SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

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

Intersession Meeting 21A

August 6, 2018

Virtual Meeting via Teleconference and Webex

John Paul Stenbit Chair	Bradford W. Parkinson 1st Vice-Chair	James J. Miller Executive Director

SPACE-BASED POSITIONING NAVIGATION & TIMING

NATIONAL ADVISORY BOARD

Agenda for Intersession Meeting 21A

Telecon/Webex

Meeting number: 995 034 805
Meeting password: uuU7bDX*
Meeting link: https://nasa.webex.com/nasa/j.php?MTID=m3a798cfd100a8f388553d41b6343cd96

USA Toll Free #: 1-844-467-4685
USA Local/Toll #: 1-720-259-7012
Participant Passcode: #: 106724

12:00-12:10 PM (10 mins)	**MEETING OPENS** *Call to Order & Administrative Notes*	Mr. James J. Miller, *Executive Director, PNT Advisory Board, NASA Headquarters*
12:10-12:25 PM (15 mins)	Welcome Comments & Meeting Objectives *PNT Board Focus & Priorities*	Hon John Stenbit, *Chair, PNT Advisory Board*
12:25-1:55 PM (90 mins)	PNT Board Working Group / Subcommittee Reports to Chair on PNT Topic Papers ***Deliverable 1: Topic/Issue Paper to PNT EXCOM***	PNTAB Working Group Leads
	Agriculture	Mr. Ron Hatch
	Aviation and Aerospace	Mr. Scott Burgett
	Critical Infrastructure and Timing	Adm Thad Allen
	Military	Lt Gen Larry James
	Policy and Governance	Mr. Dana Goward
	Science	Dr. Gerhard Beutler
	Spectrum	Dr. Sergio Camacho-Lara
	Transportation (Non-Aviation)	Mr. Russell Shields
1:55-2:10 PM (15 mins)	Opening Remarks for Spectrum Recommendations *Follow-Up from 21st PNT Board Meeting of May 16-17 – non-recused members*	Governor Jim Geringer, *2nd Vice-Chair*
2:10-3:40 PM (90 mins)	PNT Board Recommendations & Analysis of Impacts from Broadband Proposal(s) ***Deliverable 2: PNT Board Memo(s) to PNT EXCOM***	Dr. Bradford Parkinson, *1st Vice-Chair*
3:40-4:00 PM (20 mins)	Afternoon Wrap-Up & Next Steps *Time permitting*	All Members
4:00	**ADJOURNMENT**	

All presentations & PNT Advisory Board developed Recommendations and associated materials will be posted online for the public record at: https://www.gps.gov/governance/advisory/

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PNT Advisory Board

Intersession Meeting 21A

Executive Summary

Intersessional Meeting 21A of the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board (PNTAB) met virtually on August 6, 2018. The goals of this session were to:

- Finalize and approve the PNTAB Topics Paper
- Finalize and approve the PNTAB Memorandum on Spectrum Issues to be provided as a recommendation to the PNT Executive Committee (EXCOM)

High-Level Action Items:

- Mr. James J. Miller to complete editorial revisions of the Topics Paper and provide the final version to Chair John Stenbit for final signature. Once the document has been signed, Mr. Miller will post it on www.gps.gov.
- Mr. James J. Miller to complete editorial revisions of the Memorandum/Recommendation on Spectrum Issue and provide the final version to Dr. Brad Parkinson for final signature and submittal to the PNT EXCOM. Once the document has been signed, Mr. Miller will post it on www.gps.gov.

Other Action Items:

- At the next session of the PNTAB (PNTAB-22), delve further into the topic of impacts on automotive safety if GPS signals are not accessible to users. The PNTAB is encouraged to invite a speaker to present on this issue.

The meeting was convened on Monday August 6, 2018, at 12:00 p.m. Eastern Time.

Board Convenes
Call to Order
Mr. J.J. Miller, *Executive Director*
National Space-Based Advisory Board on Positioning, Navigation, and Timing

Mr. J.J. Miller called to order Intersession Meeting 21A of the National Space-Based PNT Advisory Board (PNTAB). This is a follow-up meeting tasked at the 21st PNT Advisory Board Meeting held May 16-17, 2018, in Baltimore, Maryland. The meeting will be chaired by the Honorable John Stenbit, as well as Dr. Brad Parkinson and Governor Jim Geringer. Mr. Miller thanked all board members and interested stakeholders that have called in and began with a roll call to confirm there was quorum and whether a board member is recused from the spectrum discussion:

Roll Call & Recusals		
John Stenbit	Present	Recused
Bradford Parkinson	Present	
James E. Geringer	Present	
Admiral Thad Allen	Present	
Penina Axelrad	Present	
John Betz	Present	
Dean Brenner	Present	Recused
Scott Burgett	Present	Recused
Joseph D. Burns	Present	Recused
Martin C. Faga		
Ronald R. Hatch	Present	Recused
Larry James	Present	
Peter Marquez	Present	
Terence J. McGurn	Present	Recused
Timothy A. Murphy	Present	Recused
T. Russell Shields	Present	
Gerhard Beutler	Present	
Sergio Camacho-Lara	Present	
Ann Ciganer	Present	Recused
Arve Dimmen	Present	
Dana Goward	Present	
Matt Higgins		
Refaat M. Rashad	Present	

Mr. Miller then provided some informational context, reminding participants that the PNT Board was first established per Presidential Policy and firmly supported through three Administrations. The PNTAB is intended to provide independent counsel to the Deputy Secretary-level PNT EXCOM, which oversees the management of the Global Positioning System (GPS) and related PNT systems. It is vital to note that it is the specific national leadership of the United States Air Force, and their distinguished operation of the GPS constellation and its radio services, that enables all of this work and applications to even be contemplated.

PNT Board deliberations are governed by the Federal Advisory Committee Act, or FACA, which means that discussions are open to the public and meeting minutes will be posted online at GPS.gov within 90 days for the record. All presentations shown today should be available on the same web link by close of business today. As a reminder, all PNT Board members are nominated by PNT EXCOM Federal Agencies and appointed by the National Aeronautics and Space Administration (NASA) Administrator to provide perspectives from those users we serve from outside the government. As expected, a PNT Board will be comprised of GPS experts, and we therefore have a robust balance of nearly every sector represented. And in this manner, PNT Board Recommendations serve a critical role in examining issues from the unique and transparent perspectives of Special Government Employees (SGEs) and Representatives. Their time is volunteered, but all the more valuable, as they are providing direct user feedback to service providers. As SGEs deliberate, they must abide by established ethics laws that require them not to engage in any discussions that may create a potential conflict of interest. And because some of our topics are closing out complex topics from past discussions, if a member does believe that the appearance of a potential conflict on a particular matter is arising, we ask that they do not engage and clearly recuse themselves from that portion of the discussion.

* * *

Opening Remarks / Part 1 of Meeting: Topics Paper
Hon John Stenbit, *Chair*

Mr. Stenbit noted that, since he is recused from the spectrum discussion, he would chair the portion of the meeting relating to the PNTAB Topics Paper. The 2nd part of the meeting will chaired by Gov. Geringer (2nd Vice-Chair), and include a briefing from Dr. Parkinson (1st Vice-Chair). The discussion on the PNTAB Topic Paper will include briefings from various subcommittees, including a briefing on general spectrum issues unrelated with the topic that will be discussed in the 2nd part of the meeting.

1) Agriculture – Briefer: R. Hatch

The agriculture sector is among the first high precision users of GPS. Precision control of farm vehicles has revolutionized agriculture. As an example, automated steering allows improved accuracy and operation at night, in dust, and in fog. There are many economic and environmental benefits including precision application of water, seeds, nutrients and pesticides which, in turn, avoids overlap and unnecessary application of pesticides. Estimated benefits to the U.S. agricultural sector are over US$ 30 Billion annually, which in California alone is estimated at over US$ 2 Billion annually.

There is an opportunity for additional economic benefits including, for example, an Australian study of "Controlled Traffic Farming," in which all farm vehicles follow the same paths, thus limiting soil compaction where the plants are grown. In this particular example, the study demonstrated the following benefits:

- 68% increase in farm gross margin
- 67% decrease in farm labor costs
- 90% reduction in soil erosion
- 93% reduction in nitrogen loss through soil runoff
- 52% reduction in carbon dioxide emissions and associated diesel use
- 45% reduction in repair and maintenance costs

There are, however, a number of potential threats to GPS use in agriculture. High precision applications require wide bandwidths and very sensitive receivers to achieve the inch-level accuracy needed for many applications. This is particularly important in marginal environments where high precision is needed even when there is partial blockage of signals, such as caused by foliage along tree-lined boundaries. The fertilizer has to be injected directly over the seeds even under such conditions.

In summary, precision agriculture applications often require repeatability which depends upon reliable reception of GPS signals. However, high precision, sensitive GPS receivers are vulnerable to strong signals in the nearby spectrum environment. GPS use in agriculture requires stable acquisition & lock of the GPS signal.

The huge economic benefits of high precision GPS to agriculture need to be carefully protected. Because high precision requires the use of the entire spectrum bandwidth available to GPS receivers, the Agriculture Subcommittee recommends that the GPS spectrum be protected from any changes that would affect reliable reception of GPS signals for high precision uses such as agriculture.

2) Aviation & Aerospace – Briefer: S. Burgett

GPS provides the essential and fundamental infrastructure for real-time navigation of all types of aircraft from drones to commercial and military aircraft. Augmented by space and ground based systems, GPS supports all phases of flight including taxi, takeoff, climb, cruise, descent, approach and landing in all weather conditions. This requires accuracy, integrity, availability and continuity. For example, disruption of GPS during a landing will require a pilot to abort a landing and perform a "go around." Also, space missions, including human spaceflight and operational satellites, make widespread use of GPS for onboard positioning and timing. Specific examples include: (1) commercial Low Earth Orbit (LEO) constellations for worldwide internet and weather rely on GPS for orbit determination; (2) launch vehicles rely on GPS with inertial and other sensors to support all mission phases and (3) GPS measurements from orbiting satellites provide critical data for weather prediction, scientific analysis of global water distribution and space weather.

Aviation and aerospace applications require aggressive protection of the GPS spectrum to ensure it continues to allow innovation and support future applications. The availability of systems to interfere with or deny GPS has dramatically increased over the last decade and, also, technologies are available for intentional jamming (blocking the GPS signal) and spoofing (providing false signals to GPS receivers). This is why there is a need to protect aviation users, especially in urban environments where such devices are more likely to be present.

Therefore, the Aviation & Aerospace Subcommittee recommends the following:

- Continue to support the deployment and improvement of four signals for civil users. These four signals are designated: L1 C/A, L2C, L5 and L1C.
- Protect GPS spectrum for aviation users – especially operating in congested urban areas
- Upgrade Interim Ground Segment to control GPS III satellites and enable monitoring of GPS Civil Signals—required to bridge between current Control Segment (OCS) and the modernized Control Segment (OCX)
- Improve requirements/capabilities of aviation and space-borne receivers to enhance, among other things, Receiver Autonomous Integrity Monitoring (RAIM), as well as robustness to interference and spoofing
- Establish a process for approving usage of international Global Navigation Satellite System (GNSS) signals in the U.S.

