SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

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

Thirtieth Meeting

April 24-25, 2024

The Antlers Hotel

Colorado Springs, Colorado

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

Mr. James J. Miller, *Executive Director*

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Agenda – Day 1

(Presentations Available at: https://www.gps.gov/governance/advisory/)
(Livestream: https://www.youtube.com/channel/UCPHKLQqvVFZdJFkis5AAIBg)

Wednesday, April 24, 2024

Times indicated in U.S. Central Time

9:00-9:05 (5 min)	**BOARD CONVENES** *Call to Order, Logistics, & Announcements*	Mr. James J. Miller, *Executive Director, National Space-based PNT Advisory Board, NASA HQ*
9:05-9:25 (20 min)	Welcome & Introductions – Opening Remarks from Chair – Meeting Goals & Objectives: PTA Focus	ADM Thad Allen (USCG, ret.), *Chair;* Dr. Brad Parkinson, *1st Vice Chair;* Hon. Jim Geringer, *2nd Vice Chair*
9:25-10:15 (50 min)	Subcommittee Highlights: (10 min each) – Communications & External Relations (CER) – Education & Science Innovation (ESI) – Emerging Capabilities, Applications, & Sectors (ECAS) – International Engagement (IE) – Strategy, Policy, & Governance (SPG)	Subcommittee Chairs – Mr. Dana Goward – Dr. Jade Morton – Dr. Frank van Diggelen – Mr. Matt Higgins – Hon. Jeff Shane
10:15-10:30	**BREAK**	
	Focus of the Day: PTA Is Urgently Needed; Near-Term Improvements Are Possible	
10:30-11:00 (30 min)	Motivation for Better PTA	Lt Gen Michael Hamel (USAF, ret.), *PTA Subcommittee Member*
11:00-11:30 (30 min)	PTA Challenges: Overview of How to Overcome Them	Dr. John W. Betz, *PTA Subcommittee Chair*
11:30-12:30	**LUNCH *(Summit I Room)***	
	Theme 1: Protecting GPS/GNSS Use	
12:30-12:40 (10 min)	Protect Overview	Dr. Thomas Powell, *PTA Subcommittee Vice Chair*
12:40-1:00 (20 min)	Smartphone-Based Interference Detection	Dr. Dennis Akos, *University of Colorado Boulder*
1:00-1:20 (20 min)	FCC Enforcement Bureau's Role in Protect	Mr. Michael Rhodes, *FCC Enforcement Bureau*
1;20-1:30 (10 min)	Protect Summary	Dr. Thomas Powell, *PTA Subcommittee Vice Chair*
1:30-1:45 (15 min)	Discussion of Protect Theme	All members, led by Chair
1:45-2:00	**BREAK**	
	Theme 2: Toughening GPS/GNSS	
2:00-2:30 (30 min)	Toughen Introduction	Mr. Timothy Murphy, *PTA Subcommittee Vice Chair*
2:30-3:00 (30 min)	Pragmatic Steps toward Toughen	Mr. Logan Scott, *PTA Subcommittee Member*
3:00-3:15 (15 min)	Discussion of Toughen Theme	All members, led by Chair
3:15-3:30	**BREAK**	
	Theme 3: Augmenting GPS/GNSS	
3:30-3:45 (15 min)	Augment Introduction	Dr. John W. Betz, *PTA Subcommittee Chair*
3:45-4:25 (40 min)	Augment Positioning, Navigation, and Timing	Mr. Logan Scott, *PTA Subcommittee Member* Mr. Scott Burgett, *PTA Subcommittee Member*
4:25-4:30 (5 min)	Augment Summary	Dr. John W. Betz, *PTA Subcommittee Chair*
4:30-4:45 (15 min)	Discussion of Augment Theme	All members, led by Chair
4:45-5:00 (15 min)	PTA Way Ahead Summary	Dr. John W. Betz, *PTA Subcommittee Chair*
5:00-6:00 (1 hour)	Member Deliberations, Key Highlights, and Closing Thoughts from Day 1	All members, led by Chair
6:00	**ADJOURNMENT**	

Agenda – Day 2

(Presentations Available at: https://www.gps.gov/governance/advisory/)
(Livestream: https://www.youtube.com/channel/UCPHKLQqvVFZdJFkis5AAIBg)

Thursday, April 25, 2024

Times indicated in U.S. Mountain Time Zone

9:00-9:05 (5 min)	**BOARD CONVENES** *Call to Order*	Mr. James J. Miller, *Executive Director, National Space-Based PNT Advisory Board, NASA HQ*
9:05-9:15 (10 min)	PNTAB Leadership Observations from Day 1	ADM Thad Allen (USCG, ret.), *Chair;* Dr. Brad Parkinson, *1st Vice Chair;* Hon. Jim Geringer, *2nd Vice Chair*
	Theme 4: Comparing Satnav Capabilities	
9:15-10:15 (1 hr)	Discussion Comparing Capabilities of Different Satellite-Based Navigation and Timing Systems	All members, led by Dr. Brad Parkinson, *1st Vice Chair*
10:15-10:30	**BREAK**	
	Theme 5: Updates from International Members & Representatives	
10:30-12:00 (1 hr 30 min)	Countries/Associations – Australia – Croatia – United Kingdom – Consumer Technology Association (CTA) – Resilient Navigation and Timing (RNT) Foundation – International Air Transport Association (IATA)	Representatives (15 min each) – Mr. Matt Higgins – Prof. Renato Filjar – Prof. Terry Moore – Mr. David J. Grossman – Mr. Dana Goward – Hon. Jeff Shane
12:00-12:25 (25 min)	Roundtable Discussion & Next Steps	All members, led by Chair
12:25-12:30 (5 min)	Wrap-Up – Determine date & venue for next meeting	ADM Thad Allen (USCG, ret.), *Chair;* Dr. Brad Parkinson, *1st Vice Chair;* Hon. Jim Geringer, *2nd Vice Chair*
12:30-1:30 (1 hr)	**LUNCH – Working as needed *(Summit I Room)***	
1:30	**ADJOURNMENT**	

Table of Contents

Executive Summary

The National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board, or PNTAB, held its 30th public meeting on April 24-25, 2024, at the Antlers Hotel in Colorado Springs, Colorado. The meeting was held under the provisions of the Federal Advisory Committee Act (FACA), with appropriate public notification & documentation for the public record. A fact-finding preparatory meeting was held on April 23.

This report summarizes the discussions & deliberations during this meeting. Snapshots of the briefings presented have also been embedded. Links to the briefings & livestream recordings are embedded in the meeting agenda (pp 3-4).

The meeting focused on the topic of Protecting, Toughening, and Augmenting (PTA) the Global Positioning System (GPS), and other Global Navigation Satellite Systems (GNSS), for all users. Three new recommendations we approved at this meeting.

On July 19, ADM Allen (Chair) signed a Memorandum to the Defense and Transportation Deputy Secretaries, also co-chairs of the National-Space-Based PNT Executive Committee (EXCOM) co-chairs, summarizing the findings, deliberations, and recommendations (see pp 8-11).

The next PNTAB meeting is scheduled for Dec. 5-6, 2024, in Redondo Beach, California.

July 19, 2024, Memorandum from Adm Allen to DoD/DOT Deputy Secretaries

SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

19 July 2024

MEMORANDUM

FROM: Thad Allen, Admiral (USCG, Ret), Chair, National Space-based Positioning, Navigation, and Timing (PNT) Advisory Board

TO: Honorable Kathleen H. Hicks
Deputy Secretary, Department of Defense
Co-Chair, National Space-based PNT Executive Committee

Honorable Polly E. Trottenberg
Deputy Secretary, Department of Transportation
Co-Chair, National Space-based PNT Executive Committee

SUBJECT: Report of the 30th National Space-based PNT Advisory Board Meeting and Associated Activities

Madam Co-Chairs,

The National Space-based PNT Advisory Board (PNTAB) held its 30th session on April 24-25, 2024, in Colorado Springs. The meeting was held under the provisions of the Federal Advisory Committee Act, with appropriate public notification and documentation for the public record. At this meeting, the Board reaffirmed the recommendations in my January 27, 2023, report and approved three additional recommendations (see Enclosure). The Colorado Springs session was guided by the Board's Protect, Toughen, and Augment (PTA) of the Global Positioning System (GPS) for all users, our longstanding framework to organize our advice. The scope of our work continues to broaden to consider the evolving capabilities of: (1) all Global Navigation Satellite Systems (GNSS), (2) complementary PNT technologies (terrestrial and space-based), and (3) ongoing policy, strategy, and governance challenges presented by global GNSS competition and execution of the GPS program. I delayed this report as further context was provided at the EXCOM's Executive Steering Group (ESG) meeting held on May 29, 2024, and in subsequent classified briefings by the 2nd Space Operations Squadron (2SOPS).

PNTAB Chair's Bottom Line Up Front (BLUF)

- Reliable and resilient PNT (space-based and terrestrial) faces a broad spectrum of risks and challenges. Regarding GPS specifically and U.S. PNT generally, existing policies, resourcing, and governmental program management are fragmented and dispersed across multiple departments and agencies. While GPS is a Dept. of Defense (DoD) program, the well-intentioned framework of an EXCOM to manage the interrelation of military and civil users is ineffective and non-responsive to existing and emerging risks regarding not only GPS, but the larger spectrum of U.S. PNT capabilities. Space Policy Directive 7 (SPD-7), U.S. Space-based PNT Policy, must be revisited and the term "space-based" should be removed from its title.

- GPS and associated PNT capabilities are an essential component of America's critical infrastructure, supply chains and everyday life, particularly in the provision of timing services. It has become in effect a public utility, not unlike rural electrification or broadband access, except that the provider is DoD. DoD, through the Army Corps of Engineers, maintains the Nation's commercial ports and waterways infrastructure through a clear and resourced structure. However, GPS and other U.S. PNT capabilities lack a cohesive national governance structure related to the provision and civil use of these services. America's continued over-reliance on GPS for PNT makes critical infrastructure and applications vulnerable to a variety of well documented accidental, natural, and malicious threats.

- At the same time, a broad spectrum of both space and terrestrial based capabilities are emerging that offer potential for greater PNT resiliency and added capability. These numerous technologies are rapidly evolving and, in some cases, competing. But as noted above, there is currently no adequate structure in the federal government to assess, prioritize and acquire capability that improves PNT resiliency and enhances capability. The "default setting" is the GPS program managed by DoD. While the PNTAB is the designated advising entity for the federal government regarding civil users, there are limits in our ability to assess and make recommendations.

- There are significant reasons to be concerned. GPS is now lagging the capabilities found in other GNSSs – notably Galileo (European Union) and BeiDou (China). In the case of BeiDou, the system's enhanced resiliency and capability should be considered an element of "soft power and an element of great power competition".

- The Administration must revisit SPD-7 to establish a clear strategy, bolstered by a revised governance framework with clear roles and responsibilities extending to the creation of programs of record with resourcing plans to execute agency assigned responsibilities. To achieve this, a revised SPD-7 should include the locus of authority and accountability for PNT decision-making beyond DoD GPS program management and be capable of addressing the spectrum of challenges that have evolved, and continue to evolve, with the ubiquity of these services across technology and society for civil users.

Confronting New Challenges

Our fact-finding activities and deliberations over the past year have primarily focused on the evolving civil space-based and terrestrial PNT capabilities of the U.S. and other nations. There can be no questioning the importance of U.S. leadership in establishing space-based PNT as a global utility. GPS was the world's first truly advanced and precise GNSS. Moreover, the decisions by Presidents Reagan and Clinton to make GPS available free of charge and with full accuracy to all users made GPS one of America's most profoundly important gifts to the world. Those decisions established a precedent that international GNSS providers now follow and made GPS the standard against which other GNSS are compared. Those decisions also democratized navigation and timing.

Our country now faces new challenges. Domestically, we rely almost exclusively on GPS as the principal source of PNT. As noted above, it has also become a public utility. A great many incidents over the past several years have left no doubt that the system is vulnerable to disruption, both inadvertent and intentional. Because so much of our country's critical infrastructure and supply chains rely on GPS, that infrastructure is itself vulnerable to disruption. The Board's most recent meeting was devoted to an exploration of ways to protect, toughen, and augment GPS in the interest of greater reliability for civil users, and produced recommendations for near-term mitigation.

The Board has also been monitoring the capabilities of other GNSSs. We find that there are capabilities in those other systems that GPS does not have, and we worry that a growing gap could call into question America's traditional global standing as the default provider of space-based PNT.

I intend these periodic reports to document what will be a sustained, ongoing effort by the Board to identify how U.S. PNT capabilities continue to compare with or vary from those of other providers, as well as the risks and vulnerabilities to civil users associated with any perceived gaps. This report provides an initial framework we intend to use and to document our progress and guide future efforts to obtain "input from state and local governments, industry, and academia on developments in the application of space-based PNT technologies and advise the EXCOM on policy and service impacts." (SPD-7, section 5(d)(vii)). The framework was presented as a matrix at our Colorado Springs meeting to identify and compare the capabilities and attributes of the leading GNSSs (see Enclosure). It lists some important features of other GNSSs that are not yet available on GPS. The matrix will be populated, revised, updated, and reported to you as our work continues. Although a "work in progress", it is the Board's hope that this framework will be of use to the EXCOM in the preparation of its report to the National Space Council early next year pursuant to SPD-7 (section 5(d)(iii)), "assessing current and planned civil space-based PNT services and whether they are projected to remain competitive with foreign space-based PNT services."

Based on our initial working comparison, we have concluded that our PNT capabilities have fallen behind those of other GNSSs, notably the European Union's Galileo and China's BeiDou. Efforts to date show a troubling shortfall in GPS's greater vulnerability to jamming and spoofing than systems featuring more robust signals. For example,

- GPS's long-planned L5 signal, if made operational, would help to close that gap. Accordingly, the Board recommends setting the L5 signal healthy for non-safety-of-life use and encouraging adoption of multifrequency and dual system receivers, specifically GPS and our allies' Galileo.

- User access to better antennas would reduce further GPS vulnerability to disruption, but the International Traffic in Arms Regulations continue to restrict access to such equipment. In the Board's view, there is no clear justification today for such restrictions.

These are two examples regarding GPS's capabilities in the framework that the Board is bringing to the EXCOM's attention. Let me be clear, while this is a work in progress it is also meant to be a cause for greater involvement by the EXCOM principals.

Conclusion

In addition to noting the apparent superiority of some features of other GNSSs and the implications for U.S. leadership, the Board considered possible reasons why GPS has lagged. Briefly stated, our conclusion is that PNT in general and GPS in particular have not been accorded their rightful prominence in the national policy agenda. Existing policies – set forth primarily in Executive Order 13905 and SPD-7 – while properly identifying the general requirements of sound PNT policy – do not attach the appropriate priority or urgency to the sustainment of U.S. leadership. Moreover, decision-making regarding GPS is distributed among many agencies and is, in every case, the subject of coordination and consensus. Despite the way in which some adversaries have used GNSS as a tool in the great power competition that defines today's geopolitics, we have been unable to discern any clear strategy for restoring the U.S. to its long-standing leadership position in this essential sector.

These findings were reinforced just earlier this year by the release of the National Security Memorandum on Critical Infrastructure Security and Resilience (NSM-22, April 30, 2024). We were surprised to discover that GPS is nowhere mentioned in that important document. We fail to understand why, despite its pivotal importance to so many sectors of economic activity and to America's strategic well-being, GPS is not yet recognized as critical infrastructure.

Simply put, the Board believes that the 20-year-old framework for GPS governance and the current policy statements establish neither the priority that the system deserves nor sufficiently clear accountability for its performance.

The Board believes it is time to take a fresh look at our approach to PNT governance and establish a clear strategy for re-establishing an unquestioned position of leadership for the U.S. To be successful, such a strategy requires a governance structure characterized by clearer authority and accountability. Ideally, the administration should propose legislation to Congress that would support this goal with a clear mandate (authorization) and resources (appropriations) adequate to the task.

Your PNT Advisory Board represents GPS's diverse, interconnected, domestic and international PNT user base. Our most compelling mission is to provide to the EXCOM meaningful advice that: (1) is received and considered, (2) results in policy, operational, and funding actions that address risk and reduce capability gaps, and thus (3) ensures the availability to civil and military users reliable PNT in the interest of America's economy, its national security, and its standing in the world.

We look forward to advising you personally at the September 12, 2024, EXCOM meeting.

Respectfully,

Adm (USCG, ret.) Thad Allen, Chair, PNTAB

Enclosure:
- Recommendations Approved at the PNTAB-30 Session
- Table, "Comparing Advanced GNSS Capabilities and Plans"

CC:
- Chirag Parikh, Executive Secretary, National Space Council
- Bill Nelson, Administrator, NASA
- Pamela Melroy, Deputy Administrator, NASA
- Ken Bowersox, Associate Administrator, Space Operations Mission Directorate, NASA
- Kevin Coggins, Deputy Associate Administrator for Space Communications and Navigation, NASA
- James J. Miller, Executive Director, PNTAB, NASA
- Kevin M. Mulvihill, Deputy Chief Information Officer, DoD
- Robert Hampshire, Deputy Assistant Secretary for Research and Technology, DOT
- Karen Van Dyke, Director, PNT/Spectrum Management, Office of Assistant Sec. for Research & Tech., DOT
- Harold Martin, Director, PNT National Coordination Office – for distribution to PNT EXCOM departments & agencies

Enclosure:

Recommendations Approved at the PNTAB-30 Session

- **PNT30-01:** PNT EXCOM direct the U.S. Space Force to establish a way for "good enough" monitoring of GPS L5 signals using existing capabilities and set L5 signals healthy subject to a "use at your own risk" caveat, just as is done with L2C today. We recommend establishing a deadline of September 2024.
- **PNT30-02**: PNT EXCOM direct Federal Chief Information Officers to acquire and install multifrequency dual-system (GPS-Galileo) receivers to complement GPS use. The Department of Transportation and the Department of Homeland Security should actively encourage critical infrastructure users to adopt multifrequency dual-system (GPS-Galileo) receivers.
- **PNT30-03:** PNT EXCOM assign a lead agency and single individual with clear responsibility and authority for the end-to-end prompt detection, characterization, and removal of significant sources of interference to GNSS in the U.S.

Comparing Advanced GNSS Capabilities and Plans

PNT Sources & Modernization Efforts			
	United States	China	
Global Navigation Satellite System[1]	GPS	BeiDou	
Low Earth Orbit - based PNT Satellites	RDT&E by govt and industry Satelles timing (fee-based)	Deployment on-going[2]	
Terrestrial Broadcast	None deployed	eLoran in east and offshore	eLoran being installed in the west[3]
Fiber-based timing	Some major telecoms have deployed	Comprehensive national program w/ 295 timing centers, 20,000km fiber[4]	
Authentication/ integration of timing*	National Guard NITRO pending cancellation	National system being implemented[5]	
*China's terrestrial timing network is designed to integrate space-based, terrestrial broadcast, and fiber-transmitted time in a coherent and consistent architecture.			

Green = Most advanced feature, or national system funded and being completed

Yellow = Less capable, or some efforts in progress but no national system planned

Red = No national capability, none planned

[1] Chairman's letter Jan 2023 and Board's preliminary GNSS comparison matrix for GPS, BeiDou, and Galileo
[2] Numerous announcements, papers. See for example presentation at UNOOSA
[3] Numerous Chinese academic papers, several media announcements see for example: "The Paper – Accelerate construction High-precision, Ground-based Timing System"
[4] National Time Service Center, Chinese Academy of Sciences
[5] Ibid 3 & 4. Strategy outlined in presentation at 2019 Stanford PNT Symposium

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Session of Wednesday, April 24, 2024

Board Convenes
James J. Miller, *Executive Director, PNTAB; National Aeronautics and Space Administration (NASA)*

Mr. Miller provided some introductory remarks.

Welcome everyone to the 30th PNT Advisory Board advisory meeting since 2007, and our first meeting being held in beautiful Colorado Springs. ADM Thad Allen (U.S. Coast Guard, ret.), our chair, is unable to participate in person, however he is with us in spirit, and may join us virtually this morning if his schedule allows. Therefore, Dr. Brad Parkinson will Chair today's meeting on his behalf.

The focus of the meeting today is the board's long-standing program to Protect, Toughen, and Augment GPS and GNSS for all users. As such, the meeting agenda was organized by our member Dr. John Betz, the chair of our PTA subcommittee, and so we would like to recognize the contributions of him and his team as we progress through today's agenda.

As a reminder, 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.

We also strive to post all briefings within 24 hours of their presentation, and several may be posted already thanks to the good work of our colleague at the U.S. Dept. of Commerce (DOC), Mr. Jason Kim. As a reminder, our open meetings are also being livestreamed and recorded for greater public access and public documentation.

Board recommendations are provided as independent advice and council, and the U.S. Government (USG) reserves the right to accept, or not, the input provided by this committee. It is important to the overall process, however, for the Board to continue to receive feedback on what could be supported and what may have to be set aside in times of fiscal constraint.

That said, as members deliberate today, please remember to abide by established ethics laws that require us not to engage in any discussions that may create a potential conflict of interest. If a member does believe that the appearance of a conflict on a particular topic is emerging, we simply request that you clearly recuse yourself from that subject matter.

Finally, just a final note of appreciation for all the preparatory work that has set the stage for today and thank you to all the members who have joined us today, some of which may be finishing their time with us after several years of contributions such as Dr. Penny Axelrad. Dr. Parkinson, with this, I certify that there is a quorum to begin, and the floor is yours.

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Welcome & Introductions
Dr. Brad Parkinson, *1st Vice Chair, PNAB*

Dr. Parkinson greeted the members. He stated that these are the people who really understand GPS and represent some grave responsibilities in terms of trying to do the right thing. He wished ADM Allen the very best and hoped for his speedy recovery. This meeting is an experiment, and we have delegated a substantial portion of it directly to the PTA Subcommittee, under Dr. Betz. They've been working very industriously to make this meeting a success, but this Board has not focused on a single thematic subject in the past. He is expecting it's going to be an enormous success, and stated that if it is successful, the Board will try to repeat the process with a different subcommittee at the next meeting.

Our goals and objectives today are to delve into this subject of PTA: Protect, Toughen, and Augment in such a way that we can have a complete understanding of what this is all about and, hopefully, have some recommendations that can be executed by the federal government, should they elect to do so. We're going to start out with subcommittee highlights. Dr. Parkinson stated that there will only be five subcommittee highlights, since most of the meeting will be focused on the sixth subcommittee: PTA. He asked if anyone around the table has a comment.

> Dr. Betz thanked the Mr. Goward and the Resilient Navigation and Timing (RNT) Foundation for a terrific reception last evening and, in particular, the highlights of listening to Gen Thompson's (USAF, ret.) very insightful and useful comments made during the reception on the previous day.

Dr. Parkinson agreed, stating that a public "thank you" is the right way to do it. Dr. Parkinson then invited the members to begin their subcommittee highlights.

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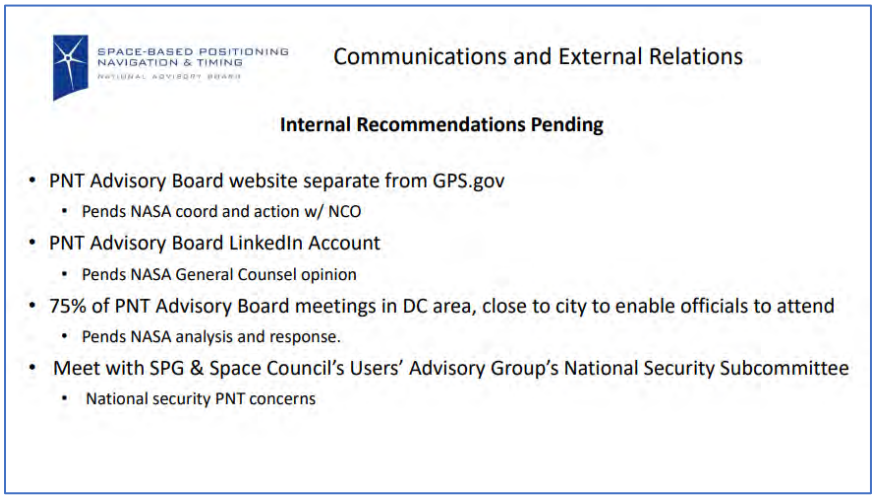
Subcommittee Updates

1) Communications & External Relations (CER) / Mr. Dana Goward

Mr. Goward presented the list of members in the CER Subcommittee and noted that the goal of this subcommittee is to consider ways to effectively communicate to folks the recommendations that the other five subcommittees propose, so that they get the attention and action that they deserve. Lt Gen Hamel is a new addition to the subcommittee. (Slide 1)

There have been several internal recommendations for the Board to consider, in terms of better ways that we can communicate (Slide 2). One of the big ones is that we've noticed the closer that our meetings have been to Washington, DC, the more government officials participate in-person. We've asked NASA to look and see if we can get at least 75% of our meetings in the Greater DC Area, hopefully as close to downtown and convenient to our audience as possible.

Slide 1



Slide 2

We all swim in the GPS and PNT ocean, but it's a relatively narrow niche. It would be good to get information about this body out to the larger PNT community (Slide 1). As a result of that, our group collaborated on a piece for publication, which is featured in GPS World both online and in print. We've had good feedback from outside the Board, saying, "we now understand what you do." We've also heard from some members of the Board who said, "I sent this to my boss, so they know where I've gone for two weeks a year and what I'm doing, and it was very helpful." We're always looking for other ways to talk about what we do and the things we say to folks outside of the community. If anybody has access or suggestions of places we should look to publish, please don't hesitate to let us know.

Dr. Parkinson pointed out the irony of the slide, where if you look over to the right you will see the Turkish company that's selling 16-element anti-jam receivers.

In terms of larger issues, we've several specific recommendations to the USG (Slide 4). One of the things that we found is that we have to be very careful about how we talk about GPS. We all love and care for GPS, and we're concerned that it is being superseded by other space-based systems. If we make recommendations about improving the GPS signals and the control segment, that may not be productive because those are long-term projects requiring lots of attention from the USG, lots of focus, lots of money invested. In fact, they could end up being counterproductive. However, if we have some blue-sky, long-term ideas, those may be worthwhile, and this Board has a duty to make those recommendations, we need to be careful and practical in terms of our recommendations, ensuring that they are more focused and can be executed in a reasonable amount of time and cost.

Slide 3

Slide 4

More detailed and technical recommendations need to be placed in a more political context: a great power competition (Slide 5). Using the example of the fact that China has pulled significantly ahead of us as, underlines our need to provide more focus and attention for a whole-of-government effort towards PNT. The Board would care about PNT, and we would want to do better about PNT even if there wasn't a China there. We'd care about terrorists and accidents. We would care about resilience regardless, but certainly, the fact that China has reemerged as a significant player on the stage and is attracting attention to help focus our minds and efforts on resetting our PNT effort and governance. This is the way that we recommend we approach the topic in terms of communicating it outside of this group. All of the detailed, more specific recommendations would be subordinate or included in this overall whole-of-government effort to do better in terms of a holistic and resilient approach to PNT.

Slide 5

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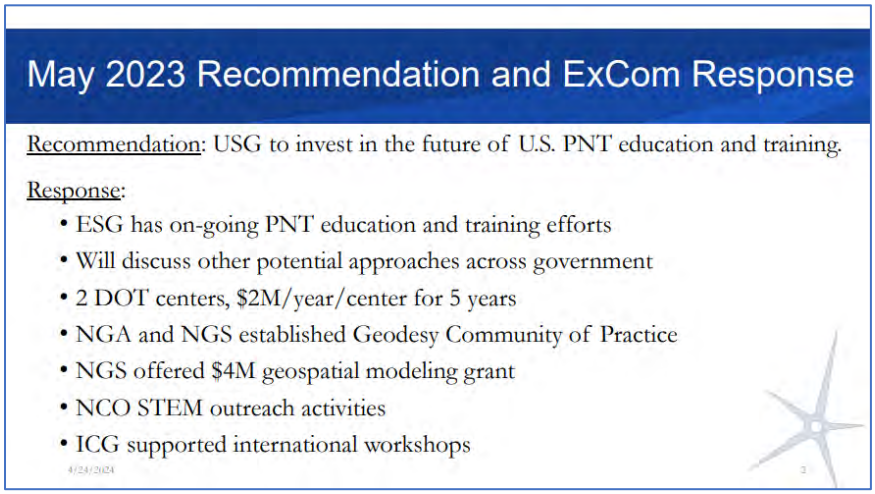
2) Education & Science Innovation (ESI) / Dr. Jade Morton

Dr. Morton greeted the room and stated that she will be representing the ESI Subcommittee to present some highlights of its findings and recommendations (Slide 1). Dr. Moore is the 1st Vice Chair and Dr. Greiner-Brzezinska is the 2nd Vice Chair. There are several members who participated in the discussions we held here yesterday including Prof. Filjar, Dr. Walter, Mr. Shields and Dr. Mitelman (who is not a member of the Board). The focus for this subcommittee is U.S. PNT Workforce Education and Training. Our objective is to recommend ways to assess the current state and the future needs for PNT research and education industries. In addition to that, we would like to make some actionable recommendations so that we could improve the need in those areas.

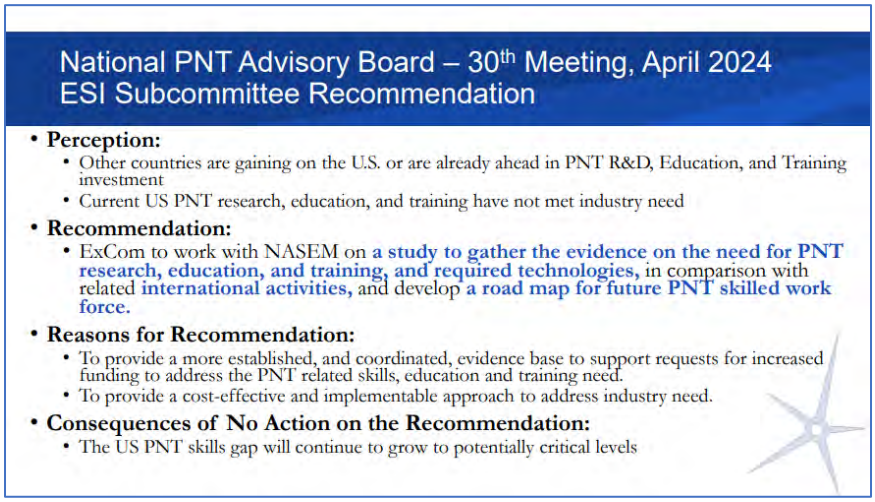
Back in May 2023, the subcommittee made a recommendation for the USG to invest in the future of U.S. PNT education and training (Slide 2). In January of this year, we saw the responses from the Executive Steering Group (ESG) posted on www.GPS.gov. A summary of their response is: (1) There are on-going PNT education and training efforts; (2) The ESG is willing to discuss other potential approaches across government; (3) There have been two Department of Transportation (DOT) centers established. Each of them is receiving $2 million per year for five years; (4) The National Geospatial-Intelligence Agency (NGA) and the National Geodetic Survey (NGS) have established a Geodesy Community of Practice, and this community includes efforts in research education and workforce training; (5) In addition, NGS has offered a $4 million of geospatial modeling grant and for the academic partners in our community; (6) NCO has a number of outreach activities addressing PNT educations, specifically in the broader Science, Technology, Engineering, and Mathematics (STEM) fields; (7) The United Nations (UN) International Committee on GNSS (ICG) has supported multiple international workshops. The subcommittee welcomes these actions. However, any further investment should be based on a study on the need in specific disciplines and the level investment should be assessed based on those specific needs.

Slide 1



Slide 2

As a result of this discussion, the subcommittee would like to revise its previous recommendation (Slide 3). The recommendation was based on the perception that other countries are gaining on the U.S., or are already ahead, in PNT and education and training investment. We believe that the current U.S. PNT research education training is not meeting industry's needs. Thus, our recommendation is: EXCOM to work with NASEM (National Academies of Science, Engineering, and Medicine) or other organizations, on a study to gather the evidence on the need for PNT research education training and related technologists. The focus should not be just narrowly focused on PNT itself but follow a multidisciplinary approach. That study should be done in comparison with related international activities and help develop a roadmap for future PNT skilled workforce. The purpose of the revised recommendation is to provide more established, coordinated, and evidence base to support requests for increased funding to address the PNT related skills education and training needs. This will allow us to provide a more cost-effective and implementable approach to address industry needs. If we don't take action, the consequence is that the U.S. PNT skill gap will continue to grow and potentially reach critical levels.



Slide 3

Discussion:

Dr. Parkinson asked if there is reception or acceptance of this by NASA. Has this recommendation been pre-coordinated in any way?

Dr. Morton said they have been speaking to some of the NASA representatives. She believes there is potential.

Dr. Parkinson said that we need to re-coordinate this to some extent.

Dr. Parkinson asked the members for any supporting or dissenting opinions.

Dr. Moore reminded the Board this recommendation was already approved at a previous meeting. All they've done is slimline it to, hopefully, make it more effective.

Dr. Parkinson asked the room if there was any opposition to the refined recommendation.

**There was no comment from the room and the revised recommendation was accepted.*

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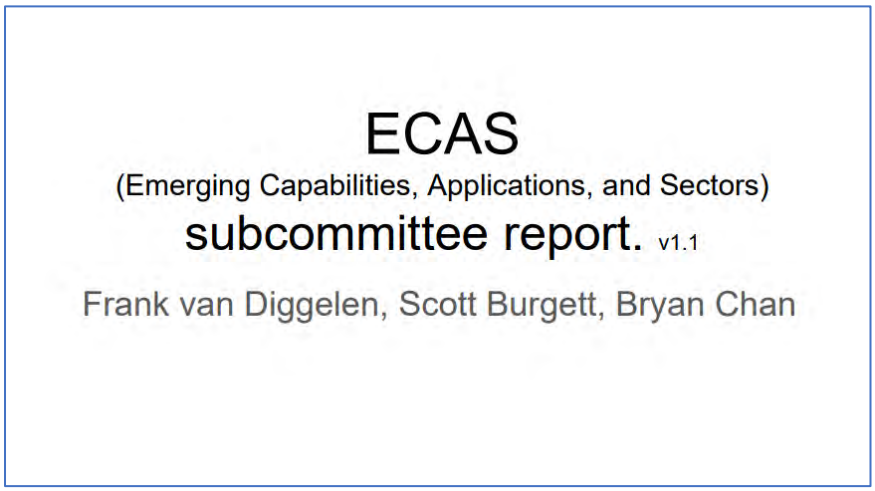
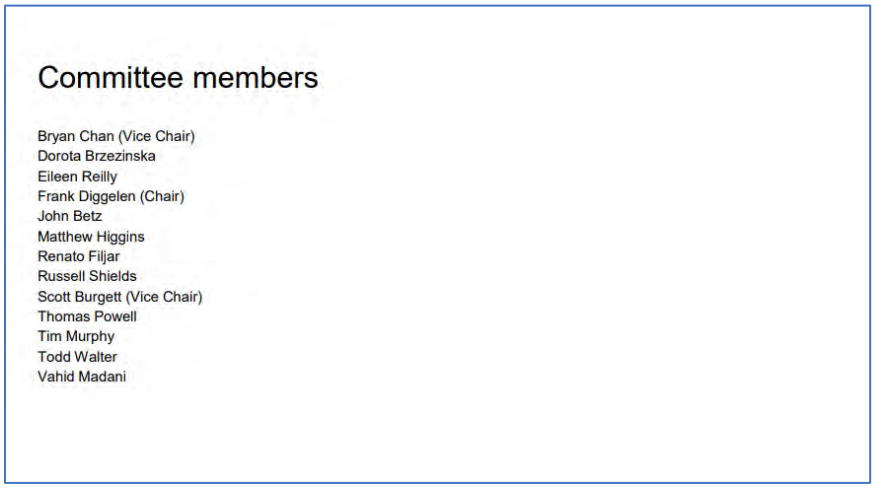
3) Emerging Capabilities, Applications, & Sectors (ECAS) / Dr. Frank van Diggelen

Dr. van Diggelen introduced the ECAS Subcommittee and its membership (Slides 1-2).



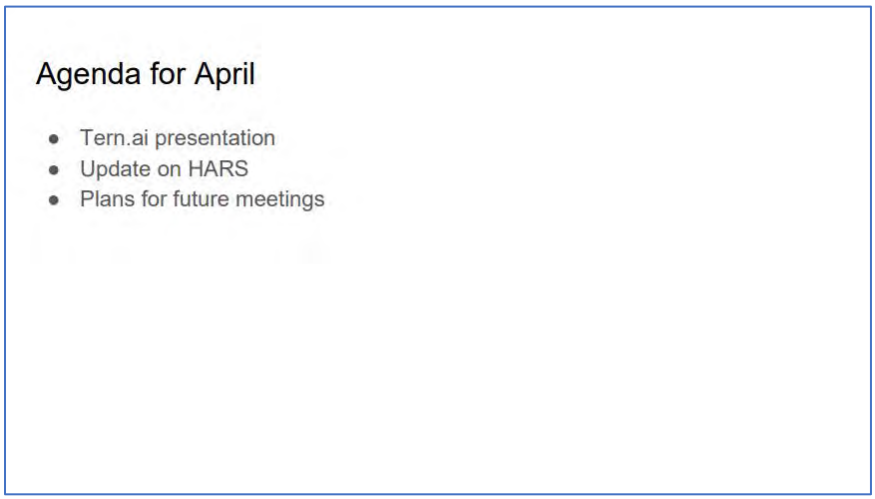
Slide 1



Slide 2

Recent activities include: (1) a fact-finding meeting with TERN AI, and (2) updating its HARS (High Accuracy and Robustness Service) proposal that was previously approved by the board. The subcommittee is also planning for future meetings (Slide 3).

Shaun Moore, the CEO and co-founder of TERN AI, gave a very interesting presentation. TERN AI is a startup company that wants to do location using digital 3D maps and car sensors, and no GNSS (Slide 4).



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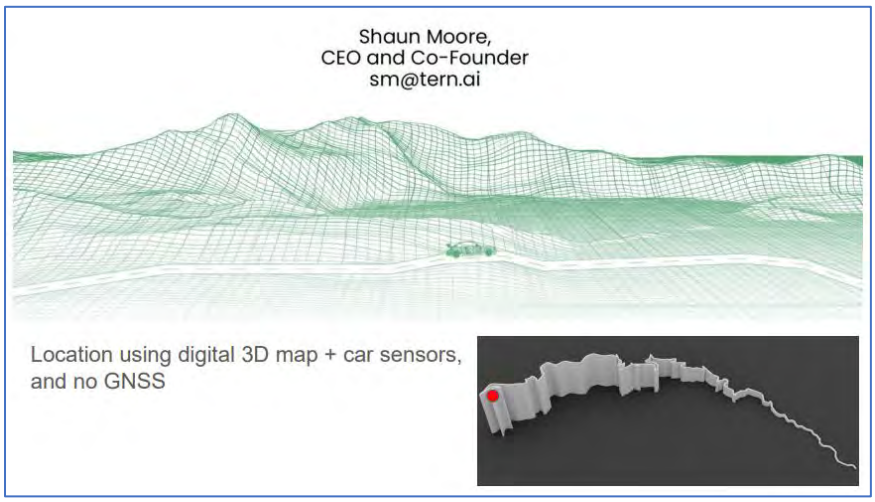
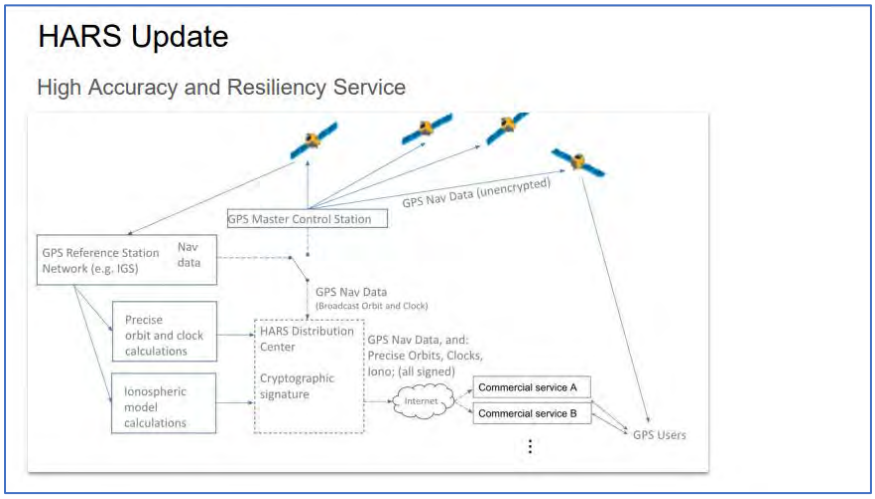


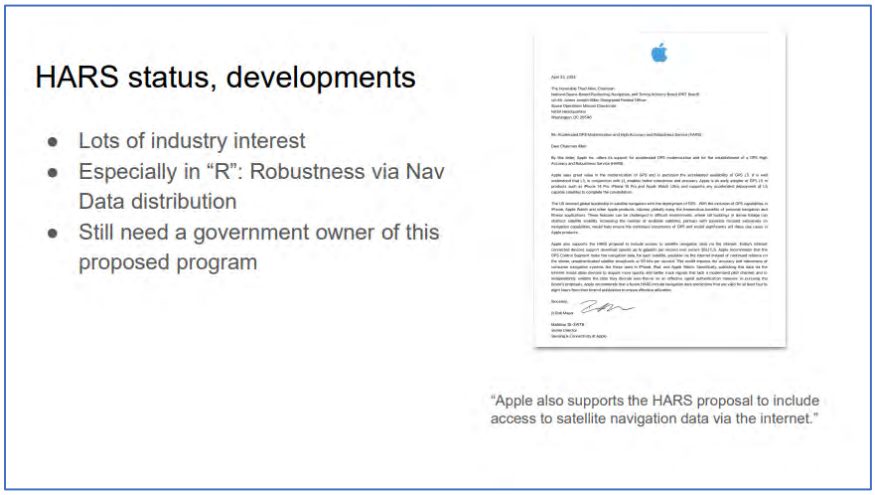
Slide 4

As noted earlier, the HARS proposal has already been adopted by the Board (Slide 5). The main idea is to have a service that provides corrections to the orbits and clocks, as well as providing the navigation data through an alternative distribution network, namely the internet.

This has seen a tremendous amount of industry interest in the last several months, especially in the "R" part: resilience / robustness (Slide 6). We now have a letter from Apple to the Board giving its support to HARS. This was unsolicited; Apple found out about HARS through the White Paper posted on www.gps.gov. The most important thing for this program to become a reality is that it needs an owner agency within the USG. It needs a body such as the U.S. Space Force (USSF), or similar, to own it, pay for it, and build it. It's a small program in the scheme of things costing less than a satellite to provide this kind of data over the internet. The subcommittee also had talks from groups, such as the Jet Propulsion Laboratory (JPL), who have the capability of doing the modeling for the corrections and collecting the navigation data and redistributing it. The technology is there, but we need an owner to help GPS become a leader amongst the GNSS without having to put any hardware in space, just by adding capability on the ground.



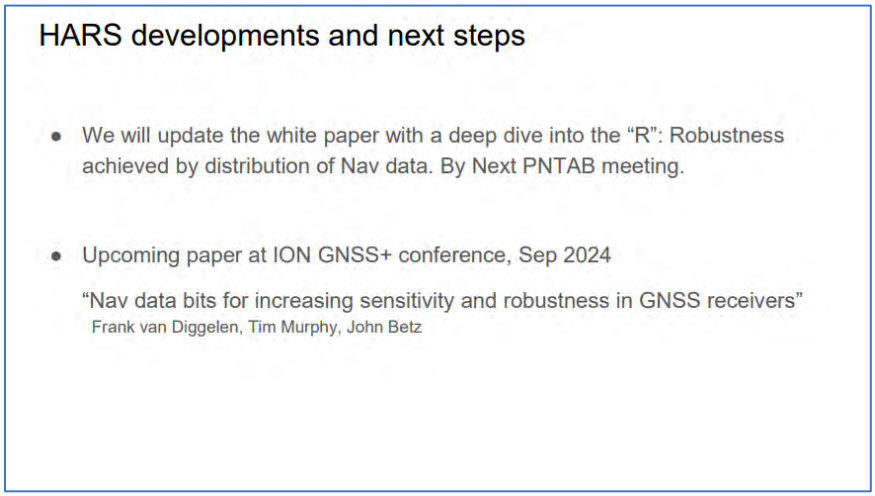
Slide 5



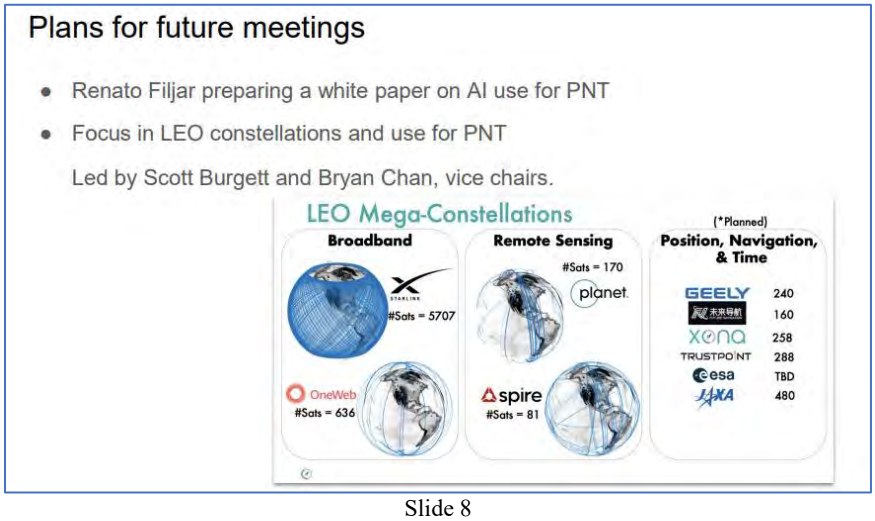
Slide 6

In terms of developments and next steps, the "robustness" part is what we've found people are caring for (Slide 7). We will update the white paper over the next six months with a deep dive into how the navigation data provides robustness, and we'll have an update to that paper by the next meeting. We also have an upcoming paper at the Institute of Navigation (ION) GNSS conference in September 2024, focusing on the use of navigation data bits to increase sensitivity and robustness.

The ECAS Subcommittee has a wide remit. For the next meeting, Prof. Filjar is preparing a white paper on Artificial Intelligence (AI) use for PNT. We also plan to focus on Low Earth Orbit (LEO) constellations for use in PNT, and that work will be led by subcommittee co-chairs Dr. Burgett and Mr. Chan. There are thousands of LEO satellites already in space for communications, but more importantly, there are hundreds planned by funded companies, and government agencies such as the European Space Agency (ESA) and Japan Space Agency (JAXA), for PNT (Slide 8).



Slide 7



Slide 8

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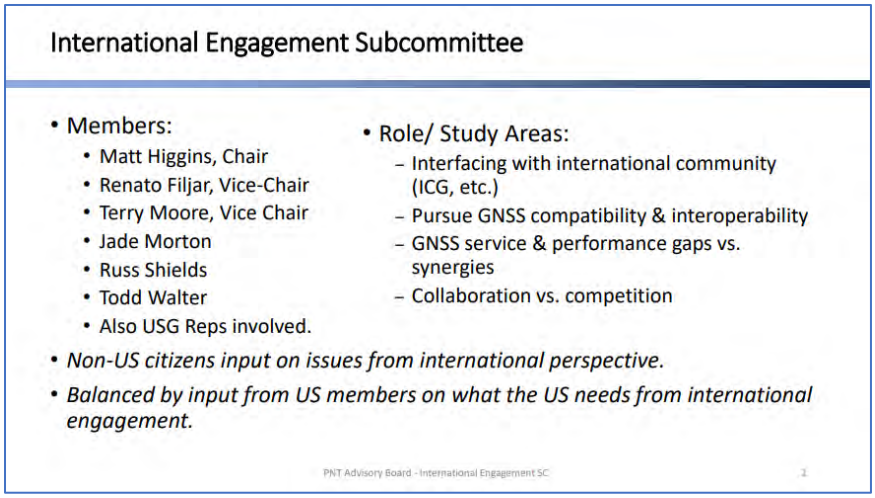
4) International Engagement (IE) / Mr. Matt Higgins

Mr. Higgins noted that IE Subcommittee membership has not changed much, and it continues to have USG representatives involved in its activities (Slides 1-2). At yesterday's meeting, the subcommittee hosted Mr. Auerbach from the Department of State (DOS), Dr. Erikson from USSF, and Sasha Mitelman from DOT. It's been very useful to have USG people sitting at our meetings. The subcommittee also includes international Board members. As of late, the subcommittee has been focusing on GNSS services versus performance gaps.

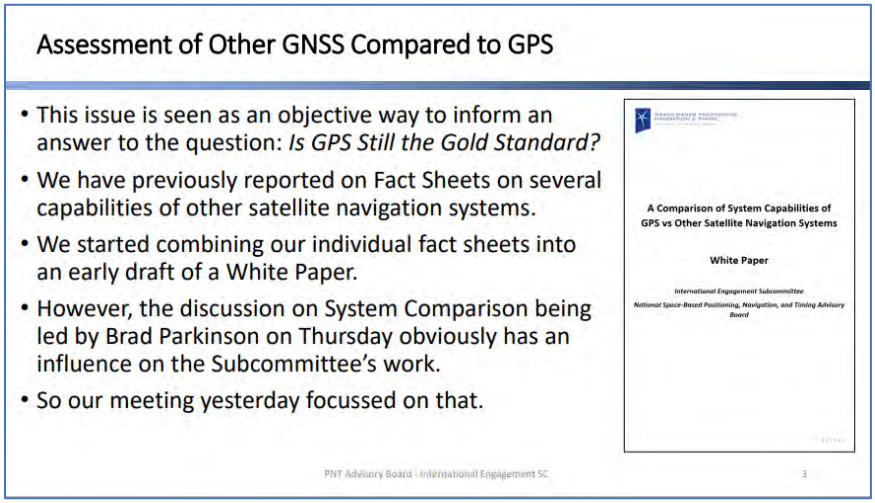
Slide 1



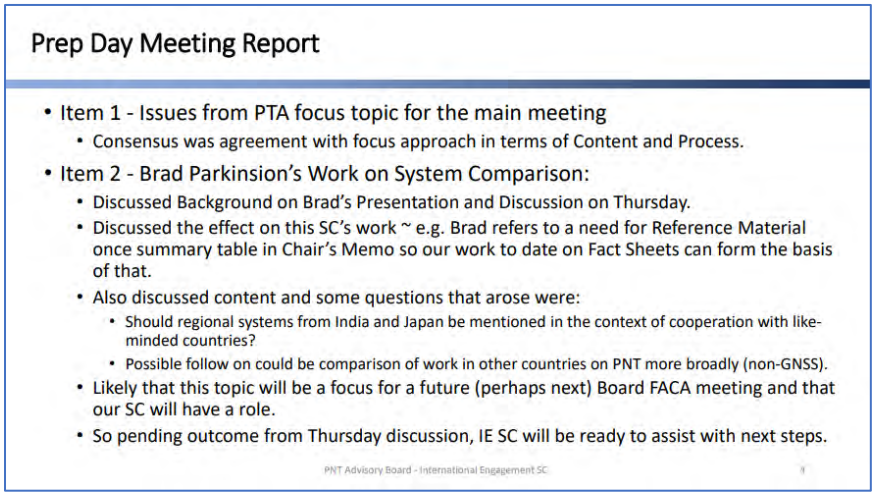
Slide 2

As shown on Slide 3, the subcommittee has developed factsheets to document some of the features of other GNSSs that aren't currently available on GPS, all aimed at the question on whether GPS still the Gold Standard. At the December 2023 Board meeting, we started the process of combining our individual fact sheets into an early draft of a white paper. Tomorrow Dr. Parkinson will lead a high-level discussion on some of the issues we discussed in detail at our preparatory meeting yesterday in the afternoon.

At yesterday's fact-finding meeting, there was a general agenda item to focus on this issue, and the subcommittee has consensus that this is a good way to move forward (Slide 4). We're happy to be involved in future meetings that use this focused approach. The main thing we discussed was the work that Dr. Parkinson has been doing on GNSSs comparison, where he asked for some input from himself (Mr. Higgins), Dr. Moore, and Prof. Filjar. This is going to be discussed in detail tomorrow. You'll see in Dr. Parkinson's presentation that he refers to the need for reference material on the more technical details and background, which is exactly what the fact sheets were intended to do.

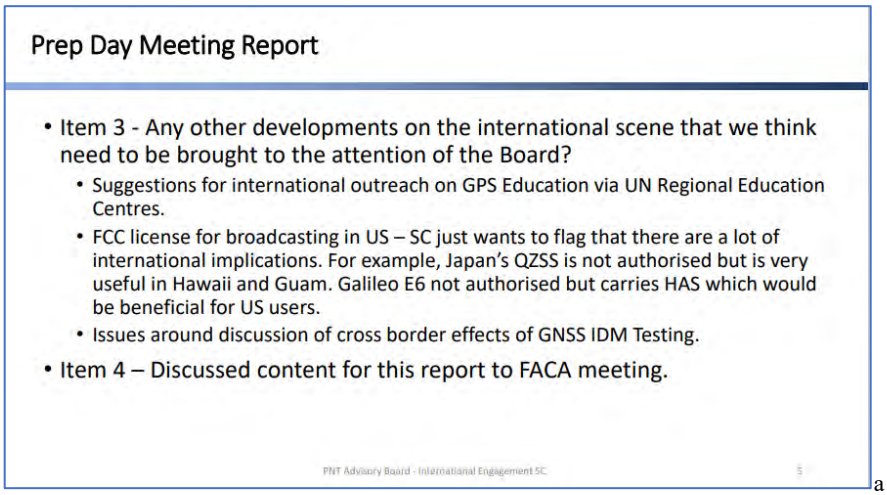


Slide 3



Slide 4

The following question came up: should the regional systems from India (Navigation with Indian Constellation, or NAVIC) and Japan Quasi-Zenith Satellite System (QZSS) be mentioned in the context of cooperation with like-minded countries? Possible follow-on work to the comparison on GNSSs could include a comparison of PNT more broadly across nations. That may be a good follow-on process because there is interesting work going on across several countries regarding alternate PNT. It's likely that this topic be the focus for a future meeting. Pending the outcomes of Dr. Parkinson's discussion, the subcommittee is ready to help where it can. (Slide 5)



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Slide 5

Discussion:

Dr. Parkinson stated that, in terms of perceived and actual international capability, there is an interest in ensuring that the policy statement of what we are trying to do as a nation is backed up by a set of metrics, if we are to compare these GNSSs in any way. It must also be backed up by the details that drive those metrics. In parallel with that, if we make a recommendation, we get immediately back into the issue that Hon. Shane discussed, which is how do you have any kind of a cohesive process of trying to improve things? The thought is that at our next meeting, we may want to focus on the combination of governance (i.e., being able to carry out decisions and have a cohesive policy) and what should be driving that in terms of our interest in ensuring that GPS is second to none, if that is our goal. Dr. Parkinson asked members to provide their observations at tomorrow's session. They should think about whether we should, at the next Board meeting, dive deep on these subjects and spend the majority of the time figuring out how we can put teeth in recommendations on governance, and how we can describe the situation in a way that at the highest level of government they understand what we're trying to say.

Mr. Higgins thanked Dr. Parkinson and stated that the subcommittee would be happy to get involved in any future, focused meeting. If it's a two-pronged issue, then we would concentrate on the technical characteristics of systems side and the Strategy, Policy, and Governance (SPG) Subcommittee would focus on the policy issue. The other agenda item we have is to discuss are other international developments. One avenue that the U.S. could explore would be to do some outreach on GPS education via the UN Regional Education Centers.

Mr. Auerbach raised the issue of the Federal Communications Commission (FCC) licensing for broadcasting in the United States. Most of the discussion in the Board has been in regard to BeiDou signals being used in the U.S., but there are a lot of other international implications. Some examples include QZSS, which is not authorized in the U.S. but is still very useful in Hawaii and Guam. Similarly, Galileo's HAS, which is on E6 (a signal not authorized in the U.S.) and would also be beneficial to U.S. users. There are two sides to the coin, and that needs to be discussed. Additionally, countries are doing interference and detection monitoring testing near their borders, and such interference can spill over the border and affect others, which has always been a problematic discussion.

Dr. Betz stated that, from his understanding, the FCC process is that if a service provider would like a systemwide waiver, the service provider needs to apply for that waiver. So, if his understanding is correct, then the ball would be in QZSS's court to apply for that waiver. Has the U.S. had any discussions with them in the ICG or elsewhere to suggest that they apply for that waiver?

Mr. Auerbach said that, yes, they need to apply for a waiver. The U.S. has not had discussions with them on this issue.

Mr. Higgins said that in Australia it was eventually decided that the licensing of GNSS wasn't like that of satellite communications. They have moved to a situation where, in the case of GNSS, if it's recognized in the International Telecommunications Union (ITU) then it's also recognized in Australia, which is a much easier approach in terms of administration. Mr. Higgins agreed with Dr. Betz in suggesting that QZSS apply for a waiver for use in the United States. The waiver for Galileo took quite a while, so a waiver for QZSS may also take quite a while.

Dr. Parkinson stated that it's ironic that the principal beneficiaries are U.S. citizens and yet the burden of getting approval for those U.S. citizens to use it somehow drops onto Japan. It seems like it's the wrong way to go about it.

Mr. Goward agreed, noting that the Board has an FCC representative speaking later in the day. He may not be from the right bureau, but we might be able to ask him questions. He asked Mr. Higgins if his bullet point on slide 5, "cross effects of GNSS Interference, Detection, and Mitigation (IDM) testing," suggests that the situation is in the Baltic is a result of an overflow of an IDM test.

Mr. Higgins said no.

Mr. Higgins concluded his presentation by reiterating the value of having the USG personnel attend their subcommittee meetings.

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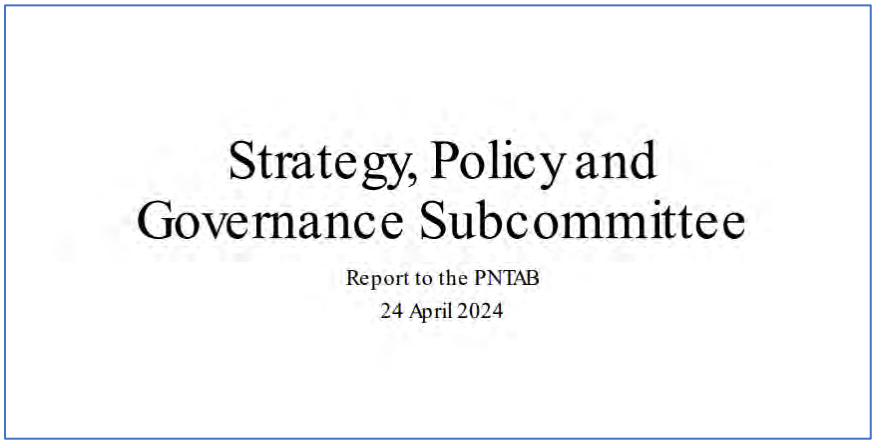
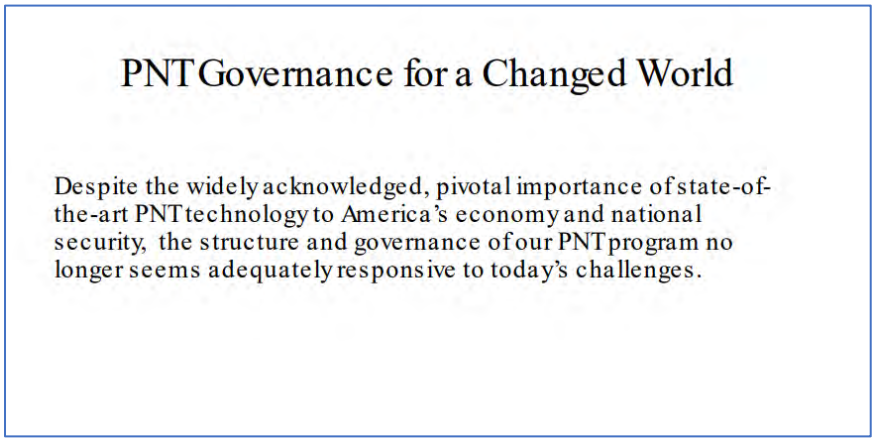
5) Strategy, Policy, & Governance (SPG) / Hon. Jeff Shane

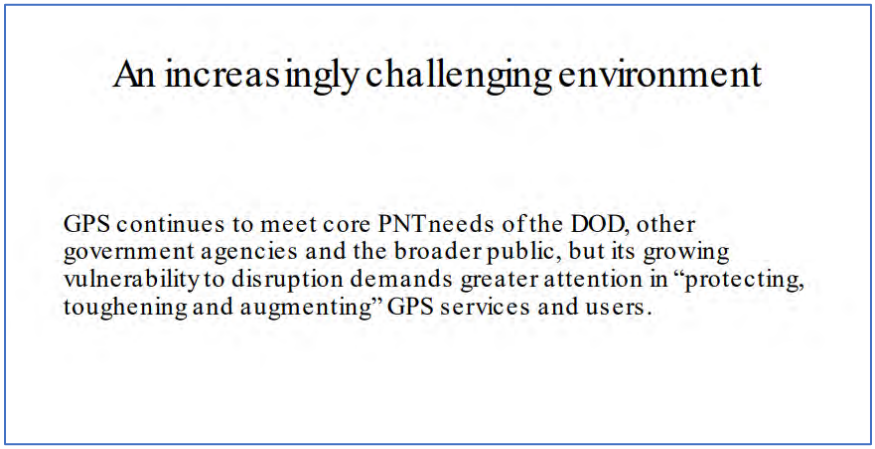
The Hon. J. Shane said that the SPG Subcommittee held a fact-finding meeting during yesterday's prep. session and discussed ways in which the world was changing. At the end of the meeting Gen Willie Shelton (USAF, ret.) tossed out that phrase, "PNT governance for a changing world," and the subcommittee thought that captured its theme perfectly. It was adopted as the title of this presentation, the point being that despite its importance, we know that we're not giving the attention to PNT in our country that we should. (Slides 1-2). We are in a changed world (Slide 3). An obvious way in which it's changed, PNT-wise, is the number of stories we see in the news about jamming and spoofing.



Slide 1



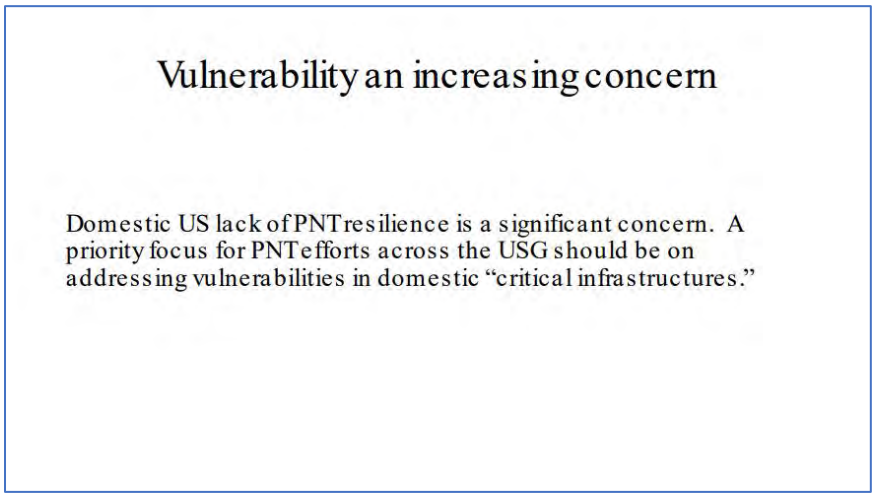
Slide 2



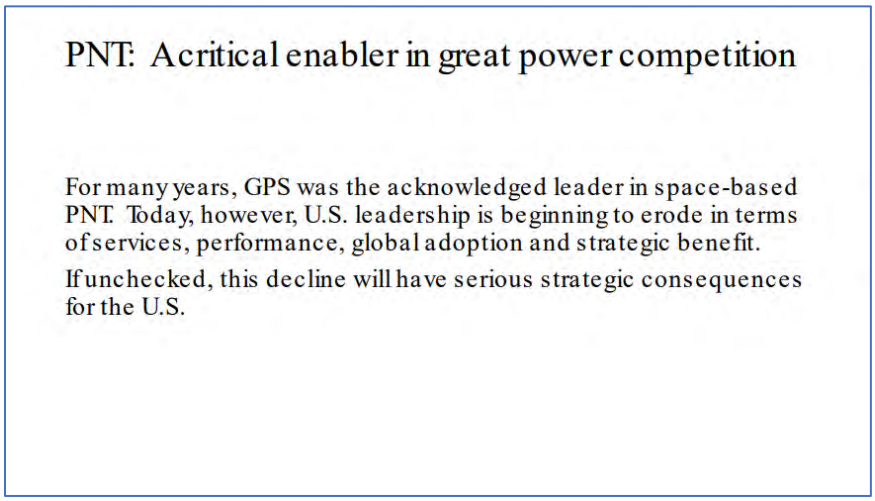
Slide 3

It's happening routinely in conflict zones, of course, but we experience anomalies and disruptions far too often domestically (Slide 4). We know there are ways to toughen PNT, but we aren't seeing it. Thus, there is a requisite urgency attached to addressing that need.

