SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

NATIONAL SPACE-BASED POSITIONING, NAVIGATION, AND TIMING (PNT) ADVISORY BOARD

Seventeenth

Meeting

May 18-19, 2016

Gaylord National Resort and Convention Center
Woodrow Wilson Ballroom A

201 Waterfront Street, National Harbor, MD 20745

John Paul Stenbit
John Paul Stenbit
Chair

James J. Miller
James J. Miller
Executive Director

National Space-Based Positioning, Navigation, and Timing Advisory Board

Gaylord National Resort and Convention Center, Woodrow Wilson Ballroom A
201 Waterfront Street, National Harbor, MD 20745

Agenda

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WEDNESDAY, MAY 18, 2016

9:00 - 9:05
BOARD CONVENES
Call to Order & Announcements
Mr. James J. Miller, *Executive Director, PNT Advisory Board, NASA Headquarters*

9:05 - 9:15
Introduction of 17th Meeting Focus: *GPS "Threats & Opportunities"*
Mr. John Stenbit, *Chair*

9:15 - 9:45
GPS Spoofing & Jamming: *Uncovering Vulnerability Truths & Myths*

VIEW PDF (1022 KB)
Dr. Brad Parkinson, *1st Vice-Chair*

9:45 - 10:00
Welcome Remarks on behalf of PNT Executive Committee (EXCOM)
Dr. Dava Newman, *Deputy Administrator, NASA*

10:00 - 10:10
Recent PNT EXCOM Topics
National Coordination Office (NCO) Policy Perspective
VIEW PDF (564 KB)
Mr. Harold "Stormy" Martin, *Director, National Coordination Office for Space-Based PNT*

10:10 - 10:35
Global Positioning System (GPS) Status & Modernization Progress
Current & Emerging Services
VIEW PDF (3 MB)
Lt Col Andrew Zinn, *Chief, GPS Plans and Requirements, GPS Directorate, U.S. Air Force*

10:35 - 10:50
Update on GPS Space Service Volume (SSV) for Space Ops & Science
VIEW PDF (1005 KB)
Mr. Joel Parker, *NASA Goddard Space Flight Center*

10:50 - 11:10
PNT Board Recommended Criteria for Spectrum Assessments
VIEW PDF (791 KB)
Dr. Brad Parkinson, *1st Vice-Chair*

11:10 - 11:35
GPS Adjacent Band Compatibility (ABC) Assessment
VIEW PDF (720 KB)
Ms. Karen Van Dyke, *Director for PNT, Department of Transportation (DOT), Office of the Secretary (OST)*

11:35 - 12:00
Presentation of Roberson and Associates Testing Results
VIEW PDF (440 KB)
Dr. Ken Zdunek, *Vice President and Chief Technical Officer, Roberson and Associates*

12:00 - 1:00
LUNCH – *Special Government Employees (SGE) Annual Ethics Review*

1:00 - 1:20
U.S. International Engagements & Partnerships
Bilateral & Multilateral Collaboration
VIEW PDF (537 KB)
Mr. Ken Hodgkins, *Director, Office of Space and Advanced Technology, U.S. Department of State*

1:20 - 1:45
Activity Overview of Emerging PNT Services & Capabilities
United Kingdom Government Perspective
VIEW PDF (1 MB)
Mr. Andy Proctor, *Chair, UK Government PNT Group and UK Delegate to ESA Navigation Board*

1:45 - 2:10
International GNSS Service (IGS) Orbit Dynamics, Modeling, & Timing
IGS Advances & Future Applications
VIEW PDF (4 MB)
Dr. Marek Ziebart, *Professor of Space Geodesy, University College of London*

2:10 - 2:35
Networks for Robust Civil Signal Performance Monitoring & RFI Detection
VIEW PDF (2 MB)
Dr. Yoaz Bar-Sever, *Program Manager, Global Differential GPS (GDGPS), NASA JPL*

2:35 - 2:50
BREAK

2:50 - 3:15
Satellite Time and Location (STL): *Development and Testing of an Iridium Based Position Navigation and Time Capability*
VIEW PDF (1 MB)
Dr. Gregory Gutt, *Chief Technology Officer, Satelles*

3:15 - 3:40
Techniques for Radio Frequency Spectrum Mapping from Space
VIEW PDF (2 MB)
Mr. Russ Matijevich, *Vice-President, HawkEye 360*

3:40 - 4:05
Emerging Microsystem Technologies for Autonomous PNT
Advances from Defense Advanced Research Projects Agency (DARPA)
VIEW PDF (3 MB)
Dr. Robert Lutwak, *Program Manager, Microsystems Technology Office, DARPA*

4:05 - 4:30
The Use of GPS for Vehicle Control Applications
Integrating Techniques for Intelligent Transportation Systems (ITS)
VIEW PDF (3 MB)
Dr. David M. Bevly, *Professor, Department of Mechanical Engineering, Auburn University*

4:30 - 5:00
GPS Timing Challenges and Robustness Needs for Critical Infrastructures:
Examples from Telecom, Broadcast and Power Distribution Industries

VIEW PDF (545 KB)
Mr. Magnus Danielson, *Senior System Architect, Net Insight AB (Ltd)* & Alison Silverstein, *Program Manager, North American Synchrophasor Initiative*

5:00
ADJOURNMENT

THURSDAY, MAY 19, 2016

9:00 - 9:05
BOARD CONVENES
Call to Order
Mr. James J. Miller, *PNT Advisory Board Executive Director, NASA HQ*

9:05 - 9:30
Announcements & Agenda
Quick Thoughts & Member Feedback from May 18 Deliberations
Mr. John Stenbit, *Chair;* Dr. Bradford Parkinson, *1st Vice-Chair;* Gov. Jim Geringer, *2nd Vice-Chair*

Representative PNT Board Member Updates & Perspectives

9:30 - 9:55
CEPT ECC Recommendation that Authorizes Commercial GNSS Pseudolite Operations Indoors in the RNSS Band in Europe
VIEW PDF (180 KB)
Ms. Ann Ciganer, Mr. Mike Swiek, & Dr. Kurt Zimmerman, *GPS Innovation Alliance*

9:55 - 10:20
Multi-GNSS Monitoring by International GNSS Service (IGS) and International Committee on GNSS (ICG)
VIEW PDF (651 KB)
Dr. Gerhard Beutler, *International Association of Geodesy*

10:20 - 11:00

- Representative Concise "Snippets" at Member's Discretion:
  - Mr. Arve Dimmen, *Norwegian Coastal Administration*
  - Mr. Dana Goward, *Resilient Navigation and Timing Foundation*
  - Mr. Matt Higgins, *International GNSS Society*
  - Dr. Refaat Rashad, *Arab Institute of Navigation*
  - Dr. Sergio Camacho-Lara, *U.N. Center of Science and Space Technology*

11:00 - 11:15
BREAK

11:15 - 12:00
PNT Board Member Roundtable Discussion
Prepare Recommendations for June 23, 2016, PNT Executive Committee
All PNT Board Members

12:00 - 1:00
LUNCH - *Working*

1:00
ADJOURNMENT

Dates and times are as originally scheduled and do not reflect actual presentation times.

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17th PNT ADVISORY BOARD SESSION

EXECUTIVE SUMMARY:

The 17th session of the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board met on May 18-19, 2016, at the National Harbor, Maryland. The principal goal of this session was to develop recommendations to present to the June 23, 2016 meeting of the PNT Executive Committee (EXCOM).

HIGH-LEVEL ACTION ITEMS:

- Mr. John Stenbit, Chair, asked the board members to provide a topics of interest list including, but not limited to, aviation, automated transportation, infrastructure, science, Global Navigation Satellite System (GNSS) receiver improvement, and GNSS spectrum protection. This information is to be used in the creation of standing subcommittees.
- Dr. Bradford Parkinson, 1st Vice-Chair, was tasked with drafting, in concert with other board members, a letter with recommendations on GNSS spectrum assessments for the EXCOM.
- Mr. Stenbit noted he would review and discuss the outcomes of the next Executive Steering Group (ESG) of the EXCOM with board members.
- Mr. Stenbit noted that board members would be tasked with preparing the information needed for the June 23, 2016 EXCOM session.
- Mr. Stenbit noted that the board would "flesh out" three key issues that would need to be addressed in any transition document for the EXCOM.

OTHER ACTION ITEMS:

- Mr. Jeffrey Auerbach, Dept. of State (DOS), said he would inform the board on the current status of the U.S. agreement with the European Union, first negotiated in 2004.
- Maj Gen David Thompson said that he would share as much publicly-releasable information as possible on the SVN 23 incident from the Air Force before the next Advisory Board meeting.
- Mr. Kenneth Hodgkins, DOS, noting the remarkable achievements in the past 30 years in space-based PNT, urged the board to undertake a formal historical assessment of how such progress had been achieved.
- Mr. Dana Goward, board member, said his organization would be happy to investigate the creation of a consortium of GPS users that could speak with authority to Congress, and others, on issues that could threaten current and future GPS use.
- Maj Gen Thompson, noting that the Air Force is getting ready to finalize its technical plans, said he would welcome any suggestions from the board regarding technologies it may wish the Air Force to review, including user and ground control equipment.

MEETING NOTES

The 17th meeting of the National Space-Based Positioning, Navigation, and Timing Advisory Board was called to order on Wednesday, May 18, 2016 at 9:00 a.m.

Board Convenes

Call to Order & Announcements
Mr. James J. Miller, *Executive Director, PNT Advisory Board*
NASA Headquarters

Mr. Miller called to order the 17th meeting of the Space-Based PNT Advisory Board. He thanked the co-Chairs and participants for attending, and also thanked Maj Gen David Thompson for his presence to provide the perspective of Air Force Space Command (AFSPC). The National Aeronautics and Space Administration (NASA) established the Advisory Board to give varied perspectives on space-based PNT. The body is subject to Federal Advisory Committee Act (FACA) rules. Sessions are public, comments are on the record, and formal meeting minutes will be posted on www.gps.gov within 90 days. FACA regulations call for a membership balanced by perspective and function. The Executive Branch has long sought advice; one early example is when U.S. President George Washington sought the advice of a committee during the Whiskey Rebellion of 1794. There are a number of ethics rules FACA members are required to follow such as, for example, members with a conflict of interest on a particular item must publicly recuse themselves from discussing that item. The Advisory Board, as an independent non-governmental body, allows the airing of views that might not otherwise be presented. The ultimate goal of the 17th Advisory Board session is to develop recommendations for presentation to the June 23, 2016 meeting of the PNT EXCOM. Also, Dr. Dava Newman, Deputy Administrator, NASA, will provide a perspective from the Advisory Board's official sponsoring body.

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Introduction of 17th Meeting Focus: "Threats and Opportunities"
Mr. John Stenbit, *Chair*

Mr. Stenbit, Chair noted the board is tactically worried about defense and strategically worried about offense. The most important issue cited in the previous day's work session is spectrum protection and interference. Additionally, various good ideas have been put forth for improving GPS service to national and international users. In his view, the board is properly balancing threats and opportunities.

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GPS Spoofing & Jamming: Uncovering Vulnerability Truths and Myths
Dr. Brad Parkinson, *1st Vice Chair*

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/stenbit-parkinson.pdf

Dr. Parkinson provided a high-level review on the topic of "spoofing". The board's primary objective is that of assured PNT service to all users. Given that no foreseeable alternative to GNSS exists, this objective is under threat. Those threats include re-purposing of adjacent frequency bands; deliberate or unintentional jamming, and spoofing. The strategic response from the board is to "Protect, Toughen, and Augment" GNSS. Spoofing is a serious threat. In a recent spoofing experiment, an $80 million yacht was turned off course. Spoofing is defined as deliberately creating of false signals. This can be achieved in a number of ways. There are also a number of ways to prevent spoofing and, in his view, competent GNSS receivers should implement them. However, such defenses are under-deployed. It is essential to develop and use competent receivers that can cross-check multiple signals and field more selective antennas. The checks on the signal integrity that will soon be available must be employed. Positioning cross-check involving multi-GNSS systems will identify the source of spoofing. While other approaches are possible, cross-checks are the most cost-effective technique. Currently cross-checking techniques are, in general, not used because equipment manufacturers understate the threat.

Dr. Parkinson's emphasized the central message is that spoofing must be eliminated, and for that purpose he recommended a three-step draft statement for the Advisory Board to consider: (1) develop a formal national threat model for PNT applications in critical infrastructure; (2) establish a framework for using foreign GNSS once integrity validation is established; and (3) establish a nationwide back-up to GPS with existing infrastructure (e.g. Enhanced Loran, or eLoran, which was initially approved, then cancelled, and is now again under consideration).

Ms. Neilan asked how frequently spoofing occurs.

Dr. Parkinson said he does not know. Spoofing is not well monitored, and most known cases have been artificially created by academics for the purpose of testing. Still, the publicity being given to spoofing may lower user confidence in GPS and, thus, it is essential that equipment manufacturers start implementing cross-checks.

