United States
Position Navigation and Timing Advisory Board (PNTAB)
Current Activities and Focus

Professor Bradford Parkinson

Stanford University

Co-Chair US PNTAB

Original Program Director of GPS

Background PNTAB

- Primary PNTAB Objective:
  - Assured *PNT* for all Users
- Therefore our Focus is ***PTA Program***
  - ***P***rotect the **radio spectrum** + identify + prosecute interferers
  - ***T***oughen GPS receivers against natural and human interference
  - ***A***ugment with additional PNT sources and Techniques
- We Advocate ***Three Foundational GNSS Principles***:
  - ***Transparency*** - System and Signal definition, FMEA, *Timely* insight into Operations, Development and Deployment
  - ***Performance Standards:***A Clearly written and offically published - Satellitenumbers and geometry, Accuracy, Inherent System Integrity etc.
  - ***Integrity*** Establishing methods for independent and timely user notifications of integrity breach

PTA: Specific Current Efforts

- Protect GNSS: Establish criteria for testing adjacent band interference signals
- Toughen GNSS: Authorize use of other GNSS signals
- Augment GNSS: Enhanced Loran (eLoran)

PNTAB Recommendations (1)

(Letter of 29 August to Sctys. Work and Mendez)

1. **Formally Designate GPS as a Critical Infrastructure Sector for the United States**
    - **14 of 16 current CIs deeply dependent**
2. **Develop a Formal National Threat Model for PNT Applications in Critical Infrastructure**
    - **Build on earlier Van Dyke effort at DOT**
3. **Prevent the Proliferation of Licensed Emitters in GPS Frequency Bands**
    - **Threat continues**
4. **Establish a Nationwide CONUS Back-Up to GPS with Existing Infrastructure (eLoran)**
    - **Previously accepted by EXCOM, requires refocus**

Innovation and the GPS Signal - Current and Future Dependency

- 1983 – 2016, Civil GPS community exploits GPS signal and system reliability/availability to ***create applications that go way beyond the nominal "system characteristics",*** including:
  - **Monitoring Techtonic Plate motion to fractions of an inch in 3 dimensions**
  - **Fully automatic landing of Airplanes**
  - Safety of Life - First Providers
  - **Automatic control of land vehicles – Cargo Cranes to bulldozers**
  - **Robotic Farming and many more**

Red – Precision, Wide Band Receivers

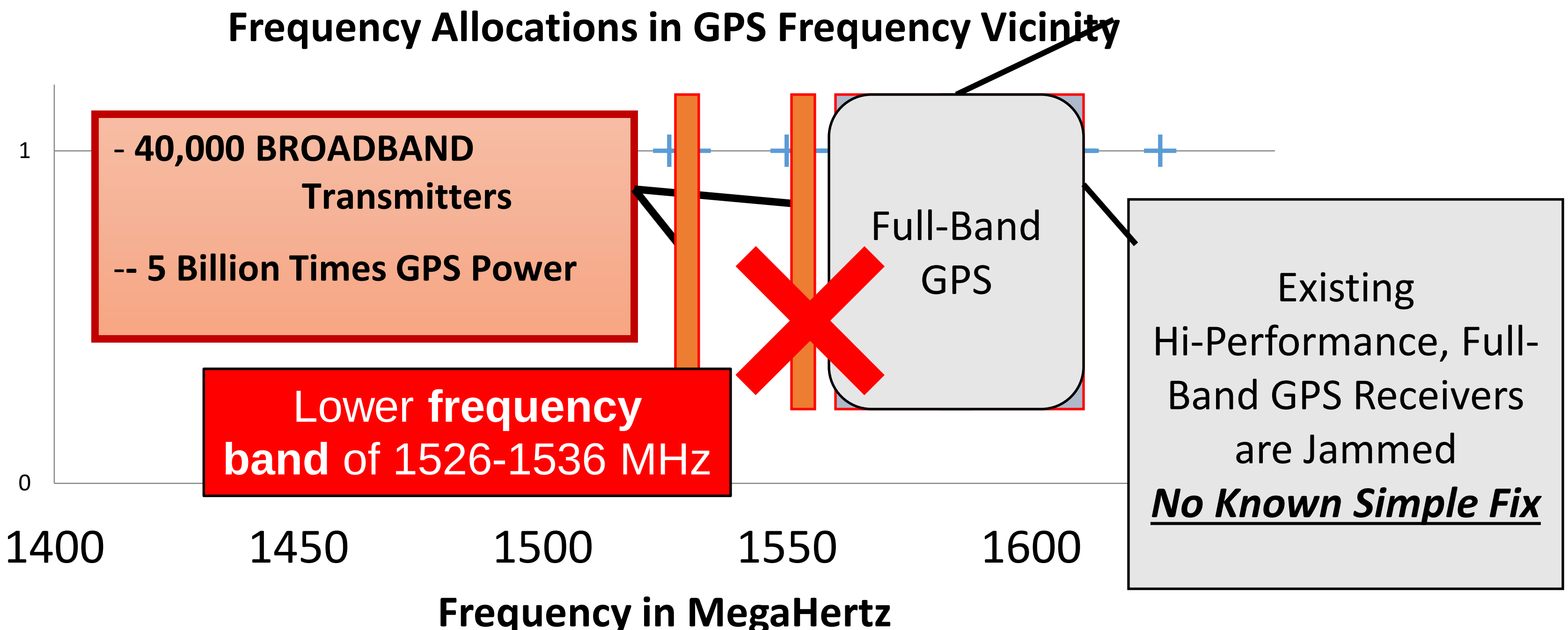
- These innovations led to estimate by USG of over $55B per year of tangible economic benefits