We all love to think of GPS as the Gold Standard when it comes to space-based PNT, and without question, it certainly still is (Slide 5). But maybe it's just 18-karat gold, while some other systems are beginning to look like 24-karat gold. We'll be talking later in our meeting about capabilities that other GNSS have that GPS doesn't, at least not yet. One of those GNSSs is China's BeiDou. We know that China is aggressively marketing BeiDou to compete with GPS, using its system as a way to establish greater influence and even dependence, particularly among developing economies. It's become a feature of China's Belt and Road Initiative, and it's merely the latest episode in China's long history of seeking to gain influence in developing countries through investment and other forms of assistance. However, it would be a mistake to characterize this activity as inherently sinister. After all, the U.S. wrote the book on the use of foreign assistance to cement relationships and alliances. But what we should probably treat as more worrisome is that China appears way ahead of us in developing a multiplicity of domestic PNT systems. Our colleague Mr. Goward and his RNT Foundation have been documenting this phenomenon for a while. What it means is that in the event of a conflict, however unlikely it is, our single source of PNT could be disabled but China's multi-PNT capability would continue to function. That's a position we don't want to be in, but it's one that we are being very slow to address. (Slide 5)



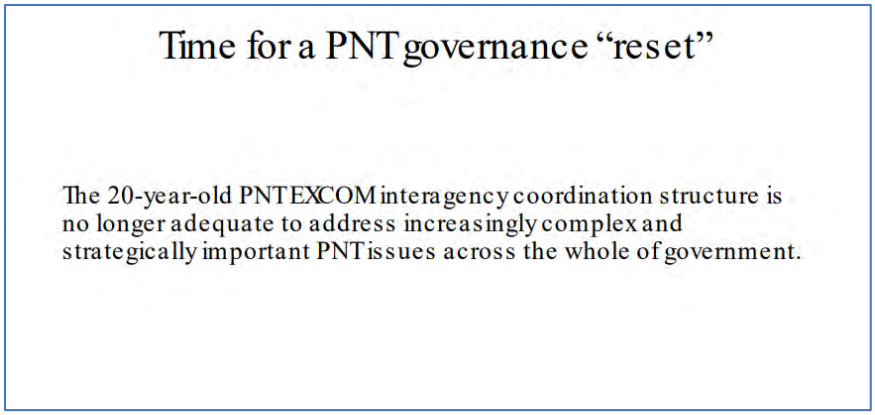
Slide 4



Slide 5

The SPG subcommittee believes there is a governance problem (Slide 6). In no way is our concern about governance meant to imply criticism of the people who built GPS, operate it, continue to maintain it and improve it over time, and encourage the development of Complementary PNT (CPNT) technologies throughout our country. On the contrary, we salute you. What you accomplish every day is nothing short of a miracle. The system itself is a miracle and let's never forget that GPS was America's gift to the world, possibly the greatest gift that any nation has ever given to the world. If America hadn't invented and deployed GPS, there would be no GLONASS, Galileo, and BeiDou. Those systems are nothing less than tributes to American ingenuity and leadership. Unfortunately, what is most miraculous about what you do every day is that you do it without the quality of support that you and the American people deserve. We think that's because the governance framework, which was designed 20 years ago and enshrined in a National Security Presidential Directive 39 (NSPD-39), a framework that made sense at the time, is no longer responding sufficiently to the strategic, geopolitical, and spectrum allocation challenges that America faces today. It's not about a lack of competence; it's about a lack of emphasis and urgency. We think it's time for a change.

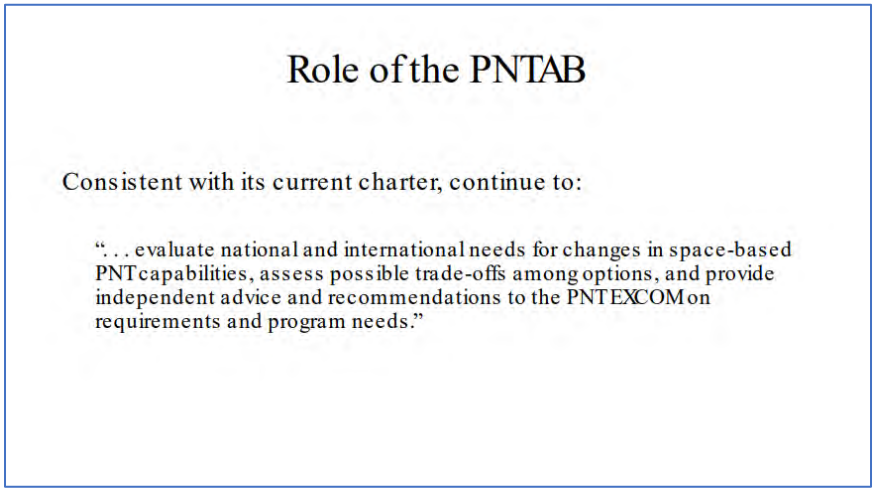
We need a new and more contemporary policy declaration that acknowledges the importance of PNT as an element in America's critical infrastructure (Slide 7). We also need a revised approach to governance, one that ideally invests genuine decision-making authority in a single, properly empowered entity that has clear authority to advocate for the funding that's necessary, both at the Office of Management and Budget (OMB) and before Congress. This is a very big ask, but we shouldn't treat it as beyond reach. The fact that GPS may be lagging in some of the capabilities emerging in other GNSSs should be treated as an opportunity to demonstrate the kind of leadership we have so often seen in our government. It's a wake-up call. Whenever the U.S. has perceived itself as behind in some strategically important way, it has stepped up, usually with positive results. Launching an updated contemporary PNT strategy should be seen as nothing less than the stuff of legacy. We accelerated the modernization of our air traffic control system with a program that we branded NextGen. We reformed the way international aviation works with a program that we called Open Skies. And Hollywood now knows all about the Manhattan Project. What should we call this initiative for GPS? We've kicked around the term GPS+ but wondered if that diminishes the importance of terrestrial PNT. Maybe we should have a naming contest, but we shouldn't have it until there's something to name.



Slide 6

Slide 7

We need a new and more contemporary policy declaration that acknowledges the importance of PNT as an element in America's critical infrastructure (Slide 8). We also need a revised approach to governance, one that ideally invests genuine decision-making authority in a single, properly empowered entity that has clear authority to advocate for the funding that's necessary, both at OMB and before Congress. This is a very big ask, but we shouldn't treat it as beyond reach. The fact that GPS may be lagging behind some of the capabilities emerging in other GNSS should be treated as an opportunity to demonstrate the kind of leadership we have so often seen in our government. It's a wake-up call. Whenever the U.S. has perceived itself as behind in some strategically important way, we have stepped up, usually with positive results. Launching an updated contemporary PNT strategy should be seen as nothing less than the stuff of legacy. We accelerated the modernization of our air traffic control system with a program that we branded "NextGen." We reformed the way international aviation works with a program that we called "Open Skies." And Hollywood now knows all about the Manhattan Project. What should we call this initiative? We've kicked around GPS+, but I wonder if that diminishes the importance of terrestrial PNT. Maybe we should have a naming contest, but we shouldn't have it until there's something to name.



Slide 8

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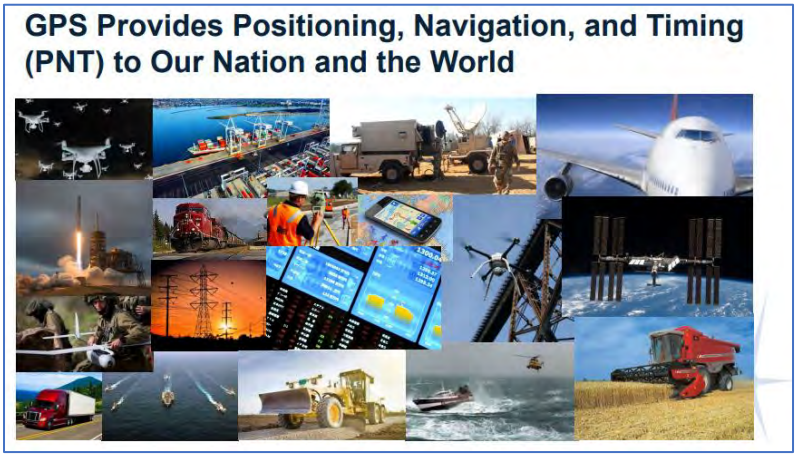
Focus of the Day: PTA Is Urgently Needed; Near-Term Improvements Are Possible

Motivation for Better PTA
Lt Gen M. Hamel, *Board Member*

Lt Gen Hamel greeted the Board and stated he feels fortunate to be able to join such impressive group of individuals that have devoted a good part of their life's energies into trying to promote both the value, as well as trying to help managing the singularly most complicated enterprise that he has witnessed across the USG. (Slide 1).

The intent of this briefing is to provide an overall picture of the environment we face, particularly domestic and from a civil U.S. perspective (Slide 2). This is not the universe of all GNSS issues; it really is focused on the pressing needs we have, and we're going to be linking this back to critical infrastructure. We have not really dug very deep into matters related to defense and national security for a whole variety of reasons, but increasingly we're seeing that the role of PNT, and particularly GPS, in our critical infrastructures is growing and has parallel vulnerabilities and risk factors. In many cases (it was said very well by Col Ray when we visited 2 SOPS, Second Space Operations Squadron, a couple days ago) the fact of the matter is for the American public, this is speculative. When we start seeing examples where there's failures of PNT/GPS and our fundamental enabling infrastructures and services, that's when there's going to be a breach of trust, between the USG and citizens. Focusing on critical infrastructure is a very important place to really be putting our energy, and the there are many practical, executable, and near-term steps that can be taken that can truly improve the posture that we have as a nation as well as protect, toughen, and augment capabilities. In part of this is to both report out of the proceedings, but the other part is creating a foundation of how we can help educate, and from our vantage point. There's a lot of actors out there, all of which use GPS and PNT, but there's seldom the kind of holistic view that we have in this group. Hopefully this will bring some urgency and imperative to the problem. We've got to find ways that we can offer up practical, executable steps. Lt Gen Hamel commended Dr. Betz's leadership. If ever there was a process and a challenge of herding cats, this was it. There are a wide range of topics that will be discussed here. Even within our group, how we've had cross talk with the other subcommittees, and now there is a coalescing now around a couple of topics that we can get more focus and energy behind. This will be a big part of the purpose for tomorrow as we review the biddings and arrive at our final report.



Slide 1

Slide 2

Since his days as a young officer he has dipped in and out of GPS in many different positions. Every time he meets with the Board he finds out things that he never knew, because this is a complicated set of topics. The diversity of skills that we have here has made a huge difference. The members here are largely of technical backgrounds, and this is perhaps one of the most ultimate GPS and PNT systems of systems challenges. It goes across so many different boundaries with so many interfaces, so it's important to be able to figure out how you decompose and parse out pieces of this because you can't solve the problem in its entirety if you just start off at the very highest level. What is the focus? We're not really going to be terribly welcomed; we might start making a lot of recommendations regarding GPS III and beyond. Those are long-term investments. It's important to look at the other aspects of the system of systems: the user end of this, because this is a shared set of responsibilities. It is not just the government's role to produce signals that ultimately end up as a service that's embedded in some kind of commercial or civil use. Users must take on responsibility for how they employ this, and more about practical things that can be done will be discussed here. Lt Gen Hamel stated that he's come to appreciate the whole PTA framework. One of our challenges needs to be, "what do we describe this to the EXCOM that we're serving, as well as a broader public? What is PTA?" Additionally, it's a strategic framework that can help link together the national policy statements. We are not lacking in national policy. The question is, "how does it get decomposed into actionable steps that can be implemented not just by the government, as well as by users, industry and others?" These charts will lead into Dr. Betz's presentation about how we march through these constituent elements in that decomposition process. Lt. Gen. Hamel also stated that he believes that there's no appreciation of the reach of the capabilities that GPS provides and the degree to which everyday life is dependent upon it (Slide 3).

We now have 50 years under our belt from initial concept to a place now where this is an indispensable capability. GPS is still the leader in the world, we just haven't figured out a way to adequately describe that or to figure out what the elements are that have made that success. GPS was amongst the very first open system in terms of making it widely available to any industry player or academic to come in, examine, question, and improve upon this. There was an ecosystem that really played to the strengths of the U.S., and it was both that combination of government steadfast investment in this over many years, as well as the innovation that has led to the place that we find ourselves today. One of the things in terms of measuring success is asking, "how many users are there out there?" GPS is still the foundational, the most trusted, the most pervasive capability around the globe, which is something we never want to take our eyes off. We also see that we're at the convergence of massive changes in technologies, some of which was government-induced but most of which came from the private sector. As a result, we're no longer thinking about electronic radios or software computers. There's a convergence and a miniaturization that is now fueling how these things are advancing into all manner of applications that few people would have ever even imagined 20-30 years ago. The massive private investment and the speed of innovation that comes with this is something we've always got to be looking to because that is one of the strengths that we have in this country. We're going to be doing a lot more focus, I think under Dr. Parkinson's leadership of really getting to the heart of what are the metrics and how we choose the right factors, attributes, and characteristics that are important in describing what is the nature of these services. We also must acknowledge that this widespread assimilation in all these places is creating an incredibly inviting target for both non-state actors and competitors as we go forward on every plane.

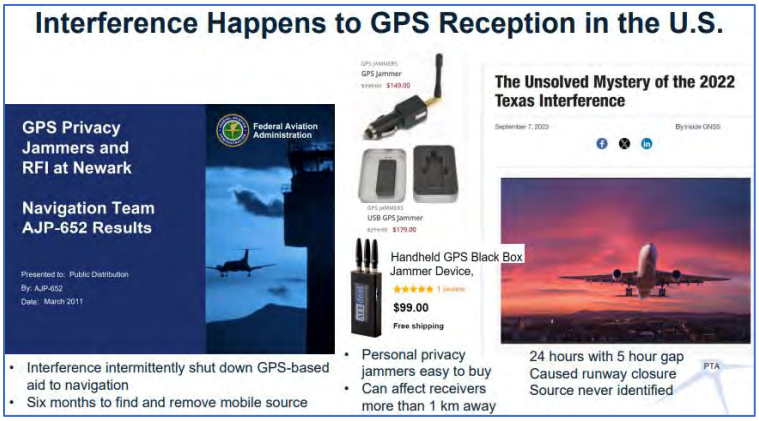
The theme of this discussion is to seek renewed attention. We're seeing a coalescing of factors, some of which are political, some of which are technological, some of which are political and military. There may be a call towards having some fundamental reexamination of all these questions. At the same time, we've got to be able to help understand what practical steps are and things that can be done by government leaders, all of which have different pieces of responsibilities associated with this. We need to be able to help them think through things that they can move the ball forward as opposed to having an almost unsolvable problem on their doorsteps. We must take a holistic look at the issue. One of the things we must acknowledge is that with a big global system like GPS, the time it takes from identifying a new service, a new capability until it can be integrated and made operationally available is going to be measured in decades and in billions of dollars. We know the pace of technology evolution and assimilation is operating on years, not months. We must figure out ways to segment the problem and create stability. It must evolve with time, but the real focus needs to be on its uses and how enable it to be exploited to its full potential.

Slide 3

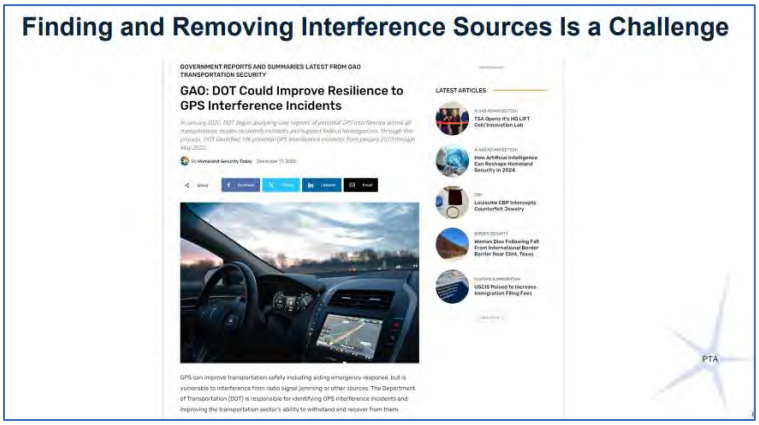
Challenges relate to both critical infrastructure and private concerns, and spectrum is one (Slide 4). In 1997, at a conference in Geneva, things were going badly for the U.S. because the rest of the world thought it would be nice to box in the U.S. on spectrum allocations for GPS (we were trying to introduce M-code), and it took a lot of push back. Spectrum is one of the ultimate pieces of real estate in the information age, and that is going to be a critical part of our "protect" agenda. One can go on the internet and purchase a device that can wipe use of GPS for several km. That's what we're dealing with. Some events are not intended to be malicious, but what could adversaries do? It doesn't take a lot of imagination to paint extraordinarily damaging scenarios.

Slide 4

The other issue is knowing there is interference, locating it, and either mitigating or shutting it off (Slides 5-6). These are not just a few isolated cases; we must anticipate what it means to have this on a national scale where determined adversaries or disruptors want to make a miserable day. It wasn't too long ago we had a gas pipeline that shut down the East Coast for an extended period. That disruption wasn't PNT-related, but these vulnerabilities with our infrastructures and the lack of hardness in many of these services is an incredible potential vulnerability that needs to be front and center in our thoughts and discussions.



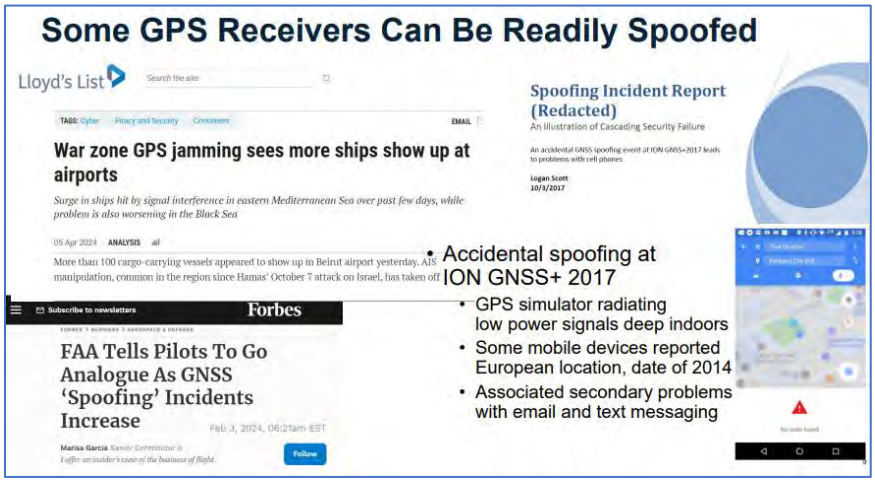
Slide 5



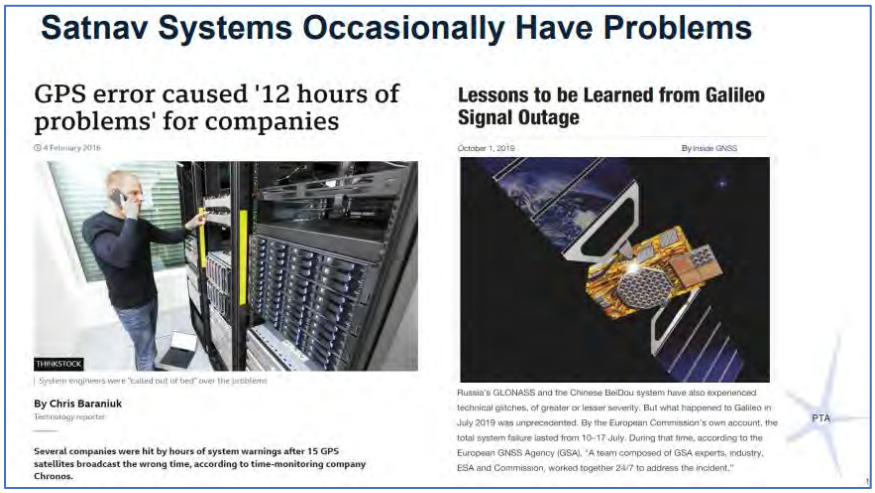
Slide 6

One of the things we're trying to get to the point of is not pointing blame, but to understand that one of the strengths and reasons why GPS and PNT have so rapidly progressed is that it has become easy to get a wide range of equipment incorporated in things at very inexpensive prices (Slide 7). It has invited a floodgate of different kinds of equipment without assuring its safe use. As we all understand, a lot of the receivers do not have the level of attention in their design and testing required in public safety applications. There's a user-end responsibility. The service provider is supposed to be able to make wise decisions about how they use this and to be assured that when products are integrated into their operations, they will meet the expectation of standard and protection.

These are not perfect systems. Sometimes the systems on orbit or through the control centers do have problems (Slide 8). There must be ways in which you can recover from that within acceptable time periods and operate through it.



Slide 7



Slide 8

Lt Gen. Hamel stated that Dr. Betz would now take over the presentation. The real point of today's discussion should regard how this get used, particularly in domestic applications and critical infrastructure uses. What are the practical things that perhaps can be offered up? Is there a government agency that believes this is part of their responsibilities to start promoting some of these things?

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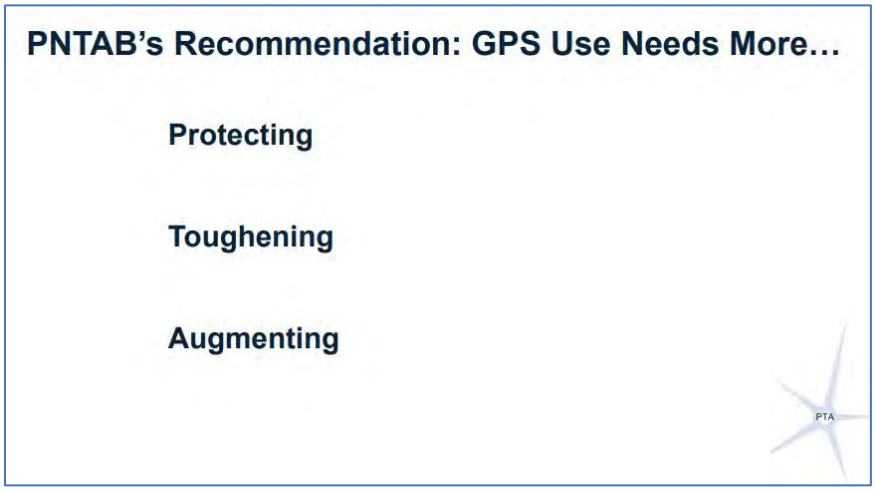
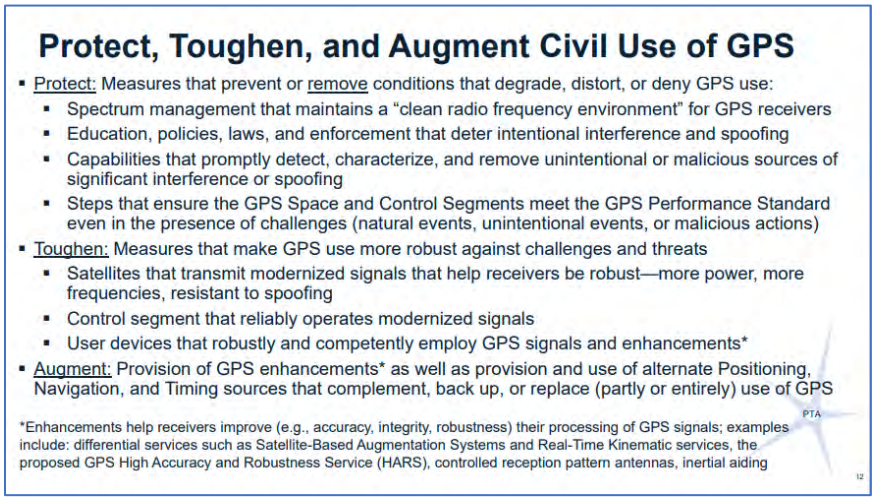
PTA Challenges: Overview of How to Overcome Them
Dr. John Betz, *Board Member*

Dr. Betz noted it was almost a decade ago that Dr. Parkinson came up with Protect, Toughen, and Augment to describe what's needed for the use of GPS (Slide 1). We're going to discuss that structure today.

One of the things we realized was that even though we've lived with those three words for a while, we were never aware of what they mean and what the boundaries are between them. So, we came up with a wordy set of definitions (Slide 2): (1) Protect is preventing or removing bad things that could happen to GPS use, (2) Toughen is making receivers more robust and more competent in using GPS, and (3) Augment involves two different things, a traditional use like a satellite-based augmentation system (which involves making the use of GPS better) and also providing alternative sources of PNT. Therefore, we're defining Augment to be both the enhancements to GPS as well as the alternative sources of PNT. So, hopefully, if we need to as a Board, we'll be able to reference these definitions, or inputs to these definitions, in describing what we mean by these three words.



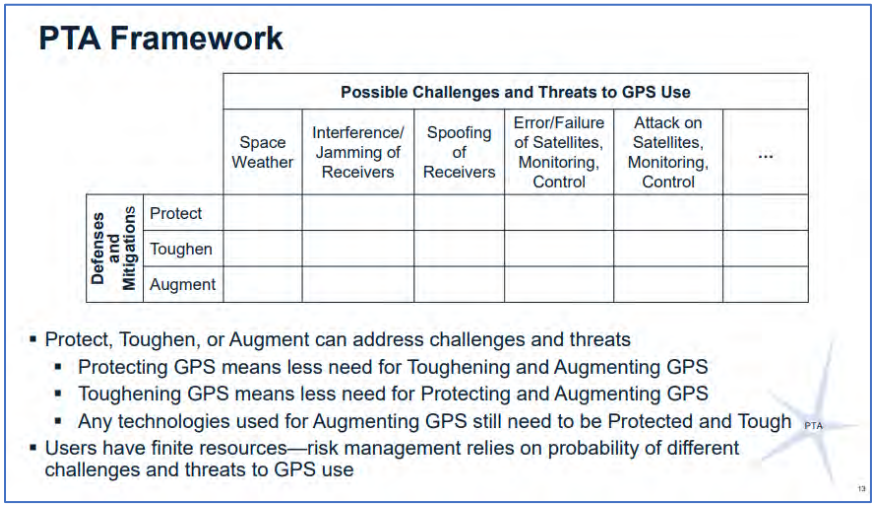
Slide 1



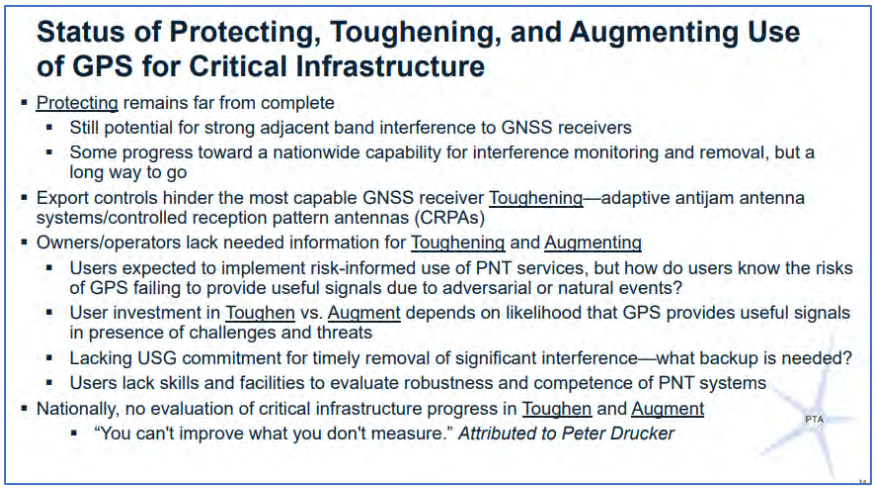
Slide 2

This report reviews the PTA framework (Slide 3). Along the top of the matrix are different challenges and threats to the use of GPS, and they can be natural, they can be accidental, or they can be malicious. PTA can provide ways of dealing with these different challenges and threats. To a large extent, we've found that PTA can be interchangeable. For example, if you protect well against interference, you don't need to have receivers that are as tough against interference. Also, it you do a really good job of protecting and toughening against a threat, maybe you don't need to worry about augmenting as much. So, there's an ability to trade how much of each of these is available or is used. One of the things that we recognize with augment is that anytime you start using an alternative source, it itself needs to be protected and toughened, so it's not enough that you use another source. We've got additional protecting and toughening to do on every additional source that we bring in. One of the things that we also realized is that users are going to bear a significant responsibility for dealing with these challenges and threats. As we've seen, U.S. policy says that there needs to be user risk management, but that's going to rely on the probability of these different challenges and threats.

Slide 4 reviews the status of PTA for use of GPS in critical infrastructure. Protecting remains far from complete. We know that the challenge from strong adjacent band interference is dormant, but it's not dead. We know that there's some progress towards a nationwide capability for interference detection and removal, but it's far from available today. We know that export controls still hinder the most powerful way to toughen receivers. And we know that owner-operators and critical infrastructure lack the information they need to toughen and augment. They're expected to do risk-informed work, but they don't know what the risks are. They're expected to choose in some way between toughening and augmenting, but they don't know how likely it is that GPS is going to stop providing useful signals. They're lacking a USG commitment to remove interference in some stated amount of time, so they don't know how long their backup devices need to work. And they don't have the skills and the facilities to evaluate how tough the devices are that they want to buy and use. Nationally, there's no evaluation of progress in critical infrastructure toughening and augmenting. As a famous management consultant said, "you can't improve what you don't measure," so we're left with a lot of work to do in PTA.



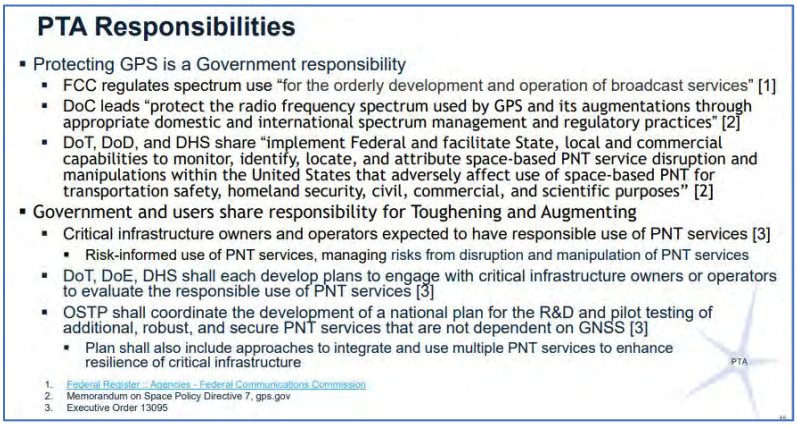
Slide 3



Slide 4

Where do the responsibilities lie for PTA (Slide 5)? We went back to the recent government documents providing guidance, and it's clear that protecting GPS is a USG responsibility shared among multiple departments and agencies. The FCC is supposed to provide for the orderly development & operation of broadcast services, which includes GPS. DOC is supposed to lead the protection of the radio frequency spectrum used by GPS and its augmentations. There's a shared responsibility between DOT, the Department of Defense (DoD), and the Department of Homeland Security (DHS) to implement the ability to detect, characterize, and remove interference sources. The USG and users also share responsibility for toughening & augmenting critical infrastructure. Owners and operators are expected to responsibly use PNT services and take risk-informed steps, but they don't know what the risks are. Three departments: Transportation, Energy, and Homeland Security, are each supposed to be developing plans to engage with critical infrastructure owners and operators and evaluating how responsible their use of PNT services is. The Office of Science and Technology Policy (OSTP) has put together a national plan for research and development (R&D). So, there are a lot of different organizations and agencies and departments involved, and the question that we've been asking this morning and many other times in the past is, "is this all being organized well enough together?"

The Subcommittee investigated near-term pragmatic ways to improve critical infrastructure use of GPS & PNT (Slide 6). As Mr. Scott likes to point out, once we've raised the bar enough, we start to get herd immunity, where bad actors realize they're not going to have enough of an effect to try to do bad things. We're going to focus on what's available or almost available, and on actionable steps that have near-term impact. Out of that will come some advice to a whole set of stakeholders, much more than the EXCOM. We will provide some advice to the USG on protecting spectrum use, on detecting, characterizing, and removing sources of interference. Removing sources of interference is very important from a military point of view. We need to be concerned about that whole kill chain, and we haven't done our job until the interference source is removed. We want to talk about what the government can do for toughening receivers for aviation and other safety of life applications, and how the government can help provide information to owner-operators so they can do a better job of toughening and augmenting. We're going to provide some thoughts for user equipment manufacturers for how they can either do a better job or publicize that they've done a better job, and we're going to try to provide some advice to owner-operators as well. One of the things that we'd like the Board to think about today is how to communicate this better; how can we get it to the people who are going to be able to use it?



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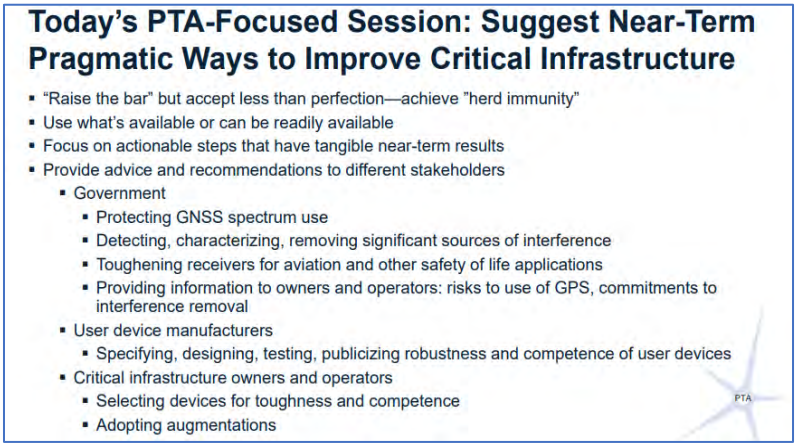

Slide 6

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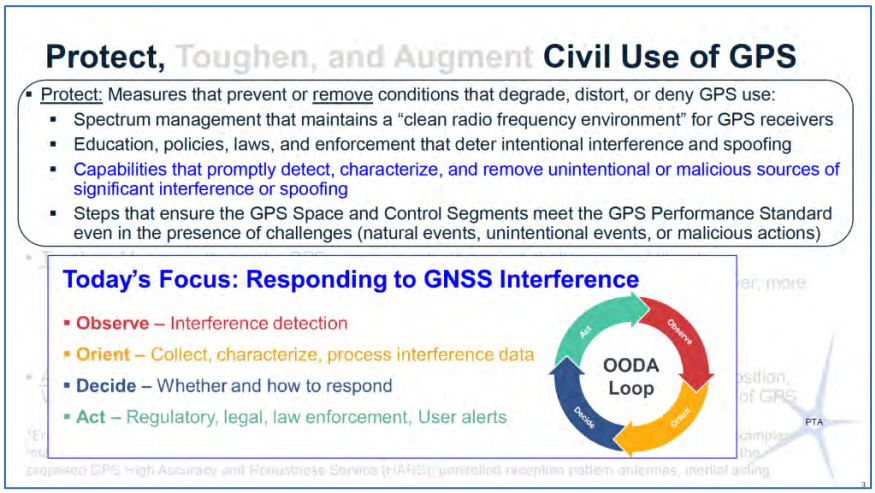
Theme 1: Protecting GPS/GNSS Use

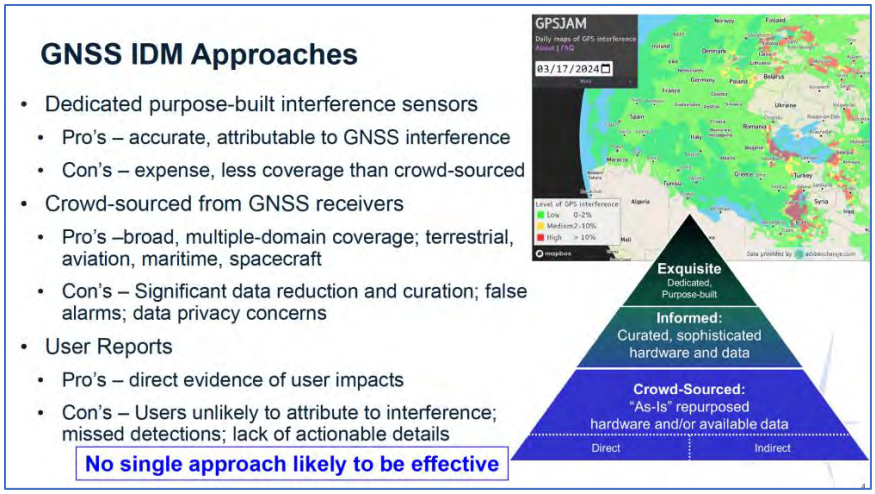
Protect Overview
Dr. Thomas Powell, *PTA Subcommittee Vice Chair*

Dr. Powell noted there are two excellent guest speakers lined up: Dr. Dennis Akos from the University of Colorado and Mr. Mike Rhodes from the FCC Enforcement Bureau. They're going to talk to you about some of the things that they're doing. They're going to mention a real-world interference event that both were either personally or their organizations were involved in. This forms a good case study for the problem of protecting and removing interference. At the end, we'll have some discussion about potential metrics for interference detection and mitigation, and perhaps some candidate Board recommendations for the board to consider. Slide 1 restates he "protect" problem from Dr. Betz's previous chart. There are several other aspects of "protect," including regulatory. But for this portion of the day, we're going to focus on interference detection and mitigation. The Observe, Orient, Decide, Act (OODA) Loop, which was a model developed for military operations but could apply to the problem of detecting and mitigating interference. It involves four steps: observe the situation, collect data to orient yourself, decide whether and how to respond, and you act, whether it's regulatory or legal. But it's a decent model for organizing the response to GNSS interference.



Slide 1

If you've been to past Board meetings you've heard about a number of ways to detect interference (Slide 2). They range from purpose-built interference sensors, which are exquisite sensors that could be placed at specific locations that can provide very high-quality telemetry and data about what's going on in the environment. Those are very valuable, and they're very accurate. However, the downside is that they tend to be more expensive, and you can't put them everywhere. In the middle of the slide, there are crowdsourced ways of determining interference, and we've seen a number of ways to do this. Dr. Akos is going to talk about a technique that he uses, using smartphones to locate interference. It seems to be a very effective way to do it. Some of the pros are there's lots of these devices available, and generally, they have much better coverage. You can use smartphones on the ground. The picture in the upper right is from www.GPSjam.org and it shows what you can do with ADS-B data from aircraft. One of the shortcomings of that is that you can only get this data where commercial aircraft happen to be flying. So, if you have a conflict zone where there are no aircraft, you may not have coverage. You also have the potential for false alarms if the sensors are not purpose-built and can flag the difference between true interference and some other source. At the bottom is user reports, and the user reports can be valuable if you have a knowledgeable user who knows how their system works and would recognize that their receiver isn't working right. Those users are probably rare, and most often if a user experiences some malfunction in the receiver, they might think it's a software issue, or the GPS satellite is doing something wrong. It's probably the lowest quality form of interference detection and much more likely to have false alarms. The bottom line here is that no single approach is effective, so if you want to have something that's truly effective, it's probably going to have to involve a collective approach using both exquisite and crowdsourced sensors.



Slide 2

Slide 3 shows a recent interference event. It's very timely; this occurred within the last few months. It involved both and it involved the GNSS band. It was the GLONASS band, but nevertheless, it was a GNSS band. Through a sequence of events, Dr. Akos was contacted, and he just happened to be working on some of his research on using smartphones to detect these things. The plot that you see in the slide is one where he drove around and was able to help mitigate the interference. Denver is also a big city, so there was an FCC field office there. It wasn't Mr. Rhodes, but it was the local field representative in Denver who was able to go knock on a door eventually and get this interference source to stop.

Slide 3

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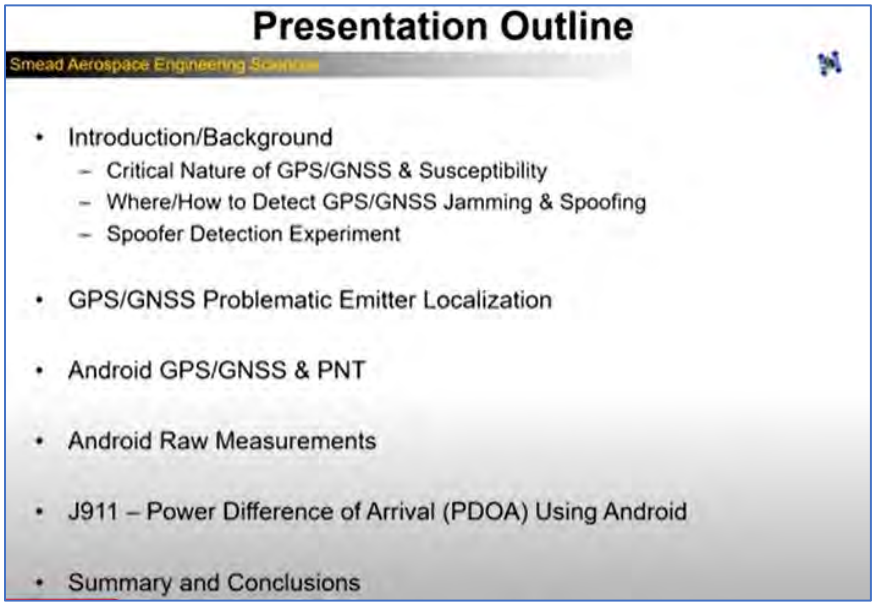
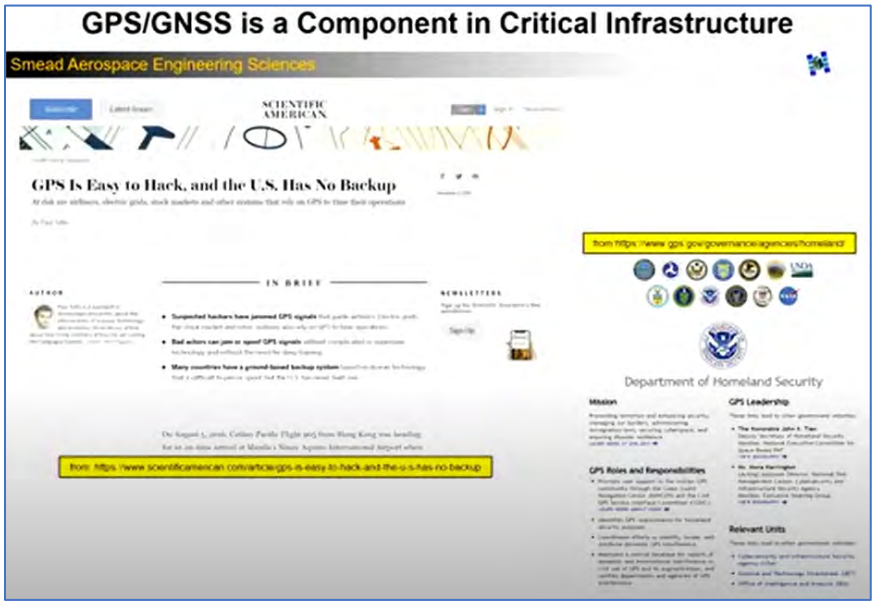
Smartphone-Based Interference Detection
Dr. Dennis Akos, *University of Colorado Boulder*

Dr. Akos introduced himself and said he'd first provide some framing material for what's going on, followed by the research he's been involved in (Slide 1). The latter includes a discussion on the problem of emitter localization, Android [smartphone] PNT measurements, and some experiments he's conducted on the J911 concept pioneered by Mr. Scott.

A key motivation for this research is that GPS/GNSS is a component of critical infrastructure (Slide 2).



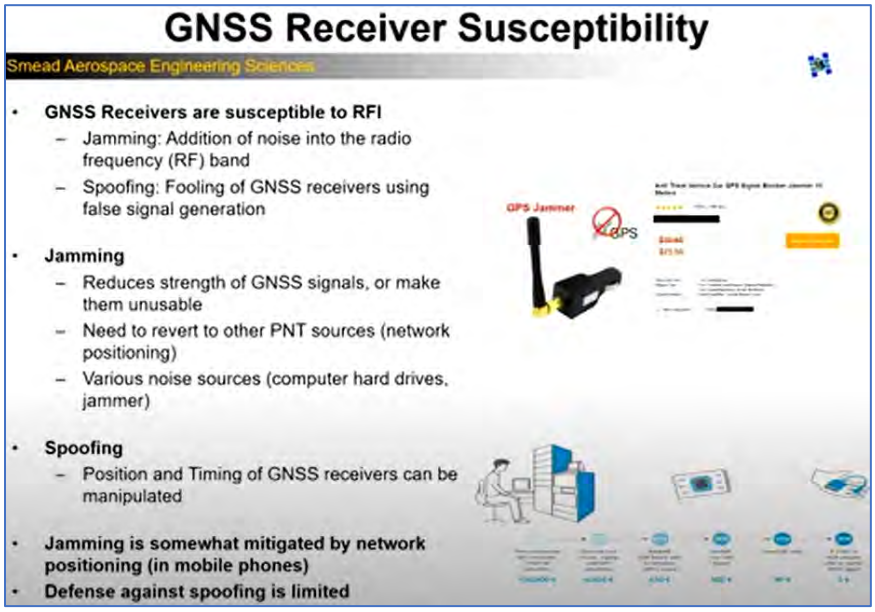
Slide 1



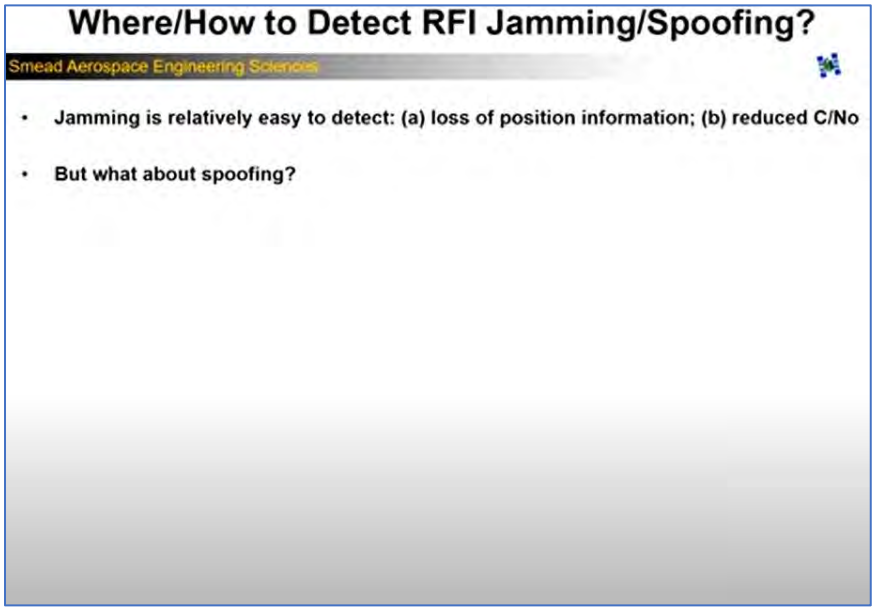
Slide 2

GNSS receivers are susceptible to interference (Slide 3). Jamming and spoofing is the focus of this research, and they've looked at what can be done next.

Jamming is relatively easy to detect (Slide 4). If you look at your phone or watch, and are not getting a position solution, then you know you have jamming going on. A little more subtle, you could have weaker jamming causing reduced signal-to-noise, but that is also relatively easy to detect. However, spoofing is more difficult to detect.



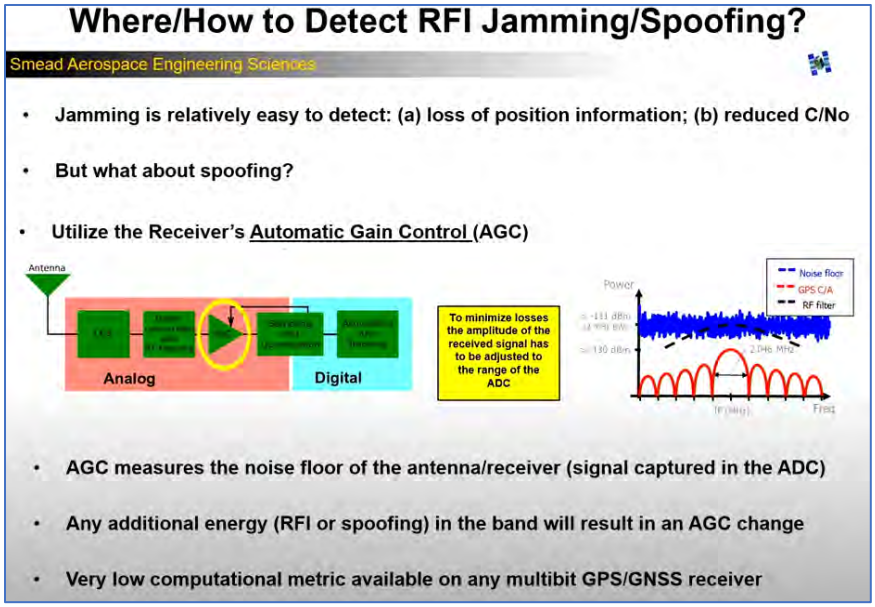
Slide 3



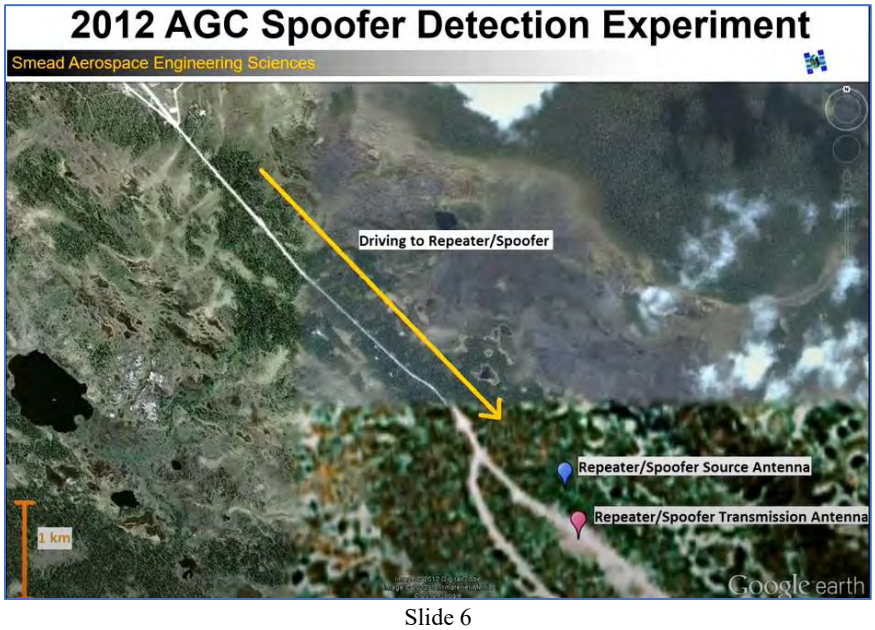
Slide 4

Dr. Akos' team has done a lot of work on the idea of using a receiver's automatic gain control (AGC) (Slide 5). GPS signals are unique in that the receiver power is lower than the thermal noise floor. Nearly all multi-bit receivers have this concept of AGC. What that's doing is trying to match the input power to the analog-digital converter so that it does the optimal signal processing. In GPS, with the power level below the noise floor, when you do this, you're really assessing what the noise power is. So, what AGC is really doing is measuring the noise power, and any additional energy, whether interference or spoofing, will result in this AGC change. This is a very low computational metric available on any multibit GPS/GNSS receiver.

Slide 6 provides an example. This was an early experiment conducted in Sweden over 10 years ago. They took a couple receivers and drove them towards a repeater/spoofer.



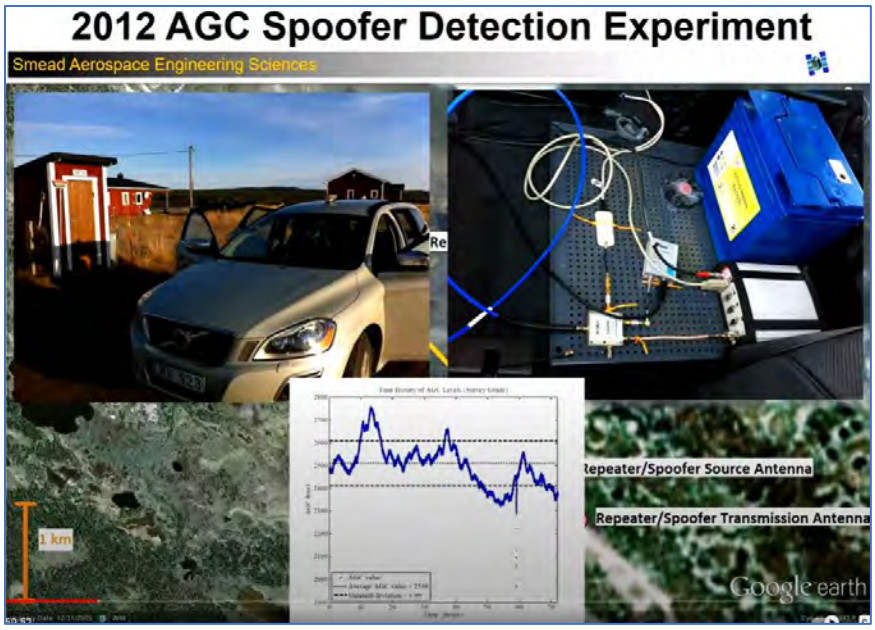
Slide 5



Slide 6

The car included some Commercial Off the Shelf (COTS) receivers, and prior to the experiment some of the AGC measurements were calibrated (Slide 7).

Slide 8 shows the spoofing source antenna in this experiment.

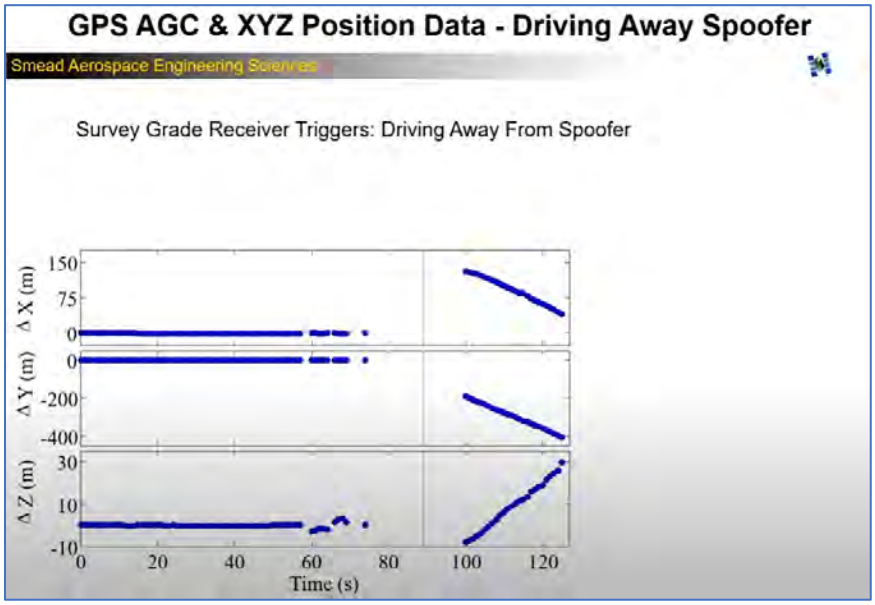


Slide 7

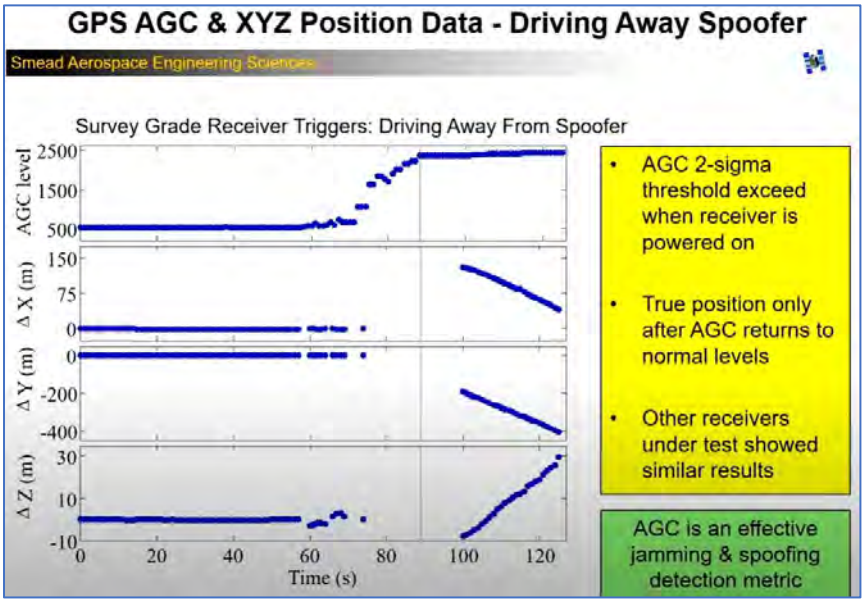
Slide 8

Slide 9 shows a picture of the measurements. The receiver shows the position (x,y,z), where the receiver is apparently not moving. However, when looking out the window you see you are moving, so obviously there is a problem. As you move farther away (right of the graph) the receiver loses capture and spoofer picks up the true signal.

By bringing in the AGC metric, you can see why the position cannot be trusted (Slide 10). This shows how AGC is an effective metric to detect jamming and spoofing.



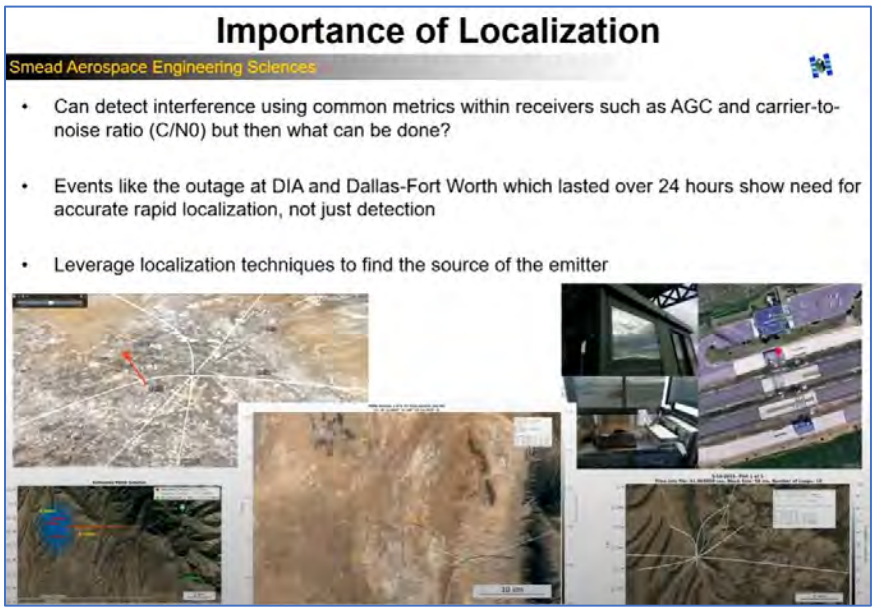
Slide 9



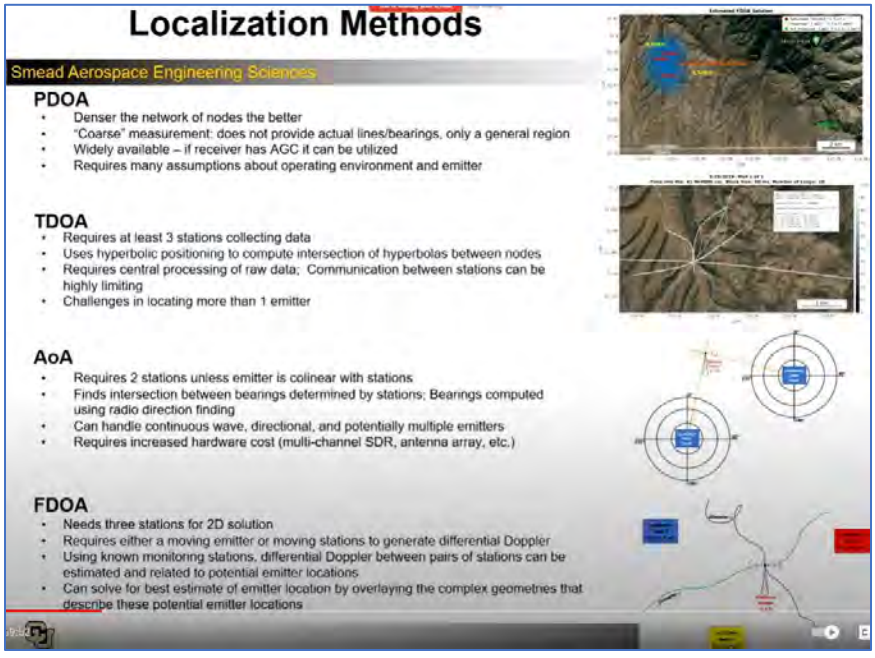
Slide 10

So, now that we know there is a problem, how do you locate these emitters (Slide 11)? Jamming events, such as the one at the Dallas International Airport and Dallas-Fort Worth, show why we need rapid localization.

Slide 12 summarizes the localization methods that were used. This briefing is going to focus on the Power Difference of Arrival (PDOA) method.



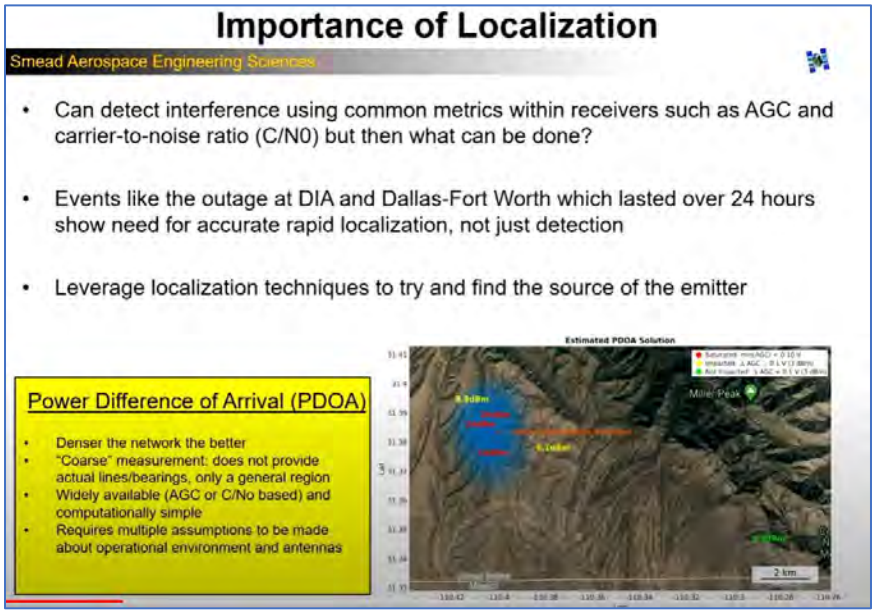
Slide 11



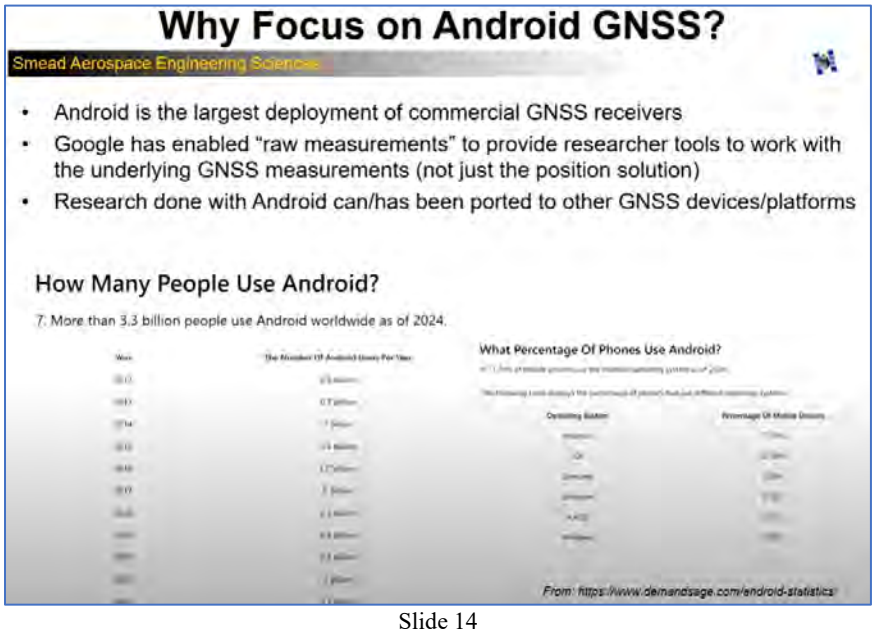
Slide 12

The concept behind PDOA is simple (Slide 14). If the emitter is close, it will show more power than someone on the other side of the road. So, we aggregate power measurement from everybody else. Whomever sees the most power, we approximate by free space path loss to computer where the signal is going to be. PDOA is a coarse measurement that doesn't actually provide lines or bearings. It only provides a general region. That's why the idea of having a dense network is important.

So, because the denser the network the better, Android GNSS provides a good platform to use this technique for localization of interference sources (Slide 13). Android is the largest deployment of commercial GNSS receivers. Google has done an outstanding job in providing raw measurements to researchers.



Slide 13

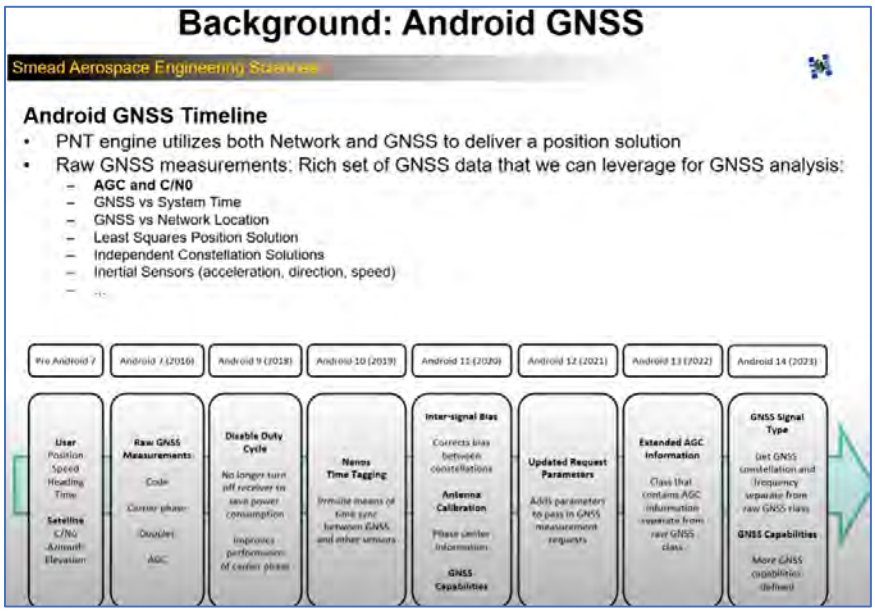


Slide 14

As shown in Slide 15, there are many benefits in using Android GNSS vs. Apple iPhone GNSS, particularly its a larger market share and provides raw measurements. AGC is a key piece that Google has added.

Slide 16 shows how Android GNSS has evolved over time. Pre Android 7 they only had the basic measurements one gets from a GPS receiver but starting with Android 7 the raw GNSS measurements were also made available (Slide 16).