Mr. Goward expressed concern that spoofing has become available at the consumer level. In fact, there was an event where kits to assemble spoofers were offered for US$300. Which techniques should consumer-level devices use against such threats?

Dr. Parkinson said his recommendation is more general. A full blown threat assessment regarding GPS is needed, and good receivers should be able to screen out crude spoofing devices such as those described by Mr. Goward.

Dr. Enge noted that spoofers are designed to be undetectable, which is why it is difficult to know when or how often such attacks occur.

Mr. Goward expressed concern that the government is not moving fast enough in its reconsideration of eLoran.

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Welcome Remarks on Behalf of PNT EXCOM
Dr. Dava Newman, *Deputy Administrator, NASA*

Dr. Parkinson introduced Dr. Newman, and noted he is particularly pleased that NASA has appointed an engineer with a very strong background in space as Deputy Administrator.

Dr. Newman noted the presence of many friends and colleagues, and that she is excited to represent NASA to the PNT EXCOM. The PNT Advisory Board was established in 2007 as NASA's contribution to PNT. She is thoroughly impressed with the members' hard work in the past as well as its plans for the future. Dr. Newman acknowledged Maj Gen Thompson's contribution by making the PNT board meeting a high priority, and she also thanked the international members serving on the board.

Dr. Newman referred to international GNSS systems, asking how they could be made interoperable and enhanced for the global good. Service to GPS and GNSS users worldwide is supported by the board's efforts to Protect, Toughen and Augment. GPS contributes substantially to prosperity areas such as weather forecasting, early disaster warning, precision agriculture, transportation, and others. For example, GPS contributed more than US$68 billion to the U.S. economy in 2013 alone. Dr. Newman praised the continued exploration of GPS capabilities, including the development of the GPS Space Service Volume to support users in space as well as new applications on the horizon.

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Recent PNT and EXCOM Topics: National Coordination Office (NCO) Policy Perspective
Mr. Harold "Stormy" Martin, *Director,*
National Coordination Office for Space-Based PNT

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/martin.pdf

Mr. Harold Martin said the best analogy for the ubiquity of GPS is the Internet. GPS is essential to the global information infrastructure and its free and open nature has prompted hundreds, if not thousands, of applications. GPS has advanced many scientific aims. Everyone agrees that it provides a great benefit to agriculture, transportation, and many other areas. Therefore, what would the impact be if, hypothetically, GPS were absent for a day, a week, month, or longer? How would power grids, precision agriculture, telecommunications, and transit operations be affected?

GPS policy consistency greatly benefits its users. The U.S. government remains committed to free user access, worldwide, without user fees, and encourages compatibility and interoperability. The U.S. pledged to maintain the constellation needed to meet civil and national security needs. It also supports international activities to detect, mitigate, and increase resiliency to interference.

There is a long-term mandate to develop, acquire, and maintain backup PNT capability. Along with this mandate, the EXCOM has been looking at the larger question: what consequences would follow disruption of GPS either regionally or internationally? Prevention comes in part from sustained emphasis on GPS modernization, for great credit is due to AFSPC. Further protection comes from global collaboration with partner agencies and nations. It is no surprise that over the past quarter century other countries have invested billions to create their own systems. The U.S., through the DOS continues to work with these countries.

For five years the EXCOM has regarded spectrum management as a strategic topic, and this is likely to remain an issue for years to come. Regarding critical infrastructure, 14 of the 16 critical infrastructures rely on GPS for their timing function; and all 16 use GPS in some form or fashion. In terms of PNT resilience, earlier this year North Korea had jammed GPS over South Korea and affected thousands of users. The first step towards resilience is to define what a backup system requires. Also, if one is forced to prioritize, timing affects far more users than positioning and navigation. Defining and meeting backup requirements will take time.

Mr. Martin concluded by calling attention to current efforts to educate users and work within the federal government to develop backup capabilities.

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Global Positioning System (GPS) Stats & Modernization Process: Current & Emerging Services
Lt Col Andrew Zinn, *Chief*
GPS Plans and Requirements, GPS Directorate
U.S. Air Force

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/zinn.pdf

Lt Col Zinn briefed on behalf of Col Steve Whitney of the GPS Directorate (GPS-D) at LA Air Force Base, CA. The program office is divided into several major programs covering the space, ground, and user equipment segments. Lt Col Zinn is from the Chief Engineer's office. His primary tasks are GPS requirements and plans & technology for the next generation of GPS satellites. The GPS constellation is in very good shape with 31 active satellites. The actual system performance continues to exceed the GPS performance standard by an increasing margin for both civil and military signals. The L2C and L5 signals are coming on-line satisfactorily and are available for test purposes.

The launch of GPS IIF satellites is the most aggressive launch program since the 1990s. GPS III, the newest block, will carry four civil signals. GPS III satellite vehicles (SVs) 1-8 are under contract, and GPS III SVs 9 & 10 will be contracted soon. The first GPS III satellite completed vacuum testing in record time and should be ready for launch next year.

A competition will follow after GPS III SV 10. It is hoped this will drive down costs, extend research into industry capability, and potentially facilitate launching multiple SVs on a single booster. A Capability Development Document (CDD) update will seek Joint Requirements Oversight Council (JROC) approval to add regional military protection by means of M-Code regional increased power, a successor to what used to be called 'spot beam'. The original GPS Next Generation Operational Control System (OCX) schedule, contained in the 2010 contract award, has turned out to be unrealistic. Currently, quarterly reviews are held to measure progress, affirm scheduling, and mobilize resources. Furthermore, contingency plans are being made to respond to any new OCX issues. In terms of Military GPS User Equipment (MGUE), the emphasis is now on MGUE card development and the integration into the lead platforms, with the individual services doing further integration. The first increment of cards is now being tested.

In summary, the GPS Directorate's perspective is to:

- First, recognize GPS as a global utility;
- Second, embrace the Space Enterprise Vision of Gen John Hyten, Commander, U.S. Space Command;
- Third, appreciate the need for alternate PNT sources;
- Fourth, address the cost and schedule aspects of OCX; and
- Fifth, explore operational modernized signal capabilities prior to OCX delivery.

Looking into the future, in addition to pursuing towards resiliency to jamming and spoofing, we understand multi-GNSS is the way of the future and are working to see how we can enable that. We look to the PNT Advisory Board to help us understand the role of the GPS program office to enable multi-GNSS system. We envision GPS to be at the core and remain as the 'trusted source', but not the sole source of PNT.

Dr. Parkinson noted that it had been Mr. Stenbit's decision when he was at the DoD to give the modernized signal to nine satellites, thereby providing a five-year lead, and commended Lt Col Zinn on the long-sought inclusion of the laser retro-reflectors in the baseline for GPS III SV11-32 and, also, for mentioning multi-GNSS receivers. In his view the role of the AF is not just GPS, but PNT and therefore also GNSS improvements. Dr. Parkinson also commented that AFSPC has done a marvelous job for many years.

Maj Gen Thompson thanked Dr. Parkinson for his comments and also praised the early addition of the M-Code. He noted that 19 satellites are already broadcasting the M-Code signal.

Mr. Goward asked for further information regarding the incident when SVN 23 was decommissioned that resulted in 12 hours of GPS time signal discrepancies.

Lt Col Zinn said he is not at liberty to discuss certain details. However, actions have been taken to prevent reoccurrence. A section on "Best Practices" will be added to the performance standard and emphasize data checking and the need for good receivers. Fortunately, GPS was designed in such way that the positioning function was not affected.

Maj Gen Thompson added that challenges will always exist as resources and requirements are balanced. The central test his organization faces is to be "good stewards" of the system. Regarding OCX, a transparent approach has been taken to resolve any issues, including quarterly reviews with OCX contractors. OCX is a "no fail" mission and, thus, will not fail. In terms of PNT resilience, the issue is now viewed as two layers: (1) the resilience of the PNT, including the ground user segments; and (2) the broader perspective that expands to other GNSS systems and means of providing backup. AFSPC is well aware of the incredible reliance on GPS, the relative fragility of the system, and the steps needed to mitigate that fragility. Finally, regarding GNSS adjacent band use, any decision will be based on physics, engineering, and data.

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Update on Space Service Volume (SSV) for Space Ops and Science
Mr. Joel Parker, *NASA Goddard Space Flight Center*

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/parker.pdf

Mr. Parker explained that over past 10-15 years new applications for GPS use 'above the constellation' have emerged. The use of GPS for real-time navigation within the SSV offers numerous benefits. These include: improved real-time navigation performance; quicker trajectory maneuver recovery; reduced need for expensive on-board clocks; increased satellite autonomy, and better performance in High Earth Orbit (HEO) and Geosynchronous Orbit (GEO) missions.

GPS specifications for the SSV are currently defined in terms of the main lobe signals. Recent observed data shows that far greater accuracy and availability is achieved if both the main lobe and side lobe signals are used. Moreover, there are a number of missions that rely on the use of side lobes to meet their full mission requirements. GPS should be the Gold Standard for both terrestrial and space applications. Efforts are underway to identify stakeholders requiring such capabilities. Currently NASA is a key civil stakeholder of the Geostationary Operational Environmental Satellite (GOES) - R Series, or GOES-R, whose mission intends to extend accurate weather forecasting from 3-5 days to 5-7 days. To achieve such goal, GOES-R has very stringent requirements that cannot be met without some of the capabilities currently enabled by the GPS side lobes. Thus, NASA has been working in conjunction with the Air Force to define a set of proposed GPS SSV requirements that would meet the needs of GOES-R. NASA has also received key endorsements from the military and civil sides, including the Space and Missile Systems Center/Space Superiority Systems Directorate (SMC/SY) and National Oceanographic and Atmospheric Administration (NOAA). International providers of weather data are also important stakeholders. Since the last Advisory Board meeting there has been progress on two key issues – NASA and Air Force's partnership on implementation, and the assurance of navigation resiliency. The Way Ahead includes completing the Interagency Forum for Operational Requirements (IFOR) process and finalizing the NASA/Air Force Memorandum of Agreement (MOA). The proposed requirements update for the GPS SV11+ CDD would enable HEO/GEO users to support their requirements and, also, would facilitate long term planning of civil and military missions. Furthermore, this step would, in NASA's view, align with Gen J. Hyten's "Vision for Space."

> Gov. Geringer asked if international efforts are underway to protect the use of side lobes for space applications.
>
> Mr. Parker noted that foreign weather services are regarded as stakeholders. Direct conversations have not yet occurred, though coordination is under way with the ICG. Further, work is proceeding with other GNSS providers to determine what use, if any, they can make of their own side lobe capabilities. The general intent of this proposal is for GPS to remain the Gold Standard not just for terrestrial users but, also, for space users.

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Briefings & Discussion on Radio Navigation Satellite Services (RNSS) Spectrum Protection

Mr. Stenbit, Chair, said Dr. Parkinson would be in charge of the next three presentations on spectrum and spectrum protection, and would deliver the first talk himself.

Dr. Parkinson noted the next three presentations, and related discussion, on RNSS spectrum protection could present potential conflict of interest issues to some board members.

The following board members recused themselves from the discussions: Ms. Ann Ciganer, Mr. Ron Hatch, Mr. Tim Murphy, Mr. Dean Brenner, Mr. Joe Burns, Dr. Per Enge, and Mr. John Stenbit.

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PNT Board Recommended Criteria for Spectrum Assessment
Dr. Brad Parkinson, *1st Vice Chair*

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/parkinson2.pdf

Dr. Parkinson presented a list of issues that should be addressed when assessing spectrum, including 64 examples of GPS applications affected by spectrum reassignment. Because GPS is a passive system free of direct user charges, it is difficult to determine the exact number of users. Important applications include, for example, monitoring plate tectonics; fully automatic landing of aircraft; automatic control of land vehicles; and others. GPS enables tangible benefits of US$55 billion a year, a figure that does not include the value of safety of life applications. Future uses are likely to add tens of billions of dollars in value.

The potential degradation of the GPS signal should not be measured only against specific receiver types but, also, problems to the broader user base and the nation as a whole. The burden of proof should rest on those attempting to repurpose the frequency bands adjacent to GPS. The board is recommending the following six criteria for spectrum assessment:

- Meet the 1 dB degradation criteria. This is a longstanding and sanctioned international standard.
- Consider all GNSS signals.
- Assess all classes of precision receivers. While such receivers are small in number, they are of great economic consequence. Precision receivers require a very wide bandwidth to ensure accuracy. New designs may reduce this requirement, but legacy equipment will remain for a while. Farmers, for example, are locked into a given system and will not welcome being obligated to replace their equipment.
- Demonstrate full understanding of the assumptions behind the analysis and test parameters. Since many critical PNT operations are potentially near wide-band transmitters, decision-makers need to fully understand the assumptions used in analysis and testing.
- Ensure compliance with authorized transmitting power levels.
- Provide phase-out time for legacy equipment.

In summary, GPS is a dual-use civil and military system, with new applications continuously emerging. Any analysis must look to these emerging and applications and address the needs and concerns of all user groups.

Ms. Neilan said that legacy equipment is still much in use, including applications measuring sea level change that will have a huge impact over the coming decades.