<u>Future – Documented Expectation</u> – Literally 10s of B$ savings per year

- FAA's NextGen is totally dependent on GPS availability
- Intelligent Highways Program - GPS has essential role

We strongly believe: Any significant degradation to the GPS System that would damage these benefits, ***<u>Independent of any stated original characteristic, would be greatly detrimental to the User's interest</u>***

Existential Threat to GPS – FCC Re-allocation of Nearby Band to Higher Power



Problems:

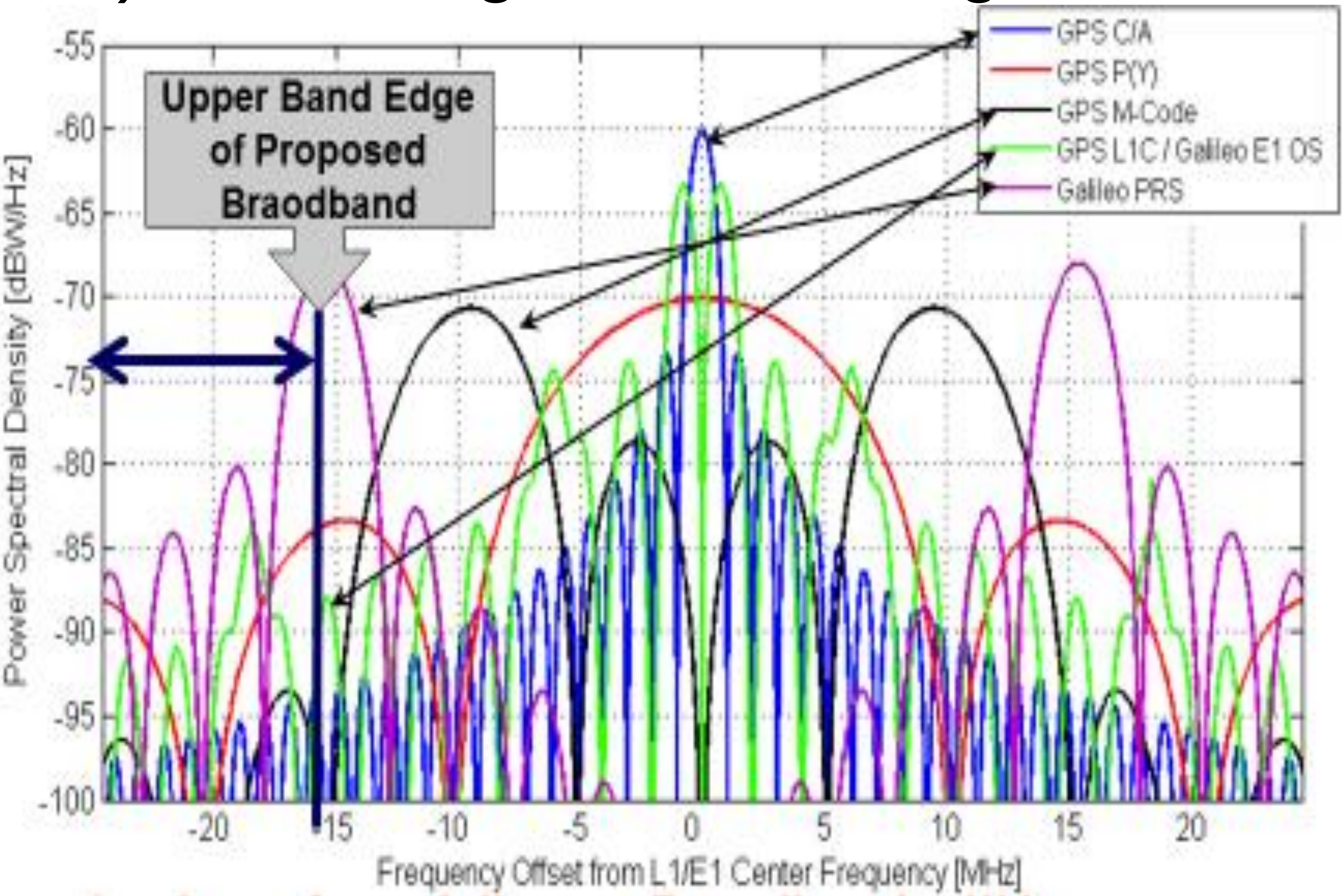
Proximity (geographic and RF spectrum) and ***Power***