3) Critical Infrastructure and Timing – Briefer: Admiral T. Allen

It is an understatement to say GPS provides PNT infrastructure. It is necessary for virtually everything, including the financial industry and the increasing regulation of those transactions, as well as power generation and transmission. GPS becomes a single point of failure. While there are clocks to sustain this service, many of these have a finite life and require the timing signal to be refreshed. A lot of the issues related to GPS and its vulnerability were addressed in NSPD-39 (U.S. Space-Based Position, Navigation, and Timing Policy, 15 December 2004). Admiral Allen recommended an audit and revision of NSPD-39 to see that the threats are all addressed, since it is close to fifteen years old.

The proposed repurposing of nearby spectrum threatens critical and high value uses of GPS. Jamming and spoofing of GPS receivers is also a growing problem. There is, however, opportunity in emerging alternative capabilities for PNT as well as the development of more competent and robust receivers.

The Critical Infrastructure and Timing Subcommittee recommends the following:

- Adopt spectrum regulations that protect current and future uses of GPS and GNSS
- Implement nationwide capabilities for prompt and effective interference detection & mitigation
- Encourage manufacturers to offer more competent and robust receivers and antennas, and owner/operators to field them
- Encourage diversification of PNT sources; remove Federal Communications Commission (FCC) requirement for licensing use of foreign GNSS
- Implement Enhanced Loran (eLoran) as a backup for GPS timing in the continental United States, subject to verification of cost and performance. Further, agencies should be strongly encouraged to continue development of other capabilities.

4) Military – Briefer: Gen L. James

While the PNTAB focuses on civil aspects, we need to remember that GPS would not work without the Air Force's stewardship of GPS and its continued interface with the civilian community. GPS utilization also permeates virtually every aspect of military operations and must provide assured PNT capability in a multitude of contested environments.

A variety of threats exist to deny and disrupt GPS access for military operation, including jamming and spoofing of receivers, as well as attacks on ground segments and satellites.

There is, however, an opportunity to address these threats through new GPS space segment, ground segment, and user segment capabilities, including: GPS block III and IIIF satellites, M-Code with increased power and Military GPS User Equipment (MGUE) Increment 2.

Thus, the Military subcommittee recommends the following actions:

- Fully support GPS block III and IIIF procurement
- Conduct military exercises in challenging PNT environments
- Upgrade GPS ground segment
- Rapidly develop MGUE Increment 2
- Demonstrate the utility of backup/augmentation with international GNSS signals
- Accelerate deployment of anti-jam technology on military platforms

5) Policy and Governance – Briefer: D. Goward

Challenges persist regarding the use of signals from multiple GNSS. Uses of space-based PNT services have grown far beyond the scope of what existed when the current policy and governance was established. In the last 14 years unanswered policy questions and a rapidly evolving technology environment have resulted in many NSPD-39 mandates being unexecuted. A more coherent governance structure must be implemented to ensure current and future mandates are met.

The Policy and Governance subcommittee has identified a number of threats in various areas:

- Monitoring Performance of GPS Civil Signal – Efforts to establish a monitoring regime to ensure we meet our commitments have, to date, been poorly supported and funded, especially as it relates to the civil user segment where capabilities exist but are not resourced or integrated in a national monitoring framework
- Interference Detection and Mitigation (IDM) – The PNTAB knows of no systematic government efforts to either detect interference with GPS signals or to mitigate their effects
- International Data Sharing – Since GPS is both a civil and a military system, how information sharing requests should be adjudicated has remained an open question. The PNT governance structure is dispersed functionally and the various roles of agencies and departments lack integration.
- Complementary and Back-up System – Senior Government officials have twice announced plans to meet this NSPD-39 mandate, once in 2008 and again in 2015. No action has been taken.
- Spectrum Protection –The FCC's expertise with radio-communications, and its lack of expertise in radio-navigation, continues to be a challenge for GPS stakeholders. Comprehensive and coherent governance may require legislation to update foundational laws and regulations. The FCC has responded to some chronic interference incidents, but has extremely limited capability and capacity.
- Use of Multiple GNSS Constellations within the United States – Cell phone and satellite navigation receiver manufacturers have incorporated non-U.S. GNSS within their equipment. Yet FCC rules require any non-federal receiver in the U.S. using non-U.S. signals to be licensed. None of the millions of receivers in the U.S. have yet been licensed.

Therefore, we make the following recommendations:

- Civil users in the U.S. should be allowed to legally access GNSS without an individual license and use non-U.S. GNSS signals
- The Administration should consider revisions to current policy guidance and an integrated governance framework that addresses current fragmentation of resources and accountability

6) Science – Briefer: G. Beutler

Today, use of GNSS is indispensable for earth and atmospheric science. Organizations, such as the International GNSS Service (IGS), provide global geophysical products including contributions to the International Terrestrial Reference Frame (ITRF), Earth Rotation Parameters (ERPs) and ionosphere and troposphere models. These enable us to determine precise GNSS orbits and clock corrections. Precise GNSS orbits and clock corrections are the backbone for precise orbit determination (POD) of most LEO satellites and gravity field determination. Precise GNSS orbits and clock corrections are also the basis for high-accuracy terrestrial navigation and positioning.

There are, however, a number of threats to scientific applications such as these. GNSS satellite and operations information is not openly available (see IGS white paper[1]). Such information would enable far better geophysical products that, in turn, would improve GNSS capabilities. Also, at this time laser retro-reflector arrays (LRAs) are not currently deployed on all GNSS satellites, specifically GPS, although there are plans to include them on future GPS block IIIF satellite vehicles. While scientific GNSS receivers are the "Formula-1" GNSS user equipment, extracting "the last bit of information" is extremely vulnerable to interference. The use of high precision receivers is rapidly expanding into industrial and mass market applications, including safety-of-life applications like automated passenger vehicles. As a result, the dependency on improved orbits and clocks produced within the IGS continues to increase.

There are also many opportunities for science applications. The combined use of all available GNSS will make science products more robust and, in general, more accurate. Also, global climate change monitoring, including the detailed sea level monitoring over decades, depends to a great extent on precise multi-GNSS monitoring. High-accuracy GNSS monitoring based on all available systems is performed in the IGS, a scientific service of the International Association of Geodesy (IAG) that is based on a voluntary collaboration of more than 400 governmental and other organizations distributed all over the globe. Moreover, high-accuracy GNSS applications are not only important for science. They are relevant for a much larger international community. For example, virtually every first-order national survey is nowadays based on GNSS. Also, GNSS are routinely used for time and frequency synchronization and are essential for the establishment and dissemination of Universal Coordinated Time (UTC), which is based on an ensemble of atomic clocks at the time labs.

Therefore, the Science subcommittee recommends the following:

- Remove bureaucratic obstacles hindering the use of all GNSS open services
- Endorse all measures to mitigate or to avoid interference
- Equip all future GPS satellites with laser retro-reflector arrays to enable independent orbit validation
- Provide open access to GPS satellite and operations characteristics for precise GPS orbit determination
- Encourage all GNSS providers to provide the same open access
- Endorse global monitoring and coordinating activities for scientific and other high precision GNSS applications performed, e.g., by the IGS and the International Committee on GNSS (ICG), established under the auspices of the United Nations (UN), particularly in the area of multi-GNSS

7) Spectrum – *(note: the briefer, Dr. Camacho-Lara, had connection problems, so the chairman skipped to the next presentation)*

8) Transportation (Non-Aviation) – Briefer: R. Shields

Every sector of surface transportation depends on GPS or other GNSS. Uses include navigation, traffic information, transportation management, Vehicle-to-Vehicle (V2V) communications, automated driving, logistics, and many aspects of maritime transportation. The worldwide economic value of GPS in surface transportation is estimated to exceed US$ 25 Billion per year.

Dependence on GPS and other GNSS has reached the level where, in practice, they are the only source of PNT data for many land vehicles and ships. This is a single point of failure. Also, signal interference, intentional or unintentional, threatens all GNSS. A conversion from satellite use to ground use of communications frequencies close to GPS would

[1] https://kb.igs.org/hc/en-us/articles/115000802772-IGS-White-Paper-on-Satellite-and-Operations-Information-for-Generation-of-Precise-GNSS-Orbit-and-Clock-Products-2017
Editorial note: the URL on the briefing slides does not work. Use this link instead.

significantly degrade GPS in land vehicles. Also, spoofing and jamming are increasingly becoming real threats, especially as connected and automated vehicles are rolled out.

There are opportunities in emerging alternative backup capabilities for PNT and developing more competent and robust receivers.

Therefore, the Transportation (Non-Aviation) subcommittee recommend the following:

- Keep spectrum for terrestrial communications adequately separated from Space-to-Earth GPS spectrum. The cost of accidents in the U.S. is estimated to be well over US$ 500 Billion a year to our economy. If we could even reduce just 10% of that, it represents a US$ 50 Billion improvement to our economy.
- Adopt approaches to harden GPS devices to recognize jamming and spoofing and counteract them
- Encourage GNSS manufacturers to offer more competent and robust receivers and antennas, and encourage product manufacturers to incorporate enhanced GNSS receivers in their products
- Encourage diversification of PNT sources (including having the FCC stop the need for individual licensing to use foreign GNSS).
- Select and implement backup capabilities for GPS per NSPD-39

7) Spectrum – *(note: the original briefer still had connection problems, so Ms. Ciganer briefed in his place)*

GPS and other GNSS operate in spectrum allocated by the International Telecommunications Union (ITU) to Radionavigation Satellite Services (RNSS).

Access to radio frequencies free of harmful interference is crucial for reliable GPS/GNSS receiver performance because GPS/GNSS receivers operate below the ambient noise level. Thus, emissions (both in band and nearby bands) which raise the noise level in the RNSS spectrum can harm the functioning of GPS/GNSS receivers and constrain the development of new innovative applications.

To mitigate these threats, the Spectrum subcommittee recommends the following:

- When setting national regulations, apply the ITU Radio Regulations and Recommendations to avoid introducing interference in the RNSS spectrum
- Interference detection and mitigation infrastructure is needed to monitor the RNSS spectrum and ensure regulations are followed
- Adopt and enforce policies to prohibit the manufacture, import, sale, and use of illegal jammers
- Support the proposal at the ICG regarding the international general exchange of information related to GNSS spectrum protection and interference detection and mitigation
- Coordinate with the National Space Council (NSpC) on GPS/GNSS spectrum issues as it will participate in ITU's next World Radiocommunications Conference (WRC) in November 2019

* * *

1:02 pm. - At this point there was a motion to authorize publication of the briefing slides and Topics Paper, the latter with minor editorial (non-substantive) fixes to the modified draft recommendation. There was a roll-call vote with a majority of 'ayes', and no 'nays'. The motion carried.

1:06 pm. – The chairman, J. Stenbit, recused himself from the upcoming discussion of a Spectrum Issue, and turned the meeting over to Governor J. Geringer, the 2nd Vice-Chair.