Gov. Geringer noted Dr. Parkinson's reference to the required accuracy, and noted that as GPS evolved, so did the expectation for increased accuracy. Thus, users have a legitimate expectation that their devices will work beyond the original standards. Case law is quite clear on this point. Once a dependency is created one cannot return to the original standards.

Dr. Camacho-Lara emphasized the importance of keeping the 1 dB standard, and noted he is expecting

from the U.N. Committee on the Peaceful Uses of Space, a multi-year plan where countries will show how they were addressing the issue on interference. Changing the 1 dB requirement now would greatly complicate that task. Of the 193 countries involved in this UN undertaking, some 40 maintain the 1 dB criteria in their own activities.

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GPS Adjacent Band Compatibility (ABC) Assessment
Ms. Karen Van Dyke, *Director for PNT*
DOT OST

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/vandyke.pdf

Ms. Van Dyke noted the EXCOM first addressed the topic of adjacent band activity in 2012. She cited a letter from then EXCOM co-Chairs Aston B. Carter, Deputy Secretary of Defense, and John D. Porcari, Deputy Secretary of Transportation, stating that 500 MHz of spectrum should be made available "without affecting existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needs." This letter prompted the Department of Transportation (DOT) to conduct studies of adjacent band compatibility, including multi-GNSS. The development of these tests was time-consuming, as it emphasized an open and transparent process, including public workshops and Federal Register Notices. Testing was conducted on April 25-29, 2016 at the Army Research Laboratory's Electromagnetic Vulnerability Assessment Facility, White Sands Missile Range, New Mexico.

Mr. Steve Mackey, DOT, described the range of test participants and the test regimen. Testing involved eighty receivers from six GPS/GNSS receiver categories, ranging from general aviation to high precision. The two main tests were: (1) a 1 MHz bandpass noise test; and (2) a 10 MHz LTE test. Nine signals were tested, including Space-Based Augmentation Systems (SBAS) and GNSS (GPS, GLONASS, BeiDou and Galileo). The GPS L2 signal was also used as some receivers experience problems if they are not receiving it. Mr. Mackey also provided information on the chamber diagram, the test grid, the interference test signal frequencies, and the power profiles. The test grid was reviewed with various participating bodies. Twenty-two different frequencies were tested; all received the 1 MHz bandpass noise test, and 18 received the 10 MHz test. The primary data metric was to collect the information needed to develop an Interference Tolerance Mask (ITM) for each receiver. To the extent possible, data was also collected on the state of each receiver at each time step throughout the test.

Ms. Van Dyke added that, in her view, the tests went better than anticipated. Many things that could have gone wrong but didn't. The emphasis has been on getting all the data properly analyzed and avoid looking for a quick answer. Follow-on steps will include lab testing to demonstrate reproducibility; receiver acquisition testing on a limited number of receivers; evaluation of the 1 dB Signal-to-Noise Ratio (SNR) degradation; development of use-case scenarios; evaluation of appropriate propagation models, and development of maximum tolerable transmitter power levels as a function of frequency offset.

Gov. Geringer noted that Dr. Parkinson's six test principles included signal dropout and re-acquisition of signal. Have these been tested in the DOT-led tests?

Ms. Van Dyke said they have not.

Mr. McGurn asked if it has been possible to test the effects of dynamics on the receiver, or the platform that will carry the receiver.

Ms. Van Dyke said no dynamic testing has occurred. Some aspects of that issue will be taken into account in the use-case scenarios.

Mr. Goward asked why is DOT, rather than the National Institute of Standards and Technology (NIST), conducting these tests? In his view the subject merits more than a one-week test by DOT.

Ms. Van Dyke noted that a private group had proposed such testing in 2011, and Mr. Porcari believed the

DOT should act rather than react. The agency needed better information about what power levels could be tolerated, so it did not have to conduct individual reviews of every proposal for adjacent band use that was brought forth. However, while DOT conducted the tests, the process went through extensive coordination with other agencies and private groups.

Dr. Parkinson said that if US$63 billion of annual benefits are at risk, the government should be able to afford more than a one week test to protect such value. The Federal Communications Commission (FCC) is, apparently, not participating in these tests. Also, the information on acquisition and re-acquisition is lacking, even though it is a major receiver problem, particularly for the Federal Aviation Administration (FAA). The central question is how the PNT user gains assurance that the system is dependable. The DOT has done a great job given the limited resources that have been assigned. However, given the gravity of the issue perhaps six to twelve months of testing would be justified.

Ms. Van Dyke said that prior to the test week, over a year had gone into the preparation of the test regimen. Also, time frames have not been attached to next steps. A significant amount remains to be done, but hopefully the results from the week long tests are sufficiently representative for people to find them useful.

Mr. Higgins said that from the perspective of precision users he does not understand the ramping of the jamming level used in the tests. As an example, a survey receiver arrives in the field, is turned on and needs to acquire signal with whatever level of jamming is occurring at that time. Also, re-acquisition testing could address this issue for precision receivers where, for example, the signal on a moving survey vehicle could be lost if it goes under a bridge or short tunnel.

Ms. Van Dyke noted that from DOT's perspective, the purpose was to determine what power levels receivers could tolerate. She is aware of the wide range of receivers, which is why the jamming levels were been ramped up.

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Presentation of Roberson and Associates Testing Results
Dr. Ken Zdunek, *Vice President and Chief Technical Officer*
Roberson and Associates

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/zdunek.pdf

Dr. Zdunek explained he's been over 35 years in the wireless industry, and that Roberson and Associates (RAA) does consulting for both public and private clients (queried by Dr. Parkinson, he identified the individuals at his firm with expertise in GPS). Dr. Zdunek said that, in his view, compelling evidence exists that the co-existence plan developed by Ligado and presented to the FCC would allow terrestrial operation in the band adjacent to GPS and GNSS. The issue of co-existence is crucial, and everyone involved understands that the dependency on GPS and supports its continued integrity. Dr. Zdunek developed three points: (1) the context of the co-existence testing; (2) details of the five test procedures used; and (3) a summary of the test results. Dr. Zdunek provided two samples of test results: a Garmin eTrex operating under in open sky and in motion; and Garmin eTrex under impaired GPS signals and in motion.

Dr. Zdunek reported his conclusions on the consumer GPS device and Ligado's development. First, the RAA has successfully tested GPS user performance metrics for four 10 MHz bands. Second, the work demonstrates the feasibility of using Key Performance Indicators for GPS Devices. Third, 16 devices have been tested successfully, including two smartphones. Fourth, comparisons of device performance with or without LTE demonstrate no impact on GPS user performance. And finally, the 1 dB degradation did not predict the impact of adjacent band signals on GPS device positioning performance.

Mr. Shields observed that the National Highway Transportation Safety Agency has spent 15 years and billions of dollars testing and developing vehicle-to-vehicle communication, a technology that could save thousands of lives. Also, both General Motors and Toyota have announced that this technology is entering production. Both efforts are based on the understanding that interference for in-vehicle positioning systems

will not exceed 1 dB, including interference from other on-board devices. In his view, Dr. Zdunek's presentation does not appear to address this situation.

Dr. Zdunek said the filing of results includes that information. Regarding the 1 dB, no information has been obtained that this standard applies to adjacent band performance. He invited anyone to compare the results obtained with the information from the user's functional metric to determine if that is a reliable standard for adjacent band performance.

Gov. Geringer asked Dr. Zdunek whether he, or Roberson and Associates, have a relationship with Ligado.

Dr. Zdunek said his organization is independent of Ligado, and that they are being paid by Ligado's outside counsel. The tests were performed with very little oversight from Ligado. The tests themselves were developed independently, though Ligado and others commented on its design. In his view, the test results provide compelling evidence that Ligado's proposal to the FCC would allow these two to coexist.

Gov. Geringer commented that a lack of interference is not the same as proving it is safe. In addition, he is a little uneasy on whether this evaluation is truly independent.

Dr. Zdunek said he is uncertain as to the basis of the question. His group has interacted extensively with the public safety community, which provided important feedback. Discussions continued with stakeholder groups as test results are published. He noted the location accuracy used is something the manufacturers advertise. The tests are not of the manufacturers' claims, but of the actual performance of the device.

Dr. Parkinson said it appears that a number of receivers, for which no problems were anticipated, have been tested. Also, as noted in the six-point criteria for testing, we should include re-acquisition of a signal following any interruption. For example, power spikes can interrupt reception of GPS signals. Regarding high precision receivers, if he could be assured that sub-millimeter accuracy in three dimensions is not affected, then that would be a good starting point for further discussion. Until the impact on high precision is understood, the Advisory Board is likely to remain unconvinced. The six-point criteria exist for good reasons, and it is doubtful the difficult problems have been adequately tested.

Dr. Zdunek said he is not in a position to respond fully to Dr. Parkinson's concerns. Some three-dimensional devices were tested. Regarding signal reacquisition, this remains part of the on-going discussion.

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U.S. International Engagements and Partnerships
Bilateral & Multicultural Collaboration
Mr. Kenneth Hodgkins, *Director*
Office of Space & Advanced Technology
U.S. Department of State

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/hodgkins.pdf

Mr. Hodgkins noted that great progress has been made in creating a system of systems – six different national space-based navigation satellite systems that operate similarly. This has not happened by chance: a huge amount of work has been done by governments and by the Advisory Board. This is consistent with U.S. space policy which includes a statement that "Foreign PNT services may be used to complement services from GPS." Many years of bilateral negotiations have led to compatibility (i.e. the ability of systems to operate without interfering with each other) and in some cases interoperability. Also, the United Nations (UN) created the ICG as a forum for multilateral discussions. The Department of State sponsored the 10th ICG meeting, held on November 1-5, 2015 in Boulder, Colorado. The meeting convened over 200 participants from 28 nations. Also, 13 Advisory Board members participated. Also, ICG Working Group C, on Information Dissemination and Capacity-building, issued a recommendation that "ICG member countries consider the value of National and Regional PNT Advisory Committees and share their findings at ICG meetings when available." There are seven areas of significant

accomplishment at the ICG:

1. Interference detection and mitigation (IDM) & spectrum protection – recommendation that providers promote the implementation of protection measures.
2. Interoperability – five bilateral meetings had been held in this area.
3. International Multi-GNSS monitoring and Assessment (IGMA) – recommendation that a trial project be initiated between ICG and IGS to demonstrate a global GNSS monitoring and assessment capability.
4. Space Service Volume – providers would be asked to report on developments.
5. Space weather – how to reduce the impact of solar flares on satellites.
6. Orbital debris mitigation.
7. Service center cooperation.

Following ICG-10, the ICG Experts Meeting on December 14-18, 2015, held in Vienna, Austria, drew over 60 experts from 33 countries and organizations. The event focused on a two-day seminar on spectrum protection and IDM. Finally, the U.S. has participated in a number of other international events and fora, as well as bilateral cooperation efforts.

The U.S. government encourages worldwide use of GPS services and cooperation with other GNSS providers. Thus, international outreach is a priority. The ICG-10 meeting, hosted this year by the U.S., made notable progress on multilateral cooperation in IDM, as well as in interoperability and civil signal monitoring. International progress has not occurred by chance and, thus, it is important to understand how we got to where we are today. Twenty years ago it would have been difficult to believe that, one day, a body such as the Advisory Board would exist. Mr. Hodgkins was part of an early group that traveled to the Soviet Union to discuss possibilities for engagement. Little was accomplished on that trip, but it did prompt some thinking. Between 1989 and 1996, U.S. GPS policy encouraged the U.S. to act internationally. In 1999, the UN held its Third Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III). This eventually led to the 2004 agreement between the U.S. and European Union regarding GPS and Galileo. Through further international cooperation, today the world enjoys the benefits of a GNSS system of systems. This reflects the model set early on by the United States. Thus, it would be useful for the Advisory Board to undertake a historical assessment on how it has gotten to where it is now.

Mr. Stenbit said he is pleased that everything described by Mr. Hodgkins had occurred, but noted that in the early 2000s, the U.S. was inclined to oppose Galileo.

Mr. McGurn added that while he has been a critic of GLONASS, in recent months GLONASS has provided much more information than in the past. GLONASS has new websites with menus that provide monthly, weekly, and daily information. Thus, it is apparent that the Russians have developed a greater appreciation on the advantages of transparency.

Dr. Parkinson congratulated Mr. Hodgkins and DOS for its efforts.

Gov. Geringer seconded that comment. He noted that when Mr. Hodgkins described the "system of systems" it brought to mind the Committee on Earth Observation Satellites (CEOS), where such concept was evaluated and found valuable. He asked if DOS has served as chair in this committee.

Mr. Hodgkins said he was one of the drivers leading to CEOS being created. The group has a permanent Secretariat located in Geneva, Switzerland. The ICG was modeled on CEOS.

Gov. Geringer urged the board to discuss whether an opportunity exists to further the GNSS "system of systems," particularly as both CEOS and ICG have secretary-level participation.

