FDD) cellular handset spectrum in the L-band or below. FDD handset bands in L-band or below are currently underutilized.
- Contrary to Ligado's assertion, the FCC Order and Authorization does not provide "total protection" to all GPS devices and users at the 1dB level. The DOT maintains that the FCC would need to reduce its authorization of Ligado operations from the currently-approved 10 watts to approximately one milliwatt (a factor of 10,000) to protect all existing GPS receivers.
- Contrary to Ligado's assertion, the FAA did not conclude that 10 watts was sufficient to protect all aviation use of GPS. 10 watts protects only certain GPS receivers—those that are certified, Instrument Flight Rule (IFR) capable and outside a 250' horizontal assessment zone. Ligado emissions can impact certified aviation GPS receivers when aircraft are within 250' (e.g., aircraft at terminals and helicopter or drone/UAV operations at lower altitudes). Significantly, 10 watts does **not** protect aviation VFR rated receivers used by drones/UAVs, many VFR aircraft, GPS handheld/electronic flight bag and some helicopter safety systems (H-TAWS/EGPWS). The 10 watt Ligado emission can impact VFR (non-certified) GPS receivers at distances up to one kilometer. High precision drones/UAVs used for mapping, survey, construction, and agriculture can be impacted at distances up to 3 kilometers. In light of all of these caveats, the FAA did not conclude that the 10 watts protects all aviation use of GPS.
- Contrary to Ligado's assertion, the DOT testing did not solely rely on the 1dB degradation level metric to make determinations about harmful GPS interference. In fact, DOT's testing identified many receivers that completely failed at the FCC authorized 10 watt power level. During this testing, the GPS receivers lost lock on all visible satellites, rendering complete loss of GPS function, not just "harmful interference." Thus, these receivers were rendered completely nonfunctional at the 10 watt power level approved by the FCC for Ligado operations and even lower power levels in many instances. A direct correlation was also identified between the 1dB

metric and important performance metrics such as the length of time needed for a GPS receiver to begin providing a position output. Even within Ligado Networks' sponsored NASCTN and Roberson & Associates testing, there is evidence that harmful interference will occur if the Ligado network is deployed: their studies also demonstrate loss-of-lock by some receivers during testing.

Of special note is a possible conflict of interest – a filing by Mr. Dennis Roberson, who serves on the TAC FCC Federal Advisory Committee. His firm – Roberson & Associates, a technology and management consulting company - was hired by Ligado's counsel – Covington and Burling LLP – to perform constrained testing of a very limited set of GPS receivers under less than representative test conditions.

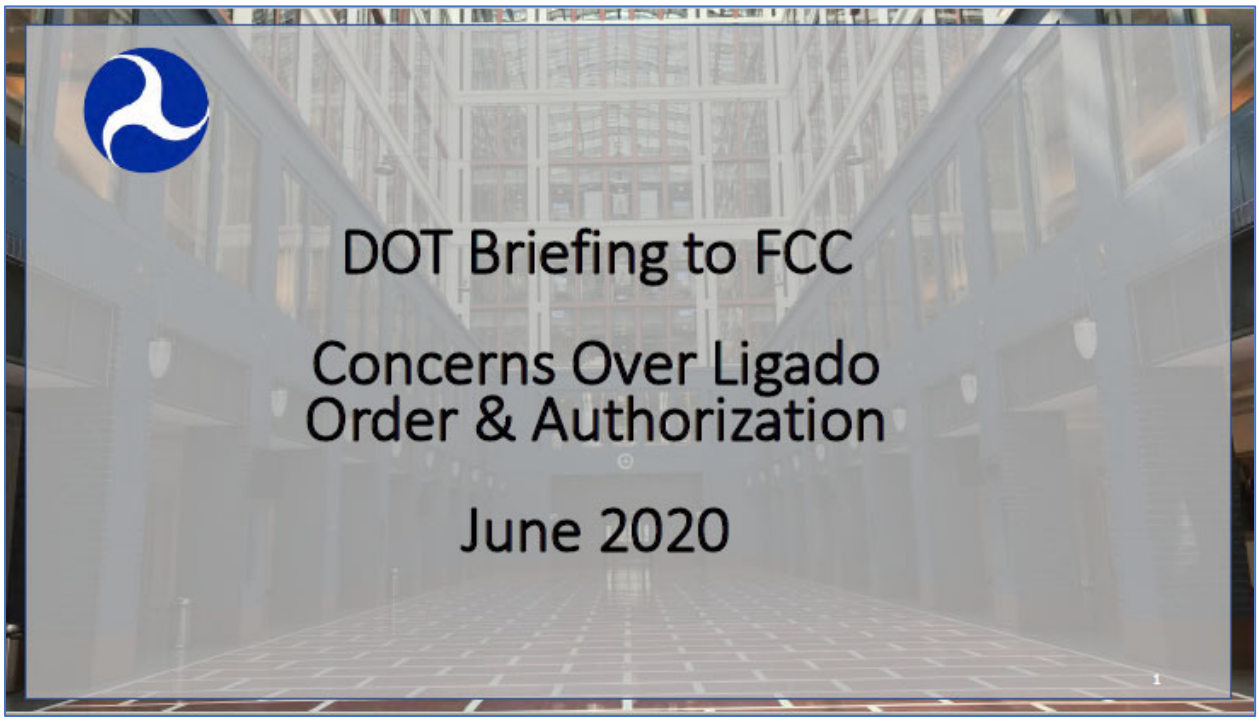
Also of note is that Julius Knapp, Chief of the Federal Communications Commission's Office of Engineering, was well aware of the GPS receiver overload by adjacent band terrestrial use in 2012. Yet, the FCC Chairman holds firm that the Ligado decision was based upon sound FCC engineering (led by Mr. Knapp). Please refer to Mr. Knapp's statement (included) before the House Oversight and Investigations Subcommittee of the Energy and Commerce Committee from September 2012.