* * *

Part 2 of Meeting: Memorandum on Spectrum Issue to the PNT EXCOM
Gov. J. Geringer, *2nd Vice-Chair*

The potential threats discussed earlier could potentially be dwarfed by the reallocation of spectrum adjacent to the GPS signal to a ground-based system. It could substantially affect the economic security of our nation, our national security, personal security and safety. Those things have all been briefly highlighted in the preceding presentations and recommendations. So, as we go forward now we will be talking about what we've referred to as "myths in the media that were dispelled at our 21st PNTAB meeting." Dr. Parkinson will elaborate on those as well. If I were to characterize this set of misunderstandings or myths, I would use words such as misleading, inaccurate or generally a display of lack of knowledge of how GPS works and how technically flawed some of these comments are.

1:10 PM - Gov. Geringer gave the floor to Dr. Parkinson.

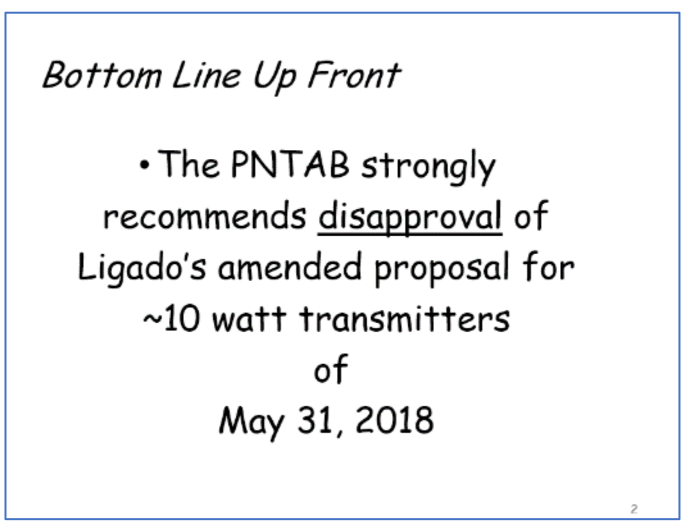
Analysis of Ligado May 2018 Proposal and Assessment - August 2018
Dr. B. Parkinson, *1st Vice-Chair*

We've discussed our charter, which is assuring PNT for the current and for the future, for the benefit of the United States as well as humanity. We're not chartered to negotiate, but we are chartered to advise the PNT EXCOM. One particular matter has occupied a lot of our time over the past five years or so, and it relates to a change in the spectrum allocation in an adjacent band of our primary GPS frequency. This has been historically known as the MSS (Mobile Satellite Services) band, which is relegated to very quiet communication signals from space, presumably for hand mobile-phones that are wandering around somewhere, not within range of either wireless or a local communications link. That gave us some trouble back in the 2011 time period because that allocation initially requested 15 kW of power, and it later came down to 1.5 kW.

About two or three meetings ago a representative of a company called Ligado verbally proposed 20 W, but an even newer FCC filing done in May is essentially yet another proposal to broadcast at about 10 W. So, we have spent a lot of time with this effort in working groups to assess what we think about that from a purely scientific basis. Our decisions and recommendations are made on the basis of physics, not on the basis of anything else, and I'd like to personally thank everyone who contributed to this [draft memo on screen], but I'd also have to add that any member of the advisory board is free to chime in, request modifications, or express challenges to the charts I am about to show. So, this is just a draft and my sincere hope is that by the end of this meeting we will have a PNTAB position.

<u>Slide #1</u>: Title Page *(skipped)*

<u>Slide #2</u>: We'd like to do a bottom line up front, which is that the PNTAB strongly recommends <u>disapproval</u> of Ligado's amended proposal for ~10 W transmitters that was submitted to the FCC on May 31, 2018.



Slide #3:

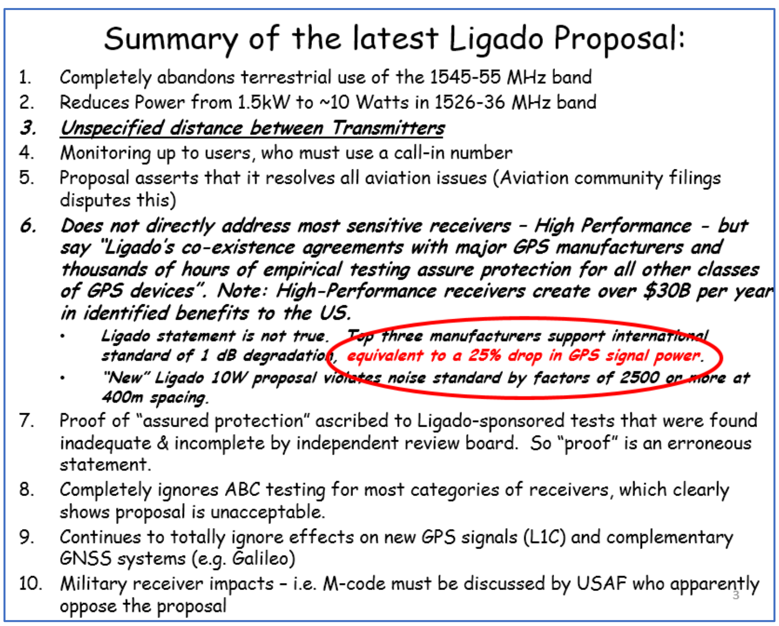
Summarizing what that proposal was, it completely abandons terrestrial use of the closer [to GPS] band of 1545-55 MHz band and reduces that power in the further distant band (1526-36 MHz band) from 1.5 kW to ~10 W. It did not specify the distance between transmitters. Ligado has suggested that the analysis that was done for aviation would apply. That analysis resulted in a minimum distance of 433 meters, but it was not clear that they are putting that as an absolute minimum, or whether they have some other minimum. They [Ligado] also stated that monitoring is up to the users, who must use some form of a call-in number if they think there's a problem.

It asserts that it [the analysis] resolves all aviation issues, however there have been a number of very strong filings by the aviation community that dispute that claim. It does not directly address the most sensitive receivers, the so-called High Performance used by precision agriculture, and many surveying and scientific endeavors, but the submittal stated that Ligado's co-existence agreements with major GPS manufacturers and thousands of hours of empirical testing assure protection for all other classes of GPS devices.

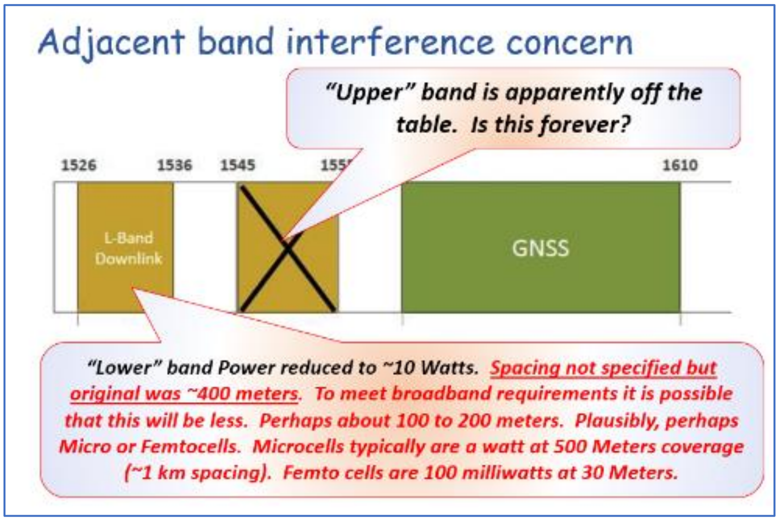
Now, as an aside I know that our previous economic study noted that High-Performance receivers create at least US$30 Billion per year in identified benefits [to the U.S.].

The Ligado statement is simply not true. The top three manufacturers support the international standard of 1 dB degradation, which for those not familiar with the topic, is equivalent to suggesting we can tolerate a 25% drop in GPS signal power. That's what the equivalence is. And, incidentally, such an intrusion with interference power is generally thought to be the total interference, not the interference allocated to just one source. And, if you go in the actual data that we have, the Ligado ~10 W proposal violates that [the 1 dB] standard by a factor of over 2,000 at a spacing of over 400 meters. That's a pretty big point to make. And, the proof of assured protection that Ligado ascribes to their [sponsored] tests was found incomplete and inadequate by an independent review board. So "proof" is certainly an overstatement.

As a matter of fact, their filing completely ignores the Department of Transportation (DOT) Adjacent Band Compatibility (ABC) testing for most categories of receivers, which shows again that proposal is clearly unacceptable. And it continues to totally ignore any future-looking position for PNT, particularly the new GPS signals (for example, L1C) and complementary GNSS systems (e.g. Galileo, which has one wideband signal that is, apparently, particularly susceptible. It also ignores the military receiver impacts, but that concern has to be discussed by the Air Force because it starts to involve classified aspects.



Slide #4: As a reminder, the adjacent band interference concern looks like this:

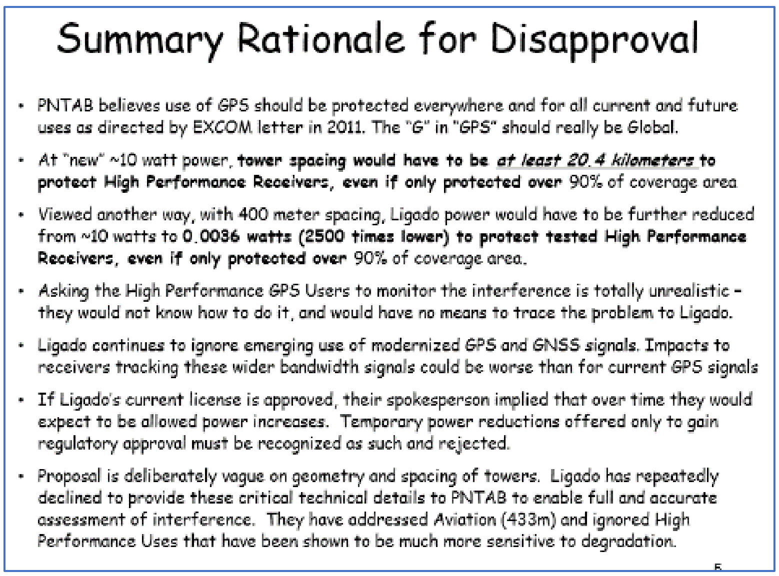


We have spectrum across this horizontal band, and with GNSS (and particularly GPS) shown in green. The "upper" Ligado band, shown there, is apparently off the table but there is concern by some as to whether that's forever. The "lower" Ligado band is one where the power is reduced to ~10 W and, again, the spacing of the transmitters was not specified. To meet broadband requirements, it is certainly possible that they will go to less [spacing] possibly to about 100 to 200 meters. There are a number of commercial installations of such transmitters called 'micro' or 'femtocells'. Microcells are typically one watt at 500 meters, although that can vary quite a bit. Femtocells, although quieter, are obviously much denser in terms of the number of cells that are around.