Mr. Hodgkins said such discussion might prove quite useful, and that he will would consider ways where bilateral and ICG activities could further meet the general public needs for PNT services.

Dr. Beutler praised Mr. Hodgkins' presentation. Efforts at the IGS to monitor the Earth represent the

opposite side of the same coin.

Dr. Camacho-Lara said a group could be organized to follow up on Mr. Hodgkins' proposal that a formal record be made of how existing GNSS cooperation has come to be.

Mr. Stenbit, suggested this be discussed on the following day.

Also, in response to a question on the DOS' position on Europe's use of in-band pseudolites, Mr. Stenbit said this is outside Mr. Hodgkins' purview.

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Activity Overview of Emerging PNT Services & Capabilities
United Kingdom Government Perspective
Mr. Andy Proctor, Chair
United Kingdom (UK) Government PNT Group, and UK Delegate to the ESA Navigation Board

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/proctor.pdf

Mr. Proctor explained he works for InnovateUK, which focuses on supporting future technologies and trends, and assisting private companies to realize benefits. InnovateUK seeks to realize a US$ 10 return on every US$ 2 invested. The organization has invested US$10 million in GNSS, including: US$ 7 million in advanced navigation and precision farming, and US$ 2 million in Galileo receivers and antennas. Recently, US$ 10 million has been invested to address urban data challenges. The organization also works to convene multiple government departments to create outcomes greater than the sum of their parts. Such groups are intended to balance government users, policy makers, procurement specialists, technologists and regulators. InnovateUK does not provide formal advice to ministries, but it is frequently consulted on an informal basis.

A commonly discussed topic is the role of the UK in Galileo, where the UK is heavily involved, particularly in satellite production. Two more Galileo satellites will be launched next week. Also, two Galileo satellites are in orbits other than intended, but the European Space Agency (ESA) has succeeded in reversing what could have been a major setback by devising means whereby the satellites can be useable so long as certain modifications to ground stations are made. Galileo should reach full operational capability by 2020.

The UK is also working to develop its own Publicly Regulated Service (PRS). Two key challenges are that the cost must not be prohibited, and that service must be secure. In the past year, three projects have been completed:

1. Epic Scout, which solves the challenge associated with key delivery and management of autonomous receivers.
2. Explorers, the first ever demonstration of two novel concepts for cloud-based PRS receivers.
3. Permit, the first ever demonstration of combined positioning from military GPS and Galileo PRS.

On December 31, 2015, a number of European countries shut down Loran-C. The UK has kept its Loran station transmitting for trials on precise timing. Enhanced Loran (eLoran) could provide the services to sectors with a critical dependence on timing. In his view, eLoran could even be operated as a commercial enterpriser.

Other efforts include the UK Quantum Technologies program, a five-year effort to invest US$350 million to exploit research by creating new products.

In summary, InnovateUK is at the heart of technology innovation in the UK. Also, Mr. Proctor noted several questions he has been mulling, including:

- Where should we go next with PNT?
- Could we survive without space-based PNT for three days or longer?
- Do we understand the risks and their likelihood?

- Is it valid to back up a space-based capability with another space-based capability?

These are important questions we should all consider.

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International GNSS Service (IGS) Orbit Dynamics, Modeling & Timing
IGS Advances & Future Applications
Dr. Marek Ziebart, *Professor of Space Geodesy*
University College of London

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/ziebart.pdf

Dr. Ziebart noted that one of the principal functions of the IGS is to push research into a better understanding of orbits and clocks. Better understanding of orbits enables better clock performance. Calculations for the reference frame must take the forces acting upon the satellite into account. The primary influence is earth gravity, along with solar gravity, lunar gravity and, to a minor extent, planetary gravity. Other influences include solar radiation pressure, where photons impart momentum on the satellite. As the photons hit the satellite some of their energy is absorbed as heat, and some of it radiated back into space. This results in additional perturbations on the satellite due to thermal forcing and antenna thrust impact. If solar radiation pressure were ignored, over 12 hours a satellite's positioning data can be off by approximately 200 meters.

Solar radiation pressure is addressed by creating computer simulations of the space vehicles to determine the momentum and heat transferred. The effect of thermal gradients on the solar panels is similar to sails on a ship where errors in modeling may send it in the wrong direction.

Antenna thrust is the re-radiation of photons into space and its resulting recoil effect. A GPS satellite typically receives about 15 watts per square meter of radiation, which creates an 8-meter error every 12 hours.

When factoring thermal effects the orbit error drops dramatically, and adding the effect of antenna thrust further reduces the error. Thus, better one understood the physics of space and the engineering of the spacecraft, the more one can improve the ability to predict its orbit and, in turn, improved orbit calculation permit improved clock accuracy.

On a philosophic note, GPS is extraordinary and has changed the world in ways most people are not even aware. Faraday could not have possibly foreseen that his work would lead eventually to the Internet, nor can those today working in their fields of expertise foresee all the outcomes of their own efforts. In summary, the IGS is at the forefront of research in various areas with, in turn, unforeseeable outcomes. Modeling radiation pressure is key to these efforts and, as such, the IGS seeks support from the Advisory Board to gain access to the structural and material data of GPS satellites and, thus, further improve orbit calculations and clock accuracy.

Mr. Stenbit said the Advisory Board is not empowered to provide such information.

Dr. Ziebart responded that an Advisory Board endorsement of this idea would be beneficial.

Dr. Beutler added that this information is being requested from all GNSS providers, not just GPS. The more one knows about a satellite the more accurate the analysis will be.

Dr. Ziebart noted that satellites increasingly have more power, and require larger solar panels, which in turn increases the surface area affected by solar radiation.

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Networks for Robust Civil Signal Performance Monitoring & RFI Detection
Dr. Yoaz Bar-Sever, *Program Manager, Global Differential GPS,*
NASA Jet Propulsion Laboratory

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/bar-sever.pdf

Dr. Yoaz Bar-Sever explained that threats to GPS service include integrity failures, jamming, and spoofing. Better situational awareness to these threats is possible by using global and regional real-time GPS monitoring networks. NASA's Global Differential GPS System (GDGPS) includes over 80 JPL-owned real-time global tracking providing 20-fold observation redundancy. This means that at any time every individual GPS satellite is observed by at least 20 ground stations. Hundreds of additional sites operated by partner agencies contribute to provide additional redundancy. The large footprint GPS satellite signals is key to improving its resiliency by using GDGPS. Recently a live demonstration of GDGPS resilience to spoofing was successfully carried out for the U.S. Air Force. These ground networks enable reliable and accurate orbit determination which, in turn, allows global integrity monitoring.

GPS jamming and spoofing are localized effects that to be detected require dense local networks. Continuous Operating Reference Stations (CORS) networks in the U.S., Europe, and Japan provide high quality data needed – the U.S. tracking network itself has more than 1,000 sites, mostly real-time. Commercial tracking stations at places such as airports could also be incorporated into a monitoring network. The coordination of data from ground networks can be used to reveal where an interference event, or spoofing, is taking place. In densely monitored areas it might be even possible to identify the jamming source, and spoofing could be recognized by comparing the navigation messages received at several ground stations. The ultimate possibility would be to also crowd source the data from smartphones. For example, some success has already been achieved by crowd sourcing information during earthquakes. In conclusion,

- First, existing GPS tracking networks, technologies, and operational capabilities enable effective and low cost GPS integrity monitoring and RFI situational assessment.
- Second, big-data mining and crowdsourcing offers additional approaches to high-resolution threat assessment.
- Third, consideration should be given to installing reference sites near airports.
- Fourth, GPS situation assessment capabilities could be extended to other GNSS constellations.

Dr. Enge noted that using networks to cope with jamming and spoofing seems incomplete. For example, wouldn't changes in user equipment to force jammers to send more power, in turn, make it easier to locate the jamming source?

Dr. Bar-Sever said his briefing is a about a monitoring service could be a partial solution to jamming and spoofing. While not a complete solution, it is nevertheless low-cost since it makes use of existing resources.

Dr. Enge asked what the cost would be, and when such a system could be operational.

Dr. Bar-Sever said about 5,000 GPS receivers would need to the incorporated at a cost of, perhaps, several million US$ per year. Useful information should be available within 12 months.

An Advisory Board member commented that the Department of Homeland Security (DHS) should be very interested in this.

Mr. Stenbit said that at the moment it is sufficient just to know the order of magnitude of the prospective cost.

Mr. Higgins noted there are currently available receivers that do 'spectrum sniffing' as part of the receiver. In some places such receivers are being already implemented as older receivers reach the end of their useable life.

Maj Gen Thompson said additional or enhanced signal monitoring is among the issues the DoD is working on.

Mr. Stenbit said he recognizes this is not an easy problem to solve.

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Satellite Time and Location (STL)
Development and Testing of an Iridium-Based Position, Navigation, and Time Capability
Dr. Gregory Gutt, *Chief Technology Officer*
Satelles

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/gutt.pdf

Dr. Gregory Gutt explained that STL is a position and time capability hosted on the Iridium constellation. Following years of development, worldwide service was launched in April 2016. The system provides PNT independently of GPS. It has three capabilities: (1) providing precision time without local infrastructure; (2) providing indoor positioning without local infrastructure; and (3) delivering trusted location extremely resistant to spoofing. A new paradigm would be to use this capability to provide proof of location to enable better cybersecurity. The largest Internet attack in history happened at a trunk router in Spain where for approximately 30 minutes one-fifth of the world's Internet traffic was re-routed to China. STL is uniquely positioned to provide proof of where one is, not just where one is supposed to be.

Iridium is the world's largest satellite constellation and, like GPS, it operates in the L-Band. Therefore, existing equipment could be easily modified to capture STL signals. Iridium can produce a reliable timing signal despite not using expensive atomic clocks. Iridium was initially launched in 2000, and because of that it has been suggested the system is outdated. This is not true, as a US $3 billion full replacement of the Iridium Block 1 system is planned. Also, because Iridium satellites orbit only at 500 miles altitude they in fact deliver far greater signal power, approximately 1,000 times stronger than GPS. Therefore, Iridium can reach into place where GPS cannot, such as building interiors. STL is available worldwide because Iridium is available worldwide. Each of the 64 satellites has 48 spot beams – over 3,000 in all. Multiple commercial applications already exist. Because an Iridium receiver can be mounted inside a building, the costs of placing an antenna on top of the building is eliminated. STL is a three-dimensional system, with similar vertical and horizontal accuracies. Also, sub-microsecond timing accuracy was obtained in one measurement, and sub-100 nanosecond timing is achievable with the right clocks.

On the January 26, 2016, when some GPS clocks were off by 13 microseconds, Iridium noticed the anomaly. It is apparent that GPS was subjected to spoofing. Iridium uses Cesium clocks at various ground sites so the system can "flywheel" through such occurrences. Thus, there are great advantages in having a second system so that the outputs from both systems can be compared and, if they do not agree, the fault can be identified and countermeasures taken. A GPS satellite has a footprint that 'light up' approximately 1/3 of a hemisphere. Thus, a signal measured in North Dakota can, for example, match a signal measured in Mexico, therefore creating a challenge to GNSS as to where exactly one is located. STL offers a trusted location since it is independent and difficult to spoof.

Mr. Faga asked whether worldwide use of the system could create signal power problems for the Iridium satellites by demanding too much power.

Dr. Gutt said he believes the entire land mass of earth can be covered. Over large oceans, a simplified version will be offered to meet most maritime user requirements.

Lt Col Zinn asked if the system is, like GPS, completely passive. If not, is there a limit on the number of users it can support?

Dr. Gutt said all the users in a given area can be supported. The system is passive in the sense that user equipment is not engaged in transmitting.

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Techniques for Radio Frequency Spectrum Mapping from Space
Mr. Russ Matijevich, *Vice-President*
HawkEye 360

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/matijevich.pdf

Mr. Matijevich explained that HawkEye 360 was founded in September 2015 with the objective of bringing new capabilities to the commercial space market, including detection and location of RF sources. It is developing a system that can identify, locate, and attribute RF signals transmitted from the surface and collected in space. This new capability aligns with U.S. Space Policy 2010, which encourages robust and competitive commercial space activities, and also increased U.S. resilience. For several years his company has worked with both public and private sectors to understand their requirements. The proposed system consists of a constellation of small satellites flying in loose formation, and each with less than 15 kg mass, working in concert to detect and geolocate RF signals between 50 MHz and 1 GHz. The system can also collect GPS interference data. The first cluster of satellites is expected to be launched by September 2017 at a cost of less than $10 million. Potential benefits could also include, with some design modifications, monitoring of GNSS interference sources. If such interest exists, then HawkEye 360 will undertake studies and demonstrations.

Mr. Matijevich acknowledged that some find the idea of a private company gathering signals from space to be unnerving. However, the company intends to be a good steward. HawkEye 360 is mindful of the potential impact on Operational Security (OPSEC) and privacy. It will not collect the signals' internal information, the data is encrypted from end-to-end, and is actively working with U.S. interagency members and Congress to provide insight into its operations. The effort is privately-funded by a Boston venture capital firm, Allied Mines.