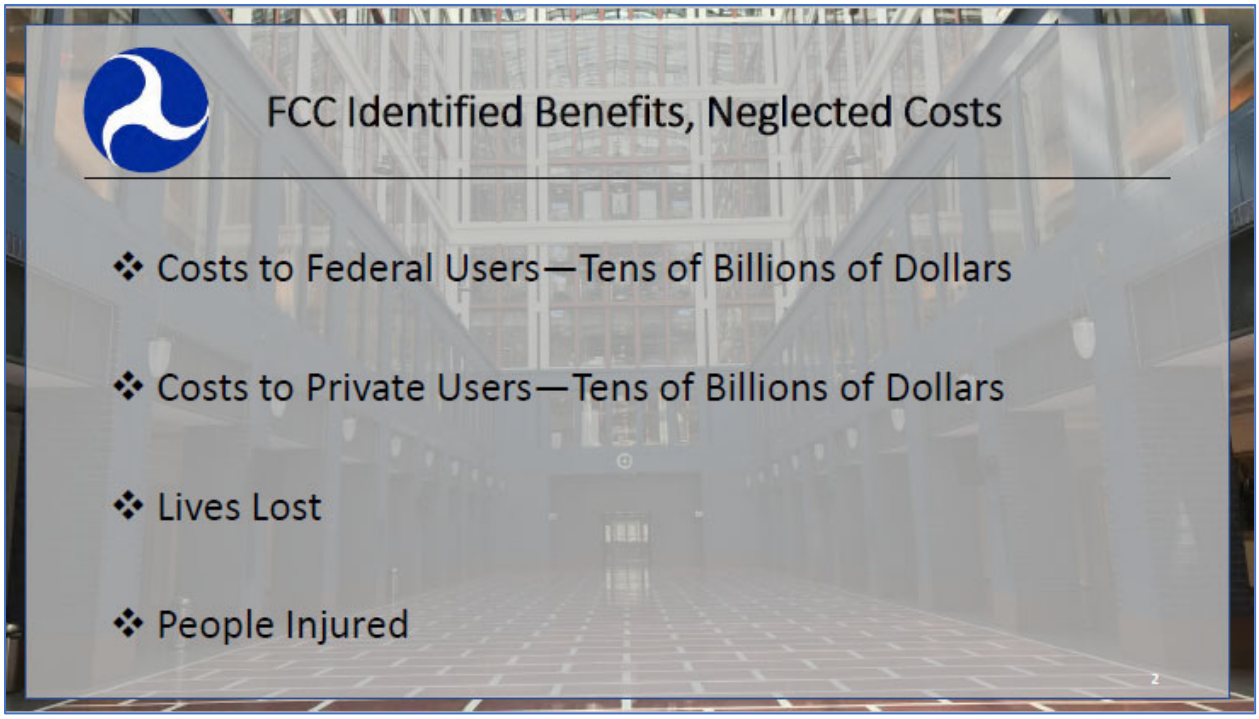
Wishful thinking and hoping that things will work out is not an effective strategy and cannot repeal the laws of physics. I urge you to reverse the FCC's decision approving Ligado's proposal.

Additional Materials:

1. Addendum1.Slides.SullenbergerStatement.1Jul2020
2. Addendum2.Knapp2012Testimony.SullenbergerStatement.1Jul2020

Addendum 1


DOT Briefing to FCC
Concerns Over Ligado Order & Authorization
June 2020
1

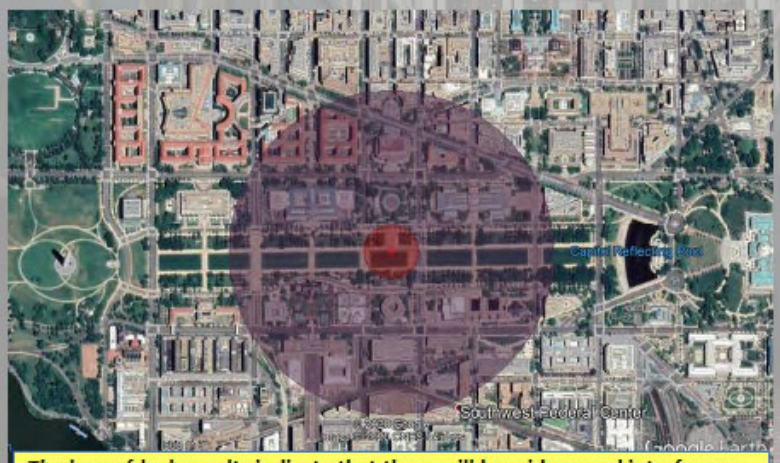

FCC Identified Benefits, Neglected Costs
❖ Costs to Federal Users—Tens of Billions of Dollars
❖ Costs to Private Users—Tens of Billions of Dollars
❖ Lives Lost
❖ People Injured
2

Emergency Response Scenario

Interference or degradation includes increased GPS and Global Navigation Satellite System (GNSS) satellite acquisition times, reduced position accuracy, false position information, or loss of signal lock resulting in no position solution.

3

Effect of One Ligado Base Station on GPS (Loss of Lock) Based on DOT ABC Testing



- FCC O&A Statement that DOT only looked at 1 dB Criteria is not accurate
- 9.8 dBW base station placed on National Mall

High precision GPS receivers (used, e.g., for surveying, construction)

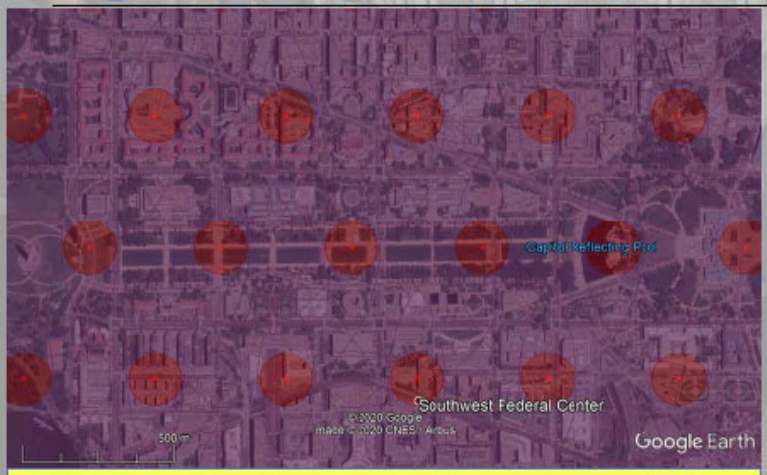
Timing GPS receivers (used, e.g., by cell towers, Communications/ IT, finance, energy, Federal mission systems)

General-purpose GPS receivers (used, e.g., by personal navigation, emergency response, UAVs)

The loss-of-lock results indicate that there will be widespread interference issues under any definition of harmful interference.