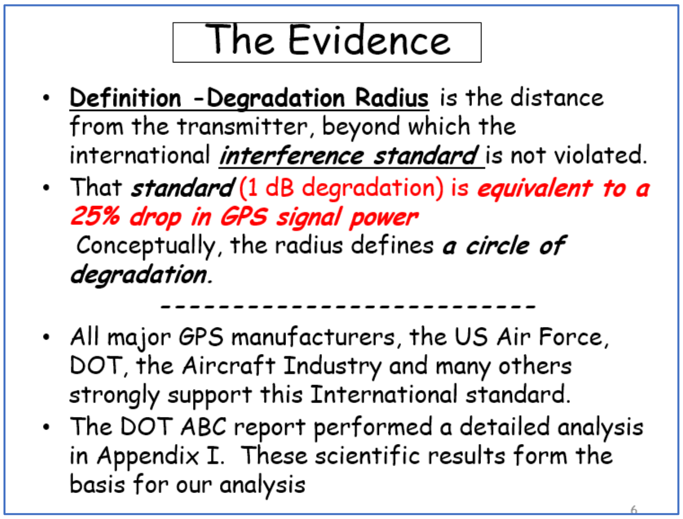
Slide #5:

Rationale for our recommended disapproval. We believe use of GPS should be protected everywhere and for all current and future uses as directed by a PNT EXCOM letter in 2011, and that the "G" in "GPS" should really be global in use and in geography. The new ~10 W transmitter proposal would have to have tower spacing of over 20 kilometers to protect the High Performance Receivers (HPR), even if it was only protecting 90% of the coverage area. This is just a summary, later I'll show the details of the scientific evidence that led us to this conclusion. We can [also] view it another way. We can say ok, with 400 meters what power could be tolerated that does not endanger GPS over more than 10% of the coverage area, and that answer is .0036W (compared to the ~10 W proposed limit, about 2500 times lower).

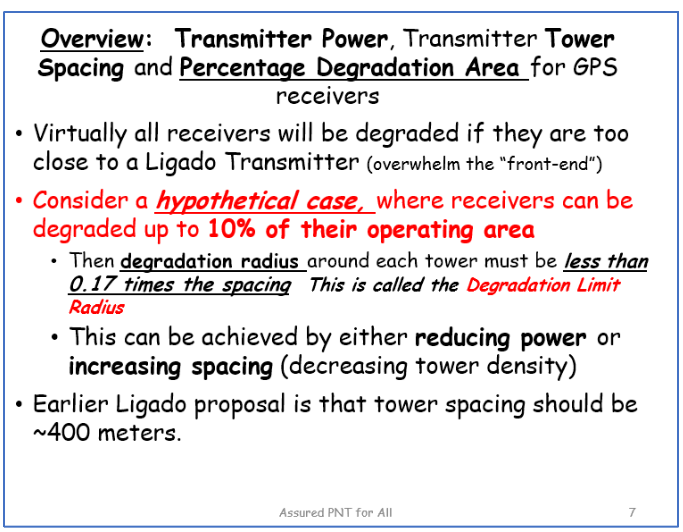
We also feel that asking GPS users, particularly the High Performance Users, to monitor the interference, and figure out where it's coming from, is unrealistic. If you speak to the average surveyor he knows he has a yellow box, knows what it does, knows how to operate, but when it comes to it not working he doesn't have a clue. Also, this ignoring / glossing over the emerging use of GPS and GNSS signals is very troublesome and the impact to receivers tracking these wide bandwidth / more capable signals could be much worse than the narrow-band signal that most civilians rely on. If the current license is approved, their spokesman implied that over time they would expect to be allowed power increases. All we can say about that is that temporary power reductions offered only to gain regulatory approval must be recognized as such and rejected. In other words, if there's ever going to be a modification, the GPS users and manufacturers have to be able to rely on whatever that [new] allocation is. And, of course, the proposal is deliberately vague on geometry and spacing of towers. When we asked Ligado representatives we were told that the spacing was proprietary. This is a critical detail for PNT. It is required to enable a full and accurate assessment of interference. So, although they have addressed aviation with the statement that the analysis was done at 433 meters, that is hardly a commitment to a minimum spacing for their proposal.



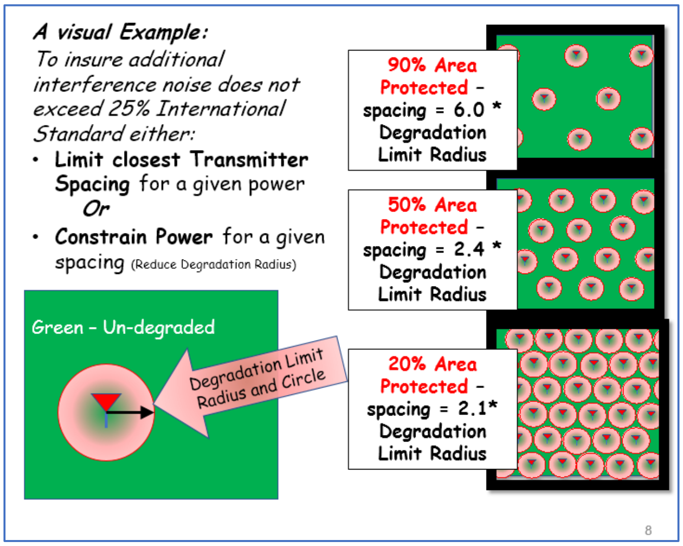
Slide #6: Now let's turn to the evidence in greater detail and see where all these statements come from. We're going to find something called the "degradation radius", and that's the distance from the transmitter beyond which the interference standard is not violated. Again, that standard –as a reminder- is equivalent to a 25% drop in GPS signal power. That radius defines a circle within which there is exposure by GPS receivers to degradation. Now, it turns out that this standard, apparently controversial to the proposer (Ligado), is supported by all major GPS manufacturers, the US Air Force, DOT, the Aircraft Industry and many others. The DOT Adjacent Band Compatibility report performed a detailed analysis [shown] in Appendix I, and these scientific results from the firm basis for what we're trying to do.



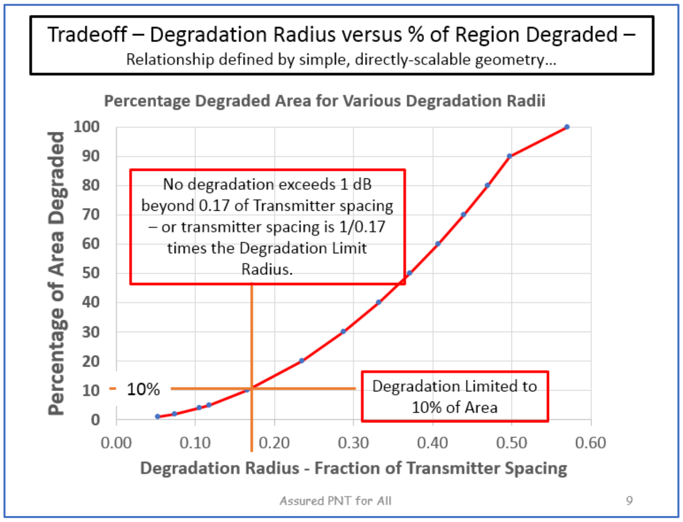
Slide #7: Let's consider a pivotal set of tradeoffs. Those tradeoffs relate to the transmitter power, transmitter spacing, and the percentage of area that might be degraded for GPS types of receivers. Virtually all receivers will be degraded if they're too close to a Ligado transmitter because the front-end of that receiver will probably get overwhelmed. It's not a matter of what spectrum they're in, it's a matter of too much power too close. But, consider a hypothetical case. Let's say [hypothetically] receivers can be degraded within up to 10% of their operating area, i.e. 10% of the region where Ligado is placing these transmitters. It turns out there is a simple geometric relationship. Each tower must be spaced such that the degradation radius is only 17% of the spacing (or .17). We call that the degradation limit because it defines the exposure area, and you can achieve it by either reducing the power of the transmitters or increasing their spacing, effectively decreasing the tower density. The earlier Ligado proposal was that their tower spacing should be at about that aviation number somewhere in the order of 400 meters.



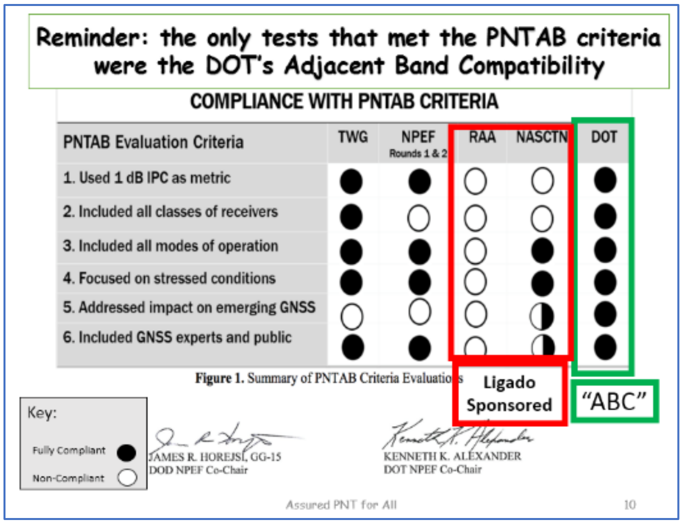
Slide #8: So, I tried to put together a visual example so that you can see what we're talking about, and this is looking at the 25% interference noise standard by either limiting the closest transmitter spacing for a given power, or constraining the power for a given spacing. In this diagram the green areas are going to be "un-degraded", and the rose-colored areas are the circles defined by that degradation radius. So if you consider that you want to have 90% of your area protected, the degradation radius must not exceed 17% of the distance between transmitters. Stated in another way, the spacing has to be at least 6 times that degradation limit radius. To an overhead observer the picture looks something like the picture in top right of slide. The 50% situation would look something like the picture in the middle, where the spacing is 2.4 or more times the degradation limit radius. And, if you look at a more severely degraded situation where only 20% is protected, the picture looks something like the bottom right.



Slide #9: So we now have the technical way of calculating that, and it is a very simple calculation it turns out. This plot is a reminder of what that might look like. On the left is the percentage of area that is degraded, and across the bottom is the degradation radius expressed as a fraction of the spacing between transmitters. So, in our case, the percentage of area degraded is 10% and we can find the fraction of what the transmitter spacing should be. We ended up with the .17 of the desired spacing, or less of that spacing.

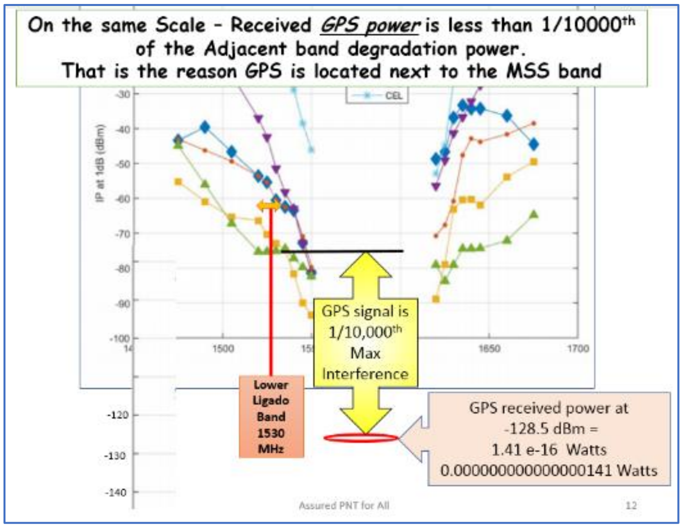


Slide #10: There are five groups of tests shown here across the top. The Ligado-sponsored tests are in the red box, and the DOT ABC test is shown in the green box. This evaluation was done at the behest of the EXCOM. Black means fully compliant, white means non-compliant, and the point is that DOT testing is the only fully-compliant set of tests conducted. That report has been published. It's very extensive and examined a massive number of cases and alternatives, and it looks at 80 GPS receivers to be certain they're a representative sampling.