Mr. Stenbit asked if geolocation is being undertaken using Time Difference of Arrival (TDOA).

Mr. Matijevich said TDOA and Frequency Difference of Arrival (FDOA) are used in combination.

Mr. Stenbit asked how data is brought to ground.

Mr. Matijevich said work is underway to partner worldwide service provider that owns a network of ground stations. In a worst case scenario, where one may be going down the middle of the ocean, there would be a 45 minute gap to bring the data back to the ground. In this example the information would be stored for later use.

Dr. Pace asked if HawkEye 360 has dealt with the FCC.

Mr. Matijevich said interactions with the FCC has been positive, and licensing has been discussed. The FCC has not said the mission is impermissible.

Mr. McGurn asked how time is managed across satellites to synchronize Time of Arrival (TOA).

Mr. Matijevich said GPS is used. Additionally, the company will have its own atomic clock on a chip to maintain time on-board the spacecraft.

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Emerging Microsystem Technologies for Autonomous PNT
Advances from Defense Advanced Research Projects Agency (DARPA)
Dr. Robert Lutwak, *Program Manager*
Microsystems Technology Office, DARPA

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/lutwak.pdf

DARPA's two goals for PNT include: (1) provide GPS-level performance under all application scenarios; and (2) look 20-30 years into the future for enhancements of PNT.

DARPA is currently working on state-of-the-art clocks capable of holding an accuracy down to a nanosecond. Chip-scale atomic clock are quite revolutionary as they allow a nanosecond to be held for three hours, which would cover most DoD missions. Installing better clocks in receivers produce not just better reception but also improved anti-spoofing protection. DARPA is following a two-fold approach. The first consists of exploiting the considerable possibilities for improvements in Micro-Electro-Mechanical Systems (MEMS) design. The second is working, in particular with enabling component technology, to move sophisticated approaches out of the laboratory and into the real world. For example, when working on time error accumulation in clocks, temperature and magnetic sensitivities are commonly overlooked. In consequence, the metrics used to measure clock performance are not the ones most relevant to real-world performance. Progress has been made on efforts to develop miniature atomic clocks, and the Atomic Clock with Enhanced Stability (ACES) program is currently in source selection. The goal is to continue running the clocks on battery power while producing performance comparable to that of cesium atomic clocks.

An important application area for the DoD is that of munitions navigation, where there are concerns with environments where GPS satellite-visibility may not be adequate. Many DoD missions involve a time of flight between 3 to 180 seconds. Pure inertial navigation systems (INS) can hold course for about 3 seconds, navigation-grade INS can hold path on free inertial for about 180 seconds. A typical navigation system contains both GPS and INS, where GPS is continuously recalibrating the INS. However, it is likely to be operating off the INS because of its greater bandwidth, but the performance is largely dependent on the gyroscopes. Thus, DARPA is also involved in the development of state-of-the-art gyroscopes, including the Micro-scale Rate-Integrating Gyroscope (MRIG).

Also, some MEMS devices are outperforming low-end ring-laser gyroscopes. One such effort is the Precise Robust Inertial Guidance for Munitions (PRIGM) program, with the goal is to deliver HG9900 performance in a drop-in replacement of existing tactical-grade MEMS. It is hoped there will be flight demonstrations of this technology by 2020.

Finally, other longer term efforts include having the ability to navigate through gun launches, during which on-board navigation devices can get 'upset'.

Mr. Stenbit said the prospects described are very exciting.

Dr. Parkinson said he has great enthusiasm for DARPA's work, and noted that accelerometers don't just measure acceleration but they measure specific force, which includes gravity. Thus, somehow one needs to take gravity into account. The point is that the vertical channel is inherently unstable and you have to go through a double integration. It would be nice to include gravity gradient mapping, or other technology, to get the initial gravity right. Also, without GPS it is unlikely most within a battlefield could achieve 10-meter accuracy. This, and other caveats, such as narrowing the bandwidth and going through a double integration, may be lost to persons in the audience that do not realize what cautions must be applied.

Dr. Lutwak said he does not disagree. He was referring to holding the position for three seconds with the assumption that one knows the initial fix. Dr. Lutwak added that he is aware of the recent uproar because of a statement made to the press that GPS would become unnecessary because everything would be tracked by inertials. He does not believe anyone in the inertial community ever claimed that GPS would be replaced entirely.

Dr. Parkinson said he understands what Dr. Lutwak is saying, but he is concerned that there could be an

unintended consequence where someone in high leadership engaged in allocating funds may decide that GPS may no longer be necessary.

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The Use of GPS for Vehicle Control Applications
Integrating Techniques for Intelligent Transportation Systems (ITS)
Dr. David M. Bevly, *Professor*
Department of Mechanical Engineering, Auburn University

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/bevly.pdf

Twelve years ago, DARPA kick-started interest in autonomous vehicle control with its Grand Challenge offering US$ one million to the creators of a vehicle that could drive 150 miles autonomously in the desert. This caused many people to innovate. Another important factor is reducing vehicular fatalities which, in fact, is the main cause of death for persons aged 1-30. Half of these fatalities occur during lane changes. Therefore, technologies that provide better lane control will greatly reduce such death rate. There are a number of emerging technologies for vehicle control, and they all require information such as: vehicle position, orientation, and direction of travel. Most of the time GPS can be used to provide these. However, GPS has gaps such as, for example, its signals cannot not reach underground parking garages and it they're susceptible to interference.

A potential alternative to GPS is 'perception positioning', where a region is visually mapped and then vehicles drive using optical recognition. Perception positioning requires frequent map updates. Also, optical sensors have field-of-view limitations. Therefore, a potential solution is to combine GPS and perception positioning. Dr. Bevly presented a number of case studies including: traction control, lane-keeping technologies (sideslip control), and automatic path following. With multiple antennas on a vehicle it is possible to determine attitude (or orientation), three-dimensional velocity (which also indicates highway slope), precise spacing information between vehicles, and timing information.

There have been a number of developments in the technology for vehicle-to-vehicle communication, traction control, and vehicle positioning.

Vehicle-to-vehicle (V-to-V) communication developments include a 'Basic Safety Message' with time, elevation, and other measurements. Various manufacturers are experimenting V-to-V using GPS as the sole provider of the Basic Safety Message, whereas other such as Google rely on perception positioning.

Accurate knowledge of lateral velocity (or sideslip) of a vehicle is a key requirement for traction control. Studies show that the integration of GPS and INS is able to capture slower sideslips compared to other equipment.

Many new automobiles have as many as six camera, in addition to GPS, and other technologies can be used for vehicle positioning. Combining these could produce a superior positioning system. Automobiles in an urban canyon, where they may receive only two GPS signals, could compensate with information from such sensors.

Another concept is 'vehicle convoying' (or automated path following), where 20-30 vehicles could be driven with a small amount of personnel. GPS can provide very accurate relative vectors across the vehicles. In commercial vehicles convoys, the ability to connect data on throttle and breaking would allow trucks to travel closer together and gain fuel economy of as much as 10-12%.

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GPS Timing Challenges and Robustness Needs for Critical Infrastructures
Examples from Telecom, Broadcast and Power Distribution Industries
Ms. Alison Silverstein, *PM*
North American Synchrophasor Initiative
Mr. Magnus Danielson, *Senior System Architect*
Net Insight AB

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/danielson-silverstein.pdf

Ms. Silverstein noted that North American Synchrophasor Initiative (NASPI) is a GPS customer. Telecommunications and power distribution systems require time-synchronized grid measurements, which in turn is dependent on GPS timing. PNT systems such as GPS have a variety of potential failure modes, each with different consequences on particular categories of users. Thus, the Advisory Board is being sought to help mitigate potential failures to these critical users groups.

Mr. Danielson noted that both telecommunication and broadcast industries rely on PNT. Telecom today needs stable frequency, but there is a trend towards using signal 'phase' to obtain stable time. Receiver monitoring is needed to identify potential GPS signal problems and alert the user. In practice, few people in telecom and broadcast industries monitor their own GPS receivers to detect such problems. On January 26, 2016, GPS SVN 23 was removed from the GPS constellation and, as an unintended consequence, GPS clocks started to behave strangely. In Berlin, all vendor equipment failed. Broadcasters experienced failure of digital transmissions. One trading market was not able to time-stamp its transactions. In summary, many customers were angered. This is not about casting blame but, rather, acknowledging the broad impact of a glitch in the system as in case of interference or spoofing of GPS signals. Other potential issues include the insertion of leap-seconds.

Ms. Silverstein explained that synchrophasor technology involves high-speed grid monitoring that is time-synchronized to Universal Coordinated Time (UTC) with microsecond accuracy. However, it cannot be developed to mission critical status unless networks and timing become more reliable. On-site user problems stem from, among other factors: poor quality GPS receivers, software errors, absence of firmware updates, local jamming and spoofing, and sloppy programs for time-handling. It is thought that perhaps up to 90% of the time problems in a power system involving a lost signal or bad timing are the result of user error. Errors or spoofing of the time signal of a phasor can cause false calculations to the phase angle. Differing ways of calculating leap seconds have also caused problems. In summary, the concern is that timing errors from any source can result in incorrect synchronization.

Mr. Danielson suggested possible PNT-level remedies, including:

- First, improve signal robustness checks
- Second, multi-frequency use – L1 C/A; L2C; L5
- Third, use of multi-GNSS systems
- Fourth, multiple receivers
- Fifth, jamming and spoofing detection and/or prevention
- Sixth, GPS-independent networks

Ms. Silverstein noted her group is attempting to resolve power field problems, including documentation of the problem, information sharing, developing recommendations for longer-term research into timing problem detection and interoperability, and updating industry standards. The NASPI Time Synchronization Task Force has been set up, and is engaging power system representatives, national laboratories, research organizations, and private sector experts. NASPI has two overall goals: (1) find ways to improve timing reliability within the power sector and raise resilience for synchrophasor technology and grid operations; and (2) leverage timing delivery of expertise and resources available beyond the power sector. NASPI plans to release a major product by March 2017.

> Dr. Betz noted that a presentation in the morning stressed the need for competent receivers and, after this briefing, clearly competent installation and operation is also needed.

Ms. Ciganer said many problems can be fixed by teaching people to do proper installations.

Mr. Danielson said a typical GPS receiver installation costs at least US$ 5,000. Users would need persuasion to install something that is considerably more costly. In his view the focus should be on relatively easy things, for example, finding ways to modernize systems using multiple receivers.

Ms. Silverstein noted that while software solutions are not inexpensive to develop, they can be made so they're inexpensive to deploy. There are many potential solutions to such issues, some of which may not yet be known.

Mr. Higgins asked what network density is required with a synchrophasor.

Ms. Silverstein said the technology is about 15 years old. It has just passed through its second cycle of Institute of Electrical and Electronics Engineers (IEEE) standards updates. In the U.S., about 2,000 units are deployed today. Some utilities have done an excellent job; others are lagging.

* * *

Adjournment:

In closing for the day, Mr. Stenbit, thanked all for their participation. He noted that where interference is concerned the group is currently on hold. On the following week a teleconference is scheduled to discuss plans for the June 26, 2016 EXCOM meeting. The Advisory Board members should be prepared to discuss what technical issues need to be raised to the EXCOM. Today's Advisory Board meeting has been devoted to a transparent process of discovering what various people are doing. Mr. Stenbit urged the group to reflect on the technical issues discussed today.

* * *

The Thursday, May 19, 2016 session of the National Space-Based Positioning, Navigation, and Timing Advisory Board convened at 9:03 a.m.

Board Convenes / Board Discussion

Mr. Stenbit opened the session by characterizing the previous day's meeting as long, interesting and leaving much to be discussed. Due to an unavoidable scheduling conflict, he would be absent between 10:30 and 11:30 a.m. The Advisory Board could use that time to discuss the three topics for possible presentation to the EXCOM:

First, the Advisory Board thought it was wise to hear a report from a group that had been studying GPS adjacent band issues. The board already had scheduled a DOT report on the same subject. Prior to these reports the board had already drafted a six-point list of criteria for GNSS spectrum assessments. In his view two things are crucial:

1. The testing regimen should be consistent. This means, in particular, that interference with the adjacent bandwidth of more than 1 dB at the noise floor should not be permitted. This is important as it allows a 'presumption of innocence' to those who abide. Also, while the DOT testing had not been framed by the 1 dB consideration, it nonetheless provided data that would allow it to be addressed.
2. One of the briefings showed that, irrespective of the 1 dB standard, for a representative set of transmitters certain things are not affected under particular circumstances. This approach is analogous to asking for receivers to be licensed instead of the transmitters themselves. If adopted, such a practice could cause the regulatory process to collapse. That's why the 1dB standard is of highest importance. Also in his view, that briefing did not exhaust the six-point criteria for spectrum assessment and, thus, has not lay to rest the concerns expressed several years ago.

Second, he will respond to the EXCOM on the issue of eLoran, of which he will say no more right now.