4

Effect of Many Ligado Base Stations on GPS (Loss of Lock) Based on DOT ABC Testing



The loss-of-lock results indicate that there will be widespread interference issues under any definition of harmful interference.

- FCC O&A Statement that DOT only looked at 1 dB Criteria is not accurate
- 9.8 dBW base stations separated by 433 m in hexagonal grid on National Mall

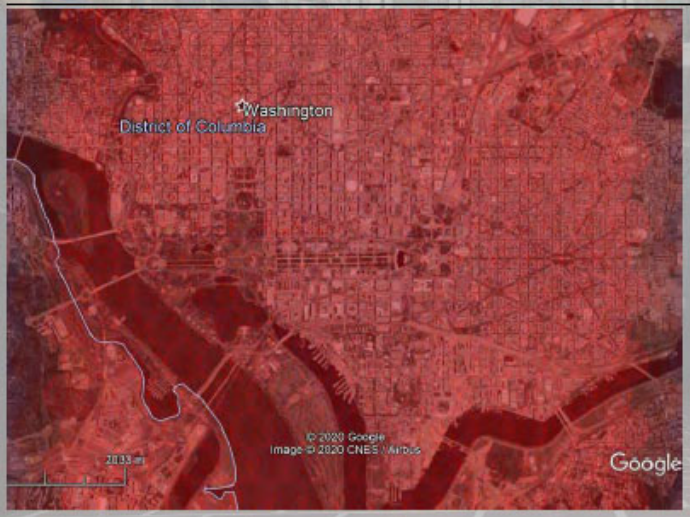
High precision GPS receivers (used, e.g., for surveying, construction)

Timing GPS receivers (used, e.g., by cell towers, Communications/ IT, finance, energy, Federal mission systems)

General-purpose GPS receivers (used, e.g., by personal navigation, emergency response, UAVs)

5

Effect On GPS of Many Ligado Base Stations (1 dB)



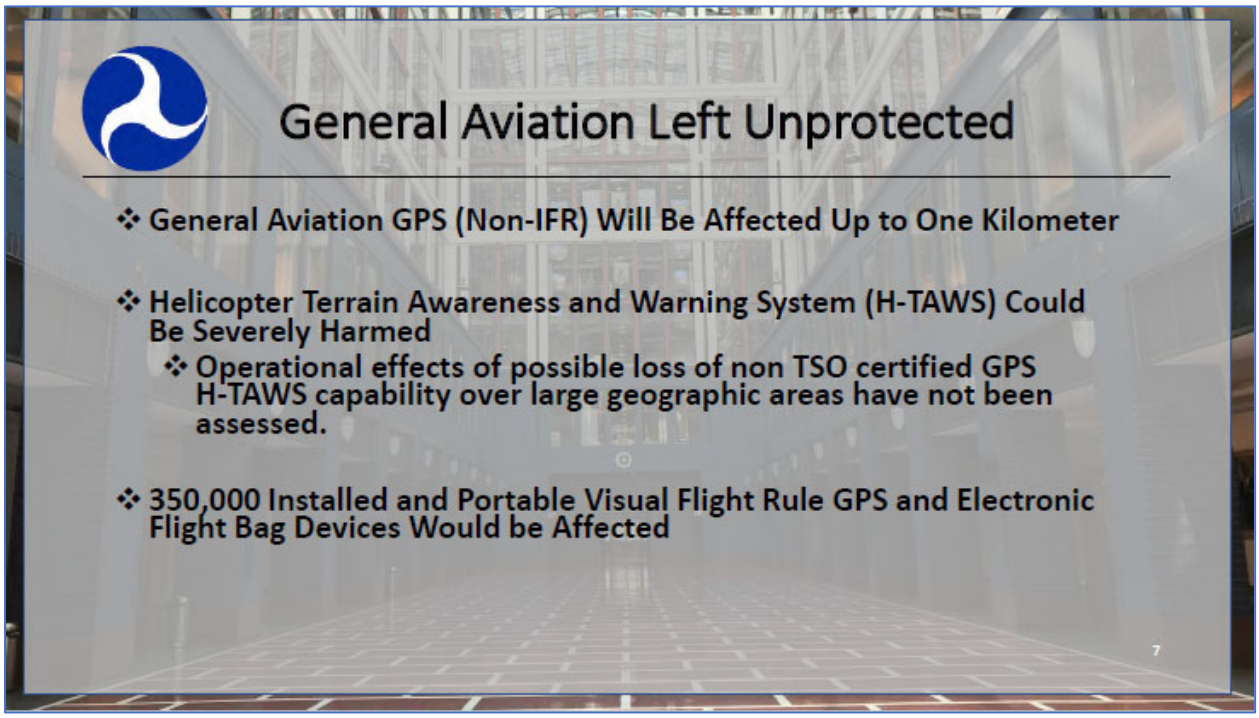
- 9.8 dBW base stations separated by 433 m in hexagonal grid
  - Blanketed Impact for All Receiver Categories