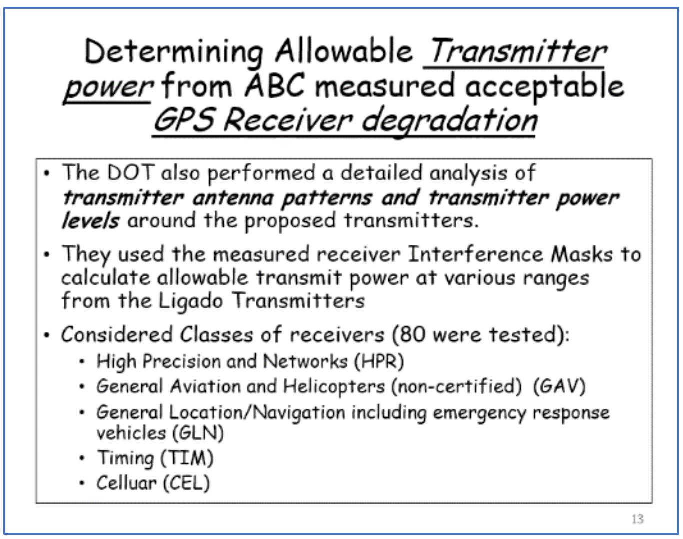


Slide #11: *(skipped)*

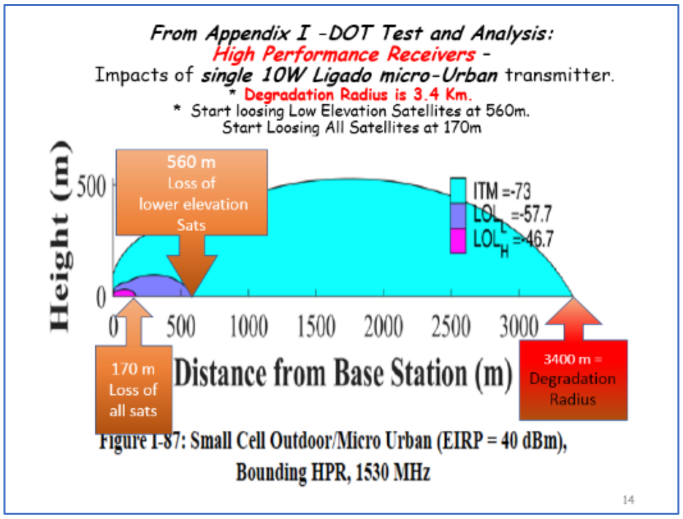
Slide #12: This is perhaps the most important chart out of that whole briefing / report. What we've got here [on the left] is the power, shown in something called dBm. The point is that the distance between each of the horizontal lines represents a factor of 10 increase. Thus, the difference between -50 and -70 dBm represents a factor of 100 times in power. Each color curve represents a different class of GPS receiver. For example, the High Performance Receiver, or HPR, are the orange/square data points on the chart. When you are close in frequency, the acceptable power before you start risking degradation is very low. The further away you are in frequency the more tolerant GPS is to such interference. We'll be using these numbers, particularly the High Performance Receivers, in our calculation of tolerable power. Also, I've moved the chart up (so to speak) and extended the power (which is getting less and less as we go down) to show the real essential nature of our problem, and that is that GPS is a very weak signal. This is the amount of power a GPS receiver has to work with when it receives that very distant signal from space. It's like a 40 W [incandescent] lightbulb [450 lumens in brightness] 12,000 miles away. That's why GPS has difficulty coping with nearby signals. Note how GPS can tolerate interference up to 10,000 times the GPS signal, but beyond that it gets into trouble. Fortunately, in the early days the FCC allocated the adjacent frequency to similar weak signals from space in the so-called MSS band. The point is, the GPS signal is very tolerant of adjacent band interference, but unfortunately the GPS signal is simultaneously very weak.



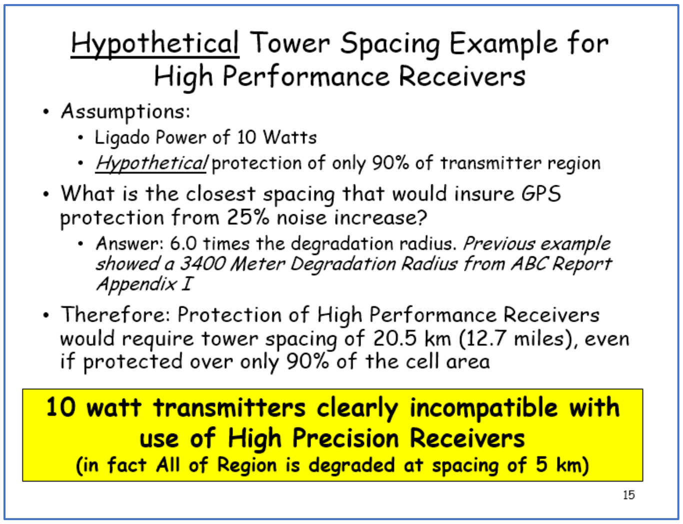
Slide #13: In the previous slide we had the received signals at the GPS receiver, and that doesn't tell you what a transmitter is allowed to do. Fortunately, the ABC testing included a detailed analysis of transmitter antenna patterns and transmitter power level, so that you can figure out what that received power really meant in terms of the transmission that was permissible. They used the receiver interference masks I just showed [in the previous slide]. You can use those to calculate the allowable transmit power at various ranges. They considered the five classes of receivers I just showed, and some 80 receivers.



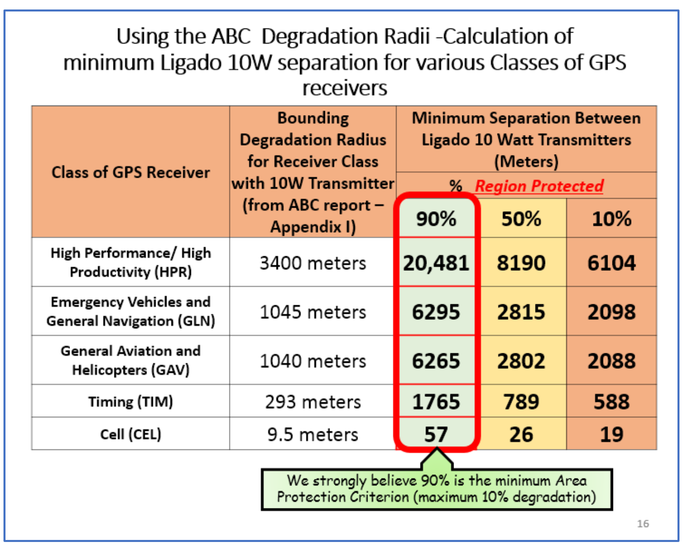
Slide #14: Here is a representative result. This is a plot of height in meters (the transmitter is assumed to be located at coordinate 0, 0) vs. the distance from the transmitter or base station. For high performance receivers it turned out that the DOT actually did the 10 W case (or very close), and were able to determine in the light blue the areas both in height and in horizontal displacement where a high performance receiver class started to become degraded. The answer, in terms of what we used before, the degradation radius, is 3,400 meters (3.4 km away). At that distance high performance receivers begin to become degraded. There are two other colors in little boxes on the chart. One is the plot of where a receiver begins not just to be degraded, but totally lose lower elevation satellites, and it turns out that happens at 560 meters. And, the loss of all satellites begins at about 170 meters.


From Appendix I -DOT Test and Analysis:
High Performance Receivers -
Impacts of single 10W Ligado micro-Urban transmitter.
* Degradation Radius is 3.4 Km.
* Start loosing Low Elevation Satellites at 560m.
Start Loosing All Satellites at 170m
560 m
Loss of
lower elevation
Sats
170 m
Loss of
all sats
3400 m =
Degradation
Radius
Height (m)
Distance from Base Station (m)
ITM =-73
LOL =-57.7
LOL =-46.7
Figure I-87: Small Cell Outdoor/Micro Urban (EIRP = 40 dBm),
Bounding HPR, 1530 MHz
14

Slide #15: We're going to use that degradation radius now and move to the next step. How densely they can we place the transmitters? The assumption for this spacing is Ligado power of 10 W and that we're going to protect only 90% of the transmitter region. The question is, what is the closest spacing? We already have the answer, it is six times the degradation radius. We know the degradation radius is 3,400 meters, therefore for protection of high performance receivers the tower spacing would have to be at least 20.5 km (or 12.7 miles). So, the 10 W transmitter is clearly incompatible with any reasonably dense laydown. In fact, if the transmitter spacing were just 5 km then all the region is degraded, not just 90%.

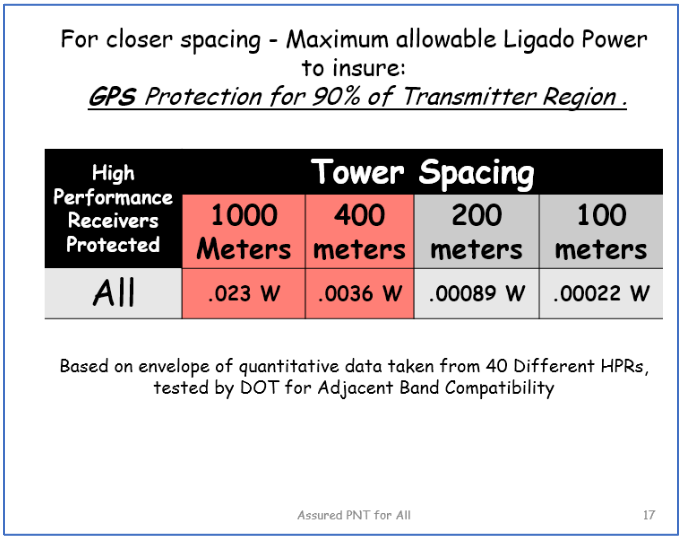


Slide #16: We can take that a step further because we have all these classes of receivers, and you can go into appendix I [of the DOT ABC report] and pluck out (and we have it in the backup charts) the degradation radii for all major classes of receivers that were tested by DOT. This shows the five classes of receivers, their bounding degradation radius, and then what the minimum separation would have to be among the ~10 W transmitters if you want to protect 90%, 50%, or 10% of the region. The data point we just got (for 90%) to protect the high performance receiver is 20 km, and if you go to emergency vehicles or general navigation the separation is about six km for both. Thus 90% is the absolute minimum protection criteria that should be accepted. In other words, degradation over more than 10% of the area is not acceptable.