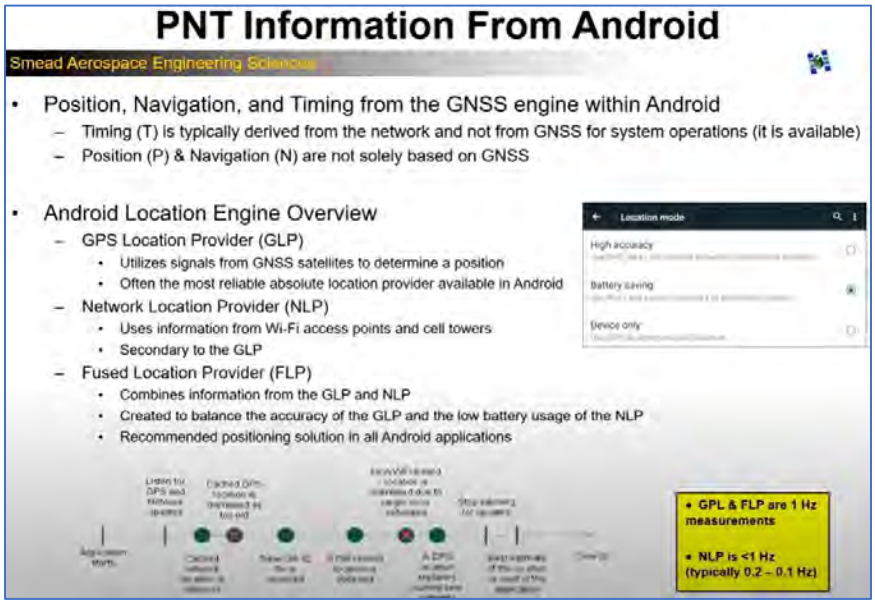
Slide 15



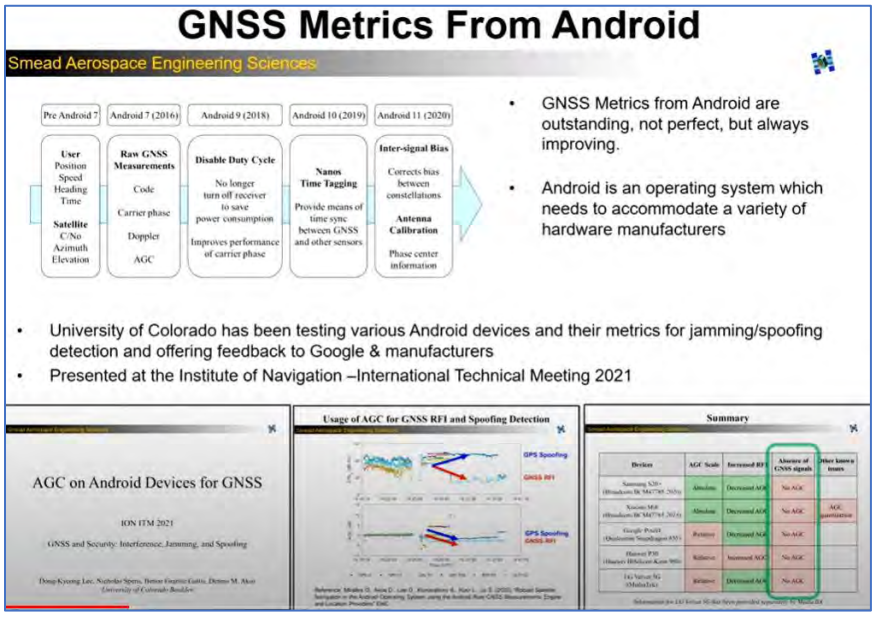
Slide 16

When using an Android, timing is typically derived from the network, and position/navigation are not solely based on GNSS (Slide 17). The phone fuses together both the GPS and network location [by communication signal triangulation]. Their testing shows that phones are heavily reliant on what GPS is saying.

Slide 18 describes the GNSS metrics. When the study was conducted in 2020, they had the Android 11. The paper, "AGC on Android Devices for GNSS," was published at the 2021 ION International Technical Meeting (ITM). In the chart on the bottom right (Summary) note the AGC data. Android is just an operating system, so the problem they faced was who made the chipsets inside the phone report the measurements. AGC is simply a power measurement, and you don't need any GNSS measurements to get this power measurement. Ideally, they should be decoupled. But, in the earlier versions they were only getting AGC when they were also getting GNSS signals.



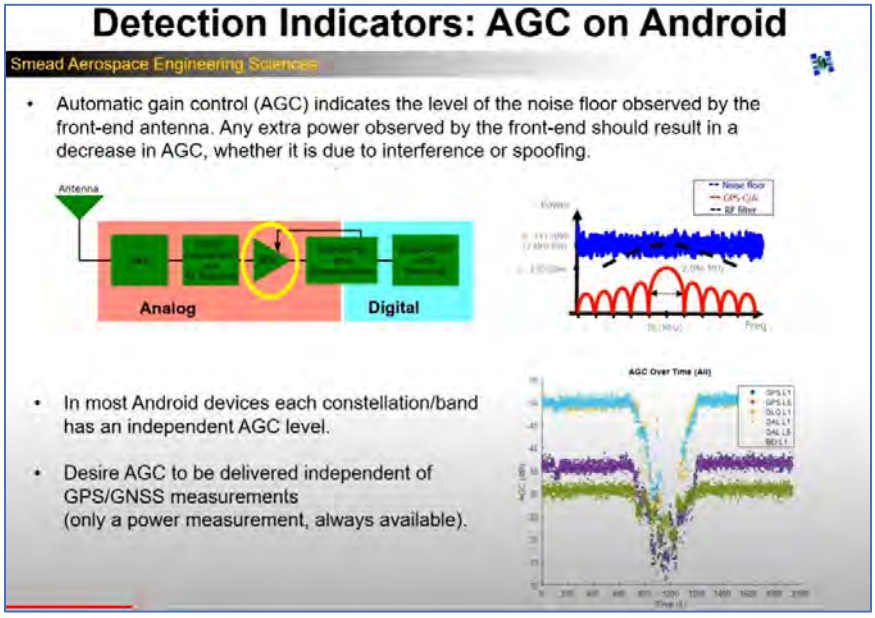
Slide 17



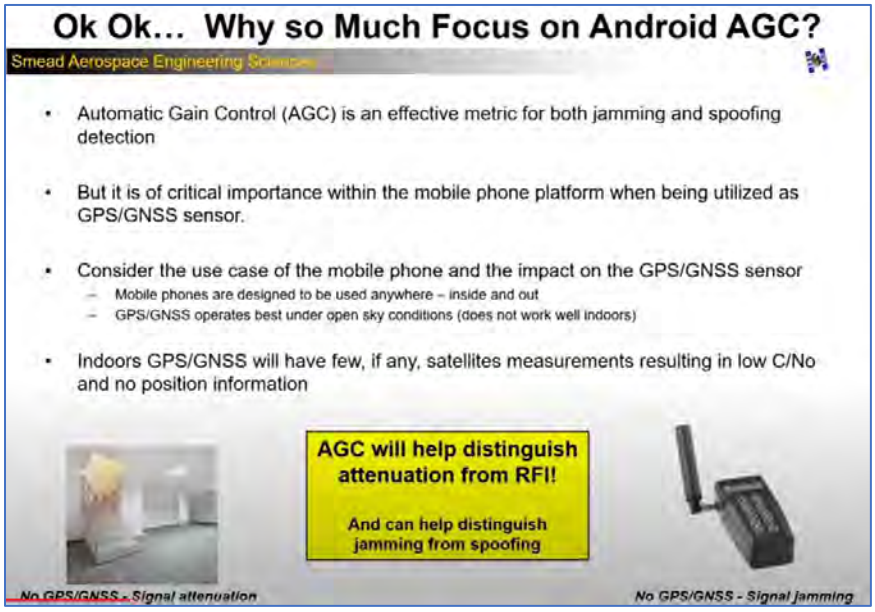
Slide 18

In most Android devices each constellation/band has its own independent AGC (Slide 19). It is only a power measurement which is always available, and that is what happens when introducing interference and looking at the AGC metric over time.

Slide 20 summarizes why they are focused on Android AGC as a GPS/GNSS sensor. The key advantage is the ability to compare the AGC measurements with the GNSS measurements. When GNSS measurements are not available, for example indoors, that's where AGC comes into play. Indoors there will be few, if any, satellite measurements, which will result in a low signal-to-noise and no position information. AGC will help distinguish attenuation from interference and to distinguish jamming from spoofing.



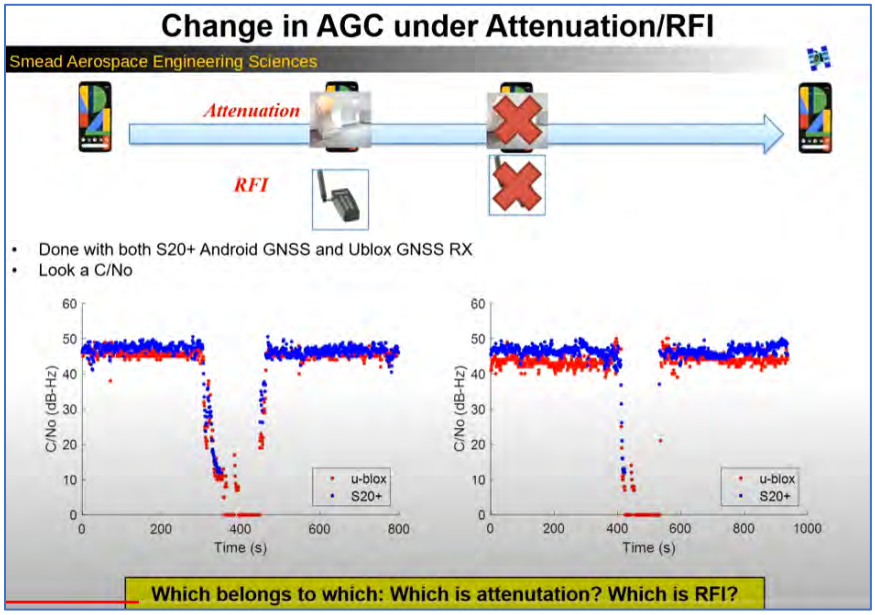
Slide 19



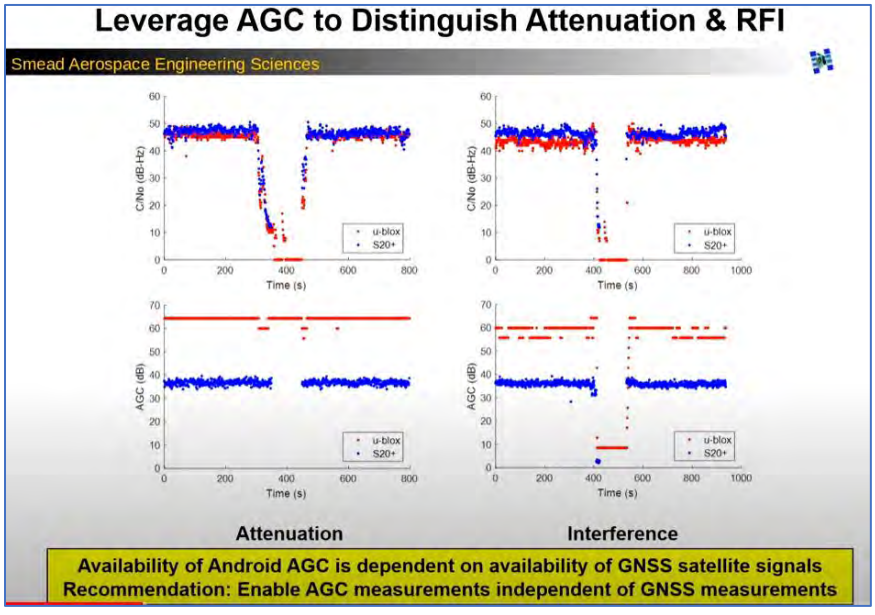
Slide 20

They did a simple experiment by taking an Android S20+ phone with a Ublox GNSS Rx and looked at the signal-to-noise ratio (Slide 21). Then they introduced one case of attenuation (took it to the basement) and another case introducing. The objective was to see what the signal-to-noise ratio was for these two cases. The dip in the graphs below show the change in signal-to-noise when under attenuation and interference, and if you look at the two plots it's very difficult to tell which one is due to attenuation and which one is due to interference.

Slide 22 at the top shows the signal-to-noise ratio for both instances, and at the bottom it shows the AGC. Now it is easier to distinguish attenuation (plots on the left) from interference (plots on the right). This shows that the availability of AGC in the Android phone is dependent on the availability of the GNSS signals. Thus, they recommended to enable AGC measurements to be independent of the GNSS measurements. This is the case now with smartphones using the Android 13, or better, operating system (see Slide 16 for a comparison among Android smartphones). The University of Colorado continues to assess Android devices for their GNSS performance. We have Google to thank for these improvements.



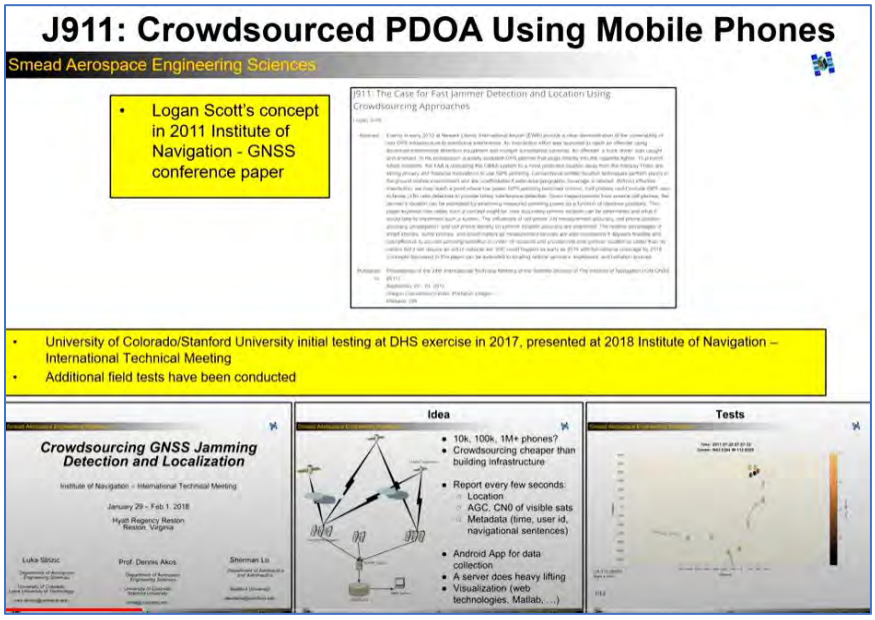
Slide 21



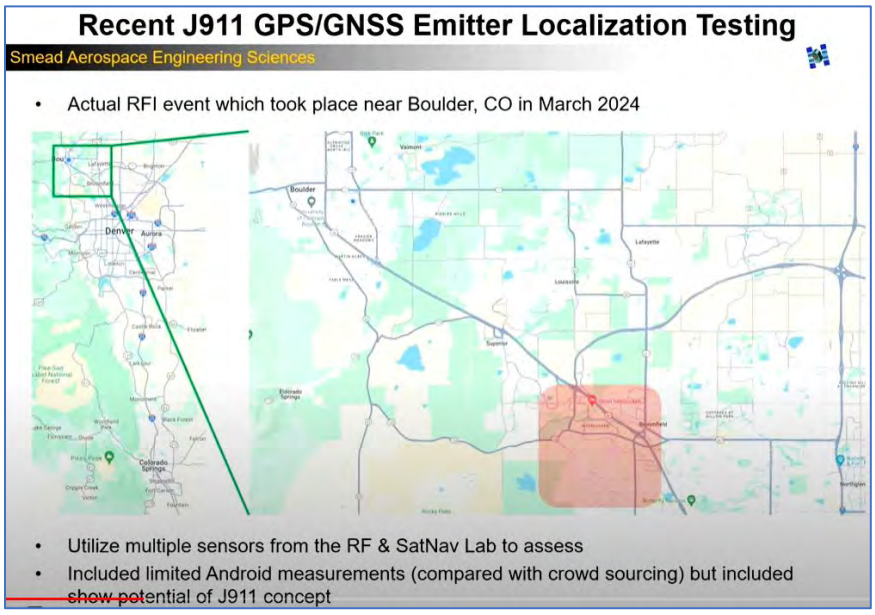
Slide 22

Slide 23 describes the J911 concept, where PDOA is crowdsources using mobile phones. This concept was presented by Mr. Scott in 2011 and followed by initial testing at the University of Colorado in 2017. This was done with pre-AGC in the phones.

Slide 24 depicts emitter localization testing in March 2024. This is the event that Dr. Powell alluded to earlier today. This was an actual interference event and provided a chance to show the potential of the J911 concept even when using limited Android measurements. The region in red is where interference was detected with other equipment.



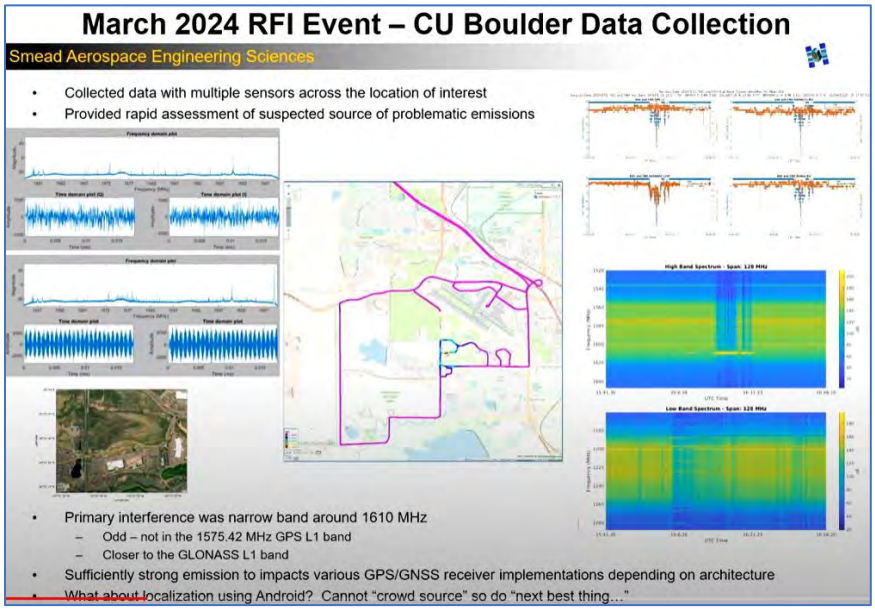
Slide 23



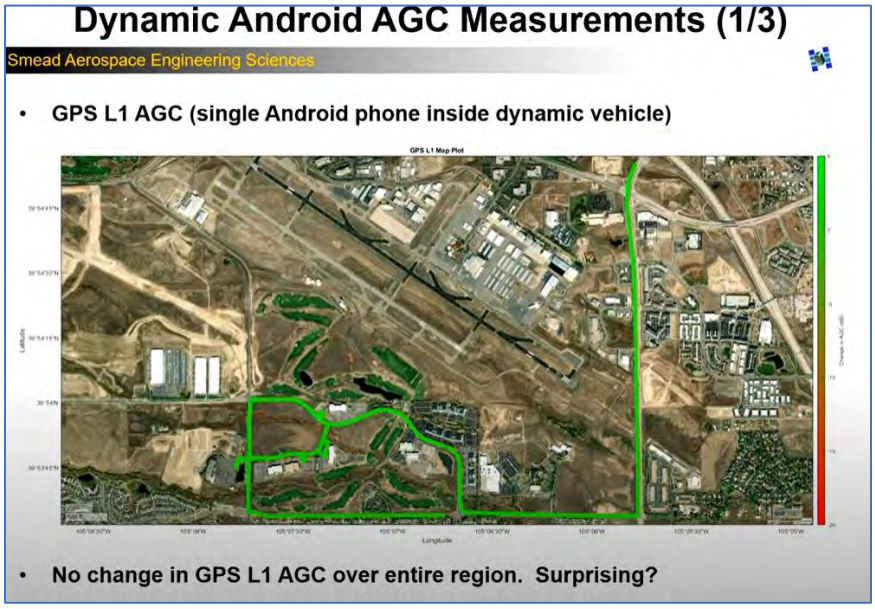
Slide 24

Data was collected using multiple sensors across the area of interest, and they got a rapid assessment of the source of problematic emissions (Slide 25). As shown in the plots on the left, oddly enough the interference was not in the GPS L1 band, but closer to the GLONASS L1 band. However, the emission was sufficiently strong to impact some GNSS receivers depending on the architecture they used. The plots on the right show what the measurements looked like as they drove around. It was very clear from these plots where the hot spot was. So, how do these compare with Android AGC measurements?

Slides 26-28 depicts the dynamic Android AGC measurements. On Slide 26 shows the measurements with a single Android phone inside the vehicle. As they drove around, they didn't see changes in the GPS L1 AGC over the entire region.



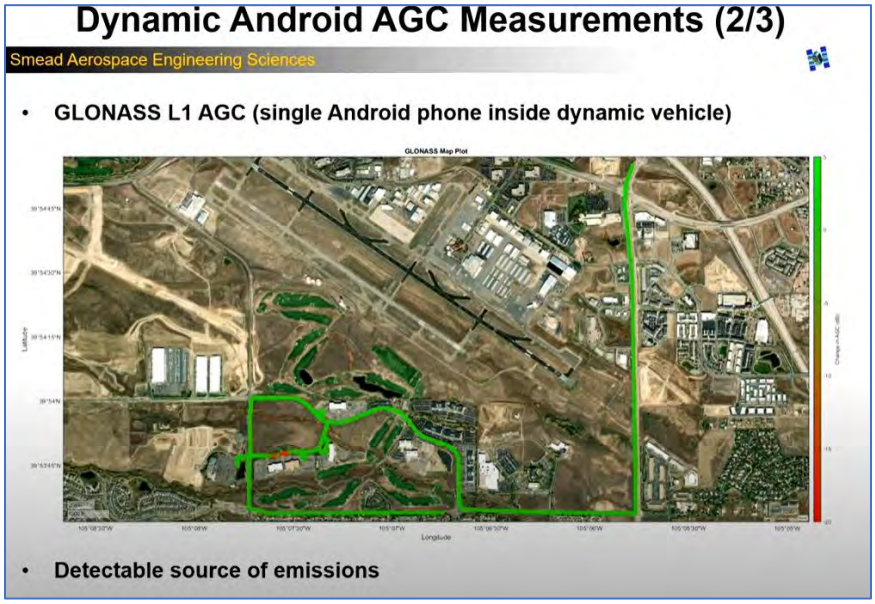
Slide 25



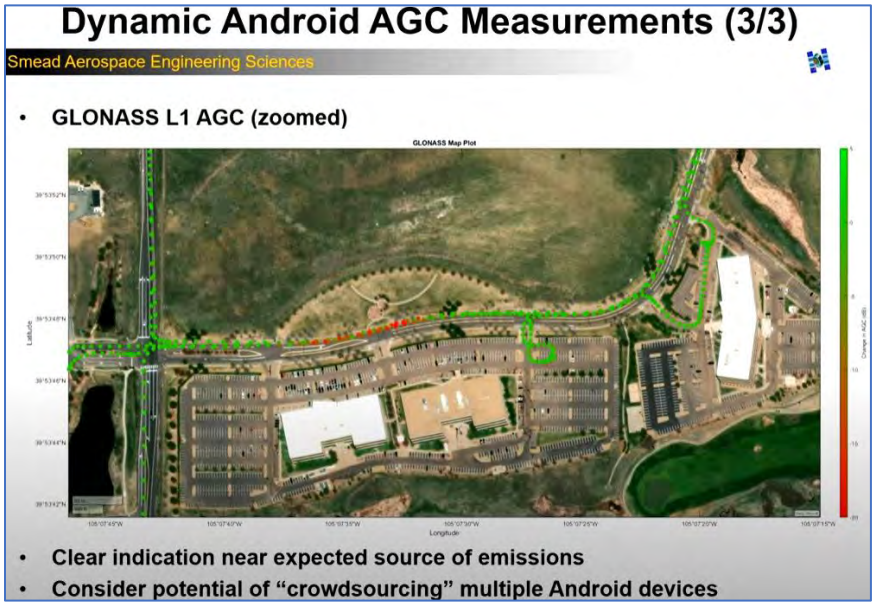
Slide 26

Slide 27 shows the changes in GLONASS L1 AGC. Note the red trace towards the bottom left of the map showing the detectable interference to GLONASS. The phone provided a better indication of what had happened compared to the measurements using other equipment.

Slide 28 shows a zoomed version, clearly showing the area of interference. This demonstrates the potential of this concept by crowdsourcing multiple Android devices.

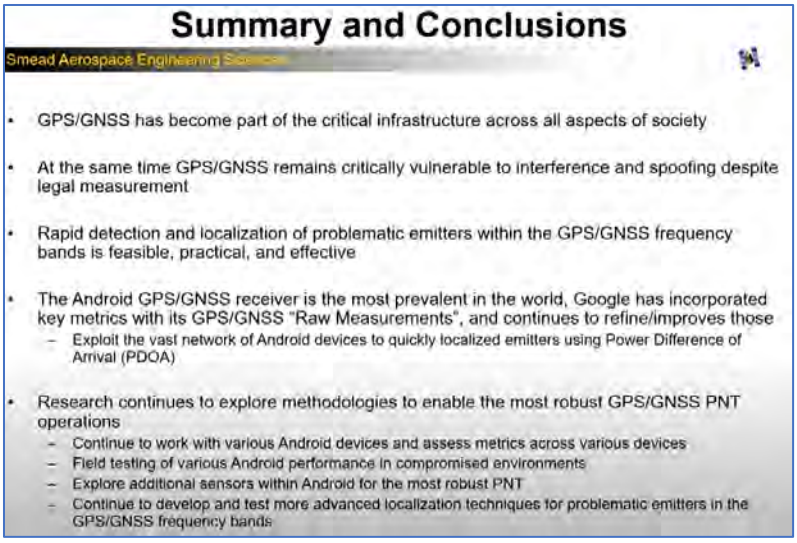


Slide 27



Slide 28

To wrap things up, rapid detection and localization of problematic emitters within GPS/GNSS frequencies is feasible and effective using Android GPS/GNSS receivers and the PDOA technique (Slide 29). Research is continuing at the University of Colorado Boulder to further explore methodologies to enable robust GPS/GNSS PNT operations.



Slide 29

Discussion:

Dr. Parkinson asked Dr. Akos if he has knowledge whether Apple may relent in allowing users or other software to gain greater knowledge of what's going on.

Dr. Akos said he doesn't know. He thinks the capability may be there, but as a researcher it's been much easier for him to work with Google because of the availability of raw measurements.

Dr. Parkinson noted other research that has been conducted instead using TDOA (Time Difference of Arrival) from three locations that enabled to pin down an interference source. He asked if Dr. Akos is working at all in that direction?

Dr. Akos said he has. It works great for wide band, and even spoofing. However, it doesn't work as well if it's Carrier Wave (CW) because you can't cross-correlate.

Prof. Filjar said he assumes Dr. Akos is also able to identify the spoofing if it is targeting a specific GNSS system, not just GPS. Is there a chance to get insight into Dr. Akos' crowdsourcing data?

Dr. Akos said that regarding spoofing, GNSS is unique in that signal tends to be below the noise floor across all the bands. But, if one has a dynamic platform it becomes difficult to just mess up the power. Other techniques have been explored, such as multiple correlators. As for crowdsourcing, they only have 30-40 datasets.

Prof. Filjar said he'd like to discuss opportunities for collaboration in building such a database.

Dr. Akos agreed. He noted that different vendors report AGC in different ways across different platforms, so the challenge is how to use those in an effective fashion.

Mr. Goward asked Dr. Akos to say more on how he got the alert for the March 2024 interference event in Boulder, CO.

Dr. Akos said he received an e-mail from a friend at The Aerospace Corporation noting there was a "funny thing" happening in the area and gave him a vague picture as to where. Afterwards, he went out and found the interference was unintentional, and the operators immediately shut it down.

Dr. van Diggelen noted that if Dr. Akos believes this jamming detection / localization capability can be directly incorporated into the actual user interface of phones, he should send a letter to Google management noting all users would benefit.

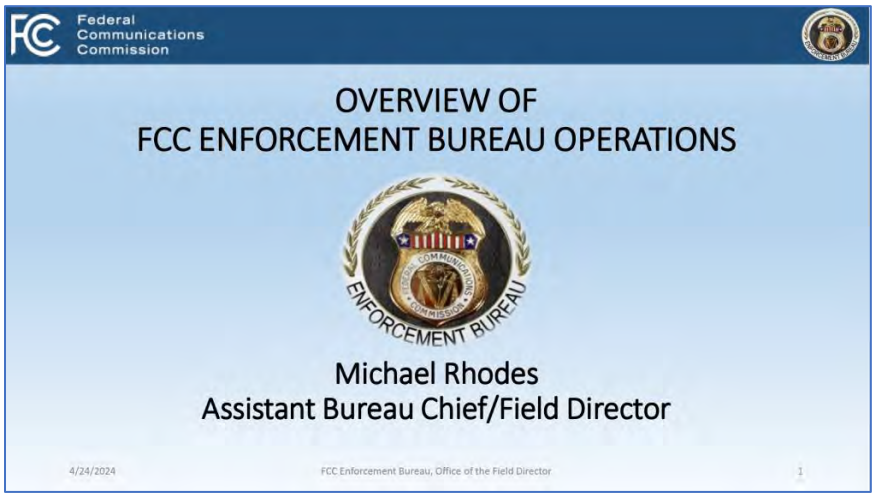
Dr. Parkinson asked Dr. van Diggelen to write such letter. Since the Board represents a wide panoply of users, it strengthens the argument of providing benefits across the board.

Dr. van Diggelen agreed that such approach would help in starting the conversation.

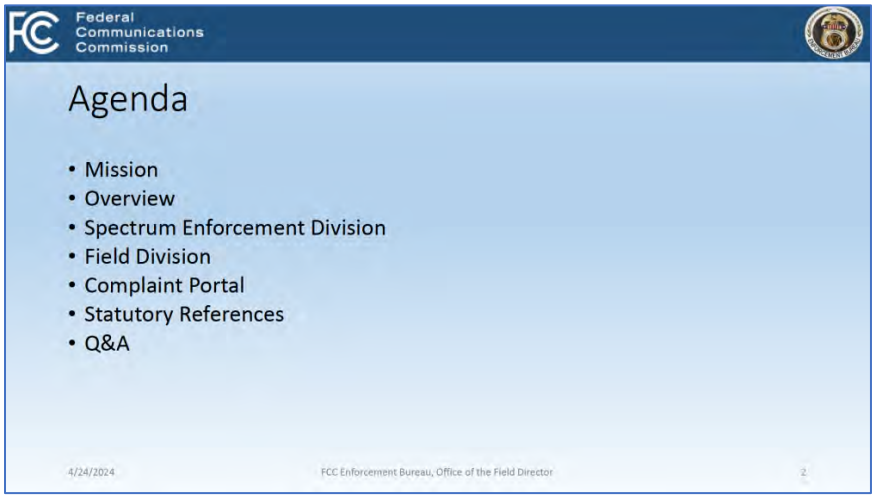
***

FCC Enforcement Bureau's Role in Protect
Mr. Michael Rhodes*, Federal Communications Commission (FCC) Enforcement Bureau*

Mr. Rhodes introduced himself and reviewed the briefing agenda (Slides 1-2). It includes an overview of the FCC and the two divisions that are most important to PNT, namely, the Spectrum Enforcement Division and the Field Division (or Office of the Field Director). This is followed by the Complaints Portal and, for the lawyers, the Statutory References.



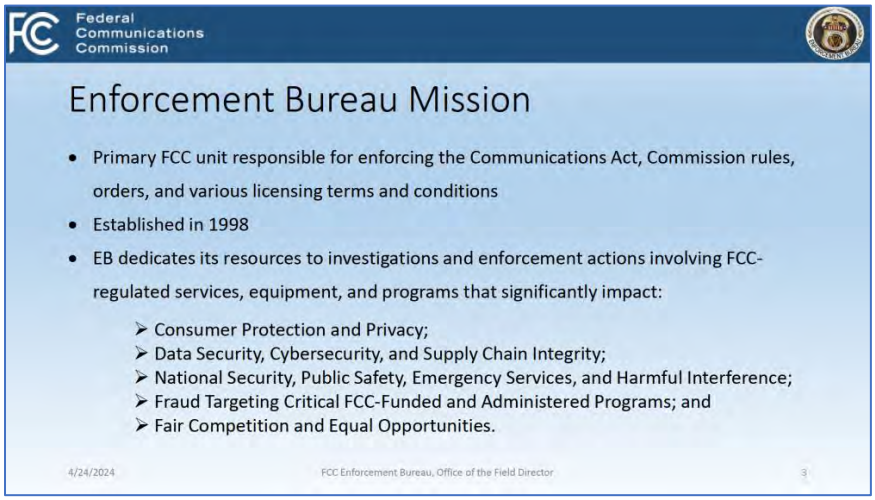
Slide 1



Slide 2

The Enforcement Bureau was established in 1998 (Slide 3). Prior to that all bureaus in the FCC did their own enforcement. This bureau does not make the rules.

Within the Enforcement Bureau there are a number of other divisions (Slide 4). The Telecommunications Consumers Division enforces robocall rules, fraudulent telemarketing, and accessibility complaints. The Market Disputes Resolution Division adjudicates disputes between market entities like common carriers and data providers, utility pole attachment disputes, etc. The Investigations and Hearing Division is responsible for non-technical matters such as indecency, misrepresentation, underwriting, auction collusion etc. The Fraud Division covers the fraudulent use of funds from universal service funds and other FCC programs. The next two divisions, *Spectrum Enforcement Division* and *Office of the Field Director*, are the two divisions most relevant to PNT.

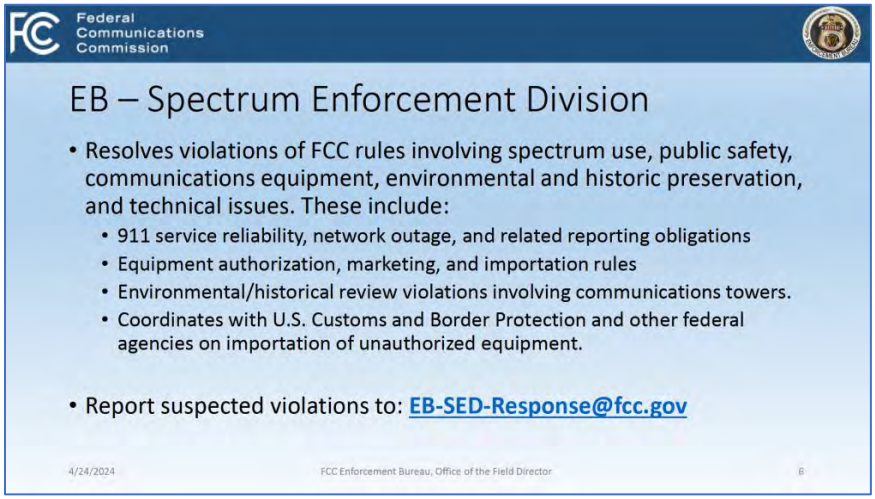


Slide 3

Slide 4

The name Spectrum Enforcement Division, or SED, resolves violations of FCC rules involving spectrum use, public safety, communications equipment, environmental and historic preservation, and technical issues (Slide 5). SED investigates 911 and other network outages. It also handles equipment authorization violations of the rules (radiation limits, etc.) set by the Office of Engineering and Technology. SED also works closely with the DHS and U.S. Customs and Border Protection on imports. The e-mail address EB-SED-Response@fcc.gov is available for the public to report suspected violations of equipment marketing rules.

Mr. Rhodes works in the Office of the Field Director (Slide 6). It has 13 staffed field offices with about 50-60 agents. These are federal agents and carry a badge. They investigate jammers, unauthorized operations, intruders (such as someone making radio transmissions in a public safety system), unintentional interference, pirate radio broadcasting, tower marking & lighting (and tower lighting outages). The office also supports the Federal Emergency Management Agency (FEMA) on communications restoration in the event of disasters, as well as supporting national security events such as the Superbowl, UN General Assembly, political conventions, inaugurations, World Cup, etc.

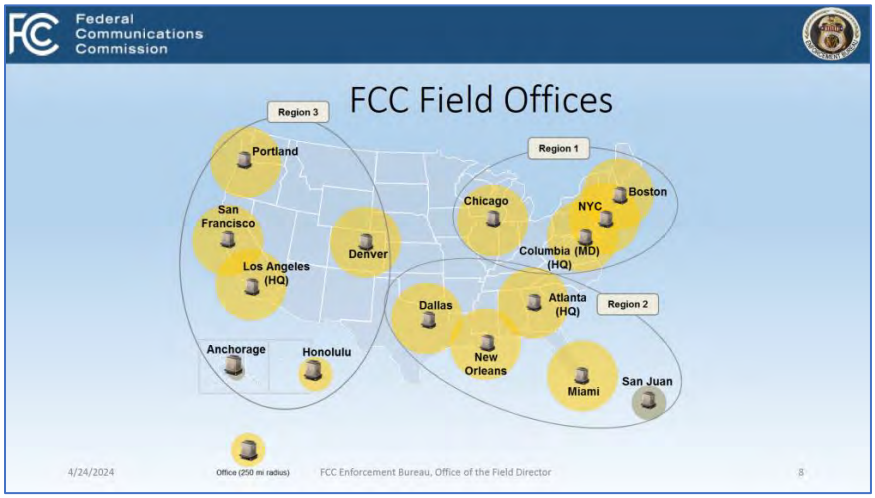


Slide 5

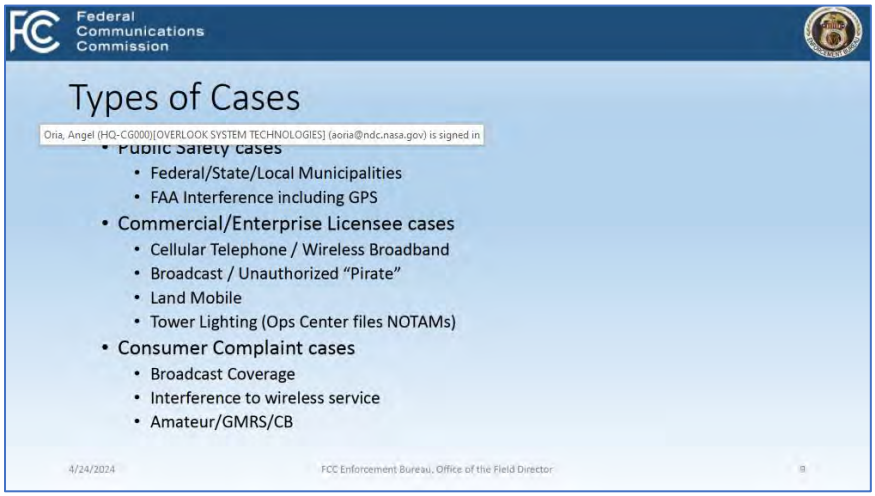
Slide 6

Slide 7 is a map of the FCC field offices. There are also offices in San Juan (Puerto Rico) and Alaska with contractors for quick deployment, though agents can also be sent.

Field agents work on many types of cases (Slide 8), which requires them to the FCC rules across a wide variety of areas. They cover public safety cases for federal, state, local municipalities, and public safety entities such as the Federal Aviation Authority (FAA) (including interference to GPS). They also cover commercial and enterprise licensee cases such as cellular carriers, broadcasts, and tower lighting. Finally, the cover other cases such as consumer complaints on broadcast coverage, interference to wireless services, as well as amateur / GMRS (General Mobile Radio Service) / CB (Citizen's Band).



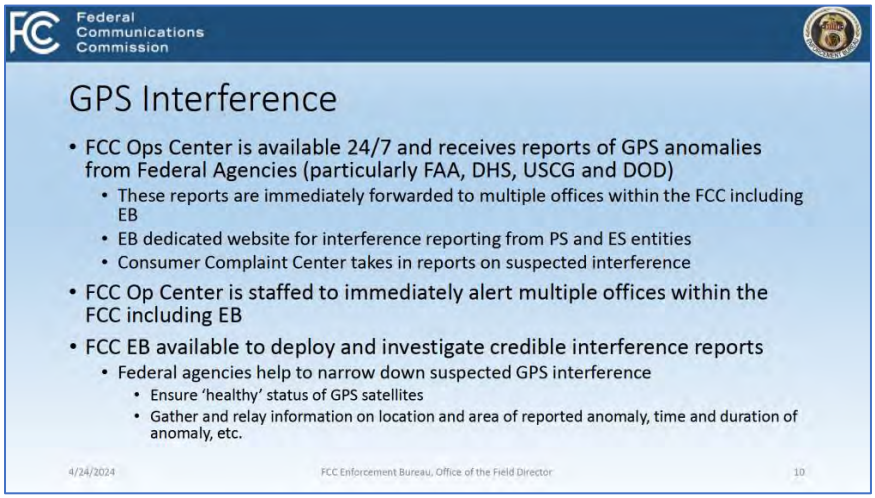
Slide 7



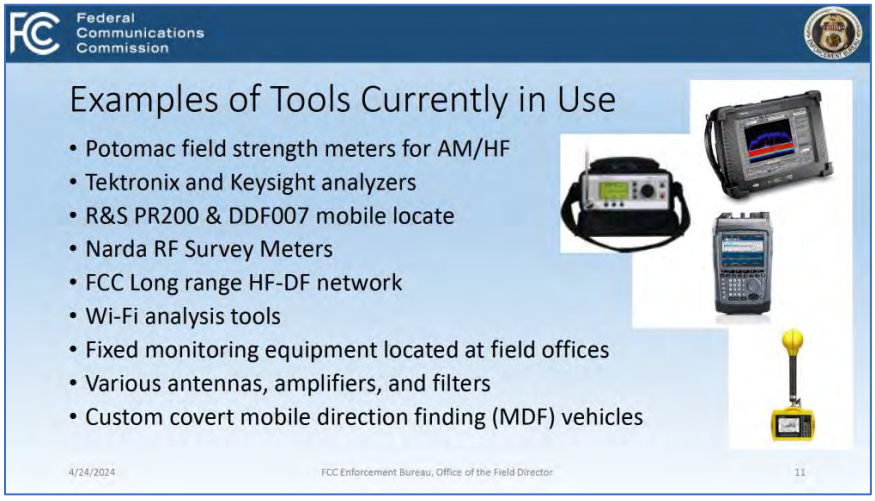
Slide 8

On the issue of GPS interference, the FCC has an operations center (Slide 9). It's staffed 24/7 response center and receives the reports on GPS anomalies from Federal agencies, particularly from the DHS/DOT Navigation Center (NAVCEN). These reports are immediately forwarded to a number of offices and bureaus within the FCC, including Mr. Rhodes'. There is also a Consumer Complaints Center that takes reports on suspected interference. GPS anomaly reports within the U.S. are immediately sent out to the appropriate field office for investigation. The biggest issue are the credible interference reports, such those in an airport due to GPS repeaters (or re-radiators).

Slide 10 depicts a few examples of the tools used by the FCC. These tools enable the FCC to enforce rules and regulations across all the radio spectrum, from AM broadcast band all the way up to the GHz range (high frequency). One of their biggest assets are the custom covert mobile direction finding (MDF) vehicles.



Slide 9



Slide 10

MDF are custom trucks with a covert antenna built in the rooftop (Slide 11). It includes automatic five-band switching, from AM up to 3 GHz. The FCC also has dome-antennas, both off-the-shelf and custom designed, that can be put on top of these trucks to extend the frequency range up to 8 GHz.

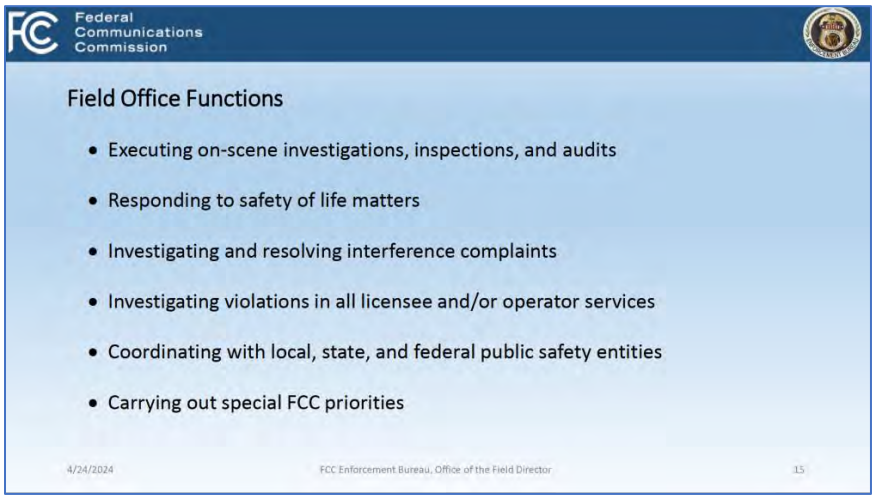
There is an Equipment Management Group in Powder Springs, Georgia, that builds and outfits all the FCC trucks and also does all the custom equipment and custom equipment and software development (Slide 12).

Slide 11

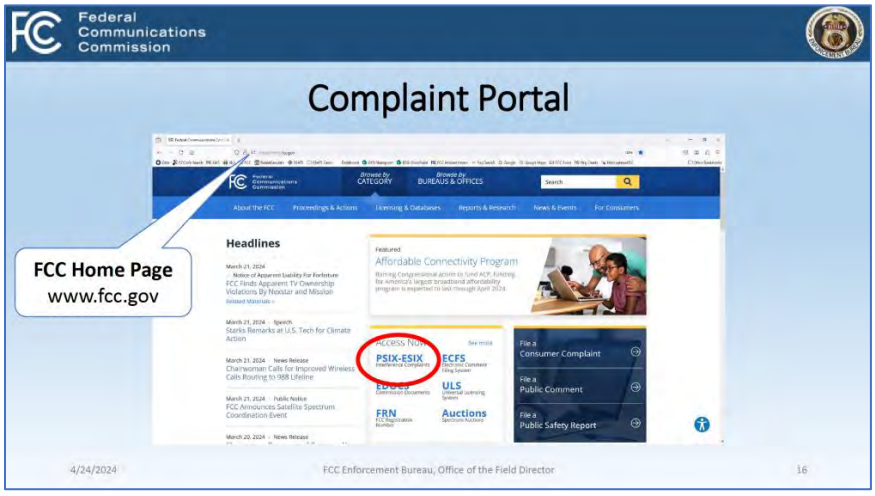
Slide 12

Back to the Field Office Functions, there are a lot of things going on (Slide 13). It does inspections and on-the-scene investigations. FCC agents can knock on the door. They'll typically call local law enforcement for help. The offices respond to safety-of-life matters in a timely manner and respond to all kinds of violations.

There is a Complaints Portal right off the homepage of the FCC (www.fcc.gov) (Slide 14). The FCC calls this the PSIX-ESIZ (Public Safety Interference and Enterprise Safety Interference) portal.



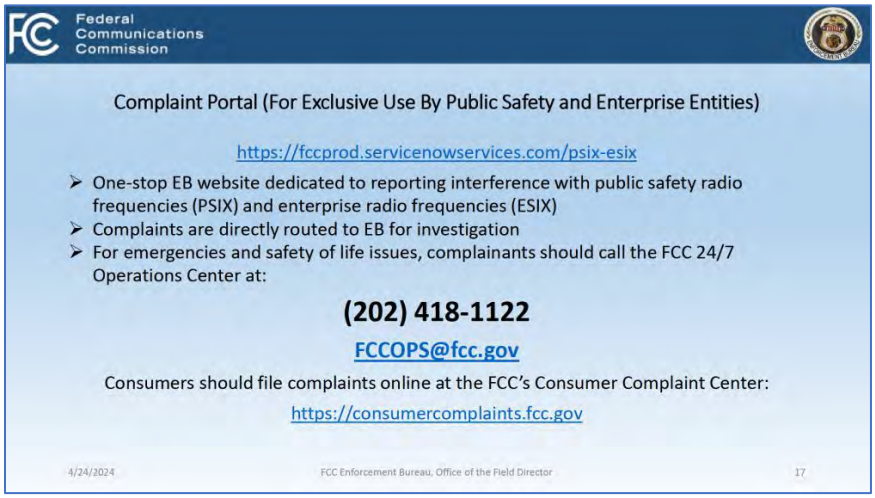
Slide 13



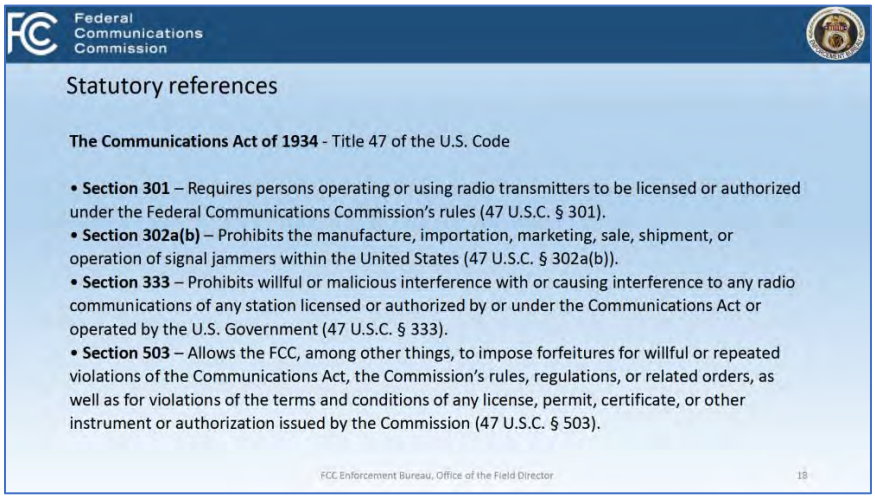
Slide 14

Slide 15 includes the URL to the PSIX-ESIX webapge. It's a one-stop Engineering Bureau website dedicated to ingesting these reports, and then they get routed to the correct agency for action. There is also a phone number for emergencies and safety-of-life issues, (202) 418-1122. The Engineering Bureau is not, typically, a first responder but tries to respond within 24 hours for safety-of-life issues. There is also an e-mail for consumer complaints (FCCOPS@fcc.gov).

Slides 16-18 include the statutory references. Slide 16 provides the sections of the U.S. codes typically used by the FCC regarding interference, particularly jammers. Note that section 302a(b) prohibits the operation of a jammer, not its possession. Therefore, the FCC needs to catch violators while they are using the device.



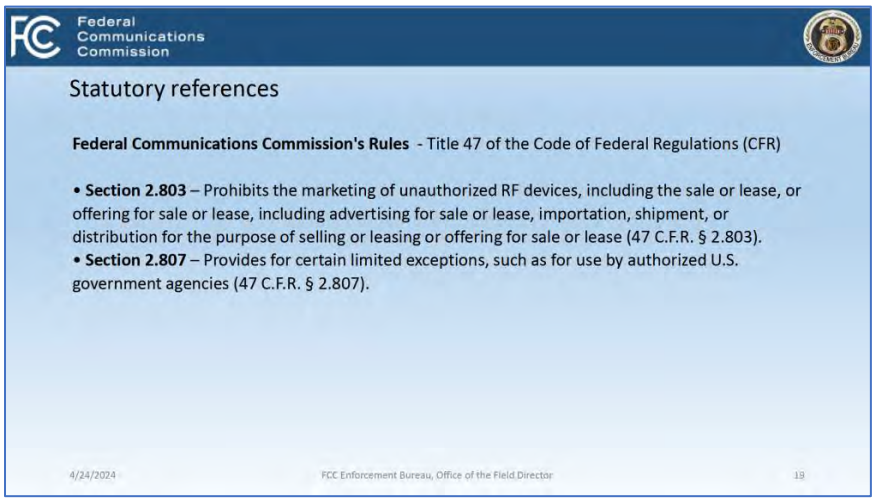
Slide 15



Slide 16

Slide 17 covers the same thing, though on the equipment side. Section 2.803 prohibits marking, importing, selling, or distributing such devices without authorization.

Many U.S. states have their own intentional interference laws that augment what the FCC does (Slide 18). The FCC does a lot of work with local and state officials. The FCC has no seizure authority.



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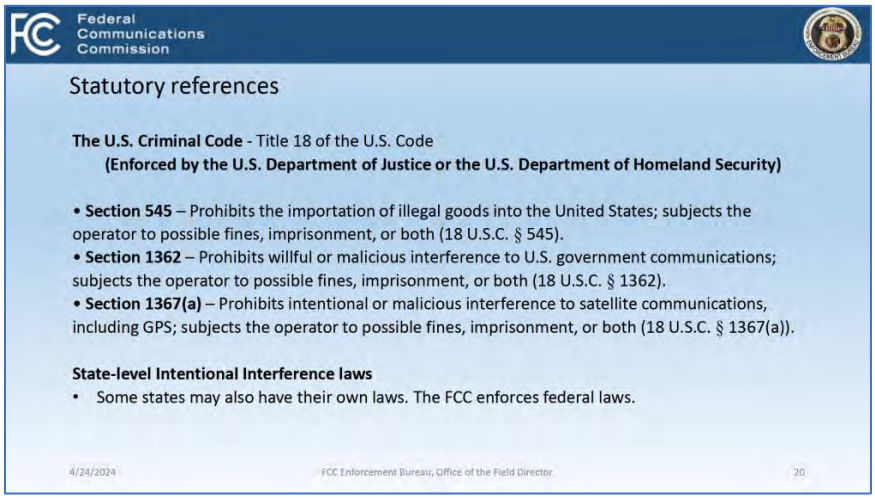
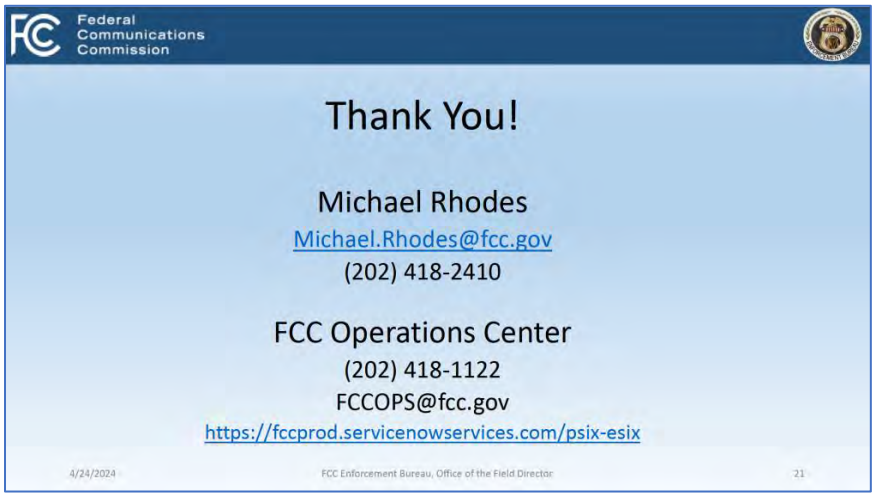


Slide 18

Mr. Rhodes concluded and said he would be happy to take questions (Slides 19). GNSS is a hot topic these days. The FCC is investigating such issues, but at this time cannot comment on them.



Slide 19

Discussion:

Mr. Burns asked about an incident on Easter Weekend incident in Broomfield. He has flown in and out of there many times, and if an aircraft were making an approach that would technically be a safety-of-life issue. Does the FCC have an agreement with local authorities, say the Broomfield Police, to shut down the transmitter?

Mr. Rhodes said they don't have an agreement with local enforcement. The FAA has its own enforcement people, and the FCC works closely with them on these types of issues.

Mr. Burns said he knows that the transmitter was shut down and is curious on who asked for that.

Mr. Rhodes said that incident was reported by a surveyor through NAVCEN.

Mr. Goward noted there are a lot of instances where interference is used by organized crime. For example, in Mexico it is believed that these devices are used in 80% of cargo thefts. Interference detection devices are reasonable affordable, so does the FCC work with local authorities to help them? Are there any initiatives for the FCC to share its authorities with them through legislation?

Mr. Rhodes said there are no initiatives at the moment.

Dr. Parkinson added that he doesn't understand why someone isn't working to resolve the apparent loophole that allows people to possess a jammer. This also relates to the issue about the FCC not having authority to seize the device. These seem to be gaping holes in the ability to enforce the things we'd like done. Is this a conscious constraint? If so, what rationale was there?

Mr. Rhodes said he does not know. It's a statutory thing that comes from Congress.

Dr. Parkinson asked if there is someone at the FCC advocating changing that.

Mr. Rhodes said there's no one that he's aware of. It's a frustration also for the FCC.

Dr. Parkinson said that perhaps that's something the Board could recommend? There should be a power to arrest when such incidents are malicious. In his view, delegating this to the state level is inadequate. On another issue, this Board in the past has advocated the use of phased-array antennas to steer nulls for spoofers and/or jammers. An interesting consequence of that would be that, if done right, those same antennas could be used to pinpoint the azimuth (direction) of the interference source. Thus, he urged Mr. Rhodes to keep an eye on what may develops because, if their use is authorized, Dr. Parkinson believes the cost will come down and thus help proliferate their use by the FCC Field Offices, and maybe even encouraging local law enforcement to buy them.

Mr. Rhodes said their vehicles do have a multi-element antenna, though not specifically for GPS.

Dr. Parkinson said that the sensitivity to detect interference would be far greater if it were specific to GPS.

Mr. Scott noted that he believes the fine for use of a jammer could be up to $100,000, and it seems that most of the jammers being used are associated with trucking activity. If truck drivers, as part of their Class C license, had a question on there about what the maximum fine for is running one of these things, that might help dissuade them a little bit. This is just a thought.

Mr. Miller added that the Board reports to the National Space-based PNT EXCOM, which is co-chaired by the deputy secretaries of defense and transportation. Thus, Mr. Rhodes' briefing will be very helpful to those of us that staff our representatives to the EXCOM when advocating for legal changes. Thus, Mr. Miller would like to invite the FCC to participate in the next EXCOM meeting. The Board could also, perhaps, propose some legislative changes or recommendations to help the FCC.

Dr. Betz asked Mr. Rhodes if he's aware, at the local or state police level, whether operating a jammer could be probable cause for stopping a vehicle?

Mr. Rhodes said he does not know.

Dr. Betz added that his thought is that equipping police cruisers with jammers detectors could assist them to stop suspicious activity.

Mr. Goward responded that at least one state police is already doing that.

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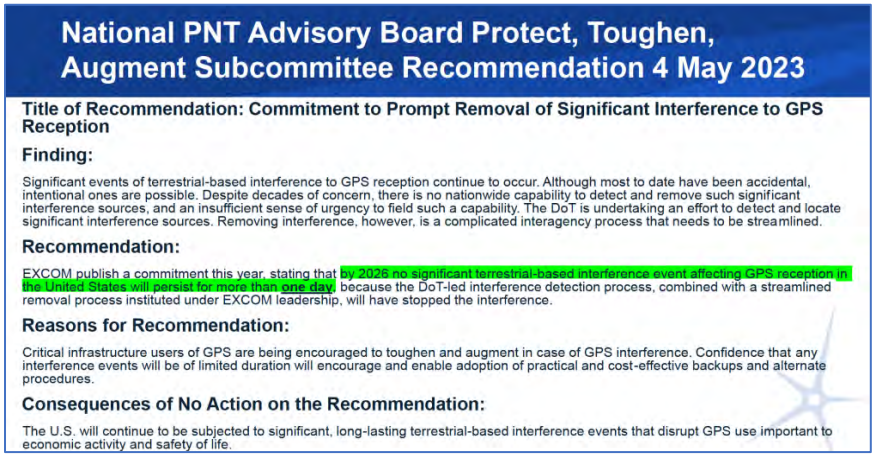
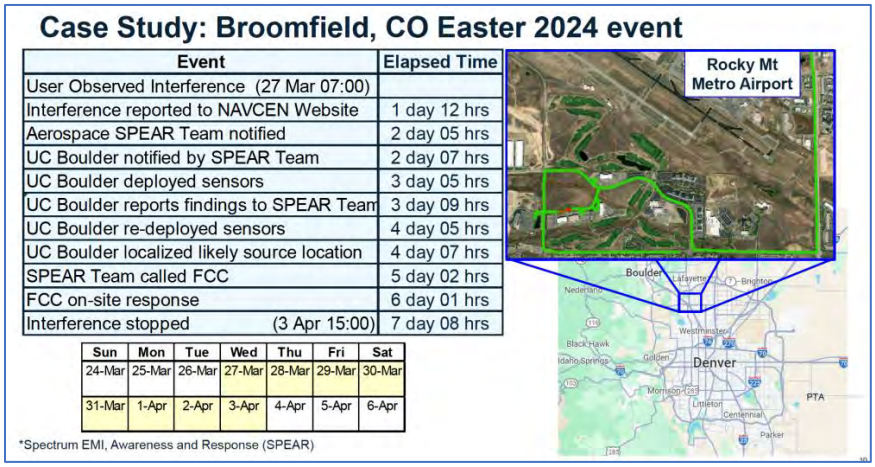
Protect Summary
Dr. Tom Powell, *Board Member*

In May of last year, the Board presented a recommendation regarding the detection and stopping interference (Slide 1). Slide 2 shows the timeline for the Broomfield Event. It took about a week from the time the first user noticed interference to where the FCC was able to make the interference stop. There are many intermediate steps in between, including the steps taken by Dr. Akos and his students to locate the interference. In many ways, this is a good news story because it's a great example of interagency collaboration where the FCC was able to come out and make a difference. Also, it was a good demonstration of the value of some of the technology that Dr. Akos discussed: the ability of smartphones to locate these things. On the other hand, it took a week, and it was a very fortunate set of circumstances. This event happened to occur in a major city where there happened to be an FCC field office next to a university where there happened to be a world-class researcher who just happened to be working on this problem. Even then, it took a week to mitigate. This illustrates the challenge of not only finding interference but also shutting them down.



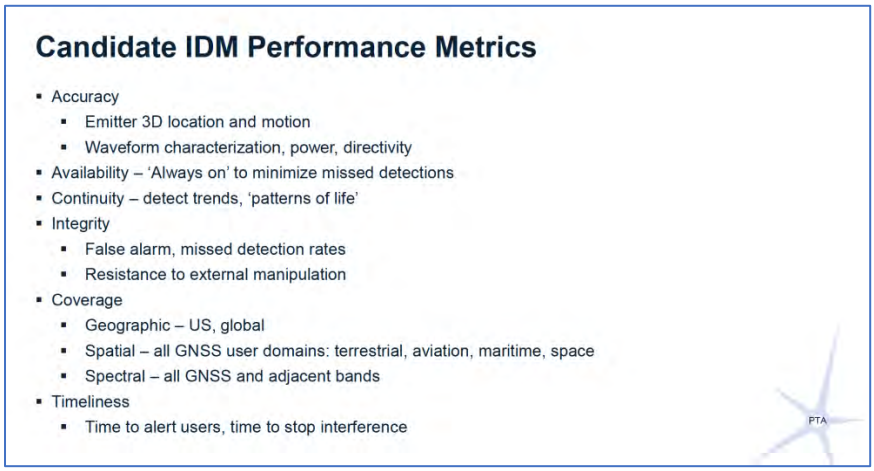
Slide 1



Slide 2

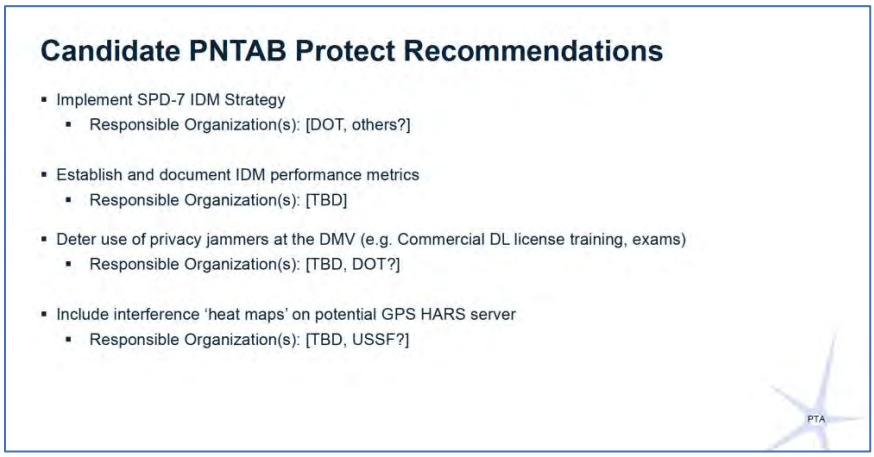
Are current practices for interference detection and mitigation effective, and if not, how can they be improved? One of the things that you'll see on the next chart is a set of metrics. We talk about metrics performance metrics for other GNSS accuracy availability Integrity, but we could propose a set of metrics for interference detection and mitigation performance. Slide 3 depicts some candidate metrics, and they should look very similar to Positioning, Velocity, and Time (PVT) metrics to include things like accuracy, availability, and integrity, but these are applied not to PVT accuracy but to finding and locating jammers. For accuracy, you want to know where this thing is coming from. Sometimes these things are moving, so you must be able to determine if these things are moving. You'd like to know what the waveform is. Is it a jamming waveform, spoofer, or repeating waveform? You'd like these systems to be on 24/7 to be able to detect these things. There may be patterns of life. If there's criminal activity where they're going down the same road at the same time every day, that would be useful to law enforcement agencies. Additionally, you don't want a lot of false alarms, and if you have an automated system, you want to make sure that can't be manipulated. Ideally, you would like the coverage to be global. You would like to cover not only terrestrial users, but space users can also be subject to

interference. The timeliness to make it stop, but also let users know that something's going on. Again, these are metrics for the board to consider that perhaps could be published in a letter as to things that could be applied to this problem.



Slide 3

Slide 4 shows some candidate recommendations that the board might consider. SPD-7 has an interference detection and mitigation strategy, so the Board could reinforce the need to implement that strategy as quickly as possible. The Board could make a recommendation to establish and publish metrics regarding IDM performance metric. If you put a question on the commercial driver's license test about the amount of money that you get fined for using jammers, that might deter use, so the Board could make a recommendation on something of that sort. Finally, if you had heat maps where interference is occurring, you could make that available through the HARS service. Dr. Powell noted that he is open to other recommendations.



Slide 4

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Discussion of Protect Theme
All Members

Dr. Parkinson said that if there isn't a program or somebody in charge of this within the USG, it's not going to happen. Such a person would work to get the laws changed, to get them to draft potential legislation that would enable local law enforcement to take some of the actions that would enhance all this, and perhaps even work with the cell providers because it's in their interest to know when their phones are no longer locatable. For the board's discussion here, who should be in charge and how do they get funded? Are they under Ms. Van Dyke at DOT? It affects a lot of civil transportation in a lot of ways. But unless you put somebody in charge of doing this, it isn't going to happen.

Dr. Betz stated that one of the things presented in the earlier briefing was that this is a shared responsibility between three departments, and of course we raised the question at that point, so maybe it would be useful to hear Ms. Van Dyke's perspective whether there is an organization that's really leading the charge here or who it should be.

Ms. Van Dyke commented that SPD 7 names three departments, but the Secretary of Transportation is designated as the lead. For aviation, in the U.S. we see interference to GPS almost every single day. They're not always significant incidents, but as we're getting better at detecting interference, we're realizing it's more than just the reports that had been coming in, and greater awareness of interference in GPS is occurring. When NSPD-39 was being rewritten to become SPD-7, we put our hand up because it's near and dear to us daily, but of course it is an interagency partnership and beyond just DHS and DoD. There is a need to embrace assets from other organizations, as well as recognize the need at the state and local level. We saw an excellent presentation by Mr. Rhodes from the FCC. DOT does not have that mitigation, so the partnership with the FCC and law enforcement is really the key to bringing all of this together. Ms. Van Dyke applauded the Board for taking this on and exposing some of the gaps that do need to be addressed and closed.