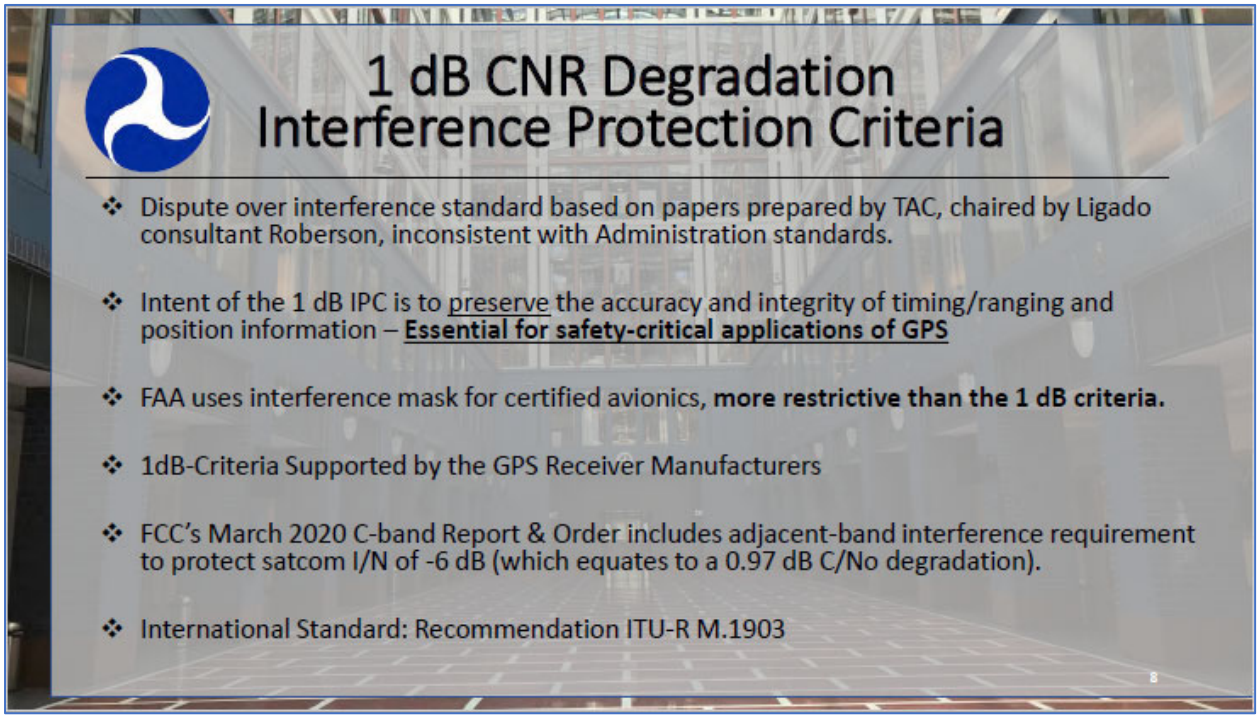
High precision GPS receivers degraded (used, e.g., for surveying, construction)

General-purpose GPS receivers degraded (used, e.g., by personal navigation, emergency response, UAVs)

Timing GPS receivers degraded (used, e.g., by cell towers, Communications/ IT, finance, energy, Federal mission systems)

6


General Aviation Left Unprotected
General Aviation GPS (Non-IFR) Will Be Affected Up to One Kilometer
Helicopter Terrain Awareness and Warning System (H-TAWS) Could Be Severely Harmed
Operational effects of possible loss of non TSO certified GPS H-TAWS capability over large geographic areas have not been assessed.
350,000 Installed and Portable Visual Flight Rule GPS and Electronic Flight Bag Devices Would be Affected
7


1 dB CNR Degradation
Interference Protection Criteria
Dispute over interference standard based on papers prepared by TAC, chaired by Ligado consultant Roberson, inconsistent with Administration standards.
Intent of the 1 dB IPC is to preserve the accuracy and integrity of timing/ranging and position information – Essential for safety-critical applications of GPS
FAA uses interference mask for certified avionics, more restrictive than the 1 dB criteria.
1dB-Criteria Supported by the GPS Receiver Manufacturers
FCC's March 2020 C-band Report & Order includes adjacent-band interference requirement to protect satcom I/N of -6 dB (which equates to a 0.97 dB C/No degradation).
International Standard: Recommendation ITU-R M.1903
8

Maximum Tolerable Power Level for GPS/GNSS Receivers at 1530 MHz

Deployment	Stand off distance (m)	Max Tolerable EIRP (dBW)			
		GLN	HPR	TIM	CEL
Macro Urban	10	-31.0	-41.9	-20.6	10.9
	100	-11.0	-21.9	-0.6	31
Micro Urban	10	-29.8	-41.2	-20.1	10.7
	100	-9.8	-21.1	-0.1	30.8

Deployment	Stand off distance (m)	Max Tolerable EIRP			
		GLN	HPR	TIM	CEL
Macro Urban	10	0.8 mW	64 μW	8.7 mW	12.3 W
	100	79.4 mW	6.5 mW	0.9 W	1.26 kW
Micro Urban	10	1 mW	76 μW	9.8 mW	11.7 W
	100	104 mW	7.8 mW	1 W	1.2 kW

At proposed Ligado spacing, power must be reduced from 10 Watts to about one milliwatt (factor of 10,000) to protect all existing receivers

9

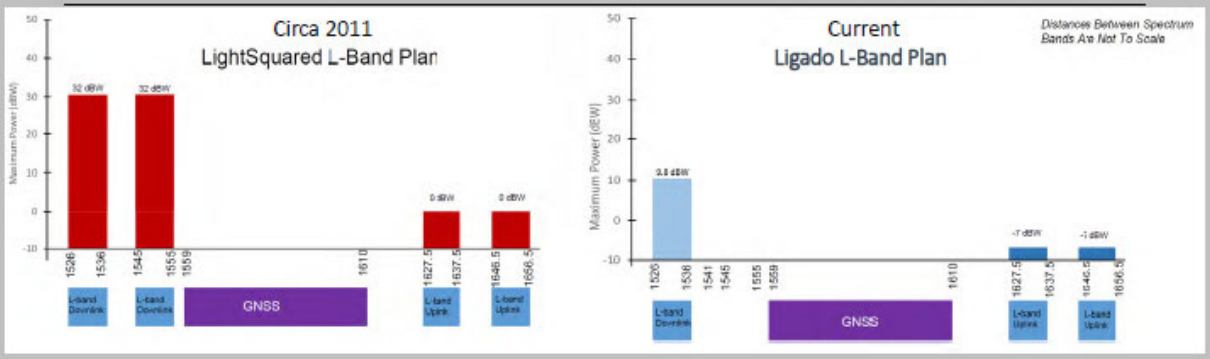
Summary of DOT Concerns

- The DOT GPS Adjacent Band Compatibility (ABC) test results clearly demonstrate there will be widespread disruption to GPS receivers.
- DOT serves as the Civil Lead for GPS and is concerned about the millions of receivers that will experience interference
  - The majority of civil GPS receivers are not U.S. Government devices and will not qualify for repair or replacement paid for by Ligado.
- FCC should thoroughly assess and account for the economic costs and burdens that will result.
  - Many GPS/GNSS receivers are hermetically sealed so it is not possible to retrofit them with new antennas.
  - Furthermore, many receivers are integrated into end-user applications making adversely affected GPS users unable to retrofit or replace their GPS receivers.