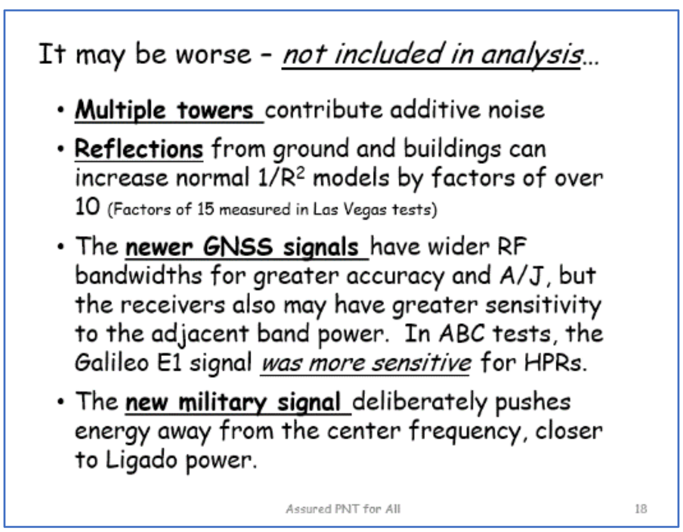

Using the ABC Degradation Radii -Calculation of minimum Ligado 10W separation for various Classes of GPS receivers

Class of GPS Receiver	Bounding Degradation Radius for Receiver Class with 10W Transmitter (from ABC report – Appendix I)	Minimum Separation Between Ligado 10 Watt Transmitters (Meters) % Region Protected		
		90%	50%	10%
High Performance/ High Productivity (HPR)	3400 meters	20,481	8190	6104
Emergency Vehicles and General Navigation (GLN)	1045 meters	6295	2815	2098
General Aviation and Helicopters (GAV)	1040 meters	6265	2802	2088
Timing (TIM)	293 meters	1765	789	588
Cell (CEL)	9.5 meters	57	26	19

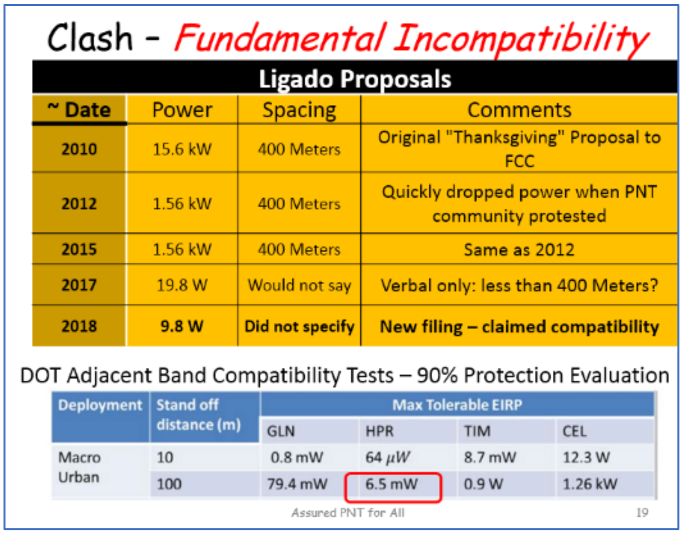
Slide #17: You can look at it differently. You can say, ok, for closer spacing what power level would be acceptable? If you look at the high performance receivers, to protect them all, at one km spacing the power level would have to be .023 W, and at 400 meters the acceptable power level is .0036 W. And, again, this performance envelope is based on 40 different high performance receivers.



Slide #18: But, you have to be cautious. It could actually be worse than that. We didn't include some things in the analysis. If there are multiple towers, obviously the noise will go up depending on the geometry. More important, reflections from the ground and the buildings can increase the amount of power in a particular zone or area, and as a matter of fact a factor 10 in increase of noise or disturbance power is possible, and even as high as 15 was measured in an earlier set of tests in Las Vegas, Nevada. The newer GNSS signals have wider bandwidths for greater accuracy, but they also may have a greater sensitivity and, in fact, DOT ABC tests actually looked at the Galileo GNSS and discovered they were more sensitive than some of the high performance receivers. The new military signals deliberately pushes energy away from the center frequency, which would also be impacted from Ligado's proposed power.



Slide #19: So, the clash is simply fundamental incompatibility. If you look at the transmit power that Ligado advocated in 2017, informally, of 20 W has come down to very close to 10 W. The new filing claims compatibility, but the evidence that we have seen seems to suggest very strongly that compatibility is not there. And, if you look at the so-called maximum 'tolerable power' at various stand-off distances (again, this is the degradation radius), the high performance receivers can only tolerate 6.5 mW max tolerable EIRP, which corresponds to a tower spacing of 600 meters.



Clash – *Fundamental Incompatibility*

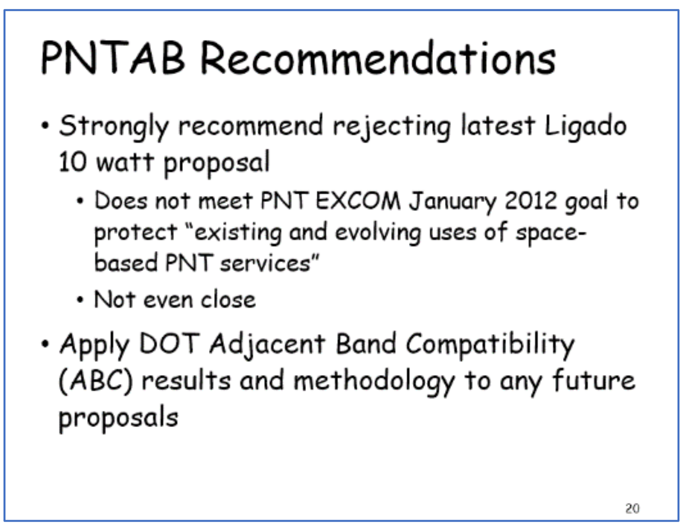
Ligado Proposals

~ Date	Power	Spacing	Comments
2010	15.6 kW	400 Meters	Original "Thanksgiving" Proposal to FCC
2012	1.56 kW	400 Meters	Quickly dropped power when PNT community protested
2015	1.56 kW	400 Meters	Same as 2012
2017	19.8 W	Would not say	Verbal only: less than 400 Meters?
2018	**9.8 W**	**Did not specify**	**New filing – claimed compatibility**

DOT Adjacent Band Compatibility Tests – 90% Protection Evaluation

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

Slide #20: So, that brings me to our recommendations. We strongly recommend rejecting the latest Ligado ~10 W proposal. We don't think it meets the PNT EXCOM January 2012 goal to protect "existing and evolving uses of space-based PNT services". As a matter of fact, and this is not a quantitative statement, it isn't even close. If we take anything coming forward as a proposal, the DOT ABC results and methodologies should be applied to it.



Discussion on Briefing Presented by Dr. Parkinson

Gov. Geringer opened the floor to questions from non-recused members. None were forthcoming.

Dr. Parkinson said that since there are no non-concurs with the briefing, the PNTAB should go to the memorandum.

There was a motion to vote on approval of the briefing and to move onto the discussion of a PNTAB memorandum to the PNT EXCOM. The motion was seconded and the vote took place:

Vote on PNTAB Approval of Briefing and to Move onto Discussion of Memorandum to the PNT EXCOM		
John Stenbit		Recused
Bradford Parkinson	Yes	
James E. Geringer	Yes	
Admiral Thad Allen	Yes	
Penina Axelrad	Yes	
John Betz	Yes	
Dean Brenner		Recused
Scott Burgett		Recused
Joseph D. Burns		Recused
Martin C. Faga		
Ronald R. Hatch		Recused
Larry James	Yes	
Peter Marquez	Yes	
Terence J. McGurn		Recused
Timothy A. Murphy		Recused
T. Russell Shields	Yes	
Gerhard Beutler	Yes	
Sergio Camacho-Lara	Yes	
Ann Ciganer		Recused
Arve Dimmen	Yes	
Dana Goward	Yes	
Matt Higgins		
Refaat M. Rashad	Yes	

J.J. Miller: We have more than 50% +1 concurrence so the motion carries.

Discussion on Memorandum to PNT EXCOM

Dr. Parkinson reviewed the draft memorandum paragraph by paragraph. He noted there were a few typos in a few numbers in the briefing slides, and a Board member noted a minor grammar fix.

Gov. Geringer commented that the US$ 500 Billion figure in losses due to automotive accidents mentioned by Mr. Shields during a discussion in the 1st part of this meeting is something that would be useful if we could quantify the losses that would result from loss of the GPS signal.

Dr. Parkinson recommended that the PNTAB delve further into this topic (GPS impact on automotive safety) at the next session (PNTAB-22) later in the year. The Board should try to get a speaker to present on this issue.

Mr. Shields commented that the cost impact he mentioned earlier are based on published figures. Applications such as Vehicle-to-Vehicle communication are 100% dependent on GPS.

Dr. Axelrad asked for minor text change to clarify that the example used in the letter regarding protecting GPS over 90% of a given area (which is the same as tolerating degradation over 10% of a given area) is just that, an example, and that the Board is not in any way implying such level of degradation would be acceptable.

DRAFT Modified Memorandum (page 1 of 3) – Note: this version includes the typos and edits discussed at the meeting

Draft Letter from PNT AB to EXCOM Chairs Regarding Ligado Proposal (V11)

Dear EXCOM Chairs and Members,

On the 31st of May 2018, Ligado Networks amended its FCC license modification applications. They have proposed reducing initial transmitter power to 10 watts and abandoning use of the band closest to GPS frequencies. Unfortunately, they have not specified transmitter spacing nor do they propose a feasible scheme for monitoring their interference levels, expecting the GPS user to contact them instead.

We recognize the need for efficient spectrum management. At the same time, we believe it is imperative that we follow the EXCOM stricture to not affect current and future GPS uses. To pursue this purpose, we strongly support "no more than 25% (1dB) noise degradation" that is the long accepted international standard for evaluating interference to GPS and similar systems.

Ligado has never agreed that this International Standard applies to their proposed use of the adjacent band. They have suggested that the major GPS manufacturers have agreed with their position. This is clearly untrue. Trimble, Deere, and Garmin have all recently responded with filings that specifically support use of the 25% degradation standard[1]. They explicitly reject Ligado's critique of this standard and Ligado's attempts to use other, unconventional criteria that would not protect all GPS uses.

We believe GPS users should be protected everywhere. But even if the nation decided to apply the 1 dB criterion to only 90% of the area surrounding Ligado transmitters, their new proposal must be rejected. Their revised ~10-watt maximum EIRP proposal far exceeds the power level that can be tolerated by the GPS-user community at the previous spacing of ~400 meters by a factor of over 2000.

We believe avoiding degradation over at least 90% of the region near Ligado transmitters is absolutely minimum protection for GPS receivers in each class. This would be a hypothetical 90% Protection Evaluation. This is not an endorsement of this level, since we would greatly prefer 100% protection. The DOT Adjacent Band Compatibility (ABC) study is the only validated test[2] to verify degradation at various received power levels.