A Short Checklist of Issues with Testing Sponsored by Ligado

1. Meeting the ***1 dB*** Degradation Criteria
2. Assessing ***All GNSS Signals***
3. Assessing ***all classes of Precision Receive***rs
4. Fully Understanding the ***Assumptions*** behind Analysis and Test Parameters
5. ***Ensuring Compliance*** with Authorized Transmitting Power Levels
6. Assessing ***Phase-out Time*** for Legacy Equipment

Burden of proof should be on the proposers of repurposing - And should Address All User Categories

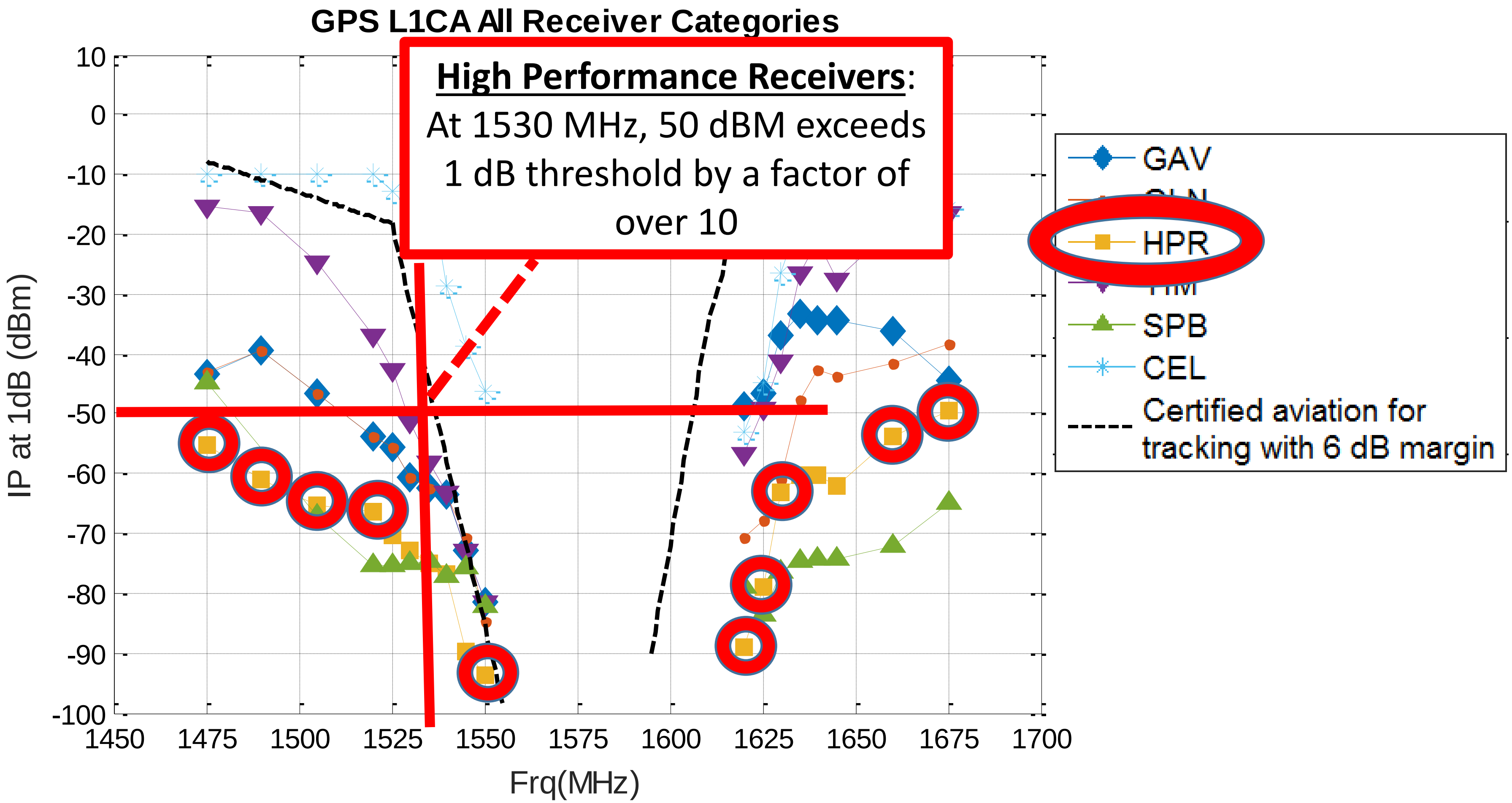
2) Assessing All GNSS Signals



Public Results
of
Recent DOT Sponsored Testing
Regarding Adjacent Band Interference