Lt Gen Hamel commented that these have been wonderful presentations, and it's doing exactly what you set out to do. The reason we're looking at all the P's, the T's, and the A's is to understand what the collective needs and demands are, particularly relating to critical infrastructure. We have good reason for why we are where we are today, but the world is changing. We should perhaps be crafting some kind of recommendation that takes us up a level or two and says, "there's a lot of good things going on, but they're totally inadequate to the scale of the problem and the consequences we have out there." We need to develop a national operational capability for IDM. It needs to have a lead agency and it needs to be focused on assuring the availability and assuredness of this in our critical infrastructures. That would lead things in a different direction to say, "DOT has a really core interest for transportation," and ask, "does that really envelop the broader set of dependencies that we have overall?" Can we frame the problem in such a way that it goes beyond the lots of little good things that are going on? This requires a scale that is completely beyond how it's being conceived today.

Dr. Betz stated that a white paper that includes multiple integrated recommendations, everything from the changes to statutes to ownership and coordination to metrics for developing the national operational capability that's needed, would at least get our thoughts together in an integrated way. The question is, what do we do with that white paper that makes it useful? Do we try to deliver it to the appropriate person in DOT? Does it become an Inside GNSS or a GPS World article to get publicity? If we're able to assemble that message, what's the right way to make it a useful message?

Lt Gen Hamel stated that this is the first time he's heard anything about the Crucible conferencing process and structure, and at 2 SOPS, you have a tactical-level apparatus that brings together multiple departments that seem to be doing good work but is way under scaled to the dimensions associated with this. How do you take capabilities are there already and what are the things that can grow to a national approach that can link into all the critical infrastructure? That's the enormity and the dimension of the problem, and we can't isolate it to just saying it's at an airport over here."

Dr. Parkinson commented that it is lacking to assign one responsibility to three different departments, all of whom are going to assign different priorities internally. Until there's one person at the federal level who oversees this and advocates for it, it's going to continue to just get rolled down, kick down the road. There will be no sense of urgency. He stated that the person belongs in DOT.

Dr Betz said that DOT has raised their hand to take responsibility.

Dr. Parkinson asked, "who is the person?"

Ms. Van Dyke answered, SPD-7 identifies the Secretary of Transportation. We've partnered with the Defense Innovation Unit (DIU). It's beyond DOT alone. This week, MITRE is holding an PNT Situational Awareness Workshop, bringing together folks DoD and DHS. The first step is having automated interference detection that gives us situational awareness so we can geolocate as quickly as possible and then feeding that into the mitigation process. It is a partnership. DOT considers itself to be the lead, but there is a big outside component. DoD has been actively engaged and bringing all that information together is what's critical.

Dr. Betz commented that the Board seems to have the beginnings of an integrated view of how to address this issue of finding and removing interference, but it is not sure how to get that integrated view listened to by somebody who can take action from it.

Dr. Parkinson stated that there is a difference from being a lead to being in charge. It may be important to hear virtually at every meeting from the program director for the operations at the national level, and what the status is and how we can help them. The two Deputy Secretaries must agree on assigning a person who's dedicated full-time to doing this and that they mutually encourage their organizations to do that. It's high-level visibility and there is some way in terms of accountability in making a schedule and trying to get some of this done, that we have clear insight into what's happening.

Hon. Shane commented that the operation of jamming equipment by the manufacturer is a violation of federal law under the Communications Act of 1934. The issue we're talking about is an enforcement issue, and to suggest that it needs to be in one place is to sort of ignore the importance of the Department of Justice (DOJ) in enforcing federal law. We need to know what the current protocol is if indeed we identify a source of interference. Is there a number to call at DOJ? Is there a U.S. Marshal who's in charge of that? We just don't know. Hon. Shane stated that more research into what is actually going on in terms of mitigation would enhance our ability to make coherent recommendations in the area.

Dr. Betz answered, saying that earlier today we were told you can call NAVCEN or the FCC line that Mr. Rhodes gave. We know how inputs get into the system.

Hon. Shane said that is without arresting authority; without the ability to enforce the law. Maybe there is the ability to mitigate the interference but not to impose consequences on the bad actor.

Dr. Betz stated that the champion must do a whole set of things. We found out there are legislative gaps, there's acquisition of capabilities to drive, there's coordination across agencies and law enforcement at different levels, there's operations and enforcement. Those are all the things that that champion must make happen.

Hon. Shane said that this is a great conversation because, we've heard about education needs, we've heard about enforcement needs, everything is becoming part of a unified field theory of PNT strategy, and that's exactly what this Advisory Board should be doing. So, we should keep going, we're doing well.

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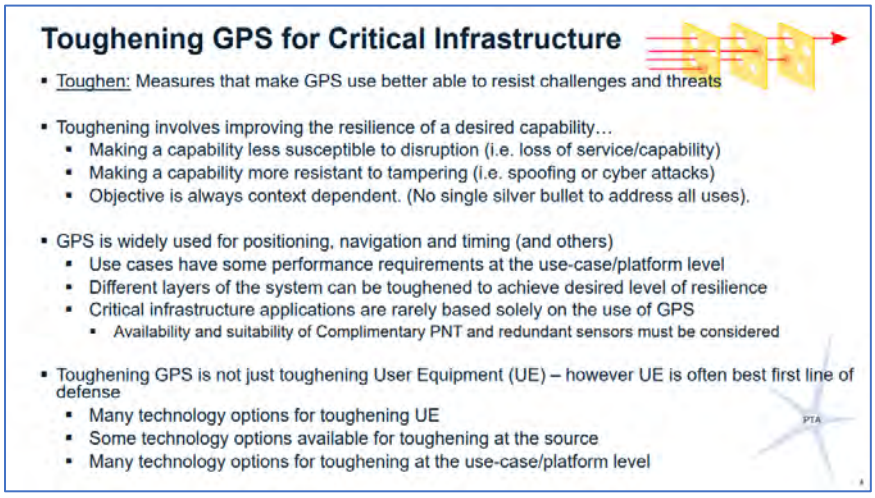
Theme 2: Toughening GPS/GNSS

Toughening Introduction
Tim Murphy, *Member, PNTAB*

Mr. Murphy greeted the Board and said he would first provide some background and then talk about techniques for toughening at the source (Slide 1). Then he would hand it over to Mr. Scott, who would talk about toughening user equipment and pragmatic aspects of toughening equipment. Afterwards Mr. Murphy would return to discuss toughening at the platform or use case level. We have a few recommendations both for things the USG might do and things that industry should be encouraged to do.



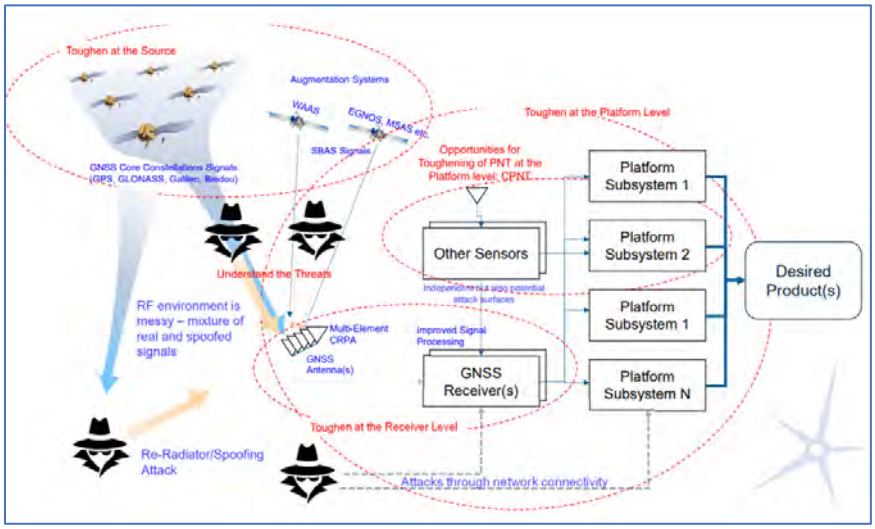
Slide 1

Toughening are measures that make GPS better able to resist challenges or threats. A broader definition of toughen includes toughening your desired capability. Toughening the GPS part of it is an important aspect of that, but really you need to be protecting your entire system. Toughening involves resilience of a desired capability and making that capability less susceptible to disruption. That may or may not depend entirely on GPS. Also, toughening is about making it resistant to active tampering: denial of service versus outright spoofing. The objective is always context dependent. There's no one-size-fits-all solution. GPS is widely used for PNT and there are many use cases for GPS. It may use positioning, it may use velocity, it may use timing, it may use various aspects of this, and virtually always it combines the information with other information to derive some new product that's of use. Critical infrastructure applications are rarely based solely on the use of GPS. In the 90's, in aviation, we flirted briefly with this notion of sole means navigation. Then the Volpe Report came out and that was sort of rightly so abandoned, and now we talk at most about primary means of navigation. Toughening GPS is not just toughening the user equipment. However, the user equipment is often the best first line of defense, so we will talk a lot about that in the next hour. But there are also technology options for toughening at the source, the system itself, and at the use case level or the platform level.

Slide 2 shows a typical, generic notion of a system that uses GPS to produce a desired product. This could be vehicle fleet management system or a port management system. Includes receivers connected through communications networks to any number of subsystems within the overall system, and those things will work together to produce a desired output. We want to protect against threats, and we should approach this as if it's a cybersecurity issue or a system security issue in general. The first thing we need to do is understand the threats, and in GPS the threats can come in many ways, but primarily through the RF signals themselves, either in the form of jamming or spoofing. But jamming and spoofing can both take on a wide variety of characteristics and manifest in many ways. Your system is also potentially susceptible to attacks through networks and connectivity and other cyber-attacks. So really, a system integrator for any kind of critical infrastructure needs to take that all into account because these are all valid attack surfaces that you need to harden your system against. That includes all of the internal communications within your system because you may have a whole network of GNSS receivers over a wide area, and they're all connected by a communications network. That communications network is now something that you need to protect from a cybersecurity standpoint.

We can toughen at the GNSS receiver level, which is a good and necessary thing to do. It's often the best first line of defense. However, it's not guaranteed to be sufficient. First, you're never going to have a perfectly hard receiver, and if you don't understand the level of hardness of your receiver when you integrate it into the rest of the system, you're not going to really understand what the impact on your desired product is. A couple of the big potential things for hardening at the source are the use of multi-element Controlled Reception Pattern Antennas (CRPAs). This subcommittee has produced a recommendation to remove CRPAs from the ITAR list. CRPAs are great if you can keep the energy out of your receiver. Although they are not a panacea, they are a very

powerful tool in protecting GNSS receivers. We could also toughen the system at the source by making changes to the system so it's harder for people to tamper with it in a fashion that would be undetected. This is difficult to do because making changes to the system itself is expensive and time-consuming. Plus, if you make a change to the system, you must also make a change in the user equipment, so syncing those two things up can be quite challenging. Another way to harden your source or toughen your overall system is to add other sensors, and this again can happen in a spectrum of ways. Those sensors can be tightly coupled into your GNSS receiver, or they might be independent sensors to measure parameters that you would use in the development of your desired product. This is along the lines of what we've been talking earlier about CPNT PNT, or multi-nav. Ultimately, we need to toughen at the platform level and understand how we're protecting the particular use case, particularly with respect to critical infrastructure.

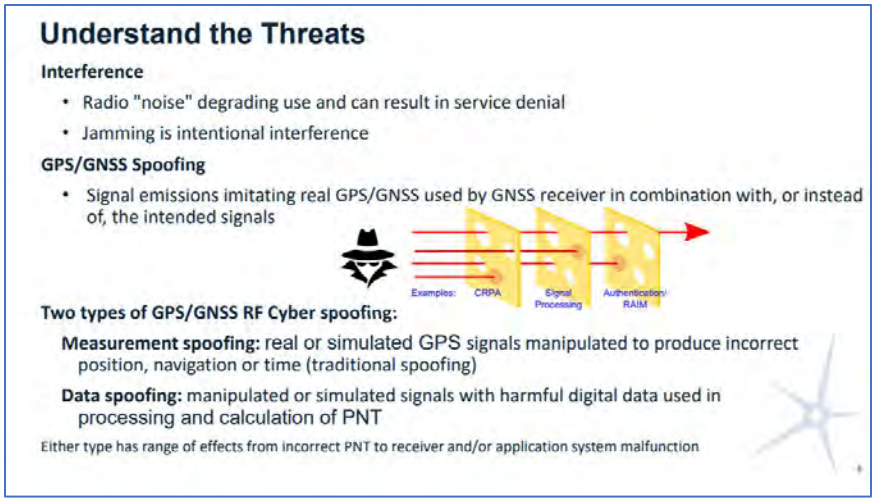


Slide 2

The first step in all this is to understand the threat. The primary ones that we're interested in are interference and spoofing. However, the system integrator really needs to take all the cyber threats into account, so if you have a system that's connected with any kind of a communication system, you must analyze those in terms of their attack surfaces. Interference can be just radio noise, or it can be intentional jamming, and it doesn't matter to the receiver. The receiver doesn't care about the intent.

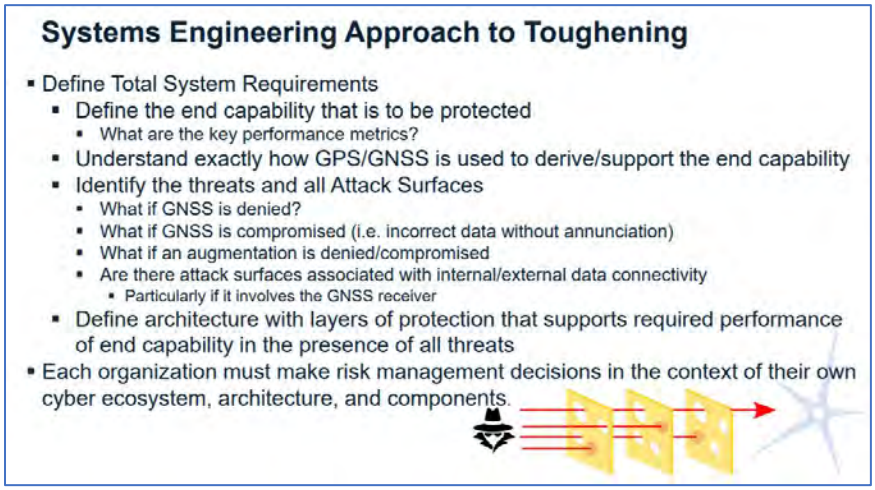
Spoofing is when there are signals that look like GPS signals and are intended to mislead or hamper the operation of the receivers. There are two types of GNSS spoofing that we worry about: (1) measurement spoofing is where we cause the receiver to measure the wrong delay, and phase; and (2) data spoofing, where we feed the receiver bogus data, and often those things both happen. The effects can be quite different because if you give bad data to the receiver, you might impact the performance of that receiver for a substantial period. There have been instances in the field where we've seen GPS receivers be bricked entirely by having bad data put into the receivers. The system integrator needs to understand all these threats and then assess the risks for the various kinds of threats, and the protection against the threats will come in a layered approach. There's no one technique that will protect you from all the things. Typically, you'll have to have layers of protection for your system.

Slide 3 (next page) is an example of how you know you may have a system that has a CRPA as its first layer, and it does some advanced signal processing as its second layer. Typically, you may have 20 or 30 different layers of defense to work through and analyze to make sure that every identified threat gets caught by one of those layers of defense. It can either be turned into a loss of service or mitigated to continue to operate.



Slide 3

Slide 4 shows a simplified notion of good systems engineering when you're trying to toughen a system. The first thing you do is figure out what you're defining as your system. What are my total system level requirements? What am I trying to produce? What are the key metrics in terms of performance? If I have a critical infrastructure problem, I might be providing a service that people are using for safety of life. That may have a much higher integrity and continuity of service than some other service that is not safety of life but is still critical. I can probably live without electricity for 10 minutes more than I can withstand having an autonomous landing system lie to me for 10 minutes if I've got 250 people on board the aircraft. You must begin with the end in mind and understand what you're trying to protect, and then understand your system and exactly how GPS is used to support that end capability. As GPS fails in different ways, you need to understand the impact on the output of your system. Then you must identify all the attack surfaces, not just GPS if it is used but it's also used in conjunction with other navigation aids, radios, or sensors. You must consider what if they're also tampered with? Additionally, you need to understand the ramifications if your augmentation systems are denied or compromised. You also need to define an architecture with these layers of protections that will still support your required performance at the end and capability and the presence of all the threats. Some of those layers might be redundant systems or voting systems. Each organization must do this risk management job in the context of their own cyber ecosystem architecture. No one size fits all, so the responsibility is on the system integrator to do this kind of analysis.

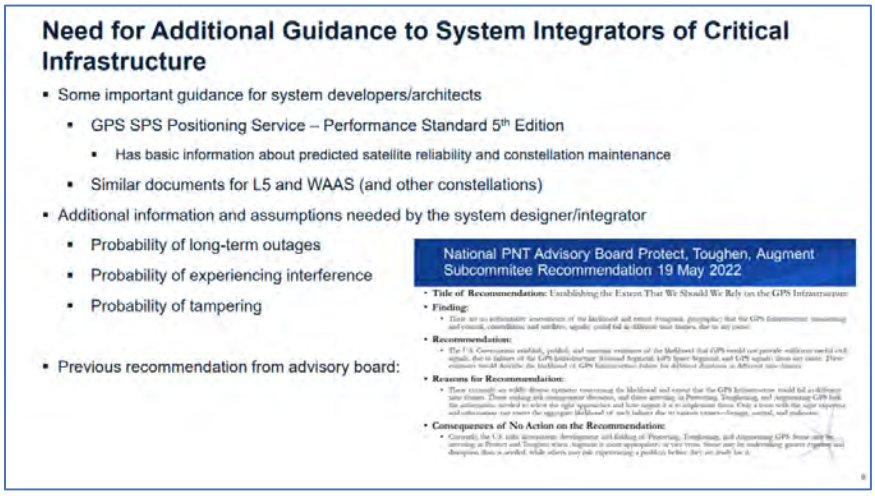


Slide 4

There is a gap in the amount of information that is available to people doing these risk studies. However, there is a lot of relevant guidance already out there. DHS has a resilient conformance framework that gives some good advice (Slide 5). None of these things are compulsory and none of them are complete, but they do have some good information. However, there are also some gaps that none of these are addressing at this point. In the previous day, we had a nice presentation in the prep meeting on the status of the IEEE P1952 standard that's under development, and that may be useful for people that are trying to do this system level integration for critical infrastructure. Even though SAE-ARP 4754A is aviation specific, it's a good guide on how to do good top-level systems engineering in a safety-critical system.

Slide 5

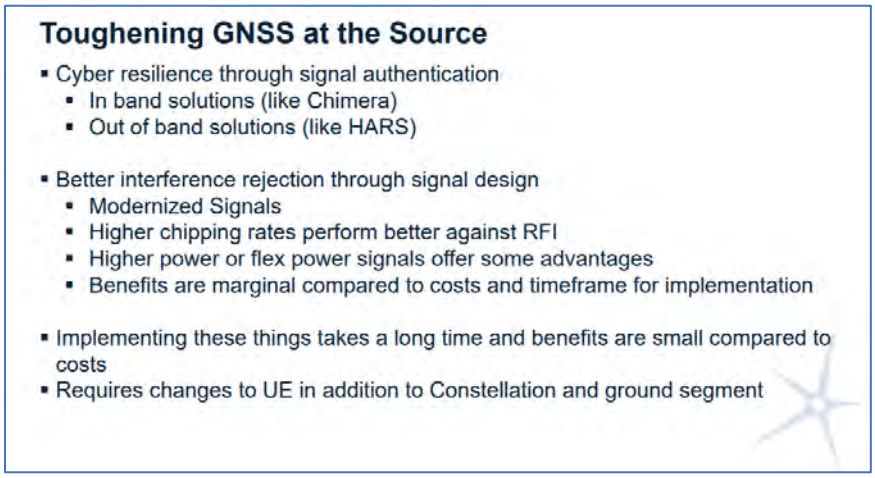
We need additional guidance (Slide 6). We have some guidance on system performance with GPS in the form of the system performance standard, and that defines some basic things like what you can assume for the probability of an individual satellite failure. What it doesn't include are the probability of a long-term outage and the probability of experiencing interference. That might not even be possible to characterize, except regionally or in specific cases. You may have different probabilities of experiencing interference, including the probability that somebody's going to tamper with your system. That is all left up to the system integrator who's trying to do the risk assessment, and this is where the USG might provide some additional benefit. We already have a recommendation on this from two years ago. We might tweak this recommendation to make it clearer that what we're looking for is guidance. We're not looking for a performance commitment. We can give good, educated advice on what to expect in terms of long-term outages or the probability of a total constellation failure, but that would have a different level of assurance than what we put in the performance spec.



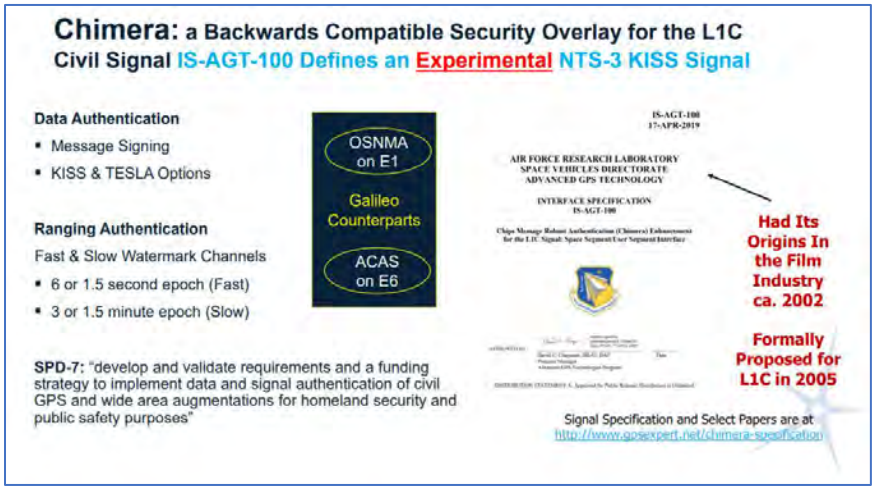
Slide 6

We could revisit our recommendation from two years ago and make it clearer regarding what kind of guidance we think the government could put together. We could toughen GNSS at the source, and we can do that in a couple of different ways (Slide 7). There's a proposal to do it in-band with a solution called Chimera, and we've also got a proposal to do an out-of-band solution, which is HARS. You can also toughen at the source by doing things like using better signals and higher chipping rates, but there's limited trade space left there because its largely bandwidth limited, and those things are very expensive because you must replace the entire constellation. The benefits would be marginal compared to the costs. Any of these are going to take a long time, but some will take less time than others. If you toughen at the source like this, you're always going to have some change at the user equipment level to be able to take advantage of those changes that you made, so it's a cooperative effort between the air and the ground.

Chimera is a proposal that has gained a lot of traction, but there's no commitment to it yet (Slide 8). We are at least committed to the point where we're getting ready to do an experiment on NTS-3 to look at it. In the distant future when we have more software-based satellites, this sort of thing may be easier to do. It does bring some baggage along because again if I'm using cryptographic means to authenticate these signals, then I must have key management across the system, so the user equipment would now have to buy into key management. This is not a big deal for the military because they've been doing that forever. It is a bigger deal for the commercial side.

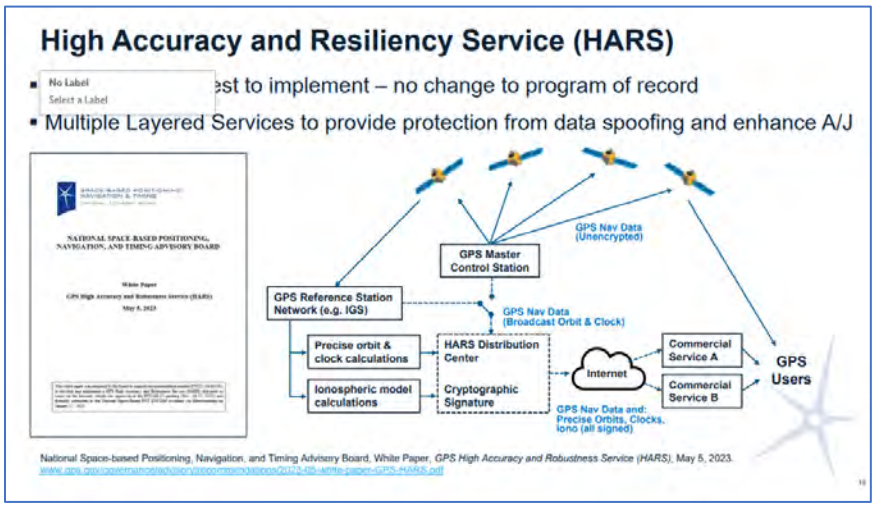


Slide 7



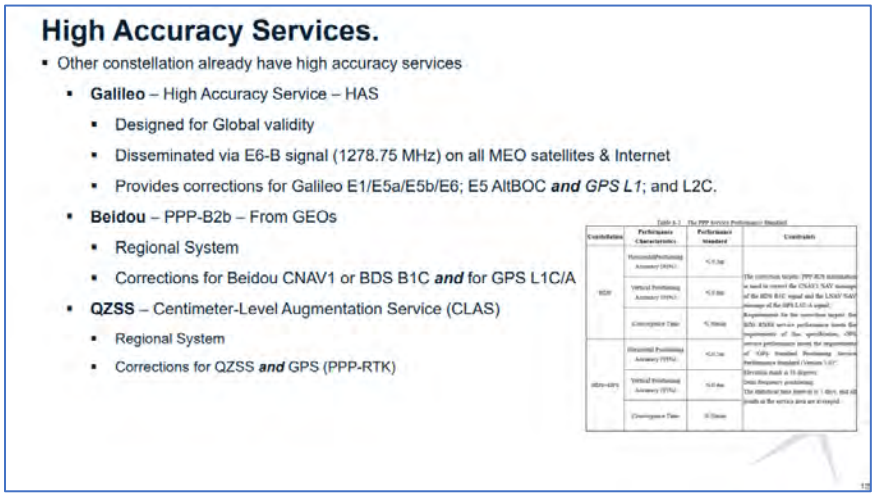
Slide 8

Galileo is already offering authentication at the source through their Open Service Navigation (OSN) capability. They also offer a High Accuracy Service (HAS) on the E6 signal. GPS HARS (Slide 9), as proposed by the Board, does not have to require a change the program of record nor requires to launch new satellites. We can provide information through a secure side channel that the user could use to help authenticate the signals, particularly in data spoofing. Of all the things that we could do in terms of hardening at the source, GPS HARS is the one that could be done the quickest, and really it could be the most effective.



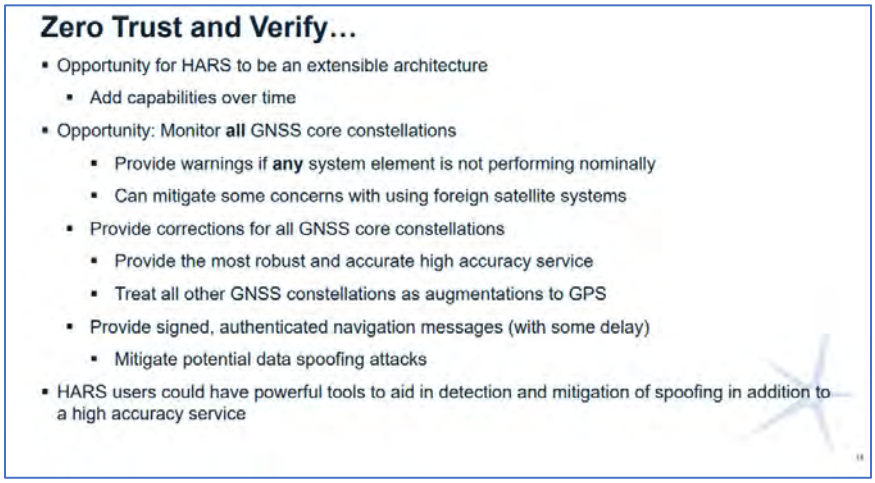
Slide 9

With respect to HAS, other GNSSs are already offering such this service. Galileo has a HAS with Global each (Slide 10). They're offering it on E6b. They provide corrections through their satellite constellation for all their signals: E1, E5, E5b, E6, and E5 AltBOC. They also provide corrections for GPS L1 and GPS L2C. BeiDou has a Precise Positioning System (PPP) service; but it's only available through their GEOs right now. It's a regional service, but they are also providing corrections for their own signals and for GPS L1 C/A. So, there's precedent already for HAS to be offered through the constellations that provide corrections for other constellations. QZSS is another example of this because they provide corrections for not only their own satellites but also GPS, and those are PPP-RTK type solutions that are sub-decimeter level accuracies.



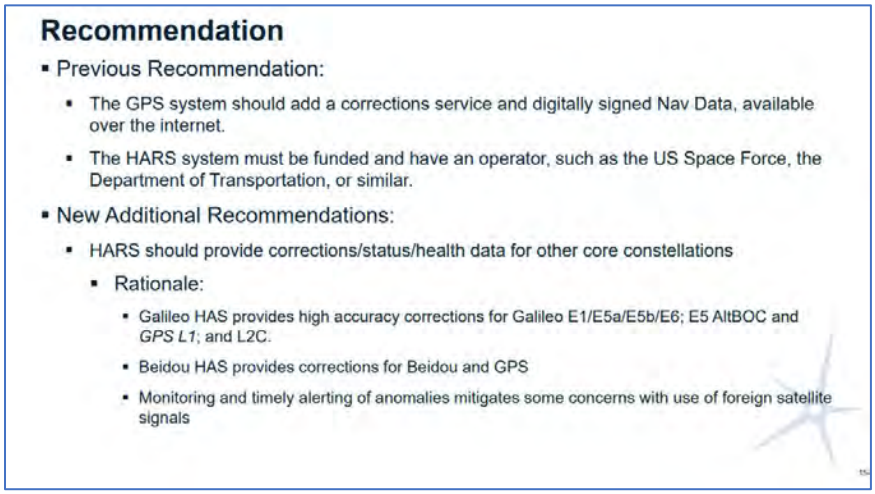
Slide 10

Anytime we're dealing with GNSS, we should adopt a zero-trust cyber mentality on this to verify anything, because even if the UGS provides the highest integrity and accuracy capability that it can, we don't know that we're not being spoofed (Slide 11). When we get signals, we must verify that they're good signals. So, we're always going to have to do some level of crosschecking, have some level of redundancy, or other capabilities that we can compare things to. Therefore, there's an opportunity to build HARS to be like an extensible architecture where we could start by providing corrections and resiliency services for a couple of GNSS constellations and then add capabilities over time. For example, we could build a network so that it will monitor all GNSSs core constellations and give some information to the users about their status. If we see something strange happening in another GNSS, we can warn our constituents about the use of that constellation. This could help mitigate some of the concerns that people have about using foreign satellite systems. In essence, we could be treating all the constellations as if they're augmentations to GPS by wrapping corrections around them, doing integrity monitoring for them, doing continuous measurement of their performance, and benchmarking. All of that could be useful to people who will ultimately use these constellations anyway. One of the things that we've talked about with HARS is to send these authenticated navigation message bits. If we're going to do it, we should do it for multiple constellations. HARS could be a powerful tool to aid in the detection and mitigation of spoofing.



Slide 11

We already have a recommendation about HARS, and we could modify it to be a little more specific to support multiple constellations (Slide 12).



Slide 12

Next, Mr. Scott will give us some more pragmatic things about toughening GPS receivers.

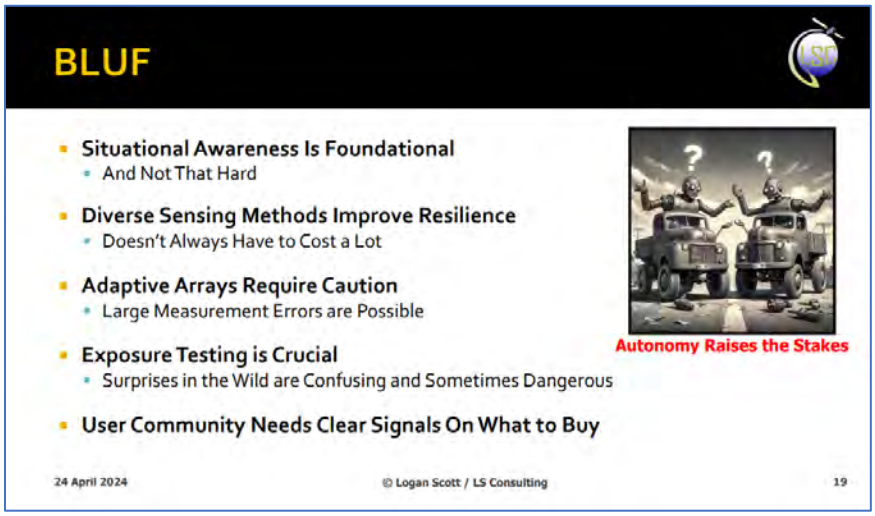
***

Pragmatic Steps Toward Toughen
Mr. Logan Scott, *Member, PNTAB*

Mr. Scott said his briefing would focus on some of the more pragmatic next steps that can be taken to harden receivers (Slide 1).

Slide 2 depicts the Bottom-Line Up Front (BLUF). Situational awareness is the foundation of all of this. If you don't know that you're being jammed, interfered with, or under cyberattack then you don't stand a chance. The second thing is that when you're trying to achieve resilience and situational awareness, having multiple sensors can help you tremendously. Third, adaptive arrays have been proposed as a mechanism for hardening systems, and they are definitively the big guns for anti-jamming. But there are some cautions that need to be discussed. You can't just install one of those and expect everything to be all right. Fourth, if you don't expose your equipment to actual threats, and see what they do, you don't really know what you've got. The first time a receiver is exposed to a new threat, the failure rate is almost 100%. Finally, the user community is not necessarily all that well informed. Some communities, such as power grids, telecommunications, etc., are informed, but there are other communities such as Sheriff's associations that are not that well informed even still need high integrity systems. In addition, as you add autonomy to these systems (and not just vehicles, but also information management, shipping, etc.) the bar is raised further.

Slide 1

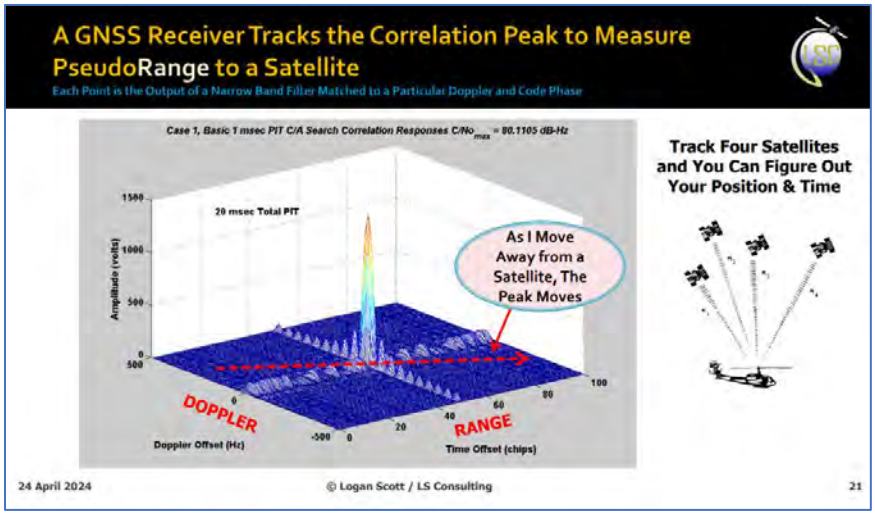


Slide 2

There are a few definitions we need to start with, specifically jamming vs. spoofing (Slide 3). The objective of jamming is, usually, trying to deny access to GNSS over a wide certain area. On the other hand, spoofing can take several forms. One of the more pernicious forms is cyberattack, where the receiver is being attacked through the front-door. However, you can also build back doors through the supply chain. The objective of spoofing is, usually, trying to convince you that somewhere or sometime where you are not. This may take the form of an attack on one receiver or on many. As an example, there are now many boats and Uber vehicles located at the Beirut International Airport as consequence of a spoofing attack. Finally, we need to define the jamming structure, which is where features of the signal are attacked.

Slide 4 provides a brief introduction to how GPS signals are tracked. Every receiver generates a range doppler map where it is trying to track the peak of that point, and as that point moves around that's an indication of range to the satellite. So, with four measurements of ranges you can figure out where you are and what time it is. Most receivers do not develop a full range doppler map as shown in this figure.

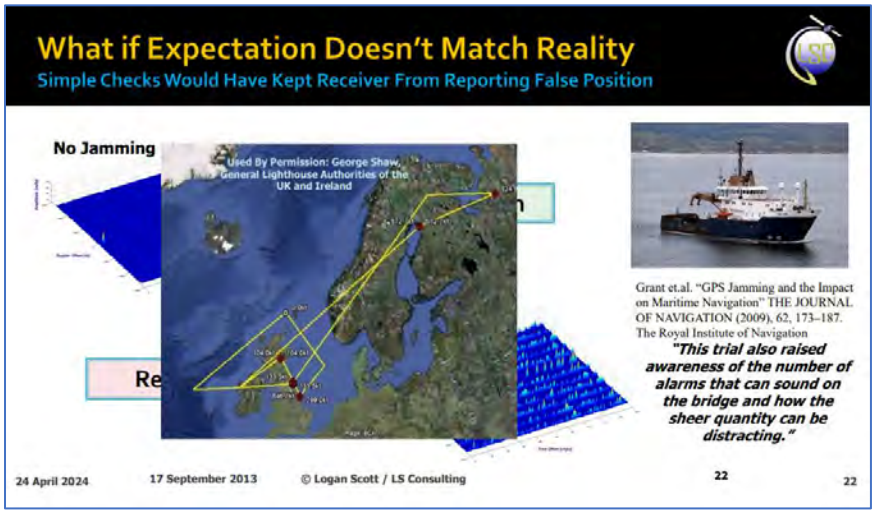
Slide 3



Slide 4

So, what happens if you take a receiver that expects to see what's on the top left in Slide 5 and present it with what's on the bottom (J/S - 24 dB)? This is not that hard to do. All that is PRN 1 of the GPS L1 C/A code, and a one-Watt jammer with an effective range of 30-40 km. One of the points on the figures is the actual signal, but the receiver now has to track many pointy bits. So, how does the receiver react to this? Back in 2009 they did a trial with a buoy tender called "Pole Star", and soon it showed it was flying at Mach 1 over Norway and Finland. Interestingly, there were a lot of alarms generated and sounding off in the bridge. They knew something was going on but had no idea it was the GPS receiver. One of the more interesting alarms was the satcom system indicating it had lost connection to the Geostationary communication satellites as it was pointing the antenna in the wrong direction. This is what can happen with an uninformed receiver.

Situational awareness is the first step that needs to be taken (Slide 6). The first element are your tools, that is, what kind of signals you have available and what kind of data sources you have. The second element are the obstacles you have. Multipath is certainly one, but this briefing is going to focus on the interference environment (Cyber is also a key one, but it will not be covered today). The third element is what one is trying to do. This includes your requirements for accuracy, continuity, integrity, and so on.

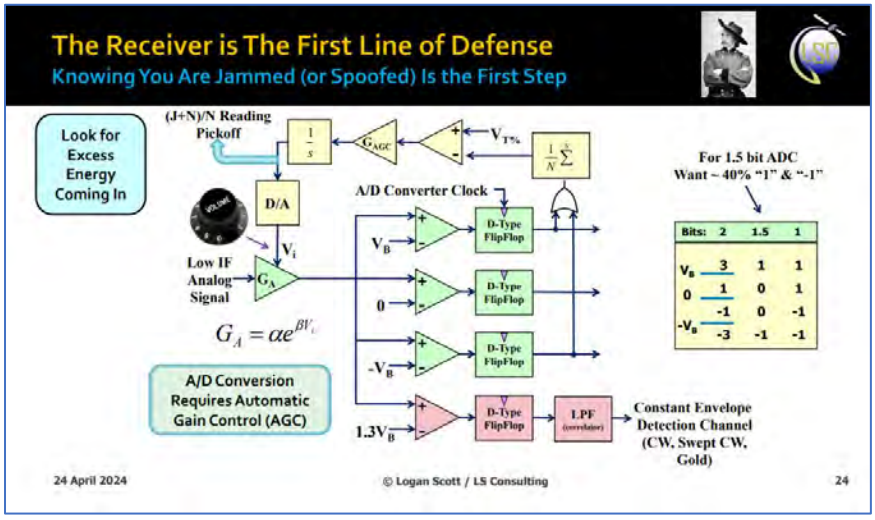


Slide 5

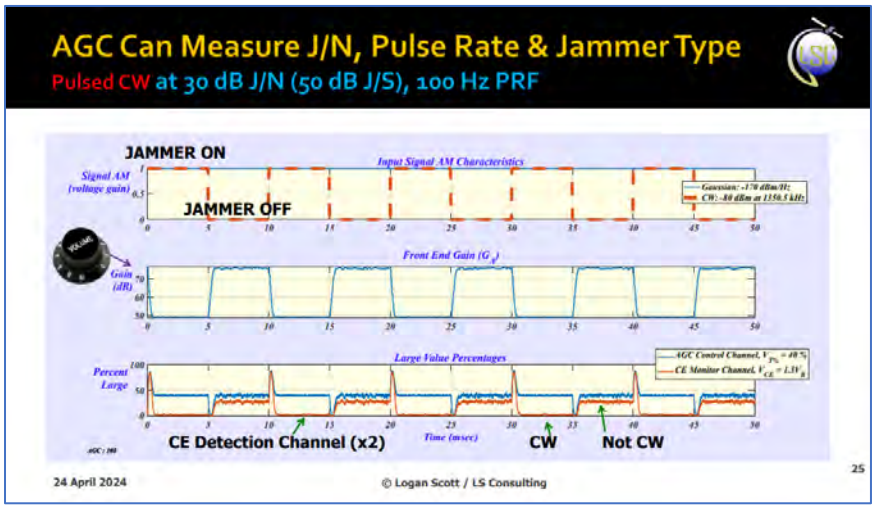
Slide 6

The receiver is the first line of defense (Slide 7). The green shapes represent the analog-to-digital converter. In order for that to work, you need to have the correct amount of gain in your receiver's front end (in essence, it's a volume control). This is represented by the yellow shapes. When it sees a lot of energy coming in it turns down the volume, and when it sees too little energy coming end then it turns up the volume. As indicated by the blue shapes, this enables us to read off what the jamming levels are. The red shapes are how we can see if the incoming jamming signals have gaussian characteristics or constant envelope characteristics. The dead giveaway in most jamming signals is that they have a constant envelope. Thus is the circuit shaded in red activates, that is an indication that jamming power is coming in.

Slide 8 shows an example of how this might operate. The top shows a jammer turning on and off every 5 milliseconds (ms). The line in the middle shows how the AGC reacts very quickly (in under a 1 ms timeframe). At the bottom, the red line is showing an indication of the type of jammer (whether CW or otherwise). To the best of Mr. Scott's knowledge, every receiver has an AGC in it.



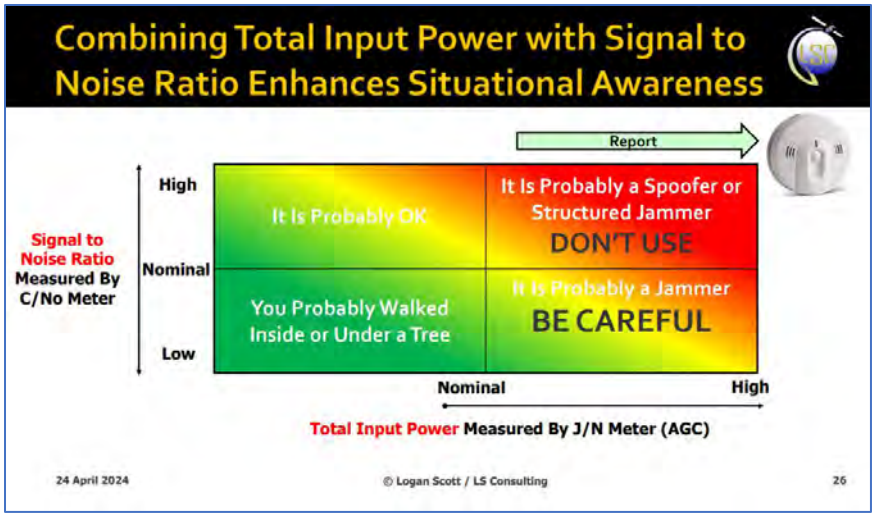
Slide 7



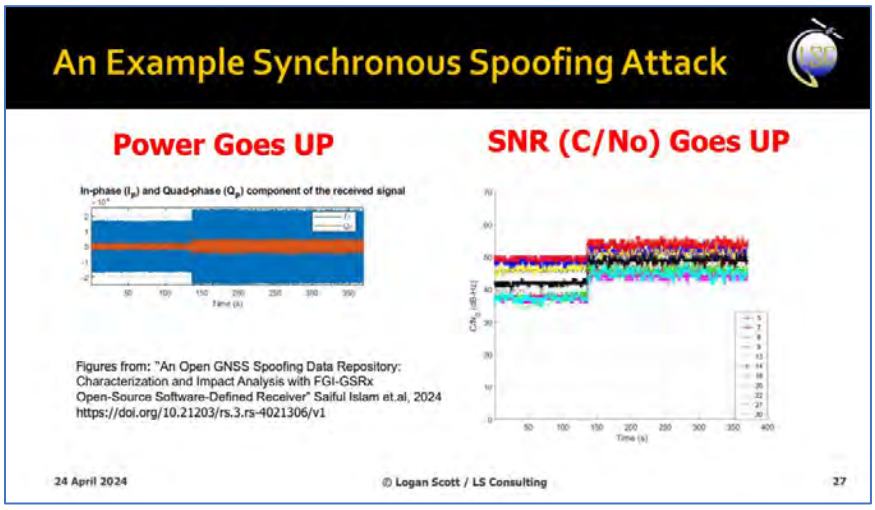
Slide 8

There are two major elements that can be used to maintain situational awareness (Slide 9). One is AGC, and the other is the signal-to-noise ratio. If one is down in the bottom left quadrant (low signal-to-noise ratio, and no AGC reaction), it's probably due to having walked indoors or under a tree. If the signal-to-noise ration starts to go higher, but the AGC is not reacting, one is probably still in the safe zone (top left quadrant in the chart). But, moving towards the right in the chart, one needs to start being very careful. If the signal-to-noise ratio is going up, that's a strong indication of a spoofer or structured jammer. At this point we have the basis for creating a "fire alarm". The alarm indicates one needs to start using other sources of information to figure out where he is.

Slide 10 shows an example of a spoofing attack. On the left we see the power going up, and on the right we see the signal-to-noise ratio also going up. Looking at the two pictures, one can see where the spoofing started.



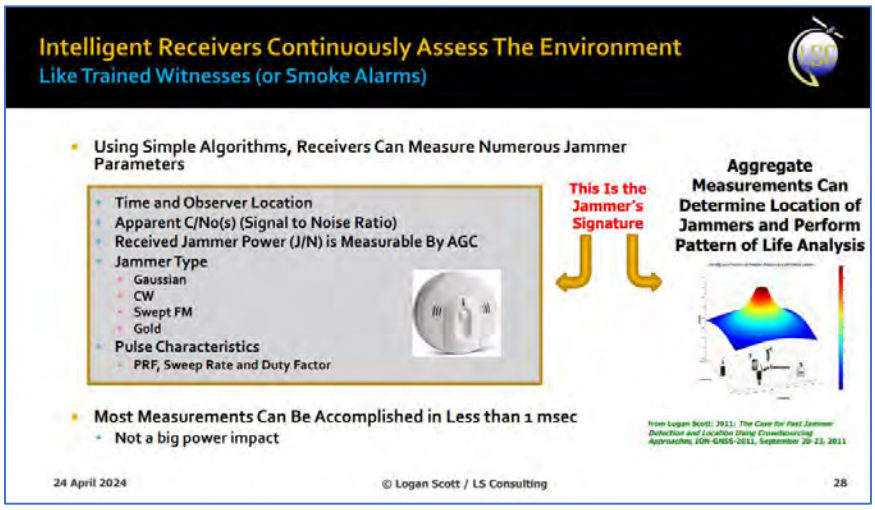
Slide 9



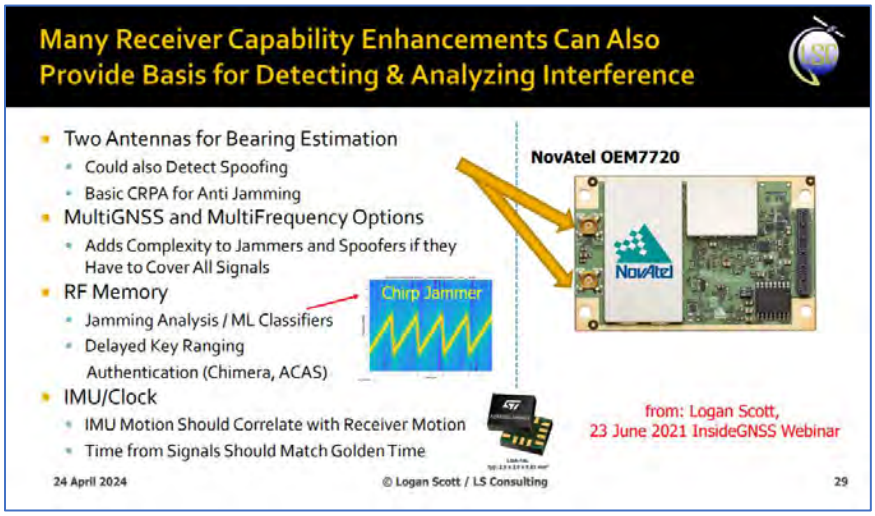
Slide 10

Summarizing, if you have an intelligent receiver, it is essentially continuously assessing the environment (Slide 11). Receivers can measure numerous jamming parameters, as shown in this chart. The combination of these parameters enables one to identify the type of jamming. Most of these measurements can be made in less than one millisecond. So, at the local level this is like a "fire alarm", but if we can take this information and report it to a centralized location. If there is a crowd of such sensors, then the combined measurements can be used to localize the jamming source and conduct a pattern of life analysis. For example, ten years ago in Portland, Oregon, they set up a test near the airport and noticed that every third or fourth truck driving by had a jammer. They were all trash trucks heading towards the Port, so it doesn't take a lot of imagination to realize that could have been an illegal trash dumping operation. So, a pattern of life analysis is key for global situational awareness.

As one moves into more advanced receivers, there are additional capabilities that can be used (Slide 12). For example, the NovAtel receiver on the slide has two inputs, and their purpose is for obtaining a bearing or, in other words, to know where the vehicle is pointing. But, at the same time, those two inputs can also be used to detect spoofing because in a typical spoofer all the signals come from the same direction. It is also possible to construct a simple adaptive array for timing operations. Multi-GNSS and multi-frequency options also make it harder for a spoofer as it forces the spoofer to operate at more frequencies. Ultimately, this will force more power to come out of that source, which in turns makes it more detectable. Something else a lot of receivers now have is RF memory, which enables us to do jamming analysis. This memory can also be used for some of the delayed key systems such as Chimera, ACAS, and so on. Finally, if the receiver has an Inertial Measurement System (IMU) and/or clock, those can also be used to identify that interference is happening.



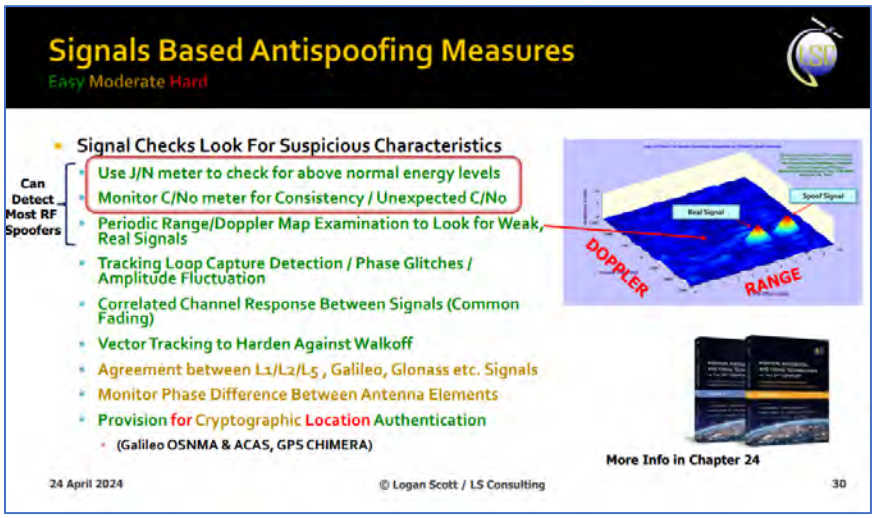
Slide 11



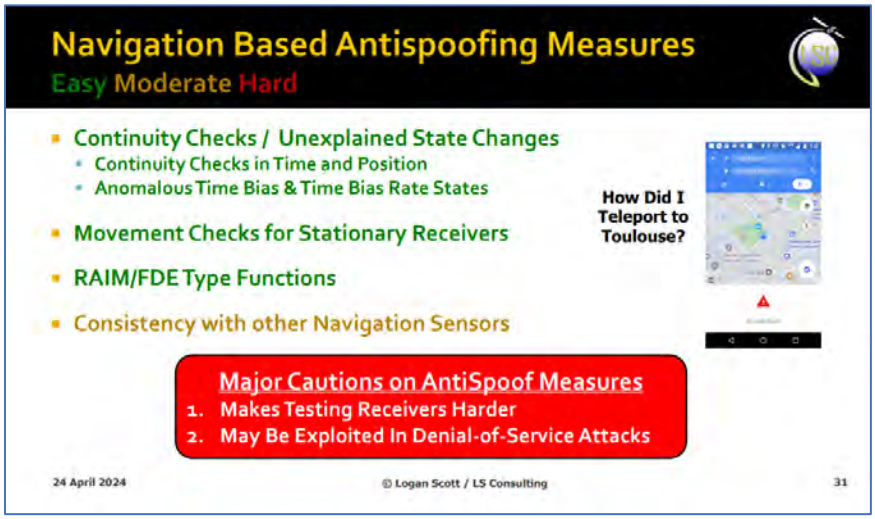
Slide 12

Slide 13 summarizes the signal-based techniques that can be used to detect spoofing. When talking about diagnosing and maintaining situational awareness, the situation is not unlike doctor taking your temperature first. The first two bullets in the slide (J/N & C/N_0) are akin to the doctor finding out your temperature is higher than it should. The next step one might take is to examine the periodic range vs. Doppler map to look for the weaker (but real signal). The two strong peaks indicate specifically that there is spoofing going on. As shown in Slide 13, there are additional techniques (shown in that can come into play.

There are also navigation-based techniques that can be used to detect spoofing (Slide 14). For example, there was an incident in Portland in 2017 where a number of cellphones were told they were in Toulouse, France. This is an example of an unexplained state change (location) is revealing spoofing. Also, if a receiver suddenly shows a jump in time, that is also indicating potential spoofing. A sudden jump of just one millisecond (ms) might at first not seem a lot, but in navigation terms it would be equivalent to jumping 300 km in position. So, looking at the time bias and time bias rate states can be very revealing in terms of whether spoofing may be occurring. It is possible for a spoofer to cover a change in position, but it is very difficult for it to do so with time. However, a major caution with such anti-spoofing measures. For example, if a receiver is turned off for a certain period of time and then turned back on, a spoofer could try to give it an erroneous future date. If this receiver is then turned off again, the erroneous date would remain in its memory and, potentially, would not accept a real signal when turned back on. Thus, we need to be cautious when designing anti-spoof measures.



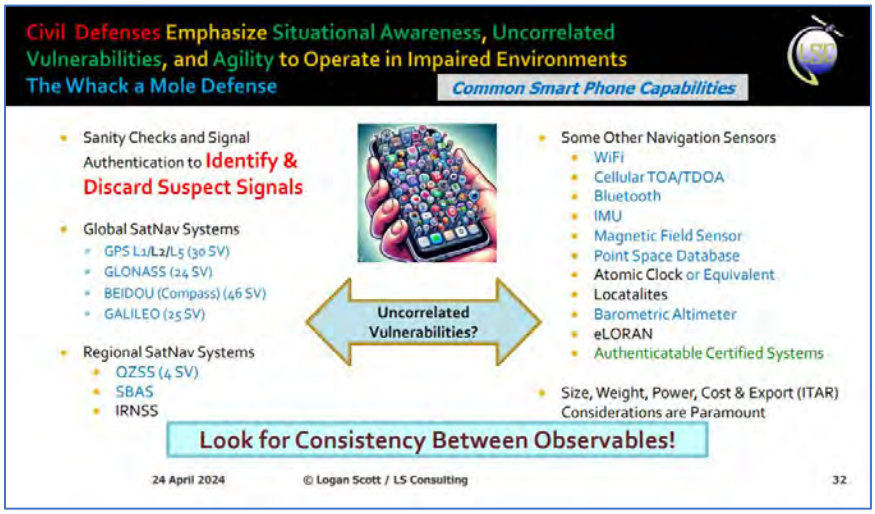
Slide 13



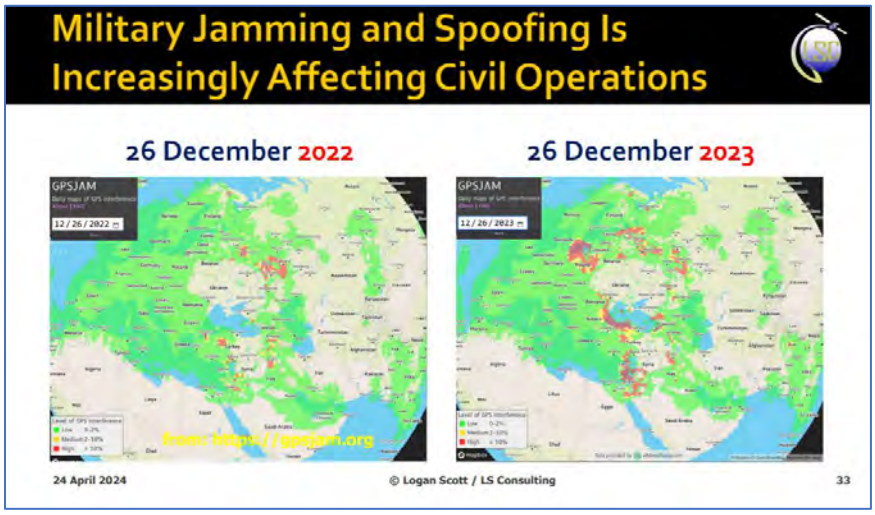
Slide 14

In the civil arena, situation awareness can be described as a whack-a-mole defense (Slide 15). In other words, the core job is to identify and discard suspect signals. While there are many Satnav signals that can be analyzed, there are also other sensors that can be used to correlate the data and indicate problems. As an example, in the 2017 incident at the Port of Portland, while the GNSS signals appeared to indicate the phones were in Toulouse, the WiFi signals indicated otherwise. However, because so much trust was put in the GNSS signals the smartphones ignored the WiFi signals. So, looking for uncorrelated vulnerabilities is key to developing your situational awareness.

The world situation has changed quite a bit in the last few years, such as the war in Ukraine, and now we have military operations significantly affecting civil operations (Slide 16). So, at this point one might ask if there are military approaches that could be used in a civil environment. The answer is yes.



Slide 15



Slide 16

Military defenses can be described as a "bunker defense" (Slide 17). There is a signal out there, and the user wants to get that signal. To operate in such environments adaptive arrays are the way to go. These are the "big guns" of anti-jamming, so they need to be carefully handled so they don't end up being used for nefarious purposes. A typical adaptive array will improve the resistance to jamming by a factor of 1000 to 10 million (30 to 70 dB). Another way to think about this is that if such jammer has an effective area of 1000 square miles, but we put one of these adaptive arrays on our receiver, the effective area of that jammer will go down to under 1 square mile.

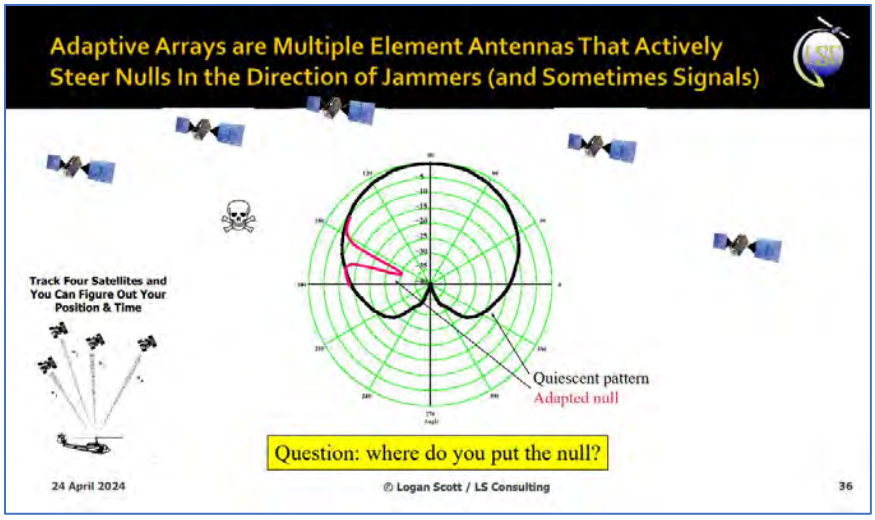
Next, we are going to take a deeper dive into adaptive arrays in a civil context (Slide 18).

Slide 17

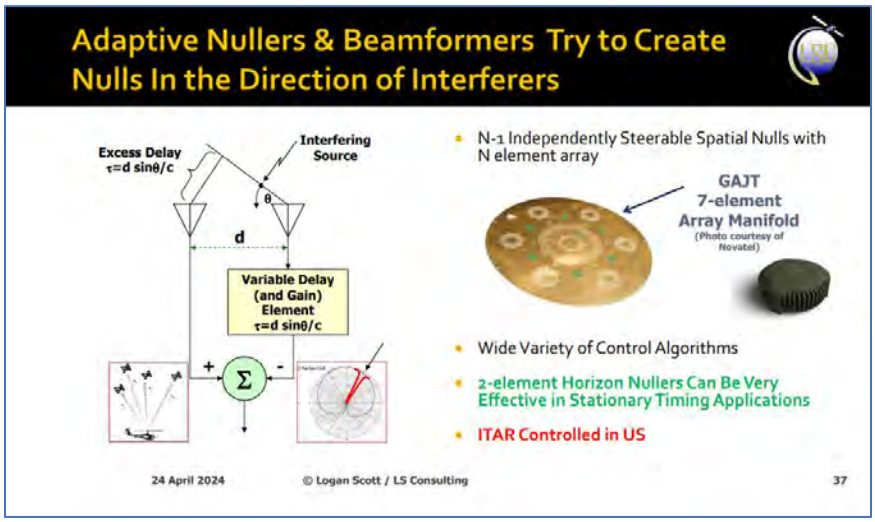
Slide 18

In Slide 19, the black line on the graph depicts the antenna pattern of a typical non-adaptive receiver. Such antennas are typically designed to have omnidirectional coverage. So, if a jammer shows up, we'd like to do is have that antenna have very low gain in the direction of the jammer (red line on the graph). The consequence of this is that while we take out the jammer, we might also be taking the signals from a GPS satellite or two. If we have a lot of other signals to work from multiple GNSS, the impact will not be necessarily big.

Slide 20 shows how these things work. On the left two antennas are shown. Thus, an incoming signal will hit one antenna before it hits the other. So, there is an excess delay between the two signals as they are captured by the antennas. What we can do is take the first antenna signal, introduce a delay equal to the excess delay on the second antenna, subtract them, and then the antenna pattern is going to have a "null" in the direction of that interference. These are the basics on how this works. So, if you have "N" elements then you can take out N-1 jammer independently. The big drawback, however, is these antennas become large and not practical for smartphones. But they are ok for airplanes, vehicles, and much of the critical infrastructure. A core aspect of adaptive arrays is that they are International Traffic in Arms Regulations (ITAR) and/or Export Administration Regulations (EAR) controlled and, therefore, not available to most civil users.



Slide 19



Slide 20

However, there are some cautions we need to be aware of regarding adaptive arrays (Slide 21). Their objective is to maximize the signal-to-noise ratio and will do whatever it takes to do this. So, if the real signal and the jammer signals happen to come from the same direction, the outcome is sort of like looking directly into the Sun where the adaptive array will tend to 'squint' which, in turn, can cause very large errors in the observables. On the graph in the slide, we are getting an 8.6-meter (m) pseudorange error from the small antenna. This shows our need to be very careful when having high accuracy requirements in their system because large errors, much larger than the antenna diameter, can be cause. Also, note that L5 errors are typically lower by a factor of 10 so, when using adaptive arrays, it is well advised to use the GPS L5 signal.

Dr. Parkinson asked Mr. Scott to clarify what he meant by large errors.

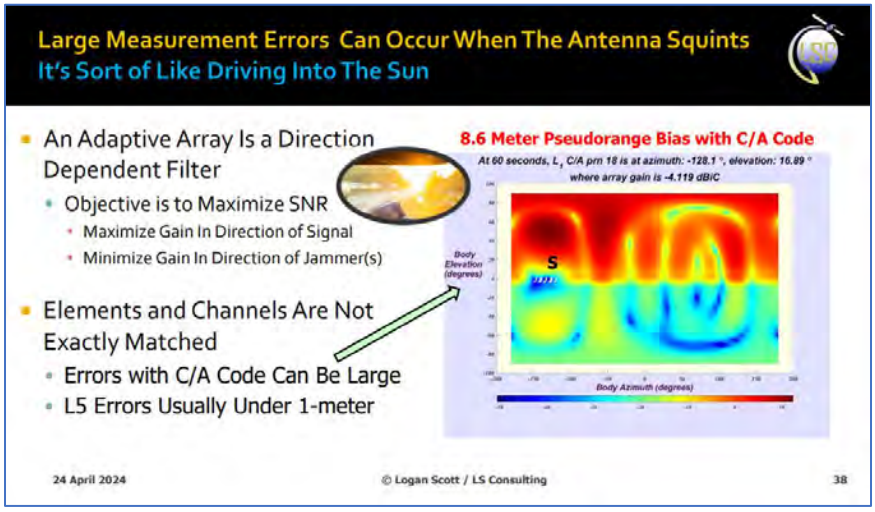
Mr. Scott responded that 20-30 m errors can be generated.