10

Additional Information for the PNT Advisory Board's Consideration

Proposals for Use of Spectrum Adjacent Band to GPS L1



- At 9.8 dBW (~10 watts) at 100 meters from the transmitter, Ligado signals are **2 Billion times greater power** than GPS
- GPS is a faint signal – 20 watts of power from 20 million meters away

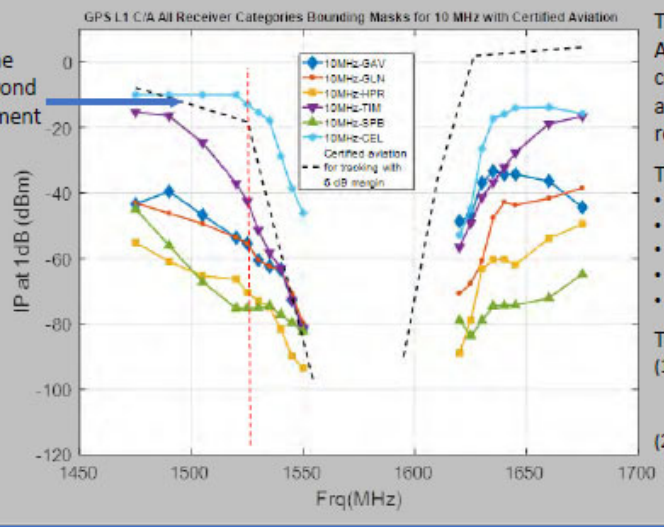
DOT ABC Testing Did Not Consider JUST the Most Sensitive Receivers

- The statement that DOT only considered "worst-case" device results at each frequency were publicly reported" is incorrect. At each frequency, the DOT Report included:
  - (1) Most sensitive receiver
  - (2) 10% receiver results
  - (3) Median receiver results
  - (4) 90% receiver results
  - (5) Most robust receiver
- All of this data was included in Appendix B of the DOT ABC report
- The "most sensitive" DOT ABC test results were used to develop a summary "bounding mask" for each category of receiver equipment to ensure protection of the most sensitive receivers in each category from adjacent band power

2

Summary of 10 MHz Bounding Masks GPS L1 C/A

All points/receivers below the dashed line will be impacted beyond the aviation "assessment cylinder"



The statement in the FCC Order & Authorization that DOT only considered "worst-case" device results at each frequency were publicly reported" is <u>not accurate</u>.

The DOT Report includes:

- Most sensitive receiver
- 10% receiver results
- Median receiver results
- 90% receiver results
- Most robust receiver

The DOT Report also provides:

(1) Loss-of-lock results (low elevation satellites and complete loss of lock on all satellites)

(2) Analysis of time-to-acquire the GPS signal

1

Ligado's Settlement Agreements With GPS Receiver Manufacturers Does Not Mean There Will Be No Interference

- Ligado's Settlement Agreements with the GPS Receiver Manufacturers have been misrepresented – they were business deals to have the Ligado lawsuits against the manufacturers dropped
- DOT met with engineers from all of the companies who signed settlement agreements and were told that their products would still be interfered with
- A number of the same receiver manufacturers participated in the DOT Adjacent Band testing and agree with the results from that testing
- The receiver manufacturers who signed agreements with Ligado all stand behind use of the 1-dB CNR degradation interference protection criteria and have filed on the FCC docket stating so

DOT Certified Aviation Analysis Caveat

- The DOT Adjacent Band Assessment Report notes: "there were unresolved concerns expressed by several, though not all, operators about the assessment zone and its impacts to aviation operations and safety."
  - See 2016 RTCA Tactical Operations Committee report that was attached to RTCA's June 2020 *ex parte* submission
- DOT Report also states: "The FAA has not completed an exhaustive evaluation of the operational scenarios in developing this assessment zone. Further, the current analyses do not include an operational assessment of the impact of the assessment zone in densely populated areas. For example, the risk posed to people and property for operations such as unmanned aircraft systems (UAS) using certified avionics may be significant as such aircraft may be required to operate within the assessment zone."

Note: Cylinders repeat every 433 meters, adding to overall airspace complexity.

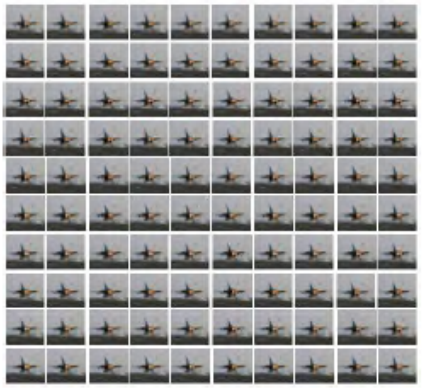
GPS Signal vs. Ligado Noise

Signal: Leaves Rustling. (0-10 dB)

Noise: Jet Takeoff (140-150 dB)

0 dB = barely audible sound
Every 10 dB increase =factor of 10 power increase; i.e., 20 dB = 10X the power of 10 dB, 30 dB = 100X the power of 10 dB, etc.