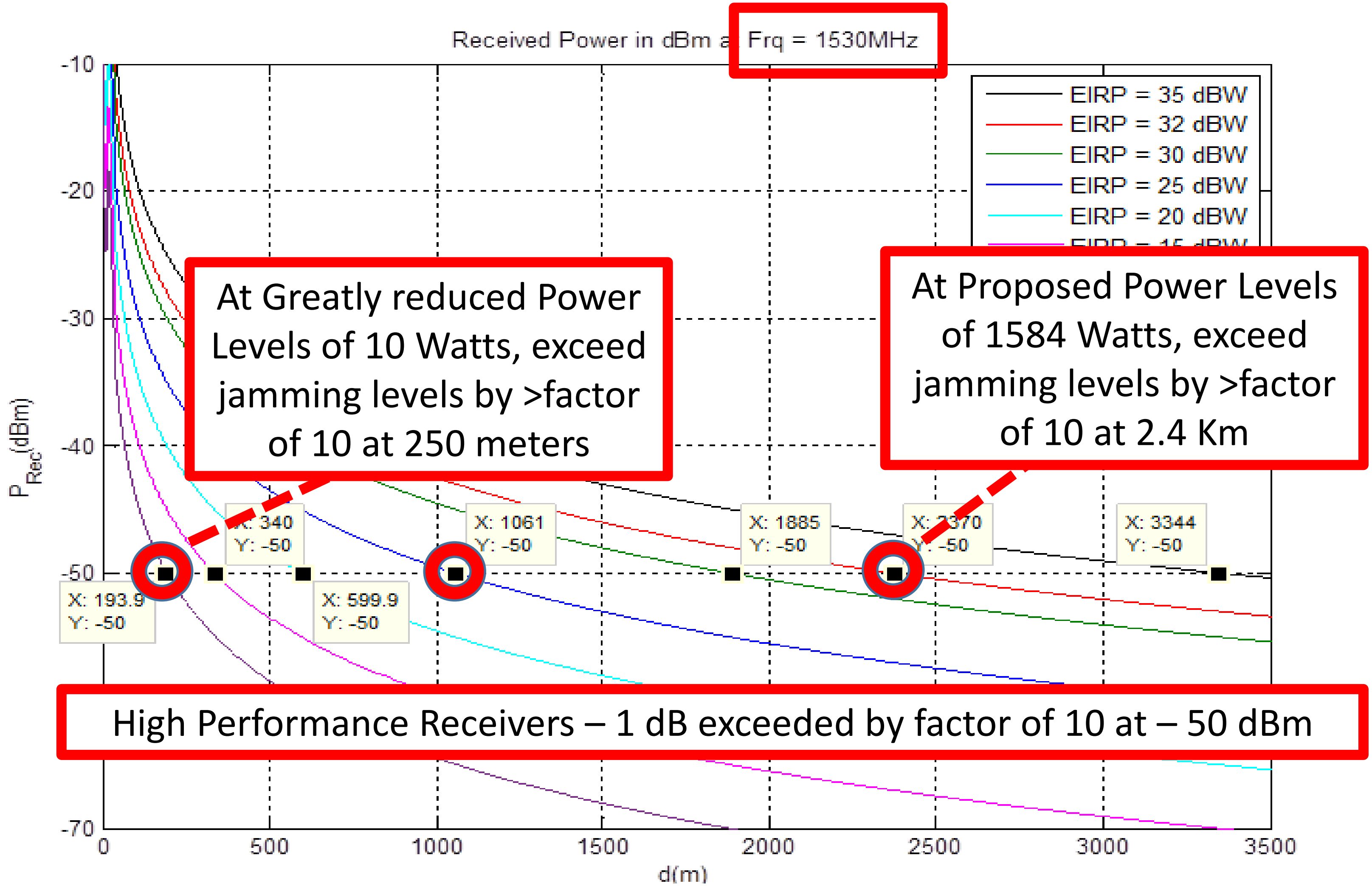
(Courtesy of Karen Van Dyke - released in October 2016)

L1 C/A Bounding Masks Compared With Certified Aviation Mask



From DOT Testing

Example Min. Separation Distance vs. Received Power Single Transmitter with Free Space Path Loss



PNTAB - Conclusions and Recommendations to EXCOM (October 2016)

- Standards and criteria to demonstrate no harm must be set by technical experts, not by advocates with a conflict of interest
- Any repurposing of spectrum adjacent to GPS/GNSS must demonstrate no harm to existing ***and evolving*** uses of space-based PNT services. Reaffirm 2012 EXCOM letter - ensure that adjacent band spectrum proposals ***"are implemented without affecting existing and evolving uses of space-based PNT services"***

A Parting Thought…

- PNTAB has been a strong, independent, and effective advisory body to the US Government
- US PNTAB derives great benefit from formal participation by non-US members
- Other GNSS Service Providers might consider some similar arrangement

Questions?