Third, Dr. Scott Pace's comment that the U.S. position with respect to frequency bands has always addressed the entire GNSS band, and not just the GPS band, is the correct position. Some people viewed this position as overly theoretical unless Galileo reception in the U.S. is approved in the near future. In fact, there are many good reasons for such approval including improving signal robustness and assist towards mitigating both jamming and spoofing.

Mr. Stenbit asked Ms. Karen Van Dyke, if DOT testing had included multi-GNSS receivers. Ms. Van Dyke said it had.

Ms. Van Dyke was asked if a Galileo PRS receiver had been included. She said she believed not.

Dr. John Betz said Galileo had two signals centered at the same L1 frequency. One was an open service signal; the other PRS concentrated its power near the 1559 MHz, thereby stretching the wide band. That, he said, made it important to test a PRS receiver to determine adjacent band affects.

Mr. Stenbit cited this as one reason he preferred a transmitter-based process. He believed pressing for Galileo approval would allow a concrete rather than theoretical approach to what was required to achieve exhaustiveness of receiver testing.

Mr. Stenbit noted that in Wednesday's session, board members had also raised various matters, and he urged them to put on the record any comment they would like to make.

Dr. Powell asked if the six criteria developed by Dr. Parkinson can be reviewed.

Dr. Parkinson said he will distribute the chart.

Dr. Marquez noted the pending U.S. Presidential election. Should the Advisory Board provide input to briefing books being prepared for the new administration regarding the new NSPD?

Mr. Stenbit agreed that something should be prepared. However, it is not a matter the Advisory Board should raise to the EXCOM.

Dr. Rashad noted the board has so far been inclined to discuss threats to the system. Perhaps equal attention should be paid to opportunities for PNT systems.

Dr. Camacho-Lara said he wished to discuss what actions pertinent to international users might be taken prior to the next meeting on the 1 dB degradation issue.

Mr. Stenbit agreed that international implications are important and should be kept in mind.

Mr. Shields noted that considerable R&D has been directed to adding GPS to all vehicle types. He favors and would support efforts to protect GPS reliability as it related to surface transportation over the coming decades. GPS-based applications could greatly reduce vehicle-related deaths, medical costs, and federal expenditures on those disabled in accidents.

Mr. Goward added there are a number of potential policy recommendations that have not yet been considered by the board, including: reconsideration of the Federal Communications Act; revision of NSPD-39; division of responsibility between departments, and overall governance.

Dr. Enge noted that while issues such as ground monitoring networks and noise floor have been discussed, little attention had been paid to "toughening." If user equipment could be toughened by 20 dB, then persons attempting to interfere with GNSS signals would need to use jammers of 10-100 Watt rather than 0.1-1 Watt. This would facilitate efforts to detect jammers. The noise floor would still need protection. In his view, toughening receivers and protecting the noise floor could go forward in tandem.

Mr. Stenbit suggested that Dr. Enge's position might be the perfect guidance statement on the subject.

Mr. Betz said that between 2001 and 2020, a total of US$ 50 billion will have been invested in space-based navigation. However, receivers are still being incompetently installed. Competent installation affects matters beyond just interference. All responsible parties must stop playing defense and start playing offense.

Dr. Axelrad commented there is value in continuing to improve GPS' capabilities, including the development of the GPS Space Service Volume and GPS-based science. The U.S. should continue to lead in all areas. Further, the issue of Galileo use in the U.S. needs to be resolved so U.S. users are not denied access to the best receivers.

Mr. Stenbit said Dr. Axelrad's statement is one reason he favors the creation of a standing subcommittee on science issues.

Dr. Parkinson expressed wholehearted agreement. Some people are urging restrictions on GPS by arguing that some of its functionality was not part of GPS' original intention. The board should help frame a counter-argument.

Dr. Axelrad asked if the FCC has not participated in the PNT EXCOM.

Mr. Stenbit confirmed that is the case.

Dr. Axelrad said that if the FCC is going to be engaged in licensing, it needed to be brought into the process.

Mr. Stenbit said the proper approach for this should be through the National Telecommunications and Information Administration (NTIA).

Gov. Geringer noted that one question was fundamental: what constitutes GPS governance? The role played in this by the FCC was unclear. Also, at the FCC persons constitute a majority vote.

Mr. Allen believed review of the NSPD-39 could create a 'work stream' allowing problematic issues to be addressed. He recommended creating such a work stream and volunteered to assist with the task.

Mr. Stenbit said that while this approach is different from what he has proposed, the Advisory Board should do whatever is useful to the next administration.

Mr. Allen said it would be useful to know which career people would handle GPS-related matters prior to the arrival of the new political appointees.

Mr. Martin observed that the NSPD-39 is an Executive Branch document. Therefore, it is unlikely to address the FCC which was a Congressionally-sanctioned body. The FCC has attended EXCOM meetings for some years in an observer capacity.

Mr. Faga said he is very impressed with the previous day's technical presentations, which reinforce the importance of protecting GNSS innovation.

Mr. Miller noted that NASA is busy preparing transition team books for the next administration. Should the board develop briefing papers that bring key GNSS-related points to the attention of those bodies that are developing transition team books?

Mr. Stenbit said the board needs to make a decision on how to proceed on this.

Mr. Miller said he would welcome Air Force involvement. Further, in working with the Air Force, attention should be paid to such low-hanging fruit as integrity monitoring and development of the SSV.

Maj Gen David Thompson endorsed the comments from Mr. Stenbit and Mr. Miller.

Mr. Dimmen said he agrees that spectrum protection and the inclusion of the Galileo signal are important issues. These tie to what Dr. Rashad and Mr. Faga said about protecting the inherent opportunities of GNSS. Transportation autonomy is an area of particular interest and concern.

Mr. Higgins emphasized the importance of spectrum protection, particularly as high-dynamic precise receivers become the standard in UAVs and other applications. As for the point raised by Dr. Parkinson that some claim GPS is used for things beyond its original intention, that's not unlike saying that since the Internet was not designed for video streaming, one then should not use it for that purpose.

Mr. Stenbit said the 1 dB noise barrier is important because it allows people to proceed with innovations with the confidence that their creations can be implemented.

Mr. Higgins, on the topic of fully-supported complementary PNT, noted that while he supports eLoran there are many applications that eLoran cannot support.

Dr. Beutler said the discussion of multi-GNSS in the previous day was very important, and that he did not entirely understand the discussion about emitting more noise in the terrestrial environment. In the IGS, one criterion for selecting sites is that they have low voice walls. It is important to recognize that high precision signals are essential to science.

Ms. Neilan expressed general agreement with the views expressed. She noted that while much discussion was focused on multi-GNSS, the political issue of multi-user GNSS in the U.S. remained unresolved. IGS operated on a multi-GNSS basis, with 140 reporting stations. She shared Dr. Axelrad's emphasis on the importance of science applications; e.g. in such areas as sea level change. She volunteered to serve on an Advisory Board subcommittee on science if one was constituted.

Mr. Stenbit requested assistance to identify science-related matters in which he needs to be well versed.

Ms. Neilan said she recently returned from the IGS workshop in Sydney, Australia, where a very sobering talk was given about sea level change. For those interested, all the presentations from this workshop are posted online.

Ms. Ciganer said she would like to introduce a new criterion under "Protection" that would be applied to "Augment." The criterion is that no complementary or alternative PNT should be allowed to degrade GPS and GNSS signals.

Mr. Hatch said insufficient attention has been paid to the need to "Toughen" receivers. Why are we permitting timing receivers that do not check for UTC? This is a critical issue.

Mr. McGurn said that if the board is going to expand its efforts to protect the GPS and GNSS bands, it will require clarification from the FCC about what bands needed protection. Furthermore, if the board is charged with protecting the band, then use of that band should be available.

Mr. Murphy said the discussion reinforces his belief that spectrum protection is crucial. Aviation is fully committed to this. He agrees with Dr. Enge that toughening has an important part to play. Export issues are also involved. In his view frequency diversity cannot happen quickly enough. Being restricted from using GLONASS or Galileo is a great roadblock to receiver development and could postpone implementation of some applications until 2025.

Mr. Burns said the board needs to clarify its strategic position, and he volunteers to assist in such task. From the aviation perspective, while the Automatic Dependent Surveillance – Broadcast (ADS-B) band is due for implementation around 2020, as of yet there are no policy statements on it. UAVs are completely dependent on GPS. At this time perhaps one million UAVs are in use. Unless some form of protection is created, it would not take much to bring them all down.

Ms. Neilan said she agrees a strategic plan is needed, but is uncertain how the board can accomplish this given the pending change in administration. Could development of a strategic plan dovetail with the development of a transition plan?

Mr. Stenbit challenged board to also consider long-term issues. These include protection; scientific activities; automatic vehicles, and others. In each area the board could be more effective than acting as a committee of the whole. Every board meeting is faced with a deluge of issues which he would like to address in a consistent manner.

Gov. Geringer said that discussion of Protect, Toughen, and Augment, reminds him of discussions he had with department heads when he served as Governor. A department head would seek a budget increase, and then he would ask: "To achieve what"? He would apply the same question now. What is the fundamental strategy by which individual actions are to be justified? The focus should not just be on defining the process but also on determining the desired outcome.

Dr. Parkinson said much depends on whether the federal government adopts strategy similar to that adopted by the board. Federal policy will determine priorities and expenditures. Board members are in intense agreement on many points and, consequently, are frustrated by what they see as uninformed decisions made by others. The board cannot compel the EXCOM or the FCC to share its own perspective. The EXCOM and FCC are composed of highly intelligent persons, even though they're not adequately informed. In consequence, it is difficult for them to distinguish between information that is wrong, and information that is both wrong and hazardous.

Maj Gen Thompson noted that the Air Force is ready to complete its list of intended PNT innovation efforts and welcomes suggestions from the Advisory Board on technologies the Air Force should consider, including user equipment and ground control. Considerable discussion has occurred at the Air Force Research Laboratory (AFRL) in Albuquerque, NM, on: (1) open architecture in future user equipment; and (2) enabling multi-GNSS capability. Maj Gen Thompson noted that when he first took the concept of open architecture to Los Angeles Air Force Base (AFB) and Wright-Patterson AFB there was some resistance. Maj Gen Thompson added that he welcomes advice from the Advisory Board.

Ms. Van Dyke said the DOT supports Protect, Toughen, and Augment and, thus, would also support any strategic statement to such affect. Beyond that, the DOT is the civil lead agency and wants to ensure protection of all applications, including safety-of-life and science. Also, education is essential to address why Protect, Toughen, Augment is so important. Such efforts should focus on addressing a core group of experts because the general public is unlikely to share all of the Advisory Board's concerns.

Mr. Martin said multiple references have been made to developing a transition paper for the next administration for the EXCOM. The various departments comprising the EXCOM are most likely already at work on documentation that reflects their individual department concerns. Should the EXCOM itself prepare such a document and, if so, what items does the Advisory Board feel should be included?

Mr. Stenbit said the question should not be posed in a vacuum. Rather, the Advisory Board should work on developing three key issues for the EXCOM that need to be addressed in any transition document.

Mr. Martin agreed. Whatever recommendations the Advisory Board wishes to make should be included in its presentation to the June 2016 EXCOM meeting.

Mr. Stenbit said that Advisory Board members, acting in cohorts, will be tasked with assembling information needed for preparing the briefing papers to be presented to the EXCOM.

Mr. Allen reported he has attended the annual NOAA conference on space in Colorado. Portions of the general policy statement drafted at that session may be of use to the board.

Dr. Parkinson re-emphasized the need for education. Many federal government actions can be traced to political pressure. Would it be possible to assemble a 'GPS Users Consortium' that can speak with

authority on current and future threats to GPS? Such an effort requires a sponsor because, in his experience, start-ups lacking a sponsor always fail.

Mr. Goward said his organization would be pleased to assist.

Ms. Neilan agreed education is very important. There are system providers in the international community that could also assist.

Mr. Higgins noted the ICG contains many key user groups, and links could be established with the national organizations tied to the ICG.

Ms. Ciganer noted Dr. Parkinson's fundamental distinction between radio navigation and radio communications is key, and while this distinction is intuitive to Advisory Board members it is not understood by others.

Mr. Stenbit said very good comments have been made, a number of which have influenced his views.

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European Conference of Postal and Telecommunications Administrations (CEPT) European Communications Committee (ECC) Recommendation that Authorizes Commercial GNSS *Pseudolite Operations Indoors in the RNSS Band in Europe*
Mr. Kurt Zimmerman
GPS Innovation Alliance

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/ciganer-zimmerman-swiek.pdf

Mr. Zimmerman noted that the potential use of ground-based pseudolites (PLs) within the European RNSS band is a very serious issue and directly related to the board's effort to "Protect." Some European telecommunications organizations still intend to license PLs in the RNSS band. The immediate concern focuses on the European Communications Committee (ECC) Recommendation 1108, which would authorize use of indoor PLs in the RNSS band. This recommendation was based on a handful of studies that, in his view, are questionable. In fact, the ECC reports acknowledges that partial or total signal degradation could follow from PL use. Further, these studies also acknowledge that PLs could rather easily be used to create spoofing and jamming. Therefore, in his view authorizing PL use would contravene the International Telecommunication Union (ITU) standards for frequency authorizations.