With GPS, We are Trying to Hear Rustling Leaves…



Through the Noise of 100 Jets

GPS Receiver

Addendum 2:

Joint Written Statement of
Julius P. Knapp
Chief, Office of Engineering and Technology
Mindel De La Torre
Chief, International Bureau
Federal Communications Commission
Before the House Oversight and Investigations Subcommittee
Energy and Commerce Committee
U.S. House of Representatives

"The LightSquared Network: An Investigation of the FCC's Role"

September 21, 2012

Good morning Chairman Stearns, Ranking Member DeGette, and Members of the Oversight and Investigations Subcommittee.

My name is Julius Knapp, and I am Chief of the Federal Communications Commission's Office of Engineering and Technology (OET), where I have served as an engineer for 38 years. OET is the Commission's primary resource for engineering expertise and provides technical support to the Chairman, Commissioners, and the FCC's Bureaus and Offices.

I appreciate this opportunity to join my colleague, Mindel De La Torre, Chief of the FCC's International Bureau, in appearing before you today. My portion of the testimony will focus on the FCC's role in evaluating and attempting to resolve spectrum interference issues in connection with Mobile Satellite Service (MSS) in the L-band. Ms.

1

De La Torre will address the process and historical context related to granting Ancillary Terrestrial Component (ATC) authority to MSS providers.

At the Commission, we are focused on ensuring that businesses and consumers are able to take full advantage of the economic opportunities presented by underutilized spectrum, but only when consistent with public health and safety. In this decade-long proceeding to remove regulatory barriers and align the service rules for the L-band with the rapid evolution of mobile communications technologies and markets, the Commission considered a unique proposal that had the prospect of attracting new private investment, increasing competition, bringing additional broadband service to rural and hard-to-reach regions, and creating thousands of jobs. This proposal was the direct result of proceedings designed to ensure that MSS spectrum would be utilized to its maximum potential.

As with any proceeding before the Commission that has a potential for spectrum interference with nearby spectrum users, the FCC relies on licensees and stakeholders to raise interference concerns to ensure the timely resolution of such complaints. During the decade preceding the November 2010 waiver request, the GPS industry had numerous opportunities – detailed below – to inform the Commission of the receiver overload interference issue ultimately raised in 2010.

Despite participating in multiple proceedings, and raising *other* interference issues that were ultimately resolved to the GPS industry's satisfaction, it did not do so. The FCC would have investigated any complaints as soon as they were raised and attempted to mitigate at that stage. Nevertheless, when GPS receiver manufacturers and service providers ultimately informed the Commission of the potential for legacy device overload

interference in the L-band, the Commission halted the licensee's proposed commercial service. To be clear, in November 2010, the GPS industry was not complaining about out of band emissions or interference caused by handsets, or the power levels authorized for the L-band – they were instead notifying us of their own receivers potentially picking up signals from the neighboring band.

In responding to those GPS concerns, the Commission acted responsibly to protect national security and public safety while simultaneously attempting to find a solution to the GPS overload interference issue. We worked equally with all interested entities, including the NTIA, DOD, other federal agencies, and the United States GPS Industry Council (USGIC) to assess LightSquared's proposal and to encourage the parties to work together to resolve this matter. The process was fact-based, transparent, and in accordance with the Commission's established policies and procedures. I stand behind the work of our engineers and other technical experts.

Spectrum Management Responsibilities and GPS Issues

Spectrum is of vital importance to our economy. It is, however, a finite and increasingly scarce resource. Accordingly, the Commission has focused its efforts on ensuring that this resource is used to the greatest degree possible to spur competition, increase investment and innovation, and create jobs. At the same time, we are dedicated to the protection of homeland security and national defense, and we recognize the needs of existing licensees to utilize spectrum for a broad range of commercial and noncommercial purposes.

The FCC and the NTIA share responsibility for managing the radio spectrum. The FCC is responsible for use of the spectrum by the commercial sector and state and local governments. The NTIA is responsible for federal government use. These shared responsibilities require that the FCC and the NTIA coordinate on such matters as the prevention and resolution of harmful interference issues. Under a 70-year old Memorandum of Understanding with the Department of Commerce, the FCC and the NTIA coordinate activities on spectrum matters of mutual interest.

The need to ensure proper coordination of spectrum resources is well known to this Committee. Last week, for instance, the Communications and Technology Subcommittee held a hearing on "Creating Opportunities through Improved Government Spectrum Efficiency." As the Subcommittee's hearing memorandum noted, "[u]sing spectrum more efficiently and with modernized equipment could help Federal agencies better fulfill their objectives while freeing spectrum for broadband services." Those goals – particularly increasing spectrum efficiency and freeing spectrum for broadband services while enabling Federal agencies to fulfill their objectives – have driven the Commission's efforts to reduce regulatory barriers for use of the L-band spectrum.

The GPS-MSS conflict involves unfiltered or poorly filtered GPS legacy devices bleeding into the spectrum of neighboring users, with the result being receiver overload. Thus, the interference at issue today does *not* result from MSS/ATC L-band users emitting signals into the GPS spectrum. Rather, it results from legacy GPS devices listening into the band next door to them. In effect, we discovered that some GPS legacy equipment effectively treats the GPS spectrum and the L-band spectrum as one band.

When faced with conflicting uses and interference complaints such as these, the Commission's engineers and technical experts have always initiated fact-based, transparent reviews of interference complaints. The Commission's goal in proceedings such as these is to foster cooperative, engineering solutions to what sometimes seem to be impossible problems. This process is dependent upon the active participation of all stakeholders and the timely reporting of essential technical information to the Commission.

In particular, the Commission relies on receiver manufacturers and service providers to report interference issues because they are best positioned to understand the parameters and limitations of their own equipment. The Commission does not possess the technical specifications for the hundreds of types of GPS devices utilized by commercial users, government contractors, and government entities. Moreover, since the FCC does not regulate GPS devices, we are not prepared to test such devices or determine their capabilities and interference issues.

Manufacturers and service providers have the relevant information, and they also have the incentive to notify the Commission of the potential for receiver overload so as to avoid problems with their services and products. The Commission routinely hears from parties that are concerned that new services will cause interference. In this instance – unlike any other that I can recall in my decades at the FCC – the GPS industry did not do so until very late in the proceeding. Once the Commission received that information, it acted quickly to prevent any public safety problems. The lack of technical data provided in response to earlier Commission proceedings prevented us from addressing that issue

until well after permission had been granted in 2003 for MSS providers to use the L-band for terrestrial service.