Backups and Additional support

A few (64!) Example Applications: ***<u>High Precision in Red</u>---***

Areas	Example applications
Aviation	Area navigation, approach, landing up to Cat III, NextGen
Agriculture	AutoFarming: crop spraying, precision cultivating, yield assessment
Automotive	Turn-by-turn guidance, OnStar, driverless cars
Emergency and Rescue Services	911, ambulance, fire, police, rescue helicopters, emergency beacons, airplane and ship locaters, OnStar
Intelligent Transportation	Train control and management, UAVs, Intelligent Highways
Military	Rescue, precision weapon delivery, unit and individual location
Recreation	GeoCaching, control of models, hiking, outdoor activities
Robotics and Machine Control	Bull dozers, Earth graders, mining trucks, oil drilling
Scientific	Earth movement and shape, atmosphere, weather forecasting, climate modeling, ionosphere, space weather, tsunami warning, soil moisture, ocean roughness, wind velocity, snow, ice, and foliage coverage, ……
Survey and GIS	Mapping, environmental monitoring, tagging disease outbreaks
Timing	Cell phone towers, banking, power grid
Tracking	Fleets, assets, equipment, shipments, children, Alzheimer's patients, wild life, animals, law enforcements, criminals, parolees, ……

1) The 1 dB C/N_0 Degradation Criterion

- 1 dB C/N_0 is Longstanding International Standard

  (Consensus at WRC 2012)
  - Only one contributor to Noise Floor (add scintillation and other sources)
  - In particular, it is well understood for radar systems - another faint timing signal application.
- 1 dB criterion designed to protect all modes of GPS operation – Loss of Lock, but- -
  - ***Acquisition is the most fragile and difficult operation***
  - ***For Precision – a major issue is pico-second jitter***
- 1 decibel (dB) degradation of carrier-to-noise ratio (C/No) = reducing satellite power by 21%,
- Impacts are very situationally dependent – example aircraft reacquisition problem
- NTIA, in the past, has defended this standard

Any change to 1 dB criterion would

- **be reviewed by PNT community and require good justification**
- **establish a domestic and international precedent**
- **apply to other space systems, domestic and international, including all U.S. government satellite systems.**

3) Assessing Precision Receivers

- Over two billion GNSS receivers worldwide - small percentage classified as *precision receivers*.
  - But these, over a million users, enable 30.1B$ of 55.7B$ in annual (US) economic benefits.
  - These include, for example, precision real-time measurements of earth-fault movement in three dimensions (with accuracies better than 1 millimeter)
  - precision control of bulldozers and road grading equipment in cities and rural areas.
- Precision receivers must use very wide bandwidth for accuracy
  - More susceptible to interference than ordinary GNSS receiver.
  - Not just Tracking - impact on ***measurement jitter is more critical***
- New Designs may somewhat reduce (but not eliminate) susceptibility
  - Receivers are retained for many years . Repacement and renewal timing a very real issue.
  - To completely understand impacts - carefully evaluate representative wide-band (precision) receivers

Question: What analyses and tests have been performed or proposed for the many classes of precision users – for *both signal acquisition* and tracking?

4) Fully Understanding the Assumptions behind Analysis and Test Parameters – Relate to real Operational Conditions

- Many critical PNT operations potentially very near Wide-Band Transmitters
  - Usually vectored and tracked using PNT from GPS
    - Includes Emergency Services - police, fire, and ambulance operations
    - Critical control of airplanes during airport taxiing operations.
  - Urban Rescue/Police Helicopters may be a particularly vulnerable example
- Location of 911 emergency calls referenced back to GPS position -more accurate than position triangulation from cellular towers.
- To avoid destructive interference, essential for decision-makers to fully understand the assumptions used in analysis and testing. Including:
  - the line of sight distance between potential source of interference and critical users (3D Users).
  - frequency separation from all GNSS bands
  - Proposed repurposing geographical laydown (Transmitter density)
  - Signal structure and characteristics

Question: What assumptions and constraints have been placed on the parameters (such as power, frequency, and distance) used in existing or proposed analyses?