Those results inform that, to insure degradation not exceed 10% of the Region (90% Protection) for *High Performance* receivers, either

[1] Comments filed on Ligado's May 31, 2018 Amended License Modification Application in Docket 11-109
Comments of Garmin International, Inc. July 9, 2018: "In its Amendment, Ligado again criticizes the use of a standard metric-a 1 dB decrease in a GPS device's carrier-to-noise-density ratio ("C/No") (the "1 dB Standard") – as a threshold determinant of harmful interference to a GPS receiver's operation." "As Garmin has documented extensively in the record, the 1 dB Standard is the long-established and appropriate determinant of harmful interference to GPS and other Radio Navigation Satellite Service (RNSS) receivers"
Comments of Trimble Inc. July 9, 2018: "To the extent that, in evaluating the Modification Applications, the Commission addresses the standard for determining the potential for harmful interference to Global Positioning System ("GPS") and Global Navigation Satellite System ("GNSS") devices and applications, it should dismiss Ligado's calls for the rejection of the long-established interference protection criterion for GPS/GNSS receivers of a 1 dB decrease in the Carrier-to-Noise Power Density Ratio ("C/No") and the proposed alternative use of key performance indicators ("KPIs")."
Comments of Deere and Company, July 9, 2018: "Deere nonetheless advises that its position with respect to Ligado's Amended Modification Applications must not be interpreted as acquiescence in or, in any way agreement with, Ligado's continued efforts to depart from long-accepted practice and establish a new metric for determining potential harm to GPS and other GNSS systems based on Key Performance Indicators ("KPIs"). Deere does not agree with this approach and reaffirms its staunch support for application of a one (1) dB decrease in Carrier-to-Noise Power Density ("C/N0") (the "1 dB Standard") as the appropriate metric for determining whether a GPS receiver has experienced harmful interference."
[2] National PNT Systems Engineering Forum (NPEF) GAP Analysis, March 5, 2018.

DRAFT Modified Memorandum (page 2 of 3) – Note: this version includes the typo fixes and edits discussed at the meeting

- Ligado maximum power **can be no more than 0.0036 Watts**, at the 400-meter spacing they had earlier planned. Tolerable power would be 3/10ths of 1 % of their proposed ~10 watts. (see appendix)

Or

- **The closest spacing of Ligado transmitters is 20000 meters**[3] (over 12 miles) for their proposed

Class of GPS Receiver	Bounding Degradation Radius for Receiver Class with 10W Transmitter (from ABC report – Appendix I)	Minimum Separation Between Ligado 10 Watt Transmitters (Meters) % Region Protected		
		90%	50%	10%
High Performance/ High Productivity (HPR)	3400 meters	20,481	8190	6104
Emergency Vehicles and General Navigation (GLN)	1045 meters	6295	2815	2098
General Aviation and Helicopters (GAV)	1040 meters	6265	2802	2088
Timing (TIM)	293 meters	1765	789	588
Cell (CEL)	9.5 meters	57	26	19

~10-watt power levels. (see table below for other classes)

While the GPS high performance receivers are the most sensitive to interference, they are also the most valuable. The recent PNT EXCOM study ascribed over 31B$ in annual benefits to this class alone.

As restrictive as these criteria are, they may need to be even more so if Ligado is to operate without unduly interfering in real-world conditions. When performing the calculations to arrive at these criteria, we did not consider the following points that probably impose greater restrictions:

- The aggregate noise created by transmissions from multiple towers,
- Reflections from the ground and buildings which can increase interference by a factor of 10 or more,
- The impact on PNT uses of newer GNSS signals, such as those from Europe's Galileo system,

[3] Separation to insure degradation not exceed 10% for other classes of receivers is in the following Chart (see appendix for explanation of ABC data that gives the Bounding Degradation Radius):

DRAFT Modified Memorandum (page 3 of 3) – Note: this version includes the typo fixes and edits discussed at the meeting

- Impacts on Military Users.

In addition, it is not reasonable that one interference source, Ligado, be allowed to use up the whole interference budget for GPS.

We believe there are further serious concerns about the impact of Ligado's proposed operations on special, and scientific users of GPS that should be fully explored, such as:

- Weather data and forecast,
- Unmanned Aerial Vehicles (UAVs)
- Space-based receivers.

This risk is far too great, and far too many questions remain for Ligado's proposal to be approved. While there are many broadband alternatives (Ligado would be a very small percentage of this national asset), there is only one GPS. Any impairment to current and future uses is clearly contrary to the national interest.

Therefore, implementation of their current, ~10-watt, operating scheme will create totally unacceptable interference for a great number of GPS users in the United States. In fact, despite power limits in their current amended application, it is possible they could be allowed to increase this power over time. This would be even more destructive to GPS uses.

This is the consensus of the PNTAB. We strongly recommend your opposition to the Ligado proposal.

Bradford W. Parkinson, Vice-chair

On behalf of the PNTAB

(Chairman and several other members recused to avoid any appearance of conflict)

* Data from the Department of Transportation's Adjacent Band Compatibility Study was used to reach these conclusions. This study, the third formal examination of this issue by the administration, met all our criteria for a credible effort.

** Calculations and graphs used to support these results are provided in the attachment.

There was a motion to vote on approval of the modified (i.e. with the edits discussed above) memorandum. It was seconded and a vote was carried out:

Vote on the approval of the modified memorandum for submission to the PNT EXCOM		
John Stenbit		Recused
Bradford Parkinson	Concur	
James E. Geringer	Concur	
Admiral Thad Allen	Concur	
Penina Axelrad	Concur	
John Betz	Concur	
Dean Brenner		Recused
Scott Burgett		Recused
Joseph D. Burns		Recused
Martin C. Faga		
Ronald R. Hatch		Recused
Larry James	Concur	
Peter Marquez	Concur	
Terence J. McGurn		Recused

Timothy A. Murphy		Recused
T. Russell Shields	Concur	
Gerhard Beutler	Concur	
Sergio Camacho-Lara	Concur	
Ann Ciganer		Recused
Arve Dimmen	Concur	
Dana Goward	Concur	
Matt Higgins		
Refaat M. Rashad	Concur	

J.J. Miller: We have more than 50% +1 concurrence so the motion carries. The PNTAB will complete editorial revisions (i.e. non-substantive changes), sign it, and submit the recommendation to the PNT EXCOM.

Dr. Parkinson noted, for the record, that there were no “Non-Concurs’ to the motion or proposed actions.

* * *

Wrap up

Dr. Parkinson noted this has been the result of an enormous amount of effort, and he wished to thank everyone involved.

Mr. Miller concluded by also thanking the meeting support staff for their efforts.

* * *

Gov. Geringer adjourned the Intersession Meeting 21A of the National Space-Based PNT Advisory Board at 2:17 p.m.

* * *

Editorial note:

The spectrum recommendation to the PNT EXCOM was issued on August 10, 2018, and is available at:

https://www.gps.gov/governance/advisory/recommendations/2018-08-letter-to-excom.pdf

For completeness, the letter is also included in Appendix E of these minutes. The letter's enclosure with supporting calculations and graphs are Dr. Parkinson's briefing slides for this meeting.

Appendix A: PNT Advisory Board Membership

Biographies available at: https://www.gps.gov/governance/advisory/members/

Special Government Employees

SGE's are experts from industry or academia who temporarily receive federal employee status during Advisory Board meetings.

- **John Stenbit** (Chair), former Assistant Secretary of Defense
- **Bradford Parkinson** (Vice Chair), Stanford University
- **James E. Geringer** (Second Vice Chair), Environmental Systems Research Institute (ESRI), former Governor of Wyoming
- **Thad Allen**, Booz Allen Hamilton
- **Penina Axelrad**, University of Colorado Boulder
- **John Betz**, MITRE
- **Dean Brenner**, Qualcomm
- **Scott Burgett**, Garmin International
- **Joseph D. Burns**, Sensurion Aerospace
- **Martin C. Faga**, private consultant (retired MITRE)
- **Ronald R. Hatch**, private consultant (retired John Deere)
- **Larry James**, Jet Propulsion Laboratory
- **Peter Marquez**, Andart Global
- **Terence J. McGurn**, private consultant (retired CIA)
- **Timothy A. Murphy**, The Boeing Company
- **T. Russell Shields**, Ygomi

Representatives

Representatives are individuals designated to speak on behalf of particular interest groups.

- **Gerhard Beutler**, International Association of Geodesy (Switzerland)
- **Sergio Camacho-Lara**, United Nations Regional Education Center of Science and Space Technology - Latin America and Caribbean (Mexico)
- **Ann Ciganer**, GPS Innovation Alliance (U.S.)
- **Arve Dimmen**, Norwegian Coastal Administration (Norway)
- **Dana Goward**, Resilient Navigation and Timing Foundation (U.S.)
- **Matt Higgins**, International GNSS Society (Australia)
- **Refaat M. Rashad**, Arab Institute of Navigation (Egypt)

Executive Director

The membership of the Advisory Board is administered by a designated federal officer appointed by the NASA Administrator:

- **James J. Miller**, Executive Director

Special Counselors

- **Mr. Kirk Lewis**, Institute for Defense Analyses (IDA)
- **Dr. Tom Powell**, The Aerospace Corporation

Appendix B: Presentations & Documentation

Presentations are available at: https://www.gps.gov/governance/advisory/meetings/2018-08/

1. Introduction / PNTAB Topics Paper Briefing / All PNTAB Members
2. Analysis of Ligado May 2018 Proposal and Assessment - August 2018 / B. Parkinson

The PNTAB Spectrum Recommendation to the PNT EXCOM was issued on August 10, 2018. It is available at: https://www.gps.gov/governance/advisory/recommendations/2018-08-letter-to-excom.pdf

Appendix C: Callers & WebEx Attendance

Audio: 213 participants

WebEx Logins:

RZ	Rebecca Zia (int) (Host, me)
AS	Aaron Sankin (ext)
AC	Adam Chao (ext)
AG	Adam Greenstone (int)
AR	Anand Raghu (ext)
AR	ANTHONY RUSSO (int)
BP	Bradford Parkinson (ext)
BL	Brenda Lyons (int)
BW	Brian Woo (ext)
CC	Charlene Chen (ext)
C	chris (ext)
CH	Chris Hegarty (ext)
CN	Chris Nolter (ext)
CW	chris watson (ext)
CH	Curtis Hay (General Motors) (ext)
DG	Dana A Goward (ext)
D	Dave (ext)
DG	David Grossman (ext)
DP	David Pooley (HQ AFSPC) (ext)
DD	Dee Ann Divis (ext)
DM	Drew McKnight (ext)

E	ec.galileo (ext)
ED	Ed Drocella (ext)
H	Hadi (ext)
IK	Igor Kertzman (ext)
JP	James Platt (ext)
JD	JENNIFER DONALDSON (int)
J	Jihye (ext)
JD	Jimmy Durden (int)
JB	Joe Burns (ext)
JB	John Betz (ext)
JH	John Higgins (ext)
JK	Jonathan Krautmann (ext)
LL	L Kirk Lewis (ext)
LP	Lisa Perdue (ext)
L	Louis (ext)
LL	Lt Col Steve Lewis (ext)
MD	Marc DuBois (ext)
MK	Michael Kerlan (ext)
MS	Michael Striffolino (ext)
MM	Michal Mati (ext)

NL	Nick LaSorte (NTIA) (ext)
N	nishant (ext)
NK	Norman Knight (int)
RC	Robert Crane (ext)
RH	Ron Hatch (ext)
RH	Ron Hatch (ext)
RS	Russ Shields (ext)
SV	steven vogel (ext)
T	Terry (ext)
TM	Tim Murphy (ext)
VG	Valerie Green (ext)
VS	VICTOR SPARROW (int)
WB	will bruns (ext)
WN	WILLIAM NOTLEY (int)
WW	William Wang (ext)