A Decade of Promoting Greater Use of MSS Spectrum[*]

A more detailed summary of the Commission's ten-year history of MSS proceedings demonstrates that the Commission consistently, across the tenures of three FCC Chairmen, worked to enable terrestrial use of MSS spectrum. This history further shows that the Commission acted in accordance with established procedures and allowed multiple opportunities for public participation. Also, the Commission staff exercised delegated authority only where consistent with Commission rules and provided at least 48 hours advance notice to individual Commissioners to inquire about these decisions.

The proceedings relevant to this hearing began in 2001, when LightSquared's predecessor-in-interest, Mobile Satellite Ventures (MSV), along with another company, ICO Global, petitioned the Commission to allow for the addition of an ancillary terrestrial component (ATC) to integrate terrestrial services with their mobile satellite services. These parties argued that the public would benefit from this terrestrial component because it would enhance coverage in locations where reliable satellite service was challenging, particularly urban areas.

Later in 2001, the Commission issued a Notice of Proposed Rulemaking seeking comment on MSV's petition and the appropriate technical rules for protecting GPS operations. The Notice specifically invited comment on the requirements necessary to protect GPS against harmful interference. In July 2002, MSV and the USGIC submitted

[*] Attached as "Appendix A" to this testimony is a timeline providing the complete procedural history of the MSS/ATC and LightSquared's proposal.

for the record of that proceeding, a joint agreement on emission limits into the GPS spectrum and stated that this agreement would adequately protect GPS receivers.

In 2003, the Commission approved rules to permit MSS licensees to operate up to 1,725 ATC base stations to provide mobile service to areas where satellite signals are degraded or blocked (specifically urban areas and inside of buildings). The USGIC filed a petition for reconsideration of the out-of-band emission rules, noting that the rules failed to adopt the emission limits specified in the 2002 agreement. USGIC noted that the limits were necessary to protect against the potential deployment of tens of thousands of cell towers and millions of mobile devices. Again, however, the receiver overload issue was *not* raised in opposition comments or in petitions for reconsideration or applications for review.

In 2003, SkyTerra (formerly MSV, now LightSquared) requested authority (*i.e.*, a license) to offer an MSS/ATC service. The International Bureau sought public input on this request. It again received no comments raising receiver overload interference.

In 2004, the International Bureau, on delegated authority, applied the Commission's 2003 Order on ATC authorizations to permit SkyTerra to offer an integrated MSS/ATC service to users equipped with dual-mode handsets. SkyTerra was authorized to deploy a terrestrial network using the 1,725 base stations permitted under the Commission's then-existing rules. Once again, no parties raised the overload interference issue in response to the grant of this authorization, and no parties filed a petition for reconsideration of the authorization.

In 2005, in response to petitions for reconsideration of its 2003 Order, including the one filed by USGIC, the Commission revised its MSS/ATC rules. The new rules

removed the limitation on the number of terrestrial base stations (1,725) so long as operations met certain technical parameters. The Commission also noted that MSV agreed to comply with the tighter limits on out-of-band emissions in a manner consistent with the recommendations of the USGIC and the Executive Branch (including the Department of Defense). The Commission also affirmed its commitment in the Order to coordinate any ATC authority with NTIA to assure adequate protection of the GPS. The Commission received no reports or complaints of potential overload interference following the release of this order – which had explicitly lifted the base station limit.

Between 2006 and 2008, the International Bureau granted modifications to SkyTerra MSS operations, but none of the modifications implicated its authority to deploy an unlimited number of terrestrial base stations under its ATC authority.

In 2009, Harbinger and SkyTerra filed an application for transfer of control of SkyTerra to Harbinger. SkyTerra also filed an application for modification of its MSS/ATC authorization including a request for waiver of several technical rules. The International Bureau placed both filings out for public comment. The GPS community, including USGIC, filed comments raising concerns that the existing out-of-band emission limits would be insufficient to protect indoor reception of GPS from mobile devices due to emissions from mobile devices communicating with the base stations. Once again, no party raised the separate receiver overload interference issue.

Later in 2009, SkyTerra and the USGIC submitted a joint letter to the Commission stating that the out-of-band emissions interference issue had been resolved. The joint letter did not raise the different receiver overload interference issue.

In 2010, the Commission released its National Broadband Plan. The Plan, in Recommendation 5.8.4, identified the 40 MHz of L-band spectrum (then licensed to SkyTerra) in its call for the FCC to accelerate terrestrial deployment in the MSS spectrum bands. No entity raised the receiver overload interference issue in response to this recommendation.

In March 2010, the three Commission Bureaus (the Office of Engineering and Technology, the International Bureau, and the Wireless Telecommunications Bureau) jointly issued two orders. The first of those orders granted Harbinger's request to acquire SkyTerra. That Order detailed Harbinger's plans to construct a hybrid-satellite-terrestrial network and noted Harbinger's intention to cover 90 percent of the U.S. population via the terrestrial component of its network. That Order imposed conditions on Harbinger that required it to build out this network but did not alter or waive any MSS/ATC rules. In the second Order, the International Bureau granted Harbinger's request for a modification of its MSS/ATC authorization. Again, no parties or entities raised the receiver overload interference issue in response to either of these Orders.

In July 2010, the Commission initiated a rulemaking to provide greater flexibility to deploy terrestrial service in the MSS bands, including the L-band. In September 2010, *for the first time*, the USGIC filed comments raising the possibility of receiver overload interference to GPS receivers at a distance of about 100 meters from ATC base stations. This interference would be greater for devices that did not use state-of-the-art filtering such as certain mobile consumer GPS devices. In its comments, the USGIC noted that it had worked collaboratively with the MSS/ATC operators in the past and had reached mutually acceptable agreements to avoid interference into the GPS band. USGIC also

expressed a belief that solutions would be available to mitigate the receiver overload interference issue.