It is also disconcerting that European agencies are contemplating permitting PL use even though such devices are illegal in the U.S., where their manufacturing, licensing, or sale is prohibited. Mr. Zimmerman said he does not understand why anyone would wish to use ground-based PLs, as the cost of installing them carries a substantial cost in signal degradation. This has been raised by other studies, such as European study #183 that not only opposes outdoor PL use as a hazard to aviation, also notes that indoor use can pose a similar hazard due to leakage from interior setting. ECC Recommendation 1108 would effectively legalize such activity. The pertinent European agency – the CEPT, which has 48 member nations – is roughly analogous to the U.S. FCC in that it is not answerable to federal authority. To date, 14 nations have voted to proceed. Thus, we're just one step away from legalization.

Ms. Ciganer asked if this "Yes" position will be announced at a meeting scheduled for August 26, 2016.

Mr. Zimmerman said he is uncertain as to the date. There may be a rationale for withdrawing the CEPT recommendation because it may require use of dedicated GPS PRN codes which, he hopes, the U.S. Air Force will oppose.

Mr. Ciganer added that unexamined aviation use cases should be another significant rationale for withdrawing the proposal.

Mr. Zimmerman recommends withdrawal of ECC Recommendation 1108 and suggests that the U.S. Congress, in conjunction with the EU, create joint legislation supporting such a step. By definition, the "complementary" uses contemplated in the recommendation imply that they should not detract from the existing system (i.e. 'augment' and the expense of 'protect' and 'toughen'). He urges U.S. agencies to review this from the standpoint of self-interest, e.g. how does the U.S. Dept. of State view this risk? Does the Dept. of Defense believe in-band PL use threatens military operations in Europe? It is essential that the CEPT member states that have voted "Yes" understand the risk they would be authorizing.

Dr. Parkinson said it appears some massive lobbying group exists on behalf of PLs. What is the market for them?

Mr. Zimmerman said he is unaware of any substantial market for PLs.

Dr. Parkinson asked if Galileo has taken a position the issue.

Dr. Pace suggested that the problem may stem from some organizational weakness within the European Union's (EU) structure. In bilateral discussions both the EU and Galileo have been supportive of our concerns, but yet many CEPT representatives are still making decisions while lacking sufficient understanding on the issue. Thus, he endorses the actions suggested by Mr. Zimmerman.

Mr. Faga asked what PRN codes would PLs use. Could they opt for unused PRN codes?

Mr. Zimmerman said they could pick any previously unused code. He does not know how it could be stipulated they use a specific unused code and, thus, any small company could make an arbitrary decision. Generally, however, manufacturers regard as a selling point to be able to say they're employing a code already in use.

Dr. Parkinson said this will create cross-correlation issues.

Mr. Faga asked whether the PLs can do position reporting similar to what is achieved with satellites.

Mr. Zimmerman said that was examined early on, and it remains uncertain. A user could be receiving both satellite and PL signals and not know which one to trust.

A question was posed whether the 2004 U.S.-EU GPS-Galileo agreement is still in effect.

Dr. Pace said the agreement was signed in 2004 and to last ten years. However, the "ten years" run from the date of ratification, which took years to achieve. Also, the agreement does not contain a "sunset" clause, which means it is automatically extended for three to five years unless either the EU or the United States give a three months' notice of intention to withdraw. Neither party has given such notice. The U.S. regards itself as still bound by the agreement.

Mr. Jeffrey Auerbach, audience member and foreign affairs officer at the Dept. of State, noted that ratification occurred in 2011. Thus, the agreement will hold until 2021.

Dr. Parkinson asked Mr. Auerbach to please confirm those dates and report back to the board.

Mr. Auerbach said he will**.**

Ms. Ciganer noted there are obligations to protect current service levels in Europe and elsewhere. The question users would ask relative to PLs is whether they feel safer and have better service as a result of their implementation.

Dr. Parkinson said that just because the proposal is clearly implausible it does not mean it should not be taken seriously. It will probably take about one hour to educate the EXCOM on the issue. Therefore, further discussion should be tabled because this matter cannot be raised until the next EXCOM meeting.

Ms. Ciganer noted the GPS Industry Association sent a 12-page letter to the EXCOM in June 2014. Various European bodies noted this letter was meticulously researched and welcomed.

Ms. Ruth Neilan suggested this matter also be addressed by the ICG.

Dr. Parkinson welcomed the suggestions, and thanked Mr. Zimmerman for an excellent presentation on a thorny problem.

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Multi-GNSS Monitoring by the IGS and ICG
Dr. Gerhard Beutler
International Association of Geodesy

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/beutler.pdf

Dr. Beutler reviewed the history of the IGS since its creation in 1989, and stressed the importance of the continuity that such a longstanding organization has created. The IGS is an interdisciplinary, multi-GNSS service that supports both Earth Sciences and society in general. GNSS also enables applications such as time and frequency transfers. Such applications, however, require orbit accuracies of just a few centimeters, which can only be achieved if the properties of all GNSS are known. Also, many parameters, ranging from ephemerides to receiver-specific biases are determined through monitoring. In turn, Earth Science using GNSS is not possible without GNSS performance monitoring.

All these circumstances create the rationale for the IGMA that is being done by both the IGS and the ICG. The purpose of the IGMA ICG Joint Trial Project is to demonstrate a global GNSS monitoring & assessment capability. The project will be launched as soon as possible, and will occur in two phases. The first phase involves monitoring a limited set of parameters in post processing to determine the system level performance for each GNSS. The second phase will, through the use of monitoring/assessment capabilities, strive for real-time processing, user-level performance monitoring, and a combined product and assessment function. The existing network of multi-GNSS stations has over 3,100 sites. The trial project should be launched in October/November 2016. A report on the trial project implementation status will be made to the ICG-11 meeting soon thereafter.

Finally, Dr. Beutler presented a statement regarding the efforts of the IGS at the 16th Advisory Board session in Boulder, Colorado. The statement requests that the Advisory Board note and endorse the important role played by the IGS, whose 200 voluntarily-participating agencies worldwide pool their resources to generate precise GNSS products and make them freely available for science and society.

Mr. Stenbit, said he accepts the statement, and noted that Dr. Beutler's presentation adds to his ability to defend the importance of the 1 dB noise level given how many people depend on it.

Mr. Allen suggested adding a comparison of the User Range Error to the broadcast User Range Accuracy.

Dr. Beutler said the list he presented is not intended as final.

Mr. Goward said he's read that as the number of GNSS satellites in orbit reached 70, they could start to interfere one another and raise the noise floor.

Dr. Beutler responded that the 55 satellites currently in use have not created such a problem, and he does not anticipate the 12 satellites to be launched by Galileo and BeiDou will pose any problems.

Dr. Betz noted that the interference between satellite navigation systems is handled on a bilateral basis. The significant factor is not the number of satellites, but the specific signal and constellation designs. The design is based on very conservative assumptions to ensure there is no harmful interference. This allows for confidence that no problems be created, including in the future when all GNSS systems are operating with their full constellations.

Dr. Parkinson added that he's heard similar concerns expressed. However, those persons who have worked on the technical aspects of the matter are assured that the concerns are without basis.

Mr. Stenbit noted that difficulties have occurred in consulting with Galileo, but once initial problems were overcome it was clear that all concerned were diligently committed to avoiding signal conflict. The goal is that while there is hope that all users will be better off, there is a commitment that no user will be worse off.

Ms. Neilan presented a slide from the 2016 IGS Workshop and noted there was a very good presentation from Dr. Oliver Montenbruck, Manager of the Multi-GNSS Experiment. A great deal of other useful information was presented has been made available.

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Representative PNT Board Member Updates & Perspectives

Mr. Arve Dimmen
Norwegian Coastal Administration

Mr. Dimmen commented on the Galileo launch scheduled for the following fall, and noted that although he does not fully understand all the ramifications of not permitting use of Galileo in the U.S., it is regrettable as Galileo offers huge benefits to all users. There are great opportunities at hand, particularly regarding the safety and efficiency of transportation.

Mr. Dana Goward
Resilient Navigation and Timing Foundation

Mr. Dana Goward, commenting on the GPS SVN 23 incident, noted Maj Gen Thompson has promised as much publicly-releasable information would be made available as soon as possible. Mr. Goward distributed a hard copy of information from the DHS and a near-final copy of report by Mr. Magnus Danielson of Net Insight A&B on the various impacts of that GPS event. Both the incident and the reporting should be useful in convincing other GNSS operators of the importance of uninterrupted services. Also, regarding the reference to GPS having an annual value of US$ 60 billion, he is gravely concerned that the figure is hazardously misleading. It greatly underestimates the true value and, thus, we should be wary in citing that figure. Mr. Goward recommended that the Advisory Board use qualitative rather than quantitative measures to avoid being hazardously misleading.

Mr. Matt Higgins
International GNSS Society (Australia)

Mr. Matt Higgins noted he is a member of an Australian advisory board that is equivalent to the PNT Advisory Board. Also, Mr. Gary Johnson, chair of the Australian body, is the current chair of IGS. The advisory group has created a sub-group to look at business model issues – how federal and state governments and private enterprise can best coordinate their efforts. There are on-going discussion on a possible SBAS for Australia. Also, there are efforts to create dynamic positional data for Australia. Australia has slid 1.4 meters to the northeast since 1994. Australia is now home to 100 multi-GNSS stations, 70 of which are fully capable of tracking all GNSS on multiple frequencies. In December 2016 an IGS conference will be held in Sydney, and everyone is welcome to attend.

Dr. Refaat Rashad
Arab Institute of Navigation (Egypt)

Briefing: http://www.gps.gov/governance/advisory/meetings/2016-05/rashad.pdf

Dr. Refaat Rashad said that if one has a problem, the first question to ask is whether anything can be done about

it. If the answer is "yes," it leads to additional questions, such as: How big is the problem? How did it start? What will it cost to fix it? Who will pay that cost? The problem faced by the board is that the signals employed by GPS and other GNSS systems are vulnerable. While the system faces threats, major disruptions have not yet occurred. However, while threats to the system may not be imminent, the fact that they can happen at any time creates uncertainty. The intelligent response is to "buy insurance". One such insurance policy is eLoran, which is affordable and easy to expand. It could be financed by the system's beneficiaries, both private and public. Also, discussions often turned to the terms "challenges" and "opportunities", but it is important that the board keep in mind they're opposite sides of the same coin. Focusing on opportunities will lead to progress in science, and in other areas, and will also encourage the development of much-needed solutions.

Dr. Sergio Camacho-Lara
United Nations Regional Education Center of Science and Space Technology - Latin America and Caribbean

Dr. Camacho-Lara returned to a proposal he made earlier. The scientific and technical subcommittee of the U.N. Committee on Peaceful Uses of Outer Space (COPUOS) has the ICG proposal in its report for the subcommittee to explore the feasibility of exploring issues related to GNSS protection interference and mitigation. Further, the subcommittee has stated its intention to raise awareness of the issue among the member states. The recommendation made by ICG WG-A to the ICG have been accepted and brought up to the subcommittee, with the ultimate intention of creating a multi-year work plan and inviting member states to report on their own efforts at protection and mitigation of interference. It was further recommended by ICG WG-A that the subcommittee's consideration lead to a series of voluntary recommendations to member states – first by the committee; then, if accepted, by the 193 member states. This is in line with the Advisory Board's discussion about the importance of spectrum protection and the need to maintain the 1 dB margin. Dr. Camacho-Lara asked whether this effort can be combined with the previous day's proposal made by Mr. Ken Hodgkins (DOS) regarding coordination with other GNSS. Such coordination requires the cooperative efforts of many persons and there should be a formal record of what has been achieved. An Advisory Board subcommittee should be charged with preparing such record, which could be used with multiple audiences to underscore GPS' importance to the political, academic, and general public environment. Further, the Advisory Board should also consider assigning the topic of spectrum protection to a standing subcommittee.

Maj Gen David Thompson
Air Force Space Command

Maj Gen Thompson said he will follow-up on reporting more fully to the board on the GPS SVN 23 incident. Previously he worked with US Strategic Command (USSTRATCOM), where one of his tasks was chairing a GPS response team. This organization continues to work, primarily with U.S. government agencies, to establish a process where operational centers can report in real-time any GPS issues that may occur. Setting up this process is not simple because the overall vulnerability of the system, and the importance of rapid identification of problems, is not yet fully recognized. Finally, Maj Gen Thompson noted that his conversations with NASA during these past few days have increased his understanding of the need to reassess the importance of the GPS SSV to support the needs of all users in high earth orbit.

* * *

Wrap-Up & Adjournment

Mr. Stenbit, the board Chairman, noted that the past three days have been very productive. The meeting day preceding the open session was very important as it allowed board members to inform him which issues they would like to address and, also, led to the creation of standing subcommittees including, but not limited to, aviation, automated transportation, infrastructure, science, receiver improvement, and spectrum protection. Moving forward, the Advisory Board needs a more strategic approach. The creation of these subcommittees should ensure that our work continues between the full Advisory Board meetings.