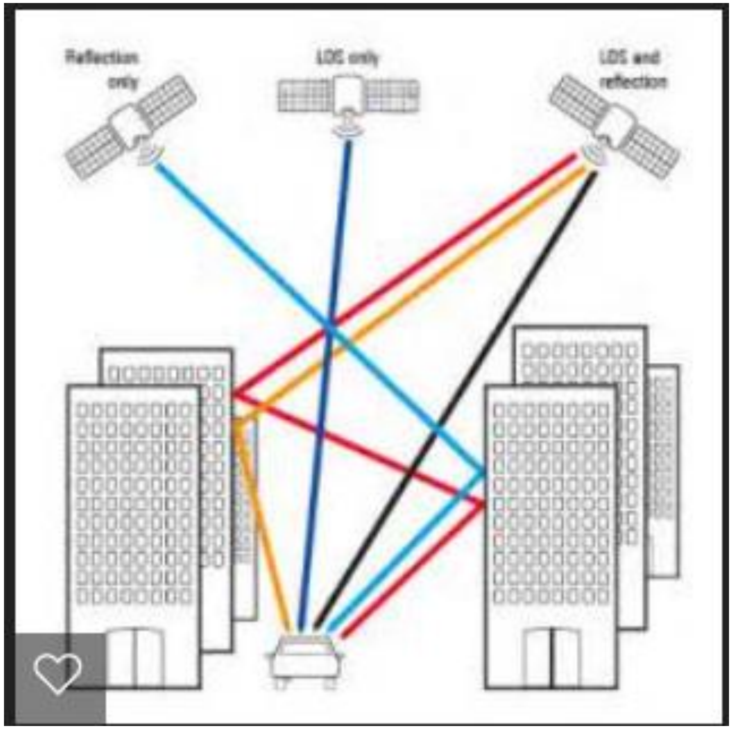
5) Ensuring Compliance with Authorized Transmitting Power Levels

Question: What methods and processes are offered to monitor and ensure that terrestrial transmitters operate within authorized power and deployment constraints?

6) Phase-out Time for Legacy Equipment

- Existing GPS equipment designs were based on assurances by the FCC that adjacent bands would be reserved primarily for earth-to-ground communications with correspondingly weak signals.
- To repurpose the adjacent bands would dictate a different GNSS receiver front end.
- Future equipment could be designed to be more resilient to strong terrestrial transmissions, if they are to be authorized, but there would still be millions of users with equipment designs that were based on the previous FCC assurances.

Question: What phase in or delay time could be expected before initiation of higher power terrestrial transmissions?



Line of Sight and reflected signals can cause errors

GNSS signal attenuation can occur in suburban and rural areas as well as in urban canyons, due to foliage. GNSS satellites are obstructed but a cell tower has line-of-sight to the road.

SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL EXECUTIVE COMMITTEE

JAN 13 2012

UNITED STATES OF AMERICA

The Honorable Lawrence E. Strickling
Assistant Secretary for Communications and Information
U.S. Department of Commerce
Washington, DC 20230

Dear Assistant Secretary Strickling:

At the request of the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA), the nine federal departments and agencies comprising the National Space-Based Positioning, Navigation and Timing (PNT) Executive Committee (EXCOM) have tested and analyzed LightSquared's proposals to repurpose the Mobile Satellite Services (MSS) frequency band adjacent to Global Positioning System (GPS) frequencies to permit another nationwide terrestrial broadband service. Over the past year we have closely worked with LightSquared to evaluate its original deployment plan, and subsequent modifications, to address interference concerns. This cooperative effort included extensive testing and analysis of GPS receivers. Substantial federal resources have been expended and diverted from other programs in testing and analyzing LightSquared's proposals.

It is the unanimous conclusion of the test findings by the National Space-Based PNT EXCOM Agencies that both LightSquared's original and modified plans for its proposed mobile network would cause harmful interference to many GPS receivers. Additionally, an analysis by the Federal Aviation Administration (FAA) has concluded that the LightSquared proposals are not compatible with several GPS-dependent aircraft safety-of-flight systems. Based upon this testing and analysis, there appear to be no practical solutions or mitigations that would permit the LightSquared broadband service, as proposed, to operate in the next few months or years without significantly interfering with GPS. As a result, no additional testing is warranted at this time.

The EXCOM Agencies continue to strongly support the President's June 28, 2010 Memorandum to make available a total of 500 MHz of spectrum over the next 10 years, suitable for broadband use. We propose to draft new GPS Spectrum interference standards that will help inform future proposals for non-space, commercial uses in the bands adjacent to the GPS signals and ensure that any such proposals are implemented without affecting existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needs.