Dr. Parkinson said the largest error he's seen was in the range of 5-8 m.

Mr. Scott said that was a particular pseudorange he was running. Typically, large was ~10 m for L1 C/A and ~1 m for L5.

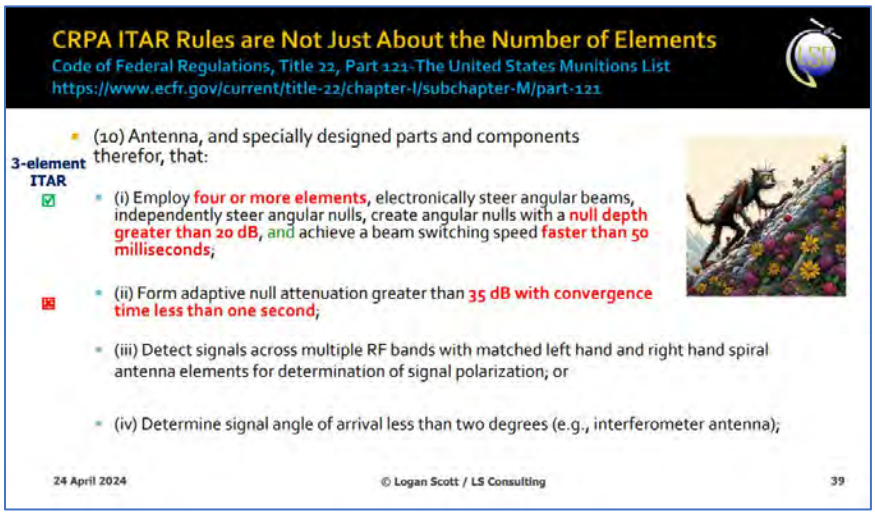
Dr. Parkinson said he just wanted to make sure listeners didn't come out with the wrong impression about huge errors in adaptive arrays. Typically, a user might look at the Dilution of Precision (DOP) and be able to throw that datapoint out since it could maybe be an integrity violation.

Mr. Scott agreed that is possible but, in any case, this ties back to the issue of situational awareness. If trying to land an aircraft, even a 10 m error could become a big deal.



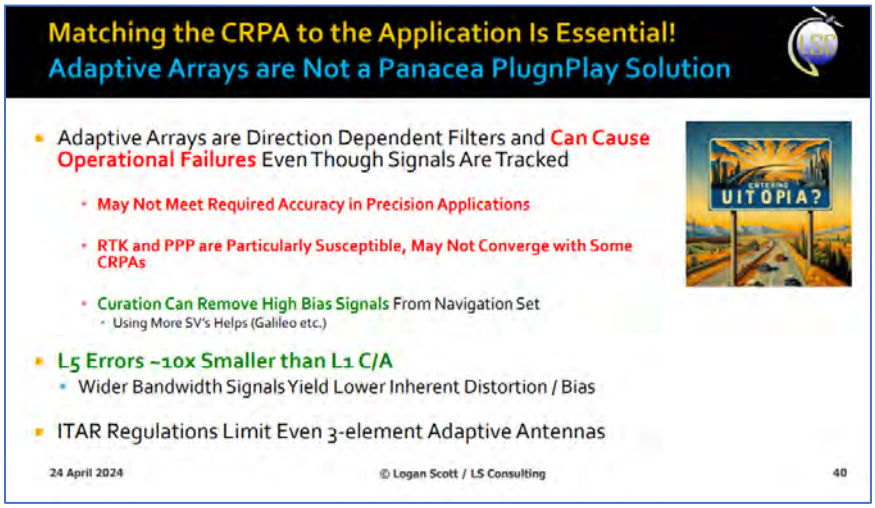
Slide 21

On the issue of ITAR, it is important to note that it is not just about the number of elements in an antenna array (Slide 22). Just because someone has a two-element antenna, it still doesn't mean they are ITAR compliant. The constraints are also how deep such 'nulls' are. In fact, honestly it is hard to build an antenna as bad as some of the numbers in the ITAR regulation.



Slide 22

Closing out the CRPA talk, adaptive arrays are not just a plug-n-play panacea (Slide 23). There can be operational failures if one does not properly match the CRPA to the application. It is very important to understand whether one is dealing with a 'nuller' antenna, or a beam forming antenna, and match those to the application. It is also important to note that Real Time Kinematic (RTK) and PPP applications are particularly sensitive to adaptive arrays. There may be a situation where initially everything works great, but then someone turns out a jammer and the adaptive array itself gives you a great signal-to-noise ratio, but the observables are so messed up that you can't converge the RTK algorithm. Having said that, there are ways to curate the signals and identify which ones are likely to have the high bias. So, if an adaptive array is attached to such receiver there are ways to overcome this. In addition, if doing a new installation, it is definitively recommended to put in L5 even if it is not yet set as 'healthy' by the GPS operator.



Slide 23

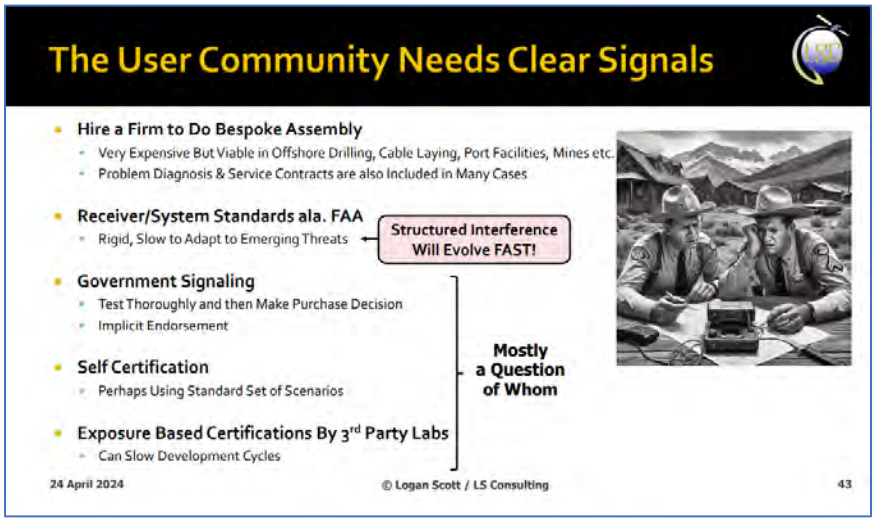
It is possible to have all the right parts to toughen a receiver, and yet still put them together wrong (Slide 24).

Initial results can be discouraging (Slide 25). Mr. Scott noted that he has never been able to build a system that works properly the first time. The only way to learn this is through testing. During the Portland Spoofing Incident, he found the failure rate to be 100% across all the manufacturers he tested. They all thought they were in Toulouse. Testing for jamming and spoofing is also a conundrum because it is mostly like conducting an Electronic Attack (EA). It is important to understand what form an EA might take, but in doing so it is important not to propagate EA technology that could potentially end up being used by an adversary. Thus, it is a bit of a loop where testing has to be done, but in we need to be cautious that such testing does not lead to improving EA capabilities.

Slide 24

Slide 25

In summary, it is important that the user community be well informed (Slide 26). A spoofer could, for example, cause a lot of confusion and chaos among emergency responders. Therefore, high value applications (offshore drilling, etc.) typically hire a firm to do a Bespoke Assembly [i.e., custom made, or producing custom made articles]. It can be expensive, but they can maintain this and keep it operational. Another approach is to set standards in a way that they can quickly adapt to a changing threat environment. The rest of the approaches in Slide 26 is mainly a question of who should do the testing. One could be a government laboratory doing such testing, but then purchasing such equipment could risk it also being perceived as implicit endorsement. This is workable in some industries, but certainly not in all. Another approach could be self-certification, but someone that is for example only used to dealing only with civil receivers may not have the expertise to know how to launch an EA. So, they would need to go to a company to buy a suite of equipment to conduct EAs for use during testing. Finally, another model is for testing to be performed by third party laboratories. There is some merit in that, but also caution as this could also slow down development cycles.



Slide 26

Discussion:

Dr. Parkinson asked for more insight on why L5 drops so much in terms of a typical error due to a phased array ranging signal.

Mr. Scott responded that it typically has to do with the bandwidth of the antenna, where you are getting more precision because you have a wider bandwidth. It is almost like a multipath phenomenon that the antenna itself generates.

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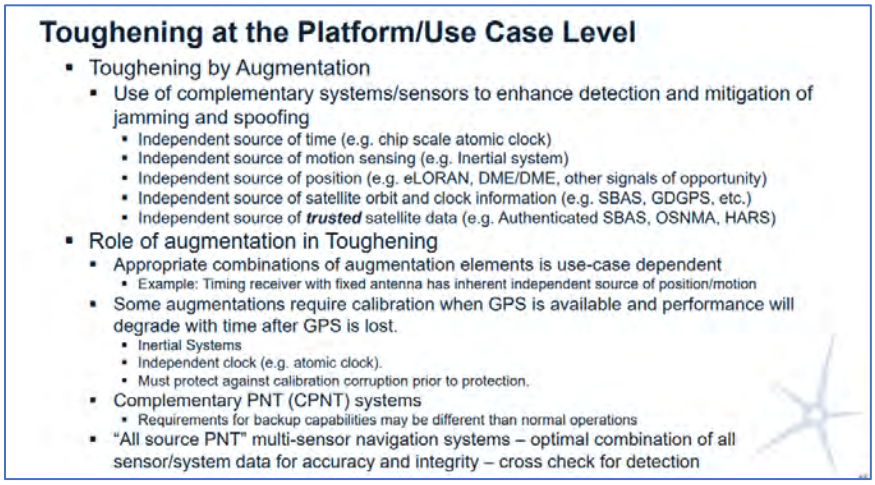
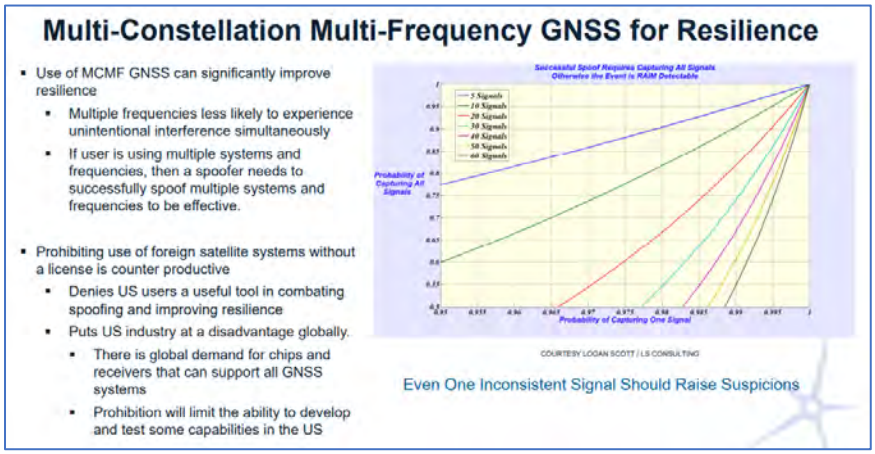
Additional Remarks on Toughen at a User Level
Tim Murphy, *PTA Subcommittee Vice Chair*

Sometimes it is difficult to separate a "toughening" measure from an "augmentation" (Slide 1). In many cases we augment to toughen. One can use complementary systems or sensors to enhance the ability detect and mitigate the jamming/spoofing. We could start independent source of time, such as a chip scale atomic clock, which if integrated into a receiver will help harden it. If the chip scale atomic clock is part of a network of receivers, it has also become an augmentation to the overall system. At the end of the day, we are doing the same thing through toughening and augmenting. If combining this with other independent sources (eLoran, DME, etc.), we can altogether have an independent source of PNT. We could then also add an independent source of trusted satellite data, such as GPS HARS. The appropriate combination of these augmentation elements contributed to toughening use of GNSS. This leads into the topic of CPNT systems. In his view, there are high-reliability critical infrastructure applications that need fully capable and independent (from GNSS) systems to provide PNT because it is very difficult to toughen GNSS to a point where any level of jamming is covered. Therefore, "all source PNT", or multi-sensor navigation, is something that all GNSS users should be encouraged to consider, and not just as a fallback but also as a tool to enable fault detection and exclusion (of jamming).

The use of multi-constellation and multi-frequency GNSS is, in his view, also a powerful tool to improve resilience (Slide 2). It helps raise the bar against a spoofer. If using three GNSS constellations, the spoofer needs to spoof all three. As noted by Mr. Scott earlier in the day, this means the spoofer needs to generate more power, mimic the clock motion of three different system, etc. This is why in his view prohibiting the use of foreign GNSS is a counterproductive move on the part of the U.S. This is just going to deny U.S. users a useful tool to combat spoofing and improve resilience. Some have made an argument that if one is using two GNSS constellations, what is the benefit in using a third one? In Mr. Murphy's view there is some benefit there. Beyond that, it also puts U.S. industry at a disadvantage.



Slide 1



Slide 2

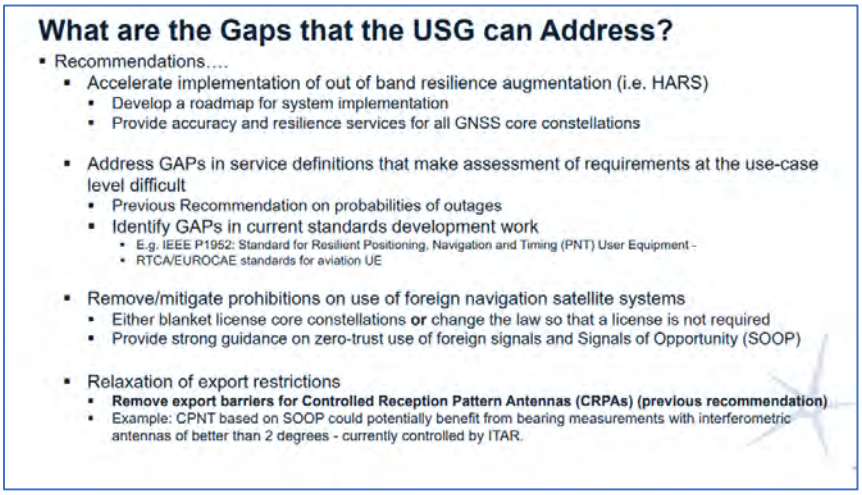
So, what are the gaps that the USG could address? Slide 3 includes some recommendations.

First, the USG should implement HARS, and the first step is to develop a roadmap for system implementation and include an architecture that is modular so that we can add capabilities over time. Since HARS would be delivered over the internet, that information would also be useful for other things such as the dissemination of information about other GNSS. This could include, for example, a clearinghouse on spoofing information. If a user can log onto a server to get HARS data, they could also get information on whether interference has been reported in the area. This could perhaps be branded as something different than the current HARS proposal, but the same servers collecting and securely disseminating that information could be leveraged.

Second, the USG should revisit the service definitions and, perhaps, get some rewording. This was a recommendation the board discussed two years ago and, perhaps, should be revisited. The USG could also identify any gaps it sees in current work to develop standards, such as Institute of Electrical and Electronics Engineers (IEEE) P1952 (Standard for Resilient PNT User Equipment) and RTCA/EUROCAE standards for aviation user equipment. The latter was stood up recently to develop standards for testing jamming and spoofing resilience.

Third, the USG should mitigate or remove existing prohibitions for the use of foreign GNSS in the U.S. Mr. Murphy noted he likes the Australian model where what is legal under ITU should be ok to receiver signals, understanding that you're using them at your own risk and are responsible to verify and protect yourself. This could be done either by going through the current process for blanket licensing of all GNSS signals or by changing the law. In the process of doing that, the USG could provide strong guidance on the concept of zero-trust use of foreign satellite signals. This is not unlike the USG providing GPS signals but noting that it is not responsible for guaranteeing a user is being spoofed.

The last recommendation is for relaxation of export restrictions, where the Board has already made a recommendation on. The USG is apparently working on this. However, in Mr. Murphy's view in addition to the CRPAs restriction raised by the Board, we should go further and revise the ITAR restriction of better than two-degree beading measurements for interferometric antennas.



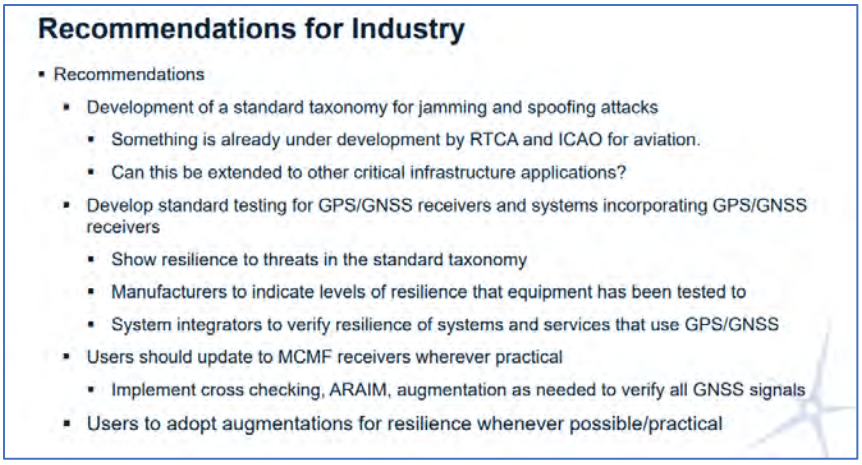
Slide 3

So, what about recommendations for Industry (Slide 4)?

First, industry should develop a standard taxonomy for jamming and spoofing so that everybody is at least talking about the same thing. As mentioned earlier, RTCA and the International Civil Aviation Organization (ICAO) have done some work in this area, which is now being extended through a new subgroup within NSC-159 (National Security Council 159). This approach could be extended to support other critical infrastructure. This would enable simulator, receiver manufacturers, and system integrators to all be on the same page.

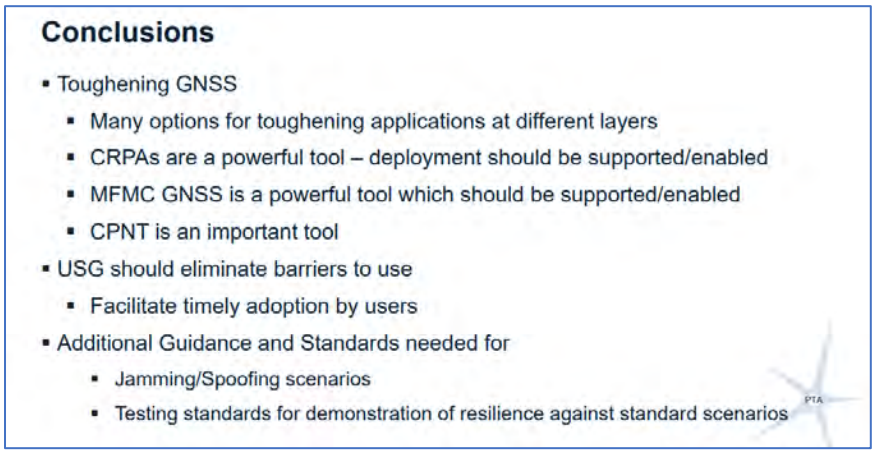
Second, industry should move briskly towards multi-constellation / multi-frequency (MCMF) receivers, where practical, and implement cross-checking through ARAIM (Advanced Receiver Autonomous Integrity Monitoring) and/or integrated independent sensors.

Finally, users should adopt these augmentations for resilience wherever possible.



Slide 4

In conclusion, this briefing has described a lot of options for toughening at different layers where one is trying to protect a system (Slide 5). CRPAs are a powerful tool, though they should be used carefully to ensure one is not compromising the performance in other ways. MCMF GNSS is also a powerful tool to support toughening. So, the USG should eliminate existing barriers to their use while providing additional guidance and standards for jamming/spoofing scenarios as well testing.



Slide 5

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Discussion of Toughen Theme
All Members

Dr. Parkinson asked Mr. Murphy to comment on the issue of L5 in terms of maximum CRPA errors and signal diversity.

Mr. Murphy responded that the sooner we get to GPS L5, the better. It really helps with the incidental interference issue on GPS L1 C/A. However, Mr. Murphy was uncertain on how much the commercial world has started to adopt L5. In the aviation world they are paced by standards development. RTCA is still working on a MOPS (Minimum Operational Performance Standards), so the aviation world can't field anything on an airplane or even provision for it. In fact, a standard for such antenna isn't out yet.

Dr. Betz noted that since there is no safety-of-life certified equipment that uses L5, there is no danger to safety-of-life by setting the L5 signal to "healthy". Thus, the rest of the critical infrastructure can use L5.

Mr. Murphy said he has no argument there.

Mr. Scott noted that the L1 C/A signal has some structural vulnerabilities, and those could be sneaked past an adaptive array. Thus, there are many cautions one should use with CRPAs. With the L5 signal, however, it has a much better design. Thus, it's not just a better signal in terms of bandwidth but it is also harder to play games with.

Dr. Betz proposed that the board debate on a recommendation for L5 to be turned to "healthy" as soon as possible, in advance of the GPS Next Generation Operational Control System (OCX) capability by using some other suitable monitoring approach.

Mr. Murphy said that, putting his aviation hat on, he does want L5 to be set healthy before they field the first receiver that uses it. He doesn't want to have to field a receiver that have some artificial means to turn L5 off and then have to perform a software update to that receiver later.

Mr. Higgins asked if there has been much work done in testing the advantages of E5a (Galileo equivalent to L5) and whether that can inform the business case for L5.

Dr. Betz said he believes it certainly would because that would provide many satellites in view when combining E5a with L5.

Mr. Higgins asked if testing has been done.

Dr. Parkinson asked if, at the very least, extensive analysis has been done.

Dr. Betz said that extensive analysis has certainly been done by the Europeans for a decade or more about the benefits of jointly using GPS L5 and Galileo E5a.

Mr. Murphy added that having plenty of satellites is helpful, for example, when operating at the geomagnetic equator in a high scintillation environment where one is losing half the satellites and must smooth of hundreds of seconds to beat the noise down, yes, it would be desirable to have available as many satellites as possible. While this may seem to be a "corner condition", there are a lot of aviation users operating under such an environment.

Mr. Scott reminded the Board that adaptive arrays can create squirrely effects and should be part of the safety-of-life considerations.

Dr. Parkinson asked if anyone knew whether RTCA is working on the combination of L5 and CRPAs.

Mr. Murphy noted that the RTCA is not working on any standards for CRPAs.

Dr. Parkinson expressed concern about the apparent lack of urgency on trying to work the problem.

Dr. Betz noted that the jamming resistance difference between a good L5 receiver and a good L1 C/A receiver is about 15dB (or a factor of 30) in jamming power.

Mr. Murphy added that's the primary thing RTCA is working on, which is the MOPS to add L5.

Dr. Parkinson asked if RTCA takes all these taskings from the FAA.

Mr. Murphy responded that it doesn't anymore. RTCA is no longer a FACA committee, but an independent standards organization. The terms of reference are driven by consensus of industry saying whether there is a demand for things. Ten years ago, the FAA drove the agenda, but this is now not as true as it used to be.

Dr. Parkinson commented that he was shocked to hear this.

Mr. Murphy added that unless you have a couple of receiver manufacturers to show up and say that they would certify to a standard, then RTCA will not develop such standard.

Dr. Parkinson said that, from what he's hearing, it appears the government has no leverage over causing RTCA to address almost anything.

Mr. Murphy said he wouldn't characterize it as having no leverage, but the USG certainly used to have much more leverage before it cut RTCA loose as an advisory committee.

Gen Shelton said he tried 15 years ago to set L5 as healthy, but he was shut down. He agreed that it's time to revisit this.

Dr. Betz said he would try to word a draft recommendation for the Board to consider on the following day.

Mr. Murphy added that it's not just the RTCA that is the problem. The dual frequency standards at ICAO have just been finished and are currently out for state letter review, but he doesn't know when they will become applicable.

Dr. Betz said that, in the meantime, we still need to push for L5 to be set healthy, so we don't lose the window of opportunity.

Mr. Murphy agreed that we shouldn't be withholding any use of L5 just based on aviation certification. He said he doesn't have any visibility into whether commercial receivers are putting L5 in.

Dr. Parkinson introduced Mr. Michael Ritter (Hexagon) and asked him to provide additional insight.

Mr. Ritter said everyone is using L5 on the commercial side, from cellphones to high precision receivers. Hexagon, and others, are monitoring L5, and there is nothing wrong with it. They do the same for the Galileo E6 signal. In fact, L5 & E6 would give a tremendous advantage. Current CRPAs are not designed for L5 due to legal restrictions, but that could be easily fixed.

Dr. Betz noted that the issue here is that we are teaching receiver manufacturers to violate the GPS Interface Control Document (ICD) and use signals that are set "unhealthy".

Mr. Murphy said that would still be in line with the zero trust but verify philosophy. Just because the satellite is telling you the signal is "unhealthy", if there are tons of data from another source saying it's perfectly good then why wouldn't we use it?

Mr. Chan added that in the automotive space, traditional GNSS receivers are using L5 as well.

Mr. Higgins noted that there may be a sort of "feedback loop" going on, where ICAO is not in a hurry because GPS is not in a hurry.

Dr. Walter noted that the Wide Area Augmentation System (WAAS) dual-frequency service will not be valuable until it has at least 23 GPS satellites with L5. Years ago, there was a rush to put up L5-capable Geosynchronous Orbit (GEO) satellites, but they will be retired without ever really providing L5 service. So, WAAS will be ready when L5 is ready. However, standards-setting and safety-of-life takes a very long time. WAAS will need at least a couple of years to hammer out all the standards and finish the development of the ground system for the L5 monitoring.

Dr. Parkinson commented that this should be done in parallel. Each of these pieces should be running as fast as they can.

Dr. Powell asked if we could make a recommendation to decouple safety-of-life off the critical path for 2 SOPS to set L5 as healthy?

Dr. Betz said that's the point. If there are no certified safety-of-life receivers out to use L5, then there is no certified safety-of-live concern with setting it healthy right now. That's the way he'll try to word the recommendation.

Dr. Walter said that if 2 SOPS can meet what's in the GPS Performance Standard (which describes fault rates, etc.), then they should be able to set L5 as healthy. Aviation users will still not be able to use L5 until they are certified.

Ms. Van Dyke said that, unfortunately, the GPS Architecture Evolution Plan (AEP) was not modified for L5 and that's been the challenge. While there is L5 monitoring out there, there is no L5 monitoring through the GPS control segment like was done for M-Code early use. Because L2 is in the AEP, L2C is currently set as usable but at your own risk.

Dr. Betz said that's the same thing the Board is talking about for L5 (setting as healthy but use at your own risk).

Mr. Scott said he agrees with Mr. Murphy in that prohibiting the reception of other foreign GNSS signals in the U.S. is a misguided policy that is putting U.S. manufacturers at a disadvantage. In fact, he is not sure what problem the U.S. thinks it is solving by maintaining such prohibition. He likes the Australian approach that Mr. Murphy talked about.

Mr. Grossman said he agreed with the comments made by Mr. Murphy & Mr. Scott on multi-GNSS / multi-frequency use.

Mr. Murphy added that receiver manufacturers are going to make such receivers regardless, and users will buy those in this country and use them anyway. Expending the money to enforce such prohibition is, in his view, crazy. Instead, we should be prosecuting people that are actively jamming. If they are going to use L5, we (USG) can help monitor the signal.

Lt Gen Hamel said he does not agree with those statements. There are concerns about governments, such as the People's Republic of China, intervening in industry, product development, etc. BeiDou's forward messaging link is troubling because it goes directly into the equipment, and we have no idea of the provenance of all the chipsets. Any statement from the Board should indicate that there is goodness in having the maximum number of inputs available to improve resilience. but subject to determination on whether there are unacceptable vulnerabilities particularly in critical infrastructure applications.

Dr. Betz noted that, in his view, once we are using both GPS and Galileo satellites it is not clear that there is enough benefit in also taking BeiDou and its potential risks.

Dr. Powell noted that to use BeiDou one does not necessarily have to buy a BeiDou chipset. They publish an ICD, and from that one can code up a receiver. So, we can mitigate some of those supply-chain risks.

Dr. Betz asked if we're then going to inspect every receiver used in critical infrastructure to understand the provenance of that chip and software it came with? That would not be practical.

Dr. Betz said it appears the board has a recommendation to remove the prohibition on foreign signals and asked Mr. Murphy to write a recommendation for discussion on the following day.

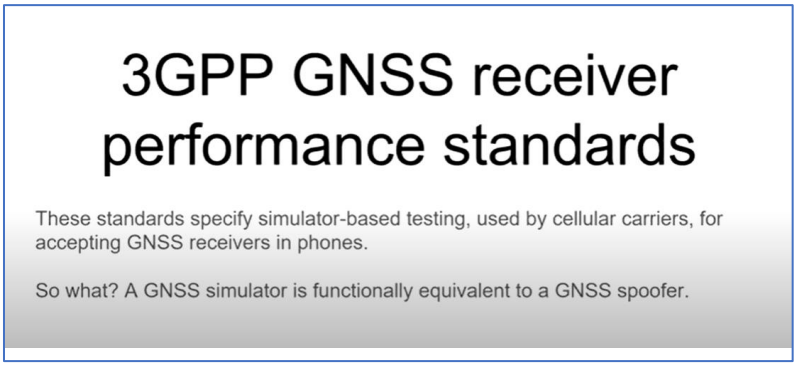
Mr. Murphy said this will require more offline discussions to come up with a well-thought-out recommendation.

Dr. Betz noted that for signals such as E6, used by Europe's Galileo and Japan's QZSS, the issue is different since it's a spectrum allocation issue. Perhaps the board can invite a speaker to its next meeting to brief on this topic.

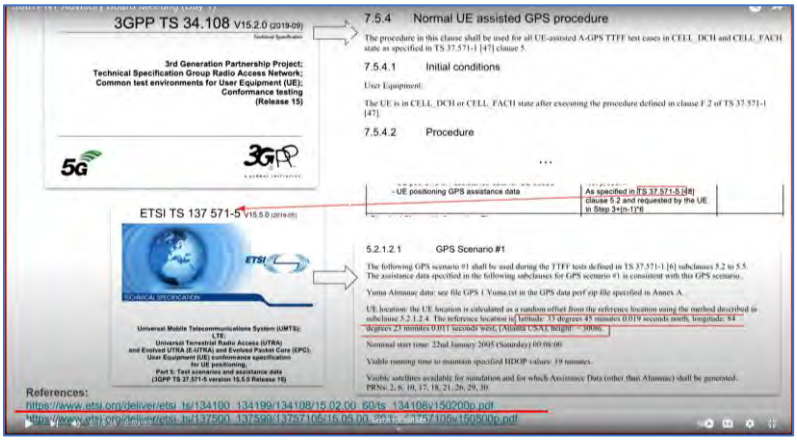
Mr. Murphy commented that there seems to be a gap between protecting the spectrum and whether a signal can or cannot be used.

Dr. Betz noted that perhaps there can be a compromise where use is permitted but there is no associate protection.

Dr. van Diggelen presented a set of slides with the standards used by carriers (Verizon, etc.) to test if GPS works before they accept a phone (Slides 6-7). First, there are standards that specify the performance required for the GNSS simulator used for the test. Such simulators are functionally equivalent to a GNSS spoofer. Then there are standards on the specific scenarios that phone must pass. In Slide 7, the 3rd Generation Partnership Project (3GPP) Technical Specification describes the procedure for testing Assisted GPS, which in turn refers to a European Telecommunications Standards Institute (ETSI) specification. So, the phone is subjected to a simulator that will generate a specific signal, and then it must provide the position data shown in the ETSI specification. Slide 7 shows one of the scenarios required as part of the test.



Slide 6



Slide 7

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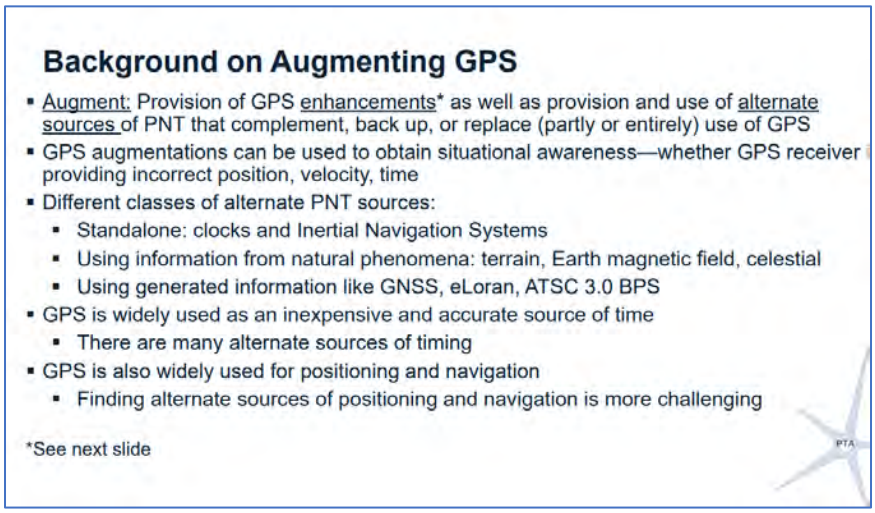
Theme 3: Augmenting GPS/GNSS

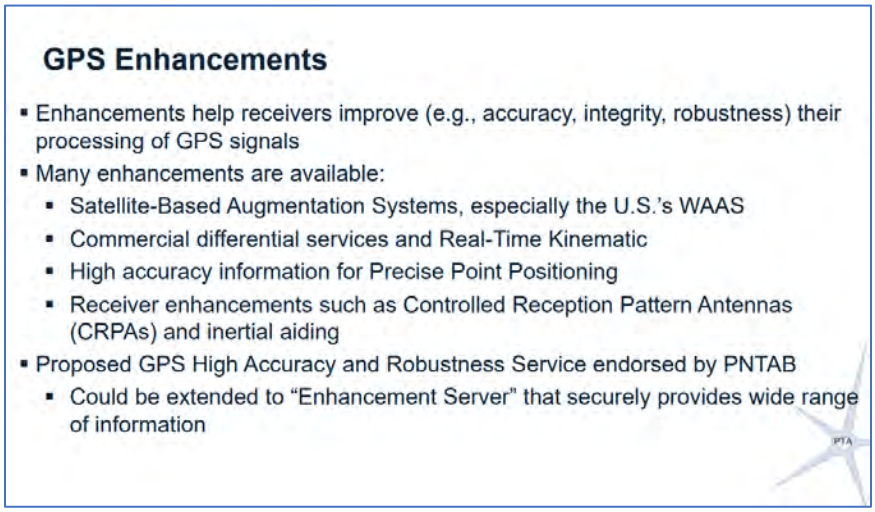
Augment Introduction
Dr. John Betz, *Chair, PTA Subcommittee*

Earlier today we talked about the definition of "Augment" being the combination of providing enhancements, which Mr. Murphy pointed out receivers can use in many ways including toughening, as well as the provision of alternate sources of PNT (Slide 1). As Mr. Schott pointed out, augmentations provide useful situation awareness on whether the GPS receiver is providing good data. There are lots of classes of alternate PNT sources. Some are standalone, although they need to be initialized. Some use natural phenomena. Some use information that is generated intentionally. We know that GPS is used extensively for timing critical infrastructure and is also used for positioning and navigation. As we'll see, it is easier to come up with good alternate sources for time than it is for positioning and navigation.

We mentioned earlier in the definitions that there are these enhancements that can be included as augmentations (Slide 2). They help the receiver improve accuracy, robustness, and other things. There are enhancements that have been around for decades, such as Space-Based Augmentation Systems (SBAS). There are also commercial differential and RTK services. There is high accuracy information for PPP. And there are enhancements such as CRPAs and inertial aiding. This afternoon we are going to focus on the alternate sources of PNT, not on these enhancements.



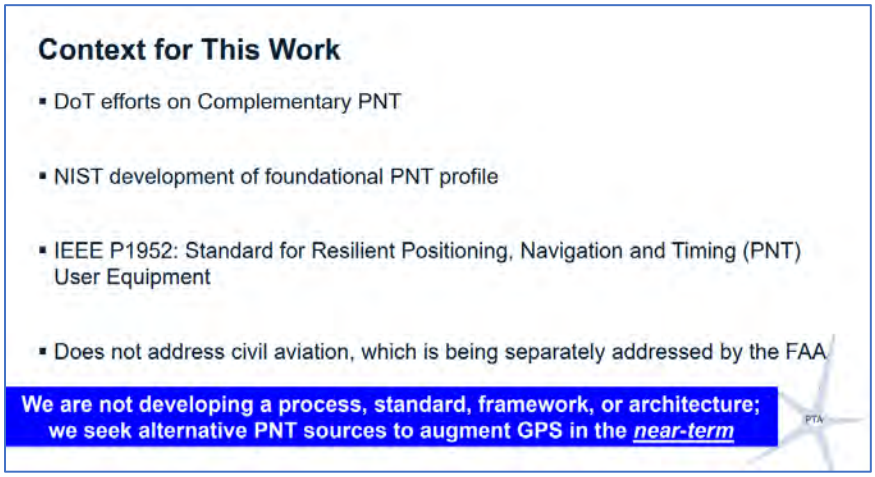
Slide 1



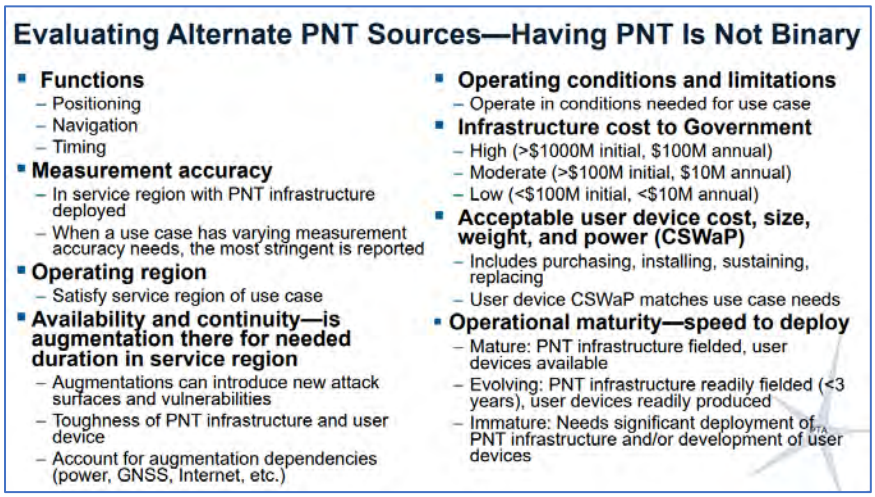
Slide 2

For context, there are other ongoing efforts (Slide 3) such as DOT's CPNT, National Institute of Standards and Technology (NIST) development of development of a foundational PNT profile, IEEE development of standards. The Board's objective is to seek alternative PNT sources to augment GPS in the near term. It is not to duplicate these other efforts in developing processes, standards, frameworks, architectures, nor to address civil aviation.

The PTA Subcommittee looked at the presentation to the Board last December which looked into a number of use cases[1]. The MITRE Corporation had done some work for DHS that included defining a set of use cases for critical infrastructure. Based on that, the subcommittee took those use cases and evaluated potential alternate PNT technologies. As shown on Slide 4, there are a lot of criteria that need to be satisfied for a PNT source to be useful in critical infrastructure use cases. The subcommittee took these criteria and did a DRAFT evaluation of candidate alternate PNT sources. The objective of this initial evaluation is to elicit feedback from the Board. In reviewing these alternate PNT sources, a key issue was the unknown toughness of the user devices.



Slide 3

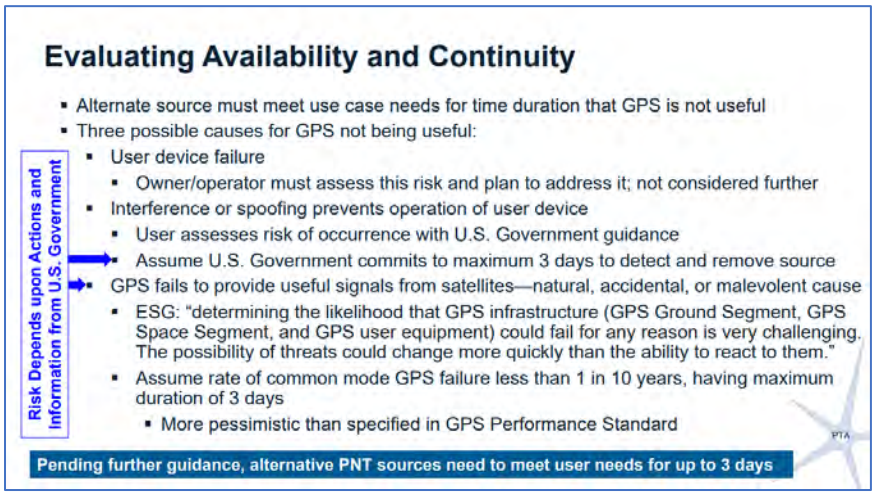


Slide 4

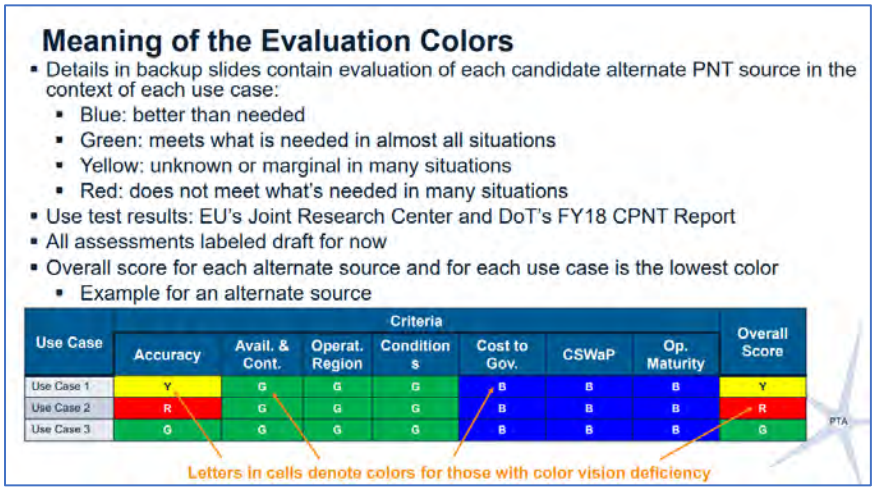
[1] J. Betz et al, "Canonical Use Cases for Critical Infrastructure," Briefing to PNTAB, 5 Dec 2023. See: https://www.gps.gov/governance/advisory/meetings/2023-12/betz.pdf

The alternate source must meet the use case needs during the time that GPS is not available (Slide 5). Three reasons that GPS could not be available are: user device failure, interference, or spoofing that prevents operation of the device, or GPS satellites failing to provide useful signals. Regarding interference, this effort assumed the USG is committed to a maximum of three days to detect and remove its source (the Subcommittee decided to give the USG a break compared to the one-day period in a proposed recommendation discussed earlier today). Regarding the provision of useful signals from GPS satellites, the subcommittee assumed a failure less than one event in 10 years and having a maximum duration of three days. The blue text in Slide 4 highlights two key areas where any operator of critical infrastructure is relying on information from the USG.

Different alternate PNT sources were evaluated against the use cases that were presented to the Board in December. The meaning of the evaluation colors is described in Slide 6. Blue indicates that the alternate source does better than the use case needs. Green indicates that the use case needs are met in almost all situations. Yellow indicates when it is unknown or marginal in many situations. Finally, red indicates it does not meet the use case needs in many situations. Two key sources for analyzing the performance included DOT's CPNT report conducted in response to the FY2018 National Defense Authorization Act (NDAA) and the more recent European Union's (EU) Joint Research Center report. In evaluating the overall performance, the subcommittee took the lowest value across each row. All these assessments are labelled DRAFT and intended for discussion by the Board. At the end of the day, only these overall scores are presented. The complete set of slides will be uploaded to www.GPS.gov.



Slide 5



Slide 6

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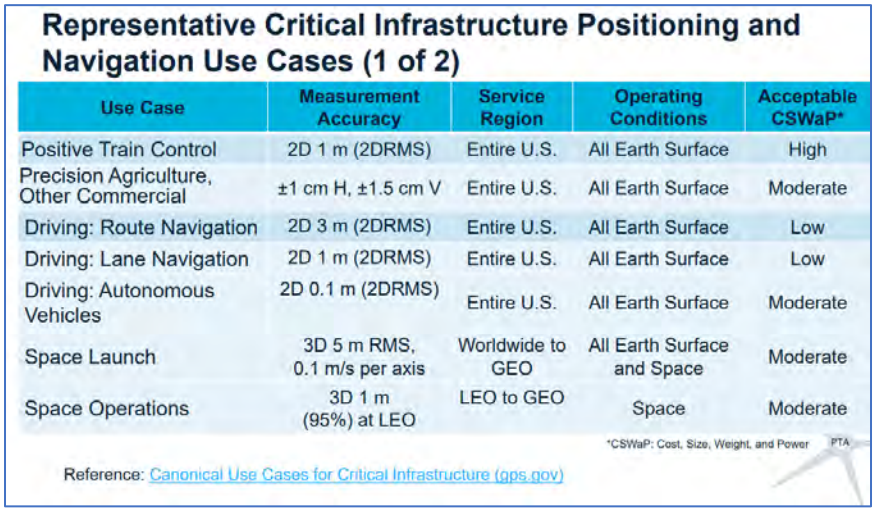
Examining Alternate PNT Augmentations
Mr. Scott Burgett, *PTA Subcommittee Member*
Mr. Logan Scott, *PTA Subcommittee Member*

1) Positioning and Navigation (Mr. Scott Burgett)

Mr. Burgett explained he's held multiple virtual meetings with Prof. Filjar, Mr. Logan Scott, and Dr. Powell to assess and score various alternate sources for positioning and timing. The team relied a lot on DOT's CPNT Report and the EU's Joint Research Center Report. The first thing to look at are the representative critical infrastructure positioning and navigation use cases (Slides 1-2), which were taken from Dr. Betz's briefing, "Canonical Use Cases for Critical Infrastructure," presented to the Board last December[2].



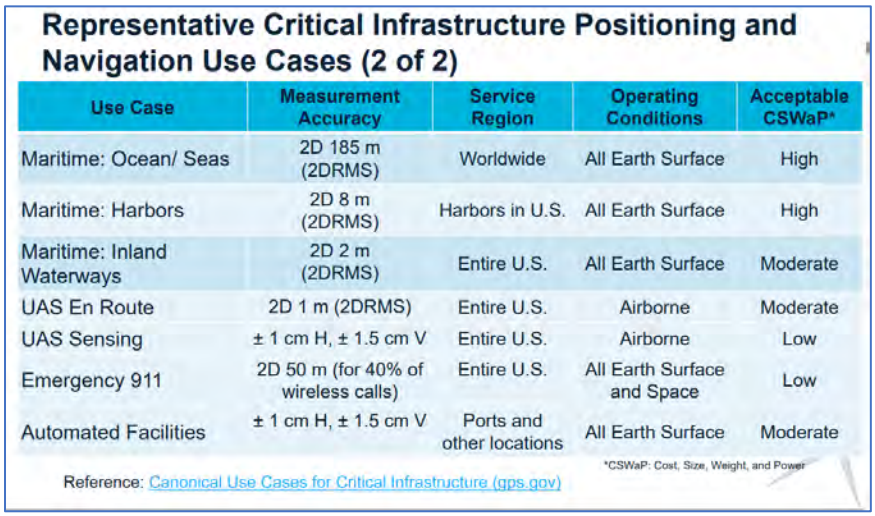
Representative Critical Infrastructure Positioning and Navigation Use Cases (1 of 2)

Use Case	Measurement Accuracy	Service Region	Operating Conditions	Acceptable CSWaP*
Positive Train Control	2D 1 m (2DRMS)	Entire U.S.	All Earth Surface	High
Precision Agriculture, Other Commercial	±1 cm H, ±1.5 cm V	Entire U.S.	All Earth Surface	Moderate
Driving: Route Navigation	2D 3 m (2DRMS)	Entire U.S.	All Earth Surface	Low
Driving: Lane Navigation	2D 1 m (2DRMS)	Entire U.S.	All Earth Surface	Low
Driving: Autonomous Vehicles	2D 0.1 m (2DRMS)	Entire U.S.	All Earth Surface	Moderate
Space Launch	3D 5 m RMS, 0.1 m/s per axis	Worldwide to GEO	All Earth Surface and Space	Moderate
Space Operations	3D 1 m (95%) at LEO	LEO to GEO	Space	Moderate

*CSWaP: Cost, Size, Weight, and Power

Reference: Canonical Use Cases for Critical Infrastructure (gps.gov)

Slide 1



Representative Critical Infrastructure Positioning and Navigation Use Cases (2 of 2)

Use Case	Measurement Accuracy	Service Region	Operating Conditions	Acceptable CSWaP*
Maritime: Ocean/ Seas	2D 185 m (2DRMS)	Worldwide	All Earth Surface	High
Maritime: Harbors	2D 8 m (2DRMS)	Harbors in U.S.	All Earth Surface	High
Maritime: Inland Waterways	2D 2 m (2DRMS)	Entire U.S.	All Earth Surface	Moderate
UAS En Route	2D 1 m (2DRMS)	Entire U.S.	Airborne	Moderate
UAS Sensing	± 1 cm H, ± 1.5 cm V	Entire U.S.	Airborne	Low
Emergency 911	2D 50 m (for 40% of wireless calls)	Entire U.S.	All Earth Surface and Space	Low
Automated Facilities	± 1 cm H, ± 1.5 cm V	Ports and other locations	All Earth Surface	Moderate

*CSWaP: Cost, Size, Weight, and Power

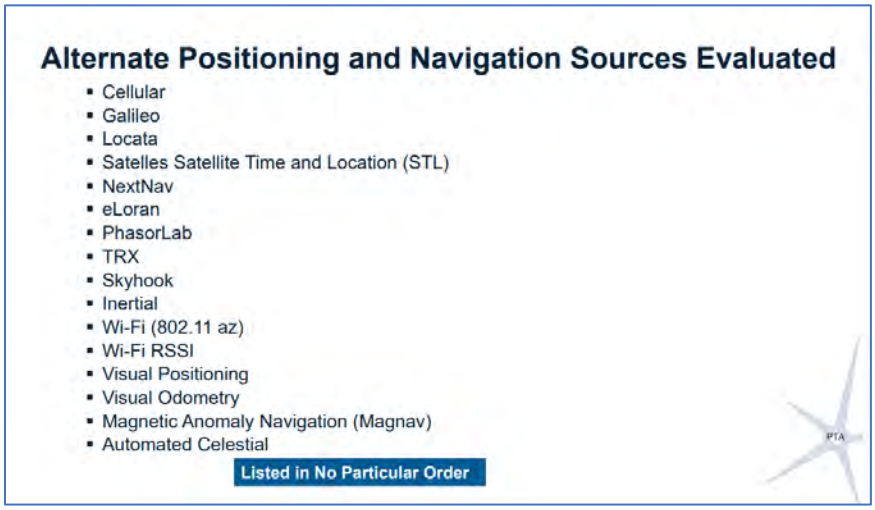
Reference: Canonical Use Cases for Critical Infrastructure (gps.gov)

Slide 2

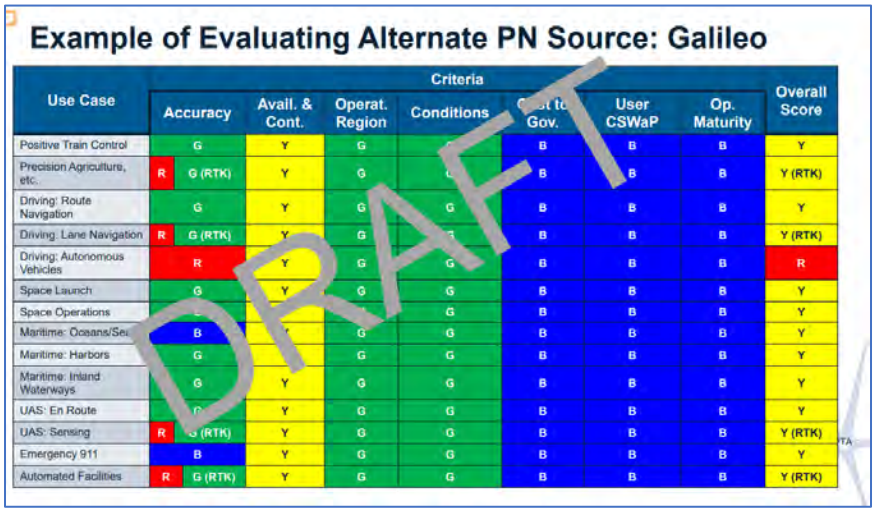
[2] https://www.gps.gov/governance/advisory/meetings/2023-12/betz.pdf

The team then developed a representative list of alternative positioning and navigation sources (Slide 3). The list shown here is not in any particular order. The list is not exhaustive, but the team believes it covers most of the technology that is out there, and varies widely including satellite and terrestrial beacon technologies, Wi-Fi-based technologies, inertial systems, etc. The team studied these technologies and scored them vs. the representative use cases shown in Slides 1-2.

Slide 4 shows an example of the scored card for one of the alternate positioning and navigation sources considered, the Galileo GNSS. The uses cases are shown in the left column, the scoring for the different criteria is shown in the middle columns, and the overall score is shown in the right column. As Dr. Betz noted earlier, the overall score reflects the worst scoring of the criteria that were evaluated. For example, when evaluating Galileo vs. the precision agriculture use case, in terms of accuracy it is nowhere near providing the required accuracy level (and the score is shown as red). However, when combined with RTK it becomes accurate enough (and the score shown as green). In terms of availability and continuity, note the entire column is scored as 'yellow' because it was very difficult for the team to score it as 'green' because of unknown factors in knowing how tough the receivers or how robust Galileo constellation is in the long term. Otherwise, Galileo works well in meeting the rest of the criteria.



Slide 3

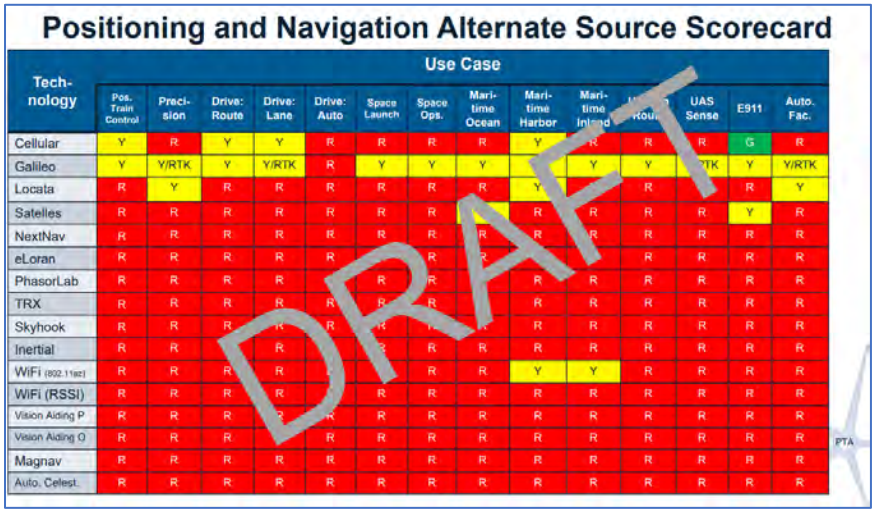


Use Case	Criteria							Overall Score
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Gov.	User CSWaP	Op. Maturity	
Positive Train Control	G	Y	G	G	B	B	B	Y
Precision Agriculture, etc.	R G (RTK)	Y	G	G	B	B	B	Y (RTK)
Driving: Route Navigation	G	Y	G	G	B	B	B	Y
Driving: Lane Navigation	R G (RTK)	Y	G	G	B	B	B	Y (RTK)
Driving: Autonomous Vehicles	R	Y	G	G	B	B	B	R
Space Launch	G	Y	G	G	B	B	B	Y
Space Operations	G	Y	G	G	B	B	B	Y
Maritime: Oceans/Sea	B	Y	G	G	B	B	B	Y
Maritime: Harbors	G	Y	G	G	B	B	B	Y
Maritime: Inland Waterways	G	Y	G	G	B	B	B	Y
UAS: En Route	G	Y	G	G	B	B	B	Y
UAS: Sensing	R G (RTK)	Y	G	G	B	B	B	Y (RTK)
Emergency 911	B	Y	G	G	B	B	B	Y
Automated Facilities	R G (RTK)	Y	G	G	B	B	B	Y (RTK)

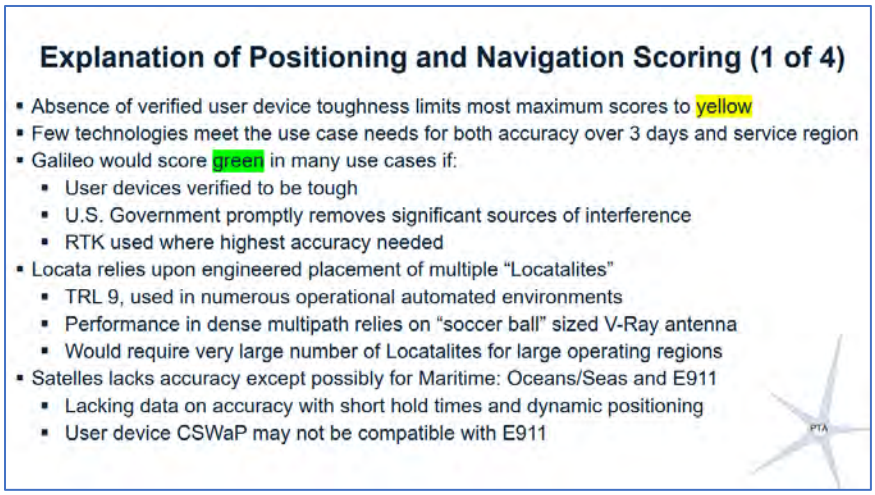
Slide 4

Slide 5 shows the DRAFT overall score card for the various alternate positioning and navigation sources that were studied. The technologies are listed in the left column, and the other columns show the DRAFT scores for the various use cases. The vast majority of these technologies were scored 'red' by the team. There are many potential reasons for this. For example, while Locata provides excellent local performance, deploying it to cover large regions would be prohibitively expensive. This evaluation should be considered as DRAFT. The key message is that, currently, the best augmentation for GPS is Galileo.

Slides 6-9 provide additional information on the scoring.



Slide 5



Slide 6

Explanation of Positioning and Navigation Scoring (2 of 4)

- NextNav is a terrestrial beaconing solution
  - Accuracy is not sufficient for most applications
  - High TRL and low CSWaP
  - Would require a very large number of beacons for large service regions
  - Three day continuity requires high CSWaP clocks in master beacons
- eLoran assessed as operationally immature: time required for site preparation, acquisition and installation of transmitters, cybersecure master control station and software, connectivity between transmitters and master control station and reference stations
  - Even then, accuracy and user device CSWaP limited to Maritime: Harbors and Inland
- PhasorLab uses dense mesh network of cooperative devices for relative navigation
  - Performance highly influenced by network density and multipath
  - Not suited for large service regions with sparse cooperative devices
- TRX is a mobile dismount solution not designed for most use cases
  - Intended for keeping track of personnel in GPS contested areas

Slide 7

Explanation of Positioning and Navigation Scoring (3 of 4)

- Skyhook uses WiFi signals of opportunity and a map of these signals to create a high TRL, low user CSWaP, Round Trip Timing (RTT) solution
  - Accuracy not sufficient for most applications
  - Signals of opportunity inconsistent and non-existent in remote areas; depend on power and Internet availability
- Inertial drift does not provide needed accuracy over three days
- WiFi (802.11az) uses fine timing measurement accurate to about 2 meters or better
  - Does not cover large and remote service regions
  - Dependent on power and Internet
- WiFi (RSSI) measures received signal strength (RSSI) from several Access Points to Determine Position
  - Does not cover large and remote service regions
  - Dependent on power and Internet

Slide 8

Explanation of Positioning and Navigation Scoring (4 of 4)

- Magnav assessed as operationally immature: sensors, platform calibration, map availability
- Visual aids positioning limited by weather, nighttime, availability of maps for entire service regions
- Visual aids odometry limited by weather and nighttime; unable to sustain accuracy over three days
- Automated Celestial limited by weather and user device CSWaP

Slide 9

Discussion:

Mr. Goward noted that the message appears to be that there are no quick fixes to this issue. If we were having this conversation back in 1973, the conclusion would have been that GPS would not make the cut either [just as Galileo hasn't, as depicted in Slide 4]. Thus, while this analysis shows that there are no short-term solutions that would address all the issues, we still need as soon as possible rather than pushing the issue down the road.

Dr. Betz suggested reprising this point during the discussions at the end of the "Augmentation" section.

Mr. Shields asked what application they were thinking about when assessing automated driving.

Mr. Burgett said they used the representative use cases described in Slide 1, which has very high accuracy requirements (0.1 m). They didn't think of a particular use case within automated driving.

Mr. Shields noted that the mainstream car companies only use GNSS in instances where a car is being towed. The requirements shown for automated driving are correct, but they would be met by means other than GNSS (on-board sensors, etc.).

Dr. Betz agreed and said that if autonomous driving is not a helpful use-case for this analysis, it can be removed and we can stick it with the lane navigation use case.

Mr. Chan said that for Galileo the big limiting factor appears to be the no assurance or certification of user equipment. He asked Mr. Burgett to elaborate on what body or organization would be acceptable to provide such certification.

Dr. Betz said that they'll also talk about that at the end.

Mr. Scott asked under the evaluation for eLoran (Slide 7), why is the criteria shown relevant if we are talking about a having a reliable backup.

Dr. Betz said that evaluation was made under the assumption of implementing a backup in the short-term (under three years). He added that follow-on work can include an assessment of the methodology for assessing what can be done in the long term to help augment critical infrastructure. Right now, the focus is just on the short-term.

Mr. Higgins asked, regarding Locata, presumably the assessment was done based on the current demonstration using Wi-Fi frequencies? The reason for mentioned this is that if Locata had dedicated spectrum, then it could be used for at much longer distances and therefore much less expensive to deploy.

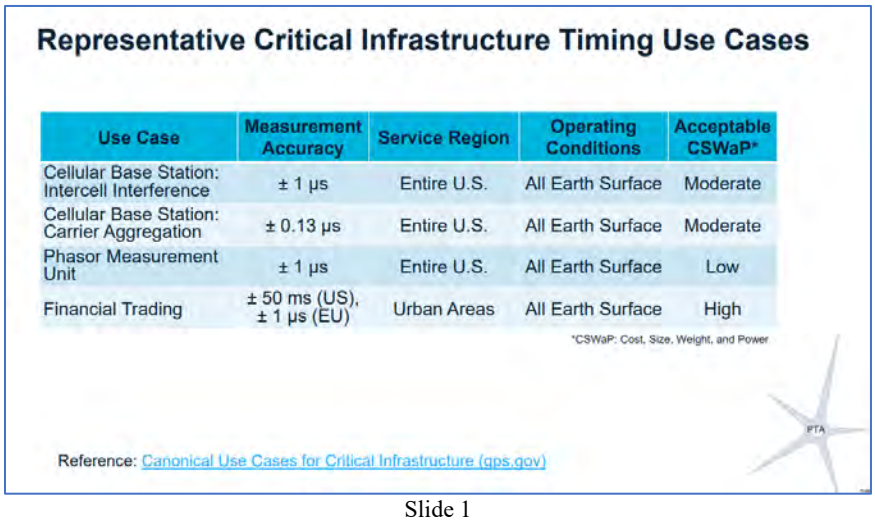
Mr. Burgett agreed. This assessment just covered short-term implementation (within three years).

Mr. Burgett then turned the presentation over to Mr. Scott for the discussion on timing.

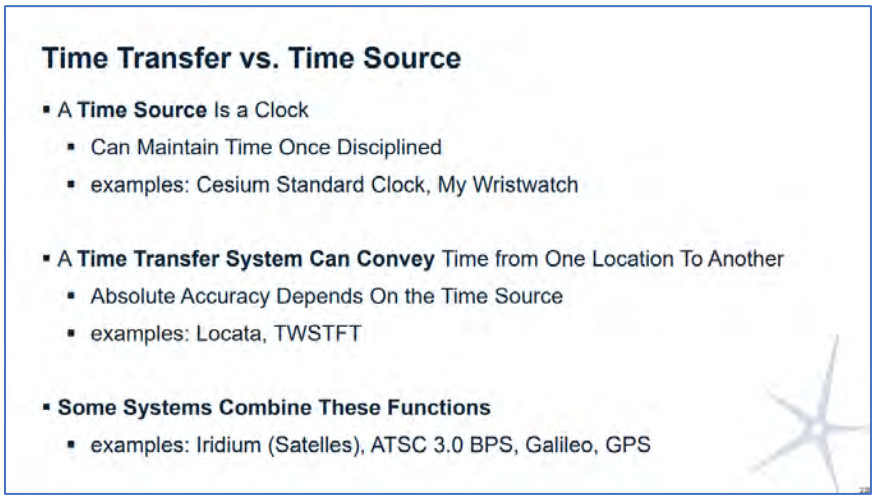
2) Timing (Mr. Logan Scott)

Mr. Scott noted this was a collaborative effort with Dr. Pat Diamond, Mr. Vahid Madani, and Dr. J. Betz. Slide 1 describes the representative use cases for timing. Cellular base stations need to be time coordinated to keep them from interfering with each other. Base carrier aggregation is used for very high data rates rather than having just one transmitter. In addition, the data may be transmitted by totally different systems (Verizon, T-Mobile, etc.). Phasor measurement unit applications include, for example, fire mitigation in power grids to determine exactly where a power line has gone down and allow the power company to de-energize that particular line. Finally, financial trading is also a very important timing use case, particularly in high-speed trading. Timestamps are very important across the financial sector. Note how the requirements in the EU are much more stringent than in the U.S.

Slide 2 provides the definition of a time source vs. a time transfer system. A time source is a clock, which may be a high-end Cesium Standard Clock or a simple wristwatch. At some point the wristwatch needs to be "disciplined" to keep holding onto accurate time. Another possibility to get time is a time transfer, which are systems that can transfer time from one location to another, but it doesn't necessarily guarantee accuracy on the other end. If we were to hook a Locata system to our wristwatch, then it will transfer the wristwatch time (which is wrong by a couple of seconds) very accurately (within 1 nanosecond). Thus, while the transfer is accurate, the time being transferred is not. There are systems out there that are trying to combine the time source and time transfer functions. The most notable one is GPS, which provides time that can be traced to NIST time. Other systems include Galileo, Satelles, and the ATSC 3.0 BPS (Broadcast Positioning System) standard provided by television operators.