Dr. Parkinson, the 1st Vice Chair, noted that Mr. Stenbit has given him an action item to draft a letter, based on board discussions, to be sent to the EXCOM once it gets approved by the Advisory Board. He will undertake this task with assistance of several board members.

Mr. Stenbit noted that a telephone call is scheduled on the following week with the ESG. At this meeting he will report on the board's discussions. There is a draft in circulation among board members on the three topics he recommended earlier. Comments from board members regarding the upcoming EXCOM meeting are welcome and much appreciated.

Dr. Parkinson, said he has a sense of urgency on the letter intended for the EXCOM.

Gov. Geringer, the 2nd Vice Chair, invoked the memory of the now departed long-time Advisory Board Chair Dr. James Schlesinger to present two quotes. The first quote is from physicist Richard Feynman, "Never yield to pressure to deliver something." That is, the board should not feel pressured to deliver something that it may believe is unready and that could potentially compromise the integrity or performance of the GPS system. The second quote is from Shakespeare, "Love all, trust few, do wrong to none."

Mr. James Miller, the board Executive Director, added that Dr. Newman has contacted him to express her pleasure in participating in yesterday's morning's session. Mr. Miller also urged the group to bear in mind that for a recommendation to be accepted, it needs to be measureable. The six-point program developed by Dr. Parkinson regarding receiver tests is a good example of this. Finally, consideration should be given to scheduling the next full Advisory Board meeting for either the week of December 5th or December 12th later this year.

With this, Mr. Stenbit, Chair, gaveled the meeting to a close.

The 17th session of the National Space-Based Positioning, Navigation, and Timing Advisory Board adjourned Thursday, May 19th, 2016 at 12:05 p.m.

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Appendix A: PNT Advisory Board Membership

Special Government Employees

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

- **John Stenbit** (Chair), MITRE
- **Bradford Parkinson** (Vice Chair), Stanford University
- **James E. Geringer** (Second Vice Chair), ESRI
- **Thad Allen**, Booz Allen Hamilton
- **Penina Axelrad**, University of Colorado
- **John Betz**, MITRE
- **Dean Brenner**, Qualcomm
- **Scott Burgett**, Garmin International
- **Joseph D. Burns**, Sensurion Aerospace
- **Per K. Enge**, Stanford University
- **Martin C. Faga**, MITRE
- **Ronald R. Hatch**, consultant to John Deere
- **Larry James**, Jet Propulsion Laboratory
- **Peter Marquez**, Planetary Resources
- **Terence J. McGurn**, private consultant (retired CIA)
- **Timothy A. Murphy**, The Boeing Company
- **Ruth Neilan**, Jet Propulsion Laboratory
- **T. Russell Shields**, Ygomi

Representatives

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

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

Executive Director

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

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

Special Counselors

- **Mr. Kirk Lewis**, Institute for Defense Analyses (IDA)
- **Dr. Scott Pace**, The George Washington University (GWU)
- **Dr. Tom Powell**, Aerospace

Appendix B: Presentations

- GPS Spoofing & Jamming/Dr. Brad Parkinson
- Recent PNT EXCOM Topics/Mr. Harold "Stormy" Martin
- Global Positioning System (GPS) Status & Modernization Progress/Lt Col Andrew Zinn
- Update on GPS Space Service Volume (SSV) for Space Ops & Science/Mr. Joel Parker
- PNT Board Recommended Criteria for Spectrum Assessments/Dr. Brad Parkinson
- GPS Adjacent Band Compatibility (ABC) Assessment/Ms. Karen Van Dyke
- Presentation of Roberson and Associates Testing Results/Dr. Ken Zdunek
- U.S. International Engagements & Partnerships/Mr. Kenneth Hodgkins
- Activity Overview of Emerging PNT Services & Capabilities/Mr. Andy Proctor
- International GNSS Service (IGS) Orbit Dynamics, Modeling, & Timing/Dr. Marek Ziebart
- Networks for Robust Civil Signal Performance Monitoring & RFI Detection/Dr. Yoaz Bar-Sever
- Satellite Time and Location (STL)/Dr. Gregory Gutt
- Techniques for Radio Frequency Spectrum Mapping from Space/Mr. Russ Matijevich
- Emerging Microsystem Technologies for Autonomous PNT/Dr. Robert Lutwak
- The Use of GPS for Vehicle Control Applications/Dr. David M. Bevly
- GPS Timing Challenges and Robustness Needs for Critical Infrastructures/Mr. Magnus Danielson & Ms. Alison Silverstein
- CEPT ECC Recommendation that Authorizes Commercial GNSS Pseudolite Operations Indoors in the RNSS Band in Europe/Ms. Ann Ciganer, Mr. Mike Swiek & Dr. Kurt Zimmerman
- Multi-GNSS Monitoring by International GNSS Service (IGS) and International Committee on GNSS (ICG)/Dr. Gerhard Beutler

Appendix C: Sign-In Sheet

Wednesday, May 18

Advisory Board
- John Stenbit, Chair, PNTAB
- Penina Axelrad, University of Colorado/Boulder
- John Betz, MITRE
- Gerhard Beutler, AIUB
- Dean Brenner, Qualcomm
- Joe Burns,
- Ann Ciganer, OPSIA
- Harold Martin, NCO
- Terry McGurn
- Ruth Neilan, NASA Jet Propulsion Laboratory
- Refaat Rashad, Arab Institute of Navigation
- Russell Shields, Ygomi
- Karen Van Dyke, Department of Transportation

Other NASA
- Barbara Adde, NASA
- R. J. Balanga, NASA
- Yoaz Bar-Sever, NASA Jet Propulsion Laboratory
- Carrie Clapper, NASA
- Jennifer Donaldson, NASA
- Steve Fisher, NASA Jet Propulsion Laboratory
- Larry James, NASA Jet Propulsion Laboratory
- A.J. Oria, NASA/Overlook
- Joel Parker, NASA
- Tony Russo, NASA
- Luke Winternitz, NASA

Other Attendees
- Seiji Amai, IGNSS
- D. J. Anand, NIST
- Jeffrey Auerbach, Department of State
- Jean-Luc Bald, EU embassy
- Frank H. Bauer, NASA
- Doug Bevly, Auburn
- Andrew Bonds, Next Federal
- Eugene Brown,
- Billy Cain, FAA
- Garrett Clark, NextFed
- Milton Clary, DoD Space Advisor
- Rob Crane, National Coordination Office
- Clark Cohen, PNT
- Magnus Danielson, Net Insight
- Kim DeBow,
- Dee Ann Divis, *Inside GNSS*
- John Dragseth, Department of Homeland Security
- Alan Evans, Pennsylvania State University
- Martin Foulger, Spirent
- Sherron Fulton, Orbital Tech
- Jewff Gicke, Optimum Tech
- Gregory Gutt, Satelles

Jonathan Hardiss, NIST
Katherine Harskamp, Overlook Systems Technologies, Inc
John Hildebrand, Optimum Technologies
Ken Hodgkins, Department of State
Capt. Russell Holmes, United States Coast Guard
Larry Hothem, USGS
David Howard, Department of Energy
Aaron Jensen, US Census Bureau
Matt Jones, BoeingJason Kim, Department of Commerce
Ya-Shian Li-Babond, NIST
David Logsden, Comp TIA
Tim Logue,
Robert Ludwak, DARPA
Stephen Mackey, Volpe
Sarah Mahmood, Department of Homeland Security
Stephen Malys, National Geographic Association
Russ Matijevich, Hawkeye360
Chris Mindnich, National Coordination Office/Overlook
Jeff Miller, AYA
Ed Morris, Bait
Cuong Nguyen, NIST
Michael O'Conner, Satelles
David Olsen, Federal Aviation Administration
Scott Pace, George Washington University
Tony Park
Rudy Peschel, United States Coast Guard, retired
Tom Powell, Aerospace
Andy Proctor, UK Government PNT Group and UK Delegate to ESA Navigation Board
Vernon Simmons, Cassidy & Associates
Alison Silverstein, NASPI
Doug Smith, Ligado
Capt. Scott Smith, United States Coast Guard
Geoff Stearn, Ligado
Frank Van Grass, Ohio University
Mike Violet, SAP/AQSE
M. E. Washington, Joint Staff
Sungpil Yoon, National Oceanic and Atmospheric Association
Kurt Zimmermann, GPSIA
Lt. Col. Drew Zinn, United States Air Force
Ken Zdunek, Roberson & Associates
Marek Ziebart, UCL

Thursday, May 19

Advisory Board
- John Stenbit, PNTAB
- John Betz, MITRE
- Ruth Neilan, NASA Jet Propulsion Laboratory

Other NASA Employees
- Carry Clapper, NASA
- Camy Janes, NASA Jet Propulsion Laboratory
- Joel Parker, NASA

Other Attendees
- Seiki Amai, JGPSC
- Billie Cain, Federal Aviation Administration
- Dee Ann Divis, *InsideGNSS*
- Larry Hothem, United States Geological Survey
- Rich Lee, iPosi, Inc.
- Ya-Shian Li-Babmol, NIST
- Rudlofo Lavaque, NASA
- Tim Logue,
- Stephen Makey, Volpe
- Dave Olsen, Federal Aviation Administration
- Scott Pace, George Washington University
- Tony Park
- Amy Proctor, InnovateUK
- Joe Rolli, Harris
- John Schnabel, Harris
- Kurt Zimmermann, GPSIA/Trimble

Appendix D: Acronyms & Definitions

ABC	Adjacent Band Compatibility (DOT-led GPS ABC Assessment)
ACES	Atomic Clock with Enhanced Stability
ADS-B	Automatic Dependent Surveillance – Broadcast
AF	Air Force
AFB	Air Force base
AFRL	Air Force Research Laboratory
AFSPC	Air Force Space Command
BeiDou	China's GNSS
CDD	GPS Capabilities Development Document
CEOS	Committee on Earth Observation Satellites
CEPT	European Conference of Postal and Telecommunications Administrations
COPUOS	Committee on the Peaceful Use of Outer Space
CORS	Continuous Operating Reference Stations
DARPA	Defense Advanced Research Projects Agency
dB	decibel
DHS	Department of Homeland Security
DOS	Department of State
DOT	Department of Transportation
ECC	European Communications Committee
eLoran	Enhanced Loran
ESA	European Space Agency
ESG	Executive Steering Group
EXCOM	Executive Committee
EU	European Union
FAA	Federal Aviation Administration
FACA	Federal Advisory Committee Act
FDOA	Frequency Difference of Arrival
FCC	Federal Communications Commission
Galileo	European Union's GNSS
GEO	Geosynchronous Orbit
GDGPS	NASA's Global Differential GPS System
GHz	gigahertz
GLONASS	Russia's GNSS
GNSS	Global Navigation Satellite System
GOES-R	GOES R-Series
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
HEO	High Earth Orbit
ICG	International Committee on GNSS
IDM	Interference detection and mitigation
IFOR	GPS Interagency Forum for Operational Requirements
ITM	Interference tolerance mask
IEEE	Institute of Electrical and Electronics Engineers
IGMA	International Multi-GNSS Monitoring and Assessment
IGS	International GNSS Service
INS	Inertial Navigation System

ITS	Intelligent Transportation System
ITU	International Telecommunication Union
JROC	Joint Requirements Oversight Council
kg	kilogram
LTE	Long Term Evolution (a standard for high-speed wireless communication for mobile phones and data terminals)
MEMS	Micro-Electro-Mechanical Systems
MGUE	Military GPS User Equipment
MHz	megahertz
MRIG	Micro-scale Rate-Integrating Gyroscope
NASA	National Aeronautics and Space Administration
NASPI	North American Synchrophasor Initiative
NIST	National Institute of Standards and Technology
NOAA	Memorandum of Agreement
NSPD	National Security Presidential Directives
NTIA	National Telecommunications and Information Administration
OCX	Next Generation Operational Control System
OPSEC	Operational Security
PL	Pseudolite
PNT	Positioning, Navigation, and Timing
PNTAB	PNT Advisory Board
PRIGM	Precise Robust Inertial Guidance for Munitions
PRN	Pseudorandom Noise
PRS	Galileo Publicly Regulated Service
R&D	Research and Development
RAA	Robertson and Associates
RF	Radiofrequency
RFI	Radiofrequency Interference
RNSS	Radio Navigation Satellite Services
SBAS	Space-Based Augmentation System
SMC/SY	Space and Missile Systems Center/Space Superiority Systems Directorate
SNR	Signal-to-Noise Ratio
SV	GPS Satellite Vehicle
SVN	GPS Satellite Vehicle Number
SSV	Space Service Volume
STL	Satellite Time and Location
TDOA	Time Difference of Arrival
TOA	Time of Arrival
UK	United Kingdom
UN	United Nations
USSTRATCOM	United States Strategic Command
UTC	Universal Coordinated Time
V-to-V	Vehicle to Vehicle
WG	Working Group