Ashton B. Carter

ASHTON B. CARTER
EXCOM Co-Chair
Deputy Secretary of Defense

JOHN D. PORCARI
EXCOM Co-Chair
Deputy Secretary of Transportation

PNTAB Recommended Criteria – Testing to Date

Criteria	Ligado Proposal and Completed	DOT-Planned
"implemented without affecting existing and evolving uses of space-based PNT services"	Apparently excluded future Apps and GNSS systems	A major objective, but resource constrained
Strictly apply the **1 dB Interference Criterion** (IPC)	Do not yet accept the International Standard	Endorse and accept 1 dB IPC
Protect **all classes** of receivers, (including precision/timing receivers)	Limited Evaluation of Precision	Limited by testing resources
Protect **all operating modes**, (including signal acquisition/reacquisition)	Acquisition and Reacquisition not yet planned	Limited by testing resources
Protect **all uses** of all emerging (GNSS) signals	No plans for considering Galileo	Limited by testing resources
Use maximum authorized transmitted interference powers and propagation models	Unknown, but was a major point of contention last time	Unknown, but was a major point of contention last time
Include Internationally recognized PNT Testing Expertise on team	Apparently none	Some GNSS signals tested; more work needed

Backup 2 - specific comments on NIST testing

- <u>To justify replacing the 1 dB criterion for tolerable interference would require a very extensive justification looking at many worst case GPS/GNSS operational situations.</u> By not using the widely accepted and previously employed 1 dB degradation criterion, NASCTN is taking on a daunting task. Working with the many receivers, receiver operating modes and operating conditions needed to identify and adequately measure other key performance indicators will require an extensive amount of resources and time to be done correctly. Finding cases and conditions where the impact is acceptable is not sufficient; the proposed testing must explore all relevant cases and conditions to demonstrate that the impact is not unacceptable. It appears that they do not have the needed resources and time, and instead are planning to use an overly simplistic test that will not provide the needed information. http://gpsworld.com/gpsia-submits-filings-supporting-1-db-standard-for-gps-adjacent-band-assessment
- <u>Plan should add goal of answering the key question: determining the level of LTE interference that can be accepted by satnav receivers operating satisfactorily under ***all*** relevant conditions</u> . This fundamental goal should be added to the Preface. If NASCTN does not have the resources and time to do this for a large number of receivers and conditions, then it would be better to do this thoroughly for a small number of receivers that previous testing has shown to be particularly sensitive to LTE interference, rather than use an overly simplistic approach on a larger number of receivers. Note especially the change from "GPS receivers" to satnav receivers. The test plan has taken a first step in this respect by including WAAS receivers, but signals from other satnav systems are already being used extensively in the U.S., and other signals will be used as well, consistent with U.S. policy.
- <u>Plan should address highly stressed conditions – the "envelope" conditions.</u> When we asked during the telecon, we were told that it is not the objective of this effort to find what margin is left for LTE when satnav receivers are operating in stressed conditions. If the tests do not provide this result, then they do not provide the needed information for assessing LTE compatibility with satnav receivers. No one source of interference can take up all the margin, which receivers rely upon to handle a large set of different stresses, including other sources of interference. Many of the following comments involve more detailed technical aspects of this observation and recommendation, pointing out several of the ways that this test plan does not meet the objective it states in the first sentence of its Section 3 "to develop a rigorous testing methodology and collect supporting data to establish the impact of LTE signals on GPS devices." Instead, the current test plan only establishes the impact on a limited number of GPS devices operating in their most interference-resistant mode under relatively unstressed conditions.

NIST Comments (2)

- <u>Plan should include all receiver classes, receiving modes and states, particularly those that are well known to be most sensitive to interference, e.g. acquisition (cold start) and reacquisition.</u> The test plan currently involves getting a device under test (DUT) into steady state tracking mode, then evaluating the effect of different levels of interference on the tracking performance. Since steady state tracking is usually the most robust, interference-resistant mode of receiver operation, the results of this test do not adequate assess LTE impacts on receiver operation. Instead, for each interference configuration, including the baseline with no interference, tests should evaluate receiver performance in every mode and state of operation, defining and observing the Key Performance Indicators appropriate to that mode and state of operation. This would be an expansion to the flowcharts shown on pages 21 and 22 of the test plan. As examples, cold start acquisition should evaluate the time to first fix, carrier phase differential receivers should evaluate time for ambiguity resolution, and many receivers should be tested for error-free reading of the data message. Handling rising and setting satellites, as well as satellites disappearing and appearing due to blockage, are additional conditions under which the effects of interference must be evaluated.
- <u>Plan should include moving receivers.</u> The test plan states that receivers will be tested when stationary. Many receiver functions are stressed by the acceleration, jerk, and vibrations associated with receiver motion. Receiver susceptibility to interference should be evaluated under significant dynamics, not only the easy case of no dynamics. As a minimum, vehicle dynamics should be included for devices that might be used in vehicles.
- <u>Plan should include other sources of interference.</u> The test plan does not include any other sources of interference, despite the fact that satnav receivers often operate under conditions where there is some level of out of band and in band interference. Stressing levels of other interference should be used during the testing in order to assess how much additional interference from LTE can be tolerated. As examples, there is and will be intrasystem interference from other GPS signals and satellites, intersystem interference from current and future satnav systems, interference from FCC Part 15 devices, interference from UWB devices, as well as other spectrum uses in adjacent bands.