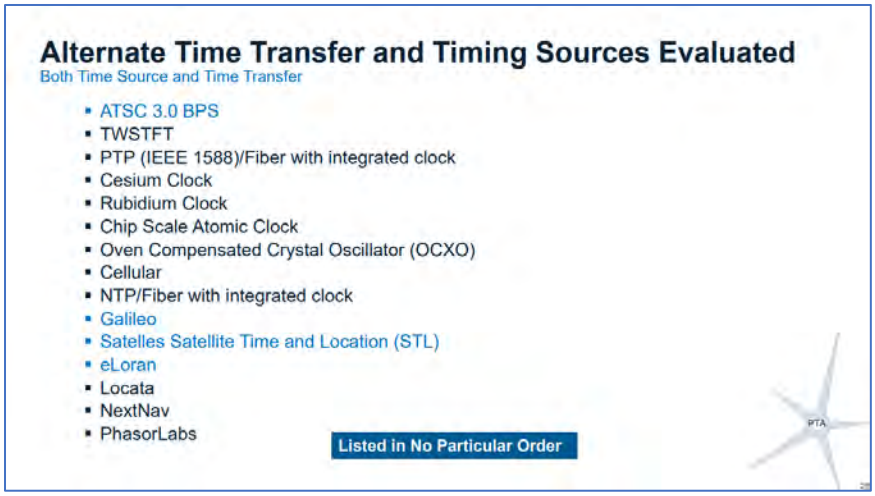
Slide 1



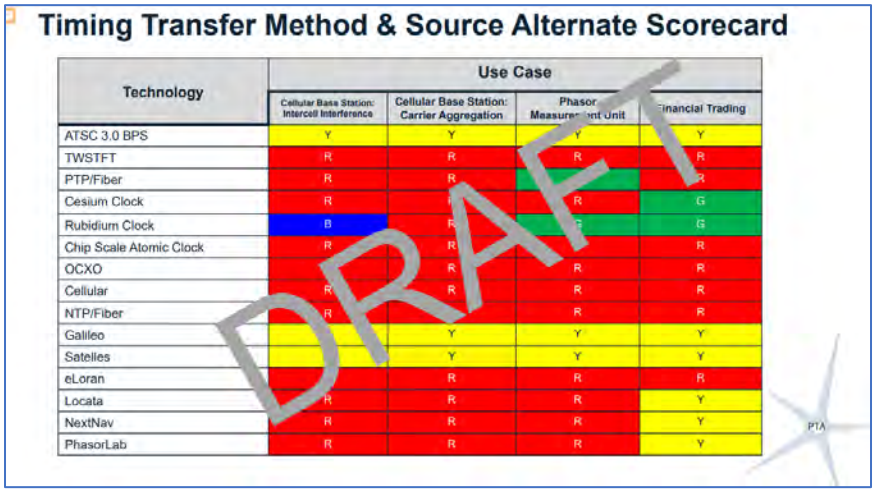
Slide 2

Slide 3 lists, in no particular order, the time transfer and timing sources that were evaluated. The ones highlighted in blue are those that combine a time source, usually traceable to NIST, and time transfer.

Slide 4 describes the evaluation that was conducted. Note this scorecard has a little more "green" and "yellow" than the scorecard for positioning and navigation in the briefing by Mr. Burgett (Slide 5 in the previous briefing). Timing is easier to perform. However, in assessing the use cases there is a presumption that the user equipment "knows" where it is geographically. So, we are trying to provide time to stationary receivers at known locations. GPS and Galileo don't have this restriction, but for purposes of this discussion all the application cases are assumed to be stationary. Also, note how the performance of the Rubidium clocks are outstanding. As of this morning only two of the GPS satellites are using Rubidium clocks, the rest are using Cesium Clocks.



Slide 3

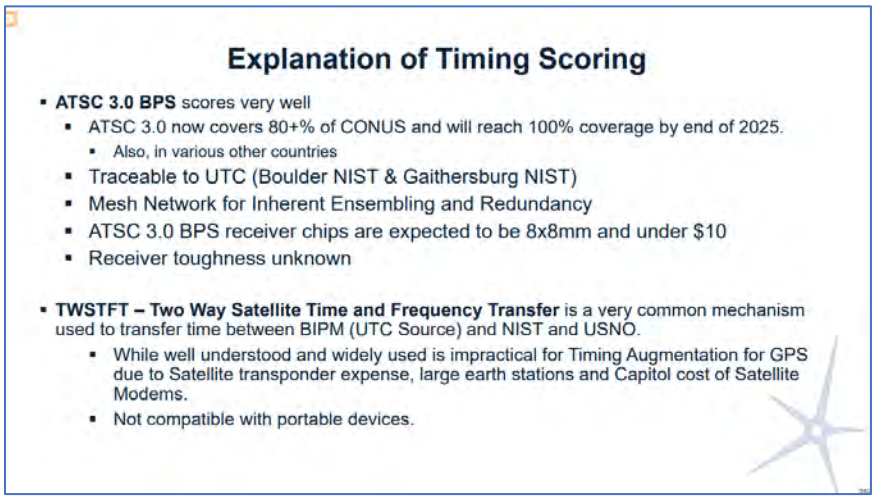


Slide 4

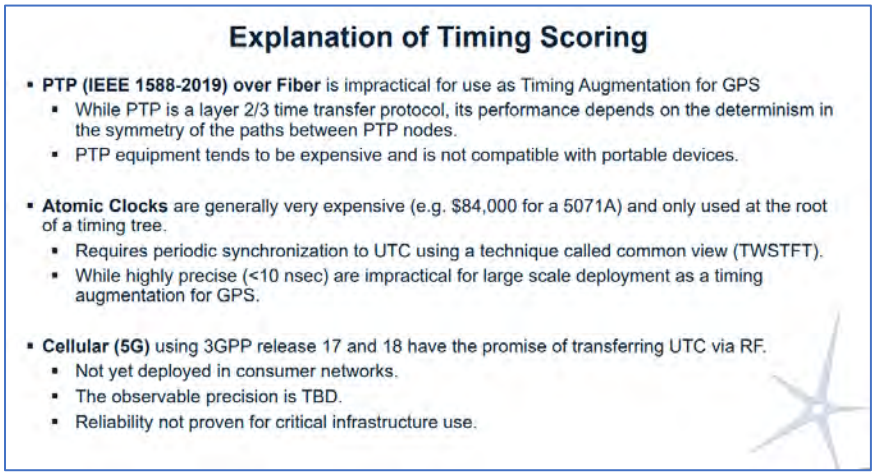
Slides 5-8 show how the team got to the assessment in Slide 4.

As depicted in Slide 5, ATSC scores very well. They're not doing this out of the goodness of their heart, but because they want to preserve their spectrum and provide public use of their television spectrum. This is currently under construction and testing. They expect 100% coverage by the end of 2025. They're not using GPS time as a source. Their source is traceable to NIST in Boulder (CO) and Gaithersburg (MD). A mesh network is enabled by use of very tall towers. There are about 200 million receivers deployed in India, which enables them to see aerial TV on their cellphones. The receiver toughness is unknown as the receivers are still under test. Moving on to TWSTFT (Two Way Satellite Time and Frequency Transfer), it is a very accurate system but requires a non-very portable high-gain antenna pointed up at a satellite. Also, this is a time transfer system, so it is only as accurate as accurate as whatever your timing source is.

Slide 6 provides an explanation for the scoring of PTP over Fiber, Atomic Clocks, and Cellular. PTP is a protocol, and if you put it over fiber, it provides very good accuracies. The cellular industry seems to be moving towards this. This is a time transfer protocol, and many times the source is GPS. Atomic clocks can be very expensive. Cesium Clocks have a fairly limited time life. Rubidium clocks typically last longer. Also, atomic clocks need to be synchronized to something, either by something like TWSTFT or Locata. These clocks, while very precise, are impractical for large scale deployment. Finally, Cellular gets its time from various sources, but within the 3GPP specification releases 17 & 18 it appears they can provide time to other devices too. But, again, this brings us back to the issue of traceability.



Slide 5



Slide 6

Slide 7 provides an explanation for the scoring of Secure Network Time Protocol (NTP), Galileo (GNSS), and Iridium / Satelles. NTP provides time over the internet and provides millisecond accuracy (over fiber it is more precise). Just about every computer gets its time this way. However, NTP can be subject to delays over the internet and there is also a question whether the path is symmetric. Galileo E1 & E5 signals (but not the E6 signals) are approved in the U.S. While Galileo is one of the best complementary systems for GPS, there are common vulnerabilities with GPS since they are similar systems. Iridium is an operational system consisting of 66 satellites orbiting at about 670 km altitude, so typically 1-2 satellites will be in view. If the user knows where he is, the time transfer accuracy is about 50 nanoseconds relative to UTC (Coordinated Universal Time). Iridium does not have any GPS dependency. The catch is that if you are a user, you must pay for it. There are also some questions as to the receiver toughness given then narrow band of the signal, but the signal is also much stronger than GPS.

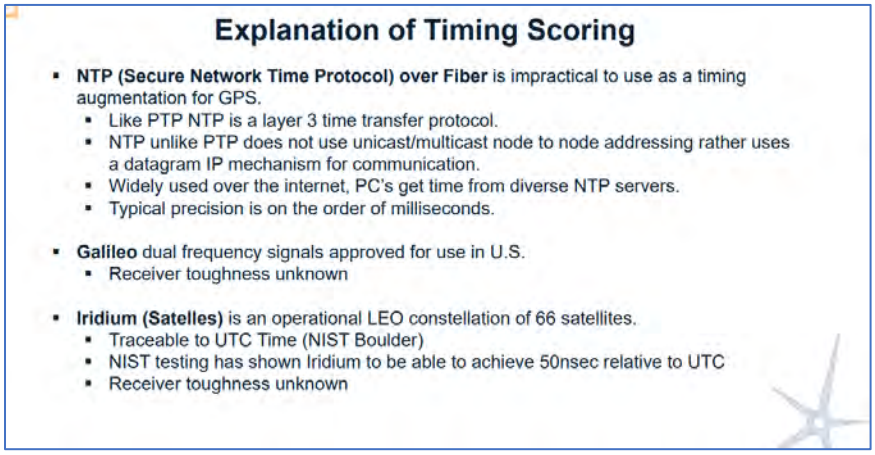
Slide 8 discusses Locata, eLoran, NextNav, and Phasorlabs. Locata provides time transfer capabilities, and in JRC (European testing) demonstrated 1.7 nanosecond time transfer accuracy at 105 km. For eLoran, the core issue is the time to deployment. However, its timing accuracy is pretty good providing you know where you are. NextNav has demonstrated high precision time transfer (about 20 nanoseconds), but it operates in the 909-928 MHz band (Industrial, Scientific, and Medical) band and requires many beacons. Finally, PhasorLabs has achieved very good performance during testing. It is essentially a mesh network operating in the 2.4 GHz ISM band. Its main drawback, in Mr. Scott's view, is that it is basically at TRL 6-7.

Mr. Goward noted, regarding the 2nd bullet under eLoran, that in its day Loran-C served all over Alaska.

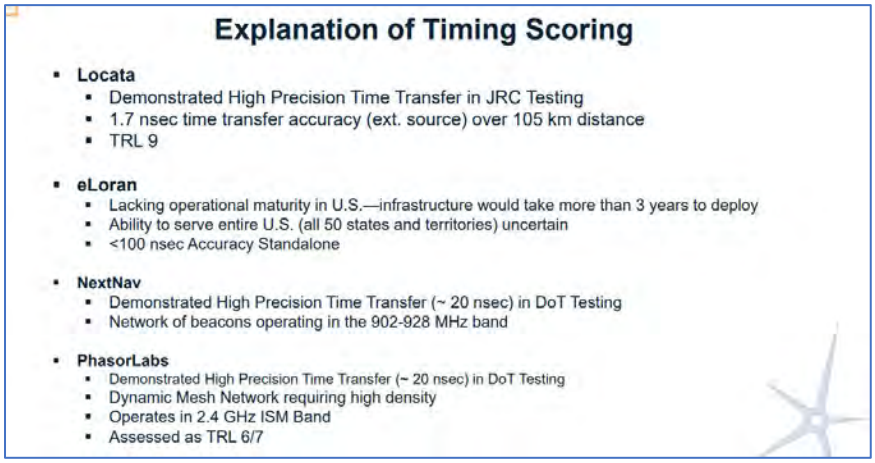
Mr. Scott agreed and added that these viewgraphs are updated.

Mr. Goward asked if this analysis includes maritime coverage.

Mr. Scott said no. The analysis was done strictly for time.



Slide 7



Slide 8

Discussion:

Mr. Goward noted that to put eLoran up to provide timing coverage, one would only need a fraction of the towers and, therefore, could be deployed in less than three years. The deployment of eLoran could be as easy as AM towers, which is something being done all the time.

Mr. Scott agreed, and noted this was just a preliminary analysis. He added that cellular networks used to use eLoran as their primary timing source.

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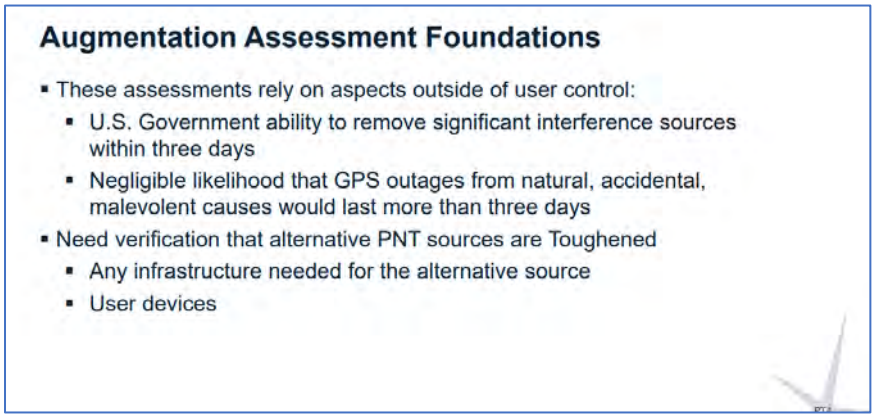
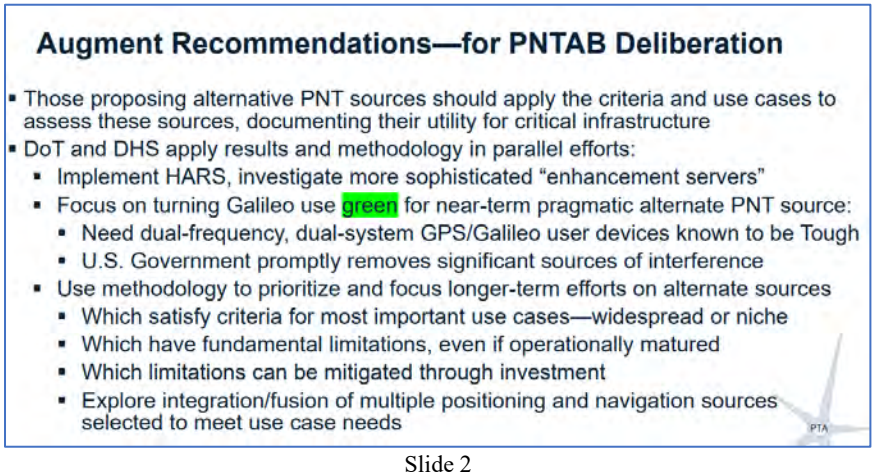
Augment Summary
Dr. John Betz, Chair, *PTA Subcommittee*

Dr. Betz noted he would be providing a wrap-up for the discussion on augmentations (Slides 1-2). To recap, several assumptions were made for this analysis (Slide 1). This included an assumption that either the USG would be able to remove the interference source within three day or a negligible likelihood of the interference lasting longer than three days. There is also some uncertainty whether the receivers, or infrastructure behind it, was "tough" enough. Another focus was on a sense of urgency to deploy such alternative PNT sources and what the nation could potentially do within three years.

Slide 2 includes some recommendations for deliberation. The criteria could be useful in other analyses. Only one example has been conducted and with incomplete information. A more thorough analysis is required. When someone comes up with a new potential technology, they should consider these use cases and evaluation criteria and provide their own scoring. DOT and DHS could also benefit from this type of structure to: (1) implement GPS HARS, (2) turn the use of Galileo to "green", and (3) prioritize long term (over three years) efforts, including exploring the integration/fusion of multiple PNT sources.



Slide 1



Slide 2

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Discussion on Augment Theme
All Members

Mr. Goward asked that the board talk more about the assumption about three-day resolving. The USG didn't have to do anything at the Dallas interference event since that was a 24-hour event with its effects resolved within 48 hours. What was the rationale for using a three-day threshold instead of, say, two days or less?

Dr. Betz agreed that the three-day threshold was quite gentle. In fact, the Board has recommended a USG commitment to remove any significant source of interference within one day. However, the three-day threshold reflects additional time to resolve cyber issues at the ground level. It was a guess since the Board does not have guidance from the USG on what kinds of GPS outages should be expected. That was another recommendation the Board has made to remove that uncertainty.

Lt Gen Hamel wondered if there is another dimension that should be considered, which is having a consolidated number and import of users out there. Not everyone would need as backup the same level of precision provided by GPS. Do we have any sense of the user population and how they map against critical infrastructure?

Dr. Betz said that when the use cases were defined, the subcommittee tried to span the space of different kinds of needs rather than focusing on the number of users. The idea was to let others decide on which user group to focus on. In fact, even within a specific user group, such as precision agriculture, the economic impact would be much higher during prime planting (or harvesting) season compared to the middle of winter.

Mr. Madani noted that when recommending to "turning to Green" the use of Galileo, the Board should not lose sight of the fact that there are ways this can be corrected on the user side rather than the USG. Currently, in the energy sector most of the receivers in use cannot support dual GPS-Galileo use. There is further work needed in terms of risk assessments for these users to convince them to make the expenditure to upgrade their receivers.

Dr. Betz suggested being even broader than that. Adopting any one of these alternate PNT sources will require a user investment to integrate these into their existing systems. This is why the subcommittee has focused on what gives the biggest "bang for the buck" and soonest.

Mr. Higgins said that regarding the number and importance of users affected, in places like Australia where the infrastructure is highly networked, sprinkling a few clocks across this network would not provide a good backup. Many of these users, including defense users, need a high precision timing backup across large areas. And, when doing this, we're back to finding out that the best way to do this is from space.

Mr. Burns said that most aerial drone operators have rapidly adopted multi-GNSS, in part due to it being simple and there being no regulations for small drones anyways. Also, when it comes to precision navigation, they are not relying on GNSS and, instead, use alternative forms of navigation (whether optical, lidar, or other method). For drones en-route, one meter precision is sufficient.

Dr. Betz added that there are technologies the subcommittee did not look at, such as those mentioned by Mr. Burns. In the case of drones, yes, one could probably just cross that use case as already having met is critical needs.

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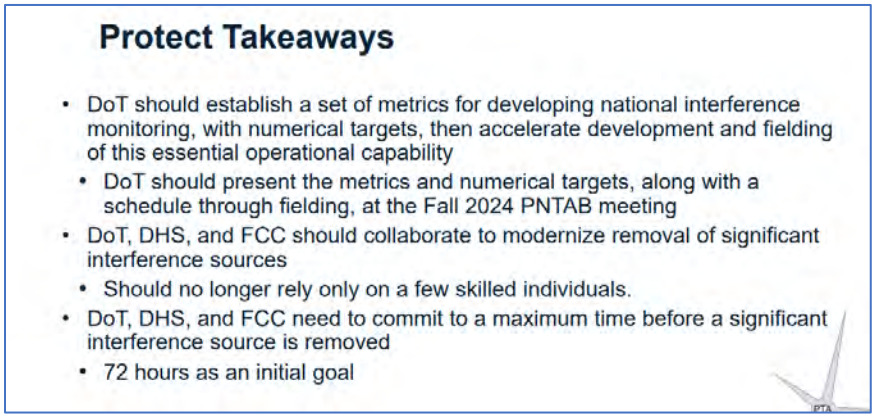
PTA Way Ahead Summary
Dr. John Betz, Chair, *PTA Subcommittee*

1) Protect Takeaways (Slide 1)

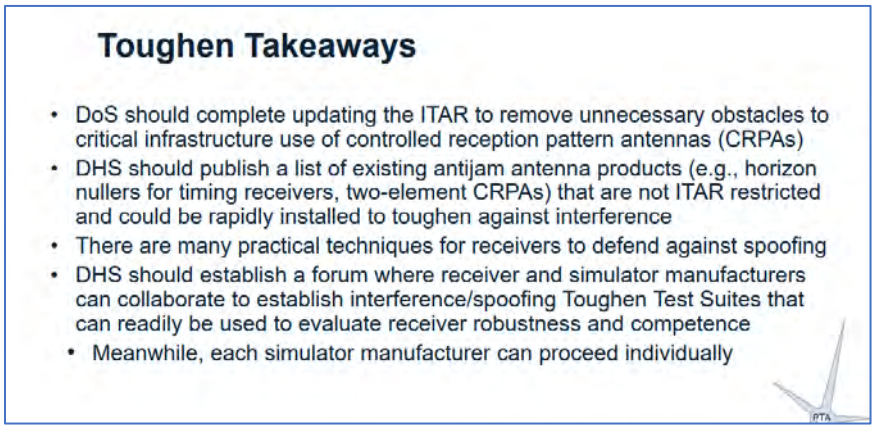
Slide 1 describes a set of key takeaways on "Protect" for the Board to consider. First, DOT should perhaps establish a set of metrics such as those outlined by Dr. Powell for developing national interference monitoring capability similar to what they've started to assemble, and have numerical targets so people understand what DOT is trying to accomplish. Once this is done, DOT should accelerate its development and fielding as an essential operational capability. The Board would be very eager to hear at its next meeting about these metrics, numerical targets, and a schedule for fielding. Second, DOT, DHS, and the FCC should collaborate on the removal of significant interference sources and think about how to modernize that for the 21st century so that it doesn't rely more than it should on a few skilled individuals. Third, there is an opportunity for DOT, DHS, and FCC to commit to a maximum time before a significant interference source is removed. The three-day time presented by the board was just an initial goal. Dr. Betz would be more than happy to go back to the 24-hour period the Board has recommended in the past.



Slide 1

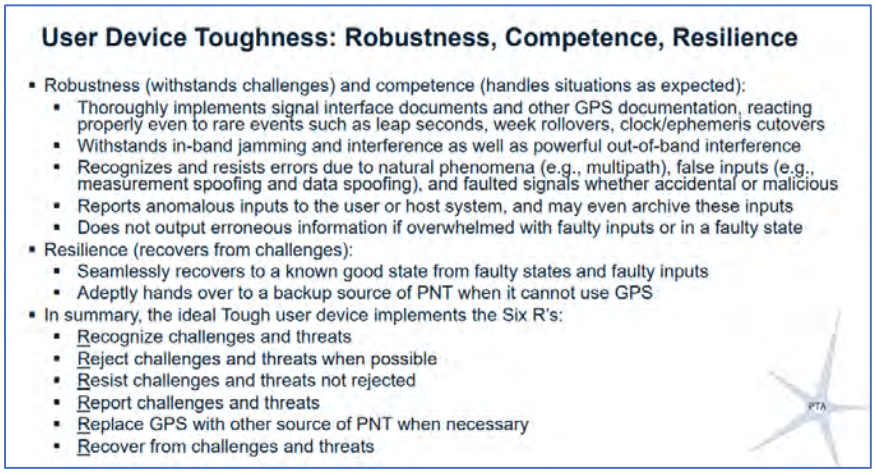
2) Toughen Takeaways (Slides 2-5)

As shown on Slide 2, regarding updating ITAR, the Board is eager to hear what the on-going changes are. The Board also believes there are existing anti-jam antennas that could provide some benefit and don't fall under current ITAR restrictions. It would be very useful if DHS were to assemble such a list so that it could be publicized for owners/operators. This might be two-element antennas that could take out as few as a single jammer. The Board also heard some highly technical talks from Dr. Akos and Mr. Scott on defending against spoofing. A lot of the things we hear in the press talk about spoofing as some mystical unbeatable goblin that is going to eat up GPS receivers. However, we've seen there are many practical techniques to defend against spoofing attacks, and they just need to be implemented. The Board also believes DHS should establish a forum where receiver and simulator manufacturers can collaborate to establish some Toughen Test Suites that can be part of what simulator manufacturers sell and that receiver manufacturers could use to report their scores on. Each simulator manufacturer could proceed individually. Finally, though not mentioned in this slide, GPS L5 should be made useful as soon as possible.



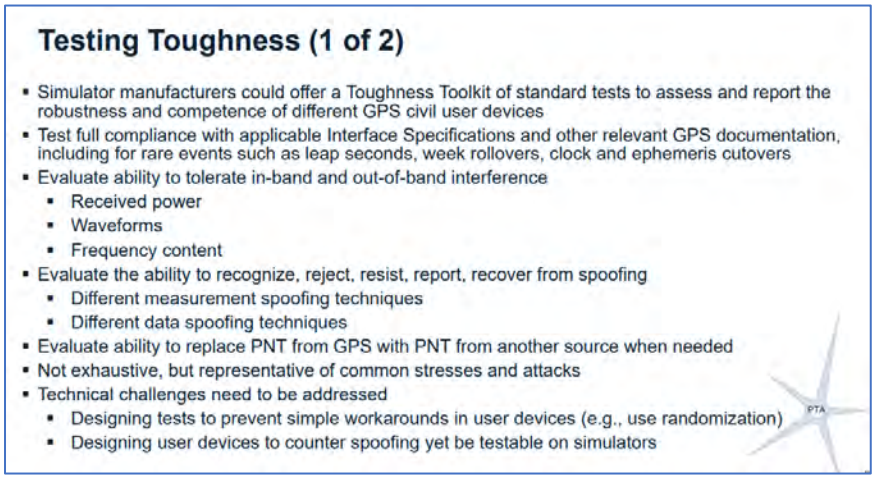
Slide 2

Slide 3 describes a few more thoughts on toughness. Sometimes we worry so much about alternative sources of PNT that we forget about the opportunity to make GPS receivers far tougher. Toughness is a combination of robustness, competence, and resilience. Robustness means it can take challenges and keep working. Competence means it handles situation the way you would expect and avoid situations such as the example we heard about 100 ships reporting they were at Beirut Airport. This includes things such as: (1) thoroughly implements signal interface documents and other GPS documentation, reacting properly even to rare events such as leap seconds, week rollovers, clock/ephemeris cutovers; (2) withstanding in-band jamming and interference as well as powerful out-of-band interference; (3) recognizing and resisting errors due to natural phenomena, false inputs, and faulted signals whether accidental or malicious; (4) reporting anomalous inputs to the user or host system, and even archiving these inputs; (5) not outputting bad information but outputting no information with a warning flag. Resilience is seamlessly recovering to a known good state when something bad is happening and then handing it over to a backup source of PNT. A simple way to think about all this (robustness, competence, and resilience) are the six R's: recognizing problems, rejecting problems, resisting problems when you can't reject them, reporting them, replacing GPS with other sources when you need to, and recovering back to your known state. So, if we find a receiver with these six R's we'll know we're in great shape.



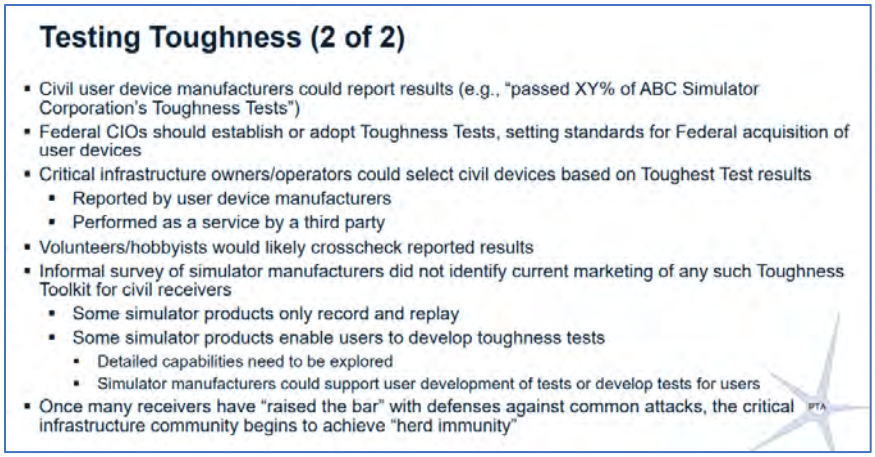
Slide 3

Slides 4-5 provide some ideas on how to find receivers that have these six R's. As shown on Slide 4, the suggestion is to expand on what we discussed in a previous slide on why simulator manufacturers don't offer a "Toughness Toolkit" that stresses receivers with common interference and spoofing tests. These need not be the most exotic, but rather be the standard things that receivers are likely to see. Certainly, they should: (1) Test full compliance with the ICDs; (2) Evaluate the ability to tolerate in-band and out-of-band interference with different power levels, waveforms, and frequency content; (3) Evaluate the ability to recognize, reject, resist, report, recover from spoofing, including both measurements and data spoofing; and (4) Evaluate ability to gracefully hand over to another PNT source when needed instead of corrupting that other source. There are some technical challenges that have been talked about earlier today including designing test tests to prevent simple workarounds in user devices (e.g., use randomization), and designing user devices to counter spoofing yet still be testable on simulators.



Slide 4

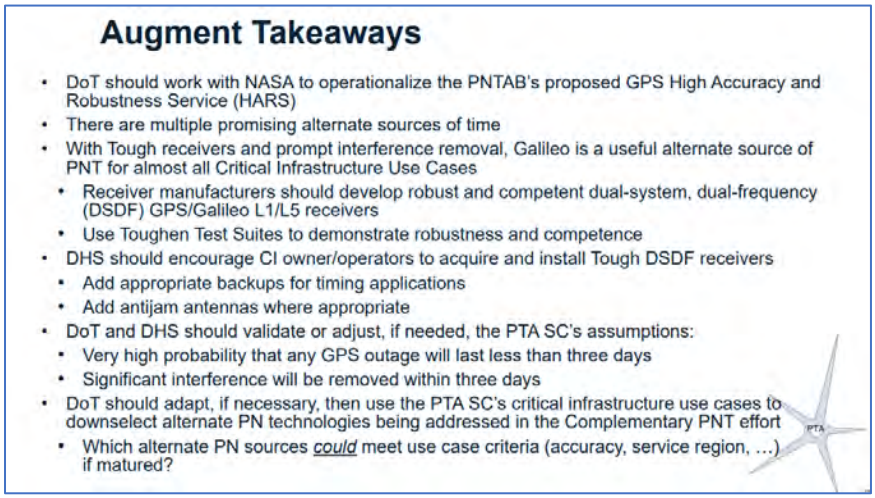
As discussed on Slide 5, if we had such toughness toolkits from simulator manufacturers, then a civil user device manufacturer could report results. Now we start to have an idea of the toughness of these devices without having to go through certification or licensing. Federal Chief Information Officers (CIOs) should establish or adopt Toughness Tests, setting standards for Federal acquisition of user devices. This will, in turn, encourage manufacturers to report that they are compliant with such standards. Over the past few months an informal survey was conducted of simulator manufacturers and several of them said they had the capability to do that but didn't see a market for it. Perhaps this could be turned into a "virtuous cycle" where demand could be stimulated by publicity from the Board. While this approach is not perfect, once many receivers have "raised the bar" with defenses against common attacks then we'll have accomplished something worthwhile.



Slide 5

3) Augment Takeaways (Slide 6)

Slide 6 summarizes some of the augment takeaways. Dr. Betz noted that the topic of GPS HARS has been discussed many times today, so he won't bring it up again. If we have tough receivers then Galileo is a useful alternative source to GPS for critical infrastructure, particularly if we have DSDF receivers. Also, DHS should be encouraging owners/operators to install these receivers with appropriate backups and antijam antennas. Finally, there is an opportunity to revisit what the subcommittee has done over the past few months and adjust/validate its assumptions and use cases. The methodology that has been presented could become an important tool to help down select alternate technologies.



Slide 6

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Member Deliberations
All Members, led by the Chair

Dr. Parkinson thanked Dr. Betz, and noted he particularly liked the takeaways on testing GPS/GNSS receivers for toughness. The next step is figuring out how to incentivize both simulator and receiver manufacturers to embark upon doing that.

Dr. Betz suggested that the Board begin by publicizing this idea, and maybe talking to individuals at these companies, to see if they are interested in this. Many of the simulator manufacturers already have the technology to do this, so it's a question of them adding such "Toughness Toolkit" capability in their marketing to users.

Dr. Parkinson wondered if there is an opportunity for the Board to write papers for technical magazines, such as GPS World and Inside GNSS, that would highlight what the Board found and entice them since this is something that affects their bottom line. This could probably also include technical magazines about aerial (and other) unmanned systems.

Dr. Walter noted that RTCA (formerly known as the Radio Technical Commission for Aeronautics) has also been developing a set of scenarios that can be used to test receivers for resilience. This work has been on-going for a couple of years. It has been a challenging task to identify sufficient scenarios. Another issue is that because these are open standards, our adversaries also know what manufacturers and users have tested against. Dr. Walter has been working with the RTCA, and they would certainly welcome more participation.

Dr. Parkinson commented that it would be useful for the board if Dr. Walter and/or Mr. Tim Murphy could arrange for RTCA to send some to the next Board meeting and brief on these issues. Perhaps the USG can make some suggestions to RTCA.

Mr. Murphy said that the USG can ask RTCA to write standards. The USG just can't direct them to do so like it used to. The big change after RTCA lost its FACA status is that industry can now pursue things that the FAA would not have supported in the past. This also means that RTCA can't do MOPS anymore, nor other documents that will not be supported by the FAA. Folks the Board knows, such as Mr. Bruce DeCleene and Dr. Chris Hegarty, are part of the RTCA Advisory Committee.

Dr. Parkinson asked Mr. Murphy to ask Mr. Bruce DeCleene, Dr. Chris Hegarty, or someone else to come talk to the Board. The Board could set up a three-hour slot with the PTA Subcommittee during the Prep. Day, and perhaps also have a summary during the FACA days.

Mr. Murphy said it is possible.

Mr. Goward encouraged everybody not to forget the maritime aspect, including the deployment of offshore wind farms, such as is already happening on a large scale in Europe.

Dr. Betz agreed on the importance of including the maritime aspect, and pointed out that three of the fifteen use cases developed by the PTA subcommittee are maritime. However, he acknowledged that the use cases did not consider fixed maritime such as offshore wind farms anchored to the sea floor.

Dr. Parkinson asked Board members if they feel there are any recommendations missing from the takeaway briefing that Dr. Betz just presented.

Mr. Goward asked that the specific wording for these recommendations be provided to the Board for review.

Dr. Parkinson agreed.

Lt Gen Hamel noted that these were takeaways and need to be translated into formal recommendations. Board members could have differences of views that need to be ventilated before the Board's discussion on the following day.

Dr. Betz expressed concern about adding more recommendations to the Board's stack given the responses it has gotten from the USG so far. For most of the takeaways that have been discussed (except the discussion on setting L5 to healthy), working with technical magazines might be more effective when reaching out to industry compared to submitting a formal recommendation to the USG.

Mr. Scott noted that a missing aspect is that of cyber. Just about every computer in the room has a trusted platform module that provides low level primitives for testing of the identity of the computer for signing documents, etc. When using GPS to determine position and then forwarding that to someone else, there are many opportunities for man-in-the-middle attacks. This is why the cyber aspect is also part of securing PNT in critical infrastructure applications.

Dr. Parkinson said that's an interesting observation. The challenge is that the Board's "in jar" is full, so the Board needs to prioritize which recommendations it wants to bring forth. The Board also needs to decide whether it wants to reiterate previous recommendations it has submitted to the PNT EXCOM.

Dr. Betz agreed with Dr. Parkinson's concern about reiterating recommendations. The Board has received responses from the PNT ESG to its recommendations, so at this point it would also need to say which responses the Board didn't like.

Mr. Murphy asked if the Board needs to modify a recommendation in response to the response.

Dr. Parkinson asked if the Board needs to go back and prioritize the recommendations it has already submitted. This could include both the recommendations that have been implemented as well as those still being worked on.

Mr. Goward noted there seems to be consensus in the Board about asking the USG to accelerate the implementation of its recommendations. For example, it appears the Board has a good technical recommendation in asking the USG to accelerate the implementation of GPS L5. On the other end, in terms of the Board's strategic recommendations (whole-of-government approach, PNT governance, etc.), those are a bit of reiteration of the Board's recommendation on celebrating the GPS 50th anniversary and recommitting to it. There was a lot in that recommendation and, perhaps, now needs to be more specific. Perhaps the Board can make an observation to the effect that the U.S. is losing the PNT race to other nations and, therefore, a whole-of-government effort is needed but a good PNT governance is needed to get there.

Dr. Parkinson said that perhaps the Board should also tack on the recommendation on ITAR. The Board has not yet seen the results of the USG review of ITAR as discussed at the PNTAB 29th meeting. If we include this recommendation, along with GPS L5 and PNT governance it would bring the total number of recommendations up to three.

Prof. Moore noted that the idea of looking at the recommendations that have been submitted, and the response to those, is what the EDI Subcommittee has done. It acknowledged the response, and then said what would need to be additionally done.

Dr. Parkinson said he thought that was a good way to do it.

Lt Gen Hamel noted that, as ADM Allen has stated, the Board needs a crisp statement that can be included in updated memorandum to the Deputy Secretaries.

Dr. Betz said he's been thinking about the PNT Governance recommendation. This recommendation is needed, but if we look at where we stand in the calendar (and the upcoming U.S. election in Nov. 2024), there will be a change in administration come January. The question for the Board is whether this is the right thing to do in an outgoing administration or is it better to save this and make it part of the welcome to the new administration.

Hon. J. Shane suggested that we treat this administration as "receptive" to the best recommendations the Board can provide. These recommendations could, at least, help trigger a conversation on the topic regardless of whether the administration changes or not.

Dr. Parkinson said it appears we have three recommendations on the table: GPS L5, PNT Governance, and ITAR.

Dr. Betz asked if GPS HARS would be added to the list.

Lt Gen Hamel noted that one of the things coming out of all this is that we are starting to see an intersection of all these issues. Including issues such as GPS HARS, or even the idea of more use of Galileo, add emphasis to the overall importance of PNT.

Dr. Betz agreed and suggested presenting this issue as one of toughened dual-constellation dual-frequency receivers.

Lt Gen Hamel noted that we should also add "with our friends and allies" to such recommendation.

Dr. Parkinson said it appears we have the following recommendations: GPS L5, governance ITAR, GPS HARS, and dual-constellation dual-frequency receivers. What else should be included?

Dr. Betz noted that DHS and DOT advocate the rapid adoption of dual-constellation dual-frequency receivers across critical infrastructure.

Dr. Parkinson said he believed the Board could reach consensus on the use of GPS and Galileo, but not other GNSS (either GLONASS or BeiDou).

Lt Gen Hamel suggested including what the finding/conclusion was about a topic within a recommendation. This creates a supporting rationale for what the Board is trying to achieve.

Dr. Parkinson said the consensus seems to be that we recommend encouraging dual-system dual-frequency receivers (specifically GPS and an ally [Galileo]), while recognizing that at least one manufacturer is already producing receivers that can track all GNSS signals. We can also list what the Board's five priorities are and couch them with language to emphasize our sense of priority. These include GPS L5, PNT Governance, reiterating ITAR, GPS HARS, and dual-system receivers.

Prof. Moore noted there was an agreement earlier to refine the recommendation on education.

Dr. Parkinson said everyone agrees with that recommendation. The issue is whether adding them makes it more or less likely for the USG to address the other five.

Dr. Betz wondered if the Board should think about a parallel way to communicating besides submitting recommendations to the PNT EXCOM, and whether the Board should take on establishing a communication channel with technical magazines and the public. This would enable us to communicate all these issues with the public. This is something that could perhaps be worked on by the CER Subcommittee.

Mr. Goward suggested perhaps having a memorandum to the DepSecs describing the overarching concerns and, in parallel, also sending a separate more detailed list to the ESG and others.

Dr. Parkinson said we can take a shot at developing such dual list.

Mr. Shields noted that the recommendation on education is the kind of thing that should go to a publication, not the USG. Also, the board should consider bringing the recommendations to the DepSecs down to just two or three.

Mr. Scott suggested that the Board include the recommendation on a National Interference, Detection, and Mitigation System.

Mr. Miller noted that he has spoken with Mr. Chirag Parikh (Executive Secretary, National Space Council) and, because Space Policy Directive 7 (SPD-7) is under the purview of the National Space Council, Mr. Parikh has offered to bring the Board's leadership into USG discussions regarding updates to U.S. PNT Policy.

Hon. Shane said that, looking at the Board's Charter, he doesn't see a duty to write articles for publication in the media. The Board should be cautious about writing beyond what it is expected to do.

Mr. Miller responded that, unless the Board is prohibited, it can send articles within reasonably restrictions.

Hon. Shane said he believes it should be fine for the Board to write articles to amplify recommendations that have already been submitted and are on public record.

Dr. Parkinson suggested that the Board focus on the key five recommendations, and work on flushing out the wording and rationale.

Lt Gen Hamel noted that the recommendation on establishing a National IDM capability should include wording on designating a USG official to be responsible for its implementation.

Ms. VanDyke noted that SPD-7 already designates DOT to lead such effort. A workshop is going on this week at MITRE to pull together on-going efforts into an initial operating capability.

Dr. Parkinson asked Lt Gen Hamel to work on flushing out the recommendation on establishing a National IDM capability.

Ms. VanDyke said she would be happy to provide an update at the next meeting.

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Session of Thursday, April 25, 2024

PNTAB Leadership Observations from Day 1

Dr. Parkinson stated that he thought yesterday was a very productive day. However, we need to be cautious and remind everyone that findings are not official in any way until the Board has agreed to them. He would be giving a preliminary talk about comparisons of GNSS. There have been some issues that have come up. Dr. Betz would comment on those issues, and then we have some opportunities to further clarify some things.

Dr. Betz stated that, regarding the work the subcommittee has done, particularly on augment, all those results were labeled draft. They're the result of an initial assessment. They have not been adopted or validated by the Board at this point. They are initial and draft. There is an opportunity for people to provide additional input if there's information that we missed in doing that evaluation, but we would suggest that you look carefully at the criteria that we employed to do those initial assessments. If there are some candidate systems that would not consider themselves suited for some of the use cases and prefer not to be evaluated for those use cases, we'd be happy to remove those evaluations as well. We view this as the beginning of a conversation, not the end of a conversation. We'll probably set something up where people can submit any comments or additional information, and then the PTA Subcommittee will take that information into account.

Mr. Miller thanked Dr. Betz and Dr. Parkinson. This is our 32nd in 17 years, and we've always strived to allow not only our members but also the public, the stakeholders to also provide input. That's very important to cast that net as wide as possible. The Board's website has an email address where the public provide feedback. If there are some charts or some things put out there that the public would like more of a say in, we would like that feedback because we can go beyond what we have already presented and posted and solicit feedback so that at the next meeting we'll be prepared to go through and see where we are in terms of our public feedback. We're certainly not working in a vacuum. It remains very important for us to make sure that we're representing users as a whole.

Ms. Van Dyke thanked Mr. Miller and stated that DOT and all involved in CPNT, are embracing commercial PNT technologies to have PNT resiliency. It's important to recognize some of the challenges that these companies are facing. DOT held an industry roundtable a couple of years ago, and one of the big challenges is the fact that GPS is provided without any service fees within the United States. So, that's a big hurdle to overcome with private companies. Some of these companies are publicly traded, and there are a lot of concerns from what was presented yesterday. DOT is trying to ensure that we do have a diversity of PNT technologies, both space-based and terrestrial, and particularly that these commercial technologies are successful for our collective goal in having PNT resiliency. There's no one size fits all, so we're looking forward to DOT setting up our CPNT test ranges, to evaluate technologies, and better understand the services that they can provide. We just ask the Board to keep in mind some of the challenges that these companies are facing and the fact that they depend on investments, and that some of them are publicly traded.

Dr. Parkinson stated that it is unfair to evaluate certain providers based on something they never claimed that we wanted to do. We must be cautious in throwing use cases out there that were never suggested to be used. We're going to cast a wide net in getting opinions, comments, and criticisms because that's where this Board should be.

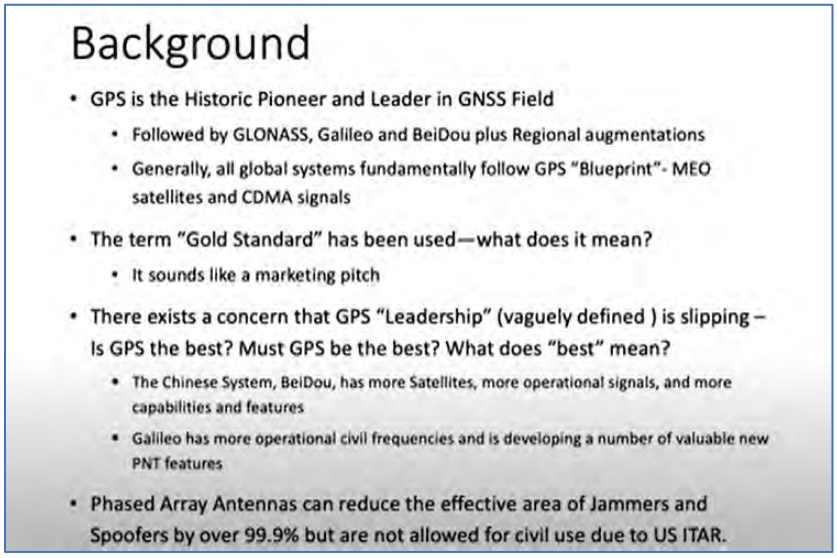
Mr. Goward stated that he received some immediate feedback last night and this morning, almost exclusively from terrestrial companies. Some of the companies are reluctant to send an email or be identified. They see this as the "Space-based" PNT Advisory Board, and they see a lot of space folks on the Board, but not very many terrestrial folks. They want to be as circumspect as possible while at the same time expressing their concern. This is something that the Board needs to keep in mind as we think about whether "space-based" needs to stay in our name.

Dr. Parkinson said that the other item of business is to go back and revisit those six recommendations that we came up with. There was a creative suggestion: maybe we could cram them all into one. Although that may not work, maybe we can combine some of them.

Theme 4: Comparing Satnav Capabilities

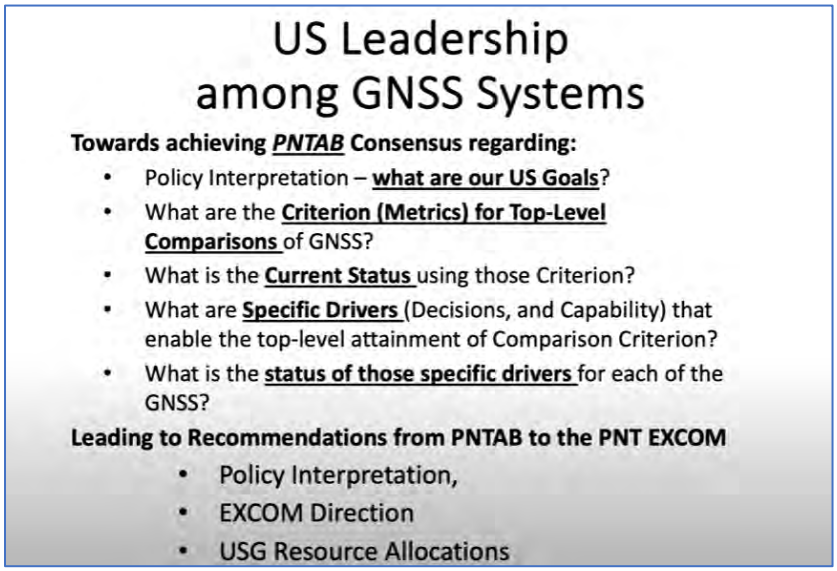
Discussion Comparing Capabilities of Different Satellite-Based Navigation and Timing Systems
Dr. Brad Parkinson, *1st Vice Chair, PNTAB*

Dr. Parkinson noted his briefing would cover the topic of U.S. leadership. This briefing should be considered as a DRAFT intended to elicit feedback from Board members. GPS is the historic pioneer leader, which was then followed by other global and regional systems. They all follow the same fundamental blueprint (Slide 1). We have heard many times the term "Gold Standard," and have also heard a lot of push back on it. Some have called it a "marketing pitch". There is a concern that the GPS' leadership may be slipping. Must GPS be the "best", and what does "best" mean? Other systems have more satellites and more operational features. So, what can we do about that? We have not yet authorized the most effective countermeasures to interference, such as authorizing multi element phased array antennas for civil use.



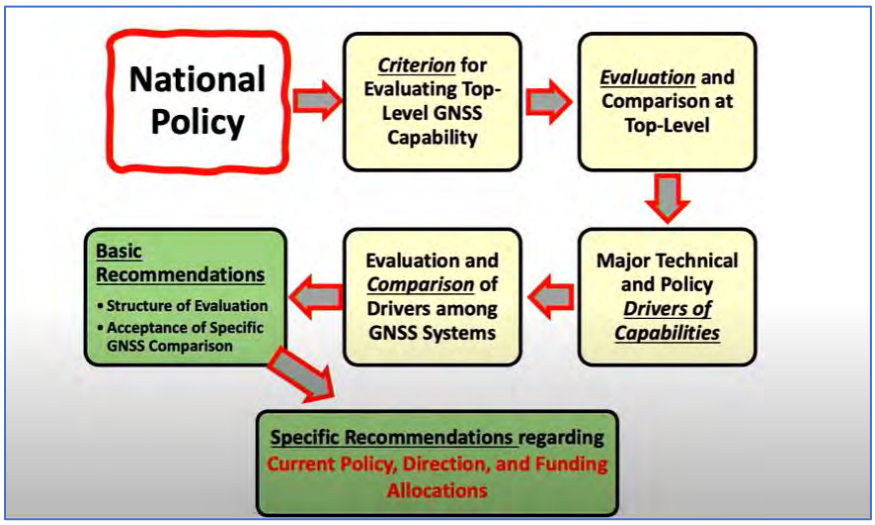
Slide 1

Our objective today is to get a consensus amongst the board to put together a structure in terms of: (1) policy level goals, (2) what are the metrics we could use to address this question of leadership, (3) what the status of GPS against these criteria, and (4) what are the specific drivers (features, etc.) for each GNSS (Slide 2). The intent is to eventually develop recommendations to the PNT EXCOM, including interpretation of U.S. PNT Policy, direction requested from the EXCOM, and then perhaps influencing U.S. Government resource allocations.



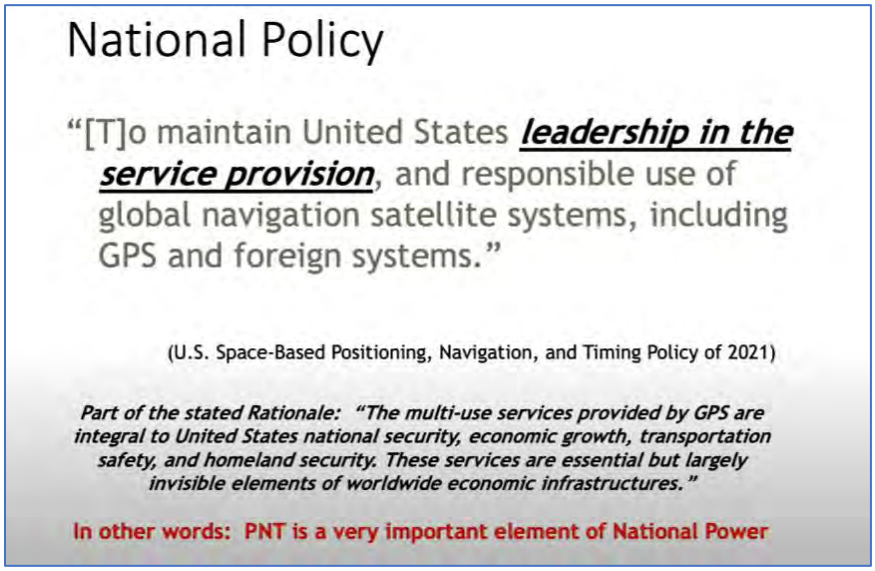
Slide 2

Slide 3 explains how this process would work. It begins with a statement of national policy, followed by criteria for evaluation, and then a top-level comparison among GNSS. As noted earlier, the criteria presented today are just an initial starting point for the board to develop them further. Then we come down to what are the technical and policy drivers for those capabilities, and then attempt an evaluation among the GNSS systems. This will lead to basic recommendations on the evaluation process followed by specific recommendations on what we should have as a goal and then the actions that could be taken.



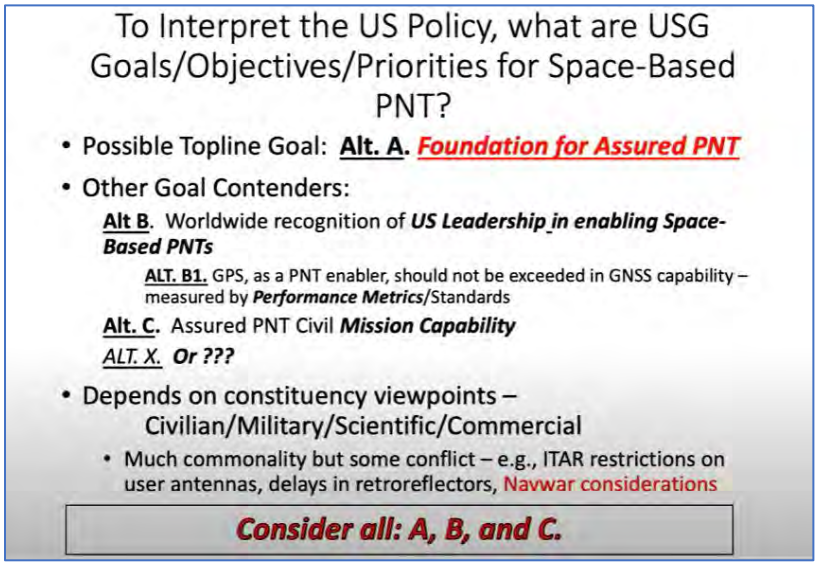
Slide 3

So, let's start with the statement of National Policy (Slide 4). Straight out SPD-7, we have a statement to maintain U.S. leadership and service provision, and responsible use of GNSS, including GPS and foreign systems. This is what we are trying to elaborate on. Within SPD-7 there is also a stated rationale that recognizes the importance of PNT as an element of National Power.



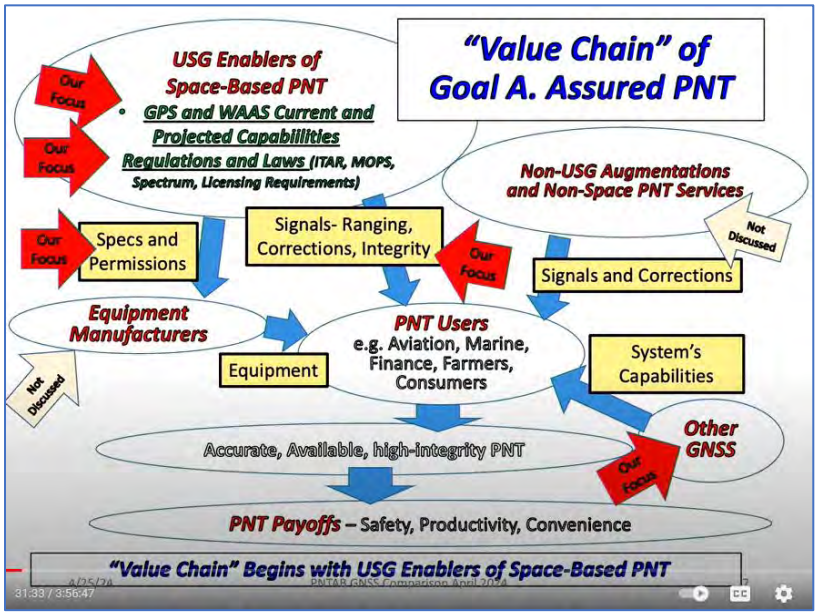
Slide 4

So, considering that policy, what should our goal be? (Slide 5). What does leadership mean? A number of alternatives are offered on this slide. One such goal (A) could be the foundation for assured PNT, but Dr. Parkinson find that a little vague. Another goal (B) could be worldwide recognition that GPS is the leader, which is a pretty strong statement. Or, perhaps, the goal (B1) could that GPS, as a PNT enabler, should not be exceeded by other GNSS capabilities. Another alternative for a goal (C) could be that of assured PNT civil mission capability. The latter is kind of like "A" [Foundation for Assured PNT], so perhaps the two could be combined. In Dr. Parkinson's view, the Board's goal should be a combination of all three options. An important point that has been made is whether you're achieving that or not will depend a lot on where you sit, whether civilian, military, scientific, or commercial. Dr. Parkinson asked the board to think about that.



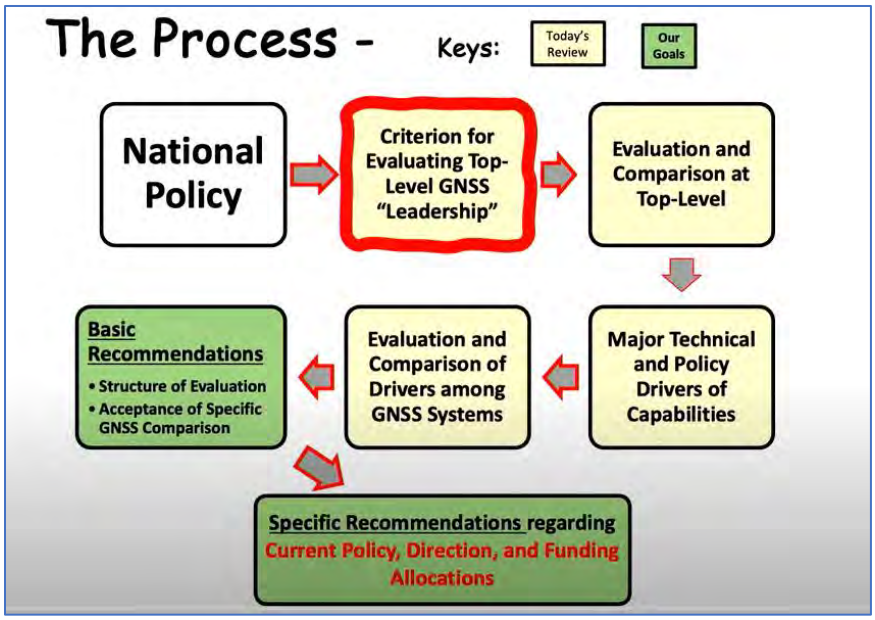
Slide 5

Slide 6 describes the "Value Chain" of the goal of Assured PNT (Goal "A"). The USG enablers of space-based PNT include GPS and WAAS, as well we regulations and laws. Then come the specifications and permissions, which go to the equipment manufacturers. In turn they produce equipment. We will not go into that level. On the other hand, we have the signals, corrections, and integrity, which we believe should be on the table as providers. Ultimately these are the drivers for accurate, available, and high-integrity PNT. Finally, we should include the other GNSS, which are also legitimately on the table. On the other hand, non-USG augmentations are also important, but that's not what we are not discussing here. Finally, it should be noted this analysis deliberately omits GLONASS as, in Dr. Parkinson's view, it is not a serious competitor.

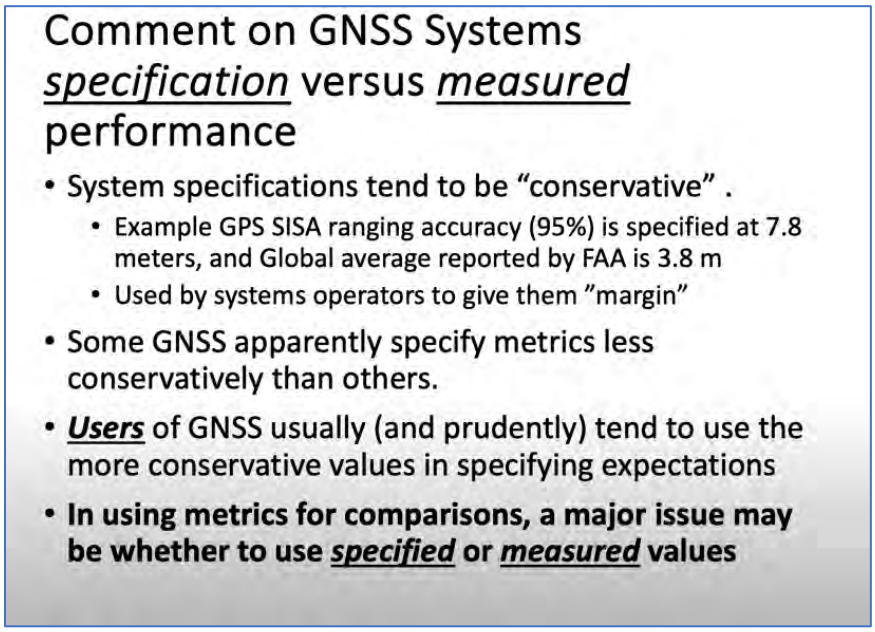


Slide 6

Next, let's move into the next box in our process, which is the potential criterion for evaluation the top-level leadership (Slide 7) and some comments (Slide 8). How are we going to evaluate this? System specifications tend to be conservative because people that are committing themselves to do something also want to give themselves some margin. One such example is GPS accuracy. We need to be very careful on what specific number we use when trying to quantify things.

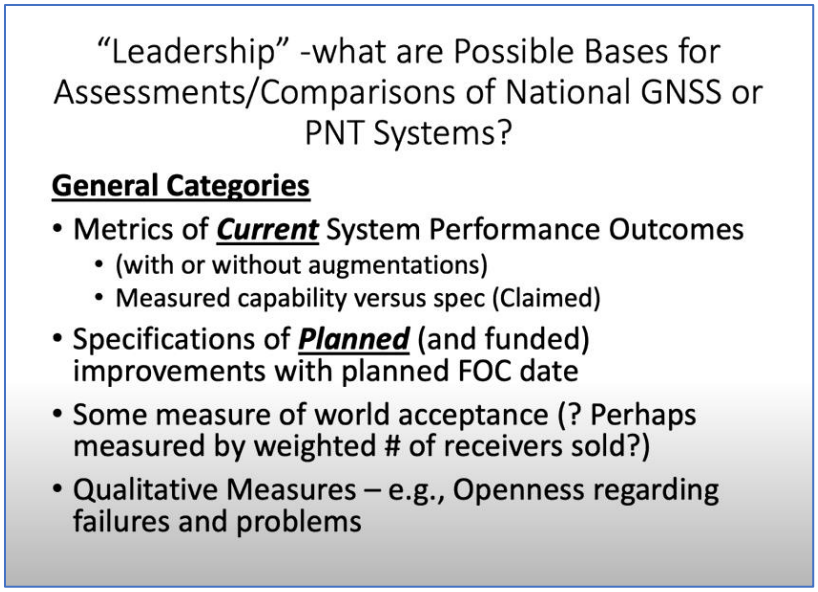


Slide 7



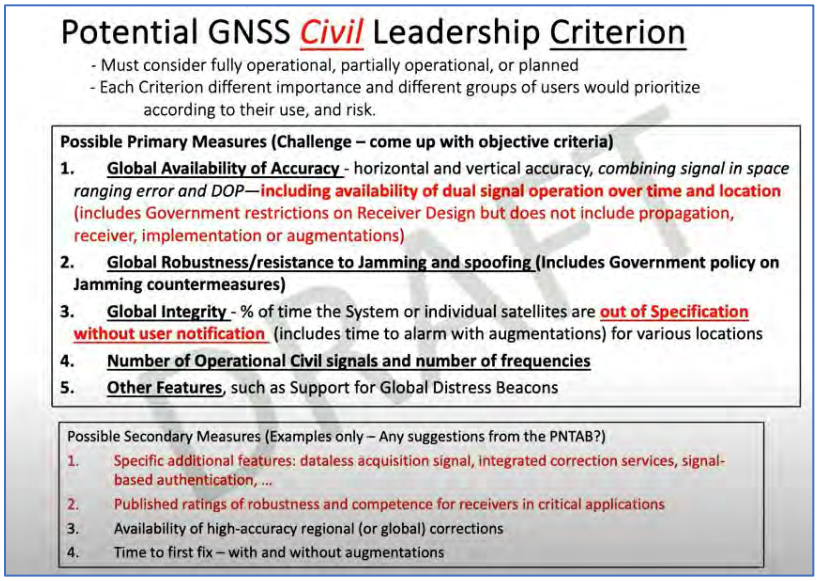
Slide 8

Next, what are the bases for these assessments (Slide 9). Are we going to use current system performance, or are we going to use planned capabilities? We must sort all that out. Also, if we want to have some measure of world acceptance, how do we measure that? We could try to count the number of receivers in use today, but then most receivers manufactured today can listen to almost everything. Then there are some qualitative measures that enter this discussion, such as openness when we have incidents with a GNSS and whether the provider is telling us what is happening and how it will be fixed. Some of the current GNSS providers have shown a less than satisfactory openness. We need to determine how to put this into the hopper.



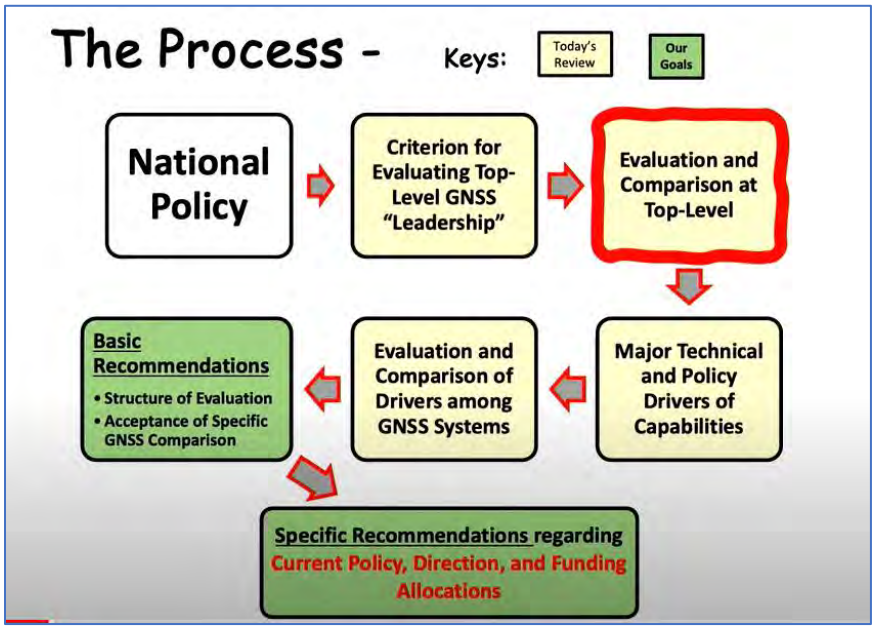
Slide 9

Let's look now at some possible criteria to assess GNSS civil leadership (Slide 10). Global availability of accuracy is one of the primary measures and, in Dr. Parkinson's opinion, should also include dual frequency operation. This should also include any restriction on receiver design or what the provider can give to the user. The second measure is global robustness and resistance to jamming and spoofing in terms of signal characteristics (spreading, etc.). Satellite power is also a major input to this. There are also measures a provider could take against spoofing. Apparently, Galileo has started putting authentication pieces into its signal. A consequence of that is that a user would be less susceptible to spoofing. The third measure could global integrity, measures when the system or individual satellites may be out of specification without notifying the user. This includes such things as "time to alarm". In the case of WAAS, the FAA's self-imposed limit is for notification within six seconds. The fourth measure is the number of operational civil signals and the number of frequencies. Finally, the fifth measure are other features such as, for example, support for global distress beacons. We have possible secondary measures as shown in the chart. This could include, for example, embedding the WAAS corrections within the GPS signals. The FAA is already doing this since the WAAS signals is also a ranging signal. This, of course, would raise questions on how it would be implemented, where the information comes form, and misdetection and false alarms. On the topic of published ratings of robustness, the board had a nice discussion on techniques that we may want to encourage. There is also the availability of high accuracy corrections, such as the board's proposals for GPS HARS. Another classic parameter is the time to first fix, which is often in the hands of the designer but nonetheless could be a contender.