Appendix D: Acronyms and Definitions

$	U.S. Dollar Currency
ABC	DOT GPS Adjacent Band Compatibility Study
CRECTEALC	Regional Center for Space Science and Technology Education for Latin America and Caribbean, affiliated to the United Nations
dB	decibel
dBm	Power ratio is expressed in decibels (dB) with reference to one milliwatt (mW)
DOT	Department of Transportation
EIRP	Effective Isotropic Radiated Power
eLoran	Enhanced Loran
ERP	Earth Rotation Parameters
ETSI	European Telecommunications Standards Institute
EXCOM	Executive Committee
FACA	Federal Advisory Committee Act
FCC	Federal Communications Commission
FRN	Federal Register Notice
Galileo	European GNSS
GLONASS	Russian GNSS
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS III	GPS Block III SVs 1-10
GPS IIIF	GPS Block III SVs 11-32
GRACE	Gravity Recovery and Climate Experiment
HPR	High Performance Receivers
Hz	Hertz
IAG	International Association of Geodesy
ICG	International Committee on GNSS
IDM	Interference Detection and Mitigation
IGS	International GNSS Service
ITRF	International Terrestrial Reference Frame
ITU	International Telecommunications Union
km	kilometer
L1 C/A	1st GPS Civil Signal
L1C	4th GPS Civil Signal (interoperable with Galileo)
L2C	2nd GPS Civil Signal (commercial)
L5	3rd GPS Civil Signal (safety-of-life / aviation)
LEO	Low Earth Orbit
Ligado	Ligado Networks is an American satellite communications company developing a satellite-terrestrial network to support 5th Generation (5G) and IoT applications in North America.

Loran	Long-Range Aid to Navigation (typical refers to the system up through Loran-C, now decommissioned in the U.S)
LRA	Laser Retro-reflector Array
m	meters
M-Code	GPS encrypted signal
MGUE	Military GPS User Equipment
MHz	Megahertz
MSS	Mobile Satellite Services
mW	milliwatt
NASCTN	National Advanced Spectrum and Communications Test Network
NASA	National Aeronautics and Space Administration
NCO	National Coordination Office (located at the Department of Commerce in Washington, D.C.)
NSpC	National Space Council
NTIA	National Telecommunications and Information Administration
OCS	GPS Operational Control Segment
OCX	Modernized GPS Operational Control System
PNT	Positioning, Navigation, and Timing
PNTAB	National Space-Based PNT Advisory Board
POD	Precise Orbit Determination
RAIM	Receiver Autonomous Integrity Monitoring
RNSS	Radio Navigation Satellite Service
SGE	Special Government Employee
SV	GPS satellite vehicle
U.S.	United States
UAV	Unmanned Aerial Vehicle
UN	United Nations
U.S.	United States of America
USAF	U.S. Air Force
USGC	U.S. Coast Guard
UTC	Universal Coordinated Time
V2V	Vehicle-to-Vehicle
W	Watt
kW	kilowatt
WRC	World Radiocommunications Conference

Appendix E: 10 August 2018 Spectrum Recommendation to the PNT EXCOM

SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

August 10, 2018

Honorable Patrick M. Shanahan, Deputy Secretary of Defense
Honorable Jeffrey A. Rosen, Deputy Secretary of Transportation
Co-Chairs, National Executive Committee for Space-based Positioning, Navigation and Timing
Herbert C. Hoover Building, Room 2518
1401 Constitution Ave., NW
Washington, D.C. 20230

Subject: PNT Advisory Board (PNTAB) Recommendation to PNT Executive Committee (EXCOM) Regarding Latest Ligado Proposal

Dear EXCOM Chairs and Members,

On the 31st of May 2018, Ligado Networks amended its Federal Communications Commission (FCC) license modification application. They have proposed reducing initial transmitter power to ~ 10 watts and abandoning use of the band closest to Global Positioning System (GPS) frequencies. Unfortunately, they have not specified transmitter spacing nor do they propose a feasible scheme for monitoring their interference levels, expecting the GPS user to contact them instead.

We recognize the need for efficient spectrum management. At the same time, we believe it is imperative that we follow the PNT EXCOM stricture to not adversely affect current and future GPS uses. To pursue this purpose, we strongly support "no more than 25% (1 dB) noise degradation", which is the long accepted international standard for evaluating interference to GPS and similar systems.

Ligado has never agreed that this international standard applies to their proposed use of the adjacent band. They have suggested that the major GPS manufacturers have agreed with their position. This is clearly untrue. Trimble, Deere, and Garmin have all recently responded with filings that specifically support use of the 25% degradation standard[1]. They explicitly reject Ligado's critique of this standard and Ligado's attempts to use other, unconventional criteria that would not protect all GPS uses.

We believe GPS users should be protected everywhere. But even if the nation decided to apply the 1 dB criterion to only 90% of the area surrounding Ligado transmitters, their new proposal must be rejected. Their revised ~ 10 watt

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[1] Comments filed on Ligado's May 31, 2018 Amended License Modification Application in Docket 11-109:
Comments of Garmin International, Inc. July 9, 2018: "In its Amendment, Ligado again criticizes the use of a standard metric-a 1 dB decrease in a GPS device's carrier-to-noise-density ratio ("C/No") (the "1 dB Standard") – as a threshold determinant of harmful interference to a GPS receiver's operation." "As Garmin has documented extensively in the record, the 1 dB Standard is the long-established and appropriate determinant of harmful interference to GPS and other Radio Navigation Satellite Service (RNSS) receivers"
Comments of Trimble Inc. July 9, 2018:"To the extent that, in evaluating the Modification Applications, the Commission addresses the standard for determining the potential for harmful interference to Global Positioning System ("GPS") and Global Navigation Satellite System ("GNSS") devices and applications, it should dismiss Ligado's calls for the rejection of the long-established interference protection criterion for GPS/GNSS receivers of a 1 dB decrease in the Carrier-to-Noise Power Density Ratio ("C/No") and the proposed alternative use of key performance indicators ("KPIs")."
Comments of Deere and Company, July 9, 2018: "Deere nonetheless advises that its position with respect to Ligado's Amended Modification Applications must not be interpreted as acquiescence in or, in any way agreement with, Ligado's continued efforts to depart from long-accepted practice and establish a new metric for determining potential harm to GPS and other GNSS systems based on Key Performance Indicators ("KPIs"). Deere does not agree with this approach and reaffirms its staunch support for application of a one (1) dB decrease in Carrier-to-Noise Power Density ("C/N_0") (the "1 dB Standard") as the appropriate metric for determining whether a GPS receiver has experienced harmful interference."

maximum Effective Isotropic Radiated Power (EIRP) proposal far exceeds the power level that can be tolerated by the GPS-user community at the previous spacing of ~400 meters by a factor of over 2,500.

We believe avoiding degradation over at least 90% of the region near Ligado transmitters is the absolute minimum protection for GPS receivers in each class. This would be a hypothetical 90% Protection Evaluation. This is not an endorsement of this level since of course, all users would prefer 100% protection. The Department of Transportation (DOT) Adjacent Band Compatibility (ABC) study is the only validated test[2] to verify degradation at various received power levels.

Those results inform that to insure degradation not exceed 10% of the Region (90% Protection) for *High Performance* receivers, either:

- **Ligado maximum power can be no more than .0036 watts at the 400-meter spacing they had earlier planned.** Tolerable power would be 3/10ths of 1% of their proposed ~ 10 watts. (see enclosure)

  Or

- **The closest spacing of Ligado transmitters is 20,000 meters[3]** (over 12 miles) for their proposed ~ 10 watt power level (see table below for other receiver classes)

Class of GPS Receiver	Bounding Degradation Radius for Receiver Class (with 10W Transmitter from ABC report – Appendix I)	*Minimum Separation* Between Ligado 10-Watt Transmitters (Meters)		
		% Region Protected		
		90%	50%	10%
High Performance/ High Productivity (HPR)	3400 meters	20,481	8190	6104
Emergency Vehicles and General Navigation (GLN)	1045 meters	6295	2815	2098
General Aviation and Helicopters (GAV)	1040 meters	6265	2802	2088
Timing (TIM)	293 meters	1765	789	588
Cell (CEL)	9.5 meters	57	26	19

While the GPS high performance receivers are the most sensitive to interference, they are also the most valuable. The most recent PNT EXCOM study ascribed over $31 Billion in annual benefits to this class alone[4].

As restrictive as these criteria are, they may need to be even more so if Ligado is to operate without unduly interfering in real-world conditions. When performing the calculations to arrive at these criteria, we did not consider the following points that would impose greater restrictions:

- The aggregate noise created by transmissions from multiple towers
- Reflections from the ground and buildings which can increase interference by a factor of 10 or more
- The impact on PNT uses of newer GNSS signals, such as those from Europe's Galileo GNSS
- Impacts on Military Users

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[2] National PNT Systems Engineering Forum (NPEF) GAP Analysis, March 5, 2018

[3] Separation to insure degradation not exceed 10% for other classes of receivers is in the following Chart (see enclosure for explanation of ABC data that gives the Bounding Degradation Radius)

[4] The Economic Value of GPS: Preliminary Assessment, June 11, 2015. https://www.gps.gov/governance/advisory/meetings/2015-06/leveson.pdf

In addition, it is not reasonable that one interference source, Ligado, be allowed to use up the whole interference budget for GPS.

We believe there are further serious concerns about the impact of Ligado's proposed operations on special, and scientific users of GPS that should be fully explored, such as:

- Unmanned Aerial Vehicles (UAVs)
- Weather data and forecast
- Space-based receivers

This risk is far too great, and far too many questions remain, for Ligado's proposal to be approved. While there are many broadband alternatives (Ligado would be a very small percentage of this national asset), there is only one GPS. Any impairment to current and future uses is clearly contrary to the national interest.

Therefore, implementation of their recently proposed ~ 10 watt operating scheme will create totally unacceptable interference for a great number of GPS users in the United States. In fact, despite power limits in their current amended application, it is probable they could still be allowed to increase this power over time. This would be even more destructive to GPS users.

This is the technical consensus of the PNTAB. **We strongly recommend your opposition to the Ligado proposal.**

Data from the DOT's ABC Study was used to reach these conclusions. This study, the third formal examination of this issue by the PNT EXCOM, met all scientific criteria for a credible national evaluation. Calculations and graphs used to support these results are provided in the attachment.

Sincerely,

Bradford W. Parkinson

____

Bradford W. Parkinson, 1st Vice-Chair, on behalf of the PNTAB
(PNTAB Chair and some members recused to avoid any appearance of a conflict of interest)

Enclosure: Supporting calculations and graphs

cc:
- PNT EXCOM Departments and Agencies
- Hon. Jim Bridenstine, NASA Administrator
- Dr. Scott Pace, Executive Secretary, National Space Council (NSpC)
- Hon. David Redl, Assistant Secretary for Communications and Information and Administrator, National Telecommunications and Information Administration (NTIA)
- Mr. Julius Knapp, Chief, Office of Engineering and Technology, FCC
- Mr. Harold "Stormy" Martin, Director, PNT National Coordination Office (NCO)