NIST Comments (3)

- Plan should include various received power levels and numbers of satellites. While the specified minimum received power for C/A signals is -158.5 dBW (or -128.5 dBm), received power levels can be much less than that value due to receive antenna gain, blockage due to foliage or construction materials, or tracking of reflected signals when the direct path is blocked. Also, while many GPS satellites are usually visible to a receiver with open view of the sky, visibility can be reduced to four satellites or fewer (in which case altitude hold and/or clock hold may be used) due to blockage from buildings or terrain.
- Plan must include multiple receivers simultaneously, at least in some cases. The test plan indicates it will test one receiver at a time. Yet differential systems require multiple receivers— at least one reference receiver, or base, and one user receiver, or rover. Some modern differential systems (e.g., networked differential systems) may require several reference receivers. The effect of interference must be assessed when all of these receivers are exposed to the interference, and thorough testing should examine different interference conditions for each of the reference receivers and user receivers.
- Plan should include receivers for more satnav signals, including L1C and from other GNSS. These advanced signals are the basis for many high productivity applications. Proposed test plan seems to address only receivers for GPS C/A signals and WAAS signals. GPS L1C signal receivers should also be evaluated. Further, there are other satnav systems with signals in this band, and they may be used in the U.S. At a minimum, Galileo PRS receivers, or their surrogates, should be tested as well.
- Plan should focus on absolute received power levels, not signal to interference ratio. While Appendix A in the test plan suggests use of signal to LTE interference ratio (SIR) as a metric, this metric will be of little use. At low LTE interference levels, receiver performance is only an affine function of SIR, since thermal noise and other interference have observable effects. At high LTE interference levels, receivers may respond nonlinearly to interference. Thus, the same SIR, with different levels of desired signal levels, can produce very different results in the receiver. Furthermore, there are four power levels of interference (power in the designated uplink and downlink bands, and power in the satnav band from uplink and downlink transmissions), and received satnav signals have different power levels as shown in Table 5 of the test plan. Thus, there is no such single quantity known as SIR.
- Plan should address how test data will be extrapolated to operational conditions. While the test plan does not address it, there are also significant technical issues concerning extrapolation of test chamber results to operational conditions. Variations in path loss, transmit and receive antenna gains, and overlapping transmitter coverage are a few examples of the many issues that need to be addressed in performing an adequate extrapolation.

NIST Comments (4)

- At a minimum, the test plan and test report should clearly and prominently ***highlight*** limitations of the testing, and the resulting restrictions on drawing conclusions from the tests. Given that the current plan for testing will not involve all representative and realistic stresses, and that only a limited number of receivers will be tested, and then only in their most robust modes, the results will not provide useful results concerning how much LTE interference can be tolerated by satnav receivers. Buried on page 24 of the test plan is the admission that, "the conclusions that can be drawn from this test will be limited to the specific set of devices under test, and will not be rigorously generalizable to the population of all devices." Currently the limitations of this testing are not clearly stated in the test plan's Preface, Background, or Scope. These limitations should be highlighted and detailed prominently in the Test Plan and Test Report. Otherwise, it will be easy for these limitations to go unrecognized, and consequently for any test results to be misinterpreted as actually informing about the level of LTE compatibility with satnav receivers, when they really only provide limited insights: for a small number of receivers, under relatively benign conditions, when the receivers are operating with ample margin.
- To have credibility with the PNT community, it is clear that real PNT expertise must be added to the test team. If the plan is to answer the real question, the satnav community can provide assistance. If the objectives of this test plan include the recommendation from comment 2: "To develop a technically and operationally valid way to determine the level of LTE interference that can be tolerated by satnav receivers operating satisfactorily under all relevant conditions," then there are many constructive suggestions that satnav experts can provide. Some of them are outlined here, but NASCTN's willingness to consider and incorporate them, only indicated today, does not allow time to provide them before the comment deadline on 13 June.
- The test plan review process should be open and formal. The test plan should be subject to a regular, formal comment process, since its results are likely to influence a decision that will potentially affect hundreds of millions of PNT users. Note that the manufacturers generally do not represent the major classes of users.