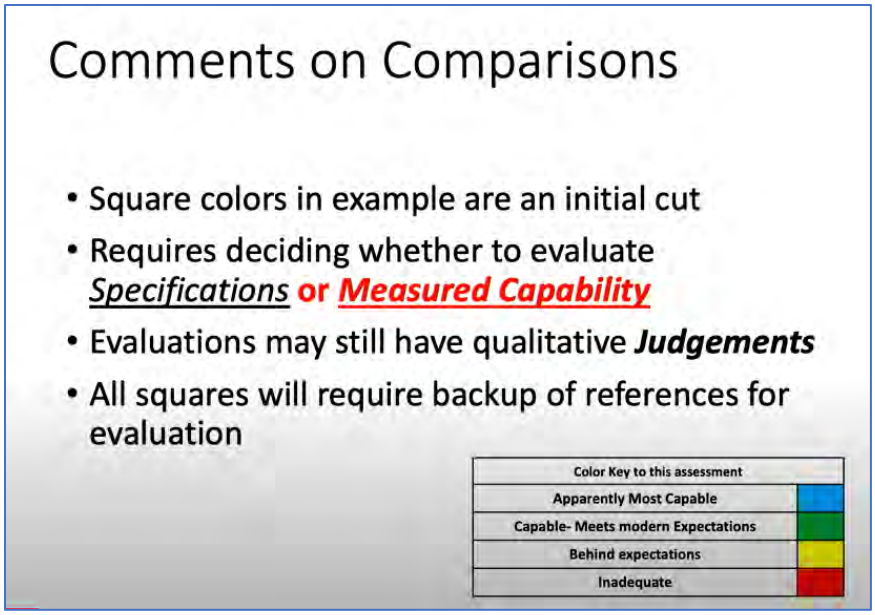


Slide 10

Let's take the trial set we just discussed and, excluding GLONASS, develop a colored chart to attempt comparing these systems. (Slides 11, 12, and 13).



Slide 11



Slide 12

On Slide 13 we are making some initial judgements. Note that DRAFT is plastered all over this.

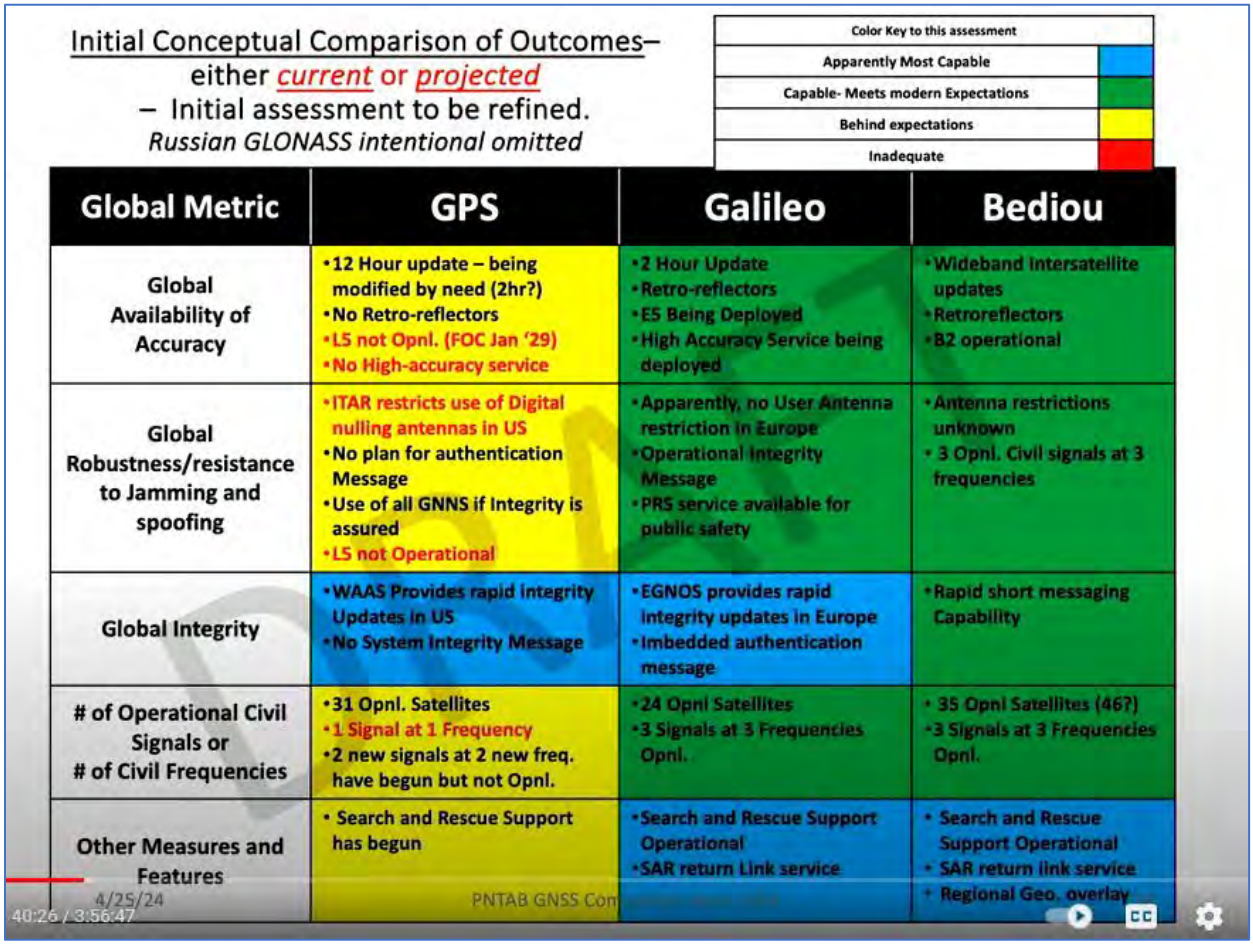
The first measure is the global availability of accuracy, where we are initially putting GPS down as yellow since L5 is not operational and does not have a HAS. On the other hand, Galileo is deploying such capabilities and BeiDou is advertising that they are also doing that.

On the second measure, global robustness/resistance to jamming and spoofing, GPS is marked down due to the unavailability of nulling antennas, no current plan for an authentication message, and L5 not yet being officially operational. As for other GNSS, we know there are foreign companies out there marketing multi-element antennas (one is already selling a 16-element antenna), even advertising in in GPS World.

On the third measure, global integrity, GPS is marked very highly as the U.S. is providing WAAS and an understanding of when it is out of specs (look at how 2 SOPS operates and how quickly it takes offline any satellite that is performing below specifications). European Geostationary Navigation Overlay Service (EGNOS) apparently has a similar capability. BeiDou has a short messaging capability, but Dr. Parkinson is not sure how it is being used.

The fourth measure is the number of operational civil signals or frequencies. Unfortunately, GPS is not yet fully broadcasting L5, and there are a lot of barriers to use it. Dr. Parkinson noted he is not sure whether the "green" is deserved for Galileo. The board needs to see whether they have achieved true Full Operational Capability from the vantage point of the user.

And then there are some other measures and features that are sometimes deemed important, such as Search and Rescue (SAR) support, but Galileo and BeiDou apparently have it already operational.



Slide 13

Mr. Murphy suggested to include another metric, "Out of Band Information Support." This is something where one can get real-time support at the NAVCEN website. Mr. Murphy is not sure whether other GNSS do that, but this is an important thing for the user.

Dr. van Diggelen noted that the inherent accuracy of the signal is strongly related to the chipping rate. We have data that shows that. GLONASS has a 600 m triangular correlation peak. This parameter is 300 m for GPS L1 C/A, and 150 m for BeiDou. The steeper the correlation peak, the more accurate the basic pseudorange measurement is on the ground. GPS L5 is, of course, better than L1. Is that represented here?

Dr. Parkinson said it is not stated here because this analysis will go to a second level for the specific capabilities that feed these conceptual comparisons. So, in his view, that's where this comment belongs.

Dr. van Diggelen said he believes that belongs under accuracy. In the chart je don't see signal design as part of the accuracy measure. Also, in his view the Board tends to over index on the system-in-space numbers. While GNSS providers give the performance number in space, most GPS receivers are on the ground and so it's the receive accuracy that matters. The system-in-space accuracy is just a small component of that, and a minority component of the error. In summary, "signal design" is a very important part of the global availability of accuracy. GPS L5 has a very good signal design but, overall, GPS falls back to yellow because L5 is not operational yet.

Dr. Parkinson agreed.

Mr. Higgins noted that the table shows the Galileo Authentication Message should probably be down under the "Integrity" measure rather than under "Resistance to Jamming".

Dr. Parkinson noted that the integrity message described here is the "Chimera" message. That is what was meant by that.

Mr. Higgins noted that BeiDou has an SBAS developing capability that should probably be reflected in the table.

Dr. Powell noted that, first, "BeiDou" is not spelled correctly in the chart. Second, for robustness, one of the bullets there is for the number of signals, which is repeated down below and isn't included for the other systems. Third, what remains is antenna restrictions is "unknown" which, in his view, may not deserve a green. The U.S. clearly has the ITAR issue, but for Galileo and BeiDou that is kind of "unknown" and perhaps doesn't also deserve a green (second row, under BeiDou).

Dr. Parkinson noted that Dr. Powell is looking at this as a "flow down", which is not where this table comes from. In his view, there are capabilities at a technical level that feed more than one of these measures. But he agreed that the bullets Dr. Powell mentioned deserve refinement.

Dr. Powell added that actually there are four civil signals for GPS.

Dr. Parkinson agreed.

The Hon. Shane commented that this chart is dramatically improved over earlier iterations. He added that, regarding when the U.S. decided as a matter of policy to eliminate Selective Availability (S/A), do we know whether there are similar decisions for Galileo and BeiDou? Do those systems have a better signal that is restricted and not being made available to the public?

Dr. Parkinson said the answer is yes, and the answer is also yes for GPS since it has a military signal whose precision, because of the chipping rate, is better and is also more resistant to jamming. However, we are strictly focusing on civil capabilities. Now, if you're asking whether Galileo has somewhere a secret switch to wiggle the signals, he honestly doesn't know. However, he suspects they don't. As for BeiDou, he has no idea.

Mr. Higgins noted that both Galileo and BeiDou came after S/A set to zero. Thus, the baseline had already been changed by GPS.

Mr. Murphy noted that another potential discriminator is political commitment. GPS many years ago submitted to ICAO a letter offering satellite navigation with a guarantee that it would issue a notice 70 years in advance should a decision be made to turn it off. He believes Europe followed that up with a letter, but he's not sure whether there has been a similar commitment by BeiDou or GLONASS.

Dr. Parkinson noted that this is a good point and, in his view, relates to "Openness" of what each system is providing. Dr. Parkinson agreed this is something we can include for global metrics.

Mr. Goward asked whether for global integrity, does the embedded authentication message with Galileo benefit all users, and does WAAS benefit all users?

Dr. Parkinson noted he specified WAAS provides coverage in the U.S.

Mr. Scott added that, regarding the Galileo message, everybody can use it. However, the EU is in essence forcing you to use their systems because there is a requirement to use an authenticated signal. Thus, by GPS not having an authenticated signal, in Europe by law one must use Galileo since it is authenticated.

Dr. Parkinson said that this point probably belongs in the deeper dive of these charts.

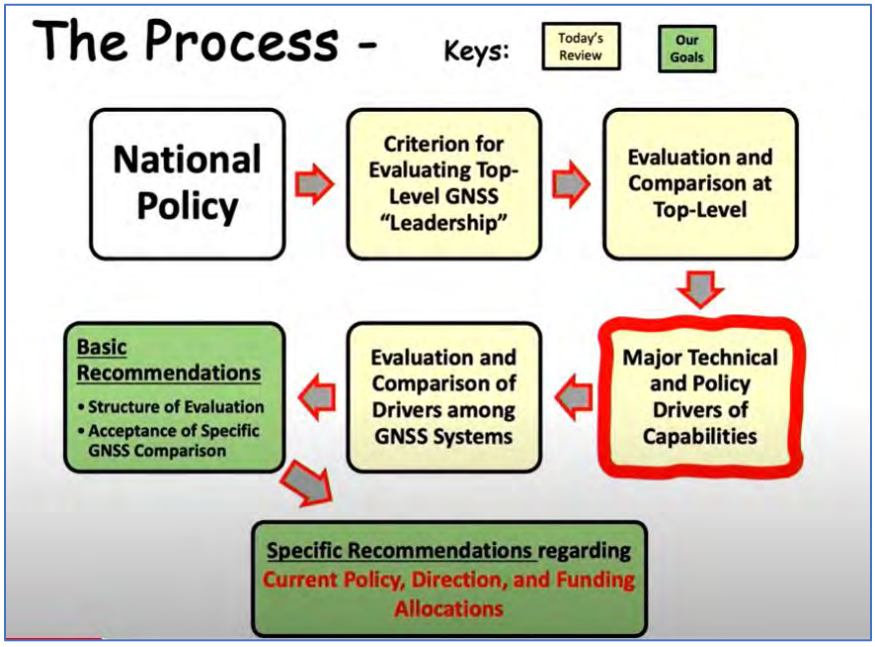
Mr. Miller noted that under "Other Measures", the Space Service Volume (extending GNSS from LEO to GEO, and eventually beyond), or SSV, is an area where we've made a lot of progress in the U.S. In addition, SPD-7 specifically asks us to look at the use of GPS, along with other systems such as Galileo, into the Cislunar space domain. This has become a priority at the UN, as articulated yesterday by Mr. Jeff Auerbach of DOS.

Dr. Parkinson agreed, but asked whether that would result in a discriminator among GNSS systems if this is something everybody is doing?

Mr. Chan said that in the second row, where it talks about resistance to jamming and spoofing, he suggested replacing those two words with just "interference". From the perspective of civil users, there are other interference types that need to be included (for example tree cover, etc.). What the user expects can change over time.

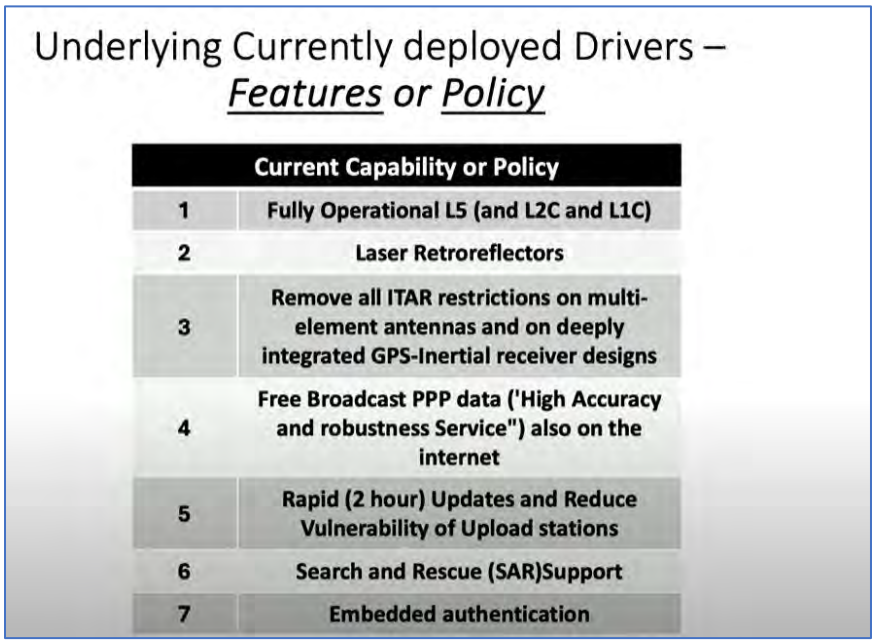
Dr. Parkinson agreed and continued with his briefing.

Now we're going to get down to the nitty gritty (Slide 14). This is currently incomplete.



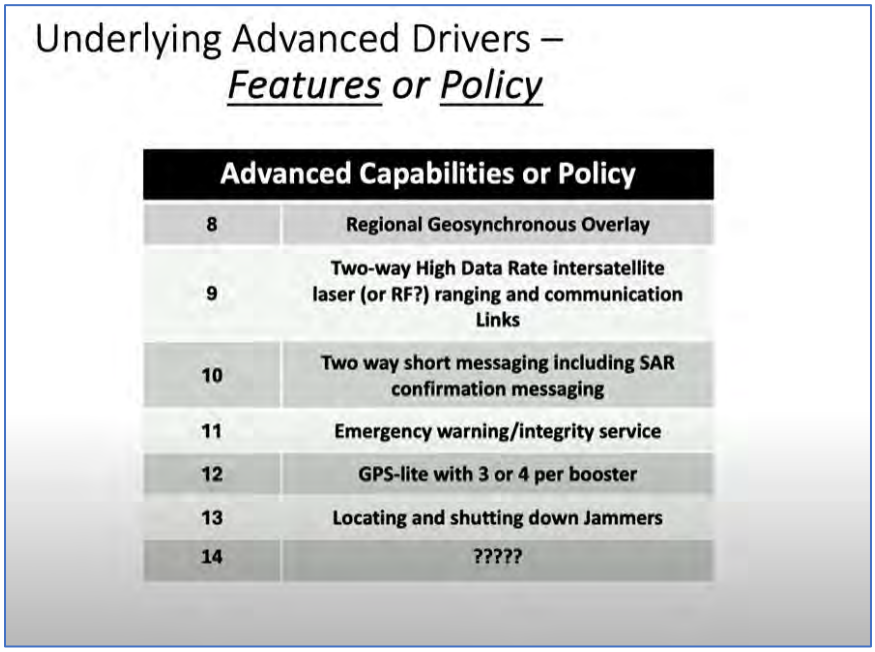
Slide 14

Slide 15 depicts current underlying capabilities and policies that drive some of the parameters. These include the global civil signals, laser retroreflectors, ITAR restrictions, free broadcast PPP such as HARS, rapid updates (which relates to clock stability), SAR, and embedded authentication.



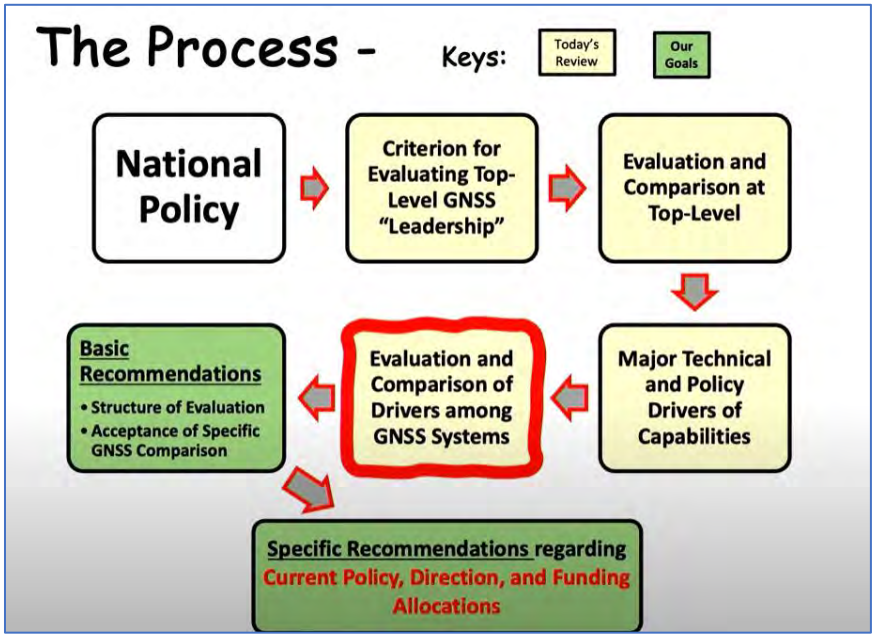
Slide 15

Slide 16 depicts the Advance Capabilities or Policy. This list could be much longer, but what we want here are the most important ones that are discriminators. These include regional geosynchronous overlays, two-way data rate transmission, two-way short messaging (including SAR confirmation), emergency warning and integrity messaging, GPS-lite with 3 or 4 per booster (which relates to how many satellites you are going to have), and locating and shutting down jammers. These two lists (Slides 15 and 16) are not prioritized. Dr. Parkinson asked the Board to think about other potential drivers of those top-level metrics.

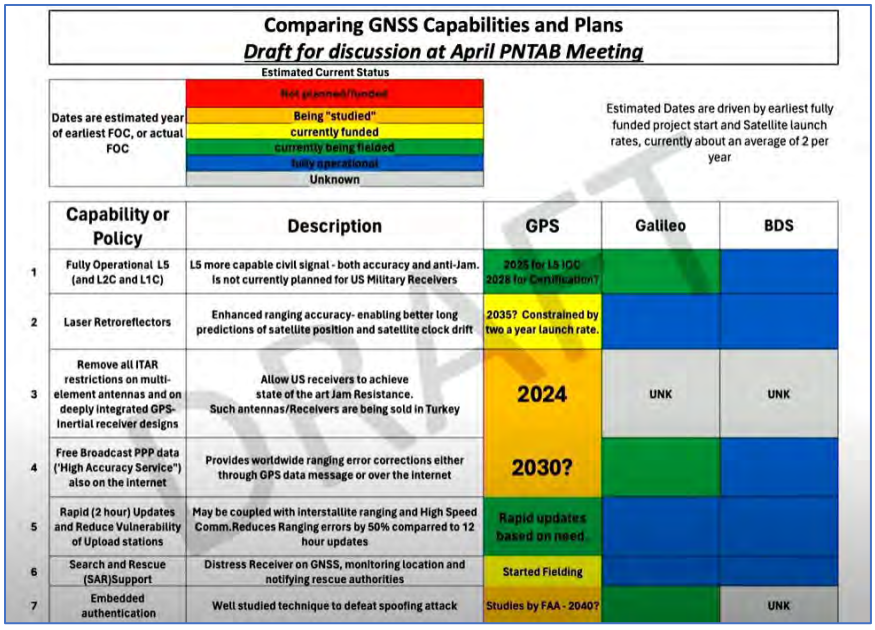


Slide 16

The next step is to do a comparison among these drivers (Slides 17 and 18). We have discussed L5 extensively. Dr. Parkinson also received information that its Initial Operational Capability (IOC) could be in 2025 and 2028 for its certification. Of course, the Board would want the "unusable" bit to be turned off as soon as possible. Laser retro-reflector arrays are currently slated beginning with GPS III SV9 or 10. The removal of ITAR restrictions appears to be underway. As for GPS HARS, the question is how long it would take us to get it online. We got good news on rapid updates when we spoke to the people at 2 SOPS, where if a satellite is acting up, they have a mechanism and procedure that will get those updates down to two hours (from 12) in order to maintain good accuracy.



Slide 17

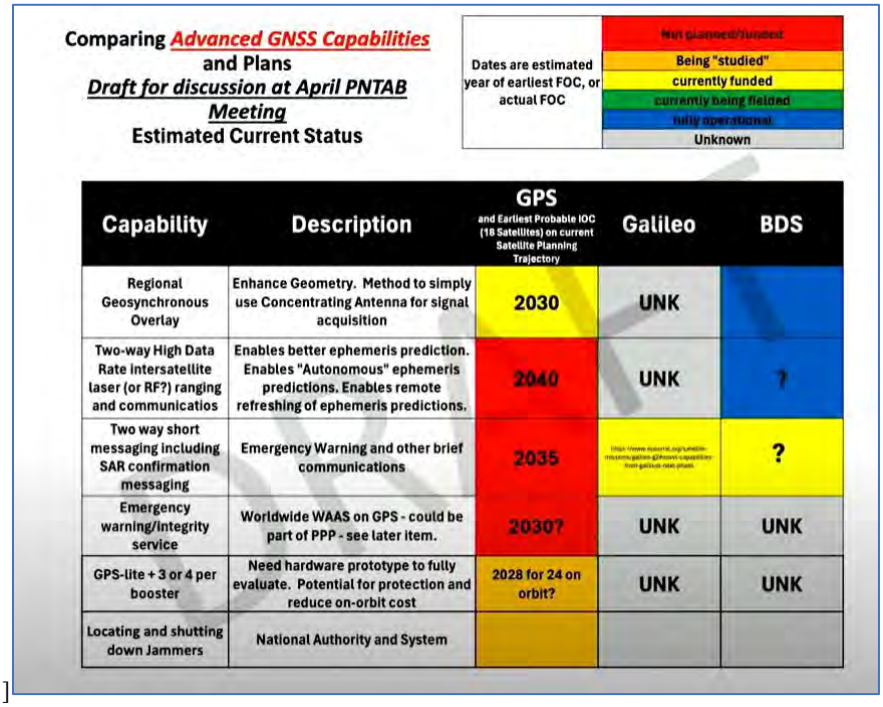


Slide 18

Slide 19 depicts the more advanced GNSS capabilities, which are also the more controversial and, in some cases, these are some of the things one may not want to do. Going down the table, Dr. Parkinson noted he can see a lot of good reasons for doing a regional geosynchronous overlay. The chart shows it as "currently funded", but that is probably an error.

Mr. Murphy commented that WAAS is already a GEO overlay.

Dr. Parkinson agreed but noted it does not cover all the civil signals.



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Slide 19

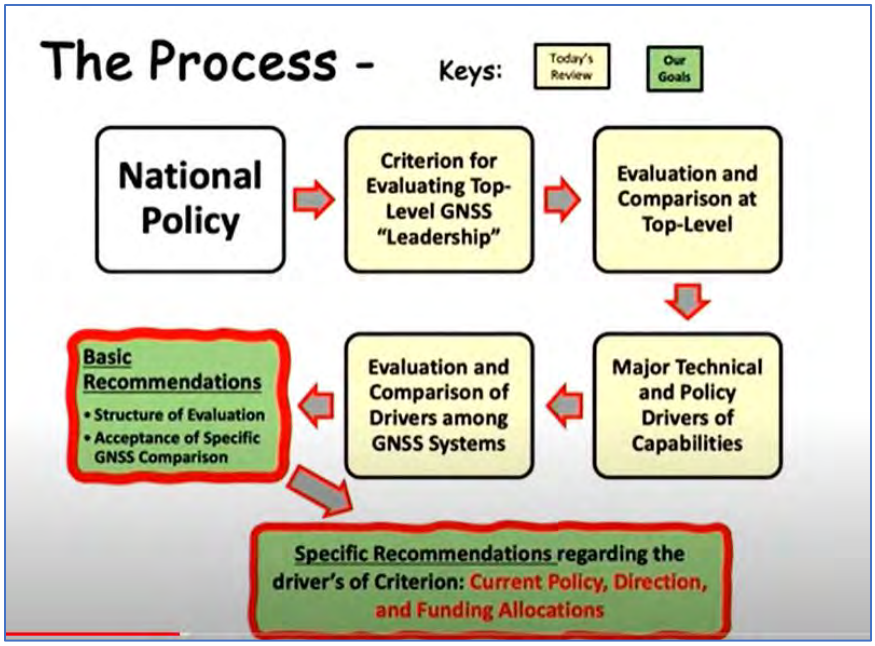
As for a two-way high data rate intersatellite ranging and communications, GPS has a limited capability but certainly not in the high comm rate that BeiDou is advertising.

Mr. Higgins said that, yes, BeiDou has that capability.

Dr. Parkinson noted that a lot of these comparisons are murky and difficult, in particular when trying to find a user-oriented assessment. This is something the board needs a lot more to back it up.

Mr. Murphy commented that another discriminator might be the competence for protecting the spectrum and legal support for protecting the system.

Dr. Parkinson agreed and noted that Mr. Higgins' subcommittee will take another cut at these charts. This briefing is intended to provide a starting point for the Board to bring a discussion on GNSS capabilities to a decision level up to affect those metrics we put in at the top. This brings us to the point in the process where we make basic recommendations, and then specific recommendations (Slide 20). Dr. Parkinson doesn't have recommendations at this time because it is premature.



Slide 20

This brings up a set of questions for the board (Slide 21). What are the key metrics? Who determines the best way to maintain or achieve them? Who takes responsibility for them? We gave a list of potential GPS improvements, so who is responsible for exploring and advocating such things? And, finally, how should they be funded? Relating to this, has the civil arm contributed to its share of GPS operation? DOT tried to do that, but OMB took it out. Dr. Parkinson asked Ms. Van Dyke if this is correct?

Ms. Van Dyke responded that, in accordance with space-based PNT policy, military and civil capabilities are segregated. One example is the monitoring of civil GPS signals, where DOT has spent over $8M on OCX to get monitoring of GPS signals and has partnered with NGA. They have also funded DOT has also funded on the order of $80M for L1C. However, this is not an annual budget to support GPS operations.

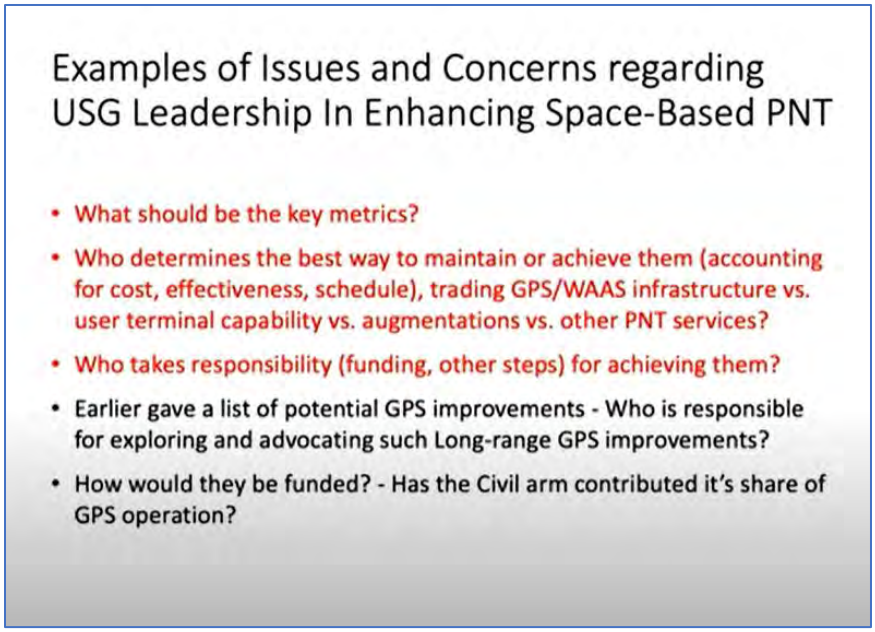
Dr. Parkinson then said that the question that is perhaps suggested here is that if additional capabilities, such as for example Chimera, are deemed needed and pushed through an OCX type of interface, who would bear the cost of inserting it? It sounds that, based on Ms. Van Dyke's comment, that would be borne by DOT.

Ms. Van Dyke said they've initiated a study on this. It has two components. The near-term component is authentication, which ties into the GPS HARS concept, and the long-term component is embedded authentication. DOT has initiated studies with USSF on what it would take for that to occur and how much it would cost. That is a decision that would be brought up to the PNT EXCOM.

Mr. Miller noted that, while we are on this slide, he would like to again bring up the issue of the SSV. In his view, this can be a discriminator. In June we are heading back to the ICG, where China has been pushing hard on how the BeiDou SSV is so much better than the GPS SSV because of the number of GNSS satellites they have (35+ including GEOs). Also, OSTP has been pushing to develop a Coordinated Lunar Time. So, there is going to be a continued connection between what we are doing for GPS in the terrestrial domain and what we want to do in the Cislunar domain. In his view, if we don't nail this down now, then we're going to be doing this at the next Board meeting anyway.

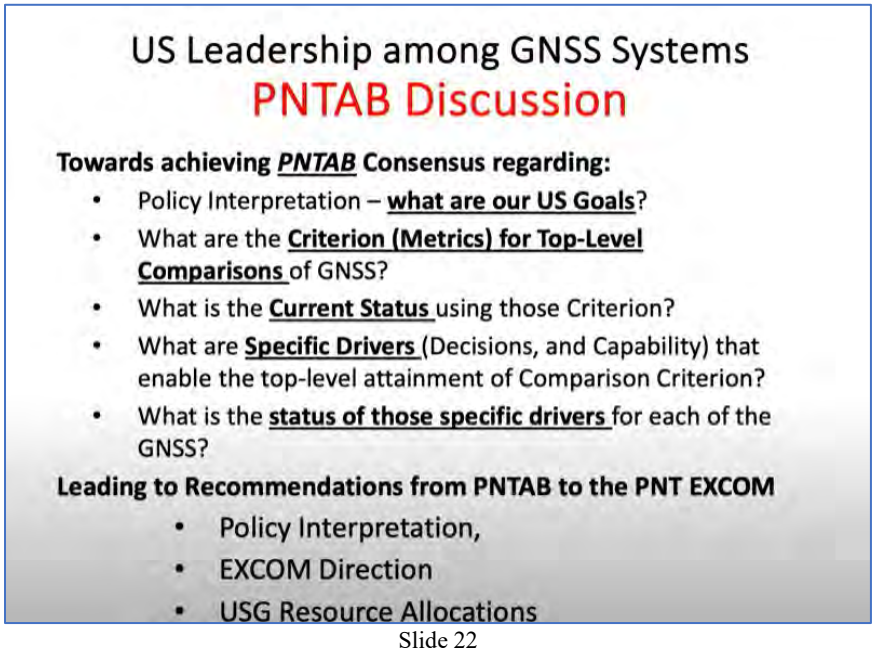
Dr. Parkinson said he has no objection to adding the SSV, and Cislunar space coverage, to the list of GNSS discriminating measures we discussed earlier. However, to him an issue is whether BeiDou can accurately characterize their signal side and back lobes, and they provide them freely and openly to the world.

Mr. Higgins suggested that earlier on, when discussing accuracy, we should also include timing accuracy.



Slide 21

Dr. Parkinson continued explaining that the intent of this briefing is to encourage dialogue as we go along. Slide 22 shows some of the questions we need to ask ourselves. Dr. Parkinson hopes that the next Board meeting can accommodate a discussion of these questions as well as the Governance issue, because the Governance issue is at the heart of what you do about this. The key questions are, what are the U.S. goals? What should the top-level criteria be? What is the status, and can we defend the numbers or judgements? What are the specific drivers? And what is the status of those drivers?



Slide 22

The number one question, in Dr. Parkinson's view, is whether this proposed structure "flies" with the Board? Does the Board think that this approach works in terms of trying to answer the question of where GNSS stands and what should we do about it?

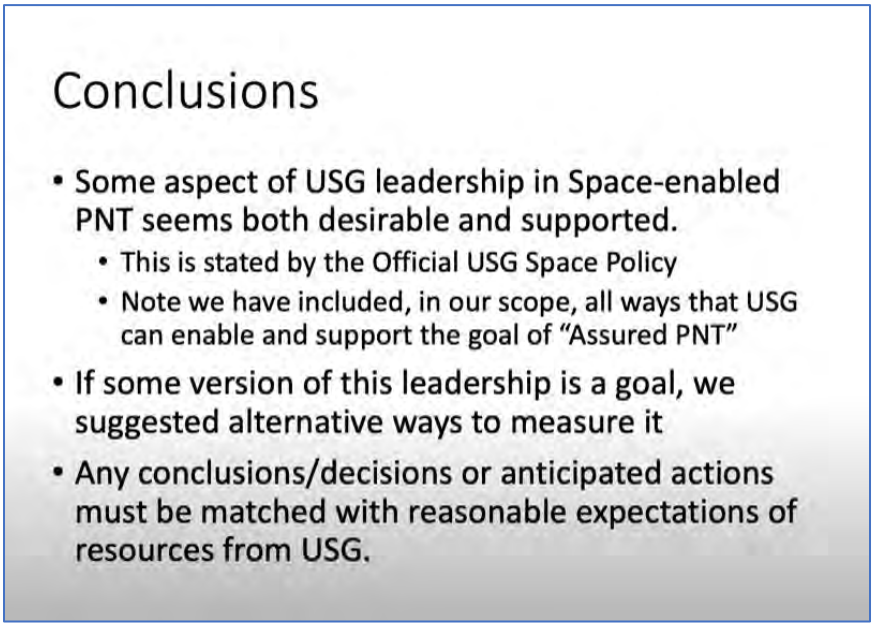
Hon. Shane noted that this raises the question on how we approach this with the government we are charged with advising. Let's imagine for a moment that we are the government and receive a list along the lines of what is being proposed here, and that we are all members of the agencies in charge of implementing them. How do we do it? Once we assign these, it becomes a very complicated process of implementing a policy change along these lines. Is this a realistic way to influence things? The Hon. Shane's thought is that the sooner we can engage the sponsoring agencies in a dialogue, the better. Instead of recommending the answers, can we encourage a process by which the government does that themselves in the hope that it can reach conclusions that make sense to them? In Hon Shane's view, we should be engaging those agencies before we provide them with all the answers. We need assurance that there is an interest in asking these questions. During the visit to Schriever SPF on April 22, we saw that a lot of this stuff is already baked into the pipeline. Are we saying those should be accelerated? Are we saying that those not in the pipeline should be added?

Dr. Parkinson responded that we haven't said anything like that yet. This is just a preamble for us to, hopefully, then engage the ESG. We would show them what appears to be our status, and based on that we think we are behind on things you might consider doing something about. The only problem Dr. Parkinson has with what the Hon. J. Shane suggested is that we risk then having another two years' delay in getting anywhere. What we are attempting here is to jump to a point where we can tell leadership that this is where we assess our status is, and if this is something they do care about in terms of policy then here are the areas we believe you should emphasize, add more funding, etc. This approach is in the Board's charter.

The Hon J. Shane said he doesn't disagree with Dr. Parkinson about what the endgame is. The question in his mind is whether we are going to "throw recommendations over the wall", or are we going to engage in a dialogue early on?

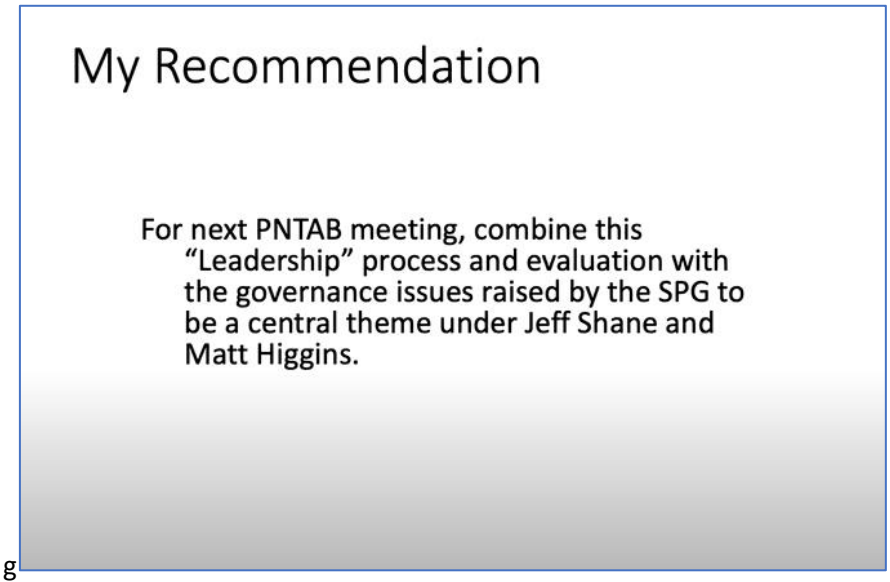
ADM Allen said he believes both Dr. Parkinson and Hon J. Shane are right. He said we need to have this conversation being had at the Deputy Administrator level and, yes, this is not something we can fix from where we are because this is a large and complicated issue. But it is our duty to provide advice on the current status, where we believe we are and where there is uncertainty, and how we need to move forward. What ADM Allen would like to see coming out of this meeting is a call for action for the deputies to get involved, and that's by raising questions that may not have answers yet, but we are the subject matter experts that can make recommendations on how to move forward. What we need is a way to communicate the conversation we just had, and ADM Allen is ready to put his signature on it. What we need now is to agree what is good enough to send in to start the conversation.

Dr. Parkinson said his hope is that, as GNSS experts, the Board provide a reasonably sound and logical basis for this comparison of where we stand, both relative to the purpose of providing assured PNT and whatever policy we have in terms of not becoming second to other GNSSs. Slide 23 depicts the conclusions of this briefing. Some aspect of leadership in PNT is both stated in policy and also desirable because it is truly an element of National Power. Some of the other GNSS operators absolutely get this. So, if this version of leadership is the goal, we have suggested a way to assess it. Finally, as noted by the Hon. J. Shane, whatever we come up with must be backed up with resources and decisions.



Slide 23

Dr. Parkinson's recommendation is that at the next Board meeting, the GNSS leadership process be combined with the governance issue (Slide 24). These two issues are co-mingled, so he recommends that this be done under the Hon. J. Shane and Mr. Higgins.



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Slide 24

Thus, the question put before the Board is whether the consensus is that we delve into this in greater depth at its next meeting.

Mr. Higgins asked if the plan is for ADM Allen to submit the draft memorandum after today's meeting.

Dr. Parkinson said yes.

Mr. Higgins added that, in that case, is the plan to tweak that table following today's discussion?

Dr. Parkinson said, again, yes.

ADM Allen added that he can link the memorandum to what the Board is going to do at its next meeting.

Dr. Parkinson said that there will be modifications to the table in the draft memorandum, and that the modified table will still be labeled as DRAFT since it is work in progress. Dr. Parkinson asked if there are any objections.

<There were no objections to following this approach>

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Theme 5: Updates from International Members & Representatives

1) Australia
Mr. Matt Higgins, *Member, PNTAB*

Mr. Higgins said he would cover a report on the IGNSS Conference that was held in Sydney, Australia in February 2024, because there was significant U.S. involvement, followed by an update on SouthPAN and other points around some space agency grants (Slides 1-2).

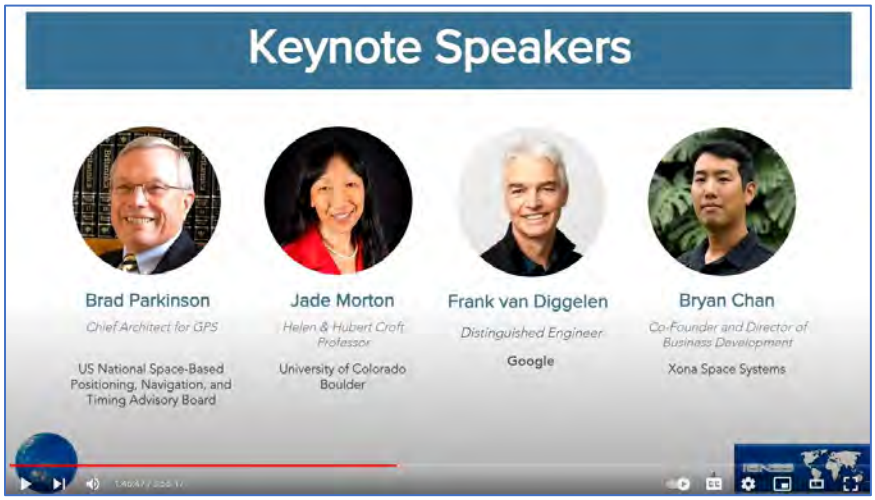
Slide 1

Slide 2

IGNSS (Slides 3-4)

IGNSS 2024 was held in February in Sydney, Australia. Dr. Parkinson opened the conference with a discussion on the 50th Anniversary of GPS. Dr. Morton and Mr. Chan presented on ionospheric issues LEO PNT, respectively. Mr. Van Diggelen presented remotely on the use of the SouthPAN precise positioning over the internet service that he and his team have done some testing in Google. (Slide 3)

Due to the great work of Mr. Rick Hamilton and Mr. Jeff Auerbach, we had a CGSIC meeting attached to the conference, and we had seven USG speakers, including Ms. Van Dyke, and that also enabled a bilateral between the Australian government and the USG. There were several representatives from across the U.S. and Australian governments, so it was a good meeting. (Slide 4)



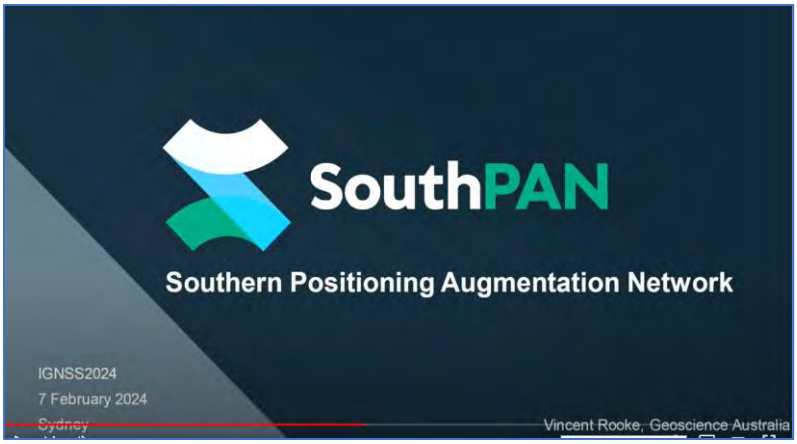
Slide 3

Slide 4

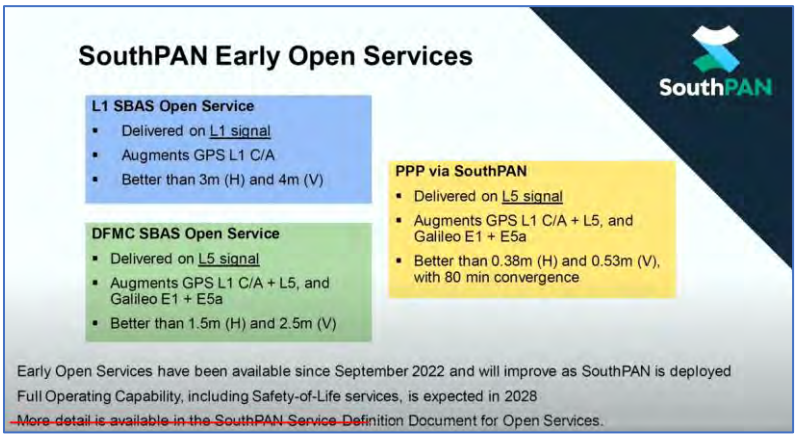
SouthPAN (Slides 5-12)

Slide 6 has been presented many times. It reiterates the idea of having three different services: L1 Legacy SBAS, Next Generation SBAS L5, and PPP vis SouthPAN (PVS), and it's currently being delivered on the L5 signal within part of the message for the SBAS. But as they get the new payload, that will move to an L5b, equivalent of E5b, which will give better bandwidth for better accuracy.

The Uralla Station in New South Wales, as well as a new station in New Zealand are being developed, and there's also been a bit of progress on development of the correction processing facilities (Slide 7).



Slide 5



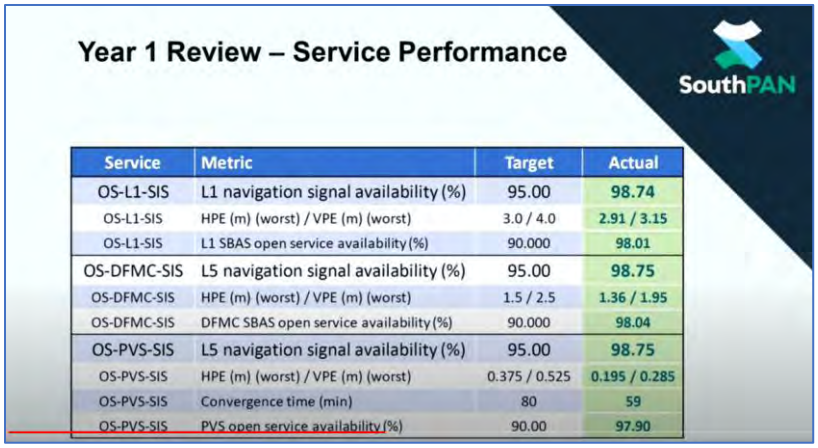
Slide 6

Slide 7

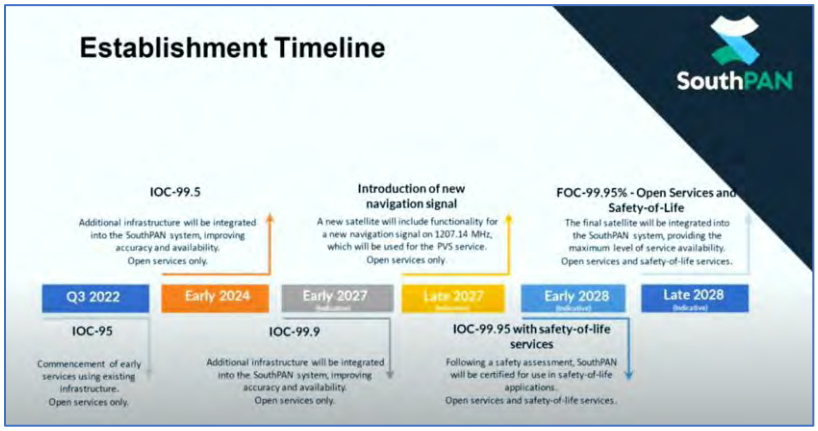
Slide 8 depicts the target vs. actual performance. The actuals in every case are performing better than the targets, which is, of course, good.

Slide 9 shows the overall timeline. Once the first new payload for GEO is available, that will raise levels of availability and confidence, but also, introduce that E5b type signal to send a more bandwidth and therefore better performance in PPP service. The long and hard process to get certification through to full operational capability will be around late 2028.

The new satellite payload is going through a Critical Design Review (CDR) in mid-2024, but when the contract will be awarded is still to be developed (Slide 10).



Slide 8



Slide 9

Slide 10

Regarding the internet services, delivery is coming soon, but there is a prototype already running and it's starting to be used and tested (Slide 11). There's a lot of work going on in the user space on use cases and the continuing business case for the continuing expenditure.

Finally, slide 12 shows the contacts and websites in both Australia and New Zealand.

Slide 11

Slide 12

Australian Companies Working in PNT (Slides 13-14)

At the last meeting, Mr. Higgins's briefing included QuantX Lab's optical clock, and at the time Dr. Parkinson asked a question about the quality of the clock, which Mr. Higgins couldn't answer at the time. Slide 14 hopefully addresses that question. They're developing this clock using optical components from the telecommunications industry. So, they're not building this bespoke optical clock, they're building a producible optical clock, which is an interesting way to do it.

Slide 13

Slide 14

Discussion:

Dr. Parkinson stated that he was not asking about the target, he was asking about what they had as test data. He asked Mr. Higgins if he could get that data.

Mr. Higgins replied, "that's their target, that was their answer."

Dr. Parkinson said that it's a great target but, "what are they actually experiencing with their prototypes?"

Mr. Higgins said that we should know within the next 6 months or so. Gilmour Space Technologies is on the Gold Coast, south of Brisbane, Australia. They've just set up a launch site towards the northern part of Queensland. It's expected to launch within the next month. The Australian Space Agency has just given a grant to Gilmour Space and the University of New South Wales (UNSW) to take the space-qualified GNSS receiver developed at UNSW and integrate it into the Gilmour Space rocket.

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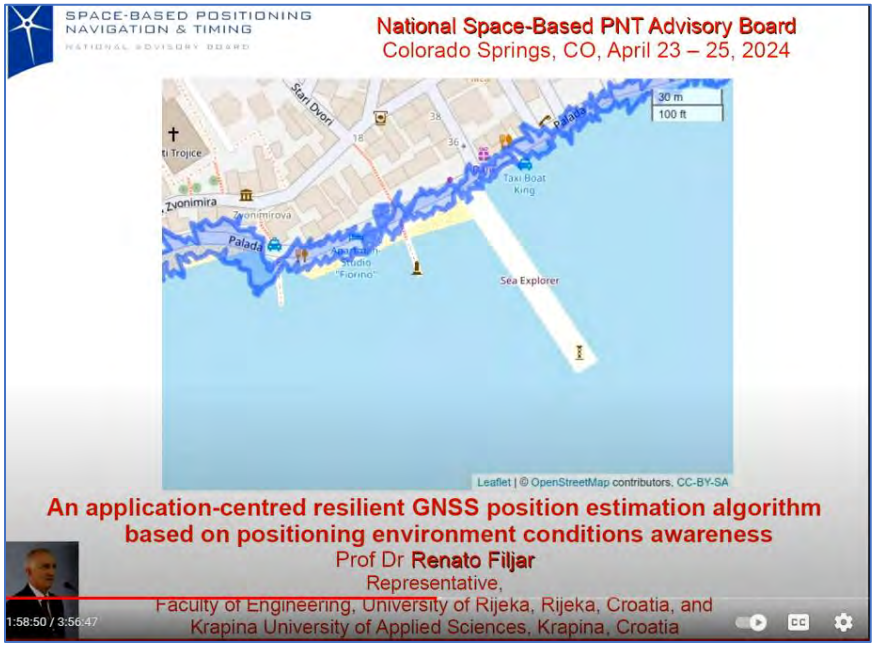
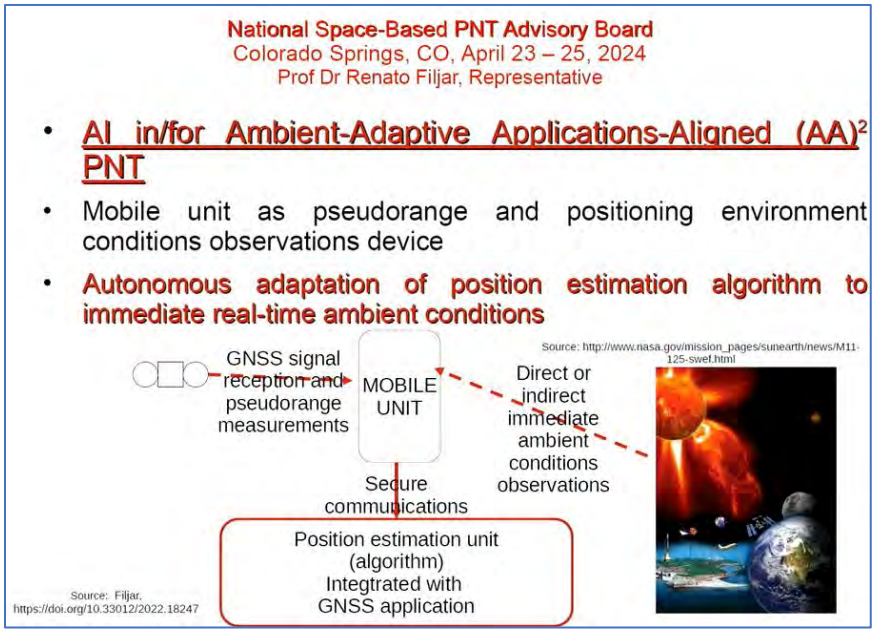
2) Croatia
Prof. Renato Filjar, *Member, PNTAB*

Prof. Filjar congratulated the Board on its 30th session. It's worth noting that there is a practice in GPS that allows us to express our proposals publicly, which speaks to transparency the standard of the GPS. Prof. Filjar stated that he would be presenting findings and potential subjects of future discussions or activities.

Ambient-Adaptive Applications-Aligned (AA)2 PNT was introduced at the previous meetings. The concept has gained interest among research groups and operational implementations. The research group, to which Prof. Filjar belongs, has developed a closed framework for the (AA)2 PNT that serves as an opportunity to test various concepts and various models, as well as introduce a very important technology of artificial intelligence in assessing situation awareness and allowing for the autonomous adaptation to the environment. This is important because GNSS and GPS applications have an increasing impact on the PNT process.



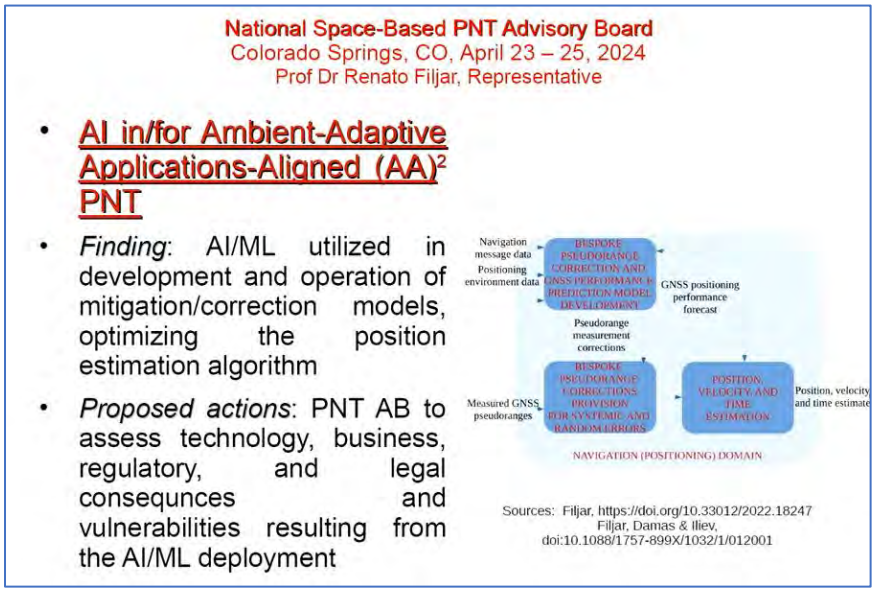
Slide 1



Slide 2

In (AA)2 PNT, artificial intelligence and machine learning have a very important role (Slide 3). Their utilization may bring some novelty and advancement and may be beneficial in targeting complex phenomena that can degrade PNT performance. The assessment of the technology, business, regulatory, and legal consequences of vulnerabilities and benefits result from the implementation of artificial intelligence and machine learning. At the next Board meeting, there will be a white paper prepared that will address the AI utilization for the PNT, and we will have an opportunity to discuss this white paper that is developed under the ECAS subcommittee. He already reported this initiative and the opportunity to address the AI deployment for the PNT.

Operators and stakeholders have an interest in setting up the facilities where GNSS spoofing and GNSS jamming can be produced so developers and operators of the GPS and GNSS applications can see if their systems are robust and reliable enough, even in case of GNSS spoofing and jamming threats. The upper image in Slide 4 shows the Joint Research Center of the European Union in Ispra, Italy, and the lower image shows the UN-Finland Workshop on GNSS Applications in 2023 in Helsinki, Finland. At a facility in Norway, a bay dedicated to exposure of the GNSS applications to controlled spoofing and jamming threats allowed industry, academia, and military to test their systems and services. Prof. Filjar's recommendation is to set up a permanent US national, controlled test facility for industry and business that would allow the testing of counter-detection and counter techniques that can mitigate the effects of GPS spoofing and jamming.

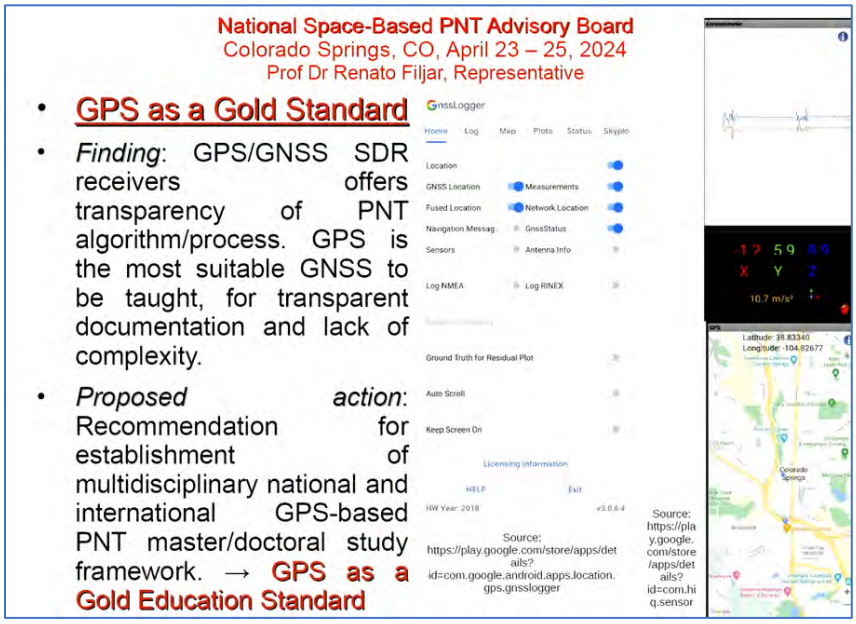


Slide 3

Slide 4

GPS is a gold standard in several ways (Slide 5). Many institutions around the world use the GPS as an initial case for teaching young specialists. PNT has become a very important subject taught at many universities in many disciplines, and the majority of those who educate young specialists start with the GPS as a blueprint and then move forward, explaining the additional features provided by other GNSS systems. GPS is transparent, it is logically structured, and it is easy to understand how satellite navigation works. Prof. Filjar recommended the establishment of a multidisciplinary national and international GPS-based PNT doctoral study framework that would even fortify the role of GPS in education.

Prof. Filjar disseminated the latest European Union Space Programme Agency (EUSPA) Market 2024 Report (Slide 6). ESA regularly issues the EUSPA Market Reports on the GNSS applications and developments from the technology and business perspectives. These reports are very well-structured to identify the trends and future developments of the application of GNSS, as well as the needs of the GNSS applications for PNT performance. Prof. Filjar proposed a recommendation for the facilitation of the national survey of GPS application needs and requirements across disciplines. That will help the adoption of the GPS as a gold standard and provide strategists an opportunity to invest money into the development of the GPS infrastructure.



Slide 5

Slide 6

In Baska, Krk Island, Croatia from June 16-18, 2024, the Baska Spatial Information Fusion Forum will be held (Slide 7). There will be many international experts speaking at the Baska Forum, and Advisory Board members plan to attend this meeting. Prof. Filjar invited the room to engage in discussion of recent developments of the PNT, remote sensing, statistical analysis, statistical learning on the spatial data, and development of the completely new market.

Slide 7

Discussion:

Mr. Murphy commented that the U.S. already has a permanent facility for jamming and spoofing trials called White Sands, New Mexico. He agreed that there should be a facility that's geared strictly towards commercial civilian use.

Prof. Filjar stated that it would be useful that this permanent facility would be open to allow a wide range of potential operators the opportunity to test their applications.

Mr. Murphy said that the U.S. had something like that in Montana and asked Prof. Filjar if European manufacturers would fly all the way over there to use it.

Prof. Filjar stated that it would be a good idea to promote it those in Europe are probably not aware of the opportunity to use it.

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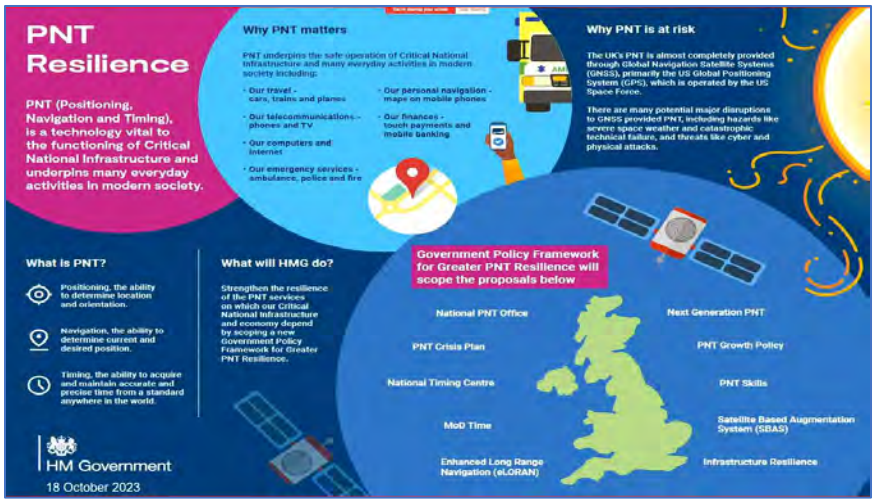
3) United Kingdom
Prof. Terry Moore, *Member, PNTAB*

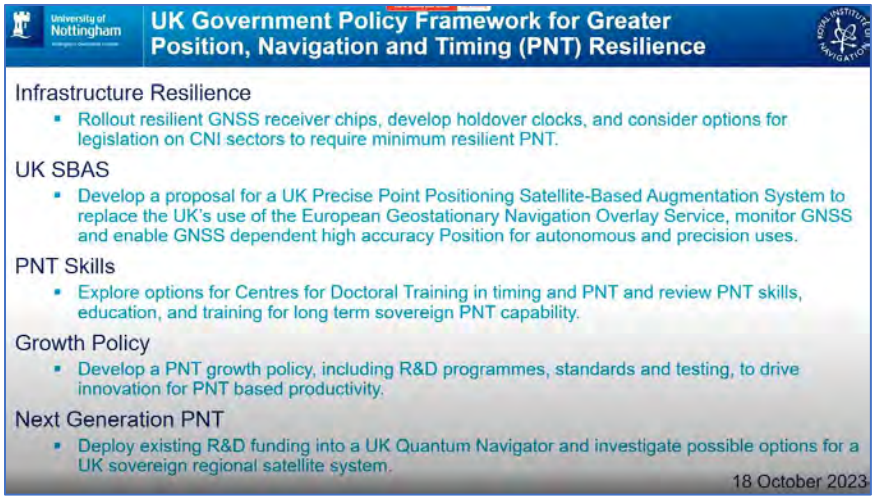
Prof. Moore greeted the Advisory Board. Slide 1 is an overview of the UK government, published in October of 2023.