In November 2010, LightSquared filed a request to modify its MSS/ATC authority further to allow sales of mobile devices that had terrestrial-only capabilities as part of an integrated MSS/ATC service. The International Bureau placed this request on public notice, and ultimately extended the comment period in response to a request for additional time. Several GPS industry participants and users objected to LightSquared's planned MSS/ATC deployment based upon the receiver overload interference issue.

On January 26, 2011, the International Bureau responded to the concerns raised by the GPS industry and other parties by preventing LightSquared from deploying commercial service in the L-band until it resolved concerns about harmful interference. The Bureau did so through a conditional waiver order that also directed LightSquared to organize and participate in a GPS interference technical working group in which all interested parties would work directly with LightSquared to resolve the interference concerns. The Technical Working Group included more than 120 participants, including representatives from the Department of Defense and other federal agencies, as well as the GPS community, various telecommunications companies, and LightSquared.

On June 30, 2011, LightSquared filed the final report of the Technical Working Group with the Commission. Based on the results of the working group's testing, LightSquared recognized that its proposed use of part of its spectrum (the "upper 10 MHz band") would result in GPS receiver overload. LightSquared offered an alternative proposal to operate only in another part of its spectrum ("the lower 10 MHz band") and to

coordinate and share the cost of underwriting a workable solution for GPS legacy precision measurement devices at risk of overload.

The FCC released the Technical Working Group's report and the alternative proposal for public comment in June 2011. After reviewing more than 3,000 comments concerning the report, in September 2011, the International Bureau and the Office of Engineering and Technology, in coordination with NTIA, released a Public Notice calling for additional testing to assess the potential for interference to GPS under the revised technical proposals.

On February 14, 2012, after that further testing, the Commission received a letter from NTIA stating that the results of the testing indicated no current, practical way to mitigate the GPS receiver overload interference issue for legacy equipment. The next day, the Commission's International Bureau issued a Public Notice seeking public comment on whether it should (1) vacate the Conditional Waiver Order, and (2) suspend indefinitely LightSquared's ATC authority to an extent consistent with the NTIA letter. The Commission staff is currently reviewing the extensive record developed in response to that Public Notice. At the current time, LightSquared cannot deploy its service commercially because of the unresolved receiver overload interference issue.

Conclusion

As we stated at the outset, at the Commission we are focused on ensuring that businesses and consumers are able to take full advantage of the economic opportunities presented by underutilized spectrum, but only when consistent with public health and safety. We are also cognizant of the underlying issue in this case concerning legacy GPS receivers and receiver standards. Accordingly, the Commission moved ahead this earlier this year to

conduct a receiver performance workshop and we expect forthcoming information. The FCC's Technological Advisory Council (TAC) is reviewing this issue and we expect a report to the Commission on this subject in the next few weeks.

This concludes our testimony and we look forward to answering your questions.

Appendix E: Proposal by Dana Goward

RESILIENT NAVIGATION and TIMING FOUNDATION

Alternative or Complimentary PNT Solutions Addressing a Stressed Spectrum Environment

Proposed PNT Advisory Board Work Areas July – October 2020

The RNT Foundation recommends the National Space-based PNT Advisory Board develop advice in support of two projects under consideration by government.

Terrestrial PNT Characteristics and Implementation

Advice to Support Department of Transportation (DoT) in its effort to establish terrestrial timing system for backup to GPS.

DoT is required by law to establish a wide-area, wireless, terrestrial timing system to act as a backup for GPS. The system must also be capable of expansion to provide navigation services. DoT is finalizing its report on candidate technologies and will confer with the Departments of Homeland Security and Defense to select one or more for implementation.

The goal of this effort is to better protect America's critical infrastructure and citizens from the impacts of GPS/GNSS disruption.

Statement of Work – PNTAB to develop recommendations for government concerning implementation of national terrestrial PNT technologies to augment GPS. Suggested areas for recommendations include:

- Cybersecurity
- Signal security
- Integration with other systems and in equipment
- Adoption and use by
    - Transportation
    - Other critical infrastructure
    - Other commercial users
    - Governmental
    - Citizen/consumer

Low Earth Orbit PNT Utilizing and Sharing the L Band

Advice to Support of PNT EXCOM in executing the space layer of the multi-level PNT architectures envisioned by the DoD PNT Strategy and the National PNT Implementation Plan.

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A LEO platform provides, especially one with compatible L Band signals consistent with today's satellite-dedicated spectrum allocations, both protection of incumbent SATNAV and SATCOM occupying the same space-to-earth spectrum, and improvements in PNT signal geometry, density, and performance.

Potential Benefits:

- Signal structure that fully protects current incumbent SATNAV-GNSS/SATCOM services with new, legacy-compatible LEOPNT range-signals
    - Presents less drop in C/No than GNSS presents to GPS or vice versa
- Increased range precision to meet emerging autonomous vehicle, IoT, high demand applications
- Increased resilience, security by raising range signal power approximately 100X over GNSS
- Higher PNT availability by reaching more urban, metro corridors, areas, while also improving obscured, in-building coverage
- Favorable L Band propagation relative to other candidate bands. Uses modern shared spectrum signal design to increase performance while taking advantage of higher signals processing levels
- DoD seeks shared spectrum solutions in "spectrum stressed" applications
- Enables partner nations to exercise control over access to signals within their jurisdiction. This Strengthens US's geo-political PNT objectives as international competition increases.
- Restores control of globally scarce space-to-earth SATNAV/SATCOM bands to PNT applications (without preempting current GEO MSS SATCOM access or capability).
    - Context: MSS SATCOM operator in the adjacent satellite space-to-earth band is currently engaging in granting secondary market rights to transmit terrestrially and recently was permitted by the FCC. Spectrum rights being sold even to potentially interfering terrestrial applications.
    - Restoring control of scarce L Band adjacent downlinks is critical to assure next generation PNT services and standards, homeland security, geo-politically sensitive PNT, and military warfighting purposes. L Band is optimal for PNT for propagation, and scales with current L Band GNSS/GPS designs.

Statement of Work – PNTAB to develop spectrum-compatible options and recommendations for future LEO PNT to augment and protect existing GPS signals and related services.