Slide 1

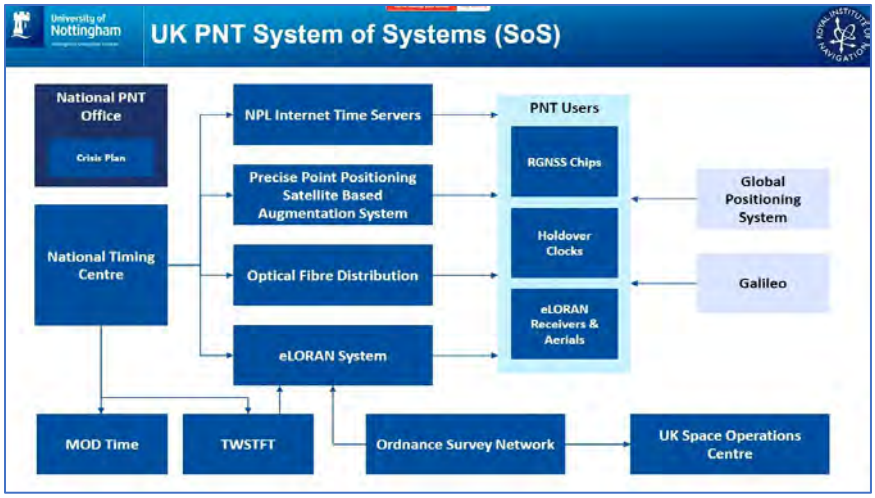
Slide 2 & 3 summarize the 10 points of the action framework: (1) The setting up the National PNT Office has now happened. There are now 10 permanent staff working in the PNT office within the Department of Science, Innovation, and Technology, and they are leading the ongoing activities to develop the business models, and to take the work further forward; (2) A key aspect is the PNT Crisis Plan: how the UK will respond to interruptions to PNT services; (3) The National Timing Center is also a key part of this. Most of the aspects of critical national infrastructure are dependent on the "T," not the "P" and the "N," so the National Timing Center can provide a stable and distributed UK version of UTC; (4) A backup to that, from a military standpoint, known as "MOD Time," will shadow the activity within the public domain at NPL to provide another framework for timing distribution; (5) The redevelopment of the eLoran to give a positioning capability in addition to timing; (6) Producing more robust and longer resilient receivers and holdover clocks; (7) Developing the UK SBAS capability has been in a prototype form for a few years. This will be expanded to give a PPP service in addition to the traditional SBAS services for aviation; (8) The PNT skills gap is being addressed in the UK through the establishment of new doctoral training centers and other forms of training; (9) The growth policy is interesting. It includes R&D programs along with standards & testing; and (10) The next generation of Technology taking PNT further forward in terms of a potential satellite system and the quantum aspects. There was a call earlier this year for a Quantum PNT hub to drive forward and steer the research activity around Quantum PNT.

Slide 2



Slide 3

Managed by the PNT office, the Timing Center is the core of this, feeding into the time distribution, PPP, and augmentation services through the SBAS (Slide 4). The Ordnance Survey Network, being the national mapping organization in Great Britain, has a network of over 100 continuously operating GNSS receivers, which are multi-constellation. They do a lot of monitoring work, and that feeds into the UK Space Operations Center. This is again a recent development from UK Space Command, that now has the Space Operations Center, which has MOD, the UK Space Agency and the Meteorological Office working together. The paler blue box on the slide represents the user aspects of this, so developing robust and resilient GNSS chips, clocks, and eLORAN receivers and antennas.

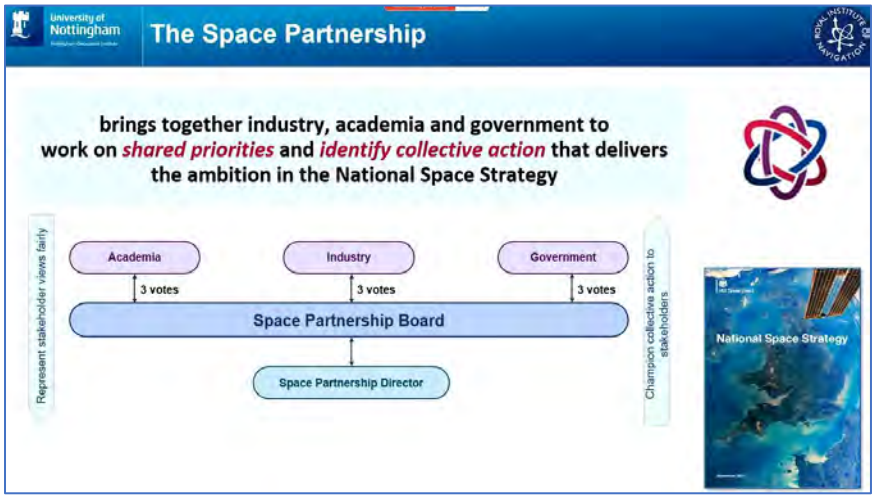


Slide 4

As show on Slide 5, the first phase is the development of the plans and proposals for the National Timing Center, he expansion of the UK SBAS from the prototype to an operational system, and the eLORAN network. At a later phase of the developments include the regional satellite system, the Quantum PNT aspects, and building on the commercial LEO PNT activities that are taking place. International discussions have included USA, Japan, Korea, Europe, Canada, Australia, and New Zealand. A key point of the program is that the PNT Office has been established and they will have to go before a comprehensive spending review for any funding to be awarded. Also, through ESA, in particular the Navigation Innovation and Support Program (NavISP), a lot of the work to support the framework is taking place under ESA. The optical clocks, the antennas for the eLORAN, and the UK test bed have all been funded through NavISP.

Slide 5

The National Space Strategy was published in 2021, and a partnership has been formed, funded by government and industry, and supported by academia, to make sure that space policy is actioned (Slide 6). The Space Partnership Board is producing a series of roadmaps across different aspects. It's also looking at the skills aspect as well across the whole space sector and trying to prioritize that engagement with ESA.



Slide 6

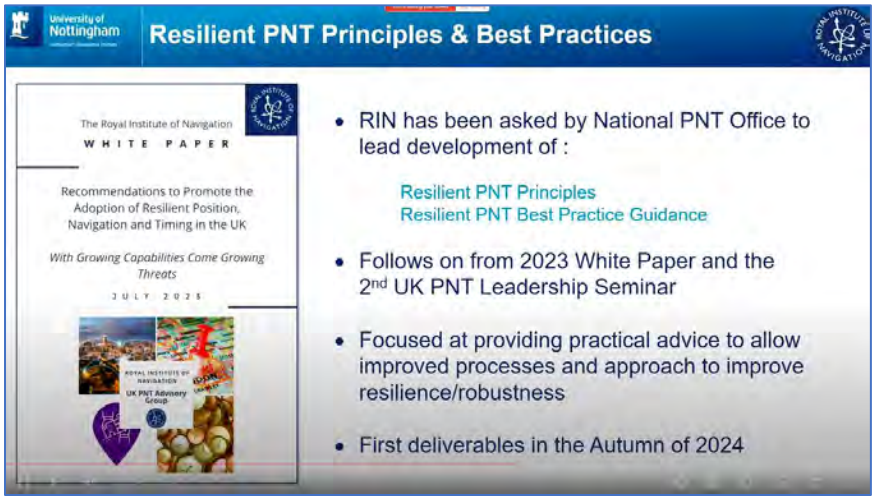
Regarding the activities that are taking place in the Royal Institute of Navigation (RIN), in the UK currently there is no equivalent to the Board to advise the PNT Office (Slides 7-9). The RIN itself is trying to provide independent guidance and advice as the PNT Office is forming.

There was a LEO PNT event in March of 2023. Two key publications have been the white paper on best practice, which fed into the National Preparedness Committee presentation. Leadership seminars are held annually in the winter. An event with the defense sector was last July, and another one is planned for June 2024. One day will be in the public domain and one day will be in a secure environment, discussing PNT activities at that crossover between the civil and defense sectors. Two areas that are under

consideration are artificial intelligence and quantum PNT activity. There is now a special working group on the PNT & AI within the PNT Advisory Group. A Quantum PNT Activity is expected to be taking place in September. (Slide 7)

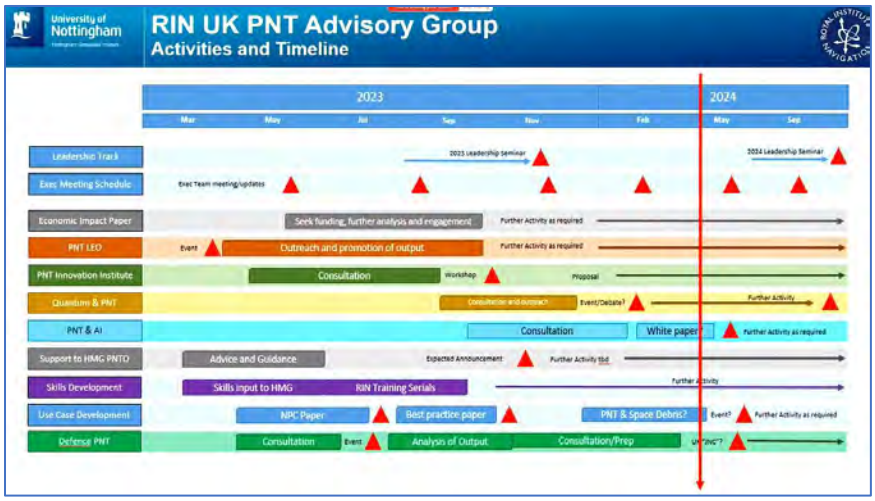
The PNT Office has approached RIN and asked them to develop further work regarding principles and the best practices. They are looking at different sectors and domains, trying to provide guidance as to how people should manage their own applications and uses of PNT to provide that resilience and robustness. (Slide 8)

Slide 7



Slide 8

The activity timeline continuously develops in terms of events and activities that are taking place (Slide 9). The RIN UK PNT Advisory Group has been looking at the role of PNT and space debris, and how that is managed in the future as it evolves across AI and Quantum. The economic impact paper done has had a second revision. We are hoping to take that forward, but it requires funding.



Slide 9

The European Navigation Conference is taking place in in May of 2024 in Noordwijk, The Netherlands, at the ESA+'s Agency's Test Center. It's been organized under EUGIN, the European Group of Institutes of Navigation, of which Prof. Moore is the chair. RIN has taken the lead in the organization of this. It's taking place in The Netherlands to show the model that we can be flexible in the future. Last year, the conference was a huge success. This year, we're oversubscribed with attendees, but we still have the capacity to take some more registrations.

Slide 11

Discussion:

Dr. Parkinson asked if there is a formal relationship between the UK and Galileo.

Prof. Moore stated that when the UK left the EU, not the ESA. ESA is a completely independent organization, separate from the political alliance of the EU. The UK has remained a very strong supporter and funder to the ESA. Therefore, the UK supports the development of activities in PNT within ESA. Because aspects of Galileo are being developed by ESA, the UK is not allowed to take part in those programs because they're no longer part of the EU. The UK remains a major contributor to most of ESA's activities, which includes LEO PNT.

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4) Consumer Technology Association (CTA)
Mr. David Grossman, *Member, PNTAB*

Mr. Grossman explained that CTA is a U.S.-based trade association representing over 1,300 companies. 80% of our members are small businesses. CTA is also known for owning and producing CES, the Consumer Electronic Show, which takes place in Las Vegas, NV every year. The chipsets and finished devices that CTA member companies produce are developed to reach markets around the globe. Mr. Grossman added that he has great concern regarding references being made about BeiDou being a receive-only service and making a comparison to TikTok. That is not productive nor is that consistent with the information. If there is information that needs to be discussed in a classified setting, our member companies would appreciate hearing that information. Slide 1 shows the current hot topics for CTA. While we're talking about GPS issues, it's important to understand what the issues policymakers in Washington are talking about and what the regulatory agencies that we work with are dealing with. What are the other issues that are before them?

Slide 1

The National Spectrum Strategy was announced at the White House and released by the National Telecommunications and Information Administration (NTIA) in November of this past year (Slide 2). On March 12, 2024, NTIA released its implementation plan for the National Spectrum Strategy. The idea is to provide a public roadmap, "for each strategic objective, identifying specific outcomes, responsible federal agencies, contributing stakeholders, and a timeline for both the beginning and the expected completion of that effort." In the original strategy released in November 2023, there is mention of GPS and GNSS, recognizing the important role they play for our nation, as well as the need to protect them from harmful interference. None of the spectrum bands that have been identified in that report are anywhere near GPS spectrum, but they're looking at the lower 3 GHz, 7 to 8 GHz band, 18 GHz, and the lower 37. As part of this implementation plan, there are various deadlines that are set for when studies are going to be completed for each of those bands. The FCC spectrum auction authority has not been renewed in over a year. It expired in March of 2023, and more than a year later, Congress is still trying to wrestle with that conversation. CTA has talked about what that means for U.S. leadership, particularly on the global stage. There are continued conversations in Congress, and we hope that those get resolved soon and we do see Spectrum auction authority renewed.

Slide 2

The U.S. Cyber Trust Mark Program is being led by the FCC (Slide 3). It continues to be a priority of this administration. The idea is to take the same concept as the Energy Star Program to the cybersecurity world for connected Internet of Things (IoT) devices. This includes everything from smart appliances to video doorbells and baby monitors. Largely the devices that are in scope are stationary, there's probably not a direct GPS/GNSS connection, but the cybersecurity conversation is very relevant and it's something this Board should be aware of. It is based on NIST IR 8425. There's a focus on international harmonization and mutual recognition, including an agreement that was announced with the EU at the end of January 2024. The approach that the U.S. is taking is different than the EU, which is mandatory. In the U.S. this is voluntary, and that's something that gives our industry and companies comfort. If this is the first time that you're hearing about this effort, we've got a lot more work to do, particularly on the consumer education front. That's something we'll be working on with the FCC, the Administration, and SISA to make sure we get the word out. What good is a label or a mark on a product, website, or store shelf if a consumer doesn't know what it means? There is a lot of excitement in industry from big-name companies, both retailers and manufacturers.

Slide 3

Federal privacy legislation is by no means a new topic. Congress has been debating the efforts to have a National Privacy Law for at least a decade. We're seeing a patchwork of state privacy laws pop up. In the last two weeks, there has been a bipartisan, bicameral effort led in the Senate by Senator Cantwell, who's the chair of the Senate Commerce Committee, and in the House by Congresswoman McMorris-Rogers, who's the chair of the House Energy and Commerce Committee. This warrants the attention of this Board. Even in an election year. it is seen momentum. The bill focuses on a few different areas: data minimization, transparency, and giving individuals the right to opt out of covered data transfers and targeted advertising. How does this relate to this group? Precise geolocation information is defined in the bill, not only as under the definition of "sensitive covered data" but also "precise geolocation information," which comes down to identifying street-level location information or the location of an individual device within a range of 1,850 ft or less. In terms of where CTA stands on it, we want to see a bill that provides a full preemption of state law. We do have some concerns about the current bill as it's been introduced. Similarly, CTA opposes a private right of action, which is currently in the draft bill. There was a legislative hearing held in the House last week, and a Senate hearing is likely to take place in the next couple of weeks.

Slide 4

There is also a bill moving through Congress that would require DOT to issue a rule that requires all new motor vehicles to have devices that can access AM broadcast stations installed as standard equipment (Slide 5). In a GPS context if this group were to go to Congress and say that "all new vehicles have to have a GPS receiver built it." In the GPS world, consumers have several different ways they can buy portable navigation units. There are several different ways they can access GPS information, and the same in the context of AM radio. If the concern is about emergency information, we have wireless emergency alerts that are provided through our cell phones. There is also satellite radio, as well as several AM and FM stations streamed through online platforms. CTA is very concerned about this effort. Even in a polarized and divided Congress this is moving at a rapid pace with many co-sponsors in both the House and Senate. There will be a legislative hearing next week in the House Energy and Commerce Committee. What's happening in the marketplace as more electric vehicles are sold, there's an interference issue between electric vehicles and AM radio stations that are very low frequency, so some automakers have already removed AM radios from their vehicles, and that prompted the introduction of this legislation. CTA's view is that should be left to the consumer and to the market.

Slide 5

Discussion:

Dr. Powell asked if the operation of an Electric Vehicle interferes with the reception of AM radio.

Mr. Grossman said that's correct, and vice versa. The counterargument to that is, "couldn't you just add more shielding in the vehicle?" Those who have electric vehicles or are familiar with the industry, know that every little bit of weight on the vehicle makes a difference in terms of performance.

Dr. van Diggelen commented that he is trying to work out what kind of number is 1,850 ft, and he can't figure it out.

Mr. Grossman stated that he wanted to point that out because he thought it would be interesting for this Board. "I actually don't know the origin of how that specific number came to be, but I'd be happy to dig into it and see how they came to it."

Hon. Shane asked how the U.S. Cyber Trust Mark Program works. Because the bad actors are clever about getting around any protection that we are capable of devising, "what kind of assurance are you going to get?"

Those in the cybersecurity world know that no company can ever make a claim that a device will be 100% impenetrable. But there is a set list of criteria, and that's what the mark represents. There's already been a notice proposed rulemaking, and there's already been a report and order adopted by the FCC just last month. Notably, it was a 5-0 vote.

Hon. Shane followed up by asking if the American Privacy Rights Act is that going to be a version of the GDPR in Europe. Having been working in Europe for so long, he believes GDPR is a huge nuisance and produces relatively little public value.

Mr. Grossman stated that this does take a very different approach. The bill sponsors are not trying to replicate GDPR. T hey're trying to create a model that fits with the way we look at regulation and policy here in the United States.

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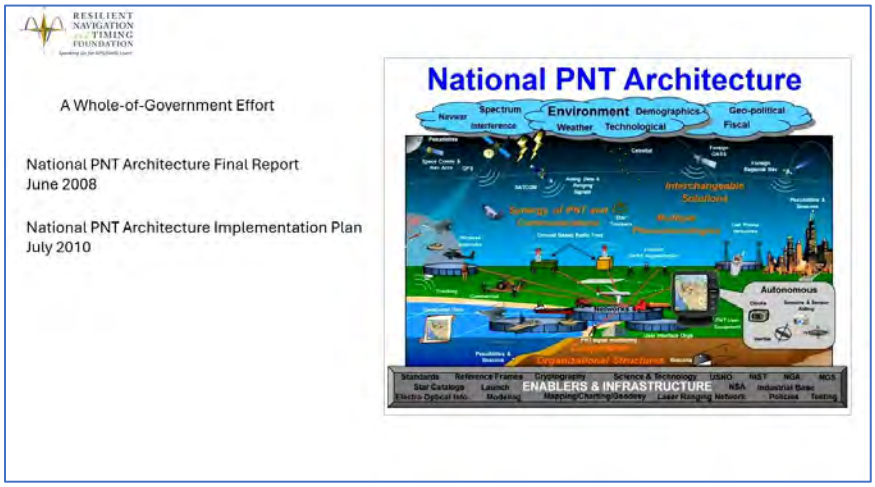
5) RNT Foundation
Mr. Dana Goward, *Member, PNTAB*

The RNT Foundation is a scientific and educational charity, and we advocate for policies and systems to protect GPS satellite, signals, and users. Almost exactly four years ago, the FCC ruled that Ligado Networks could broadcast on the frequency near GPS. You may remember that quickly after that ruling, the RNT Foundation filed a petition for reconsideration with the FCC, saying, "We think you did the wrong thing. Let's think about this again." So did seven other organizations. In that time, Ligado has been saying, "We have a final FCC decision." Recently, the court has ruled that the FCC order is non-final for purposes of judicial review. We've also been talking about working with the government, and some people have said that it's hard to work with the government. It's, in many ways, a lot harder to work inside of government. Folks have a lot more information, but at the same time, they have to be a lot more circumspective about what they can say and what they can opine on.

We have had whole-of-government efforts and approaches to PNT before (Slide 1). This was clearly not executed the way that most of us would have liked, there are other ongoing whole-of-government efforts similar to what we want to see, so that should give us some optimism and in terms of the ability to influence leadership.

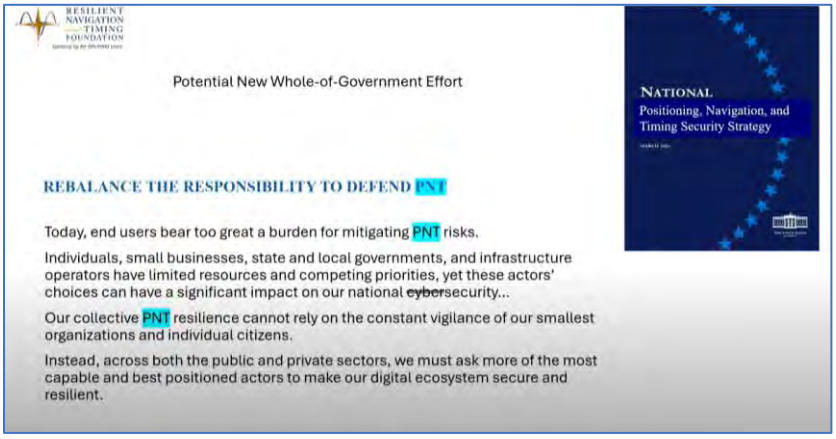


Slide 1

An example is the National Cybersecurity Strategy and Implementation Plan (Slide 2). The big assumption going into the National Cybersecurity Approach is that end users bear too much burden for mitigating the risks to themselves and the nation. In many instances, end users are not as capable of doing things and that government and big providers should bear more of the responsibility.

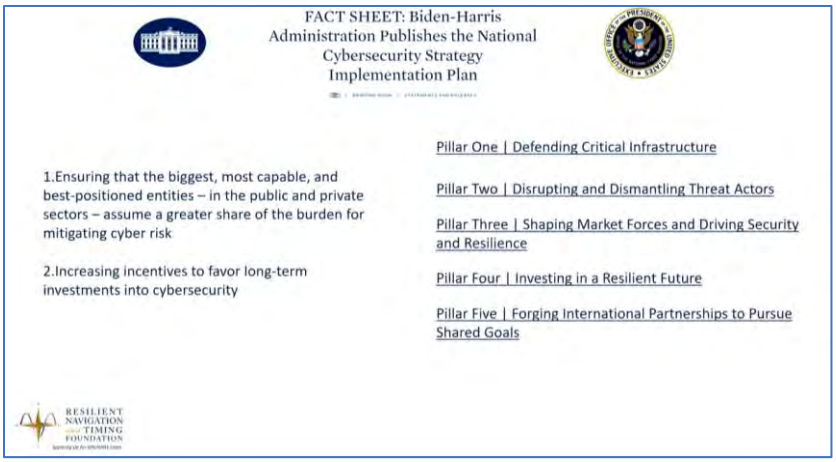
Slide 2

This could be a good template for a National PNT Strategy going forward (Slide 3). You can use the same kind of language, and it continues to make a lot of sense in terms of national policy.



Slide 3

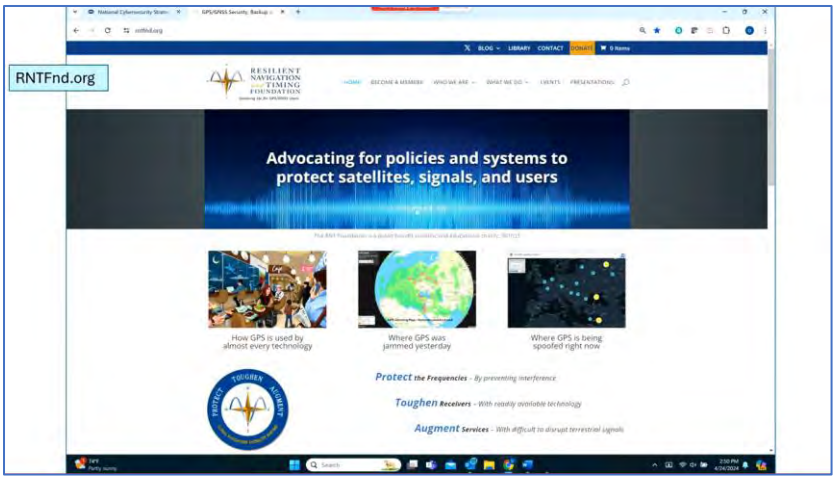
Slide 4 shows the implementation plan, including different pillars and lines of effort. It is directly applicable to the kinds of things that we want to see in PNT. PNT isn't specifically mentioned, but the government is beginning to think about these kinds of things. It wouldn't take much to apply these same kinds of things to a PNT security strategy and implementation plan (Slide 5). We have reason to be optimistic.



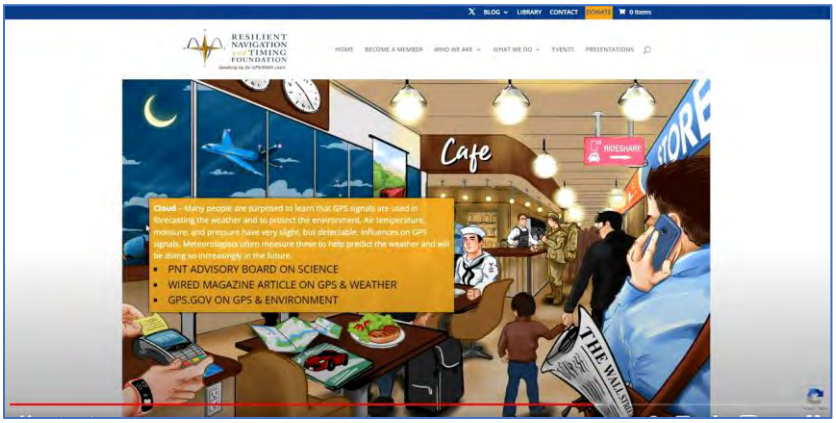
Slide 4

Slide 5

The RNT Foundation has revamped the homepage. Over on the left, is its longstanding GPS Cafe (Slide 6). It is great tool, in terms of being able to talk to people about how GPS is used in many facets of life. As you mouse over it, you can see how GPS impacts maritime, agriculture, aviation, the sky, etc. (Slide 7). If the Board gets its own website, we're happy to have this ported over and used.



Slide 6



Slide 7

The RNT Foundation website also includes a link to www.GPSjam.org is a great website (Slide 8). There we can see what yesterday's interference looks like as reported by Automatic Dependent Surveillance–Broadcast (ADS-B).

Slide 8

Finally, Zurich University of Applied Sciences developed a real-time depiction of where spoofing is going on in the world (Slide 9). You can even narrow it down to one particular aircraft that's being spoofed. If you click on the dot, it will take you to Flight Radar 24 and show you the airplane that is represented by that dot. They're not always successful in showing where the airplanes have been spoofed from and where the airplanes been spoofed to. This is not a National Intelligence tool, but it's a great open-source indicator of where things are happening and what's happening in the world.

Slide 9

The RNT Foundation website also provides visibility for Board recommendations as well as our recommendations we've made independent of the Advisory Board. We post some periodically recent news items along with our comments. The most recent report covers a transatlantic Captain who had one of his two GPS receivers jammed. He was convinced that it had jammed, it had failed, and he was also convinced that he couldn't fly across the Atlantic, despite dispatch saying he's perfectly safe to fly to the Atlantic. He didn't want to do that, and so he returned to base. It's all about the human element. It's not just about systems. Systems support people, and human element is oftentimes the most important in a good and in a bad way.

Discussion:

Dr. Parkinson stated that it was a very informative and impressive briefing.

Mr. Scott observed that the spoofing that was shown was just over the last four hours.

Mr. Goward stated that the website is updated every 10 minutes.

Prof. Filjar commented that Flight Radar 24 also introduced GPS jamming maps similar to the previous one. So, it may be worth seeing what methodologies are used.

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6) International Air Transport Association (IATA)
Hon. Jeff Shane, *Member, PNTAB*

Hon. Shane stated that his presentation is the last of the meeting and the only one representing users of the system. IATA is not a provider. It represents people that depend on PNT. IATA was set up in 1945 at a time when we were creating the basic structure of international aviation after the Second World War. ICAO, the UN agency that's responsible for aviation was created in 1944, established in 1945. It sets standards at the state level, whereas IATA was set up to set standards for commercial aviation and to create global consistency within the industry. When you have a barcode that gets your suitcase from the beginning to the end of your trip, that's an IATA standard. IATA is the glue that holds the global aviation system together, even to this day. It's also a trade association. It has 320 members, including airlines from around the world. That's only a small fraction of the number of airlines in the world, but those airlines represent more than 80% of the air miles flown. In the beginning, governments didn't quite know how to organize or regulate the price for air travel, so IATA was given antitrust immunity in order to do that. One of the big functions it had in the beginning was to organize these legalized meetings of cartels where competitors would come into a room and figure out how much it ought to cost to fly from point A to point B. It did that for decades without any objection. It was anti-competitive and meant that the cost of flying was quite high until we began to see the beginnings of liberalization during the Carter Administration. That continued to be the rule. So now, IATA is out of that business. Pricing is all being done competitively now, and the net result is that many more people are flying than could ever fly before. IATA maintains a suite of back-office systems. When you buy a ticket from a travel agent, that money has to go from the travel agent to the airline. IATA facilitates that on a global basis. Travel agents are part of the IATA system. Consulting, training, as well as products and services that are provided to airlines are also part of the suite of activities that IATA engages in. It even is engaged in safety. To be an IATA member, you must submit to a thoroughgoing safety inspection by a contractor that IATA has to maintain your membership and good standing. It is a force for good in the aviation industry. One of the things that it is looking at increasingly is PNT.

Slide 1

There's a lot going on in aviation simply because aviation depends so heavily on GNSS (Slide 2). Limiting access to some GNS systems and not allowing access to other GNS systems is a concept that the aviation industry would strongly object to. You can't be in the business of flying around the world if you can't take advantage of every GNSS that's available to you everywhere. There's a lot of activity in aviation going on because GNSS is so important to the industry today. There's collaboration among a whole host of aviation-related industries.

Slide 2

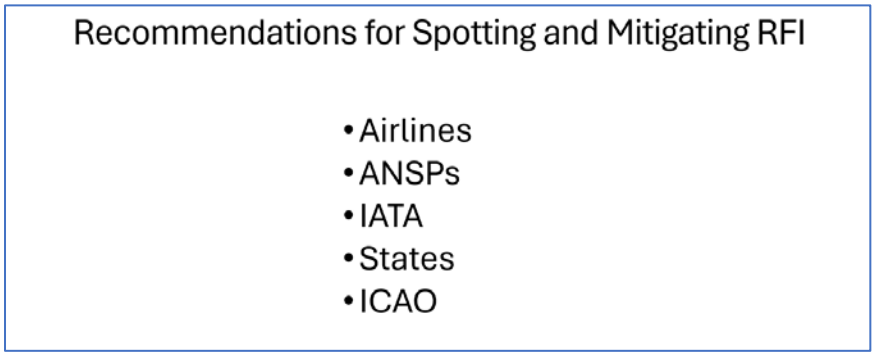
IATA has put out a safety risk assessment, which is associated with Radio Frequency Interference (RFI) (Slide 3). RFI has been a problem for aviation long before there was anything like GNSS. Aviation has depended on clean spectrum and clean transmissions from the get-go. RFI interference has long been an issue, but now it is focused quite specifically on interference with GNSS. Flight management systems, terrain avoidance warning systems, and enhanced ground proximity warning systems depend to a great extent on GNSS.

Slide 3

The maps that Mr. Goward displayed during his presentation, are all plugged into the aviation system today, such that when there is an anomaly (we know that there are a lot of anomalies over conflict zones) it's critical to the international aviation system and even to domestic aviation systems that those anomalies are identified (Slide 4). The FAA has warned airlines to turn off their GNSS receivers when they are flying over conflict zones, or any other place that's been identified as being afflicted by RFI. There are minimal operational performance standards proposed. All of this is designed to ensure the integrity of GNSS as applied to commercial aviation.

Slide 4

In January 2024, in Cologne, Germany, which is the headquarters of the European Aviation Safety Agency, there was a workshop, cooperative workshop done by IASA & IATA to discuss the effect of spoofing and jamming on aviation (Slides 5-6). More than 120 people came from several stakeholders, and the idea was to figure out a way to make GNSS more resilient for aviation purposes. The culture of aviation is one that is based on a concept called "zero defects." Aviation is an incredibly safe industry today. We haven't had a fatal crash in the U.S. since 2009. To the extent that aviation is so reliant on GPS and GNSS generally, you can imagine the importance that aviation places on clean spectrum, resilience in the system, and making sure that there are either no anomalies or if there are anomalies, they are identified in a way that they can be overcome. Slide 7 summarizes the guidance from this workshop, which calls upon stakeholders to continue to focus on this activity and develop more solutions.



Slide 5

Slide 6

Slide 7

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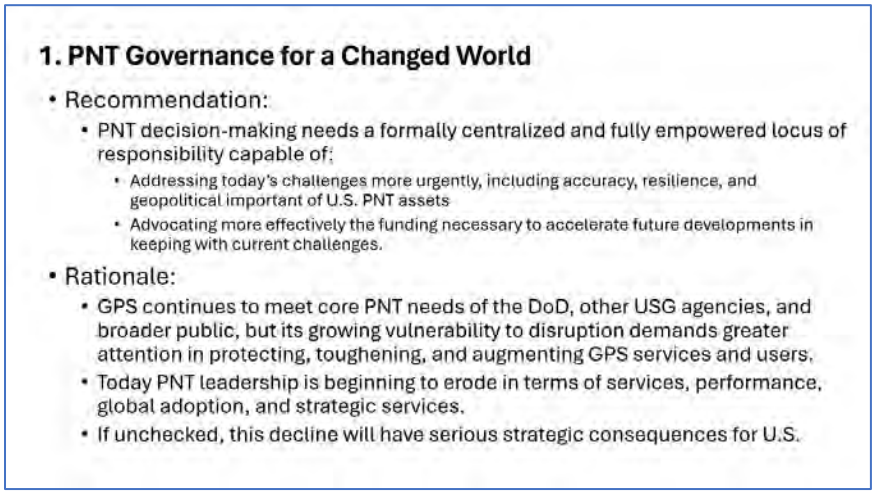
Roundtable Discussion & Next Steps

Dr. Parkinson stated that the Board has two very important issues to deal with before it closes. The first is to look at the wording of the proposed recommendations and figure out what to do with them. The first one is "PNT Governance for a Changed World" (Slide 1).



Slide 1

Dr. Betz stated that "formally centralized" and "fully empowered" can mean a lot of different things. Does that mean all the funding for anything PNT related comes from it? What is the actual role, responsibility, and authority of what we're proposing here?

Hon. Shane stated that the concept of fully empowered meant "all of the above." We have lots of coordinating bodies within government. One could argue that that's exactly what we have right now in PNT: the EXCOM. What's not clear is whether the EXCOM has the authority to do anything itself. The funding goes to the agencies that are participating, much of it to DoD. If there's to be a single source of effective PNT leadership within the government, it is going to have to have funding responsibility. This is a big ask. This may be more than it makes sense to recommend.

Lt Gen Hamel stated that yesterday the Board talked about having a category of conclusions or observations from the Board without necessarily a recommendation, and this would tee up the, "So what?" and that would lead to where do we think we need to drive to with more focus and deliberation on this topic.

Hon. Shane said that is a very helpful comment. What we really need to do is get people thinking about this stuff. Maybe the recommendation itself is too specific, too hard, and perhaps a fool's errand. However, shouldn't we be thinking about the need for a centralized source of authority and make that the kind of recommendation we're talking about?

Dr. Powell commented that this reads like a finding rather than a recommendation with an action verb.

Dr. Parkinson agreed, saying that if the statement was "please organize yourself and appoint a Tsar," then it is a recommendation. This is an urgent observation which states that we can't figure out who is in charge.

Lt Ge. Hamel commented that the subject of this is "PNT governance within the U.S." The world has changed since this apparatus has been stood up, and it's inadequate to the challenges we're facing. So, what do you do about it? This will be one of the topics that gets pursued going forward.

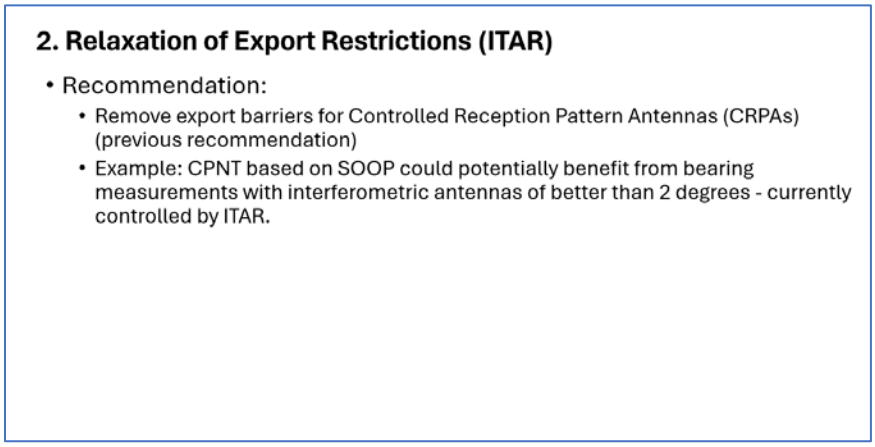
Dr. Parkinson asked the Board if they agree that this can be modified from a recommendation to an urgent observation. He also appointed Hon. Shane and Lt Gen Hamel to modify the wording as necessary. Circulate the revised version to everyone.

Mr. Goward commented that the last slide from the CER Subcommittee highlight talks about communicating this idea in terms of the whole-of-government effort needed, good work going on, current PNT governance unsuitable for a changed world, imperative the U.S. losing the PNT race to China, etc. Mr. Goward offered that information as this recommendation is being reworded.

Dr. Parkinson stated that the next step will be whether Chairman wants to include this in his two-page memo or not. If he doesn't, we still want to make this a matter of record and ensure that it is somehow communicated.

Dr. Betz stated that this would be a finding that we agree upon, but it's not accompanied by a specific recommendation.

Dr. Parkinson moved on to the recommendation "Relaxation of Export Restrictions (ITAR)" (Slide 2). He noted that in this case there should be a background that says, "We recognize that activities are going on, but we are in a little bit of a quandary because we don't know what exactly they're planning to do." It sounds like a finding, as well. The finding would be that this is still our strong recommendation, and we're dismayed that it hasn't moved forward faster.

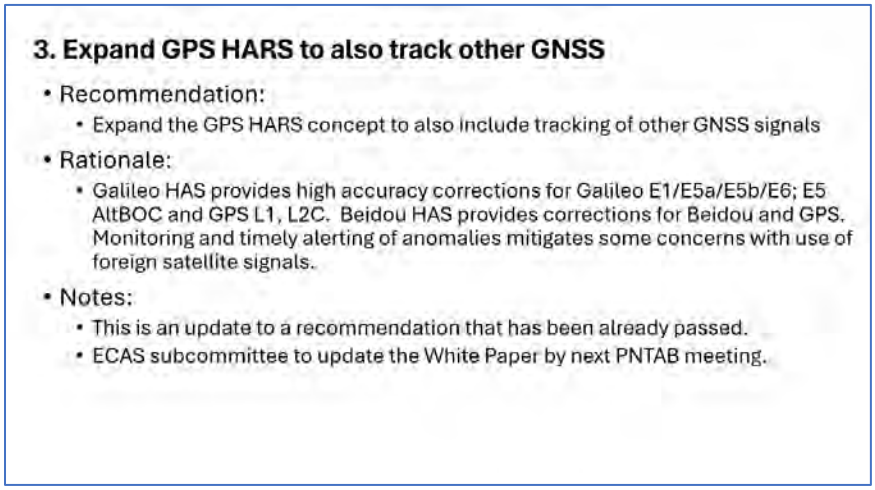


Slide 2

Dr. Betz worries that the example is obscure based on the acronyms. The first bullet is stronger without bothering the example. Mr. Murphy stated that as the originator of that example, we should do more examination into the ITAR issue and what might be impeding progress. We went with a recommendation about CRPAs. It happens that in the section on CRPA, it talks about angle of arrival limitations. We didn't make a recommendation to take that out. Maybe we need another white paper. There's a lot of research going on navigation radars. Radar manufacturers are looking at things like doppler measurements and other things that could be used to aid navigation systems. They'll run afoul of ITAR because ITAR has limitations on waveforms for low probability of intercept. This is an area that deserves more study.

Dr. Parkinson said that he read that deep integration with inertial seemed to be somehow constrained, which is another real travesty. This is going to reinforce the urgency of doing this, and we will offer a few words for incorporation in to the Memo.

Dr. Parkinson moved onto the recommendation to "Expand GPS HARS to also track other GNSS" (Slide 3), and asked if it rises to the level that it should be incorporated in the memo?



Slide 3

Dr. Powell asked if this is a supplement to the original recommendation to HARS.

Dr. Parkinson confirmed that it is.

Dr. Powell stated that the Board should revise the HARS recommend doing HARS and include Galileo.

Dr. van Diggelen stated that the consensus among the ECAS subcommittee was that beyond GPS and Galileo, anything else would make it less likely that this would get funded because throwing mentioning BeiDou adds some toxicity that people will kind of recoil from. So that was the majority but not the unanimous consensus of the subcommittee.

Mr. Murphy stated that the wording is ambiguous. We don't need to go in and say, "Do this and not that." The concept that we're going to provide corrections for other constellations is a good place to start and stop.

Dr. Parkinson agreed. We want to hear the corrections to BeiDou because that's an indication of whether there's some attempt to fool us. We may not want to get into that at this level.

Mr. Goward commented that this could be counterproductive. It seems to me the HARS idea is well accepted and the government's moving at its own pace to make it happen. This seems to be adding another layer of complexity. Not that this is wrong or bad, but maybe we should just leave well enough alone because it's not broken. It seems to be going along okay.

Dr. Parkinson stated that it isn't clear that it's going well. It's going very slowly.

Dr. Betz said that we're in the same situation here that we are with the ITAR where the government has indicated that something is happening, but we don't have any visibility into what and when. Maybe that becomes a similar finding that we understand the government is thinking about HARS and we're eager to understand more about what's actually going to happen.

Mr. Goward agreed, saying that would be good as opposed to building more on what we did.

Dr. Parkinson stressed the importance of urging them to move ahead with what is for the benefit of many users.

Lt Gen Hamel thought that the Board was heading in the direction of trying to make a strong and emphatic recommendation to create a government-sponsored program to implement this as part of our overall integrated PNT capability the nation.

Dr. Parkinson agreed but said that the point that's being raised is that we've already recommended this.

Lt Gen Hamel asked if we should remind them. Where was it that somebody got the rose pin on them to say, "We've got this great stuff going on, how are we marching to creating a program to actually deliver this, not unlike was that is a fully funded and active program that the government stands behind."

Mr. Goward stated that he hates that everything takes six months because that's how we get together, but this "recommendation" should say "you need to get your act together and have a program and then as a part of that program ... but first you have to have the program so you can execute this stuff."

Lt Gen Hamel asked if the point is a strong recommendation creating and defining a program that the government intends to provide it as a service.

Dr. Goward stated that, "All these things that need to be done and are bubbling along on idol that need to be accelerated because you don't have your act together yet."

Lt Gen Hamel said that there's a lot of subordinate things, but the first point would be strongly recommending a program get defined to implement this.

Dr. Parkinson proposed that the Board has an "observation that we don't see any expedited action going on our recommendation and that we would point out that they need to have leadership funding and a schedule."

Dr. van Diggelen stated that this draws attention to the accuracy and what we've seen over the last 6 months is that it's the resilience of the proposed system that really is resonating. The letter from Apple specifically points that out. They want the resiliency by having the navigation message. That's the big information and what Lt Gen Hamel is saying, we want to push on what we've already recommended.

Dr. Parkinson proposed that Dr. van Diggelen and Lt Gen Hamel work together on a revised product.

Lt. Gen. Hamel asked if there is any opposition to the idea of saying there needs to be a program for a multitude of reasons, and we see no evidence that a program is getting defined for this.

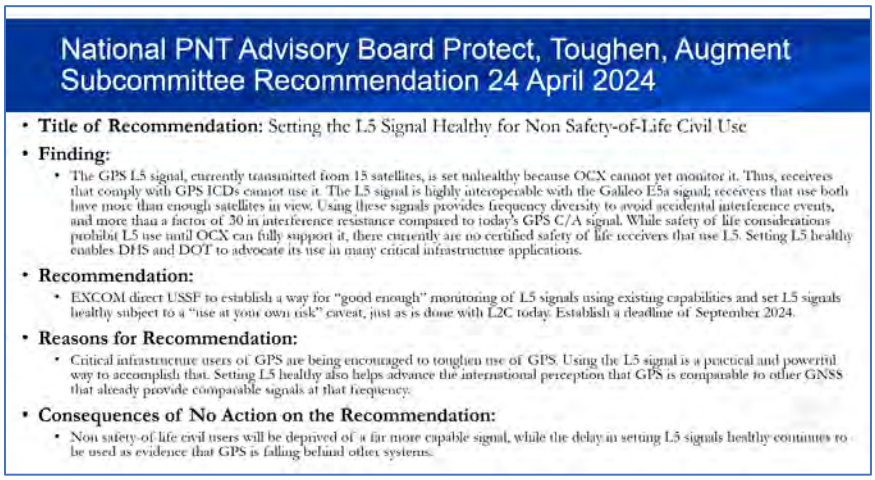
Mr. Miller supported Lt Gen Hamel. He noted we've made a lot of progress. We've got traction, but we are not there yet, and now is not the time to back off.

Dr. Parkinson stated that this is a restatement of a recommendation, not a new recommendation, but it has a greater sense of urgency.

Dr. Madani asked what the significance of the word "also" in that first sentence of the recommendation. The word "also" may not reflect anything. Nothing happened yet.

Dr. van Diggelen stated that the recommendation and its wording is moot because he and Lt Gen Hamel are tasked with revising it.

Dr. Betz brought up the recommendation on setting the L5 signal healthy for non-safety-of-life civil use. This recommendation was discussed extensively on the previous day.



Slide 4

Dr. Parkinson stated that we've discussed it enough. We know what we are asking for. It might be that this is a footnote to the headline, which is the recommendation itself.

Dr. Betz stated that it's worthwhile having these individual recommendations endorsed by the Board, even if they take a different form in the letter. This way we can point to them in the future as something that the board has endorsed.

Dr. Parkinson stated that he understood that the Board is going to have a set of these that were the current urgent ones, the other ones are not of lesser importance but perhaps of lesser urgency, and the education recommendation discussed yesterday fell in that category.

Dr. Betz stated that it was his understanding was that we agreed on the education one. Whether that gets forwarded as part of the letter or not is a different topic, precisely.

Dr. Parkinson agreed and asked if the members were okay with this recommendation. Hopefully it will end up in our Chair's letter.

Dr. Parkinson moved onto the recommendation about "Adopting Civil Use of Dual-Frequency GPS/Galileo Receivers" (Slide 5). On the previous day there was quite a bit of conversation on this one whether it was dual or triple frequencies. He stated that he doesn't have any trouble with the recommendation as worded.

Slide 5

Hon. Shane asked if this is just for purposes of the USG agency CIOs only.

Dr. Betz stated that there's two parts: First, direct Federal CIOs to do it, because that's where the government can actually direct things to happen. Second, DHS should actively encourage critical infrastructure users to do the same thing. That's the second sentence in the recommendation.

Hon. Shane asked Mr. Betz what he would say to his former mates at IATA.

Dr. Betz clarified that this needs to say "non-safety of life."

Dr. Parkinson clarified that the two complement is for non-safety of life GPS use.

Dr. Madani stated that he though two should be the minimum. And if people want to do three, go ahead.

Dr. Betz stated that he can modify the wording to say "multifrequency non-safety of life."

Dr. Parkinson stated that the wording on the formal is left in Dr. Betz's your hands. The wording on the summary is left in the hands of the NASA support staff.

Ms. Van Dyke reminded Hon. Shane that this recommendation regards critical infrastructure that's non-safety of life.

Dr. Betz stated that there are 16 sectors, and not all of them are safety-of-life sectors. Agriculture is not-safety-of life.

Mr. Scott argued that if you say safety of life, what is law enforcement? Are they safety of life or not? They should be adopting the use of dual frequency.

Dr. Betz concluded that the recommendation would say "certified safety-of-life."

Dr. Madan stated that he highlighted yesterday that there's a burden on the end user, and we're taking critical infrastructures to test and verify, as well as upgrade their system. On the energy side, I don't see any issues as long as it's reliable and they're going to test it. The word "safety," in this case may not be significant.

Dr. Betz responded, saying that the aviation community goes through a very sophisticated and complicated certification process that they will do in their own time. We're not recommending that this be done this year. So that's why we're saying, "not for certified safety-of-life applications."

Mr. Murphy asked why the Board is doing that. All the recommendation says it to is encourage critical infrastructure. We're already headed in that direction for aviation. So why are we carving it out?

Dr. Betz said the Board will leave it as is.

Mr. Higgins asked if the CIO reference is for critical infrastructure operators.

Dr. Betz states that the federal CIOs have their own PNT equipment and they're not necessarily part of the critical infrastructure sectors. So, we're recommending that Federal CIOs do this as well.

Dr. Parkinson then moved to the recommendation to appoint an authoritative Tsar who is sanctioned by all the departments to ensure that that person can "get it on." I n a side conversation that Dr. Parkinson had with Ms. Van Dyke, there is someone who is virtually in that role, but the issue here is to get all the departments lined up and say, "support that person, he's in charge."

Slide 6

Lt Gen Hamel stated that this must be identified as a national capability and there must be a program with an assigned authority and lead agency, and there needs to be an interagency operational process to it. There are elements out there, but nobody has that ownership or accountability right now.

Dr. Parkinson responded, saying that a lot of those pieces are in place, and it isn't for a lack of somebody wanting to be in charge. What this is doing is enabling and formally making that person the one in charge.

Lt. Gen. Hamel commented that it's important to have a laser focus on priorities assigned to critical infrastructure applications. This will raise the question, "How do you bring in the full interagency programmatic and operational aspects?

Dr. Parkinson strongly agreed.

Lt. Gem Hamel stated that it would be very appropriate to get a couple of people to identify and to take credit for all the good things that are going on, but recognize it's not meeting the needs in terms of time and scope of what's involved. DoD nor DHS are anywhere near as invested as they need to be in this.

Ms. Van Dyke commented that DOT is moving to having that common operating picture. Then what has to happen is those 24/7 operation centers starting with 2 SOPS and their GPS Warfighter Cell, the FAA Center, DOT's Transportation Operation Center, USCG NAVCEN, and FCC all coming together. That's part of the Crucible process that they all work when we have an interference event.

Lt Gen Hamel stated that all that's good, but the point is we know there are obstacles ahead and so who is it's going to lead plowing through those obstacles? If this lands on somebody's doorstep, how would they react? We got to somehow elevate this. This is not proceeding at a pace that's going to get us to a real solution until we know there's a program and a committed interagency operational response.

Dr. Parkinson suggested adding "clear responsibility and authority."

Ms. Van Dyke offered to follow up with Lt. Gen. Hamel offline to provide a brief view on the details.

Hon. Winfree (participating virtually) commented that there's the top line of the interagency coordination on interference monitoring and elimination. But there's a strong component that calls for law enforcement. Yesterday, FCC stated their absence of an ability to have teeth when and if they detect an interfering event. They can knock on the door and ask the person to shut it off, but they can't confiscate it. There is an element of law enforcement that's needed, and the civil agencies don't have that

bandwidth. Deputizing the U.S. Marshals or Federal Bureau of Investigation (FBI) is what we need to put some teeth into the illegality, particularly jammers and spoofers operating within the borders.

Dr. Betz read the recommendation that states, "this individual should identify current technical, legal, organizational, operational, and other obstacles and then develop a plan and submit it to the EXCOM to address them."

Dr. Parkinson commented that the Board may want to foot stomp the modification of the law to grant authority to somebody to shut the things down.

Dr. Madani stated one of the comments Mr. Rhodes from DHS made yesterday was that last February, there was an incident in the Denver area and the only people that noticed it were the FAA and airline pilots. Airline pilots have a process in place that they can report these, but there is no process if anybody other than some agency monitoring it. He asked if the Board needs to expand on this to say and establish a process for reporting.

Dr. Parkinson stated that the recommendation is asking the individual to identify current technical, legal, organizational, operational, and other obstacles. We could expand on that and try to tell them what to do, but the operational should be interpreted as including the reporting channels.

Prof. Filjar asked if we needed the word "significant" in the second line of recommendation. This significance should be somehow defined or simply say that we need the activity regarding the mitigation of sources of interference.

Dr. Betz stated that every personal privacy jammer is harmful to the receiver that's 10ft away from it. So, the idea was not to get to the point of chasing individual Personal Portable Jammers (PPJs), but instead things that are starting to affect enough of the nation, economy, and region that they merit attention.

Hon. Shane stated the first recommendation reviewed by the Board was the second of two recommendations that he put forward on one slide in his briefing yesterday. The first one being the need for a declaration of policy. This is a big deal. We may not need a fresh declaration of policy, but that was one of the primary points on that slide. He stated that Lt Gen. Hamel and himself will figure out how to incorporate that.

Dr. Parkinson asked where and when will the next meeting take place.

Mr. Miller stated that Admiral Allen wanted to put the memo up right after this meeting, but we had a lot of good discussions. There were some new things brought up, and so I have been communicating with him back and forth with him. Mr. Miller asked whoever is revising the text to include Dr. A.J. Oria and himself to ensure that we're synced, and then hopefully in a week's time, we're ready to roll on that.

Dr. Parkinson it is not doable to have a meeting in October in the Washington, DC area is not doable due to the price and upcoming election. The alternative would be the 18-22 of November, and the first two weeks in December.

The week of 2nd of December may be most ideal, and aim to be in the vicinity of Washington, DC.

Dr. Madani noted that Monday, December 2 is the Monday after Thanksgiving, which may result in more expensive flights. The Board agreed to have the meeting on December 4 - 6, 2024. December 4th would be working subcommittee sessions, day one would fall on the fifth, and day two on the sixth.

Dr. Parkinson thanked all of the Board members.

Mr. Miller announced that the NASA support team has received an Agency Honor Award for their work.

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Dr. Parkinson adjourned the meeting.

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Appendix A: National Space-Based PNT Advisory Board Membership as of the 30h Meeting

Special Government Employees

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

- Thad Allen (Chairman), 38th Commandant, U.S. Coast Guard
- Bradford Parkinson (1st Vice Chair), Stanford University
- James E. Geringer (2nd Vice Chair), Environmental Systems Research Institute
- John Betz, MITRE
- Scott Burgett, Garmin International
- Joseph D. Burns, The Airo Group
- Patrick Diamond, Diamond Consulting
- Dorota A. Grejner-Brzezinska, The Ohio State University
- Bryan Chan, Xona Space Systems Inc.
- Michael Hamel, Former Commander, Space and Missile Systems Center
- Larry James, Jet Propulsion Laboratory
- Vahid Madani, GridTology
- Jade Morton, University of Colorado Boulder
- Timothy A. Murphy, The Boeing Company
- Tom Powell, Aerospace Corporation
- Eileen Reilly, Global Train Services
- Logan Scott, Logan Scott Consulting
- T. Russell Shields, Former President and CEO, RoadDB
- William Shelton, Shelton Consulting Inc.
- Gary Thompson, North Carolina Geodetic Survey
- Frank van Diggelen, Google
- Todd Walter, Stanford University
- Gregory D. Winfree, Texas A&M Technology Institute

Representatives

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

- Renato Filjar, University of Rijeka (Croatia)
- Dana Goward, Resilient Navigation and Timing Foundation
- J. David Grossman, Consumer Technology Association
- Matt Higgins, International GNSS Society (Australia)
- Terry Moore, University of Nottingham (UK)
- Jeffrey N. Shane, International Air Transportation Association (IATA)

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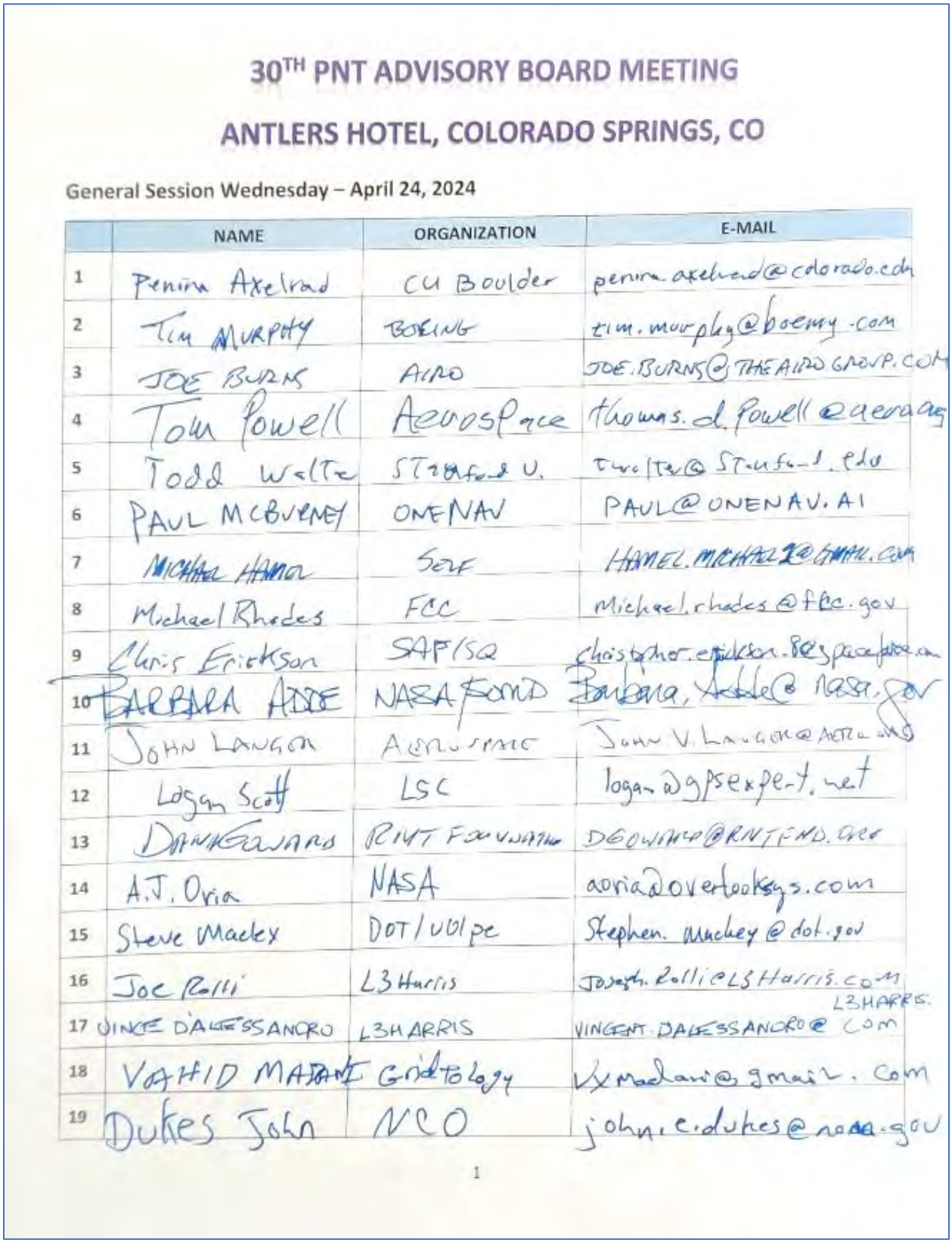
Executive Director

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

- James J. Miller, Executive Director

Appendix B: Sign-In Sheets



30TH PNT ADVISORY BOARD MEETING

ANTLERS HOTEL, COLORADO SPRINGS, CO

General Session Wednesday – April 24, 2024

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6	Paul McBurney	OneNav	PAUL@ONENAV.AI
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30TH PNT ADVISORY BOARD MEETING

ANTLERS HOTEL, COLORADO SPRINGS, CO

General Session Wednesday – April 24, 2024

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30TH PNT ADVISORY BOARD MEETING

ANTLERS HOTEL, COLORADO SPRINGS, CO

General Session Wednesday – April 24, 2024

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30TH PNT ADVISORY BOARD MEETING

ANTLERS HOTEL, COLORADO SPRINGS, CO

General Session Thursday – April 25, 2024

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18	John Betz	PNTAB	betz@mitre.org
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30TH PNT ADVISORY BOARD MEETING

ANTLERS HOTEL, COLORADO SPRINGS, CO

General Session Thursday – April 25, 2024

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Appendix C: Acronyms & Definitions

$	U.S. Dollar Currency
(AA)2	Ambient-Adaptive Applications-Aligned
2 SOPS	Second Space Operations Squadron (U.S. Space Force)
3GPP	3rd Generation Partnership Project (Mobile Telecommunications Standards)
5G	5th Generation Mobile Communications Standard
ADS-B	Automatic Dependent Surveillance–Broadcast
AEP	GPS Advance Evolution Plan
AGC	Automatic Gain Control
AI	Artificial Intelligence
AM	Radio broadcasting using amplitude modulation transmission
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
BeiDou	China's GNSS
BLUF	Bottom Line Up Front
C/N_0	Signal to Noise Ratio
CB	Citizen's Band (Radio)
CDR	Critical Design Review
CEO	Chief Executive Officer
CER	Communications & External Relations (PNTAB Subcommittee)
CGSIC	U.S. Civil GPS Service Interface Committee
CIO	Chief Information Officer
COTS	Commercial Off the Shelf
CPNT	Complementary PNT
CRPA	Controlled Reception Pattern Antennas
CTA	Consumer Technology Association
CW	Carrier Wave
dB	Decibel, a logarithmic unit that indicates ratio or gain
DHS	Department of Homeland Security
DIU	Defense Innovaiton Unit
DME	Distance Measuring Equipment (Aviation)
DOC	Department of Commerce
DoD	Department of Defense
DOJ	Department of Justice
DOP	Dilution of Precision
DOS	Department of State
DOT	Department of Transportation
E5	Galileo equivalent to GPS L5
E6	Galileo frequency band between 1260-1300 MHz. Also used by Japan and known as L6.
EA	Electronic Attack
EAR	Export Administration Regulations
ECAS	Emerging Capabilities, Applications, & Sectors (PNTAB Subcommittee)
EGNOS	European Geostationary Navigation Overlay Service
eLoran	Enhanced Long Range Navigation
ESA	European Space Agency
ESG	National Space-based PNT EXCOM's Executive Steering Group
ESI	Education & Science Innovation (PNTAB Subcommittee)
ETSI	European Telecommunications Standards Institute
EU	European Union
EUGIN	European Group of Institutes of Navigation
EUROCAE	European Organisation for Civil Aviation Equipment
EUSPA	European Union Space Programme Agency
EXCOM	National Space-Based PNT Executive Committee
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FBI	Federal Bureau of Investigation
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FY	Fiscal Year
Galileo	European GNSS
GEO	Geosynchronous Orbit

GHz	Gigahertz
GLONASS	Russia's GNSS
GMRS	General Mobile Radio Service
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS III	GPS Block III
HARS	High Accuracy & Robustness Service
HAS	High Accuracy Service
Hz	Hertz
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
ICG	International Committee on GNSS
IDM	Interference, Detection and Mitigation
IE	International Engagement (PNTAB Subcommittee)
IEEE	Institute of Electrical and Electronics Engineers
IGNSS	International GNSS Association (Australia)
IMU	Inertial Measurement Unit
IOC	Initial Operations Capability
ION	U.S. Institute of Navigation
IoT	Internet of Things
ISM	Industrial, Scientific, and Medical frequency band
ITAR	International Traffic in Arms Regulations
ITM	International Technical Meeting (ION)
ITU	International Telecommunications Union
J/S	Jamming to Signal Ratio
JAXA	Japan Space Agency
JPL	Jet Propulsion Laboratory (NASA)
km	Kilometer
L1 C/A	1st GPS Civil Signal (C/A = coarse acquisition)
L1C	4th GPS Civil Signal (interoperable with Galileo OS)
L2C	2nd GPS Civil Signal (surveying)
L5	3rd GPS Civil Signal (safety-of-life / aviation)
L-band	Operating frequency range of 1–2 GHz in the radio spectrum
LEO	Low Earth Orbit
m	Meter
M-Code	GPS Military Signal
MHz	Megahertz
MDF	Mobile Direction Finding (Vehicles)
MCMF	multi [GNSS] consternation / multi-frequency
MOD	UK Ministry of Defence
MOPS	Minimum Operational Performance Standards (Aviation)
ms	Millisecond
NASA	National Aeronautics and Space Administration
NASEM	National Academies of Sciences, Engineering, and Medicine
NAVCEN	DHS-DOT Navigation Center
NavIC	Navigation with Indian Constellation
NavISP	ESA Navigation Innovation and Support Program
NDAA	National Defense Authorization Act
NGA	National Geospatial-Intelligence Agency
NGS	National Geodetic Survey
NIST	National Institute of Standards and Technology
NSC	National Security Council
NSPD-39	National Security Presidential Directive 39 (2004 U.S. Space-based PNT Policy)
NTIA	National Telecommunications and Information Administration
NTP	Network Time Protocol
NTS-3	Air Force Research Laboratory Navigation Technology Satellite 3
OCX	GPS Next Generation Operational Control System
OMB	Office of Management and Budget
OOAD	Observe, Orient, Decide, Act
OSN	Galileo Open Service Navigation
OSTP	Office of Science and Technology Policy

PDOA	Power Difference of Arrival
PNT	Positioning, Navigation, and Timing
PNTAB	National Space-Based PNT Advisory Board
PPJ	Personal Portable Jammer
PPP	Precise Point Positioning
PRN	Pseudorandom Noise (PRN) codes are sequences of randomly distributed zeros and ones that are one millisecond long. Each GPS satellite transmits a unique PRN code.
PSIX-ESIZ	Public Safety Interference and Enterprise Safety Interference (FCC)
PTA	Protect, Toughen, and Augment, or referring to the PTA Subcommittee
PVT	Position, Velocity, and Time
QZSS	Japan's Quasi-Zenith Satellite System
R&D	Research and Development
RIN	Royal Institute of Navigation (United Kingdom)
RNT	Resilient Navigation and Timing Foundation
RF	Radiofrequency
RTCA	Formerly the Radio Technical Commission for Aeronautics, now RTCA, inc.
RTK	Real Time Kinematic
Rx	GNSS Receiver
S/A	Selective Availability
SAE	Society of Automotive Engineers
SAR	Search and Rescue
SatNav	Satellite Navigation and Timing. Sometimes referred to as SATNAV.
SBAS	Space-Based Augmentation System
SED	Spectrum Enforcement Division (FCC)
SISA	
SouthPAN	Australian Southern Positioning Augmentation Network
SPD-7	Space Policy Directive 7 for U.S. Space-Based PNT
SPF	Space Force Base
SPG	Strategy, Policy, & Governance (PNTAB Subcommittee)
SSV	Space Service Volume
STEM	Science, Technology, Engineering, and Mathematics
SV	Satellite Vehicle or Space Vehicle (USSF)
TDOA	Time Difference of Arrival
TRL	Technology Readiness Level
TWSTFT	Two Way Satellite Time and Frequency Transfer
UK	United Kingdom
U.S.	United States of America
UN	United Nations
UNSW	University of New South Wales
URL	Uniform Resource Locator (internet link)
USCG	U.S. Coast Guard
USG	U.S. Government
USSF	U.S. Space Force
UTC	Coordinated Universal Time
WAAS	FAA Wide Area Augmentation System
WiFi	Wireless networking protocol that devices use to communicate without direct cable connections. Typically refers to wireless internet local networks.

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